Two Decades of Science to Provide Knowledge and Planning Tools to Ensure the Long Term Conservation of Grizzly Bears in Alberta.

A compilation demonstrating the power of collaboration in grizzly bear research from 1998-2021 at fRI Research

Photo by Mark Bradley

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INTRODUCTION

PROGRAM BACKGROUND

The fRI Research (formerly Foothills Research Institute, and Foothills Model Forest) Grizzly Bear Program began in 1998 and was initiated in response to concerns expressed about the lack of knowledge and data on regional grizzly bear populations during the environmental hearings of the Cheviot Coal Mine. A core group of sponsors provided funding support to gather data on the movements and habitat use of the grizzly bear population in the Yellowhead Bear Management Area (BMA 3). What started out as a directed study in a small portion of grizzly bear range in Alberta expanded both in scale and scope over the next 23 years, as we created the most comprehensive dataset on grizzly bear populations in Alberta (Figure 1; Figure 2). This expansion occurred as a direct result of new program partners joining our research efforts where they saw the value these data sets, including maps and models, would have for operational activities and management. Over the course of this research program there have been a number of changes that have taken place in grizzly bear management in Alberta, which included: the redrawing of BMA boundaries based on genetic analysis of populations, the first scientific population inventory of many BMAs, the 2006 suspension of the spring grizzly bear hunt in Alberta, the preparation and implementation of the first provincial grizzly bear recovery plan in 2008, the change in status of the species to Threatened in 2010, and the designation of the first core and secondary grizzly bear conservation areas with open road density thresholds. Data sets and research results from our program played an important role in all of these management actions.

These achievements were enabled by an assembled multi-disciplinary team of committed scientists who all agreed to support our program goal *"to provide knowledge and planning tools to ensure the long term conservation of grizzly bears in Alberta".* Equally crucial to the program's success was the tremendous and ongoing support of our many partners who provided ongoing funding to allow the research and tool development to continue and expand to include all grizzly bear range in the province (Appendix 1).

Over the 23 year life span of the fRI Grizzly Bear Research Program the research team has published 164 research papers in peer reviewed scientific journals to support our partners' use and implementation of research results. This vast body of research was made possible through an outstanding team of university professors, graduate students, and researchers from across Canada and around the world who took on directed applied research questions in support of our program goal (Appendix 2).

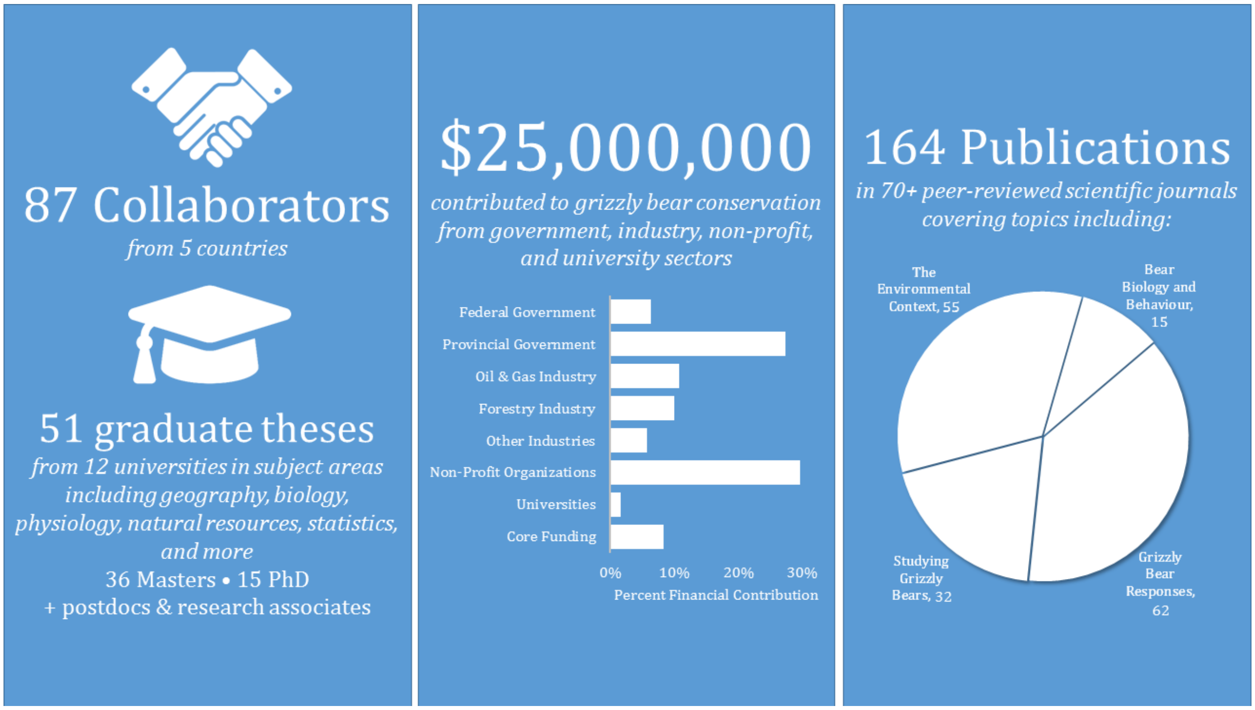

Figure 1. Summary statistics for the fRI Grizzly Bear Program from 1998 - 2021.

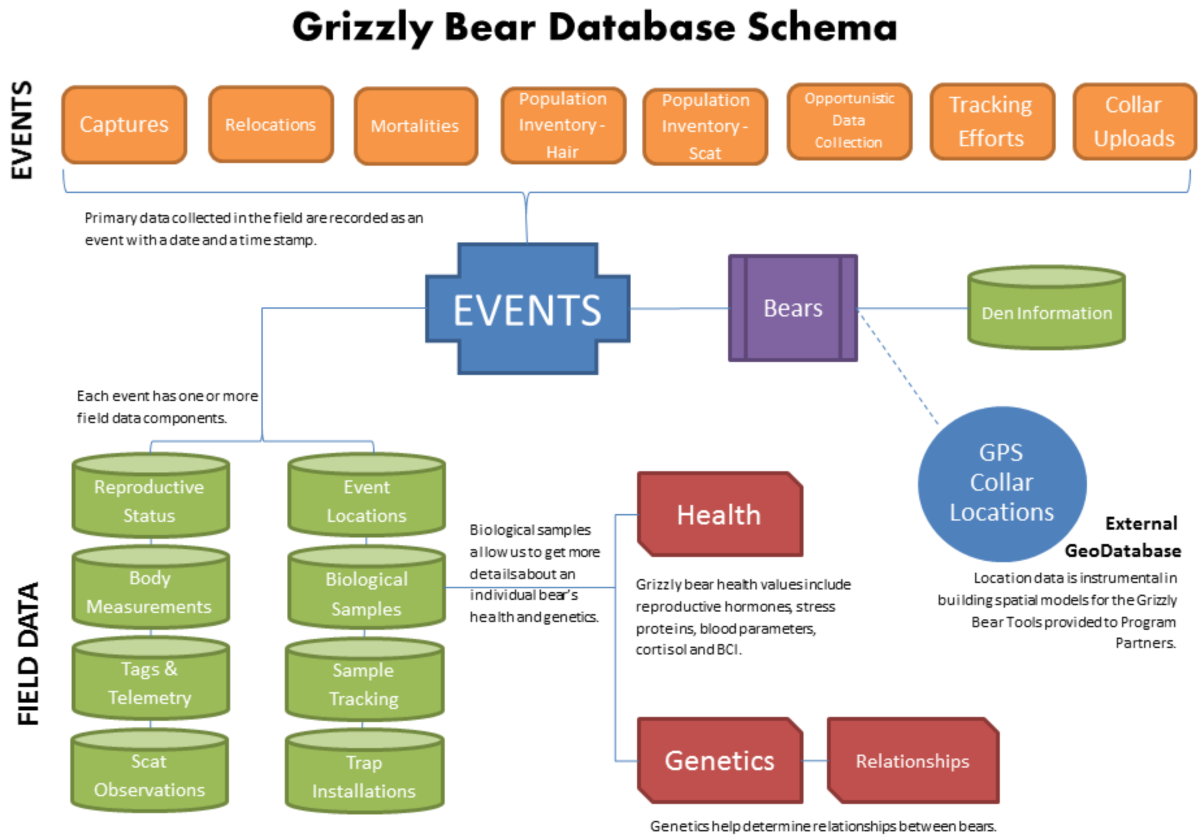

Figure 2. A depiction of the information contained in the long term grizzly bear data base. Prepared by Julie Duval.

PURPOSE AND HOW TO USE THIS DOCUMENT

It would be extremely challenging to summarize all the research results from 23 years of work. This document has been put together to showcase the research completed as part of the fRI Research grizzly bear program from 1998 to 2021, allowing the reader to understand the progress that this collaborative research effort has made towards provincial grizzly bear conservation and management. It contains the abstracts or summaries of 164 peer-reviewed scientific papers as well as 30 unpublished reports. The research covers a wide variety of topics and has been organized into sections of related work (Figure 3). The four major categories have been further divided into subcategories, within which papers have been organized largely chronologically to demonstrate the flow of research and how individual studies build on one another. It is important to recognize that the research conducted is very interconnected; the divisions here are one of many ways that the publications could have been organized, and some papers could easily have belonged to several categories or sub-categories. The authors have chosen the divisions that seemed useful to understanding the main goals and directions of the program. Therefore, since the program was geared towards management and supported by many natural resource industries, we have chosen in most cases to categorize grizzly bear responses by what they are responding to (e.g. oil and gas, roads, forestry) rather than by the nature of their response (e.g. movement, denning, stress). However, we have also provided key words at the bottom of each abstract relating to additional or overlapping themes within each publication. These key words are listed in an index at the back of the document with the page numbers of all abstracts relating to that theme. For example, if one wanted information regarding the effects of mining on grizzly bears, although there is a subsection within “Grizzly Bear Responses” focused on mining, by checking the index you can see that mining is also discussed in the more general “Habitat Quality and Fitness” subsection as well as the subsection on “Behaviour and Predation” within the “Bear Biology and Behaviour” section. Similarly, you could check the index for “DNA” and discover how key genetic analyses have been throughout the various branches of the program.

In addition to organizing the research by subject matter, we have highlighted the goals of each study for readability. Finally, the complete citation for each paper is included so that you can easily reference the complete article and further your understanding of the topics of greatest interest.

ORGANIZATION

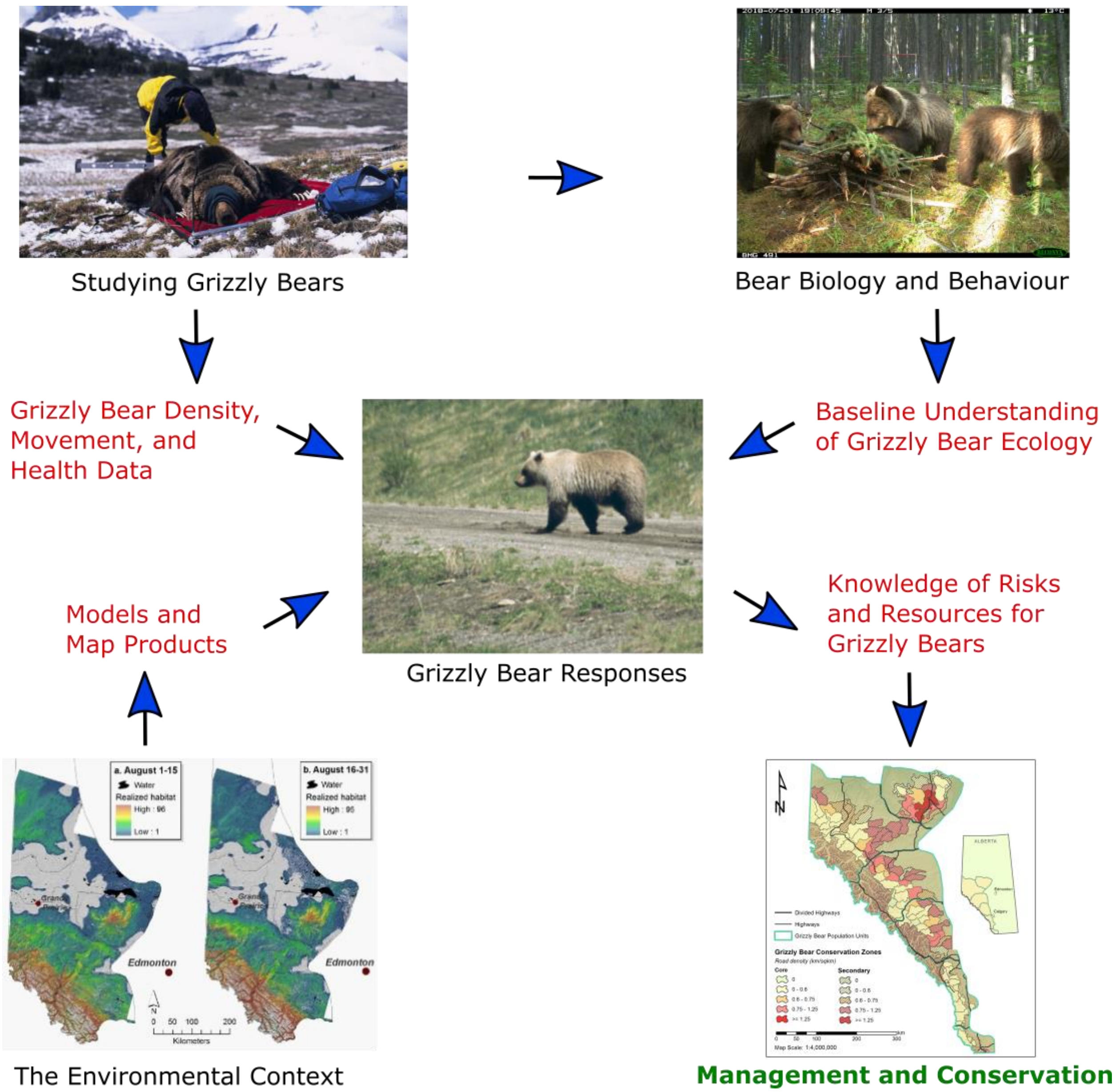

Figure 3. Flow diagram showing progression and interconnection of research subjects leading ultimately to management and conservation objectives.

<u>The Environmental Context: Processing and analyzing habitat and climate data</u>

The grizzly bear program benefitted from extensive data collection and research on the environmental context in which the grizzly bears of Alberta exist. A large portion of the data was collected through remote sensing, using satellites, drones, and even digital cameras. Remote sensing data was accompanied by field data for validation or to answer additional questions about the environment. Significant effort went into learning to effectively process and combine data into formats that could be used for further research or management. The first step and focus of many of these studies was to classify remote sensing data into landcover types – both natural and anthropogenic - that could be related to grizzly bear habitat. After establishing how to categorize a static landscape, the next step was to detect landscape change and disturbances occurring over many years. As remote sensing techniques improved, analyses moved from focusing on broad landscapes to modelling in greater complexity, capturing detailed forest structure and fine-scale disturbances such as roads. Vegetation phenology and how it influences food resources also became an important avenue of research. Finally, weather data, including snow cover, was collected to round out our understanding of the grizzly bears' environment. This research provided the map products and environmental variables that were key to modelling grizzly bear responses in the final section.

Studying Grizzly Bears: Collecting and evaluating biological data

Before reaching an understanding of grizzly bear behaviour, population status, response to industry, or best management practices, significant groundwork was required to determine the best way to collect, process, and analyse the required grizzly bear data. In this section, we first discuss procedures for estimating population numbers and demographics, providing the necessary background for determining population status and trends. Next, we compare methods of capturing grizzly bears and how to safely process the bears once they are caught, determining the best practices which were foundational to the capture program for the remainder of the studies. We also discuss the use and processing of grizzly bear health and physiology markers, such as hormones. Finally, we tackle challenges in using grizzly bear location data from GPS collars. These studies define the procedures used to determine grizzly bear status, behaviour, and responses.

Grizzly Bear Biology and Behaviour: Understanding individuals and populations

In this section, we look at general grizzly bear biology and behaviour, including population density, home range, physiology, genetics, diet, predation, and how grizzly bears interact with each other. This section is distinct from the previous section in that, although themes are similar, here the focus is on the outcome and what we can learn about grizzly bears, rather than the development of a tool or a process. It is distinct from the final section in that these studies, for the most part, do not focus on responses to the environmental context, but establish a baseline understanding of grizzly bear populations and behaviour.

Grizzly Bear Responses: Studying how grizzly bears interact with the natural environment and anthropogenic influences

This section discusses the relationship between grizzly bears and various natural and anthropogenic influences, and is catered to landscape level management. However, this research was only possible by building on the groundwork laid in the previous sections. In this section, grizzly bear numbers, condition, and behaviour data were combined with data on the physical environment to determine factors affecting grizzly bears. In particular, grizzly bear habitat selection is explored in depth, determining the environmental preferences of grizzly bears in order to make predictions of where they are most likely to be found, as well as areas of high mortality risk. This section also focusses heavily on the effects of anthropogenic disturbances on grizzly bear health, behavior, and abundance, including studies that targeted individual disturbances including roads, forestry, coal mining, and oil and gas extraction. Finally, we discuss human and wildlife conflict.

Reports and Unpublished Materials

This section contains selected additional work conducted by the fRI Research Grizzly Bear Program that has not been published in a peer reviewed journal. First we include reports on population inventories and density estimates, which provide baseline data on grizzly bear population status and in some cases how grizzly bear populations have changed through time in different BMAs. These population inventories were used to evaluate population trends and to determine and integrate management strategies. Finally, we have a section of assorted reports and materials that cover a variety of themes. Many of these reports were commissioned by industry partners and contain important management perspectives relative to specific activities. Others are internal reports containing information on the development of techniques relevant to other studies. A number of these works are not presented in traditional report format, but are compilations of multiple studies, or even a course manual. Furthermore many do not have abstracts or summaries, therefore parts of the introduction, goals, or conclusions have been provided to give an idea of the content and purpose of the document. Although speaking to a variety of themes and purposes, all of these reports were important to the overall development and impact of the grizzly bear program.

THE ENVIRONMENTAL CONTEXT

MAPPING AND CLASSIFICATION

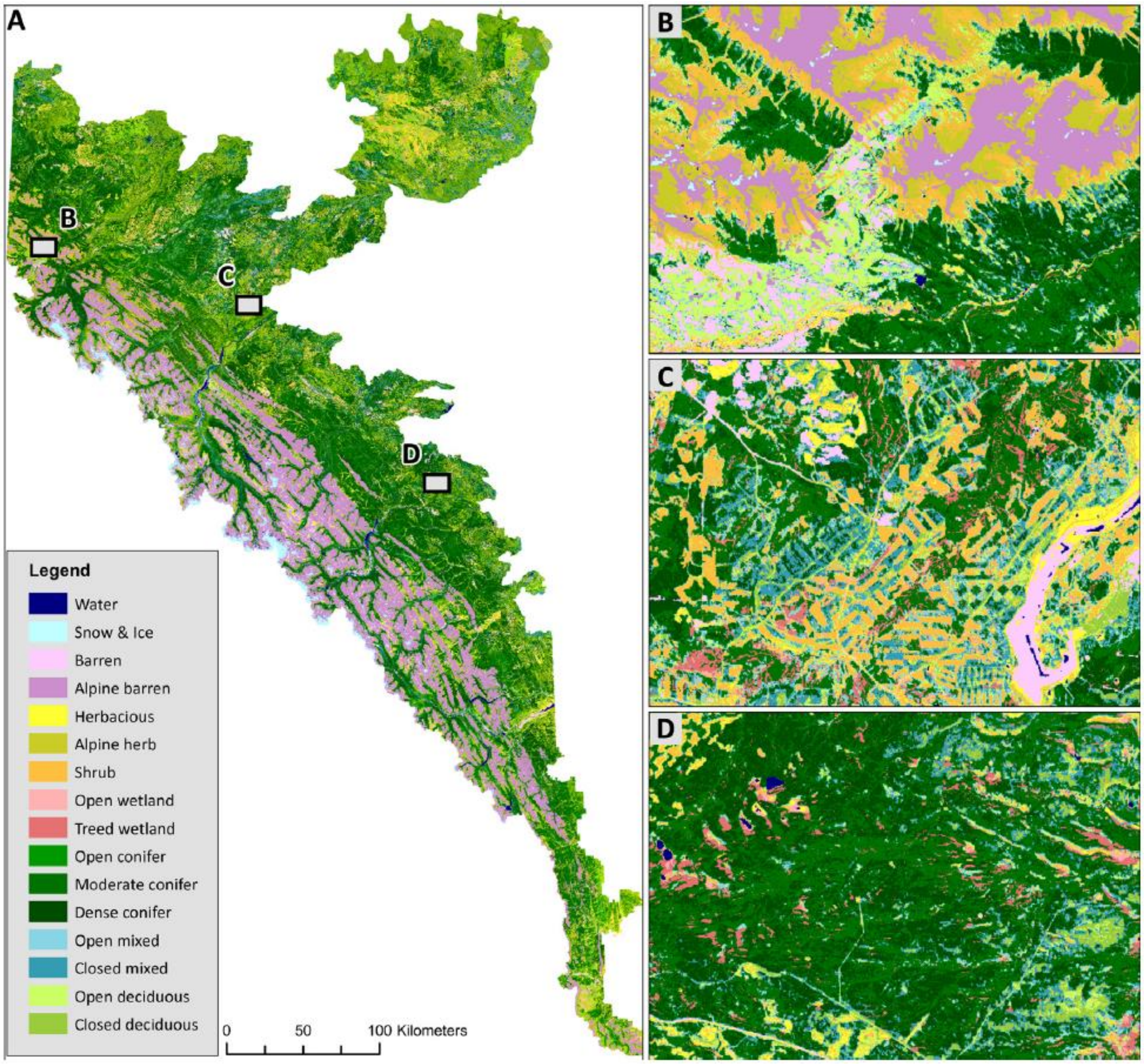

Figure 4. Overview map of the classification results for the whole study area (A) and three detail sites as indicated in the first panel, (B) mountainous areas with a recovering fire scar in the SW corner, (C) mosaic of regenerating forest harvests with a coal mine site in the east, (D) mostly continuous conifer forest interspersed with wetlands and mixed deciduous patches. Figure from Nijland et al. 2015, p. 14.

In this section, we look at studies that use mainly satellite data to classify landcover types and make habitat maps, focusing on increasing accuracy and relevance for grizzly bears.

Franklin, S. E., Stenhouse, G. B., Hansen, M. J., Popplewell, C. C., Dechka, J. A., & Peddle, D. R. (2001). **An integrated decision tree approach (IDTA) to mapping landcover using satellite remote sensing in**

support of grizzly bear habitat analysis in the Alberta Yellowhead Ecosystem. Canadian Journal of Remote Sensing, 27(6), 579–592. https://doi.org/10.1080/07038992.2001.10854899

Multi-source data consisting of 1999 Landsat satellite imagery, topographic descriptors derived from DEMs, and GIS-based vegetation inventory information have been used to generate a detailed landcover classification map to quantify and analyze the spatial distribution and configuration of grizzly bear habitat within the Alberta Yellowhead Ecosystem study area. The map is needed as part of a larger ecosystem assessment to help determine if bear movement and habitat use patterns are affected by changing landscape conditions and human activities. An Integrated Decision Tree Approach (IDTA) was developed that incorporated unsupervised (K-means) clustering, empirically-derived DEM- and GIS-based decision rules (proximity, slopes, etc.), and maximum likelihood supervised classification of forest and vegetation classes based on field sampling. This approach was based on an earlier finding, using a 1998 Landsat image in this area, that different classifiers performed at different levels of success in various classes. The map produced with the IDTA method was determined to be approximately 80% accurate (kappa = 0.783) using 494 randomly sampled points unambiguously identified on available digital orthophotography.

Map Product; Landcover; Landsat; GIS Application; Vegetation

Franklin, S. E., Peddle, D. R., Dechka, J. A., & Stenhouse, G. B. (2002). Evidential reasoning with Landsat TM, DEM and GIS data for landcover classification in support of grizzly bear habitat mapping. International Journal of Remote Sensing, 23(21), 4633–4652. https://doi.org/10.1080/01431160110113971

Multisource data consisting of satellite imagery, topographic descriptors derived from DEMs, and GIS inventory information have been used with a detailed, field-based landcover classification scheme to support a quantitative analysis of the spatial distribution and configuration of grizzly bear (*Ursus arctos horribilis*) habitat within the Alberta Yellowhead Ecosystem study area. The map is needed to determine if bear movement and habitat use patterns are affected by changing landscape conditions and human activities. We compared a multisource Evidential Reasoning (ER) classification algorithm, capable of handling this large and diverse data set, to a more conventional maximum likelihood decision rule which could only use a subset of the available data. The ER classifier provided an acceptable level of accuracy (ranging to 85% over 21 habitat classes) for a level 3 product, compared to 71% using a maximum likelihood classifier.

Landcover, Map Product; GIS Application; Classification; Landsat

Franklin, S. E., Hansen, M. J., & Stenhouse, G. B. (2002). Quantifying landscape structure with vegetation inventory maps and remote sensing. The Forestry Chronicle, 78(6), 866–875. https://doi.org/10.5558/tfc78866-6

Two input maps based on Alberta Vegetation Invertory (AVI) data and Landsat satellite imagery were generated for use in a fragmentation analysis of a large area in the Alberta Yellowhead Ecosystem to support long-term grizzly bear habitat analysis. Accuracy was assessed using visual interpretation of classes on digital orthophotography. Approximately 45% map accuaracy was obtained after applying a generalization procedure to the available AVI GIS database. Approximately 80% map accuracy was achieved using a supervised classification approach to the Landsat image. Differences in accuracy were most apparent in non-treed vegetation classes (e.g. shrub), conifer, mixedwood, and deciduous forest classes. Very large differences were observed in many of the landscape metrics computed from these two maps to quantify landscape structure. Simulating forest changes on these maps illustrated the difficulty of comparing maps generated with different geospatial technologies.

Map Product; GIS Application; Landcover; Landsat; Vegetation; Fragmentation

McDermid, G. J., Franklin, S. E., & LeDrew, E. F. (2005). Remote sensing for large-area habitat mapping. Progress in Physical Geography, 29(4), 449–474. https://doi.org/10.1191/0309133305pp455ra

Remote sensing has long been identified as a technology capable of supporting the development of wildlife habitat maps over large areas. However, progress has been constrained by underdeveloped linkages between resource managers with extensive knowledge of ecology and remote sensing scientists with backgrounds in geography. This article attempts to traverse that gap by (i) clarifying the imprecise and commonly misunderstood concept of 'habitat', (ii) exploring the recent use of remote sensing in previous habitat-mapping exercises, (iii) reviewing the remote sensing toolset developed for extracting information from optical satellite imagery, and (iv) outlining a framework for linking ecological information needs with remote sensing techniques.

Remote Sensing Review; Habitat Mapping; Forest Structure; Map Product; Landcover, Satellite Imagery

Linke, J., & Franklin, S. E. (2006). Interpretation of landscape structure gradients based on satellite image classification of land cover. Canadian Journal of Remote Sensing 32(6), 367-379. https://doi.org/10.5589/m06-031

Landscape metrics used to quantify landscape structure and pattern over time and space are increasingly required in wildlife habitat analysis and other applications in environmental management, planning, and research. In such analyses, the spatial attributes of either individual land cover classes or the entire landscape mosaic consisting of multiple land cover classes can be described by computing the respective class-and landscape-level landscape metrics. Recent studies have suggested that a parsimonious suite of independent landscape metrics, or landscape structure gradients, may be useful descriptors of spatial variation over various natural landscapes and that some of these parsimonious gradients may be fundamental to most landscape configurations as guided by the universality of the gradients (percentage of landscape or land cover classes a structure gradient occurs in), consistency (the correlation of principal component loadings of like-structure gradients across different land cover classes), and strength (average variance explained by the structure gradient across land cover classes). Landscape structure gradients can be extracted using separate principal components analyses of a list of class-and landscape-level landscape metrics obtained from land cover maps derived from geographic information system (GIS) databases or remote sensing image classifications. In this study, we examined the landscape structure gradients in the Foothills Model Forest, which is located in the Canadian Rocky Mountains Yellowhead Ecosystem, Alberta, Canada, and interpreted differences in quantified gradients of landscape structure using satellite image classification products before and after they were generalized into "polygon-like" maps by smoothing. We used 195 square (5.4 km X 5.4 km) sub-landscapes to ensure an adequate sample size for statistical testing. The class-level analysis resulted in the identification of five consistent structure gradients universally present across the eight land cover classes together explaining the majority of all class-level variation (on average about 53% for all land cover classes). The landscape-level analysis identified that a parsimonious suite of eight fundamental landscape-level structure gradients explained approximately 85% of the variance.

Classification; Satellite Imagery

Wang, K., Franklin, S. E., Guo, X., He, Y., & McDermid, G. J. (2009). Problems in remote sensing of landscapes and habitats. Progress in Physical Geography, 33(6), 747-768. https://doi.org/10.1177/0309133309350121

Wildlife habitat mapping strongly supports applications in natural resource management, environmental conservation, impacts of anthropogenic activity, perturbed ecosystem restoration, species-at-risk recovery and species inventory. Remote sensing has long been identified as a feasible and effective technology for large-area habitat mapping. However, existing and future uncertainties in remote sensing will definitely have a significant effect on the relevant scientific research. This article attempts to identify the current challenges and opportunities in remote sensing for large-area wildlife habitat mapping, and accordingly provide possible solutions and directions for further research.

Habitat Mapping; Remote Sensing Review; Map Product

McDermid, G. J., Hall, R. J., Sanchez-Azofeifa, G. A., Franklin, S. E., Stenhouse, G. B., Kobliuk, T., & LeDrew, E. F. (2009). Remote sensing and forest inventory for wildlife habitat assessment. Forest Ecology and Management, 257(11), 2262–2269. https://doi.org/10.1016/j.foreco.2009.03.005

Researchers and managers undertaking wildlife habitat assessments commonly require spatially explicit environmental map layers such as those derived from forest inventory and remote sensing. However, end users of geospatial products must often make choices regarding the source and level of detail required for characterizing habitat elements, with few published resources available for guidance. We appraised three environmental data sources that represent options often available to researchers and managers in wildlife ecological studies: (i) a pre-existing forest inventory; (ii) a general-purpose, single-attribute remote sensing land cover map; and (iii) a specific-purpose, multi-attribute remote sensing database. The three information sources were evaluated with two complementary analyses: the first designed to appraise levels of map quality (assessed on the basis of accuracy, vagueness, completion, consistency, level of measurement, and detail) and the second designed to assess their relative capacity to explain patterns of grizzly bear (*Ursus arctos*) telemetry locations across a 100,000-km^2 study area in west-central Alberta, Canada. We found the forest inventory database to be reasonably functional in its ability to support resource selection analysis in regions where coverage was available, but overall, the data suffered from quality issues related to completeness, accuracy, and consistency. The general-purpose remote sensing land cover product ranked higher in terms of overall map quality, but demonstrated a lower capacity for explaining observed patterns of grizzly bear habitat use. We found the best results using the specific-purpose, multi-attribute remote sensing database, and recommend that similar information sources be used as the foundation for wildlife habitat studies whenever possible, particularly those involving large areas that span jurisdictional boundaries.

Habitat Mapping; Landcover; Habitat Selection

Collingwood, A., Franklin, S. E., Guo, X., & Stenhouse, G. (2009). A medium-resolution remote sensing classification of agricultural areas in Alberta grizzly bear habitat. Canadian Journal of Remote Sensing, 35(1), 23–36. https://doi.org/10.5589/m08-076

Habitat loss and human-caused mortality are the most serious threats facing grizzly bear (*Ursus arctos* L.) populations in Alberta, with conflicts between people and bears in agricultural areas being especially important. However, the agricultural land being classified as a single class in current grizzly bear habitat maps limits the understanding of the bear habitat in agriculture regions. The objectives of this research were to find the best possible classification approach from a limited selection of methods for determining multiple classes of agricultural and herbaceous land cover and to create land cover maps of agricultural and herbaceous areas which will be integrated into existing grizzly bear habitat maps for western Alberta. Three different object-based classification methods (one unsupervised method and two supervised methods) were analyzed with these data to determine the most accurate and useful method. The best method was the supervised sequential masking (SSM) technique, which gave an overall accuracy of 88% and a kappa index of agreement (KIA) of 83%. When combined with bear global positioning system (GPS) location data, it was discovered that bears in agricultural areas were found in the grass - forage crops class 77% of the time, with the small grains and bare soil - fallow fields classes making up the rest of the visited land cover. The bears were found in these areas primarily in the summer months.

Agriculture; GIS Application; Habitat Selection; Map Product; Classification; Landsat

Wang, K., Franklin, S. E., Guo, X., Collingwood, A., Stenhouse, G. B., & Lowe, S. (2010). Comparison of Landsat multispectral and IRS panchromatic imagery for landscape pattern analysis of grizzly bear habitat in agricultural areas of western Alberta. Canadian Journal of Remote Sensing, 36(1), 36–47. https://doi.org/10.5589/m10-026

The grizzly bear (*Ursus arctos* L.) is a species that is widely recognized as an indicator of ecosystem health in west-central Alberta. Agricultural activities, oil and gas exploration and extraction, forestry, and recreation can all contribute to grizzly bear habitat fragmentation and loss. The purpose of this research was to compare two models of grizzly bear activity in agricultural areas of western Alberta, Canada, developed from landscape pattern metrics derived from Landsat and Indian Remote Sensing (IRS) based land cover classifications and assess if these models statistically converged on the same landscape metrics. Results were further explained by considering the influence of spatial, spectral, and thematic resolution, along with previous knowledge on grizzly bear habitat preference. The Landsat- and IRS-based analyses were compared using relationships between landscape metrics and both grizzly bear presence-absence data and frequency of use data. Results indicated that landscape spatial structure had at least some role in determining whether or not grizzly bears would use an area in an agricultural landscape. It was concluded that the thematic resolution represented the greatest impact on compositional metrics for both the grizzly bear presence-absence and frequency of use analyses, i.e., the Landsat-based product was more suited to revealing the function of the compositional metrics than the IRS-based product. Configurational metrics, however, were more sensitive to the higher spatial resolution map derived from the IRS data. Landscape management recommendations are suggested in the context of these geospatial results.

Indian Remote Sensing; Landsat; Satellite Imagery; Landcover; Agriculture

Wang, K., Franklin, S. E., Guo, X., & Cattet, M. (2010). Remote sensing of ecology, biodiversity and conservation: a review from the perspective of remote sensing specialists. Sensors (Basel, Switzerland), 10(11), 9647–9667. https://doi.org/10.3390/s101109647

Remote sensing, the science of obtaining information via noncontact recording, has swept the fields of ecology, biodiversity and conservation (EBC). Several quality review papers have contributed to this field. However, these papers often discuss the issues from the standpoint of an ecologist or a biodiversity specialist. This review focuses on the spaceborne remote sensing of EBC from the perspective of remote sensing specialists, i.e., it is organized in the context of state-of-the-art remote sensing technology, including instruments and techniques. Herein, the instruments to be discussed consist of high spatial resolution, hyperspectral, thermal infrared, small-satellite constellation, and LIDAR sensors; and the techniques refer to image classification, vegetation index (VI), inversion algorithm, data fusion, and the integration of remote sensing (RS) and geographic information system (GIS).

Satellite Imagery; Lidar; Remote Sensing Review

Franklin, S. E., He, Y., Pape, A. D., Guo, X., & McDermid, G. J. (2011). Landsat-comparable land cover maps using ASTER and SPOT images: a case study for large-area mapping programmes. International Journal of Remote Sensing, 32(8), 2185–2205. https://doi.org/10.1080/01431161003674642

The long-term record of global Landsat data is an important resource for studying Earth's system. Given the identified gaps in Landsat data and the undetermined future status of Landsat data availability, alternatives to Landsat imagery need to be tested in an operational environment. In this study, forest land cover and crown closure maps generated from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and System Pour l'Observation de la Terre (SPOT) data were compared to Landsat-based map products currently in use by the grizzly bear habitat-mapping program. Overall accuracies greater than 85% were obtained for both ASTER- and SPOT-based land cover maps. The ASTER and SPOT classification accuracies were higher than that achieved by Landsat. Crown closure maps derived from ASTER and SPOT data show a small increase in accuracy when compared to the Landsat products. Overall, these results demonstrate that ASTER and SPOT could provide alternative data sources for producing maps in the event of a gap in the Landsat data.

Landcover; Map Product; Satellite Imagery; Landsat; SPOT; ASTER

Nijland, W., Coops, N. C., Nielsen, S. E., & Stenhouse, G. (2015). Integrating optical satellite data and airborne laser scanning in habitat classification for wildlife management. International Journal of Applied Earth Observation and Geoinformation, 38, 242–250. https://doi.org/10.1016/j.jag.2014.12.004

Wildlife habitat selection is determined by a wide range of factors including food availability, shelter, security and landscape heterogeneity all of which are closely related to the more readily mapped land-cover types and disturbance regimes. Regional wildlife habitat studies often used moderate resolution multispectral satellite imagery for wall to wall mapping, because it offers a favourable mix of availability, cost and resolution. However, certain habitat characteristics such as canopy structure and topographic factors are not well discriminated with these passive, optical datasets. Airborne laser scanning (ALS) provides highly accurate three dimensional data on canopy structure and the underlying terrain, thereby offers significant enhancements to wildlife habitat mapping. In this paper, we introduce an approach to integrate ALS data and multispectral images to develop a new heuristic wildlife habitat classifier for western Alberta. Our method combines ALS direct measures of canopy height, and cover with optical estimates of species (conifer vs. deciduous) composition into a decision tree classifier for habitat - or landcover types. We believe this new approach is highly versatile and transferable, because class rules can be easily adapted for other species or functional groups. We discuss the implications of increased ALS availability for habitat mapping and wildlife management and provide recommendations for integrating multispectral and ALS data into wildlife management.

Classification; GIS Application; Landcover; Landsat; Lidar; Forest Structure; Satellite Imagery

Kearney, S. P., Coops, N. C., Stenhouse, G. B., & Nelson, T. A. (2019). EcoAnthromes of Alberta: An example of disturbance-informed ecological regionalization using remote sensing. Journal of Environmental Management, 234, 297–310. https://doi.org/10.1016/j.jenvman.2018.12.076

Humans influence ecosystems on magnitudes that often exceed that of natural forces such as climate and geology; however, frameworks rarely include anthropogenic disturbance when delineating unique ecological regions. A critical step toward understanding, managing and monitoring human-altered ecosystems is to incorporate disturbance into ecological regionalizations. Furthermore, quantitative regionalization approaches are desirable to provide cost-effective, repeatable and statistically sound stratification for environmental monitoring. We applied a two-stage multivariate clustering technique to identify 'EcoAnthromes' across a large area - the province of Alberta, Canada - at 30m spatial resolution, and using primarily remotely sensed inputs. The EcoAnthrome clusters represent regions with unique ecological characteristics based on a combination of natural ecological potential (e.g., climatic and edaphic factors) and disturbance, both natural and anthropogenic. Compared to existing expert-derived Natural Subregions in Alberta, the model-based EcoAnthromes showed greater class separation and explained more variance for an assortment of variables related to land cover, disturbance and species intactness. The EcoAnthromes successfully separated important ecological regions that are defined by complex assemblages of topography, climate and disturbance, such as gravel-bed river valleys, boreal forests, grasslands, post-fire recovery areas and highly disturbed agricultural, industrial and urban landscapes. In addition to presenting a flexible method for EcoAnthrome regionalization, we group and describe the EcoAnthromes created for Alberta and discuss how they can complement expert-derived regionalizations to aid in environmental management efforts, such as species recovery planning and monitoring for threatened species.

Anthropogenic Disturbance; GIS Application; Classification; Landcover; Map Product; Landsat

Change Detection and Analysis

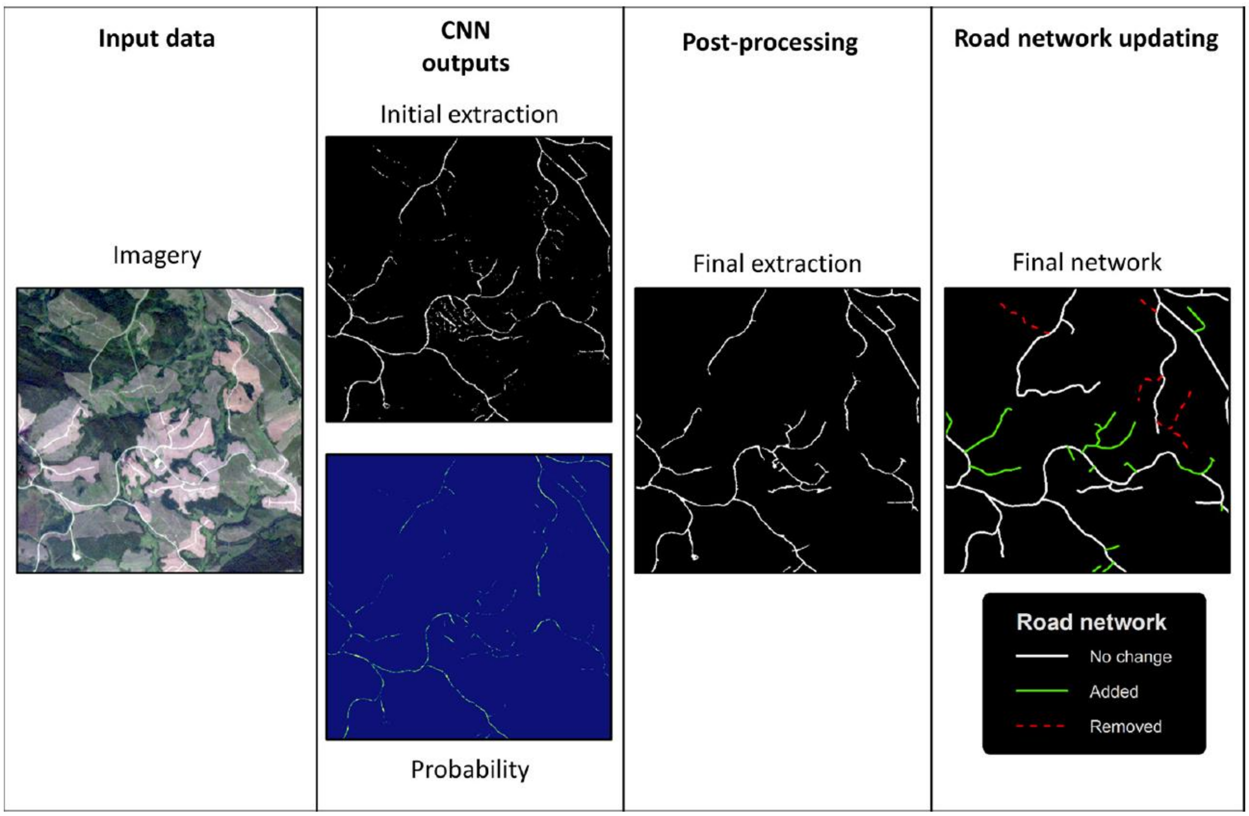

Figure 5. Example of how updating [road networks based on satellite imagery] would change the existing publicly available road network in an area with recent forest activity. Figure from Kearney et al. 2020, p. 24.

In this section, we move beyond static classification and mapping and use time series of data to document landscape changes over time, including natural and anthropogenic disturbances and forest regeneration.

Franklin, S. E., Lavigne, M. B., Wulder, M. A., & Stenhouse, G. B. (2002). Change Detection and Landscape Structure Mapping using Remote Sensing. The Forestry Chronicle, 78(5), 618–625. https://doi.org/10.5558/tfc78618-5

Satellite remote sensing has long held promise as a powerful method of detecting forest canopy changes and mapping landscape structure over vast, often multijurisdictional forest areas. Landsat Thematic Mapper (TM) spectral response, for example, can be related accurately to changes in physiology and cover at a range of small to intermediate mapping scales. These data have been available continuously for almost 20 years; many areas have earlier satellite image archives stretching back to the 1970s. When considering spatially-explicit changes to landscapes - caused by natural and human disturbances - over this time period, digital, synoptic, and repeatable satellite remotely-sensed data are emerging as the observational media of choice that forest managers must possess and use wisely. In this paper, successful use of satellite remote sensing in two of Canada's Model Forests is described. First, in the Fundy Model Forest in southeastern New Brunswick, a 15-year TM image sequence was used to detect area changes associated with different harvesting and silvicultural practices. Second, in the Foothills Model Forest in west- central Alberta, grizzly bear habitat maps have been created from multi-scene TM land cover mosaics. These map products constitute critical information on landscape change and configuration required to answer key management questions. The paper concludes with a prognosis for the future role of satellite remote sensing in sustainable forest management as data quality continues to improve (i.e., increasing spatial, spectral, temporal, and radiometric resolutions), and methods are brought into the purview of forest managers and practitioners.

Anthropogenic Disturbance; GIS Application; Landsat; Change Detection

Huettmann, F., Franklin, S. E., & Stenhouse, G. B. (2005). Predictive spatial modelling of landscape change in the Foothills Model Forest. The Forestry Chronicle, 81(4), 525–537. https://doi.org/10.5558/tfc81525-4

Modelling landscape change has been identified as one of the most significant challenges relevant to wildlife management and conservation, but many spatial tools are not well understood and there are few practical examples of their use. We present an approach to predictive spatial modelling to derive future landscape scenarios ranging from 0 to 100 years in the Foothills Model Forest. A basic input in modelling future landscapes is a land cover classification developed from satellite imagery; subsequent landscape changes are introduced with model subcomponents for forestry, fire, oil and gas exploration and development, natural succession, and vegetation growth (forest age). The resulting landscapes are used in wildlife management planning.

Satellite Imagery; GIS Application; Change Detection; Classification; Anthropogenic Disturbance

Franklin, S. E., Montgomery, P. K., & Stenhouse, G. B. (2005). Interpretation of land cover changes using aerial photography and satellite imagery in the Foothills Model Forest of Alberta. Canadian Journal Remote Sensing, 31(4), 304–313. https://doi.org/10.5589/m05-015

Aerial photographs acquired in 1948 - 1952, Corona "spy-satellite" imagery acquired in 1963, and Landsat multispectral scanner (MSS), thematic mapper (TM), and enhanced thematic mapper plus (ETM+) imagery acquired since 1974 were used to interpret land cover changes in the Foothills Model Forest of Alberta. The different image characteristics of aerial photographs and satellite sensor data require different analysis methods, but increasingly these data are being used together to determine changes in land cover and structure over a longer time period than is possible using satellite image data alone. The interpretations from this study suggest that in an active forest management area, conifer forest cover was reduced, broadleaf and mixed-forest cover was increased, and the forests were structured in smaller patches with greater edge density over the years circa 1950 - 1999. Another part of the study area, recovering from a major fire in the early part of the century, was interpreted to have experienced an increase in conifer forest area and mean patch size over this same time period. Overall, changes in the Foothills Model Forest landscape were relatively easily identified and deemed significant by resource managers; this study suggests additional work is warranted on understanding the effect of these changes in applications such as wildlife management.

Landcover, Change Detection, Satellite Imagery; Landsat; Forestry

Pape, A. D., & Franklin, S. E. (2008). MODIS-based change detection for grizzly bear habitat mapping in Alberta. Photogrammetric Engineering and Remote Sensing, 74(8), 973–985. https://doi.org/10.14358/PERS.74.8.973

Coarse resolution data from the Moderate Resolution Imaging Spectroradiometer (MODIS) was used to test the effectiveness of 250 m data to detect forest disturbances and update an existing, large-area (150,000 km^2), 30 m Landsat ETM+ and TM land-cover map product used in Grizzly Bear (*Ursus arctos*) habitat analysis. A Landsat-derived polygon layer was applied to the MOD13Q1 data product to create a polygon-based, mean NDVI time series (2000 to 2005). Image differencing of the dataset produced multiple-scale layers of change including a two-date, five-year change and a five-year composite of annual changes. Accuracy assessments based on available GIS data showed an overall accuracy as high as 59 percent. Results also show that disturbance patches larger than 15 ha were represented with an accuracy of 75 percent or higher. This offers an alternative to higher spatial resolution data for the identification of larger features and also provides general change information for those areas that may be suitable for analysis with higher spatial resolution data.

Disturbance; GIS Application; Landsat; MODIS; NDVI

McDermid, G. J., Linke, J., Pape, A. D., Laskin, D. N., Mclane, A. J., & Franklin, S. E. (2008). Object-based approaches to change analysis and thematic map update: challenges and limitations. Canadian Journal of Remote Sensing, 34(5), 462–466. https://doi.org/10.5589/m08-061

Bitemporal change analysis strategies performed in an object-based environment are prone to the generation of sliver objects: small, spurious polygons created by the inconsistent delineation of persistent change features appearing in consecutive coregistered images. The issue represents a serious methodological challenge that can limit the visual and structural quality of the finished map product if not adequately addressed. A critical analysis of annual land cover maps generated by updating and backdating object-based reference maps in a western Alberta study area revealed that sliver objects made up between 3% and 12% of the total area of change, and between 63% and 72% of the total number of change objects, despite high thematic accuracies. The results highlight the emerging need for a methodological framework designed to handle the spatial challenges posed by change analysis in an object-based environment.

Change Detection; Landcover

Linke, J., McDermid, G. J., Pape, A. D., McLane, A. J., Laskin, D. N., Hall-Beyer, M., & Franklin, S. E. (2009). The influence of patch-delineation mismatches on multi-temporal landscape pattern analysis. Landscape Ecology, 24(2), 157–170. https://doi.org/10.1007/s10980-008-9290-z

Investigations of land-cover change often employ metrics designed to quantify changes in landscape structure through time, using analyses of land cover maps derived from the classification of remote sensing images from two or more time periods. Unfortunately, the validity of these landscape pattern analyses (LPA) can be compromised by the presence of spurious change, i.e., differences between map products caused by classification error rather than real changes on the ground. To reduce this problem, multi-temporal time series of land-cover maps can be constructed by updating (projecting forward in time) and backdating (projecting backward in time) an existing reference map, wherein regions of change are delineated through bi-temporal change analysis and overlaid onto the reference map. However, this procedure itself creates challenges, because sliver patches can occur in cases where the boundaries of the change regions do not exactly match the land-cover patches in the reference map. In this paper, we describe how sliver patches can inadvertently be created through the backdating and updating of land-cover maps, and document their impact on the magnitude and trajectory of four popular landscape metrics: number of patches (NP), edge density (ED), mean patch size (MPS), and mean shape index (MSI). In our findings, sliver patches led to significant distortions in both the value and temporal behaviour of metrics. In backdated maps, these distortions caused metric trajectories to appear more conservative, suggesting lower rates of change for ED and inverse trajectories for NP, MPS and MSI. In updated maps, slivers caused metric trajectories to appear more extreme and exaggerated, suggesting higher rates of change for all four metrics. Our research underscores the need to eliminate sliver patches from any study dealing with multi-temporal LPA.

Landcover, Classification, Change Detection

Linke, J., McDermid, G. J., Laskin, D. N., McLane, A. J., Pape, A. D., Cranston, J., Hall-Beyer, M., & Franklin, S. E. (2009). A disturbance-inventory framework for flexible and reliable landscape monitoring. Photogrammetric Engineering and Remote Sensing, 75(8), 981–995. https://doi.org/10.14358/PERS.75.8.981

Remote sensing plays a key role in landscape monitoring, but our handling of these data in a multi-temporal time series is not yet fully developed. Of particular concern is the presence of spatial and thematic errors in independently created maps that distort measures of landscape pattern and constrain the reliability of change analysis. In addition, there is a need to incorporate continuous attributes of cover gradients for flexible map representations that support a variety of applications. In this paper, we present a framework for generating temporally and categorically dynamic land-cover maps that provide such a reliable and adaptable foundation. The centerpiece is a spatio-temporal disturbance-inventory database, created through semi-automated change detection and conditioned with boundary-matching procedures, which can be used to backdate and update both continuous and categorical reference maps. We demonstrate our approach using multi-annual Landsat imagery from a forested region in west-central Alberta, Canada, between the years 1998 and 2005.

Landsat, Map Product; GIS Application; Landcover, Disturbance; Landscape Monitoring

Linke, J., & McDermid, G. J. (2011). A conceptual model for multi-temporal landscape monitoring in an object-based environment. Journal of Selected Topics in Earth Observations and Remote Sensing, 4(2), 265–271. https://doi.org/10.1109/JSTARS.2010.2045881

Remote sensing plays a critical role in contemporary monitoring programs, but our strategies for processing these data using automated procedures are not always reliable. In particular, the task of separating real from spurious changes remains problematic, especially in an object-based environment where differential errors in classification quality, spatial registration, scene illumination, resolution, and object delineation have forced some operators to adopt labor-intensive visual-interpretation strategies, or employ manual interaction on an object-by-object basis. In this paper, we present an updated summary of our new disturbance-inventory approach to land-cover monitoring that combines object-based classification and change-detection strategies with boundary-conditioning routines designed to maximize the spatial and thematic integrity of the finished products. With this approach, the final maps are only altered in regions of confirmed change, and spurious gaps, slivers, stretches, and encroachments are avoided. The approach constitutes an innovative, efficient, and transparent framework that can handle all the basic landscape dynamics, including feature appearance, disappearance, succession, expansion, and shrinkage, without the need for manual editing.

Classification; Remote Sensing; Landscape Monitoring

Stewart, B. P., Wulder, M. A., McDermid, G. J., & Nelson, T. (2009). Disturbance capture and attribution through the integration of Landsat and IRS-1C imagery. Canadian Journal of Remote Sensing, 35(6), 523–533. https://doi.org/10.5589/m10-006

A primary activity required to support sustainable forest management is the detection and mitigation of forest disturbances. These disturbances can be planned, through urbanization and harvesting, or unplanned, through insect infestations or fire. Detection and characterization of disturbance types are important, as different disturbances have different ecological effects and may require unique managerial responses. As such, it is necessary for forest managers to have as complete and current information as possible to support decision making. In this study, we developed a framework to automatically detect and label disturbances derived from remotely sensed images. Disturbances were detected through traditional image differencing of medium-resolution imagery (Landsat-7 Enhanced Thematic Mapper Plus (ETM+), resampled to 30 m) but were refined and augmented through comparison with edge features extracted from high spatial resolution satellite imagery (Indian Remote Sensing (IRS) satellite 1C panchromatic imagery, resampled to 5 m). By incorporating spectral information, derived composite band values (tasselled cap transformations), spatial and contextual information, and secondary datasets, we were able to capture and label disturbance features with a high level of overall agreement (91%). Areal features, such as harvest areas, are captured and labelled more reliably than linear features such as roads, with 92% and 72% agreement when compared with control data, respectively. By incorporating rule-based disturbance attribution with remote sensing change detection, we envision the update of land cover databases with reduced human intervention, aiding more rapid data integration and opportunities for timely managerial responses.

Landsat; Indian Remote Sensing; GIS Application; Disturbance; Forestry; Classification

Hilker, T., Wulder, M. A., Coops, N. C., Linke, J., McDermid, G., Masek, J. G., Gao, F., & White, J. C. (2009). A new data fusion model for high spatial- and temporal- resolution mapping of forest disturbance based on Landsat and MODIS. Remote Sensing of Environment, 113(8), 1613–1627. https://doi.org/10.1016/j.rse.2009.03.007

Investigating the temporal and spatial pattern of landscape disturbances is an important requirement for modeling ecosystem characteristics, including understanding changes in the terrestrial carbon cycle or mapping the quality and abundance of wildlife habitats. Data from the Landsat series of satellites have been successfully applied to map a range of biophysical vegetation parameters at a 30 m spatial resolution; the Landsat 16 day revisit cycle, however, which is often extended due to cloud cover, can be a major obstacle for monitoring short term disturbances and changes in vegetation characteristics through time. The development of data fusion techniques has helped to improve the temporal resolution of fine spatial resolution data by blending observations from sensors with differing spatial and temporal characteristics. This study introduces a new data fusion model for producing synthetic imagery and the detection of changes termed Spatial Temporal Adaptive Algorithm for mapping Reflectance Change (STAARCH). The algorithm is designed to detect changes in reflectance, denoting disturbance, using Tasseled Cap transformations of both Landsat TM/ETM and MODIS reflectance data. The algorithm has been tested over a 185 x 185 km study area in west-central Alberta, Canada. Results show that STAARCH was able to identify spatial and temporal changes in the landscape with a high level of detail. The spatial accuracy of the disturbed area was 93% when compared to the validation data set, while temporal changes in the landscape were correctly estimated for 87% to 89% of instances for the total disturbed area. The change sequence derived from STAARCH was also used to produce synthetic Landsat images for the study period for each available date of MODIS imagery. Comparison to existing Landsat observations showed that the change sequence derived from STAARCH helped to improve the prediction results when compared to previously published data fusion techniques.

Change Detection; GIS Application; Disturbance; Landsat; MODIS

Hilker, T., Wulder, M. a., Coops, N. C., Seitz, N., White, J. C., Gao, F., Masek, J. G., & Stenhouse, G. (2009). Generation of dense time series synthetic Landsat data through data blending with MODIS using a spatial and temporal adaptive reflectance fusion model. Remote Sensing of Environment, 113(9), 1988–1999. https://doi.org/10.1016/j.rse.2009.05.011

Landsat imagery with a 30 m spatial resolution is well suited for characterizing landscape-level forest structure and dynamics. While Landsat images have advantageous spatial and spectral characteristics for describing vegetation properties, the Landsat sensor's revisit rate, or the temporal resolution of the data, is 16 days. When considering that cloud cover may impact any given acquisition, this lengthy revisit rate often results in a dearth of imagery for a desired time interval (e.g., month, growing season, or year) especially for areas at higher latitudes with shorter growing seasons. In contrast, MODIS (MODerate-resolution Imaging Spectroradiometer) has a high temporal resolution, covering the Earth up to multiple times per day, and depending on the spectral characteristics of interest, MODIS data have spatial resolutions of 250 m, 500 m, and 1000 m. By combining Landsat and MODIS data, we are able to capitalize on the spatial detail of Landsat and the temporal regularity of MODIS acquisitions. In this research, we apply and demonstrate a data fusion approach (Spatial and Temporal Adaptive Reflectance Fusion Model, STARFM) at a mainly coniferous study area in central British Columbia, Canada. Reflectance data for selected MODIS channels, all of which were resampled to 500 m, and Landsat (at 30 m) were combined to produce 18 synthetic Landsat images encompassing the 2001 growing season (May to October). We compared, on a channel-by-channel basis, the surface reflectance values (stratified by broad land cover types) of four real Landsat images with the corresponding closest date of synthetic Landsat imagery, and found no significant difference between real (observed) and synthetic (predicted) reflectance values (mean difference in reflectance: mixed forest $\bar{x}$ = 0.086, σ = 0.088, broadleaf $\bar{x}$ = 0.019, σ = 0.079, coniferous $\bar{x}$ = 0.039, σ = 0.093). Similarly, a pixel based analysis shows that predicted and observed reflectance values for the four Landsat dates were closely related (mean r^2 = 0.76 for the NIR band; r^2 = 0.54 for the red band; $P < 0.01$). Investigating the trend in NDVI values in synthetic Landsat values over a growing season revealed that phenological patterns were well captured; however, when seasonal differences lead to a change in land cover (i.e., disturbance, snow cover), the algorithm used to generate the synthetic Landsat images was, as expected, less effective at predicting reflectance.

Satellite Imagery; Phenology; MODIS

Hilker, T., Coops, N. C., Gaulton, R., Wulder, M. A., Cranston, J., & Stenhouse, G. B. (2011). Biweekly disturbance capture and attribution: case study in western Alberta grizzly bear habitat. Journal of Applied Remote Sensing, 5(1), 053568. https://doi.org/10.1117/1.3664342

An increasing number of studies have demonstrated the impact of landscape disturbance on ecosystems. Satellite remote sensing can be used for mapping disturbances, and fusion techniques of sensors with complimentary characteristics can help to improve the spatial and temporal resolution of satellite-based mapping techniques. Classification of different disturbance types from satellite observations is difficult, yet important, especially in an ecological context as different disturbance types might have different impacts on vegetation recovery, wildlife habitats, and food resources. We demonstrate a possible approach for classifying common disturbance types by means of their spatial characteristics. First, landscape level change is characterized on a near biweekly basis through application of a data fusion model (spatial temporal adaptive algorithm for mapping reflectance change) and a number of spatial and temporal characteristics of the predicted disturbance patches are inferred. A regression tree approach is then used to classify disturbance events. Our results show that spatial and temporal disturbance characteristics can be used to classify disturbance events with an overall accuracy of 86% of the disturbed area observed. The date of disturbance was identified as the most powerful predictor of the disturbance type, together with the patch core area, patch size, and contiguity.

Landsat; MODIS; GIS Application; Change Detection; Disturbance; Map Product; Forest Harvest

Gaulton, R., Hilker, T., Wulder, M. A., Coops, N. C., & Stenhouse, G. (2011). Characterizing stand-replacing disturbance in western Alberta grizzly bear habitat, using a satellite-derived high temporal and spatial resolution change sequence. Forest Ecology and Management, 261(4), 865–877. https://doi.org/10.1016/j.foreco.2010.12.020

Timely and accurate mapping of anthropogenic and natural disturbance patterns can be used to better understand the nature of wildlife habitats, distributions and movements. One common approach to map forest disturbance is by using high spatial resolution satellite imagery, such as Landsat 5 Thematic Mapper (TM) or Landsat 7 Enhanced Thematic Mapper plus (ETM+) imagery acquired at a 30m spatial resolution. However, the low revisit times of these sensors acts to limit the capability to accurately determine dates for a sequence of disturbance events, especially in regions where cloud contamination is a frequent occurrence. As wildlife habitat use can vary significantly seasonally, annual patterns of disturbance are often insufficient in assessing relationships between disturbance and foraging behaviour or movement patterns. The Spatial Temporal Adaptive Algorithm for mapping Reflectance Change (STAARCH) allows the generation of high-spatial (30m) and -temporal (weekly or bi-weekly) resolution disturbance sequences using fusion of Landsat TM or ETM+ and Moderate Resolution Imaging Spectroradiometer (MODIS) imagery. The STAARCH algorithm is applied here to generate a disturbance sequence representing stand-replacing events (disturbances over 1 ha in area) for the period 2001 - 2008, over almost 6 million ha of grizzly bear habitat along the eastern slopes of the Rocky Mountains in Alberta. The STAARCH algorithm incorporates pairs of Landsat images to detect the spatial extent of disturbances; information from the bi-weekly MODIS composites is used in this study to assign a date of disturbance (DoD) to each detected disturbed area. Dates of estimated disturbances with areas over 5 ha are validated by comparison with a yearly Landsat-based change sequence, with producer's accuracies ranging between 15 and 85% (average overall accuracy 62%, kappa statistic of 0.54) depending on the size of the disturbance event. The spatial and temporal patterns of disturbances within the entire region and in smaller subsets, representative of the size of a grizzly bear annual home range, are then explored. Disturbance levels are shown to increase later in the growing season, with most disturbances occurring in late August and September. Individual events are generally small in area (<10 ha) except in the case of wildfires, with, on average, 0.4% of the total area disturbed each year. The application of STAARCH provides unique high temporal and spatial resolution disturbance information over an extensive area, with significant potential for improving understanding of wildlife habitat use.

Change Detection; GIS Application; Forest Harvest; Landsat; MODIS; Landscape Monitoring; Forestry; Disturbance

White, J. C., Wulder, M. A., Gomez, C., & Stenhouse, G. (2011). A history of habitat dynamics: Characterizing 35 years of stand replacing disturbance. Canadian Journal of Remote Sensing, 37(2), 234–251. https://doi.org/10.5589/m11-034

Landscape change, specifically habitat loss and modification, is thought to have an impact on the health, productivity, distribution, and survival of grizzly bears (*Ursus arctos* L.). Although grizzly bears may preferentially seek out areas of anthropogenic disturbances for foraging opportunities, research has found that grizzly bears experience greater mortality in these areas as a result of increased human access. Additional insights on the location and rates of anthropogenic-driven landscape change are required to better understand related impacts upon grizzly bears. In this study, a time series of 14 Landsat MSS, TM, and ETM+ images were used to retrospectively document and quantify the rate of landscape change over a 35-year period from 1973 to 2008 in a 13 507 km^2 analysis area in western Alberta, Canada. The study area is located within a larger region that contains the highest density of grizzly bears in Alberta and has experienced increasingly intensive forest harvesting and oil and gas exploration activities during this period. To accommodate the differing spectral channels from MSS to TM/ETM+ sensors, the arctangent of the angle of the Tasseled Cap greenness-to-brightness components was computed for each image year, with sequential image pairs differenced and a threshold applied to identify stand-replacing disturbance events. Results indicated that 11% of the analysis area experienced some form of stand-replacing disturbance (e.g., cutblocks, roads, oil and gas well sites, seismic lines, power lines, pipelines, blowdown) between 1973 and 2008.The greatest proportion of this change (by area) occurred between 2004 and 2006 (24%), while the lowest proportion occurred between 2000 and 2001 (2%). Although the number of change events has fluctuated over time, with a minimum of 2888 change events between 1976 and 1978 (2%) and a maximum of 36 623 change events between 2004 and 2006 (29%), the mean size of change events has decreased over time: prior to 1995, mean event size was greater than 1.5 ha; after 1995, it was less than 1.5 ha. The annual rate of change was greatest between 2004 and 2006 (-1.25%), and lowest between 1981 and 1990 (-0.04%). Consideration of changes within the context of units relevant to grizzly bear management (i.e., grizzly bear watershed units and core or secondary habitat areas) indicate that the amount and rate of change was not spatially or temporally uniform across the study area. While the average change event size has decreased over time, the increasing number of change events has resulted in a larger aggregate area of change in more recent years. Landsat imagery provided a large-area, synoptic, and consistent characterization of 35 years of stand-replacing disturbance in our study area, providing information that enables an improved understanding of the complex interactions between grizzly bear distribution, abundance, health, survival, and habitat.

Change Detection; Landsat; Disturbance

Linke, J., & McDermid, G. J. (2012). Monitoring landscape change in multi-use west-central Alberta, Canada using the disturbance-inventory framework. Remote Sensing of Environment, 125, 112–124. https://doi.org/10.1016/j.rse.2012.07.011

Human disturbances are a major driver of biodiversity declines world-wide, and the intensely used Alberta forest landscape is no exception to this trend. Monitoring of such large areas is typically conducted via multi-temporal land-cover maps from remote sensing, but automated and efficient procedures for reliable, operational applications have yet to be fully developed. In an effort to contribute to this need, we developed an innovative approach to landscape monitoring: the disturbance-inventory framework, which is applied for the first time as described here to monitor annual changes in an 8800-km^2 multi-use landscape in west-central Alberta, Canada. Using this framework, we (1) report on the spatio-temporal distribution of industrial disturbances such as harvesting cutblocks, oil and gas wells, coal mines, and road/pipelines; and (2) track the associated annual changes in land-cover composition and configuration between 1998 and 2005. To enable spatially explicit analyses within the study area, we divided it into 178, 49 km^2-square landscape cells. The overall area-based annual rate of change of 0.62% for this multi-use may be considered moderate compared to other regions, where change was mainly shaped by a single use, i.e., forestry. However, the spatially explicit nature of our analysis revealed that the eastern half of the study area is subject to considerably higher rates of change, mainly due to the concurrent appearance of disturbances from forestry and the oil and gas industry. The western half, by contrast, is more restricted by rugged terrain and fewer roads. The average distance to disturbance features across the entire study area decreased from 1500 m to 1200 m over the seven years. Total forest area, mean and largest patch size, and mean shape index all decreased consistently over the same period. The detected rapid change and associated fragmentation call for ongoing monitoring of this and other multi-use landscapes, which could be undertaken using this framework.

Forestry; Landcover; GIS Application; Change Detection; Remote Sensing; Oil and Gas; Roads; Disturbance; Landscape Monitoring

White, C. F. H., Coops, N. C., Nijland, W., Hilker, T., Nelson, T. A., Wulder, M. A., Nielsen, S. E., & Stenhouse, G. (2014). Characterizing a Decade of Disturbance Events Using Landsat and MODIS Satellite Imagery in Western Alberta, Canada for Grizzly Bear Management. Canadian Journal of Remote Sensing, 40(5), 336–347. https://doi.org/10.1080/07038992.2014.987082

Mapping and quantifying the area and type of disturbance within forests is critical for sustainable forest management. Grizzly bear (*Ursus arctos*) have large home ranges and diverse habitat needs and as a result, information on the extent, type, and timing of disturbances is important. In this research we apply a remote-sensing-based disturbance mapping technique to the southeastern extent of a grizzly bear range. We apply a data fusion approach with MODIS 250 m and Landsat 30 m spatial resolution imagery to map disturbances biweekly from 2001 - 2011. A regression tree classifier was applied to classify the disturbance events based on spatial and temporal characteristics. Fire was attributed as a disturbance based on a national fire database. Results indicate that across the 130,727 km^2 study area, 4,603 km^2 of forest were disturbed over the past decade (2001 - 2011), impacting 0.35% of the study area annually. Overall, 68.7% of the disturbance events were attributed to forest harvest, followed by well sites 13.4%, fires 9.3% and road development, 8.6%. Primary source habitat contained 3.8% of disturbed land, and primary sink areas had 5.9% disturbed land. Our findings quantify habitat change, which can aid managers by identifying significant areas for grizzly bear conservation.

Landsat; MODIS; Disturbance; Management Areas; Forestry; Oil and Gas; Roads

Bourbonnais, M. L., Nelson, T. A., Stenhouse, G. B., Wulder, M. A., White, J. C., Hobart, G. W., Hermosilla, T., Coops, N. C., Nathoo, F., & Darimont, C. (2017). Characterizing spatial-temporal patterns of landscape disturbance and recovery in western Alberta, Canada using a functional data analysis approach and remotely sensed data. Ecological Informatics, 39, 140–150. https://doi.org/10.1016/j.ecoinf.2017.04.010

Landscape regionalization approaches are frequently used to summarize and visualize complex spatial patterns, environmental factors, and disturbance regimes. However, landscapes are dynamic and contemporary regionalization approaches based on spatial patterns often do not account for the temporal component that may provide important insight on disturbance, recovery, and how ecological processes change through time. The objective of this research was to quantify spatial patterns of disturbance and recovery over time for use as inputs in a regionalization that characterizes unique spatial-temporal trajectories of disturbance in western Alberta, Canada. Cumulative spatial patterns of disturbance, representing the proportion, arrangement, size, and number of disturbances, and adjusted annually for spectral recovery, were quantified in 223 watersheds using a Landsat time series dataset where disturbance events are detected and classified annually from 1985 to 2011. Using a functional data analysis approach, disturbance patterns metrics were modelled as curves and scores from a functional principal components analysis were clustered using a Gaussian finite mixture model. The resulting eight watershed clusters were mapped with mean curves representing the temporal trajectory of disturbance. The cumulative mean disturbance pattern metric curves for each cluster showed considerable variability in curve amplitude which generally increased markedly in the mid-1990's, while curve amplitude remained low in parks and protected areas. A comparison of mean curves by disturbance type (e.g., fires, harvest, non-stand replacing, roads, and well-sites) using a functional analysis of variance showed that anthropogenic disturbance contributed substantially to curve amplitude in all clusters, while curve amplitude associated with natural disturbances was generally low. These differences enable insights regarding how cumulative spatial disturbance patterns evolve through time on the landscape as a function of the type of disturbance and rates of recovery.

Disturbance; GIS Application; Forestry; Oil and Gas; Roads; Landsat

Kearney, S. P., Coops, N. C., Sethi, S., & Stenhouse, G. B. (2020). Maintaining accurate, current, rural road network data: An extraction and updating routine using RapidEye, participatory GIS and deep learning. International Journal of Applied Earth Observation and Geoinformation, 87, 102031. https://doi.org/10.1016/j.jag.2019.102031

Accurate and current road network data is fundamental to land management and emergency response, yet challenging to produce for unpaved roads in rural and forested regions using traditional cartographic approaches. Automatic extraction of roads from satellite imagery using deep learning is a promising alternative gaining increasing attention, however most efforts have focused on urban paved roads and used very high spatial resolution imagery, which is less frequently available for rural regions. Additionally, road extraction routines still struggle to produce a fully-connected, vectorized road network. In this study covering a large forested area in Western Canada, we developed and evaluated a routine to automatically extract unpaved road pixels using a convolutional neural network (CNN), and then used the CNN outputs to update a pre-existing government road network and evaluate if and how it would change. To cover the large spatial extent mapped in this study, we trained the routine using moderately high-resolution satellite imagery from the RapidEye constellation and a ground-truth dataset collected with smartphones by organizations already operating and driving in the region. Performance of the road extraction was comparable to results achieved by others using very high-resolution imagery; recall accuracy was 89-97%, and precision was 85-91%. Using our approach to update the pre-existing road network would result in both removals and additions to the network, totalling over 1250 km, or about 20 % of the roads previously in the network. We discuss how road density estimates in the study area would change using this updated network, and situate these changes within the context of ongoing efforts to conserve grizzly bears, which are listed as a Threatened species in the region. This study demonstrates the potential of remote sensing to maintain current and accurate rural road networks in dynamic forest landscapes where new road construction is prevalent, yet roads are also frequently de-activated, reclaimed or otherwise not maintained.

RapidEye; GIS Application; Roads; Satellite Imagery

LANDSCAPE STRUCTURE

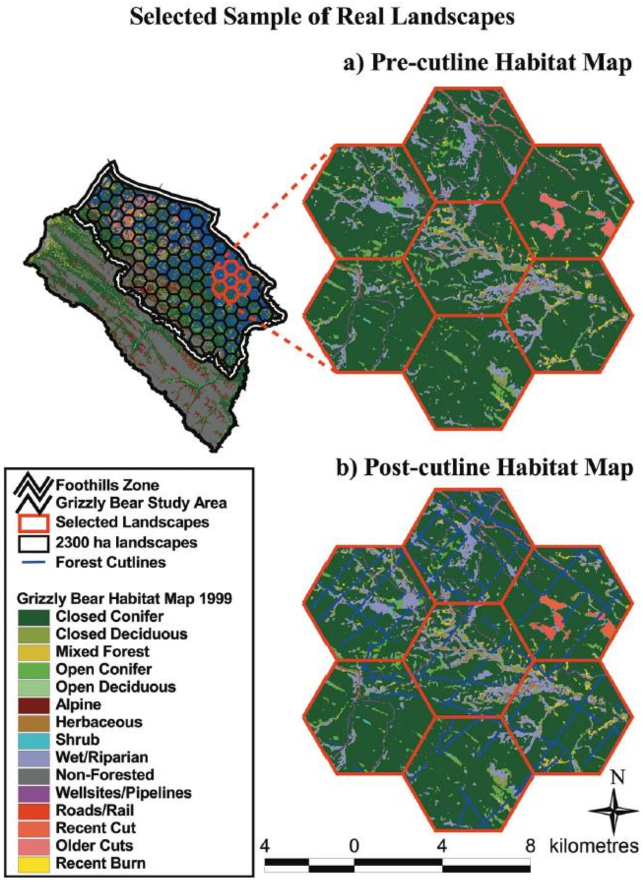

Figure 6. Selected sample of real landscapes showing (a) pre-cutline and (b) post-cutline representations of the grizzly bear land-cover map. Figure from Linke et al. 2008, p. 26.

Here, we look at finer scale classification, no longer focusing on broad scale habitat type but on determining forest structure.

Wunderle, A. L., Franklin, S. E., & Guo, X. G. (2007). Regenerating boreal forest structure estimation using SPOT-5 pansharpened imagery. International Journal of Remote Sensing, 28(19), 4351–4364. https://doi.org/10.1080/01431160701244849

Forested stand structure is an important target variable within the fields of wildlife ecology. Remote sensing has often been suggested as a viable alternative to time consuming field and aerial investigations to determine forest structural attributes. In this study, 44 stands of recently harvested, regenerating, and old growth forest within the Foothills Model Forest in west-central Alberta were selected to test the ability of pan-sharpened SPOT-5 spectral response to classify stand structure. For each stand, a Structural Complexity Index (SCI) was calculated from field data using principal components analysis. To complement the spectral response data set and further increase accuracy, the normalized difference moisture index (NDMI) and three window sizes (5 x 5, 11 x 11, and 25 x 25) of first- (mean and standard deviation) and second-order (homogeneity, entropy, contrast, and correlation) textural measures were calculated over the pan-sharpened image. Stepwise multivariate regression analysis was used to determine the best explanatory model of the SCI using the spectral and textural data. The NDMI, first-order standard deviation and second-order correlation texture measures were better able to explain differences in SCI among the 44 forest stands (r^2 = 0.79). The most appropriate window size for the texture measures was 5 x 5 indicating that this is a measure only detectable at a very high spatial resolution. The resulting classified SCI values were comparable to the actual field level SCI (r^2 = 0.74, p = 0.01) and were limited by the strong variability within stands. Future research may find this measure useful either as a separate parameter or as an indicator of forest age for use in wildlife habitat modelling.

Forest Structure; SPOT; Satellite Imagery

McLane, A. J., McDermid, G. J., & Wulder, M. A. (2009). Processing discrete-return profiling LiDAR data to estimate canopy closure for large-area forest mapping and management. Canadian Journal of Remote Sensing, 35(3), 217–229. https://doi.org/10.5589/m09-009

We performed a series of empirical experiments designed to refine the processing of discrete-return profiling light detection and ranging (lidar) data for the purpose of estimating canopy closure across a broad range of forest conditions in west-central Alberta, Canada. The following three methodological conclusions were obtained: (i) a new line- segment method based on the ratio of overstory segment distance to total distance outperformed alternative point-count techniques described previously in the literature; (ii) an absolute overstory-understory threshold of 1.4 m generated the best models overall and appeared to extend well across a range of forest types; and (iii) stratification by species composition (hardwood, softwood, and mixedwood) or moisture regime (upland and wetland) was of little influence in alternate models, suggesting good portability of these methods across a broad variety of forest conditions. A k = n cross-validation approach produced an average root mean square error (RMSE) of 7.2% for the best model with no systematic bias. In addition to contributing to the identification of sound methodological practices, these results successfully reconciled the conceptual differences between canopy closure, measured through the use of ground-based optical tools, and canopy cover, captured remotely with lidar, revealing a direct linear relationship between the two attributes.

Lidar; Forest Structure; Habitat Mapping

Linke, J., Franklin, S. E., Hall-Beyer, M., & Stenhouse, G. B. (2008). Effects of cutline density and land-cover heterogeneity on landscape metrics in western Alberta. Canadian Journal of Remote Sensing, 34(4), 390–404. https://doi.org/10.5589/m08-034

Forest cutlines are narrow, linear features created in geophysical surveys. In many areas of Canada, forest cutlines are not consistently detected using relatively coarse spatial resolution land-cover maps, such as those produced by classification of Landsat Thematic Mapper (TM) imagery. However, such features may be important in certain wildlife management applications, including those which require an assessment of landscape structure, or forest fragmentation, at various scales. Higher spatial resolution satellite imagery obtained from sensors on platforms such as Satellite Pour l'Observation de la Terre (SPOT) and the Indian Remote Sensing (IRS) system may be used to map forest cutlines for these applications. In this study, a TM-based land-cover map of western Alberta is analyzed with forest cutlines mapped from a TM-IRS fusion image, and the effect of increasing cutline density is quantified on five commonly used landscape metrics used to characterize landscape structure in grizzly bear habitat assessment. The accuracy of the fusion image interpretation was determined to be 88%. Simulated landscapes were tested first, and the study area was divided into 104 hexagon-shaped sample landscapes of about 6 km diameter each. Across these sample landscapes, cutline density and initial landscape heterogeneity were significant parameters in explaining change in three metrics, namely edge density, mean patch size, and patch context (expressed as mean nearest-neighbour distance). Patch size variability (expressed as the coefficient of variation of mean patch size) and patch dispersion (expressed as the coefficient of variation of mean nearest-neighbour distance) required additional information on cutline positioning. Overall, the density of the introduced cutline network and the pre-cutline metric value reliably predicted and quantified the response of landscape metrics of interest to grizzly bear biologists. This study shows the importance of mapping forest cutlines regarding their role in changing landscape structure quantification and points out the necessity of using additional remotely sensed data when the feature responsible for the landscape transformation is of too small a size to appear reliably in common TM-based classified imagery.

Oil and Gas; SPOT; Landsat; Indian Remote Sensing; Disturbance; Landcover

Wulder, M. A., Stewart, B. P., Andrew, M. E., Smulders, M., Nelson, T., Coops, N. C., & Stenhouse, G. B. (2009). Remote sensing derived edge location, magnitude, and class transitions for ecological studies. Canadian Journal of Remote Sensing, 35(6), 509–522. https://doi.org/10.5589/m10-007

Regionally intensive human activities related to resource extraction (i.e., harvesting, oil and gas extraction) are increasing the occurrence of edges found in some forested landscapes. Edges between different land cover types represent important transition zones for abiotic and biotic processes. However, boundary detection methods often identify edges solely in areas of high contrast, such as transitions between forest and non-forest areas, and are insensitive to the relative contrast and orientation of different transitions. Edge contrast and orientation can determine the magnitude and even the occurrence of ecological edge effects and should be measured to provide information on landscape condition and habitat potential. Wombling was applied to the wetness component of a tasselled cap transformation (TCT) of a Landsat scene acquired over a portion of the eastern slopes of the Rocky Mountains in Alberta, Canada. By incorporating wombled edge contrast and orientation, and edge class transition type obtained from a land cover dataset, the nature of all transitions between land cover classes within the image was characterized and quantified. The consistency between edges identified by wombling and other common methods of edge delineation (such as spatial clustering) and methods of edge quantification (such as landscape pattern indices, or LPIs) was also assessed. Land cover transitions showed a broad range of edge contrast. Comparisons of edge contrast and the LPI edge density showed a positive correlation (r^2 = 0.33); however, the strength of this relationship varied with the dominant land cover type (e.g., r^2 = 0.016 for broadleaf open forest to r^2 = 0.48 for dense coniferous forest). Stratifying edge contrast to higher values (i.e., >1 standard deviation) increased agreement with edge density, indicating that the LPI is preferentially relating high contrast edges. This study demonstrates how unique edge characteristics may be generated from a remotely sensed continuous variable (TCT wetness). This knowledge of the location, magnitude, and class transitions found at edges provides insights into the nature of the edge effects and enables the development and testing of hypotheses informing wildlife habitat use and selection.

Edge; Landsat; Forest Structure; Disturbance

He, Y., Franklin, S. E., Guo, X., & Stenhouse, G. B. (2009). Narrow-linear and small-area forest disturbance detection and mapping from high spatial resolution imagery. Journal of Applied Remote Sensing, 3(1), 033570. https://doi.org/10.1117/1.3283905

Widespread disturbance has brought a large amount of narrow-linear and small-area disturbance features (e.g., trails, seismic lines, forest roads, well sites, and cut blocks) to forest areas throughout the past decade. This issue has prompted research into finding the appropriate data and methods for mapping these narrow-linear and small- area disturbance features in order to examine their impacts on wildlife habitat. In this paper, we first described the characteristics of small forest disturbances and presented the nature of problem. We then presented a framework for detecting and extracting narrow-linear and small-area forest disturbance features. Using a SPOT 5 high spatial detail image and existing GIS databases, we applied the framework to map narrow-linear and small-area forest disturbance features in a Bear Management area (BMA) in the eastern slopes of the Rocky Mountains in Alberta, Canada. The results indicated that the proposed framework produced accurate disturbance maps for cut blocks, and forest roads & trails. The high errors of omission in the cut lines map were attributed to inconsistent geometric and radiometric patterns in the 'rarely-used' or 'old' cut lines. The study confirmed the feasibility of rapidly updating incomplete GIS data with linear and small-area disturbance features extracted from high spatial detail SPOT imagery. Future work will be directed towards improvement of the framework and the extraction strategy to remove a large amount of spurious features and to increase accuracy for cut lines mapping.

Forest Structure; GIS Application; SPOT; Roads; Oil and Gas; Recreation; Forestry

He, Y., Franklin, S. E., Guo, X., & Stenhouse, G. B. (2011). Object-oriented classification of multi-resolution images for the extraction of narrow linear forest disturbance. Remote Sensing Letters, 2(2), 147–155. https://doi.org/10.1080/01431161.2010.504755

Narrow linear forest disturbances (e.g. seismic cut lines) have been found to have significant effects on wildlife habitat and biodiversity (e.g. species richness and abundance). A great deal of seismic cut lines is created in oil and gas exploration in natural forest areas every year. Accurate mapping of seismic cut lines can therefore contribute to a better understanding of wildlife habitat and biodiversity. However, previous studies have indicated that seismic cut lines were fairly difficult to detect and map even with the available high-spatial resolution imagery (e.g. Satellite Pour l'Observation de la Terre, SPOT 5). Recent progress in feature segmentation and extraction software, such as Definiens Developer 7.0, has enhanced remote sensing capabilities, with the promise of being able to automate tasks. This study investigated the imagery (high resolution or very high resolution) best suited for extracting seismic cut lines using a set of rules and multi-resolution object-oriented classification methods. The data used include SPOT 5 and QuickBird multispectral images and existing Geographic Information System (GIS) databases within one bear management area (BMA) in the eastern slopes of the Rocky Mountains in Alberta. Results indicated that among the available algorithms in the Definiens Developer 7.0 package, the Lee sigma algorithm was capable of highlighting cut lines using the near-infrared (NIR) band of the SPOT 5 image and the QuickBird image. The multi-resolution segmentation was able to segment fresh cut lines when giving higher weight to the Lee sigma edge extraction layer, and the nearest- neighbour object-oriented classifier was able to classify linear features, but with noise. Classification accuracy increased following the post-classification refinement processing. The accuracy assessment indicated that, in the case of delineating fresh cut lines, the higher resolution QuickBird image performed better than SPOT 5. However, neither the QuickBird image nor the SPOT 5 image could accurately delineate relatively old cut lines.

SPOT; QuickBird; GIS Application; Forest Structure; Oil and Gas

Parsons, B. M., Coops, N. C., Stenhouse, G. B., Burton, A. C., & Nelson, T. A. (2020). Building a perceptual zone of influence for wildlife: delineating the effects of roads on grizzly bear movement. European Journal of Wildlife Research, 66(4), 1–16. https://doi.org/10.1007/s10344-020-01390-1

To monitor the extent and impact of human disturbances on landscapes and wildlife, managers often estimate zones of influence. Traditionally, zones of influence have been defined with constant width buffers around a disturbance; however, the importance of incorporating variation in landscape contexts and species responses is increasingly recognized. One way to better develop and apply these zones of influence is to understand the mechanisms of animal response to disturbance by examining their sensory detection. We explored the role of perception in wildlife responses to disturbances using a case study with grizzly bears (*Ursus arctos*) and roads in Alberta, Canada. Our objectives were, first, to model viewsheds and soundscapes around roads and, second, to determine the effect of road perception on grizzly bear movement patterns and build context-specific zones of influence for grizzly bears around roads. Results indicate that zones of influence varied widely between the standard buffer approach and our novel approach based on animal perception. In addition, response distances of bears to roads were greater in areas where roads were perceptible than areas where roads were imperceptible. Estimating a perceptual zone of influence allows managers to prioritize areas for mitigating human disturbances. Our methods may be applied to new disturbances, areas, and species. We recommend measures of perception be used to create more biologically and geographically relevant zones of influence for wildlife.

Disturbance; GIS Application; Forestry; Forest Structure; Lidar; Roads

Vegetation Distribution

Figure 7. Two project grizzly bears forage on the edge of a cutblock. Roads and cutblocks are both associated with abundant grizzly bear foods.

These studies describe research into the factors contributing to the spatial distribution of grizzly bear food resources, mainly vegetation.

Nielsen, S. E., Munro, R. H. M., Bainbridge, E. L., Stenhouse, G. B., & Boyce, M. S. (2004). Grizzly bears and forestry II. Distribution of grizzly bear foods in clearcuts of west-central Alberta, Canada. Forest Ecology and Management, 199(1), 67–82. https://doi.org/10.1016/j.foreco.2004.04.015

We assessed the occurrence and fruit production of 13 grizzly bear foods in west-central Alberta, Canada, to better understand use of clearcuts by grizzly bears. Comparisons were made between clearcuts and upland forest stands, while specific models describing food or fruit occurrence within clearcuts were developed from canopy, clearcut age, scarification, and terrain-related variables using logistic regression. Ants, *Equisetum* spp., *Hedysarum* spp., *Taraxacum officinale*, *Trifolium* spp., and *Vaccinium myrtilloides* occurred with greater frequency in clearcuts, while *V. caespitosum*, *V. membranaceum*, and *V. vitis-idaea* were more likely to occur in upland forests. No differences were evident for *Arctostaphylos uva-ursi*, *Heracleum lanatum, Shepherdia canadensis*, and ungulate pellets, an indicator of ungulate abundance. Mechanical scarification negatively impacted the occurrence of *A. uva-ursi, Hedysarum* spp., and *S. canadensis*, while weaker effects were apparent for ants and ungulate pellets. In contrast, the occurrence of *Taraxacum officinale* and *Trifolium* spp. were greater in scarified clearcuts. Age of clearcut or canopy cover was well correlated with the occurrence of most foods. For some species, however, terrain-derived variables predicted occurrence best. Fit and model classification accuracy using independent data proved good for most species. Patterns of fruit occurrence were related to canopy cover, with little support for other environmental covariates. In total, average fruit production for six fruit-bearing species was estimated at 22.9 kg/ha for clearcuts and 32.3 kg/ha for forests, a non- significant difference and generally less than that reported elsewhere in grizzly bear range. *V. caespitosum* and *V. membranaceum complex* had higher fruit production in clearcuts, while *V. vitis-idaea* had greater fruit production in forests. No difference in fruit production between clearcuts and forests was evident for the remaining species. Overall, we found that clearcuts provided a diverse array of food resources for grizzly bears, particularly roots and tubers, herbaceous materials, and ants. Although fruit production was similar between clearcuts and forests, the occurrence of other food resources likely explains the seasonal use of clearcuts by grizzly bears. We suggest that forest design and silviculture consider strategies that maximize grizzly bear food abundance, while minimizing human access. Further enhancement of foods negatively impacted by silvicultural treatments may be required.

Forestry; Food; Silviculture

Roever, C. L., Boyce, M. S., & Stenhouse, G. B. (2008). Grizzly bears and forestry I: Road vegetation and placement as an attractant to grizzly bears. Forest Ecology and Management, 256(6), 1253–1261. https://doi.org/10.1016/j.foreco.2008.06.040

Today's growing demand for timber is increasing road development in once roadless forest ecosystems. Roads create both local changes in plant communities and landscape-level changes in forest connectivity. Roads also increase human access, which can be detrimental to species such as grizzly bears. Because most grizzly bear mortalities occur near roads, we examined grizzly bear attractants near roads, which could increase bear use of roadsides and consequently increase human/grizzly bear interactions. We measured the prevalence of 16 grizzly bear foods near roads and examined patterns in road placement to better understand use of roaded habitats by grizzly bears in west-central Alberta. We found that roadsides had a higher frequency of ants, *Equisetum* spp., *Taraxicum officinale*, *Trifolium* spp., graminoids, and sedges; whereas, interior forest stands had a higher frequency of *Shepherdia canadensis*, *Vaccinium myrtilloides*, *V. vitis-idaea*, and ungulate pellets, an indicator of ungulate presence. In addition, roads near water had a greater occurrence of *Arctostaphylos uva-ursi* and *Equisetum* spp. than roads not near water, indicating that road placement influenced bear food diversity. Patterns in road placement varied between the upper and lower foothills, although models for the lower foothills predicted road placement in both regions. In the lower foothills, roads were constructed at low elevation, low soil moisture, high sun exposure, and intermediate terrain ruggedness, possibly similar to sites selected by bears. Reducing grizzly bear foods near roads should involve decreasing the width of roadside ditches, banning the planting of clover (*Trifolium* spp.), and reevaluating road placement in areas with high grizzly bear density.

Roads; Forestry; Food; Vegetation

Nijland, W., Nielsen, S. E., Coops, N. C., Wulder, M. A., & Stenhouse, G. B. (2014). Fine-spatial scale predictions of understory species using climate- and LiDAR-derived terrain and canopy metrics. Journal of Applied Remote Sensing, 8(1), 083572. https://doi.org/10.1117/1.JRS.8.083572

Food and habitat resources are critical components of wildlife management and conservation efforts. The grizzly bear (*Ursus arctos*) has diverse diets and habitat requirements particularly for understory plant species, which are impacted by human developments and forest management activities. We use light detection and ranging (LiDAR) data to predict the occurrence of 14 understory plant species relevant to bear forage and compare our predictions with more conventional climate- and land cover-based models. We use boosted regression trees to model each of the 14 understory species across 4435 km^2 using occurrence (presence - absence) data from 1941 field plots. Three sets of models were fitted: climate only, climate and basic land and forest covers from Landsat 30-m imagery, and a climate- and LiDAR-derived model describing both the terrain and forest canopy. Resulting model accuracies varied widely among species. Overall, 8 of 14 species models were improved by including the LiDAR-derived variables. For climate-only models, mean annual precipitation and frost-free periods were the most important variables. With inclusion of LiDAR-derived attributes, depth-to-water table, terrain-intercepted annual radiation, and elevation were most often selected. This suggests that fine-scale terrain conditions affect the distribution of the studied species more than canopy conditions.

Food; Lidar; Species Distribution Models; Vegetation

Larsen, T. A., Nielsen, S. E., Cranston, J., & Stenhouse, G. B. (2019). Do remnant retention patches and forest edges increase grizzly bear food supply? Forest Ecology and Management, 433, 741–761. https://doi.org/https://doi.org/10.1016/j.foreco.2018.11.031

Grizzly bears should benefit from forest harvesting strategies that emulate patterns of natural disturbance, such as wildfire, presumably because of increased foraging opportunities associated with open and edge habitats. Several studies have linked early seral habitats associated with natural and anthropogenic disturbances to increased food supply for grizzly bear. However, few have quantitatively evaluated whether food supply is higher along forest edges, particularly edges created by different forest harvesting strategies such as structure retention. Here we tested whether grizzly bear food supply was: 1) more common/abundant along forest harvest (cutblock) edges; 2) similar between undisturbed forest matrix (uncut) undisturbed forest remnants (i.e., retention patches) that were situated within forest harvests; and 3) similar in terms of responses relative to retention and forest harvest edges. To address these questions, we measured the distribution and abundance of plant-based food resources used by grizzly bears along edge distance gradients associated with to three forest treatments (cutblock, uncut forest, and retention patch) in Alberta, Canada. We then used information theory to compare models and evaluate support for factors. We found that blueberry (*Vaccinium membranaceum*, *V. myrtilloides*, and *V. vitis-idaea*.) shrubs, which are known to be sensitive to mechanical damage and soil disturbance from harvest and post-harvest site preparation, were more common/abundant near young (≤ 20 years) forest edges. Conversely, raspberry (*Rubus idaeus*) shrubs, horsetail (*Equisetum arvense*), and cow parsnip (*Heracleum lanatum*), which are known to be positively associated with soil disturbance, were generally more common/abundant away from forest edges. Blueberry, fruit production was highest at forest harvest edges and lowest in older cutblocks, as well as retention patches, which we showed contained fewer lodgepole pine (*Pinus contorta*) trees and more deciduous species. These results support the contention that understory disturbance, environmental conditions (e.g. light availability), and forest tree species composition could explain our research findings. As part of stand-level prescriptions, we recommend that forest managers consider maintaining uncut forest adjacent to cutblocks for up to 20 years post-harvest, and create more and smaller retention patches to increase the amount of forest edge. We also recommend that criteria be developed for selecting the spatial location of forest edges and retention patches such that blueberry shrubs are common/abundant in the undisturbed forest. This research demonstrated that forest harvesting strategies can increase food supply for grizzly bears and thus support recovery efforts of this provincially threatened species.

Edge; Forestry; Natural Disturbance; Food; Vegetation; Forest Structure

Souliere, C. M., Coogan, S. C. P., Stenhouse, G. B., & Nielsen, S. E. (2020). Harvested forests as a surrogate to wildfires in relation to grizzly bear food- supply in west-central Alberta. Forest Ecology and Management, 456, 117685. https://doi.org/10.1016/j.foreco.2019.117685

Grizzly bear (*Ursus arctos*) populations residing in interior ecosystems of North America are known to frequent harvested areas and areas burnt by wildfires, as both disturbances encourage growth of early seral vegetation preferred by them. This is especially evident in places where there is a paucity of large natural openings and areas with a long history of wildfire suppression, such as the foothill forests of west-central Alberta. Little has been done, however, to directly quantify and compare grizzly bear food-supply in both disturbance types and at early stages of forest regeneration. In this paper, we explore whether harvested areas can act as surrogates to wildfires for grizzly bear food-supply in west-central Alberta, Canada. We sampled known fruit-bearing and herbaceous grizzly bear foods for their occurrence, productivity, and digestible energy supply among post-harvest, post-fire, and mature forests disturbance types, and across very young (~5 yrs), young (~20 yrs), and mid (~60 yrs) age-classes for post-harvest and post-fire disturbances. A variety of foods occurred at greater frequency in post-harvest stands, with the occurrence of most foods explained by the main effects of disturbance and age-class, or in combination with one environmental covariate. Overall, fruit productivity and digestible energy from fruits were highest in the young age-class, whereas forb productivity and digestible energy from forbs were highest in the very young age-class. There were no significant differences in total available digestible energy (fruit+forb) between post-harvest and post-fire stands within any age-class, but significant differences were evident between age-classes. These results suggest that harvested areas can potentially act as a surrogate to wildfires in relation to grizzly bear food-supply, but human access remains a key challenge for harvests given their association with roads. We suggest that harvested areas could be used as management tool to maintain or enhance grizzly bear food-supply and thus contribute to population recovery efforts, especially in areas of wildfire suppression.

Forestry; Food; Roads; Vegetation; Nutrition

PHENOLOGY AND CLIMATE

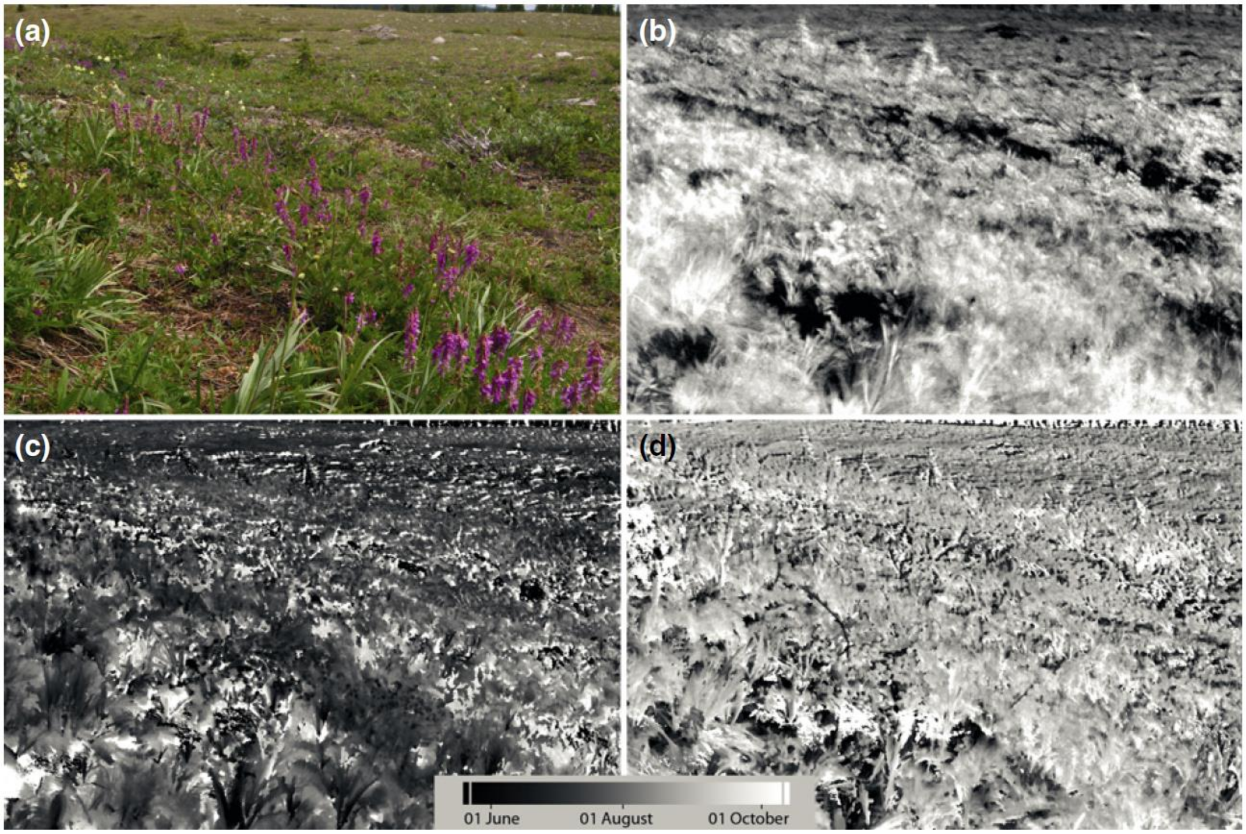

Figure 8. Examples of phenology camera data, (a) RGB image, (b) 2G-RB index image, (c) Green-up, (d) Senescence. Image from Nijland et al. 2013, p. 35.

In this section, techniques to capture vegetation phenology and annual changes to grizzly bear habitat based on climate are explored.

Hird, J. N., & McDermid, G. J. (2009). Noise reduction of NDVI time series: An empirical comparison of selected techniques. Remote Sensing of Environment, 113(1), 248–258. https://doi.org/10.1016/j.rse.2008.09.003

Satellite-derived NDVI time series are fundamental to the remote sensing of vegetation phenology, but their application is hindered by prevalent noise resulting chiefly from varying atmospheric conditions and sun-sensor-surface viewing geometries. A model-based empirical comparison of six selected NDVI time series noise-reduction techniques revealed the general superiority of the double logistic and asymmetric Gaussian function-fitting methods over four alternative filtering techniques. However, further analysis demonstrated the strong influence of noise level, strength, and bias, and the extraction of phenological variables on technique performance. Users are strongly cautioned to consider both their ultimate objectives and the nature of the noise present in an NDVI data set when selecting an approach to noise reduction, particularly when deriving phenological variables.

MODIS; GIS Application; NDVI; Phenology; Time Series

Bater, C. W., Coops, N. C., Wulder, M. A., Nielsen, S. E., McDermid, G., & Stenhouse, G. B. (2011). Design and installation of a camera network across an elevation gradient for habitat assessment.

Instrumentation Science & Technology, 39(3), 231–247. https://doi.org/10.1080/10739149.2011.564700

Developments in distributed sensing, web camera image databases, and automated data visualization and analysis, among other emerging opportunities, have resulted in a suite of new techniques for monitoring habitat at many different scales. Data from these networks can provide important information on the timing of plant phenology with implications for habitat status and condition. In this article, we describe the design and deployment of a small network of cameras established along an elevation gradient in western Alberta, Canada, with the purpose of developing a more comprehensive understanding of seasonal phenophases and the reproductive timing of understory forest vegetation. During an eight-month period in 2009, over 6,700 images were acquired across seven sites throughout the growing season, providing a rich dataset documenting phenological activity of both the under- and overstory forest components. Strong elevation and climate responses were observed. A mathematical function was fitted to the data to demonstrate the capacity to capture phenological trends. This article demonstrates the utility of these types of relatively inexpensive, portable systems for monitoring seasonal vegetation development and change at high temporal resolutions across landscapes.

Digital Cameras; Landscape Monitoring; Time Series; Phenology

Bater, C. W., Coops, N. C., Wulder, M. A., Hiker, T., Nielsen, S. E., McDermid, G., & Stenhouse, G. B. (2011). Using digital time-lapse cameras to monitor species-specific understorey and overstorey phenology in support of wildlife habitat assessment. Environmental Monitoring and Assessment, 180, 1–13. https://doi.org/10.1007/s10661-010-1768-x

Critical to habitat management is the understanding of not only the location of animal food resources, but also the timing of their availability. Grizzly bear (*Ursus arctos*) diets, for example, shift seasonally as different vegetation species enter key phenological phases. In this paper, we describe the use of a network of seven ground-based digital camera systems to monitor understorey and overstorey vegetation within species-specific regions of interest. Established across an elevation gradient in western Alberta, Canada, the cameras collected true-colour (RGB) images daily from 13 April 2009 to 27 October 2009. Fourth-order polynomials were fit to an RGB-derived index, which was then compared to field-based observations of phenological phases. Using linear regression to statistically relate the camera and field data, results indicated that 61% ($r^2 = 0.61$, df = 1, $F = 14.3$, $p = 0.0043$) of the variance observed in the field phenological phase data is captured by the cameras for the start of the growing season and 72% ($r^2 = 0.72$, df = 1, $F = 23.09$, $p = 0.0009$) of the variance in length of growing season. Based on the linear regression models, the mean absolute differences in residuals between predicted and observed start of growing season and length of growing season were 4 and 6 days, respectively. This work extends upon previous research by demonstrating that specific understorey and overstorey species can be targeted for phenological monitoring in a forested environment, using readily available digital camera technology and RGB-based vegetation indices.

Digital Cameras; Phenology; Time Series

Coops, N. C., Hilker, T., Bater, C. W., Wulder, M. A., Nielsen, S. E., McDermid, G., & Stenhouse, G. (2012). Linking ground-based to satellite-derived phenological metrics in support of habitat assessment. Remote Sensing Letters, 3(3), 191–200. https://doi.org/10.1080/01431161.2010.550330

Changes in the timing of plant phenology are important indicators of inter-annual climatic variations and are a critical driver of food availability and habitat use for a range of species. A number of remote sensing techniques have recently been developed to observe vegetation cycles throughout the year, including the use of inexpensive visible spectrum digital cameras at the stand level and the use of high temporal frequency Advanced Very High Resolution Radiometer National Oceanic and Atmospheric Administration (AVHRR NOAA) and MODerate resolution Imaging Spectroradiometer (MODIS) imagery at a satellite scale. A fundamental challenge with using satellite data to track plant phenology, however, is the trade-off between the level of spatial detail and the revisit time provided by the sensor, and the ability to verify the interpretation of phenological activity. One way to address this challenge is to integrate remotely sensed observations obtained at different spatial and temporal scales to provide information that contains both high temporal density and fine spatial resolution observations. In this article, we compare measures of vegetation phenology observed from a network of ground-based cameras with satellite-derived measures of greenness derived from a fused broad (MODIS) and fine spatial (Landsat) scale satellite data set. We derive and compare three key indicators of phenological activity including the start date of green-up, start date of senescence and length of growing season from both a ground-based camera network and 30 m spatial resolution synthetic Landsat scenes. Results indicate that although field-based estimates, generally, predicted an earlier start and end of the vegetation season than the fused satellite observations, highly significant relationships were found for the prediction of the start (R^2 = 0.65), end (R^2 = 0.72) and length (R^2 = 0.70) of the growing season across all sites. We conclude that some predictable bias exists however unlike visual field measures of the collected data represent both a spectral and a visual archive for later use.

Digital Cameras; MODIS; Landsat; Phenology

Nijland, W., Coops, N. C., Coogan, S. C. P., Bater, C. W., Wulder, M. A., Nielsen, S. E., McDermid, G., & Stenhouse, G. B. (2013). Vegetation phenology can be captured with digital repeat photography and linked to variability of root nutrition in *Hedysarum alpinum*. Applied Vegetation Science, 16(2), 317–324. https://doi.org/10.1111/avsc.12000

Question: Can repeat (time-lapse) photography be used to detect the phenological development of a forest stand, and linked to temporal patterns in root nutrition for *Hedysarum alpinum* (alpine sweetvetch) an important grizzly bear food species?

Location: Eastern foothills and front ranges of the Rocky Mountains in Alberta, Canada. The area contains a diverse mix of mature and young forest, wetlands and alpine habitats.

Methods: We deployed six automated cameras at three locations to acquire daily photographs at the plant and forest stand scales. Plot locations were also visited on a bi-weekly basis to record the phenological stage of *H. alpinum* and other target plant species, as well as to collect a root sample for determination of crude protein content.

Results: Repeat photography and image analysis successfully detected all key phenological events (i.e. green-up, flowering, senescence). Given the relation between phenology and root nutrition, we illustrate how camera data can be used to predict the spatial and temporal distribution and quality of a key wildlife resource.

Conclusions: Repeat photography provides a cost-effective method for monitoring vegetation development, food availability, and nutritional quality at a forest stand scale. Since wildlife responds to the availability and quality of their food resources, detailed information on changes in resource availability helps with land-use management decisions and furthers our understanding of grizzly bear feeding ecology and habitat selection.

Food; Digital Cameras; Time Series; Phenology; Nutrition

Nijland, W., de Jong, R., de Jong, S. M., Wulder, M., Bater, C. W., & Coops, N. C. (2014). Monitoring plant condition and phenology using infrared sensitive consumer grade digital cameras. Agricultural and Forest Meteorology, 184, 98–106. https://doi.org/10.1016/j.agrformet.2013.09.007

Consumer-grade digital cameras are recognized as a cost-effective method of monitoring plant health and phenology. The capacity to use these cameras to produce time series information contributes to a better understanding of relationships between environmental conditions, vegetation health, and productivity. In this study we evaluate the use of consumer grade digital cameras modified to capture infrared wavelengths for monitoring vegetation. The use of infrared imagery is very common in satellite remote sensing, while most current near sensing studies are limited to visible wavelengths only. The use of infrared-visible observations is theoretically superior over the use of just visible observation due to the strong contrast between infrared and visible reflection of vegetation, the high correlation of the three visible bands and the possibilities to use spectral indices like the Normalized Difference Vegetation Index. This paper presents two experiments: the first study compares infrared modified and true color cameras to detect seasonal development of understory plants species in a forest; the second is aimed at evaluation of spectrometer and camera data collected during a laboratory plant stress experiment. The main goal of the experiments is to evaluate the utility of infrared modified cameras for the monitoring of plant health and phenology. Results show that infrared converted cameras perform less than standard color cameras in a monitoring setting. Comparison of the infrared camera response to spectrometer data points at limits in dynamic range, and poor band separation as the main weaknesses of converted consumer cameras. Our results support the use of standard color cameras as simple and affordable tools for the monitoring of plant stress and phenology.

Digital Cameras; Time Series; Phenology; Landscape Monitoring

Vartanian, M., Nijland, W., Coops, N. C., Bater, C., Wulder, M. A., & Stenhouse, G. (2014). Assessing the impact of field of view on monitoring understory and overstory phenology using digital repeat photography. Canadian Journal of Remote Sensing, 40(2), 85–91. https://doi.org/10.1080/07038992.2014.930308

Phenological patterns of the components within forest ecosystems, such as understory vegetation, are important indicators of climate variability, productivity, and additional ecosystem services such as food and habitat availability for wildlife. Proximal sensing systems can provide detailed phenological records at a relatively low cost. As interest in these datasets increases, we need additional information regarding the effect of different approaches on the scale of observations and camera field of view. In this research, we examine the impact of field of view on the capacity of cameras to detect changes in phenology of individual species in an image time series. We examine two co-located series of oblique images acquired using a fine and broad field of view and compare a number of phenological indicators, including the start and end of season derived for individual plant species. Our results indicate both fine and broad field of view camera systems are highly effective at detecting key markers of plant phenology with no significant differences between the two. This result supports environmental monitoring using cost-effective broad field of view cameras, or even - subject to some constraints - readily available camera stations installed for tourism or traffic monitoring.

Digital Cameras; Phenology

Nijland, W., Bolton, D. K., Coops, N. C., & Stenhouse, G. (2016). Imaging phenology; scaling from camera plots to landscapes. Remote Sensing of Environment, 177, 13–20. https://doi.org/10.1016/j.rse.2016.02.018

Information on the spatial and temporal patterns of plant phenology is important to develop a more comprehensive understanding of food availability and habitat for many animal species. The combination of broad scale, regional climatic, and more localized, site-level drivers presents a challenge when upscaling phenology from the plot to the region. Likewise, developing relationships between ground- or camera-based estimates and satellite imagery remains difficult due to the trade-off between temporal and spatial resolution. Landsat imagery, with its 16 day temporal resolution, is often thought of as being insufficient for timely observation of changes in vegetation throughout the year. However the free availability of the Landsat archive has enabled a major shift in the way Landsat imagery is processed moving towards pixel, rather than scene, based analyses. In this paper we build on previous research by examining the applicability and accuracy of Landsat derived phenology curves beyond deciduous stands into more mixed stands and conifer dominated forest types in the Rocky Mountains and foothills in Alberta, Canada. In addition, we discuss the application of these Landsat phenology curves to phenology of understorey species which are linked to habitat selection for free roaming wildlife, in particular grizzly bears. The agreement between Landsat- and camera-derived estimates of key phenological events was stronger for green-up (RMSE=7 days) than for senescence (RMSE=14 days). Our results show that yearly adjustment of green-up and senescence dates using available Landsat observations improved the agreement with camera-derived estimates when compared to average annual curves. Seasonal phenology transition dates accepted as valid ranged from 25% for alpine herbaceous pixels to 75% for closed deciduous, demonstrating the variable success of this approach across land cover types. Season transition dates were rejected if pixels lacked a strong enough green-up signal in Landsat spectral indices or if the estimated dates fell outside of the valid range. We conclude by investigating the spatial patterns of seasonal phenology at the Landsat scale, and assess the relative importance of regional vs. microsite conditions as well as the utility of these data for resource and wildlife management.

Landsat; GIS Application; Phenology; Digital Cameras; Forest Structure; Vegetation

McClelland, C. J. R., Coops, N. C., Berman, E. E., Kearney, S. P., Nielsen, S. E., Burton, A. C., & Stenhouse, G. B. (2020). Detecting changes in understorey and canopy vegetation cycles in West Central Alberta using a fusion of Landsat and MODIS. Applied Vegetation Science, 23(2), 223–238. https://doi.org/10.1111/avsc.12466

Aims: To model regional vegetation cycles through data fusion methods for creating a 30-m daily vegetation product from 2000 to 2018 and to analyze annual vegetation trends over this time period.

Location: The Yellowhead Bear Management Area, a 31,180-km^2 area in west central Alberta, Canada.

Methods: In this paper, we use Dynamic Time Warping (DTW) as a data fusion technique to combine Landsat 5, 7 and 8 satellite data and Moderate Resolution Image Spectroradiometer (MODIS) Aqua and Terra imagery, to quantify daily vegetation using Enhanced Vegetation Index at a 30-m resolution, for the years 2000 - 2018. We validated this approach, entitled DRIVE (Daily Remote Inference of VEgetation), using imagery acquired from a network of ground cameras.

Results: When DRIVE was compared to start and end of season dates (SOS and EOS respectively) derived from ground cameras, correlations were r = 0.73 at SOS and r = 0.85 at EOS with a mean absolute error of 7.17 days at SOS and 10.76 days at EOS. Results showed that DRIVE accurately increased spatial and temporal resolution of remote-sensing data. We demonstrated that SOS is advancing at a maximum rate of 0.78 days per year temporally over the 18-year time period for varying elevation gradients and land cover classes over the region.

Conclusions: With DRIVE, we demonstrate the utility of DTW in quantifying vegetation cycles over a large heterogeneous region and determining how changing climate is affecting regional vegetation.

DRIVE may prove to be an important method to determine how carbon sequestration is varying within fine-scale individual plant communities in response to changing climate and likely will be beneficial to wildlife movement and habitat selection studies examining the varying response of wildlife species to changing vegetation cycles under shifting climatic conditions.

Landsat; GIS Application; MODIS; Time Series; Vegetation; Climate Change

Coogan, S. C., Nielsen, S. E., & Stenhouse, G. B. (2012). Spatial and temporal heterogeneity creates a “brown tide” in root phenology and nutrition. International Scholarly Research Network, 2012, 618257. https://doi.org/10.5402/2012/618257

Spatial and temporal heterogeneity in plant phenology and nutrition benefits herbivores by prolonging the period in which they can forage on nutritious plants. Landscape heterogeneity can therefore enhance population performance of herbivores and may be a critically important feature of their habitat. The benefits of resource heterogeneity over space and time should extend not only to large herbivores using above-ground vegetation but also to omnivores that utilize below-ground resources. We used generalized linear models to evaluate whether spatial heterogeneity influenced temporal variation in the crude protein content of alpine sweetvetch (*Hedysarum alpinum*) roots in west-central Alberta, Canada, thereby potentially offering nutritional benefits to grizzly bears (*Ursus arctos*). We demonstrated that temporal patterns in the crude protein content of alpine sweetvetch roots were influenced by spatial heterogeneity in annual growing season temperatures and soil moisture and nutrients. Spatial heterogeneity and asynchrony in the protein content of alpine sweetvetch roots likely benefit grizzly bears by prolonging the period they can forage on high quality resources. Therefore, we have presented evidence of what we termed a "brown wave" or "brown tide" in the phenology and nutrition of a below-ground plant resource, which is analogous to the previously described "green wave" in above-ground resources.

Nutrition; Phenology; Food

Roberts, D. R., Nielsen, S. E., & Stenhouse, G. B. (2014). Idiosyncratic responses of grizzly bear habitat to climate change based on projected food resource changes. Ecological Applications, 24(5), 1144–1154. https://doi.org/10.1890/13-0829.1

Climate change vulnerability assessments for species of conservation concern often use species distribution and ecological niche modeling to project changes in habitat. One of many assumptions of these approaches is that food web dependencies are consistent in time and environmental space. Species at higher trophic levels that rely on the availability of species at lower trophic levels as food may be sensitive to extinction cascades initiated by changes in the habitat of key food resources. Here we assess climate change vulnerability for *Ursus arctos* (grizzly bears) in the southern Canadian Rocky Mountains using projected changes to 17 of the most commonly consumed plant food items. We used presence-absence information from 7088 field plots to estimate ecological niches and to project changes in future distributions of each species. Model projections indicated idiosyncratic responses among food items. Many food items persisted or even increased, although several species were found to be vulnerable based on declines or geographic shifts in suitable habitat. These included *Hedysarum alpinum* (alpine sweet vetch), a critical spring and autumn root-digging resource when little else is available. Potential habitat loss was also identified for three fruiting species of lower importance to bears: *Empetrum nigrum* (crowberry), *Vaccinium scoparium* (grouseberry), and *Fragaria virginiana* (strawberry). A general trend towards uphill migration of bear foods may result in higher vulnerability to bear populations at low elevations, which are also those that are most likely to have human-bear conflict problems. Regardless, a wide diet breadth of grizzly bears, as well as wide environmental niches of most food items, make climate change a much lower threat to grizzly bears than other bear species such as polar bears and panda bears. We cannot exclude, however, future alterations in human behavior and land use resulting from climate change that may reduce survival rates.

Vegetation; Conflict; Species Distribution Models; Climate Change

Erickson, A., Nitschke, C., Coops, N., Cumming, S., & Stenhouse, G. (2015). Past-century decline in forest regeneration potential across a latitudinal and elevational gradient in Canada. Ecological Modelling, 313, 94–102. https://doi.org/10.1016/j.ecolmodel.2015.06.027

The regeneration niche of trees greatly narrows the fundamental niche and is sensitive to climatic change. Development from seed and phenology are regulated by biological and environmental controls, shaping forest successional pathways. We hypothesized that recent climate change is reducing regeneration suitability in northern forests. We used a process-based ecophysiological model to examine changes in forest regeneration conditions across an elevational and latitudinal gradient in Alberta, Canada from 1923 to 2012. We compared these results to a recent empirical study in the region to infer the recent drivers of regeneration change in northern forests. Our results suggest that these forests are experiencing climatically driven declines in conditions suitable for regeneration. Contrary to previous findings indicating poorer current conditions in low elevation forests, we found more stable regeneration potential there, attributable to a relative abundance of soil moisture. Rocky soils resulted in modeled losses of soil moisture at higher elevations, potentially preventing upslope migrations of species despite warming. We identify potential mechanisms driving unexpected tree regeneration patterns described in previous studies. Our simulations suggest a delayed response of forest regeneration to warming throughout the past 90 years.

Climate Change; Phenology; Species Distribution Models

Berman, E. E., Bolton, D. K., Coops, N. C., Mityok, Z. K., Stenhouse, G. B., & Moore, R. D. (2018). Daily estimates of Landsat fractional snow cover driven by MODIS and dynamic time-warping. Remote Sensing of Environment, 216, 635–646. https://doi.org/10.1016/j.rse.2018.07.029

Understanding seasonal snow cover dynamics is critical for management of hydrological regimes, habitat availability for wildlife species, forest fire risk assessment and recreational demands. Although data products provided at 500 m spatial resolution by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor provide important and readily available information on snow cover, capturing snow dynamics at finer spatial resolutions remains problematic due to the lack of high temporal and spatial resolution data, which limits the number of available observations each year. In this paper we present a new approach to create a daily time-series of 30-m snow observations (called SNOWARP), derived from daily MODIS Normalised Difference Snow Index (NDSI) snow cover data to capture the temporal dynamics of snow cover and Dynamic Time Warping (DTW) to re-order historical Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager (OLI) observations to account for inter-annual variability. The SNOWARP product was produced for 2000-2018 for an area of Western Alberta (approximately 30,000 km^2) and was calibrated against a network of time-lapse cameras and snow pillows. Results indicate the RMSE of the SNOWARP fractional product ranges from 31.3% - 68.3%, while F score of the SNOWARP binary product ranges from 87.7% - 98.6% when compared to ground truth data. Capturing fractional snow cover at a fine spatial and temporal scale is important due to the spatial heterogeneity of snow cover, particularly in mountainous regions with implications for biodiversity assessment and monitoring. SNOWARP demonstrates a novel method to increasing the temporal resolution of Landsat-derived snow cover data, providing valuable insights on regional snow cover dynamics for use in a range of applications.

Landsat; MODIS; GIS Application; Digital Cameras; Snow; Time Series; Climate

Studying Grizzly Bears

Survey Methods and Population Inventory

Figure 9. A grizzly bear investigates a scent bait surrounded by barbed wire used to collect hair for DNA analyses.

In this section, we describe the development of the survey methods required to monitor population range and density.

Wasser, S. K., Davenport, B., Ramage, E. R., Hunt, K. E., Parker, M., Clarke, C., & Stenhouse, G. (2004). Scat detection dogs in wildlife research and management: application to grizzly and black bears in the Yellowhead Ecosystem, Alberta, Canada. Canadian Journal Zoology, 82(3), 475–492. https://doi.org/10.1139/z04-020

We report the development and application of a method using domestic dogs (*Canis familiaris* Linnaeus, 1758) to systematically locate wildlife scat over large remote areas. Detection dogs are chosen for their strong object orientation, high play drive, and willingness to strive for a reward. Dogs were trained to detect grizzly bear (*Ursus arctos* Linnaeus, 1758) and black bear (*Ursus americanus* Pallas, 1780) scats over a 5200-km^2 area of the Yellowhead Ecosystem, Alberta, Canada. DNA from scat provided the species and (for grizzly bears only) sex and individual identities of the animal at each location. Concentrations of fecal cortisol and progesterone metabolites from these same grizzly bear scats provided indices of physiological stress and reproductive activity (in females), respectively. Black and grizzly bears were most concentrated in the northern portion of the multiuse study area, where food is most abundant yet poaching-related mortality appears to be heaviest. Physiologic stress was also lowest and female reproductive activity correspondingly highest for grizzly bears in the north. The scat-based distributions corresponded to concurrently collected hair-snag data in 1999 and global positioning system radiotelemetry data (of grizzly bears) in 1999 and 2001. Results suggest that the scat dog detection methodology provides a promising tool for addressing a variety of management and research questions in the wildlife sciences.

Population Inventory; DNA; Stress; Cortisol; Hormones; Reproduction; Distribution; Hair Snag; Scat; Black Bear

Boulanger, J., Stenhouse, G., & Munro, R. (2004). Sources of heterogeneity bias when DNA mark-recapture sampling methods are applied to grizzly bear (*Ursus arctos*) populations. Journal of Mammalogy, 85(4), 618–624. https://doi.org/10.1644/BRB-134

One of the challenges in estimating grizzly bear (*Ursus arctos*) population size using DNA methods is heterogeneity of capture probabilities. This study developed general tools to explore heterogeneity variation using data from a DNA mark-recapture project in which a proportion of the bear population had GPS collars. The Huggins closed population mark-recapture model was used to determine if capture probability was influenced by sex or collar status. In addition, trap encounter rates were estimated by comparing the closest distance from traps where hair was snagged of bears that were captured, with bears for which we had radiolocations but were not captured. Results of the Huggins analysis suggested that sex, distance of bear DNA capture from grid edge, and whether a bear was radiocollared potentially affected capture probabilities. The encounter rate analysis estimated that 63% of bears that encountered traps were snagged, and that males encountered more traps than females. The following conclusions arise from this study. First, the distance of DNA capture of bears relative to the grid edge should be modeled as an individual covariate to ensure robust estimates of superpopulation size when closure violation is suspected. Second, sampling should be intensive to minimize heterogeneity and to ensure all bears encounter traps. Finally, estimators that are robust to heterogeneity variation should be used, given the various sources of heterogeneity variation.

DNA; Hair Snag; Population Inventory; Capture Methods

Boulanger, J., Proctor, M., Himmer, S., Stenhouse, G., Paetkau, D., & Cranston, J. (2006). An empirical test of DNA mark – recapture sampling strategies for grizzly bears. Ursus, 17(2), 149–158. https://doi.org/10.2192/1537-6176(2006)17[149:AETODM]2.0.CO;2

Despite the widespread use of DNA mark - recapture for estimation of grizzly bear (*Ursus arctos*) population size, there have been no designed experiments of DNA sampling strategies. We designed a large-scale study (8,820 km^2) in the foothills of Alberta, Canada, to test sampling strategies associated with the hair snag DNA method. The main sampling method for this project used a traditional design in which bait sites were moved within 180 7 x 7 km grid cells for 4 2-week sampling sessions in the spring of 2004. However, we also tested other strategies concurrently with the traditional design. We sampled fixed sites within each cell to test the utility of moving sites compared to the less-expensive method of not moving sites. We also placed a second, lower strand of barbed wire on bait sites to see if this could identify cubs, which are not typically sampled by the usual knee- height strand of barbed wire. We compared summary statistics, capture probability variation, population estimates, and the precision of population estimates for each design. The moved-sites designs captured more bears each session, captured more individual bears (especially females), and displayed population estimates that were 15 - 25% higher for females. Estimates for males were similar between designs. These results suggest that the moved-sites designs were more efficient in sampling the entire population at the 7 x 7 km grid cell size. These results highlight the need for all bears to have adequate trap encounter opportunities to ensure unbiased estimates. It also demonstrates the utility of collecting enhanced data sets to test and optimize DNA sampling strategies.

DNA; Capture Methods; Hair Snag; Population Inventory

Boulanger, J., White, G. C., Proctor, M., Stenhouse, G., Machutchon, G., & Himmer, S. (2008). Use of occupancy models to estimate the influence of previous live captures on DNA-based detection probabilities of grizzly bears. The Journal of Wildlife Management, 72(3), 589–595. https://doi.org/10.2193/2006-447

Large carnivores potentially change their behavior following physical capture, becoming less responsive to the attractants that resulted in their capture, which can bias population estimates where the change in behavior is not appropriately modeled. We applied occupancy models to efficiently estimate and compare detection probabilities of previously collared grizzly bears (*Ursus arctos*) with bears captured at DNA hair-snag sites that were not previously collared. We found that previously captured bears had lower detection probabilities, although their detection probabilities were still > 0, implying that they were still visible to be sampled via the DNA hair-snag grid, which was able to detect finer differences in capture probabilities of previously collared bears compared with Huggins closed-captures population models. To obtain relatively unbiased population estimates for DNA surveys, heterogeneity caused by previous live capture should be accounted for in the population estimator.

DNA; Capture Methods; Hair Snag; Population Inventory

Proctor, M., McLellan, B., Boulanger, J., Apps, C., Stenhouse, G., Paetkau, D., & Mowat, G. (2010). Ecological investigations of grizzly bears in Canada using DNA from hair, 1995-2005: a review of methods and progress. Ursus, 21(2), 169–188. https://doi.org/10.2192/1537-6176-21.2.169

Grizzly bears (*Ursus arctos*) occur across British Columbia and in Alberta in mostly forested, mountainous, and boreal ecosystems. These dense forests make sighting bears from aircraft uncommon and aerial census impractical. Since 1995, we have used genetic sampling using DNA from bear hair collected with barbed wire hair traps to explore a suite of ecological questions of grizzly bears in western Canada. During 1995 - 2005, we conducted large-scale sampling (1,650 to 9,866 km^2 grids) in 26 areas (covering a combined 110,405 km^2), where genetic identification of 1,412 grizzly bears was recorded. Abundance estimation was the primary goal of most surveys. We also used DNA from bear hair to examine population trend, distribution, and presence in areas where grizzly bears were rare, as well as population fragmentation in a region with a high human population. Combining spatial variation in detecting bears with that of human, landscape, and ecological features has allowed us to quantify factors that influence grizzly bear distribution, population fragmentation, and competition with black bears (*U. americanus*), and to map variation in bear densities. We summarize these studies and discuss lessons learned that are relevant to improving sampling efficiency, study designs, and resulting inference.

Density; Fragmentation; Distribution; Population Inventory; Population Trend; Hair Snag; Black Bear

Rovang, S., Nielsen, S. E., & Stenhouse, G. (2015). In the trap: detectability of fixed hair trap DNA methods in grizzly bear population monitoring. Wildlife Biology, 21(2), 68–79. https://doi.org/10.2981/wlb.00033

A significant challenge to monitoring wildlife that are secretive, wide ranging, and at low densities is the need to achieve adequate detection rates. Knowledge of spatial patterns in occupancy and the spatial and/or temporal patterns in detectability allows for stratification of traps and improved detection rates. This study investigated how local variation in habitats affected the detectability of grizzly bears in west-central Alberta when monitored with a fixed DNA hair snag design. Bear hair samples were collected in 2011 at 60 sites across 1500 km^2 over six sessions, each 14 days in length, between June and August. Microsatellite analysis of hair samples revealed grizzly bear detections at 25 of 60 sites and 21 individual bears. We investigated occupancy and detectability of grizzly bears at the patch and landscape scales using detection histories and program PRESENCE. At the patch scale, grizzly bear detection was highest when sites were placed near streams with clover and in intermediate levels of forest crown closure. At the landscape scale, probability of detection increased near streams and oil and gas wellsites, especially when food resources and wellsite density in the surrounding area was low. Our results highlight the importance of considering local food resources and habitat conditions during placement of fixed DNA hair snag sites. Detectability was not found to vary over time, suggesting that sampling in west-central Alberta can occur at any time between June and August.

DNA; Hair Snag; Population Inventory; Oil and Gas; Food; Population Monitoring

Phoebus, I., Boulanger, J., Eiken, H. G., Fløystad, I., Graham, K., Hagen, S. B., Sorensen, A., & Stenhouse, G. (2020). Comparison of grizzly bear hair-snag and scat sampling along roads to inform wildlife population monitoring. Wildlife Biology, 2020(3). https://doi.org/10.2981/wlb.00697

Wildlife managers conduct population inventories to monitor species, particularly those at-risk. Although costly and time consuming, grid-based DNA hair-snag sampling has been the standard protocol for grizzly bear inventories in North America, while opportunistic fecal DNA sampling is more commonly used in Europe. Our aim is to determine if low-cost, low-effort scat sampling along roads can replace the current standard. We compare two genetic non-invasive techniques using concurrent sampling within the same grid system and spatially explicit capture-recapture. We found that given our methodology and the present status of fecal genotyping for grizzly bears, scat sampling along roads cannot replace hair sampling to estimate population size in low-density areas. Hair sampling identified the majority of individual grizzly bears, with a higher success rate of individuals identified from grizzly bear samples (100%) compared to scat sampling (14%). Using scat DNA to supplement hair data did not change population estimates, but it did improve estimate precision. Scat samples had higher success identifying species (98%) compared with hair (80%). Scat sampling detected grizzly bears in grid cells where hair sampling showed non-detection, with almost twice the number of cells indicating grizzly bear presence. Based on our methods and projected expenses for future implementation, we estimated an approximate 30% cost reduction for sampling scat relative to hair. Our research explores the application of genetic non-invasive approaches to monitor bear populations. We recommend wildlife managers continue to use hair-snag sampling as the primary method for DNA inventories, while employing scat sampling as supplemental to increase estimate precision. Scat sampling may better indicate presence of bear species through greater numbers and spatial distribution of detections, if sampling is systematic across the entire area of interest. Our findings speak to the management of other species and regions, and contribute to ongoing advances of monitoring wildlife populations.

Hair Snag; Scat; DNA; Population Inventory; Population Monitoring

CAPTURE AND HANDLING

Figure 10. A captured grizzly bear is sedated and processed prior to being fitted with a GPS collar.

Capturing grizzly bears in a manner that minimizes impact comes with many challenges. Here we describe the wealth of research into the best practices and protocols for safe and effective grizzly bear capture.

Cattet, M. R., Christison, K., Caulkett, N. A., & Stenhouse, G. B. (2003). Physiologic responses of grizzly bears to different methods of capture. Journal of Wildlife Diseases, 39(3), 649–654. https://doi.org/10.7589/0090-3558-39.3.649

The physiologic effects of two methods of capture, chemical immobilization of free-ranging (FR) bears by remote injection from a helicopter and physical restraint (PR) by leg-hold snare prior to chemical immobilization, were compared in 46 grizzly bears (*Ursus arctos*) handled during 90 captures between 1999 and 2001. Induction dosages and times were greater for FR bears than PR bears, a finding consistent with depletion of, or decreased sensitivity to, catecholamines. Free-ranging bears also had higher rectal temperatures 15 min following immobilization and temperatures throughout handling that correlated positively with induction time. Physically restrained bears had higher white blood cell counts, with more neutrophils and fewer lymphocytes and eosinophils, than did FR bears. This white blood cell profile was consistent with a stress leukogram, possibly affected by elevated levels of serum cortisol. Serum concentrations of alanine aminotransferase, aspartate aminotransferase, and creatine kinase were higher in PR bears that suggested muscle injury. Serum concentrations of sodium and chloride also were higher in PR bears and attributed to reduced body water volume through water deprivation and increased insensible water loss. Overall, different methods of capture resulted in different patterns of physiologic disturbance. Reducing pursuit and drug induction times should help to minimize increase in body temperature and alteration of acid-base balance in bears immobilized by remote injection. Minimizing restraint time and ensuring snare-anchoring cables are short should help to minimize loss of body water and prevent serious muscle injury in bears captured by leg-hold snare.

Capture Methods; Physiology; Stress

Cattet, M., Boulanger, J., Stenhouse, G., Powell, R. A., & Reynolds-Hogland, M. J. (2008). An evaluation of long-term capture effects in ursids: Implications for wildlife welfare and research. Journal of Mammalogy, 89(4), 973–990. https://doi.org/10.1644/08-MAMM-A-095.1

The need to capture wild animals for conservation, research, and management is well justified, but long-term effects of capture and handling remain unclear. We analyzed standard types of data collected from 127 grizzly bears (*Ursus arctos*) captured 239 times in western Alberta, Canada, 1999 - 2005, and 213 American black bears (*U. americanus*) captured 363 times in southwestern North Carolina, 1981-2002, to determine if we could detect long-term effects of capture and handling, that is, effects persisting ≥1 month. We measured blood serum levels of aspartate aminotransferase (AST), creatine kinase (CK), and myoglobin to assess muscle injury in association with different methods of capture. Serum concentrations of AST and CK were above normal in a higher proportion of captures by leghold snare (64% of 119 grizzly bear captures and 66% of 165 black bear captures) than capture by helicopter darting (18% of 87 grizzly bear captures) or by barrel trap (14% of 7 grizzly bear captures and 29% of 7 black bear captures). Extreme AST values (.5 times upper reference limit) in 7 (6%) grizzly bears and 29 (18%) black bears captured by leghold snare were consistent with the occurrence of exertional (capture) myopathy. We calculated daily movement rates for 91 radiocollared grizzly bears and 128 radiocollared black bears to determine if our activities affected their mobility during a 100-day period after capture. In both species, movement rates decreased below mean normal rate immediately after capture (grizzly bears: $\bar{X}$ = 57% of normal, 95% confidence interval =45-74%; black bears: 77%, 64-88%) and then returned to normal in 3-6 weeks (grizzly bears: 28 days, 20-37 days; black bears: 36 days, 19-53 days). We examined the effect of repeated captures on age-related changes in body condition of 127 grizzly bears and 207 black bears and found in both species that age-specific body condition of bears captured ≥2 times (42 grizzly bears and 98 black bears) tended to be poorer than that of bears captured once only (85 grizzly bears and 109 black bears), with the magnitude of effect directly proportional to number of times captured and the effect more evident with age. Importantly, the condition of bears did not affect their probability of capture or recapture. These findings challenge persons engaged in wildlife capture to examine their capture procedures and research results carefully. Significant capture-related effects may go undetected, providing a false sense of the welfare of released animals. Further, failure to recognize and account for long-term effects of capture and handling on research results can potentially lead to erroneous interpretations.

Capture Methods; Body Condition; Black Bear

Cattet, M. R. L., Stenhouse, G., & Bollinger, T. (2008). Exertional myopathy in a grizzly bear (*Ursus arctos*) captured by leghold snare. Journal of Wildlife Diseases, 44(4), 973–978. https://doi.org/10.1242/jeb.089763

We diagnosed exertional myopathy (EM) in a grizzly bear (*Ursus arctos*) that died approximately 10 days after capture by leghold snare in west-central Alberta, Canada, in June 2003. The diagnosis was based on history, post-capture movement data, gross necropsy, histo-pathology, and serum enzyme levels. We were unable to determine whether EM was the primary cause of death because autolysis precluded accurate evaluation of all tissues. Nevertheless, comparison of serum aspartate aminotransferase and creatine kinase concentrations and survival between the affected bear and other grizzly bears captured by leghold snare in the same research project suggests EM also occurred in other bears, but that it is not generally a cause of mortality. We propose, however, occurrence of nonfatal EM in grizzly bears after capture by leghold snare has potential implications for use of this capture method, including negative effects on wildlife welfare and research data.

Capture Methods; Body Condition

Cattet, M. R. L., Bourque, A., Elkin, B. T., Powley, K. D., Dahlstrom, D. B., & Caulkett, N. A. (2006). Evaluation of the potential for injury with remote drug-delivery systems. Wildlife Society Bulletin, 34(3), 741–749. https://doi.org/10.2193/0091-7648(2006)34[741:EOTPFI]2.0.CO;2

We evaluated the potential for different types of remote drug-delivery systems (RDDS) to injure target animals. We recorded dart velocity, time, and distance from projector muzzle at 8.5-millisecond intervals by Doppler radar chronograph for 4 types of RDDS. We used darts of different volume and unique combinations of charges, power settings, and distances in accordance to manufacturer's recommendations. Variation in the drop of repeated shots was >10 cm for 28 of 90 trials (5 replicates per trial) with heavy-mass darts having the lowest precision. Impact velocities were high (>50 m/sec) in many trials using heavy darts and some trials using light-mass, rapid-injection darts. We evaluated the permanent wound cavity (PWC) formed by firing dye-filled darts into ordnance gelatin covered tightly by a fresh elk hide and into the thighs of calf carcasses. Rapid-injection darts fitted with end-ported needles consistently 1) forced hair and skin beneath the hide; 2) formed a PWC that was 2-3×— the needle length; and 3) pulled the hide away from the gelatin before the dye was completely ejected into the gelatin. We conclude injury to target animals is minimized in RDDS that use lightweight, slow-injection darts, fitted with side-ported needles and broad-diameter needle seals, and that impact target animals at moderate velocity (40-50 m/sec) with high precision. We recommend against using darts with rapid-injection mechanisms and end-ported needles because of their potential to cause deep, chronic wounds.

Capture Methods; Drug Administration

Cattet, M. R. L., Caulkett, N. A., & Stenhouse, G. B. (2003). Anesthesia of grizzly bears using xylazine-zolazepam-tiletamine or zolazepam-tiletamine. Ursus, 14(1), 88–93. https://doi.org/10.2307/3872961

The immobilization features and physiological effects of combinations of xylazine-zolazepam-tiletamine (XZT) and zolazepam-tiletamine (ZT) were compared in 46 wild grizzly bears (*Ursus arctos*) handled during 90 captures. Although induction time was similar between drugs, induction dosage and volume were less with XZT than with ZT. Induction of immobilization with XZT was predictable and smooth, and muscle relaxation was good during the period of immobilization. XZT was tolerated safely at 2-3 times the recommended dosage of 6-7 mg/kg (xylazine at 2.4-2.8 mg/kg + ZT at 3.6-4.2 mg/kg with X and ZT mixed in a 2:3 ratio). Bears anesthetized with XZT had slower pulse rates and higher rectal temperatures than bears anesthetized with ZT. The risk of hyperthermia at higher ambient temperatures (≥25°C) was of potential concern with XZT. Although transient hypoxemia (hemoglobin oxygen saturation [SpO_2] ≤ 85%) developed immediately following induction in some bears, it was not severe enough to pose significant health risk. The provision of supplementary oxygen during hypoxemia resulted in increased SpO_2 and decreased pulse rate. Bears anesthetized with XZT had higher serum glucose concentrations than bears anesthetized with ZT, a finding likely explained by the α2- adrenergic effects of xylazine to increase hepatic glucose production and decrease pancreatic release of insulin. Although the time to complete reversal of effects was highly variable, the effects of XZT anesthesia could be reversed with the α2-antagonist drug yohimbine.

Anesthesia; Drug Administration; Capture Methods

Ozeki, L. M., Fahlman, A., Stenhouse, G., Arnemo, J. M., & Caulkett, N. (2014). Evaluation of the accuracy of different methods of monitoring body temperature in anesthetized brown bears (*Ursus arctos*). Journal of Zoo and Wildlife Medicine, 45(4), 819–824. https://doi.org/10.1638/2014-0039.1

There is some evidence that the handheld rectal thermometer does not accurately measure core temperature in bears. The objective of this study was to compare body temperature measured by the handheld digital thermometer (HDT), deep rectally inserted core temperature capsules (CTCs), and gastrically inserted CTCs in anesthetized brown bears (*Ursus arctos*). Twenty-two brown bears were immobilized with a combination of zolazepam-tiletamine and xylazine or medetomidine. After immobilization, one CTC was inserted 15 cm deep into the animal's rectum (DRTC) with a standard applicator, and another CTC was inserted into the stomach (GTC) via a gastric tube inserted orally. Temperature was measured every 5 - 10 min with an HDT. Paired temperature data points were analyzed with the Bland-Altman technique for repeated measurements and regression analysis with a significance level of 0.05. The mean difference ±SD of the difference between HDT and GTC readings was 0.27 ± 0.47°C and the 95% limits of agreement (LoA) were 1.20 and -0.66°C. The determination coefficient (r^2) found between these methods was 0.68 ($P < 0.0001$). The mean difference ± SD of the difference between HDT and DRTC readings was 0.36 ± 0.32°C and the 95% LoA were 1.0 and -0.28°C. The r^2 between HDT and DRTC was 0.83 ($P < 0.0001$). The mean difference ± SD of the difference between the two insertions of the VitalSenset capsules was -0.06 ± 0.24°C and the 95% LoA were 0.42 and -0.54°C. The r^2 found between GTC and DRTC was 0.91 ($P < 0.0001$). This study demonstrates that DRTC provided accurate measurement of core temperature and that HDT did not accurately measure core temperature, compared with GTC in anesthetized brown bears.

Capture Methods; Anesthesia

Ozeki, L. M., Caulkett, N., Stenhouse, G., Arnemo, J. M., & Fahlman, A. (2015). Effect of active cooling and α-2 adrenoceptor antagonism on core temperature in anesthetized brown bears (*Ursus arctos*). Journal of Zoo and Wildlife Medicine, 46(2), 279–285. https://doi.org/10.1638/2014-0052R.1

Hyperthermia is a common complication during anesthesia of bears, and it can be life threatening. The objective of this study was to evaluate the effectiveness of active cooling on core body temperature for treatment of hyperthermia in anesthetized brown bears (*Ursus arctos*). In addition, body temperature after reversal with atipamezole was also evaluated. Twenty-five adult and subadult brown bears were captured with a combination of zolazepam-tiletamine and xylazine or medetomidine. A core temperature capsule was inserted into the bears' stomach or 15 cm into their rectum or a combination of both. In six bears with gastric temperatures ≥40.0°C, an active cooling protocol was performed, and the temperature change over 30 min was analyzed. The cooling protocol consisted of enemas with 2 L of water at approximately 5°C/100 kg of body weight every 10 min, 1 L of intravenous fluids at ambient temperature, water or snow on the paws or the inguinal area, intranasal oxygen supplementation, and removing the bear from direct sunlight or providing shade. Nine bears with body temperature >39.0°C that were not cooled served as control for the treated animals. Their body temperatures were recorded for 30 min, prior to administration of reversal. At the end of the anesthetic procedure, all bears received an intramuscular dose of atipamezole. In 10 bears, deep rectal temperature change over 30 min after administration of atipamezole was evaluated. The active cooling protocol used in hyperthermic bears significantly decreased their body temperatures within 10 min, and it produced a significantly greater decrease in their temperature than that recorded in the control group.

Capture Methods; Anesthesia

Fandos Esteruelas, N., Cattet, M., Zedrosser, A., Stenhouse, G. B., Küker, S., Evans, A. L., & Arnemo, J. M. (2017). A Double-Blinded, Randomized Comparison of Medetomidine-Tiletamine-Zolazepam and Dexmedetomidine-Tiletamine-Zolazepam Anesthesia in Free-Ranging Brown Bears (*Ursus arctos*). Plos One, 12(1), e0170764. https://doi.org/10.1371/journal.pone.0170764

We compared anesthetic features, blood parameters, and physiological responses to either medetomidine-tiletamine-zolazepam or dexmedetomidine-tiletamine-zolazepam using a double-blinded, randomized experimental design during 40 anesthetic events of free-ranging brown bears (*Ursus arctos*) either captured by helicopter in Sweden or by culvert trap in Canada. Induction was smooth and predictable with both anesthetic protocols. Induction time, the need for supplemental drugs to sustain anesthesia, and capture-related stress were analyzed using generalized linear models, but anesthetic protocol did not differentially affect these variables. Arterial blood gases and acid-base status, and physiological responses were examined using linear mixed models. We documented acidemia (pH of arterial blood < 7.35), hypoxemia (partial pressure of arterial oxygen < 80 mmHg), and hypercapnia (partial pressure of arterial carbon dioxide ≥ 45 mmHg) with both protocols. Arterial pH and oxygen partial pressure were similar between groups with the latter improving markedly after oxygen supplementation ($P < 0.001$). We documented dose-dependent effects of both anesthetic protocols on induction time and arterial oxygen partial pressure. The partial pressure of arterial carbon dioxide increased as respiratory rate increased with medetomidine-tiletamine-zolazepam, but not with dexmedetomidine-tiletamine-zolazepam, demonstrating a differential drug effect. Differences in heart rate, respiratory rate, and rectal temperature among bears could not be attributed to the anesthetic protocol. Heart rate increased with increasing rectal temperature ($P < 0.001$) and ordinal day of capture ($p = 0.002$). Respiratory rate was significantly higher in bears captured by helicopter in Sweden than in bears captured by culvert trap in Canada ($P < 0.001$). Rectal temperature significantly decreased over time ($p \leq 0.05$). Overall, we did not find any benefit of using dexmedetomidine-tiletamine-zolazepam instead of medetomidine-tiletamine-zolazepam in the anesthesia of brown bears. Both drug combinations appeared to be safe and reliable for the anesthesia of free-ranging brown bears captured by helicopter or by culvert trap.

Capture Methods; Anesthesia; Drug Administration

Genetics, Health and Physiology

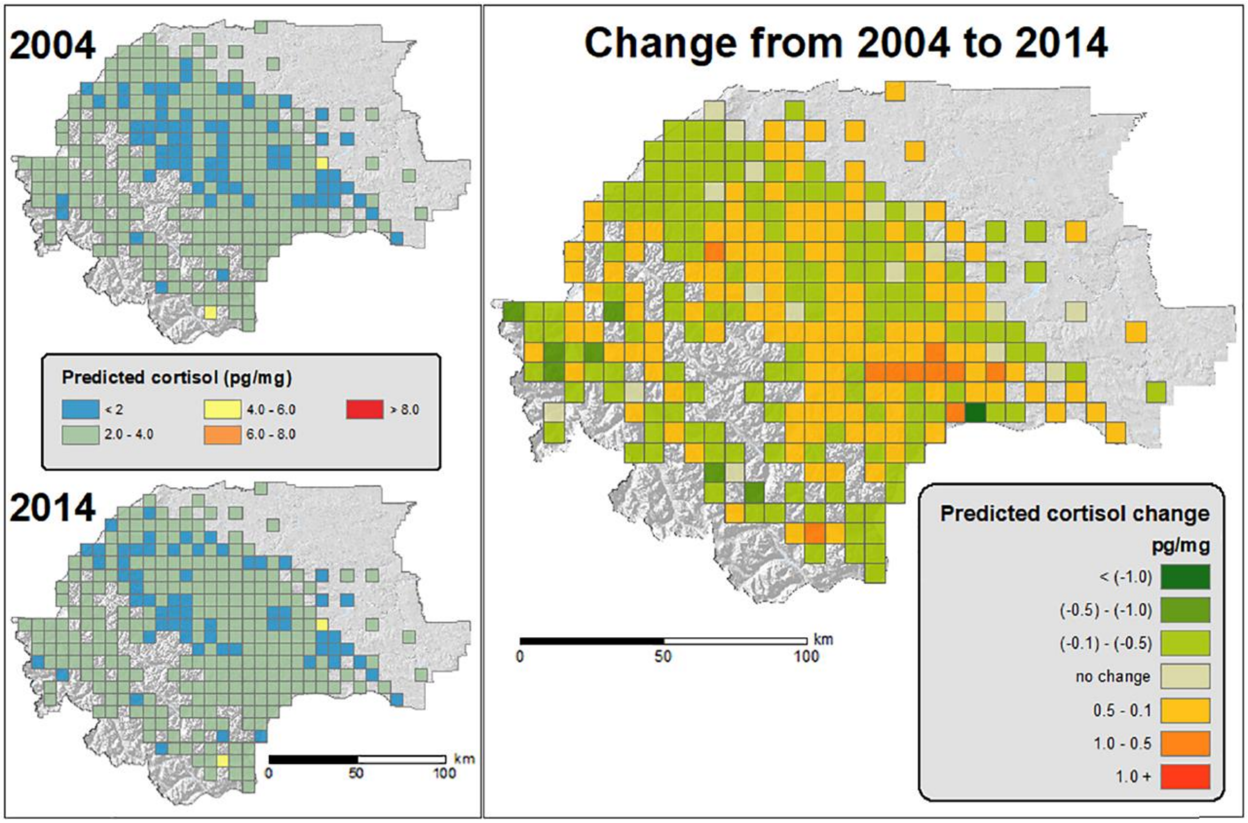

Figure 11. Predicted hair cortisol concentrations in 2004 and 2014 and over time from landscape variables in the most supported model (anthropogenic disturbance and food resource availability). Only this model was supported (Δ AIC_c = 0.00) when year was included in the final candidate models; however, predicted hair cortisol concentrations were generated from the final model without year. Therefore, unidentified change associated with sample year is likely present. Figure from Wilson et al. 2020, p. 54.

In this section, we discuss the methods developed for studying grizzly bear genetics, health and reproductive status, and physiology based on biological samples, collected from captured and captive bears.

Aarnes, S. G., Hagen, S. B., Andreassen, R., Schregel, J., Knappskog, P. M., Hailer, F., Stenhouse, G., Janke, A., & Eiken, H. G. (2015). Y-chromosomal testing of brown bears (*Ursus arctos*): Validation of a multiplex PCR-approach for nine STRs suitable for fecal and hair samples. Forensic Science International: Genetics, 19, 197–204. https://doi.org/10.1016/j.fsigen.2015.07.018

High-resolution Y-chromosomal markers have been applied to humans and other primates to study population genetics, migration, social structures and reproduction. Y-linked markers allow the direct assessment of the genetic structure and gene flow of uniquely male inherited lineages and may also be useful for wildlife conservation and forensics, but have so far been available only for few wild species. Thus, we have developed two multiplex PCR reactions encompassing nine Y-STR markers identified from the brown bear (*Ursus arctos*) and tested them on hair, fecal and tissue samples. The multiplex PCR approach was optimized and analyzed for species specificity, sensitivity and stutter-peak ratios. The nine Y-STRs also showed specific STR-fragments for male black bears and male polar bears, while none of the nine markers produced any PCR products when using DNA from female bears or males from 12 other mammals. The multiplex PCR approach in two PCR reactions could be amplified with as low as 0.2 ng template input. Precision was high in DNA templates from hairs, fecal scats and tissues, with standard deviations less than 0.14 and median stutter ratios from 0.04 to 0.63. Among the eight di- and one tetra-nucleotide repeat markers, we detected simple repeat structures in seven of the nine markers with 9-25 repeat units. Allelic variation was found for eight of the nine Y-STRs, with 2-9 alleles for each marker and a total of 36 alleles among 453 male brown bears sampled mainly from Northern Europe. We conclude that the multiplex PCR approach with these nine Y-STRs would provide male bear Y-chromosomal specificity and evidence suited for samples from conservation and wildlife forensics.

DNA; Relatedness; Black Bear; Polar Bear

Cattet, M., Stenhouse, G. B., Janz, D. M., Kapronczai, L., Anne Erlenbach, J., Jansen, H. T., Nelson, O. L., Robbins, C. T., & Boulanger, J. (2017). The quantification of reproductive hormones in the hair of captive adult brown bears and their application as indicators of sex and reproductive state. Conservation Physiology, 5(1), cox032. https://doi.org/10.1093/conphys/cox032

Recognizing the potential value of steroid hormone measurements to augment non-invasive genetic sampling, we developed procedures based on enzyme-linked immunoassays to quantify reproductive steroid hormone concentrations in brown bear (*Ursus arctos*) hair. Then, using 94 hair samples collected from eight captive adult bears over a 2-year period, we evaluated (i) associations between hair concentrations of testosterone, progesterone, estradiol and cortisol; (ii) the effect of collecting by shaving vs. plucking; and (iii) the utility of reproductive hormone profiles to differentiate sex and reproductive state. Sample requirements (125 mg of guard hair) to assay all hormones exceeded amounts typically obtained by non-invasive sampling. Thus, broad application of this approach will require modification of non-invasive techniques to collect larger samples, use of mixed (guard and undercoat) hair samples and/or application of more sensitive laboratory procedures. Concentrations of hormones were highly correlated suggesting their sequestration in hair reflects underlying physiological processes. Marked changes in hair hormone levels during the quiescent phase of the hair cycle, coupled with the finding that progesterone concentrations, and their association with testosterone levels, differed markedly between plucked and shaved hair samples, suggests steroids sequestered in hair were likely derived from various sources, including skin. Changes in hair hormone concentrations over time, and in conjunction with key reproductive events, were similar to what has been reported concerning hormonal changes in the blood serum of brown bears. Thus, potential for the measurement of hair reproductive hormone levels to augment non-invasive genetic sampling appears compelling. Nonetheless, we are conducting additional validation studies on hair collected from free-ranging bears, representative of all sex, age and reproductive classes, to fully evaluate the utility of this approach for brown bear conservation and research.

Hormones; Cortisol; Reproduction; Stress; DNA

Cattet, M., Stenhouse, G. B., Boulanger, J., Janz, D. M., Kapronczai, L., Swenson, J. E., & Zedrosser, A. (2018). Can concentrations of steroid hormones in brown bear hair reveal age class? Conservation Physiology, 6(1), coy001. https://doi.org/10.1093/conphys/coy001

Although combining genetic and endocrine data from non-invasively collected hair samples has potential to improve the conservation of threatened mammals, few studies have evaluated this opportunity. In this study, we determined if steroid hormone (testosterone, progesterone, estradiol and cortisol) concentration profiles in 169 hair samples collected from free- ranging brown bears (*Ursus arctos*) could be used to accurately discriminate between immature and adult bears within each sex. Because hair samples were acquired opportunistically, we also needed to establish if interactions between hormones and several non-hormone factors (ordinal day, year, contact method, study area) were associated with age class. For each sex, we first compared a suite of candidate models by Akaike Information Criteria model selection, using different adult-age thresholds (3, 4 and 5 years), to determine the most supported adult age. Because hair hormone levels better reflect the endocrine state at an earlier time, possibly during the previous year, then at the time of sampling, we reanalysed the data, excluding the records for bears at the adult-age threshold, to establish if classification accuracy improved. For both sexes, candidate models were most supported based on a 3-year-old adult-age threshold. Classification accuracy did not improve with the 3-year-old bear data excluded. Male age class was predicted with a high degree of accuracy (88.4%) based on the concomitant concentrations of all four hormones. Female age class was predicted with less accuracy (77.1%) based only on testosterone and cortisol. Accuracy was reduced for females, primarily because we had poor success in correctly classifying immature bears (60%) whereas classification success for adult females was similar to that for males (84.5%). Given the small and unbalanced sample used in this study, our findings should be viewed as preliminary, but they should also provide a basis for more comprehensive future studies.

Hormones; Stress; Cortisol; Hair Snag

Chow, B. A., Hamilton, J. W., Alsop, D., Cattet, M., Stenhouse, G., & Vijayan, M. M. (2010). Grizzly bear corticosteroid binding globulin: cloning and serum protein expression. General and Comparative Endocrinology, 167(2), 317–325. https://doi.org/10.1016/j.ygcen.2010.03.027

Serum corticosteroid levels are routinely measured as markers of stress in wild animals. However, corticosteroid levels rise rapidly in response to the acute stress of capture and restraint for sampling, limiting its use as an indicator of chronic stress. We hypothesized that serum corticosteroid binding globulin (CBG), the primary transport protein for corticosteroids in circulation, may be a better marker of the stress status prior to capture in grizzly bears (*Ursus arctos*). To test this, a full-length CBG cDNA was cloned and sequenced from grizzly bear testis and polyclonal antibodies were generated for detection of this protein in bear sera. The deduced nucleotide and protein sequences were 1218 bp and 405 amino acids, respectively. Multiple sequence alignments showed that grizzly bear CBG (gbCBG) was 90% and 83% identical to the dog CBG nucleotide and amino acid sequences, respectively. The affinity purified rabbit gbCBG antiserum detected grizzly bear but not human CBG. There were no sex differences in serum total cortisol concentration, while CBG expression was significantly higher in adult females compared to males. Serum cortisol levels were significantly higher in bears captured by leg-hold snare compared to those captured by remote drug delivery from helicopter. However, serum CBG expression between these two groups did not differ significantly. Overall, serum CBG levels may be a better marker of chronic stress, especially because this protein is not modulated by the stress of capture and restraint in grizzly bears.

Capture Methods; Cortisol; Protein; Stress; DNA

Macbeth, B. J., Cattet, M. R. L., Stenhouse, G. B., Gibeau, M. L., & Janz, D. M. (2010). Hair cortisol concentration as a noninvasive measure of long-term stress in free-ranging grizzly bears (*Ursus arctos*): considerations with implications for other wildlife. Canadian Journal of Zoology, 88(10), 935–943. https://doi.org/10.1139/Z10-057

Human-caused landscape change negatively affects the sustainability of many wildlife populations. In Alberta, Canada, grizzly bears (*Ursus arctos* L., 1758) live in one of the most populated and heavily exploited landscapes in which the species survives. Long-term physiological stress in individual animals may be the predominant mechanism linking landscape change with impaired wildlife population health. Hair cortisol concentration has been validated as a biomarker of long-term stress in humans and domestic animals; however, limited work has examined factors that may affect its measurement or interpretation. We have measured cortisol in as few as five guard hairs of a grizzly bear and have identified factors influencing hair cortisol concentration in this species. Hair cortisol varies with hair type, body region, and capture method. It is not influenced by colour, age, sex, environmental exposure (18 days), or prolonged laboratory storage (>1 year) and does not vary along the length of the hair shaft. Recommendations for prudent use of hair cortisol analysis in grizzly bears are discussed with implications for the development of hair cortisol concentration as a tool to monitor long-term stress in other wildlife.

Capture Methods; Stress; Cortisol

Cattet, M., Macbeth, B. J., Janz, D. M., Zedrosser, A., Swenson, J. E., Dumond, M., & Stenhouse, G. B. (2014). Quantifying long-term stress in brown bears with the hair cortisol concentration: a biomarker that may be confounded by rapid changes in response to capture and handling. Conservation Physiology, 2(1), cou026. https://doi.org/10.1093/conphys/cou026

The measurement of cortisol in hair is becoming important in studying the role of stress in the life history, health and ecology of wild mammals. The hair cortisol concentration (HCC) is generally believed to be a reliable indicator of long-term stress that can reflect frequent or prolonged activation of the hypothalamic-pituitary-adrenal axis over weeks to months through passive diffusion from the blood supply to the follicular cells that produce the hair. Diffusion of cortisol from tissues surrounding the follicle and glandular secretions (sebum and sweat) that coat the growing hair may also affect the HCC, but the extent of these effects is thought to be minimal. In this study, we report on a range of factors that are associated with, and possibly influence, cortisol concentrations in the hair of free-ranging brown bears (*Ursus arctos*). Through two levels of analyses that differed in sample sizes and availability of predictor variables, we identified the presence or absence of capture, restraint and handling, as well as different methods of capture, as significant factors that appeared to influence HCC in a time frame that was too short (minutes to hours) to be explained by passive diffusion from the blood supply alone. Furthermore, our results suggest that HCC was altered after hair growth had ceased and blood supply to the hair follicle was terminated. However, we also confirmed that HCC was inversely associated with brown bear body condition and was, therefore, responsive to diminished food availability/quality and possibly other long-term stressors that affect body condition. Collectively, our findings emphasize the importance of further elucidating the mechanisms of cortisol accumulation in hair and the influence of long- and short-term stressors on these mechanisms.

Hair Snag; Body Condition; Capture Methods; Cortisol; Stress

Kroshko, T., Kapronczai, L., Cattet, M. R. L., Macbeth, B. J., Stenhouse, G. B., Obbard, M. E., & Janz, D. M. (2017). Comparison of Methanol and Isopropanol as Wash Solvents for Determination of Hair Cortisol Concentration in Grizzly Bears and Polar Bears. MethodsX, 4, 68–75. https://doi.org/10.1016/j.mex.2017.01.004

Methodological differences among laboratories are recognized as significant sources of variation in quantification of hair cortisol concentration (HCC). An important step in processing hair, particularly when collected from wildlife, is the choice of solvent used to remove or "wash" external hair shaft cortisol prior to quantification of HCC. The present study systematically compared methanol and isopropanol as wash solvents for their efficiency at removing external cortisol without extracting internal hair shaft cortisol in samples collected from free-ranging grizzly bears and polar bears. Cortisol concentrations in solvents and hair were determined in each of one to eight washes of hair with each solvent independently.

- There were no significant decreases in internal hair shaft cortisol among all eight washes for either solvent, although methanol removed detectable hair surface cortisol after one wash in grizzly bear hair whereas hair surface cortisol was detected in all eight isopropanol washes.
- There were no significant differences in polar bear HCC washed one to eight times with either solvent, but grizzly bear HCC was significantly greater in hair washed with isopropanol compared to methanol.
- There were significant differences in HCC quantified using different commercial ELISA kits commonly used for HCC determinations.

Stress; Cortisol; Hair Snag; Polar Bear

Carlson, R. I., Cattet, M. R. L., Sarauer, B. L., Nielsen, S. E., Boulanger, J., Stenhouse, G. B., & Janz, D. M. (2016). Development and application of an antibody-based protein microarray to assess stress in grizzly bears (*Ursus arctos*). Conservation Physiology, 4(1), cow001. https://doi.org/10.1093/conphys/cow001.

A novel antibody-based protein microarray was developed that simultaneously determines expression of 31 stress-associated proteins in skin samples collected from free-ranging grizzly bears (*Ursus arctos*) in Alberta, Canada. The microarray determines proteins belonging to four broad functional categories associated with stress physiology: hypothalamic-pituitary-adrenal axis proteins, apoptosis/cell cycle proteins, cellular stress/proteotoxicity proteins and oxidative stress/inflammation proteins. Small skin samples (50 - 100 mg) were collected from captured bears using biopsy punches. Proteins were isolated and labelled with fluorescent dyes, with labelled protein homogenates loaded onto microarrays to hybridize with antibodies. Relative protein expression was determined by comparison with a pooled standard skin sample. The assay was sensitive, requiring 80 µg of protein per sample to be run in triplicate on the microarray. Intra-array and inter-array coefficients of variation for individual proteins were generally <10 and <15%, respectively. With one exception, there were no significant differences in protein expression among skin samples collected from the neck, forelimb, hindlimb and ear in a subsample of $n = 4$ bears. This suggests that remotely delivered biopsy darts could be used in future sampling. Using generalized linear mixed models, certain proteins within each functional category demonstrated altered expression with respect to differences in year, season, geographical sampling location within Alberta and bear biological parameters, suggesting that these general variables may influence expression of specific proteins in the microarray. Our goal is to apply the protein microarray as a conservation physiology tool that can detect, evaluate and monitor physiological stress in grizzly bears and other species at risk over time in response to environmental change.

Protein; Stress

Wilson, A. E., Sergiel, A., Selva, N., Swenson, J. E., Zedrosser, A., Stenhouse, G., & Janz, D. M. (2021). Correcting for enzyme immunoassay changes in long term monitoring studies. MethodsX, 8, 101212. https://doi.org/10.1016/j.mex.2021.101212

Enzyme immunoassays (EIAs) are a common tool for measuring steroid hormones in wildlife due to their low cost, commercial availability, and rapid results. Testing technologies improve continuously, sometimes requiring changes in protocols or crucial assay components. Antibody replacement between EIA kits can cause differences in EIA sensitivity, which can hinder monitoring hormone concentration over time. The antibody in a common cortisol EIA kit used for long-term monitoring of stress in wildlife was replaced in 2014, causing differences in cross reactivity and standard curve concentrations. Therefore, the objective of this study was to develop a method to standardize results following changes in EIA sensitivity. We validated this method using cortisol concentrations measured in the hair of brown bears (*Ursus arctos*).

- We used a simple linear regression to model the relationship between cortisol concentrations using kit 1 and kit 2.
- We found a linear relationship between the two kits (R^2 = 0.85) and used the regression equation (kit2 = (0.98 × kit1) + 1.65) to predict cortisol concentrations in re-measured samples.
- Mean predicted percent error was 16% and 72% of samples had a predicted percent error < 20%, suggesting that this method is well-suited for correcting changes in EIA sensitivity.

Stress; Cortisol; Hormones

Wilson, A. E., Michaud, S. A., Jackson, A. M., Stenhouse, G., Coops, N. C., & Janz, D. M. (2020). Development and validation of protein biomarkers of health in grizzly bears. Conservation Physiology, 8(1), coaa056. https://doi.org/10.1093/conphys/coaa056

Large carnivores play critical roles in the maintenance and function of natural ecosystems; however, the populations of many of these species are in decline across the globe. Therefore, there is an urgent need to develop novel techniques that can be used as sensitive conservation tools to detect new threats to the health of individual animals well in advance of population-level effects. Our study aimed to determine the expression of proteins related to energetics, reproduction and stress in the skin of grizzly bears (*Ursus arctos*) using a liquid chromatography and multiple reaction monitoring mass spectrometry assay. We hypothesized that a suite of target proteins could be measured using this technique and that the expression of these proteins would be associated with biological (sex, age, sample location on body) and environmental (geographic area, season, sample year) variables. Small skin biopsies were collected from free-ranging grizzly bears in Alberta, Canada, from 2013 to 2019 (*n* = 136 samples from 111 individuals). Over 700 proteins were detected in the skin of grizzly bears, 19 of which were chosen as targets because of their established roles in physiological function. Generalized linear mixed model analysis was used for each target protein. Results indicate that sample year influenced the majority of proteins, suggesting that physiological changes may be driven in part by responses to changes in the environment. Season influenced the expression of proteins related to energetics, reproduction and stress, all of which were lower during fall compared to early spring. The expression of proteins related to energetics and stress varied by geographic area, while the majority of proteins that were affected by biological attributes (age class, sex and age class by sex interaction) were related to reproduction and stress. This study provides a novel method by which scientists and managers can further assess and monitor physiological function in wildlife.

Health; Stress; Protein; Physiology; Reproduction

Carnahan, A. M., van Manen, F. T., Haroldson, M. A., Stenhouse, G. B., & Robbins, C. T. (2021). Quantifying energetic costs and defining energy landscapes experienced by grizzly bears. Journal of Experimental Biology. In press.

Animal movements are major determinants of energy expenditure and ultimately the cost–benefit of landscape use. Thus, we sought to understand those costs and how grizzly bears (*Ursus arctos*) move in mountainous landscapes. We trained captive grizzly bears to walk on a horizontal treadmill and up and down 10% and 20% slopes. The cost of moving upslope increased linearly with speed and slope angle, and this was more costly than moving horizontally. The cost of downslope travel at slower speeds was greater than the cost of traveling horizontally but appeared to decrease at higher speeds. The most efficient walking speed that minimized cost per unit distance was 1.19±0.11 m s^{-1}. However, grizzly bears fitted with GPS collars in the Greater Yellowstone Ecosystem moved at an average velocity of 0.61

±0.28 m s^{-1} and preferred to travel on near-horizontal slopes at twice their occurrence. When traveling uphill or downhill, grizzly bears chose paths across all slopes that were ∼54% less steep and costly than the maximum available slope. The net costs (J kg^{-1} m^{-1}) of moving horizontally and uphill were the same for grizzly bears, humans and digitigrade carnivores, but those costs were 46% higher than movement costs for ungulates. These movement costs and characteristics of landscape use determined using captive and wild grizzly bears were used to understand the strategies that grizzly bears use for preying on large ungulates and the similarities in travel between people and grizzly bears that might affect the risk of encountering each other on shared landscapes.

Physiology; *Movement; Telemetry***Cattet, M. R. L., Caulkett, N. A., Obbard, M. E., & Stenhouse, G. B. (2002). A body-condition index for ursids. Canadian Journal of Zoology, 80(7), 1156–1161. https://doi.org/10.1139/z02-103**

In this investigation a body-condition index (BCI) was developed for polar bears (*Ursus maritimus*), black bears (*Ursus americanus*), and grizzly bears (*Ursus arctos*), based on residuals from the regression of total body mass against a linear measure of size, straight-line body length (SLBL). Transformation of mass-length data from 1198 polar bears, 595 black bears, and 126 grizzly bears to natural logarithms resulted in a linear relationship between mass and length. However, the relationship in polar bears differed from that in black and grizzly bears. SLBL had a close positive relationship with skeletal (bone) mass in polar bears (n = 31) and black bears (n = 33), validating the use of SLBL as an accurate index of body size. There was no correlation between SLBL and BCI for polar bears (r = 0.005, p = 0.87, n = 1198) or for black bears and grizzly bears (r = 0.04, p = 0.30, n = 721), indicating that the BCI was independent of body size. The BCI had a close positive relationship with true body condition, measured as the standardized residual of the combined mass of fat and skeletal muscle against SLBL, in polar and black bears that were dissected to determine individual tissue masses. The BCI also had a close positive relationship with the standardized residual of fat mass against SLBL. Estimation of BCI values for polar bears, or for black bears and grizzly bears, is facilitated by prediction equations that require measurement of total body mass and SLBL for individual animals.

Health; Body Condition; Physiology; Polar Bear; Black Bear

Timmins, T. L., Hunter, A. J. S., Cattet, M. R. L., & Stenhouse, G. B. (2013). Developing Spatial Weight Matrices for Incorporation into Multiple Linear Regression Models: An Example Using Grizzly Bear Body Size and Environmental Predictor Variables. Geographical Analysis, 45(4), 359–379. https://doi.org/10.1111/gean.12019

In this study, we develop spatial autoregressive (SAR) models relating grizzly bear body length to environmental predictor variables in the Alberta Rocky Mountains. We examine the ability of several different spatial neighborhoods to model spatial dependence and compare the estimated parameters and residuals from a standard linear regression model (LRM) with those from three types of SAR models: error, lag, and Durbin. Further, we examine variable selection in the presence of negative dependence by repeating the modeling process using a SAR model. Two findings are that significant negative spatial dependence was present in the residuals of the LRM and that the choice of spatial neighborhood greatly affects the ability to detect spatial dependence. The incorporation of appropriate spatial weights into SAR models improves the fit and increases the significance of the parameter estimates vis-à-vis the linear model. The results of this study indicate that negative dependence may not have as severe negative effects on variable selection and parameter estimation as positive dependence. An examination of spatial dependence in regression modeling appears to be an important means of exploring the appropriateness of a sampling framework, predictor variables, and model form.

Body Condition; Body Size

Using Telemetry Data

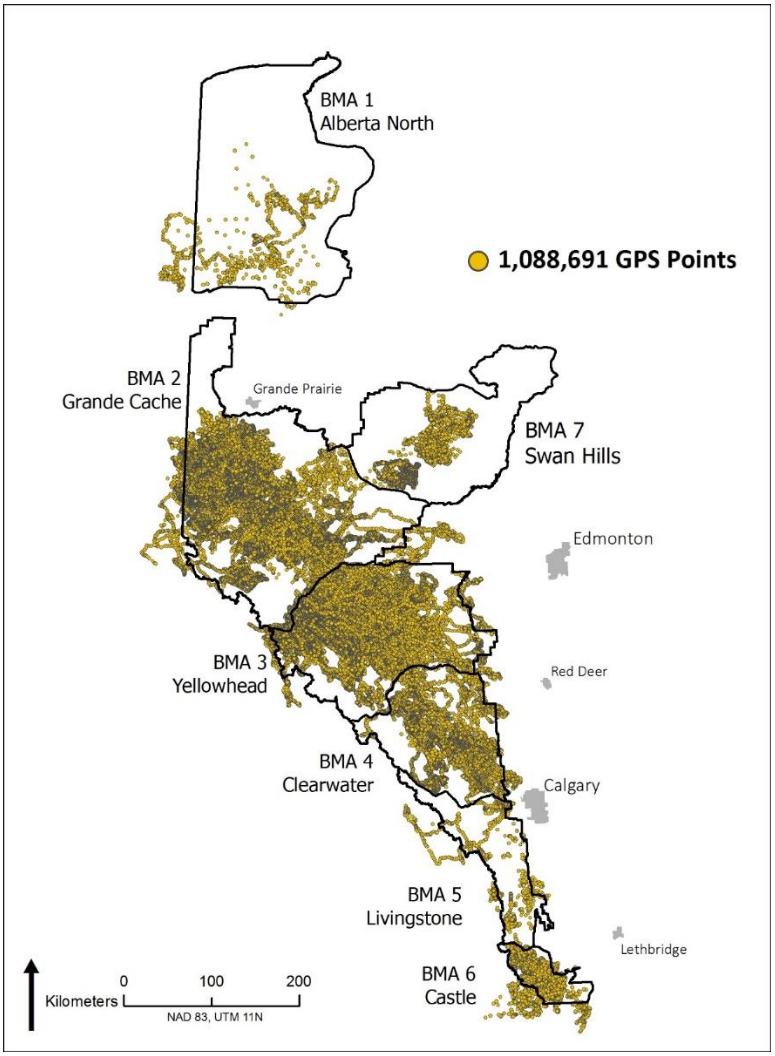

Figure 12. Grizzly bear telemetry data across all BMUs.

GPS collar data requires processing and manipulation to most effectively use to understand grizzly bear behavior. We describe advances in using telemetry data here.

Frair, J. L., Nielsen, S. E., Merrill, E. H., Lele, S. R., Boyce, R. S., Munro, R. H. M., Stenhouse, G. B., & Beyer, H. L. (2004). Removing GPS collar bias in habitat selection studies. Journal of Applied Ecology, 41(2), 201–212. https://doi.org/10.1111/j.0021-8901.2004.00902.x

1. Compared to traditional radio-collars, global positioning system (GPS) collars provide finer spatial resolution and collect locations across a broader range of spatial and temporal conditions. However, data from GPS collars are biased because vegetation and terrain interfere with the satellite signals necessary to acquire a location. Analyses of habitat selection generally proceed without correcting for this known sampling bias. We documented the effects of bias in resource selection functions (RSF) and compared the effectiveness of two bias-correction techniques.

2. The effects of environmental conditions on the probability of a GPS collar collecting a location were modelled for three brands of collar using data collected in 24-h trials at 194 test locations. The best-supported model was used to create GPS-biased data from unbiased animal locations. These data were used to assess the effects of bias given data losses in the range of 10-40% at both 1- and 6-h sampling intensities. We compared the sign, value and significance of coefficients derived using biased and unbiased data.

3. With 6-h locations we observed type II error rates of 30-40% given as little as a 10% data loss. Biased data also produced coefficients that were significantly more negative than unbiased estimates. Increasing the sampling intensity from 6- to 1-h locations eliminated type II errors but increased the magnitude of coefficient bias. No type I errors or changes in sign were observed.

4. We applied sample weighting and iterative simulation given a 30% data loss. For a biased vegetation type, simulation reduced more type II errors than weighting, most probably because the original sample size was re-established. However, selection for areas near trails, which was influenced by a biased vegetation type, showed fewer type II errors after weighting existing animal locations than after simulation. Both techniques corrected 100% and ≥80% of the biased coefficients at the 6- and 1-h sampling intensities, respectively.

5. Synthesis and applications. This study demonstrates that GPS error is predictable and biases the coefficients of resource selection models dependant upon the GPS sampling intensity and the level of data loss. We provide effective alternatives for correcting bias and discuss applying corrections under different sampling designs.

Telemetry; Habitat Selection

Gau, R. J., Mulders, R., Ciarniello, L. M., Heard, D. C., Chetkiewicz, B., Boyce, M., Munro, R., Stenhouse, G., Chruszcz, B., Gibeau, M. L., Milakovic, B., Parker, K. L., & Chetkiewicz, C. B. (2004). Uncontrolled field performance of Televilt GPS-Simplex collars on grizzly bears in western Canada. Wildlife Society Bulletin, 32(3), 693–701. https://doi.org/10.2193/0091-7648(2004)032[0693:UFPOTG]2.0.CO;2

Commercially available telemetry collars for wildlife that employ Global Positioning System (GPS) devices generally have the ability to gather a large volume of precise location data. We appraised the performance of 12-channel Televilt GPS-Simplex™ collars (Televilt/TVP Positioning AB, Lindesberg, Sweden) deployed across western and northern Canada on grizzly bears (*Ursus arctos*). Of 71 collar deployments between 2000 and 2002, 38 were retrieved and performed according to their programmed schedule, 20 were retrieved and had some degree of failure, and 13 experienced catastrophic failures and were not retrieved. In addition to these deployments, 10 collars failed predeployment. GPS collar fix success rates were greater for the retrieved collars from the Northwest Territories than for the 4 study areas in British Columbia and Alberta ($F_{4,50}$ = 10.82, P < 0.001); thus, the latter areas were grouped for further analyses. Collar fix success rates in the British Columbia and Alberta study areas differed between the retrieved collars that functioned normally ($\bar{x}$ = 65%, SE = 2.3, n = 28) and collars retrieved with failure events ($\bar{x}$ = 56%, SE = 4.3, n = 17; t_{43} = -2.09, P = 0.043). Fix success rates were lower the longer collars were in the field (r_s = -0.35, n = 45, P = 0.020). Locations from the GPS collars had a mean dilution of precision of <4 for 2D and 3D locations and thus had a good degree of precision. We were satisfied with the volume and quality of the location data; however, we advise other researchers that significant time and money may be lost troubleshooting problems with the Televilt Simplex system. Other recommendations for future and current users are considered.

Telemetry; British Columbia

Boyce, M. S., Pitt, J., Northrup, J. M., Morehouse, A. T., Knopff, K. H., Cristescu, B., & Stenhouse, G. B. (2010). Temporal autocorrelation functions for movement rates from global positioning system radiotelemetry data. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1550), 2213–2219. https://doi.org/10.1098/rstb.2010.0080

Autocorrelation has been viewed as a problem in telemetry studies because sequential observations are not independent in time or space, therefore violating assumptions for statistical inference. Yet nearly all ecological and behavioural data are autocorrelated in both space and time. We argue that there is much to learn about the structure of ecological and behavioural data from patterns of autocorrelation. Such patterns include periodicity in movement and patchiness in spatial data, which can be characterized by an autocorrelogram, semivariogram or spectrum. We illustrate the utility of temporal autocorrelation functions (ACFs) for analysing step-length data from GPS telemetry of wolves (*Canis lupus*), cougars (*Puma concolor*), grizzly bears (*Ursus arctos*) and elk (*Cervus elaphus*) in western Alberta. ACFs often differ by season, reflecting differences in foraging behaviour. In wilderness landscapes, step-length ACFs for predators decay slowly to apparently random patterns, but sometimes display strong daily rhythms in areas of human disturbance. In contrast, step lengths of elk are consistently periodic, reflecting crepuscular activity.

Movement; Habitat Selection; Distribution; Anthropogenic Disturbance; Telemetry

Smulders, M., Nelson, T. A., Jelinski, D. E., Nielsen, S. E., & Stenhouse, G. B. (2010). A spatially explicit method for evaluating accuracy of species distribution models. Diversity and Distributions, 16(6), 996–1008. https://doi.org/10.1111/j.1472-4642.2010.00707.x

Aim: Models predicting the spatial distribution of animals are increasingly used in wildlife management and conservation planning. There is growing recognition that common methods of evaluating species distribution model (SDM) accuracy, as a global overall value of predictive ability, could be enhanced by spatially evaluating the model thereby identifying local areas of relative predictive strength and weakness. Current methods of spatial SDM model assessment focus on applying local measures of spatial autocorrelation to SDM residuals, which require quantitative model outputs. However, SDM outputs are often probabilistic (relative probability of species occurrence) or categorical (species present or absent). The goal of this paper was to develop a new method, using a conditional randomization technique, which can be applied to directly spatially evaluate probabilistic and categorical SDMs.

Location: Eastern slopes, Rocky Mountains, Alberta, Canada.

Methods: We used predictions from seasonal grizzly bear (*Ursus arctos*) resource selection functions (RSF) models to demonstrate our spatial evaluation technique. Local test statistics computed from bear telemetry locations were used to identify areas where bears were located more frequently than predicted. We evaluated the spatial pattern of model inaccuracies using a measure of spatial autocorrelation, local Moran's I.

Results: We found the model to have non-stationary patterns in accuracy, with clusters of inaccuracies located in central habitat areas. Model inaccuracies varied seasonally, with the summer model performing the best and the least error in areas with high RSF values. The landscape characteristics associated with model inaccuracies were examined, and possible factors contributing to RSF error were identified.

Main conclusions: The presented method complements existing spatial approaches to model error assessment as it can be used with probabilistic and categorical model output, which is typical for SDMs. We recommend that SDM accuracy assessments be done spatially and resulting accuracy maps included in model metadata.

Movement; Habitat Selection; Species Distribution Models; Distribution; Telemetry

Bear Biology and Behaviour

Natural History

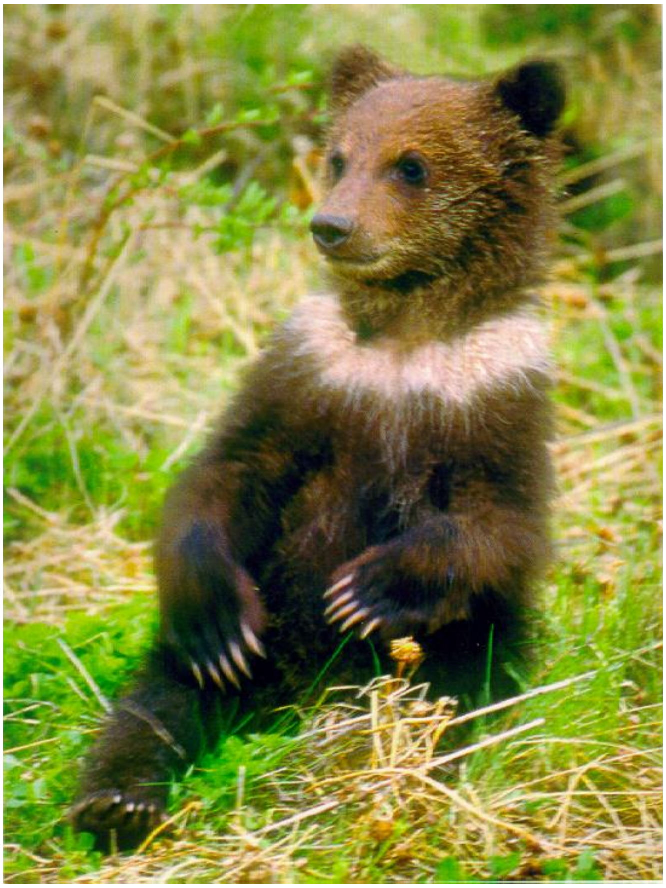

Figure 13. The cub of GBP collared bear.

In this section, we report data on grizzly bear natural and life history, including reproductive rates, home ranges, and denning.

Mace, R., Carney, D. W., Chilton-Radandt, T., Courville, S. A., Haroldson, M. A., Harris, R. B., Jonkel, J., McLellan, B., Madel, M., Manley, T. L., Schwartz, C. C., Servheen, C., Stenhouse, G., Wallyer, J. S., & Wenum, E. (2011). Grizzly bear population vital rates and trend in the Northern Continental Divide Ecosystem, Montana. Journal of Wildlife Management, 76(1), 119-128. https://doi.org/10.1002/jwmg.250

We estimated grizzly bear (*Ursus arctos*) population vital rates and trend for the Northern Continental Divide Ecosystem (NCDE), Montana, between 2004 and 2009 by following radio-collared females and observing their fate and reproductive performance. Our estimates of dependent cub and yearling survival were 0.612 (95% CI = 0.300–0.818) and 0.682 (95% CI = 0.258–0.898). Our estimates of subadult and adult female survival were 0.852 (95% CI = 0.628–0.951) and 0.952 (95% CI = 0.892– 0.980). From visual observations, we estimated a mean litter size of 2.00 cubs/litter. Accounting for cub mortality prior to the first observations of litters in spring, our adjusted mean litter size was 2.27 cubs/litter. We estimated the probabilities of females transitioning from one reproductive state to another between years. Using the stable state probability of 0.322 (95% CI = 0.262–0.382) for females with cub litters, our adjusted fecundity estimate (m_x) was 0.367 (95% CI = 0.273–0.461). Using our derived rates, we estimated that the population grew at a mean annual rate of approximately 3% ($\lambda = 1.0306$, 95% CI = 0.928–1.102), and 71.5% of 10,000 Monte Carlo simulations produced estimates of $\lambda > 1.0$. Our results indicate an increasing population trend of grizzly bears in the NCDE. Coupled with concurrent studies of population size, we estimate that over 1,000 grizzly bears reside in and adjacent to this recovery area. We suggest that monitoring of population trend and other vital rates using radioed females be continued.

Population Trend; Reproduction; Mortality

Smulders, M., Nelson, T. A., Jelinski, D. E., Nielsen, S. E., Stenhouse, G. B., & Laberee, K. (2012). Quantifying spatial-temporal patterns in wildlife ranges using STAMP: A grizzly bear example. Applied Geography, 35(1-2), 124–131. https://doi.org/10.1016/j.apgeog.2012.06.009

Geographical spatial analysis approaches are ideally applied to studies of wildlife habitat use when spatial data, such as telemetry data or spatial ranges, are available. For instance, it is often desirable to quantify spatial-temporal patterns of home ranges, which are typically delineated as polygons and represent areas of habitat that support wildlife functions. Changes to home ranges over time are often presented as variation in mean polygon area. This two-dimensional approach ignores potentially important spatial-temporal characteristics of habitat use, including site fidelity, range contraction, and expansion. Using Spatial-Temporal Analysis of Moving Polygons (STAMP) we examined a set of movement data for a subpopulation of adult female grizzly bears (*Ursus arctos*) for the period from 1999 to 2003 in the Rocky Mountain foothills region of Alberta, Canada. Home range change was quantified over two-year periods and evaluated on the basis of variable offspring dependency (i.e., whether the females had no cubs, cubs-of-the-year (COY), or yearling cubs) and foraging season. Solitary bears showed the greatest amount of home range fidelity, with an increase in range size during the mating season. Female grizzly bears with offspring experienced substantial home range change. Sows with COY had a reduced maternal home range size, especially during mating season, while those with yearling offspring had an increased home range size. The patterns of home range change were consistent with those expected if some combination of mobility and infanticide were the driving ecological mechanisms. We conclude that offspring dependency does not impact the degree of site fidelity but does impact the nature of home range change experienced. We also suggest that the spatial-temporal change in female grizzly home ranges could be used to infer breeding status and as a population monitoring tool. A geographical approach to home range change provides a simple and quantitative approach to mapping spatial-temporal patterns of habitat use and animal movement.

Home Range; Family Dynamics; Population Monitoring

Graham, K., & Stenhouse, G. B. (2014). Home range, movements, and denning chronology of the Grizzly Bear (*Ursus arctos*) in west-central Alberta. Canadian Field-Naturalist, 128(3), 223–234. https://doi.org/10.22621/cfn.v128i3.1600

An understanding of the natural history of the Grizzly Bear (*Ursus arctos*) is important for recovery planning. We present data on home range size, movements and denning chronology collected using Global Positioning System (GPS) collars on Grizzly Bears in west-central Alberta. Mean annual kernel estimates for adult (1034 ± 656 (SD) km^2) and subadult (1298 ± 1207 km^2) males were larger than those for females with cubs of the year (213 ± 212 km^2) and lone adult females (337 ± 176 km^2) but not different from sub-adult females, females with yearlings, or females with ≥ 2-yr old cubs ($P > 0.05$). Mean rates of movement among female age–reproductive classes were different from each other ($Z_9 < 2.70$, $P > 0.05$) but not different from sub-adult males ($Z_9 < 2.70$, $P > 0.05$). Rates of movement of adult males were significantly different only from those of females with cubs of the year ($Z_9 = 3.94$, $P = 0.001$). the greatest amount of movement occurred in June and the least in october. Bears traveled fastest in the morning and evening and slowest at night. Pregnant females had the longest denning period (175 days, ± 16 days SD). No difference was detected in denning duration among the remaining five age–sex–reproductive classes ($P > 0.05$). GPS collars provided large location datasets from which accurate home range estimates, hourly movement rates, and precise denning dates were determined. examining similarities and differences in the basic biology of Grizzly Bears from various locations will improve our understanding of the plasticity of this species and the potential impacts of habitat and climate change.

Home Range; Movement; Denning; Reproduction

Diet and Physiology

Figure 14. A collared grizzly bear feeds on grasses and clover with her cub nearby.

In this section, grizzly bear diet and physiology including nutritional requirements, gut composition and how their body functions during hibernation are explored.

Schwab, C., Cristescu, B., Boyce, M. S., Stenhouse, G. B., & Ganzle, M. (2009). Bacterial populations and metabolites in the feces of free roaming and captive grizzly bears. Canadian Journal of Microbiology, 55(12), 1335–1346. https://doi.org/10.1139/W09-083

Gut physiology, host phylogeny, and diet determine the composition of the intestinal microbiota. Grizzly bears (*Ursus arctos horribilis*) belong to the Order Carnivora, yet feed on an omnivorous diet. The role of intestinal microflora in grizzly bear digestion has not been investigated. Microbiota and microbial activity were analysed from the feces of wild and captive grizzly bears. Bacterial composition was determined using culture-dependent and culture-independent methods. The feces of wild and captive grizzly bears contained log 9.1 ± 0.5 and log 9.2 ± 0.3 gene copies·g^{-1}, respectively. Facultative anaerobes Enterobacteriaceae and enterococci were dominant in wild bear feces. Among the strict anaerobes, the *Bacteroides-Prevotella-Porphyromonas* group was most prominent. Enterobacteriaceae were predominant in the feces of captive grizzly bears, at log 8.9 ± 0.5 gene copies·g^{-1}. Strict anaerobes of the *Bacteroides-Prevotella-Porphyromonas* group and the *Clostridium coccoides* cluster were present at log 6.7 ± 0.9 and log 6.8 ± 0.8 gene copies·g^{-1}, respectively. The presence of lactate and short-chain fatty acids (SCFAs) verified microbial activity. Total SCFA content and composition was affected by diet. SCFA composition in the feces of captive grizzly bears resembled the SCFA composition of prey-consuming wild animals. A consistent data set was obtained that associated fecal microbiota and metabolites with the distinctive gut physiology and diet of grizzly bears.

Food; Physiology; Microbiology

Schwab, C., Cristescu, B., Northrup, J. M., Stenhouse, G. B., & Ganzle, M. (2011). Diet and environment shape fecal bacterial microbiota composition and enteric pathogen load of grizzly bears. PLoS ONE, 6(12), e27905. https://doi.org/10.1371/journal.pone.0027905

Background: Diet and environment impact the composition of mammalian intestinal microbiota; dietary or health disturbances trigger alterations in intestinal microbiota composition and render the host susceptible to enteric pathogens. To date no long term monitoring data exist on the fecal microbiota and pathogen load of carnivores either in natural environments or in captivity. This study investigates fecal microbiota composition and the presence of pathogenic *Escherichia coli* and toxigenic clostridia in wild and captive grizzly bears (*Ursus arctos*) and relates these to food resources consumed by bears.

Methodology/Principal Findings: Feces were obtained from animals of two wild populations and from two captive animals during an active bear season. Wild animals consumed a diverse diet composed of plant material, animal prey and insects. Captive animals were fed a regular granulated diet with a supplement of fruits and vegetables. Bacterial populations were analyzed using quantitative PCR. Fecal microbiota composition fluctuated in wild and in captive animals. The abundance of *Clostridium* clusters I and XI, and of *C. perfringens* correlated to regular diet protein intake. Enteroaggregative *E. coli* were consistently present in all populations. The *C. sordellii* phospholipase C was identified in three samples of wild animals and for the first time in *Ursids*.

Conclusion: This is the first longitudinal study monitoring the fecal microbiota of wild carnivores and comparing it to that of captive individuals of the same species. Location and diet affected fecal bacterial populations as well as the presence of enteric pathogens.

Predation; Physiology; Food; Microbiology

Coogan, S. C. P., Raubenheimer, D., Stenhouse, G. B., & Nielsen, S. E. (2014). Macronutrient optimization and seasonal diet mixing in a large omnivore, the grizzly bear: a geometric analysis. PloS One, 9(5), e97968. https://doi.org/10.1371/journal.pone.0097968

Nutrient balance is a strong determinant of animal fitness and demography. It is therefore important to understand how the compositions of available foods relate to required balance of nutrients and habitat suitability for animals in the wild. These relationships are, however, complex, particularly for omnivores that often need to compose balanced diets by combining their intake from diverse nutritionally complementary foods. Here we apply geometric models to understand how the nutritional compositions of foods available to an omnivorous member of the order Carnivora, the grizzly bear (*Ursus arctos* L.), relate to optimal macronutrient intake, and assess the seasonal nutritional constraints on the study population in west-central Alberta, Canada. The models examined the proportion of macronutrients that bears could consume by mixing their diet from food available in each season, and assessed the extent to which bears could consume the ratio of protein to non-protein energy previously demonstrated using captive bears to optimize mass gain. We found that non-selective feeding on ungulate carcasses provided a non-optimal macronutrient balance with surplus protein relative to fat and carbohydrate, reflecting adaptation to an omnivorous lifestyle, and that optimization through feeding selectively on different tissues of ungulate carcasses is unlikely. Bears were, however, able to dilute protein intake to an optimal ratio by mixing their otherwise high-protein diet with carbohydrate-rich fruit. Some individual food items were close to optimally balanced in protein to non-protein energy (e.g. *Hedysarum alpinum* roots), which may help explain their dietary prevalence. Ants may be consumed particularly as a source of lipids. Overall, our analysis showed that most food available to bears in the study area were high in protein relative to lipid or carbohydrate, suggesting the lack of non-protein energy limits the fitness (e.g. body size and reproduction) and population density of grizzly bears in this ecosystem.

Food; Predation; Vegetation; Nutrition

Coogan, S. C. P., Raubenheimer, D., Stenhouse, G. B., Coops, N. C., & Nielsen, S. E. (2018). Functional macronutritional generalism in a large omnivore, the brown bear. Ecology and Evolution, 8(4), 2365–2376. https://doi.org/10.1002/ece3.3867

We combine a recently developed framework for describing dietary generalism with compositional data analysis to examine patterns of omnivory in a large widely distributed mammal. Using the brown bear (*Ursus arctos*) as a model species, we collected and analyzed data from the literature to estimate the proportions of macronutrients (protein, carbohydrate, and lipid) in the diets of bear populations. Across their range, bears consumed a diversity of foods that resulted in annual population diets that varied in macronutrient proportions, suggesting a wide fundamental macronutrient niche. The variance matrix of pairwise macronutrient log- ratios indicated that the most variable macronutrient among diets was carbohydrate, while protein and lipid were more proportional or codependent (i.e., relatively more constant log- ratios). Populations that consumed anthropogenic foods, such agricultural crops and supplementary feed (e.g., corn), had a higher geometric mean proportion of carbohydrate, and lower proportion of protein, in annual diets. Seasonally, mean diets were lower in protein and higher in carbohydrate, during autumn compared to spring. Populations with anthropogenic subsidies, however, had higher mean proportions of carbohydrate and lower protein, across seasons compared to populations with natural diets. Proportions of macronutrients similar to those selected in experiments by captive brown bears, and which optimized primarily fat mass gain, were observed among hyperphagic prehibernation autumn diets. However, the majority of these were from populations consuming anthropogenic foods, while diets of natural populations were more variable and typically higher in protein. Some anthropogenic diets were close to the proportions selected by captive bears during summer. Our results suggest that omnivory in brown bears is a functional adaptation enabling them to occupy a diverse range of habitats and tolerate variation in the nutritional composition and availability of food resources. Furthermore, we show that populations consuming human- sourced foods have different dietary macronutrient proportions relative to populations with natural diets.

Human Use; Food; Nutrition

Chow, B. A., Hamilton, J., Cattet, M. R. L., Stenhouse, G., Obbard, M. E., & Vijayan, M. M. (2011). Serum corticosteroid binding globulin expression is modulated by fasting in polar bears (*Ursus maritimus*). Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 158(1), 111–115. https://doi.org/10.1016/j.cbpa.2010.09.017

Polar bears (*Ursus maritimus*) from several subpopulations undergo extended fasting during the ice-free season. However, the animals appear to conserve protein despite the prolonged fasting, though the mechanisms involved are poorly understood. We hypothesized that elevated concentrations of corticosteroid binding globulin (CBG), the primary cortisol binding protein in circulation, lead to cortisol resistance and provide a mechanism for protein conservation during extended fasting. The metabolic state (feeding vs. fasting) of 16 field sampled male polar bears was determined based on their serum urea to creatinine ratio (>25 for feeding vs. <5 for fasting). There were no significant differences in serum cortisol levels between all male and female polar bears sampled. Serum CBG expression was greater in lactating females relative to non- lactating females and males. CBG expression was significantly higher in fasting males when compared to non- fasting males. This leads us to suggest that CBG expression may serve as a mechanism to conserve protein during extended fasting in polar bears by reducing systemic free cortisol concentrations. This was further supported by a lower serum glucose concentration in the fasting bears. As well, a lack of an enhanced adrenocortical response to acute capture stress supports our hypothesis that chronic hunger is not a stressor in this species. Overall, our results suggest that elevated serum CBG expression may be an important adaptation to spare proteins by limiting cortisol bioavailability during extended fasting in polar bears.

Cortisol; Stress; Polar Bear

Rode, K. D., Stricker, C. A., Erlenbach, J., Robbins, C. T., Cherry, S. G., Newsome, S. D., Cutting, A., Jensen, S., Stenhouse, G., Brooks, M., Hash, A., & Nicassio, N. (2016). Isotopic Incorporation and the Effects of Fasting and Dietary Lipid Content on Isotopic Discrimination in Large Carnivorous Mammals. Physiological and Biochemical Zoology, 89(3), 182–197. https://doi.org/10.1086/686490

There has been considerable emphasis on understanding isotopic discrimination for diet estimation in omnivores. However, discrimination may differ for carnivores, particularly species that consume lipid-rich diets. Here, we examined the potential implications of several factors when using stable isotopes to estimate the diets of bears, which can consume lipid-rich diets and, alternatively, fast for weeks to months. We conducted feeding trials with captive brown bears (*Ursus arctos*) and polar bears (*Ursus maritimus*). As dietary lipid content increased to ~90%, we observed increasing differences between blood plasma and diets that had not been lipid extracted ($\Delta^{13}C_{tissue\text{-}bulk\ diet}$) and slightly decreasing differences between plasma $\delta^{13}C$ and lipid-extracted diet. Plasma $\Delta^{15}N_{tissue\text{-}bulk\ diet}$ increased with increasing protein content for the four polar bears in this study and data for other mammals from previous studies that were fed purely carnivorous diets. Four adult and four yearling brown bears that fasted 120 d had plasma $\delta^{15}N$ values that changed by <±2‰. Fasting bears exhibited no trend in plasma $\delta^{13}C$. Isotopic incorporation in red blood cells and whole blood was ≥6mo in subadult measured in younger and smaller black bears (*Ursus americanus*). Our results suggest that short-term fasting in carnivores has minimal effects on $\delta^{13}C$ and $\delta^{15}N$ discrimination between predators and their prey but that dietary lipid content is an important factor directly affecting $\delta^{13}C$ discrimination and indirectly affecting $\delta^{15}N$ discrimination via the inverse relationship with dietary protein content.

Food; Polar Bear; Black Bear

Jansen, H. T., Leise, T., Stenhouse, G., Pigeon, K., Kasworm, W., Teisberg, J., Radandt, T., Dallmann, R., Brown, S., & Robbins, C. T. (2016). The bear circadian clock doesn't 'sleep' during winter dormancy. Frontiers in Zoology, 13(42). https://doi.org/10.1186/s12983-016-0173-x

Background: Most biological functions are synchronized to the environmental light:dark cycle via a circadian timekeeping system. Bears exhibit shallow torpor combined with metabolic suppression during winter dormancy. We sought to confirm that free-running circadian rhythms of body temperature (Tb) and activity were expressed in torpid grizzly (brown) bears and that they were functionally responsive to environmental light. We also measured activity and ambient light exposures in denning wild bears to determine if rhythms were evident and what the photic conditions of their natural dens were. Lastly, we used cultured skin fibroblasts obtained from captive torpid bears to assess molecular clock operation in peripheral tissues. Circadian parameters were estimated using robust wavelet transforms and maximum entropy spectral analyses.

Results: Captive grizzly bears housed in constant darkness during winter dormancy expressed circadian rhythms of activity and Tb. The rhythm period of juvenile bears was significantly shorter than that of adult bears. However, the period of activity rhythms in adult captive bears was virtually identical to that of adult wild denning bears as was the strength of the activity rhythms. Similar to what has been found in other mammals, a single light exposure during the bear's active period delayed subsequent activity onsets whereas these were advanced when light was applied during the bear's inactive period. Lastly, in vitro studies confirmed the expression of molecular circadian rhythms with a period comparable to the bear's own behavioral rhythms.

Conclusions: Based on these findings we conclude that the circadian system is functional in torpid bears and their peripheral tissues even when housed in constant darkness, is responsive to phase-shifting effects of light, and therefore, is a normal facet of torpid bear physiology.

Physiology; Denning

BEHAVIOUR AND PREDATION

Figure 15. Remains of a bighorn sheep carcass documented at a grizzly bear GPS cluster. Photo by Leonie Brown.

Here we explore how telemetry data can be used to predict grizzly bear behaviour, focusing on predation.

Cristescu, B., Stenhouse, G. B., & Boyce, M. S. (2015). Predicting multiple behaviors from GPS radiocollar cluster data. Behavioral Ecology, 26(2), 452–464. https://doi.org/10.1093/beheco/aru214

Advancements in GPS radiotelemetry allow collection of vast data for a variety of species including those for which direct observations are typically not feasible. Predicting behavior from telemetry data is possible, but telemetry fix rate can influence inferences, and animal behavior itself can affect fix success. We use multinomial regression to predict behavior from GPS radiocollar data field validated with behavioral state information. Our study organism was a facultative carnivore, the grizzly bear (*Ursus arctos*) (n = 10) from a threatened population in Alberta, Canada, monitored during 2008-2010. Models using GPS cluster parameters alone successfully predicted ungulate consumption, whereas bear bedding was sufficiently identified by models that included site-level information. Predicting more complex behaviors required models incorporating both cluster parameters and habitat characteristics. No model reliably predicted vegetation feeding, probably because this activity is shorter than the time required for cluster formation. Models built using infrequent fix rates underestimated all behaviors, with bear presence at ungulate carcass sites least sensitive to fix rate variability. Behavior influenced fix success, with highest fix acquisition occurring when bears fed on vegetation. Placing predictions into a conservation context, we show that grizzly bears modify their behavior as they move through a landscape with complex human-activity patterns on reclaimed open-pit mines, foothill, and mountain regions. The modeling approach we tested needs further applications across species and ecosystems including behavioral monitoring, quantifying activity budgeting, and identifying areas/habitats important for specific behaviors that may warrant conservation.

Telemetry; Mining; Behaviour; Habitat Use; Predation; Bedding

Kermish-wells, J., Massolo, A., Larsen, T. A., Musiani, M., & Stenhouse, G. B. (2017). **Space-time clusters for early detection of grizzly bear predation.** **Ecology and Evolution, 8(1), 382–395.** **https://doi.org/10.1002/ece3.3489**

Accurate detection and classification of predation events is important to determine predation and consumption rates by predators. However, obtaining this information for large predators is constrained by the speed at which carcasses disappear and the cost of field data collection. To accurately detect predation events, researchers have used GPS collar technology combined with targeted site visits. However, kill sites are often investigated well after the predation event due to limited data retrieval options on GPS collars (VHF or UHF downloading) and to ensure crew safety when working with large predators. This can lead to missing information from small-prey (including young ungulates) kill sites due to scavenging and general site deterioration (e.g., vegetation growth). We used a space-time permutation scan statistic (STPSS) clustering method (SaTScan) to detect predation events of grizzly bears (*Ursus arctos*) fitted with satellite transmitting GPS collars. We used generalized linear mixed models to verify predation events and the size of carcasses using spatiotemporal characteristics as predictors. STPSS uses a probability model to compare expected cluster size (space and time) with the observed size. We applied this method retrospectively to data from 2006 to 2007 to compare our method to random GPS site selection. In 2013-2014, we applied our detection method to visit sites one week after their occupation. Both datasets were collected in the same study area. Our approach detected 23 of 27 predation sites verified by visiting 464 random grizzly bear locations in 2006-2007, 187 of which were within space-time clusters and 277 outside. Predation site detection increased by 2.75 times (54 predation events of 335 visited clusters) using 2013-2014 data. Our GLMMs showed that cluster size and duration predicted predation events and carcass size with high sensitivity (0.72 and 0.94, respectively). Coupling GPS satellite technology with clusters using a program based on space-time probability models allows for prompt visits to predation sites. This enables accurate identification of the carcass size and increases fieldwork efficiency in predation studies.

Predation; Telemetry; Food

Cristescu, B., Stenhouse, G. B., & Boyce, M. S. (2014). **Grizzly bear ungulate consumption and the relevance of prey size to caching and meat sharing.** **Animal Behaviour, 92, 133–142.** **https://doi.org/10.1016/j.anbehav.2014.03.020**

Prey consumption forms a large part of prey-handling time, and knowledge of where prey is ingested can inform management of predator-prey systems. Safeguarding habitats that promote prey consumption could enhance populations of facultative or obligate carnivores of conservation concern. We investigated habitat characteristics at 124 sites where radiocollared adult grizzly bears, *Ursus arctos* (*N* = 9) consumed ungulates, and we contrasted these sites with paired random sites. We developed a priori models incorporating the potential effects of ungulate and plant food distribution as well as risks of detection by humans and other carnivores on consumption site choice, and evaluated which factors best explain grizzly bear food-caching behaviour. Ungulates were consumed in forested areas, close to edges, and where horizontal cover was high, whereby vegetation impeded visibility of the ungulate carcass. Distance to roads had no effect on the distribution of prey consumption sites, but carcasses were further from trails than expected. Models incorporating presence/absence of key non-ungulate bear foods had little weight of evidence ($w_i \leq 0.01$). Food-caching behaviour did not appear to be related to variation in resource availability or risk of food spoilage but was significantly influenced by prey size. Although bears chose sites that minimized detection risk, spent more time at larger carcasses and cached 75.9% of ungulates, 50% of consumption sites had other carnivore sign, which was more likely to be present at large carcasses.

Predation; Landcover; Roads; Trails; Forest Structure; Human Access

GENETICS AND INTRASPECIFIC INTERACTIONS

Figure 16. Three curious grizzly bear cubs investigating a scent bait at a hair snag site.

In this section, we use data on grizzly bear genetics and movement to better understand grizzly bear population boundaries and interactions between grizzly bears.

Stenhouse, G., Boulanger, J., Lee, J., Graham, K., Duval, J., & Cranston, J. (2005). Grizzly bear associations along the eastern slopes of Alberta. Ursus, 16(1), 31–40. https://doi.org/10.2192/1537-6176(2005)016[0031:GBAATE]2.0.CO;2

We used Doncaster's test to differentiate home range overlap in range use from mutual attraction in grizzly bears (*Ursus arctos*) based on global positioning system (GPS) telemetry data. From a sample of 61 collared bears, 404 pairs of GPS locations placed 2 or more bears ≤500 m from each other at about the same time (within 3 hr). From these 404 pairs, 68 were significantly positive associations (mutual attraction) in which 65% were male-female (MF) and 35% were the same sex. Most MF associations involved adults. Male and female bears had associations with 1.8 and 1.2 partners/year, respectively. Associations between males occurred twice as often in the pre-berry season than in the berry season, whereas female-female (FF) associations occurred more frequently in the berry season. The length of same-sex associations was significantly shorter than MF associations. Fifty-one percent of MF pairs associated more than once within a single year. For MF associations, the mean distance between individuals was 152 m. Our findings suggest that grizzly bears can spend a considerable amount of time interacting with conspecifics and that behavioral interactions between grizzly bears are more complicated than we understand. Human activity that affects grizzly bear associations could disrupt social behavior and ultimately reproduction.

Home Range; Reproduction; Behaviour

Mowat, G., Heard, D. C., Seip, D. R., Poole, K. G., Stenhouse, G., & Paetkau, D. W. (2005). Grizzly (*Ursus arctos*) and black bear (*U. americanus*) densities in the interior mountains of North America. Wildlife Biology, 11(1), 31–48. https://doi.org/10.2981/0909-6396(2005)11[31:GUAABB]2.0.CO;2

We collected hair samples from bears and used microsatellite genotyping to identify individual bears on three study areas near the Canadian Rocky Mountains. We estimated density of grizzly bears *Ursus arctos* in eight different ecosystems across five study areas, including the reanalysis of two previously published data sets. We also estimated black bear *U. americanus* density for two ecosystems in one study area. Grizzly bear density was lowest in boreal and sub-boreal plateau areas, moderate in the Rocky Mountain east slopes and highest in the Rocky Mountain west slopes. Presumably these gross differences are related to ecosystem productivity. In the Rocky Mountain west slopes, grizzly bear density was lower in populations that were partially isolated from the continuous bear population to the north. Presumably, these differences have more to do with human impacts on habitat and survival than ecosystem productivity, because productivity in partially isolated areas was similar to productivity in adjacent continuous populations. We show that large differences in bear density occur down to the ecoregion scale; broader ecosystem classes such as Banci's (1991) grizzly bear zones, ecoprovinces or ecozones would include areas with major differences in density and are therefore too coarse a scale at which to predict grizzly bear density. There appears to be little movement across ecoregion boundaries further suggesting that this may be an appropriate scale at which to extrapolate density. Differences in density across finer-scale ecosystems are likely due to seasonal movements and not population level differences in density. Average bear movements were longer in less productive ecosystems. Female grizzly bears did not appear to leave their home ranges to fish for salmon *Oncorhynchus* spp., and extra-territorial movements by males appeared to be rare, in both ecosystems which supported spawning salmon.

Population Inventory; Density; Fragmentation; Hair Snag; Human Use; Black Bear

Proctor, M. F., Paetkau, D., Mclellan, B. N., Stenhouse, G. B., Kendall, K. C., Mace, R. D., Kasworm, W. F., Servheen, C., Lausen, C. L., Gibeau, M. L., Wakkinen, W. L., Haroldson, M. a., Mowat, G., Apps, C. D., Ciarniello, L. M., Barclay, R. M. R., Boyce, M. S., Schwartz, C. C., & Strobeck, C. (2012). Population fragmentation and inter-ecosystem movements of grizzly bears in western Canada and the northern United States. Wildlife Monographs, 180(1), 1–46. https://doi.org/10.1002/wmon.6

Population fragmentation compromises population viability, reduces a species' ability to respond to climate change, and ultimately may reduce biodiversity. We studied the current state and potential causes of fragmentation in grizzly bears over approximately 1,000,000 km^2 of western Canada, the northern United States (US), and southeast Alaska. We compiled much of our data from projects undertaken with a variety of research objectives including population estimation and trend, landscape fragmentation, habitat selection, vital rates, and response to human development. Our primary analytical techniques stemmed from genetic analysis of 3,134 bears, supplemented with radiotelemetry data from 792 bears. We used 15 locus microsatellite data coupled with measures of genetic distance, isolation-by-distance (IBD) analysis, analysis of covariance (ANCOVA), linear multiple regression, multi-factorial correspondence analysis (to identify population divisions or fractures with no a priori assumption of group membership), and population-assignment methods to detect individual migrants between immediately adjacent areas. These data corroborated observations of inter-area movements from our telemetry database. In northern areas, we found a spatial genetic pattern of IBD, although there was evidence of natural fragmentation from the rugged heavily glaciated coast mountains of British Columbia (BC) and the Yukon. These results contrasted with the spatial pattern of fragmentation in more southern parts of their distribution. Near the Canada-US border area, we found extensive fragmentation that corresponded to settled mountain valleys and major highways. Genetic distances across developed valleys were elevated relative to those across undeveloped valleys in central and northern BC. In disturbed areas, most inter-area movements detected were made by male bears, with few female migrants identified. North-south movements within mountain ranges (Mts) and across BC Highway 3 were more common than east-west movements across settled mountain valleys separating Mts. Our results suggest that relatively distinct subpopulations exist in this region, including the Cabinet, Selkirk South, and the decades-isolated Yellowstone populations. Current movement rates do not appear sufficient to consider the subpopulations we identify along the Canada-US border as 1 inter-breeding unit. Although we detected enough male movement to mediate gene flow, the current low rate of female movement detected among areas is insufficient to provide a demographic rescue effect between areas in the immediate future (0-15 yr). In Alberta, we found fragmentation corresponded to major east-west highways (Highways 3, 11, 16, and 43) and most inter-area movements were made by males. Gene flow and movement rates between Alberta and BC were highest across the Continental Divide south of Highway 1 and north of Highway 16. In the central region between Highways 1 and 11, we found evidence of natural fragmentation associated with the extensive glaciers and icefields along the Continental Divide. The discontinuities that we identified would form appropriate boundaries for management units. We related sex-specific movement rates between adjacent areas to several metrics of human use (highway traffic, settlement, and human-caused mortality) to understand the causes of fragmentation. This analysis used data from 1,508 bears sampled over a 161,500-km^2 area in southeastern BC, western Alberta, northern Idaho, and northern Montana during 1979 - 2007. This area was bisected by numerous human transportation and settlement corridors of varying intensity and complexity. We used multiple linear regression and ANCOVA to document the responses of female and male bears to disturbance. Males and females both demonstrated reduced movement rates with increasing settlement and traffic. However, females reduced their movement rates dramatically when settlement increased to >20% of the fracture zone. At this same threshold, male movement declined more gradually, in response to increased traffic and further settlement. In highly settled areas (>50%), both sexes had a similar reduction in movements in response to traffic, settlement, and mortality. We documented several small bear populations with male-only immigration, highlighting the importance of investigating sex-specific movements. Without female connectivity, small populations are not viable over the long term. The persistence of this regional female fragmented metapopulation likely will require strategic connectivity management. We therefore recommend enhancing female connectivity among fractured areas by securing linkage-zone habitat appropriate for female dispersal, and ensuring current large source subpopulations remain intact. The fragmentation we documented may also affect other species with similar ecological characteristics: sparse densities, slow reproduction, short male-biased dispersal, and a susceptibility to human-caused mortality and habitat degradation. Therefore, regional inter-jurisdictional efforts to manage broad landscapes for inter-area movement will likely benefit a broad spectrum of species and natural processes, particularly in light of climate change.

Climate Change; Fragmentation; DNA; Roads; Human Use; British Columbia

Nielsen, S. E., Shafer, A. B. A., Boyce, M. S., & Stenhouse, G. B. (2013). Does learning or instinct shape habitat selection? PloS ONE, 8(1), e53721. https://doi.org/10.1371/journal.pone.0053721

Habitat selection is an important behavioural process widely studied for its population-level effects. Models of habitat selection are, however, often fit without a mechanistic consideration. Here, we investigated whether patterns in habitat selection result from instinct or learning for a population of grizzly bears (*Ursus arctos*) in Alberta, Canada. We found that habitat selection and relatedness were positively correlated in female bears during the fall season, with a trend in the spring, but not during any season for males. This suggests that habitat selection is a learned behaviour because males do not participate in parental care: a genetically predetermined behaviour (instinct) would have resulted in habitat selection and relatedness correlations for both sexes. Geographic distance and home range overlap among animals did not alter correlations indicating that dispersal and spatial autocorrelation had little effect on the observed trends. These results suggest that habitat selection in grizzly bears are partly learned from their mothers, which could have implications for the translocation of wildlife to novel environments.

Habitat Selection; Translocations; Behaviour; DNA

Shafer, A. B. A, Nielsen, S. E., Northrup, J. M., & Stenhouse, G. B. (2013). Linking genotype, ecotype, and phenotype in an intensively managed large carnivore. Evolutionary Applications, 7(2), 301–312. https://doi.org/10.1111/eva.12122

Numerous factors influence fitness of free-ranging animals, yet often these are uncharacterized. We integrated GPS habitat use data and genetic profiling to determine their influence on fitness proxies (mass, length, and body condition) in a threatened population of grizzly bears (*Ursus arctos*) in Alberta, Canada. We detected distinct genetic and habitat use (ecotype) clusters, with individual cluster assignments, or genotype/ecotype, being correlated (Pearson $r = 0.34$, $P < 0.01$). Related individuals showed evidence of similar habitat use patterns, irrespective of geographic distance and sex. Fitness proxies were influenced by sex, age, and habitat use, and homozygosity had a positive effect on these proxies that could be indicative of outbreeding depression. We further documented over 300 translocations occurring in the province since the 1970s, often to areas with significantly different habitat. We argue this could be unintentionally causing the pattern of outbreeding, although the heterozygosity correlation may instead be explained by the energetic costs associated with larger body size. The observed patterns, together with the unprecedented human-mediated migrations, make understanding the link between genotype, ecotype, and phenotype and mechanisms behind the negative heterozygosity-fitness correlations critical for management and conservation of this species.

GPS Collar; Habitat Use; DNA; Fitness; Habitat Selection; Translocations

Grizzly Bear Responses

Grizzly Bear Habitat and Management Area Determination

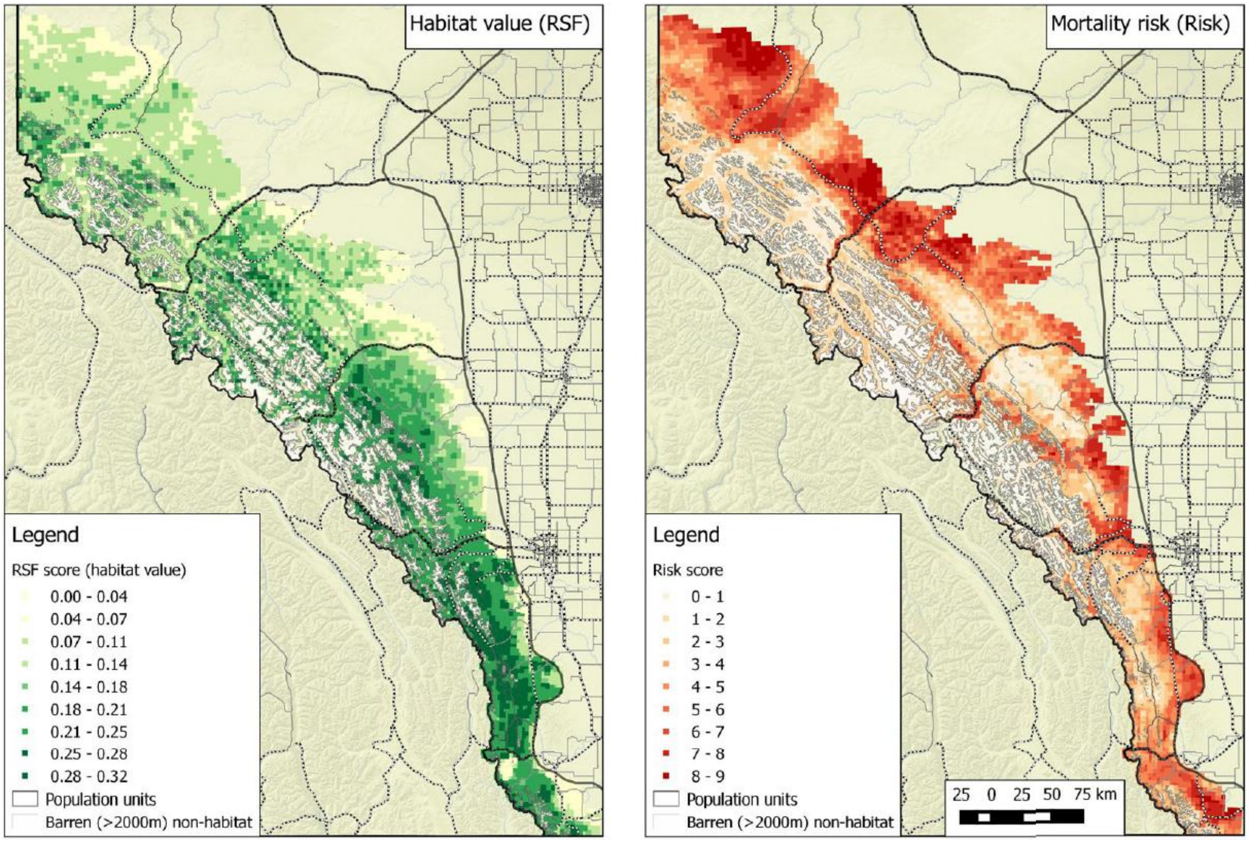

Figure 17. Resource selection function (RSF) scores for grizzly bear habitat (left graph) and mortality risk scores (right graph) used as mark point covariates in the density surface model for analysis of Alberta grizzly bear inventory data (2004-8). In both cases increasing RSF and Risk score suggest increasing habitat value and increasing levels of mortality risk. Figure taken from Boulanger et al. 2018, p. 75.

While in *The Environmental Context* grizzly bear habitat components were classified and mapped, in this section, information on grizzly bear location, movement, and survival were used to determine areas where grizzly bears were found in relation to these habitat types, and the core grizzly bear areas for management were defined.

Nielsen, S. E., Boyce, M. S., Stenhouse, G. B., & Munro, R. H. M. (2002). Modeling grizzly bear habitats in the Yellowhead ecosystem of Alberta: taking autocorrelation seriously. Ursus, 13, 45–56. https://www.jstor.org/stable/3873186

We used resource selection functions (RSF) to estimate relative probability of grizzly bear (*Ursus arctos*) use for habitats, landscape features, and areas of varying human access density across a 5,342-km^2 study area in west-central Alberta, Canada. Models were developed based on 1999 data at both the population and individual levels for the spring and summer–autumn seasons. Individual-based RSF models revealed strong differences in selection among animals. Models developed for the summer–autumn season fit better than models of the spring season. High greenness values, derived from Landsat imagery, corresponded well with grizzly bear habitat use. Significance of parameters was frequently overestimated when using logistic regression models that were unadjusted for autocorrelation or pseudoreplication, both in individual-based models and in population-based models. Although not affecting predictability of bears at the individual-level, such biases may lead to inappropriate conclusions without adjustment. Population-based models further showed bias without correction for pseudo-replication within individuals (unit of replication). Consideration of variance inflation factors and nesting of telemetry points on the individual enhances the reliability of habitat modeling. We found problems predicting grizzly bear habitat use when local habitat index models were used. The RSF models presented here improve such models while also generating information on the contribution of particular environmental variables.

Habitat Selection; RSF; Landsat; Management Areas

Popplewell, C., Franklin, S. E., Stenhouse, G., & Hall-Beyer, M. (2003). Using landscape structure to classify grizzly bear density in Alberta Yellowhead Ecosystem bear management units. Ursus, 14(1), 27–34. https://www.jstor.org/stable/3872954

Landscape metrics derived from a Landsat-5 Thematic Mapper (TM) satellite image classification of landcover were used to quantify the structure of grizzly bear (*Ursus arctos*) habitat within bear management units (BMUs) in the Yellowhead Ecosystem in west-central Alberta, Canada. Statistical relationships were developed using 3 bear density classes that were based on DNA data obtained in 1999 from 192 hair snagging stations distributed within 9-km^2 grid cells. The relative differences among the available 16 BMUs were quantified and interpreted using 4 landscape metrics (edge density, mean patch size, mean-nearest-neighbor, and patch size covariance). Using discriminant functions, greater than 80% accuracy was achieved with these metrics in classification of BMUs with low, medium, and high bear density classes. BMUs with higher bear density had lower edge density and greater mean patch size; BMUs with lower bear density had greater patch size covariance and mean nearest neighbour distance.

Edge; Density; DNA; Management Areas; Landsat; Landcover

Nielsen, S. E., Stenhouse, G. B., & Boyce, M. S. (2006). A habitat-based framework for grizzly bear conservation in Alberta. Biological Conservation, 130(2), 217–229. https://doi.org/10.1016/j.biocon.2005.12.016

Grizzly bear (*Ursus arctos* L.) populations in Alberta are threatened by habitat loss and high rates of human-caused mortality. Spatial depictions of fitness would greatly improve management and conservation action. We are currently challenged, however, in our ability to parameterize demographic rates necessary for describing fitness, especially across gradients of human disturbance and for land cover types. Alternative approaches are therefore needed. We describe here a method of estimating relative habitat states and conditions as surrogates of fitness using models of occupancy and mortality risk. By combining occurrence and risk models into a two-dimensional habitat framework, we identified indices of attractive sinks and safe harbour habitats, as well as five habitat states: non-critical habitats, secondary habitats (low-quality and secure), primary habitats (high-quality and secure), secondary sinks (low-quality, but high risk), and primary sinks (high-quality and high risk). Primary sink or high attractive sink situations were evident in the foothills where bears were using forest edges associated with forestry and oil and gas activities on Crown lands, while primary habitats or safe harbour sites were most common to protected alpine/sub-alpine sites. We suggest that habitat states and indices be used for setting baseline conditions for management and comparison of habitat conditions over time and identification of grizzly bear conservation reserves. A no net loss policy of critical habitats could be used to maintain existing habitat conditions for landscapes threatened by human development. Under such a policy, conversions of primary habitat would require restoration of equivalent amounts of primary sinks through decommissioning of roads.

Management Areas; Map Product; Habitat Mapping; Fitness; Mortality; Forestry; Oil and Gas

Nielsen, S. E., Cranston, J., & Stenhouse, G. B. (2009). Identification of priority areas for grizzly bear conservation and recovery in Alberta, Canada. Journal of Conservation Planning, 5, 38–60.

In Alberta, Canada, high rates of human-caused mortality threaten the long-term persistence of grizzly bears. To reduce this threat, the provincial grizzly bear recovery team suggested that core conservation areas of at least 2,400 km^2 be delineated for each of seven population units where open access road density is limited to 0.6 km/km^2 and buffered by secondary conservation areas where road density is limited to 1.2 km/km^2. We used a habitat model based on 81 radio- collared grizzly bears and a road network to identify core conservation areas for six population units using two comparative techniques: (1) simulated annealing; and (2) contours of safe harbor habitat - an index of secure habitat. Model effectiveness was evaluated by comparing grizzly bear detections (occupancy) in conservation areas to existing protected areas at 2,295 hair-snag sites. Habitat was similar among techniques, while simulated annealing resulted in lower road densities and higher occupancy rates. Overlap among techniques was 46% of combined area. Using results from both analyses, Alberta Sustainable Resource Development modified core areas to follow watershed boundaries, nearly doubling their extent to 33,364 km^2. Secondary conservation areas buffering and/or connecting core areas added an additional 23,224 km^2. Grizzly bear occupancy in final core areas did not differ significantly from protected areas, while occupancy was 4 to 6 times lower in secondary conservation areas. We suggest that the comparative modeling approach used strengthened decision support and value of models and that effectiveness monitoring and adaptive management be used to adjust future management strategies and locations of core area boundaries.

Access Management; Management Areas; Roads; Hair Snag; Protected Areas; Map Product; Security

Nielsen, S. E., McDermid, G., Stenhouse, G. B., & Boyce, M. S. (2010). Dynamic wildlife habitat models: Seasonal foods and mortality risk predict occupancy-abundance and habitat selection in grizzly bears. Biological Conservation, 143(7), 1623–1634. https://doi.org/10.1016/j.biocon.2010.04.007

Most current wildlife habitat models, such as resource selection functions, typically assume a static environment, extrapolate poorly in space and time, and often lack linkages to population processes. We submit that more mechanistic habitat models that directly consider bottom-up resources affecting growth and reproduction (i.e., food) and top-down limitations affecting survival are needed to effectively predict habitat quality, especially in the presence of rapid environmental change. Here we present a general model for estimating potential habitat quality (relating to growth and reproduction) and realised habitat quality (accounting for survival) using basic knowledge of the species' seasonal diet, predicted locations of food resource patches and regional patterns in mortality risk. We illustrate our model for a threatened population of grizzly bears in west-central Alberta. Bi-monthly potential habitat quality successfully predicted habitat selection by radio-collared grizzly bears, while multi-seasonal realised habitat quality predicted patterns in occupancy-abundance as measured from unique bears at hair-snag sites. Bottom-up resources therefore predicted patterns of habitat selection, while top-down processes (survival) were necessary to scale-up to population measures. We suggest that more direct measures of resources and environments that affect growth, reproduction and survival, as well as match the temporal scale of animal behaviour, be considered when developing wildlife habitat models.

Habitat Selection; Mortality; Food

Apps, C. D., McLellan, B. N., Proctor, M. F., Stenhouse, G. B., & Servheen, C. (2016). Predicting spatial variation in grizzly bear abundance to inform conservation. The Journal of Wildlife Management, 80(3), 396–413. https://doi.org/10.1002/jwmg.1037

Understanding the spatial structure of populations is fundamental to effective assessment, planning, and management for species conservation. Because of their sensitivity and public interest, grizzly bears (*Ursus arctos*) are focused upon in some localized development issues and proactive conservation initiatives. Knowledge regarding the spatial context of regional grizzly bear populations is important, but often a defensible representation of probable population distribution, core areas, and connectivity is lacking. We describe the development and assessment of a regional landscape model of grizzly bear density and distribution. Our study region comprised 180,000 km^2 and 20 management units of southeast British Columbia and southwest Alberta. Our meta-analysis was based on data from 20 independent grizzly bear population surveys across the region. While accounting for differing design parameters among surveys, we contrasted grizzly bear detections against sampling representation relative to scale-dependent landscape factors. Our predictors pertained to the influence of climate, terrain, land cover, vegetation indices, and human activity. Associations within survey areas were consistent with ecological influences on grizzly bear foods and human influences on grizzly bear mortality risk and landscape avoidance. A multiple logistic regression model based on independent components of ecological variation fit well the data pooled across the region and within individual survey areas. Average values of detection probability among survey areas predicted population density (R^2 = 0.64 or 0.79 depending on one outlier). Our results support application of our model across southeast British Columbia and southwest Alberta for assessment and planning that requires regional and local context of grizzly bear population abundance and distribution, and inference of core areas and population connections among them. For any geographic area, a population estimate can be obtained that is reflective of surveys used in the model. Spatial predictions for any defined population are likely to be more reliable than those extrapolated from tracking data of individual animals given limitations typical of such sampling. Ultimately, model output provides regional population context for environmental assessment, management, and conservation planning, nested within which should be finer- scale data and prediction where available.

Distribution; Density; Connectivity; Human Use; Population Inventory; Management Areas; British Columbia

Boulanger, J., Nielsen, S. E., & Stenhouse, G. B. (2018). Using spatial mark-recapture for conservation monitoring of grizzly bear populations in Alberta. Scientific Reports, 8(5204), 1–15. https://doi.org/10.1038/s41598-018-23502-3

One of the challenges in conservation is determining patterns and responses in population density and distribution as it relates to habitat and changes in anthropogenic activities. We applied spatially explicit capture recapture (SECR) methods, combined with density surface modelling from five grizzly bear (*Ursus arctos*) management areas (BMAs) in Alberta, Canada, to assess SECR methods and to explore factors influencing bear distribution. Here we used models of grizzly bear habitat and mortality risk to test local density associations using density surface modelling. Results demonstrated BMA-specific factors influenced density, as well as the effects of habitat and topography on detections and movements of bears. Estimates from SECR were similar to those from closed population models and telemetry data, but with similar or higher levels of precision. Habitat was most associated with areas of higher bear density in the north, whereas mortality risk was most associated (negatively) with density of bears in the south. Comparisons of the distribution of mortality risk and habitat revealed differences by BMA that in turn influenced local abundance of bears. Combining SECR methods with density surface modelling increases the resolution of mark-recapture methods by directly inferring the effect of spatial factors on regulating local densities of animals.

Population Monitoring; Density; Hair Snag; Distribution

HABITAT QUALITY AND FITNESS

Figure 18. A grizzly bear travels along a resource road.

Here, we describe how various aspects of habitat quality influence grizzly bear stress and fitness. This section includes discussions of anthropogenic disturbances along with natural habitat variation.

Boulanger, J., Cattet, M., Nielsen, S. E., Stenhouse, G., & Cranston, J. (2013). Use of multi-state models to explore relationships between changes in body condition, habitat and survival of grizzly bears *Ursus arctos horribilis*. Wildlife Biology, 19(3), 1–15. https://doi.org/10.2981/12-088

One of the principal goals of wildlife research and management is to understand and predict relationships between habitat quality, health of individuals and their ability to survive. Infrequent sampling, non-random loss of individuals due to mortality and variation in capture susceptibility create potential biases with conventional analysis methods. To account for such sampling biases, we used a multi-state analytical approach to assess relationships between habitat, health and survival of grizzly bears *Ursus arctos horribilis* over a 10-year period along the east slopes of the Canadian Rockies in Alberta, Canada. We defined bear health states by body condition estimated from the relationship between weight and body length. We used a sequential model building process to first account for potential sampling biases, and then explored changes in body condition relative to habitat use and survival. Bears that used regenerating forest habitats (mostly due to forest harvesting) containing a diversity of age classes were more likely to see gains in their body condition, whereas bears that used older forests were more likely to see reductions in body condition. Survival rate was reduced most by road densities which in turn were positively correlated with regenerating forest habitat. Human activities which promote young regenerating forests, such as forest harvesting, therefore promotes improved health (increased body condition) in bears, but are offset by reductions in survival rates. Multi-state analyses represents a robust analytical tool when dealing with complex relationships and sampling biases that arise from dynamic environments.

Mortality; Health; Body Condition; Capture Methods; Forestry; Roads

Nielsen, S. E., Cattet, M. R. L., Boulanger, J., Cranston, J., McDermid, G. J., Shafer, A. B., & Stenhouse, G. B. (2013). Environmental, biological and anthropogenic effects on grizzly bear body size: temporal and spatial considerations. BMC Ecology, 13(1), 1–31. https://doi.org/10.1186/1472-6785-13-31

BACKGROUND: Individual body growth is controlled in large part by the spatial and temporal heterogeneity of, and competition for, resources. Grizzly bears (*Ursus arctos* L.) are an excellent species for studying the effects of resource heterogeneity and maternal effects (i.e. silver spoon) on life history traits such as body size because their habitats are highly variable in space and time. Here, we evaluated influences on body size of grizzly bears in Alberta, Canada by testing six factors that accounted for spatial and temporal heterogeneity in environments during maternal, natal and 'capture' (recent) environments. After accounting for intrinsic biological factors (age, sex), we examined how body size, measured in mass, length and body condition, was influenced by: (a) population density; (b) regional habitat productivity; (c) inter-annual variability in productivity (including silver spoon effects); (d) local habitat quality; (e) human footprint (disturbances); and (f) landscape change.

RESULTS: We found sex and age explained the most variance in body mass, condition and length (R^2 from 0.48-0.64). Inter-annual variability in climate the year before and of birth (silver spoon effects) had detectable effects on the three-body size metrics (R^2 from 0.04-0.07); both maternal (year before birth) and natal (year of birth) effects of precipitation and temperature were related with body size. Local heterogeneity in habitat quality also explained variance in body mass and condition (R^2 from 0.01-0.08), while annual rate of landscape change explained additional variance in body length (R^2 of 0.03). Human footprint and population density had no observed effect on body size.

CONCLUSIONS: These results illustrated that body size patterns of grizzly bears, while largely affected by basic biological characteristics (age and sex), were also influenced by regional environmental gradients the year before, and of, the individual's birth thus illustrating silver spoon effects. The magnitude of the silver spoon effects was on par with the influence of contemporary regional habitat productivity, which showed that both temporal and spatial influences explain in part body size patterns in grizzly bears. Because smaller bears were found in colder and less-productive environments, we hypothesize that warming global temperatures may positively affect body mass of interior bears.

Body Size; Climate; Landcover; Climate Change; Family Dynamics

Bourbonnais, M. L., Nelson, T. A., Cattet, M. R. L., Darimont, C. T., Stenhouse, G. B., & Janz, D. M. (2014). Environmental factors and habitat use influence body condition of individuals in a species at risk, the grizzly bear. Conservation Physiology, 2(1), cou043. https://doi.org/10.1093/conphys/cou043

Metrics used to quantify the condition or physiological states of individuals provide proactive mechanisms for understanding population dynamics in the context of environmental factors. Our study examined how anthropogenic disturbance, habitat characteristics and hair cortisol concentrations interpreted as a sex-specific indicator of potential habitat net-energy demand affect the body condition of grizzly bears (n = 163) in a threatened population in Alberta, Canada. We quantified environmental variables by modelling spatial patterns of individual habitat use based on global positioning system telemetry data. After controlling for gender, age and capture effects, we assessed the influence of biological and environmental variables on body condition using linear mixed-effects models in an information theoretical approach. Our strongest model suggested that body condition was improved when patterns of habitat use included greater vegetation productivity, increased influence of forest harvest blocks and oil and gas well sites, and a higher percentage of regenerating and coniferous forest. However, body condition was negatively affected by habitat use in close proximity to roads and in areas where potential energetic demands were high. Poor body condition was also associated with increased selection of parks and protected areas and greater seasonal vegetation productivity. Adult females, females with cubs-of-year, juvenile females and juvenile males were in poorer body condition compared with adult males, suggesting that intra-specific competition and differences in habitat use based on gender and age may influence body condition dynamics. Habitat net-energy demand also tended to be higher in areas used by females which, combined with observed trends in body condition, could affect reproductive success in this threatened population. Our results highlight the importance of considering spatiotemporal variability in environmental factors and habitat use when assessing the body condition of individuals. Long-term and large-scale monitoring of the physiological state of individuals provides a more comprehensive approach to support management and conservation of species at risk.

Body Condition; Disturbance; Cortisol; Health; Forestry; Oil and Gas; Roads; Stress; Reproduction

Bourbonnais, M. L., Nelson, T. A., Cattet, M. R. L., Darimont, C. T., & Stenhouse, G. B. (2013). Spatial analysis of factors influencing long-term stress in the grizzly bear (*Ursus arctos*) population of Alberta, Canada. PloS One, 8(12), e83768. https://doi.org/10.1371/journal.pone.0083768

Non-invasive measures for assessing long-term stress in free ranging mammals are an increasingly important approach for understanding physiological responses to landscape conditions. Using a spatially and temporally expansive dataset of hair cortisol concentrations (HCC) generated from a threatened grizzly bear (*Ursus arctos*) population in Alberta, Canada, we quantified how variables representing habitat conditions and anthropogenic disturbance impact long-term stress in grizzly bears. We characterized spatial variability in male and female HCC point data using kernel density estimation and quantified variable influence on spatial patterns of male and female HCC stress surfaces using random forests. Separate models were developed for regions inside and outside of parks and protected areas to account for substantial differences in anthropogenic activity and disturbance within the study area. Variance explained in the random forest models ranged from 55.34% to 74.96% for males and 58.15% to 68.46% for females. Predicted HCC levels were higher for females compared to males. Generally, high spatially continuous female HCC levels were associated with parks and protected areas while low-to-moderate levels were associated with increased anthropogenic disturbance. In contrast, male HCC levels were low in parks and protected areas and low-to-moderate in areas with increased anthropogenic disturbance. Spatial variability in gender-specific HCC levels reveal that the type and intensity of external stressors are not uniform across the landscape and that male and female grizzly bears may be exposed to, or perceive, potential stressors differently. We suggest observed spatial patterns of long-term stress may be the result of the availability and distribution of foods related to disturbance features, potential sexual segregation in available habitat selection, and may not be influenced by sources of mortality which represent acute traumas. In this wildlife system and others, conservation and management efforts can benefit by understanding spatial- and gender-based stress responses to landscape conditions.

Stress; Cortisol; Protected Areas; Disturbance

Wilson, A. E., Kearney, S., Wismer, D., Macbeth, B., Stenhouse, G., Coops, N. C., & Janz, D. M. (2020). Population-level monitoring of stress in grizzly bears between 2004 and 2014. Ecosphere, 11(7), e03181. https://doi.org/10.1002/ecs2.3181

Grizzly bears (*Ursus arctos*) in west-central Alberta occupy an increasingly human-dominated landscape. Natural resource extraction activities are hypothesized to increase stress in animals that reside in such changing landscapes by influencing habitat and resource availability. Our study aimed to determine whether stress, represented by hair cortisol concentration (HCC), was associated with variables related to landscape conditions in a population that increased by 7% annually from 2004 to 2014. Hair samples (n = 157) were collected using barbwire hair snags placed throughout the Yellowhead bear management area in Alberta, Canada. Candidate models were developed a priori representing hypotheses related to biologically and ecologically plausible relationships between HCC and landscape variables. Generalized linear model analysis with landscape attributes representing anthropogenic disturbance, food resource availability, and terrain conditions was used to determine potential drivers of HCC. We found support ($\Delta AICc \leq 2.00$) for three models that included variables from each hypothesis. Anthropogenic variables had the greatest impact on HCC; increasing oil and gas well-site density resulted in reduced HCC, while increasing distance to coal mines resulted in elevated HCC. Hair cortisol concentration also increased as forest crown closure became more variable, while HCC decreased as the soil wetness (represented by compound topographic index) increased. Some forms of anthropogenic disturbance have been linked to increased food availability for this species. Therefore, we suggest that changes in landscape conditions from 2004 to 2014 may have indirectly increased food abundance and ultimately resulted in a reduction in HCC at a population level during this time period. Measuring HCC provides a non-invasive and important monitoring strategy to assess the impact of environmental change on residing species and should be considered in landscape management decisions.

Cortisol; Hair Snag; Physiology; Stress; Anthropogenic Disturbance; Oil and Gas; Mining; Food; Population Monitoring

ANTHROPOGENIC DISTURBANCE

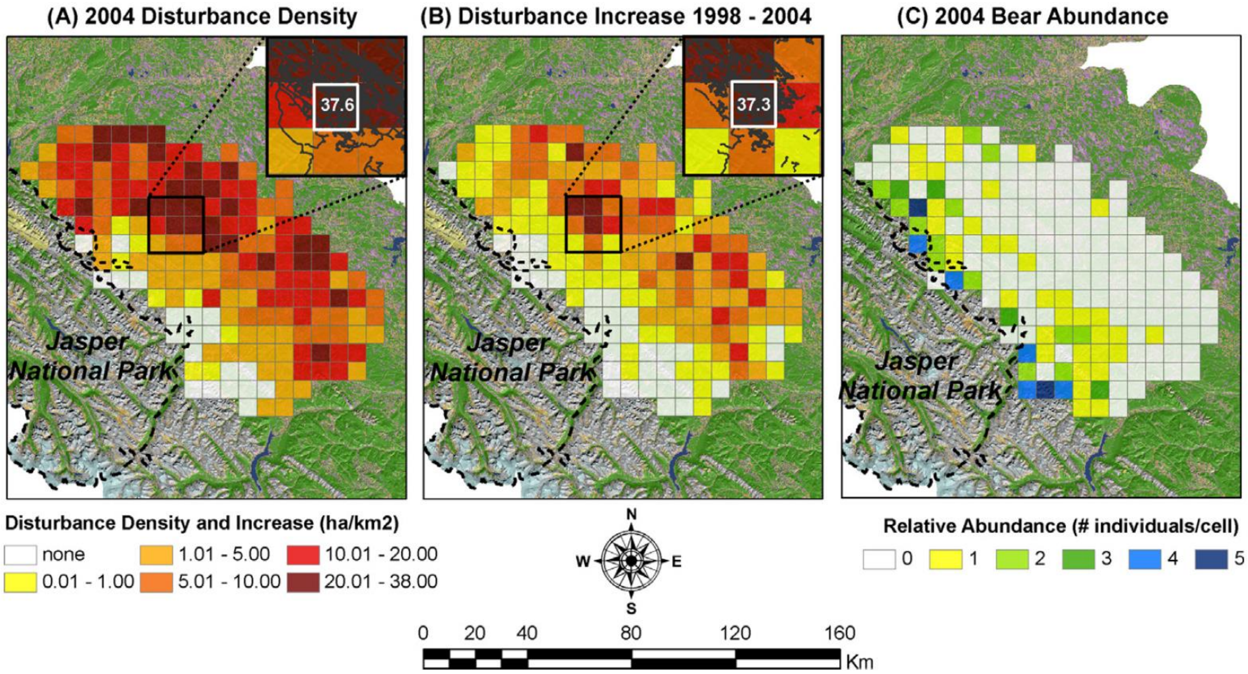

Figure 19. Distribution of (A) cumulative disturbance density existing in the study area at year 2004, and (B) the total increase in cumulative density between the years 1998 and 2004, and (C) the relative abundance of grizzly bears in the year 2004, based on repeated DNA-hair-sampling counts, across 178 landscape cells of the study area. Enlarged inserts show the underlying distribution of the actual cumulative disturbance features by 2004 (B) and of the new disturbance features gained between 1998 and 2004. Figure taken from Linke et al. 2013, p. 80.

This section contains studies that look at the effects of multiple types of human disturbances on grizzly bear density or behaviour.

Linke, J., McDermid, G. J., Fortin, M. J., & Stenhouse, G. B. (2013). Relationships between grizzly bears and human disturbances in a rapidly changing multi-use forest landscape. Biological Conservation, 166, 54–63. https://doi.org/10.1016/j.biocon.2013.06.012

Grizzly bear (*Ursus arctos*) populations across their range are being threatened by anthropogenic development and associated increases in human-caused mortality. However, details surrounding the impact of cumulative human effects are not yet fully understood, as prior research has focused primarily on habitat selection of individual disturbance features, rather than the spatio-temporal dynamics of aggregated disturbance processes. We used grizzly bear relative-abundance information from a DNA population inventory alongside a GIS database of human footprint dynamics to gain insight into the relationships between human disturbance features and the spatial distribution of grizzly bears in west-central Alberta, Canada: a landscape experiencing heavy resource development. We used candidate model-selection techniques and zero-inflated Poisson regression models to test competing hypotheses about disturbance processes, neighborhood effect and landscape characteristics. The best model explained about 57% of the overall variation in relative grizzly bear abundance. Areas with lower 'disturbance exposure' (i.e. high mean distance to new disturbances over time), lower 'neighborhood disturbance' (i.e. disturbance density around those areas), and higher 'availability of regenerating forest', were associated with higher bear abundance. In addition, areas located further away from an adjacent protected area exhibited a higher probability of 'excess absences', accounting indirectly for the cumulative effects of disturbance and the history of human-caused mortality. Our results suggest that managing the spatio-temporal exposure of grizzly bears to new disturbance features may be an important consideration for conserving this species in rapidly changing landscapes.

Forestry; Human Use; Oil and Gas; Roads; Disturbance; Forestry; Density; DNA

Berland, A., Nelson, T., Stenhouse, G., Graham, K., & Cranston, J. (2008). The impact of landscape disturbance on grizzly bear habitat use in the Foothills Model Forest, Alberta, Canada. Forest Ecology and Management, 256(11), 1875–1883. https://doi.org/10.1016/j.foreco.2008.07.019

The Rocky Mountains in Alberta, Canada are subject to a growing number of human activities that cause landscape disturbances. This region is important for large carnivore species such as grizzly bears, whose population decline is a serious management concern. Understanding the impact of landscape disturbance on grizzly bear habitat use is necessary to effectively manage this region and beyond. The goal of this research is to explore the spatial-temporal pattern of habitat use and to characterize the impact of disturbance on use through time. Research was conducted using radio-telemetry location data of female grizzly bears from 1999 to 2003. Kernel home ranges were created annually for three foraging seasons: hypophagia, early hyperphagia, and late hyperphagia. For each season, locations (30m x 30m grid cells) were characterized by the temporal persistence or variability in annual use by grizzly bears. Spatial-temporal trends were then compared for disturbed and undisturbed landscapes. Results indicate that in some foraging seasons, particularly hypophagia, the grizzly bear population's use of disturbed areas was proportionally higher than use in undisturbed areas. In other foraging seasons the trends are less clear, but all show instances of preferential selection of disturbed areas. Given that grizzly bear mortality tends to rise when bears use disturbed areas, this preferential selection of disturbed areas is a management concern. To enhance conservation efforts it may be beneficial to control human use in high-quality habitats. This protection may be most important for high-quality habitats used in the spring, as bears appeared to use smaller areas during this period.

Habitat Use; Disturbance; Home Range; Mortality

Sorensen, A. A., Stenhouse, G. B., Bourbonnais, M. L., & Nelson, T. A. (2015). Effects of habitat quality and anthropogenic disturbance on grizzly bear (*Ursus arctos*) home range fidelity. Canadian Journal of Zoology, 93(11), 857–865. https://doi.org/10.1139/cjz-2015-0095

In the Rocky Mountain eastern slopes of Alberta, Canada, grizzly bears (*Ursus arctos horribilis* Ord, 1815) live in a landscape heavily impacted by industrial development and human disturbance. We characterized the role of changing habitat quality and new disturbance features on patterns of grizzly bear seasonal home-range fidelity and drift by comparing consecutive-year seasonal home ranges. We relied on the geographic technique "spatial-temporal analysis of moving polygons" (STAMP) to examine changes in habitat quality and new development between zones of home-range fidelity, expansion, and contraction. Areas considered to be high-quality habitat were selected at a greater frequency than available and retained in zones of home-range fidelity, but also vacated during home-range contraction. Areas of decreasing habitat quality were equally present in zones of contraction, expansion, and stability. The proportion of new forest harvest areas and roads developed within the past year did not differ between zones of home-range change, but the proportion of new well sites was higher in contraction zones than in stability zones. Our results showed that while considerable drift occurs, changes in habitat quality and recent anthropogenic disturbances cannot account for annual variation in home ranges, suggesting other important factors influencing behaviour and movement.

Anthropogenic Disturbance; Home Range; Roads; Oil and Gas

Pigeon, K. E., Nielsen, S. E., Stenhouse, G. B., & Côté, S. D. (2014). Den selection by grizzly bears on a managed landscape. Journal of Mammalogy, 95(3), 559–571. https://doi.org/10.1644/13-MAMM-A-137

Hibernation is an adaptive strategy to avoid harsh environmental conditions and seasonal limitations in food and water. Unlike most hibernators, grizzly bears (*Ursus arctos*) are aroused easily while in dens and disturbances while denning can result in fitness costs if bears become active during this period. Our objectives were to determine den selection of male and female grizzly bears at multiple spatial scales in the boreal forest and Rocky Mountains of Alberta, Canada. Grizzly bears in Alberta are designated as threatened. However, little is known about den selection by grizzly bears in the boreal forest and the current land and forest management plans do not include any mitigation measures to minimize possible impacts on the denning habitat of grizzly bears. We compared dens to random available locations within fall home ranges using geographic information system - derived anthropogenic, land cover, landscape, and food resource variables. Male and female grizzly bears had similar habitat requirements when selecting dens, and females did not avoid sites associated with a greater probability of encountering males. At the broadest scale investigated, grizzly bears avoided wetlands, and selected high-elevation, dry conifer stands with abundant high-quality spring food. At more localized scales, grizzly bears selected areas of low road densities and dense conifers associated with little high-quality autumn food. Slope angle had the most influence on den selection followed by percent autumn food, road densities, percent wetland, and percent spring food. We recommend limiting human disturbance, including open roads, within core grizzly bear conservation areas for areas with high suitable den habitat.

Denning; Landcover; Food; Roads

Stewart, B. P., Nelson, T. A., Laberee, K., Nielsen, S. E., Wulder, M. A., & Stenhouse, G. B. (2013). Quantifying grizzly bear selection of natural and anthropogenic edges. Journal of Wildlife Management, 77(5), 957–964. https://doi.org/10.1002/jwmg.535

Understanding the use of edges by threatened species is important for conservation and management. Whereas the effects of anthropogenic edges on threatened species have been studied, the effects of natural edges are unknown. We studied grizzly bear (*Ursus arctos*) habitat selection in relation to different landscape-level measures of edge, both natural and anthropogenic. We used a database of global positioning system telemetry data collected from 26 grizzly bears from 2005 to 2009 in the foothills of the Rocky Mountains in west-central Alberta, Canada. We quantified grizzly bear locations relative to natural edges extracted from satellite-derived land cover data and anthropogenic edges from existing vector datasets (roads, pipelines, and forest harvests). To compare edge distance from observed telemetry points statistically, we generated a distribution of expected points through a conditional randomization of an existing resource selection function describing grizzly bear habitat use without respect to edges. We also measured the density of edges within home ranges and compared this to the overall population to create an edge selection ratio. In general, females selected anthropogenic edges, whereas males selected natural edges. Both sexes selected the natural transition (edge) of shrub to conifer. Females had a greater selection ratio for road edges than males in all seasons, and males had a greater selection ratio for roads in the fall than in other seasons. Only females selected for pipeline edges. Our results indicated that edge habitat was selected by both males and females, mostly in the fall. Given human access to bear habitat is often facilitated by anthropogenic edges (e.g., roads), improved management of these features may minimize human conflicts. In particular, we highlight the importance of the natural transition of shrub to conifer to grizzly bears.

Edge; Disturbance; Roads; Forestry; Oil and Gas; Habitat Selection; Satellite Imagery

Finnegan, L., Viejou, R., MacNearney, D., Pigeon, K. E., & Stenhouse, G. B. 2021. Unravelling the impacts of disturbance type and regeneration on movement of threatened species. Landscape Ecology. In press.

Context: Anthropogenic disturbance alters animal movements. Large mammals require large areas to meet their needs, and they encounter anthropogenic disturbances frequently during daily movements.

Objectives: We assessed the impact of disturbance on the daily movements of two large threatened mammals, and examined the nuances of movement response to type and regeneration of disturbances.

Methods: We calculated daily net displacement and sinuosity of grizzly bears and caribou in west-central Alberta, Canada using GPS locations. We assessed links between daily movements and densities of roads, pipelines, seismic lines, harvest blocks, and wellsites. We also considered the effect of harvest block and seismic line regeneration based on LiDAR-derived vegetation height.

Results: During early winter, net displacement of caribou increased relative to densities of wellsites and harvest blocks. Grizzly bear net displacement increased and sinuosity decreased relative to densities of non-linear disturbances during spring. During summer, grizzly bear net displacement increased relative to secondary road density and decreased relative to wellsite density. During fall, grizzly bear net displacement decreased relative to secondary road density and increased relative to harvest block and pipeline density.

Conclusions: Caribou and grizzly bears adjusted their movements in response to disturbances, but each species responded differently and in accordance with its seasonal ecology. Assessing the impacts of disturbance on threatened species across spatio-temporal scales and seasons provides useful insights for multi-species conservation strategies.

Disturbance; Roads; Forestry; Oil and Gas; Movement; Lidar; Caribou

ROADS

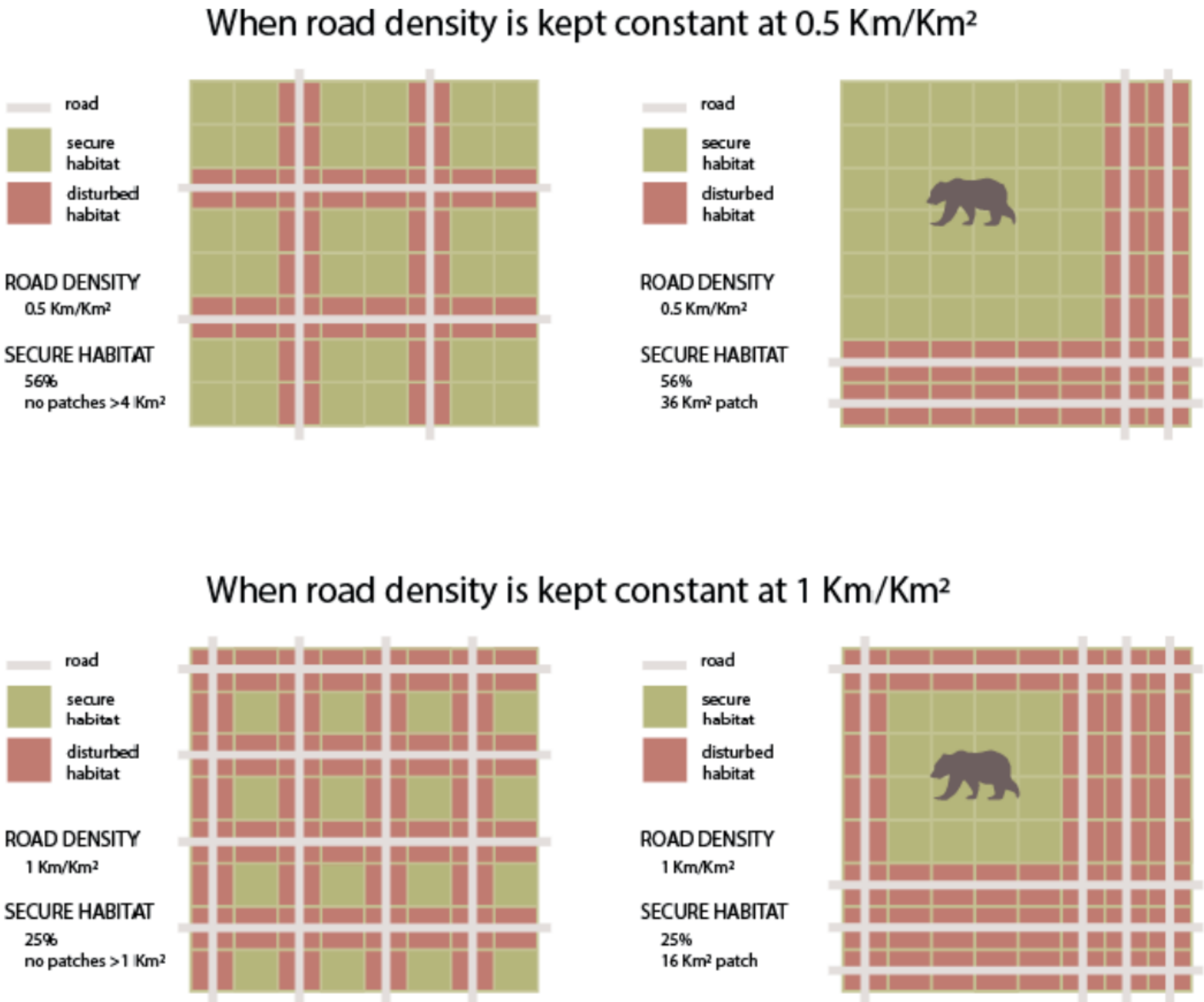

Figure 20. Schematic of the relationship between road density and the proportion of secure grizzly bear (Ursus arctos) habitat. Evenly spaced roads across a unit can result in small patches of secure habitat (i.e., areas >500 m from an open road) that require female bears to cross roads often during a day (panels on left). Managing road distribution to yield larger patches of secure habitat (panels on right), even at similar road densities, should benefit females and result in healthier grizzly bear populations. Figure from Proctor et al. 2020, p. 88.

Here, we specifically focus on the effects of roads, which represent easy human access into grizzly bear habitat, and are associated with high mortality rates for grizzly bears.

Roever, C. L., Boyce, M. S., & Stenhouse, G. B. (2008). Grizzly bears and forestry II: Grizzly bear habitat selection and conflicts with road placement. Forest Ecology and Management, 256(6), 1262–1269. https://doi.org/10.1016/j.foreco.2008.06.006

Timber harvesting and oil and gas extraction create ecological change beyond just the footprint of the resource extraction. These activities also create a permanent network of roads that can have lasting effects on forest ecology. Grizzly bears (*Ursus arctos*) suffer higher mortality when in close proximity to roads, yet bears in the foothills of west-central Alberta, continue to use these high-risk areas. We examined the hypothesis that bears were not necessarily attracted to logging roads but that these roads were placed in habitats that bears preferred. Using a resource selection function, we examined patterns in road placement and identified areas that had characteristics similar to roaded habitats (henceforth road- like habitats). We then quantified grizzly bear response to roads and road-like habitats. Of the 30 bears sampled, we found that 17 selected areas closer to roads than random and 11 selected road-like habitats. Road-like habitats were selected by subadults and some adult females but were not a good predictor of adult male habitat selection. Seasonally, grizzly bears selected habitats closer to roads in spring and early summer but selected road-like habitats more in late summer and fall, indicating that bears may be attracted to disturbed habitats in spring and undisturbed habitats in fall. We conclude that roaded habitats were selected by some grizzly bears but road placement in low-elevation valleys alone does not account for the strong selection preference. Although road placement likely plays a role, other factors such as clearcut association with roads may compound the attractiveness of roaded habitats to grizzly bears. The tradeoff between mortality risk and high-quality forage near roads must be addressed to prevent these areas from acting as attractive sinks.

Roads; Forestry; Oil and Gas; Habitat Selection

Roever, C. L., Boyce, M. S., & Stenhouse, G. B. (2010). Grizzly bear movements relative to roads: application of step selection functions. Ecography, 33(6), 1113–1122. https://doi.org/10.1111/j.1600-0587.2010.06077.x

Access management is among the most important conservation actions for grizzly bears in North America. In Alberta, Canada, nearly all grizzly bear mortalities are caused by humans and occur near roads and trails. Consequently, understanding how bears move relative to roads is of crucial importance for grizzly bear conservation. We present the first application of step-selection functions to model habitat selection and movement of grizzly bears. We then relate this to a step-length analysis to model the rate of movement through various habitats. Grizzly bears of all sex and age groups were more likely to select steps closer to roads irrespective of traffic volume. Roads are associated with habitats attractive to bears such as forestry cutblocks, and models substituting cutblocks for roads outperformed road models in predicting bear selection during day, dawn, and dusk time periods. Bear step lengths increased near roads and were longest near highly trafficked roads indicating faster movement when near roads. Bear selection of roads was consistent throughout the day; however, time of day had a strong influence over selection of forest structure and terrain variables. At night and dawn, bears selected forests of intermediate age between 40 and 100 yr, and bears selected older forests during the day. At dawn, bears selected steps with higher solar radiation values, whereas, at dusk, bears chose steps that were significantly closer to edges. Because grizzly bears use areas near roads during spring and most human-caused mortalities occur near roads, access management is required to reduce conflicts between humans and bears. Our results support new conservation guidelines in western North America that encourage the restriction of human access to roads constructed for resource extraction.

Roads; Habitat Selection; Forestry; Movement; Access Management

Graham, K., Boulanger, J., Duval, J., & Stenhouse, G. (2010). Spatial and temporal use of roads by grizzly bears in west-central Alberta. Ursus, 21(1), 43–56. https://doi.org/10.2192/09GR010.1

Resource extraction activities in Alberta, Canada, have produced a large increase in the number of roads in grizzly bear (*Ursus arctos*) habitat. High road densities have been associated with high grizzly bear mortality rates in some areas. We used GPS data from grizzly bears in west-central Alberta, Canada, 1999-2005 to examine (1) frequencies at which grizzly bears crossed roads (standardized by number of locations/bear and length of road segments), using a crossing index analysis among age-sex classes, traffic volumes, seasons, and time of day; (2) habitat attributes surrounding crossing locations, using a resource selection function analysis to discern if certain habitats and road types were associated with crossing areas; and (3) grizzly bear distribution near roads as a function of age-sex class and season to determine if bears were near roads more or less frequently than expected. Females had higher crossing indices than males for all seasons and daylight hours. Crossings occurred most often at narrow, unpaved roads near creeks and in open areas with high greenness scores. In spring, females with cubs were within 200 m of roads more frequently than expected. In autumn, subadult females were within 200 m of roads more frequently than expected, whereas adult males displayed the reverse pattern. These results indicate that females had a greater chance of encountering humans. Reducing the density of roads in grizzly bear habitat or reducing human presence on these roads, especially during the spring and fall seasons, may reduce the human-caused mortality to female grizzly bears. Creating or leaving a dense tree buffer along roads that traverse open habitats could provide a visual shield from passing vehicles, which may reduce grizzly bear-human encounters and human-caused mortalities.

Roads; Forestry; Habitat Selection; Edge

Boulanger, J., & Stenhouse, G. B. (2014). The impact of roads on the demography of grizzly bears in Alberta. PLoS ONE, 9(12), e115535. https://doi.org/10.1371/journal.pone.0115535

One of the principal factors that have reduced grizzly bear populations has been the creation of human access into grizzly bear habitat by roads built for resource extraction. Past studies have documented mortality and distributional changes of bears relative to roads but none have attempted to estimate the direct demographic impact of roads in terms of both survival rates, reproductive rates, and the interaction of reproductive state of female bears with survival rate. We applied a combination of survival and reproductive models to estimate demographic parameters for threatened grizzly bear populations in Alberta. Instead of attempting to estimate mean trend we explored factors which caused biological and spatial variation in population trend. We found that sex and age class survival was related to road density with subadult bears being most vulnerable to road-based mortality. A multi-state reproduction model found that females accompanied by cubs of the year and/or yearling cubs had lower survival rates compared to females with two year olds or no cubs. A demographic model found strong spatial gradients in population trend based upon road density. Threshold road densities needed to ensure population stability were estimated to further refine targets for population recovery of grizzly bears in Alberta. Models that considered lowered survival of females with dependant offspring resulted in lower road density thresholds to ensure stable bear populations. Our results demonstrate likely spatial variation in population trend and provide an example how demographic analysis can be used to refine and direct conservation measures for threatened species.

Roads; Mortality; Reproduction

Nelson, T., Long, J., Laberee, K., & Stewart, B. (2015). A time geographic approach for delineating areas of sustained wildlife use. Annals of GIS, 21(1), 81–90. https://doi.org/10.1080/19475683.2014.992366

Geographic information systems (GIS) are widely used for mapping wildlife movement patterns, and observed wildlife locations are surrogates for inferring on wildlife movement and habitat selection. We present a new approach to mapping areas where wildlife exhibit sustained use, which we term slow movement areas (SMAs). Nested within the habitat selection concepts of home range and core areas, SMAs are an additional approach to identifying areas important for wildlife. Our method for delineating SMAs is demonstrated on a grizzly bear (*Ursus arctos*) case study examining road density. Our results showed that subadult females had significantly higher road densities within SMAs than in their potential path area home ranges. The lowest road density was found in the SMAs of adult male grizzly bears. Given increased mortality risks associated with roads, female encampment near roads may have negative conservation implications. The methods presented in this manuscript compliment recent developments to identify movement suspension and intensively exploited areas defined from wildlife telemetry data. SMA delineation is sensitive to missing data and best applied to telemetry data collected with a consistent resolution.

Roads; Home Range

Kite, R., Nelson, T., Stenhouse, G., & Darimont, C. (2016). A movement-driven approach to quantifying grizzly bear (*Ursus arctos*) near-road movement patterns in west-central Alberta, Canada. Biological Conservation, 195, 24–32. https://doi.org/10.1016/j.biocon.2015.12.020

Advances in GPS telemetry and remote sensing technologies provide researchers with abundant data that can be used to investigate detailed questions about wildlife behavior. Existing methods for linking wildlife movement to remotely sensed landscape data generally rely on the application of subjectively derived distance thresholds to represent proximity (i.e., near or far) relative to disturbance, thereby possibly limiting the scope of research questions and insight gained. We develop an alternative method based on semivariogram modeling that quantifies consistency in movement parameters as a function of distance to disturbance features. Our approach uses movement data to identify spatially explicit scales of wildlife response to linear features. We illustrate the benefit of movement-driven approaches for generating hypotheses about wildlife movement with grizzly bear (*Ursus arctos*) movement data. We concentrate specifically on building hypotheses to explain how seasonal mortality is linked to near road movements. The movement-driven method demonstrated consistency in step length (i.e., spatial scales of response) ranging from 35 m - 90 m from roads, depending on age, sex, and season. Given this pattern, our data suggest a minimum vegetation buffer of 90 m to serve as screening cover along roadsides to improve survival in this ecosystem. More broadly, our generalizable method can identify definitive spatial scales of response around human disturbance features in any wildlife system, thereby providing managers with movement-driven insight to reduce impacts on wildlife in multi-use landscapes.

Roads; Movement; Mortality; Disturbance

Parsons, B. M., Coops N. C., Kearney S. P., Burton C., Nelson T. A., & Stenhouse G. B. 2020. Road visibility influences habitat selection by grizzly bears (*Ursus arctos horribilis*). Canadian Journal of Zoology. e-First. https://doi.org/10.1139/cjz-2020-0125

Anthropogenic disturbances, including roads, are known to influence animal habitat selection and mortality. In this study, we consider the role of sensory perception in understanding why and how animals respond to disturbances. Our goal was to investigate the effect of visual perception (visibility) around roads on grizzly bear (*Ursus arctos* Ord, 1815) habitat selection and mortality in Alberta, Canada. We used detailed topographic and vegetation data from airborne Light Detection and Ranging (lidar) to estimate visibility around roads. We modelled habitat selection as a function of road visibility and environmental variables using GPS telemetry data from 39 grizzly bears and integrated step selection analysis (iSSA). Finally, we assessed mortality risk in visible areas by comparing habitat selection between grizzly bears that died and those that survived. We found that grizzly bears were less likely to select visible areas when moving slowly or resting, but more likely to select visible areas when traveling. We found that grizzly bears that survived selected for areas farther from roads than grizzly bears that died. However, no difference in selection for visible areas was observed. An exploratory analysis showed that grizzly bear mortalities commonly occurred in visible areas. Our findings highlight the importance of sensory perception in understanding animal behaviour.

Roads; Movement; Mortality; Forestry; Habitat Selection

Proctor, M. F., McLellan, B. N., Stenhouse, G. B., Mowat, G., Lamb, C. T., & Boyce, M. S. (2020). Effects of roads and motorized human access on grizzly bear populations in British Columbia and Alberta, Canada. Ursus, 2019(30e2), 16-39. https://doi.org/10.2192/URSUS-D-18-00016.2

The growing human footprint has placed unprecedented stressors on ecosystems in recent decades resulting in losses of biodiversity and ecosystem function around the world. Roads are influential through their direct footprint and facilitating human access; however, their influence can be mitigated. Here, we review the scientific literature on the relationship between grizzly bears (*Ursus arctos*), human motorized access, and the efficacy of motorized access control as a tool to benefit grizzly bear conservation in western Canada. We found that motorized access affected grizzly bears at the individual and population levels through effects on bears' habitat use, home range selection, movements, population fragmentation, survival, and reproductive rates that ultimately were reflected in population density, trend, and conservation status. Motorized access management was effective in mitigating these effects. Our review of the scientific literature suggests that industrial road management would be a useful tool if (a) roads exist in high-quality grizzly bear habitats with population-energy-rich food resources; (b) open road densities exceed 0.6 km/km^2; (c) less than at least 60% of the unit's area is >500 m from an open road in patch sizes of ≥10 km^2. Motorized access management would be most beneficial in threatened populations, in areas where roads occur in the highest quality habitats, within and adjacent to identified linkage areas between population units, and in areas that are expected to exceed motorized route thresholds as a result of resource extraction activities. Evidence suggests benefits of motorized access management are more likely to be realized if habitat quality is integrated and is best if managed at scales that optimize the benefit of distribution, survival, reproduction, and density of female grizzly bears. We encourage land use managers developing access rules to consider a wider spectrum of biodiversity and overall habitat conservation, and suggest landscape road targets that will benefit bear conservation.

Roads; British Columbia; Access Management

HUMAN RECREATION

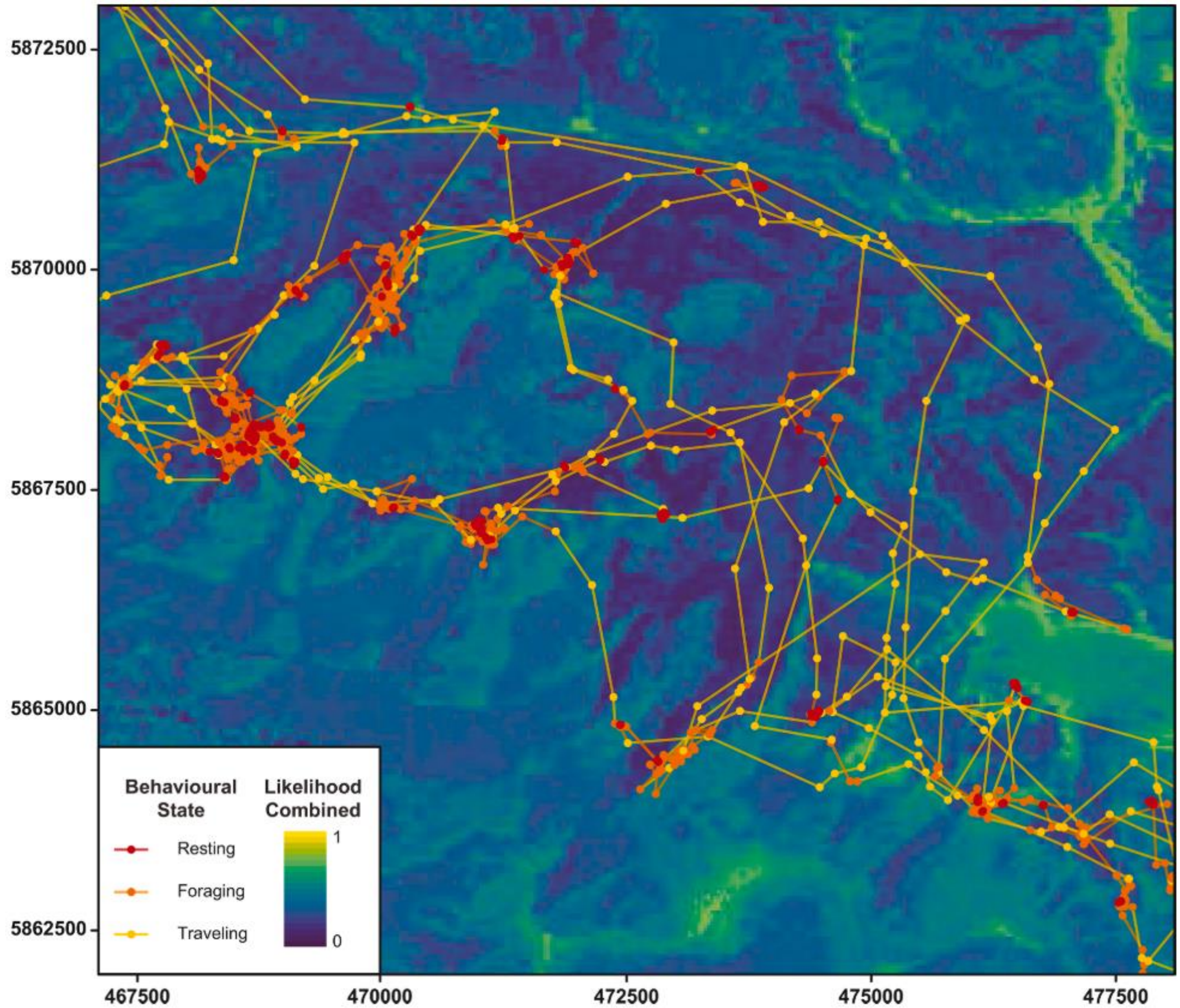

Figure 21. Example of movement states for a grizzly bear overlaying a recreation and tourism likelihood layer. Figure from Goodbody et al. 2021, p. 90.

In this section we address how human activity levels, particularly recreation, influence grizzly bear behaviour.

Ladle, A., Avgar, T., Wheatley, M., Stenhouse, G. B., Nielsen, S. E., & Boyce, M. S. (2019). Grizzly bear response to spatio-temporal variability in human recreational activity. Journal of Applied Ecology, 56(2), 375–386. https://doi.org/10.1111/1365-2664.13277

1. Outdoor recreation on trail networks is a growing form of disturbance for wildlife. However, few studies have examined behavioural responses by large carnivores to motorised and non-motorised recreational activity — a knowledge gap that has implications for the success of human access management aimed at improving habitat quality for wildlife.

2. We used an integrated step selection analysis of grizzly bear (*Ursus arctos*) radio-telemetry data and a spatio-temporal model of motorised and non-motorised human recreational activity to examine how

human recreational activity on trails affects both habitat selection and movement behaviour of individual bears. Grizzly bears were captured and radiocollared in the west-central Alberta Rocky Mountains and Foothills, and trail cameras were deployed on trails to obtain data on human recreational activity.

3. We found that models including data on recreational activity outperformed trail-proximity models when interactions with movement covariates were included. Responses were highly variable among individuals and across classes: males, females, and females with cubs.

4. Male and solitary female grizzly bears increased avoidance of trails with a high probability of motorised activity as well as displaying increased movement rates in response to motorised recreation. Females with cubs did not increase avoidance, however they had the largest response in terms of higher movement rates. In contrast, for all classes, selection for proximity to trail increased when probability of non-motorised activity was high, and the effect on movement was dampened relative to the motorised response.

5. Synthesis and applications. By combining selection and movement into a unified modelling framework, we show that bears alter selection and movement behaviour in response to trails and recreation, and that such responses are determined by the type of recreational activity. Reduced selection and increased movement in proximity to motorised trails could affect bears' ability to exploit foraging opportunities in these areas. Future access management actions for grizzly bear recovery should consider frequency and type of linear feature use by humans rather than solely relying on thresholds relating to feature densities.

Human Use; Recreation; Habitat Selection; Access Management

Goodbody, T. R. H., Coops, N. C., Srivastava, V., Parsons, B., Kearney, S. P., Rickbeil, G. J. M., & Stenhouse, G. B. 2021. Mapping recreation and tourism use across grizzly bear recovery areas using social network data and maximum entropy modelling. Ecological Modelling 440, 109377. https://doi.org/10.1016/j.ecolmodel.2020.109377

Understanding biodiversity pressures associated with recreation and tourism is a major challenge for conservation planning and landscape management. While estimates of landscape use are often collected using mechanisms such as park entry fees and traffic density estimates, these data do not provide substantial detail about the spatial location or intensity of recreation and tourism across biodiversity management areas. To better predict patterns of recreation and tourism likelihood to support conservation planning, we used social network data from Facebook(™), Flickr(™), Google(™), Strava(™), and Wikilocs(™) along with a suite of remote-sensing-derived environmental covariates in a maximum entropy (MaxEnt) presence-only modelling framework. Social network samples were compiled and processed to reduce sampling bias and spatial autocorrelation. Road access, climate data, and remote sensing covariates describing vegetation greenness, disturbance, topography, and moisture were used as predictor variables in the MaxEnt modelling framework. Our focus site was a grizzly bear (*Ursus arctos*) management area in west-central Alberta, Canada. Individual models were developed for each social network dataset, as well as a combined model including all the samples. Mean cross-validated AUC, partial ROC, and true skill statistics (TSS) were used to evaluate model accuracy. Results indicated that the covariates proposed were able to best model Strava and Wikilocs activity (TSS = 0.69 and 0.50, respectively), while samples from Flickr or the combination of all social networks were least accurate (TSS = 0.32). The "access" covariate was most important for MaxEnt training gain across a number of social network models, highlighting the importance of access for recreation and tourism likelihood. The summer heat moisture index and normalized burn ratio were also useful spatial covariates in many predictions. Recreation and tourism likelihood maps were combined with grizzly bear telemetry data to examine how recreation and tourism may affect grizzly bear behaviour. All social network models found a similar influence on grizzly bear behaviour, with increasing recreation and tourism use resulting in decreased foraging behaviour and increased rapid movement, suggesting that the models developed here are useful tools for predicting grizzly bear behaviour and planning conservation strategies for the species.

Human Use; Recreation; Behaviour

INDUSTRY

Figure 22. Two grizzly bear cubs play on a disturbed mine site.

These studies examine relationships between grizzly bears and forestry, mining, and oil and gas extraction practices.

Forestry

Nielsen, S. E., Boyce, M. S., & Stenhouse, G. B. (2004). Grizzly bears and forestry I: Selection of clearcuts by grizzly bears in west-central Alberta, Canada. Forest Ecology and Management, 199(1), 51–65. https://doi.org/10.1016/j.foreco.2004.04.014

We examined if clearcuts were selected as habitats by grizzly bears (*Ursus arctos* L.) in west-central Alberta during three seasons: hypophagia, early hyperphagia, and late hyperphagia. Our objectives were to describe seasonal habitat selection of clearcuts using resource selection functions at two scales. At the first scale, we assessed patch or third-order selection by comparing use (radiotelemetry) with study area-wide random locations and a dummy variable identifying whether locations occurred within or outside of clearcut boundaries. At the second scale, we assessed within-patch or fourth-order selection by comparing locations (use and random) found within clearcuts and environmental covariates of terrain, silviculture, and landscape metrics. Finally, we examined diurnal versus crepuscular/nocturnal use of clearcuts by comparing the two with an expected 50:50 ratio. At the third-order scale, grizzly bears used clearcuts with respect to their availability for hypophagia and late hyperphagia, while selecting clearcuts more than expected during early hyperphagia. Fourth-order habitat selection revealed that landscape metrics, silviculture, and terrain were important predictors of grizzly bear use during hypophagia and late hyperphagia, while terrain appeared to be the most important predictor during early hyperphagia. Overall, grizzly bears avoided clearcut interiors and preferred clearcuts with higher perimeter-to-edge ratios. Clearcuts were significantly more likely to be used during crepuscular/nocturnal periods. Intermediate-aged (~30 years old) clearcuts were selected during hypophagia, whereas recent and old clearcuts were selected during late hyperphagia. Bears tended to avoid clearcuts with Donaren mound preparation, while selecting clearcuts with Bracke or shark-fin barrel dragging. These results suggest that landscape metrics, site preparation history, terrain, and season were important factors determining the use of clearcuts by grizzly bears. Future forest planning should strive to maximize habitat quality by: (1) increasing perimeter-to-edge ratio for clear-cut shapes; (2) using low impact and/or positively associated site preparation treatments like Bracke and shark-fin barrel dragging; and (3) limiting human access to areas predicted as high-quality habitat.

Forestry; Habitat Selection; Silviculture

Nielsen, S. E., Stenhouse, G. B., Beyer, H. L., Huettmann, F., & Boyce, M. S. (2008). Can natural disturbance-based forestry rescue a declining population of grizzly bears? Biological Conservation, 141, 2193–2207. https://doi.org/10.1016/j.biocon.2008.06.020

Forest managers are increasingly considering historic patterns of natural forest disturbance as a model for forest harvesting and as a coarse-filter ecosystem management tool. We evaluated the long-term (100-year) persistence of a grizzly bear population in Alberta, Canada using forest simulations and habitat modelling. Even with harvesting the same volume of timber, natural disturbance-based forestry resulted in a larger human footprint than traditional two-pass forestry with road densities reaching 1.39 km/km^2 or more than three times baseline conditions and suggested maximum levels of security for grizzly bears. Because bears favour young forests and edges where food resources are plentiful, a future shift to young forests and more edge habitat resulted in a 20% projected increase in habitat quality and a 10% projected increase in potential carrying capacity. Human-caused mortality risk, however, offset any projected gains in habitat and carrying capacity resulting in the loss of all secure, unprotected territories, regardless of forest harvest method, within the first 20–30 years of simulation. We suggest that natural disturbance-based forestry is an ill-suited management tool for sustaining declining populations of grizzly bears. A management model that explicitly considers road access is more likely to improve grizzly bear population persistence than changing the size of clearcuts. In fact, large clearcuts might be counter productive for bears since a diversity of habitats within each bear's home range is more likely to buffer against future uncertainties.

Forestry; Roads; Population Inventory; Access Management

Stewart, B. P., Nelson, T. A., Wulder, M. A., Nielsen, S. E., & Stenhouse, G. B. (2012). Impact of disturbance characteristics and age on grizzly bear habitat selection. Applied Geography, 34, 614–625. https://doi.org/10.1016/j.apgeog.2012.03.001

Grizzly bears (*Ursus arctos*) have complex reactions to forest disturbances due to their use of forest clearings for foraging, their large home ranges, and the continued human expansion into undisturbed grizzly bear habitat. The goal of this paper is to quantify how grizzly bears interact with forest disturbances over time in west-central Alberta in order to inform habitat management decisions. This is accomplished using a four-decade remotely sensed disturbance history and detailed grizzly bear movement and habitat use information. Global positioning systems (GPS) collars were used to collect telemetry data for 22 adult grizzly bears (8 females, 14 males) from 2005 to 2009 in the eastern slopes of the Canadian Rockies. The resultant telemetry data were partitioned based on known biological variation in habitat selection into sex and seasonal groups. Density of grizzly bear telemetry locations was calculated for each forest disturbance and compared to expected density via a randomization conditioned on observed trends in overall habitat use. The comparison of observed and expected density of grizzly bear telemetry locations allowed disturbances to be labelled as selected or avoided. Each disturbance was attributed with characteristics (area, elevation, average tasselled cap transformation (TCT) greenness, and distance to nearest populated place), which were compared between selected and avoided disturbances using a Manne Whitney U-test. Male bears selected for 30 - 40-year-old disturbances more frequently than younger disturbances; females demonstrated equal selection of all ages of disturbances except those less than 10 years old. Females selected for disturbances more in the summer and fall than the spring. Disturbances selected by female bears were larger, with lower TCT greenness, and a consistent elevation (1250-1300 m) across seasons and disturbance age. Male bears showed lower selection of disturbances in the fall than in other seasons, and lower selection than females in the summer and fall. Compared to females, disturbances selected by males were larger, and more likely to show seasonal variation in greenness and elevation. Both sexes selected for larger disturbances of all ages, although disturbance size has generally decreased through time. Limiting human access to disturbances with characteristics attractive to grizzly bears will reduce grizzly bear and human interactions, and reduce mortality.

Forestry; Habitat Selection; Disturbance; Density

Phoebus, I., Segelbacher, G., & Stenhouse, G. B. (2017). Do large carnivores use riparian zones? Ecological implications for forest management. Forest Ecology and Management, 402, 157–165. https://doi.org/10.1016/j.foreco.2017.07.037

As part of forest management guidelines, most North American jurisdictions require the preservation of forested areas adjacent to streams and rivers (i.e. riparian zones). Forested buffer strips with restrictions on timber harvest and road-building (i.e. riparian buffer zones) were originally implemented to protect aquatic functions and resources. Riparian buffer zones now also target terrestrial habitats and wildlife. Even so, forestry managers who implement guidelines seldom consider the value of riparian zones (RZs) for large carnivores, partly due to a lack of data available. In the present study, our objective was to understand the role of riparian zones and riparian buffer zones for large carnivores in managed boreal forests. We used nine years of GPS telemetry data (2007-2015) from radio collared grizzly bears (*Ursus arctos*) in the Kakwa region of west-central Alberta, Canada to quantify both the use (i.e. the amount of time grizzly bears spend in RZs) and selection (i.e. use in relation to the available riparian habitat) of RZs. We examined the effects of season, sex, distance class (0-30 or 30-60 m from streams and rivers), and the surrounding forest (harvested versus non-harvested) on use and selection of RZs. We found grizzly bears spent 19.1% of their time within 60 meters from streams and rivers. Selection of RZs declined relative to the distance from streams and rivers (10.8% within 0-30 m and 8.4% within 30-60 m). During summer, grizzly bears selected RZs in harvested areas and avoided them in non-harvested areas. There was no difference in selection of RZs in harvested areas between males and females; however, in non-harvested areas, females avoided RZs and selected RZs less compared to males. These results, particularly the selection of RZs in harvested areas where RZs consist mostly of riparian buffer zones, suggest that riparian buffers provide valuable grizzly bear habitat in multiple-use landscapes. Forest management practices can support grizzly bear habitat conservation efforts by implementing riparian buffer zones in identified grizzly bear habitat and considering grizzly bear habitat use of RZs and riparian buffers as one component of riparian zone management.

Forestry; Habitat Selection

Kearney, S. P., Coops, N. C., Stenhouse, G. B., Nielsen, S. E., Hermosilla, T., White, J. C., & Wulder, M. A. (2019). Grizzly bear selection of recently harvested forests is dependent on forest recovery rate and landscape composition. Forest Ecology and Management, 449, 117459. https://doi.org/10.1016/j.foreco.2019.117459

Forests in the early stages of regeneration are valuable habitat for threatened grizzly bear (*Ursus arctos*) populations inhabiting the interior mountains of North America, with forest management affecting the timing, prevalence, and quality of such habitats. Forest harvesting can lead to early-seral habitat, however the quality and duration of post-harvest habitat compared to natural disturbances (e.g., wildfire), is not known. North American silvicultural practices are mandated to ensure tree regrowth following harvesting, and a rapid rate of growth in managed tree regeneration may lead to a shorter time window during which attractive early-seral habitat is available to bears compared to natural forest disturbances. The distribution of natural disturbances across forested landscapes may also be an important consideration in the response of bears to forest harvesting. In this study, we analyzed grizzly bear habitat selection for 160 collared grizzly bears across 118,000-km^2 (68% of their known habitat) in Alberta, Canada, using metrics of forest disturbance and recovery derived from a 33-year satellite time series. We developed seasonal resource selection functions to evaluate (1) if selection of recently harvested forests was contingent upon the availability of natural disturbances, (2) how habitat selection within disturbed areas varied across disturbance types, and (3) how habitat suitability changed over time during the first 30 years of forest recovery following various disturbance types. Results showed that, compared to areas not recently disturbed, grizzly bears were up to three times more likely to select for harvested forests when natural disturbances were limited in their home range, while selection of harvested forests was neutral when natural disturbances were abundant. When available, grizzly bears were more likely to select for natural disturbances compared to harvested locations, especially during Hypophagia (spring) and Hyperphagia (fall). Selection of harvested locations was inversely related to forest recovery assessed by spectral analysis and decreased sharply 15-20 years post-harvest, at which point it tended to be lower than pre-disturbance. This study demonstrates the utility of vegetation, disturbance, and recovery metrics derived from satellite time series for enriching our understanding of wildlife habitat selection in dynamic landscapes. Our results also have implications for forest management in regions where grizzly bear habitat availability and selection patterns are important. While rapid forest recovery following harvest is desirable and beneficial for a multitude of ecological and economic objectives, it appears to minimize the period of attractive early-seral habitat for grizzly bears.

Forestry; Anthropogenic Disturbance; Natural Disturbance; Habitat Selection; Landsat; Time Series

Mining

Cristescu, B., Stenhouse, G. B. B., Symbaluk, M., & Boyce, M. S. (2011). Land-use planning following resource extraction - lessons from grizzly bears at reclaimed and active open pit mines. Proceedings of the Sixth International Conference on Mine Closure, 207–217. https://doi.org/10.36487/ACG_rep/1152_89_Cristescu

Gauging the success of industrial reclamation requires targets to be set for restoring ecosystem structure and function. An indication of reclamation success is if wildlife recolonise, forage, rest, reproduce and survive on reclaimed areas. The grizzly bear is a threatened species that exists at low densities in Alberta, Canada and facilitates a variety of ecosystem processes. To make suggestions for mitigating the effects of open pit mining on this species, we collected and analysed biological data for grizzly bears on and around Cheviot, Luscar and Gregg River coal mines in west-central Alberta. During 2008 - 2010, we captured and attached GPS radio collars on 12 adult bears on and around mines which allowed us to intensively track their movements. We visited bear-used GPS locations in the field to assess bear activity and microhabitat characteristics. Bears selected reclaimed mines and areas near mines extensively in late spring and early summer to forage on forbs sown as part of mine reclamation and to depredate ungulate calves and lambs. In the fall, bears moved primarily in areas outside mines to forage on berries in preparation for winter denning. Bears often bedded in dense tree cover which underlines the importance of maintaining original vegetation patches in planning mine operations. The animals sometimes crossed the major active mine haul road and moved on and near trails designated for human access on mine leases. High mortality risk associated with expansion of human access into previously remote areas is a major threat to long-term persistence of the grizzly bear population. Defensive driving and potentially enforcement of speed restrictions on mine haul roads in areas with high frequency of bear crossings, provisioning for ecological movement corridors and proper waste management practices will help prevent human-bear conflict during the active mining phase. Following closure of mines, access management along designated trails will reduce the risk of conflicts. Imposing access restrictions, along with preserving undisturbed habitat patches and restoring the original vegetation cover will enable coexistence of people and bears on a shared landscape.

Mining; Habitat Selection; Predation; Food; Bedding; Access Management

Cristescu, B., Stenhouse, G. B., & Boyce, M. S. (2013). Perception of human-derived risk influences choice at top of the food chain. PLoS ONE, 8(12), e82738. https://doi.org/10.1371/journal.pone.0082738

On human-used landscapes, animal behavior is a trade-off between maximizing fitness and minimizing human-derived risk. Understanding risk perception in wildlife can allow mitigation of anthropogenic risk, with benefits to long-term animal fitness. Areas where animals choose to rest should minimize risk from predators, which for large carnivores typically equate to humans. We hypothesize that high human activity leads to selection for habitat security, whereas low activity enables trading security for forage. We investigated selection of resting (bedding) sites by GPS radiocollared adult grizzly bears ($n = 10$) in a low density population on a multiple-use landscape in Canada. We compared security and foods at resting and random locations while accounting for land use, season, and time of day. On reclaimed mines with low human access, bears selected high horizontal cover far from trails, but did not avoid open (herbaceous) areas, resting primarily at night. In protected areas bears also bedded at night, in areas with berry shrubs and *Hedysarum* spp., with horizontal cover selected in the summer, during high human access. On public lands with substantial human recreation, bears bedded at day, selected resting sites with high horizontal cover in the summer and habitat edges, with bedding associated with herbaceous foods. These spatial and temporal patterns of selection suggest that bears perceive human-related risk differentially in relation to human activity level, season and time of day, and employ a security-food trade-off strategy. Although grizzly bears are presently not hunted in Alberta, their perceived risks associated with humans influence resting-site selection.

Mining; Bedding; Food; Edge; Human Access; Protected Areas

Cristescu, B., Stenhouse, G. B., & Boyce, M. S. (2015). Grizzly bear diet shifting on reclaimed mines. Global Ecology and Conservation, 4, 207–220. https://doi.org/10.1016/j.gecco.2015.06.007

Industrial developments and reclamation change habitat, possibly altering large carnivore food base. We monitored the diet of a low-density population of grizzly bears occupying a landscape with open-pit coal mines in Canada. During 2009 - 2010 we instrumented 10 bears with GPS radiocollars and compared their feeding on reclaimed coal mines and neighboring Rocky Mountains and their foothills. In addition, we compared our data with historical bear diet for the same population collected in 2001 - 2003, before extensive mine reclamation occurred. Diet on mines (n = 331 scats) was dominated by non-native forbs and graminoids, while diets in the Foothills and Mountains consisted primarily of ungulates and *Hedysarum* spp. roots respectively, showing diet shifting with availability. Field visitation of feeding sites (n = 234 GPS relocation clusters) also showed that ungulates were the main diet component in the Foothills, whereas on reclaimed mines bears were least carnivorous. These differences illustrate a shift to feeding on non-native forbs while comparisons with historical diet reveal emergence of elk as an important bear food. Food resources on reclaimed mines attract bears from wilderness areas and bears may be more adaptable to landscape change than previously thought. The grizzly bear's ready use of mines cautions the universal view of this species as umbrella indicative of biodiversity.

Mining; Food; Vegetation

Cristescu, B., Stenhouse, G. B., Symbaluk, M., Nielsen, S. E., & Boyce, M. S. (2016). Wildlife habitat selection on landscapes with industrial disturbance. Environmental Conservation, 43(4), 327-336. https://doi.org/10.1017/S0376892916000217

Technological advancements in remote sensing and telemetry provide opportunities for assessing the effects of expanding extractive industries on animal populations. Here, we illustrate the applicability of resource selection functions (RSFs) for modelling wildlife habitat selection on industrially-disturbed landscapes. We used grizzly bears (*Ursus arctos*) from a threatened population in Canada and surface mining as a case study. RSF predictions based on GPS radiocollared bears (n during mining = 7; n post mining = 9) showed that males and solitary females selected areas primarily outside mineral surface leases (MSLs) during active mining, and conversely inside MSLs after mine closure. However, females with cubs selected areas within compared to outside MSLs irrespective of mining activity. Individual variability was pronounced, although some environmental- and human-related variables were consistent across reproductive classes. For males and solitary females, regional-scale RSFs yielded comparable results to site-specific models, whereas for females with cubs, modelling the two scales produced divergent results. While mine reclamation may afford opportunities for bear persistence, managing public access will likely decrease the risk of human-caused bear mortality. RSFs are powerful tools that merit widespread use in quantitative and visual investigations of wildlife habitat selection on industrially-modified landscapes, using Geographic Information System layers that precisely characterize site-specific conditions.

Mining; Habitat Selection

Cristescu, B., Stenhouse, G. B., & Boyce, M. S. (2016). Large Omnivore Movements in Response to Surface Mining and Mine Reclamation. Scientific Reports, 6(19177). https://doi.org/10.1038/srep19177

Increasing global demands have resulted in widespread proliferation of resource extraction. Scientists are challenged to develop environmental mitigation strategies that meet societal expectations of resource supply, while achieving minimal disruption to sensitive "wilderness" species. We used GPS collar data from a 9-year study on grizzly bears (*Ursus arctos*) (n = 18) in Alberta, Canada to assess movements and associated space use during versus after mining. Grizzly bear home range overlap with mined areas was lower during active mining except for females with cubs, that also had shortest movements on active mines. However, both females with cubs and males made shorter steps when on/ close to mines following mine closure and reclamation. Our results show differences in bear movement and space-use strategies, with individuals from a key population segment (females with cubs) appearing most adaptable to mining disturbance. Preserving patches of original habitat, reclaiming the landscape and minimizing the risk of direct human-induced mortality during and after development can help conserve bears and other wildlife on industrially modified landscapes.

Mining; Home Range; Movement

Oil and Gas

Linke, J., Franklin, S. E., Huettmann, F., & Stenhouse, G. B. (2005). Seismic cutlines, changing landscape metrics and grizzly bear landscape use in Alberta. Landscape Ecology, 20, 811–826. https://doi.org/10.1007/s10980-005-0066-4

Besides providing habitat to the grizzly bear (*Ursus arctos*) and other wildlife, the Rocky Mountain foothills of Alberta, Canada hosts considerable mining, seismic oil and gas exploration and production, and forest harvesting activities. Worldwide, such human activities influence the configuration and composition of the landscape. We assessed seismic cutline effects on landscape structure and grizzly bear use during early summer of 1999 and 2000. We studied five female and two male bears, which were GPS-collared in the spring following den emergence. The area available to this population was stratified into 49 km^2 hexagon-shaped sub-landscapes. The scale of this stratification was determined by patterns of bear movement. Fourteen compositional and configurational landscape metrics were calculated within each landscape unit, and bear use points were pooled or 'binned' within each unit. Landscape use was related to landscape metrics using a Generalized Linear Model (GLM). We found that seismic cutline proportion did not explain landscape use by grizzly bears; however secondary effects of cutlines on landscape structure did. Declining use was mainly associated with increasing proportions of closed forest, and increasing variation of inter-patch distances, while use was mainly increasing with increasing mean patch size. An earlier investigation had demonstrated that adding seismic cutlines to grizzly bear habitat caused increases in the variation of inter-patch distances. Since the landscape structure of this grizzly bear population will continue to change as a function of increased levels of resource extraction activities in the near future, it is crucial to further study the detailed meaning of landscape structure at the large and small scale for effective conservation efforts.

Oil and Gas; Habitat Use; Forest Structure

Laberee, K., Nelson, T. A., Stewart, B. P., McKay, T., & Stenhouse, G. B. (2014). Oil and gas infrastructure and the spatial pattern of grizzly bear habitat selection in Alberta, Canada. The Canadian Geographer, 58(1), 79–94. https://doi.org/10.1111/j.1541-0064.2013.12066.x

Oil and gas development is increasing in areas of Alberta, Canada that are also home to threatened grizzly bear (*Ursus arctos*) populations. While impacts of forest disturbances on bears have been heavily studied, research on the impacts of oil and gas activities is limited. Our research goal was to test the hypothesis that grizzly bears select locations of oil and gas development randomly, using grizzly bear telemetry data collected from 2005 to 2010 in the Kakwa region of Alberta. Maps of probability of resource use by bears were generated and used to conditionally randomize telemetry data to classify bear locations as being closer, farther, or no different than expected from oil and gas features. Our results indicated that bears were generally observed closer to oil and gas features during spring. Adult males were farther than expected to all features during the summer season. During fall, adult females showed avoidance of all oil and gas features during the day, but were closer at night. Active wellsites were avoided by all bears in the fall, and roads were avoided more than pipelines. Spatial analysis and geographic information science are ideal tools for examining the influence of landscape features on wildlife.

Oil and Gas; Habitat Selection

McKay, T., Sahlén, E., Støen, O., Swenson, J., & Stenhouse, G. (2014). Wellsite selection by grizzly bears *Ursus arctos* in west-central Alberta. Wildlife Biology, 20(5), 310–319. https://doi.org/10.2981/wlb.00046

Oil and gas development is widespread in west-central Alberta, yet little is known about the potential impacts of oil and gas activities on grizzly bear habitat use. Focusing on the impacts of one component of energy development, we studied the selection patterns of radio-collared grizzly bears in relation to oil and gas wellsites in the Kakwa region of west-central Alberta. For each grizzly bear foraging season (spring, summer, and fall), we calculated a population level resource selection function (RSF) to assess the probability that bears would select for wellsites versus non-wellsite habitat. We used mixed-effects logistic regression and model selection to examine factors that could influence the probability of wellsite use, including: grizzly bear reproductive status, wellsite age, wellsite operational status, surrounding road and wellsite densities, adjacent forest canopy cover, and adjacent habitat. Bear reproductive status, surrounding road and wellsite densities, and adjacent canopy cover had the most influence on the probability of wellsite use. Females used wellsites more than expected in all seasons, and males selected for wellsites in summer and fall. Males used wellsites less than females, and females with young used wellsites more than both single females and males. Bears were more likely to use wellsites that had lower densities of disturbance (roads and wellsites) in the surrounding area. In the fall, older wellsites were also more likely to be used by bears. In areas with human access, grizzly bears attracted to anthropogenic features are at a higher risk of human-caused mortality; therefore, their use of wellsites could have negative results for this threatened population.

Oil and Gas; Habitat Selection

Finnegan, L., Pigeon, K. E., Cranston, J., Hebblewhite, M., Musiani, M., Neufeld, L., Schmiegelow, F., Duval, J., & Stenhouse, G. B. (2018). Natural regeneration on seismic lines influences movement behaviour of wolves and grizzly bears. PLoS ONE, 13(4), e0195480. https://doi.org/10.1371/journal.pone.0195480

Across the boreal forest of Canada, habitat disturbance is the ultimate cause of caribou (*Rangifer tarandus caribou*) declines. Habitat restoration is a focus of caribou recovery efforts, with a goal to finding ways to reduce predator use of disturbances, and caribou-predator encounters. One of the most pervasive disturbances within caribou ranges in Alberta, Canada are seismic lines cleared for energy exploration. Seismic lines facilitate predator movement, and although vegetation on some seismic lines is regenerating, it remains unknown whether vegetation regrowth is sufficient to alter predator response. We used Light Detection and Ranging (LiDAR) data, and GPS locations, to understand how vegetation and other attributes of seismic lines influence movements of two predators, wolves (*Canis lupus*) and grizzly bears (*Ursus arctos*). During winter, wolves moved towards seismic lines regardless of vegetation height, while during spring wolves moved towards seismic lines with higher vegetation.

During summer, wolves moved towards seismic lines with lower vegetation and also moved faster near seismic lines with vegetation <0.7 m. Seismic lines with lower vegetation height were preferred by grizzly bears during spring and summer, but there was no relationship between vegetation height and grizzly bear movement rates. These results suggest that wolves use seismic lines for travel during summer, but during winter wolf movements relative to seismic lines could be influenced by factors additional to movement efficiency; potentially enhanced access to areas frequented by ungulate prey. Grizzly bears may be using seismic lines for movement, but could also be using seismic lines as a source of vegetative food or ungulate prey. To reduce wolf movement rate, restoration could focus on seismic lines with vegetation <1 m in height. However our results revealed that seismic lines continue to influence wolf movement behaviour decades after they were built, and even at later stages of regeneration. Therefore it remains unknown at what stage of natural regeneration, if any, wolves cease to respond to seismic lines.

Caribou; Oil and Gas; Movement

Sorensen, A., Denny, C., McKay, T., & Stenhouse, G. (2021). Response of grizzly bears (*Ursus arctos*) to pipelines in Alberta. Environmental Management. In press.

This research provides the first in-depth analysis of fine-scale grizzly bear habitat selection and movement patterns in response to the linear footprints cleared for below ground pipelines in Alberta. Using an extensive set of GPS location data from collared grizzly bears, we were able to determine that grizzly bears selected for younger pipelines (mean age since last construction~6.5 years), which are known to have a greater abundance of important bear foods. Bears also selected for wider corridors that were disturbed for construction more than once. During the spring season, sex/age class was an important predictor of grizzly bear use of pipelines, with adult female bears more likely to use these features than other sex/age classes. Examination of movement patterns revealed that pipeline density influenced grizzly bears' movement rates and path straightness, particularly in the spring, when bears moved more slowly and movement paths were more tortuous in areas with higher pipeline densities. These movement patterns are consistent with foraging behaviour and further indicate that bears are not exhibiting avoidance behaviors or displacement by pipeline features, and pipelines may be functioning as seasonally important foraging areas for grizzly bears in Alberta.

Oil and Gas; Movement; Disturbance; Habitat Selection; Food

Food

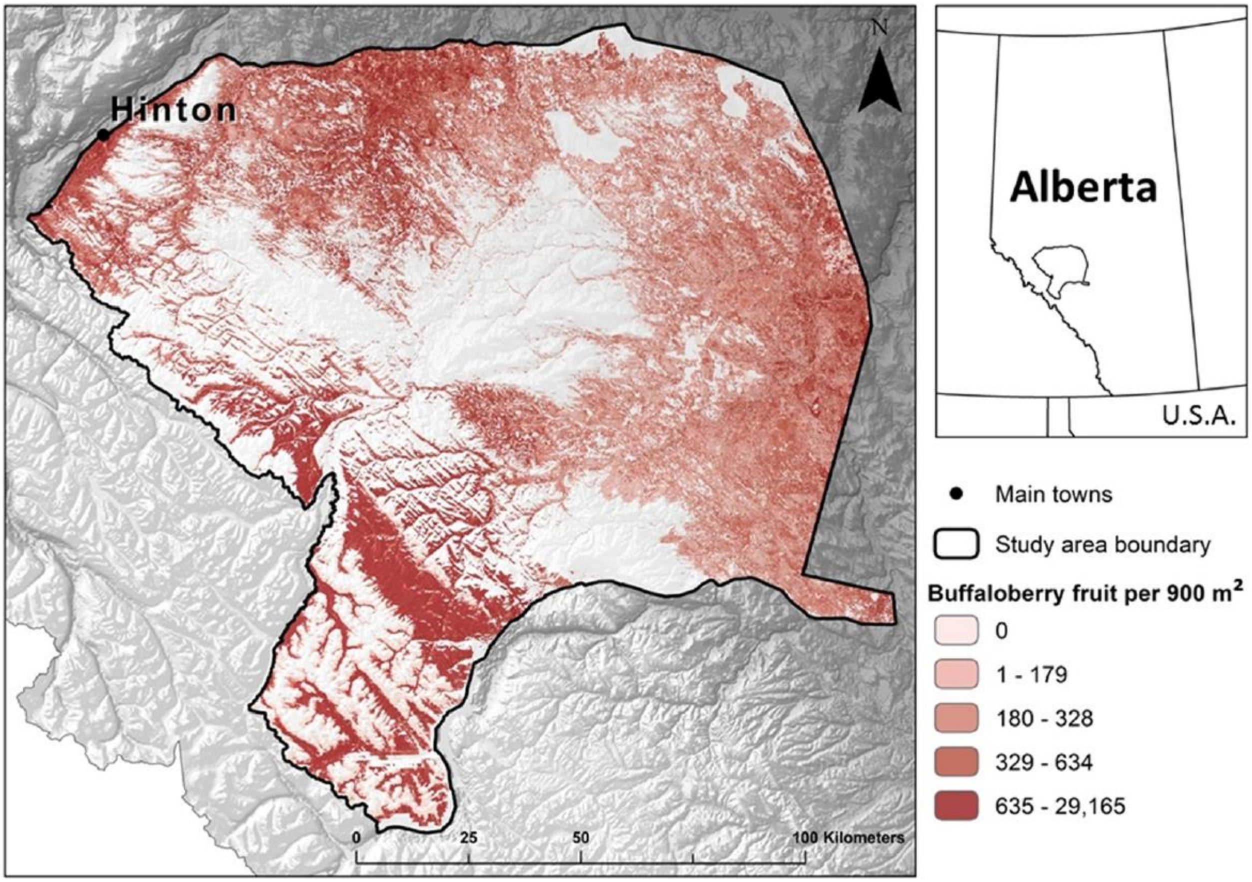

Figure 23. Location of the study area near Hinton, Alberta, Canada defined by a buffaloberry fruit density model (fruit/900 m^2) by Nielsen et al. (2017). Fruit density is symbolized based on quantile classification. Figure from Denny et al. 2018, p. 101.

This section regards the relationship between grizzly bears and the distribution of food resources.

Munro, R. H. M., Nielsen, S. E., Price, M. H., Stenhouse, G. B., & Boyce, M. S. (2006). Seasonal and diel patterns of grizzly bear diet and activity in west-central Alberta. Journal of Mammalogy, 87(6), 1112–1121. https://doi.org/10.1644/05-MAMM-A-410R3.1

Seasonal food habits and activity patterns were examined for grizzly bears (Ursus arctos) in west-central Alberta, Canada, to better understand habitat requirements in a threatened population. Food habits were based on an analysis of 665 feces collected from 18 grizzly bears between April and October 2001 - 2003. Trends in the use of foods were comparable to those of other central Rocky Mountain populations, with minor differences likely reflecting regional habitat and forage availability. Five activities (bedding, sweet vetch digging, insect feeding, frugivory, and ungulate kills) were identified for each of 1,032 field-visited global positioning system radiotelemetry locations from 9 female grizzly bears. We predicted the probability of each activity during relevant periods by time of day (crepuscular, diurnal, and nocturnal) and habitat. Selection ratios were used to assess which habitat and time periods were selected. Activity patterns changed considerably over a 24-h period, with foraging activities occurring mostly during diurnal and crepuscular periods and bedding at night. Habitats were important predictors of activity. Forested areas were selected for bedding areas, whereas digging, insect-foraging, and frugivory activities were associated with herbaceous, recently disturbed forest and open-canopy forests. We suggest that researchers consider behavior and time of day in analyses of habitat selection to improve explanations of habitat use and mechanisms of selection.

Food; Vegetation; Behaviour; Forestry; Forest Structure; Bedding

Nielsen, S. E., Larsen, T. A., Stenhouse, G. B., & Coogan, S. C. P. (2017). Complementary food resources of carnivory and frugivory affect local abundance of an omnivorous carnivore. Oikos, 126(3), 369–380. https://doi.org/10.1111/oik.03144

A major unresolved question for omnivorous carnivores, like most species of bears, is to what degree are populations influenced by bottom-up (food supply) or top-down (human-caused mortality) processes. Most previous work on bear populations has focused on factors that limit survival (top-down) assuming little effect of food resource supply. When food resources are considered, most often they consider only the availability/supply of a single resource, particularly marine-subsidized or terrestrial sources of protein (carnivory) or alternately hard or soft mast (frugivory). Little has been done to compare the importance of each of these factors for omnivorous bears or test whether complementary resources better explain individual animal and population measures such as density, vital rates, and body size. We compared landscape patterns of digestible energy (kcal) for buffaloberry (a key source of carbohydrate) and ungulate matter (a key source of protein and lipid) to local measures in grizzly bear *Ursus arctos* abundance at DNA hair snag sites in west-central Alberta, Canada. We tested support for bottom-up hypotheses in either single (carnivory [meat] versus frugivory [fruit]) or complementary (additive or multiplicative) food resources, while accounting for a well-known top-down limiting factor affecting bear survival (road density). We found support for both top-down and bottom-up factors with complementary resources (co-limitation) supported over single resource supplies of either meat or fruit. Our study suggests that the availability of food resources that provide complementary nutrients is more important in predicting local bear abundance than single foods or nutrients (e.g. protein) or simply energy per se. This suggests a nutritionally multidimensional bottom-up limitation for a low density interior population of grizzly bears.

Food; Nutrition; Predation; DNA; Hair Snag; Roads

Denny, C. K., Stenhouse, G. B., & Nielsen, S. E. (2018). Scales of selection and perception: landscape heterogeneity of an important food resource influences habitat use by a large omnivore. Wildlife Biology, 2018(1). https://doi.org/10.2981/wlb.00409

Variation in food abundance and distribution influences animal foraging behavior, but response is contingent on the amount of resource heterogeneity detected, which is consistent with environmental 'grain' size. Large mammals presumably perceive their surroundings at broad spatial scales, but the importance of landscape-level food resource properties for habitat use is generally less understood. We evaluated the role of heterogeneity of Canada buffaloberry *Shepherdia canadensis*, defined by fruit distribution and variability in patch quality (fruit density), in grizzly bear *Ursus arctos* habitat selection by comparing patch- and landscape-level foraging strategies (resource use). Our objectives were to: 1) identify the spatial scale at which grizzly bears select buffaloberry fruit resources; 2) determine whether patch- or landscape-level foraging strategies explain resource use; and 3) assess the importance of resource heterogeneity in structuring habitat selection. Buffaloberry patch and landscape variables were combined with GPS radio-telemetry data from eight collared grizzly bears in west-central Alberta, Canada, to fit resource selection functions (RSFs). We found that a spatial scale of 1887 m, corresponding to an average travel distance for bears over 5.5 h, was the most supported scale for buffaloberry use. Landscape-level foraging strategies generally had more support than those of the patch-level, with spatial heterogeneity of buffaloberry patches best explaining grizzly bear selection for fruit resources. Bears selected for areas with a wider distribution of buffaloberry fruit and greater variability in patch quality, thus providing both a higher probability of shrub encounter and greater contrast between resource patches. A negative interaction between distribution and variability, however, indicated a tradeoff where use of areas with a more widespread fruit distribution decreased when variability in resource quality was high. These results demonstrate the influence of food resource heterogeneity on animal habitat use and emphasize the value in considering spatial scale in studies of animal-resource interactions.

Food; Habitat Selection; Nutrition

Nielsen, S. E., Boyce, M. S., Stenhouse, G. B., & Munro, R. H. M. (2003). Development and testing of phenologically driven grizzly bear habitat models. Ecoscience, 10(1), 1–10. https://doi.org/10.1080/11956860.2003.11682743

We developed and compared three habitat models for estimating the relative probability of occurrence, by month, for grizzly bears (*Ursus arctos*) in Jasper National Park (JNP), Alberta. These models included 1) a habitat map derived from remote sensing Landsat imagery; 2) food-index models generated from the predicted occurrence of bear foods and assigned monthly importance values; and 3) probabilistic food models representing the occurrence of each bear food. Resource selection function (RSF) models for grizzly bears were generated using 3,924 global positioning system (GPS) radiotelemetry locations and the above habitat models. Comparisons were made among RSF models, by month, using Akaike's Information Criterion (AIC). In all seven months (April to October), food-index models performed poorly. In April and July, the remote-sensing habitat map predicted bears best, while the food-probability models performed best in the remaining five months. Overall, we found substantial improvement by using food-probability models for predicting JNP grizzly bear occurrence. Remote-sensing maps, although predictive, may not reveal underlying mechanisms and fail to recognize the dynamic nature of seasonal grizzly bear habitats. The disconnect between food-index and food-probability models suggests that monthly food importance values require additional parameterization. Development of spatial food models on phenologically important scales more closely matches the resources and temporal scales at which animals perceive and use resources.

Habitat Selection; Phenology; Density; Food

McClelland, C. J. R., Coops, N. C., Kearney, S. P., Burton, A. C., Nielsen, S. E., & Stenhouse, G. B. (2020). Variations in grizzly bear habitat selection in relation to the daily and seasonal availability of annual plant-food resources. Ecological Informatics, 58, 101116. https://doi.org/10.1016/j.ecoinf.2020.101116

Determining how resource availability changes daily, seasonally and annually, and how wildlife react to these changes, is valuable for managing wildlife. For vegetative resources phenological information can be used to determine availability and model the distribution of available resources. This study develops a set of annually varying species distribution models using maximum entropy modeling for eight grizzly bear key plant-food species using 1635 food occurrences collected between 2001 and 2017. Seasonal availability (phenology) of plant-food species were then estimated daily at a 30 m resolution for the period 2000-2017 using ground data collected at 15 sites in 2015 and 2018 combined with newly created fine scale phenology product DRIVE (Daily Remote Inference of Vegetation). These food availability layers were then used to develop resource selection functions with grizzly bear GPS collar data to describe daily and seasonal habitat selection and to compare how this changes over a three-year period based on changes in mean annual precipitation. Results demonstrated that grizzly bears selected areas where key plant-food species were available and that habitat selection varied between wet and dry years dependant on season and species. In dry spring conditions, selection for root species was stronger and occurred earlier than for an average and wet year. In the wet summer, length of selection for forb species increased, while strength of selection for wet and dry years was species dependant. In the fall, strength of selection for berry species between wet and dry years was species dependant, but overall selection for berry species was prolonged in the dry fall year. This research aids in predicting how inter-annual differences in climate affect grizzly bear habitat selection and provides insights to managers regarding how changes in management practices that encourage growth of understory vegetation could be used to maximize food resources regionally for grizzly bears and other wildlife.

Habitat Selection; Phenology; Food; Vegetation; Species Distribution Models; Climate

Pigeon, K. E., Côté, S. D., & Stenhouse, G. B. (2016). Assessing den selection and den characteristics of grizzly bears. The Journal of Wildlife Management, 80(5), 884–893. https://doi.org/10.1002/jwmg.1069

Hibernation has evolved as an adaptive strategy to avoid harsh environmental conditions associated with a lack of resources, and the choice of hibernacula can affect the fitness of individuals. Most habitat selection studies, including investigations of overwintering sites, are based on data collected from land inventories or remote sensing databases used in a geographic information system (GIS). Although rarely used, forest stand ecological data gathered at fine spatial scales may enhance our understanding of selection processes. Our objectives were to enhance previous GIS-based investigations of den use by grizzly bears (*Ursus arctos*) with field-based investigations and determine whether males and females selected dens in response to food availability, within-stand characteristics related to concealment cover, or factors affecting the structural stability of dens. We studied den selection for 10 male and 21 female grizzly bears at the home- range scale and within the den vicinity using data collected at 42 den sites, 168 adjacent sites, and 345 random locations within the Rocky Mountains and boreal forest of Alberta, Canada between 2001 and 2012. Within their autumn home range, male and female grizzly bears selected sites with greater concealment cover, greater canopy cover, and more abundant sweet-vetch (*Hedysarum* spp.) compared to availability. Poor model performance when comparing den sites to adjacent sites within the den vicinity suggests that male and female grizzly bears select sites at scales larger than 0.1 km. We found no difference in the dimensions and characteristics of dens excavated by males and females, nor in the structural stability of dens dug under a mature tree or in open areas, and no selection for a specific type of mineral soil or percentage of boulders and cobbles. Our results corroborate previous resource selection functions using remote sensing and land inventory data but show that home-range scale analyses can fail to assess selection of potentially influential, ecologically important within-stand characteristics such as food abundance and lateral cover. Within-stand data are typically unavailable through current habitat maps and field data can enhance our understanding of fine-scale selection. To minimize human-bear interactions and disturbances at dens, we recommend integrating field-based investigations to high-priority denning areas identified from resource selection functions, and to further improve conservation efforts, we recommend taking into account within-stand data to describe behaviors occurring during the active and inactive periods.

Denning; Food; Security; Forest Structure; Anthropogenic Disturbance

Pigeon, K. E., Stenhouse, G., & Côté, S. D. (2016). Drivers of hibernation: linking food and weather to denning behaviour of grizzly bears. Behavioral Ecology and Sociobiology, 70(10), 1745–1754. https://doi.org/10.1007/s00265-016-2180-5

Climate-induced changes in the phenology of hibernation for bear species could result in altered energy budgets, reduced cub survival and fitness and increased human-bear conflicts. Using 11 years of data,

we determined the amount of variation in den entry and den exit dates that could be attributed to sex and reproductive status, weather and berry availability for 15 male and 58 female grizzly bears (*Ursus arctos*). We estimated berry availability during autumn using a probability surface of berry productivity within the home range of 13 individuals over 3 years. Sex and reproductive status explained 22 and 14% of the variation in den entry and den exit dates, respectively. Weather did not influence the timing of den entry but berry availability in autumn explained 39% of the variation observed in den entry, and high berry availability was associated with late den entry. Elevation and spring temperatures, and elevation and winter precipitation, respectively, explained 26 and 21% of the variation observed in den exit dates. Increasing spring average monthly maximum temperature by 4°C resulted in bears emerging from dens 10 days earlier and an increase of 1.25 m in snow precipitation delayed den exit by 1 week. We demonstrate that although the phenology of hibernation for grizzly bears depends on sex and reproductive status, den entry appears to be driven by food availability, while den exit is more linked to weather. Extended growing seasons and mild meteorological conditions should result in shorter denning periods for grizzly bears.

Denning; Food; Phenology; Climate

CLIMATE

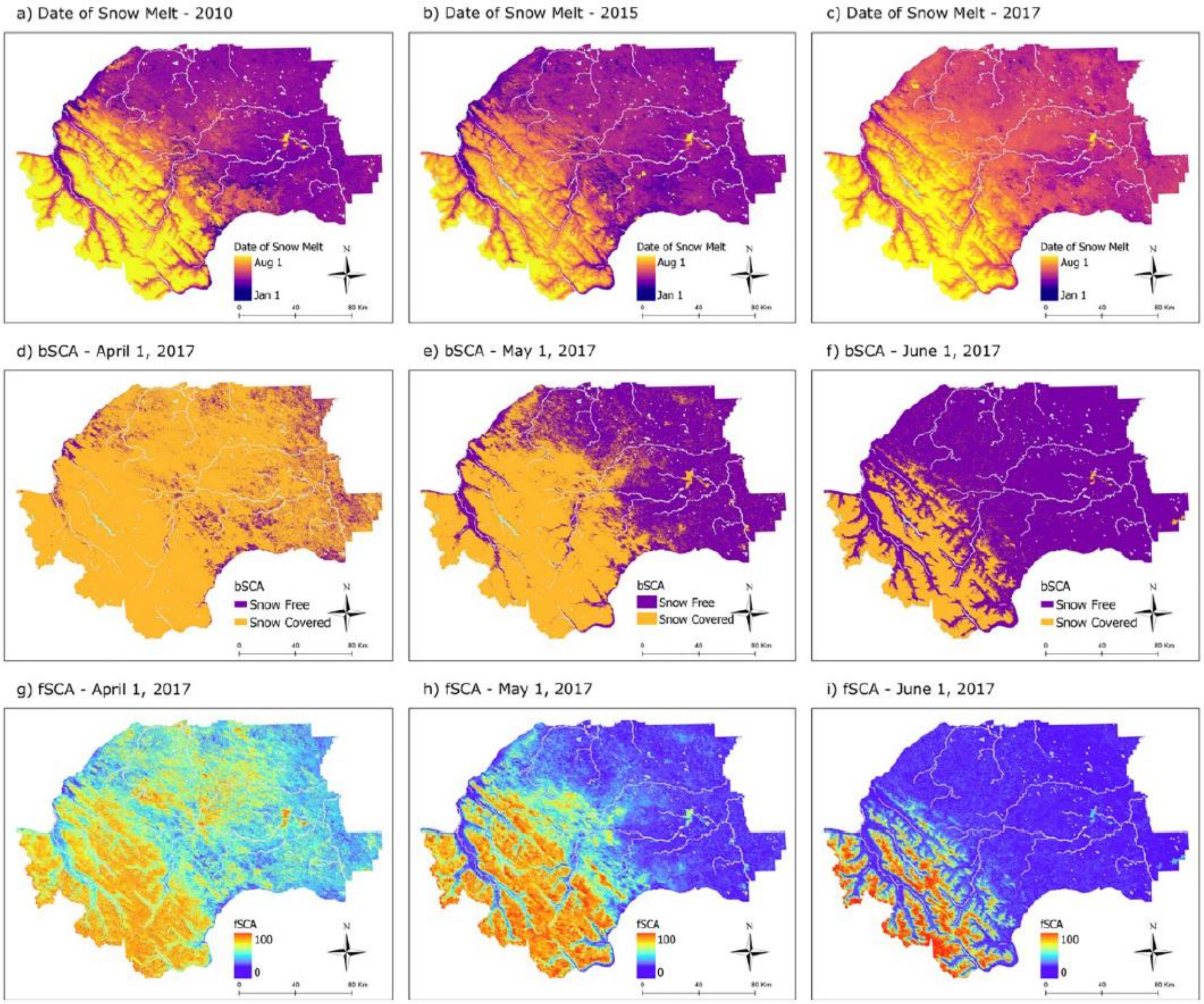

Figure 24. The three snow metrics derived from SNOWARP (Berman et al. 2018) at 30 m spatial resolution for years 2009-2017. a-c) Annual date of snow melt shown for spring 2010, 2015, and 2017. Days since snow melt (DSM) was produced by subtracting date of snow melt from the date associated with each grizzly bear telemetry location. d-f) daily binary snow covered area (bSCA) shown on April 1, May 1, and June 1, 2017. g-i) daily fractional snow covered area (fSCA) shown on April 1, May 1, and June 1, 2017. Figure from Berman et al. 2019, p. 106.

Here we describe how grizzly bears respond to climate and weather variables.

Pigeon, K. E., Cardinal, E., Stenhouse, G. B., & Côté, S. D. (2016). Staying cool in a changing landscape: the influence of maximum daily ambient temperature on grizzly bear habitat selection. Oecologia, 181, 1101–1116. https://doi.org/10.1007/s00442-016-3630-5

To fulfill their needs, animals are constantly making trade-offs among limiting factors. Although there is growing evidence about the impact of ambient temperature on habitat selection in mammals, the role of environmental conditions and thermoregulation on apex predators is poorly understood. Our objective was to investigate the influence of ambient temperature on habitat selection patterns of grizzly bears in the managed landscape of Alberta, Canada. Grizzly bear habitat selection followed a daily and seasonal pattern that was influenced by ambient temperature, with adult males showing stronger responses than females to warm temperatures. Cutblocks aged 0-20 years provided an abundance of forage but were on average 6 °C warmer than mature conifer stands and 21- to 40-year-old cutblocks. When ambient temperatures increased, the relative change (odds ratio) in the probability of selection for 0- to 20-year-old cutblocks decreased during the hottest part of the day and increased during cooler periods, especially for males. Concurrently, the probability of selection for 21- to 40-year-old cutblocks increased on warmer days. Following plant phenology, the odds of selecting 0- to 20-year-old cutblocks also increased from early to late summer while the odds of selecting 21- to 40-year-old cutblocks decreased. Our results demonstrate that ambient temperatures, and therefore thermal requirements, play a significant role in habitat selection patterns and behaviour of grizzly bears. In a changing climate, large mammals may increasingly need to adjust spatial and temporal selection patterns in response to thermal constraints.

Climate Change; Climate; Phenology; Habitat Selection; Forestry

Pigeon, K. E., Cardinal, E., Stenhouse, G. B., & Côté, S. D. (2017). Recognizing the importance of an all-inclusive approach to brown bear conservation now and into the future. Oecologia, 185, 347–350. https://doi.org/10.1007/s00442-017-3950-0

In their critique of our recent article in Oecologia (Pigeon et al. Oecologia 181:1101-1116, 2016a) investigating the influence of ambient temperature on brown bear habitat selection, Ordiz et al. (2017, current issue) argue that we downplay the role of human disturbance on bear behavior, and that we wrongly report on the findings of Ordiz et al. (Oecologia 166:59-67, 2011). We argue that our previous article in Oecologia (Pigeon et al. 2016a) by no means downplays the influence of human factors on bear behavior, and that we correctly stated that Ordiz et al. (2011) did not adequately consider the potential influence of temperature on their findings. Finally, we stress the relevance of considering all-inclusive approaches to the common goal of successful wildlife conservation.

Climate Change; Human Use; Phenology; Habitat Selection; Climate; Forestry

Berman, E. E., Coops, N. C., Kearney, S. P., & Stenhouse, G. B. (2019). Grizzly bear response to fine spatial and temporal scale spring snow cover in Western Alberta. PLoS ONE, 14(4), e0215243. https://doi.org/10.1371/journal.pone.0215243

Snow dynamics influence seasonal behaviors of wildlife, such as denning patterns and habitat selection related to the availability of food resources. Under a changing climate, characteristics of the temporal and spatial patterns of snow are predicted to change, and as a result, there is a need to better understand how species interact with snow dynamics. This study examines grizzly bear (*Ursus arctos*) spring habitat selection and use across western Alberta, Canada. Made possible by newly available fine-scale snow cover data, this research tests a hypothesis that grizzly bears select for locations with less snow cover and areas where snow melts sooner during spring (den emergence to May 31st). Using Integrated Step Selection Analysis, a series of models were built to examine whether snow cover information such as fractional snow covered area and date of snow melt improved models constructed based on previous knowledge of grizzly bear selection during the spring. Comparing four different models fit to 62 individual bear-years, we found that the inclusion of fractional snow covered area improved model fit 60% of the time based on Akaike Information Criterion tallies. Probability of use was then used to evaluate grizzly bear habitat use in response to snow and environmental attributes, including fractional snow covered area, date since snow melt, elevation, and distance to road. Results indicate grizzly bears select for lower elevation, snow-free locations during spring, which has important implications for management of threatened grizzly bear populations in consideration of changing climatic conditions. This study is an example of how fine spatial and temporal scale remote sensing data can be used to improve our understanding of wildlife habitat selection and use in relation to key environmental attributes.

Habitat Selection; Climate; Climate Change; Snow

Rickbeil, G. J. M., Coops, N. C., Berman, E. E., McClelland, C. J. R., Bolton, D. K., & Stenhouse, G. B. (2020). Changing spring snow cover dynamics and early season forage availability affect the behavior of a large carnivore. Global Change Biology, 26(11), 6266-6275. https://doi.org/10.1111/gcb.15295

Changing climates are altering wildlife habitats and wildlife behavior in complex ways. Here, we examine how changing spring snow cover dynamics and early season forage availability are altering grizzly bear (*Ursus arctos*) behavior post-den emergence. Telemetry data was used to identify spring activity dates for 48 individuals in the Yellowhead region of Alberta, Canada. Spring activity date was related to snow cover dynamics using a daily percent snow cover dataset. Snow melt end date, melt rate, and melt consistency explained 45% of the variation in spring activity date. We applied this activity date model across the entire Yellowhead region from 2000 to 2016 using simulated grizzly bear home ranges. Predicted spring activity date was then compared with a daily spring forage availability date dataset, resulting in "wait time" estimates for four key early season forage species. Temporal changes in both spring activity date and early season forage "wait times" were assessed using non-parametric regression. Grizzly bear activity date was found to have either remained constant (95%) or become earlier (5%) across the study area; virtually no areas with significantly later spring activity dates were detected. Similarly, the majority of "wait times" did not change (85%); however, the majority of significant changes in "wait times" for the four early season forage species indicated that "wait times" were lessening where changes were detected. Our results show that spring activity date is largely dictated by snow melt characteristics and that changing snow melt conditions may result in earlier spring activity. However, early season food stress conditions are likely to remain unchanged or improve as vegetation phenology also becomes earlier. Our findings extend the recent work examining animal movement in response to changing phenology from migratory birds and ungulates to an apex predator, further demonstrating the potential effects of changing climates on wildlife species.

Climate Change; Climate; Phenology; Remote Sensing; Denning

HUMAN-WILDLIFE CONFLICT

Figure 25. A grizzly bear investigates a baited culvert trap. Bears involved in conflicts are frequently captured and translocated away from the area.

In this section, we present research on reported conflicts between grizzly bears and humans, as well as the fate of translocated problem bears.

Northrup, J. M., Stenhouse, G. B., & Boyce, M. S. (2012). Agricultural lands as ecological traps for grizzly bears. Animal Conservation, 15(4), 1–9. https://doi.org/10.1111/j.1469-1795.2012.00525.x

Human-carnivore conflicts on agricultural lands are a global conservation issue affecting carnivore population viability, and human safety and livelihoods. Locations of conflicts are influenced by both human presence and carnivore habitat selection, although these two aspects of conflict rarely have been examined concurrently. Advances in animal tracking have facilitated examination of carnivore habitat selection and movements affording new opportunities to understand spatial patterns of conflict. We reviewed 10 years of data on conflicts between grizzly bears and humans in southwestern Alberta, Canada. We used logistic regression models in a geographic information system to map the probability of bear-human conflict from these data, and the relative probability of grizzly bear habitat selection based on global positioning system radiotelemetry data. We overlaid these maps to identify ecological traps, as well as areas of secure habitat. The majority of the landscape was seldom selected by bears, followed by ecological traps where most conflicts occurred. Only a small portion of the landscape was identified as secure habitat. Such mapping methods can be used to identify areas where conflict reduction strategies have the greatest potential to be effective. Our results highlight the need for comprehensive management to reduce conflicts and to identify areas where those conflicts are most problematic. These methods will be particularly useful for carnivores known to be in conflict with agriculture, such as large carnivores that prey on livestock, or pose a threat to human safety.

Agriculture; Conflict; Security; Habitat Selection

Cristescu, B., Stenhouse, G. B., Goski, B., & Boyce, M. S. (2016). Grizzly bear space use, survival, and persistence in relation to human habitation and access. Human-Wildlife Interaction, 10(2), 240–257. https://doi.org/10.26077/zrs9-sy67

Previous studies showed that the likelihood of a bear becoming a nuisance and thus being removed from a population (i.e., relocated or killed) depends on numerous factors such as natural food supply, sex, age, and reproductive status. Distances from a bear's home range and activity centers to conflict zones such as towns, roads, and trails used by humans also affect the incidence of nuisance behavior and have been documented for grizzly/brown bears (*Ursus arctos*) in North America and Europe. But those studies did not quantify the relative influences by various factors on distance from conflict zones, or the effects of distance on the likelihood of becoming a nuisance. We tested the latter 2 aspects using data gathered for other purposes on 9 adult research grizzly bears using areas within 500 m of Cadomin, Canada, during an 8-year study between 2000 and 2010. GPS radio collars yielded 565 location positions, of which 87% (490) were for 3 females. Bear distances to the settlement varied mostly as a function of seasonal natural food supply and foraging intensity (spring hypophagia, summer mesophagia, and fall hyperphagia); distances were less a function of sex, reproductive status, age, day of the week (proxy for high human presence), or individual differences. However, females occurred disproportionately more than males (92%) in a 500-m radius from town. Bears were closest to Cadomin in spring and fall, but feeding and bedding activity occurred within 500 m of the settlement across seasons. By contrast, bear distances from roads and trails differed less as a function of season than they did among individuals, but that revealed nothing about nuisance potential. Adult female G040, the single research bear that became a problem because it entered the settlement and foraged there, did not tend to be closer to roads and trails than most bears. During the year that G040 visited Cadomin, her average distance from that settlement ($\bar{x} \pm 2$ SE: 281 ± 51 m, $n = 37$) was not closer than distances of the other bears to Cadomin (303 ± 11 m, $n = 512$), although it was closer than her mean distance during the 2 other years on which we have data (387 ± 90 m, $n = 10$). Based on these findings and bear-related occurrences reported by residents, we conclude that seasonal and annual deficits of prime natural foods, and availability of anthropogenic foods, remain the best predictors of nuisance activity for bears in general.

Conflict; Human Use; Fitness; Roads; Trails; Bedding; Mortality

Milligan, S., Brown, L., Hobson, D., Frame, P., & Stenhouse, G. (2018). Factors affecting the success of grizzly bear translocations. The Journal of Wildlife Management, 82(3), 519-530. https://doi.org/10.1002/jwmg.21410

Evaluations of wildlife translocation can be traditional assessments of survival and reproductive success or can be expanded to include valuable but seldom used measures of behavior and physiology in reference to baseline data from a resident population. In Alberta, Canada where grizzly bears (*Ursus arctos*) are listed as a threatened species, there has been research on resident grizzly bear populations but limited follow-up of translocated individuals associated with management actions. We determined an outcome for 110 grizzly bear translocation events (77 failed events, 33 successful events) between 1974 and 2014. We used logistic regression to investigate the effects of individual bear characteristics, management strategies, and habitat factors on translocation success. A translocation event was successful if the bear did not require further management action and if the bear survived at least one year without homing. We also compared the home range size, habitat selection, and denning behavior of translocated bears to the resident population over time to assess the long-term effects of translocation. The odds of translocation success were higher if bears were moved early in the year and decreased by 47% for each unit increase in the level of mortality risk (based on road density, water, and edge features) at the release site. The odds of homing decreased substantially at translocation distances >100 km, but bears translocated outside the Bear Management Area (BMA) of capture had annual home ranges that were 3.25 times larger on average than resident bears. Translocated bears were initially selecting high quality habitat similar to areas used by resident bears, but this behavior appeared to decline after the first year of translocation. Den entry dates, den exit dates, and the denning period of translocated bears did not differ significantly from resident bears. Our findings can aid managers in making more informed decisions when considering translocation as a tool for managing human-bear conflict or supporting grizzly bear conservation efforts.

Conflict; Translocations; Mortality; Roads; Edge; Home Range; Denning

Coogan, S. C. P., Coops, N. C., Janz, D. M., Cattet, M. R. L., Kearney, S. P., Stenhouse, G. B., & Nielsen, S. E. (2018). Towards grizzly bear population recovery in a modern landscape. Journal of Applied Ecology, 56(1), 93-99. https://doi.org/10.1111/1365-2664.13259

(*Note: Abstract not available; this is the conclusion*). The complex, interactive, and multidimensional factors acting upon grizzly bears in Alberta necessitates an interdisciplinary and multiscalar scientific approach to their population recovery and management. The data and subsequent insight acquired from such an approach will better inform decision makers, and may ultimately contribute towards improving public faith in the scientific processes informing decision making. Importantly, however, to have a societal and political impact it is imperative that scientists broadly communicate their research in a way that non- specialists can understand, while simultaneously establishing the rigorous state- of- the-art science underpinning grizzly bear research. Improving public understanding of research related to the ecology, management, and conservation of the bears may go a long way towards fostering the social tolerance necessary for co-existing with a healthy grizzly bear population in Alberta, which is a lesson learned from the European successes. Furthermore, such an approach may assuage the public's lack of faith in science communication dissonant with their own personal beliefs. Great science, and public understanding and acceptance of it, is necessary for large carnivore conservation, especially if societal values and ethics ultimately shape management policy. Given the recent situation in BC, the question arises as to whether population recovery in Alberta will lead to an end of the hunting moratorium in that province? This is a question that we, of course, cannot answer. Certainly, however, we need the aforementioned science to help direct actions that most efficiently and effectively increase the population size, to determine when then population has recovered, and to manage that population post-recovery, before the possibility of a sustainable grizzly bear hunt could even be evaluated. Eventually, if population recovery is successful, a grizzly bear trophy hunt in Alberta will be up to society and government to decide. But we have to get there first, and that requires directed monitoring and applied research.

Hunting; British Columbia; Remote Sensing; Nutrition

REPORTS

Note that not all reports have summaries or abstracts, therefore, other sections of the report, usually pulled from the objectives and or conclusion, have been included.

POPULATION INVENTORY AND DENSITY ESTIMATES

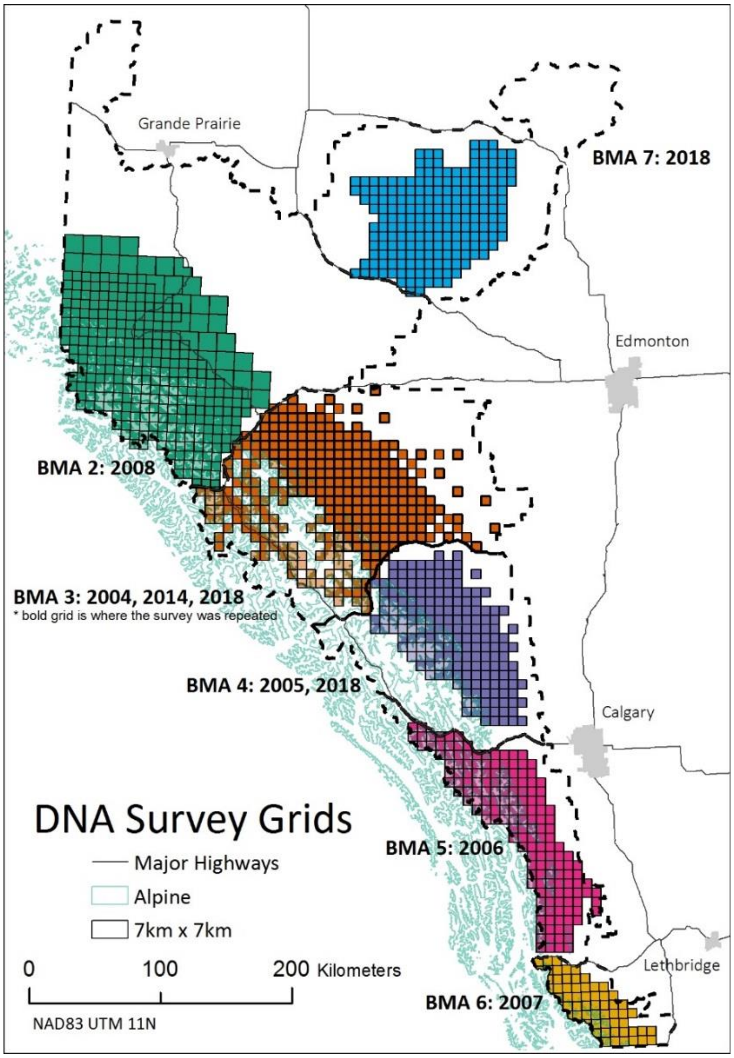

Figure 26. Survey grids used for DNA-based population inventories in all BMAs.

These reports show population estimates in various bear management units over the years, revealing population growth.

Boulanger, J., Stenhouse, G., Proctor, M., Himmer, S., Paetkau, D., & Cranston, J. (2005). 2004 population inventory and density estimates for the Alberta 3B and 4B grizzly bear management area. Report prepared for Alberta Sustainable Resources Development, Fish and Wildlife Division.

This report provides grizzly bear population and density estimates for the Alberta 3B and 4B grizzly bear management areas. Recent DNA analysis with provincial DNA samples has shown that these two management areas are in fact one genetically distinct population unit, hence this inventory project was designed to sample a single population unit. In the spring of 2004 a DNA sampling grid (8820 km^2) was sampled. One hundred and eighty 7x7 km grid cells were sampled with 1 DNA bait site for 4 sampling sessions. Each bait site was moved between sessions to ensure adequate coverage of cell areas. Thirty-nine bears were captured in bait sites, and 5 other bears were identified with other forms of sampling. The distribution of bears was clumped along the west side of the study area with virtually no bears detected in the southeast part of the sampling grid. Data-based tests and GPS collared bears suggested that bears traversed across the western border therefore violating the assumption of population closure. The estimate of the superpopulation of bears (including dependent offspring) in the grid and surrounding area was 53 (SE=8.3, CI=44 to 80). The average number of bears on the sampling grid was estimated by multiplying the superpopulation number by the proportion of GPS bear locations on the sampling grid (0.79) to estimate an average number of bears on the sampling grid at any one time of 42 (SE=7.3 CI=36 to 55). This number was divided by the sampling grid area (8820 km^2) to derive a density estimate of 4.79 bears per 1000 km^2 (SE=8.82 CI=4.10 to 6.28). The levels of precision of this project were one of the highest attained in any previously conducted DNA census in British Columbia and Alberta.

Population Inventory; Density; Hair Snag; DNA; British Columbia

Boulanger, J., Stenhouse, G., MacHutchon, G., Proctor, M., Himmer, S., Paetkau, D., & Cranston, J. (2005). Grizzly bear population density estimates for the 2005 Alberta (proposed) Unit 4 Management Area inventory. Report prepared for Alberta Sustainable Resource Development, Fish and Wildlife Division.

This report provides grizzly bear population and density estimates for a study area that includes the Alberta Provincial grizzly bear management area 4 (proposed) and a small eastern portion of Banff National Park. This area encompassed the current Alberta Bear Management Areas 4C, and portions of 3B, 7, 13 and 15. In 2005, a DNA hair capture grid (8477 km^2) was sampled. One hundred and seventy three 7x7 km grid cells were sampled with 1 hair capture bait site for 4 sampling sessions. Thirteen 7x7 cells were located wholly within Banff Park to meet the assumption of population closure. In addition, 11 transect cells were sampled in plains areas to detect occupancy of bears in these areas (but were not used in the mark-recapture analysis). Each bait site was moved between sessions to ensure adequate coverage of cell areas for cells within the main sampling grid. Forty one individual bears were captured in bait sites on the main sampling grid, and 1 other bear was captured in the transect grid cells. The distribution of bears was clumped along the west side of the study area. Data-based tests and GPS collared bears showed that closure violation was minimally violated with 95% of GPS collared bears locations occurring on the sampling grid. The estimate of the superpopulation of bears (including dependent offspring) in the grid and surrounding area was 47 (SE=3.99, CI=44 to 60). The average number of bears on the sampling grid was estimated by multiplying the superpopulation number by the proportion of GPS bear locations on the sampling grid (0.95) to estimate an average number of bears on the sampling grid at any one time of 45.41 (SE=3.96 CI=41 to 52). The average number of bears at any one time was divided by the sampling grid area (8477 km^2) to derive a density estimate of 5.25 bears per 1000 km^2 (SE=0.47 CI=4.87 to 6.09) on the sampling grid. The capture probabilities (an index of sampling efficiency) for this project were the highest recorded for any DNA mark-recapture project in British Columbia or Alberta, since this technique was introduced in 1996. As a result, the precision of estimates was very high despite the lower population size of bears in the sampling area.

Population Inventory; Density; Hair Snag; DNA; Management Areas; British Columbia

Alberta Grizzly Bear Inventory Team. (2007). Grizzly bear population and density estimates for the 2006 Alberta Unit 5 Management Area inventory. Report prepared for Alberta Sustainable Resource Development, Fish and Wildlife Division.

As part of ongoing grizzly bear management efforts in Alberta the Department of Sustainable Resource Development has been conducting population estimates in bear management units (BMA's) along the eastern slopes of Alberta. This work is focused on establishing current population status and spatial distribution of grizzly bears in these BMA's. This report provides grizzly bear population and density estimates for a study area that includes the Alberta Provincial grizzly bear management area 5 (BMA 5), Kananaskis and Peter Lougheed Provincial Parks, and a part of Banff National Park. In 2006, a DNA hair capture grid (7639 km^2) was sampled. One hundred and sixty 7x7 km grid cells were sampled with 1 hair capture site for 4 sampling sessions. Of these, nineteen 7x7 cells were located wholly within Banff Park to assist with population closure. In addition, 8 transect cells were sampled in plains areas in the southeast to detect occupancy of bears in these areas (but were not used in the mark-recapture analysis). Each hair capture site was moved between sessions to ensure adequate coverage of cell areas for cells within the main sampling grid. Eighty five individual bears were captured at sites on the main sampling grid. The distribution of bears was clumped along the west side of the study area. Data-based tests and GPS collared bears showed that the population was not geographically closed with 67.6% of VHF or GPS collared bears locations occurring on the sampling grid. The estimate of the superpopulation of bears (bears including dependent offspring, within the sampling grid and surrounding area during the time that sampling was conducted) was 133 (SE=18.12, CI=109 to 183). The average number of bears on the sampling grid was estimated by multiplying the superpopulation number by the proportion of GPS/VHF collared bear locations on the sampling grid (0.676) to estimate an average number of bears on the sampling grid at any one time of 89.9 (SE=15.73 CI=75 to 116). The average number of bears at any one time was divided by the sampling grid area (7639 km^2) to derive a density estimate of 11.77 bears per 1000 km^2 (SE=2.06 CI=9.9 to 15.2) on the sampling grid. We recommend that for management purposes the estimate of the average number of bears on the sampling grid area (89.9) be used.

Population Inventory; Density; Hair Snag; DNA

Grizzly Bear Inventory Team. (2008). Grizzly Bear Population and Density Estimates for Alberta Bear Management Unit 6 and British Columbia Management Units 4-1, 4-2, and 4-23 (2007). Report prepared for Alberta Sustainable Resource Development, Fish and Wildlife Division, British Columbia Ministry of Forests and Range, British Columbia Ministry of Environment, and Parks Canada.

This project represents a joint effort of three jurisdictions: Alberta, British Columbia, and Waterton National Park, to estimate grizzly bear population size in the Alberta Bear Management Unit 6; British Columbia Management Units 4-01, 4-02, and part of 4-23; and Waterton National Park. This area contains a contiguous population unit and therefore it was deemed essential that these areas be sampled as one unit to meet mark-recapture model requirements as well as to provide an estimate for a single, biologically based grizzly bear population unit. This population unit is also part of what Americans call the "Northern Continental Divide Ecosystem" and is connected to bears south of the US-Canada border. A systematic DNA sampling grid of 125 7x7 km grid cells was placed within the inventory area with 63 cells in British Columbia, 55 in Alberta, and 7 with sites in both provinces during the course of the project. The analysis was challenged by non-uniform distributions of radio collared bears that prevented traditional methods of correcting estimates for closure violation. We therefore developed a new regression method that directly estimates radio collared bear residency as a function of distance from the bear's home range center to the sampling grid edge as well as the geographic location of the bear's home range center relative to likely movement barriers. This information was used to estimate residency of bears captured in DNA efforts and was integrated with mark-recapture estimates to provide closure corrected population estimates. Another challenge to the project was the probable reduction of capture probabilities of grizzly bears due to extensive live capture and radio collaring in the project area. It has been hypothesized that live capture makes bears more cautious and less likely to leave hair at hair snag bait sites. We applied a recently developed method to estimate reduction in capture probabilities and estimate the number of collared bears present on the sampling grid. This analysis documented lower capture probabilities of previously collared bears, but also estimated a relatively low number of collared bears present on the sampling grid. Simulation results suggest that the overall effect of collared bears on population estimates was minimal. Overall, 110 grizzly bears were identified on the entire sampling grid. Residency of bears was determined by the province in which a bear's mean capture location was situated. Using this criterion, 83 bears were captured on the B.C. grid and 27 on the Alberta grid. Six male bears were captured on both the Alberta and British Columbia sampling grid, however, the mean capture location of all these bears fell within British Columbia. In general, the capture success of bears was lower than previous projects in Alberta, especially in the Alberta section of the sampling grid. We therefore applied meta-analysis mark-recapture methods to provide more robust estimates of population size with the sparse data from the project. Using these methods we arrived at an estimate of the average number of bears on the entire grid of 228.4 (SE=22.47, CI=151-314). The average number of bears on the sampling grids of Alberta and British Columbia was 51.2 (SE=12.6, CI=34.4-86.7) and 177.9 (SE=34.8, CI=129.9-271.1), respectively. The average number of bears on the grid at any one time was divided by the sampling grid areas to derive density estimates of 18.1 (SE=4.47, CI=12.1-30.6), 54.7 (SE=10.7, CI=39.7-83.5) and 37.6 (SE=3.7, CI=31.5-46.2) bears per 1000 km^2 for Alberta, British Columbia, and the entire sampling grid respectively.

Population Inventory; Density; Hair Snag; DNA; British Columbia

Alberta Grizzly Bear Inventory Team 2008. (2009). **Grizzly Bear Population and Density Estimates for the 2008 DNA Inventory of the Grande Cache Bear Management Area (BMA 2).** **Report Prepared for Alberta Sustainable Resource Development, Fish and Wildlife Division**.

This report details population size and density estimates for grizzly bears in the Grande Cache Bear Management Area (BMA 2) and Jasper National Park north of Highway 16 which were sampled using DNA hair snares in the early summer of 2008. The large land area (management area = 48,617 km^2, grid area sampled = 19,502 km^2), and low road density in portions of BMA 2 made sampling of this area using the 2004-2007 intensive mark-recapture designs prohibitively expensive. We therefore used a stratified sampling design that optimized sampling intensity based upon likely grizzly bear densities and effective grizzly bear habitat area. The sampling grid was 19,502 km^2 and included the Willmore Wilderness Area, Kakwa Wildland Park and Jasper National Park north of Highway 16. Three subgrids were used to sample within the main grid each of which varied in terms of whether hair-snag sites were moved between sessions and hair site density. A specialized covariate-based mark-recapture model was used to confront capture probability variation caused by stratified sampling. As with previous years, GPS collared bear movement data from research programs were used to estimate closure violation and produce closure corrected estimates. Two hundred and sixty nine bears were identified from hair snag samples and 2 more male bears were identified at rub trees in Jasper National Park for a total of 271 bears identified in DNA sampling. Of these, 161 were females and 110 (108 detected with hair snags, 2 with rub trees) were males. The resulting estimate of the superpopulation of bears that inhabited the grid and surrounding area was 388 (SE=58.7, CI=317-566). Using GPS bear-based estimates of movement on and off the grid, this estimate was scaled to the average number of bears on the sampling grid at any one time of 353.3 (SE=53.52, CI=288-516). The resulting density of 18.11 bears per 1000 km^2 (SE=2.74, CI=14.8-26.4) was estimated by dividing the average number of bears on the sampling grid by the total grid area (19,502 km^2). The large sampling grid spanned a wide range of bear densities and human use levels so this density estimate should be interpreted in unison with distribution maps of bear detections on the sampling grid, and relative density estimates of grid sub-areas.

Population Inventory; Density; Hair Snag; DNA

Boulanger, J., Cranston, J., Nielsen, S., & Stenhouse, G. (2009). Estimation of grizzly bear population size for the Swan Hills management unit using DNA sampling and habitat-relative occupancy models. Report prepared for Alberta Sustainable Resource Development.

Grizzly bear population inventory work has been underway in various population units along the eastern slopes of Alberta. As of the time of the preparation of this report two population units have not been inventoried, the Swan Hills and the Alberta North units. In order to provide a science based estimate of possible grizzly bear population size in the Swan Hills unit we utilized existing data sets from the previous DNA inventory work to provide estimates for the purpose of a species status review. We used an objective, multi-scale approach to estimating occupancy-habitat associations based on DNA hair snag information and predicted (extrapolated) occupancy to similar habitats (natural sub-regions) in the Swan Hills grizzly bear management unit. Assuming similar habitat and population conditions among reference areas (the foothills adjacent to the Rocky Mountains) and the Swan Hills, we estimated population size for the Swan Hills Grizzly Bear Management Unit. Estimates of population size ranged from 11.6 to 21.2 for the core Swan Hills area and a population size of 2.0 to 3.9 individuals for the edge area. The model-averaged estimate for the Swan Hills was 23.2 (CI=5.9-70.9) bears. We suggest that if required, the best way to test these model predictions would be to sample bear DNA in the Swan Hills using a reduced sampling effort design to create a data set to further refine relative occupancy models. Additional data are presented from research findings of GPS collared bears illustrate the isolation of the Swan Hills grizzly bear population. Despite no recorded interchange among populations (Swan Hills and Grande Cache), the long-term maintenance of the Swan Hills population is likely due to periodic (albeit rare) successful colonization (dispersal) from the Grande Cache unit. We believe that data from recent field research indicate that habitat and other ecological conditions of the most northern grizzly bear population unit (Alberta North) differ significantly from all other population units. We therefore suggest that a different sample driven approach be used to provide population estimates for this unit for future management needs as habitat-occupancy methods using reference populations are unlikely to satisfy assumptions used in the model.

Population Inventory; Density; Hair Snag; DNA

Stenhouse, G.B., Boulanger, J., Efford, M., Rovang, S., McKay, T., Sorensen, A., and Graham, K. (2015). Estimates of Grizzly Bear Population Size and Density for the 2014 Alberta Yellowhead Population Unit (BMA 3) and South Jasper National Park Inventory Project. Prepared for Weyerhaeuser Ltd., West Fraser Mills Ltd, Alberta Environment and Parks, and Jasper National Park.

The first provincial grizzly bear DNA population inventory assessment was conducted in Bear Management Area 3 (BMA 3) within the Yellowhead population unit in 2004. Ten years after this first inventory, funding and support were provided by provincial and federal government agencies along with two forest management tenure holders to repeat and expand the second grizzly bear population inventory in 2014. The area studied in 2014 included BMA 3, along with an expansion into the White Goat Wilderness Area to the south. In addition, for the first time, the southern portion of JNP (JNP) was inventoried. The study design for this project incorporated our current knowledge of the study areas, applied spatially explicit capture recapture (SECR) methods, and used DNA hair samples collected using non-invasive approaches. The goals of this study were to: 1. Apply a study design that would allow direct comparison of 2014 results with 2004 data in BMA 3, 2. Provide an estimate of the current population size within BMA 3, 3. Compare the spatial distribution of grizzly bears on the current landscape, and determine how this distribution relates to that found in 2004, and 4. Conduct a DNA inventory of south JNP (adjacent to provincial BMA 3) to gain information on grizzly bear occupancy and density for this area. Overall, 108 unique bears were detected within the 2014 sampling area, including 63 bears in BMA 3, 16 bears in the White Goat Wilderness Area, and 29 bears in south JNP. The SECR population estimate indicates that the population estimate for BMA 3 is 74.2 grizzly bears (CI = 56.2-98.0) while the south JNP population estimate is 54.0 grizzly bears (CI = 39.8-73.2). An additional 10.4 (CI=7.6-14.2) bears are estimated in the White Goat and surrounding area. When viewed as a single ecosystem, the population estimate would be 138.6 grizzly bears, with a confidence interval of 114.6 to 167.7 animals. These new population estimates indicate the population of bears in BMA 3 has increased since the previous population inventory work was completed in 2004. Estimates for the 2004 DNA sampling grid based on SECR analysis was 36 bears (CI 28.6-45.3) in 2004 compared to 71.3 bears (CI 53.9-94.2) in 2014. Our findings represent an annual population rate of increase of approximately 7%, which is higher than commonly seen in most interior grizzly bear populations in North America. The reasons for this observed rate of population increase are unclear and require additional investigation and analysis to determine whether current and past management actions are contributing to this rate of increase. In 2008, a DNA-based population estimate was completed in the northern half of JNP. Combining the north JNP population estimate with current data results in an estimated total of 113 grizzly bears residing within the boundaries of JNP. However, this estimate is based on the assumption that grizzly bear densities in north Jasper have remained constant since 2008. Results from this inventory indicate that spatially explicit methods obtain robust estimates with less sampling effort through the use of sampling stratification. These techniques can be employed in future population inventory work in other provincial BMAs to reduce overall project costs.

Population Inventory; Population Trend; Density; Hair Snag; DNA

Stenhouse, G., Boulanger, J., Phoebus, I., Graham, K., & Sorensen, A. 2020. Estimates of Grizzly Bear Population Size and Density for the Alberta Clearwater Population Unit (BMA 4) in 2018 with Comparisons to 2005 Data. Prepared for Alberta Environment and Parks, Spray Lake Sawmills, West Fraser Timber, and Forest Resource Improvement Association of Alberta.

The first grizzly bear DNA population inventory conducted in the Clearwater Bear Management Area (BMA 4) took place in 2005. In 2018, thirteen years following this first assessment, funding and support was provided by two regional forestry companies, and the provincial government, to conduct a second grizzly bear population inventory in BMA 4.

The primary objectives of the 2018 inventory were to obtain an up-to-date estimate of grizzly bear abundance, distribution and density in BMA 4, to compare these findings with the 2005 inventory results, and to investigate the utility of newly created provincial genetic datasets to contribute to grizzly bear population monitoring efforts. We designed sampling and analysis approaches to allow for comparisons between the two time periods. The findings in this report are from the genetic analysis (DNA) of grizzly bear hair collected using non-invasive barb wire techniques and employed scent lures at sampling sites.

The 2018 BMA 4 survey detected 64 bears (35 males and 29 females) compared to 42 bears (17 males and 25 females) in 2005. The 2018 inventory had lower grizzly bear detection success rates than in 2005, which had the highest detection rates out of all grizzly bear DNA inventories in Alberta to date. However the lower detection rates in 2018 still provided a sound population estimate for this area and allowed a direct comparison with the 2005 inventory results.

As was the case in 2005, the 2018 results showed that many detections occurred along the western side of the study area with a declining density gradient to the east. Most bears were detected in core habitat areas, but bears were also found in secondary habitat areas. Existing modelling tools (Resource Selection Functions [RSFs] and mortality risk [RISK]), which are currently used to guide management practices, proved useful as parameters to model grizzly bear habitat selection within the sampling grid. We found RSF to be a better predictor of grizzly bear densities than RISK. Higher densities of grizzly bears occurred in higher RSF areas, particularly in the core zone. However, higher bear densities were also found in some low RSF habitats that also had lower RISK. These areas corresponded to some of the mountainous areas along the eastern boundary of Banff National Park.

The spatially explicit capture-recapture (SECR) analysis indicates that the population estimate for BMA 4 is 88 grizzly bears (CI = 59-130) while the population estimate in 2005 was 42 bears (CI = 32-50). Density estimates for this population in 2018 were 9.64 grizzly bears/1000 km^2 (CI= 6.54-14.27) while the 2005 densities were 4.39 grizzly bears/1000 km^2 (CI= 3.52-5.48). These new population and density estimates indicate an increasing population of grizzly bears in BMA 4, which has more than doubled in size since the previous population inventory work in 2005.

Open model analysis of the data also found relatively high apparent survival for female bears (0.96, CI=0.86-0.99) which further supports the documented demographic increase. This rate of survival should be treated cautiously given that it is based on bears detected in the 2005 and 2018 surveys and therefore it assumes a constant survival rate for the 13-year period between surveys.

A comparison of estimates of density and abundance between 2005 and 2018 suggest increases in both core and secondary habitats with the largest relative increase occurring in secondary areas. This finding has important management implications.

Analysis of home range centers of detected bears using base detection models revealed that most home range centers were in the core area with only 4 of 17 male and 1 of 25 female home range centers falling in the secondary area. The home range centers for bears detected in both 2005 and 2018 also revealed a high level of fidelity for females with minimal change in home range centers, however, male bears showed lower fidelity. From a distribution perspective, the data also suggests that female bears are spreading eastward over time while male bears continue to occupy similar areas. This eastward spread of bears requires further study and the collection of additional data to support management decisions. Higher densities of bears were found in areas with high RSF values and high RISK values, which can be conceptualized as attractive sinks (if mortality sources are not managed) and these higher densities could be due to success in managing bears and their habitats, and reducing mortality pressure in these areas, therefore allowing increases in density.

Long-term provincial genetic data sets, when coupled with DNA inventory data, proved their utility by allowing a greater understanding of bear survival, reproduction and movements of bears within this bear management unit (and provincially) and for the purposes of monitoring these population elements over time. The delay in processing scat samples that were also collected during field sampling sessions may have negatively impacted the genetic laboratory extraction rates. We had no individual scat sample results to use in the population estimation work.

Our findings represent an annual population rate of increase in BMA 4 over a 13-year period of approximately 6%, which is higher than commonly seen in most interior grizzly bear populations in North America. However, this rate of population increase was similar to that found in 2014 within the adjacent Yellowhead BMA 3 population unit to the north. Determination of the reasons for these observed rates of population increase are important for ongoing management decisions but are currently unclear and require additional investigation and analysis to determine how current and past management actions are contributing to this rate of increase.

Population Inventory; Population Trend; Density; Hair Snag; DNA; Population Monitoring; Home Range; Mortality

Stenhouse, G., Boulanger, J., Graham, K., Phoebus, I., McClelland, C., & Pigeon, K. (2021). Estimates of Grizzly Bear population size, density and distribution for the Alberta Swan Hills Population Unit (BMA 7). Prepared for West Fraser, Millar Western Forest Products, Vanderwell Contractors, Forest Resource Improvement Association of Alberta, and Alberta Environment and Parks.

In 2018, a collaborative project was undertaken between regional forest tenure holders and the Alberta Government (Alberta Environment and Parks) to provide the first assessment of the grizzly bear population in the Swan Hills Bear Management Area (BMA 7). Since the Swan Hills area has never had a DNA based population estimate, this project was intended to provide a base level for future comparisons to monitor population trends. Using genetic samples gathered through non-invasive barbwire hair snagging, we sampled 9,800 km^2 of grizzly bear habitat with a grid sampling design over a 6-week period from May to July 2018. The study design used was based on previous knowledge of grizzly bears and habitats within BMA 7, combined with past experience and data from other spatially explicit capture-recapture grizzly bear population inventory work that our research team has undertaken in other provincial BMAs since 2004. This project provides the first estimates of grizzly bear abundance and density for the Swan Hills area. During this inventory, we submitted 750 hair samples for DNA analysis. 507 of these were genetically determined to be black bears, 100 were from grizzly bears. From these grizzly bear samples, 93 grizzly bears were identified to the individual, with 39 unique bears identified (21 females and 18 males). The Swan Hills project had lower sampling efficiency compared to other projects conducted in Alberta. This was a result of the low proportion of grizzly bears detected in more than one sampling session, and a high proportion of new grizzly bears detected in the final sampling session. This low redetection frequency was anomalous when compared to other grizzly bear DNA mark-recapture projects performed in the province. To confront sparse data from the BMA 7 project we used a meta-analysis approach to estimate density that used data from the adjacent BMA 2 survey that was conducted in 2008. This analysis suggested the density of grizzly bears to be 12.6 bears per 1,000 km^2 which resulted in an average estimated number of bears between 150 and 152 (CI=69-330) in core and secondary areas. However, the precision of estimates was low (CVs of 35-41%) and the low numbers of redetections was the primary factor for the poor precision of these estimates. Although we cannot fully explain the low redetection rates of bears in this study, it is likely that a high-density black bear population in this BMA could have influenced grizzly bear responses (i.e. attraction) to the sampling sites. Based on the large amount of black bear hair identified, the presence of black bear hair at most sampling sites in all sessions, and supported by the identification of a large number of black bear scats, we feel such an effect is possible, although not fully understood.

We did see that the detection of family groups (4 cubs - in two family groups) in the last sampling period had an effect on population estimates by creating potential demographic closure within the analysis framework. When these four bears that were sampled together at one site, and identified as cubs through genetic analysis, were excluded from the analysis (mothers were retained), the population estimate decreased by 30 bears. This demonstrates the effect of potential demographic closure and the sparse nature of the data set on the population estimate. The population estimate of grizzly bears in the Swan Hills using the data set without the 4 cubs mentioned above (cubs identified only during the last session) is 118.6 bears (CI=62-226). As a result, the estimates from this project are relatively imprecise and should be interpreted with caution.

Given the high CV and lack of estimate precision found with BMA 7 data, we conducted an additional analysis where a similar detection function found for BMA 2 (2008) was applied to the Swan Hills data set. The results of this analysis showed that when the cubs detected during the final sampling session were removed from the analysis and similar detection rates for BMA 7 and BMA 2 were assumed, population estimates changed to 56 - 64 grizzly bears and densities were 3.5 - 5 bears per 1,000 km^2 with an increase in precision to a CV of 14%. These results, based on detection rates which were similar to those found in most other grizzly bear inventory work in Alberta, provided grizzly bear density estimates similar to what has been observed in other provincial BMAs.

Using the new Alberta grizzly bear genetic database, we did not find previous history on any of the 39 unique bears identified within this inventory, nor did we identify any offspring from the 10 grizzly bears that were captured and collared in 2005 and 2006 as part of other research efforts in BMA 7. This is in stark contrast to the 2018 BMA 4 inventory where 40% of the identified grizzly bears had a known history, as determined through genetic sampling. This may indicate elevated mortality rates in BMA 7 but we recognize that no ongoing grizzly bear collaring efforts have taken place in this area since 2006. We also did not detect any grizzly bear movement across Highway 43 during our sampling period. Genetic analysis of grizzly bears detected in BMA 7 clearly showed that these bears are from a genetically distinct population, suggesting no or very limited immigration.

The main challenge for the 2018 Swan Hills DNA inventory is low precision, resulting in wide confidence limits on population estimates. For this reason, we suggest that these estimates be interpreted cautiously, and that the lower bound of the confidence limit of 62 bears be used for management purposes at this time. We note that the lower bound of the confidence limit (62) roughly corresponds to the population estimate of grizzly bears if a detection function similar to BMA 2 is assumed (56–64 bears).

Population Inventory; Population Trend; Density; Hair Snag; DNA

ADDITIONAL INTERNAL REPORTS AND PUBLICATIONS

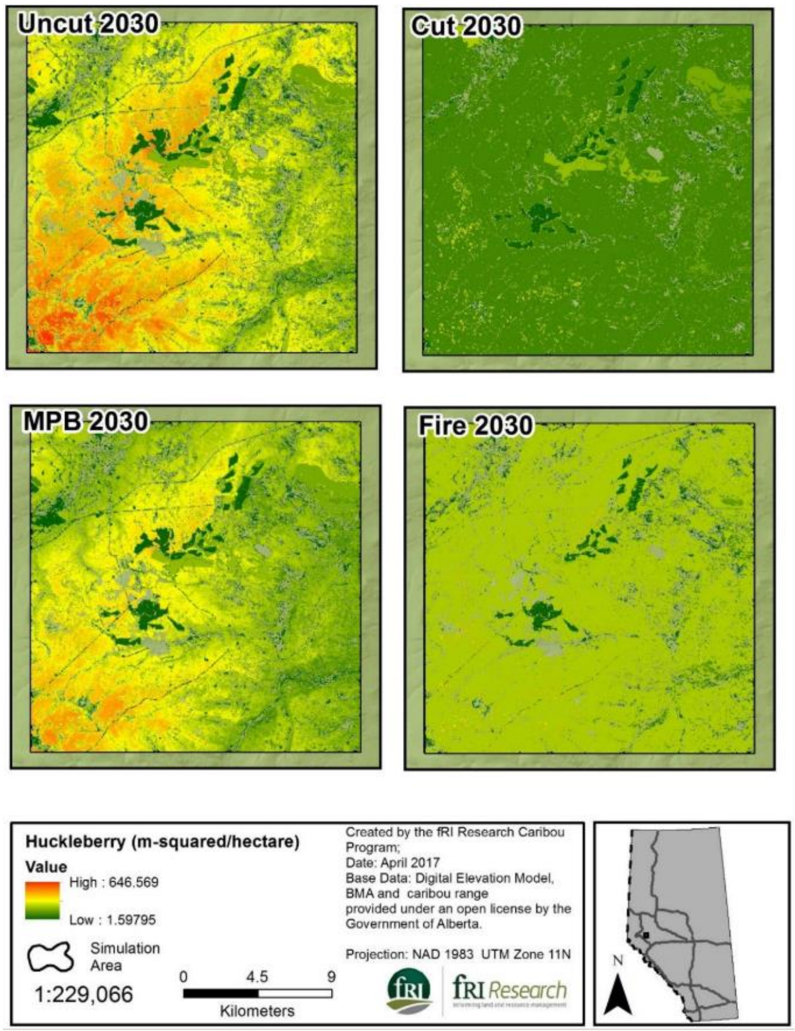

Figure 27. Simulation of huckleberry abundance under four mountain pine beetle related management scenarios in a 20 km by 20 km area in the West-Central study area in Alberta. The scenarios predicted abundance in 2030 after a change to the pine within the area in 2018. These changes included unchanged (Uncut), infected with 60% MPB (MPB), burned by a wildfire (Fire), or harvested for timber (Cut). The MPB scenario is extrapolated beyond the available data after 8 years. Figure is taken from Nobert et al. 2017, p. 131.

This section contains reports and other works of various themes, organized chronologically.

Lee, J., & Stenhouse, G. (1999). Comparison of grizzly bear telemetry location data with a grizzly bear habitat model. Unpublished Report, Foothills Model Forest.

Goal: The intent of this exercise was to:

- transform bear movement data from Russell et al. (1979) into a computer compatible format,
- explore how these bear locations relate to the habitat attributes assigned to the habitat polygons in which they occurred,
- provide information on the temporal and spatial distribution of grizzly bears in this portion of the "new" study area to aid in the planning of radio collar deployment and DNA sampling sites,

- recalculate home range sizes and compare these with those originally reported and examine home ranges in pre and post-berry seasons.

Summary: Grizzly bears were found in higher habitat quality types more frequently than the simple distribution of those habitats would suggest. Additionally, the mean monthly habitat quality value of the habitats chosen increased as the berry season progressed. However, it is not surprising that bears would be choosing higher quality habitat. The large proportion of occurrences in un-vegetated habitat polygons requires further investigation. Bears may be utilizing some food source other than plants or perhaps responding to factors other than vegetation (i.e. carrion, escape terrain, mineral licks, conspecific avoidance, etc.). The assignment of habitat quality values for these areas may need to be further refined. Home ranges calculated in this report compared closely with those calculated by hand in Russel et al. 1979. This would lend confidence to the reliability of the digitizing process used in this report. The mean female home range size falls within the range of home range areas used to develop Bear Management Units within Jasper National Park. The data indicated larger home ranges in the pre-berry season. Russell et al. (1979) refer to this and attributed it to a poorer, more dispersed food supply at that time of the year in combination with increased movements related to breeding activity. However, the discrepancy in the number of data points in the different seasons need to be considered. This analysis, although limited in scope, supports the habitat potential component of the Cumulative Effects Assessment model currently in use in Jasper National Park. Further testing and validation of the CEA model components will take place as a primary component of the Foothills Model Forest Grizzly Bear Research Project.

Classification; Habitat Selection; Home Range; Telemetry

Schwab, B. L., & Stenhouse, G. B. (2003). <u>Landscape Connectivity and Movement Corridors for Grizzly Bears in the Yellowhead Ecosystem, Alberta: A Preliminary Assessment.</u> Unpublished Report.

Maintaining habitat connections for movement across fragmented landscapes is important for the long-term conservation of grizzly bear populations. Grizzly bears range across multiple jurisdictions and therefore an integrated management approach is necessary to ensure their long-term persistence. As a result, the focus of this analysis is on applying graph theoretic methods in conjunction with Remote Sensing, GIS and GPS data to study and quantify landscape connectivity associated with female grizzly bears within the Yellowhead Ecosystem, Alberta.

The graph theoretic model as presented here can be used as an analytical tool for conservation planning. The approach provides important information regarding habitat patch sensitivities to removal, edge properties relating to corridor identification and overall connectivity measures for the study area landscape. Additionally, the graph theory approach has the ability to identify habitat patches and movement paths most sensitive to development and furthermore important to overall conservation efforts. Bear behavior in general can be difficult to model as each individual bear behaves differently. However, when combined with RSF models the graph theoretic model incorporates bear biology specific to habitat selection. As such, the graph theoretic model included aspects of both general foraging and movement behaviors specific to female grizzlies. As LCP modeling and thus edge connections were intended to reflect movement, specific emphasis was made to validate this portion of the research. Iterative removal of habitat patches or nodes was shown to affect both spatial dispersal patterns and resulting connectivity rates. As habitat patches were removed from the home range a bear’s ability to traverse the landscape was shown to decrease. However, this was dependent on habitat patch size and placement within the landscape. For example, patches on the periphery had a limited effect while patches central to the graph structure were of greater importance. The threshold distance or the distance at which connectivity decreased to the point where a graph disconnects into subgraphs was identified 2.5 km for the FMFGBRP landscape. The identification of critical thresholds must be interpreted with caution as the measures presented here were not related to female movement. The results indicated by the graph theory approach are based solely on the spatial configuration of habitat patches and corresponding distance of edge connections between nodes.

Movement; Connectivity; Fragmentation; Habitat Selection

Stenhouse, G., Boyce, M., & Boulanger, J. (2003). Report on Alberta Grizzly Bear Assessment of Allocation. Report prepared for Alberta Sustainable Resource Development.

A review of available data was undertaken to assist in management of the harvest of grizzly bears in Alberta. A small team of experts was tasked with this review under the direction of the Minister of Sustainable Resource Development. The team's goals included the review of the current model being used to allocate hunting licenses, an analysis of the available mortality data held by the department, and the identification of data needs to assist in grizzly bear management efforts. The review found that the model currently used in predicting population size and thus the allocation of licenses is incomplete and will continue to predict exponential growth rates when this is not biologically possible. Solutions and modifications to this model are suggested that will improve the allocation of hunting licenses to prevent possible over harvest. The mortality data used in this report is not as strong as it could be given the current registration process. Minor but important changes are possible to strengthen this data for future management needs and are outlined in this report. The ongoing maintenance and evaluation of a comprehensive database is seen as a key component of all current and future grizzly bear management efforts. Our review of the available mortality data suggests that there are three Bear Management Areas (BMA's) that exhibit a declining trend in the age of females in total mortalities (units 2B, 4B and 4C). This represents a potentially serious management concern and steps to reduce overall mortality rates in these BMA's are necessary. In other BMA's a conservative legal harvest can be maintained if additional inventory work is undertaken and current habitat conditions are revisited to update our allocation formula. Further the review revealed that female bears continue to form a major component of overall total mortalities and measures to reduce this are necessary. Problem bear management actions continue across the province, however we have identified three key areas in which ongoing and regular problems persist. Efforts should be made to work with stakeholders in these areas to reduce problem bear occurrences and department staff directed to ensure that conservation priorities are a key component of problem bear management. Other issues concerning grizzly bear hunting are discussed and suggestions are made on approaches to resolve aspects that result in an overall increase in total human-caused mortality in the province. We see opportunities to rectify current deficiencies in the data necessary to justify hunting license allocations. These include updating recent inventory data on this species, completing a comprehensive mortality/relocation database, and tracking landscape changes that affect the habitat carrying capacity for each BMA. In order to improve our grizzly bear management capability, additional resources are required in these areas.

Hunting; Mortality; Conflict; Population Inventory

Stenhouse, G., Dugas, J., Boulanger, J., Hobson, D., & Purves, H. (2003). Grizzly Bear Cumulative Effects Assessment Model Review for the Regional Carnivore Management Group.

This report evaluates model runs from the grizzly bear Cumulative Effects Assessment (CEA) Model when compared with data gathered during the first three years of the Foothills Model Forest Grizzly Bear Research Program. The CEA model used habitat maps for the pre- and post-berry seasons and default assumptions on the effects of low and high intensity human use and linear features buffers used by Jasper National Park. The data gathered by the Foothills Model Forest Grizzly Bear Research Program included DNA mapping results and grizzly bear GPS telemetry locations. The model outputs evaluated are:

• Habitat Effectiveness (HE) – The actual ability of an area to support grizzly bears based on habitat values and the effects of human activities;

• Security Areas – The identification of areas suitable to support a foraging adult female grizzly bear. Individual model runs used the following assumptions:

- Default parameters based on the CEA model assumptions and best available data;
- Low human use assumption for all areas;
- High human use assumption for all areas;
- 50% buffer reduction for linear features;
- 75% buffer reduction for linear features.

Based on comparisons between model outputs and Foothills Model Forest data, Habitat Effectiveness and Security Area outputs were not significantly correlated to the distribution of bears from DNA data. These outputs were not correlated to level of use by GPS collared bears and were negatively correlated to the distribution of GPS collared bears. When compared with each other, the distribution of DNA bears and GPS bears were not correlated suggesting that the two methods were estimating different distributions. In this case, the DNA method was most likely the least biased as sampling effort was equal in each grid cell within a Bear Management Unit (BMU). CEA HE model outputs were also compared with Resource Selection Function (RSF) model probabilities. During the pre-berry season, at low HE values, RSF probabilities and HE outputs had a similar relationship. However, there was no relationship at higher HE values or in the post-berry season. Although model runs were not predictive of bear distribution, this failure does not necessarily mean that the model lacks validity. The model's ability to predict grizzly bear use of BMUs may be enhanced through improvements to the base habitat map or by reassessing the assumptions used. Since these runs, an improved habitat map using an Integrated Decision Tree (IDT) process has been developed. Use of this product as a base habitat map may improve model effectiveness. Ongoing research into the effects of human access and intensity of human use on grizzly bear activity will be used to reassess the assumptions used in the model. The research may also identify other environmental or social factors that affect habitat use by grizzly bears and which may be incorporated into new approaches to understand relationships between grizzly bear habitat use and landscape conditions.

Classification; Human Use; DNA; Distribution

Proctor, M., & Paetkau, D. (2004). A genetic-based spatial analysis of grizzly bears in Alberta. Report prepared for Alberta Sustainable Resource Development Fish and Wildlife Division.

Grizzly bears are wide-ranging carnivores whose populations extend over large geographic areas (and ignore jurisdictional boundaries) and traditional management units tend to be too small for grizzly bear populations. Effective management can be improved by knowing if bears are spatially structured, naturally or as a result of anthropogenic forces, allowing management strategies to be specifically tailored to groups of bears living in separate sub-populations. This report is a result of a genetic-based spatial analysis of Alberta grizzly bears with the objective of delineating biologically-based sub-populations that may be useful for defining management units. To improve rigour and develop an inter-provincial view of grizzly bear population structure, our analysis included Alberta grizzly bear samples combined with those in adjacent portions of British Columbia from a previous effort. We found that Alberta's grizzly bears form five such groups whose boundaries roughly coincided with the major east-west Highways 3, 1, 11, and 16 in central and southern Alberta. These sub-divisions in Alberta's grizzly bear population may be the basis for delineating biologically-based management units. Managers will need to incorporate these results with jurisdictional, practical, and logistical considerations when contemplating final management unit boundaries. While it is difficult to distinguish natural from anthropogenic fragmentation, these results suggest that the human environment is likely influencing the spatial dynamics of grizzly bears in Alberta. While the boundaries between sub-units do appear to be permeable, further population level work, such as abundance estimates for these units and consideration of connectivity enhancement, would be advisable.

Management Areas; Fragmentation; DNA; British Columbia

Stevens, S., & Duval, J. (2005). Ecology of grizzly bears in the Cheviot, Luscar and Gregg River mine areas (1999 - 2004). Submitted to Elk Valley Coal Corporation, Cardinal River Operation and Foothills Model Forest Grizzly Bear Research Project.

Elk Valley Coal Corporation, Cardinal River Operations (CRO) initiated this project as part of its commitment to address grizzly bear issues within the context of the Cheviot Mine development. Since 1999, The Foothills Model Forest Grizzly Bear Research Project (FMFGBRP) has studied grizzly bears in a 10,000 km^2 areas that includes the Cardinal River Operations and has made significant advances in improving our understanding of grizzly bear use of this landscape. This research program has also developed tools and models to assist industry sectors to make informed decisions towards grizzly bear conservation and management. CRO requested the FMFGBRP conduct a detailed analysis, using data from the 6 years of integrated grizzly bear research, which would summarize current knowledge and understanding of grizzly bear use of the Cheviot, Luscar and Gregg River Mines. This analysis will establish pre-development baseline grizzly bear use in the Cheviot Mine area, and provide insight into grizzly bear use in and adjacent to active/reclaimed open pit coal mines. Based on these assessments, this project will provide important grizzly bear information that can be incorporated into the planning and the operational development of the Cheviot Mine. This report is presented in 3 chapters. Each chapter analyses grizzly bear and mining activity data to achieve the following 3 goals:

1. Provide a summary of current knowledge and understanding of grizzly bear use of the landscape within and around the Cheviot Mine (pre-development).

2. Provide a summary of current knowledge and understanding of grizzly bear use of the landscape within and around the Cardinal River Operations (CRO) Luscar and Gregg River Mines (during active mining and reclamation activities).

3. Design a long-term grizzly bear monitoring program for the Cheviot Mine.

Section 1 and 2 of this report includes a summary of geographical ranges of radiomarked bears occurring in each area, physiological characteristics from the capture data, a summary of den site parameters and a diet analysis. Across each study area we also extracted habitat quality, probability of mortality risk and movement corridors based on pre-established, peer reviewed GIS-based models. Section 3 outlines a DNA monitoring program designed to detect bear abundance, distribution and demography coinciding with future mining sites in the Cheviot area.

Mining; Mortality; Movement; Food; Denning

Nielsen, S. E. (2007). Seasonal grizzly bear habitat for six population units of Alberta, Canada. Unpublished Report.

Critical to management and conservation of remaining grizzly bear populations in Alberta are spatial depictions of habitat. Given a consistent and objective habitat product, resource stakeholders can communicate potential impacts of future land-use actions on grizzly bear populations and suggest alternatives that minimize habitat degradation. To date, there have been a number of models or maps representing grizzly bear habitat. Although these maps have proven useful in local resource and grizzly bear management, such products have been limited in spatial extent, often being available for only a portion of a population unit. Moreover, existing products are often scaled differently making comparisons or integration difficult. Here I present a consistent set of seasonal grizzly bear habitat products representing the relative probability of habitat use for six of seven grizzly bear population units in Alberta. This represents an area of 132,076 km^2 (55% of currently defined grizzly bear range in Alberta). I describe the model approach, discuss habitat predictions, and assess model accuracy. These results provide for the first time a consistent and objective definition of grizzly bear habitat across multiple population units of Alberta. Although this represents an important step for management and conservation of grizzly bears, further considerations of mortality risk, food resources, and animal density should be given. Moreover, large-scale modeling and mapping of grizzly bear habitat requires trade-offs in detail. Undoubtedly, more specific definitions of grizzly bear habitat can be estimated for smaller regions of population units by using more detailed geo-spatial datasets and limiting the extent of environmental gradients assessed. For example, not all spatial datasets are available for Alberta grizzly bear range. Forest stand history, which has been shown to be important for predicting bear habitat use, has been difficult to compile and map consistently across Forest Management Agreements. Specific to environmental gradients, it has become apparent that grizzly bear habitat use for specific landcover types can vary substantially among grizzly bear population units or even within larger population units as a function of elevation gradients, natural sub-regions, or differences in learned behaviors of animals. Despite limitations, evaluation of grizzly bear habitat maps suggests good to excellent predictive accuracy. Future habitat modeling should consider models having flexible habitat coefficients based on landscape context and resource gradients, while also integrating estimates of mortality risk predicting habitat states or safe harbor and attractive sink habitats as described in Nielsen et al. (2006).

Classification; Habitat Mapping

Stenhouse, G. B., Cattet, M., Franklin, S., Janz, D., McDermid, G., Nielsen, S. E., Vijayan, M., Cranston, J., & Boulanger, J. (2008). <u>**New Tools to Map, Understand, and Track Landscape Change and Animal Health for Effective Management and Conservation of Species at Risk.**</u> **Report prepared for Alberta Advanced Education and Technology and Alberta Sustainable Resource Development.**

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 program has been divided into three key elements:

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 proteomic 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 Application 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.

Remote Sensing; GIS Application; Health; Physiology; Stress

Foothills Research Institute. (2009). Land & Resource Management Planning for Grizzly Bears. Course manual prepared for ENFORM.

Over the past 10 years the Foothills Research Institute has conducted a major grizzly bear research program throughout most of the existing grizzly bear habitat in Alberta. As a result, there have been major developments in the area of grizzly bear management in the province. Some of these developments include:

- the Endangered Species Conservation Committee (ESCC) recommendation to change the status of grizzly bears to threatened,
- the development and approval of a provincial grizzly bear recovery plan,
- the first structured inventory of provincial grizzly bear populations,
- the suspension of the spring hunt, and most recently,
- the implementation of some recommended recovery actions.

As managers were synthesizing the wealth of new data and knowledge relative to grizzly bears in Alberta, our team members continued to focus efforts on providing new planning tools and products to ensure the long-term conservation of grizzly bears in the province. In short, the past 10 years has been a time of tremendous accomplishment in terms of grizzly bear management.

The goal of this course is to help you understand the information compiled by the research team over the past 10 years, and to assist you to better utilize the GIS Applications in your work in order to integrate the needs of grizzly bears into broader land use planning activities. This course will not make you an expert in the various areas and disciplines that we will discuss. When you complete this course we hope that you are able to analyze and assess various land use activities and understand their potential impacts on local grizzly bear populations. Further you will be introduced to some of the possible mitigation actions which could be recommended to reduce negative impacts on grizzly bears and their habitats.

GIS Application; Habitat Mapping; Anthropogenic Disturbance

Stenhouse, G. B. (2012). Brown bears in Alberta and Sweden. Final research report prepared for Alberta Innovates - Phase 1 (2009 -2011).

A research collaboration to understand patterns of brown bear population viability in human-dominated boreal landscapes of Alberta-Scandinavia; applications towards conservation management. This report has been divided into several distinct chapters.

Chapter 1. **One species, two populations, three patterns of growth; brown bears in Canada and Sweden.** Andreas Zedrosser, Marc Cattet, Jon E. Swenson, and Gordon Stenhouse

Comparing life history traits of populations of a species living in similar habitats, but separated by great distance, may help us understand the evolutionary pressures a species is exposed to. We compared age-specific body size and mass, patterns of growth, and sexual size dimorphism (SSD) of male and female brown bears between Alberta, Canada and Sweden. We also compared the influence of population density, habitat quality and productivity (NDVI), and reproduction on size and mass between the areas. Females attained 90% asymptotic size and mass at the same age in both areas, but Alberta females were always significantly larger and heavier than Sweden females and were on average 11% longer and 17% heavier when reaching 90% asymptotic size and mass. The smaller Swedish females reproduced earlier (primiparous at 75% asymptotic mass) and had larger litters than Alberta females (primiparous at 84% asymptotic mass), perhaps due to differences in population trends (increasing in Sweden, stable or decreasing in Alberta) or long-term exploitation history. There was no statistical difference between the growth curves for male mass and only a trend towards a difference in size between the areas, resulting in a more pronounced SSD in Sweden than Alberta. NDVI was positively related to size and mass of both sexes in both areas. Reproduction was costly for females, because females with offspring were smaller than lone females. We found only limited effects of population density on size and mass. Our results suggest that the adaptive responses of a species to selective pressures vary between areas and populations, and may be shaped by habitat conditions, population status, as well as human pressure. This stresses the importance of population-specific knowledge for conservation and management.

Body Size; Reproduction; Population Density

Chapter 2. **Advancements in the development of hair cortisol concentration as an indicator of long-term stress in brown bears.** Marc Cattet, Gordon B. Stenhouse, Andreas Zedrosser, Jon E. Swenson, Bryan J. Macbeth, David M. Janz, Mathieu Dumond, Michael Proctor, Harry Reynolds, Luvsamjamba Amgalan, Odbayar Tumendemberel, and Derek Craighead

Measurement of the concentration of cortisol in hair has recently emerged as a promising indicator of long-term stress across a suite of mammals that includes humans, domestic and laboratory animals, and captive and free-ranging wildlife. Despite a spate of publications on the application of HCC, few report on its validation which includes the identification of variables that could compromise its soundness as an indicator of long-term stress. In this study, we extend previous developmental research to investigate what factors influence HCC at the level of individual brown bears (*Ursus arctos*), with the aim of eventually employing HCC at the population level as a wildlife conservation tool. We compared HCC values from 785 brown bear hair samples collected by various methods (hair snag, live-capture, hunter-kill) over 16 years and representing four geographic areas (Alberta, Sweden, Nunavut, and Mongolia) across the species' Holarctic distribution, and found a four-fold difference between the highest (Alberta live-capture: 2.90 pg/mg) and lowest median HCC (Mongolia hair snag: 0.77 pg/mg). HCC was influenced by sex and age, as well as physical attributes (body mass and body length), but not in a consistent manner across populations. Through a detailed analysis of data from live-captured bears in Alberta, we also identified body condition, season of hair collection, and several capture-related factors that influence HCC, including the presence of radio-telemetry devices (radio-collars and/or radio ear-tags). In general, we found no evidence to discount HCC as a reliable indicator of long-term stress in individual bears, and suggest the next step is to widen the application of HCC to ascertain its effectiveness at the population level. We provide two examples of how this might be done using HCC values from five bear management units in Alberta. The first applied HCC as a direct measure of long-term stress and underscores the need to confirm associations between HCC and fitness parameters to firmly establish the value of HCC for monitoring of long-term stress in populations. The second applies HCC as an indirect marker of body condition status to show there may be some value in using HCC to monitor body condition trends, especially in food-limited environments.

Stress; Cortisol; Body Condition; Food; Body Size

Chapter 3. **Habitat selection for regenerating clear-cut forests by brown bears: A comparative analysis between Alberta and Sweden.** Scott E. Nielsen, Andreas Zedrosser, Jerome Cranston, Jonas Kindberg, Gordon B. Stenhouse, and Jon E. Swenson

Brown bears are generalist omnivores that frequently use disturbed habitats – including young regenerating clear-cut forests – to meet their resource (food) demands. Little is known, however, about how specific forest management practices, including silvicultural treatments and harvest design (e.g., size and shape of clear-cuts), effect bear habitat, how this varies among sex and offspring status classes and populations, and how availability of these or alternate habitats affects their habitat use (i.e., functional responses in habitat selection). To address these knowledge gaps, we examined seasonal habitat selection of regenerating clear-cut forests ≤ 60 years of age by brown bears for two long-term studies occurring in different hemispheres (Alberta and Sweden), but within a shared Holarctic boreal forest ecosystem. Using ~1.9 million GPS telemetry locations for 157 individuals across 12 different years (1999-2010 in Alberta; 2005- 2010 in Sweden), we developed seasonal (monthly) habitat selection models between May and October for each individual bear and evaluated secondly how selection (response variable) varied among bears (sex-offspring classes), seasons, habitat availability, and study areas using generalized linear models. We found that brown bears selected regenerating clear-cut patches relative to all other habitats available (mostly mature forests) with peak selection occurring most often between 10 to 25 years post-harvest in Alberta and 20 to 40 years post-harvest in Sweden. Bears in Sweden selected clear-cut consistently across all seasons, while bears in Alberta reduced their selection for clear-cuts in late summer and fall when younger-aged clear-cuts were selected. This seasonal reduction in habitat selection for clear-cuts in Alberta may be due to negative effects associated with mechanical site preparation (scarification) that reduce populations of long-lived fruiting shrubs, while providing a short-term pulse in short-lived fruiting resources, such as raspberry, in younger clear-cuts. In both study areas, dominant bears selected larger clear-cut patches over that of smaller clear-cuts suggesting that security (hiding cover) was less important than the size of the resource patch which presumably would increase foraging efficiency. Recent trends in Alberta towards harvesting larger clear-cuts may therefore benefit dominant individuals assuming human access is managed. Females with cubs of the year, however, selected for smaller clear-cuts presumably for greater security and avoidance of dominant males. We found evidence for functional responses in habitat selection where availability of habitats being selected affected selection for those habitats. Future work should consider the effects of silvicultural treatments, including silvicultural thinning which is common in Sweden, but rare in Alberta, on food resource abundance and habitat use by brown bears.

Habitat Selection; Forestry; Forest Harvest

Cattet, M., Coops, N., Janz, D., Nielsen, S., & Stenhouse, G. (2015). **Research to Support Recovery and Long Term Conservation of Grizzly Bears in Alberta.** **Final Technical report for Alberta Innovates - Bio Solutions and Program Partners.**

This document represents the full technical summaries of Alberta Innovates Bio Solutions Grant number VCS-11-008 “Research to support recovery and long term conservation of grizzly bears in Alberta”, which was supported by Alberta Innovates Bio Solutions and government and industry partners. This report is presented in chapter format by research themes and the authorship of each chapter is identified within each subject area.

Note: Several chapters were published in peer-reviewed journals and are listed elsewhere in this document, so abstracts were not reprinted here.

Declining resilience of northern forests due to human influences on climate and wildfire. Adam Erickson, Nicholas C. Coops, Craig Nitschke, and Gordon Stenhouse

In western Canada, expanding human activity is theorized to shift the successional and evolutionary trajectory of forests. Forest dynamics are under a number of human influences, from regeneration to disturbance regimes. Regeneration underlies the migrational response of forests to directional change, modified by dispersal, competition, disturbance, soils, and light. Here, we fuse a process-based regeneration model with a cellular automaton-based forest dynamics model to probe the long-term resilience of forests in the southern Canadian Rockies. We show that a shift toward smaller, more frequent fires and diminishing regeneration conditions are reducing the ability of forests to track warming, amplifying climatic disequilibrium and reducing resilience. Tree species regeneration niches moved toward higher elevations and latitudes, driven by changes in soil water balance, as boreal fire regimes migrated northward. We anticipate that ecosystems to the south will migrate into the region in the coming years.

Climate Change; Habitat Mapping; Remote Sensing

Northward-migration of boreal fires and emergence of Anthropocene regimes. Adam Erickson, Nicholas C. Coops, and Gordon Stenhouse

Much attention has been paid to the effects of climatic change on fire regimes and carbon feedbacks in northern forests of North America. Yet, these studies largely ignore non-climatic anthropogenic factors evident in the historical record that may equally explain recent fire regime variability. Here, we conduct an analysis of past-century fire regimes across a latitudinal and elevational gradient in western Canada. The region experienced intensifying anthropogenic activity in recent decades, serving as a model of future continental conditions under current anthropogenic trajectories. We found that fire regimes here shifted from large, lightning-caused fires in remote areas to more frequent, smaller, human-caused fires in anthropogenic corridors. Over the past half-century, annual fire seasons lengthened (mean = +1 day/year) due to rising temperatures (mean = +) and human-caused ignitions (mean = +). Fires occurred more frequently at higher latitudes and lower elevations. Area burned increased at higher elevations and declined at lower elevations, where suppression is prevalent. While warming conditions produced more severe fuel conditions, other factors, such as fire suppression, industrial and recreational activity, and a forest demographic shift likely attenuated fuel conditions. We provide the first evidence of a northward migration of boreal fire regimes, accelerated by a southern boreal transition to Anthropocene fire regimes without historical analogue.

Climate Change; Habitat Mapping; Remote Sensing; Anthropogenic Disturbance

Nutritional landscapes of grizzly bear carrying capacity for population recovery. Scott E Nielsen, Sean CP Coogan, Claudia Lopez, Tyler J Bateman, Andrew CR Braid, Nikhil Lobo, Terry Larsen & Gordon B Stenhouse

Grizzly bear populations in Alberta are listed as a threatened species. Bear populations in the Foothills and Mountains of west-central Alberta have some of the lowest densities in Alberta and other interior populations of North America. The problem has been attributed to human-bear conflicts such as poaching and road accidents. This represents a top-down view of limitations in bear populations.

Nevertheless, nutritional conditions in bear habitats may also play a role in the observed low densities in Alberta by affecting reproductive success of female bears and reducing densities of bears through lower carrying capacities. In this research theme we have taken the approach of mechanistically defining habitat for grizzly bears by understanding, modeling, and relating food resource supply to bear populations. Specifically, we focus on estimating macronutrients of key grizzly bear foods in space and time to relate to patterns in bear abundance, limitations in reproduction (denning constraints), and estimates of carrying capacity. Not all of the available resources (food) can however be consumed by bears. Because of this, we focus on understanding consumption of one critical food resource, buffaloberry (*Shepherdia canadensis*), by the community of frugivores (birds, small mammals, and bears).

Food; Reproduction; Denning; Nutrition

The Measurement of Reproductive Hormones in the Hair of Brown Bears, and an Assessment of their Amounts in Relation to Reproductive Status, Stress, Body Condition, and Capture History. Marc Cattet and David Janz

In this study, we developed and validated laboratory techniques to accurately and reliably measure three steroid hormones – estradiol, progesterone, and testosterone – that are indicative of reproductive function in the hair of brown bears. Although techniques to measure these hormones in other biological media, including blood serum and urine, are well established, the use of hair required the development of new procedures. Nevertheless, use of hair to potentially support the recovery of brown bears in Alberta offers several advantages over other biological media. Hair can be collected from animals without capturing them, e.g. with the use of hair traps. This avoids the potentially confounding influence of stress caused by capture and handling and, consequently, reduces the likelihood of adversely affecting the health and fitness of brown bears. Hair is easy and inexpensive to prepare for storage; simply air-dry, seal in paper envelopes and store at indoor ambient temperature. Samples can be assigned to individual animals through DNA extraction and analysis. Finally, because steroid hormones in hair do not degrade appreciably over time or after exposure to the environment, it opens the possibility of conducting analyses using archived samples, including museum specimens.

The deliverables of this research are:

- new laboratory techniques utilizing enzyme-linked immunoassays to accurately and reliably measure three reproductive hormones – estradiol, progesterone, and testosterone – in the hair of brown bears.
- verification that reproductive hormone dynamics in the hair of captive adult brown bears coincides with changes in their reproductive status and annual activity patterns;
- preliminary results to suggest that reproductive hormone profiles in the hair of free-ranging brown bears are influenced by other factors, including indicators of long-term stress (e.g., high hair cortisol concentration and/or poor body condition) that did not appear to be acting on captive bears; and
- evidence to demonstrate that hair cortisol levels in dependent offspring bears are directly influenced by their mother’s age and capture history.

Hair Snag; DNA; Reproduction; Hormones; Stress; Relatedness; Cortisol

Larsen, T. A., Sorensen, A., McClelland, C. J. R., & Stenhouse, G. B. (2016). Do oil and gas activities and access control measures affect the distribution, abundance and movements of grizzly bears? A report prepared for Alberta Upstream Petroleum Research Fund (AUPRF).

To understand how oil and gas activities and access control measures, particularly gates, influences grizzly bears and their habitats in Alberta, we used multiple data sources including spatial layers representing roads with and without gates, GPS locations from collared grizzly bears, and counts of unique bears from a recent (2014) population inventory. In the first section of this report, we inventory gates within core and secondary grizzly bear conservation areas and evaluate how the presence or absence of gated and other types of roads (road removal scenarios) contributes to the amount of sink habitat for grizzly bears. In section two, we investigate the response (habitat use, movement) of grizzly bears to roads with and without access control measures by determining whether or not bears select or avoid habitats adjacent to roads as well as the frequency of crossings associated with roads. In the third and final section, we investigate relationships between the abundance of grizzly bears and the oil and gas footprint (roads, well-sites, and pipelines).

Key research findings:

- The vast majority of grizzly bear mortalities documented in BMA 3 between 2000 and 2015 occurred near major access routes (primary and secondary roads) compared to decommissioned roads or roads with gates.
- Access control features (gates) were not common within the study area and reduced highway vehicle access potential for about 440 km of road. BMA 3 has about 21,650 km of road.
- Many of the gates were likely ineffective in reducing vehicle access as most were not locked (62%), some could be bypassed with a highway vehicle (10%), and others (6%) had secondary access points.
- Increases in sink habitat (high quality habitat with high bear mortality risk) for grizzly bear were largely associated with secondary type roads with no noticeable reduction in the amount of sink habitat associated with gated roads as determined by existing habitat state models.
- Grizzly bears do not respond (habitat use, road crossings) differently to roads with and without access control measures (gates) suggesting gates currently are doing little to reduce human-caused mortality risk.
- Further research is required to test the effectiveness of access control measures by installing gates in strategic locations at the landscape level.
- The problem of roads relative to grizzly bear mortality risk is not dependent on the type of road or the associated land use activity for which the roads are constructed, and current management strategies which focus on reducing and minimizing road densities are warranted and supported by this research.
- Access control measures which would limit motorized human use of roads in grizzly bear habitat, along with education and enforcement measures, would also serve to reduce human caused grizzly bear mortality rates.

Oil and Gas; Human Access; Access Management; Mortality

Nobert, B. R., Larsen, T. A., Pigeon, K. E., Stenhouse, G. B., Wismer, D., Duval, J., Coops, N. C., Nijland, W., Pickell, P., & Finnegan, L. (2017). Potential impacts of mountain pine beetle and mountain pine beetle management on caribou and grizzly bear food supply. Final report prepared for Alberta Agriculture and Forestry and Forest Resource Improvement Association of Alberta.

Mountain pine beetle (MPB, *Dendroctonus ponderosae*) is a destructive biological agent of mature pine in western North America with the potential for considerable ecological and economic damage to forest resources. In Alberta, the eastern slopes of the Rocky Mountains are especially at risk from MPB due to the abundance of mature pine forest. Alberta's MPB management strategy focuses on the removal of infected and susceptible pine stands through timber harvest, wildfires, and single-tree cut and burn (hereafter 'MPB control'). MPB and Alberta's MPB management strategy considerably alter pine stands by modifying canopy and understory vegetation, and there is therefore growing concern about the potential impact of these landscape changes for species at risk such as caribou (*Rangifer tarandus*) and grizzly bears (*Ursus arctos*). Caribou and grizzly bears are threatened under Alberta's Wildlife Act, and co-occur in portions of Alberta's mountain, foothill, and boreal forest regions that have recently been impacted by MPB. To better understand how caribou and grizzly bears may be impacted by MPB and Alberta's MPB management strategy, we examined how MPB infestation, timber harvest, wildfire, and MPB control could alter caribou and grizzly bear food supply (i.e., species presence and abundance) within the Chinchaga and West-Central regions of Alberta. We recorded presence-absence and abundance of 49 understory species of shrubs, forbs, graminoids, mosses, lichens, and ants including 33 caribou and grizzly bear foods, at 734 sites within pine and non-pine dominated forest stands in Chinchaga and West-Central Alberta during the 2014 and 2015 growing seasons. We recorded data within five strata representing the main variations in landscapes affected by MPB and MPB management: 1) Uncut – old growth fire origin stands, 2) Cut – regenerating timber harvested stands, 3) Fire – regenerating wildfire stands, 4) MPB kill – MPB infested stands and 5) MPB control – single tree cut and burn stands. First, we utilized field data to construct species-specific occurrence and abundance models based on landscape, climate, disturbance, and habitat variables such as terrain, canopy cover, climate normals, time since disturbance, percent MPB killed trees, and presence of MPB control. We then constructed distribution maps of dominant pine stands and MPB red-attack from 2001 to 2011 using a combination of Alberta Vegetation Inventory (AVI) data and a boosted regression tree model based on Landsat imagery to fill in gaps in AVI coverage. Finally, using our species-specific models and distribution maps, we simulated the change in abundance of five caribou and five grizzly bear food groups over a 40 year time span based on scenarios that reflected the field sampling strata (Uncut, MPB kill, Cut, Fire, and MPB control). The five caribou food groups represented important summer (deciduous shrubs, grasses, and mushrooms) and winter foods (arboreal lichens and terrestrial lichens). The five grizzly bear food groups reflected the variation in diet throughout their active period (herbs, ants, roots, secondary fruiting shrubs, and primary fruiting shrubs). For pine stands, the most abundant caribou foods based on percent cover were grass, alder (*Alnus* spp.), and willow (*Salix* spp.), and the most abundant grizzly bear foods were lingonberry (*Vaccinium vitis-idaea*), huckleberry (*Vaccinium membranaceum*, West-Central only), velvet-leaf blueberry (*Vaccinium myrtilloides*), and dwarf blueberry (*Vaccinium cespitosum*). Other non-food species that were relatively abundant in pine stands were bunchberry (*Cornus canadensis*), fireweed (*Chamerion* spp.), moss, Labrador tea (*Rhododendron* spp.), and non-pine saplings. Based on occurrence and abundance models, the percentage of MPB kill and MPB control was associated with high occurrence and abundance of grass, fireweed, and shrubs, and low abundance of terrestrial lichens and moss. MPB control sites had a higher amount of downed trees, pine-saplings, mushrooms, and ants compared to healthy and MPB infested pine stands. However, models simulating the projected changes in food abundance indicated that timber harvest and wildfires typically had a greater influence on understory vegetation abundance relative to a healthy uncut pine stand when compared to MPB infested and MPB control stands. We found that the most important caribou foods, terrestrial lichens, were typically lower within wildfire and timber harvested stands initially (<10 years) compared to MPB infested or MPB control stands. However, older (>10 year) regenerating wildfire and timber harvest stands showed higher terrestrial lichen abundance than healthy uncut pine stands. Based on these simulation models, grizzly bear foods were also generally most abundant in timber harvest and wildfire stands (1 - 40 years). However, primary fruiting shrubs (i.e., buffaloberry (*Shepherdia Canadensis*), huckleberry, cranberry (*Viburnum edule*), honeysuckle (*Lonicera* spp.) and velvet-leaf blueberry), were typically lower in timber harvest and wildfire stands compared to MPB infested, MPB control, and healthy pine stands. We also found that MPB control resulted in a higher abundance of pine saplings compared to MPB infested stands, and this result therefore supports MPB control as a management option to promote pine forest rehabilitation after MPB infestation. Finally, we used our understory species occurrence and abundance models, and the ESRI ArcGIS program to build an ArcGIS tool that enables forest managers to predict the abundance of caribou and grizzly bear food in West-Central and Chinchaga, Alberta. We developed this ArcGIS tool to allow land-use planners to evaluate the potential impacts of MPB and MPB management strategies on the abundance of caribou and grizzly bear foods based on proposed or alternative management scenarios. Ultimately, this project increases our understanding of the links among MPB attacks, MPB management approaches, and important foods for caribou and grizzly bears in West-Central and Chinchaga, Alberta, and the spatially explicit ArcGIS tool resulting from this project, can be used to guide management decisions that can assist caribou and grizzly bear conservation and recovery.

Mountain Pine Beetle; Caribou; Forestry; Food; GIS Application; Natural Disturbance

Sorensen, A., Milligan, S., Larsen, T., Graham, K., Geir Eiken, H., Hagen, S., Grete Aarne, S., Marie Bardalen Fløystad, I., Stenhouse, G. (2017). Using scat DNA and citizen science to determine grizzly bear distribution and abundance in West-Central, Alberta. Prepared for Alberta Environment and Parks and Alberta Conservation Association.

Projects that involve citizen scientists are burgeoning, particularly in ecology and the environmental sciences. A significant advantage of citizen science is that it offers a way to collect information across large spatial extents that would otherwise not be economically feasible. In North America, traditional non-invasive hair-based DNA methods that have been used to estimate grizzly bear abundance and distribution remain too costly for long-term monitoring. It has been recognized that a citizen science based approach similar to that used to monitor European brown bear populations may offer a cost-effective solution for Alberta. However, spatial and temporal heterogeneity in detection probabilities are inherent challenges with citizen science, which can lead to lead to imprecise estimates that question the utility of the results for management. Strong sampling designs are very important in these types of projects. New projects involving citizen science should first evaluate potential study designs to determine the amount of volunteer effort that is needed and how data should be collected to ensure acceptable data quality relative to the goal and precision of population estimates. The primary objectives of this project were to (1) develop and test a non-invasive scat-based DNA approach for estimating grizzly bear abundance and distribution that engages citizens — particularly hunters and trappers — in the collection of scientific information. Our second objective was to (2) compare estimates of grizzly bear abundance and distribution from scat-based DNA methods to estimates from hair-based DNA methods, and (3) evaluate the costs and benefits of scat-based and hair-based genetic inventories to further assess the value of engaging citizens in grizzly bear population monitoring in Alberta. To enable citizen volunteers to collect grizzly bear scat and record other important data (including search effort), we distributed scat collection kits and developed a smartphone application: the Grizzly Scat App. During the same period (August to October), we had fRI staff conduct transect surveys along linear features and quantified search effort. Scat samples were also collected opportunistically by fRI staff involved with the capture program and the hair-based genetic sampling project. Overall, 6 samples were collected by volunteers, 130 samples were collected from 154 transect surveys (with an average transect distance of 4.5 km), and 132 samples were collected opportunistically. A total of 196 samples (73%) were sent to the Norwegian Institute of Bioeconomy Research (NIBIO) in Svanhovd, Norway for genetic analysis. Bear DNA was extracted from 159 samples (81%), of which 105 samples (66%) were determined to be grizzly bear and 54 samples (34%) were determined to be black bear. From samples identified as grizzly bear, 45 samples (43%) successfully provided an individual DNA profile based on at least 2 markers, and 21 samples (20%) successfully provided an individual DNA profile based on at least 6 markers. From these 21 samples, we identified 17 individual bears (9 male, 8 female), including 6 individuals (3 male, 3 female) undetected by hair-based genetic sampling and previously unknown to researchers. We were unable to directly compare grizzly bear abundance and distribution estimates from scat-based genetic sampling to estimates from hair-based genetic sampling due to the low volunteer participation, which resulted in reduced spatial coverage of sampling effort, fewer than expected scat samples, and thus few individual grizzly bear detections from scat. However, when we compare effort and detectability post-hoc, the average number of bears detected per sample unit was nearly the same. This suggested that similar results could be achieved by scat-based DNA inventories as hair-based DNA inventories if the number of sample units (i.e. volunteers) were increased. Significant cost savings could also be achieved with a greater number of citizen volunteers. We conclude that scat-based genetic sampling cannot replace hair-based genetic sampling for the purpose of grizzly bear population inventories at this time; however, the use of scat sampling to provide DNA data to support long-term grizzly bear population monitoring, particularly occupancy showed promise. The results of our study highlight the need to improve the implementation of a large scale large scale citizen science based project specific to grizzly bears in Alberta that focuses significant effort on strategies to improve volunteer participation and engagement.

Population Inventory; Density; Hair Snag; DNA; Scat; Black Bear; Population Monitoring

Sorensen, A., Trout, L., Jackson, H., & Stenhouse, G. (2019). Forest management and planning for grizzly bears: Applying science-based management tools in multiple stages of forest harvest planning. Prepared for Forest Resource Improvement Association of Alberta.

In Alberta's Rocky Mountain Foothills, grizzly bear habitat is frequently altered through natural resource extraction activities which can alter landscape composition, configuration, and security for wildlife species. Using a priori knowledge of grizzly bear habitat requirements, a forest harvest scenario was "hand-crafted" by professional foresters with input and guidance from biologists, with the aim of minimizing negative impacts on grizzly bear habitat, while minimizing human-caused mortality risk, within operational limits. A separate forest harvest scenario was also drafted in a "business as usual approach" (BAU) through the use of Stanley and Woodstock forest management modeling software, incorporating different road access and cutblock designs. Research biologists from the fRI Research Grizzly Bear Program then examined the impacts of these different harvest scenarios on habitat availability and security using existing grizzly bear modeling tools that had been developed using 22 years of research findings. The Habitat State tool incorporates both habitat quality (as measured by resource selection function (RSF) models) and habitat security (as measured by mortality risk models) into a single value, and can quantify changes to this value across a given study area with the proposed anthropogenic development. Habitat state values increased with both the proposed Business as Usual and the Grizzly Bear plan (increases of 58.67% and 42.67% respectively). With the addition of access controls to the Grizzly Bear plan, restricting motorized access by the public, habitat state values increased 45.33%. The observed increase in habitat quality (RSF), regardless of harvest scenario, was not unexpected as prior research has demonstrated that forest harvesting is known to provide a diverse array of food resources for grizzly bears, particularly roots and tubers, herbaceous materials, and ants. Clear differences in habitat security were observed between different harvest scenarios, with all scenarios resulting in increased risk, but the addition of access controls to the Grizzly Bear plan succeeded in the aim of minimizing the increase in human-caused mortality risk. Ultimately, the BAU plan resulted in a net positive change in Habitat State, greater than that observed in the GB Plan, due to the spatial arrangement of smaller harvest areas and larger road network creating significantly more edge habitat. This large increase in habitat quality outweighed the accompanying increase in mortality risk, when the two components are equally weighted in the Habitat State Tool. This finding highlighted the importance of incorporating more edge habitat in the GB Plan, which featured a get in/get out approach focused on harvesting large (if not all) forest patches along a minimal road network. Minimizing existing and anticipated motorized access in grizzly bear habitat has been identified as a high priority activity for provincial recovery of this species, since areas with higher road densities are associated with an increased risk of human-caused mortalities. While the Business as Usual plan resulted in an 18.87% increase in open road densities, incorporating access control measures in the Grizzly Bear plan resulted in an increase of only 2.12%. Effectively, since forest harvesting does improve grizzly bear habitats, this plan is a means to manage for road density over the long-term, which is arguably the most important element to support long term grizzly bear conservation in the Alberta Foothills.

Forest Harvest; Forestry; Roads; Edge; Food; Access Management

Larsen, T. A., Graham, K., Denny, C. K., & Stenhouse, G. B. (2019). Linkages between Forestry Practices, Ungulates, and the Habitat Use, Predation Behavior, and Biological Performance of Grizzly Bears in and Adjacent to Woodland Caribou Range. Prepared for Forest Resource Improvement Association of Alberta.

The project goal was to examine relationships between forestry practices, forest dwelling ungulates, and the habitat use patterns, predation behavior, and biological performance of grizzly bears in and adjacent to west-central Alberta caribou ranges. The report was organized into chapters:

1. In Chapter 1, we developed habitat models of moose and elk distribution/abundance with winter aerial survey data that was representative of forested environments. More specifically, we investigated the effect of forestry practices related to harvest age classes, edges, and caribou ranges on their relative distribution/abundance.

2. In Chapters 2 and 3, we created a script that identified grizzly bear Global Positioning System (GPS) location clusters and sampled clusters during the 2016 and 2017 field seasons. We then reported on field observations of grizzly bear activity (i.e. foraging, resting, etc.) and specifically related to ungulate predation or scavenging events. The team then compiled activity datasets from historic projects and linked them to GPS location clusters.

3. In Chapter 4, we assessed the response of grizzly bears to mapped predictions of relative moose and elk distribution/abundance using resource selection analysis. We also examined how time spent in mountain ecosystems versus the forested environment, latitude, and caribou range influenced selection. In particular, we contrasted grizzly bear behavior in and outside of caribou ranges within Weyerhaeuser Grande Prairie Forest Management Agreement (WGP) area.

4. In Chapter 5, we developed a model that predicted whether or not grizzly bear GPS location clusters were likely to be ungulate remains. We then developed a model that predicted whether or not clusters with ungulate remains were small or large in sizes.

5. In Chapter 6, we examined spatial relationships between grizzly bear GPS location clusters indicative of moose predation in forested environments. We determined whether or not forestry practices, caribou management, or the relative abundance of moose influenced grizzly bear predation behavior.

6. In Chapter 7, we tested the hypothesis that grizzly bear biological performance (i.e. body condition, mass, and length) was functionally related to the amount of ungulate biomass bears used. At the same time, we assessed whether or not landscape level effects associated with ecosystem productivity due to latitude and elevation differences in food supply affected performance.

Key findings:

1. After we accounted for habitat and anthropogenic factors (e.g. road density), moose were predicted to increase in relative abundance with the average amount of harvested forest at a scale of 3.14 km^2 (1 km radius). However, we found little evidence that forest harvesting influenced elk distribution or abundance. Elk counts were on average higher in west-central caribou ranges and moose were not. We also showed that moose were more abundant in forested environments at lower elevations and higher latitudes within the study area. This suggested that gradients in ecosystem productivity and anthropogenic disturbances were important factors that influenced moose populations across landscapes.

2. Of 1128 grizzly bear GPS location clusters visited in 2016 and 2017, 99 (8%) were associated with terrestrial animal matter. Of these, 89 (90%) were ungulates most being moose (60%), then elk (22%) and sheep (13%). Neonate moose comprised 74% of moose remains. Adult male grizzly bears had the most observations with ungulate remains followed by subadult females, subadult males, and adult females. Ungulate remains were more common in forested environments outside of Jasper National Park. Moose, and especially neonates, were an important bear food resource.

3. Grizzly bears habitat selection was stronger where moose and elk were relatively more abundant. However, the selection of ungulate habitat by bears was not strongest during the ungulate calving period, which can be attributed to individual variation and other influential factors such as finding mates. We showed that selection of moose habitat increased with latitude and outside of mountain environments. We also found that bears that lived in WGP did not responded to moose but selection for elk habitat increased as they spent more time in caribou ranges. These findings suggest that grizzly bears predation behaviour may be influenced by moose and elk abundance, which in our study area occur at relative low densities.

4. We successfully used field observations of grizzly bear activity and GPS location clusters to predict whether or not clusters were associated with ungulate remains and if they were small or large in size. We found that variables related to cluster time of day, time of year, season, total time spent (i.e. duration), and average distance between GPS locations, allowed for accurate prediction of grizzly bear predation events (82%).

5. When we investigated the spatial connection between grizzly bear GPS location clusters and moose remains, predation was more likely to occur at higher latitudes, in uncut forest near forest harvest edge, and where moose were relatively more abundant. These results were further evidence that grizzly bear predation behavior was influenced by moose populations.

6. We found support for our hypothesis that the amount of ungulate biomass acquired through predation/scavenging positively influenced female grizzly bear biological performance. In general, females were in better condition, heavier, and longer as carnivory increased. Of particular significance at high estimated levels of ungulate biomass, subadult females were predicted to be as heavy as adults and adult females with a newborn cub, with body condition as good as other females. These results are evidence of a mechanistic link between biological performance and grizzly bear population productivity. This explained why local grizzly bear abundance in west-central Alberta was related to ungulate availability.

Management Implications: Moose and in particular neonates were linked to forestry practices and ecosystem productivity, and their importance to grizzly bears was confirmed with multiple data sources. Most importantly we showed a mechanistic link between ungulate consumption and the biological performance of a population of grizzly bears in west-central Alberta. We did not find evidence that deferred forest harvesting in caribou ranges reduced moose populations nor did we detect that grizzly bears were less likely to predate moose. However, harvesting in or near caribou range could increase moose populations leading to higher predation rates and grizzly bear population density. From the perspective of moose, caribou ranges have functioned to maintain populations at a level lower than where there was forest harvesting. Elk on the other hand were more abundant in caribou ranges and grizzly bears selected habitat where they were more likely to be abundant. From the perspective of elk, caribou ranges appear to play a role in maintaining elk populations and with that an important food for grizzly bears. Overall, there is an opportunity outside of caribou ranges, and in areas where grizzly bear population are relatively low (i.e. BMA 3), to maintain or increase ungulate populations to aid in provincial recovery efforts.

Forestry; Forest Harvest; Predation; Food; Caribou; Density; Telemetry

Phoebus, I., Boulanger, J., Bourbonnais, M., Larsen, T., McClelland, C., Sorensen, A., Wismer, D., & Stenhouse, G. (2019). Evaluating grizzly bear habitat use and response to new approaches to forest management, harvesting, and access planning in core grizzly bear conservation areas – are new approaches possible to support recovery efforts? Prepared for Forest Resource Improvement Association of Alberta.

This project was undertaken to determine if forest management activities (and ongoing oil and gas activities) could occur on a common land base where grizzly bear recovery efforts are underway. To answer this broad question we utilized short-term (2013-2018) and in some instances longer-term data (2004-2018) to investigate research questions which included:

1. The distribution and abundance of grizzly bears within the study area and how this might have changed over time,

2. how the movement of bears might have changed or been altered by anthropogenic factors including new roads and forest harvesting,

3. can new approaches to monitor grizzly bear populations through DNA sampling assist in future population abundance and occupancy monitoring, and

4. how grizzly bears are responding to new and existing access control measures within the study area.

The foundation underlying these research questions relied on extensive remote sensing based data sets that provided the context for the environmental conditions that study animals were exposed to during the time period of data collection. Although we have reported on some primary topics of landscape change in this report (roads, harvesting, well sites, pipeline and secure habitat patches) additional analysis will occur in 2019 to analyze additional landscape change metrics where grizzly bear response may be evident.

1. Population Abundance and Distribution:

- The average number of bears estimated on the Pembina grid in 2018 was 22.7 (SE=12.2, CI=8.4-60.9, CV=53.7%). The ratio of density estimates within the Pembina study area from 2004 to 2018 suggests an increase by a factor of 7.32 which amounts to an annual rate of increase of 15%. This increase occurred while landscape change within the study area continued. Results suggest minimal movement of bears detected in more than one year, which supports the concept that bears are not being displaced over time by landscape change factors.

2. Grizzly Bear Movements:

- Grizzly bear movement rates were positively associated with increasing anthropogenic disturbance densities associated with roads, forest harvest blocks, and infrastructure. Both males and females strongly increased movement rates when road densities were high. Selection of roads was strongly scale-dependent.
- We found that grizzly bears tended to select landscapes with higher productivity and resource availability that were topographically complex, while avoiding landscapes where conditions limited productivity.
- Grizzly bears with poorer body condition have the highest probability of engaging in risky behaviour in high quality habitat associated with anthropogenic disturbance.

3. New approaches to DNA sampling:

- Both hair and scat based DNA sampling methodologies could identify individual grizzly bears and their gender; however, full DNA extraction rates were higher for hair samples compared to scat extraction rates.
- Hair and scat collection, can support recovery efforts by better informing on the distribution of grizzly bears, their persistence within their home ranges, and the fate and survival of translocated bears.

4. Grizzly Bear Response to Access Control Measures:

- Gates used to control access within grizzly bear conservation areas were associated mainly with oil and gas activities rather than forestry activities. The majority of gates were potentially ineffective as access control measures. Gates had a measurable impact on road density calculations for some watersheds within core and secondary watershed units in BMA 3.

Population Inventory; Density; Hair Snag; Scat; DNA; Human Access; Body Condition; Movement; Oil and Gas; Access Management; Roads; Forestry

Larsen, T., Darlington, S., Wismer, D., Stenhouse, G., & Finnegan, L. (2020). Woodland Caribou and Grizzly Bear Response to Mountain Pine Beetle Attack and Control in West-Central Alberta. Final Technical Report prepared for the fRI Research Mountain Pine Beetle Ecology Program.

In 2006, the Alberta Government implemented a management strategy to reduce the potential for mountain pine beetle (*Dendroctonus ponderosae*) outbreaks along the Rocky Mountain eastern slopes. This decision was based on an influx of MPB from British Columbia, which at the time was experiencing an epidemic level outbreak with beetles spreading across the province's southern and central interior killing millions of trees. There was concern that beetle populations could reach similar levels in Alberta; affecting contiguous areas of mature uncut lodgepole pine (*Pinus contorta*) that is critical habitat for federally threatened southern mountain caribou (*Ranger tarandus caribou*) populations, and core habitat for grizzly bears (*Ursus arctos*) designated threatened at the provincial level.

The government's forest management strategy over the short term was to slow MPB spread by identifying and cutting-and-burning green MPB infested trees ('green control'). Where MPB infestations were too high for green control to be effective, stand level harvesting was to be used to change the age distribution and reduce landscape level MPB susceptibility over the long-term. However, in caribou ranges forest harvesting is limited because habitat disturbance can alter predator-prey dynamics and compromise caribou persistence and recovery efforts. In this case, green control might be a viable option to slow MPB expansion in caribou ranges while minimizing habitat disturbance at low infestation levels, particularly as much of the region was deemed climatically unsuitable for MPB populations to survive and reproduce. It is likely, however, that with changing climatic conditions and large areas of susceptible pine, MPB will eventually spread into caribou zones meaning that not every pine tree killed by MPB will be managed. As part of forest management there is need for strategic plans regarding how MPB infested trees are managed over time while considering both caribou and grizzly bear habitat needs for these two provincially threatened species.

Previous caribou and grizzly bear research conducted in Alberta and elsewhere has improved ecological knowledge of these species, and resulting habitat models have assisted with forest management planning. For example, resource selection function (RSF) models built as planning tools have allowed managers to forecast changes in habitat value for caribou and grizzly bears based on changes associated with human activities and other environmental characteristics. This work serves as a foundation on which to base management decisions for caribou and grizzly bears surrounding disturbances associated with development from the energy and forestry sectors. However, knowledge of how these species might respond to disturbances associated with MPB attack and control is limited. A recent study conducted by fRI Research aimed at understanding how MPB might change food supply for caribou and grizzly bears. RSF models that incorporate caribou and grizzly bear response to MPB attack and control would complement this existing food- based research, and provide further insight into the ecology of these species and inform decisions regarding MPB management planning.

We initiated this two year research project to investigate caribou and grizzly bear response to novel conditions created from MPB infestations and management activities. Our primary objective was to quantify, and evaluate changes in, the relative habitat value of mature uncut pine forests for caribou and grizzly bears following MPB attack and control in west-central Alberta. We used GPS locations collected from the Narraway (2001-2017) and Redrock-Prairie Creek (1998-2017) caribou herds and from grizzly bears from the Grande Cache (BMA 2) and Swan Hills (BMA 7) bear management areas (2003-2016), forest inventory (AVIE) and other habitat datasets, and MPB attack and control locations to conduct habitat analysis at multiple spatial and temporal scales. For caribou, we focused on early and late winter, which is when these central mountain caribou herds use the Alberta foothills. For grizzly bears, we considered spring, summer, and fall seasons which coincides with when bears are most active.

Our approach was two-fold. First, at the landscape level (i.e., animal home range) we conducted univariate analysis to determine the population level availability of mature uncut forested stands, and in particular pine dominant stands (50-100% overstory composition) and areas within 250 m of early (1-4 years), intermediate (5-8 years), and late (9-12 years) MPB attack and control stages. We then quantified the amount of time caribou and grizzly bears spent in these habitats, and whether responses were positive (selection), negative (avoidance), or neutral (use was similar to availability). Second, at the landscape level we built multivariable RSF models to estimate population level regression coefficients describing how caribou and grizzly bears response to mature pine, the availability of pine (functional response for grizzly bears only), and the proximity of stands affected by MPB attack or control (landscape models). Within these RSF models, we controlled for anthropogenic footprint and other environmental factors known to influence caribou and grizzly bears behavior. We then built separate RSF models with GPS locations that occurred in mature pine taller than 10 meters only to evaluate how caribou and grizzly bears respond to structural characteristics of forest stands and the previously aforementioned variables (pine only models). As a secondary project objective, we considered developing an interactive planning tool with the RSF models based on interest from our partners.

Key results for female grizzly bears from Bear Management Areas Grande Cache and Swan Hills:

1. Univariate analysis
    - Grizzly bears avoided mature uncut forest in all seasons, especially pine dominant stands
    - Grizzly bears selected other habitats that were mostly harvested forests.

- Grizzly bears either selected or showed a neutral response to areas within 250 m of MPB attack and control with no apparent differences that can be attributed to season or stage.

2. Multivariable landscape models
   - Across seasons, grizzly bears avoided mature pine dominant stands.
   - As the amount of pine in a grizzly bear's home range increased, so did selection for other habitats most comprised of regeneration forest harvests.
   - Generally, grizzly bears response to habitat near MPB attack and control was positive.
   - In spring and fall, grizzly bear selection for MPB attack and control increased at later stages, but in summer selection decreased at later stages.
3. Multivariable pine only models
   - When grizzly bears used mature pine forest exclusively, they avoided pine dominant stands in spring and summer, but in fall they selected pine where over story composition was ≥80%.

Overall, our results suggest that mature uncut pine dominant stands are seasonally important for caribou, albeit dependent on season and herd, and that caribou avoid habitat in close proximity to MPB attack and control. In contrast, our results suggest that mature pine, especially pine dominant stands, are less seasonally import for grizzly bears, and that bears select habitat near MPB attack and control. Combined, these findings suggest that MPB infestations and activities to control infestations are more likely to improve habitat conditions for grizzly bears than caribou. However, because of the relative low intensity of MPB infestations within our study area, we did not have enough data to thoroughly assess caribou and grizzly bears response to MPB over longer time-frames and at higher densities of infestation. Regardless, the information and models generated from this research fills a knowledge gap, improves our understanding of caribou and grizzly bear ecology, and can help land and wildlife managers make decisions regarding MPB and forest management planning in caribou and grizzly bear ranges.

Mountain Pine Beetle; Caribou; Forest Harvest; Food; Habitat Selection

Denny, C., Larsen, T. A., Nielsen, S. E., Coogan, S., & Stenhouse, G. B. (2020). Grizzly bear carrying capacity estimates for Bear Management Area 4 using models of food resource supply. Report prepared for Forest Resource Improvement Association of Alberta.

Objectives: The first objective was to develop spatially-explicit vegetation, ant, and ungulate models to predict the total digestible energy (kilocalories) potentially available for grizzly bears in Clearwater Bear Management Area (BMA 4) in west-central Alberta. Distribution, abundance, and fruit density where applicable were modelled for 22 food items of varying importance in grizzly bear diets: 18 plant species and genera (fruit, herbs, and roots), ant colonies in mounds and coarse woody debris, and three ungulate species, namely moose (*Alces alces*), elk (*Cervus canadensis*), and sheep (*Ovis canadensis*). The second objective was to convert digestible energy to carrying capacity estimates at the watershed level, using the relationship between food supply and population size from a reference population in a protected area. This project builds on previous "nutritional landscapes" research conducted for BMA 3.

Conclusion: Conservation plans for wildlife species should acknowledge the important bottom-up effects of food resource availability and how this influences the integrity of populations at risk. Carrying capacity estimates derived from food supply offer key insights to evaluate the success of current management actions and guide future initiatives, and are thus an integral component supporting the recovery of grizzly bear populations in Alberta.

Food; Nutrition

Larsen, T., Graham, K., & Stenhouse, G. (2020). Relationships between natural resource extraction footprint and the distribution and abundance of grizzly bears in Alberta. Prepared for Forest Resource Improvement Association of Alberta, Weyerhaeuser, West Fraser, and Husky Energy.

This report provides the first evaluation of how natural resource extraction activities influence the abundance and distribution of grizzly bears in Alberta. Using long term genetic datasets from multiple population inventories over the period 2004-2014, and gathered from five of the seven provincial Bear Management Areas, we combined DNA data from these inventories to matching landscape condition data that captured the natural resource footprint at the time of data collection. Using both univariate and multivariate analysis approaches, we investigated the possible effects of resource extraction footprint (forestry, oil and gas, pipelines and mining) on male and female grizzly bear distribution and abundance at two scales including the standard grid cell size (7 x 7 km; 49 km^2) and the neighbourhood surrounding a cell (441 km^2). We also included elements of human activity in the modeling process to compare the possible influence of these variables, which are more related to landscape or legacy effects, on abundance and distribution of bears. Results showed that male and female grizzly bears were affected by natural resource extraction activities related to the forestry and energy sectors in a similar manner. We also found that the bear distribution models mirrored abundance models, so inferences about changes in grizzly bear populations could be determined from either model. Although footprint associated with forest harvesting, well sites, and pipelines excluding roads were negatively correlated with the probability of grizzly bear occurrence, the variable road density fit the data better. Road density was an important predictor of male and female grizzly bear distribution. We interpreted these findings as compelling evidence that across grizzly bear range in Alberta, roads associated with natural resource extraction activities limit the distribution/abundance of grizzly bears. We suspected that it is not the actual changes in vegetation that come with industrial footprint, rather it is more about the ability of humans to access areas of grizzly bear habitat. Grizzly bears were also found more likely to occur where there was old mine footprint. This type of land use activity differs markedly from other natural resource extraction activities because human access and activities are restricted in these areas. This finding suggests that reclaimed open pit coal mines in grizzly bear habitat have the unique role of supporting and enhancing local grizzly bear populations (at the BMA scale) and facilitating recovery efforts. We conclude that natural resource extraction industries can likely occur within grizzly bear range without compromising persistence of bear populations provided that long-term food supply is maintained and sources of mortality typically associated with areas near roads are managed closely. Maintaining food resources and road density thresholds previous established are important components of making land management decisions within grizzly bear range.

Forestry; Oil and Gas; Mining; Density; Disturbance; Roads

Stenhouse, G. B., & Parsons, B. M. (2020). A Review of 23 Years of Grizzly Bear Research in and around Open Pit Coal Mines in West Central Alberta. Report prepared for Teck Coal Ltd.

In contrast to the predictions of the 1996 EIA that open pit coal mines in the region would create barriers to grizzly bear movement across the landscape, grizzly bears have been found to be highly adaptable to change, and reclaimed open pit coal mines in this region, with the current abundance of food resources, are in fact important habitats for resident grizzly bears. There has been no evidence from long term research in this region that open pit coal mines are having a detrimental effect on regional grizzly bear populations.

A goal of mine reclamation in these areas should be to recognize and maintain this valuable habitat for this threatened species. In fact, reclaimed mines with access management and firearm restrictions can act as local refugia, or safe havens, for grizzly bears. Mine reclamation can play a key role in grizzly bear population survival and conservation if bear-human conflict is kept low; however, if human access restrictions are removed, the reclaimed areas could quickly turn into a population sink, an area where grizzly bears are attracted to but face unsustainable levels of mortality. Landscape and vegetation restoration and enhancement as well as careful planning regarding human access and activity are important elements of an effective reclamation plan that will recognize the ecological needs of grizzly bears.

Mining; Density

fRI Research Grizzly Bear Program. (2020). **GBTools User Guide.**

This document describes how the models and tools developed by the fRI Research Grizzly Bear Program (fRIGBP) can be used to analyze grizzly bear habitat and inform decision-making in support of grizzly bear conservation. The 2020 release of fRIGBP deliverables are being provided to program sponsors in support of the fRIGBP's primary mission: *"To provide land and resource managers with the knowledge and tools necessary to ensure the long-term conservation of grizzly bears in Alberta."*

The fRIGBP 2020 deliverable contents contain:

- fRIGBP theses and journal publications
- GBTools: GIS tools for forecasting the effect of user-supplied development scenarios on grizzly bear habitat
- Base input data: land cover, canopy, access, regional and terrain variables updated to 2018 landscape conditions
- Updated mortality risk, rsf and habitat state outputs reflective of 2018 landscape conditions

The GBTools application can be used for three purposes:

- To update the habitat maps in order to maintain their currency in a rapidly-changing landscape
- To forecast the effect of a development scenario on habitat quality
- To compare, quantitatively, the relative impact of multiple scenario

GIS Application; Map Product

Appendix 1: List of Program Partners

The research laid out in this document would not have been possible without the tremendous support from our many partners in industry, government, academia, and non-profits.

- Alberta Advance Education and Technology
- Alberta Conservation Association
- Alberta Energy Regulator
- Alberta Sustainable Resource Development
- Alberta Tourism and Parks
- Anadarko-CNR-ACC
- ANC Timber
- Anderson Exploration Ltd.
- Banff National Park
- Blue Ridge Lumber
- BP Canada Energy Company
- Buchanan Lumber/Tolko OSB
- Canfor
- CBC Radio
- Canadian Co-op Wildlife Health Centre
- Canadian Natural Resources Ltd.
- Cedar Mueller
- Canadian Forest Sevice
- Coal Valley Resources Ltd.
- Coalspur Mines Ltd.
- Conoco
- ConocoPhillips (GP)
- Conservation Biology Institute
- Devon Canada
- DMI
- DMI Services
- Edson Forest Products
- Elk Valley Coal Corp. (CRC)
- EnCana
- Environment Canada
- Fording Coal
- Forest Resources Improvement Association of Alberta (FRIAA)
- Friends of Kananaskis Country
- Gateway Pipeline
- Government of Canada
- Grande Cache Coal Corporation
- Gregg River Resources
- Hinton Fish & Game Association
- Hinton Wood Products (West Fraser)
- Husky Oil
- Inland Cement
- Jasper National Park
- Joss Wind Power Inc.
- Manning Forestry Research Fund
- McGraw-Hill Ryerson Ltd.
- Municipal District of Bighorn
- Millar Western Forest Products Ltd.
- Millennium EMS Solutions Ltd.
- Mountain Equipment Co-op
- Natural Resources Canada
- Natural Resources Service
- Nature Conservancy
- NatureServe Canada
- Nexen
- Norbord
- Pembina Pipeline
- Petro Canada Oil and Gas
- Prairie Mines & Royalties ULC
- Peregrine Helicopters
- Progress Energy
- PTAC Petroleum Tech Alliance
- Rangeland Conservation Service Ltd.
- Repsol Oil & Gas Canada Inc.
- Rocky Mountain Elk Foundation
- Seven Generations Energy Ltd.
- Shell Canada Energy
- Slave Lake Pulp
- Spray Lake Sawmills
- St'at'imc Government Services
- Stoney Tribal Administration
- Suncor
- Sundance Forest Industries Ltd.
- Sundre Forest Products
- Talisman
- Teck Coal Ltd.
- Trans-Canada PipeLines Ltd.
- University of Alberta

- University of British Columbia
- University of Calgary
- University of Laval
- University of Saskatchewan
- University of Washington
- Waterton Lake National Park
- Weyerhaeuser
- Wild Year Productions Ltd.
- World Wildlife Fund Canada

APPENDIX 2: LIST OF GRADUATE STUDENTS AND THESES

It would be remiss to create a summary of the work of the fRI Research GBP without acknowledging the many students and supervisors that put in countless hours towards thesis projects. Many of these students also published papers based on their work, and these are listed in the main body of this document. To acknowledge the important contribution of supervisors, they have been included at the end of each citation. In addition, where available, a link to the completed thesis is included. Including this list of theses highlights the amazing job that the program has done in creating long-term relationships within the project, as we see names of multiple MSc students become names of supervisors of their own students. The fRI Research GBP also employed many of the students working with their data. This section also shows the contribution of the program to building up the next generations of scientists.

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Alejandra Zubiria Perez. 2020**. Evaluating the role of movement behaviour and habitat familiarity on translocated grizzly bear success using an agent-based modelling approach.** *MSc Thesis. Department of Geography, University of Victoria, Victoria, BC.* C Bone. https://dspace.library.uvic.ca/handle/1828/12119

APPENDIX 3: LIST OF PAPERS IN PREPARATION AND REVIEW

The work of the Grizzly Bear Program is ongoing. This appendix lists some of research that was in progress but not yet published by the end of the program.

Cattet, M., Janz, D., Kapronczai, L., Erlenbach, J., Jansen, H., Nelson, O. L., Robbins, C., & Stenhouse, G. (Under review). **Cortisol levels in blood and hair of unanesthetized grizzly bears (*Ursus arctos*) following intravenous cosyntropin injection.**

Wilson, A., Wismer, D., Stenhouse, G., Coops, N., & Janz, D. (Under review). **Landscape condition influences energetics, reproduction, and stress biomarkers in grizzly bears**.

Perez, A., Bone, C., & Stenhouse, G. B. (Under review). **Simulating impacts of learning and memory in translocated grizzly bears in west-central Alberta**.

Kearney, S. P., Larsen, T., Goodbody, T. R. H., Coops, N. C., & Stenhouse, G. B. (Under review). **Characterizing off-highway road use with remote sensing, social media and crowd-sourced data: an application to grizzly bear (*Ursus arctos*) habitat.**

Perez, A. Z., Bone, C., & Stenhouse, G. (Under review). **Evaluating the role of environmental familiarity and behaviour in the success of wildlife translocation: A grizzly bear case study using agent-based modelling.**

Rickbeil, G., Coops, N., Kearney, S., Berman, E., McClelland, C., Parsons, B., Wilson, A., Goodbody, T., Bourbonnais, M., Nielsen, S., Janz, D., van Manen, F., & Stenhouse, G. (Submitted December 2020). **Geospatial wildlife science by design: a synthesis of novel data and approaches developed by the GrizzlyPAW program.**

McClelland, C. J. R., Denny, C. K., Larsen, T. A., Stenhouse, G. B., & Nielsen, S. E. (Submitted Feb 2021). **Landscape estimates of carrying capacity for grizzly bears using nutritional energy supply for management and conservation planning.**

Stenhouse, G. B., Larsen, T., McClelland, C. J. R., Graham, K., Wilson, A., Wismer, D., Frame, P., & Phoebus, I. (Submitted March 2021). **Response of a Large Carnivore to Translocation into a Novel Environment.**

Zubiria Perez, A., Bone, C., & Stenhouse, G. (Submitted March 2021). **Evaluating the role of environmental familiarity and behaviour in the success of wildlife translocation: A grizzly bear case study using agent-based modelling.**

Wilson, A., Stenhouse, G., Cattet, M., & Janz, D. (In preparation). **Incorporating physiology into long-term monitoring of large carnivores.**

Wilson, A., Stenhouse, G., Coops, N., & Janz, D. (In preparation). **Reproductive biomarkers in serum of grizzly bears and applications for conservation.**

Nielsen, S., Boulanger, J., Larsen, T., Denny, C., & Stenhouse, G. (In preparation). **Population trends in grizzly bears explained by landscape change and food supply**.

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