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Development of Modeling Tools to Address Cumulative Effects on the Summer Range of the Bathurst Caribou Herd – A Demonstration Project

Editors: John S. Nishi and Anne Gunn

Contributing Authors: Jan Z. Adamczewski, Matt J. Carlson, Colin J. Daniel, Anne Gunn, Chris J. Johnson, John S. Nishi, Don E. Russell, J. Brad Stelfox, and David Taylor

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Contributing Authors (in alphabetical order)

Jan Z. Adamczewski
Wildlife Division
Environment and Natural Resources
Government of the Northwest Territories
Box 1320
Yellowknife, NT X1A 2L9

Matt J. Carlson
ALCES Landscape and Land-use Ltd.
136 Barrette Street
Ottawa, ON K1L 8A1

Colin J. Daniel
Apex Resource Management Solutions Ltd.
937 Kingsmere Avenue
Ottawa, ON K2A 3K2

Anne Gunn
368 Roland Road
Salt Spring Island, BC V8K 1V1

Chris J. Johnson
Ecosystem Science & Management Program
University of Northern British Columbia
333 University Way
Prince George, BC V2N 4Z9

John S. Nishi
EcoBorealis Consulting Inc.
ALCES Landscape and Land-use Ltd.
Box 39, Site 2, RR1
Millarville, AB T0L 1K0

Don E. Russell
Box 10038
Shadow Lake Environmental Consultants
Whitehorse, YK Y1A 7A1

J. Brad Stelfox
ALCES Landscape and Land-use Ltd.
Box 61196 Kensingon RPO,
Calgary, AB T2N 4S6

David Taylor
Taylor Geomatics
53 Calder Crescent
Yellowknife, NT X1A 3A9

ABSTRACT

We summarize a demonstration project that was initiated to integrate different modeling tools and approaches for assessing cumulative effects on barren-ground caribou. Our approach was to integrate different types of information and link modeling techniques that have been used previously to explore habitat selection (resource selection functions), energetic intake and expenditure, and land-use dynamics and simulation, and to refine those tools for understanding cumulative effects of mines and other developments in the Bathurst caribou herd's summer range. We also included results from a study of Dogrib (Tłı̨chǫ) traditional knowledge to add a longer-term perspective to the habitat selection assessment. Our goals were to: 1) modify, apply and integrate existing datasets and link modeling approaches for barren-ground caribou to show how the models can be applied as learning and decision support tools in northern Canada; and 2) develop a basis for collaborative learning about cumulative effects and barren-ground caribou with a broader group of people including representatives from governments, industry, and a co-management board. While we successfully integrated the different datasets and linked the models, our objectives were not to assess cumulative effects as such, but rather to demonstrate how it may be done in a collaborative and inter-disciplinary manner.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. INTRODUCTION

By: John Nishi, Anne Gunn, Chris Johnson, and Jan Adamczewski

Cumulative effects[1] assessment (CEA) has been a long standing issue in northern Canada. The concerns repeatedly came to the forefront during the assessment of cumulative effects for caribou (*Rangifer tarandus groenlandicus)* of the Bathurst herd during the environmental assessments for three diamond mines in the Northwest Territories (NWT), 1996-2003. The report of the environmental assessment panel of the Ekati diamond mine concluded that, "... further work is needed on the cumulative effects of exploration activities on wildlife in the region" (CEAA 1996). There were sufficient public concerns that cumulative effects assessment was recognized as among the outstanding issues for the Diavik diamond mine (CEAA 1999). Similarly, during the environmental review of the Snap Lake project – the third diamond mine in the NWT – concerns were raised about cumulative effects for caribou (MVEIRB 2003).

Those environmental assessments for the three mines revealed a lack of agreement on approaches to describe cumulative effects for caribou. While there were tools (models) available, there were limits to their technical and social acceptability for the NWT. For example, concerns raised during the hearings for the Diavik diamond mine led to

[1] Cumulative effects are changes to the environment that are caused by an action in combination with other past, present and future human actions. From an environmental management perspective, 'cumulative effects are the end result of independent decisions that may have a small impact singly, but taken together have unanticipated or unintended effects' (Antoniuk et al. 2009b).

collaboration during technical sessions to include data from the Bathurst herd for an energetic model (CEAA 1999, D. Russell pers. comm.). However, the concerns about different approaches persisted. During the cumulative effects assessment for the Snap Lake diamond mine, MVEIRB (2003, p. 129) commented that "most Parties, including GNWT, expressed concern that little quantitative analysis or use of available models was undertaken to support cumulative effect predictions or increase confidence in DeBeers' conclusions." On the other hand, the proponent contended that the models were insufficiently validated to be applied to cumulative effects analysis in the NWT (MVEIRB 2003, p. 156).

Recognizing the need to refine the tools was part of the rationale for a project by Gunn et al. (2001b) to use available data for the Bathurst caribou herd based on the energetic model developed for the Porcupine herd (Kremsater et al. 1989, Russell et al. 2005). The energetic model traces how an individual caribou allocates the energy from its forage to its own body mass and the chances of having and raising a calf. As far as possible, Gunn et al. (2001b) used data for the Bathurst herd but acknowledged gaps in the availability of data on, for example, caribou habitat selection and the inclusion of traditional knowledge. During the time since 1996, the availability of scientific and traditional knowledge on animal movements and habitat selection was rapidly increasing through studies supported by the West Kitikmeot Slave Study (WKSS) (Griffith et al. 2001, Gunn et al. 2001a, Legat et al. 2001), which itself was a collaborative project between governments and industry.

The WKSS studies were the basis for progress on assessing cumulative effects using habitat selection at a regional scale by multiple species including grizzly bears, wolves, wolverine and barren-ground caribou (Johnson et al. 2005). By incorporating camps and exploration sites, as well as mines in the habitat selection analyses, Johnson et al. (2005) were able to reveal how caribou were avoiding the vicinity of mines. Boulanger et al. (2012) used both satellite collars and observations from aerial surveys to update the earlier analyses to describe the extent of this avoidance which is termed the zone of influence (ZOI) around a mine.

These two threads – greatly increased amount of information and a more detailed measure of the ZOI for caribou in the vicinity of mines – have paved the way for an updated approach to cumulative effects. A third thread was the progress made in scenario analysis approaches using the ALCES® landscape simulation model to inform strategic land-use planning (Carlson et al. 2010, Carlson et al. 2011, Francis and Hamm 2011), and to evaluate management strategies and potential cumulative effects of industrial activities on key indicators such as boreal caribou (Schneider et al. 2003, ALT 2009, and see Nishi et al. 2007).

As well as the amount of information and the refinement of approaches including modeling that would contribute to assessing cumulative effects, there was also a change in the governance context. Prompted by the comprehensive assessment for the Diavik diamond mine (CEAA 1999), Aboriginal organizations, industry, environmental non-governmental organizations, the federal and territorial governments and the Mackenzie Valley Environmental Impact Review Board have collaboratively developed the NWT Cumulative Effects Assessment and Management Strategy and Framework (CEAMF), although in 2008 it changed its name to NWT Environmental Stewardship Framework. One of CEAMF's initiatives includes an emphasis on monitoring through the NWT Cumulative Impact Monitoring Program – CIMP[2] (see AANDC 2011). These programs kept the focus on cumulative effects and caribou even though between 2003 and 2007 there were no major proposed developments on the Bathurst herd's range.

Part of the changing governance context for cumulative effects was also reflected by the Government of the NWT (GNWT) in its Caribou Management Strategies (2006-2010, and 2011-2015), which committed to developing cumulative effects modeling tools for barren-ground caribou (GNWT 2006, 2011). Added to the concerns about cumulative effects was concern over the declining Bathurst herd after surveys in 2006 (Nishi et al. 2007, Boulanger et al. 2011) and in 2009 (Adamczewski et al. 2013, Nishi et al. 2014 In Prep). The population trend and concerns over harvest management would require development of management options based on a holistic perspective considering all potential natural and anthropogenic (human-caused) impacts to herd productivity and mortality (Tłįchǫ Government and GNWT 2010).

[2] www.nwtcimp.ca

The extent of the concerns and a willingness to collaborate over cumulative effects was emphasized during a workshop with a broad audience in February 2008 in Yellowknife (Adamczewski et al. 2013). The workshop was a response to the GNWT's commitments as well as CEAMF and its strategy for developing tools to measure cumulative effects. Both GNWT and to CEAMF (through CIMP) supported and funded the workshop and the results of the workshop and the proposed approach have been reported (Nishi et al. 2009 In Prep., Adamczewski et al. 2013).

The workshop was attended by approximately 70 people representing Aboriginal governments, co-management boards, biologists from Yukon, NWT and Nunavut, industry representatives, universities and members of the public. The workshop included an overview of information on the Bathurst caribou herd, presentations of models that have been used to assess effects of development on caribou, and lastly, feedback from the workshop participants as "responses to the presentations of the modeling approach".

During the workshop, support was evident for a demonstration project to use energetic, habitat selection based on science and traditional knowledge and a landscape models to focus on assessing impacts of mines and other developments in the Bathurst herd's summer range, with use of mapped traditional knowledge (TK) in the modeling. A commitment was made to include existing mapped traditional ecological knowledge, using an approach used previously in boreal caribou studies (Gunn et al. 2004). There was a clear acknowledgment that integrating the different datasets and linking the models raised many technical issues. These were further identified and solutions proposed at a technical meeting in Calgary in July 2008. The biologists, modellers and a TK specialist (A. Legat) reviewed the integrated approach and planned next steps toward the demonstration project.

Demonstration Project Goals

Our first goal in this demonstration project was to modify, apply and integrate existing datasets as input, and to ensure that models for barren-ground caribou could be linked to show how the models may be applicable as learning and decision support tools for governments and wildlife co-management boards in the NWT (and potentially elsewhere in the northern Canada). The initial focus was on the Bathurst caribou summer range while recognizing that the work will need to be scaled up to the annual range, with potential application to other herds and regions.

Our second and longer-term goal was to develop a basis for collaborative learning about cumulative effects and barren-ground caribou with a broader group of government, industry, and community representatives. To achieve this goal, we proposed to use the simulation modeling tools and emphasize a "management-by-objective" approach to improve our collective understanding of ecological and socio-economic interactions and trade-offs when considering human activities on caribou range.

Project Objectives

During the initial project scoping and discussions, we outlined the following five objectives:

1. Update and refine habitat selection models (Johnson et al. 2006) for the Bathurst caribou summer range, explore and develop a methodology to incorporate Tłı̨chǫ knowledge on caribou habitat use, and describe the possible ZOI for caribou by displacement from preferred habitats and ranges. Knowledge gaps and technical issues and their solutions would be addressed.

2. Re-visit and run linked energetics and demographics models (Gunn et al. 2001b, Russell et al. 2005) with updated ecological data for the Bathurst herd, and the revised habitat selection models, to explore behavioural, nutritional and demographic consequences of caribou responses to disturbance and natural environmental variability.

3. Incorporate a population dynamics module in ALCES to provide an overall modeling framework for simulating effects of natural and anthropogenic factors on barren-ground caribou; and modify the model structure to accept RSF coefficients and outputs from the energetic model.

4. Develop linkages among the models, which would provide the basis for creating and sharing common data inputs/outputs and could link models dynamically or through the creation of functional relationships and/or relational databases.

5. Review the demonstration project and cumulative effects modeling approaches with a NWT audience and plan next steps collaboratively.

Overall Approach of the Demonstration Project

The approach we emphasized was to develop and test simulation models to explore cumulative effects based on the collective knowledge of caribou ecology; this strong dependence on modeling may initially seem off-putting to many caribou users because computer models are not an intuitively simple methodology. However, models are simply a reflection of our current understanding and are also the basis for decision-making (Sterman 2002). Models are an effective and efficient means of managing, analyzing, interpreting and presenting large amounts of diverse information. If used in an iterative manner subject to ongoing scrutiny and critical thinking, models can test for uncertainty in assumptions, strength of conclusions, help define management options, and thus provide a basis to a broader adaptive management framework (Starfield 1997, Williams 2011).

We designed our approach around three principles for understanding cumulative effects on barren-ground caribou. Firstly, the cumulative effect of industrial development must be assessed in the context of a suite of natural and anthropogenic factors that interactively and cumulatively affect caribou populations over time (Cameron et al. 2005). Describing and analyzing cumulative effects needs models simply because so many factors (including weather, predation, hunting, and others) affect caribou, along with industrial development. Previously, many of those environmental influences were not addressed in cumulative effects assessment (Duinker and Greig 2007).

The second principle is to ensure that the geographic and temporal scales of assessment are ecologically relevant and appropriate to the caribou herd of interest. What this means is that cumulative effects assessments for caribou should encompass multiple scales that minimally include what are typically defined as local and regional study areas over multiple years; but assessments also need to be scaled up to the ecologically relevant seasonal and annual ranges of the caribou herd and understood over longer, multi-decadal time frames (Figure 1).

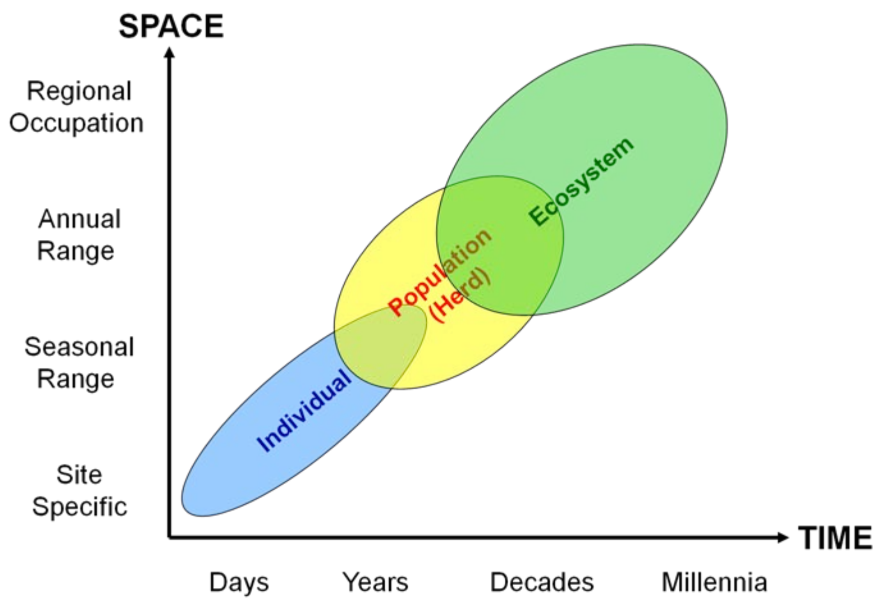

Figure 1: Relevant spatial and temporal scales for assessing cumulative effects on caribou.

Our third principle was that we would design an approach that would incorporate TK. This means that cumulative effects assessment would also tap into the vast amount of information held by TK holders about caribou on the landscape with the benefit that this information stretches back in time prior to the earliest biological studies.

An integrated modeling approach builds on the strengths of various models. The linked energetics and demographics models have a strong base in caribou biology at the level of the individual and the population. Foraging behaviour of individual caribou potentially altered by disturbance is linked to diet, then to body condition, which in turn is linked to population productivity in the demographic model. The habitat selection models (Johnson et al. 2006) estimate use and avoidance of habitat and landscape features by caribou (Boulanger et al. 2012) and can also include spatial aspects of TK about caribou range. The output of the habitat model can be used to estimate a caribou's seasonal diet, which is the link to the energetics and population models. By developing these types of linkages, we can assess how individual feeding behaviour and habitat use and avoidance at a seasonal range scale may be related to population-level changes in caribou. By modeling different levels of environmental variation (e.g. early vs. late green-up, and good vs. bad insect years), we can simulate the effects of natural environmental variation with the effects of human activity on caribou at the level of the individual and the population. Another key aspect of this overall approach is to integrate the biological models with strategic landscape simulation models, which are designed to explore implications of regional patterns and strategies in land-use. This integration should provide a transparent basis for applying the best available biological and TK to the broader issues of managing human impacts across the annual range of a barren-ground caribou.

Report Organization

The objective of this report is to summarize our approach to developing the tools for cumulative effects assessment on barren-ground caribou. We make the linkages among TK, landscape and individual caribou monitoring data and show how modeling can integrate all that information to project possible changes across the caribou ranges. As part of fostering a collaborative approach to assessing cumulative effects on caribou, we have also included more detailed technical appendices which further explain how we used available information as input to the models. The report is organized as these chapters (Chapters 2, 3, and 4) that summarize each of the modeling approaches for primarily a general audience. Chapter 5 is a synthesis and outlines options for next steps. Additional details are provided in the technical appendices which describe the specific details for data input and model development. This level of detail is an essential part of the demonstration project as those details are the key for other people to apply and build on this proposed approach and methodology. Through the demonstration project (Table 1), we produced various reports, presentations and contributed to a recent book on cumulative effects.

Table 1: Summary of reports produced through the demonstration project.

Nishi, J., A. Gunn and J. Adamczewski. 2009. Modeling cumulative effects on summer range of the Bathurst caribou herd: a demonstration project. Unpublished report NWT Cumulative Impact Monitoring Program: Capacity Building & Monitoring Projects 2008-2009. Online [url]: www.nwtcimp.ca/projectlist.html
Gunn, A., C.J. Johnson, J.S. Nishi, C.J. Daniel, M. Carlson, D.E. Russell, and, J.Z. Adamczewski. 2011. Addressing Cumulative Effects in the Canadian Central Arctic – Understanding the Impacts of Human Activities on Barren-ground Caribou. Chapter 8. In eds. P. R. Krausman and L. K. Harris. Cumulative Effects in Wildlife Management: A Critical Aspect of Impact Mitigation. Taylor and Francis. 274pp.
Adamczewski, J., J. Nishi, A. Gunn, T. Antoniuk, C. Johnson, D. Russell, T. Blondin, A. Legat, D. Beaulieu, J. Virgl, M. Chocolate Pasquayak and B. Wooley. 2013. Modeling Cumulative Effects in Barren-ground Caribou Range: Proceedings of a Workshop in Yellowknife, February 2008. Environment and Natural Resources, Government of the Northwest Territories. Manuscript Report 233. 90pp.

Gunn, D., D.E Russell, C.J Daniel, R.G White and G. Kofinas. In Press. CARMA's tools and approach for collaborative assessment of cumulative effects. Expanded Abstract, submitted to Arctic Ungulate Conference, Rangifer.

CHAPTER 2. UNDERSTANDING THE SPATIAL RESPONSES OF CARIBOU TO HUMAN-CAUSED DISTURBANCE

By: Chris Johnson

Background

The responses of animals to human developments and disturbance are commonly observed, but such responses are varied and complex. As examples, individual animals may choose not to use habitats near a road or mine because the forage has changed. Likewise, human presence may be perceived as a threat to survival, once again forcing an individual to move away from such areas (Frid and Dill 2002). These responses can result in increased energetic costs resulting from greater vigilance and movement as well as habitat loss through the abandonment of portions of a seasonal range (Bradshaw et al. 1998, Seip et al. 2007). When many individuals demonstrate such responses a population can change distribution or in worst-case situations decline in numbers (Johnson and St-Laurent 2010). Although it is difficult to measure these biological effects directly, we can infer a cost to caribou by the way they distribute themselves near mine sites and other types of industrial development. Thus, understanding the distribution of caribou relative to human developments can provide key insights on the costs to individual animals and ultimately populations.

Species distribution models are now a common and well-accepted technique for quantifying the response of animals to human disturbance, as well as other factors such as terrain, predators or forage (Guisan and Thuiller 2005). These “models” take many forms depending on study objectives and available data. The first and most simple species distribution models can be traced back to habitat suitability indices that were developed using expert opinion (United States Fish and Wildlife Service 1981). Beginning in the mid-1990s, new animal-tracking technologies, such as satellite and GPS collars, resulted in more descriptive databases of animal locations. These data in combination with the mainstream application of GIS and the increase in the accessibility of complex multivariate statistical methods resulted in a rapid evolution in the complexity, utility, and application of species distribution models.

Currently, there are many techniques for understanding and mapping the distribution of a species (Johnson and Gillingham 2005). Most approaches are premised on a set of empirical data or the knowledge of experts that describe the current or past distribution of a species, a set of environmental variables that might explain spatiotemporal variation in distribution, including human disturbances, and a statistical model to correlate observed distribution with predictor covariates (Guisan and Zimmermann 2000). Choice of technique or model is dependent on the type of occurrence data for the species of interest, sampling strategy, and the modelling question or application (Johnson et al. 2006).

There are a number of direct and indirect applications of species distribution models to cumulative impacts analyses and supporting regulatory frameworks. This can include the identification of important habitat resources or features and the avoidance of infrastructure or other disturbance events. The work of Mace et al. (1996, 1999) initially demonstrated the potential of species distribution models to quantify disturbance responses of animals at both the patch and landscape scales. Working with an extensive data set of grizzly bear (*Ursus arctos*) locations, they demonstrated that bears had a lower probability of occurrence in areas with a high density of roads (Mace et al. 1996). Mace et al. (1999) then used a similar modelling approach to quantify the cumulative reduction in the availability of bear habitat resulting from human activities. Similarly, Carroll et al (2001) used species distribution models to quantify the impacts of human-caused landscape alteration on the broad distribution of a number of carnivore species found across the Rocky Mountain region of western North America. In addition to quantifying the relationship between distribution and environment, this modelling approach is flexible enough to represent the spatial variation in birth and death processes (Nielsen et al. 2004).

Working at a coarser level of ecological inference and spatial resolution, species distribution models are a useful technique for identifying ZOIs around human developments. These ZOI represent the area where wildlife respond negatively (i.e., source of behavioural disturbance) or positively (i.e., a wildlife attractant) to a proposed or existing development. An observed impact might correspond with an avoidance response, where animals shift their distribution away from a development, altered behaviour in the vicinity of a facility, or changes in the types or quality of habitat used by animals. Conversely, a ZOI may elicit a positive response, where the abundance of a species is higher within a certain distance from development compared to what would have occurred had the disturbance not been present. A scavenger attracted to a development is an example.

Thus, a positive ZOI may not result in a positive effect on wildlife as it may result in a greater proportion of the population coming in to conflict with the development.

Working within the confines of environmental assessment studies and regulation, the ZOI can determine the total area of effect, serve as a metric for regional measures of cumulative effects, or help guide monitoring and mitigation strategies. As examples, woodland caribou (*R. t. caribou*) in northern Alberta demonstrated an avoidance distance of 1,000 m for oil and gas wells and 250 m for seismic lines (Dyer et al. 2001). Similarly, woodland caribou in Quebec avoided a zone of 1,250 m around paved roads (Leblond et al. 2011). Nelleman et al. (2001) reported a zone of avoidance of 2.5-5.0 km for reindeer (*R. t. tarandus*) responding to power lines, resorts, and roads.

Although an intuitive concept, the ZOI and measures of significance are difficult to quantify (Quinonez-Pinon et al. 2007). This is especially apparent where multiple developments interact in a cumulative way. Also, the ZOI should be premised on the type of animal response that is observed, and there may be multiple zones depending on the source of effect. Direct mortality via road access, for example, is normally restricted to the area in the immediate vicinity of the road corridor or road density across a larger area. Habitat alteration or avoidance responses relative to noise or human presence may occur over a larger spatial extent. Recent research has focused on developing techniques that indicate statistically meaningful responses of animals to human activities or facilities that can then be translated to ZOI used in regulatory frameworks (Bennett et al. 2009, Boulanger et al.

2012). When empirical data are absent or there is less scientific rigour in the review process expert opinion is used to estimate probable zones (e.g. AXYS and Penner 1998). Often, the processes to collect such ecological data are flawed (Johnson and Gillingham 2004), making a strong case for the application of formal and repeatable species distribution models for such purposes.

Species distribution models and their associated outputs are easily adapted and applied to other resource management or conservation processes and models. These multi-model approaches often integrate maps, illustrating the location and amount of selected habitats, with predictive movement models, population viability analyses or habitat supply models. Johnson et al. (2005), for example, used maps of the distribution of high-quality habitats for a number of Arctic species, including caribou from the Bathurst herd, to quantify the impacts of possible development scenarios on the distribution and availability of habits and population numbers (Johnson and Boyce 2004). Similarly, Carroll et al. (2003) linked species distribution and spatially explicit population models to understand the relative value of a range of reintroduction strategies for wolves (*Canis lupus*) under current and predicted future landscape conditions. These applications and others (e.g. Weclaw and Hudson 2004, Nielsen et al. 2006, Gustafson et al. 2007) provided the methodological inspiration for our integrated multi-model cumulative impacts approach.

Methods and Data

The objective for this portion of the study was to use a type of species distribution model, resource selection functions (RSF), to quantify the effects of mines and other human disturbances on the distribution of Bathurst caribou. RSFs allowed us to identify the strength of selection by caribou for particular vegetation communities or avoidance of areas adjacent to human developments (Johnson et al. 2005). The continuous avoidance function provided by the RSF was instrumental in identifying a ZOI around mines and other developments currently found on the range of the Bathurst caribou herd. This allowed us to quantify current and estimate future cumulative impacts of development on the total area of seasonal high-quality caribou habitat (Johnson et al. 2005). Also, the function allowed us to model the energetic costs of disturbance (see Chapter 3) relative to the habitats used by caribou and the propensity of caribou to use habitats distant from mine sites.

RSFs are generated using a collection of animal locations that are contrasted with a set of locations that represent the availability of habitats (also known as resources) or random distances to some feature such as a mine. Variation in the distribution of caribou locations, relative to random locations, results in statistically derived (weighting) coefficients. A positive coefficient suggests that the animal or population is selecting a particular categorical resource, such as a land cover type. Likewise, a negative coefficient for a measured distance suggests that an animal is more likely to be found in a habitat as the distance from a human disturbance feature (i.e., a feature such as a road or mine) increases (Table 2, Figure 2). Weighting coefficients for each covariate (e.g. land cover type, distance to mine) in the RSF model can be applied to GIS data resulting in maps of the predicted distribution of seasonal caribou habitat across the study area (Johnson et al. 2005). As demonstrated in this project, those weighting coefficients can be used to understand the probabilistic distribution of caribou across land cover types at various distances from mines and other human disturbances.

Location Data for Caribou

For the demonstration project, we adopted the methods and data used previously for the Bathurst herd (Johnson et al. 2005). However, the habitat classification and distribution data for caribou were updated (Appendix A). We applied 13 years of location data collected by satellite collars deployed on 67 female caribou (Gunn et al. 2001a, Gunn et al. 2011b).

Recognizing the long-term dynamics of the Bathurst herd and the wealth of knowledge held by Aboriginal communities, we used a traditional use study focused on the harvesting of caribou (Legat et al. 2001) to derive additional distribution information. In that study, Tłįchǫ elders described locations where they had hunted caribou since 1932 as well as trails used by caribou across a portion of the annual range of the Bathurst herd. Each hunting location was considered as a separate datum and the trails were converted into point locations with a 5 km interval to ensure independence. The TK was gathered from elders that hunted the western portion of the study area and did not consider the footprint or habitats around the diamond mines. Thus, we used the TK to model the responses of caribou to land cover only.

Habitat Data

We investigated how vegetation community and the stage of plant growth influenced the distribution of caribou. The area of the summer range above treeline was best described by the Northern Land Cover of Canada (Olthof et al. 2008). Below treeline, we used vegetation data from the Canada-wide Earth Observation for Sustainable Development of Forests project (Wulder et al. 2004). When combined, legends from both sources resulted in 27 land cover classes that were further aggregated to 18 classes with sufficient coverage across the summer range for statistical analysis (2, Appendix A).

Since variation in green plant biomass and phenology influenced seasonal selection of plants by caribou (Griffith et al. 2002), we used normalised difference vegetation index (NDVI), derived from Landsat satellite imagery, to measure the response of caribou to seasonal changes in plant availability and nutritional quality. We calculated maps of NDVI at 10 day intervals and then attributed each caribou location to the closest interval in time (≈±5 days). We also generated variables that represented the difference in NDVI value over the successive 10 day periods, nonlinear terms, and interactions between vegetation class and NDVI (see Appendix A).

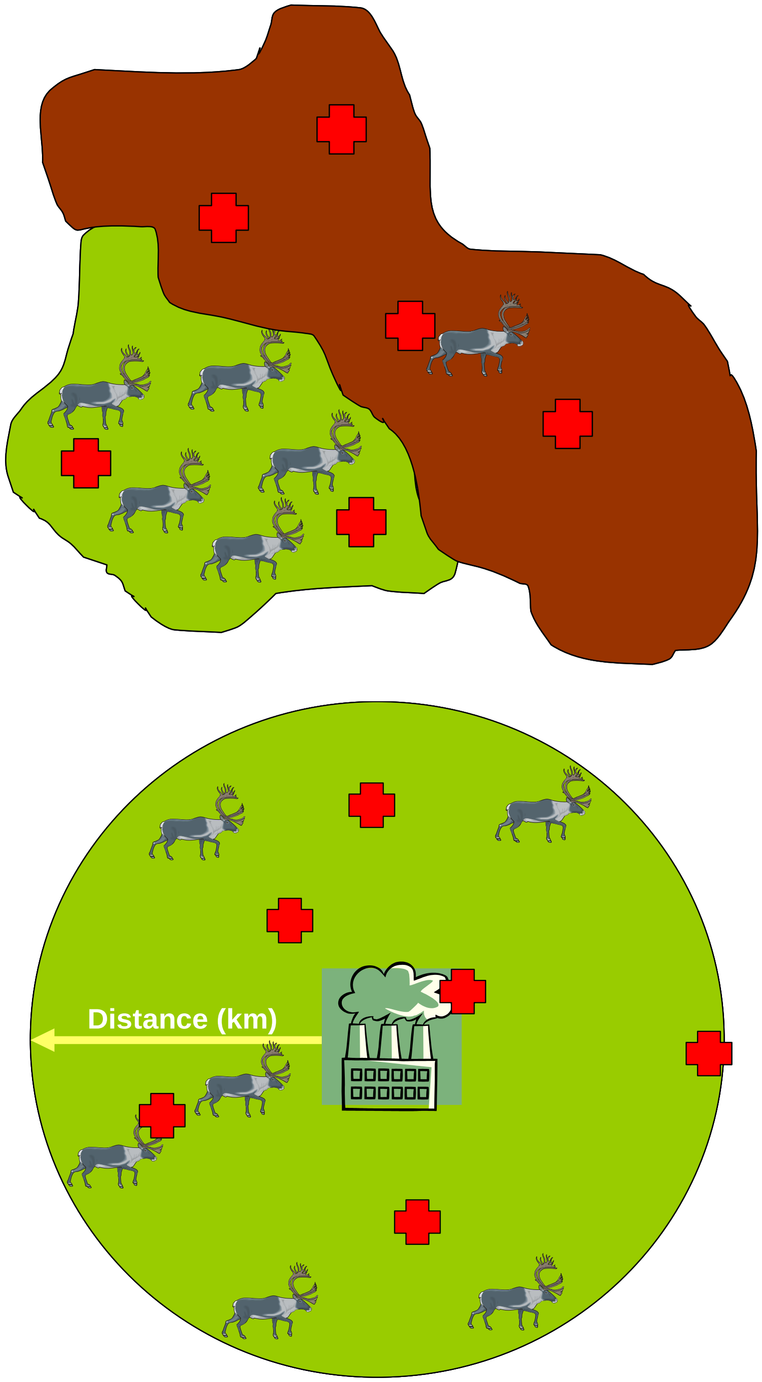

Figure 2: Distribution of caribou quantified using a hypothetical RSF. In the top panel, a greater proportion of caribou locations in the green habitat would reveal habitat selection and a positive weighting coefficient. In the bottom panel, caribou are distributed farther from the factory relative to the random locations (red cross) suggesting avoidance of that feature.

Table 2: Description of land cover classes used to identify resource selection of caribou from the Bathurst herd, NWT and Nunavut, Canada. Data were derived from the Northern Land Cover of Canada (NLC; Olthof et al. 2008) and Earth Observation for Sustainable Development of Forests project (EOSD; Wulder et al. 2004).

Source	Land Cover	Description	Area (%)
NLC/EOSD	No vegetation	No classification or covered by ice/snow.	NA
NLC	Tussock graminoid	Moist tussock tundra with <25% dwarf shrubs (<40 cm) and moss; may include lichens.	13.36
NLC	Wet sedge	Primarily graminoids and bryoids, includes cotton grass that is saturated for a significant portion of the growing season; may include <10% dwarf shrubs <40 cm tall.	3.59
NLC	Graminoid dwarf shrub	Moist to well drained non-tussock tundra with 50-100% cover of primarily low to prostrate dwarf shrubs.	5.44
NLC	Low shrub	Moist to wet erect tall shrub (>40 cm) consisting of dwarf birch (*Betula*), willow (*Salix*) and/or alder (*Alnus*); may contain <10% prostrate dwarf shrubs.	11.36
NLC	Tall shrub	Moist to wet erect tall shrub (>40 cm) consisting of dwarf birch (*Betula*), willow (*Salix*) and/or alder (*Alnus*); may contain <10% prostrate dwarf shrubs.	2.65
NLC	Prostrate dwarf shrub	>50% cover consisting of prostrate dwarf shrubs and graminoids; contain <10% lichen and moss.	8.83
NLC	Sparse vegetation-bedrock	Barren surfaces on consolidated bedrock with 2-10% vegetation cover of graminoids and dwarf shrubs.	2.31
NLC	Sparse vegetation-till	Barren surfaces on bedrock and colluvium with 2-10% vegetation cover of graminoids and	0.31

Source	Land Cover	Description	Area (%)
		dwarf shrubs.	
NLC	Sparse vegetation-cryptogam	Unconsolidated barren surfaces having experienced significant cryoturbation; 2-10% vegetation cover consisting of graminoids and cryptogam plants.	1.07
NLC	Wetlands	Water table intersects land surface for part of year; consists of sedge, moss, and low-shrub wetlands.	2.50
NLC/EOSD	Barren	Unvegetated with <2% cover on bedrock or talus.	6.57
NLC/EOSD	Water	Standing water.	28.39
EOSD	Bryoids	Minimum of 20% ground cover bryophytes and lichens.	3.69
EOSD	Shrub-tree	Minimum 20% of ground cover is 1/3 shrubs.	6.51
EOSD	Wetland-tree	Water table near or above soil surface promoting wetland or aquatic processes; the majority of vegetation is coniferous, broadleaf, or mixed wood forest.	1.14
EOSD	Wetland-shrub	Water table near or above soil surface promoting wetland or aquatic processes; the majority of vegetation is tall, low, or a mixture of tall and low shrub.	0.79
EOSD	Herb	Dry or wet area (water table near or above soil surface promoting wetland or aquatic processes) where the majority of vegetation is herbaceous plants.	1.05

Human Disturbance Data

We selected three general types of human disturbance features that would aggregate cumulatively to influence the distribution of caribou. Drawing from the methods of Johnson et al. (2005), the distance of each caribou and random location was calculated from existing diamond and a gold mine (Figure 3). Recognizing that not all mines were in operation during the study period, distances were relative to active mines, on an annual time scale. We also hypothesized that mineral exploration would influence the distribution of caribou. Thus, we calculated the distance from caribou and random locations to areas of the summer range where mineral exploration activities occurred. This included known point sources, buffered by 10,000 m, and broader areas for which an active mineral lease was on record. We hypothesized that the avoidance response of caribou to human disturbance would decrease as distance from the disturbance feature increased. Thus, we fit a nonlinear quadratic term to each disturbance variable (Table 2).

Resource Selection Function Models

We identified combinations of resource and disturbance variables that served as hypotheses to explain patterns in the distribution of Bathurst caribou. We generated candidate models for three time periods of distinctive behaviour across the summer range: post calving (14 June – 5 July), early summer (6 July – 18 July), and late summer (19 July – 22 August). We used conditional logistic regression to generate the coefficients for each candidate RSF. Statistical models were constructed using locations collected from collars deployed on caribou as well as locations generated using TK, weighted to have the same numerical influence as the more frequent collar data.

We used an information-theoretic approach to identify the most parsimonious model of the set of models we tested (Anderson et al. 2000). Akaike's information criterion (AIC_c), corrected for small sample sizes, identified the model with the greatest explanatory power that minimised bias and maximised precision of the model parameters. We reported the Akaike difference ($AIC_c\,\Delta$), calculated as the AIC_c score of each model subtracted from the model with the lowest score, and the Akaike weight (w), representing the approximate probability that the highest ranked model was the best model of the set. We used a two-step process to fit and evaluate models. We first fitted a set of models that represented habitat as determined by land cover or NDVI. Once we identified the most parsimonious habitat variable we incrementally fitted the three human disturbance variables: exploration site, mine sites, and mineral leases.

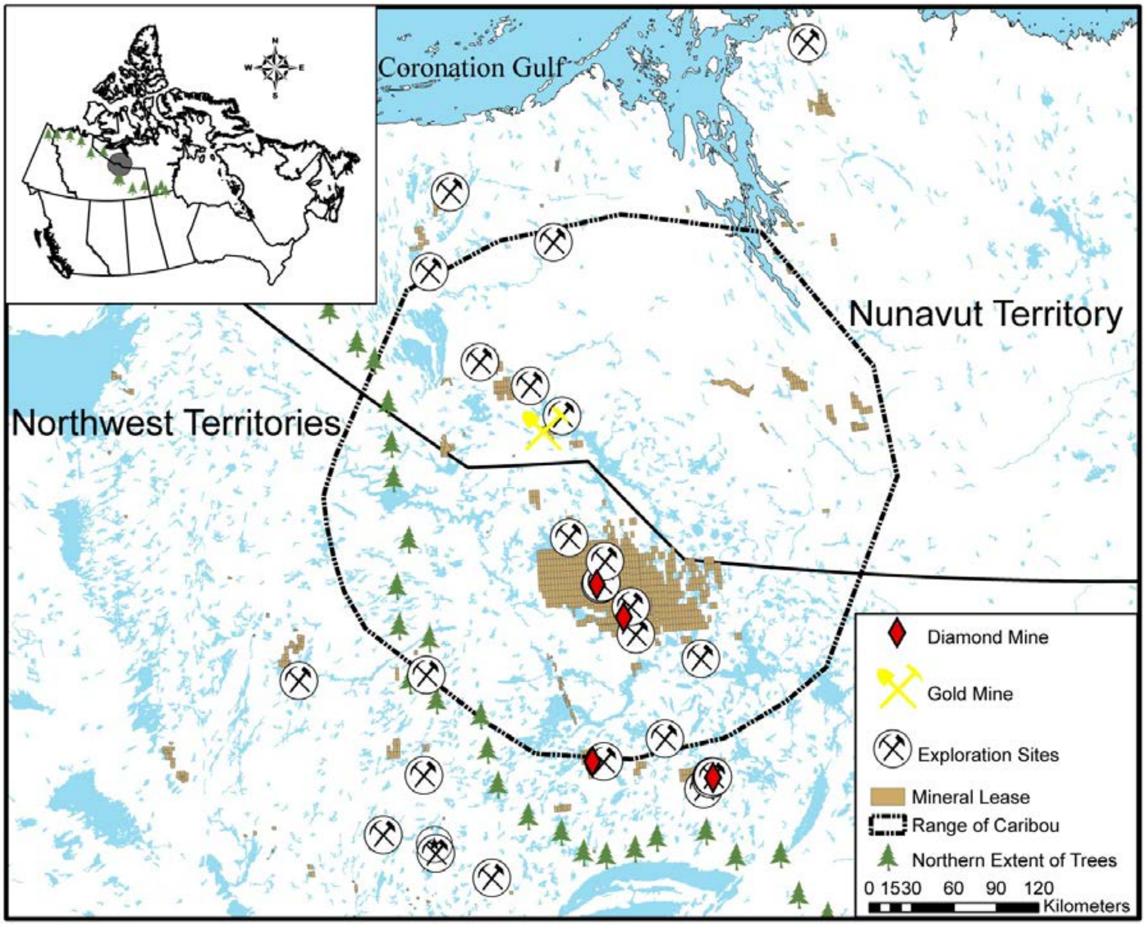

Figure 3: Location of human disturbance features across the post-calving and summer ranges of the Bathurst caribou herd, NWT and Nunavut, Canada.

Table 3: Description of variables used to construct RSF models quantifying the seasonal resource selection and distribution of Bathurst caribou.

Variable Name	Description
Land cover	Percent land cover within error radius surrounding satellite collar caribou location or caribou trail/harvesting location (Legat et al. 2001); land cover classes described in Table 1.
NDVI	NDVI at caribou locations; NDVI imagery was generated for 10 day intervals beginning on June 11 and ending August 22.
NDVI difference	Difference in NDVI as the summer progressed; difference represents NDVI value for a particular location date minus NDVI for same location after 10 day interval; represented the rate of change in plant phenology and green-up;

Variable Name	Description
Exploration site	Distance (m) to the ZOI (10,000 m circular buffer) around a recorded point source of known exploration activity.
Mine site	Distance (m) to the nearest mine (Ekati, Diavik, Lupin) footprint.
Mineral lease	Distance (m) to the nearest mineral lease

Results and Discussion

We used the observations of Tłı̨chǫ elders and 13 years of data collected with satellite collars to fit ten RSF models for each of the post calving, early summer and late summer seasons. For all seasons, the best model of habitat selection included a covariate for land cover (Table 3, ΔAIC = 0). In contrast to other studies of barren-ground caribou (Kelleyhouse 2001, Griffith et al. 2002, but see Parrett 2007), the NDVI variables were not as useful for explaining the seasonal distribution of Bathurst caribou. Following that result, we fit a number of additional models that included land cover with combinations of the three disturbance variables. In all cases, the best model was the most complex including land cover variables (Table 3) and a covariate for exploration site, mine site, and mineral lease.

During the post calving season, Bathurst caribou most strongly selected the tussock graminoid land cover class. To a lesser extent, caribou selected for the wet sedge, graminoid dwarf shrub, and low shrub classes (Figure 4). Caribou demonstrated a nonlinear avoidance response to mine site, exploration site, and mineral lease variables, although, the statistical relationship was imprecise (i.e., confidence interval (CI) overlapped 0) for all but the mine site covariate. The non-linear relationships suggested that the avoidance responses of caribou decreased as the distance from a mine site increased.

During early summer, caribou selected for the tussock graminoid, wet sedge, low shrub, and tall shrub cover types (Figure 5). Although caribou demonstrated an avoidance response to mine sites, the relationship was not statistically significant. The most parsimonious RSF model suggested that collared caribou had a higher relative probability of habitat use close to exploration sites and avoided areas of the early summer range that had mineral leases.

0Relative to the other seasons, resource selection by Bathurst caribou during late summer involved a larger number of plant communities. Caribou selected the tussock graminoid, wet sedge, graminoid dwarf shrub, low shrub, tall shrub, sparse vegetation-cryptogram, barren, bryoids, and wetland-tree land cover types (Figure 6). Caribou demonstrated a non-linear avoidance response to the mine site, exploration site, and mineral lease variables, although, the statistical relationship was imprecise (Figure 6).

Results from this portion of the pilot study were exploratory, but largely consistent with previous findings. Johnson et al. (2005) found similar patterns of avoidance, and in some cases selection, for human disturbances across the seasonal ranges of the Bathurst caribou.

As with Johnson et al. (2005), Boulanger et al. (2012) used the same set of caribou locations as applied in the current study to identify the ZOI around the Ekati and Diavik diamond mines. Also, they conducted a second analysis premised on an independent set of caribou locations collected using aerial survey techniques. They reported a ZOI of 14 and 11 km based on the aerial survey and satellite collar data, respectively.

Table 4: Results of information theoretic model selection procedure to select the most parsimonious RSF for Bathurst caribou during the post calving, early summer and late summer seasons. Models were first fitted to determine the best habitat covariate followed by a second iteration that included disturbance variables.

	Model Selection Metric			
	K	**AIC$_C$**	**ΔAIC**	***w***
Post Calving RSF				
Land cover	11	5,369.7	0.0	1.000
NDVI	1	5,469.8	100.0	<0.001
NDVI^2	2	5,471.8	102.0	<0.001
NDVI difference	2	5,486.7	116.9	<0.001
NDVI interaction	11	5,456.2	86.5	<0.001
Land cover + Disturbance				
Land cover + exploration site^2	13	5,323.2	45.1	<0.001
Land cover + mine site^2	13	5,332.3	54.2	<0.001
Land cover + mineral lease^2	13	5,362.3	84.2	<0.001
Land cover + exploration site + mine site + mineral lease	17	5,278.1	0.0	1.000
Early Summer RSF				
Land cover	16	3,542.3	0.0	1.000

	Model Selection Metric			
	K	**AIC$_C$**	**ΔAIC**	***w***
NDVI	1	3,620.4	78.0	<0.001
NDVI[2]	2	3,621.8	79.4	<0.001
NDVI difference	1	3,638.9	96.6	<0.001
NDVI interaction	12	3,643.9	101.6	<0.001
Land cover + Disturbance				
Land cover + exploration site[2]	18	3,512.8	77.8	<0.001
Land cover + mine site[2]	18	3,448.6	13.6	0.001
Land cover + mineral lease[2]	18	3,544.6	109.6	<0.001
Land cover + exploration site + mine site + mineral lease	22	3,435.0	0.0	0.999
Late Summer RSF				
Land cover	16	7,445.3	0.0	1.000
NDVI	1	7,722.9	277.6	<0.001
NDVI[2]	2	7,708.6	263.3	<0.001
NDVI difference	1	7,735.2	289.9	<0.001
NDVI interaction	13	7,692.4	247.1	<0.001
Land cover + Disturbance				
Land cover + exploration site[2]	18	7,442.6	105.2	<0.001
Land cover + mine site[2]	18	7,365.0	27.6	<0.001
Land cover + mineral lease[2]	18	7,431.3	93.9	<0.001
Land cover + exploration site + mine site + mineral lease	22	7,337.4	0.0	1.000

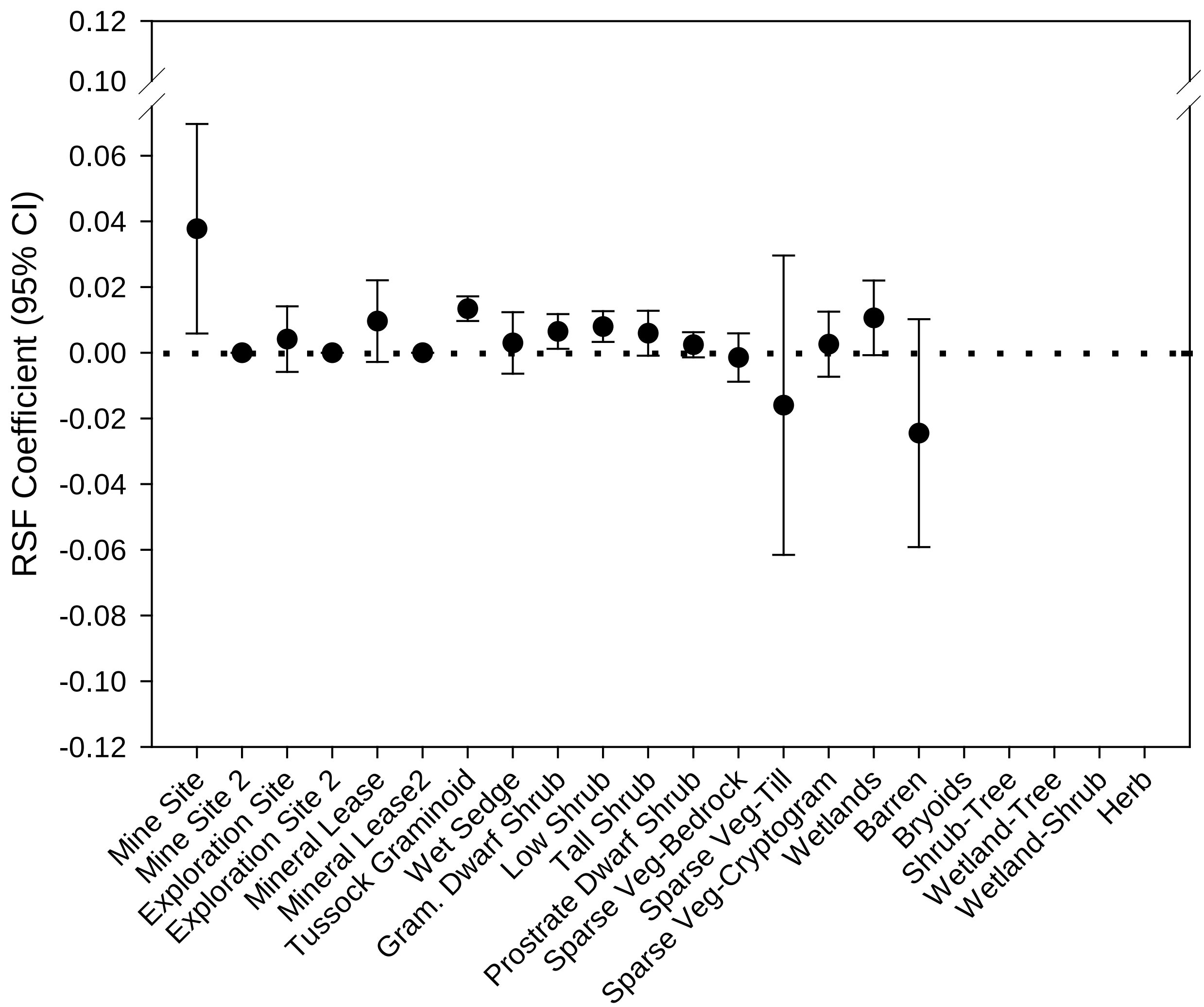

Figure 4: Strength of selection for land cover types and avoidance of disturbance features recorded across the range of the Bathurst caribou herd during the post-calving season. Error bars that do not overlap 0 represent a statistically significant response. The notation "2" indicates a non-linear quadratic term for a disturbance variable measured as the distance from the nearest disturbance feature.

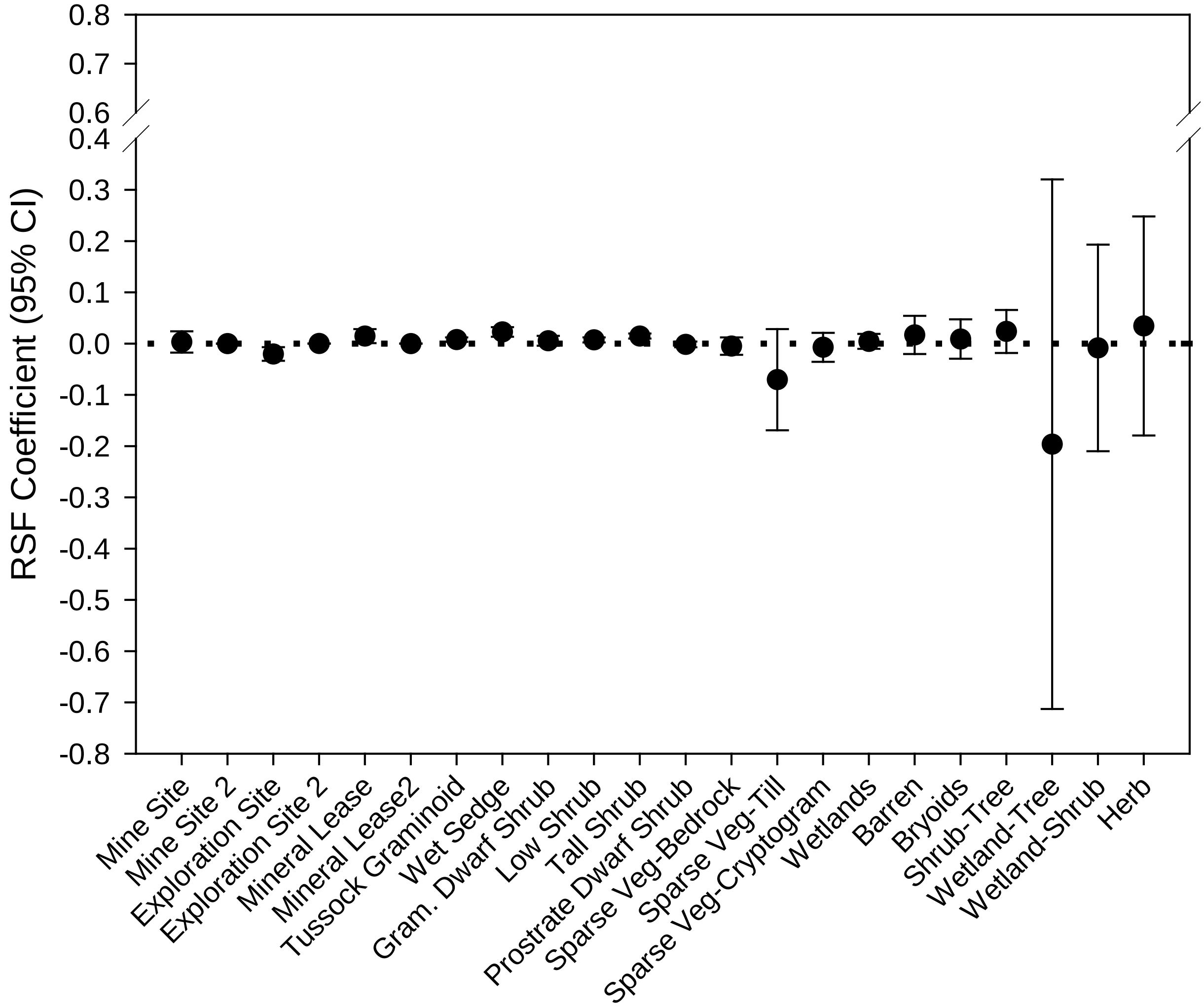

Figure 5: Strength of selection for land cover types and avoidance of disturbance features recorded across the range of the Bathurst caribou herd during the early summer season. Error bars that do not overlap 0 represent a statistically significant response. The notation "2" indicates a non-linear quadratic term for a disturbance variable measured as the distance from the nearest disturbance feature.

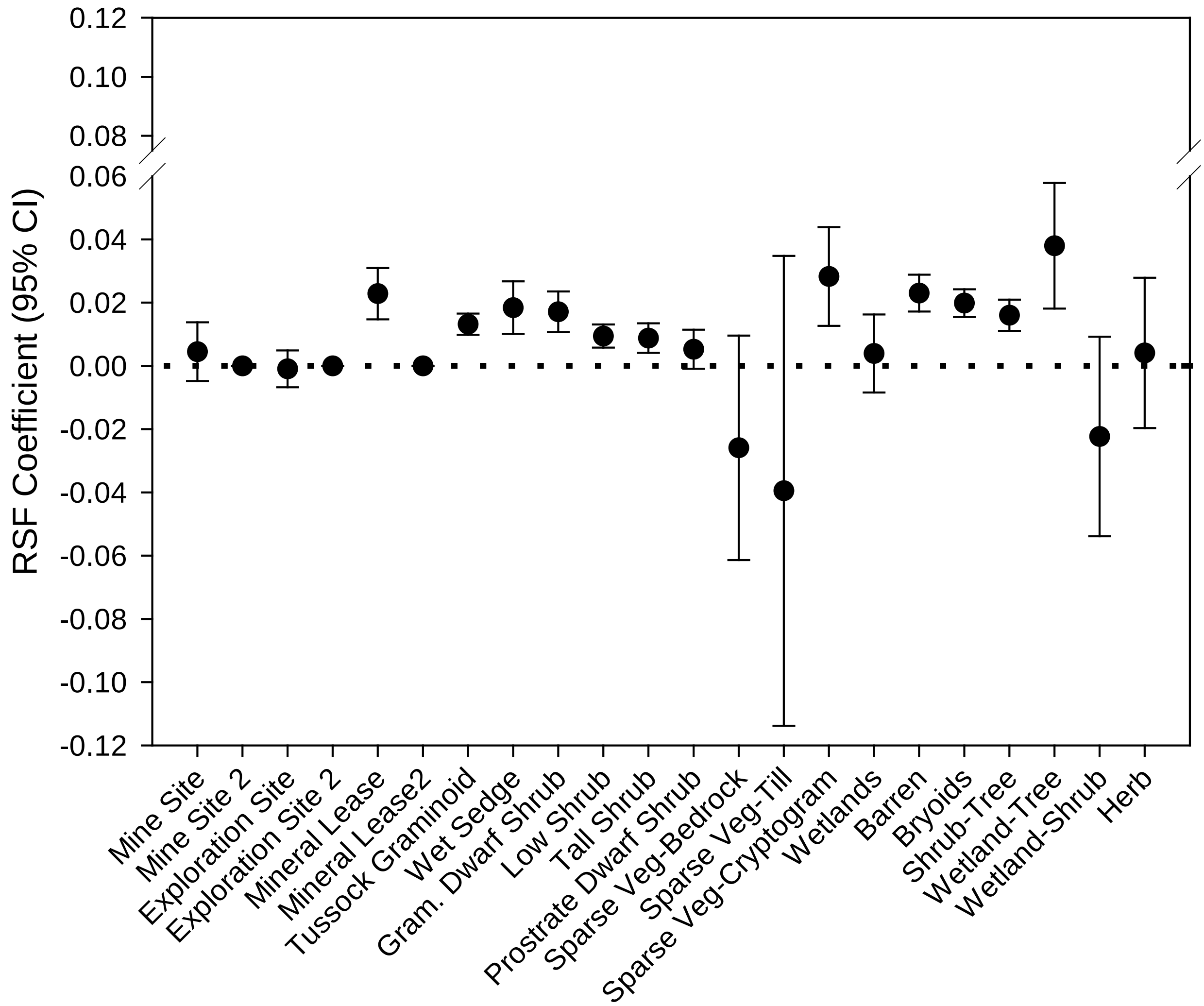

Figure 6: Strength of selection for land cover types and avoidance of disturbance features recorded across the range of the Bathurst caribou herd during the late summer season. Error bars that do not overlap 0 represent a statistically significant response. The notation “2” indicates a non-linear quadratic term for a disturbance variable measured as the distance from the nearest disturbance feature.

When compared to other studies of the habitat selection and disturbance responses of Bathurst caribou (Johnson et al. 2005, Boulanger et al. 2012) we employed TK and a greater time series of satellite collar data. Aboriginal harvesters have an intimate and long-term understanding of how caribou use the land and how the ecology of caribou might change in response to human developments. Such understanding is often not respected or applied by biologists and is rarely documented alongside or in conjunction with scientific studies (but see Santomauro et al. 2012). Our work has demonstrated that TK and science-based observations of caribou ecology can be integrated to address common questions focused on the conservation and management of caribou populations. Although the TK was informative for understanding how caribou were distributed relative to plant communities that knowledge was not collected in a way that allowed us to understand how caribou avoided mine sites. Future work, perhaps premised on Bayesian logic, might result in statistical techniques that allow the wisdom and knowledge of elders and harvesters to be integrated with the scientifically documented disturbance responses of caribou (Low Choy et al. 2009).

Quantifying the disturbance responses of caribou and the resulting ZOIs around human developments is complicated by the knowledge source (i.e. TK and science-based), sampling protocol for data collection, statistical technique, and scale of inference. For example, there are numerous methods for documenting the non-linear threshold responses of animals to disturbance stimuli with results potentially being influenced by method of choice (Ficetola and Denoel 2009). Indeed, even well studied populations of caribou provide no simple answers to how much disturbance is acceptable or how animal responses to human disturbance can be measured in the context of natural variation in behaviour and population processes. After 40 years of impacts research for barren-ground caribou (*R. t. granti*) calving near the Prudhoe Bay oil facility, there is still much debate about the significance of observed disturbance responses (Joly et al. 2006, Noel et al. 2004, 2006).

We suggest a cautious interpretation of the results presented here. Inter-animal variation in behaviour, considerable decline in the size of the Bathurst herd during the life-time of the current mines (Boulanger et al. 2011), and a relatively small effect-size for caribou-disturbance responses all suggest a high-level of uncertainty when trying to determine a precise static finding. During this project, we found that results were sensitive to the data employed for analysis. In particular, the incorrect inclusion of some disturbance distances resulted in caribou selecting versus avoiding mine sites. The sensitivity of results to data error is likely due to the product of relatively few mines across a very large study area, and that the mines were in different in phases of the mining life cycle. Although the influences of mines and exploration activities may be large for individual caribou, the total area of disturbance across the post-calving and summer range (Figure 2) is still relatively small. Only a minor proportion of the Bathurst herd such as 7-10% might be exposed to current mining activities during any one year, but the degree of exposure will vary with the size and migratory movements of caribou aggregations. Other populations of caribou found across southern Canada are facing massive change in habitats and predator-prey relationships where the effects are much more easily documented (Festa-Bianchet et al. 2011). Further monitoring using broad-scale collaring initiatives and the insights of people on the land are still warranted for the Bathurst herd. This is especially the case if the rate of development were to increase.

Despite the uncertainties in findings, the results from the pilot study, in combination with other work, suggest that disturbance effects are real for Bathurst caribou. Existing knowledge and data provide an opportunity to forecast and manage for future mines and importantly the cumulative impacts of disturbance across the central Arctic. Understanding changes in the distribution of caribou is an essential first step in documenting such impacts. However, the significance of those changes in distribution for population growth and ultimately the number of caribou will require mechanistic links to the productivity of individual female caribou (Johnson and St-Laurent 2010). In combination, the methods developed during the pilot project will provide insights on the number of caribou that might be found across a landscape facing incremental development pressures.

CHAPTER 3. PROPOSED APPROACH FOR USE OF ENERGETICS MODELLING TO UNDERSTAND POTENTIAL EFFECTS OF DEVELOPMENT FOR BATHURST CARIBOU ON SUMMER RANGE

By: Colin Daniel, Don Russell and Matt Carlson

Introduction

The typical response of caribou to human development (e.g. a large open pit mine) can include a reduction in foraging time as a behavioural response for caribou close to the development (based on measured activity budgets), increased activity costs (e.g. due to avoidance of human activity) and displacement away from the development that may result in foraging in different plant communities. The purpose of the energetics modelling component of this project was to simulate the response of an individual caribou cow, in terms of changes in body condition, to these various possible effects of development.

The energetics model has evolved over 30 years of study of the Porcupine caribou herd (Russell et al. 2005). The model predicts the daily growth of a caribou cow and her calf as a function of activity budgets, forage quality, and forage quantity (Figure 1). The model consists of two sub-models. The first is the energy sub-model, which predicts daily changes in a cow's metabolizable energy intake (MEI) by calculating the cow's food intake and then simulating the functioning of the cow's rumen and her digestive kinetics on an hourly basis. The MEI predicted by the energy sub-model is then fed into a growth sub-model, which calculates the cow's energy balance and the subsequent change in weight of both the cow and her calf on a daily basis based on differential allocation of energy to gestation, lactation and deposition and/or depletion of fat and protein reserves.

This chapter documents the initial findings of the energetics modelling component of this overall demonstration project, including its connection to the RSF analysis presented in Chapter 2. The chapter begins with a discussion of the methods used for this demonstration project, including the initial data sources used to parameterize the energetics model, followed by a brief presentation of preliminary results and recommendations for next steps.

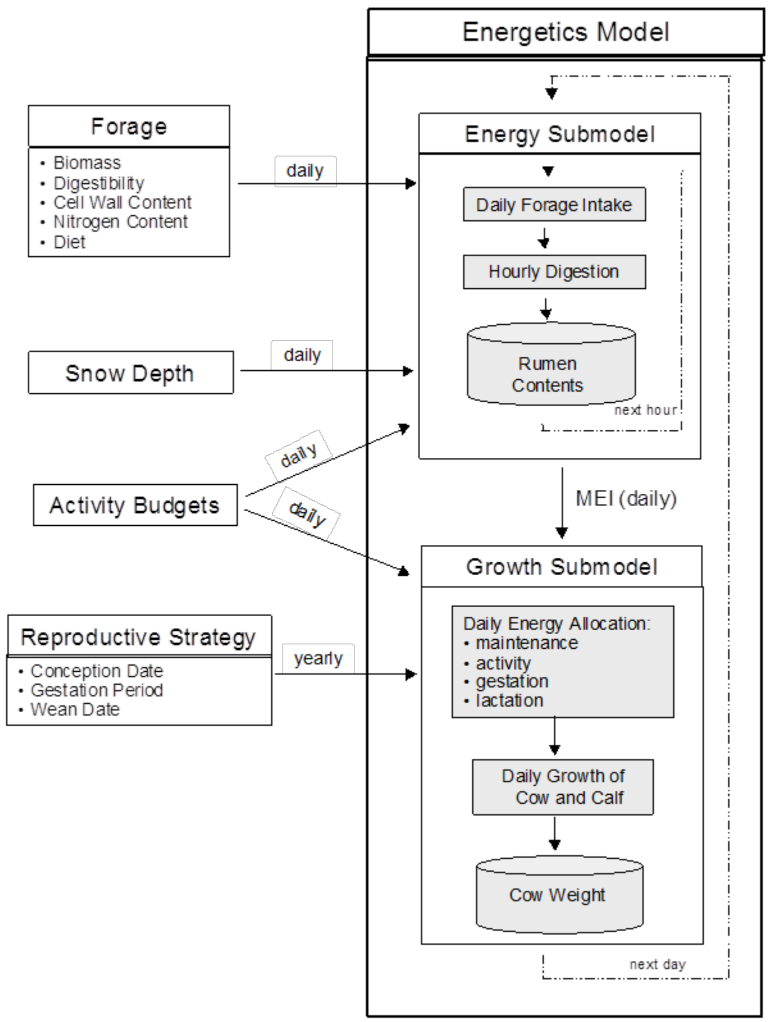

Figure 7: Generalized structure of the caribou energetics model (from Russell et al 2005).

Methods and Data

Habitat Types and Development Zones

The study area for this analysis was defined as the summer range of the Bathurst caribou herd. The total size of the study area was 196,521 ha (Appendix A). The study area was stratified into a series of habitat types and development zones (Appendix A): these landscape strata served to both identify the resource variables to be used in the RSF analysis, and to specify the scope for certain inputs to the body condition model. As listed in Table 1, 18 mutually exclusive habitat types were defined for the RSF analysis. For the purposes of the body condition model, the landscape was also divided into two development zones: areas within 30 km of mine sites, and those areas beyond 30 km of the mines. A 30 km buffer was selected as this was considered the maximum distance over which mine operations might affect caribou on the Bathurst range, based upon the best available estimate of the ZOI of the Diavik mine as of the time of this analysis (Diavik Diamond Mines Inc. 2008); note that since this analysis Boulanger et al. (2012) has estimated the ZOI of the combined Diavik and Ekati mines to be approximately 14 km.

To simplify the specification of model inputs in the body condition model, the 18 habitat types used in the RSF model were aggregated into ten types for the body condition model (Table 5). As summarized in Figure 8, composition of the development zone was similar to the overall study area, although some differences existed including scarcity of the prostrate dwarf shrub and sparsely vegetated habitat types and an abundance of dry shrub and bryoids habitat types relative to the study area.

Table 5: Description of the ten habitat types used in the body condition model.

Body Condition Habitat Type	Name	Description	Corresponding RSF Habitat Classes	Total Area (km^2)	Area within Development Zone (km^2)
0	Other		no vegetation, water	48,741	3,834
1	Forest	From sparse to dense coniferous forest (11.5%), decid, mixed (2.5%).	forest	17,938	1,115
2	Shrub tundra	25% of the vegetated cover, consisting mainly of dwarf birch (Betula) and / or willow (Salix). Remaining cover consists of graminoids, lichen and may contain prostrate dwarf shrubs and bare soil.	low shrub, tall shrub	30,896	1,485
3	Tussock graminoid tundra	Moist tussock tundra with < 25% dwarf shrubs < 40 cm tall and moss. May also include lichen.	tussock graminoid	29,608	1,606
4	Sparsely vegetated areas	Bare rock, barren, frost boils	sparse vegetation, barren	12,771	456
5	Prostrate dwarf shrub	Dryas / heath, usually on bedrock or till. Generally dry > 50% vegetated cover consisting of prostrate dwarf shrubs, graminoids and may contain < 10% lichen and moss.	prostrate dwarf shrub	16,206	255
6	Dry shrub	At least 20% ground cover which is at least one-third shrub.	shrub	10,529	951
7	Wetlands	Moss dwarf-shrub wetlands.	wetlands, herb	6,865	509
8	Non-tussock graminoid tundra	Moist to dry non-tussock tundra with 50-70% vegetated cover. Vegetation includes a mixture of graminoids, dwarf erect < 40 cm and prostrate dwarf shrubs. May also include trace amounts of lichen and moss.	graminoid dwarf shrub	8,324	337
9	Bryoids	Minimum of 20% ground cover or one-third of total vegetation must be a bryophyte or lichen.	bryoids	9,785	907
10	Wet sedge	Wet sedge including cottongrass that is saturated for a significant part of the growing season, also includes moss and may include < 10% dwarf shrubs < 40 cm tall.	wet sedge	4,858	368
			Totals:	196,521	11,823

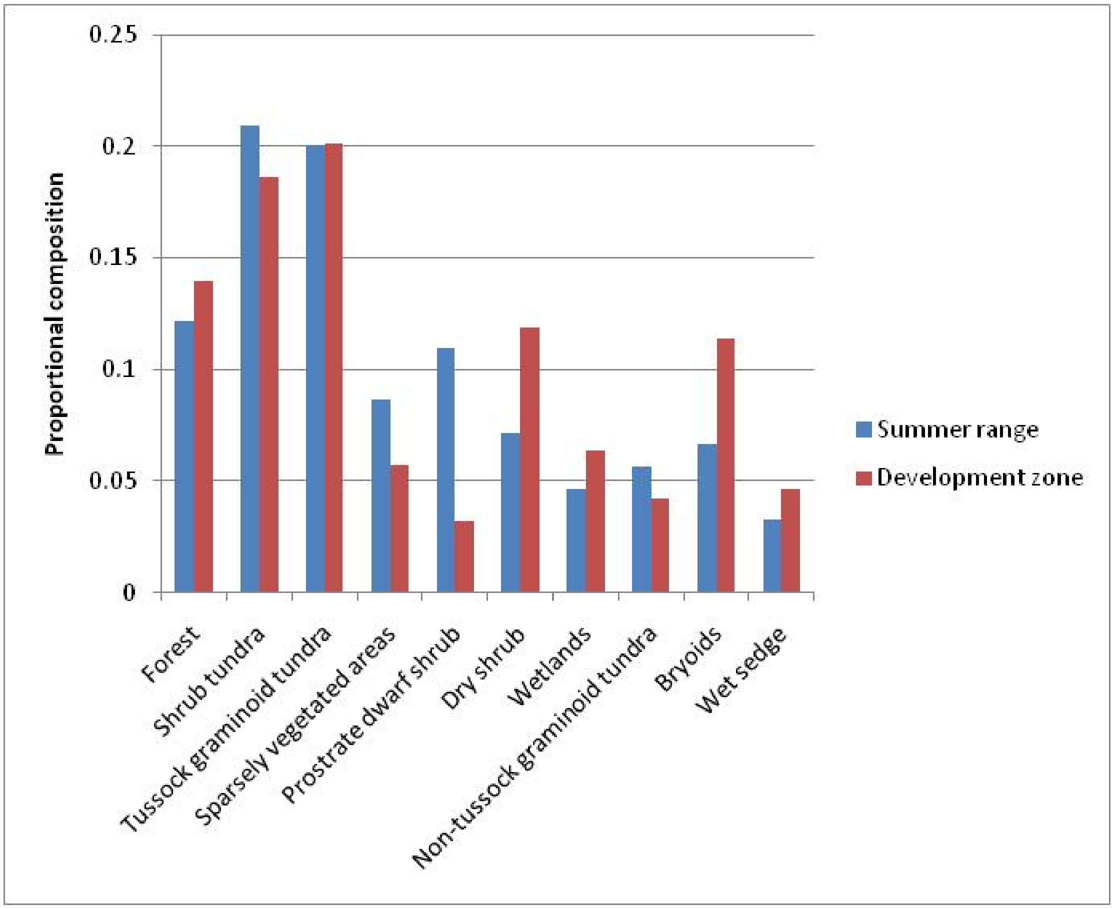

Figure 8: Composition of the study area (i.e., summer range) and the development zone within the summer range (i.e., 30 km zone surrounding active mine sites).

Temporal Extent

The start and end dates of this analysis were constrained to the period over which caribou typically used their summer range: the start date for body condition models runs was set to June 14 (Julian Day 165), representing the normal end of the calving period for the Bathurst herd; the end date for model runs was set to October 15 (Julian Day 288), representing the start of the rut.

To facilitate model parameterization, the temporal extent of the analysis was divided into four seasons:

- Post-calving: June 14 – July 5 (Julian Day 165-186)
- Early summer: July 6 – July 18 (Julian Day 187-199)
- Late summer: July 19 – August 22 (Julian Day 200-234)
- Non-RSF period: August 23 – October 15 (Julian Day 235-288)

The first three seasons correspond to the seasons used in the RSF analysis, while the last season corresponds to those days that extend beyond the RSF timeframe.

Alternative Climate and Development Scenarios

To explore the sensitivity of body condition model predictions to different possibilities regarding future climate and development, a total of nine different scenarios were considered for the runs of the body condition model. As outlined in Table 6, each scenario consisted of an assumption regarding the level of development (none, current, or double current development) and climate (average, worst-case and best-case).

Table 6: Alternative scenarios for the body condition model.

Scenario	Level of Development	Climate Year-Type
1	None	Average
2	Current	Average
3	2x Current	Average
4	None	Worst-case (high snow, high insect, short green-up)
5	Current	Worst-case (high snow, high insect, short green-up)
6	2x Current	Worst-case (high snow, high insect, short green-up)
7	None	Best-case (low snow, low insect, long

Scenario	Level of Development	Climate Year-Type
		green-up)
8	Current	Best-case (low snow, low insect, long green-up)
9	2x Current	Best-case (low snow, low insect, long green-up)

With respect to the level of development, "current" scenarios represent current mining activity on the Bathurst summer range (see Chapter 2 and Figure 3). Based on the scenarios outlined in Table 6, a total of 11,823 ha, or 6% of the summer range was considered within the development zone; the "no development" scenarios assumed that no development occurred on the summer range, while the "2-times (2x) current development" scenarios assumed that the total area within the development zone was double that of current conditions. The 2x current development scenarios were intended to provide an indication of the sensitivity of model predictions to possible future increases in development activity.

For the climate year-types, the "average" climate scenarios represented current average climatic conditions. The worst-case climate scenario was intended to represent the worst possible combination of climatic conditions for caribou: high winter snow levels, high summer insect harassment and a short green-up period for plant biomass. Similarly the best-case climate scenario represented the best possible climatic conditions (i.e., low winter snow levels, low insect harassment and long green-up).

The nine scenarios were selected to illustrate the sensitivity of model predictions to a range of possible assumptions regarding development and climate. As this analysis was intended as a demonstration only, the number of scenarios considered was kept low due to the manual setup time required for each run when using the current body condition model. A future version of the body condition model will be able to handle multiple scenarios and stochastic simulations in an automated way, making it much simpler to assess the effects of uncertainty in model inputs over a broader range of possible future scenarios.

Model Inputs

Plant Biomass

A set of plant groups was defined for the body condition model – these plant groups were in turn used as the basis for specifying other forage-related model inputs, such as biomass and quality. In this analysis we used the same ten plant groups used in previous work with the body condition model (Russell et al. 2005), which were as follows:

- Moss
- Lichens
- Mushrooms
- Horsetails
- Graminoids
- Deciduous shrubs
- Evergreen shrubs
- Forbs
- Standing dead
- Eriophorum (cotton-grass) flowering heads

The first body condition model input was the annual maximum biomass of each plant group, which was specified for each habitat type (see Table 7).

Table 7: Maximum biomass (kg•ha-1) for each plant group by habitat type.[3]

Plant Group	Habitat Type									
	Forest	Shrub tundra	Tussock graminoid	Sparsely vegetated	Dwarf shrub	Dry shrub	Wet-lands	Non-tussock graminoid	Bryoids	Wet sedge
Moss	250	100	125	5	5	50	250	10	100	250
Lichen	150	25	20	25	20	20	5	5	150	30
Mushroom	10	15	2	2	2	5	10	5	10	10
Horsetail	6	2	2	2	2	2	10	35	2	2
Graminoid	5	5	60	2	15	5	35	35	5	70
Deciduous	40	90	40	5	20	30	35	40	5	20
Evergreen	50	40	25	65	80	40	45	30	10	20
Forb	5	5	10	20	25	5	5	10	2	5
Standing dead	0	0	80	0	10	0	0	5	0	10
Eriophorum	0	0	5	0	0	0	0	0	0	2

The second model input was a description of the phenology of each plant group over the growing season, which for this analysis was characterized using three dates: a start date (i.e., start of plant emergence), peak date (i.e., date of maximum biomass) and end date (i.e., end of plant senescence). As shown in Table 8, these dates varied as a function of the climate scenario, representing changes in the pattern of plant phenology associated with early and late green-up.

[3] Maximum biomass values were estimated by D. Russell (pers. comm.) for the Bathurst summer range. As these figures represent average values across the entire range, the maximum biomass experienced by an individual animal was assumed to be three times higher than these figures due to the patchy distribution of the plants that an animal typically encounters when feeding.

Table 8: Julian dates for plant emergence, peak biomass and senescence associated with each plant group and climate scenario[4].

		Julian Date by Climate Year-Type		
Plant Group	**Phase**	**Worst**	**Average**	**Best**
Moss	Emergence	160	150	140
	Peak	220	210	180
	Senescence	250	255	270
Lichen	Emergence	160	150	140
	Peak	220	210	180
	Senescence	250	255	270
Mushroom	Emergence	190	180	170
	Peak	260	250	220
	Senescence	275	280	280
Horsetail	Emergence	160	150	140
	Peak	220	210	180
	Senescence	250	255	270
Graminoid	Emergence	162	152	137
	Peak	216	206	181
	Senescence	252	257	272
Deciduous	Emergence	168	158	137
	Peak	223	213	181
	Senescence	263	268	274
Evergreen	Emergence	159	149	146

[4] Plant phenology is based upon previous work using the body condition model to predict the effects of the Diavik mine development on caribou (AXYS 1999).

		Julian Date by Climate Year-Type		
Plant Group	**Phase**	**Worst**	**Average**	**Best**
	Peak	225	215	185
	Senescence	249	254	278
Forb	Emergence	163	153	137
	Peak	222	212	193
	Senescence	249	254	269
Standing dead	Emergence	220	210	180
	Peak	250	260	270
	Senescence	300	300	300
Eriophorum	Emergence	155	145	135
	Peak	170	160	150
	Senescence	195	200	200

Resource Selection

An RSF developed for the Bathurst herd (Chapter 2; C. Johnson, pers. comm.) was used to generate simulations of caribou movement for this analysis. The RSF used in this analysis was of the form:

$$RSF = \exp(\sum b_i H_i + b_{19} D + b_{20} D^2),$$

where RSF was the RSF score, H_i was percent cover for each of the 18 RSF habitat types (as listed in Table 2), D was the distance to active mine sites, and b_i were coefficients from the RSF model. The RSF score can be interpreted as the probability of a caribou occurring in a location with composition defined by b_i and D, relative to a random location on the landscape (Johnson et al. 2005). An RSF score >1 implies that a location is being selected for, whereas a RSF score <1 implies that a location is being selected against.

The RSF was used to estimate two RSF scores for each habitat type: one score that applied outside the development zone and a second score that applied inside the development zone. To generate a RSF score for a given habitat type, we assumed that percent cover (i.e., b_i) was 100% for the habitat type in question and 0% for all other cover types. When calculating the RSF score that applied inside the development zone, the distance from an active mine site (i.e., D) was set at 15 km (i.e. the mid-point of the assumed 30 km development zone width). When calculating the RSF score that applies outside of the development zone, the distance from an active mine site was set at 30 km.

Based on these assumptions, the equations for calculating the RSF scores for a specific habitat type can be expressed as follows:

$$RSFIN_h = \exp(100*b_h + 15*b_{19} + 15^2*b_{20})$$

$$RSFOUT_h = \exp(100*b_h + 30*b_{19} + 30^2*b_{20})$$

where:

$RSFIN_h$ = RSF score within the development zone for habitat type *h*

RSFOUT = RSF score outside of the development zone for habitat type *h*

b_h = RSF coefficient for habitat type *h*

b_{19} and b_{20} = RSF coefficients for the distance from development

Separate RSF coefficient estimates (i.e., values for b_i) were provided by C. Johnson (pers. comm.) for each of three seasons: post-calving, early summer, and late summer; 1,000 bootstrapped estimates of the 20 coefficients were provided for each of the three RSF seasons to reflect uncertainty in the coefficient estimates[5].

Activity Budget

The activity budget specified the proportion of time spent by the caribou each day engaged in each activity type. The activity types currently recognized by the model included foraging, lying, standing, walking, running, with the proportion of total foraging time further broken down into time spent eating and time spent pawing.

As shown in

Table 9, activity budgets were specified for each possible climate scenario, in order to account for the effects of snow depth and insect harassment on caribou activity. Activity budgets were selected for model runs as follows:

- For the “best” climate scenarios, the caribou followed “low” insect level activity budgets for the entire simulation;
- For the “average” and “worst” climate scenarios, the caribou followed the “average” and “high” insect level activity budgets for Julian Days 190-208,

[5] The bootstrapped estimates included occasional negative estimates of b_{19}, the coefficient expressing the change in RSF score with distance from development. A negative coefficient implies that caribou are selecting for areas closer to disturbances. Negative estimates of b_{19} are thought to reflect model uncertainty rather than true selection for areas closer to disturbances (Chris Johnson, pers. comm.). Therefore, when randomly sampling bootstrapped coefficient estimates, samples with negative coefficients for b_{19} were excluded.

respectively; for all other days the caribou followed the "low" insect level activity budget; and

- The "development" activity budget was followed on those days when the caribou was located within the development zone; otherwise the caribou followed the "no-development" activity budget.

Table 9: Caribou activity budgets used in a scenario analysis for each combination of development and insect level[6].

		Proportion of Day by Activity Type					Proportion of Foraging Time	
Development	**Insect Level**	**Foraging**	**Lying**	**Standing**	**Walking**	**Running**	**Eating**	**Pawing**
No	Low	0.43	0.14	0.03	0.31	0.10	0.88	0.00
Yes	Low	0.47	0.07	0.00	0.29	0.18	0.88	0.00
No	Average	0.37	0.08	0.16	0.25	0.13	0.80	0.00
Yes	Average	0.38	0.04	0.11	0.26	0.21	0.80	0.00
No	High	0.32	0.02	0.30	0.20	0.16	0.72	0.00
Yes	High	0.31	0.03	0.21	0.21	0.23	0.72	0.00

Snow Depth

While not required to run the model on the summer range (i.e., from June 14 – October 15), snow depths on the winter range were required as an input in order to generate different

[6]Activity budgets under conditions of "no-development" were based upon preliminary field data from L. Witter gathered from 2007-2008 for the Bathurst caribou summer range, and synthesized by D. Russell (pers. comm.). These activity budgets were then adjusted to account for the effects of development using previous work by Murphy et al. (2000) on the central Arctic herd.

initial conditions for the model runs for each climate scenario. Snow depths were provided for each possible climate scenario (see Table 10).

Table 10: Snow depths used to establish initial conditions for the model runs.[7]

		Snow depth (cm) by Climate Scenario		
Date	**Julian Day**	**Best**	**Average**	**Worst**
1-Feb	32	50	68	72
13-Mar	72	53	63	72
16-Apr	106	42	50	64
10-May	130	8	15	56
26-May	146	0	0	45
5-Jun	156	0	0	9

Running the Model

The following section describes the approach used to run the body condition model for each of the nine scenarios previously identified in Table 6.

Calculate the Average Time Spent in Each Landscape Stratum

Running the body condition model required an estimate of the proportion of time spent in each landscape stratum within the summer range, where landscape stratum refers to a combination of habitat type and development zone. For the post-calving, early summer, and later summer seasons, this proportional use of each landscape stratum was estimated

[7] Snow depth values correspond to those used in previous work modelling the effects of the Diavik mine on caribou energetics (AXYS 1999).

by simulating caribou movement based on the RSF. This required calculating selection probabilities seasonally for each landscape stratum using the RSF coefficients, and then simulating the random selection of a landscape stratum each day based on these seasonal selection probabilities. The result was a time series specifying the landscape stratum selected by the animal for each day of each season – which we refer to here as a "movement scenario".

For a given season, generating a single movement scenario required the following steps. First, a set of 20 RSF coefficient estimates was randomly selected from the 1,000 bootstrapped sets of coefficient estimates for that season. As described previously, the coefficient estimates were then used to calculate RSF scores for each RSF landscape stratum[8]. A seasonal selection probability was calculated for each RSF landscape stratum as follows:

$$P_{i,s}=RSF_{i,s} * Area_i / \sum(RSF_{i,s} * Area_i)$$

where:

- $P_{i,s}$ = the selection probability for stratum *i* in season *s*;
- $RSF_{i,s}$ = the RSF coefficient for stratum *i* in season *s*; and
- $Area_i$ = the area within landscape stratum *i*.

[8] There are 36 RSF landscape strata, one for each combination of 18 RSF habitat types and two development classes (within development zone and outside of development zone).

These selection probabilities ($P_{i,s}$) were then used to randomly select a single landscape stratum for each day of the simulation.

The process described above for simulating caribou movement is inherently stochastic, as it is influenced by two sources of variability: a) the random selection of a set of coefficient estimates from the 1,000 bootstrapped estimates; and b) the random selection of a landscape stratum each day using the selection probabilities described above. Due to this stochasticity, no two caribou movement scenarios predict exactly the same pattern of habitat use. In order to summarize this stochastic behaviour for use in the deterministic body condition model, we calculated the proportional use of each landscape stratum within a season by averaging the results across a set of 100 randomly generated movement simulations.

Sets of 100 randomly generated movement simulations were completed for each of the three levels of disturbance to be assessed by the body condition model (no development, current development, and 2x current development). Movement simulations were also completed for 3x, 4x, and 5x current development scenarios, in an effort to better understand the sensitivity of the predictions regarding habitat use to varying levels of development.

Caribou movement could not be simulated for the “non-RSF” period (i.e. August 23 – October 15) because RSF coefficients were not generated for this period. Instead, caribou were assumed to be selecting the “forest” habitat type for this entire period.

Specify the Condition of the Animal at the Start of the Simulation

Generating a reasonable initial condition for the animal on June 14 was accomplished using three “initialization” runs of the body condition model from January 1 until June 14, with each of these runs predicting the condition of an average pregnant, lactating adult female under one of three different assumptions regarding snow depth. Snow depth values from January 1 to June 14 were set to reflect conditions on the Bathurst winter range for the appropriate climate scenario (i.e., for low, average and high snow years – see Table 6). Activity budgets from January 1 – June 14 were set to values previously used in the 1999 Diavik mine assessment (AXYS 1999). All other model inputs were set to values developed previously representing average conditions for the Porcupine caribou herd (D. Russell, pers. comm.).

Run the Body Condition Model

The next step was to run the body condition model from June 14 to October 15 for each of the nine scenarios identified in Table 6. The body condition of the animal at the start of each run (i.e., June 14) was set according to the appropriate initial conditions predicted at the end of one of the three initialization runs (see Step 2 above). The model was then run forward through each of the four seasons using the model inputs described above, predicting the daily body condition of an average lactating adult cow for each of the nine scenarios.

Predict Change in Population Parameters

Having run the body condition model for a suite of scenarios, the last step was to relate predicted changes in body condition to changes in one or more population parameters. Figure 9 shows the relationship between the fall cow weight and birth rate the following spring, as determined using data from the central Arctic and Porcupine herds (D. Russell, pers. comm.):

$$BR = e^{N} / (1 + e^{N})$$

where:

BR = birth rate

$$N = B_0 + (B_1 \times BW)$$

BW = fall body weight (kg)

Using this relationship and the body weight predicted by the model on October 15 for each of the nine scenarios, the resulting birth rate was predicted for each scenario.

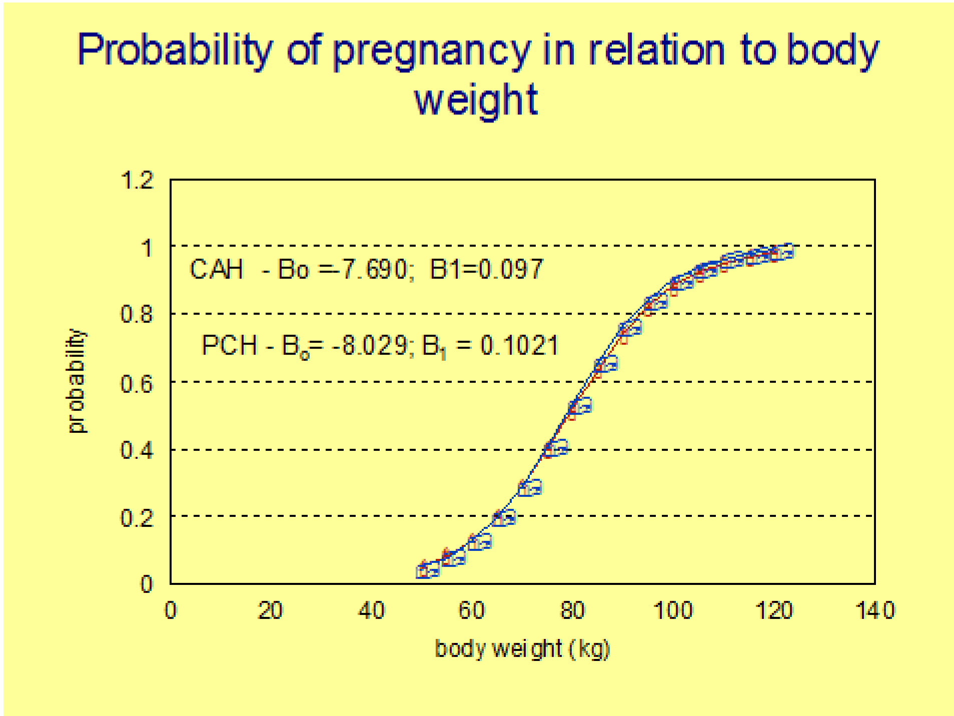

Figure 9: Relationship between probability of pregnancy and the body weight in the previous fall (PCH = Porcupine caribou herd; CAH = central Arctic herd).

Preliminary Results

Resource Selection

The RSF based movement simulations were used to predict the proportion of time spent by caribou in each habitat type (Table 11); these average figures were then used to calculate biomass and diet inputs for all body condition simulations.

Table 11: Proportion of time spent within each habitat type for the current disturbance scenario, as estimated by caribou movement simulations.

Habitat type	Proportion of time spent by caribou within habitat types: Post-calving	Early summer	Late summer	Entire RSF period
Forest	0	0	0	0
Shrub tundra	0.28	0.05	0.13	0.16
Tussock graminoid tundra	0.46	0.04	0.17	0.24
Sparsely vegetated areas	0.04	0.08	0.19	0.12
Prostate dwarf shrub	0.09	0.01	0.04	0.05
Dry shrub	0	0.22	0.09	0.09
Wetlands	0.06	0.51	0.13	0.18
Non-tussock graminoid tundra	0.06	0.01	0.07	0.05
Bryoids	0	0.05	0.13	0.08
Wet sedge	0.03	0.03	0.04	0.04

Table 12 shows the proportion of time spent within the development zone for each season, as calculated from the movement simulations. Reflecting the small amount of development within the summer range, exposure of caribou to the development zone was calculated as 3.6 days from June 14 – August 22. Over the entire RSF period, the proportion of time spent within the development zone (5.1%) was similar to the proportion of the summer range occurring within the development zone (6.0%).

Table 12: Time spent within the development zone under current development levels, as estimated by 100 randomly generated RSF based caribou movement simulations.

	Average time spent within development zone	
Season	**# of Days**	**Proportion of Season**
Post-calving	0.5	0.023
Early summer	1.2	0.091
Late summer	1.9	0.054
Entire RSF period	3.6	0.051

Based on this analysis, scenarios representing "current development" were modeled assuming that the animal was in the development zone for a total of four days during the RSF period. The distribution of these days was set to match the averages predicted by the caribou movement simulations (Table 12) for each of the RSF seasons:

- Post-calving (June 14 – July 5): one day in the development zone
- Early summer (July 6 – July 18): one day in the development zone
- Late summer (July 19 – August 22): two days in the development zone

Monitoring data for the Bathurst herd suggested that caribou cows remain in the vicinity of the active mine sites on the summer range until shortly before the rut (CARMA 2012). As a result, we assumed that cows would spend the same proportion of time in the development zone during this period as during the other seasons. For the post-RSF period (i.e., August 23 – October 15), the number of days spent by caribou in the development zone was calculated as:

[Proportion of time in development zone over entire RSF period] × [Total number of days in non-RSF period]

$$= 0.051 \times 53 \text{ days} = 2.7 \text{ days}$$

Based on this calculation the body condition model exposed a caribou cow to an additional three days within the development zone during the post-RSF period for "current" development scenarios, for a total of seven days of time spent in the development zone over the entire summer period.

For all four seasons the dates for each season's development zone exposure were set to occur on consecutive days and occurring in the middle of each season (i.e., beginning on June 24, July 12, August 4 and September 17). For the "2x current development" scenarios, the number of consecutive days of exposure to development each season were doubled (i.e., post-calving: two days; early summer: two days, late summer: four days; post-RSF: six days).

Body Condition

Initial conditions were calculated using the three “initialization” runs. These values were in-turn used as the starting condition for the animal for the nine alternative scenarios:

- animal weights predicted following a “low” snow year were used to initialize the model on June 14 for all “best” climate scenarios;
- animal weights predicted following an average snow year were used to initialize the model on June 14 for all “average” climate scenarios; and
- animal weights predicted following a “high” snow year were used to initialize the model on June 14 for all “worst” climate scenarios.

Table 13 provides a summary of both the initial conditions (i.e., June 14) and the predictions made by the model at the end of the summer (i.e., October 15) for each of the nine possible scenarios. While the initial body weight of the animal appears to drive the body weight in the fall, changing the level of development appears to result in little change in predicted fall body weight. Figure 10 provides a time series depiction of these results for three of the nine scenarios – note that the other six scenarios are not displayed in this figure as they overlap so closely with the three shown due to the negligible effect of development on predicted body weight.

Table 13: Initial and final predicted body weight for each scenario.

Scenario #	Level of development	Climate year-type	Body weight (kg)	
			June 14	October 15
1	None	Average	82.4	81.6
2	Current	Average	82.4	81.5
3	2x Current	Average	82.4	81.3
4	None	Worst-case	76.1	75.6
5	Current	Worst-case	76.1	75.5
6	2x Current	Worst-case	76.1	75.4
7	None	Best-case	87.7	86.0
8	Current	Best-case	87.7	85.9
9	2x Current	Best-case	87.7	85.7

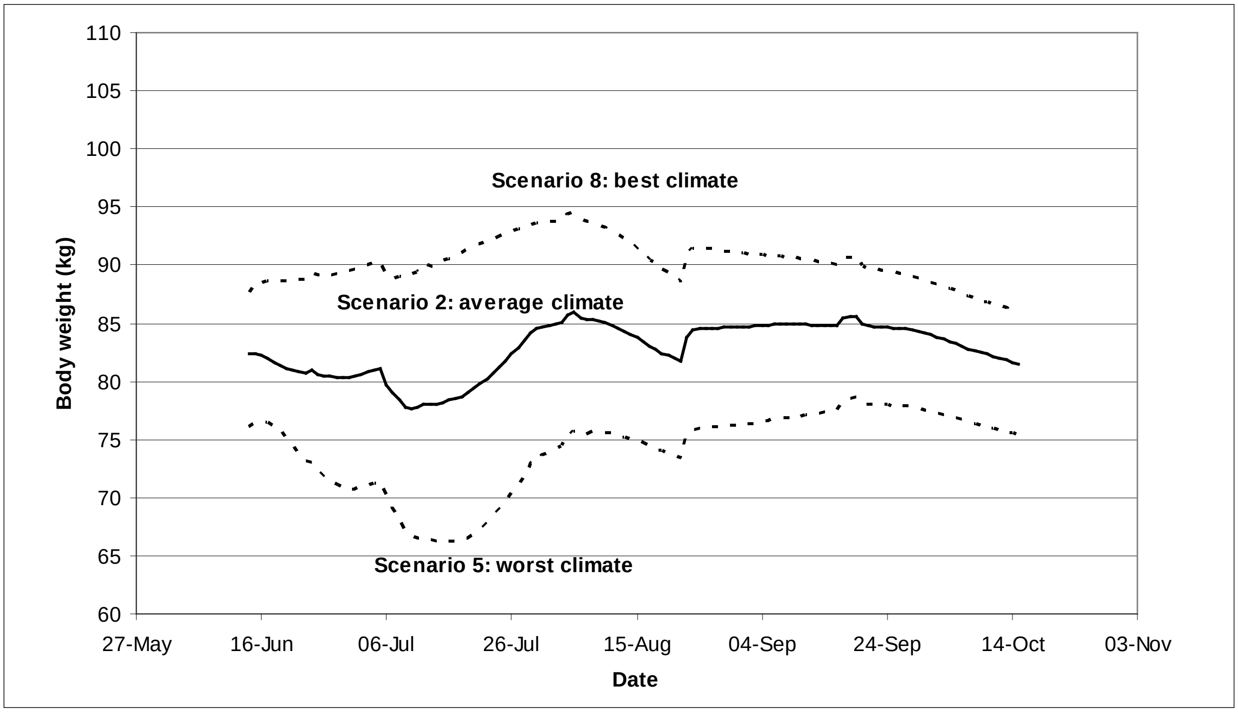

Figure 10: Predicted body weight over time for the three scenarios representing current development (i.e., Scenarios 2, 5 and 8).

Discussion

The objective of the demonstration project was to establish the feasibility of linking modelling approaches in support of cumulative effects assessment for the Bathurst caribou herd. In this regard we believe the project was a success: an RSF model was developed to predict habitat use of caribou on the Bathurst summer range, which in turn was used to predict biomass availability as an input to a body condition model; the body condition model was then used to predict changes in cow body weights. Together these two modelling approaches provide a way to simulate and explore the effects of alternative assumptions regarding future climate and development on the body condition of caribou cows.

Resource Selection

The movement simulations suggested that on average an individual caribou cow spends approximately 5% of the summer season, or seven days total (from June 15 - October 15), within the ZOI of current active mines. Furthermore the habitat composition within the development zones was found to be similar to that of the entire study area. Use of the development zone did differ slightly between seasons, with caribou spending a greater proportion of their time within the development zone as the summer progressed. We suspect, however, that this finding may be a function of the location of the mine sites within the summer range rather than a differential response of caribou to mine sites across seasons. Caribou tend to move south across the range as the summer progresses towards where the active mine sites are located (Figure 11, CARMA 2012).

It should be noted that several assumptions were made during the caribou movement simulations. Firstly, we assumed that the habitat composition of post-calving, early summer, and late summer ranges were equivalent to the overall summer range, which was an oversimplification of summer habitat use by caribou. However, given the limitations of the telemetry dataset, we elected not to conduct extensive sensitivity analyses on habitat use assumptions, but to rather focus attention on demonstrating feasibility of the methodology. Similarly we assumed that the development zone surrounding future mine sites would have the same composition as the development zone surrounding current mine sites. We also assumed that the portion of time caribou spend near any additional future development was similar to current conditions. Finally, we assumed that the habitat type visited by a caribou on a given day was not influenced by the habitat types in its vicinity on the previous day, but rather by the relative abundance of habitat types across the entire summer range.

A major shortcoming of this analysis was that the spatial aspects of caribou movement were greatly simplified. Figure 11 shows the location of collared Bathurst cows in relation to the current development zones on four dates during the summer: June 14 (beginning of post-calving), July 5 (end of post-calving), July 18 (end of mid-summer) and August 22 (end of late summer). From this figure it was clear that typically Bathurst cows were not close to any development through the post-calving period, that cows interacted with the northern mines in early summer, and that they interacted somewhat with the northern mines in the late summer. In no period did cows interact with the southern mine sites, based on a collared sample of 71 Bathurst cows from 1996-2006. As a result, to assume that a two-fold increase in the level of development would correspondingly increase the time spent by caribou in the development zone by a factor of two from current levels may drastically underestimate the potential impact of additional development, as it is possible that any additional development may occupy a different proportion of the caribou's range than at present. For example, one additional mine in the middle of the June 14 distribution (Figure 11) could have significant impacts on the herd. It is also conceivable that the present distribution of caribou has already adapted to the presence of mine sites, and thus we now see little interaction with development.

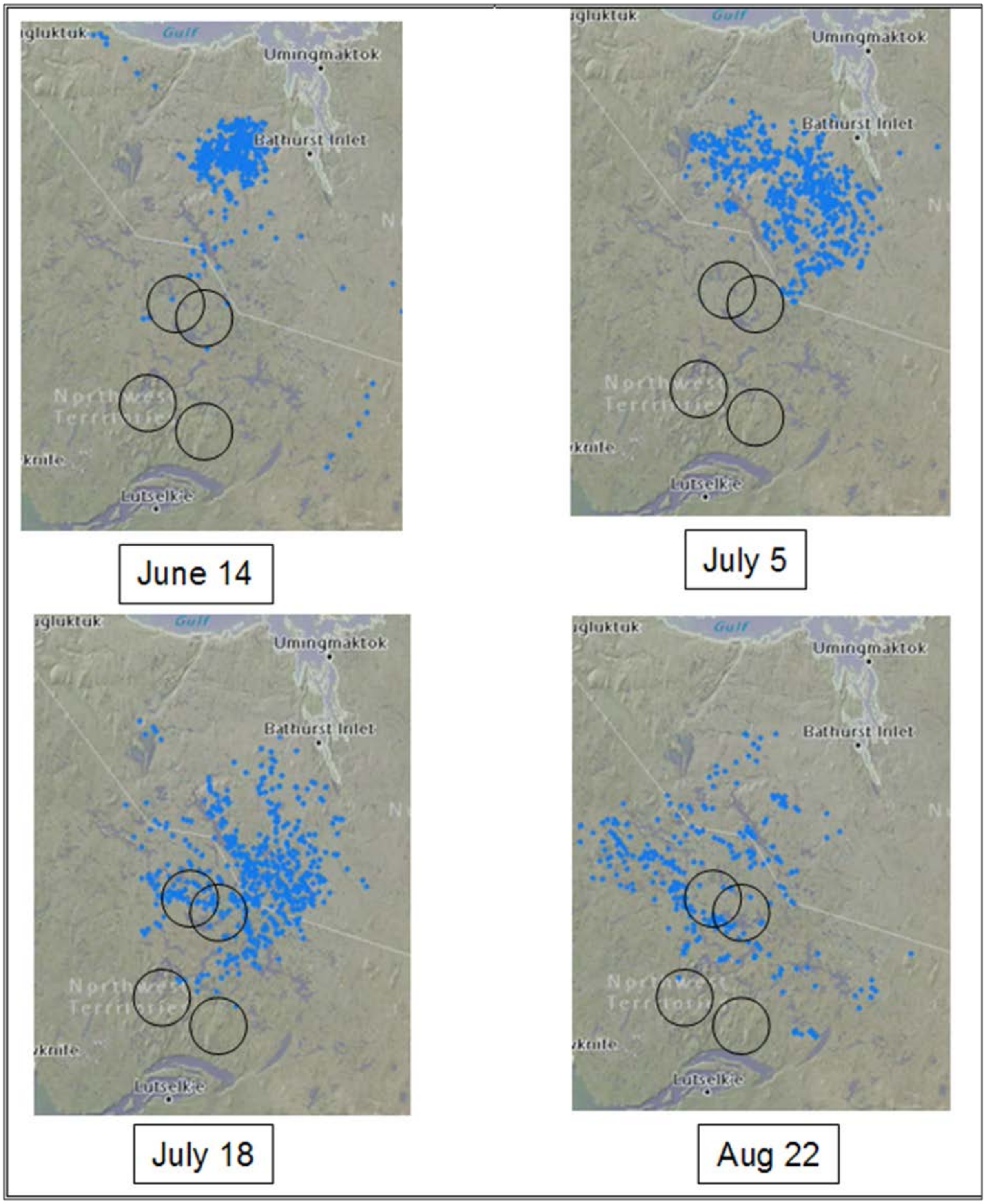

Figure 11: Location of collared Bathurst cows in relation to current mines sites with associated ZOIs. Location of collared cows screen captured from animation (CARMA 2012).

Body Condition

Figure 12 compares predicted and actual body weights for adult cows. As this figure shows, the fall body weights predicted by the model were, on average, lower than those recorded in the field for 2008. The "average" climate scenario predicted a body weight of 85 kg on September 10, which was 11 kg less than the average weight of 96 kg observed on this date in 2008. Even the "best" climate scenario predicted a body weight of 91 kg on September 10, which was still 5 kg lower than the observed average weight for that date. Furthermore, actual observations indicated that adult cows increased by an average of 11 kg in body weight from March 12 to September 10, 2008, while the model predicted no increase in weight over the course of the simulation (i.e., from June 15 – October 15).

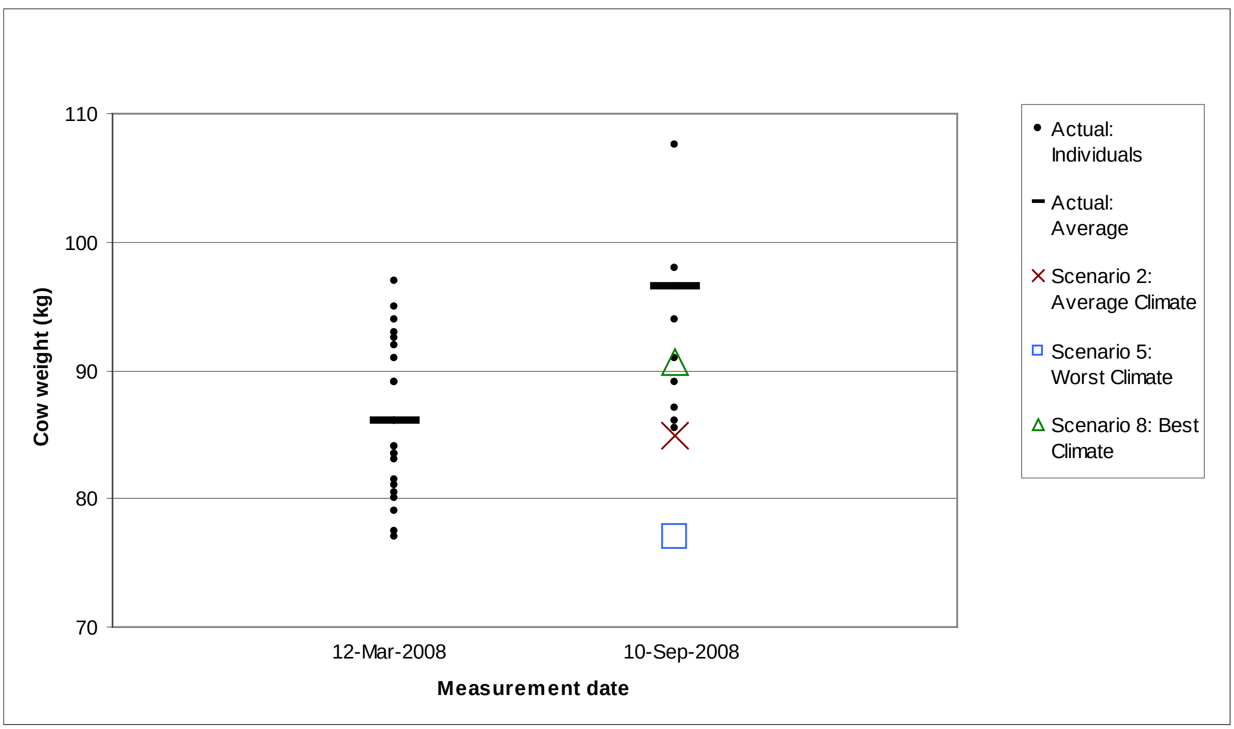

Figure 12: Comparison of predicted and actual body weights. Actual weights were recorded for adult (age 3+) cows from the Bathurst herd in 2008 on two different dates. Predicted weights are displayed for the three scenarios representing current development (i.e., Scenarios 2, 5, 8) for September 10.

There are a number of possible explanations for this discrepancy between predicted and actual weight gain:

1. Activity budgets for this analysis were summarized from unanalyzed raw data obtained from L. Witter who was working on a Master's thesis (Witter 2010, and see Witter et al. 2012a, and 2012b). A summary of these data showed a dramatic increase in activity costs during the insect season as compared to similar data on the Porcupine caribou herd (Russell et al. 1993). It is possible that the activity budgets used in this analysis overestimate the proportion of time the animal spends in higher energy activities (e.g. walking and running), which would in turn lead to predictions of lower body weights over the summer.

2. Biomass values by plant type, for each of the ten habitat types represented in this demonstration project, were estimated using expert opinion (see Table 7).

3. It is possible that the biomass densities used in this analysis are lower than those actually encountered by caribou on their summer range, thus lowering the metabolizable energy intake of the animal during the simulation and ultimately contributing to a lower predicted fall body weight. In the model, instantaneous intake of plant groups is a function of biomass encountered; thus using a "best guess" at average biomass of plant groups across habitat types and arbitrarily tripling that value to represent encounter rates may dramatically underestimate intake rates, especially if vegetation in sparsely vegetated habitat is highly clumped. It would be useful to have access to raw data plots where biomass or percent cover was measured to look at the coefficient of variation within habitat types.

4. The body condition model used in this analysis does not represent the latest understanding of caribou energetics: in particular it does not capture the dynamics associated with the allocation of nitrogen and protein in the animal. A more recent version of the model is currently under development, with updated relationships, which should provide better predictive capability in the future.

In addition, no data were available to estimate the initial condition of animals for the simulation – i.e., the fat, muscle and body weights of animals on June 15 – under three different assumptions regarding prior winter severity; rather these initial conditions were estimated using runs of the model with a mixture of model parameters taken from the winter ranges of the Porcupine and Bathurst herds. The results presented previously suggest that the condition of the animal at the start of the summer season may play a critical role in determining the condition of the animal by the time of the rut. More work needs to be done to determine the range of body conditions that one might expect on June 15 for the summer season simulations to ensure that summer range predictions are meaningful.

Because of these uncertainties regarding the absolute predictions of body weight, we decided not to make predictions regarding the resulting birth rates for each scenario for this demonstration project. In particular, because the relationship between birth rate and body weight is non-linear, it is difficult to predict even relative changes in birth rate across scenarios without reasonable predictions of fall body weight. For example a 1 kg decrease in fall body weight of a 85 kg cow will result in a 2.2% decrease in probability of pregnancy compared to a 1.4% decrease for a 95 kg cow (Figure 9). Subject to the assumptions we identified our preliminary results do suggest that, given there are only very small differences in body weights predicted for varying levels of development, one would not expect to see significant differences in birth rates across the various levels of development considered in this analysis.

With respect to the predicted effects of development, our preliminary results suggest that there are two key energetic consequences associated with animals spending time near operating mines:

1. The activity budget data used in this preliminary analysis suggested that caribou expend slightly more energy in proximity to development activities – essentially the animals spend more time running and less time standing/lying. For this analysis, the daily increase in activity cost associated with time spent in the development zone was estimated to be approximately 3,700 $kJ \cdot day^{-1}$ (880 $kcal \cdot day^{-1}$) for each day spent in the development zone. Under current development levels, in which the animal was estimated to spend six days in the development zone over the summer period, this additional energy cost amounted to approximately 22,000 kJ (5,280 kcal) over the entire summer.

2. These same activity budget data also suggested that caribou spend a greater proportion of their time foraging when they are within close proximity to development. For this analysis, food intake for animals in the development zone was

estimated to increase by approximately 230 g·day^{-1}. This added food intake serves to compensate for the increased activity cost described above, resulting in model predictions of no net effect on the animal's body weight due to time spent in the development zone. However in the data set by Murphy et al. (2000) used for activity in the vicinity of development, no measure of eating intensity (the proportion of foraging time actually spent eating) was taken. It is plausible that animals were more vigilant near human activity: as a result while foraging time is higher, eating intensity could be substantially lower – similar to the low eating intensities recorded during insect harassment.

It is important to note that the only energetic effect of development represented in our modelling was the change in activity budget that resulted from being within 30 km of an active mine. Under the current development levels, the average caribou was only predicted to be inside the 30 km development zone for approximately six of 123 total days in the summer (i.e. 5% of the time), and for each day spent inside the development zone the change in activity budget was relatively small. If the development zone were further reduced to match the ZOI predicted by Boulanger et al. (2012) of 14 km, then the effect on activity budget would be even less.

The model results also suggested that climate and environmental conditions play an important role in determining the body condition of animals and their subsequent birth rate. It also suggests that the energetic consequences of the summer range cannot be analysed in isolation from the winter range: based on this preliminary analysis, the effect of winter snow, and the resulting condition of animals entering the summer range, may be the single largest determinant of the animal's body condition in the fall.

While the effects of climate and development were each explored independently in this analysis, we did not consider the possible interaction between development and climate change. It is quite possible that there may be additional effects on caribou of development in the face of a changing climate. For example, McNeil et al. (2005) reported that Bathurst caribou density in the development zones was significantly higher in years with higher insect harassment. If climate change results in warmer summers in the future, resulting in increased levels of insect harassment for the herd, then this may result in increased use of development zones by caribou.

A key assumption in this analysis was that the activity budgets developed through studies of the impact of the Prudhoe Bay development on the central Arctic herd (Murphy et al. 2000) were appropriate for describing the change in activity that occurs in proximity to mine development for the Bathurst herd. Given the very different nature of these two analyses, the validity of this assumption is questionable.

Finally, it is important to note that while the objective of this demonstration project was to contribute to an assessment of cumulative effects, to-date the only development considered in our analysis has been active mine sites, as the location of other forms of development on the Bathurst summer range is much more difficult to quantify. For other activities to have a significant impact on caribou energetics, however, either the footprint of the development must be of the same order of magnitude as the mine sites considered in this analysis, or alternatively the energetic consequence of the additional development must be significantly greater than that demonstrated here for the active mine sites.

Recommendations

Based upon the results of this demonstration project, we provide several recommendations regarding possible next steps associated with this modelling work.

1. **Refined activity budgets.** At present only very limited activity budget information exists for the Bathurst herd in a format suitable for use with the body condition model – i.e., in the format provided in

2. Table 9 – and so our preliminary analysis relies heavily on two sources: values extrapolated from the central Arctic herd under different development conditions, and an initial analysis of raw data from the Bathurst herd (L. Witter, pers. comm.). A refined analysis of activity budget data augmented with more extensive behaviour sampling, specific to the Bathurst herd and/or mine development, would allow us to draw more definitive conclusions regarding the possible effects of development on the Bathurst herd.

3. **Identify additional development activities**. In this analysis, development zones were identified as those areas within 30 km of current mine sites. Other forms of

development, such as mine leases, exploration sites, linear features, and fishing or hunting camps, were excluded from this assessment. As part of a cumulative effects assessment for the Bathurst summer range, it will be important in the future to identify the nature and extent of the full range of development activities that might impact upon caribou.

4. **Collect additional body condition data on the summer range**. Limited data currently exists on the body condition of caribou on the Bathurst summer range. Additional measurements of body condition for individuals on the summer range would help improve the model predictions in two key areas:

   - To establish better initial conditions for the simulations (i.e., establish the body condition of animals on June 15) – in particular, to understand the range in body condition for animals entering the summer range – including measurements in years of varying winter climate. Our preliminary analysis suggested that the body condition of cows entering the summer range may be a key determinant of their fall weight and, in turn, their subsequent reproductive success.

   - To validate model predictions between June 15 and October 15. If the body condition model is to contribute meaningfully to a larger demographic analysis, it will be important to ensure that model predictions for body condition fall within the range of historical variability observed for the herd. Additional body condition measurements between June 15 and October 15 would help to validate model predictions.

5. **Collect biomass/diet information.** Currently the body condition model is quite sensitive to biomass encountered by caribou while ingesting food. It is important therefore that either raw data are made available or estimates of biomass variability within habitat types are collected and summarized.

6. **Repeat analysis using revised body condition model.** As discussed previously, this demonstration project was undertaken using an out-of-date version of the body condition model; a new (unpublished) version of the model was released in 2011. Repeating this analysis using the revised model will accomplish the following:

    1. include the latest understanding regarding energetics and nitrogen dynamics in our predictions;

    2. include stochastic simulations, where the effects of uncertainty in input parameters can be quantified; and

    3. validate model predictions (assuming additional body condition data are available).

7. **Consider additional effects of body condition on demographic parameters.** At present the approach outlined in this demonstration project considers only the effect of body condition on a single demographic parameter: the birth rate of the herd. Once the body condition model is properly parameterized and validated for the Bathurst herd, consideration should be given to predicting the effect of body condition on a wider range of demographic factors (e.g. post-natal mortality, as has been previously modelled for the Porcupine caribou herd).

8. **Incorporate the results of a revised analysis into a model of population dynamics for the herd.** To-date this demonstration project has considered only the energetic consequences of climate and development on caribou. In order to understand the changes in herd numbers across years, a broader demographic analysis, integrating factors such as harvest, predation, natural mortality and immigration/emigration, will be required.

CHAPTER 4. POTENTIAL USE OF ALCES (A LANDSCAPE CUMULATIVE EFFECTS SIMULATOR) TO EXPLORE CUMULATIVE EFFECTS FOR THE BATHURST HERD

By: John Nishi, Matt Carlson, and Brad Stelfox

Background

ALCES® is a landscape model which can simulate environmental and human-related changes and track a wide variety of environmental, biological, and socio-economic indicators as landscape change unfolds. ALCES has been used effectively to help broad groups of stakeholders understand the trade-offs from landscape change and industrial development at a regional scale and to explore plausible scenarios and land-use strategies (Schneider et al. 2003, Carlson et al. 2007, ALT 2009, Carlson et al. 2010, Carlson et al. 2011, Francis and Hamm 2011).

The following points summarize key aspects of ALCES as shown in Figure 13.

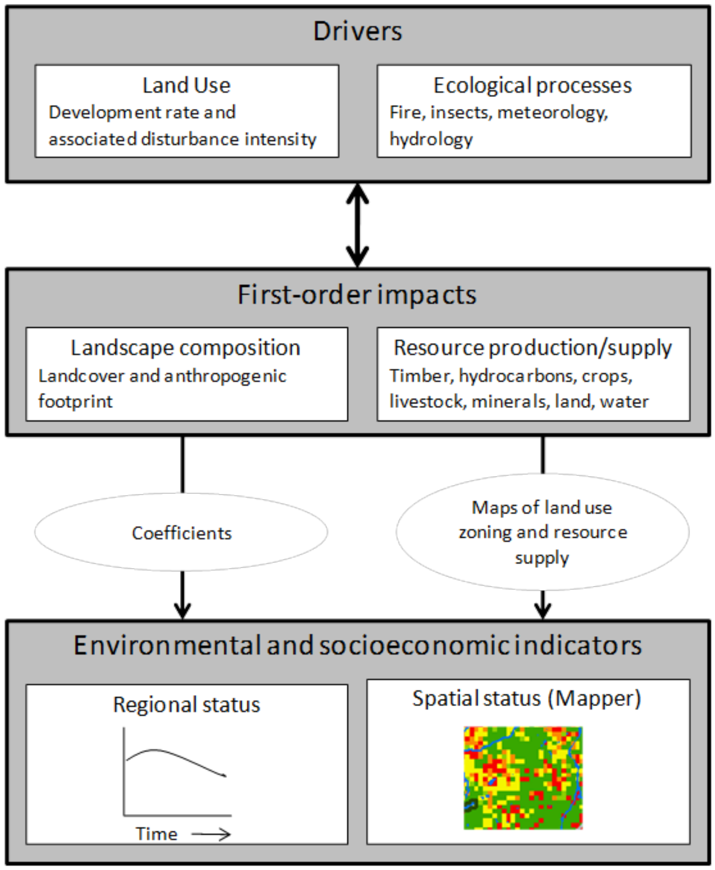

Figure 13: Overview of the ALCES land-use simulation model.

1) ALCES is designed to explore and represent changes in land base composition caused by land uses and ecological processes. The various land uses and ecological processes can be turned on or off depending on the needs of the scenario analysis. For each land use operating in a region, the user defines development rates, the portion of the landscape available for development, and management practices such as the intensity and lifespan of associated industrial footprints. The influence of natural disturbances (fire and insects) and plant succession on landscape composition are also tracked. Hydrological processes are addressed with surface and groundwater modules, and climate change effects can be incorporated by

defining temporal changes in natural disturbances rates, successional trajectories, land cover, meteorology and hydrology.

2) The first-order effects tracked by ALCES are landscape composition and resource production/supply. Using an annual time-step (although monthly time steps can be used for the meteorology and hydrology modules) the model modifies the area and length of up to 20 land cover and 15 anthropogenic footprint types in response to natural disturbances, succession, landscape conversion, reclamation of footprints, and creation of new footprints associated with simulated land-use trajectories. ALCES tracks resource production and supply using approaches that are typical of sector-specific models. By tracking resource supply, ALCES can reduce or stop the expansion of a land use if resource supply becomes inadequate.

3) Coefficients are used to tie performance of key indicators (biological, environmental, and/or socio-economic) to the first-order dynamics in resource (commodity) production and landscape composition (i.e., changes in abundance and composition of land cover and footprint types). A wide range of indicators are available so that trade-offs between diverse ecological and socioeconomic objectives can be assessed. Types of indicators that can be tracked by ALCES include wildlife habitat and populations, water quality and quantity, biotic carbon storage, air emissions, employment, gross domestic product, and social indicators such as family income and educational attainment.

4) ALCES is a spatially stratified model, which means that it tracks the area, length, and quantity of each footprint separately for each land cover type. ALCES itself does not track the explicit geographic location of these features (e.g. latitude and longitude).

However, the development of ALCES Mapper™ has extended the capacity to represent ALCES output on maps and conduct geospatial analyses based on spatially directed footprint growth. ALCES Mapper allows users to specify the general location (i.e., where specified land use footprints can or cannot occur) and pattern (e.g. dispersed versus contagious) of future development. The tool divides the study area into grid cells of user defined size, and calculates the initial landscape and footprint composition within each cell. Footprint growth and reclamation, land cover change, natural disturbances, commodity production and other variables as reported by ALCES are then applied to each cell, tracked, and displayed spatially. This feature provides flexibility to map transformations of landscapes through time according to different spatial rules, and is useful for visualizing the implications of different zoning or resource utilization strategies. Maps of future landscape condition are then analyzed to evaluate the spatial response of indicators such as wildlife habitat to potential future landscapes associated with land-use scenarios.

Methodology

As the modeling links between caribou behaviour, habitat use and avoidance, and population-level responses for the demonstration project were developed, we also considered how those relationships may be integrated into ALCES to help people understand the trade-offs between industrial development on the landscape and the risk of reduced resilience in barren-ground caribou populations. Although landscape composition can be linked to changes in habitat quality, another important pathway for simulating population-level effects to caribou is through changes in birth and death rates. For example, direct and indirect impacts to habitat and caribou behaviour caused by land use change and climate variability may result in low birth rates due to a reduction in body condition. On the other hand, caribou mortality rate may be affected by predation from wolves and other predators such as grizzly bears, as well as hunting by people.

At the start of the demonstration project, we knew it would be important to build upon previous work and help develop a suite of modeling tools that could show a clear linkage between caribou population demography and changing landscape characteristics. For example, when the energetics model was being developed for the Porcupine caribou herd, the researchers also developed a spreadsheet caribou calculator (see PCMB 2010) to explore how changes in one attribute such as pregnancy rate may affect herd growth rate. An alternative approach to projecting changes in population trend was developed by Boulanger et al. (2011) for the Bathurst herd using a mathematically more complex ordinary least squares (OLS) model that weighted input parameters by reliability and precision of the data. However, neither the caribou calculator nor the OLS models were designed to incorporate the influence of dynamic habitat and landscape conditions on rates of births or deaths.

But based on studies of boreal caribou, it has been shown that predation rates may vary with habitat and that habitat changes resulting from industrial activity may enhance predation risk (see Dyer 1999, McCutchen 2007, Latham et al. 2011). Other studies have made very clear the relationship between habitat characteristics and the risk of predation

(Garrott et al. 2009, Laundre et al. 2010). And perhaps one of the most important potential effects of industrial development – to the detriment of caribou – is the creation of transportation infrastructure (i.e., roads and airstrips), which may change hunting patterns (see Brinkman et al. 2007) and contribute to increased harvest pressure through improved access and mobility of hunters (Bergerud et al. 1984, Bergerud et al. 2008).

We also considered that the scale of effects from industrial development will likely depend on the relative occurrence and density of human footprints within seasonal ranges. As described previously, direct and indirect changes to caribou habitat and behaviour caused by human land use footprints (mines and transportation corridors) may be expressed through reduced birth rates due to a decline in body condition. Natural disturbances may also influence composition and abundance of habitat types; for example, ALCES may be parameterized to simulate potential impacts of fire regimes on caribou winter ranges within the forest-tundra biome. Likewise caribou mortality as affected by predation from wolves and hunting by people may vary with habitat conditions and road access. These reasons led us to develop a population dynamics module within ALCES that would link birth and death rates to both human-caused landscape and habitat changes as well as natural variability in climate and environmental conditions. With this fundamental improvement, we think that ALCES would be better suited to strategically assess impacts of multiple stressors on barren-ground caribou because it would be able to simulate relevant processes across a herd's annual range over long time frames, i.e., multiple decades.

In Appendix C, we describe the population dynamics (Pop-Dyn) module that was incorporated within ALCES as a means of directly simulating wildlife populations on a defined landscape that was subject to both natural and anthropogenic disturbances. The goal of developing the Pop-Dyn module was to link coarse-scale demographic drivers of single or multiple interacting wildlife populations to a dynamic landscape in one modeling platform, so that a user can explore relationships among industrial activities, land-use management strategies, and predator-prey relationships (including hunting)[9]. With respect to this pilot project, a goal for incorporating the Pop-Dyn module was to accommodate data outputs and functional relationships derived from the RSF and energetic models (Chapters 2, 3 respectively) as inputs in to caribou population dynamics.

Next Steps

A proposed approach for using ALCES depends on results from the habitat selection and energetic models; Johnson (Chapter 2, Appendix A) and Daniel et al. (Chapter 3, Appendix B), outlined how resource selection functions and body condition models can be used to develop a relationship between landscape composition and birth rate, which could provide subsequent input in to ALCES. Here we also suggest that climate models could be used to parameterize trajectories for plant phenology, snow depth and insect abundance, and relationships among these variables and birth rate could be derived using the energetics model. Caribou survey results and population modeling efforts (e.g. Boulanger and Gunn

[9]A version of the Pop-Dyn module in ALCES was subsequently used by the Athabasca Landscape Team (2009) to conduct scenario analyses of boreal caribou populations in northeast Alberta (Antoniuk et al. 2009a). The model was also used to develop conservation education presentations on wildlife harvesting in collaboration with Yukon Government (www.env.gov.yk.ca/wildlifebiodiversity/wildlife_management_presentations.php).

2007, Boulanger et al. 2011) would provide information to parameterize the population dynamics model. A proposed ALCES modeling approach would synthesize other research findings to assess the cumulative effects of a range of stressors on the long-term sustainability of the Bathurst caribou herd.

Exploring and Simulating Potential Effects of Climatic Variation

As described by Daniel et al. (Chapter 3, Appendix B), the energetics model was parameterized for the summer range. Their work showed that the energetics model can be used to evaluate and link the relative effects of climate variability on body condition and therefore birth rate of caribou cows. Consequently, the energetics model can be used to derive functional relationships among environmental parameters that are driven by climatic variation (i.e. snow depth, insect harassment indices, and timing and rate of green-up), to body condition and ultimately expected birth rates in female caribou. Through integration with RSF analyses described by Johnson (Chapter 2, Appendix A), it is possible to use the body condition model – informed by an array of RSF coefficients – to conduct simulation experiments that would provide empirical inputs and functional (dose-response) relationships in to ALCES.

For example, a simulation experiment would be designed and conducted to assess birth rates associated with three levels of each climate variable: current, moderate change, and large change. The experiment would follow a factorial design such that all levels of each climate variable would be assessed in combination with all levels of the other climate variables. The result would be a database of 81 birth rates, each associated with a unique combination of levels across the four climate variables. The database would then be used to parameterize ALCES to incorporate climate impacts on the caribou population. ALCES simulations would simulate relevant climate variables based on random variation about expected climate trends for the study area. Based on the array of climate variables simulated for a given year, ALCES would then select the appropriate birth rate from the database of birth rates derived from the body condition model. When designing the simulation experiment, it will be of critical importance to ensure that the climate variables used as inputs in the body condition model are variables that can be simulated by ALCES (Table 14).

Table 14: Input variables for the body condition model that can be manipulated in a simulation experiment to derive relationships linking birth rate to climate-related variables tracked by ALCES. The relationships could be used to parameterize ALCES for exploring scenarios that assess potential impacts of climate change on caribou.

Climate-related variables simulated by ALCES	Relevant energetics model input variable
Timing of snowmelt Simulated in ALCES by extrapolating 30-year trend from Dye (2002).	**Start date of the growing season phenology** Start dates will be selected to be compatible with snowmelt trends extrapolated from Dye (2002).
Summer temperature Simulated in ALCES based on climate projections for the Bathurst summer range (e.g. Brotton and Wall 1997). Temperature will be related to an approximate index of insect harassment derived from relationships between insects and temperature on the Porcupine summer range (Russell et al. 1993).	**Activity budget** Activity budgets for low, average and high insect levels are available for the Bathurst herd (Daniel et al. in Chapter 3, Appendix B).
Winter precipitation Simulated in ALCES based on climate projections for the Bathurst winter range (e.g. Brotton and Wall	**Initial body condition** The effect of snow depth on body condition at the start of the summer season are available from

Climate-related variables simulated by ALCES	Relevant energetics model input variable
1997).	previous work modelling the effects of the Diavik mine on caribou energetics, as described by (Daniel et al. in Chapter 3 and Appendix B).
Shift in climatic habitat for shrubs Simulated in ALCES as a gradual conversion of tussock graminoid to shrub tundra. The rate of conversion will be extrapolated from historical trends from Sturm et al. (2001).	**Habitat use** A caribou simulation model[10] will be applied to estimate habitat use associated with various levels of tussock tundra conversion to shrub tundra.
Fire rate on the winter range Trend in fire rate will be based on projections from Balshi et al. (2009).	**Initial body condition** Further field research is needed to estimate inputs needed by the body condition model[11].

[10]As described by Daniel et al. (Chapter 3, Appendix B), a caribou movement simulation model has been developed to provide habitat use inputs to the energetics model. The caribou movement simulation model simulates habitat use based on habitat preferences (based on RSF coefficients) and landscape composition.

[11]Croft et al. (2008) and Barrier and Johnson (2011) describe ongoing research that is assessing the effects of burns on habitat use by caribou in the Bathurst winter range. It may be possible to apply the results from the research to assess the effect of burn area on birth rate and/or mortality rate, perhaps using the body condition model parameterized for the winter range. The apparent concordance between fire rate and declining population trends suggests that this research is high priority.

CHAPTER 5. DISCUSSION AND NEXT STEPS

By: Anne Gunn, John Nishi, and David Taylor

In this section, we review our progress on meeting the goals for the demonstration project. With respect to objectives 1-4, this report (and see Appendices) provides technical details of our collaborative work in four general areas:

a) we updated and refined the habitat selection model (with specific effort to incorporate Tłįchǫ knowledge);

b) we used updated ecological data for the Bathurst herd for the energetic model and linked the revised habitat selection model to the energetic model which allowed us to incorporate changes in diet relative to whether caribou shifted away from the vicinity of the mines or changed their activity patterns;

c) we were successfully able to link the habitat and energetic models; and

d) we developed a population dynamics module within ALCES (a landscape simulation model) to integrate functional relationships from other models.

The fifth objective (review the demonstration project and cumulative effects modeling approaches with a NWT audience and plan next steps collaboratively) is more broadly discussed in this chapter.

The objectives for the demonstration project were not to specifically assess cumulative effects, but rather to develop and refine the approaches needed to conduct cumulative effects assessments. Our primary results from the demonstration project showed that linking the different modeling approaches was feasible and practical, although additional work is required to develop a full suite of functional relationships that will serve as both outputs and inputs between various models. The habitat selection modeling (through development of RSF coefficients) reflected the complexity of habitat use by caribou during calving and post-calving but also showed how we can translate habitat selection to estimate seasonal diet and forage intake. The energetic model was able to simulate nutritional value of the diet depending on environmental conditions such as the rate of greening through the period of assessment. The model shows how the forage intake of an individual cow is allocated to meet her maintenance needs for energy, as well as the reproductive needs to grow a fetus and support a calf under different environmental conditions. Variability in a cow's daily activity patterns affects rates of energy (and protein) intake and expenditure, which is simulated through her behavioural responses to disturbance from industrial activities and/or insect harassment.

We also report that the demonstration project allowed us to implement our three principles. Firstly, we were able to include environmental variation both through effects on caribou forage as well as on the caribou themselves. This suggests that assessments of cumulative effects, which focus only on impacts of industrial exploration and development projects, are quite limited because they do not consider the important and synergistic effects of short and long-term environmental variation. In other words the environmental context and natural range in environmental variability is important to determining the cumulative effect of industrial developments.

Our second principle for approaching cumulative effects was to be able to incorporate multiple scales. The energetic model works between individual and population scale while the habitat selection model incorporated several spatial scales. Our third principle was to incorporate the knowledge of the Aboriginal elders into cumulative effects assessment. The strong link between Aboriginal people and their landscapes means that much TK has a spatial component and that can be translated into spatial data suitable for modeling caribou habitat selection. This project represents an initial effort into a useful and exciting area for further work and collaboration.

The demonstration project has been a valuable collaborative learning experience; it showed that tackling complex problems involving caribou ecology in a changing world may be addressed in part by pooling peoples' collective experience as we have each come from different disciplines and professional experiences (i.e., government, university, private industry, and communities). One example of overcoming technical challenges was illustrated by the baseline habitat work that linked remote sensing vegetation data with on-the-ground observations by hunters that covered an extensive time span. While we have relied upon satellite telemetry we acknowledge that there are other approaches that include Aboriginal knowledge and caribou sightings during aerial surveys or from the ground that may be readily used in modeling habitat selection.

Through the demonstration project, we have tried to provide information so that others may use similar approaches. For example, we have provided details on using available databases to run habitat selection analyses (Appendices A, B). Through both the demonstration project and similar initiatives through CARMA (www.carmanetwork.com), progress has been made to ensure that model tools are more easily accessible. Some next steps for the energetic model are to refine a modular approach for sharing parameters between herds and develop a built-in capability to edit model inputs in spreadsheet software (i.e., Microsoft Excel).

Similarly, although ALCES is a commercially available product with associated license fees (www.alces.ca), there has been an extensive group of collaborators who have developed the landscape simulation modeling approach as a freely available web-based learning application for students (www.albertatomorrow.ca). The Alberta Historical Land Use and Landscape Data Library (www.abll.ca/library/Library_Home) exemplifies the depth and breadth of land use data that have been compiled and made available for people to explore and understand landscape dynamics in the province of Alberta, and serves as one example of the type of collaborative on-line internet-based approach to data access that could be compiled with a focus on understanding changing land uses and landscapes occupied by barren-ground caribou herds in the NWT.

Since we started work on the demonstration project, there has been a growing trend toward on-line collaboration and data management so that people can share, integrate and visualize data. The demonstration project contributes to ensuring that our integrative linking of models is consistent with this trend for on-line accessibility. Availability of data and models is an important *step towards meeting our goal to* show how the models will be applicable as learning and decision support tools for governments and wildlife co-management boards in the NWT, and potentially elsewhere in the north.

Our emphasis on improved data management, coordination, and on-line access was partly based on the myriad challenges we encountered when compiling the initial landscape data to describe land use in the study area (see Appendix A). For example, although several government departments across three levels of government collect land use information, the available datasets that were in a usable form were limited. Two specific examples of data inconsistency issues were: a) only a 66% rate of agreement between land use permit datasets provided by Aboriginal Affairs and Northern Development Canada and the Mackenzie Valley Land and Water Board, and; b) of the matching permit records there was an average difference of 35 km in geographic location with a maximum difference of over 200 km. There was also an information gap regarding activities that did not require a land use permit, which may include up to a 200 person-day camp, frequent air traffic, low level flights, helicopter traffic, and other activities done in the course of prospecting, staking, or locating a mineral claim. So although these activities have been identified as potential sources of disturbance and stress to caribou, there were no empirical data to describe their occurrence or extent.

While we have taken steps to promote availability of both the approach (scaling from individual caribou habitat selection to population-scale dynamics) and the models we used, we obviously recognize that other models for habitat selection, energetic and population dynamics are available. For example, we note that while the recent environmental assessment for the Dezé's Taltson Hydro Expansion project (MVEIRB, www.reviewboard.ca/registry/project) included, in 2010, energetic and population dynamics models, they were different models. Similarly, impact assessment of the proposed Gahcho Kué Diamond Mine on the summer range of the Bathurst herd (DeBeers Canada 2010) has also adopted a similar approach, but through the use of different models. We recognize that use of different models is sometimes a consequence of their availability (commercial or open source), but nevertheless, we suggest that there are significant advantages to collaboration on the consistent use of models and modeling approaches during environmental assessments. By improving accessibility of data, data management and the models, the Demonstration Project has facilitated collaborative use.

As well as different models for energy costs and population dynamics, we are also aware of rapid advances in spatial modeling. There are approaches to using GIS modeling to integrate spatial disturbances with gradients in nutrients and other habitat attributes (Kostylev and Hannah 2007). These approaches have the advantage of having being presented as easily-visualized ‘layers’ for the individual habitat attributes that are superimposed on landscapes easily recognizable to people who live on them. We also are aware of the progress made in understanding how caribou balance the risk of exposure to predation with having enough to eat and reproduce. Although these are complex ecological questions, use of individually-based caribou models is shedding light on these questions (McCutchen 2007, Semeniuk et al. 2012). While we did not apply these models, we suggest that they may be useful in future methodology for CEAs and for example, those models will be useful in exploring the mechanisms such as the causes of the ZOI around development sites.

It can be difficult for non-technical audiences to appreciate ongoing discussions during environmental assessments about one model versus another. One solution is a collaborative approach to tackling and investigating aspect, of ecological complexity by sharing models. For example we note that environmental assessments for mines in the NWT now all use CALPUFF model for projecting air quality and the internationally recognized model is readily available (www.src.com/calpuff/calpuff1.htm).

Being mindful of environmental assessment audiences by building familiarity with our generalized approach to cumulative effects assessment is a contribution to our second and longer-term goal which is to develop a basis for collaborative learning about cumulative effects and barren-ground caribou with a broader group of government, industry, and community representatives. However, while we suggest that sharing approaches and models is important, we are also aware of the need to use herd and range-specific databases whenever possible (see Chapter 3 for an example). Russell (2011) gives a recent example of the applicability of the habitat selection and energetic model approach to the cumulative effects assessment of a proposed large open pit mine, roads and railway complex in Nunavut.

In the NWT, environmental and herd monitoring data at a landscape scale are key sources of information that are routinely collected by government agencies; monitoring of caribou distribution and activity patterns by the mining companies tends to be limited more towards regional and local study area scales. The demonstration project has showed how monitoring data may be used to inform scenario analyses, and to evaluate the plausible direction, extent, and magnitude of cumulative effects. In turn, basic assumptions and projected outcomes from scenario analyses can be tested through monitoring and used to assess the applicability of mitigation. Our experience through the demonstration project suggests that it would be useful and efficient to develop a closer linking of cumulative effects assessment approaches to a regulatory framework that is part of overall assessment and management. An example of a framework linking monitoring, mitigation and adaptive management is the Wek’èezhìi Land and Water Board’s 2010 draft Guidelines for Adaptive Management - a Response Framework for Aquatic Effects Monitoring (see also Racher et al. 2010).

The monitoring data we used for the demonstration project were largely the same datasets typically collected by wildlife managers although we recognize that the required sampling precision for population compared to cumulative effects assessment may differ. Likewise, the output of cumulative effects models includes assessments and projections of population effects such as birth rates, survival and herd trend. Thus, cumulative effects assessment at the annual range scale of barren-ground caribou are similar in scale and scope to range-wide management planning for caribou herds. We suggest that one of the broader lessons emphasized from the demonstration project is the importance of including strategic cumulative effects assessment approaches in collaborative adaptive management planning for the Bathurst herd.

The potential cumulative effects of hunting, industrial development, and climate change represent the most important issues facing managers of caribou and reindeer populations throughout the circumpolar Arctic (Vistnes et al. 2009). In northern Canada, most barren-ground caribou herds have declined to low levels with recovery possibly underway for some herds (Gunn et al. 2011a). This highlights current concerns because of the combined challenges of a) diagnosing the contributing factors and implementing appropriate management actions that will encourage herd recovery over the short term, and b) developing and implementing collaborative land-use strategies and management plans across annual ranges that will ensure that herds are healthy and have the requisite space and resilience to thrive over the long term. This leads us to urge that CEA, monitoring and mitigation should focus on herd resilience (including sustainable hunting) and be an integral part of adaptive co-management planning for barren-ground caribou.

The demonstration project has fine-tuned approaches to cumulative effects that should improve the ability of resource agencies to work with the stakeholders and explore complex socio-ecological problems, alternative futures, and identify desired outcomes along with supportive policy options. In particular, we suggest that inclusion of elders' knowledge into a habitat selection model is a useful link with past and current habitat use, and represents an important area for future collaboration.

Successful application of CEAs has come through use of scenarios analyses and simulation models that allow a broader group of stakeholders to explore plausible land use scenarios (Duinker and Greig 2007, Alcamo 2008, Mahmoud et al. 2009). During the demonstration project, we recognized that the manner by which development scenarios are defined is a key aspect of CEAs. In the context of wildlife and land use management, a collaborative approach to developing and defining scenarios increases credibility and acceptance of CEAs rather than scenarios that are proponent-driven. The collaboration is needed in the application of CEA tools and also in the subsequent monitoring and management.

Specific recommendations for follow-up:

1. A brief plain language summary for a general audience should be developed and posted on the GNWT-ENR website to summarize the work done, but more importantly to highlight the need to continue advancing tools and approaches for understanding and managing cumulative effects on barren-ground caribou.
2. A follow-up meeting should be convened so that results from the demonstration project can be presented to participating organizations of the 2008 workshop whose support was the impetus for this work (see Adamczewski et al. 2013). Two possible discussion items include:
    a. review of project results, and discussion of next steps to further develop collaborative methods, approaches, and best practices for CEA of barren-ground caribou; and
    b. application of CEA tools and approaches to address cumulative effects management in comprehensive barren-ground caribou management plans.

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PERSONAL COMMUNICATION

Ian Olthof, Environmental Scientist, Natural Resources Canada, Ottawa, ON

L. Witter. Graduate Student, Natural Resources and Environmental Studies Institute. University of Northern British Columbia. Prince George, BC.

Chris Johnson. Associate Professor, Natural Resources and Environmental Studies Institute. University of Northern British Columbia. Prince George, BC.

D. Russell. Biologist, Shadow Lake Environmental Consulting. Whitehorse, YT.

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APPENDIX A. TECHNICAL SPECIFICATIONS FOR DATA USED IN THE HABITAT SELECTION ANALYSES

By: David Taylor and Chris Johnson

Objective

For this study we needed to relate land activity with caribou locations. To do this we need information about where and when activities are taking place and we need to relate these activities to known and simulated random caribou locations.

General Information

Projection: For this project all raster files, all distance and area calculations and most vector files were projected to Lambert Conformal Conic, Standard Parallels of 60°N and 66°N, Projection origin of 0°N and 115°W and the NAD 83 Datum. This projection was used to align with other projects. The project period of interest was 1996-2008 and June 1 to August 22.

Software: OziExplorer 3.954q, ArcGIS 9.3 SP1, Geomatica 10.0, Microsoft Office 2007 and AP PDF to TIFF Batch Converter from Adultpdf.com Inc.

From the spatial perspective the RSF model depends on the relationship between the dataset of known and randomly generated caribou locations and a variety of other layers. The RSF analysis requires matching the caribou location with the disturbance and land features by location and date. To facilitate the temporal match a single caribou location file was used. However, the land features were separated by year and compared to the single master caribou location file. This simplified the GIS processing in that a single caribou location file could be compared to each of the 12 annual land feature files for each of the disturbance and land cover datasets. The distance to disturbance from a caribou location was matched to the appropriate date at the RSF analysis stage.

For each caribou real or random location several things are required.

1. The distance to the nearest relevant disturbance feature. Since disturbances are known to have changed over the 12 year study period an attempt was made to determine the year a particular disturbance appeared and the year the disturbance disappeared. Date ranges were attributed to all disturbances. Generally attribute selections were used to extract relevant disturbances into 12 "annual activity files".

2. The NDVI value at the location. The NDVI data available included three observations per month for most of the study period. No local aggregating was performed on the NDVI data.

3. The percent compositions of the land cover class in the vicinity of the point location. The vegetation cover was assumed to remain constant over the study period.

Data Sources

Multiple data sources were used for the required model inputs.

Caribou Locations

The known and randomly generated caribou locations layer was developed by C Johnson and provided as a comma separated value (CSV) file with 52,063 records. Each location contained an easting and northing in the working projection, a unique ID number and additional fields. This file was imported in to Excel and from there into ArcMap and exported as a shape file the extraneous fields were deleted. This master file (BUR.shp) was copied for each of the subsequent sets of analysis to provide the locations that were to be attributed. Argos quality 1, 2 and 3 positions were used. The estimated error in position for these points is less than 1,500 m.

Traditional Knowledge

These data were obtained from *Caribou Migration and the State of their Habitat*[12]. The report contains (11) 11x17 inch colour maps. The maps appear to have been scanned to PDF at 200 DPI from 11x17 inch pages of a paper copy of the report. The paper maps were printed at a 1:7,466,000 scale in an unidentified projection and datum. The paper copy of the maps had been folded. These PDF files were converted to TIFF at 200 DPI and individually georeferenced in OziExplorer with six control points generated from the two degree interval geographic grid printed on the maps. The maps appeared to contain 1:250,000 scale lake and river features in the background. It is not known what scale the data were originally collected or digitized.

[12] Dogrib Treaty 11 Council 2001. Caribou Migration and the State of their Habitat, West Kitikmeot Slave Study Society.

Features of interest were then screen digitized using OziExplorer then exported with geographic coordinates to shape file for use in ArcGIS. ArcGIS was used to project the coordinates to the working projection.

Positional accuracy was tested by locating recognisable features and comparing their coordinates in ArcGIS with reference 1:250,000 scale map data. Six feature points were compared and found to be within 1 km of the corresponding reference map location. Positional accuracy of the digitized information is estimated at better than 3,500 m.

Two pieces of information were digitized to obtain an indication of traditional hunting areas; “Caribou Harvest Sites” and annual “Harvest” polygons.

Eleven maps were scanned; maps 1-10 contain polygons labelled “YYYY Harvest” where YYYY represents a year between 1925 and 1998. The two maps in the report containing the 1925-1934 data were not scanned at high resolution and were not digitized. The outer perimeters of all the harvest areas on each map were digitized as one polygon. This resulted in ten polygons each containing five or six years of annual harvest data.

Map 11 was digitized to obtain “Caribou Harvest Sites” as a point layer. No particular year is attributed to the harvest sites. Map 11 was also digitized to obtain “Caribou Trails in the

?eka'ati Area" as lines, the "Mowhi Boundary – 1921" and "Caribou Water Crossings". The crossings on the map were drawn as lines across the water body. Each crossing was digitized as an individual line.

Feature quality assessment. Since a screen digitizing technique was used it was relatively easy to compare the original data with the digitized data by overlaying one on the other to look for missing features. It is likely that all features were digitized with the following exception; harvest sites that were grouped closely together may be under represented.

Vegetation

Several Arctic area land cover classifications were considered; see Appendix A for a links, references and summary information about them. It was determined to use a combination of the "New circa 2000 Land Cover Map of Northern Canada" (NLC) and the "EOSD Land Cover Classification" (EOSD). The rational for this was that these two classifications and an agricultural classification will form the basis of a Canada wide land cover dataset to be published by the federal government sometime in the next few years[13]. The land cover classes in the NLC were modelled from the CAVM classification[14]. This connection to the CAVM classification may improve the ability of the model to extend geographically to other caribou ranges. Additionally the other classifications had more limited geographic range or were lower resolution.

[13]Personal conversation I Olthof, CCRS, Nov 21, 2008.

[14]Personal conversation I. Olthof, CCRS, November 21, 2008.

The NLC data is available as 1:250,000 map sheet tiles. Each file uses the same legend and the same Canada Lambert projection.

C. Johnson downloaded and merged the NLC and projected it to the project's working projection.

The EOSD data is available as 1:250,000 map sheet tiles within zip files grouped by territory. This study area covers parts of both Nunavut and the NWT. Both territorial zip files were downloaded.

The procedure used to build the EOSD mosaic:

- "Create Raster Dataset" to create a new layer in a file geodatabase with 1-8_bit_Unsigned channel in the working projection.
- "Mosaic" with Method=Last, Color Map Mode=First, Color Matching Method=None, Ignore Background value=0, NoData Value=0 was used to add all the required EOSD tiles into the output image.
- "Copy Raster", default settings was used to create a tiff file for use in Geomatica.

The EOSD and NLC contained overlapping classification values. The NLC used values between 0 and 15; the EOSD used values between 0 and 223. PCI Geomatica was used to renumber the mosaiced EOSD classes to two schemes that would allow the EOSD to be merged with the NLC. See Appendix B for the class renumber scheme and class descriptions.

The Geomatica process for reordering the EOSD used the PCI model tool with nested if statements. The model statements were built in Excel then adapted to a Geomatica procedure. This technique reduces the possibility of typographic errors resulting in an incorrectly renumbered file.

The NLC image is clipped along an irregular line referred to in the documentation as the "treeline". The EOSD image extends north of the southern edge of the NLC image. This results in an extensive region of overlap. Both images use a 0 (zero) data value to represent no data.

ArcGIS was used to merge the resulting three files into two output files, Annual1 and Summer2.

- "Mosaic" with Method=Last, Color Map Mode=First, Color Matching Method=None, Ignore Background value=0, NoData Value=0 was used to add the NLC image into the output image.

- “Copy Raster”, default settings was used to create a tiff file for export.

The image merge was specified to give the NLC classification precedence over the EOSD image. This resulted in all non-zero NLC data being present in the final image. However, the EOSD image data will replace any NLC zero value location where the images overlap.

In Geomatica all files originally had a pseudo-colour table (PCT) with assigned colours. PCTs from TIFF files translate to colour maps in ArcGIS. When ArcGIS merges files with colour maps the output class numbers are affected by how the colour maps relate. There were a number processing options available, however, none were really appropriate for this particular dataset. Additionally, ArcGIS, at this version, has very poor colour map management tools. To make the merge work it was necessary to replace the renumbered EOSD colour map with a dummy colour map file that contained all 0-32 class values. Since there is no way to edit the colours assigned the resulting file was visually unappealing. The workaround for this was to create an ArcGIS layer file containing the 32 colours needed for the merged files. Since the Layer file is specific to ArcMap any TIF files exported will not contain the assigned colours.

A better way to do this would be to merge the NLC and EOSD mosaics in Geomatica, create the new colour map and export to TIF. The resulting files would automatically look acceptable in ArcGIS without the overhead of the layer file and the TIF files would be more portable.

NDVI

NDVI data were received from W Chen and J Li via a 900 Megabyte zip file posted to an ftp site. The file contained 792 raw/aux file pairs containing (1) 32-bit real (floating point) channel of data created by Geomatica. The data values ranged from -1.0 to +1.0. The data were in a projection of LCC -95, 0 origins with standard parallels of 49 and 77 and a datum of NAD 83. The data consisted of three files for each month from January 1, 1985 to December 21, 2006. Files are named as follows: YYYYMMNN_ndvi where YYYY is the year, MM is the month, and NN is one of 01, 11 or 21. These files were not directly usable in ArcGIS. The RSF analysis preferred integer data the NDVI values were scaled to a range of 0-200.

A Geomatica script was written to process all NDVI files as follows:

1. Import to PCI PIX format with 1-32 bit real channel.
2. Export to TIF format with 1 32-bit real channel.
3. Add one 8-bit channel.
4. Scale 32-bit data to 8-bit <8-bit Value> = ROUND[((<32-bit value) + 1) * 100].
5. Export to TIF with 8-bit channel.

To attach the NDVI to a copy of the caribou location master file the following steps were used.

1. Imported the BUR.shp to a PCI PIX file (BUR.pix) resulting in a vector segment with a point layer containing the caribou locations.

2. Manually copied the master BUR.pix to the NDVI folder named for each of the 11 available years (1996-2006) as burYYYY.pix.

3. Used a Geomatica script to attach the 8-bit NDVI value for all available files into the appropriate year file using the PCI function vimage. This resulted in a PIX file for each year containing a field for each source NDVI file available for that summer season. The field contained the NDVI value for that date. E.g. for 1996 a file bur1996 contained the fields Rec_ID, 19960601_ndvi, 19960611_ndvi, 19960621_ndvi...19961021_ndvi. Finally the resulting PIX file point layer was exported to a shape file. Due to the field name limit in the dBase file the field name was truncated to 10 characters (e.g. 19960601_N).

4. Access was used to link to all the resulting shape attribute dBase files on the Rec_ID and a query built to select all fields from all years. An XLS and CSV file were exported containing the Rec_ID and all 166 NDVI values of the relevant dates for all points.

QA tests were done by linking the XLS file back to the BUR Layer in ArcGIS. Random points were overlaid with random 32-bit NDVI raster files, the appropriate fields were found to contain the expected value. In addition, C Johnson provided a file with Rec_ID, NDVI values and locations. These were compared to the source files and found to match.

Mining Related Human Disturbances

The previous study had difficulty in determining where human disturbances occurred (Johnson et al. 2005). For this project several different data sources were used in an attempt to quantify the disturbance regime. Mine footprint land use permit applications (LUP), mineral leases and mineral claims were all used individually to help build the picture of human disturbances.

Known Footprint of Existing Mines

Mine footprint data is a component of the human disturbance layers that were considered. Mine footprint-by-year data was requested from Ekati, Diavik and DeBeers only Ekati provided data. The Ekati footprint file contains polygons representing the mine footprint. There is an attribute associated with each polygon that represents the year that the area was initially used. With the Ekati file as a model, mine footprints were estimated from Google Earth, Spot imagery available from GeoBase and reviewing the Kennedy Lake file on the Mackenzie Valley Land and Water Board website. This resulted in a polygon file annotated by year of expansion for the Lupin, Ekati, Diavik, Snap Lake and Kennedy Lake mine sites. The Lupin mine footprint was assumed to have not changed over the study period. Probably the annual mine and exploration reports published by NWT Government and Nunavut Government could have been used to further refine mine expansion data.

The following Spot images were used:

- S4_10909_6336_20070624_p10_1_utm12.tif

- S5_11028_6453_20060613_p10_1_utm12.tif
- S5_11050_6428_20060613_p10_1_utm12.tif

It is unknown if there are other developments out there that generate a significant amount of activity during the summer. It is unknown if the activity around the mine relates to the road footprint that was provided or that is detectable from the available Spot imagery. It is unknown if the Google Earth and Spot images accurately reflect mine footprint. The year of expansion to a particular area could only be estimated from one or two images over the 12 year study period.

Once the aggregate mine layer was completed, an ArcGIS vbs script Select_analysis function with a selection criteria of "Year" <= YYYY", where YYYY represented the each of the project years was used to select the relevant footprints. The selected features were then exported to a shape file names MineFPYYYY, where YYYY represents each year of the study.

Land Use Permit Applications

Land use permit application files were requested from the Mackenzie Valley Land and Water Board (MVLWB), Wek’èezhìi Land and Water Board (WLWB) and Aboriginal Affairs and Northern Development Canada (AANDC) Yellowknife regional office. Several agencies in Nunavut were contacted but no similar territorial databases were found.

AANDC, MLWB and WLWB all create a permit application database from permit applications that are submitted. The WLWB area of interest encompasses all our study area south of the Nunavut/NWT border. The WLWB area of interest is completely contained within the MVLWB area of interest. The AANDC database covers all areas in our study area except activities initiated after 1999 on Nunavut owned lands. Since no dataset for Nunavut owned lands was discovered, it is unknown what human disturbances are present on those lands.

Data were received from AANDC on 11/24/2008; from MVLWB on 11/1/2008; no files were received from the WLWB. Because no files were received from the WLWB in time to use in this study the utility of that dataset was not evaluated and the following observations pertain to the AANDC and MVLWB files only. Both AANDC and the MVLWB update their datasets in a timely fashion when new applications are received. It will be assumed that both represent the same snapshot in time even though there is a three-week difference in the creation time of the two files.

Since a database record is created prior to the permit being approved, the status must be checked to ensure that the application record relates to an approved permit.

AANDC processing; the LUP data were requested from AANDC and data file was received as an Excel spreadsheet. There are few records dated prior to 2003 in this dataset

MVLWB data was requested from the MVLWB it was received as an Access file. These were exported to Excel and imported to ArcGIS as a Shape file. There are few records prior to 1999 in this dataset.

Both files were clipped to the extent of the summer range using a "Find by Location" query with the "Bathurst Summer Range" layer. Because neither dataset seemed to have information for the late 90s it was decided to use the data that C. Johnson had collected for the previous study for the time period 1996-2002. For the period 2003-2008 the AANDC data was used because it had data for Nunavut as well as the NWT.

- There are 22 records in the MVLWB dataset that pertain to the Wek'èezhìi jurisdiction.
- There are 14 records in the AANDC dataset that pertain to the Wek'èezhìi jurisdiction.
- 200 records in the AANDC dataset that pertain to Nunavut or the NWT prior to 1999.
- There are approximately 104 records in the AANDC dataset that should appear in the MVLWB dataset and about 120 in the MVLWB dataset that should be in the AANDC dataset. There are about 12 records in either the AANDC or MVLWB that are duplicated in the same dataset. Of these, 79 records match by file number. After reviewing the non-matched records, there were no file numbers that looked like they should have matched but didn't. Therefore the non-matched records represent additional permit applications. Some of these applications may never have become actual permits.

- A few statistics on the distance between the AANDC LUP locations and the MVLWB locations.

Count: 79 matched LUPs, by government file numbers.
Minimum: 0 km
Maximum: 216 km
Mean: 34.8 km
Standard Deviation: 41.8 km

Mining Claims and Mineral Leases

Mining claims are an indication of exploration activity. When an explorer finds something of interest a claim is staked. The claim reserves that land for that explorer for two years. The claim can be renewed to a maximum of ten years. To maintain the claim the explorer must file a report and must spend a certain number of dollars per year per acre on the claim.

Mineral leases are an indication of exploration activity that probably represents more activity than does a claim. If a prospector holds a claim for ten years it must be converted to a lease. To create a lease, the area must be surveyed. To maintain the lease an annual fee is paid.

AANDC maintains a spatial dataset of claim and lease locations. They also maintain a tabular database of lease and claim history and status. This database has a file report number that can be used to locate the report that indicates the results of the work done on the lease/claim. The work done on a lease/claim doesn't have to be annual and it doesn't have to occur on site. There is no way to tell without reading the file report if onsite work was done at any particular time.

If certain thresholds are met, then a land use permit or water license is also required.

A third spatial layer, called "Prospecting Permits" or "Exploration Permits" is also available from AANDC. The spatial layer for this data only goes back to 2003 so this data was not used.

Outfitter and Ecotourism Camps

Those point features were buffered 1,000 m. We recognised that hunters may use the lake shore, thus, for hunt camps the lake shore within 20 km of the feature were buffered 5 km inland. To create this layer the following process was used:

- Lakes were selected from the 1:1,000,000 water base layers that were within 5 km of a known outfitter location.
- These lakes were buffered by 5 km.
- The outfitter locations were buffered by 20 km.
- An intersect function was done to clip the buffered lake layer by the outfitter buffer.

- The resulting file was then manually reviewed. This technique results in some areas selected that don't actually have camps near that location. This occurs when a lake with a camp at one end is within 20 km of a camp on a different lake. These areas were manually removed.

It is known that outfitters select camps for use based on the known or expected location of caribou. It is not known if a particular camp is used in any particular year.

DISCUSSION

At the time of this work, there were uncertainties and inconsistencies in the available land use datasets managed and provided by government agencies that created problems in data compilation and hindered analyses.

Although stakeholders recognize that land use may contribute to the overall cumulative effect of human activity to caribou, the data available to describe the type, intensity and temporal and spatial extents of the activity are poor. Although several government departments across three levels of government collect land use information the actual data available in a usable form were extremely limited.

The datasets that we received from AANDC did not match a similar dataset from the MVLWB. Of the 120 permit applications in the MVLWB only 79 matched by file number with the corresponding record in the AANDC database, and it was unknown why there was a large discrepancy in the two GIS datasets. Of the matching permits the maximum difference in geographic location for the same permit application was 216 km with a mean difference of 34.8 km. We did not know whether those geographic differences represented errors in the datasets or whether the activities encompassed that range of spatial extent. In either case the magnitude greatly exceeded the defined ZOI used in this project. Although the permit application documentation contained information about the permit, conversion of that information to a usable geographic form containing location, activity and time frame was beyond the scope of this project.

In this project we used the existence of a mining claim or lease to indicate mining activity. However, there was no knowledge of the level of activity that may have occurred in the areas, nor was there any spatial extent or location tied to the mining claim or lease. Similarly, there was no information about mineral exploration, unless the level of activity triggered the issuance of a land use permit.

We used the Tourism Operator License database to determine the location of recreational activities. This database did not include information about the level of hunting effort or the location of resident or aboriginal hunting locations. There is no knowledge of which commercial outfitter and ecotourism camps actually had activity in a given year. No information if foot, boat, aircraft were used.

In summary, we found several inconsistencies with land use permit datasets provided by government agencies. There was also an obvious information gap regarding activities that did not require a land use permit, which may include up to a 200 person-day camp, frequent air traffic, low level flights, helicopter traffic, and other activities done in the course of prospecting, staking, or locating a mineral claim. So although these activities have been identified as potential cumulative stressors to caribou, there were no empirical data to define their occurrence or extent.

Table A1. Descriptions of land cover datasets.

Products	Source Imagery	Grain	Extent	Pros	Cons	Documentation	Link
Circumpolar Arctic Vegetation Map (CAVM)	AVHRR summers (maximum greenness) 1993 and 1995	1 km	circumpolar Arctic tundra	extensive coverage across circumpolar Arctic	Coarse grain (pixel scale) imagery reduces accuracy in habitat selection analyses. Restricted to Arctic tundra region, does not go below tree line (winter range)	J016-011A.pdf	http://www.geobotany.uaf.edu/cavm/abstract.shtml
Canadian Arctic Vegetation Map (north of treeline)	AVHRR summers 1993 and 1996	1 km	Canadian Arctic tundra; 20 land cover classes	Canadian Arctic Subset of CAVM.	same as CAVM	Gould et al. 2003.	http://www.geobotany.uaf.edu/x_arcticgeobot/index.html
WKSS Vegetation Classification	TM 1989-1997	30 m	Slave Geologic Province, NWT	300-500 ground truth sites/Landsat image; Accuracy 51-82%; Fine grain (pixel scale) Used in previous RSF work by C. Johnson et al.	Restricted to a portion of the Bathurst range, and not generally applicable to other barren-ground caribou range	Mathews et al. 2001. West Kitikmeot Slave Study	Environment and Natural Resources, Government of the Northwest Territories

Products	Source Imagery	Grain	Extent	Pros	Cons	Documentation	Link
New Circa 2000 Land Cover Map of Northern Canada (NCL)	ETM 2000 +/-3 years	30 m	Canadian Arctic; 15 land and water cover types aligned with CAVM classes	Accuracy 71-85%; fine grain imagery with broad coverage across Canadian Arctic. will become part of nation land cover product	Free download, clipped at the northern limit of forests line. Available by 1:250K map sheet tile.	Olthof et al. 2008	http://www.geogratis.gc.ca/download/landsat_7/Northern_Land_Cover
Circa 2000 Landsat ETM+ land cover mosaic of northern Canada	ETM 2000 +/-3 years	90 m	45 classes, extends furthest south	Used WKSS ground truth data. Extends further south than CAVM or NCL	Error in the projection. Projection origin is indicated as 0 but is actually 49.0	Olthof et al. 2005	http://www.geogratis.gc.ca/download/landsat_7/NorthernCanada_mosaic/NC_Landcover.zip
EOSD Land Cover Classification	ETM 2000 +/-3 years	30 m	Southern Canada, north past the northern extent of forest	Covers all areas not included in the NCL	Does not cover a sufficient area of the summer caribou range	Wood et al. 2002.	http://cfs.nrcan.gc.ca/subsite/eosd/landsat

Table A2. Merged legend for habitat types based on "New circa 2000 Land Cover Map of Northern Canada" (NLC) and the "EOSD Land Cover Classification" (EOSD).

Origin	Source	Annual 1	Summer 2	Short Description	Description
0	NLC	0	0	No data	
1	NLC	1	1	tussock graminoid tundra (<25% dwarf shrub)	Moist tussock tundra with <25% dwarf shrubs <40 cm tall and moss. May also include lichen.
2	NLC	2	2	wet sedge	*Graminoids and bryoids* Wet sedge including cottongrass that is saturated for a significant part of the growing season, also includes moss and may include <10% dwarf shrubs <40 cm tall.
3	NLC	3	3	moist to dry non-tussock graminoid / dwarf shrub tundra	*50-70% cover.* Moist to dry non-tussock tundra with 50-70% vegetated cover. Vegetation includes a mixture of graminoids, dwarf erect <40 cm and prostrate dwarf shrubs. May also include tract amounts of lichen and moss.
4	NLC	4	4	dry graminoid prostrate dwarf shrub tundra	*70-100% cover* Upland or well drained non-tussock graminoid tundra with low to prostrate dwarf shrub heath >70% cover.
5	NLC	5	5	low shrub (< 40cm; > 25% cover)	*Erect.* Moist erect low shrub <40 cm forming more than 25% of the vegetated cover, consisting mainly of dwarf birch (*Betula*) and/or willow (*Salix*). Remaining cover consists of graminoids, lichen and may contain prostrate dwarf shrubs and bare soil.
6	NLC	6	6	tall shrub (> 40cm; > 25% cover)	*Erect.* Moist to wet erect tall shrub >40 cm forming more than 25% of the vegetated cover, consisting mainly of dwarf birch (*Betula*), willow (*Salix*) and / or alder (*Alnus*). Remaining cover consists of graminoids, lichen and may contain <10% prostrate dwarf shrubs and bare soil.
7	NLC	7	7	prostrate dwarf shrub	*Dryas/heath, usually on bedrock or till.* Generally dry >50% vegetated cover consisting of prostrate dwarf shrubs, graminoids and may contain <10% lichen and

Origin	Source	Annual 1	Summer 2	Short Description	Description
					moss.
8	NLC	8	8	sparsely vegetated bedrock	Barren surfaces with 2-10% vegetation cover on acidic, igneous, mostly consolidated bedrock. Vegetation cover generally consists of graminoids and prostrate dwarf shrubs.
9	NLC	9	9	sparsely vegetated till-colluvium (2-10% cover; Henry et al., 1986)	Barren surfaces with 2-10% vegetation cover on nonacidic and calcareous bedrock and colluvium. Vegetation cover generally consists of graminoids and prostrate dwarf shrubs (*Dryas-Salix* Tundra/Barrens on Bioclimatic Zone 1; Purple *Saxifrage*-Herb Tundra/Barrens on Bioclimatic Zone 2; Edlund and Alt 1989).
10	NLC	10	10	bare soil with cryptogam crust	Frost boils. Unconsolidated barren surfaces having experienced significant cryoturbation with 2-10% vegetation cover consisting of graminoids and cryptogam plants.
11	NLC	11	11	wetlands	Vegetated areas where the water table intersects the land surface all or part of the year. This class is represented by a general gradient of decreasing biomass with increasing latitude, from sedge, moss low-shrub wetlands at the latitude of central Hudson Bay, to moss dwarf-shrub wetlands at the latitude of south-central Baffin Island, to sedge/grass, moss wetland further north (Walker et al. 2002).
12	NLC	12	12	barren	<2% vegetation cover on nonacidic and calcareous parent material.
13	NLC	13	13	ice/snow	Areas permanently covered by snow and ice (glaciers).
14	NLC	14	14	shadow	Topographic shadow.
15	NLC	15	15	water	Areas covered by liquid standing water.
0	EOSD	0	0	No Data	
11	EOSD	14	14	Cloud	

Origin	Source	Annual 1	Summer 2	Short Description	Description
12	EOSD	14	14	Shadow	
20	EOSD	15	15	Water: Lakes, reservoirs, rivers, streams, or salt water.	
31	EOSD	13	13	Snow/Ice - includes glacier, snow, and ice.	
32	EOSD	16	16	Rock/Rubble: Bedrock, rubble, talus, blockfield, rubbley mine spoils, or lava beds.	
33	EOSD	16	16	Exposed Land: River sediments, exposed soils, pond or lake sediments, reservoir margins, beaches, landings, burned areas, road surfaces, mudflat sediments, cut banks, moraines, gravel pits, tailings, railway surfaces, burned areas, road surfaces, mudflat sediments, cut banks, moraines, gravel pits, tailings, railway surfaces,	
40	EOSD	17	17	Bryoids: Bryophytes (mosses, liverworts, and hornworts) and lichen (foliose or fruticose; not crustose); minimum of 20% ground cover or one-third of total vegetation must be a bryophyte or lichen.	
51	EOSD	18	18	Shrub Tall: At least 20% ground cover which is at least one-third shrub; average shrub height greater than or equal to 2 m.	
52	EOSD	19	19	Shrub Low: At least 20% ground cover which is at least one-third shrub; average shrub height <2 m.	
81	EOSD	20	20	Wetland-Treed: Land with a water table near/at/above soil surface for enough time to promote wetland or aquatic processes; the majority of vegetation is coniferous, broadleaf, or mixed wood.	
82	EOSD	21	21	Wetland-Shrub: Land with a water table near/at/above soil surface for enough time to promote wetland or aquatic processes; the majority of vegetation is tall, low, or a mixture of tall and low shrub.	
83	EOSD	22	22	Wetland-Herb: Land with a water table near/at/above soil surface for enough time to promote wetland or aquatic processes; the majority of vegetation is herb.	
100	EOSD	23	23	Herb: Vascular plant without woody stem (grasses, crops, forbs, graminoids); minimum of 20% ground cover or one-third of total vegetation must be herb.	
211	EOSD	24	24	Coniferous Dense: >60% crown closure; coniferous trees are 75% or more of total basal area.	

Origin	Source	Annual 1	Summer 2	Short Description	Description
212	EOSD	25	24	Coniferous Open: 26-60% crown closure; coniferous trees are 75% or more of total basal area.	
213	EOSD	26	24	Coniferous Sparse: 10-25% crown closure; coniferous trees are 75% or more of total basal area.	
221	EOSD	27	25	Broadleaf Dense: >60% crown closure; broadleaf trees are 75% or more of total basal area.	
222	EOSD	28	25	Broadleaf Open: 26-60% crown closure; broadleaf trees are 75% or more of total basal area.	
223	EOSD	29	25	Broadleaf Sparse: 10-25% crown closure; broadleaf trees are 75% or more of total basal area.	
231	EOSD	30	26	Mixedwood Dense: >60% crown closure; neither coniferous nor broadleaf tree account for 75% or more of total basal area.	
232	EOSD	31	26	Mixedwood Open: 26-60% crown closure; neither coniferous nor broadleaf tree account for 75% or more of total basal area.	
233	EOSD	32	26	Mixedwood Sparse: 10-25% crown closure; neither coniferous nor broadleaf tree account for 75% or more of total basal area.	

APPENDIX B. PROPOSED APPROACH FOR ENERGETICS MODELLING DEVELOPMENT EFFECTS ON THE BATHURST SUMMER RANGE[15]

By: Colin Daniel, Don Russell and Matt Carlson

Approach

In this section, we describe our step-by-step method for simulating habitat and diet selection by an individual cow caribou through application of the RSF analyses (described by C. Johnson in Chapter 2), followed by integration with the energetics model to derive coefficients for body fat content and conception rates that would be used to translate body condition predictions into demographic effects at a population level.

Identify Classification System for Habitat Types and Development Zones.

The first step is to decide on the classes to be used for identifying habitat types and development zones across the summer range (referred to here as "strata"). As an example, the habitat types might include 5-20 vegetation types, while the development zones might express the proximity to development (e.g. areas within a certain distance of development). Note that the strata used in the RSF analysis can differ from those used in the body condition, so long as it is possible to cross-walk from one classification system to the other. It is anticipated that the strata used in the body condition model will be an aggregation of those used in the RSF analysis.

[15]This section was written as a summary during the collaborative process of the project, and is included as an Appendix because it provides additional technical details for data analysis.

Once the strata have been identified they will serve several purposes:

- To identify the resource and development variables to be used in the RSF analysis
- To specify the scope for some of the inputs required for the body condition model: forage biomass estimates will be required for each habitat type, while activity budgets will be required for each development zone (details below).

Map Habitat Types and Development Zones.

Once the classes for RSF habitat types and development zones have been defined, the next step will be to map these within the study area. Along with their role in the RSF analysis, a summary of the area associated with each combination of habitat type and development zone will also be used as an input to the body condition model (see below).

Develop RSF Coefficients

The RSF analysis will produce coefficients for each combination of habitat type and development zone. These coefficients represent the odds ratio (or relative probability) of the caribou selecting each strata, relative to the availability of each of these strata on the landscape. The RSF coefficients will be allowed to vary seasonally (e.g. for two week periods) through the summer. Note that the exact number and duration of the RSF seasons will not affect the body condition model, as the body condition model operates on a daily time step and can be run both before and after the RSF analysis period.

Determine Caribou Use of Landscape Strata

The next step will be to determine the probability that each RSF stratum (i.e. combination of habitat type and development zone) will be encountered by the individual animal for each day of the simulation. This can be estimated from the seasonal RSF coefficients using the following equation:

$$P_{i,d}=(RSF_{i,d}*Area_{i,d})/\sum_i (RSF_{i,d}*Area_{i,d})$$

where:

- $P_{i,d}$ = probability of animal selecting stratum i on day d;
- $RSF_{i,d}$ = RSF odds ratio for stratum i on day d; and
- $Area_{i,d}$ = total area in stratum i on day d.

To illustrate how this equation functions, consider the following example using two habitat types and two development zones:

Habitat Type	Close to Development.	RSFi	Areai (ha)	RSFi*Areai	Pi
Herb	Yes	0.1	25	2.5	0.125
Shrub	Yes	0.1	50	5	0.25
Herb	No	0.2	25	5	0.25
Shrub	No	0.3	25	7.5	0.375
		Sum	125	20	1

Develop Body Condition Model Inputs

All of the model inputs required by the body condition model will be developed through literature review and expert opinion; for those inputs with significant uncertainty in their values, a range (or distribution) of values can be provided as input. The full suite of model inputs will be stored in a single Excel spreadsheet, with accompanying documentation (similar to the approach used for the 1999 Diavik analysis). Additional details regarding the requirements for these model inputs are outlined in the next section.

Run the Body Condition Model

The next step will be to run the body condition model. The objective will be to run the model stochastically – i.e., for multiple Monte Carlo simulations – in order to capture the effects of uncertainty in the inputs on model predictions. For each Monte Carlo simulation the model will do the following:

For those days of the simulation period that occur either before or after the RSF analysis, assume that the animal encounters average conditions for habitat and development when selecting body condition model inputs corresponding to that day.

For those days within the RSF analysis period, randomly select the RSF stratum used by the individual caribou that day based on the probability distribution (Pi,d) outlined above. Once a daily RSF stratum has been selected, convert this to its corresponding body condition stratum using a crosswalk from one classification system to the other. For any model inputs that vary by landscape stratum (i.e., forage availability and activity budgets), select the suite of input values that correspond to the body condition stratum selected for that day's use.

Because of the Monte Carlo approach, predictions for any model outputs (e.g. cow weight) can be expressed in terms of a mean and variance. Note that for the prototype version of the model, the only model input that will be set probabilistically will be the daily selection of landscape stratum.

Repeat Runs for Alternative Scenarios

Implementing Steps 1-6 once will generate a range of predictions for the body condition of an individual animal based upon a single set of model assumptions – typically a "current condition" scenario, with average conditions assumed for all input parameters. Assessing the effect of alternative scenarios on model predictions will generally require repeating Steps 4-6 for each alternative and comparing the output predictions across scenarios. For example, to predict the body condition that would result from a "no development" or "2x development" scenario, the area associated with each development zone in Step 4 would change, which in turn would alter the calculated use probabilities (Pi,d); this would then change the available forage and activity budgets experienced by the animal.

Alternative assumptions regarding other model assumptions – for example those that may be affected by climate change – can also be represented through additional scenarios. To demonstrate this concept in the prototype model, we propose to run the following nine scenarios:

Scenario	Development	Climate
1	None	Average
2	Current	Average
3	2x Current	Average
4	None	Worst-case (high snow, high insect, short green up)
5	Current	Worst-case (high snow, high insect, short green up)
6	2x Current	Worst-case (high snow, high insect, short green up)
7	None	Best-case (low snow, low insect, warm green up)
8	Current	Best-case (low snow, low insect, warm green up)
9	2x Current	Best-case (low snow, low insect, warm green up)

This list should provide some indication of the sensitivity of model predictions to a range of possible assumptions regarding development and climate. As this project is intended as a prototype only, the list of scenarios has been limited to <10 due to the manual setup required for each run when using the current body condition model (in particular, given that each scenario must be run manually for all of its Monte

Carlo simulations). Note that the future version of the body condition model will be able to handle multiple scenarios and Monte Carlos in an automated way, making it much simpler to examine a broader range of alternatives.

Predict Change in Population Parameters

Having run the body condition model for a suite of scenarios, the next step will be to relate predicted changes in body condition to changes in one or more population parameters. For example in the 1999 Diavik analysis, a relationship between fall body fat content and conception rates was used to translate body condition predictions into demographic effects. A similar approach would be used in this analysis to generate a relationship between pregnancy rate of the herd as a function of the level of development, the prior-winter snow depth and the summer insect level.

Model Inputs - Types in the Energetics Model

Table B1 describes the inputs required by the body condition model. Table B2 lists the full range of possible habitat types. And Table B3 shows the crosswalk between habitat types used in the RSF analyses and the corresponding habitat types in the energetics model.

Table B1. Variable defined as inputs to the model

Variable	Dimensions	Description and Data Sources
Habitat Types		Define the habitat types once for the entire analysis. The landscape over which the model is to be run will be classified into a set of mutually exclusive habitat types – these will then be used in both the RSF analysis and the body condition model. The list of all

Variable	Dimensions	Description and Data Sources
		habitat types would be an aggregation of those listed in Table 2 below.
Development Zones		Define the development zones for each model scenario. The study area will also be classified into a set of mutually exclusive development zones, indicating the level of development occurring across the landscape. As with the habitat types, this stratification of the landscape would be used by both the RSF analysis and the body condition model. In the prototype model we will define two development zones: areas close to development (e.g. within 1,000 m of major disturbances or 500 m of outfitter camps), and areas without development.
Plant Types		Define the plant types once for the entire analysis. A set of plant groups must be defined for the body condition model. We will use the same groups used in previous work with the body condition model, which are as follows: • Moss • Lichens • Mushrooms • Horsetails • Graminoids • Deciduous shrubs • Evergreen shrubs • Forbs • Standing dead • Eriophorum heads
Activity Types		Define the activity types once for the entire analysis. The activity types currently recognized by the model include the following: foraging, lying, standing, walking, running. The proportion of time spent by the animal in each of these activity types should sum to one each day. Foraging time is further divided into time spent eating and pawing.
Seasons		Define seasons for RSF analysis and each model input. To facilitate model parameterization, the entire simulation period is typically divided into several seasons. Season boundaries will need to be identified for each model input that requires them; however these boundaries can differ for each input variable (and from those used in the RSF analysis),

Variable	Dimensions	Description and Data Sources
		as the model automatically converts from seasonal to daily values before running the simulation.
Start Date and End Date		Specify the start and end date of the model runs. Use the same values as in the 1999 Diavik analysis: June 15 (Julian Day 166 – immediately after calving) to October 15 (Julian Day 288 – commencement of rut). Note that the body condition model can run for a longer duration than the RSF model by using input values averaged over the habitat types and development zones for those periods outside of the RSF analysis window.
Initial Body Condition		Specify the condition of the animal at the start of the simulation. For the first version of the model runs, we will assume the animal is a pregnant lactating cow (age 3+) at the start of the simulation, having experienced an average winter; the initial body condition of the animal will be estimated by running the model through the winter to estimate the body condition of a age 3+ pregnant/lactating cow on June 15. The initial body condition (i.e., on June 15) will be predicted for a combination of three alternative snow level years (high, average and low) and three green up timing types (cool, average, warm).
Snow Level	-Season -Greenup Type	Specify the snow level on a seasonal basis for deep and low snow years, and for alternative assumptions regarding the timing of green up. The timing of green up is defined according to three types of years: cool/short, average, and warm/long. Seasonal snow levels were developed for the 1999 Diavik analysis, for each combination of snow year and green up type.
Plant Biomass	-Season -Greenup Type -Habitat Type -Plant Group	Specify the available biomass by plant group for each of the model's habitat types, green up types and seasons, over the duration of the model run. Seasonal biomass values were developed for the 1999 Diavik analysis (by green up type and season); however these estimates are for the entire summer range of the Bathurst, and will need to be broken down by habitat type.
Forage	-Season	Specify the quality of the forage (i.e., nitrogen

Variable	Dimensions	Description and Data Sources
Quality	-Plant Group	content, digestibility and fibre content) by plant group and season. Values will be estimated using the same approach used in the 1999 Diavik analysis, based upon the generalized patterns developed for the Porcupine Caribou Herd.
Diet	-Season -Habitat Type -Plant Group	Specify the proportion of each plant group in the animal's diet, specified by season and habitat type. This will no longer be a model input; instead values will be predicted by the model as a function of the availability of plant biomass using the approach developed by Bob White, and refined in the 1999 Diavik analysis.
Activity Budget	-Season -Development Zone - Activity Type	Specify the proportion of time spent by the animal in each activity type, by season and development zone. Activity budgets were developed for the 1999 Diavik analysis, both with and without development. Activity budgets were also modified in the 1999 Diavik analysis to consider the effect of three levels of insect harassment (high, medium, low).

Table B2. List of current RSF Habitat Types (reformatted from Chris Johnson, 19 January 2009).

RSF Habitat Class	Name	Description
0	Other	
1	Tussock graminoid tundra (<25% dwarf shrub)	Moist tussock tundra with <25% dwarf shrubs <40 cm tall and moss. May also include lichen.
2	Wet sedge	Graminoids and bryoids; wet sedge including cottongrass that is saturated for a significant part of the growing season, also includes moss and may include <10% dwarf shrubs <40 cm tall.
3	Graminoid/dwarf shrub tundra	Non-tussock tundra with 50-100% vegetated cover. Vegetation includes a mixture of graminoids and dwarf shrubs. May also include tract amounts of lichen and moss.
4	Low shrub (<40cm; >25% cover)	Erect Moist erect low shrub <40 cm forming more than 25% of the vegetated cover, consisting mainly of dwarf birch (Betula) and/or willow (Salix). Remaining cover consists of graminoids, lichen and may contain prostrate dwarf shrubs and bare soil.
5	Tall shrub (>40cm; >25% cover)	Erect. Moist to wet erect tall shrub >40 cm forming more than 25% of the vegetated cover, consisting mainly of dwarf birch (Betula), willow (Salix) and/or alder (Alnus). Remaining cover consists of graminoids, lichen and may contain <10% prostrate dwarf shrubs and bare soil.

RSF Habitat Class	Name	Description
6	Prostrate dwarf shrub	Dryas/heath, usually on bedrock or till. Generally dry >50% vegetated cover consisting of prostrate dwarf shrubs, graminoids and may contain <10% lichen and moss.
7	Sparsely vegetated bedrock	Barren surfaces with 2-10% vegetation cover on acidic, igneous, mostly consolidated bedrock. Vegetation cover generally consists of graminoids and prostrate dwarf shrubs.
8	Sparsely vegetated till-colluvium (2-10% cover; Henry et al. 1986)	Barren surfaces with 2-10% vegetation cover on nonacidic and calcareous bedrock and colluvium. Vegetation cover generally consists of graminoids and prostrate dwarf shrubs (Dryas-Salix Tundra/Barrens on Bioclimatic Zone 1; Purple Saxifrage-Herb Tundra/Barrens on Bioclimatic Zone 2; Edlund and Alt 1989); bare soil with cryptogam crust - frost boils unconsolidated barren surfaces having experienced significant cryoturbation with 2-10% vegetation cover consisting of graminoids and cryptogam plants.
9	Bare soil with cryptogram crust - frost boils	Unconsolidated barren surfaces having experienced significant cryoturbation within 2-10% vegetation cover consisting of graminoids and cryptogam plants.
10	Wetlands	Vegetated areas where the water table intersects the land surface all or part of the year. This class is represented by a general gradient of decreasing biomass with increasing latitude, from sedge, moss low-shrub wetlands at the latitude of central Hudson Bay, to moss dwarf-shrub wetlands at the latitude of south-central Baffin Island, to sedge/grass, moss wetland further north (Walker et al. 2002).

RSF Habitat Class	Name	Description
11	Barren, rock/rubble, exposed	Barren: <2% vegetation cover on nonacidic and calcareous parent material; Rock/rubble (Bedrock, rubble, talus, blockfield, rubbley mine spoils, or lava beds); Exposed land: River sediments, exposed soils, pond or lake sediments, reservoir margins, beaches, landings, burned areas, road surfaces, mudflat sediments, cut banks, moraines, gravel pits, tailings, railway surfaces, burned areas, road surfaces, mudflat sediments, cut banks, moraines, gravel pits, tailings, railway surfaces.
12	Water	Areas covered by liquid standing water.
13	Bryoids	Minimum of 20% ground cover or one-third of total vegetation must be a bryophyte or lichen
14	Shrub	At least 20% ground cover which is at least one-third shrub.
15	Wetland-treed	Wetland where the majority of vegetation is coniferous, broadleaf, or mixed wood.
16	Wetland-shrub	Wetland where the majority of vegetation is tall, low, or a mixture of tall and low.
17	Herb	Vascular plant without woody stem (grasses, crops, forbs, graminoids); minimum of 20% ground cover or one-third of total vegetation must be herb.
18	Forest	Coniferous, broadleaf or mixed wood; at least 10% crown closure.

Table B3. List of habitat types for the body condition (energetics) model, including crosswalk to the corresponding RSF habitat types

Body Condition Habitat Class	Name	Description	Corresponding RSF Habitat Classes
0	Other		0, 12
1	Forest	From sparse to dense coniferous forest (11.5%), deciduous, mixed (2.5%).	18
2	Shrub tundra	25% of the vegetated cover, consisting mainly of dwarf birch (Betula) and/or willow (Salix). Remaining cover consists of graminoids, lichen and may contain prostrate dwarf shrubs and bare soil.	4, 5
3	Tussock graminoid tundra	Moist tussock tundra with <25% dwarf shrubs <40 cm tall and moss. May also include lichen.	1
4	Sparsely vegetated areas	Bare rock, barren, and frost boils.	7, 8, 9, 11
5	Prostrate dwarf shrub	Dryas/heath, usually on bedrock or till. Generally dry >50% vegetated cover consisting of prostrate dwarf shrubs, graminoids and may contain <10% lichen and moss.	6
6	Dry shrub	At least 20% ground cover which is at least one-third shrub.	14
7	Wetlands	Moss dwarf-shrub wetlands.	10, 15, 16, 17

Body Condition Habitat Class	Name	Description	Corresponding RSF Habitat Classes
8	Non-tussock graminoid tundra	Moist to dry non-tussock tundra with 50-70% vegetated cover. Vegetation includes a mixture of graminoids, dwarf erect <40 cm and prostrate dwarf shrubs. May also include trace amounts of lichen and moss.	3
9	Bryoids	Minimum of 20% ground cover or one-third of total vegetation must be a bryophyte or lichen.	13
10	Wet sedge	Wet sedge including cottongrass that is saturated for a significant part of the growing season, also includes moss and may include <10% dwarf shrubs <40 cm tall.	2

Model Outputs

The model outputs that will be compared across the nine scenarios are as follows:

- Body condition (mean and range) of an individual three-year old cow on October 15 – note that body condition can be any one of the many model outputs, including cow weight, fat weight, protein weight, etc.
- Predicted pregnancy rate associated with each scenario, through a relationship between pregnancy rate and one or more body condition measures.

- From the results of these nine scenarios we will ultimately estimate the relationship between pregnancy rate and both the level of development and climate, which will then be used in the ALCES population model for caribou.

Architecture

The system will be designed to run as follows:

Excel file for model inputs. All of the body condition model inputs will be stored in an Excel file – similar to the approach used for the 1999 Diavik analysis (Gunn et al. 2001b). Some of the modifications required to the existing Diavik input spreadsheet include:

- Add a worksheet to store the RSF coefficients and randomly generate the time series of daily landscape strata selected for each model run.
- Modify the biomass worksheet to allow values to be specified for each habitat type.
- Modify the activity worksheet to accept the latest activity budget data, and to link activity budgets to each development zone.
- Add a new results worksheet to store the results of each model simulation.
- Review all of the worksheets to ensure they are consistent with approach used in this project.

Access Transfer Tool to Connect Model to Excel

For the prototype we ran the old version of the body condition model – this version of the model required that all model inputs be transferred into an Access 97 database file. To automate the transfer of inputs from Excel to Access 97, we developed a new Access "transfer tool" that will link the Excel input spreadsheet directly to the model database; this tool will also serve to transfer the model results back to the Excel spreadsheet at the end of each model run. Note that once we move to using the new version of the body condition model, this step will not be required as the new model will be able to read inputs directly from Excel.

APPENDIX C. A POPULATION DYNAMICS MODULE IN ALCES

By: John Nishi and Brad Stelfox

Introduction

We developed and incorporated a population dynamics ('Pop-Dyn') module within ALCES so the model could explicitly simulate wildlife populations on a defined landscape that was subject to natural and anthropogenic disturbances. The goal of incorporating the Pop-Dyn module was to link coarse-scale demographic drivers of single or multiple wildlife populations to a dynamic landscape in one modeling platform, so that a user could explore relationships between land-use, management strategies, and predator-prey relationships. With respect to this pilot project, a goal for incorporating the Pop-Dyn module was to provide a model structure that would be able to accommodate results and data outputs from the RSF and Energetic models (Chapters 2, 3 respectively) as inputs in to caribou population dynamics. Following the development and incorporation of the Pop-Dyn module, ALCES was parameterized for a study area in north-east Alberta to simulate predator-prey population dynamics in boreal caribou and explore management strategies through simulation modeling (ALT 2009, Antoniuk et al. 2009a).

Modelling Approach

Since ALCES was originally designed to simulate landscape dynamics in response to natural disturbances and anthropogenic land use, it had the foundation for a dynamic habitat model and so it was relatively straightforward to incorporate multiple interacting wildlife populations. This in turn provided a basis for modeling trophic interactions among species within the broader context of plant-herbivore and predator-prey interactions, which are often referred to as 'bottom-up' and 'top-down' processes, respectively. Potential sources of anthropogenic mortality, i.e. hunting, poaching, and culling (depredation), were also included in the module design.

The module was designed to accommodate a multiple predator-prey system, with up to five species (designated as prey or predator) stratified in to two genders (male, female), and five age classes (young of year, yearling, young adult, mature adult, and old adult). So depending on complexity of the wildlife system of interest the user can run the model as a single species, or multiple interacting prey and predators.

For each species, the user provides input metrics to the Pop-Dyn module according to the following general categories:

- Body mass (for each gender and age class);
- Reproductive rates for females by age class
- Natural mortality rates by age class;
- Maximum expected density (carrying capacity);
- Immigration (rate and interval);
- Forage requirement as percent of body mass;

- Identify and rank relative quality of landscape types that contribute to suitable habitat;
- Rank relative habitat quality of seral stages for forested landscape types;
- Identify prey species for defined predator species;
- Relative vulnerability ranking of each prey species; and
- Hunter harvest characteristics.

Description of the Population Dynamics Module in ALCES

Although the Pop-Dyn module was based conceptually on an interactive vegetation and herbivore system (*sensu* Caughley 1976), it was not designed to simulate plant-herbivore dynamics using a mechanistic and fine-scaled approach (e.g. Gedir and Hudson 2000). Instead the module was designed to capture the essential elements of the model system at a broad landscape level, meaning that the 'bottom-up' processes between forage availability and population demography of herbivores are considered at a coarse temporal and spatial scale.

The module allows the user to link rates of fecundity and mortality to either animal density or forage availability. The negative feedback loop that links rates of birth and death to per capita forage availability is consistent with ecological theory, but is often challenging to populate with empirical data and relationships. The practical problem is that generally we do not possess the empirical functional response equations (or curves) that allow us to define these relationships for the systems and populations we are interested in. As such, in our experience with the module, most biologists modeling herbivore dynamics generally chose to adopt herbivore density as a driving variable instead of forage availability.

The module has an annual time step and tracks quality and area of habitat (Figure C1), and available forage biomass (Figure C2) stratified across 20 landscape types within a study area. Given the strategic focus of ALCES, parameterizing and running the Pop-Dyn module is simpler when carrying capacities (K) for species are defined deterministically based on user-defined maximum expected densities within suitable habitat, rather than simulating K as a dynamic equilibrium between population size and food abundance[16]. Nevertheless, the user has the option of determining whether reproduction for a species is to be constrained by density (habitat-K), food availability (food-K), or both.

Depending on input assumptions, birth rates are calculated as a product of user-defined fecundity rates (for each species and female age-class) and an index tied to either density, food availability, or both (Figure C3). Thus, based on the current structure of the Pop-Dyn module, herbivore populations may be limited by a user-defined maximum density, habitat availability (determined as a function of quality and quantity and translated in to food availability), predation, and anthropogenic

[16]This approach reflects a 'systems thinking' perspective (*sensu* Richmond 2000), where we have emphasized that a landscape-scale simulation model should well represent the broad-scale patterns of population dynamics as opposed to simulating all the fine-scale processes and causal demographic mechanisms in the system.

mortality; predators may be limited by user-defined maximum density, prey (i.e. food) availability and anthropogenic mortality.

Predation in the module is driven primarily by three factors. The first is habitat overlap between prey and predator species, which establishes the area (ha) and proportion of each landscape type that is shared between predator and prey, and in turn weights the proportion of the prey population that is potentially subject to predation (Figure C1, Figure C4). Noteworthy is that the model can also accommodate a linear footprint effect by which the user assigns a ZOI to anthropogenic linear features, which can increase overlap between prey and predators. For example, it has been shown that in forests, wolves travelling along seismic lines have higher predation rates on boreal caribou (see Dyer 1999, McCutchen 2007). The second factor is encounter rate between predator and prey, which is directly related to habitat overlap and total prey abundance – adjusted by age class composition (Figure C4). The module is built on the assumption that encounter rates are directly proportional to prey density. The third factor is a user-defined prey vulnerability coefficient, which attributes differential vulnerability to predation for each prey species by age class (0). Prey encounter rate is density dependent, but predation rate can be altered by a 'vulnerability' coefficient, which is a simple way for the user to define relative vulnerabilities in prey according to age class and/or sex.

The total prey biomass that is required by predators in an annual time step is then allocated to individuals of different species and age classes. This is done through an arrayed product of the total prey biomass requirement with coefficients that characterize the relative encounter rates, vulnerabilities and biomass characteristics for each species and age class of prey (Figure C5). The total number of prey (by species and age class) killed by predators in an annual time step is determined as a product of the total biomass of prey required by predators and the relative encounter rate, vulnerabilities and biomass characteristics for each species and age class of prey.

Figure C6 shows how the model structure accounts for the various sources of mortality in the population, which includes natural mortality, and anthropogenic removals – hunting and/or culling (depredation). Hunting by people, and depredation can be simulated and defined in the model, and are defined by three user inputs – switches, rates, and intervals. In short, the switch informs the model on the specific type of additional human-caused mortality that will be included. The amount of hunting or depredation is user-defined as a rate or a decimal fraction of the animal population according to species and age. The third user-defined input is the interval (in years) between hunting and/or depredation events. Natural mortality also has a user-defined switch and two user input tables for estimating minimum food mortality rate (expected rate of mortality during food shortages) and maximum food mortality rate (expected rate of mortality when food is abundant).

The importance of the ‘population structure’ sub-model (Figure C7) is that it integrates demographic rates from other sub-models, i.e. reproduction and mortality, and ‘grows’ the various wildlife populations (arrayed across species) through a linear hierarchy of stocks and flows. The most important patterns and processes to understand in Figure C7 are threefold: 1) the stocks (rectangular boxes) represent each of the three age classes as a dynamic pool that is affected by rates of inflow and outflow; 2) the main inflows that run from left to right are fecundity (i.e., births add to the abundance of young of the year – YOY), recruitment of yearlings to subadults, and recruitment of subadults to adults; and 3) the main outflow from the bottom of the stocks is age-class specific mortality. This figure includes parameters from previously described sub-models (Figure C3-Figure C6) and depicts the overall population structure and dynamic of inflows and outflows to and from each of the age classes. An additional inflow into the stock of subadults is immigration. Immigration is controlled firstly by an on/off switch (‘Immigration Switch’), and then refined by user-defined input assumptions on rate of immigration (i.e., the number of new immigrants into the subadult stock) and the interval (in years) between immigration events.

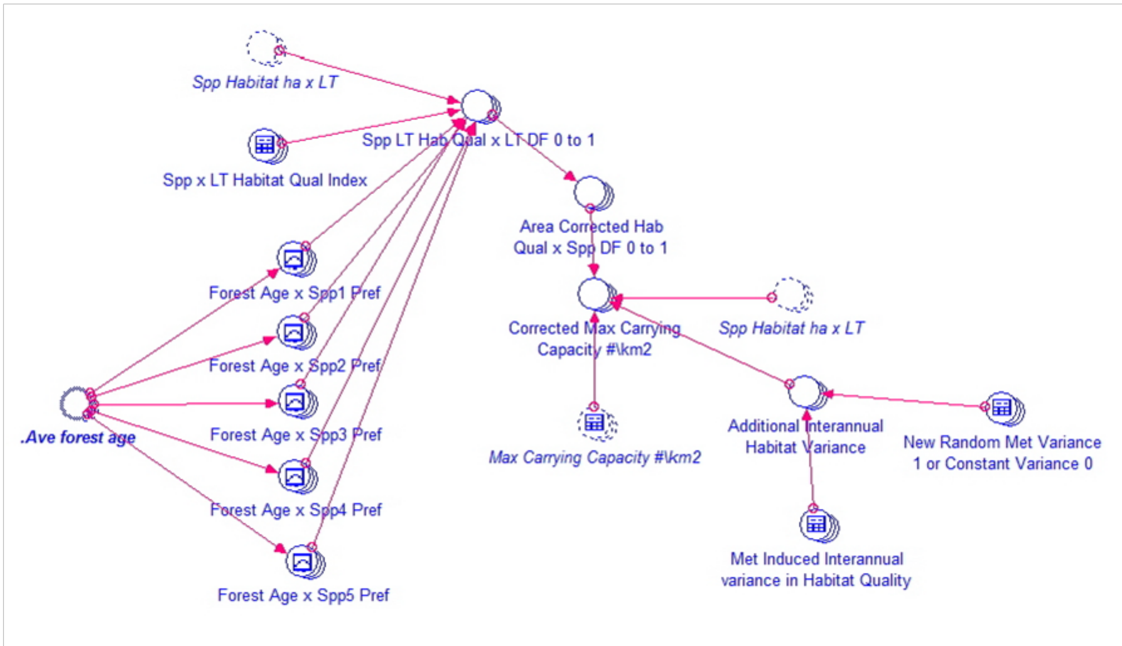
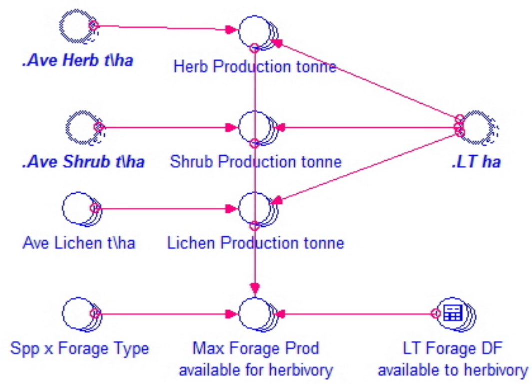
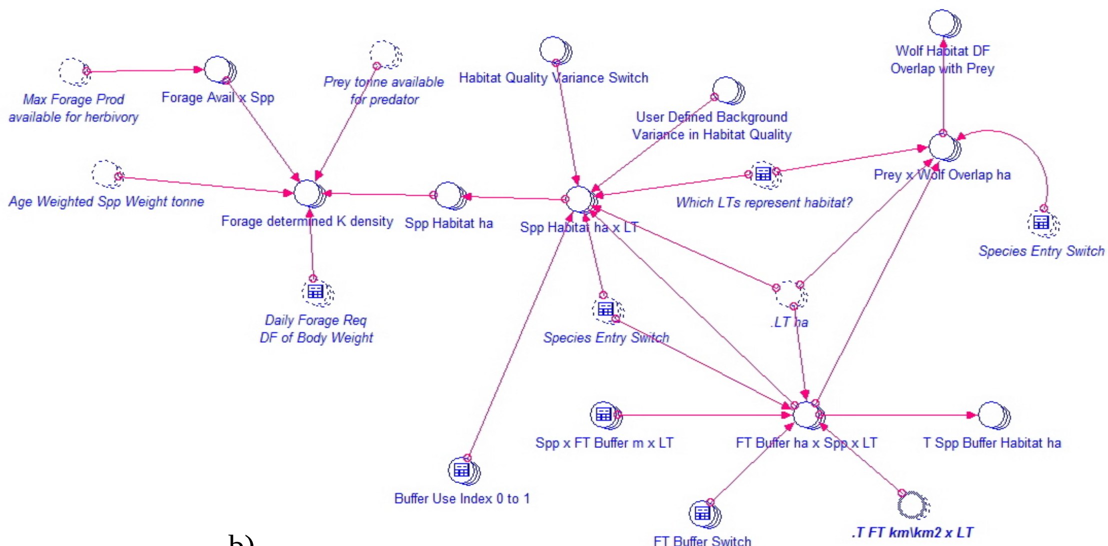


Figure C1. A STELLA® map of habitat carrying capacity in the ALCES population dynamics module. Habitat quality and area are tracked for each of 20 landscape types within ALCES to derive a habitat-based carrying capacity (i.e., Corrected max. carrying capacity #/km^2). Forested landscape types require user-defined inputs that link area of suitable habitat to seral stage. Maximum carrying capacity is a user-defined input. Variation in habitat carrying capacity can also be induced through variance in meterology and climate.



a)



b)

Figure C2. A StellA® map of food (forage) carrying capacity in the ALCES population dynamics module. Diagram a) displays how maximum forage production is calculated as a product of average forage production coefficients (by forage type) across an array of landscape types for each herbivore species, and adjusted by the proportion of forage biomass that is available to herbivory; b) shows that food carrying capacity is calculated as an array for each species and integrates total forage available across all landscape types, with average body mass and daily forage requirements (by species and age class); it also shows that anthropogenic footprints (i.e., linear features) may be buffered in a way which changes available habitat and affects overlap between predator and prey species.

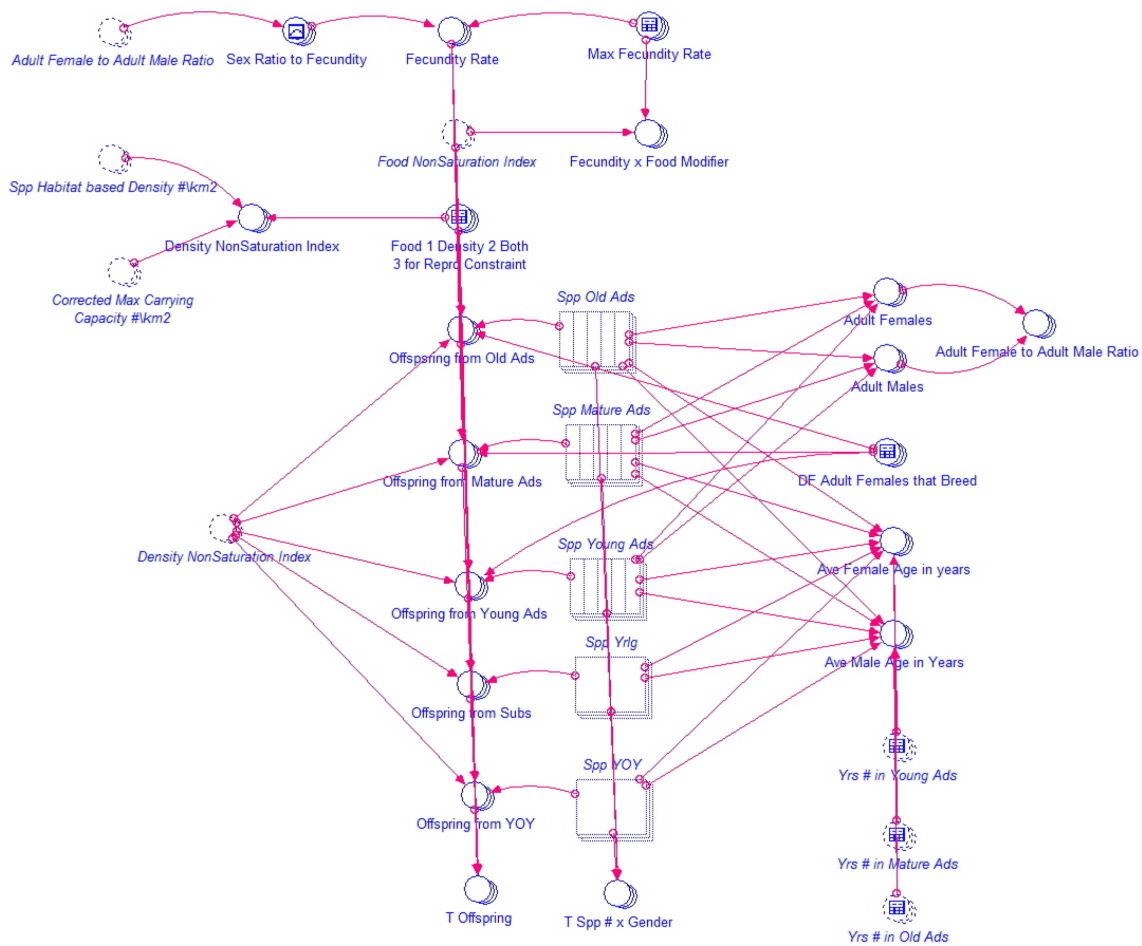


Figure C3. A STELLA® map of reproduction in the ALCES population dynamics module. Reproductive rates for each of the five cohorts across the array of species ('Spp Young of Year', 'Spp Yearlings', 'Spp Young Adults', 'Spp Mature Aduls, and 'Spp Old Adults') were calculated based on user-defined female fecundity rates, adult sex ratio, and a coefficient linked to carrying capacity, which was expressed as either a function of density('Density NonSaturation Index'), available food ('Food NonSaturation Index'), or both. The selection of the carrying capacity coefficient was determined by the user through a switch ('Food 1 Density 2 Both 3 for Repro Constraint'). At each annual time step, fecundity rates were multiplied by the current stock of animals (arrayed by sex and species) to calculate total offspring.

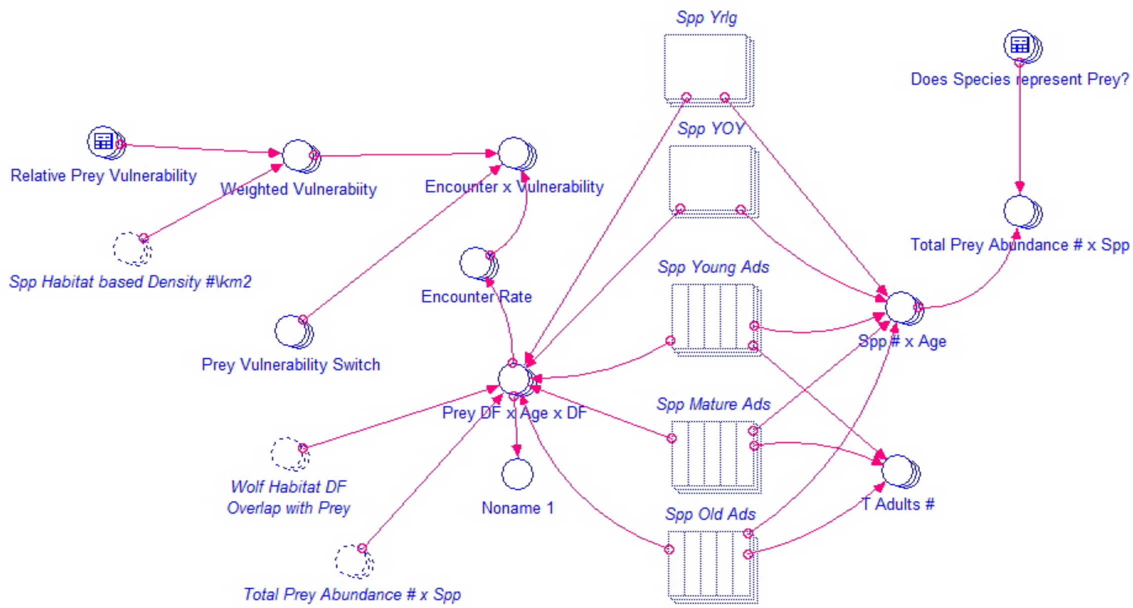


Figure C4. A STELLA® map that illustrates the influence of encounter rates and prey vulnerability on predation in the ALCES population dynamics module. Habitat overlap between predator and prey, and the relative abundance of each prey species by age class compared to total prey abundance are used to calculate encounter rate, an area-weighted proportional value that is used to determine the the total potential number of prey animals (by species and age class) that could be subject to predation. This encounter rate is adjusted further by a vulnerability coefficient that is subsequently used to calculate prey biomass to sustain predators.

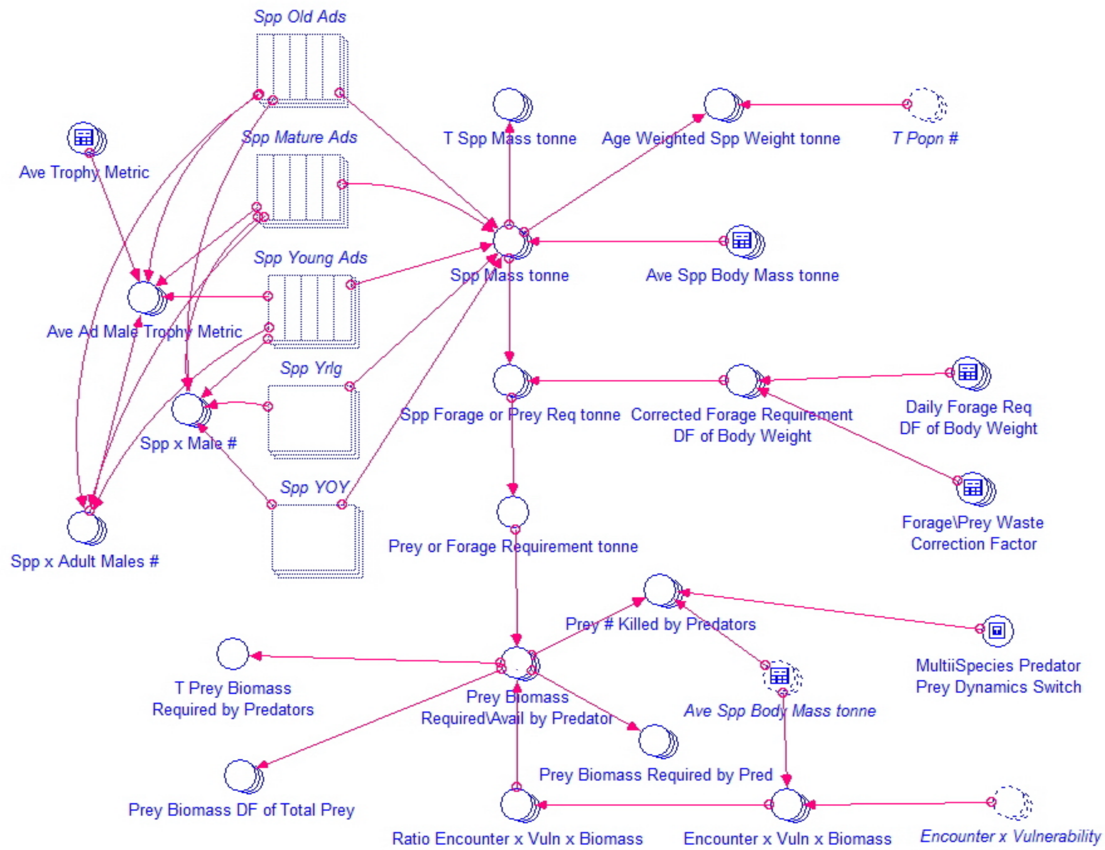


Figure C5. A STELLA® map of predation in the ALCES population dynamics module. The main part of the predation submodel is shown in a) which demonstrates how encounter rate ('Encounter Rate') and prey vulnerability ('Relative Prey Vulnerability') are main factors that drive total predation rate by wolves on prey species. The product of encounter rate and vulnerability is used to convert the total prey biomass required by predators in to the numbers of prey killed (by species and age class). Total prey biomass required by predators ('Prey of Forage Requirement') is based on the numerical abundance of predators and their individual forage requirements (expressed as proportion of their body weight ('Daily Forage Req DF of Body Weight').

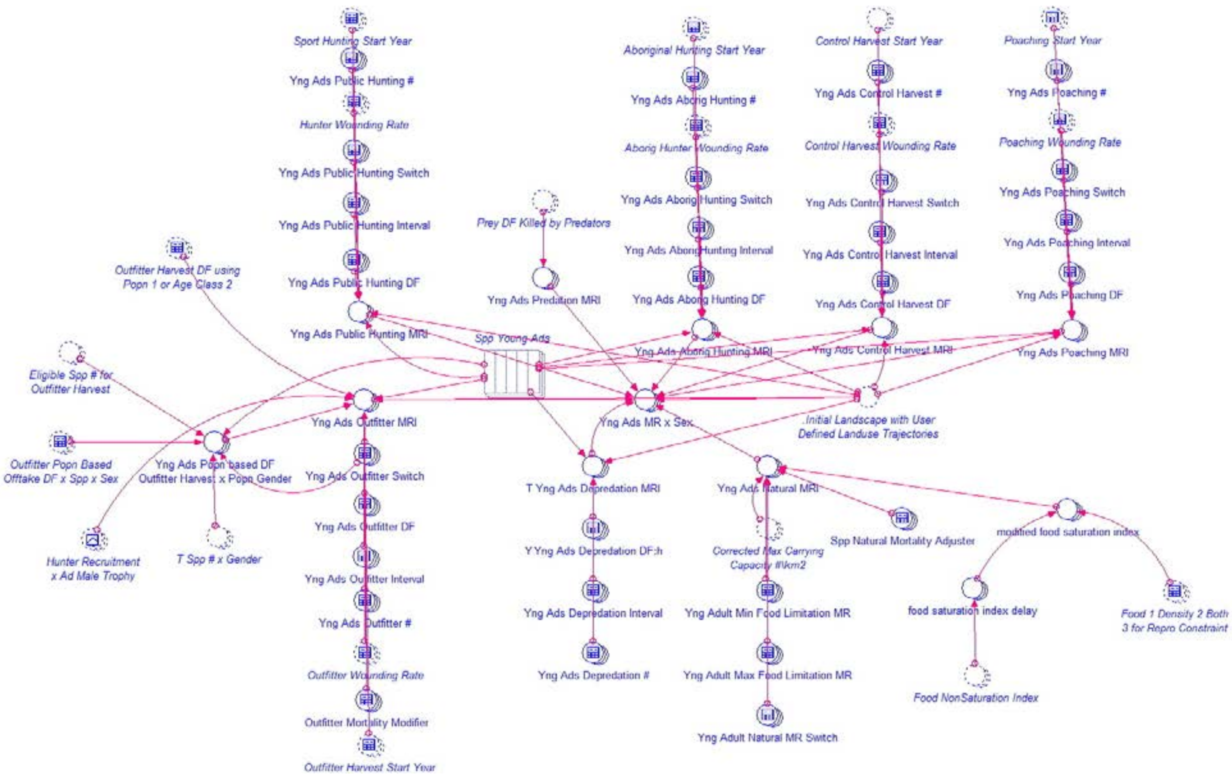


Figure C6. A STELLA® map of mortality in the ALCES population model. This diagram shows the structure for accounting several direct and indirect sources of mortality. Each discrete arrangement of icons is associated with an age class that is arrayed for all species. Examples of mortality include hunting, depredation and natural mortality.

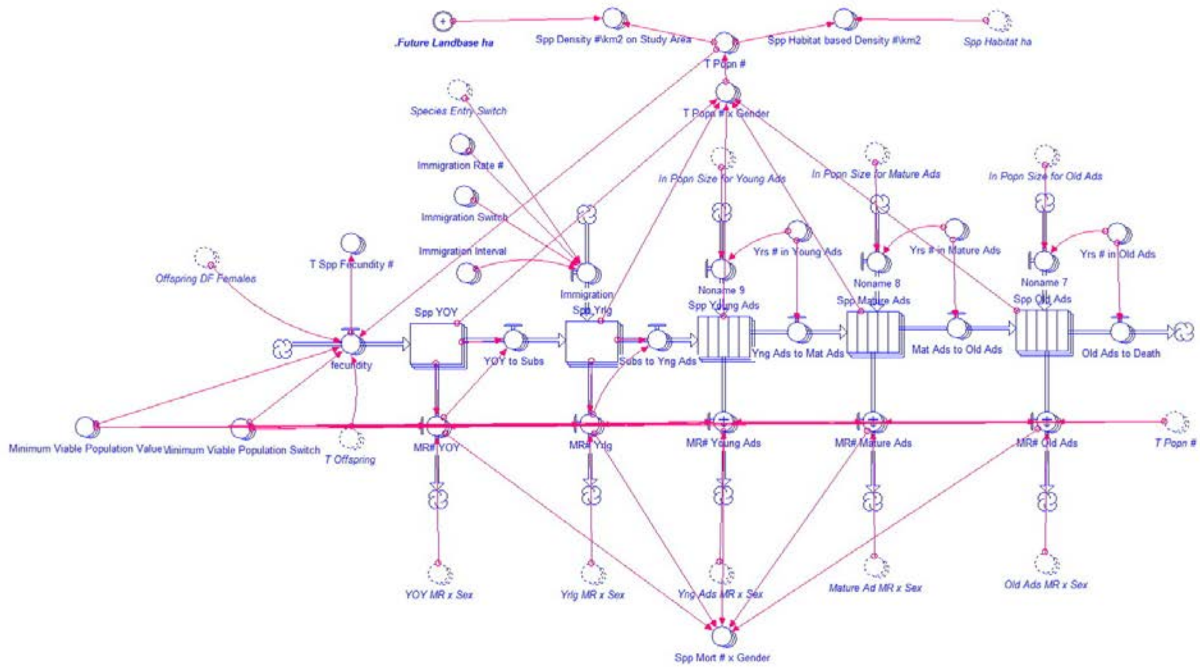


Figure C7. A STELLA® map that illustrates the structural organization of births, deaths, and recruitment according to age-classes within the population model in ALCES.