Environment Canada Environnement Canada

Scientific Review

for the Identification of Critical Habitat for Woodland Caribou *(Rangifer tarandus caribou)*, Boreal Population, in Canada

Canada

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Preface

The *Scientific Review for the Identification of Critical Habitat for Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada* was initiated to inform the development of a recovery strategy for this population of caribou. Although the review provides an analysis of the state of knowledge of boreal woodland caribou habitat and proposes a framework to support decision making, it does not provide enough guidance as to the amounts or spatial distribution of habitat disturbance that can be tolerated. Further, it has not incorporated Aboriginal traditional knowledge in a systematic way. The information provided is inadequate to enable the identification of critical habitat. Environment Canada is committed to identifying critical habitat for the boreal caribou in the recovery strategy. To that end, a series of western science studies are planned. These studies will form the basis, with other landscape information, to identify critical habitat. Expected completion date for this work is December 2010.

These western science studies will be informed by Aboriginal traditional knowledge that Environment Canada plans to collect through a series of regional workshops with Aboriginal peoples, culminating in a national workshop. The goal of these workshops will be to inform recovery planning and implementation. Environment Canada will work closely with national Aboriginal organizations to develop and hold these workshops.

Environment Canada is also planning consultations on key elements of a recovery strategy, including recovery goals and objectives, potential threat mitigation activities including land management regimes, industry best management practices, Aboriginal traditional practices, and other potential recovery activities. Consultation activities will include provinces and territories, wildlife management boards, Aboriginal groups, environmental non-governmental organizations, industry associations, and the public.

It is planned that the recovery strategy will be released in 2011. While these various streams of work are underway to inform its development, the information gathered to date on populations and threats will be widely shared to enable land managers to prudently manage the landscape in the interim.

Regular updates on progress of the work described above will be provided on the SARA Public Registry.

Scientific Review for the identification of Critical Habitat for Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada

EXECUTIVE SUMMARY

Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population (herein referred to as boreal caribou), are formally listed as Threatened under the federal *Species at Risk Act (SARA)*. The Act requires the Minister of Environment to prepare a Recovery Strategy for the species that includes, to the extent possible and based upon the best available information, an identification of its Critical Habitat and/or, if there is insufficient information available, a Schedule of Studies to determine that information. In August 2007, Environment Canada (EC) launched a science-based review with the mandate to identify Critical Habitat to the extent possible, using the best available science and/or prepare a Schedule of Studies.

This science-based review was framed as one of transparent decision-analysis and adaptive management. Thus, the Schedule of Studies produced is a key requirement of the process, designed to produce continuous improvement of results over time. The proposed Critical Habitat Identification for the spatial units associated with each boreal caribou local population is based on available quantitative data and published science, and the assumptions associated with the methodology applied. Other factors, such as the incorporation of Aboriginal traditional knowledge, and the extent to which assumptions taken in this report align with Environment Canada policy directives on Critical Habitat, may influence any potential final identification of Critical Habitat in the National Recovery Strategy.

Leading experts in landscape ecology, caribou biology, spatial habitat modeling, and population analysis were engaged to provide scientific advice on the identification of Critical Habitat for boreal caribou. Of these leading experts, 18 were part of a formal Science Advisory Group established to provide EC ongoing peer review throughout the process. An expanded group of experts contributed to the science review through a workshop held in Toronto in November 2007. A set of guiding principles was established to clearly identify the fundamental elements of the evaluation process.

SARA S.2 defines Critical Habitat as "*... the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in a recovery strategy or in an action plan for the species.*" As such, to identify Critical Habitat (CH), a recovery target must first be established. In this case, the target was expressed in the draft *National Recovery Strategy for Boreal Caribou* (Environment Canada, 2007) and provided to the EC team leading the science review. By definition therefore, for the purposes of the CH science review the Recovery Goal was that : "*boreal caribou are conserved and recovered to self-sustaining levels, throughout their current distribution (extent of occurrence) in Canada*"; and the more specific Population and Distribution Objective was: "*to maintain existing local populations of boreal caribou that are self-sustaining and achieve population growth of local populations that are not currently self-sustaining, to the extent possible, throughout the current distribution (extent of occurrence) of boreal caribou in Canada*."

Critical Habitat for boreal caribou was therefore defined as the resources and environmental conditions required for persistence of local populations of boreal caribou throughout their current distribution in Canada. Identifying Critical Habitat for local populations was framed as an exercise in decision analysis and adaptive management. Establishment of a systematic, transparent and repeatable process was a central element of the approach. The report is structured around three major questions to be addressed in the identification of critical habitat: 1) What is the current distribution of boreal caribou in Canada; 2) Where are the local populations within the current distribution of boreal caribou in Canada; and 3) What habitat conditions are required for persistence of local populations of boreal caribou in Canada?

Consideration of scale is fundamental to identifying the resources and environmental conditions required for persistence of local populations of boreal caribou throughout their current distribution. Caribou select habitat at multiple spatial scales to meet their life history requirements. At fine spatial scales, microclimate and food availability are important factors influencing caribou habitat selection. However, the primary limiting factor on boreal caribou populations is predation, associated with natural or human-induced landscape conditions that favour early seral stages and higher densities of alternative prey, resulting in increased risk of predation to caribou. Habitat conditions at the scale of local population ranges affect the demography of boreal caribou (e.g., survival and reproduction), which ultimately determines whether or not a population will persist. Therefore, in context of the Recovery Goal for this species, **local population range is the relevant spatial scale for the identification of critical habitat that includes the habitat conditions (quantity, quality and spatial configuration) required by caribou.** This is not equivalent to saying that every element within the range is critical to support a self-sustaining boreal caribou population, in all instances. However, it does provide a spatial delineation of the area of consideration when assessing the current conditions and quantifying risk relative to the recovery goal of maintaining or restoring self-sustaining local populations, for assigning potential Critical Habitat outcomes, and for planning for the management of the habitat conditions necessary to support population persistence (e.g. maintaining the functional attributes of the range).

General conclusions from the review include:

1) Critical Habitat for boreal caribou is most appropriately identified at the scale of local population range, and expressed relative to the probability of the range supporting a self-sustaining local population;

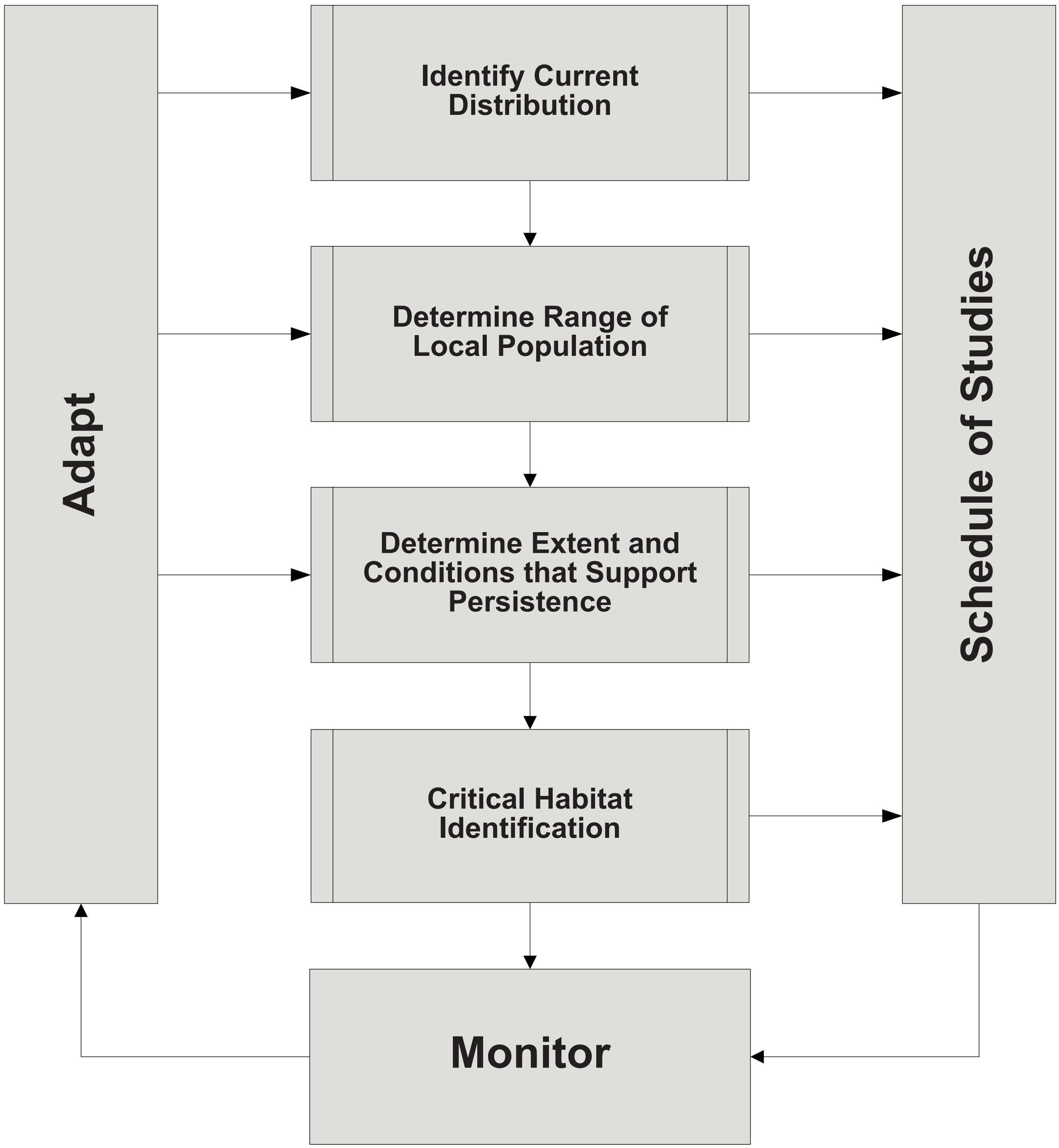
2) Range is a function of the extent and condition of habitat, where habitat includes the suite of resources and environmental conditions that determine the presence, survival and reproduction of a population;

3) Application of the Critical Habitat Identification Framework, for the 57 recognized local populations or units of analysis for Boreal caribou in Canada, yielded 3 proposed outcomes: Current Range, Current Range and Improved Conditions, or Current Range and Consider Resilience;

4) Like habitat selection by caribou, Critical Habitat identification for Boreal caribou is a hierarchical process with considerations across multiple spatial and temporal scales. Further elaboration of Critical Habitat outcomes at spatial scales finer than range, over specified time frames, may be achieved through spatial population viability analysis linked with dynamic landscape modelling;

5) Acknowledging that current knowledge and the dynamic nature of landscapes impart uncertainty, present findings should be monitored and assessed for the purposes of refinement and adjustment over time, as new knowledge becomes available (e.g., a Schedule of Studies as part of Adaptive Management).

A major product of this science review is a Critical Habitat Framework that can support decision analysis, focus future research efforts, and frame critical habitat identification in the context of adaptive management (Executive Summary Figure 1). It was anchored by synthesis and analysis of available quantitative data and published scientific information on boreal caribou population and habitat ecology, including population distribution, trends, habitat use, and conditions for persistence. Aboriginal knowledge was considered when accessible in published documents. However, a separate process to gather Aboriginal traditional knowledge was not undertaken as part of this review. The Framework was structured around the major questions identified above, and designed to incorporate the important stages of adaptive management. Application of the framework and associated decision analysis involved clear identification of knowledge gaps, necessary assumptions, and key uncertainties throughout the process, which were directed to a Schedule of Studies, as appropriate. As in any adaptive management framework, its strength lies not only in its specific output(s) at a given time, but its ability to accommodate different assumptions or new data, including but not limited to Aboriginal and Traditional Knowledge, that can be used in the framework to yield continuously improved outputs.



Executive Summary Figure 1: Critical Habitat Framework

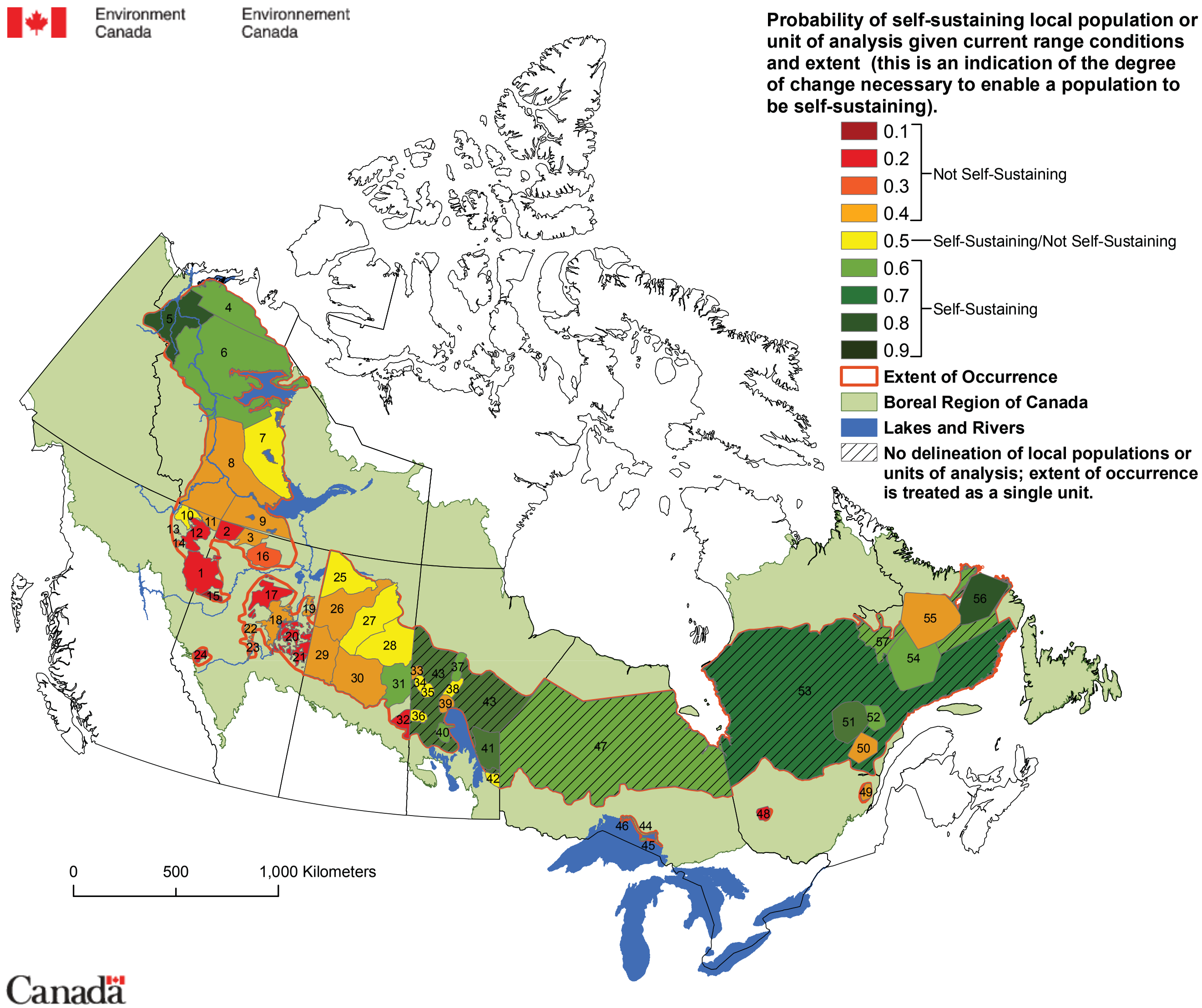
The first step in application of the Critical Habitat Framework was to determine the current distribution of boreal caribou across Canada, in order to define the national scope of Critical Habitat Identification. Information from the National Recovery Strategy for Boreal Caribou was used for the present delineation, but an environmental niche analysis was also undertaken to identify areas of uncertainty and guide future refinements of the distribution.

The second step of the Critical Habitat Framework was delineating units of analysis within the current distribution. The population and distribution objective of the draft National Recovery Strategy specify local populations as the appropriate unit of analysis with respect to the recovery goal. Local population ranges are the spatial delineation of this analysis unit. Information on local population ranges was compiled from jurisdictions across the current distribution. Where local populations were part of a continuous distribution, or had not been defined, units of analysis encompassing the extent of occurrence of caribou within the regions were delineated.

The third step in the Critical Habitat Framework determined the habitat required for persistence of boreal caribou local populations through assessment of measurable criteria of population and habitat condition for each local population range. Three measurable criteria related to persistence probability were assessed: 1) *population trend*, an indicator of whether a population is self-sustaining over a relatively short measurement period; 2) *population size*, an indicator of the ability of a population to withstand stochastic events and persist over the long-term; and 3) *range disturbance*, an indicator of the ability of a given range to support a self-sustaining local population.

These three criteria -- population trend, population size and range disturbance -- represent three lines of evidence used to evaluate local population ranges relative to their potential to support self-sustaining populations. Empirically based, categorical states were defined for each criteria: Population trend was either Declining, Stable, Increasing or Unknown; Population size categories were Very Small, Small, or Above Critical, based on a non-spatial population viability analysis; and Disturbance categories were Very Low, Low, Moderate, High or Very High, based on a national meta-analysis of boreal caribou demography and range disturbance. A probability of local population persistence was associated with each categorical state, for each criterion. Categorical states were then assigned to each local population based on available data, then combined in an integrated assessment to determine whether the weight of evidence supported a conclusion of the current range being sufficient or not sufficient to support a self-sustaining local population. Results of this evaluation are presented in Executive Summary Figure 2.

The fourth step in the Critical Habitat Framework was the proposed identification of Critical Habitat, based on the results of the assessment of the probability of the current range supporting a self-sustaining local population. The assessment was translated to proposed Critical Habitat Identification following a set of decision rules, and expressed as the range condition and/or extent required relative to current range condition and extent. Potential outcomes for each local population or unit of analysis included: Current Range - current range condition



Number	Local Population/Unit of Analysis	Integrated Probability
1	AB/BC Chinchaga	0.2
2	AB/NWT Bistcho	0.2
3	AB/NWT Steen River/Yates	0.4
4	NWT Inuvialuit	0.6
5	NWT/YK Gwich'in	0.8
6	NWT Sahtu	0.6
7	NWT North Slave	0.5
8	NWT Dehcho (N/SW)	0.4
9	NWT South Slave/SE Dehcho	0.4
10	BC Maxhamish	0.5
11	BC Calendar	0.4
12	BC Snake Sahtaneh	0.2
13	BC Parker Core	0.4
14	BC Prophet Core	0.3
15	AB Deadwood	0.1
16	AB Caribou Mountains	0.3
17	AB Red Earth	0.2
18	AB West Side Athabasca River	0.4
19	AB Richardson	0.4
20	AB East Side Athabasca River	0.2
21	AB Cold Lake Air Weapons Range	0.2
22	AB Nipisi	0.4
23	AB Slave Lake	0.3
24	AB Little Smoky	0.2
25	SK Davy-Athabasca	0.5
26	SK Clearwater	0.4
27	SK Highrock-Key	0.5
28	SK Steephill-Foster	0.5
29	SK Primrose-Cold Lake	0.4
30	SK Smoothstone-Wapawekka	0.4
31	SK Suggi-Amisk-Kississing	0.6
32	SK Pasquia-Bog	0.2
33	MB Kississing	0.4
34	MB Naosap	0.5
35	MB Reed	0.5
36	MB The Bog	0.5
37	MB Wapisu	0.6
38	MB Wabowden	0.5
39	MB William Lake	0.4
40	MB North Interlake	0.6
41	MB Atikaki-Berens	0.7
42	MB Owl-Flintstone	0.5
43	Manitoba	0.7
44	ON North East Superior	0.4
45	ON Michipicoten	0.6
46	ON Slate Islands	0.6
47	Ontario	0.6
48	QC Val d'Or	0.2
49	QC Charlevoix	0.4
50	QC Pipmuacan	0.4
51	QC Manouane	0.7
52	QC Manicouagan	0.6
53	Quebec	0.7
54	LAB Lac Joseph	0.6
55	LAB Red Wine Mountain	0.4
56	LAB Mealy Mountain	0.8
57	Labrador	0.6

Executive Summary Figure 2: Probability that current range will support a self-sustaining population of boreal caribou, based on integrated probability assignments that considered population trend and size, and level of disturbance associated with anthropogenic activities and fire (see Section 2.6.5). This Figure is not an illustration of whether a population is recoverable or not, rather, it is an indication of the degree of habitat change necessary to enable a population to be self-sustaining (e.g. to persist without the need for ongoing management intervention).

and extent are required to maintain potential for self-sustaining population; Current Range and Consider Resilience – current range condition and extent may be sufficient to absorb additional disturbance while maintaining capacity to support a self-sustaining population; Current Range and Improved Conditions – current range condition and/or extent would need to be improved to restore potential to support a self-sustaining population.

The resultant proposed Critical Habitat identification for the 57 recognized local populations or units of analysis considered was:

- Current Range for 25 local populations or units of analysis;
- Current Range and Improved Conditions for 21 local populations or units of analysis;
- Current Range and Consider Resilience for 11 local populations or units of analysis.

Further elaboration of Critical Habitat outcomes for local populations can be achieved through spatial population viability analysis linked with dynamic landscape modelling (see Section 2.6.6 and Appendix 6.7). Incorporation of landscape dynamics is necessary to understand the conditions and management options associated with recovery (Current Range and Improved Conditions) and resilience (Current Range and Consider Resilience), as well as additional risks associated with present conditions (Current Range). Such evaluations may be undertaken with varying levels of complexity and concomitant requirements for data. It is clear from the present review that minimum data requirements could be met for most areas within the current distribution of boreal caribou in Canada, particularly when viewed in the context of adaptive management.

Application of the Critical Habitat Framework provided an assessment of all local populations or units of analysis within the current distribution of boreal caribou in Canada. Like habitat selection by caribou, critical habitat identification is a hierarchical process that must consider needs across multiple spatial and temporal scales. The national evaluation focused on the scale most appropriate for considering the persistence of local populations – the local population range. Consideration of components of critical habitat at finer scales is possible where local population information can be augmented.

In summary, this review was based on a set of guiding principles and undertaken by Environment Canada with the support of an expert Science Advisory Group that provided continuous peer-review. Development of a Critical Habitat Framework provided a formal structure for assembling and analyzing data relevant to Critical Habitat identification, and the foundation for continuous improvement of knowledge through the process of adaptive management. A weight of evidence approach was used to identify the most plausible outcome of combinations of population and habitat conditions relative to the recovery goal of self-sustaining local populations.

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1.0 INTRODUCTION

1.1 Background

The Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population (herein referred to as boreal caribou), was last assessed in May 2002 as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Boreal Caribou were added to Schedule 1 of *Species at Risk Act (SARA)* and in accordance with *SARA*, the Minister of the Environment must prepare a Recovery Strategy for this species that includes an identification of its Critical Habitat (CH) and/or if there is insufficient information available, a Schedule of Studies to determine that information. A National Recovery Strategy for boreal caribou was due for posting on the SARA Public Registry by June 5, 2007. The identification of CH is a key element of posted Recovery Strategies on the SARA Public Registry (SARA S. 41 (1) (c)).

In February 2002, a National Boreal Caribou Technical Steering Committee, represented by the 10 jurisdictions involved in the recovery of the boreal caribou, was established to develop a National Recovery Strategy for Boreal Caribou. A draft strategy was completed in June 2007 and tabled as advice to all 10 jurisdictions that are responsible for caribou. Earlier drafts of the National Recovery Strategy documented extensive deliberations on the concept of Critical Habitat for boreal caribou (see also Racey and Arsenault 2007). Critical Habitat was not identified in the final draft National Recovery Strategy.

In August 2007, Environment Canada (EC) launched an expert, science-based review of the state of knowledge of boreal caribou Critical Habitat with the mandate to develop a consolidated, scientifically defensible identification of Critical Habitat, and/or a valid Schedule of Studies to support its identification. To complete this task, EC established an internal management team to conduct the review, and to compile and analyze all information relevant to this initiative. Environment Canada also engaged leading experts in landscape ecology, caribou biology, spatial habitat modeling, and population analysis to provide scientific advice in the identification of Critical Habitat for boreal caribou. Of these leading experts, 18 were part of a Science Advisory Group (SAG) mandated to provide ongoing peer review throughout the process (see Appendix 6.1 for list of SAG members). An additional group of experts participated in the science review during a 2-day workshop held in Toronto on November 19-20, 2007. This report is the product of the full scientific review.

2.0 METHODOLOGY

2.1 Framing the Critical Habitat Question for Boreal Caribou

2.1.1 SARA: Critical Habitat

SARA Section 2 defines Critical Habitat as "... the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in a recovery strategy or in an action plan for the species."
Note : SARA does not limit Critical Habitat identification to the habitat that is currently occupied by the species at risk.

2.1.2 National Recovery Strategy

To identify Critical Habitat, a recovery target must be established. This target is qualitatively expressed in the draft National Recovery Strategy for boreal caribou through the following Recovery Goal and Population and Distribution Objective:

Recovery Goal:
Boreal caribou are conserved and recovered to self-sustaining levels, throughout their current distribution (extent of occurrence) in Canada.

Population and Distribution Objective:
Maintain existing local populations of boreal caribou that are self-sustaining and achieve population growth of local populations that are not self-sustaining, to the extent possible, throughout the current distribution (extent of occurrence) of boreal caribou in Canada.
Note: "To the extent possible" appears in the population and distribution objective in recognition that technical and biological feasibility may affect the probability of conserving and/or recovering some individual local populations as described in the draft National Recovery Strategy for boreal caribou (Environment Canada 2007).

2.2 Definitions

The following definitions were established for the Boreal Caribou Critical Habitat Science Review. Development of these definitions was supported by the 2002 COSEWIC Status Assessment and 2007 draft National Recovery Strategy for boreal caribou (Environment Canada 2007), a review of relevant scientific work, and consultation with the Science Advisory Group for the review.

2.2.1 Current Distribution (Extent of Occurrence):

The area included in a polygon that encompasses the geographic distribution of all known local populations of boreal caribou (COSEWIC - Adapted from IUCN 2001), based on provincial and territorial distribution maps developed from observation and telemetry data, local knowledge (including in some cases Aboriginal and Traditional Knowledge), and biophysical analyses. The area may contain unsuitable or unoccupied habitats (see Appendix 6.2 for explanation of time frame for "Current").

2.2.2 Local Population:
A group of caribou occupying a defined area distinguished spatially from areas occupied by other groups of caribou. Local populations experience limited exchange of individuals with other groups, such that population dynamics are driven primarily by local factors affecting birth and death rates, rather than immigration or emigration among groups (see Appendix 6.2).

2.2.3 Habitat:
The suite of resources (food, shelter) and environmental conditions (abiotic variables such as temperature, and biotic variables such as competitors and predators) that determine the presence, survival, and reproduction of a population (Caughley and Gunn 1996).

2.2.4 Self-Sustaining:
A local population of boreal caribou that on average demonstrates stable or positive population growth ($\lambda \geq 1.0$) over the short term, and is large enough to withstand stochastic events and persist over the long-term, without the need for ongoing intensive management intervention (e.g. predator management or transplants from other populations).

2.2.5 Persistence:
The survival of a population expressed as a given probability or likelihood over a specified time frame. The likelihood of not achieving specified persistence levels is a measure of extinction risk. The IUCN criterion for classifying species as Vulnerable (equivalent to COSEWIC's Threatened category) is a risk of extinction ≥10% over 100 years (SSC 2001).

2.2.6 Range:
A geographic area occupied by individuals of a local population that are subjected to the same influences affecting vital rates over a defined time frame (see Appendix 6.2: Delineating Units of Analysis for Boreal Caribou Critical Habitat Identification). Range is a function of both spatial extent and habitat conditions.

2.2.7 Critical Habitat:
The resources and environmental conditions (habitat as per Section 2.2.3) required for persistence of local populations of boreal caribou throughout their current distribution in Canada. The quantity, quality and spatial configuration of resources and conditions may be influenced by both natural and human-induced factors.

2.3 Critical Habitat Identification Framework for Boreal Caribou

A *Critical Habitat Identification Framework for Boreal Caribou* (here referred to as the Framework) was developed to support a consolidated, scientifically defensible identification of Critical Habitat for boreal caribou and a complementary Schedule of Studies. The Framework is not the sole product but rather a logic model to support the process. Development of the Framework was informed by Critical Habitat identification approaches applied in Canada and elsewhere. Its systematic and transparent structure enables decision-analysis within the context of adaptive management. The approach was anchored by analysis and synthesis of available quantitative data and published scientific information of population and habitat ecology as well as boreal caribou population distribution, trends, habitat use, and conditions for persistence. Knowledge gaps and uncertainty are identified throughout the process, and feed into a Schedule of Studies designed to improve knowledge and understanding of Critical Habitat over time. Aboriginal knowledge was not included in the present review, nor are needs specific to this body of knowledge included in the Schedule of Studies.

Development of the framework and the proposed Critical Habitat identification were guided by the following set of principles:

2.3.1 Guiding Principles

1) Consider available published scientific information and seek multiple lines of evidence to support conclusions.
2) Recognize the need to address the dynamic nature of boreal systems, and the resultant effects on boreal caribou habitat.
3) Acknowledge and consider that the habitat requirements of this species operate at multiple spatial and temporal scales, including both physical and functional properties.
4) Recognize that variation in population structure, population and landscape condition, and state of knowledge may warrant different approaches to identifying Critical Habitat across the national distribution of this species.
5) Apply a precautionary approach when evidence suggests serious or irreversible harm, recognizing that absence of full scientific certainty should not be used as a reason to postpone decisions.
6) Consider the precautionary approach a provisional measure that requires follow-up activities such as research and monitoring to reduce significant scientific uncertainty and improve decision-making.
7) Apply adaptive management to identify and reduce key uncertainties, and to achieve management objectives while gaining reliable knowledge.
8) Recognize that socio-economic considerations are not part of Critical Habitat identification, but are appropriately considered in other phases of the overall SARA recovery planning process.

2.3.2 The Critical Habitat Identification Framework

The Framework is used as a logic model to organize the acquisition and analysis of the best available knowledge to identify Critical Habitat, while recognizing uncertainty. Consistent with an adaptive management process, it is acknowledged that ongoing research and monitoring will provide new knowledge that can be used to refine the identification of Critical Habitat over time. The Framework (see Figure 1) flows from the following three major questions to be addressed in the identification of Critical Habitat:

- What is the current distribution of boreal caribou in Canada?
- Where are the local populations within the current distribution of boreal caribou in Canada?
- What conditions are required for long-term persistence of local populations of boreal caribou in Canada?

Identification of Critical Habitat is an outcome of these questions, such that:

Critical Habitat is comprised of the resources and environmental conditions required for persistence of local populations of boreal caribou throughout their current distribution in Canada. The quantity, quality and spatial configuration of resources and conditions may be influenced by both natural and human-induced conditions.

Each component of the Framework (Figure 1) was informed by available quantitative data and published scientific information acquired or assembled as part of the Boreal Caribou Critical Habitat Science Review.

Each step in the framework is described below:

i) What is the current distribution of boreal caribou in Canada?

The recovery goal specifies the geographic scope of boreal caribou recovery as the current distribution for the species. The current distribution of boreal caribou across Canada was described and mapped to define the national spatial scope of Critical Habitat Identification. Current distribution delineation was based on information provided by jurisdictions. Areas of uncertainty and needs for further assessment were identified and included in the Schedule of Studies.

ii) Where are the local populations (or units of analysis) within the current distribution of boreal caribou in Canada?

The population objective of the Draft National Recovery Strategy specifies local populations as the relevant unit of analysis for achieving the recovery goal. For the purposes of Critical Habitat identification, the range associated with each local population was considered to be the unit of analysis. Several population patterns were recognized, and methods for range delineation varied according to the population pattern and the amount of animal location and movement data available. Areas of uncertainty regarding units of analysis were highlighted and included in the Schedule of Studies.

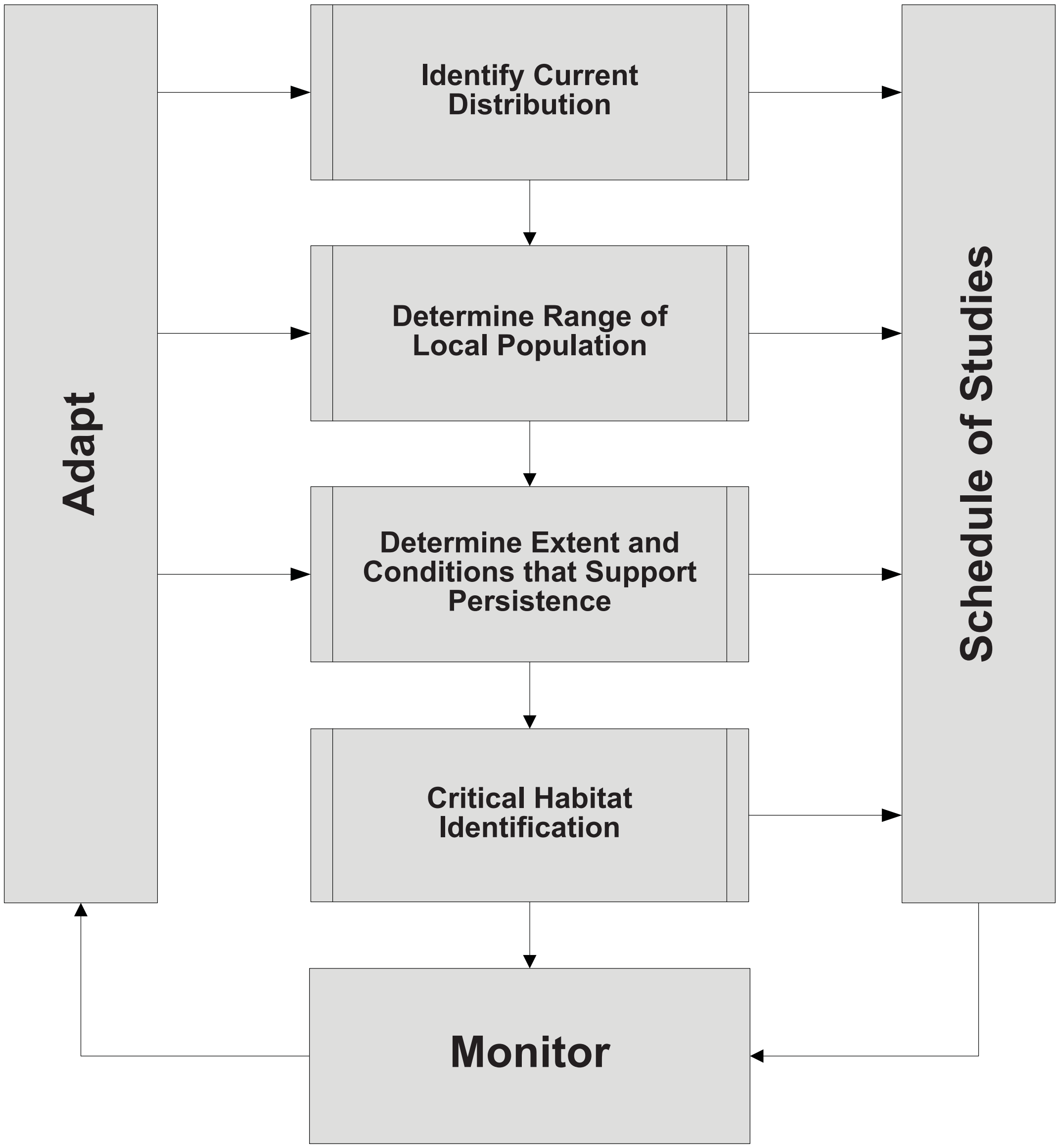


Figure 1: Critical Habitat Identification Framework for Boreal Caribou

iii) What habitat conditions are required for long-term persistence of boreal caribou populations?

The recovery objective of self-sustaining populations is expressed quantitatively as the probability of a given set of habitat conditions supporting self-sustaining (persistent) local populations. Lower probability or certainty is generally associated with greater risk. While it is not the role of science to determine "acceptable" levels of risk, a science-based approach can be applied to explore a range of persistence parameters, given available knowledge. In the absence of scientific certainty, the identification of Critical Habitat can thus be viewed **as reflecting both our current state of understanding, and an explicit expression of risk,** both of which should be evaluated and refined as new knowledge is generated.

iv) Critical Habitat Identification

A central premise of the Framework is a definition of habitat that encompasses physical and functional attributes at a scale that is aligned with the goal of self-sustaining local populations. In this context "habitat" includes physical attributes (e.g. forage plants or thermal cover) used by caribou to carry out their life functions, as well as conditions (such as degree of natural and human disturbance) within the landscape mosaic that comprises the range of a local population. This approach addressed the influence of landscape conditions on mechanisms such as predation that affect short-term population trends and long-term persistence.

The Draft National Recovery strategy (Environment Canada 2007; see also Racey and Arsenault 2007) recognized that critical habitat for boreal caribou is appropriately conceptualized as caribou ranges and their components. Consistent with this recognition, Critical Habitat identification within the framework focused on local population range as the scale at which habitat extent and conditions have the greatest influence on population persistence (see Section 2.5.2). The Critical Habitat Identification framework incorporates the need for further refinement of CH identification where necessary for local populations.

v) Monitor, Adapt and Schedule of Studies

Because Critical Habitat for boreal caribou is not a fixed entity, but an emergent property of dynamic landscapes, a robust research and monitoring program is an important component of Critical Habitat identification and management. New knowledge informs management actions that proceed with the best available information, gained through a structured process of adaptive management. Knowledge gaps and uncertainties are identified, compiled, evaluated, and reflected in a recommended Schedule of Studies. In the Schedule of Studies, emphasis is placed on the identification of key uncertainties that prevent choosing between different conceptual models representing our understanding of what comprises Critical Habitat for boreal caribou.

Over time, understanding of the necessary conditions for persistence is improved by ensuring that Critical Habitat identification is subject to evaluation and refinement. Thus the adaptive management loop is fundamental to the question of "What is Critical Habitat?" and an essential component of the framework as a decision-analysis tool to refining what Critical Habitat is in the face of uncertainty.

2.4 Habitat and Persistence

Understanding the relationship between habitat selection and scale, and how this hierarchical approach is linked to persistence, is fundamental to the identification of Critical Habitat for boreal caribou.

2.4.1 Habitat and Scale

In general, suitable boreal caribou habitat is characterized by large tracts of mature to old conifer forests with abundant lichens, or peatlands intermixed with uplands dominated by mature to old conifers (Darby and Pruitt 1984, Brown et al. 1986, Bradshaw et al. 1995, Stuart-Smith et al. 1997, Rettie and Messier 2000, Courtois 2003). However, there is variability among regions in vegetation types used.

Boreal caribou have habitat requirements at several spatial and temporal scales (Rettie and

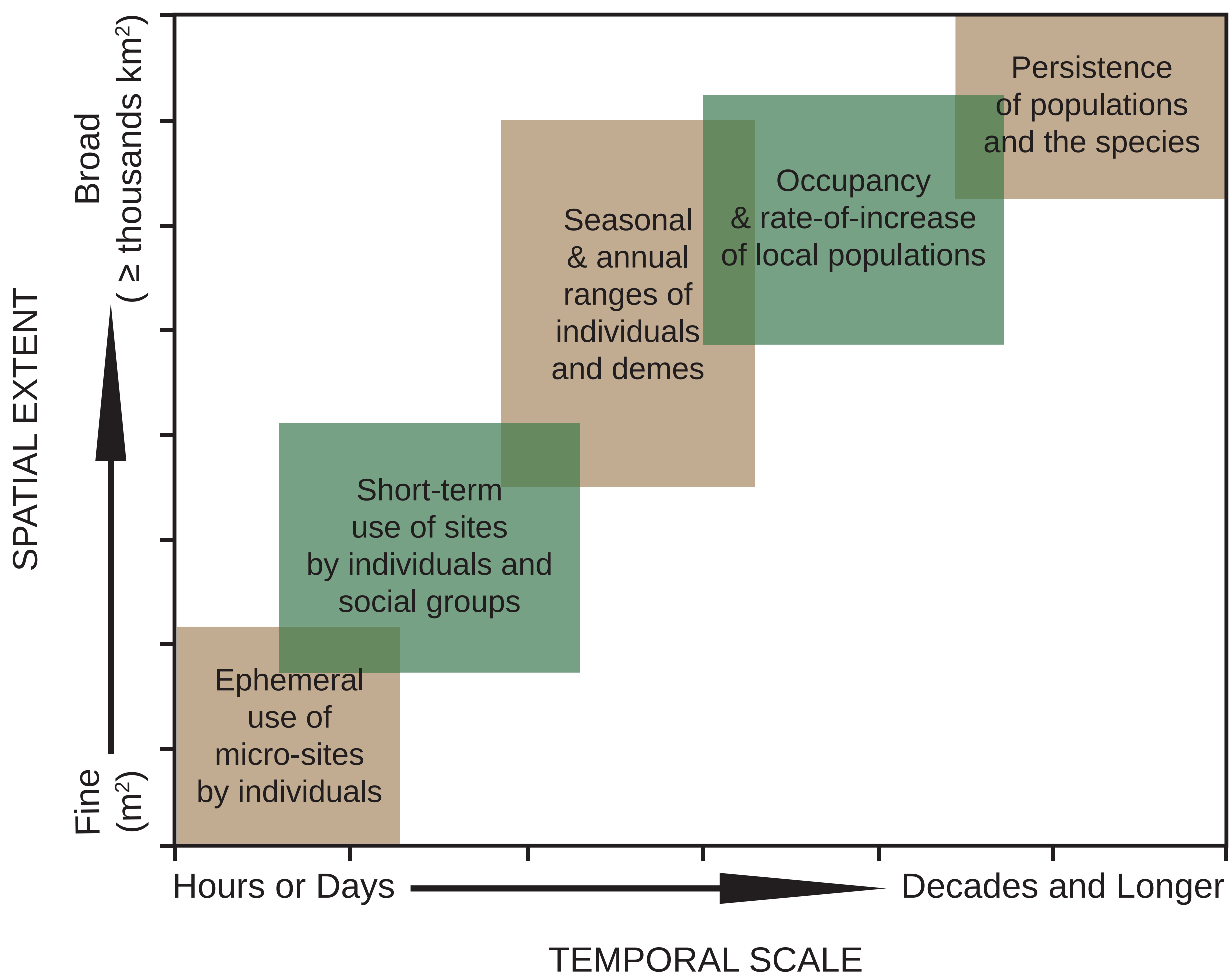


Figure 2: Boreal caribou habitat exists at multiple spatial and temporal scales, and includes both physical and functional properties. The absolute magnitude of spatial and temporal scales for habitat may vary across the national distribution of boreal caribou.

Messier 2000, Johnson et al. 2001, O'Brien and Manseau 2003) as illustrated in Figure 2. Coarser scales encompass large areas (e.g. ranges) and broad time frames (e.g., seasons, years and decades), whereas finer scales cover small areas (e.g., forest stands or habitat patches) and narrow time frames (e.g., hours and days). Boreal caribou select habitat to avoid predation at coarser scales (Bergerud 1988, Johnson et al. 2001) and then select habitat to meet forage requirements at finer scales (Schaefer and Pruitt 1991, Rettie and Messier 2000).

At coarser scales, boreal caribou local populations require large range areas that contain sufficient suitable habitat and reduce predation by allowing caribou to avoid areas of high predation risk (Rettie and Messier 2001, Brown et al. 2003). At finer scales, boreal caribou select individual habitat patches (within ranges) that provide food, particularly ground and tree lichens during late winter and early spring, and they avoid early seral-stage forests and recently disturbed areas (Schaefer and Pruitt 1991, Stuart-Smith et al. 1997, Rettie and Messier 2000). Although forest fire destroys lichens and other vegetation in the short term, it is an important factor in regenerating caribou forage over long time scales (Dunford 2003). During winters with deep or crusted snow, boreal caribou require habitats that have shallower and uncrusted snow (such as in mature coniferous stands with closed canopies) and tree lichens to enable access to forage (Vandal and Barrette 1985, Thomas and Armbruster 1996).

In general, boreal caribou require habitats that provide necessary functional attributes (the conditions and resources that provide for all of their life requirements), including physiological health, dispersion of cows during calving and post-calving periods, and refuge from predation.

2.4.2 Scale and Persistence

There is increasing recognition within scientific and management communities that factors influencing caribou populations must be considered at regional scales (see Vistnes and Nellemann 2008 for a recent review). Changes in conditions that affect the number and distribution of alternative prey species and their associated predators, resulting in reduced habitat effectiveness for caribou, impact the viability of boreal caribou populations at the scale of their range. These changes are related to disturbances that increase the amount of early seral-stage forest, promote higher densities of prey species such as moose (Alces alces) and white-tailed deer (Odocoileus virginianus), which in turn support higher predator densities, especially of wolves (Canis lupus) (Bergerud and Elliott 1986; Seip 1992; Stuart-Smith et al. 1997, Racey and Armstrong 2000; Wittmer et al. 2005, 2007). The range of a given local population of caribou may contain a variety of habitat components that are differentially used by caribou, as well as the landscape matrix between these areas. Whether habitat components within a range are selected or avoided by caribou, all affect the viability of the population in positive or negative ways, thus are important when considering the conditions necessary for persistence.

Therefore, **local population range is the relevant scale for the identification of Critical Habitat to support self-sustaining local populations of boreal caribou**, such that the range is a geographic area occupied by individuals of a local population that are subjected to the same influences affecting vital rates over a defined time frame. Range is a function of both spatial extent and habitat conditions. Extent refers to the physical area of the range and habitat conditions refer to the quantity, quality and spatial configuration of resources (including the presence of other species) within the range. A more detailed discussion of the concept of range and methods of delineation is included in Appendix 6.2.

2.5 Scientific Undertakings to Support Application of the Framework

The large amount of scientific information that exists on boreal caribou in Canada facilitated the scientific review of Critical Habitat and identification process. Relevant boreal caribou information was compiled, analyzed and synthesized to support the Framework (Figure 3).

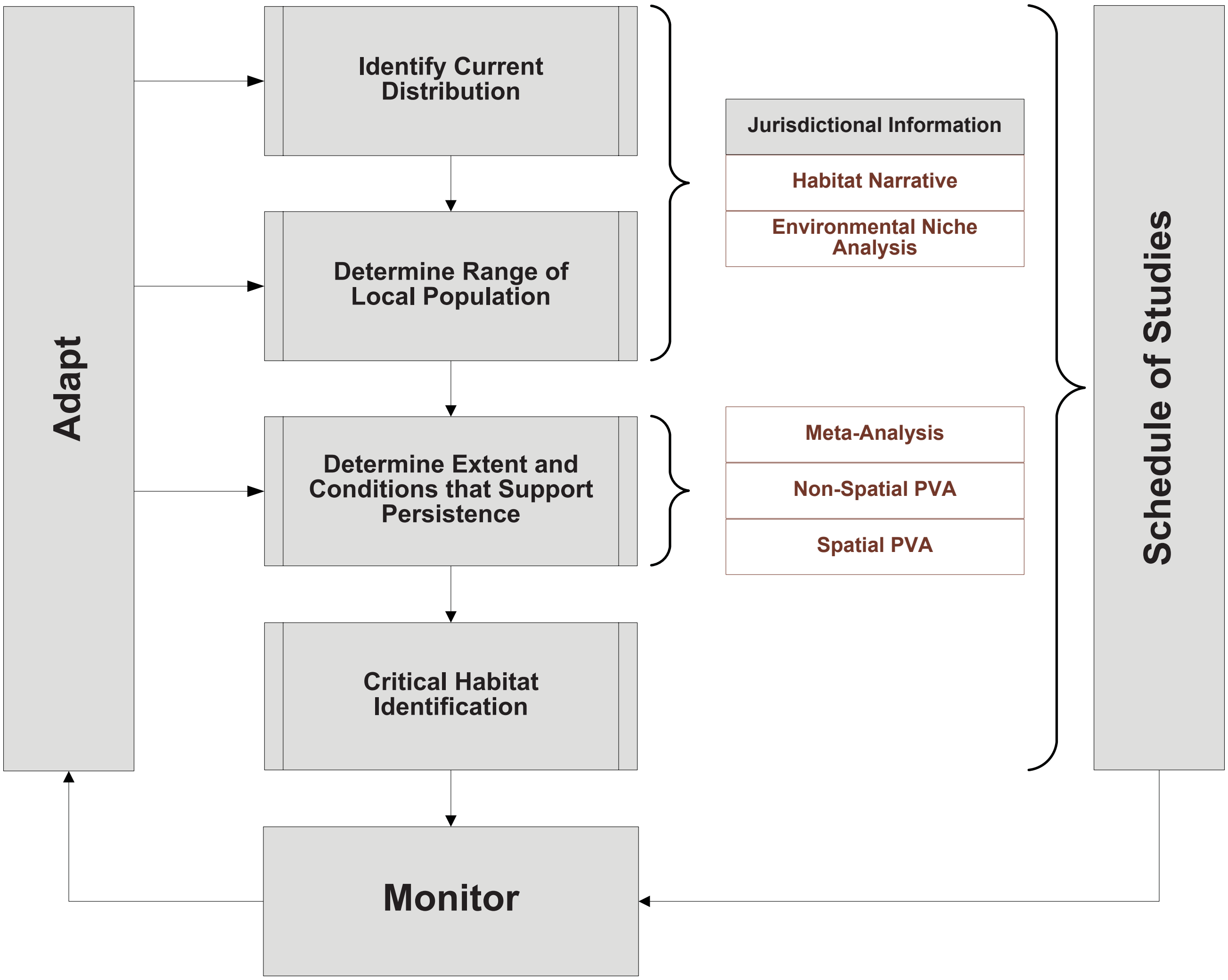


Figure 3: Science components supporting the Critical Habitat Identification Framework for Boreal Caribou

The science activities were comprised of five main components presented as Appendices to the report, and summarized here: a habitat narrative, an environmental niche analysis (ENA), a meta-analysis of population and range condition, a non-spatial population viability analysis (PVA), and spatially-explicit population viability analysis. The habitat narrative summarized existing knowledge of boreal caribou habitat use and requirements across a variety of spatial and temporal scales, throughout their distribution in Canada. The other four components represent a spatial and analytical hierarchy of methods of decreasing generality and increasing complexity. The environmental niche analysis and range-wide meta-analysis provided top-level information, followed by the non-spatial PVA, and finally the spatial PVA. Results from top-level analyses reveal overarching constraints on processes that can be examined at lower levels; lower-level results suggest factors missing from the top-level analyses, and completing the learning cycle, top-level analyses suggest the extent to which conclusions from the lower-level results may lack generality. These components informed the Critical Habitat identification process by feeding into a Critical Habitat Decision Tree (introduced in Section 2.6).

2.5.1 Habitat Narrative (Appendix 6.3)

The habitat narrative provided a description of boreal caribou habitat, including spatial and temporal aspects of biophysical attributes used throughout the species' life cycle, and considered both physical and functional characteristics of the habitat. This work summarized the primary and grey literature pertaining to caribou habitat use across the current distribution. Boreal caribou habitat-use information was extensive in some regions and quite limited elsewhere. The narrative informed the environmental niche analysis through identification of variables influencing the extent of occurrence, and potential areas of occupancy, of boreal caribou throughout their distribution. The narrative also provided detailed information to augment understanding of components of Critical Habitat that vary among and within local population ranges. The information is organized by ecological regions.

2.5.2 Environmental Niche Analysis (Appendix 6.4)

The environmental niche analysis was a tool to enhance understanding of the historic and current geographic distribution of boreal caribou, and patterns of occupancy, relative to abiotic and biotic factors. The ENA used abiotic factors (climate and topography) to characterize the potential distribution of observed boreal caribou locations, and then incorporated broad-scale biotic variables (land cover and human impact levels) to predict the pattern of occupancy within the current extent of occurrence. The ENA supports the Framework and associated decision-analysis by identifying areas of uncertainty and generating hypotheses about limiting factors, which guide sampling and refinement efforts identified in the Schedule of Studies. The results also identify areas supporting potentially suitable conditions for habitat restoration adjacent to current ranges, or potential corridors of movement between ranges.

2.5.3 Meta-Analysis of Population and Range Condition (Appendix 6.5)

A key element of the Critical Habitat Framework is determining attributes of a caribou range that support or compromise population persistence (e.g. the ability of the range to support a self-sustaining population). The meta-analysis compiled demographic data from boreal caribou populations across Canada to evaluate the hypothesized relationship between caribou population parameters (index of population condition) and levels of anthropogenic and/or natural (fire) disturbance on caribou ranges (index of range condition). Natural disturbances could also include insect outbreaks and their stand-level effects associated with climate change projections that may in fact result in a fire disturbance, however insect disturbances were not directly considered in this analysis. Results from the meta-analysis provided quantitative guidelines for one of the three assessment criteria (e.g. range condition) used in the evaluation of local populations for Critical Habitat identification (see Section 2.6.3 and 2.6.4).

2.5.4 Non-Spatial Population Viability Analysis (Appendix 6.6)

The Critical Habitat Framework requires information on population persistence. The non-spatial PVA evaluated how population persistence is affected by aspects of boreal caribou life history and population age and sex structure, using the range of published population vital rates and their variance for boreal caribou across Canada. Results of this work provided quantitative guidelines for the population size required for persistence under various demographic conditions, the second of three criteria assessed in Critical Habitat identification (see Sections 2.6.3 and 2.6.4), and informed the spatially-explicit PVA by providing information on the vital rates that most influence population dynamics of boreal caribou.

2.5.5 Spatially-explicit Population Viability Analysis (Appendix 6.7)

Spatially explicit population models have many more parameters and computational demands than a non-spatial PVA, such as simulating a dynamic landscape over time, and thus can explore only a subset of the parameter space for local populations. Spatial PVA adds consideration of landscape structure and individual movement, and when results are compared with a non-spatial PVA, helps assess whether spatial effects produce different predictions of population persistence. Application of spatial PVA can also help interpret results of the meta-analysis by offering heuristic insights of the mechanisms by which the ability of an area to support caribou scales up spatially from the scale of patch to the scale of landscape (range), and allows simulation of longer-term trends and scenarios to extrapolate relationships to future landscapes. The work completed as part of this review was a proof of concept for applications of methods exploring how landscape condition affects boreal caribou population persistence for two case study populations. Further elaboration of Critical Habitat outcomes at spatial scales finer than range, over specified time frames, can be achieved through spatially explicit population viability analysis linked with dynamic landscape modelling.

2.6 Decision Analysis to Support Identification of Critical Habitat

As concluded in Section 2.4.2, local population range (including extent and habitat conditions) is the relevant scale for the identification of Critical Habitat to support self-sustaining local populations of boreal caribou. The identification of CH requires an understanding of the ability of existing habitat (with respect to extent and condition), to support self-sustaining local populations of boreal caribou. Expanding on the Critical Habitat Framework (Figures 1 and 3), the Critical Habitat Decision Tree (herein referred to as Decision Tree; Figure 4), is a more detailed decision analysis tool. The Decision Tree outlines the logical sequence of steps necessary for the identification of CH for boreal caribou, considering the variability and uncertainty associated with ecological processes operating at the scale of local population ranges. The Decision Tree represents the alternatives available, the associated uncertainty, and the evaluation measures applied to support identification. Where possible, uncertainties were represented through probabilities (see Sections 2.6.4 and 2.6.5) and knowledge gaps were directed to a Schedule of Studies. The process of CH identification was framed as an exercise in adaptive management, integrating research and monitoring in a cycle of evaluation that addresses knowledge gaps and key uncertainties, and incorporates new knowledge to refine the identification of Critical Habitat over time.

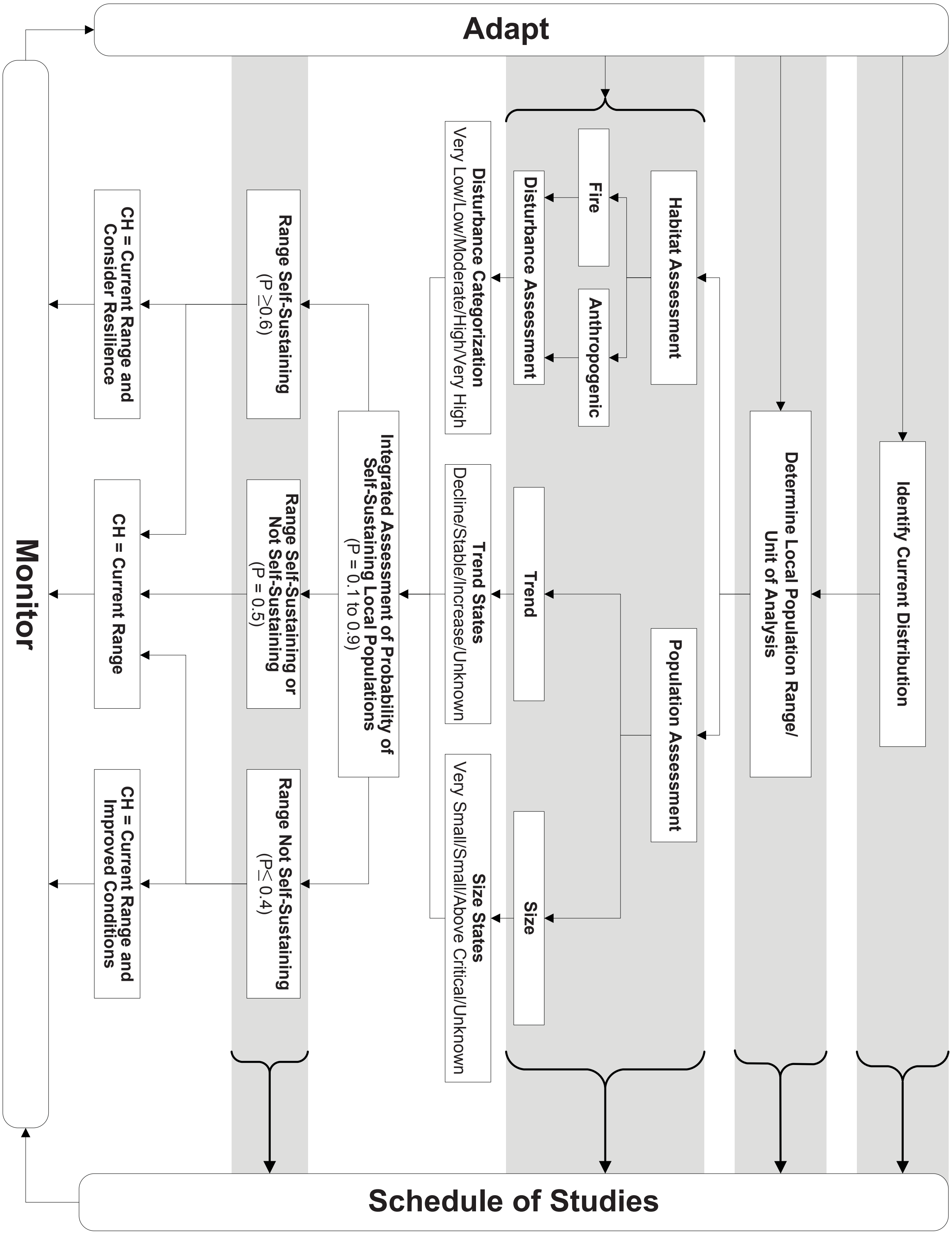


Figure 4: Boreal Caribou Critical Habitat Decision Tree

Steps in the Decision Tree are described below.

2.6.1 Identify Current Distribution

The recovery goal for boreal caribou specifies the geographic scope as the current distribution for the species. Boreal caribou are distributed in the boreal forest across seven ecozones, including nine provinces and territories, from the Yukon Territory in the west, to Labrador in the east, and extending as far south as Lake Superior[1]. Figure 5 illustrates the current distribution of boreal caribou as depicted in the Draft National Recovery Strategy, based on information provided by jurisdictions. This geographic extent was used in the present Boreal Caribou Critical Habitat Identification Framework and Decision Tree.

The current distribution (extent of occurrence) is subject to revision with new knowledge, and standard methods should be applied across the extent to ensure consistency in representation of understanding. The Environmental Niche Analysis (Appendix 6.4) can be used to identify areas of uncertainty based on available abiotic and biotic data, and therefore guide sampling efforts to refine understanding (model-based sampling), as part of the Schedule of Studies. Revisions are reflected in the Decision Tree as adjustments to future assessments, as part of the adaptive management loop.

2.6.2 Determine Local Population Range (Units of Analysis)

Application of the Decision Tree required delineation of local populations and their associated ranges. It was recognized that populations often function demographically at scales that are different from those suggested by genetic indicators (e.g. Esler et al. 2006; see Appendix 6.2 for further detail). Demographically defined local populations are the appropriate population unit for Critical Habitat identification to address the National Recovery strategy objective of self-sustaining local populations.

Local populations were defined as a group of caribou occupying an area distinguished spatially from areas occupied by other groups. Local populations experience limited exchange of individuals with other groups, such that population dynamics are driven by local factors affecting birth and death rates, rather than immigration or emigration among groups. Ecological conditions, as well as patterns and intensity of anthropogenic disturbance, vary tremendously across the national distribution for boreal caribou in Canada, resulting in variation in local population patterns. Some local populations may be spatially discrete and experience little or no exchange of individuals; other local populations may exist as part of a broader, continuous distribution where periodic exchange of individuals may be greater. Alternatively, a local population could occupy a large continuous distribution where regular exchange of individuals occurs.

[1] Boreal caribou on the island of Newfoundland are excluded from this Report and the National Recovery Strategy because the insular Newfoundland population has been designated Not at Risk by COSEWIC.

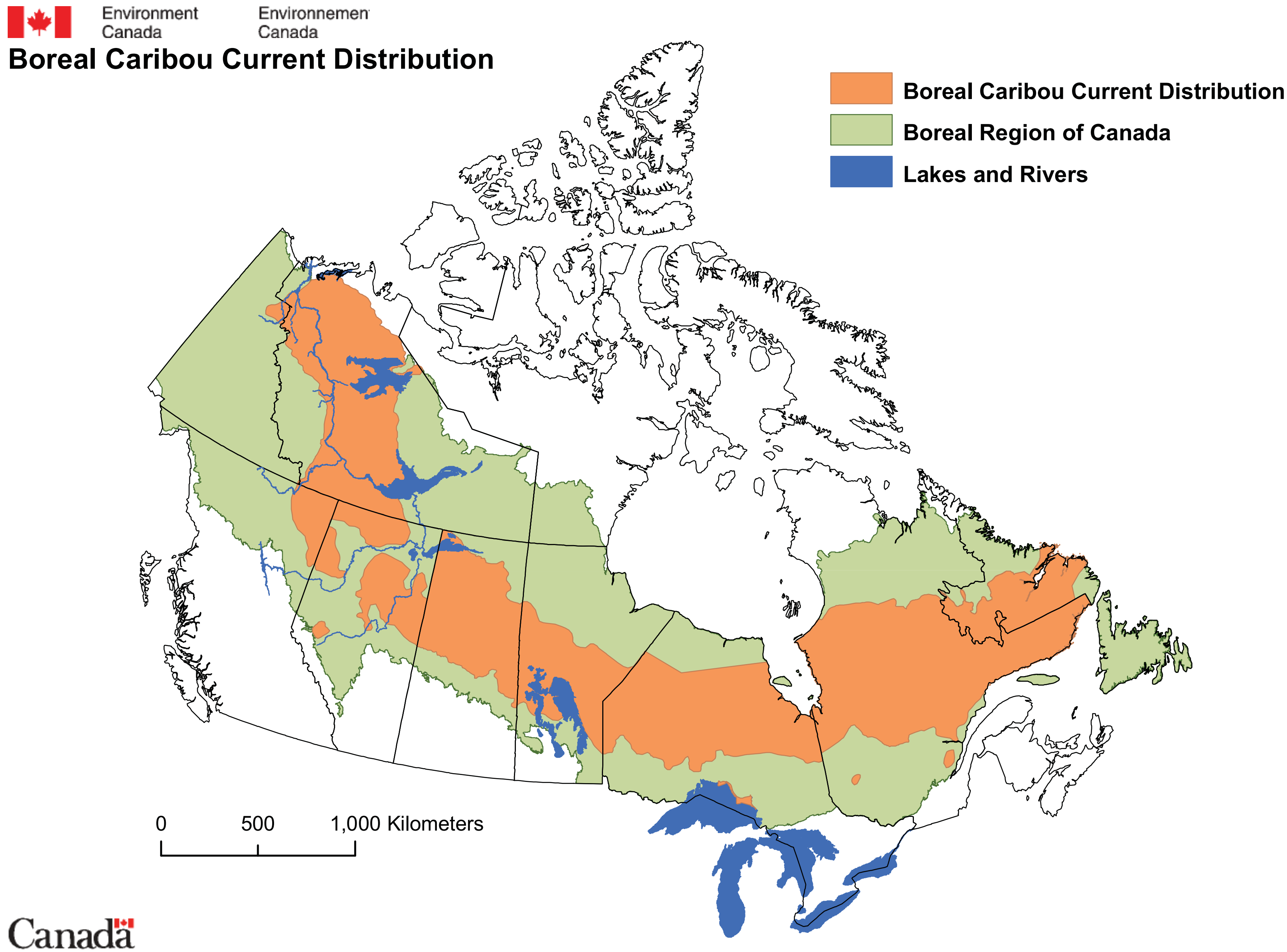


Figure 5: The current distribution of boreal caribou in Canada.

Three local population patterns for boreal caribou were recognized:

1) Discrete local population with spatially discrete ranges
2) Multiple local populations within a large area of relatively continuous habitat
3) Single large local population across a large area of relatively continuous habitat

Movement data can be used to determine immigration and emigration rates and assess population patterns of boreal caribou (Bethke et al. 1996, McLoughlin et al. 2002). However, many regions lack sufficient data covering an adequate time period to assess immigration/emigration rates for the purpose of determining spatial population structure. In the absence of sufficient immigration/emigration data, available animal movement/survey data and the degree of geographic separation of area of occupancy can be used to suggest the most plausible local population pattern for boreal caribou (see Schaefer et al. 2001, Courtois et al. 2007). Uncertainty should be addressed through a Schedule of Studies and resultant adjustments should be made to local population identification and associated unit of analysis over time.

Where natural geographic boundaries and/or habitat alteration have resulted in discrete local populations, and range boundaries were delineated based on animal movement data and forest dynamics data, resultant local population and associated range were identified as the unit of analysis for purposes of Critical Habitat identification.

Where caribou local populations are not restricted by natural geographic boundaries or habitat alteration and are distributed across large areas of relatively continuous habitat, and animal movement data are not available, the delineation of range for local populations is more difficult. The draft National Recovery Strategy (Environment Canada 2007) specifies a Population and Distribution Objective of self-sustaining boreal caribou populations throughout the current distribution (extent of occurrence) in Canada (see Section 2.1.2). Hence, for continuous distributions within which local populations were not identified, the extent of occurrence was considered the range for the present assessment. For future evaluations, Appendix 6.2 provides potential criteria for subdividing large areas of continuous habitat into local population ranges based on animal movement and/or survey data and ecological criteria. Where studies have shown that large areas of relatively continuous habitat are occupied by one local population (> than 10% emigration and immigration among groups of animals) the extent of occurrence can be divided into contiguous sub-sample units in order to ensure that the mean condition does not mask variation that may occur across the range.

Local population ranges identified by jurisdictions were used in the present application of the Decision Tree. Figure 6 depicts the resulting units of analysis. Several jurisdictions with extensive areas of continuous habitat have not yet completed the process of local population delineation and therefore only provided extent of occurrence of boreal caribou for the continuous distribution area within the jurisdictional boundaries. The identification of local populations and associated range within large continuous distribution areas is a high priority, as identified in the Schedule of Studies. When completed, the proposed Critical Habitat for these units should be re-evaluated.

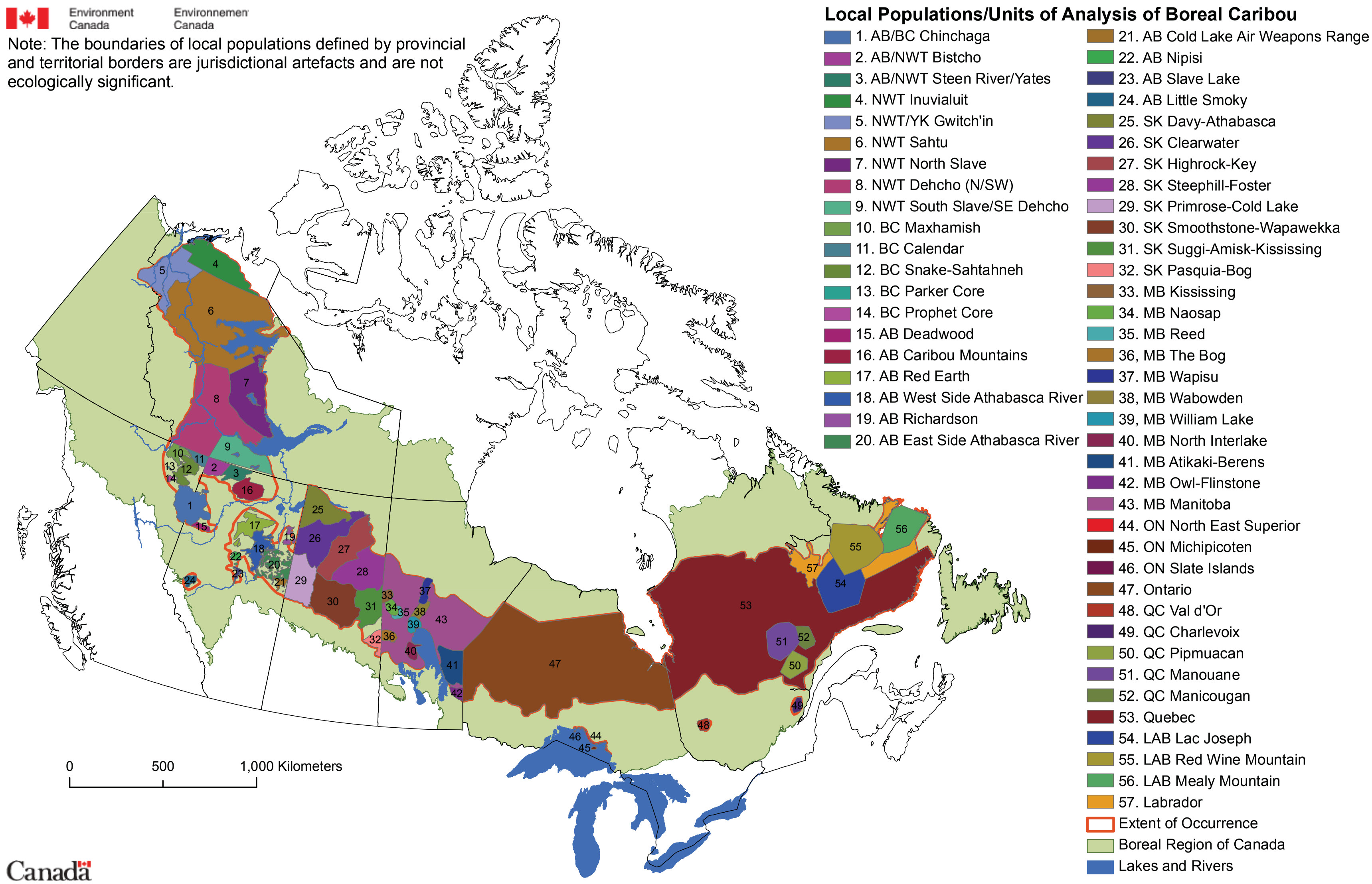


Figure 6: Boreal Caribou Local Populations and Units of Analysis for Critical Habitat Identification

Of the 57 recognized units of analysis assessed in this report, 39 represent discrete local populations and are referenced as “local populations” in the following figures and tables. Of the remaining units of analysis, 6 units in NWT resulted from subdivision of a large area of relatively continuous habitat considered to be occupied by one large population into recognized management units; 8 units in Saskatchewan represent multiple local populations and recognized management units within an area of relatively continuous habitat. The remaining 4 units of analysis found in parts of Manitoba, Ontario, Quebec and Labrador may include multiple local populations within a large area of relatively continuous habitat. In the absence of defined local populations or units of analysis for these areas, the extent of occurrence was used as the analysis unit.

2.6.3 Population and Habitat Assessment

Having identified local populations or units of analysis and associated ranges, the next step in the Decision Tree was the identification and assessment of measurable criteria of population and habitat status for each local population range. The recovery goal (and population objective) is self-sustaining local populations, here interpreted as the probability of persistence. Three measurable criteria related to persistence probability were assessed:

Population Trend: an indicator of whether a population is self-sustaining over a relatively short measurement period (approximately 3-5 years). Four qualitative states were recognized: stable, increasing, declining and unknown. Information on trend of local populations was provided by the jurisdictions in Appendix 1 of the Draft National Recovery Strategy. Updates were solicited as part of this review (see Appendix 6.8). Development of standards for measurement of this criterion is identified within the Schedule of Studies.

Population Size: an indicator of the ability of a population to withstand stochastic events and persist over the long-term. Results from the non-spatial population viability analysis (PVA) were used to derive empirical guidelines for size categories (states) related to probability of persistence (see Section 2.6.4.2 Population Size and Appendix 6.6). Three states were recognized in this review: very small (< 50), small (≥50 and ≤300), and above critical (>300). Information on size of local populations was provided by the jurisdictions in Appendix 1 of the Draft National Recovery Strategy. Updates were solicited as part of this review (see Appendix 6.8). Development of standards for measurement of this criterion is identified within the Schedule of Studies.

Range Disturbance: an indicator of the ability of a range to support a self-sustaining population. Results from a meta-analysis of demography and range disturbance (see Appendix 6.5) were used to derive empirical categories (states) for percent total range disturbance (anthropogenic and fire) related to demographic response (see Section 2.6.4.3 Range Disturbance). Five states were recognized in this review: very low, low, moderate, high and very high. Information on total range disturbance of local populations was measured from independent, national-scale data sources, consistent with methods applied in the meta-analysis.

Additional criteria were considered during the review, particularly measures of range condition in addition to disturbance. The amount, quality and spatial distribution of habitat components essential to caribou, such as winter and summer range, and calving and post-calving areas, also influence the ability of a range to support a self-sustaining population. Partitioning disturbance into natural and anthropogenic components, characterized by type, severity and distribution relative to habitat components could also help to refine evaluations. Other types of disturbances that cannot be readily extracted from maps can also influence range condition. However, access to readily available, standardized data on which to base a national assessment was a limiting factor in the current review. Development of a comprehensive Decision Tree and associated analyses are identified in the Schedule of Studies. Supplementary information (e.g. new knowledge) can also augment Critical Habitat identification through the adaptive management process.

2.6.4 Determination of States for Assessment Criteria

The population and habitat assessment criteria: population trend, population size and range disturbance, represent three lines of evidence used to evaluate local population ranges relative to their potential to support self-sustaining populations. This section describes the methods used to determine the states of assessment criteria.

2.6.4.1 Population Trend

The recognized states of population trend used in the Decision Tree and associated analyses were not rationalized beyond a literal interpretation of the trend state. For example, a population exhibiting a declining trend over a given measurement interval is, by definition, not self-sustaining, and thus has a low probability of persisting given continued decline. Alternatively, a stable or increasing population is, by definition, self-sustaining over the measurement interval, and has a moderate to high probability of persisting given continued stability or growth. Where trend was assigned a state of unknown, the population was considered to have an equal likelihood of being either self-sustaining or not, and thus may or may not persist (Table 1).

Table 1: Population trend states with corresponding values of population growth and assigned probability of persistence.

Trend State	Lamba (λ)	Prob. Persistence
Declining	≤ 0.98	0.1
Stable	0.99 to 1.01	0.7
Increasing	> 1.01	0.9
Unknown	--------	0.5

2.6.4.2 Population Size

Small populations face a high risk of extinction due to demographic stochasticity, Allee effects and emigration (Levins 1970, Shafer and Samson 1985). The situation is exacerbated when populations become isolated (Harris 1984, Belovsky et al. 1994), as is the case for most small caribou populations in Canada, due to human-caused range loss.

The non-spatial population viability analysis (PVA; Appendix 6.6) suggested that, under good demographic conditions (e.g. relatively high adult female and calf survival; Scenario 75th Percentile, Table 2), a population size of 50 had a ~10% chance of quasi extinction, within 100 years, defined as the probability of declining to a population size of 10 animals or fewer (Figure 7). This analysis further suggested that a population of 300 with moderate calf and adult female survival (MHMM, Table 2) had a 10% probability of quasi-extinction. Finally, large populations (≥ 300) had a high probability of persistence under favourable demographic conditions; however, no population size was sufficient to buffer against poor demographic conditions (low calf survival, moderate adult female survival; LHMM, Table 2; Figure 7).

Table 2. Scenario parameter values to assess population size thresholds of boreal caribou for population assessment and identification of Critical Habitat, based on calf and adult female survival (S) and variation (CV = coefficient of variation).

Scenario	Description of Scenario	Calf Survival (S_{calf})	CV[1] Calf Survival S_{calf} CV	Adult Female Survival (S_{ad})	CV Adult Female Survival (S_{ad} CV)
LHMM	Low S_{calf}; High CV of S_{calf}; Mean S_{ad}, Mean CV of S_{ad}	0.17	64%	0.85	8%
MHMM	Mean S_{calf}; High CV of S_{calf}; Mean S_{ad}, Mean CV of S_{ad}	0.38	64%	0.85	8%
75th Percentile	75thP_S_{calf}, 75thP_CV of S_{calf}; 75thP_S_{ad}, 75thP_CV of S_{ad}	0.44	51%	0.88	15%

[1] Coefficient of Variation

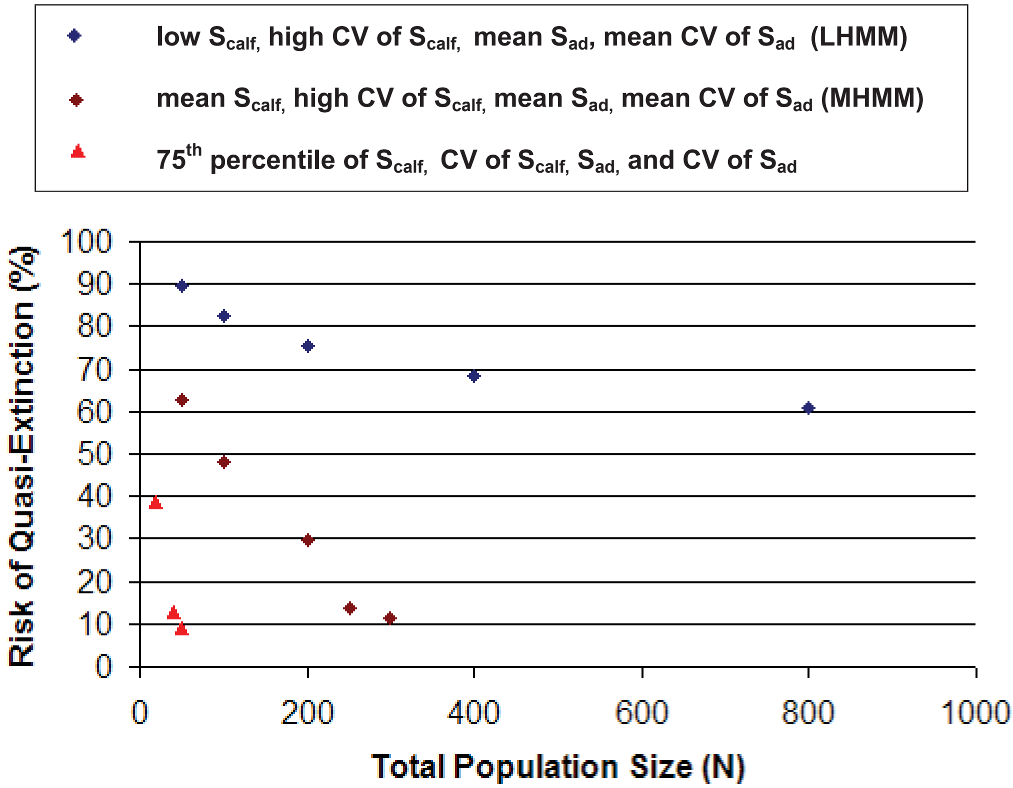


Figure 7. The effect of population size on risk of quasi-extinction under various survival rates for boreal caribou adult females and calves. Quasi-extinction is defined as the risk of the population declining to 10 animals or less over 100 yrs.

While some small populations may persist for long periods, and perhaps even expand depending on range conditions (e.g., Krausman et al. 1993, Wehausen 1999), there is general agreement that they usually require special management interventions to do so (Krausman and Leopold 1986, Krausman et al. 1993, Wehausen 1999). Further, there is usually a long lag period (two decades or more) between a population declining below a critical threshold and eventual extirpation (Tillman et al. 1994, Vors et al. 2007), and the period over which trend data for caribou populations are available is often less than the probability period associated with the most likely range perturbation under natural conditions (e.g., fire).

Therefore, the population assessment component of Critical Habitat identification recognized that very small populations (<50) are vulnerable to stochastic events and phenomena, resulting in an especially low probability of persistence, whereas local populations of >50 but <300 caribou are less vulnerable but are still at risk of quasi-extinction, and populations greater than 300 can persist indefinitely when range conditions support average adult female and calf survival. However, no population size was adequate to buffer against poor demographic conditions. Three states with corresponding population sizes and persistence probabilities were thus considered in this component of the population assessment (Table 3).

Table 3. Population size states derived from a non-spatial population viability analysis (Appendix 5.6), with corresponding population sizes and probability of persistence.

Population State	Population Size	Prob. Persistence
Very Small	< 50	0.1
Small	50 - 300	0.3
Above Critical	> 300	0.5 / 0.9*
Unknown	----------	0.5

* Declining or unknown, P=0.5; poor demographic or reference conditions
Stable or increasing, P=0.9

Given that the PVA did not include senescence (e.g. no constraints on maximum breeding age and maximum age), nor significant sources of environmental stochasticity, such as that caused by fire events, the population size thresholds could be considered liberal (e.g. conferring a greater probability of persistence than may be realized). However, the PVA also only modeled single, closed populations (e.g. no immigration or emigration). This is a reasonable assumption for very small populations and for discrete small populations. Nevertheless, where the potential for immigration exists, extinction risk may be moderated through rescue effects.

2.6.4.3 Range Disturbance

The national meta-analysis of caribou demography and range disturbance (Appendix 6.5) revealed a negative relationship between recruitment rate, as reflected in the ratio of calves to adult females in late winter population surveys, and the level of range disturbance. The percentage of the range disturbed by a non-overlapping measure of total area burned and disturbed by anthropogenic activities explained 61% of the variation in mean recruitment rates across 24 boreal caribou populations. For populations of caribou to be self-sustaining, population growth rates must be either stable or increasing. Population growth rate (λ) is a function of recruitment (R) and adult survival (S), such that $\lambda = S / (1 – R)$ (adapted from Hatter and Bergerud 1991). Thus for λ to be ≥ 1.0 (stable or increasing), R must be $\geq$ S.

The non-spatial PVA reported mean annual female survival as 85%, based on a review of boreal caribou studies from across Canada. With this adult female survival rate, a recruitment rate of 15% female calves into the total population is required for a stable population, or λ = 1.0, which is interpreted here as the condition necessary for a self-sustaining or persistent population. To achieve 15% female calves in a total population of 100 animals, assuming an equal sex ratio among calves, 14% yearlings in the population, an estimated 61% females in the adult population, and an average parturition rate of 0.76 (% yearlings, adult sex ratio and parturition rate from non-spatial PVA, see Appendix 6.6), a minimum recruitment rate of 28.9 calves/100 females is required. The non-spatial PVA suggested a positive probability of population persistence above this value, under a moderate female survival scenario, and given population size above critical (> 300 animals). Bergerud (1992) also reported that 27.7 calves/100 cows yielded a λ value of 1 based on 32 herd determinations (population survey years) of barren-ground and woodland caribou. Clearly, the appropriateness of a 15% target and associated calf to cow ratio depends on the actual survival of adult females in a given population. However, the minimum recruitment rate or threshold of 28.9 calves/100 females provided a guideline for evaluating the probability of persistence (e.g. the ability of the range to support a self-sustaining population) of local populations associated with varying levels of range disturbance, for use in the habitat assessment component of the Decision Tree.

The results of the meta-analysis were extrapolated to predict persistence probability at varying levels of total range disturbance for individual local populations. To achieve this, it was necessary to account for the uncertainty of the measured response (the estimated empirical relationship based on sampled populations) and the predicted response (the expected value for a new observation). The uncertainty of the predicted response must be included if the interval used to summarize the prediction result is to contain the new observation with the specified confidence. As with conventional confidence intervals, which quantify the certainty around the estimated empirical relationship, a probabilistic interval is used when predicting a new observation. To distinguish the types of prediction, however, the later probabilities are termed prediction intervals. Prediction intervals around the threshold recruitment value of 28.9 calves/100 cows were used to derive the disturbance states used in habitat assessment (Figure 8).

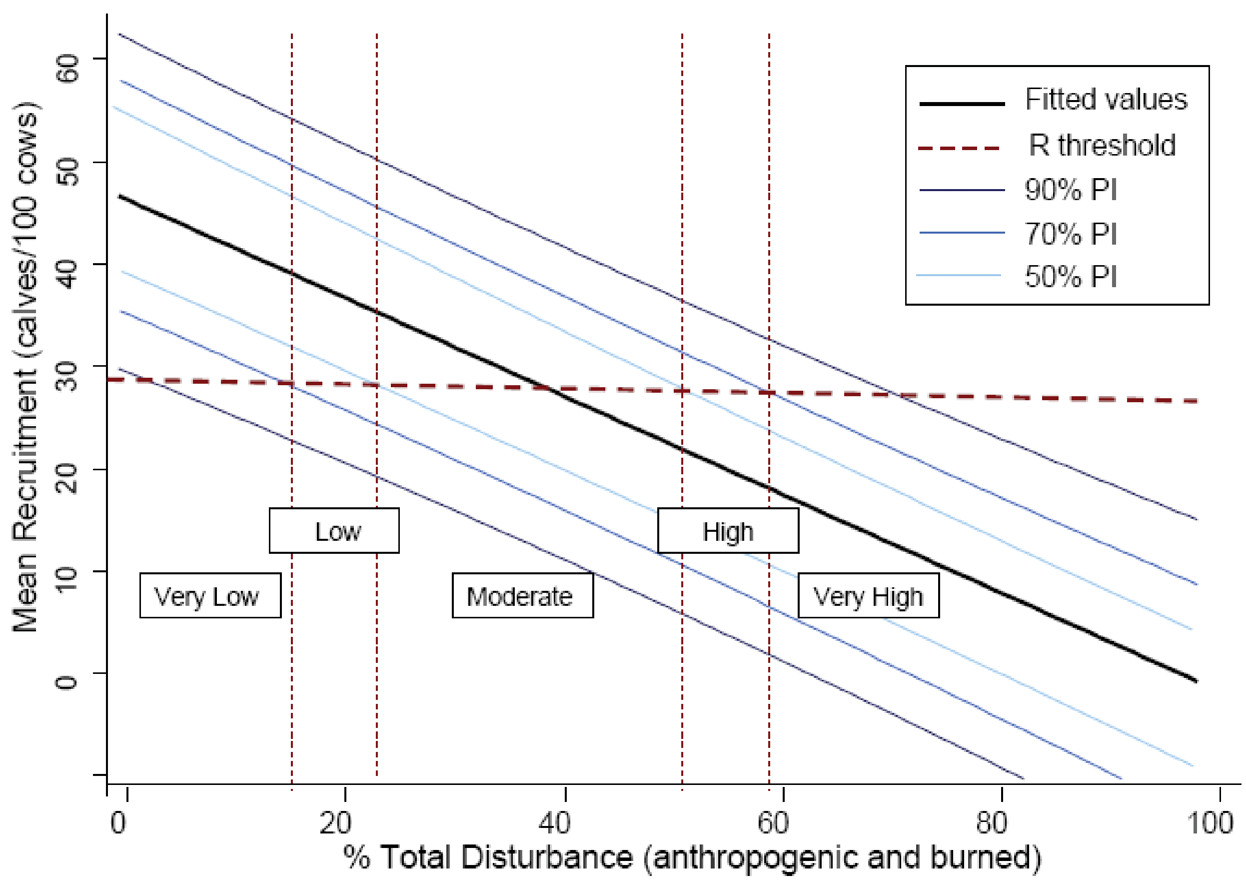


Figure 8. Disturbance states derived from the prediction intervals (PI) for the relationship between total range disturbance and boreal caribou recruitment, based on a recruitment threshold of 28.9 calves/100 cows (15% calves in total population).

The lower and upper bounds of the 50%, 70% and 90% prediction intervals defined 5 states of disturbance: very low, low, moderate, high, and very high, corresponding to values of total disturbance associated with varying levels of persistence probability (Table 4).

Table 4. Disturbance states derived from the meta-analysis of caribou demography and range disturbance (Appendix 5.5), with corresponding values of total disturbance (% anthropogenic and burned), and persistence probability, based on recruitment threshold of 28.9 calves/100 cows for a stable population.

Disturbance State	Total Disturbance	Prob. Persistence
Very Low	≤ 15%	0.9
Low	16 - 23%	0.7
Moderate	24 - 49%	0.5
High	50 - 58%	0.3
Very High	≥ 59%	0.1

While total disturbance was used to assess disturbance state for purposes of assigning persistence probability, results from the meta-analysis indicated that most of the explained variance in recruitment was attributed to the anthropogenic component of the total disturbance measure. Thus, when total disturbance was moderate or above, but the majority of the disturbance was attributed to fire, a local population range might be expected to support a higher probability of persistence than suggested by the composite measure.

2.6.5 Integrated Probability Assignments to Local Population Ranges

Once the states of individual assessment criteria were assigned to local populations of boreal caribou, the next step in the Decision Tree integrated these criteria to assign a relative probability of population persistence to each local population range. The alternative hypotheses or outcomes evaluated at the local population level were:

R_{NSS} (Range Not Self-Sustaining): current range conditions and/or extent are not adequate to support a self-sustaining population; probability of persistence is low.

R_{SS} (Range Self-Sustaining): current range conditions and extent are adequate to support a self-sustaining population; probability of persistence is moderate to high.

The Decision Tree provided a systematic means to evaluate the probability of persistence for a local population given its observed state of population trend, population size, and range disturbance. Whether states of the three criteria were known or unknown, a “prior probability” (prior) was assigned to each criterion as an expression of available quantitative data and published scientific information. A prior, which varies between 0 and 1, is an inferred probability that a hypothesis is correct, or the plausibility of an outcome given incomplete knowledge. When a state is unknown, a reference prior is assigned. This is functionally equivalent to the inferred probability of alternate hypotheses, or plausibility of different outcomes, being equal.

Assignment of prior probabilities to possible states of each criterion was based on inferred persistence probability (population trend), the statistical distribution of simulation results related directly to persistence probability (population size), and a combination of measurement and prediction uncertainty from the statistical properties of the recruitment-disturbance relationship (range disturbance). Determination of the states was described in the previous section (2.6.4). The assignment of prior probabilities reflects the probability of an observed state supporting a self-sustaining (SS) local population, given available information.

A conditional probability table for the joint distribution of criteria states was generated by averaging the individual, or marginal, priors to derive an integrated prior probability assignment for each combination set (Table 5). Integrated priors represent the prior probability distribution for the hypotheses R_{NSS} and R_{SS}. The variable SSƒR (probability of local population being self-sustaining given current range condition) is continuous from 0 to 1, with values ≤ 0.4 indicating the weight of evidence supports R_{NSS}, 0.5 placing equal weight on R_{NSS} and R_{SS} (specific conditions are evaluated to aid interpretation), and ≥ 0.6 supporting R_{SS}.

Table 5. Example portion of conditional probability table for the joint distribution of criteria states, with integrated prior probability assignments. SSƒR is the probability of a local population being self-sustaining, given present range and population conditions (See Appendix 6.8 for the complete table).

Trend		Size		Disturbance		SSƒR	Range Assessment
Declining	0.1	Very Small	0.1	Very High	0.1	0.1	R_{NSS}
				High	0.3	0.2	R_{NSS}
				Moderate	0.5	0.2	R_{NSS}
				Low	0.7	0.3	R_{NSS}
				Very Low	0.9	0.4	R_{NSS}
Stable	0.7	Small	0.3	Very High	0.1	0.4	R_{NSS}
				High	0.3	0.4	R_{NSS}
				Moderate	0.5	0.5	R_{SS}/R_{NSS}
				Low	0.7	0.6	R_{SS}
				Very Low	0.9	0.6	R_{SS}
Increasing	0.9	Above Critical	0.9	Very High	0.1	0.6	R_{SS}
				High	0.3	0.7	R_{SS}
				Moderate	0.5	0.8	R_{SS}
				Low	0.7	0.8	R_{SS}
				Very Low	0.9	0.9	R_{SS}

The result of the integrated assessment was assignment of a probabilistic outcome to each local population or unit of analysis, based on the weight of evidence supporting a conclusion of self-sustaining or not self-sustaining given current range conditions and extent.

2.6.6 Proposed Identification of Critical Habitat

The final step in the Decision Tree is the proposed identification of Critical Habitat, based on the probability of the current range supporting a self-sustaining local population (see Section 2.6.5). Critical Habitat Identification is expressed relative to the current range condition and extent for each local population or unit of analysis. Condition and extent determine the functional attributes of the range. Three Critical Habitat outcomes were considered, based on interpretation of the integrated and individual probability assignments and associated weight of evidence for range self-sustaining (R_{SS}) or not self-sustaining (R_{NSS}). The outcomes were:

- *Current Range* - current range condition and extent are required to maintain potential for self-sustaining population.
- *Current Range and Consider Resilience* – current range condition and extent may be sufficient to absorb additional disturbance while maintaining capacity to support a self-sustaining population.
- *Current Range and Improved Conditions* – current range condition and/or extent would need to be improved to restore potential to support a self-sustaining population.

The following decision rules were applied in the proposed identification of Critical Habitat for each local population or unit of analysis.

- **Where range assignment was self-sustaining (R_{SS}), based on weight of evidence from the integrated assessment ($p \geq 0.6$):**
  - If local populations or units of analysis were defined <u>and</u> all criteria had known states, **proposed Critical Habitat was identified as "Current Range and Consider Resilience".**
  - If local populations or units of analysis were not defined for large areas of continuous habitat <u>or</u> if both population criteria (trend and size) were unknown, **proposed Critical Habitat was identified as "Current Range"**, with a note that population delineation and/or data were necessary before potential resilience could be evaluated.
  - If population trend was unknown <u>and</u> population size was small or very small **proposed Critical Habitat was identified as "Current Range",** with a note to address data gap.

- If population trend was unknown and population size was above critical, **proposed Critical Habitat was identified as "Current Range and Consider Resilience"**, with a note to address data gap.

- **Where range assignment was not self-sustaining (R_{NSS}), based on weight of evidence from the integrated assessment ($p \leq 0.4$):**

  - If level of total disturbance was very low or low, **proposed Critical Habitat was identified as "Current Range"**, with a note to investigate other measures of habitat condition, non-habitat stressors and consider range extent, as appropriate.

  - If level of total disturbance was moderate, high or very high and trend was stable, **proposed Critical Habitat was identified as "Current Range"**, with a note to closely monitor trend.

  - If level of total disturbance was moderate, high or very high and population trend was declining, **proposed Critical Habitat was identified as "Current Range and Improved Conditions"**.

  - If population trend was unknown and total disturbance was moderate or total disturbance was high or very high with the anthropogenic component of disturbance low or very low, **proposed Critical Habitat was identified as "Current Range"**, with a note to address data gap.

  - If population trend was unknown and total disturbance was high or very high with anthropogenic component moderate or above, **proposed Critical Habitat was identified as "Current Range and Improved Conditions"**, with a note to address data gap.

- **Where range assignment was (R_{SS}/R_{NSS}), based on equal weight of evidence from the integrated assessment ($p=0.5$):**

  - **Proposed Critical Habitat was identified as "Current Range"**

  - If one or more of the criteria for the integrated assessment was unknown, addressing information gaps is indicated.

  - If all criteria states were known, situation was considered marginal; close monitoring of situation is recommended.

Where proposed Critical Habitat is identified as being “Current Range and Improved Conditions” or “Current Range and Consider Resilience”, this does not imply that Critical Habitat is unknown or un-identifiable. Rather, based on the current methodology, associated assumptions and data used, Critical Habitat is proposed as the Current Range, with direction on additional considerations necessary to refine the assessment. Ultimately, to meet the full requirement of “habitat that is necessary for the survival or recovery” (SARA S.2(1)), improved conditions and/or increased extent may be required (Current Range and Improved Conditions), or the Current Range could absorb additional disturbance without compromising persistence of the local population (Current Range and Consider Resilience).

3.0 RESULTS

3.1 Proposed Critical Habitat Identification for Local Populations of Boreal Caribou in Canada

The result of the application of the Decision Tree is described in Table 6. Based on this science review, proposed Critical Habitat designations are described for each local population as the Current Range, Current Range and Improved Conditions, or Current Range and Consider Resilience, based on the integrated probability assignment (Section 2.6.5) and application of decision rules (Section 2.6.6). The notes column provides explanations and considerations for each local population. These notes could be augmented by additional information available from jurisdictions. Limited, local population information was available at the time of this assessment, and for consistency, the results presented include only that information available across all populations, and considered in the present evaluation. A general description of the components of Critical Habitat to be considered within local population ranges is found in the Habitat Narrative (Appendix 6.3) and is referenced in Table 6 by ecozones and ecoregions relevant to each local population.

Application of the Critical Habitat Identification Framework to each local population or unit of analysis was based on the most current available information provided by jurisdictions for: delineation of local populations or units of analysis (where these have been defined); trend data; and population size data. Disturbance data was derived using a nationally consistent method as part of the science review. The science review did not include an assessment of data quality for data provided by jurisdictions, although Appendix 6.9 provides an indication of the level of confidence as provided by jurisdictions. National, standardized criteria and methods for boreal caribou population assessments do not exist and have been recommended as an activity in the Schedule of Studies (Section 4.4, Table 7) to improve comparability in reporting.

Table 6: Proposed Critical Habitat Identification, by local population or unit of analysis, for boreal caribou within their current distribution in Canada.

[1] Local populations refers to 57 recognized units of analysis assessed in this report; 39 represent discrete local populations; 6 units in NWT resulted from subdivision of a large area of relatively continuous habitat considered to be occupied by one large population into recognized management units; 8 units in Saskatchewan represent multiple local populations and recognized management units within an area of relatively continuous habitat. The remaining 4 units of analysis found in parts of Manitoba, Ontario, Quebec, and Labrador may include multiple local populations within a large area of relatively continuous habitat. In the absence of defined local populations or units of analysis for these areas, the extent of occurrence comprised the analysis unit.

[2] Data: see Appendix 6.9 for data source and quality used in population assessment; sources for disturbance data are described in Appendix 6.5.

[3] Range Assessment: RSS = Range self-sustaining; RNSS = Range not self-sustaining; RSS/RNSS = Range self-sustaining / Range not self-sustaining (See Section 2.6.5)

#	Local Population[1] Or Unit of Analysis	Assessment Criteria											Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Population Trend			Population Size			Range Disturbance										
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
1	AB/BC Chinchaga	Rapidly Declining/ Suspected Declining	decline	0.1	250-300	Small	0.3	10.9	58.5	62.8	Very High	0.1	0.2	R_{NSS}	AB/BC transboundary population. High weight of evidence that current range is not self- sustaining given rapidly declining, small LP, and very high total disturbance. Anthropogenic disturbance at 58% suggests need for improved condition.	Current Range and Improved Conditions	4, 9	64, 66, 137, 138
2	AB/NWT Bistcho	Suspected Declining	decline	0.1	300	Small	0.3	24.3	40.1	57.5	High	0.3	0.2	R_{NSS}	AB/NWT transboundary population. High weight of evidence that current range is not self-sustaining given suspected decline, small population and high total disturbance. Anthropogenic disturbance at 40% suggests need for improved condition. Additional trend data required.	Current Range and Improved Conditions	4	64, 65
3	AB/NWT Steen River \ Yates	unknown	unknown	0.5	300	Small	0.3	29.6	32.2	57.0	High	0.3	0.4	R_{NSS}	AB/NWT transboundary unit of analysis. Weight of evidence suggests current range is not self -sustaining given population size below critical and high total disturbance. Trend data required.	Current Range and Improved Conditions	4	64, 65
4	NWT Inuvialuit	unknown	unknown	0.5	Unknown	Unknown	0.5	2.5	0.6	3.1	Very Low	0.9	0.6	R_{SS}	Weight of evidence suggests current range is self-sustaining given very low total disturbance. Trend data and population size data required before potential resilience can be assessed.	Current Range	3, 4	33, 34, 35, 37, 50, 52

#	Local Population[1] Or Unit of Analysis	Assessment Criteria: Population Trend: Reported[2]	Population Trend: Category	Population Trend: Individual Probability	Population Size: Reported[2]	Population Size: Category	Population Size: Individual Probability	Range Disturbance: Fire%	Range Disturbance: Anthro-pogenic %	Range Disturbance: Total %	Range Disturbance: Category	Range Disturbance: Individual Probability	Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
5	NWT/YK Gwich'in	increasing	increase	0.9	500	Above Critical	0.9	30.1	7.5	36.0	Mod	0.5	0.8	R_{SS}	NWT/YT transboundary population. High weight of evidence that current range is self- sustaining with potential resilience given increasing trend, population size above critical, and moderate total disturbance comprised primarily of fire.	Current Range and Consider Resilience	3, 4, 11	33, 35, 50, 51, 52, 53, 165, 170
6	NWT Sahtu	unknown	unknown	0.5	2000	Above Critical	0.5	20.4	4.6	23.4	Low	0.7	0.6	R_{SS}	Weight of evidence suggests current range is self-sustaining with potential resilience, given large population and low total disturbance. Trend data required.	Current Range and Consider Resilience	3, 4, 5, 11	35, 36, 37, 51, 52, 53, 54, 55, 56, 57, 58, 59, 68, 170
7	NWT North Slave	unknown	unknown	0.5	700	Above Critical	0.5	36.0	1.2	36.9	Mod	0.5	0.5	R_{SS}/R_{NSS}	Equal weight of evidence that current range may or may not be self-sustaining, given large population size with moderate total disturbance, but unknown trend. Very low anthropogenic disturbance. Trend data required.	Current Range	4, 5	52, 59, 60, 63, 68, 69
8	NWT Dehcho (N/SW)	likely declining	decline	0.1	2000	Above Critical	0.5	28.2	17.7	43.3	Mod	0.5	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given suspected decline and moderate total disturbance. Anthropogenic disturbance is low. Additional trend data required.	Current Range and Improved Conditions	4, 12	51, 55, 56, 58, 59, 60, 62, 63, 64, 65, 66, 182

#	Local Population[1] Or Unit of Analysis	Assessment Criteria: Population Trend: Reported[2]	Population Trend: Category	Population Trend: Individual Probability	Population Size: Reported[2]	Population Size: Category	Population Size: Individual Probability	Range Disturbance: Fire%	Range Disturbance: Anthro-pogenic %	Range Disturbance: Total %	Range Disturbance: Category	Range Disturbance: Individual Probability	Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
9	NWT South Slave/SE Dehcho	likely declining	decline	0.1	600	Above Critical	0.5	34.6	16.0	46.7	Mod	0.5	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given suspected decline and moderate total disturbance. Anthropogenic disturbance is low. Additional trend data required.	Current Range and Improved Conditions	4, 9	64, 65, 136
10	BC Maxhamish	unknown	unknown	0.5	306	Above Critical	0.5	1.0	45.9	46.4	Mod	0.5	0.5	R_{SS}/R_{NSS}	Equal weight of evidence that current range may or may not be self-sustaining given unknown trend, large population and moderate total disturbance. Total disturbance is at the high-end of moderate class, with 46% anthropogenic disturbance. Trend data required.	Current Range	4	64, 65
11	BC Calendar	unknown	unknown	0.5	291	Small	0.3	9.4	47.4	52.2	High	0.3	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given small population and high total disturbance. Anthropogenic disturbance at 47% suggests need for improved condition. Trend data required.	Current Range and Improved Conditions	4	64, 65
12	BC Snake Sahtaneh	declining	decline	0.1	365	Above Critical	0.5	14.2	56.3	63.1	Very High	0.1	0.2	R_{NSS}	High weight of evidence that current range is not self-sustaining given declining trend and very high total disturbance. Anthropogenic disturbance at 56% suggests need for improved condition.	Current Range and Improved Conditions	4	64, 65

#	Local Population[1] Or Unit of Analysis	Assessment Criteria											Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Population Trend			Population Size			Range Disturbance										
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
13	BC Parker Core	unknown	unknown	0.5	24	Very Small	0.1	0.5	31.1	34.6	Mod	0.5	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given very small population and moderate total disturbance, with 31% anthropogenic. Trend data required.	Current Range	4	64
14	BC Prophet Core	unknown	unknown	0.5	54	Small	0.3	0.2	71.8	71.9	Very High	0.1	0.3	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given small population and very high total disturbance. Anthropogenic disturbance at 71% indicates need for improved condition. Trend data required.	Current Range and Improved Conditions	4	64
15	AB Deadwood	suspect declining	decline	0.1	40	Very Small	0.1	10.3	63.1	66.5	Very High	0.1	0.1	R_{NSS}	High weight of evidence that current range is not self-sustaining given suspected decline, very small population and very high total disturbance. Anthropogenic disturbance at 63% suggests need for improved condition. Additional trend data required.	Current Range and Improved Conditions	9	137, 138
16	AB Caribou Mountains	rapidly declining ($\lambda = 0.92$)	decline	0.1	400-500	Above Critical	0.5	43.8	24.0	54.7	High	0.3	0.3	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given rapid decline and high total disturbance.	Current Range and Improved Conditions	4, 9	64, 65, 138

#	Local Population[1] Or Unit of Analysis	Assessment Criteria: Population Trend			Population Size			Range Disturbance					Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
17	AB Red Earth	rapidly declining (λ = 0.94)	decline	0.1	250-350	Small	0.3	28.8	39.0	58.6	High	0.3	0.2	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given declining LP and high disturbance. anthropogenic disturbance at 39% suggests potential need for improved conditions.	Current Range and Improved Conditions	9	136, 139, 142
18	AB West Side Athabasca River	declining (λ = 0.99)	decline	0.1	300-400	Above Critical	0.5	4.1	42.7	44.8	Mod	0.5	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given declining trend and moderate total disturbance. Anthropogenic disturbance at 43% suggests need for improved conditions.	Current Range and Improved Conditions	9	139, 142
19	AB Richardson	unknown	unknown	0.5	<100	Small	0.3	19.7	19.9	37.1	Mod	0.5	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given small population and moderate total disturbance. Anthropogenic disturbance is low. Trend data required.	Current Range	9	136, 139
20	AB East Side Athabasca River	declining (λ = 0.95)	decline	0.1	150-250	Small	0.3	26.5	49.5	61.9	Very High	0.1	0.2	R_{NSS}	High weight of evidence that current range is not self-sustaining given small, declining population and very high total disturbance. Anthropogenic disturbance at 49% suggests need for improved conditions.	Current Range and Improved Conditions	9	139, 142, 149

#	Local Population[1] Or Unit of Analysis	Assessment Criteria											Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Population Trend			Population Size			Range Disturbance										
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
21	AB Cold Lake Air Weapons Range	rapidly declining (λ = 0.93)	decline	0.1	100-150	Small	0.3	35.0	45.7	65.9	Very High	0.1	0.2	R_{NSS}	High weight of evidence that current range is not self-sustaining given small, declining population and very high total disturbance. Anthropogenic disturbance at 46% suggests need for improved conditions.	Current Range and Improved Conditions	9	139
22	AB Nipisi	unknown	unknown	0.5	60-70	Small	0.3	6.0	46.1	49.9	High	0.3	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given small population and high total disturbance. Anthropogenic disturbance at 46% suggests need for improved condition. Trend data required.	Current Range and Improved Conditions	9	139, 142
23	AB Slave Lake	unknown	unknown	0.5	75	Small	0.3	46.8	67.7	81.9	Very High	0.1	0.3	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given small population and very high total disturbance. Anthropogenic disturbance at 68% suggests need for improved condition. Trend data required.	Current Range and Improved Conditions	9	138, 139, 145
24	AB Little Smoky	Rapidly declining (λ = 0.89)	decline	0.1	80	Small	0.3	0.2	81.5	81.5	Very High	0.1	0.2	R_{NSS}	High weight of evidence that current range is not self-sustaining given small, rapidly declining population and very high total disturbance. Anthropogenic disturbance at 82% strongly suggests need for improved conditions.	Current Range and Improved Conditions	9, 14	145, 207

#	Local Population[1] Or Unit of Analysis	Assessment Criteria											Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Population Trend			Population Size			Range Disturbance										
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
25	SK Davy-Athabasca	unknown	unknown	0.5	310	Above Critical	0.5	34.6	1.1	35.4	Mod	0.5	0.5	R_{SS}/R_{NSS}	Equal weight of evidence that current range may or may not be self-sustaining given unknown trend with large population size and moderate total disturbance. Anthropogenic disturbance is extremely low; disturbance is by fire. Trend data required.	Current Range	5, 6	69, 87
26	SK Clearwater	unknown	unknown	0.5	425	Above Critical	0.5	53.6	1.2	54.0	High	0.3	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given high total disturbance, with unknown trend. Large population size and extremely low anthropogenic disturbance (1.2%) suggests population may be self-sustaining. Trend data required.	Current Range	5, 6, 9	69, 71, 87, 88, 139
27	SK Highrock-Key	unknown	unknown	0.5	1060	Above Critical	0.5	45.6	3.0	47.3	Mod	0.5	0.5	R_{SS}/R_{NSS}	Equal probability that current range may or may not be self-sustaining given large population size and moderate disturbance. Total disturbance is at the high-end of the moderate class, but anthropogenic disturbance is very low (4%), suggesting a self-sustaining designation. Trend data required.	Current Range	5, 6, 9	71, 87, 88, 139

#	Local Population[1] Or Unit of Analysis	Assessment Criteria											Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Population Trend			Population Size			Range Disturbance										
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
28	SK Steephill-Foster	unknown	unknown	0.5	1075	Above Critical	0.5	38.6	1.9	39.9	Mod	0.5	0.5	R_{SS}/R_{NSS}	Equal weight of evidence that current range may or may not be self-sustaining given large population size and moderate total disturbance, with unknown trend. Total disturbance is at the high-end of the moderate class, but anthropogenic disturbance is extremely low (2%), suggestion a self-sustaining designation. Trend data required.	Current Range	6	88
29	SK Primrose-Cold Lake	unknown	unknown	0.5	350	Above Critical	0.5	38.6	19.5	52.0	High	0.3	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given high total disturbance. Disturbance is at the high-end of the moderate class; anthropogenic component is relatively low (14%). Trend data required.	Current Range	6, 9	88, 139, 149
30	SK Smoothstone-Wapawekka	declining w/ hab change	decline	0.1	700	Above Critical	0.5	14.7	18.2	29.5	Mod	0.5	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given declining trend and moderate total disturbance. Conditions require improvement.	Current Range and Improved Conditions	6, 9	88, 139, 148, 149
31	SK Suggi-Amisk-Kississing	unknown	unknown	0.5	430	Above Critical	0.5	12.6	7.9	19.8	Low	0.7	0.6	R_{SS}	Weight of evidence suggests that current range is self -sustaining and potentially resilient given population size above critical and very low total disturbance. Trend data required.	Current Range and Consider Resilience	6, 9	88, 148

#	Local Population[1] Or Unit of Analysis	Assessment Criteria: Population Trend			Population Size			Range Disturbance					Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
32	SK Pasquia-Bog	Threat of decline	decline	0.1	30	Very Small	0.1	12.1	25.5	35.6	Mod	0.5	0.2	R_{NSS}	High weight of evidence that current range is not self-sustaining given a very small population, suspected decline and moderate total disturbance. Additional trend data required.	Current Range and Improved Conditions	9	139, 148, 149, 155
33	MB Kississing	stable	stable	0.7	50-75	Small	0.3	39.2	12.5	50.8	High	0.3	0.4	R_{NSS}	Weight of evidence suggests that current range is not self-sustaining given small population with high total disturbance. Anthropogenic component of disturbance is low (13%). Additional trend data required.	Current Range	6	88
34	MB Naosap	stable	stable	0.7	100-200	Small	0.3	15.0	28.1	41.2	Mod	0.5	0.5	R_{SS}/R_{NSS}	Equal weight of evidence suggests current range is marginal given small, stable population and moderate total disturbance. Anthropogenic component of disturbance is moderate (28%). Additional trend data required.	Current Range	6, 9	88, 148
35	MB Reed	stable	stable	0.7	100-150	Small	0.3	6.9	22.0	28.0	Mod	0.5	0.5	R_{SS}/R_{NSS}	Equal weight of evidence suggests current range is marginal given small, stable population and moderate total disturbance. Additional trend data required.	Current Range	6, 9	88, 148

#	Local Population[1] Or Unit of Analysis	Assessment Criteria											Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Population Trend			Population Size			Range Disturbance										
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
39	MB William Lake	stable	stable	0.7	25-40	Very Small	0.1	4.1	24.2	27.6	Mod	0.5	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given very small population and moderate total disturbance. Disturbance is primarily anthropogenic (24%). Additional trend data required.	Current Range	9	148
37	MB Wapisu	stable	stable	0.7	100-125	Small	0.3	10.6	12.9	23.3	Low	0.7	0.6	R_{SS}	Weight of evidence suggests current range is self-sustaining and potentially resilient given stable trend and low disturbance. Small population presents risk. Additional trend data required.	Current Range and Consider Resilience	6	88, 89
36	MB The Bog	stable	stable	0.7	50-75	Small	0.3	10.0	19.6	28.1	Mod	0.5	0.5	R_{SS}/R_{NSS}	Equal weight of evidence suggests current range is marginal given small, stable population and moderate total disturbance. Additional trend data required.	Current Range	6, 9	88, 89, 148
38	MB Wabowden	stable	stable	0.7	200-225	Small	0.3	16.9	15.2	29.3	Mod	0.5	0.5	R_{SS}/R_{NSS}	Equal weight of evidence suggests current range is marginal given small, stable population and moderate total disturbance. Additional trend data required.	Current Range	6, 9	89, 148
40	MB North Interlake	stable	stable	0.7	50-75	Small	0.3	3.2	14.7	16.6	Low	0.7	0.6	R_{SS}	Weight of evidence suggests current range is self-sustaining given stable trend and low disturbance. Potential resilience is indicated however risk associated with small population (50-75) should be considered. Additional trend data required.	Current Range and Consider Resilience	9	148, 155

#	Local Population[1] Or Unit of Analysis	Assessment Criteria											Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Population Trend			Population Size			Range Disturbance										
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
41	MB Atikaki-Berens	stable	stable	0.7	300-500	Above Critical	0.9	25.9	5.4	28.2	Mod	0.5	0.7	R_{SS}	Weight of evidence suggests current range is self-sustaining with potential resilience given large, stable population and moderate total disturbance. Anthropogenic disturbance is very low (5%). Additional trend data required.	Current Range and Consider Resilience	6, 9	90, 148
42	MB Owl Flintstone	stable	stable	0.7	71-85	Small	0.3	23.9	23.8	43.8	Mod	0.5	0.5	R_{SS}/R_{NSS}	Equal weight of evidence suggests current range is marginal given small, stable LP and moderate total disturbance. Current conditions should be maintained.	Current Range	6	90
43	Manitoba (Remainder of boreal caribou in MB)	stable	stable	0.7	775-1585	Above Critical	0.9	20.5	9.9	29.3	Mod	0.5	0.7	R_{SS}	Delineation of local populations or units of analysis has not yet occurred. Weight of evidence suggests the extent of occurrence is self-sustaining given large, stable population and moderate total disturbance. Resilience can not be considered until units of analysis are defined and reassessed.	Current Range	6, 9, 15	88, 89, 90, 139, 148, 155, 216

#	Local Population[1] Or Unit of Analysis	Assessment Criteria											Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Population Trend			Population Size			Range Disturbance										
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
44	ON North East Superior	decreasing	decline	0.1	42	Very Small	0.1	0.0	0.0	0.0	Very Low	0.9	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given a very small and declining population. Very low disturbance suggests other factors are contributing to decline. Range extent, other measures of habitat condition, and non-habitat factors should be assessed.	Current Range and Improved Conditions (Extent)	6	94, 96, 97
45	ON Michipicoten	increasing	increase	0.9	200	Small	0.3	0.0	20.8	20.8	Low	0.7	0.6	R_{SS}	Island Population. Weight of evidence suggests current range is self-sustaining given a small, increasing population and low total disturbance. Potential resilience is indicated however risk associated with small population should be considered.	Current Range and Consider Resilience	6	96
46	ON Slate Islands	unknown	unknown	0.5	250	Small	0.3	0.0	0.0	0.0	Very Low	0.9	0.6	R_{SS}	Island Population. Weight of evidence suggests current range is self-sustaining given small population and very low total disturbance. Trend data required before resilience can be assessed.	Current Range	6	94

#	Local Population[1] Or Unit of Analysis	Assessment Criteria											Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Population Trend			Population Size			Range Disturbance										
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
47	Ontario (Estimate of total number of forest-dwelling ecotype)	unknown	unknown	0.5	~5000	Above Critical	0.5	12.6	6.3	18.5	Low	0.7	0.6	R_{SS}	Delineation of local populations or units of analysis has not yet occurred; extent of occurrence was evaluated. Weight of evidence suggests the extent of occurrence is self-sustaining given large population and low disturbance. Population units must be identified and evaluated before resilience can be assessed. Pattern of disturbance exhibits north/south gradient, with higher anthropogenic disturbance in southern portion of extent. Trend data required.	Current Range	6, 15	89, 90, 91, 94, 95, 96, 216, 217
48	QC Val d'Or	declining	decline	0.1	30	Very Small	0.1	0.2	50.3	50.3	High	0.3	0.2	R_{NA}	High weight of evidence that current range is not self-sustaining given very small, declining population and high total disturbance. Anthropogenic disturbance at 50% suggests need for improved condition.	Current Range and Improved Conditions	6	96

#	Local Population[1] Or Unit of Analysis	Assessment Criteria											Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Population Trend			Population Size			Range Disturbance										
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
49	QC Charlevoix	stable	stable	0.7	75	Small	0.3	3.6	68.4	70.3	Very High	0.1	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given small population and very high total disturbance. Stable trend with very high anthropogenic disturbance (68%) indicates need to better understand the nature of disturbance in this area. Trend should be closely monitored.	Current Range	6	99
50	QC Pipmuacan	stable	stable	0.7	134	Small	0.3	10.5	45.7	53.1	High	0.3	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given small population and high total disturbance. Stable trend indicates a need to better understand the nature of disturbance in this area. Trend should be closely monitored.	Current Range	6	101
51	QC Manouane	stable	stable	0.7	358	Above Critical	0.9	17.9	10.2	25.4	Mod	0.5	0.7	R_{SS}	Weight of evidence suggests current range is self-sustaining with potential resilience given large, stable population and moderate total disturbance. Anthropogenic component of disturbance is very low (10%).	Current Range and Consider Resilience	6	101
52	QC Manicouagan	increasing	increase	0.9	181	Small	0.3	3.0	28.8	30.5	Mod	0.5	0.6	R_{SS}	Weight of evidence suggests current range is self-sustaining given increasing trend and moderate total disturbance. Potential resilience is indicated; risk associated with small population should be considered.	Current Range and Consider Resilience	6	101

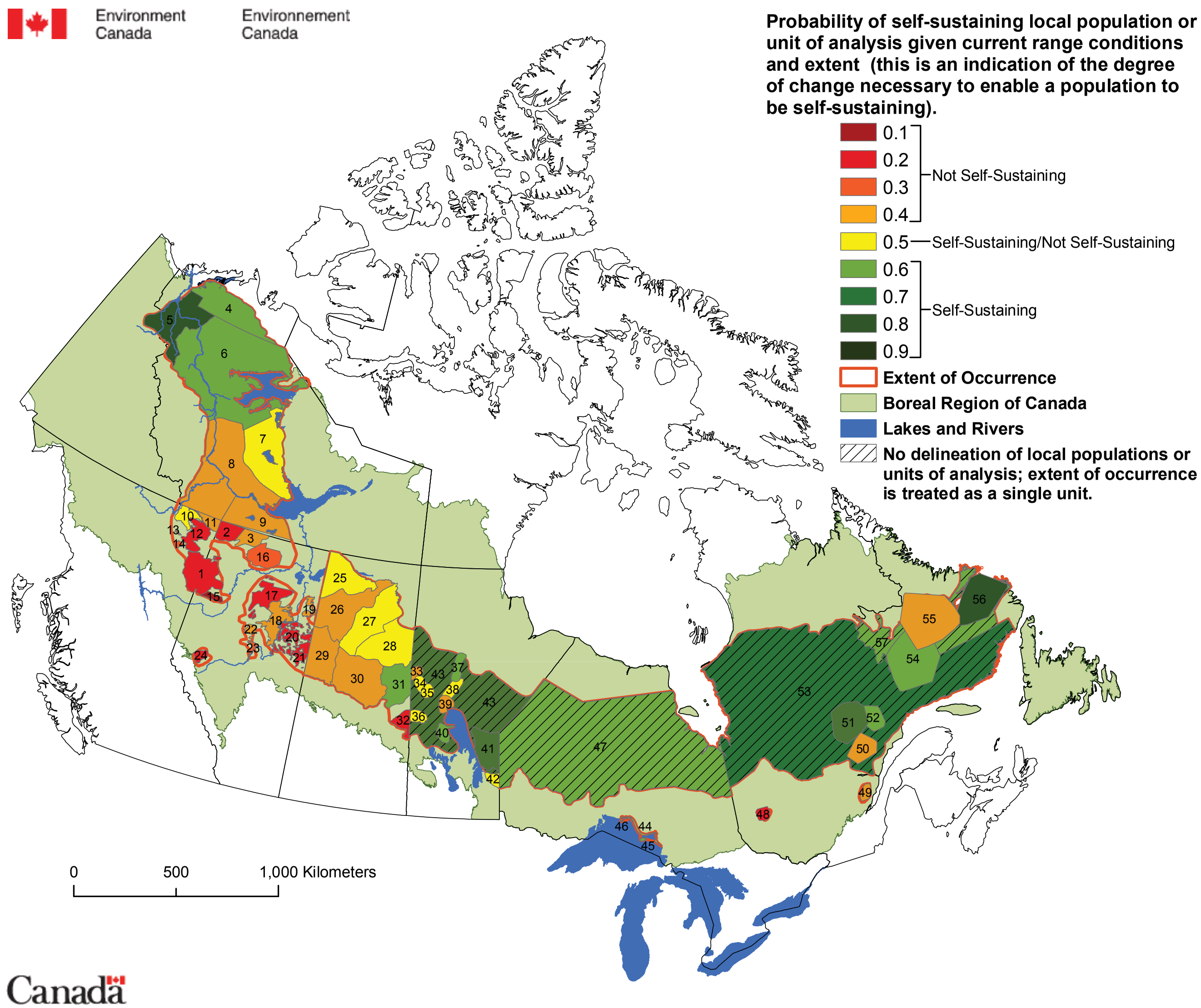
#	Local Population[1] Or Unit of Analysis	Assessment Criteria: Population Trend: Reported[2]	Population Trend: Category	Population Trend: Individual Probability	Population Size: Reported[2]	Population Size: Category	Population Size: Individual Probability	Range Disturbance: Fire%	Range Disturbance: Anthro-pogenic %	Range Disturbance: Total %	Range Disturbance: Category	Range Disturbance: Individual Probability	Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
53	Quebec (Remainder of boreal caribou in QC)	suspected stable	stable	0.7	6000-12000	Above Critical	0.9	16.7	12.9	25.9	Mod	0.5	0.7	R_{SS}	Delineation of population units has not yet occurred; extent of occurrence was evaluated. Weight of evidence suggests the current extent of occurrence is self-sustaining given a very large, stable population and moderate total disturbance. Units of analysis must be defined and evaluated before resilience can be assessed. Additional trend data required.	Current Range	5, 6, 15	72, 73, 74, 78, 80, 96, 99, 100, 101, 103, 217
54	LAB Lac Joseph	unknown	unknown	0.5	1101	Above Critical	0.5	4.1	1.9	5.9	Very Low	0.9	0.6	R_{SS}	Weight of evidence suggests current range is self-sustaining and potentially resilient given large population and very low total disturbance. Trend data required.	Current Range and Consider Resilience	5, 6	78, 80, 84, 101, 103, 105
55	LAB Red Wine Mountain	Declining	decline	0.1	97	Small	0.3	2.4	8.5	10.8	Very Low	0.9	0.4	R_{NSS}	Weight of evidence suggests current range is not self-sustaining given small, declining population. Very low disturbance indicates that other measures of habitat condition and non-habitat factors should be assessed and addressed. Human-caused mortality and other forms of anthropogenic disturbance may be significant.	Current Range	5, 6	78, 80, 84, 85, 105

#	Local Population[1] Or Unit of Analysis	Assessment Criteria											Integrated Probability (P)	Range Assessment[3]	NOTES	Proposed Critical Habitat Identification	Ecozone	Ecoregion
		Population Trend			Population Size			Range Disturbance										
		Reported[2]	Category	Individual Probability	Reported[2]	Category	Individual Probability	Fire%	Anthro-pogenic %	Total %	Category	Individual Probability						
56	LAB Mealy Mountain	stable	stable	0.7	2106	Above Critical	0.9	0.2	0.4	0.6	Very Low	0.9	0.8	R_{SS}	Weight of evidence suggests current range is self-sustaining with potential resilience given very large, stable population and very low total disturbance.	Current Range and Consider Resilience	5, 6	77, 79, 80, 82, 104, 105
57	Labrador (Remainder of boreal caribou in LAB)	unknown	unknown	0.5	unknown	Unknown	0.5	5.0	5.3	10.0	Very Low	0.9	0.6	R_{SS}	Weight of evidence suggests that current range is self-sustaining given very low total disturbance. Population trend and size data required before resilience can be assessed.	Current Range	5, 6	74, 75, 78, 79, 80, 82, 101, 103, 104, 105

To support Results interpretation, Figure 9 illustrates the integrated probability assignments to each local population, and the assessment of the most plausible outcome relative to the likelihood that the current range is self-sustaining. It is important to note that the integrated probability assignment should not be interpreted as an absolute probability of persistence, due both to variation in the generation of probabilities for each criterion, and the method by which the criteria were integrated. However, it is a weight of evidence measure relative to the question of whether a given range (the spatial delineation of a local population or unit of analysis) is likely to support a self-sustaining population as a function of the current range and population conditions. Further, it is not an indication of whether a population is recoverable or not; rather, it is an expression of the degree of habitat recovery or management intervention necessary to restore the population's ability to be self-sustaining (e.g., to persist without the need for ongoing management intervention; Section 2.2.4).

The resultant proposed Critical Habitat Identification for the 57 recognized local populations or units of analysis considered in the decision analysis was:

- Current Range for 25 local populations or units of analysis;
- Current Range and Improved Conditions for 21 local populations or units of analysis;
- Current Range and Consider Resilience for 11 local populations or units of analysis.



Number	Local Population/Unit of Analysis	Integrated Probability
1	AB/BC Chinchaga	0.2
2	AB/NWT Bistcho	0.2
3	AB/NWT Steen River/Yates	0.4
4	NWT Inuvialuit	0.6
5	NWT/YK Gwich'in	0.8
6	NWT Sahtu	0.6
7	NWT North Slave	0.5
8	NWT Dehcho (N/SW)	0.4
9	NWT South Slave/SE Dehcho	0.4
10	BC Maxhamish	0.5
11	BC Calendar	0.4
12	BC Snake Sahtaneh	0.2
13	BC Parker Core	0.4
14	BC Prophet Core	0.3
15	AB Deadwood	0.1
16	AB Caribou Mountains	0.3
17	AB Red Earth	0.2
18	AB West Side Athabasca River	0.4
19	AB Richardson	0.4
20	AB East Side Athabasca River	0.2
21	AB Cold Lake Air Weapons Range	0.2
22	AB Nipisi	0.4
23	AB Slave Lake	0.3
24	AB Little Smoky	0.2
25	SK Davy-Athabasca	0.5
26	SK Clearwater	0.4
27	SK Highrock-Key	0.5
28	SK Steephill-Foster	0.5
29	SK Primrose-Cold Lake	0.4
30	SK Smoothstone-Wapawekka	0.4
31	SK Suggi-Amisk-Kississing	0.6
32	SK Pasquia-Bog	0.2
33	MB Kississing	0.4
34	MB Naosap	0.5
35	MB Reed	0.5
36	MB The Bog	0.5
37	MB Wapisu	0.6
38	MB Wabowden	0.5
39	MB William Lake	0.4
40	MB North Interlake	0.6
41	MB Atikaki-Berens	0.7
42	MB Owl-Flintstone	0.5
43	Manitoba	0.7
44	ON North East Superior	0.4
45	ON Michipicoten	0.6
46	ON Slate Islands	0.6
47	Ontario	0.6
48	QC Val d'Or	0.2
49	QC Charlevoix	0.4
50	QC Pipmuacan	0.4
51	QC Manouane	0.7
52	QC Manicouagan	0.6
53	Quebec	0.7
54	LAB Lac Joseph	0.6
55	LAB Red Wine Mountain	0.4
56	LAB Mealy Mountain	0.8
57	Labrador	0.6

Figure 9: Probability that current range will support a self-sustaining population of boreal caribou, based on integrated probability assignments that considered population trend and size, and level of disturbance associated with anthropogenic activities and fire (see Section 2.6.5). This Figure is not an illustration of whether a population is recoverable or not, rather, it is an indication of the degree of habitat change necessary to enable a population to be self-sustaining (e.g. to persist without the need for ongoing management intervention).

4.0 DISCUSSION

4.1 Interpretation of Proposed Critical Habitat Outcomes

The application of the Critical Habitat Framework and associated Decision Analysis provided an assessment of all local populations or units of analysis within the current distribution of boreal caribou in Canada. Like habitat selection by caribou, Critical Habitat identification is a hierarchical process that must consider needs across multiple spatial and temporal scales. The national analysis focused on the scale most appropriate for considering the persistence of local populations – the local population range. Factors operating at this scale act as constraints on population dynamics, and determine whether or not a population is likely to be sustained. It has been previously demonstrated, and is implicit in this evaluation, that predation acts as a limiting factor for boreal caribou populations. Conditions present in the range of a local population determine the type, amount and distribution of habitat for caribou and other prey species with shared predators on caribou, and hence the abundance and distribution of these predators within the range. As a result, the premise of this evaluation – that Critical Habitat is most appropriately identified at the scale of the local population range – is not equivalent to saying that every element within the range is critical to support a self-sustaining boreal caribou population, in all instances. However, it does provide a spatial delineation of the area of consideration when assessing the current conditions and quantifying risk relative to the recovery goal of maintaining or restoring self-sustaining local populations, for assigning potential Critical Habitat outcomes, and for planning for the management of the habitat conditions necessary to support population persistence (e.g. maintaining the functional attributes of the range). Refinement of needs at finer spatial scales over specific timeframes is possible within the constraints of the range level designation. Guidance on important considerations is provided in the Habitat Narrative (Appendix 6.3). General parameters associated with Critical Habitat outcomes are described below.

For each local population or unit of analysis, proposed Critical Habitat was expressed as one of three outcomes, based on weight of evidence from the integrated assessment (Range Self-Sustaining or Range Not Self-Sustaining; Section 2.6.5), and application of decision rules (Section 2.6.6). These outcomes included: Current Range, Current Range and Improved Conditions, or Current Range and Consider Resilience. An interpretation of each is provided below.

Current Range: Current range condition and extent are required to maintain potential for self-sustaining population. Further degradation of the current range may compromise the ability to meet the recovery goal. Five scenarios occurred under this outcome.

1) Local populations or units of analysis for several large and relatively continuous areas within the current distribution of boreal caribou have yet to be been delineated. The present assessment considered the extent of occurrence within the relevant jurisdiction as a single unit of analysis. In some cases, this indicated a moderate to high probability of

the area supporting a self-sustaining population (P≥0.6). However, caribou in the area may consist of more than one local population. As a result, the mean condition among these populations could be masking important variation across the extent of the area considered, with implications for population sustainability and critical habitat evaluation. Population units should be identified and assessed, which could lead to alternative outcomes.

2) The uncertainty around population condition (trend unknown) in combination with moderate disturbance did not provide a clear indication of whether the current range is adequate to support a self–sustaining population (P=0.5). The first priority is to address the information gaps, then to re-assess the local population.

3) An integrated probability of P=0.5 when all parameters were known was interpreted as a marginal situation. The criteria assigned the greatest risk (lowest individual probability) should be examined, and additional local information considered.

4) Weight of evidence supported Range Not Self-Sustaining (P≤0.4) for a number of local populations, but improvements to range condition were not clearly indicated, because either (a) disturbance was very low or low, or (b) population trend was stable. Maintenance of current range in conjunction with (a) investigation of other factors negatively affecting the population, or (b) close monitoring of trend for possible lag effects is recommended. Situations falling under (b) should also be examined to better understand potential resilience to different forms of disturbance.

5) In several cases, weight of evidence supported Range Not Self-Sustaining (P≤0.4), but the total disturbance was comprised primarily of fire (e.g., the amount of anthropogenic disturbance was low or very low), and population trend was unknown. Improvements to range condition were not clearly indicated given that percent range burned explained little variation in the relationship underlying the disturbance categories, at least up to upper end of the moderate disturbance level. A better understanding of the differential effects of fire and anthropogenic disturbances on caribou demography was identified as an area for further study.

Current Range and Improved Conditions: Current range conditions and/or extent would need to be improved to restore the potential to support a self-sustaining population. Further degradation of the range may have serious consequences for local population persistence. Three scenarios occurred under this outcome.

1) For most local populations or units of analysis with weight of evidence supporting Range Not Self-Sustaining (P≤0.4), levels of anthropogenic disturbance in conjunction with population trend suggest that recovery efforts are required to restore conditions that support persistence (e.g., a reduction in anthropogenic disturbance and recovery of disturbed habitat is necessary). The nature and magnitude of restoration could be determined through spatial population modeling combined with dynamic landscape simulation.

2) For several local populations or units of analysis, a high level of total disturbance was comprised primarily of fire, with low levels of anthropogenic disturbance, but was associated with a declining population trend. The percent area burned fell outside the range of values included in the meta-analysis (Appendix 6.5), thus inference based on the documented relationship was weak. Natural recovery may be sufficient to improve range condition, but additional stressors on the population should be considered, including potential interactions between fire and anthropogenic disturbance at high levels of fire, and non-habitat factors (e.g., mortality sources).

3) In two cases, the total measured disturbance levels were low or very low, but a negative population trend indicated the need for improved range conditions and/or extent. Therefore, aspects of habitat condition other than disturbance may be affecting the local population. Non-habitat factors such as poaching, reduction in habitat quality for example low flying aircraft or other forms of disturbance not included here, and population health (disease and parasites) should also be considered. It is also possible that the current range has been reduced in extent such that it is insufficient to support a self-sustaining local population, and restoration of adjacent habitat is required to enable the population to persist. Population isolation and the need to restore connectivity should be examined.

Current Range and Consider Resilience: Current range condition and extent may be sufficient to absorb additional disturbance while maintaining capacity to support a self-sustaining population. Two scenarios occurred under this outcome.

1) Local populations or units of analysis with large or very large population size (e.g., above critical based on the non-spatial population viability analysis), stable or increasing population trend, and levels of total disturbance that were moderate, low or very low. This situation presents the least risk with respect to meeting the population objective of the recovery goal, and represents the greatest potential to apply active adaptive management to evaluate resilience (e.g., experimental management to test alternate hypotheses regarding population responses to different types and levels of disturbance).

2) Local populations or units of analysis with small population size, stable or increasing trends, and low or very low levels of total disturbance. This situation also represents a relatively high probability of achieving the recovery goal. However, the inherent risks associated with a small population size warrant a cautious approach when considering potential resilience to any additional disturbance. Nevertheless, this situation may also present an opportunity for active adaptive management.

One of the guiding principles of the science review was to recognize and address the dynamic nature of boreal systems and resultant effects on boreal caribou habitat in time and over space. Boreal landscapes are naturally dynamic, driven by processes such as fire and other disturbances and resultant forest succession. Similar landscape dynamics may be associated with certain types of anthropogenic disturbances. Recognition of such dynamics is commensurate with the scale of consideration for Critical Habitat identification – the local population range – which reflects multi-decadal dynamics of the system and species response. However, neither the spatial nor temporal dynamics within a local population range were directly addressed by this evaluation.

The non-spatial population viability analysis considered temporal components of persistence associated with demographic, and to some extent, environmental stochasticity. As well, the 50-year window for area burned considered by the meta-analysis recognized in a limited way the dynamic properties of disturbance by fire, relative to habitat recovery and response by caribou. Nonetheless, the present evaluation represents a point-in-time assessment of the current range relative to the recovery goal of self-sustaining local populations.

Further elaboration of Critical Habitat outcomes for local populations can be achieved through spatial population viability analysis linked with dynamic landscape modelling (see Section 2.6.6 and Appendix 6.7). Incorporation of landscape dynamics is necessary to understand the conditions and management options associated with recovery (Current Range and Improved Conditions) and resilience (Current Range and Consider Resilience), as well as additional risks associated with present conditions (Current Range). Such evaluations may be undertaken with varying levels of complexity and concomitant requirements for data. It is clear from the present review that minimum data requirements could be met for most areas within the current distribution of boreal caribou in Canada, particularly when viewed in the context of adaptive management.

4.2 Decision Analysis and Adaptive Management

The Decision Tree provided a structured and transparent method to evaluate individual local populations and determine prior probabilities of alternative hypotheses regarding definition of Critical Habitat, through consideration of measurable criteria assigned to categorical states based on available quantitative data and published scientific information. The prior probabilities indicated the most plausible outcome, relative to probability of persistence, for each local population or unit of analysis. At each step in the Decision Tree, any assumptions made were explicitly described, and uncertainties were identified that could be addressed through a Schedule of Studies to improve understanding.

The approach to Critical Habitat identification applied here follows established methodologies for decision-analysis in operations research and management science. In this case, the objective function is population persistence, expressed as the set of conditions necessary to support self-sustaining local populations. Syntheses of existing information, evaluation of likely outcomes, and refinement of understanding are also fundamental components of the adaptive management framework. While a more detailed Decision Tree could be developed to elucidate the relationships among criteria (variables) and identify underlying mechanisms, the simple model considered here is a “white box” that can be easily applied, evaluated, and communicated with available information, and supports a science based component of the process leading to the potential final identification of proposed Critical Habitat across a spectrum of local population conditions.

The assignment of prior probabilities and their use in the identification of Critical Habitat represents a starting point in an adaptive management cycle (Figure 4). As uncertainties are addressed through the Schedule of Studies, and new information becomes available, local population assignments can be updated. The Decision Tree can also be interpreted as a Bayesian Decision Network (BDN). The assessment criteria are equivalent to nodes in a BDN, representing variables that can assume multiple states. Associated with each node is a probability table that expresses the likelihood of each state, conditional on the state of nodes that feed into it. Weightings could be assigned to nodes to represent the relative importance of the variable on the outcome. The current process does not address interactions among the criteria or their relative influence on outcomes, so no weightings were applied to the assessment criteria (population trend, population size, and range disturbance), nor were conditional probabilities assigned to individual criteria. However, estimation methods for generating these probabilities exist, and can be incorporated over time through the adaptive management process. Development of a more comprehensive BDN is recommended as part of the Schedule of Studies, to enhance understanding and provide a formal process for updating the prior probability distribution for the recovery goal of self-sustaining local populations.

4.3 Transition to Action Planning/Recovery Implementation

As previously noted, this national analysis and proposed identification of critical habitat was conducted at a spatial scale appropriate to addressing persistence of local populations, as per the recovery goal and objectives for this species. However, habitat selection by boreal caribou is hierarchical, and where/if deemed necessary, assessments may be further refined within local population ranges to identify the habitat necessary for the recovery of the species at finer temporal and spatial scales.

A variety of approaches could be applied at the local population level to define the degree of change required in range condition and/or extent to support persistence, the appropriate management strategies for maintaining conditions where range is currently self-sufficient, and the amount of additional disturbance that might be absorbed by local populations with potential resilience. For example, the probability of persistence over specified time frames can be further quantified using spatially explicit population viability analysis to model the fate of populations relative to changing habitat conditions, and to identify probable outcomes under a range of habitat scenarios. By linking spatially explicit population and landscape simulation models, dynamic elements of the system can be incorporated (see Appendix 6.7 – spatial PVA). Further meta-analyses could be applied across multiple populations to link current conditions (e.g., vegetation composition and structure), created by natural and anthropogenic factors, to population status, and predict future trends. Similarly, a retrospective approach could be used to explore conditions for persistence, by quantifying historic variation in natural systems and examining circumstances that have contributed to persistence, recognizing the uncertainty among persistence, historical disturbances, and habitat change. Such investigations could also yield insights into the differential effects of fire and anthropogenic disturbance on caribou demography; an important distinction when considering the application of such approaches to caribou management.

4.4 Conclusions

The Boreal Caribou Critical Habitat Science Review performed by EC was undertaken with the support of an independent Science Advisory Group that provided continuous peer-review throughout the process. Development of a Critical Habitat Framework and Decision Tree provided a formal structure for assembling and analyzing data relevant to Critical Habitat identification, and the foundation for continuous improvement of knowledge through the process of adaptive management. A weight of evidence approach was used to identify the most plausible outcome of combinations of population and habitat conditions relative to the recovery goal of self-sustaining local populations.

This report contains a proposed Critical Habitat identification, based on empirical science and inherent assumptions associated with the methodology used, for each of the spatial analytical units associated with each local population. Other factors such as the incorporation of Aboriginal and traditional knowledge (ATK), and the extent to which the assumptions taken in this report align with Critical Habitat policy directives, may influence any potential final identification of Critical Habitat in the Recovery Strategy.

General conclusions from the review include:

1) Critical Habitat for boreal caribou is most appropriately identified at the scale of local population range, and expressed relative to the probability of the range supporting a self-sustaining local population;

2) Range is a function of the extent and condition of habitat, where habitat includes the suite of resources and environmental conditions that determine the presence, survival and reproduction of a population;

3) Application of the Critical Habitat Identification Framework, for the 57 recognized local populations or units of analysis for Boreal caribou in Canada, yielded 3 proposed outcomes: Current Range, Current Range and Improved Conditions, or Current Range and Consider Resilience;

4) Like habitat selection by caribou, Critical Habitat identification for Boreal caribou is a hierarchical process with considerations across multiple spatial and temporal scales. Further elaboration of Critical Habitat outcomes at spatial scales finer than range, over specified time frames, may be achieved through spatial population viability analysis linked with dynamic landscape modelling;

5) Acknowledging that current knowledge and the dynamic nature of landscapes impart uncertainty, present findings should be monitored and assessed for the purposes of refinement and adjustment over time, as new knowledge becomes available (e.g., a Schedule of Studies as part of Adaptive Management).

This science based review was framed as one of transparent decision-analysis and adaptive management. Thus, the Schedule of Studies produced is a key requirement of the process that is designed to produce continuously improving results over time. Aboriginal and Traditional Knowledge was not included in the present review, nor are needs specific to this body of knowledge identified in the Schedule of Studies.

4.5 Addressing Uncertainty – A Schedule of Studies

All readily available information, including peer-reviewed and grey literature, caribou population and location data, and biophysical and land-use data was reviewed to support the Critical Habitat Decision Analysis. A Schedule of Studies is required by SARA (S. 41(1) (c.1)) if sufficient information is not available to complete the identification of Critical Habitat. Thus, a Schedule of Studies remains a requirement of the process, as described throughout this document. The Schedule of Studies is an outline of activities (e.g., survey work, mapping, population viability analysis) designed to address knowledge gaps and uncertainties to improve the Critical Habitat identification process. These activities include new studies, improvement or continuation of existing studies, and collection of standardized data through monitoring and assessment. Aboriginal traditional knowledge was not considered in the present Science Review, except where accessible in published documents, nor are needs specific to this body of knowledge addressed in the Schedule of Studies. Aboriginal and traditional knowledge provides important information that could augment this review and improve understanding of critical habitat for boreal caribou.

The following Schedule of Studies is designed to address uncertainties identified at each step in the Decision Tree (see Figure 4).

Table 7: Schedule of Studies

Activity	Description
Identify Current Distribution: The current distribution of boreal caribou across Canada is described and mapped in order to define the national scope of Critical Habitat Identification.	
Environmental Nich Analysis	The Environmental Niche Analysis (Appendix 6.4) should be further developed and applied to identify areas of uncertainty based on available abiotic and biotic data, and therefore guide sampling efforts to refine understanding (model-based sampling) of the drivers of current distribution, as well as patterns of occupancy within the distribution. This method could also be used to identify areas with high restoration potential, and areas for enhancing population connectivity, where necessary.
Identify Unit of Analysis: The ranges of local populations are the unit of analysis for Critical Habitat Identification	
Develop a Local Population Range Mapping Standard	Develop a standardized approach to delineating local population ranges (units of analysis) that can be applied across Canada by jurisdictions responsible for the management of Boreal Caribou.
Determine Local Populations	Determine and/or update local population ranges using standardized criteria and methodology. Note: Delineation of local populations is a high priority for large continuous distribution areas currently lacking this information.

Table 7: Schedule of Studies

Activity	Description
Population and Habitat Assessment : Application of a systematic process for evaluating the probability of persistence of a local population given observed states of population and range condition.	
Develop a comprehensive Bayesian Decision Network (BDN)	Identify and incorporate measurable parameters (variables) that influence population persistence into a comprehensive BDN that specifies the conditional probabilities among variables, and provides a formal method for updating Critical Habitat assignments with new knowledge. This activity will be informed by results from additional meta-analyses and non-spatial and spatial population viability analyses.
Conduct additional meta-analyses of caribou demography and range condition	Extend analyses of national data to incorporate additional measures of population and range condition (e.g., adult survival, habitat fragmentation, forest composition), understand variation in relationships attributable to different disturbance types, other habitat measures, or regional contexts, and augment or refine criteria used to assess range condition for identification of Critical Habitat.
Refine population size thresholds in relation to probability of persistence	Further develop the Non-Spatial PVA by: ■ Incorporating maximum age and senescence ■ Evaluating interactions between selected demographic parameters, and the influence of population size on these relationships, relative to risk of extinction and expected time to extinction
Develop survey standards	Develop standardized criteria and methods for boreal caribou population assessments, including local population size and trend information.
Determine local population trends	Population demographic data are required to calculate lambda and evaluate trends of local populations, including more detailed demographic data (from survival analyses, population composition and recruitment surveys).
Determine local population sizes	Population census data are required to determine current population size.

Table 7: Schedule of Studies

Activity	Description
Critical Habitat Identification: Determining the quantity, quality and spatial configuration of habitat required for persistence of boreal caribou populations throughout their current distribution in Canada.	
Refine Quantity, Quality and Spatial Configuration of Critical Habitat for local populations	Identification and completion of case studies using spatially-explicit population modeling to explore a range of population and habitat conditions, and management scenarios, to improve understanding of habitat-based constraints on population persistence (quantity, quality and spatial configuration) and inform development of the Bayesian Decision Network. A variety of modeling approaches should be explored, to inform Critical Habitat identification and recovery planning (e.g. effective protection and recovery implementation). Alternative analytical approaches, such as additional meta-analyses, can also support this activity.
Develop and/or apply methods for determining needs and conditions to support population connectivity	Critical Habitat has been identified at the scale of the range of local populations, with the assumption that local populations experience limited exchange of individuals with other groups. Enhanced population connectivity may be necessary to support persistence of small populations, and maintenance of existing connectivity an important element of Critical Habitat for large populations. Development and/or application of methods to evaluate population connectivity and its relationship to habitat or landscape attributes is necessary. This work could be undertaken in conjunction with spatially-explicit population modeling.
Identify opportunities for active adaptive management	Uncertainties regarding the potential resilience of local populations to different levels and types of disturbance may be most effectively addressed through active adaptive management designed to test alternate hypotheses regarding population response. Parameters to support this could be identified through spatially-explicit population modelling.

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6.0
APPENDIX

6.1 Science Advisory Group Members

Mandate

The Boreal Caribou Science Advisory Group is responsible for providing scientific and technical advice to Environment Canada's review and preparation of a consolidated, scientifically defensible identification of Critical Habitat, and/or a valid Schedule of Studies to obtain such information, to be posted within a Recovery Strategy on the Public Registry (SARA S. 41 (1)(c)).

Responsibilities

The Science Advisory Group will provide open and transparent, continuous peer review and advice throughout the process of the Boreal Caribou Critical Habitat Science Review. The Science Advisory Group is not responsible for managing or directing the Critical Habitat Identification for boreal caribou.

Science Advisory Group Members

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6.2 Delineating Units of Analysis for Boreal Caribou Critical Habitat Identification

Background

Application of the Critical Habitat Identification Framework for boreal caribou and associated decision tree requires delineation of population analysis units and their associated ranges. These analysis units form the basis for analysis to determine probability of persistence, based on range quality and population parameters.

For the purposes of Critical Habitat Identification, units of analysis were provided by jurisdictions and accepted as the best available knowledge. Several jurisdictions with large continuous areas of occupied habitat have not completed local population delineation and therefore only provided extent of occurrence for continuous distribution areas. Local population delineation for these areas is a high priority as indicated in the schedule of studies.

During the Science Review process, it became evident that there was a need for a standardized protocol for identifying local populations and delineating range. There is also a need to reconcile methods for the delineation of local populations and range with variation in local population patterns, habitat fragmentation, and data availability across and within jurisdictions. The discussion below provides guidance that should be used for development of a protocol for local population identification and range delineation as part of the schedule of studies.

Local Population Pattern

Populations often function demographically at scales that are different from those suggested by genetic indicators, therefore we need to distinguish **units of analysis that are based on demography** from those that are genetically distinct (e.g., Esler et al. 2006). Based on simulation modeling, Hastings (1993) suggested a threshold of <10% migration for defining independent demographic units. Dey et al. (2006) also used simulation modeling to demonstrate that sub-populations act as one large population once migration rates reach 20%. Although the question is fundamental to understanding population processes, this topic has received limited study (Waples and Gaggiotti, 2006).

For the purposes of the Critical Habitat Identification Framework, we have defined local population as a group of caribou occupying a defined area that can be distinguished spatially from areas occupied by other groups. (Note that in most cases, the unit of analysis is the local population.) Local populations experience limited exchange of individuals with other groups, such that population dynamics are driven by local factors affecting birth and death rates, rather than immigration or emigration among groups. Ecological conditions, as well as patterns and intensity of anthropogenic disturbance, vary tremendously across the national distribution for boreal caribou in Canada, resulting in variation in local population patterns.

A local population is the smallest demographic unit with an annual rate of emigration and immigration of ≤10%. Some local populations may be spatially discrete and experience little or no exchange of individuals (≤5%). Local populations may also exist as part of a broader, continuous distribution where periodic exchange of individuals may be greater (> 5% but ≤ 10%). Alternatively, a local population could occupy a large continuous distribution whereby regular exchange of individuals occurs (> 10% immigration and emigration).

Therefore, there are three possible hypotheses proposed for local population patterns for boreal caribou, based on movement patterns:

1) discrete local populations with spatially discrete ranges
2) multiple local populations **within a large area of relatively** continuous habitat
3) one large local population across a large area of relatively continuous habitat

From a population dynamics perspective hypothesis 1 and 3 are the same, differing only in the extent of area occupied by a single population. However, there are implications for Critical Habitat Identification and delineation of the units of analysis that require differentiating these two situations as different population patterns.

There are examples in the literature of the use of animal movement data to determine immigration and emigration rates that can be in turn used to assess population patterns. McLoughlin et al. (2002) were able to determine annual exchange rates of 3.4 – 13% for females and 7-35% for males and concluded that grizzly bears populations (determined by cluster analysis of movement data) in their study area should be considered a continuous (open) population. Bethke et al. (1996) concluded, from their analysis of polar bears in the western Canadian Artic, that three populations identified in their study were relatively closed (e.g., with little immigration/emigration of radio-collared females among populations that overlapped for part of the year). The examples presented above are based on short-term studies. Dynamics of boreal ecosystems and caribou biology would need to be addressed in studies designed to assess immigration and emigration rates for boreal caribou over the long term. It should also be noted that populations fitting one hypothesis may be reassigned to an alternate hypothesis under changed environmental conditions, such as large burns and barriers imposed through human activity, or if new information is provided. Therefore, it is important that population patterns and range be periodically re-assessed and updated.

From a practical perspective, the lack of caribou movement data in some regions will preclude the ability to determine immigration/emigration rates for the purpose of determining spatial population structure. In the absence of sufficient immigration/emigration data, available animal movement and survey data and the degree of geographic separation of area of occupancy should be used to determine the most plausible hypothesis for local population pattern. The amount and quality of data used to delineate local populations and associated range varies across and within jurisdictions, and the level of certainty to support local population delineation varies accordingly. Uncertainty should be addressed through a schedule of studies and adjustments should be made to local population identification and associated unit of analysis over time.

How does range relate to the unit of analysis for application of the critical habitat decision tree?

Where natural geographic boundaries and/or habitat alteration have resulted in discrete local populations, and range boundaries have been delineated based on animal movement data and forest dynamics data, local populations and associated range are identified and constitute the unit of analysis for purposes of Critical Habitat Identification.

In areas where caribou local populations are not restricted by natural geographic boundaries or habitat alteration and are distributed across large areas of relatively continuous habitat, the delineation of range for local populations becomes more difficult. The entire extent of occurrence for a relatively continuous habitat distribution area should be included in the delineation of units of analysis. This addresses the concern that defining discontinuous ranges would eventually result in fragmentation of the continuous distribution, with loss of connectivity among local populations. In the absence of evidence to the contrary, it is also consistent with a precautionary approach.

Range Identification

Range identification can be confounded by multiple factors, which may differ among local populations, and may not be fully understood:

- the definition of range includes factors that constrain vital rates such as predation, food abundance, and other features of habitat quality;
- caribou often occupy distinct seasonal ranges, especially during summer and winter, so conditions required to maintain connectivity among landscapes used during different seasons needs to be understood;
- caribou may occupy different and shifting areas within ranges over relatively short time periods, although ‘core areas’ may be consistent over these periods;
- caribou may occupy different and shifting ranges over long time frames due to factors that are likely related to disturbances, food supply, and predator abundance, as well as direct and indirect anthropogenic disturbances and other stressors that contribute to alter natural disturbance regimes and food availability;
- ranges of local populations of caribou have changed historically and contracted in many parts of the country, so a decision needs to be taken about a ‘start date’ for range delineation;
- boreal forests change in response to natural perturbations (fire, insect outbreak, wind) and through natural vegetation succession with age. Climate change may also influence range conditions, in the short- and long-term. Even in the absence of humans, caribou respond to such changes by shifting their ranges. Hence range should not be viewed as a static condition in time or space;
- small remnant caribou populations may exist within smaller ranges than they require for long-term persistence; therefore, future range may be larger than the present range; and

- cow and bull caribou may have different range use strategies. Sexual differences in range (or total range) will not be understood unless both sexes are observed.

Therefore, ‘range use’ is a dynamic concept and delineation will require regular assessment and updating (e.g., Racey and Arsenault 2007).

Owing to these dynamics, range could be defined in probabilistic terms, based on various sources of information, but especially including data for animal locations. Ranges should be assigned in a manner analogous to home ranges derived for individual animals from location data. In this case guidelines are required for some minimum number of animals from which data are collected, including data from both sexes, and dispersal of collars across the suspected range. There are three commonly used methods for delineation of range based on location data: minimum convex polygon, a parametric kernel estimator of probability, or a non-parametric kernel estimator of probability. The former (MCP) is the least conservative and the latter two methods provide ‘probability of occupancy surfaces’ that are affected by the number of observations in the dataset. Where range is based on limited number of observations, it may be possible to assign surrounding habitat components a probability of occupancy based on niche modelling and then to use this information to improve the range estimate. Future work is required to ensure that range delineation protocols adequately address large-scale factors influencing the movement and occupancy behaviour of caribou.

Considerations in defining range for a local population

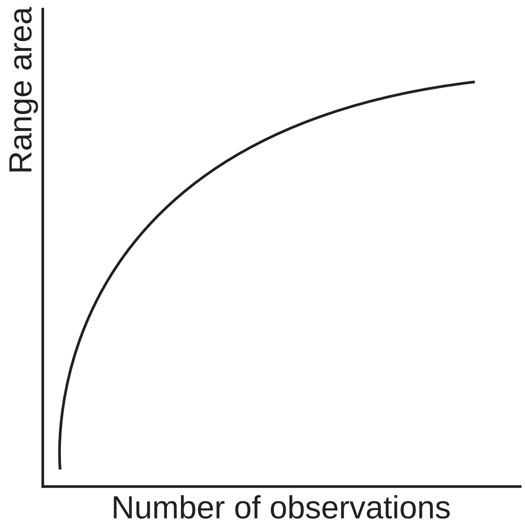
1. How is ‘current range’ defined?

Current range is defined as a geographic area within which there is a high probability of occupancy by individuals of a local population that are all subjected to the same influences affecting vital rates over a defined time frame. This definition incorporates the idea of probabilistic occupancy, functional influences, time, and space.

2. How many observations, over what time period, are required to provide a high probability that the defined range is accurate?

The number of observations required likely changes depending on the size of the population and its circumstances. An approximate answer can be determined by plotting range size against the number of observations and looking for an asymptote (Figure 1). The probability that range has been accurately defined will also depend on the quality of the data used (casual observation and aerial survey vs. radio-telemetry study, dispersion of observations across the population spatially and between sexes).

Observations made over the past 20 years should be accepted as evidence to delineate range of a local population. That amount of time allows for temporal variability in areas occupied among years and lag effects due to change. However, the final decision on appropriate time period for inclusion of observations should be based on landscape dynamics for the local population of interest.



Appendix 6.2 - Figure 1. Hypothetical plot of range size against a number of animal observations required to accurately define range.

3. Among the area estimators (MCP, parametric kernel, non-parametric kernel), which method should be used (subject to sample size considerations)?

Application of the parametric kernel and non-parametric kernel would define a smaller area that an MCP due to the removal of outliers. A precautionary approach would use the minimum convex polygon method to provide a conservative estimator of range. It is important to note that all methods are influenced, to some extent, by the number of locations (Girard et al. 2005).

4. After what time period should a range should be re-examined?

Defined ranges should be re-examined as new data becomes available and at least every 5 years.

What additional factors should be considered when delineating ranges as units of analyses for multiple local populations within a large area of continuous habitat?

The guidance below essentially provides recommended criteria for subdividing a continuous distribution into local population ranges. Therefore, the emphasis is on considerations for decisions on where to place local population range boundaries within a large area of continuous habitat. It should be noted that in areas where data availability is low, boreal caribou populations may seem to lack any obvious structure. In such cases, this guidance would be equally relevant during the process of acquiring new knowledge.

1. Animal movement and animal survey data

The most defensible and robust method to delineate units of analysis for multiple local populations in continuous habitat is to infer "surfaces" based on monitored animal movement (where the animals have been selected from a wide variety of locations across the landscape). For multiple local populations within a continuous habitat, cluster analysis of movements can be used to define group membership (Taylor et al. 2001). Bethke et al. (1996) used radio-telemetry data and cluster analysis to delineate populations of polar bears (*Ursus maritimus*) in the high Canadian Arctic. They tested for the presence of spatial clusters of animals based on movement data, then applied a home range estimator to identify the geographic range of populations for conservation purposes. Schaefer et al. (2001) and Courtois et al. (2007) used fuzzy cluster analyses to delineate caribou populations.

Systematic or non-systematic aerial or ground surveys can also be used to delimit seasonal and total range when telemetry data are not available. However, because forest-dwelling caribou are typically most dispersed in spring and summer, winter observations alone are prone to underestimation of range area.

The following criteria should be considered, in addition to, or in the absence of adequate collaring-type data and/or animal survey data, when delineating range for multiple local populations within a continuous occupied habitat distribution.

2. Spatial extent

The amount of physical area identified as range for a local population within a continuous distribution is fundamentally important for providing a large enough area to support a potentially self-sustaining local population of boreal caribou.

Available animal movement or survey data should be considered first in determining the spatial extent of the range. Further coarse level guidance for the spatial extent of range for local populations within a continuous distribution can be derived by determining the area required to support a persistent population under density and target population size assumptions. Literature and heuristic PVA results (Callaghan pers. com.) suggest somewhat greater than 300 animals for long-term population viability, given moderate rates for calf and female survival. As an example, if range-wide densities of boreal caribou are 2-3 per 100 km^2, and if a population is 300 animals, then a reasonable guideline for a unit of analysis may be in the order of 10,000 to 15,000 km^2.

Additional insight into the sizes of ranges required could be derived by examining the sizes of ranges occupied by local populations that are exhibiting $\lambda \geq 1$ and have population size > 300 occupying similar geographic areas or habitats.

3. Modifiers to spatial extent

The spatial extent must be large enough to account for natural forest dynamics and the presence of alternate habitats. Frequency and size of natural disturbance events should be considered and larger areas defined if there is a very aggressive natural dynamics cycle.

4. Evidence of shared geography

Consider any evidence, collaring or otherwise that indicates caribou move from one location to another on a seasonal basis, or share common geography for part of a year. Aboriginal knowledge can be very good in determining these connections. The fact that animals share a common connection would mean they likely need to be considered as belonging to the same range.

5. Habitat functions and behavioural responses

Large areas sharing a similar expression of habitat functions and behavioural responses warrant being kept within the same range. This would benefit caribou with behavioural patterns suited to specific landscape features or functions, and would facilitate prescription of effective protection measures. The habitat functions associated with caribou life history are expressed in many ways across Canada depending on the topography, hydrology, and surficial geology. Ultimately, this reflects how the animals appear to be achieving refuge (predator avoidance), forage (resources for subsistence) and other requirements on an annual cycle. For refuge and forage, significant behavioural responses of caribou to mountains, foothills, or other rugged terrain, lakes with islands, peatlands, large areas of older conifer forest, nutrient poor landforms, large areas of bedrock exposure etc. warrant consideration in delineating range.

Variations in habitat functions occur at all scales and only very large and significant trends should be considered here. A good example in Ontario would be the apparent linkage and interaction of animals that share Lake Nipigon and the mainland, or animals that rely on both the Hudson Bay Lowlands and the shield.

6. Predominant Risk Factors

Broad types of risk factors, both natural and human, should be considered in the delineation of range. Anthropogenic disturbance regimes and their cumulative contributions to natural ecological drivers should be considered but do not supersede ecological factors. Dominant risk factors can include forestry, oil and gas and associated roads; fire or succession, predation by wolves, disease (e.g., brainworm); or aboriginal subsistence harvest. Recognizing that risk factors can exist in many combinations, consideration of broad trends that may occur over specific geographic areas will provide additional information for decisions on where to subdivide a larger portion of continuous distribution into local population ranges.

Should the range of a single local population with a large continuous distribution be sub-sampled to identify Critical Habitat?

Delineating single local population areas that are very large (e.g., the NWT distribution as one local population analysis unit, or all of Quebec) may result in a mean condition that masks the variation across the large continuous population range. This could allow for substantial occupied range to be lost (major range recession) and erosion of the national population while still supporting a self-sustaining local population. This would be contrary to the goal and objectives in the NRS (National Recovery Strategy), which stipulates maintaining the current distribution. Such large areas would also fail to have strong demographic connections across their breadth – an important practical and theoretical consideration in Critical Habitat Identification. Therefore, it may be necessary to subdivide large continuous population ranges into smaller contiguous analysis units, as an application of the precautionary principle. These may be best derived along ecological boundaries.

Should Forest Management Unit (FMU) boundaries be used to delineate sampling units within the range of local populations within a continuous distribution?

Our recommendation is to delimit large units of analysis based exclusively on animal movement data and ecological factors as listed above. General objectives for caribou habitat (particularly forest composition and connectivity) could be determined at the scale of the range with specific objectives assigned to each FMU partly or totally included in the range. In other words, fit FMU's into the defined ranges for local populations in a continuous distribution rather than the other way around. If the FMU conforms to most of the factors identified as criteria for delineating range as above then it is likely a reasonable unit. As the FMU diverges from the criteria above, then it becomes less acceptable.

The rationale for this approach is supported by the following:

- FMU's look very different from one jurisdiction to the other (and even within a jurisdiction) varying dramatically in size and shape, and seldom conform to ecological drivers. In some jurisdictions, they are surprisingly dynamic with new configurations and amalgamations occurring frequently. In some cases FMU's may represent more than one discrete block of land separated by large distances.
- Social planning considerations should not override fundamentally important ecological drivers. However, if ecological drivers and social planning considerations are geographically close, boundaries of range may be reconciled with other existing management unit boundaries.

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6.3 Literature Review of Boreal Caribou (Ranfiger tarandus caribou) Habitat Use in Ecozones across their Distribution in Canada

Introduction

Woodland caribou (*Rangifer tarandus caribou*) are distributed in the boreal forest across nine ecozones in Canada. Several ecotypes of woodland caribou have been classified, including boreal, forest tundra, northern mountain and southern mountain, based on their adaptation to various environments (Thomas and Gray 2002). In 2002, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed the boreal caribou ecotype as threatened (Thomas and Gray 2002). The boreal caribou is a forest-dwelling sedentary ecotype of woodland caribou. The range of the listed boreal caribou extends throughout the boreal forest in nine provinces and territories, from southwest Northwest Territories to Labrador (Figure 1).

Habitat encompasses the broad suite of biotic and abiotic resources and conditions that govern the survival, reproduction, and presence of a species (Caughley and Gunn 1996). The limiting factors assembled for caribou populations include predation (Bergerud 1974, 1980, Bergerud and Elliot 1986, Seip 1991, Stuart-Smith et al. 1997, Rettie and Messier 1998, Whittmer et al. 2005), meteorological conditions (Brown and Theberge 1990), food availability (Schaefer 1988), insect harassment (Downes et al. 1986; Walsh et al. 1992), and harvesting by humans (Bergerud 1967; Edmonds 1988).

The key to understanding habitat is scale. Individual animals select habitat at multiple scales to meet their life history requirements and avoid hazards. Johnson (1980) proposed a hierarchy of habitat selection, including species range scale, home range scale, within range (seasonal) habitats, and finer scales of resource selection, driven by efforts to minimize effects of limiting factors.

Rettie and Messier (2000) hypothesized that, across spatial scales, population-limiting factors can be linked to habitat selection. This argument has two components: First, habitat selection may occur simultaneously on multiple scales, often framed as a nested hierarchy. For instance, animals may select a home range, feeding sites within the home range, and dietary items within a site (Senft et al. 1987). Second, selection at each of these scales represents a ranking of limiting factors. Animals are hypothesized to select resources (or perhaps avoid some condition) in an attempt to overcome the chief limitation at each scale; if unable to do so, they continue to select that resource at successively finer scales. The scales of habitat selection can thus reveal an ordered list of limiting factors. The broadest scales are most pertinent to survival and reproduction (Rettie and Messier 2000).

There is wide agreement that the primary proximate limiting factor for boreal caribou populations is predation, driven by natural or human-induced landscape changes that favour early seral stages and higher densities of alternative prey (Bergerud and Elliott 1986, Bergerud 1988, Ferguson et al. 1988, Seip 1992, Cumming et al. 1996, Stuart-Smith et al. 1997, Rettie and Messier 1998, Schaefer et al. 1999, Courtois 2003, Courtois et al. 2007, Vors et al. 2007). The distribution of woodland caribou appears to occur in refugia, often away from high densities of predators and their alternate prey (Bergerud et al. 1984, Bergerud 1985, Cumming et al. 1996, Rettie 1998, James 1999, Racey and Armstrong 2000). If caribou can find such refugia, then snow appears to act as a factor at slightly finer scales, such as foraging areas with softer and shallower snow cover (Stardom 1975, Brown and Theberge 1990). Finally, selection for lichens occurs at even finer scales such as feeding craters chosen for their high lichen content (Schaefer and Pruitt 1991) or graminoids and equisetum.

The scale of habitat selection should reflect the relative importance of limiting factors, whereby a limiting factor should drive selective behaviour at increasingly finer scales until the next most dominant limiting factor supersedes selection (Rettie and Messier 2000). Bergerud et al. (1984) hypothesized that minimizing exposure to predation is the strongest driver of coarse-scale caribou habitat selection. For example, at a broad scale, boreal caribou select mature conifer forests and peatland complexes, both of which support few predators or alternative prey. During calving season, cows typically select treed islands surrounded by open water in peatlands or lakes to further reduce risk of predation. The open water is hypothesized to facilitate escape from predators. Although some of these islands may support sub-optimal forage quality and quantity, the inference is that the risk of predation exceeds the need for high quality forage and that predation still remains the chief limiting factor within a home range.

At fine spatial scales, food availability and microclimate factors are considered important drivers of caribou habitat selection (Rettie and Messier 2000). During spring, female caribou feed on nutrients important for lactation (equisetum and graminoids), and during winter the exploit protein-rich sedges (*Carex spp*.) and equisetum and terrestrial and in some areas arboreal lichens (e.g., *Bryoria spp. and Alectoria sarmentosa*; Helle 1980, in Rettie and Messier 2000). During summer, when biting insects are abundant, boreal caribou have been reported to use sparsely treed ridgelines near lakeshores, purportedly to reduce insect harassment (Shoesmith and Storey 1977, Hillis et al. 1998).

Although boreal caribou are considered non-migratory, movements made between seasonal ranges (particularly pre-calving and pre-rutting) vary considerably, from almost no between-season movements in Alberta, central Saskatchewan, and southeastern Manitoba (Fuller and Keith 1981, Darby and Pruitt 1984, Bergerud 1985, Edmonds 1988, Stuart-Smith et al. 1997, Rettie and Messier 2000), to more than 20 km in northwestern Ontario (Ferguson and Elkie 2004a) or 40.5 km mean distance (range 12 – 119 km) in northeastern BC (Culling et al. 2006) and 75 km in Labrador (range 10 - 520 km; Brown et al 1986). Boreal caribou in Manitoba have been recorded moving distances of greater than 200 km (V. Crichton pers. comm.). Connectivity between seasonal habitats fulfills a potentially critical function in reducing risk of predation for boreal caribou during times of increased movement. Caribou migrating to and from their wintering areas used coniferous forests (Ferguson and Elkie 2004a, Darby and

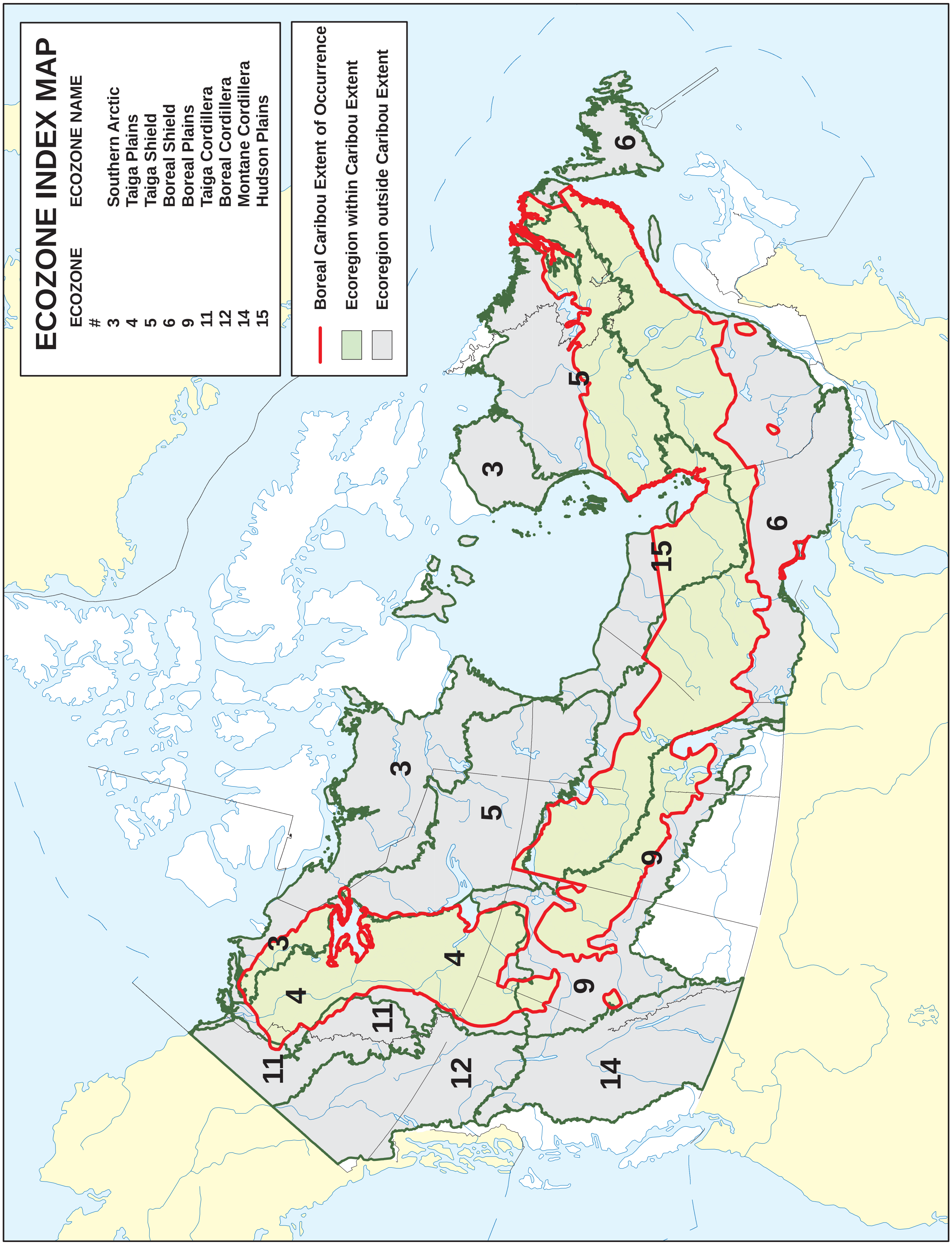
Pruitt 1984, Lefort et al. 2006). In northwestern Ontario, caribou were more likely to avoid open water, disturbed and open areas while using coniferous forests during migration to and from wintering areas (Ferguson and Elkie 2004a).

Habitat conditions over their entire range impact the viability of boreal caribou populations. The major threat to boreal caribou is increased predation that appears to be related to habitat changes that increase the number and distribution of alternative prey species and their associated predators in caribou habitat. Consequently, although special management practices may be required to protect seasonal foraging habitats, calving habitats, and migration connectivity, it is also important to manage the surrounding habitats to reduce the risk of predation, even if the caribou rarely or never “use” those habitats. Caribou do not respond to the landscape at human-centred scales; their “use” of habitats appears to extend for kilometres (Mayor et al. 2007), well beyond the bounds of conventional human perceptions. The importance of managing the matrix habitat surrounding the core habitat to reduce predation risk is recognized for the mountain ecotype of boreal caribou, which face similar issues of increased predation risk where the number and distribution of early seral ungulates has changed following habitat change (Government of British Columbia 2005).

The purpose of this report is to summarize boreal caribou habitat use from studies published in primary literature as well as government and non-government reports.

The description of habitat use is organized by Ecozone (Figure 1), the most generalized classification of the Canadian ecological unit hierarchy framework (ESWG 1995). The largest Ecozone, the Boreal Shield, is further divided into five forest regions adapted from Rowe (1972). Habitat use is reported for populations existing outside of the boreal caribou range (e.g. southern mountain or Newfoundland) if the results were thought to be informative for defining boreal caribou Critical Habitat. For each Ecozone, broad-scale caribou habitat is described, followed by, finer scale habitat for each season (calving, post calving, rutting, winter [early and late]) as well as for the travel period between seasons.

Consistent common names of plant species and habitat type were used where possible. In some cases, variations in common names occurred among Ecozones (e.g. bog, string bog, basin bog, peatland complex, treed muskeg, treed wetland, etc.).



Appendix 6.3 - Figure1. Boreal caribou distribution within nine Ecozones in Canada.

TAIGA SHIELD ECOZONE

Coppermine River Upland, Tazin Lake Upland, Selwyn Lake Upland, La Grande Hills, Southern Ungava Peninsula, New Quebec Central Plateau, Ungava Bay Basin, Kingarutuk-Fraser River, Smallwood Reservoir-Michikamau, Coastal Barrens, Winokapau Lake North, Goose River West, Mecatina River, Eagle Plateau, Harp Lake, Nipishish Lake (68, 69, 71, 72, 73, 74, 75, 77 (81), 78, 79, 80 (83, 86), 82, 84, 85)

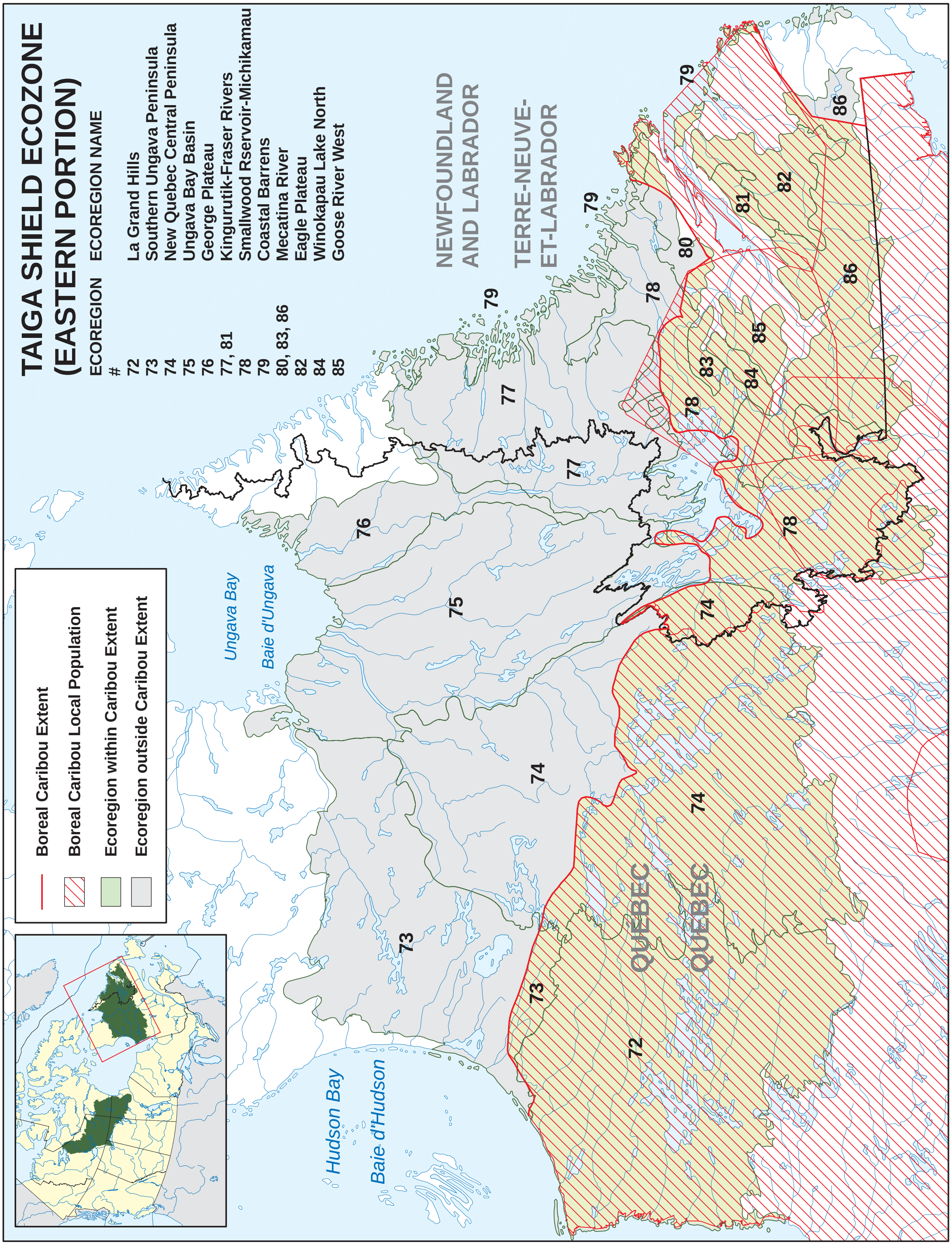
The Taiga Shield Ecozone occurs east of Hudson Bay, in northern Quebec and southern Labrador (Figure 2) and is comprised of the Taiga Forest and the Canadian Shield on broadly rolling terrain (ESWG 1995). The landscape is dominated by bedrock erratics, eskers, and hummocky and ridged morainal deposits. Many lakes, peatlands, and open forests with intervening shrublands and meadows exist in this Ecozone. Black spruce (*Picea mariana*) is the dominant tree species in the Ecozone, although open mixedwood stands of white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), and white birch (*Betula papyrifera*) dominate the southern portion of the Ecozone and open arctic tundra dominates the northern portion of the Ecozone. Open black spruce and jack pine (*Pinus banksiana*) forests dominate the centre of the Ecozone, and lichen (*Cladonia* and *Cladina*) are the primary understory species. Lichen woodlands generally occur in nutrient poor sandy soils of glacial deposits. Upland areas are well drained and prone to fire. White birch and tamarack (*Larix laricina*) are considered the dominant pioneer species post fire, and are eventually replaced by black spruce. Throughout the southern and central portion of the Ecozone, higher elevations are dominated by open arctic tundra and low shrubs. Precipitation ranges from 500 mm to over 1,000 mm per year. Mean annual area burned by forest fire is 0.14% (NRCAN 2002).

Local Caribou Populations

Six local boreal caribou populations occurring within the Taiga Shield are described in the literature. The extent of occurrence of some of these local populations overlaps with the Boreal Shield Ecozone. The following local populations are listed in the habitat use literature: *QC: Magpie, Caniapiscau, and Lac Bienville. Labrador: Lac Joseph, McPhadyen River, Red Wine Mountains, Mealy Mountains. The McPhadyen River population was associated with the Lac Joseph population but no longer exists. The Red Wine Mountains population was associated with two local populations that no longer occur: Dominion Lake and St. Augustin. Lac Joseph and Magpie are the same population, sharing a border between Quebec and Labrador*

Broad-Scale Caribou Habitat

Caribou habitat in the Taiga Shield is described as upland tundra consisting of rounded, barren hills dominated by ericaceous shrubs (*Ericaceae spp*.), lichens, grasses (graminoids) and sedges and lowlands consisting of numerous peat bogs (muskegs and string bogs), lakes,



Appendix 6.3 - Figure 2. Boreal caribou distribution within the Taiga Shield Ecozone.

rivers, and riparian valleys. Forest-wetland habitat and closed conifer forests are extensive (Brown et al. 1986). Courtois et al. (2004) described caribou habitat as dense mature conifer and open conifer with abundant lichens. Coastal areas and off-shore islands are available to caribou in the eastern portion of the Taiga Shield (Schmelzer 2004).

Seasonal Habitat and Forage

Calving Habitat

Bergerud (1963, in Schmelzer et al. 2004) described traditional calving areas as string bogs and large muskegs. The use of peninsulas or islands varies by the amount of open water in the range. Females tend to calve on islands more frequently in the Caniapiscau and Lac Bienville populations, where there is more open water.

Fidelity to calving sites seems to vary among individual caribou; some caribou return to the same site in consecutive years, some have calving locations separated by several hundred kilometres in subsequent years, and many return to a general area within their range. General calving site fidelity was recorded by Brown et al. (1986; ~87% of 103 radio-collared caribou in three populations selected a calving site within 10 km of the previous year's calving site and 33% calved within 3 km of previous year's site) and Hearn and Luttich (1987; within 15 km of the previous year's calving site, in Schmelzer et al. 2004).

Some females traveled several hundred kilometres to these general calving areas. Brown et al. (1986) recorded female caribou in the Caniapiscau population traveling between 200 and 500 km to their calving areas each year. Calving areas represent a small portion of the range; Brown and Theberge (1985) reported that cumulative area of all calving locations represented less than 3% of the available range.

Caribou disperse widely across the range during calving period and densities were estimated at below 0.03 caribou per km^2 (Brown et al. 1986). Calving sites selected by caribou from the Red Wine Mountains population were located in treed bogs (Brown and Theberge 1985) or small open wetlands (<1 km^2) and typically one female per wetland was observed (Brown et al. 1986). Many calving sites were located in islands or peninsulas (Brown et al. 1986).

Post-Calving Habitat

Caribou were relatively sedentary throughout the summer and remained in forested wetland (Brown et al. 1986). Fidelity by adult females can be most pronounced at this time of year. Females in the Red Wine Mountains herd returned, on average, to within 6.7 km of the previous year's site (Schaefer et al. 2000).

Rutting Habitat

Caribou moved greater distances during the rutting season and formed larger rutting groups. Caribou were observed in open wetlands during the rutting season (Brown et al. 1986).

Winter Habitat

Bergerud (1994, cited in Schmelzer et al. 2004) described winter range as uplands and sand flats in proximity to rivers. During winter, Lac Joseph caribou used forested wetland more than upland tundra (Brown et al. 1986; Saint-Martin and Theberge 1986, in Schmelzer et al. 2004). The extreme snow depths in the Taiga Ecozone limit the ability of caribou to access terrestrial lichen. Brown and Theberge (1990) found that cratering activity in the Red Wine Mountains population did not occur in snow depths above 125 cm and ram-hardness values of approximately 500 kg. During deep snow conditions, caribou seek bedrock erratics, where snow sheds easily (I. Schmelzer pers. comm.). Caribou form small groups and selected lakes for loafing and rumination in winter, where a clear view of predators is maintained (I. Schmelzer pers. comm.). In snow conditions below the threshold, caribou formed groups and cooperatively dug craters to access food (Brown and Theberge 1990). During winter, caribou in the Red Wine Mountains of Labrador selected bog edges as well as glacial erratics, where terrestrial lichens were abundant (Brown and Theberge 1990). In the 1980s, some of the Red Wine Mountains population wintered in mature white spruce and fir stands that provided an important alternate food source in the form of arboreal lichens (Brown 1986). Folinsbee (1975, 1978; reported in Schmelzer 2004) found used areas in winter had significantly lower snow depths than non-used areas, and snow under forest canopy was softer and shallower than snow outside of forests. In deep snow years, Mealy Mountains caribou formed groups and traveled to the alpine, windswept Mealy Mountains or in bogs along lake or ocean shore (Bergerud 1967, Hearn and Luttich 1987). During winters with low snowfall, caribou did not congregate in groups and used heavily forested areas (Bergerud 1967).

Late Winter Habitat

Caribou whose range includes mountainous habitat moved to the tundra habitat of the mountains in late winter, possibly to avoid deep snow conditions at lower elevations (Brown et al. 1986, Brown and Theberge 1990). Movements from the forest wetland habitat to upland tundra ranged from 16 – 86 km.

Travel Season Habitat

Prior to calving, caribou dispersed widely from late winter aggregations and the greatest movements of radio-collared females between successive relocations occurred during the travel season prior to calving (Brown et al. 1986). The greatest daily movement rates occurred prior to calving (up to 38 km) and during fall after the rutting season (up to 51 km, I. Schmelzer pers. comm.).

HUDSON PLAINS ECOZONE

Hudson Bay Lowland, James Bay Lowland (216, 217)

The Hudson Plains Ecozone encompasses portions of northern Ontario, western Québec and northeastern Manitoba (Figure 3) and is a low elevation plain referred to as the James Bay Lowlands. The region is a transition zone between coniferous forests to the south and tundra to the north. Poorly drained areas supporting bogs and fens are extensive and interspersed with black spruce covered ridges or tamarack stands. Sedges, mosses and lichens dominate the ground cover. Mean annual precipitation ranges from 400 mm in the northwest to 800 mm in the southeast (ESWG 1995). Mean annual area burned by forest fire is 0.09% (NRCAN 2002).

Local Caribou Populations

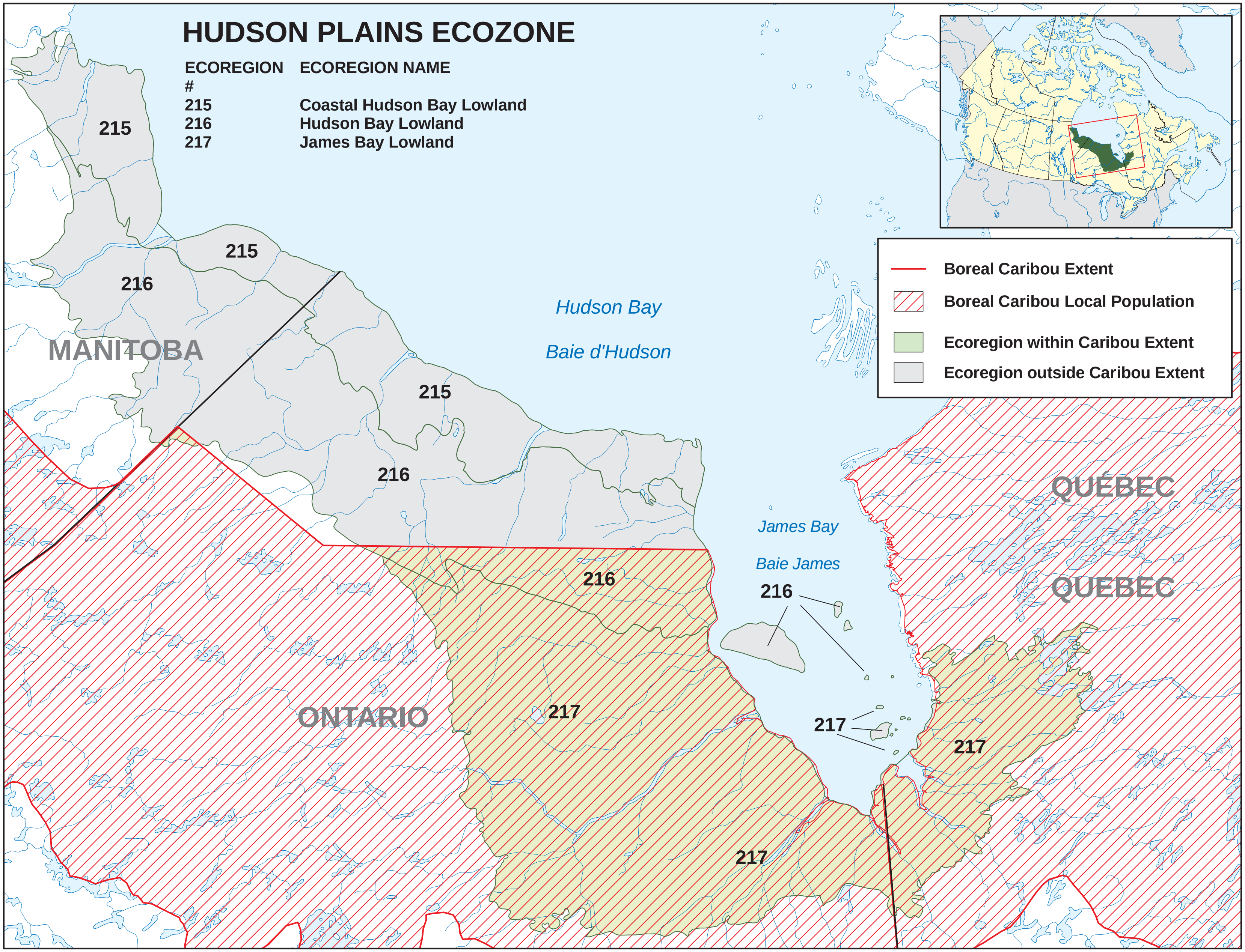
Three local boreal caribou populations occurring within the Hudson Plains Ecozone are described in the literature in addition to the continuous distribution of boreal caribou throughout the Ecozone. The extent of occurrence of some of these local populations overlaps with the Boreal Shield Ecozone. The following local populations are listed in the habitat use literature: *La Sarre, Rupert, and Michipicoton.*

Broad Scale Caribou Habitat

The most suitable caribou habitat in this region includes all ages of shrub-rich treed muskeg and mature conifer (Brown 2005). Magoun et al. (2005) described caribou habitat as poorly-drained landscapes dominated by sedges, mosses and lichens with scattered, open stands of black spruce and tamarack. The home ranges of caribou in this region were larger than those reported in the literature for other regions of Canada (Brown et al. 2003).

Seasonal Habitat and Forage

Caribou in the Hudson Bay lowlands avoided tamarack fens year round (Magoun et al. 2005). Courtois (2003) determined that at the home range scale, caribou preferred habitats susceptible to reduce predation risk by selecting mature conifers, water bodies, areas with lichens and wetlands and avoiding perturbed habitats. Forest fragmentation, however, constrained the pattern of habitat selection by caribou. Individuals living in highly fragmented landscapes did not select against perturbed habitats, presumably because they could not find enough suitable habitats in such landscapes or because they gave priority to dispersion as an anti-predator strategy. Core activity areas for winter and summer occurred did not overlap in this region and (Brown et al. 2003).



Appendix 6.3 - Figure 3. Boreal caribou distribution within the Hudson Plains Ecozone.

Calving Habitat

During calving, caribou preferred mature conifer stands without lichens, conifer stands with lichens and wetlands (Courtois 2003). Caribou were found more frequently at higher altitudes during calving than during other periods.

Post-calving

In the northeastern recovery zone of Ontario, caribou were associated with fens, bogs, and lakes during summer (Pearce and Eccles 2004).

Rutting Habitat

During the rut, caribou preferred conifer stands with lichens and wetlands, followed by mature conifer and conifer in regeneration (Courtois 2003).

Winter Habitat

In winter, caribou preferred dense conifer (Pearce and Eccles 2004), wetlands and mature conifer with lichens (Courtois 2003). Caribou selected areas where terrestrial lichens were abundant on ombrotrophic peat deposits (Brokx 1965). Lichen woodlands and lichen heaths were avoided. Most caribou wintered in raised bogs, especially in peatland complexes with abundant patches of bog (Brokx 1965).

Late Winter Habitat

In late winter, caribou used large patches of intermediate aged and mature black spruce, shrub rich treed muskeg, and mixed conifer and avoided forests with abundant deciduous species (Brown et al. 2007). In late winter, caribou selected areas with abundant mature black spruce and where contiguous patches of preferred habitat were larger. Caribou avoided forests with an abundance of deciduous trees (Brown et al. 2007).

Travel Season Habitat

In the James Bay Lowlands, home range size of caribou was positively correlated with moose (*Alces alces*) density during periods of long-range movements, and negatively correlated with moose density during sedentary periods, suggesting avoidance of moose to reduce risk of predation during most of the year (Brown 2005). Movements were greater during fall and late winter when caribou were travelling to and from summer and early winter ranges (Brown et al. 2003).

BOREAL SHIELD ECOZONE

The Boreal Shield Ecozone is vast, extending from northern Saskatchewan to Newfoundland, north of Lake Winnipeg, the Great Lakes, and the St. Lawrence River (ESWG 1995; Figure 4). The landscape is rolling, with abundant uplands and wetlands. Peatlands dominate the wetlands throughout central Manitoba, northwestern Ontario, and Labrador. Small to medium-sized lakes occur throughout the Ecozone. The dominant vegetation is coniferous trees in the northern reaches of the Ecozone, with greater abundance of mixed conifer and deciduous trees in the southern extent. Exposed bedrock outcrops and their associated lichen dominate the landscape. Shrubs and forbs occur and dominate non-forested areas. Mean annual precipitation ranges from 400 mm to 1600 mm (ESWG 1995). Mean annual area burned by forest fire is 0.36% (NRCAN 2002).

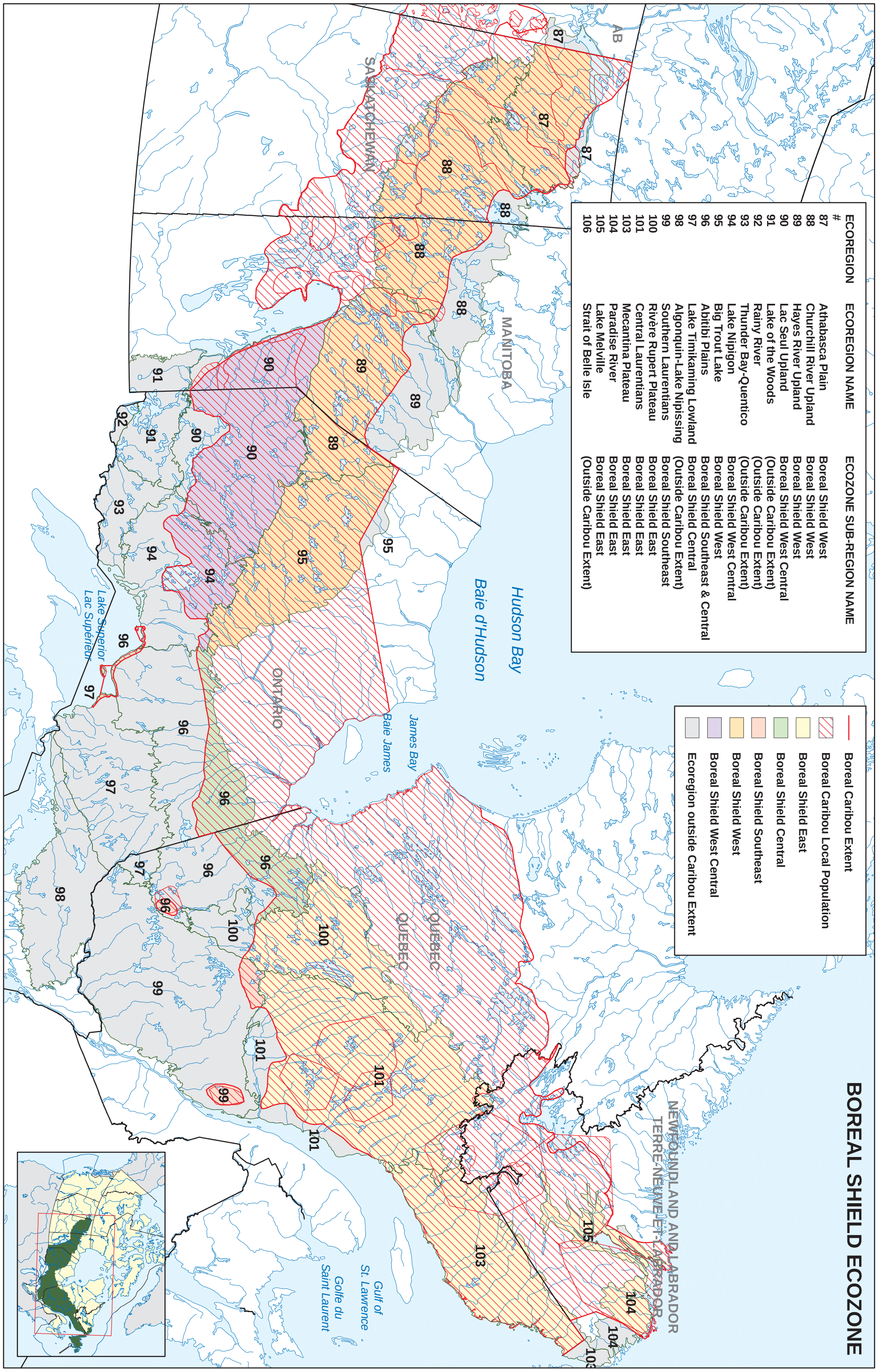
Due to the vastness of the Boreal Shield and the variation in climate, topography and types of vegetation, the habitat descriptions for boreal caribou in this Ecozone have been delineated to 5 sub regions:

1) **Boreal Shield East (Labrador/NE Québec): Rivere Rupert Plateau, Central Laurentians, Mecantina Plateau, Paradise River, Lake Melville Ecoregions (100, 101, 103, 104, 105)**
2) **Boreal Shield Southeast (Southern Québec): Abitibi Plains, Southern Laurentians Ecoregions (96, 99)**
3) **Boreal Shield Central (Western Québec, NE Ontario): Abitibi Plains, Lake Timiskaming Lowlands Ecoregions (96, 97)**
4) **Boreal Shield West Central (Lake Superior): Lac Seul Uplands, Lake Nipigon Ecoregions (90, 94)**
5) **Boreal Shield West (NW Ontario, Manitoba, Saskatchewan): Athabaska Plain, Churchill River Upland, Hayes River Upland, Big Trout Lake Ecoregions (87, 88, 89, 95)**

BOREAL SHIELD EAST

Rivere Rupert Plateau, Central Laurentians, Mecantina Plateau, Paradise River, Lake Melville Ecoregions (100, 101, 103, 104, 105)

This region extends from west-central Québec east to the northeastern extent of Québec (Figure 4). Closed stands of black spruce and balsam fir dominate the western extent of this sub region (ESWG 1995). Open stands of white spruce with lichen and white birch exist in well-drained sites. Closed stands of black spruce and balsam fir dominate the low lands, while open stand of black spruce and white spruce, with their associated lichens and feather moss dominate the well drained sites. White birch and trembling aspen also occur in well drained sites. Eastern white cedar (*Thuja occidentalis*) and black spruce dominate the wetland areas. Closed, dense stands of black and white spruce and balsam fir dominate the moist sites along riparian habitat. Bedrock outcrops are dominated by lichen. Bogs dominate



Appendix 6.3 - Figure 4. Boreal caribou distribution within the Boreal Shield Ecozone.

the lowlands and lower valleys and raised dome bogs occur in the eastern portion of the sub region. Krummholtz vegetation occurs on exposed hilltops. Mean annual precipitation ranges from 650 – 100 mm (ESWG 1995). Mean annual area burned by forest fire is 0.24% (NRCAN 2002).

Local Caribou Populations

The following local population names or local regions occur in the habitat use literature for this region: *Lac Joseph/Magpie, Petite Lac Manicouagan (Manic), and Manouane-Manicouagan (Manou); Pipmuacan (Pipmu).*

Broad Scale Caribou Habitat

Boreal caribou habitat in the northern part of their range in Québec includes continuous conifer-feather moss forests on poorly-drained sites and conifer uplands with nearly continuous terrestrial lichen ground cover (*Cladina spp., Cladonia spp.* and *Cetraria spp.*; Arseneault et al. 1997). Caribou preferred mature conifer with lichens, water bodies, and wetlands and avoided disturbed habitats (Courtois 2003).

Seasonal Habitat and Forage

Year Round Habitat

Caribou in the southern extent of this region avoided burns and clear-cuts, deciduous and mixed forests, and heath without lichens throughout the year (Courtois et al. 2007) as well as jack pine stands younger than 40 years (Crête et al. 2004). .

Calving Habitat

Caribou from four populations in the Boreal Shield East selected open wetlands, peninsulas and islands for calving habitat (Brown et al. 1986). During spring, caribou in Newfoundland selected sedges, ericaceous species, bryophytes, alder (*Alnus spp*.) and larch (Bergerud 1972). In the western extent of the region, caribou selected balsam fir, dense black spruce stands, mixed spruce-fir forests older than 40 years, and dry bare land that supported high densities of lichens (Crête et al. 2004). During the calving season, caribou avoided recent burns or harvested stands, pine stands less than 40 years-old, and jack pine stands. In the southern extent of the region, cows preferred mature conifer stands with and without lichens, and wetlands during calving season (Courtois 2003). Caribou cows did not use islands or water bodies for calving, but were found at higher altitudes than during other periods.

Post-calving Habitat

During summer, caribou selected open and forested wetlands in northeastern Québec and continued to use islands and peninsulas (Brown et al. 1986). In Newfoundland, caribou selected aquatic plants, dwarf birch (Betula glandulosa), deciduous shrubs, ericaceous species, and moss (Bergerud 1972).

Rutting Habitat

In the Boreal Shield East, caribou moved greater distances during the rutting season and formed larger rutting groups. Caribou were observed in open wetlands during the rutting season (Brown et al. 1986). In Newfoundland, caribou selected terrestrial and arboreal lichens, forbs, sedges, mosses, and coniferous and deciduous shrubs during fall (Bergerud 1972). In the southerly portion of the region, Rutting included balsam fir stands, dense spruce, spruce-fir forest older than 40 years, and dry bare land (Crête et al. 2004). Stands with abundant lichens and wetlands were preferred, followed by mature conifer and young seral stage conifer (Courtois 2003).

Winter Habitat

Caribou in this region avoided arboreal lichens, possibly because the lichen available was non-pendulous (Brown and Theberge 1990). Caribou from other Labrador/Northern Québec populations selected forested wetlands during winter (Brown et al. 1986). Some caribou used upland-tundra for loafing, but returned to lichen woodlands for feeding (Brown et al. 1986). In the southern extent of the region, caribou selected balsam fir stands, dense spruce stands, mixed spruce-fir older than 40 years, dry bare land (Crête et al. 2004), mature conifer, and wetlands. (Courtois 2003).

BOREAL SHIELD SOUTHEAST

Abitibi Plains, Southern Laurentians Ecoregions (96, 99)

This region encompasses two isolated boreal caribou populations, in southwestern Québec, and in the Laurentians of south-central Québec (Figure 4). The region is characterized by mixed forest of white spruce, balsam fir, white birch and trembling aspen (ESWG 1995). In dry sites, jack pine forests or mixed forests of jack pine, white birch, and trembling aspen occur and on wet sites, black spruce and balsam fir or tamarack stands occur. Forest understory is typically moss or lichen. Basin bogs are abundant in the northern portion of the sub region, and rock outcroppings occur more frequently in the southern extent. The eastern extent of the region is more undulating. Annual precipitation ranges from 725 mm to 1000 mm (ESWG 1995). Mean annual area burned by forest fire is 0.06% (NRCAN 2002).

Local Caribou Populations

This subregion contains only two isolated boreal caribou populations: *Charlevoix and Val-d'Or.*

Broad Scale Caribou Habitat

Boreal caribou habitat in this region includes late seral-stage black spruce-dominated lowlands and jack pine-dominated uplands (Duchesne et al. 2000). Within the range of the Charlevoix population, south of the continuous boreal caribou distribution, open black spruce forests with dwarf birch and *Ericaceae spp*. dominate (Duchesne et al. 2000). An extensive lichen community, the basis of the population's winter diet, includes *Cladina spp*., *Cladonia spp.* and *Cetraria spp*. (Duchesne et al. 2000).

Seasonal Habitat and Forage

Calving Habitat

During spring, caribou selected open, medium-closed conifer forests (Lefort et al. 2006)

Pre Rutting and Rutting Habitat

During the pre-rutting period, caribou selected open and dense mature conifer forests, including spruce, tamarack, jack pine, as well as younger coniferous forests aged 30 – 50 years (Lefort et al. 2006). During the rutting and post-rutting period, caribou selected open mature and young coniferous forests.

Winter Habitat

In early winter through late winter, caribou from the Charlevoix population selected open stands older than 70 years of the following species: balsam fir, balsam fir-black spruce, black spruce, black-spruce-tamarack, and jack pine (Lefort et al. 2006). Caribou also selected dry bare land and stands of balsam fir or fir-black spruce 30 – 50 years, young jack pine 50 years, and dense stands of 70 years (Lefort et al. 2006). Sebbane et al. (2002) reported Charlevoix caribou selected mature conifer and arboreal and terrestrial lichens during winter.

BOREAL SHIELD CENTRAL

Abitibi Plains, Lake Timiskaming Lowlands Ecoregions (96, 97)

This region encompasses the contiguous boreal caribou population in the Claybelt region of northeastern Ontario and western Québec as well as the isolated populations along the north shore of Lake Superior (Figure 4). The landscape is dominated by mixed forest of white spruce, balsam fir, white birch and trembling aspen (ESWG 1995). On drier sites, pure stands of jack pine or mixed stands of jack pine, white birch, and trembling aspen occur. Wetter sites are characterized by black spruce, balsam fir, eastern white cedar, and tamarack. In proximity to Lake Superior, eastern white pine (*Pinus strobus*), red pine (*Pinus resinosa*), yellow birch (*Betula alleghaniensis*), sugar maple *(Acer saccharum*), and red maple (*Acer rubrum*)also occur. Moss and lichen form the understory throughout the region. Bedrock outcroppings supporting lichens are predominant in the southern extent of the region and basin bogs are predominant in the northern extent. Mean annual precipitation ranges from 725 mm to 1000 mm (ESWG 1995). Mean annual area burned by forest fire is 0.04% (NRCAN 2002).

Local Caribou Populations

The following local populations are described in the literature for this region: *Pukaskwa, Slate Islands, and Pen Islands*. The region also includes local populations *Rupert and La Sarre* in the Claybelt region of Québec and un-named populations in the Claybelt region of Ontario.

Broad Scale Caribou Habitat

Boreal caribou habitat in this region includes late seral-stage black spruce-dominated lowlands and jack pine-dominated uplands (Arseneault et al. 1997, Courtois et al. 2003, Lantin et al. 2003). Near the Québec/Ontario border, boreal caribou habitat is similar to that in neighbouring Ontario, mainly consisting of open black spruce lowlands (Lantin et al. 2003). Boreal caribou habitat in Ontario is primarily composed of low-density late seral-stage jack pine or black spruce forest, and black spruce/tamarack-dominated peatlands with abundant terrestrial and moderate arboreal lichens (Bergerud 1985, Cumming et al. 1996, Antoniak and Cumming 1998, Cumming and Hyer 1998, Webb 1998, Proceviat et al. 2003, Brown 2005, Carr et al. 2007, Vors 2006, Wilson 2000). Caribou used areas with dry to moist sandy to loamy soils and shallow soils over bedrock (Wilson 2000).

Seasonal Habitat and Forage

Year Round Habitat

Caribou in the Slate Islands population forage on arboreal lichens and appeared to be at or near their carrying capacity (Cringan 1957, Bergerud 1996).

Calving Habitat

Caribou in the Claybelt region that spans Québec and Ontario selected open canopies of mature black spruce and mesic peatland with ericaceous species for calving habitat and avoided recently downed woody debris, dense shrubs, and larch (Lantin et al. 2003). Ericaceous shrubs and terrestrial lichens were more abundant in calving areas where females were observed with a calf during summer than in areas where females were seen alone (Lantin et al. 2003). The amount of vegetation cover, which would provide seclusion from predators, was similar between calving areas with or without calves.

Winter Habitat

In late winter, the probability of caribou occurrence was greater where mature black spruce was abundant and contiguous patches of preferred habitat were larger. Caribou avoided mixed conifer and deciduous forest (Brown et al. 2007). Caribou in Pukaskwa National Park used open conifer with lichens along shorelines and avoided areas with deep snow conditions (Bergerud 1985). Caribou in northeastern Ontario used areas with lower relative stand densities, relatively abundant terrestrial and arboreal lichens and significantly less snow than non-used areas (Wilson 2000).

BOREAL SHIELD WEST CENTRAL

Lac Seul Upland, Lake Nipigon Ecoregions (90, 94)

This region extends from the east side of Lake Winnipeg, Manitoba to northeast of Lake Nipigon, Ontario (Figure 4). Closed stands of black spruce, along with some jack pine, white spruce, balsam fir, white birch, and trembling aspen with ericaceous shrubs, mosses, and lichens are typical of this region (ESWG 1995). In the southern extent of the region, trembling aspen, white birch, white spruce, and balsam fir are common. Many areas of exposed bedrock that support few trees and abundant lichen occur throughout the region. Lowlands include peat bogs with open or closed black spruce and sphagnum moss (*Sphagnum spp*.). Drier sites are typified by open stands of jack pine, trembling aspen and white birch, with some black and white spruce. Many lakes and wetlands occur throughout the region. Mean annual precipitation ranges from 450 – 800 mm (ESWG 1995). Mean annual area burned by forest fire is 0.38% (NRCAN 2002).

Local Populations

Local populations listed in the literature include *Owl Lake, Aikaki Berens, the former Aikens Lake population, Lake Nipigon*, and part of the contiguous population of northwestern Ontario.

Broad Scale Caribou Habitat

Caribou habitat in northwestern Ontario, from the Ontario-Manitoba border to Lake Nipigon, consists of mature conifer uplands and conifer/tamarack-dominated lowlands (Bergerud et al. 1990, Cumming and Beange 1987, Ferguson and Elkie 2004a, 2004b, Carr et al. 2007, Vors 2006). Boreal caribou habitat in the Owl Lake and Aikens Lake ranges, Manitoba is characterized by conifer/tamarack-dominated peatlands with abundant arboreal lichens, uplands dominated by mature conifers with dense cover of ground lichens, and sparsely treed rock (Darby and Pruitt 1984, Schaefer 1988, Metsaranta et al. 2003, O’Brien et al. 2006).

Seasonal Habitat and Forage

Year Round Habitat

Caribou in northwestern Ontario used bogs and large tracts of mature forest year round

(Racey and Armstrong 2000). Caribou in the Owl Lake population, Manitoba used treed muskeg, black spruce, and jack pine dominated forests older than 50 years and with a crown closure greater than 50% (Schindler 2005).

Calving Habitat

Boreal caribou calving habitat in northwestern Ontario is described as forested wetlands/ treed bog, old burns, sparse conifer, and dense spruce (Hillis et al. 1998). Caribou used peatlands with forested islands as calving habitat (Armstrong et al. 2000). Boreal caribou in northwestern Ontario frequently used shorelines and islands of large lakes for calving; these areas likely function as spatial refugia from predation (Bergerud et al. 1990, Cumming and Beange 1987, Ferguson and Elkie 2004a, Carr et al. 2007). Although some females showed strong seasonal fidelity to calving areas, others do not (Ferguson and Elkie 2004b). Caribou in Wabakimi and Caribou Provincial Parks used peatland with forested islands for calving habitat (Armstrong et al. 2000). In Northwestern Ontario, caribou selected treed bogs and avoided shrub-rich fens during calving season (Hillis et al. 1998). In the Whitefeather forest, islands on large lakes and raised hillrocks within large muskeg areas were important sites for calving (O'Flaherty et al. 2007).

In the former Aikens Lake range, Manitoba, caribou used mature upland conifer, heavily treed bogs, and jack pine or jack pine/black spruce forests as calving habitat (Darby and Pruitt 1984). Caribou also selected islands, lakeshores and heavily treed bogs for calving habitat (Darby and Pruitt 1984).

Post Calving Habitat

Caribou in northwestern Ontario used peatland with forested islands as well as islands and shorelines during summer (Armstrong et al. 2000). Caribou in northwestern Ontario selected shorelines with closed mature black spruce stands with lower shrub density and abundance of terrestrial lichens for nursery habitat post calving (Carr et al. 2006). Caribou in the Lake Nipigon area selected islands during summer and avoided tamarack fens (Cumming and Beange 1998). Caribou in the northwest recovery zone, Ontario used mature, dense forest stands and islands during summer (Pearce and Eccles 2004). Caribou in the former Aikens Lake, Manitoba population used mature coniferous uplands more often than other habitat types during summer (Darby and Pruitt 1984).

Rutting Habitat

Caribou in the Aikens Lake, Manitoba population selected semi-open and open bogs and mature conifer uplands during rutting season (Darby and Pruitt 1984). Their diet consisted of terrestrial and arboreal lichens, sedges, and bog ericoids (*Andromeda glaucophylla, Chamaedaphne calyculata, Kalmia polifolia, Ledum groenlandicum*).

Early Winter Habitat

Caribou in the Owl Lake region, Manitoba, selected mature jack pine stands and avoided early successional stands and mixed softwood stands (Martinez 1998).

Winter Habitat

In north-western Ontario, caribou selected mature, sparsely-stocked coniferous stands (Armstrong et al. 2000). Caribou selected areas with a greater proportion of lakes 5 – 100 ha and with greater perimeter and fractal dimension than the relative distribution of available lakes, presumably to reduce detection by predators and increase the probability of escape (Ferguson and Elkie 2005). Caribou foraged in areas with significantly more lichen (mean 39% lichen ground cover) and fewer shrubs in jack pine and black spruce stands with low tree densities (mean 1552 trees/ha)), low basal areas (mean 14.1 m^2/ha), and short heights (12 m or less; Antoniak and Cumming 1998). Caribou in the northwestern recovery zone, Ontario, selected mature dense conifer stands, sparse upland conifer with available terrestrial lichens (Pearce and Eccles 2004). Caribou and moose in northwestern Ontario showed habitat partitioning during winter, but moose and wolves (*Canis lupus*) did not. Habitat partitioning provided spatial refugia for caribou from wolves, presumably reducing risk of predation (Cumming et al. 1996). In the Whitefeather forest, caribou were associated with mature conifer stands with abundant terrestrial lichens (*Cladina spp*. but especially *C. ragiferina*) and black spruce stands on poorly drained lowlands with abundant arboreal lichens (*Bryoria spp*.; O'Flaherty et al. 2007). In the Lake Nipigon area, caribou selected habitat with sandy soil, islands, and black spruce, spruce-larch, and jack pine-spruce forests (Cumming and Beange 1998). Caribou were displaced from winter habitat during an experimental log hauling operation (Cumming and Hyer 1998). Collared adult caribou moved 8-60 km away after logging activities began, and the authors suggested that chronic exposure to disturbance may cause caribou to abandon traditional wintering areas, even if the habitat itself is not disturbed by forest harvest or roads. Across northern Ontario, lichen species identified as winter forage for boreal caribou include *Cladina spp., Cladonia spp.*, and *Usnea spp*. (Antoniak and Cumming 1998, Cumming and Hyer 1998).

Caribou in the former Aikens Lake, Manitoba population selected bogs more often during winter, coincident with a change in diet (Darby and Pruitt 1984). Caribou made heavy use of bogs in the winter, and feeding sites were typically in open bogs and jack pine habitat with easy access to lichens (Schaefer 1988). Mixed conifers and areas with windfallen trees were avoided (Schaefer and Pruitt 1991). Caribou selected glacial erratics, arboreal lichens, terrestrial lichens, sedges, and ericaceous species. Caribou continued to use areas immediately post fire, but use dropped off gradually (Schaefer and Pruitt 1991). Caribou used frozen lakes for travel, escape habitat and craters for drinking overflow water (Darby and Pruitt 1984). Caribou in southeastern Manitoba selected open tamarack or black spruce bogs, intermediate to mature jack pine rock ridges, and lakes during winter (Stardom 1975). Caribou avoided vesicular ice, snow depths greater than 65 cm and snow crusts with hardness greater than 400g/cm^2 throughout the winter (Stardom 1975). Caribou in the

Owl Lake population used habitat within 1 km of a winter haul road less than expected and crossed the road less than expected (Schindler et al. 2007).

Late Winter Habitat

In mid-February, when snow hardness and depth restricted foraging in bogs, caribou in the Aikens Lake, Manitoba population moved to jack pine-rock ridges in mature coniferous stands, where they fed on *Cladonia sp. and Vaccinium myrtilloides* (Darby and Pruitt 1984). Caribou used lakes for loafing in late winter. Caribou in the Owl Lake, Manitoba population used jack pine-dominated stands, sparsely-treed rock and mature conifer-dominated uplands more often than young seral-stage conifer, mixed softwood and all hardwood stands (Martinez 1998; O'Brien et al. 2006). In March, caribou in southeastern Manitoba selected habitat along lake edges and on south or southeast facing slopes of rocky lakeshores (Stardom 1975).

Travel Season Habitat

During migration to and from wintering areas in northwestern Ontario, caribou were more likely to avoid open water, disturbed and open areas, while utilizing mainly coniferous forests (Ferguson and Elkie 2004a). In early spring, before the break-up of ice, caribou in the Lake Nipigon area migrated to 31 islands in Lake Nipigon (Bergerud et al. 1990, Cumming and Beange 1987). Spring movements were not confined to specific travel routes (Cumming and Beange 1987). Large lakes were also used during early spring by caribou in the Whitefeather forest while migrating from winter feeding grounds to calving areas (O'Flaherty et al. 2007). Caribou in the Atikaki-Berens population, Manitoba used the same migration trails during fall and spring (V. Crichton pers. comm.).

BOREAL SHIELD WEST

Athabasca Plain, Churchill River Upland, Hayes River Upland, Big Trout Lake, Ecoregions (87, 88, 89, 95)

This region extends from Lake Athabasca in northwestern Saskatchewan, southeast to the northern edge of Lake Winnipeg and east to the Hudson Plains Ecozone (Figure 4). The landscape of this region is dominated by jack pine and black spruce forests with ericaceous shrubs, mosses, and lichens (ESWG 1995). White birch, white spruce, balsam fir and trembling aspen occur in south-facing slopes. Lichen covered bedrock outcroppings are common. Black spruce and sphagnum moss occur in abundant peatlands and wetlands are extensive in the western portion of the region. Many lakes occur throughout the region. Mean annual precipitation is lower in the western portion (350 – 600 mm) than in the eastern portion of the region (550 – 775 mm; ESWG 1995). Mean annual area burned by forest fire is 1.00% (NRCAN 2002).

Local Caribou Populations

Twelve local boreal caribou populations occurring within the Boreal Shield West region are described in the literature. The extent of occurrence of some of these local populations overlaps with the Boreal Plains Ecozone. The following local populations are reported in the habitat use literature: *SK: Davy Athabaska, Highrock-Key, Steephill-Foster, Smoothstone-Wapaweka, Suggi-Amisk, MB: Sisipuk-Kamuchawie, Kississing, Naosap, Reed, Wabowden, Wapisu, Island Lake, and Gunisao-Hudwin Lakes,* and the continuous population in north-western Ontario.

Broad Scale Caribou Habitat

Boreal caribou habitat in this region is characterized by conifer/tamarack-dominated peatland complexes, and upland moderate to dense conifer forests with abundant lichens (Arsenault 2003, O'Brien et al. 2006, Hillis et al. 1998) Caribou in this region use sparsely-treed rock and mature conifer-dominated uplands (O'Brien et al. 2006) and prefer open forest that support lichens (Malasiuk 1999). Caribou generally avoid shrub-rich habitats, disturbed/fragmented areas, and hardwood-dominated stands that may support higher moose and deer (O*docoileus spp.*) populations and, consequently, higher predator populations (Rettie 1998, Arsenault 2003, Hillis et al. 1998).

Seasonal Habitat and Forage

Year Round Habitat

Caribou in the Smoothstone-Wapaweka region of Saskatchewan selected open and treed peatlands, lowland black spruce and upland black spruce/pine stands relative to other habitat types (Rettie 1998). In the Weyakwin Lake area, Saskatchewan, caribou selected jack pine, white spruce stands, upland and lowland black spruce, and open peatland and avoided burned areas (Rettie and Messier 2000). On the Naosap range in Manitoba, caribou were positively associated with arboreal lichen, spruce trees, and large diameter trees, and negatively associated with trembling aspen and higher deadfall density (Metsaranta 2007). Caribou in the Kississing, Naosap, and Reed populations selected mature coniferous stands and avoided disturbance across multiple scales (Lander 2006). Caribou in the Wabowden and Gormley area used large open and treed peatland complexes during winter and summer (Brown et al. 2000).

Calving Habitat

Caribou in the Smoothstone-Wapaweka region of Saskatchewan used peatlands and black spruce-dominated stands for calving and post-calving (Rettie 1998). In the Wabowden area of central Manitoba, caribou selected lowland black spruce, peatland with forested islands and treed muskeg for calving habitat and avoided other conifer species and deciduous cover (Hirai 1998). In the Reed Lake area of Manitoba, caribou used islands during calving

(Shoesmith and Storey 1977). Females with neonate calves were sedentary near shoreline of islands. In Northwestern Ontario, caribou selected treed bogs/ peatlands with forested Islands (Hillis et al. 1998, Armstrong et al. 2000) as well as islands and lakeshores during calving season (Armstrong et al. 2000). Caribou avoided deciduous forest, shrub-rich fens and wetlands during calving season (Hillis et al. 1998).

Post-calving Habitat

On the Naosap range, Manitoba, caribou used wooded lakeshores, upland conifer-spruce and treed muskeg and avoided hardwood forests during summer (Metsaranta and Mallory 2007, Malasiuk 1999). On the Reed Lake range, Manitoba, caribou used islands, lakeshores, and sparsely treed rock during summer (Shoesmith and Storey 1977). Caribou in the Kississing and Naosap and Reed populations selected sites with greater arboreal lichen cover during summer (Lander 2006). In the northwestern recovery zone, Ontario, caribou used islands, large contiguous patches of dense mature conifer forest (Pearce and Eccles 2004). In Northwestern Ontario, caribou used treed bog/peatland with forested islands (Hillis et al. 1998, Armstrong et al. 2000), dense conifer and mixed forest and avoided recent burns, shrub-rich fens, and dense deciduous forest or shrub during summer (Hillis et al. 1998).

Rutting Habitat

In North-western Ontario, caribou used dense conifer, sparse conifer, and mixed forests and avoided recent burns, shrub-rich fens, and dense deciduous forest or shrub during rutting season (Hillis et al. 1998). On the Atikaki-Berens range, Manitoba, rutting caribou used open riparian habitat, and bulls were recorded moving long distances (>100 km) within a short time period during rutting season (V. Crichton, pers. comm.).

Winter Habitat

On the Naosap range, Manitoba, caribou selected mature upland spruce and pine stands and treed muskeg and avoided deciduous forests during winter (Metsaranta and Mallory 2007, Malasiuk 1999). On the Kississing range, Manitoba, caribou used jack pine dominated forests during winter (O'Brien et al. 2006). Caribou in the Kississing, Naosap and Reed populations selected areas with greater visibility and further from forest edge during winter (Lander 2006). In the northwestern recovery zone, Ontario, caribou used large contiguous patches of dense mature conifer forest and sparse upland conifer during winter (Pearce and Eccles 2004). In northwestern Ontario, caribou used sparse coniferous forest (Hillis et al. 1998, Armstrong et al. 2000), dense conifer, mixed forest, treed bogs, and avoided recent burns, shrub-rich fens, and dense deciduous forest or shrub during winter (Hillis et al. 1998). Caribou in the Wabowden and Gormley area exhibited post-rut and pre-calving aggregations, where the majority of caribou congregated in mixed-sex groups in a specific area of their range (Brown et al. 2000).

Travel Seasons

Caribou in the Wabowden and Gormley area used traditional travel routes between summer and winter ranges within large peatland complexes (Brown et al. 200).

BOREAL PLAINS ECOZONE

Slave River Lowland, Clear Hills Upland, Peace Lowland, Mid-boreal uplands, Wabasca Lowlands, Western Alberta Upland, Mid-boreal lowland, Interlake Plain Ecoregions (136, 137, 138, 139 (140, 141, 144, 147, 150, 151, 152, 153, 154) 142, 145, 148, 155)

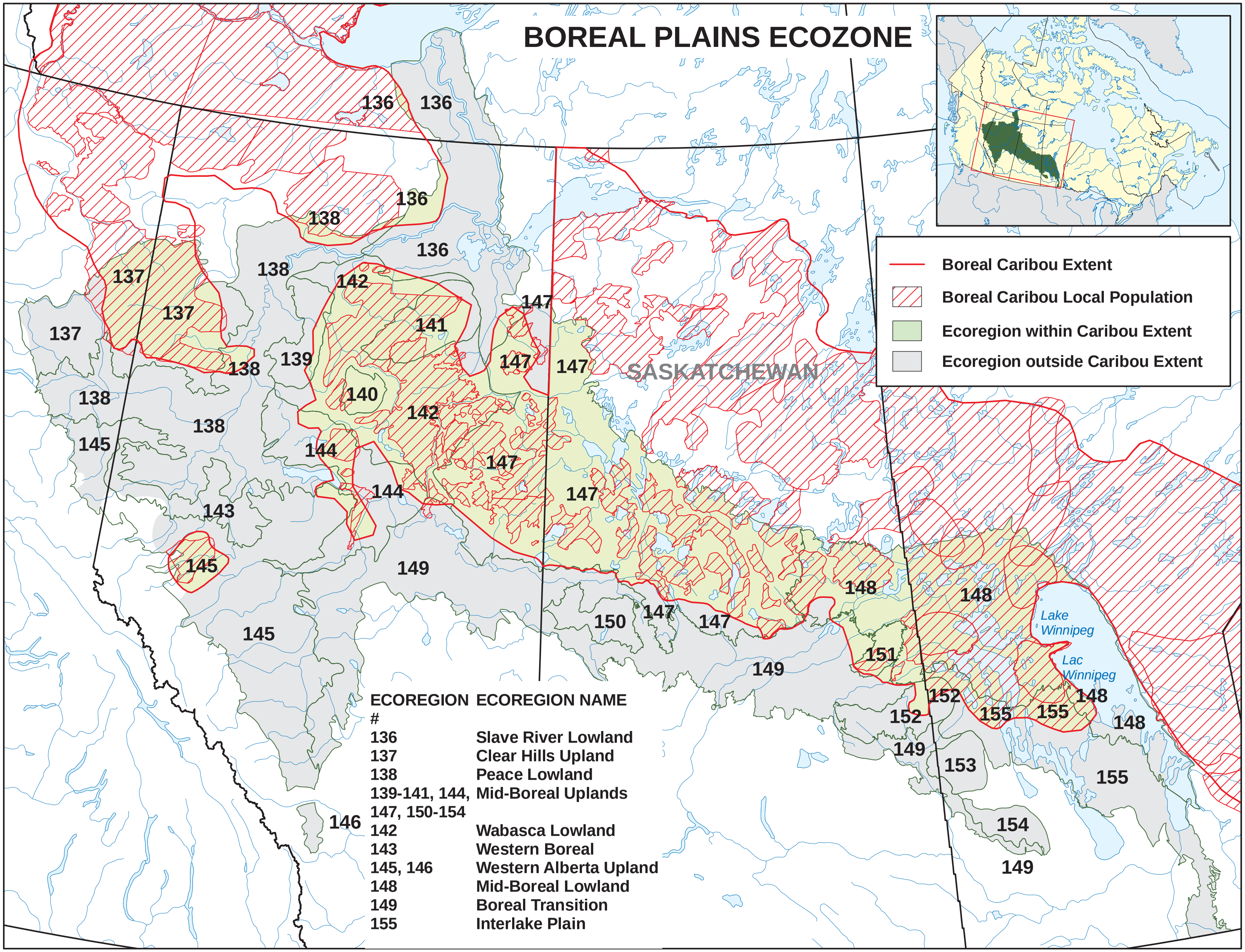
The Boreal Plains Ecozone extends from northeastern British Columbia and southern Northwest Territories to southeastern Manitoba (Figure 5), has few lakes or bedrock outcroppings and is level to gently rolling. Peatlands and wetlands are numerous throughout the Ecozone and white and black spruce, jack pine and tamarack are the dominant conifers (ESWG 1995). Black spruce and tamarack increase in dominance in the northerly sections of the Ecozone and deciduous species including white birch, trembling aspen, and balsam poplar are dominant in the transition zone adjacent to the Prairie Ecozone. Mean annual precipitation ranges from 300 to 625 mm (ESWG 1995). Mean annual area burned by forest fire is 0.44% (NRCAN 2002).

Local Caribou Populations

Twenty local boreal caribou populations occurring within the Boreal Plains are described in the literature. The extent of occurrence of some of these local populations overlaps with the Boreal Shield or Taiga Plains Ecozones. The following local populations are reported in the habitat use literature: *BC: Chinchaga, AB: Chinchaga, Hotchkiss, Deadwood, Little Smoky, Slave Lake, Cold Lake, East Side Athabaska River (ESAR), West Side Athabaska River (WSAR), Red Earth, Richardson, Caribou Mountain, SK: Primrose, Smoothstone-Wapaweka, Pasquia-Porcupine, Suggi-Amisk, MB: The Bog, North Interlake, William Lake, Naosap-Reed, Wabowden*

Broad Scale Caribou Habitat

Boreal caribou in the Boreal Plains of Alberta are associated with late seral-stage (>50 years old) coniferous forest and treed peatlands, and avoid matrix-type habitat such as diverse habitat types and edges (Stuart-Smith et al. 1997, Smith 2004, Neufeld 2006). Black spruce and tamarack are typical of poorly-drained peatland complexes in caribou ranges (Edmonds 1988, James 1999, Smith et al. 2000, McLoughlin et al. 2003, Dalerum et al. 2007) and are the primary source of lichens, including *Cladonia spp., Cladina spp. and Peltigera spp*. that are important caribou forage. Boreal caribou may use peatlands as a refuge from higher predator densities associated with abundant moose and deer populations in deciduous and mixed-wood uplands (Bradshaw 1994, McLoughlin et al. 2005, McCutchen 2007). Woodland caribou in northeastern Alberta are restricted to local populations within peatland complexes (Bradshaw et al. 1995, Stuart-Smith et al. 1997).



Appendix 6.3 - Figure 5. Boreal caribou distribution within the Boreal Plains Ecozone.

Boreal caribou habitat in the Boreal Plains Ecozone of Saskatchewan is characterized by conifer-dominated peatland complexes, and upland conifer forests with abundant lichens (Arsenault 2003). Similar to Alberta, caribou in Saskatchewan generally avoid shrub-rich habitats, disturbed/fragmented areas, and hardwood-dominated stands that may support higher alternate prey populations, and consequently, higher predator populations (Rettie 1998, Arsenault 2003).

Boreal caribou habitat in the Boreal Plains Ecozone of Manitoba is characterized by conifer-dominated peatlands with abundant arboreal lichens, primarily *Alectoria spp., Evernia spp*., *Parmelia spp., Ramalina spp.* and *Usnea spp*., and uplands dominated by late seral stage conifers with dense cover of ground lichens, mainly *Cladonia spp*. and *Cladina spp.* (Darby and Pruitt 1984, Schaefer 1988, Metsaranta et al. 2003, O'Brien et al. 2006).

Seasonal Habitat and Forage

Year Round Habitat

Caribou in northeastern Alberta selected open fens, wooded fens, and wooded bogs year round (Brown et al. 2000). Caribou selected peatlands over uplands and edge habitat (Schneider et al. 2000, McLaughlin et al. 2005). Within peatlands, bogs were selected over fen and bogs were selected if proportion of bog to non-peatland habitat was >30% (Schneider et al. 2000). Non-peatlands were avoided in landscapes where the proportion of non-peatland was >50% and use of non-peatland diminished with distance from peatlands (Schneider et al. 2000). Caribou in the Naosap-Reed population selected mature coniferous stands and avoided disturbance across multiple scales (Lander 2006).

One local population, in the foothills of west-central Alberta, frequently uses dry, upland lodgepole pine (*Pinus contorta*) and mixed pine/black spruce stands (Smith 2004, Neufeld 2006) unlike other boreal caribou populations in Alberta that exhibit a year-round preference for treed peatlands (Stuart-Smith et al. 1997). Increased lichen biomass is associated with open, mature (>80 years old) pine-dominated forests (Szkorupa 2002). Although upland habitat within the ranges of boreal caribou in Alberta is comprised mainly of jack pine and white spruce with high lichen availability (Edmonds 1988, Stuart-Smith et al. 1997, Dyer 1999, James 1999, Smith 2004, McLoughlin et al. 2003, Dalerum et al. 2007), the risk of predation is greater in upland than peatland habitat (McLoughlin et al. 2005).

Recent research in Alberta suggests that landscape disturbance and the ensuing changes in predator-prey interactions affects boreal caribou habitat use. Caribou in northeastern Alberta reduced their use of suitable habitat in close proximity to seismic lines, roads and well sites; caribou avoided roads and well sites by approximately 230 m and 1 km, respectively (Dyer 1999). The rate of caribou crossing roads was less than expected in all seasons except calving (Dyer et al. 2002). Because of this avoidance, roads may act as semi-permeable barriers to caribou movement, potentially restricting caribou use of otherwise suitable areas (Dyer 1999, Dyer et al. 2002, Smith 2004). Linear corridors such as roads and seismic lines may also facilitate wolf travel and hunting behaviour within caribou range (Dyer 1999, James 1999, McCutchen 2007).

Caribou in five subpopulations of the Smoothstone-Wapaweka region of Saskatchewan selected open and treed peatlands, lowland black spruce and upland black spruce/pine stands relative to other habitat types year round (Rettie 1998).

In the Kississing-Naosap region of Manitoba, caribou were associated with spruce trees, relatively abundant arboreal lichens, and avoided trembling aspen and deadfall (Metsaranta et al. 2003). The authors proposed that deadfall, which is abundant several years post fire, impedes travel for caribou but also for alternative prey, thus suggesting an important mechanism of fire to prevent a faunal shift in the ungulate community thus preventing increased predation risk for caribou.

Calving Habitat

Caribou in north eastern Alberta selected bogs and avoided uplands and fen/upland boundaries during calving season (James 1999). Caribou avoided habitat near seismic lines, roads, and well sites in open coniferous and closed coniferous wetlands during spring (Dyer et al. 2001). Avoidance effects (areas of reduced use) were demonstrated up to 500 m away from developments. Caribou in west-central Alberta used mature forest for calving habitat and avoided young forest, areas with high density of cut blocks, seismic lines, aspen-dominated stands, and large rivers (Neufeld 2006).

Caribou in the Smoothstone-Wapaweka region selected peatlands and black spruce-dominated stands for calving (Rettie 1998). In the Wabowden area of north central Manitoba, caribou selected lowland black spruce stands within muskeg (treed muskeg) during calving season. Caribou did not use islands for calving, and avoided deciduous forests, immature stands, and non-black spruce conifer stands (Hirai 1998).

Post-calving Habitat

In the Caribou Mountains of northwestern Alberta, caribou used forest stands older than 50 years and avoided forest stands <10 years old during summer (Dalerium et al. 2007). Caribou in northeastern Alberta avoided habitat near seismic lines, roads, and well sites in open coniferous and closed coniferous wetlands during summer (Dyer et al. 2001). Caribou in west-central Alberta used mature forest during summer and avoided stands dominated by white spruce and aspen, areas with a high density of cut blocks, seismic lines, aspen dominated stands and large rivers (Neufeld 2006). In the Smoothone-Wapaweka region of Saskatchewan, caribou selected upland black spruce/jack pine forests, lowland black spruce, young jack pine, open and treed peatlands during the post-calving season (Rettie 1998, Rettie and Messier 2000). In the Naosap region of Manitoba, caribou selected upland spruce and pine stands and treed muskeg and avoided deciduous forests during summer (Metsaranta and Mallory 2007). Caribou in the Naosap-Reed populations also selected sites with greater arboreal lichen cover during summer (Lander 2006).

Rutting Habitat

Caribou in north eastern Alberta, caribou selected and avoided fen/upland boundaries during fall (James 1999). Caribou in northeastern Alberta avoided habitat near seismic lines, roads, and well sites in open coniferous and closed coniferous wetlands during fall (Dyer et al. 2001). Caribou in west-central Alberta used mature forest during fall and avoided stands dominated by white spruce and aspen, areas with a high density of cut blocks, seismic lines, aspen dominated stands, and large rivers (Neufeld 2006).

In the Smoothone-Wapaweka region of Saskatchewan, caribou selected upland black spruce/jack pine forests, lowland black spruce, and open and treed peatlands and avoided clear cuts and burned areas during the rutting season (Rettie 1998, Rettie and Messier 2000).

Winter Habitat

In northeastern Alberta, caribou selected treed peatlands during winter (Anderson 1999). Caribou selected open fen complexes of >50% peatland coverage and forested bogs of >85% peatland and avoided uplands and non-patterned open fens (Bradshaw et al. 1995) Caribou selected seral stages > 50 years old during winter (Dalerum et al. 2007)

In west-central Alberta, caribou used mature forest during winter and avoided stands dominated by white spruce and aspen and areas with a high density of cut blocks, seismic lines, and large rivers (Neufeld 2006). In the Smoothone-Wapaweka region of Saskatchewan, caribou selected upland black spruce/jack pine forests, lowland black spruce, and open and treed peatlands and avoided clear cuts and burned areas during winter (Rettie 1998, Rettie and Messier 2000). In the Naosap region of Manitoba, caribou selected mature upland spruce and pine stands and treed muskeg and avoided deciduous forests during winter (Metsaranta and Mallory 2007). Caribou in the Naosap-Reed population also selected areas with greater visibility and further from forest edge during winter (Lander 2006).

Late Winter

In northeastern Alberta, late winter habitat consisted of treed bog, treed fen, and treed peatland (Anderson et al. 2000). Caribou feeding sites occurred in areas of high *Cladina spp.* abundance. The greatest barrier effect of roads was evident in late winter, when caribou crossed roads with moderate traffic volume six times less frequently than simulated road networks (Dyer et al. 2002).

MONTANE CORDILLERA ECOZONE

Eastern Continental Ranges (207)

The Montane Cordillera Ecozone occurs throughout much of British Columbia and a portion of southwestern Alberta (ESWG 1995). The extent of occurrence of boreal caribou overlaps with a small portion of the Eastern Continental Ranges Ecoregion in southwestern Alberta. The topography is rugged and mountainous to rolling (foothills) with intervening river valleys. Boreal caribou occur in the well forested foothill region. Dry sites are dominated by stands of lodgepole pine or lodgepole pine and black spruce. Higher elevations are dominated by mixed fir, spruce and lodgepole pine forests. Willow (*Salix spp.*) and dwarf birch meadows and grassy benches occur along river drainages. Aspen occurs throughout the foothills region on southfacing slopes (Edmonds and Bloomfield 1984). Mean annual precipitation is 600 - 800 mm in the Eastern Continental Ecoregion (ESWG 1995). Mean annual area burned by forest fire is 0.03% (NRCAN 2002).

Local Caribou Populations

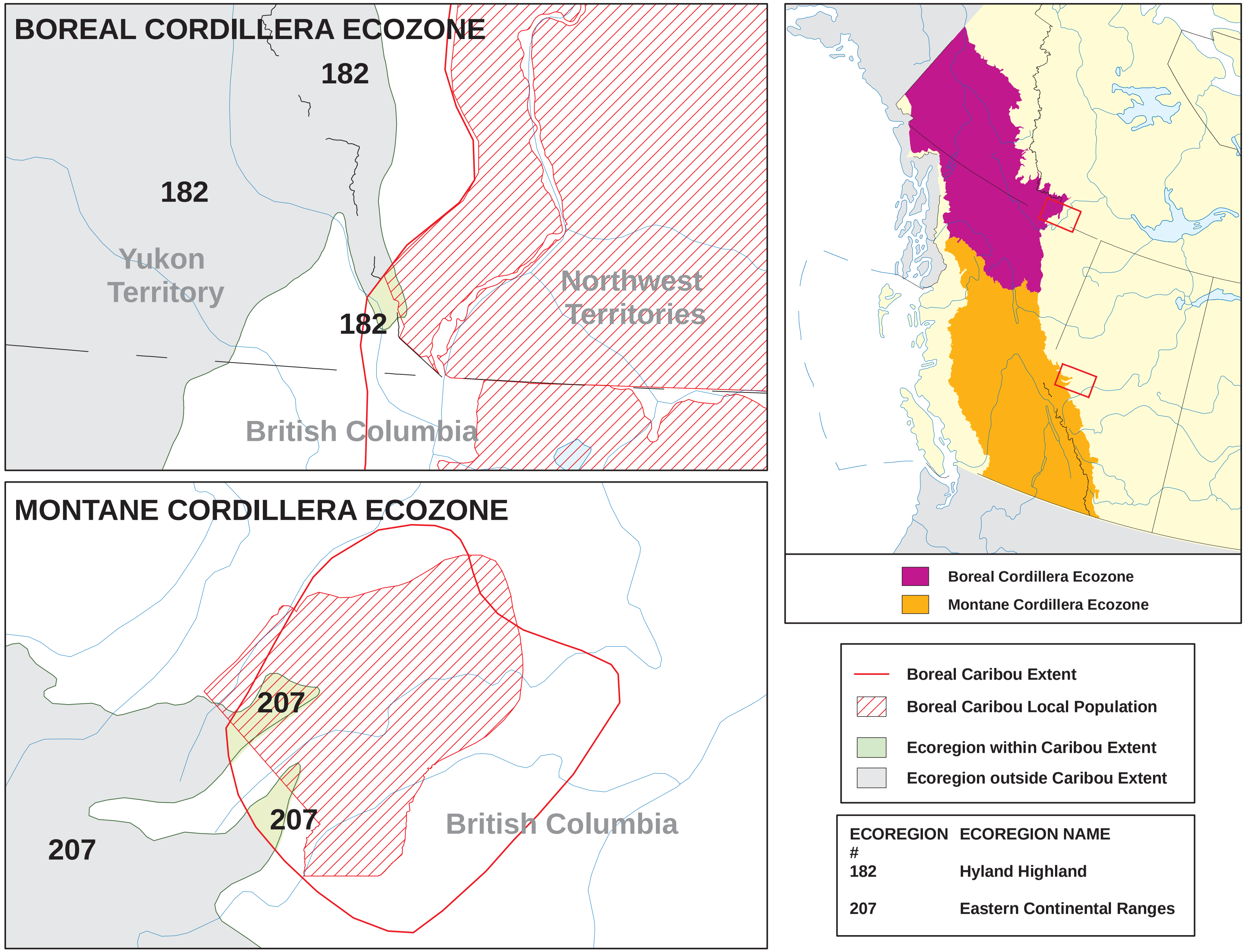
One local boreal caribou population occurs within the Montane Cordillera Ecozone, the Little Smoky, and its extent of occurrence overlaps with the Boreal Plains Ecozone.

Broad Scale Caribou Habitat

The Little Smoky population spends the entire year in the subalpine and upper foothill regions (Edmonds 1988). In west-central Alberta, boreal caribou are associated with open, pine-dominated forests greater than 80 years of age (Thomas et al. 1996, Szkorupa 2002). In west-central Alberta, terrestrial lichens are most abundant in older semi-open lodgepole pine stands (Szkorupa 2002).

Year Round Habitat

Radio-collared caribou in the Little Smoky River area were predominantly in dry, upland lodgepole pine, mixed conifer lodgepole pine/ black spruce and treed muskeg (Johnson 1980, Edmonds1993). Year round, caribou avoided areas with a large proportion of cutblock at the 1-km scale (Neufled 2006). White spruce and large rivers were negatively selected at all scales during all seasons. Terrestrial lichens are negatively associated with white spruce (Saher 2005) and rivers and white spruce provide good habitat for wolves (Neufled 2006). Caribou also strongly avoided aspen dominated stands in all seasons, presumably because aspen stands support other alternate ungulate prey species and have very low lichen availability (Neufeld 2006).



Appendix 6.3 - Figure 6. Boreal caribou distribution within the Montance Cordillera Ecozone.

Calving Habitat

Caribou in the Little Smoky population avoided areas closer to seismic lines, and showed the strongest response to seismic lines during non-winter (Neufeld 2006). During the spring and summaer, caribou selected areas habitat closer to cutblocks. The proportion larch within 1-km^2 was a significant predictor of caribou occurrence during winter and spring (Neufeld 2006).

Post-calving Habitat

During summer, caribou avoided areas with larger proportions of dominant conifer stands (increasing homogeneity; Neufled 2006).

Winter Habitat

The proportion larch within 1-km^2 was a significant predictor of caribou occurrence during winter (Neufled 2006). Caribou selected locations with a greater proportion of pine forests at the 1-km^2 scale during the winter (Neufled 2006).

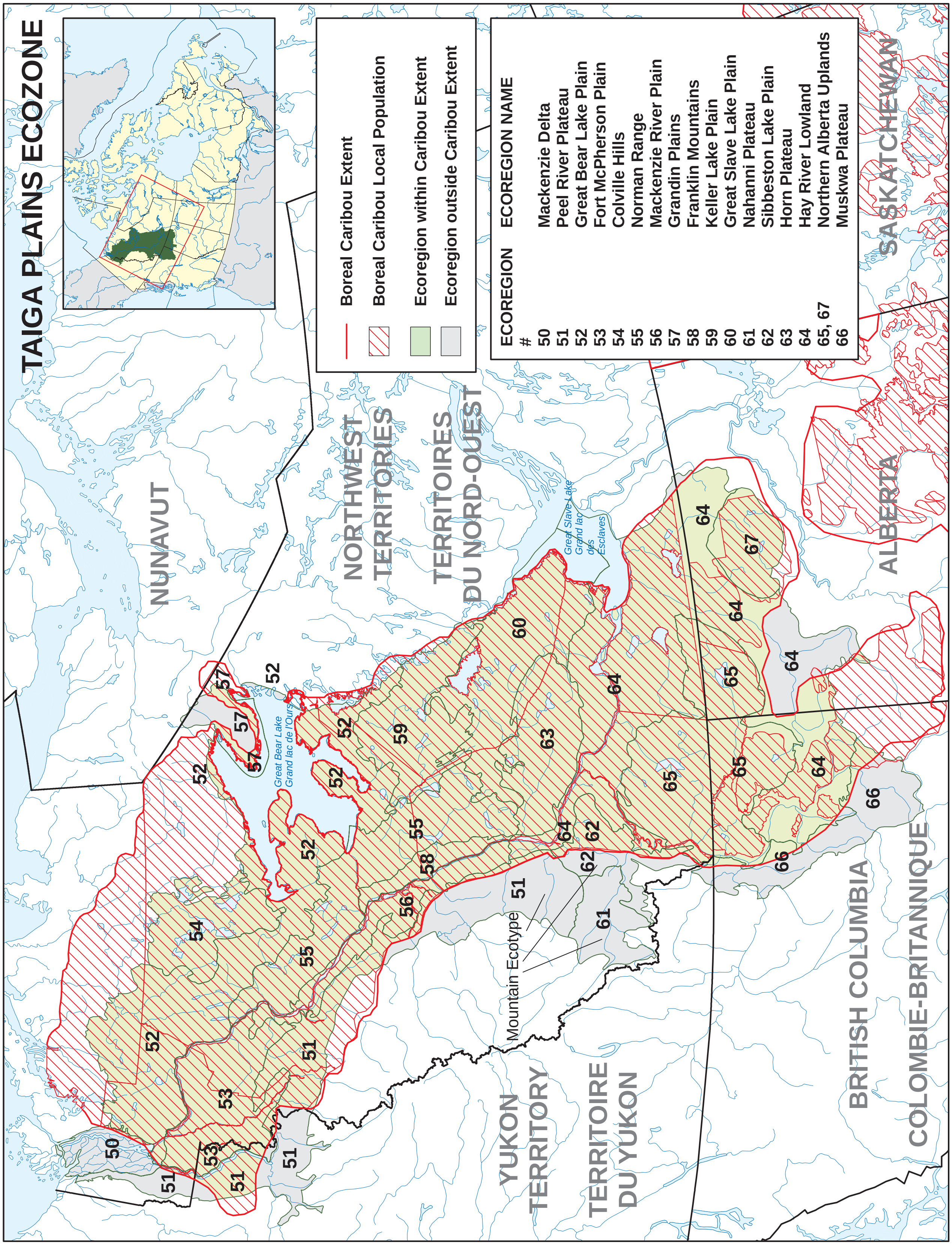
TAIGA PLAINS ECOZONE

Mackenzie Delta, Peel River Plateau, Great Bear Lake Plain, Fort McPherson Plain, Colville Hills, Norman Range, Mackenzie River Plain, Grandin Plains, Franklin Mountains, Keller Lake Plain, Great Slave Lake Plain, Sibbeston Lake Plain, Horn Plateau, Hay River Lowland, Northern Alberta Uplands, Muskwa Plateau (50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 62, 63, 64, 65, 66, 67).

The Taiga Plains Ecozone occurs in southwestern Northwest Territories, northeastern British Columbia, and northern Alberta (Figure 7). This Ecozone is bordered by Great Bear and Great Slave Lakes and is dominated by the Mackenzie River and its tributaries. The topography is generally flat to gently rolling. The landscape is dominated by peatlands, interspersed with coniferous, mixed-wood and deciduous uplands and riparian habitat. Black spruce forests with an understory of bearberry, mosses and sedges dominate the Ecozone. Uplands consist of mixedwood forests of white and black spruce, lodgepole pine, tamarack, white birch, trembling aspen, and balsam poplar (ESWG 1995). Shrub communities are numerous, consisting of dwarf birch, Labrador tea (*Rhododendron groenlandicum*) and willow. Small lakes under 1 ha are numerous throughout the landscape. Mean annual precipitation ranges from 200 – 500 mm (ESWG 1995). Mean annual area burned by forest fire is 0.44% (NRCAN 2002).

Local Caribou Populations

Six local boreal caribou populations occurring within the Taiga Plains are described in the literature. The extent of occurrence of some of these local populations overlaps with the Boreal



Appendix 6.3 - Figure 7. Boreal caribou distribution within the Taiga Plains Ecozone.

Plains Ecozone. The following local populations are reported in the habitat use literature: Bistcho, Maxhamish, Calendar, Snake-Sahtahneh, Steen River, and Caribou Mountains.

Broad-Scale Caribou Habitat

Caribou habitat in the Taiga Plains is described as large patches of spruce peatland (Culling et al. 2006) and lowland black spruce forests with abundant lichens (Gunn et al. 2002). Gunn et al. (2004) compared a Deh Cho First Nations database of harvest kill sites in living memory with caribou sightings from an aerial survey in March 2002 to determine that boreal caribou occupation did not change at the regional level. Boreal caribou were strongly associated with black spruce and lichen on uplands and in lowlands.

Seasonal Habitat and Forage

Year Round Habitat

In the Caribou Mountains of northeastern Alberta, caribou selected peatlands over uplands and edge habitat (McLaughlin et al. 2005). Within peatlands, bogs were selected over fen and bogs were selected if proportion of bog to non-peatland habitat was >30% (Schneider et al. 2000). Non-peatlands were avoided in landscapes where the proportion of non-peatland was >50% and use of non-peatland diminished with distance from peatlands (Schneider et al. 2000).

Calving Habitat

In the Trout Lake area of Northwest Territories (NT), female caribou were widely dispersed during the calving season and were typically found in groups of one to two animals (Larter and Allaire 2006). Larter and Allaire (2006) found high fidelity to calving area among years. In the lower Mackenzie River Valley, NT, caribou selected open conifer forests, tussock tundra, low shrub, riparian, recent burns, and south and west aspects (Nagy et al. 2006). Caribou avoided closed mixed forests, water, and north and east aspects. In the Snake-Sahtaneh watershed, BC, caribou were observed in small islands of mature black spruce or mixed wood within peatlands, in old burns at the edge of wetlands, in alder thickets with abundant standing water, and on lakeshores (Culling et al. 2006). Caribou showed high fidelity to calving sites (within 14.5 km) among years (Culling et al. 2006).

Post-calving Habitat

In the lower Mackenzie River Valley, NT, caribou selected open coniferous forests with abundant lichens, low shrub, riparian, tussock tundra, sparsely vegetated habitat, recent burns and west aspects and avoided closed deciduous and mixed forests (Nagy et al. 2006). Caribou in the Snake-Sahtaneh watershed, BC, used old burns and remnant unburned forest patches within the perimeter of old burns during late spring and early summer (Culling et al. 2006). In the Caribou Mountains of northwestern Alberta, caribou avoided forest stands <10 years old during summer (Dalerum et al. 2007).

Rutting Habitat

In the Trout Lake area of Northwest Territories, caribou group size and daily movement rates increased during rutting season (Larter and Allaire 2006). In the lower Mackenzie River Valley, NT, caribou selected open coniferous and mixedwood forests, low shrub, riparian, tussock tundra, recent burns and west aspects and avoided closed deciduous and avoided mixed forests, water, and north and west aspects (Nagy et al. 2006). In the Snake-Sahtaneh watershed, BC, caribou used open conifer, regenerated burns and sparsely vegetated areas during the rutting season (Culling et al. 2006). Rutting was distributed within core habitats throughout the study area, and fidelity to particular rutting areas was strong for some but not all caribou.

Winter Habitat

In the Trout Lake area of Northwest Territories, group size and movement rate was largest during winter; typical group size was 10 – 15 animals (Larter and Allaire 2006).

Early Winter Habitat

During early winter, caribou in the lower Mackenzie River Valley, NT selected open coniferous and mixedwood forests, low shrub, riparian, water and avoided closed spruce, closed deciduous and mixed forests, tall shrub north, west, and east aspects (Nagy et al. 2006). In the Snake-Sahtaneh watershed, BC, caribou were commonly observed on lakes and along lakeshores as well in fens (Culling et al. 2006).

Mid Winter Habitat

During mid winter, caribou in the lower Mackenzie River Valley, NT selected open coniferous forests with abundant lichens and riparian habitat and avoided closed spruce, open conifer forest without abundant lichens, closed deciduous and mixed wood, open mixed forest, low shrub, tall shrub, dwarf shrub, riparian, tussock tundra, water, sparsely vegetated habitat and east aspect (Nagy et al. 2006).

Late Winter Habitat

During late winter, caribou in the lower Mackenzie River Valley, NT selected open coniferous and mixed forests, riparian habitat and water and avoided closed deciduous and mixed forest, tall shrub, dwarf shrub, sparsely vegetated habitat and recent burns (Nagy et al. 2006). In the Deh Cho region, NT, caribou selected black spruce-lichen forest, fire regenerated, sparsely vegetated habitat, sphagnum moss with scattered spruce, herbaceous and tall shrub habitat (Gunn et al. 2004).

BOREAL CORDILLERA ECOZONE

Hyland Highland ecoregion (182)

The Boreal Cordillera Ecozone spans northern British Columbia and southern Yukon (Figure 1). The extent of occurrence of boreal caribou overlaps with a small portion of the Hyland Highland Ecoregion bordering British Columbia and the Yukon (Figure 6). The topography is rugged to rolling with flat-topped summits and wide valleys. Dry sites are dominated by stands of white spruce and lodgepole pine, white birch and aspen. Wetter sites are dominated by open stands of black spruce and white spruce with an understory of lichen and moss. Bogs, fens, and shrub meadows occur throughout the ecoregion. Annual precipitation is 300 – 600 mm (ESWG 1995). Mean annual area burned by forest fire is 0.41% (NRCAN 2002).

Local Caribou Populations

One local boreal caribou population occurs within the Boreal Cordillera Ecozone, the *Deh Cho*, and its extent of occurrence overlaps with the Taiga Plains Ecozone.

Broad-Scale Caribou Habitat

Caribou habitat in the Boreal Cordillera is described as large patches of spruce peatland (Culling et al. 2006) and lowland black spruce forests with abundant lichens (Gunn et al. 2002). Gunn et al. (2004) compared a Deh Cho First Nations database of harvest kill sites in living memory with caribou sightings from an aerial survey in March 2002 to determine that boreal caribou occupation did not change at the regional level. Boreal caribou were strongly associated with black spruce and lichen on uplands and in lowlands.

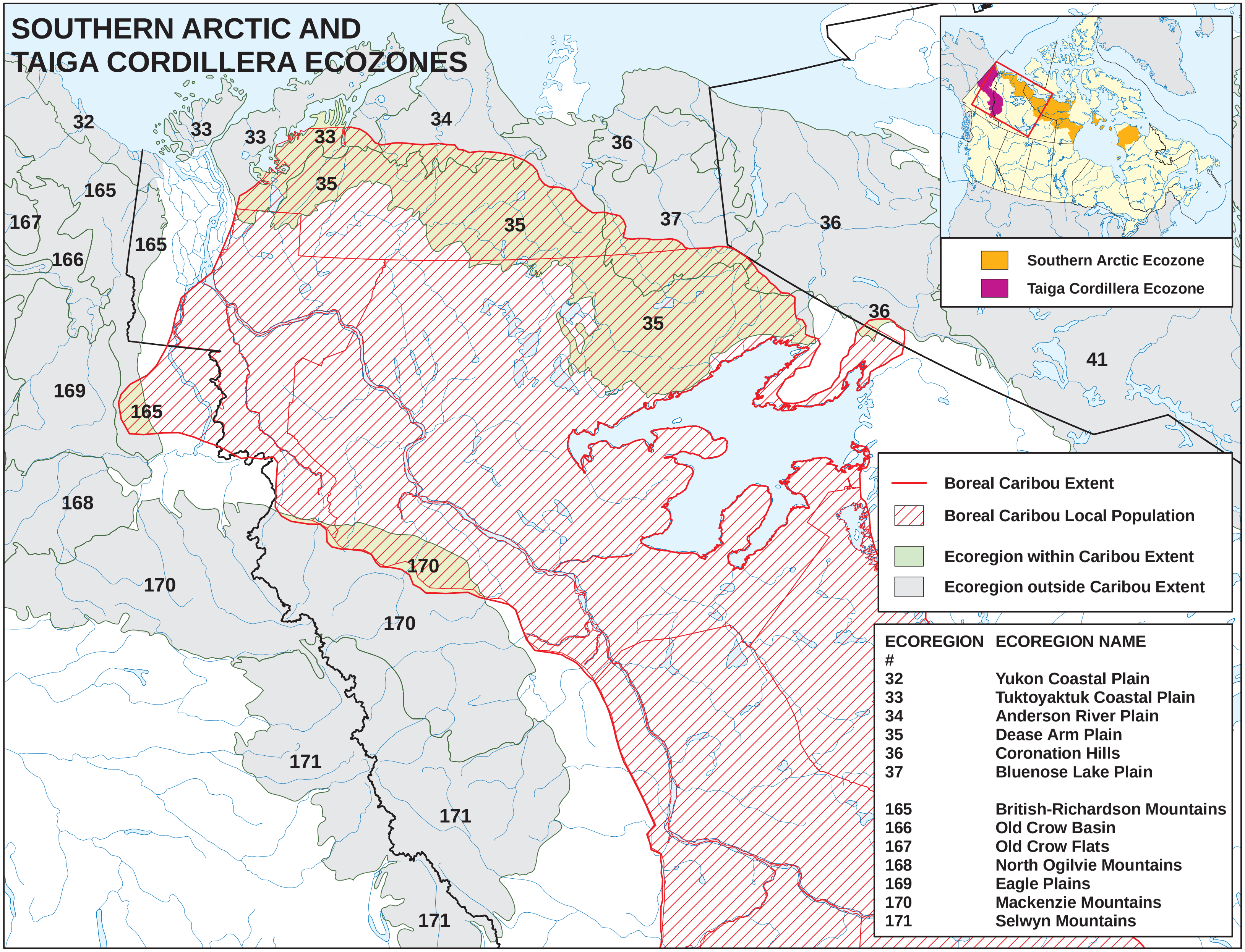
Seasonal Habitat and Forage

Year Round Habitat

Year round, the Deh Cho caribou selected open coniferous forest with abundant lichesn and avoided deciduous or mixed forest (Nagy et al. 2006). Gunn et al. (2004) found a strong relationship between caribou probability of occurrence and proportion of black-spruce/lichen within 10 X 10 km cells. Relatively strong relationships were found between the probability of caribou occurrence and the proportion of sphagnum moss, the proportion of tall shrub and herbaceous habitat, and lower proportions of fire-regeneration habitat. Presence of bison and moose reduced the probability of boreal caribou presence (Gunn et al. 2004)..

Calving Habitat

Deh Cho caribou selected open conifer forests, tussock tundra, low shrub, riparian, recent burns, and south and west aspects (Nagy et al. 2006). Caribou avoided closed mixed forests, water, and north and east aspects.



Appendix 6.3 - Figure 8. Boreal caribou distribution within the Southern Arctic and Taiga Cordillera Ecozones.

Post-calving Habitat

Deh Cho caribou selected open coniferous forests with abundant lichens, low shrub, riparian, tussock tundra, sparsely-vegetated habitat, recent burns and west aspects and avoided closed deciduous and mixed forests (Nagy et al. 2006).

Rutting Habitat

Deh Cho caribou selected open coniferous and mixedwood forests, low shrub, riparian, tussock tundra, recent burns and west aspects and avoided closed deciduous and avoided mixed forests, water, and north and west aspects (Nagy et al. 2006).

Early Winter Habitat

During early winter, *Deh Cho* caribou selected open coniferous and mixedwood forests, low shrub, riparian, water and avoided closed spruce, closed deciduous and mixed forests, tall shrub and north, west, and east aspects (Nagy et al. 2006).

Mid Winter Habitat

During mid winter, *Deh Cho* caribou selected open coniferous forests with abundant lichens and riparian habitat and avoided closed spruce, open conifer forest without abundant lichens, closed deciduous and mixedwood, open mixed forest, low shrub, tall shrub, dwarf shrub, riparian, tussock tundra, water, sparsely-vegetated habitat and east aspect (Nagy et al. 2006).

Late Winter Habitat

During late winter, *Deh Cho* caribou selected open coniferous and mixed forests, riparian habitat and water and avoided closed deciduous and mixed forest, tall shrub, dwarf shrub, sparsely-vegetated habitat and recent burns (Nagy et al. 2006). Caribou selected black spruce-lichen forest, fire-regenerated, sparsely-vegetated habitat, sphagnum moss with scattered spruce, herbaceous and tall shrub habitat (Gunn et al. 2004).

SOUTHERN ARCTIC ECOZONE

Tuktoyaktuk Coastal Plain, Anderson River Plain, Dease Arm Plain, Coronation Hills, and Bluenose Lake Plain Ecoregions (33, 34, 35, 36, 37)

The Southern Arctic Ecozone occurs in the northern region of Northwest Territories (Figure 8). Although this Ecozone covers land on either side of Hudson Bay, only the extreme western portion of the Ecozone overlaps with boreal caribou extent of occurrence (Figure 1). The topography is rolling uplands and lowlands, interspersed with many lakes, ponds and wetlands. This Ecozone is a transition from taiga and arctic tundra vegetation. Major river valleys can support clumps of stunted spruce trees, and shrub communities throughout the Ecozone consist of dwarf birch, willow, and heath species. Wetlands support sedge-moss communities. Mean annual precipitation is approximately 200 mm in the northwest (ESWG 1995). Mean annual area burned by forest fire is 0.03% (NRCAN 2002).

Local Caribou Populations

No local boreal caribou populations occurring within the Southern Arctic Ecozone are described in the literature. Further research is needed to describe boreal caribou habitat use in this Ecozone.

TAIGA CORDILLERA ECOZONE

British Richardson Mountains and Mackenzie Mountains Ecoregions (165, 170)

The Taiga Cordillera Ecozone occurs along the northernmost extent of the Rocky Mountains, and covers most of the northern portion of the Yukon and the northwestern portion of Northwest Territories (Figure 8). Steep mountainous topography, foothills and basins dominate throughout the Ecozone. Wetlands and peatlands dominate the landscape. Vegetation ranges from low shrubs, mosses and lichen of the arctic tundra, to dwarf shrubs, lichens and saxifrages of alpine tundra, and white spruce and white birch of taiga woodland. Annual precipitation ranges from 300 – 700 mm (ESWG 1995). Mean annual area burned by forest fire is 0.06% (NRCAN 2002).

Local Caribou Populations

No local boreal caribou populations occurring within the Taiga Cordillera Ecozone are described in the literature. Further research is needed to describe boreal caribou habitat use in this Ecozone.

SUMMARY

Throughout their distribution in Canada, boreal caribou are associated with mature and late seral-stage upland and lowland conifer forests and peatland complexes. Terrestrial lichens are common winter forage for boreal caribou, and lichens are most abundant in open- to mid-density mature conifer stands and peatlands. During snow-free seasons caribou forage on a much broader array of plants including grasses, sedges, herbaceous plants and lichens.

The primary anti-predator strategy that boreal caribou employ is spacing out from predators and spatially separating themselves from alternative prey (Bergerud 1996). Consequently, boreal caribou require large, contiguous tracts of habitat to maintain low population densities across their range. The use of muskeg habitat and mature conifer forests allow caribou to spatially separate themselves from the other common boreal and sub-boreal ungulates, moose and white-tailed deer (*Odocoileus virginianus*).

During the calving and post-calving season, cows are sparsely distributed on the landscape and are usually found alone with a calf. Fidelity to calving sites seems to vary among individual caribou; some caribou return to the same site in consecutive years, some have calving locations separated by several hundred kilometers in subsequent years, and many return to a general area within their range (e.g. within 10 km). Females will travel several hundred kilometers to these general areas, and they constitute a small portion of the overall range.

Across their distribution, cows select treed muskegs with open water. The presence of open water is hypothesized to reduce predation risk by affording a quick escape through water (Bergerud 1996). In the Boreal Shield Ecozone, caribou cows also select mature open conifer on shorelines and peninsulas of large lakes and shorelines of Islands in large lakes for calving habitat.

During the rutting season, boreal caribou congregate in small groups in open peatlands or open mature or young conifer forests. In winter, caribou forage in mature open conifer forests and treed peatlands. Where large lakes occur, caribou forage along the shoreline and use the frozen lakes to escape from predators. In severe winters, caribou may select dense old-growth conifer forests where snow depths are lower than in open conifer forests. In regions where snow conditions are severe, such as the Taiga Shield, caribou form groups to crater for terrestrial lichens, graminoids or equisetum. Where snow depth and hardness exceed the ability of caribou to crater through the snow, caribou seek glacial erratics or windswept areas to find lichens.

Caribou generally avoid shrub-rich habitats, disturbed or fragmented areas, hardwood-dominated or mixed stands and edge habitat that may support higher alternative prey populations, and consequently, higher predator populations.

Boreal caribou evolved an adaptation to dynamic forest ecosystem conditions in which forest fire is the dominant cause of habitat disturbance and renewal. Forest fires vary in frequency

and magnitude throughout the boreal forest of Canada, and boreal caribou populations shift their range over time in response to fire-induced changes in habitat quality. Consequently, boreal caribou require relatively large ranges to compensate for portions of the range in early seral stages.

Boreal caribou require habitat conditions that allow them to meet their life history requirements, such as adequate forage quality and quantity to allow breeding and recruitment of calves and large enough tracts of preferred habitat to allow spatial separation from predators and alternative prey throughout the year. Travel corridors linking seasonal habitats fulfill a potentially critical function in reducing risk of predation for boreal caribou during times of increased movement and travel corridors between population ranges may allow for demographic rescue of small populations by providing a source of immigrants.

Although caribou may select certain habitat types within their range to meet specific seasonal requirements, habitat conditions over their entire range impact the viability of boreal caribou populations. The habitat conditions within the matrix habitat beyond the core caribou habitat may have significant impacts on the risk of predation to boreal caribou. Consequently, although special management practices may be required to protect or perpetuate seasonal foraging habitats, calving habitats, and migration corridors, it is also important to manage the surrounding habitats to reduce the risk of predation, even if the caribou rarely or never “use” those habitats.

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6.4 Environmental Niche Analysis - Predicting potential occurrence of threatened boreal woodland caribou to support species recovery in Canada.

Introduction

The Boreal Caribou Critical Habitat Science Review has pursued four complementary analytical approaches to reflect the multi-scale, hierarchical interaction of species and their habitats; here we conducted an environmental niche analysis. We modeled the geographic extent of the environmental niche (fundamental and realized, e.g., abiotic and biotic) for boreal woodland caribou across its current extent of occurrence in Canada. While not directly incorporated into the prior analysis, the results presented here were expected to confirm the current national distribution, and contribute to the local population management in the action planning stage. For example, refined and validated niche models could inform management on priority areas for habitat restoration where the current local extent is not large enough, as well as guide monitoring programs throughout the extent of occurrence as part of the adaptive management framework. The population and distribution objectives in the National Recovery Strategy (Environment Canada 2007) are to maintain existing local populations of boreal caribou that are self-sustaining and achieve growth of populations not currently self-sustaining, throughout the current extent of occurrence. Delineation and management of these local populations are key to the recovery of boreal caribou (Environment Canada 2007).

The geographic distribution of a species is a function of its ecology and evolutionary history, determined by diverse factors operating at different spatial scales, including climate (Case and Taper 2000, Soberon 2007). We assume that a species will be present at a given point where three conditions are met: a) abiotic conditions (such as climate) are favourable, b) biotic conditions (other species) allow species to maintain populations, and c) the region is accessible to dispersal from adjacent populations (Soberon and Peterson 2005, Soberon 2007). These three conditions describe a species niche, one of the fundamental theories in ecology of how organisms use their habitats. Niche theory suggests that fitness or habitat suitability is not monotonically related to conditions or resources, but instead decreases from either side of an optimal condition (Hirzel et al. 2002). A geographic area, with the appropriate set of abiotic factors, free of competition from biotic factors for a species in which the species may theoretically occur, may be regarded as the geographical expression of the fundamental niche (Hutchinson 1957). In contrast, an area where the abiotic conditions are favourable but we also consider biotic interactions, such as competition and predation, may be considered the geographical representation of the realized niche (Hutchinson 1957). A region that has the right set of biotic and abiotic factors and is accessible to the species (via dispersal) is the potential geographic distribution of the species (MacArthur 1967, Soberon 2007).

The recent availability of species occurrence data over large regions, for example from breeding bird surveys or large-scale wildlife surveys, combined with the availability of large-scale environmental climate and biotic data, has lead to an increase in approaches to model the distribution of species (Soberon 2007). Species distribution models are one type of empirical model relating spatial observations of an organism to environmental predictor variables, using a variety of statistical techniques, from logistic regression to more complex computation approaches (Guisan and Zimmerman 2000). Guisan and Thuiller (2005) suggested that environmental predictors for species distribution models should be chosen to capture the three main types of influences on species distribution: i) limiting factors or regulators, defined as factors controlling a species ecophysiology (e.g., temperature, water, soil), ii) disturbances (natural or human), and iii) resource availability, defined as all compounds that can be assimilated by organisms (e.g., energy and water). Spatial patterns in relationships between species and their environments vary with scale, often in a hierarchical manner (Johnson 1980, Pearson et al. 2004). Environmental niche models are conceptually similar to other species distribution models commonly employed in ecology (resource selection functions (Boyce and McDonald 1999), bioclimatic envelopes (Hijmans and Graham 2006) etc.), but niche models are explicitly linked to niche theory and usually address distribution across broad regional scales (Anderson et al. 2002). Environmental niche models reconstruct species' ecological requirements (conditions or resources) and predict the geographical distribution of those requirements.

Ecological niche models (ENM) have been used to study issues in evolution (Peterson 2001), ecology (Anderson et al. 2002), and conservation (Peterson and Robins 2003). Their predictive models of species geographic distributions are important in a variety of conservation applications, such as conservation reserve design (Wilson et al. 2005), to predict the spread of invasive species (Peterson 2003), and to predict the effects of climatic change on species responses to future and past climates (Pearson and Dawson 2003, Hijmans and Graham 2006, Peterson et al. 2004). ENM models have been used to assess the distributional patterns of endangered species in many countries, including the United States (Godown and Peterson 2000), China (Chen and Peterson 2000), and eastern Mexico (Peterson et al. 2002). ENM models have also been used to incorporate multiple species and trophic interactions for example the implications for endangered spotted owls *(Strix occidentalis)* by invading barred owls (*S. varia*) facilitated by human disturbance in Washington and Oregon (Peterson and Robins 2003). Guisan et al. (2006) suggested that niche-based models may improve the sampling of rare species and Raxworthy et al. (2003) used ENM to target field surveys for under-studied reptiles and located previously undiscovered chameleon species in Madagascar.

As part of the science review process for boreal caribou, our goal was to support the identification of critical habitat by employing environmental niche analysis to understand the pattern of occupancy in the current extent of occurrence. First, we examined the potential distribution (fundamental niche) as a function of climate and topography for two 30-year time periods: 1930 to 1960 and 1971 to 2000. Boreal caribou have experienced a range contraction at the southern limit of their distribution; therefore we hypothesized that the potential distribution of woodland caribou has shifted northwards between these two periods. This analysis may help determine contributions of climate change in limiting habitat use by caribou. Second, we predicted that the pattern of occupancy (realized niche) within the current extent of occurrence by biotic predictor variables, as derived from satellite imagery and other spatially explicit sources (e.g., Petorrelli et al. 2005). Woodland caribou declines are hypothesized to result from indirect effects of anthropogenic disturbance across their range (McLoughlin et al. 2003, Laliberte and Ripple 2004, Vors et al. 2007, Wittmer 2007). Proximally, human disturbance is thought to increase primary prey densities, and hence densities of predators, like wolves and black bears, that cause caribou populations to decline through apparent competition (Seip 1992, James and Stuart-Smith 2000). Therefore, we hypothesized that the realized niche would be constrained by these biotic interactions indexed through spatial measures of human disturbance across the boreal forest. Finally, we discussed the potential contributions of environmental niche modelling to various aspects of the ongoing, adaptive process of identifying critical habitat as identified under the federal recovery plan for the species under the auspices of the Canadian Species at Risk Act.

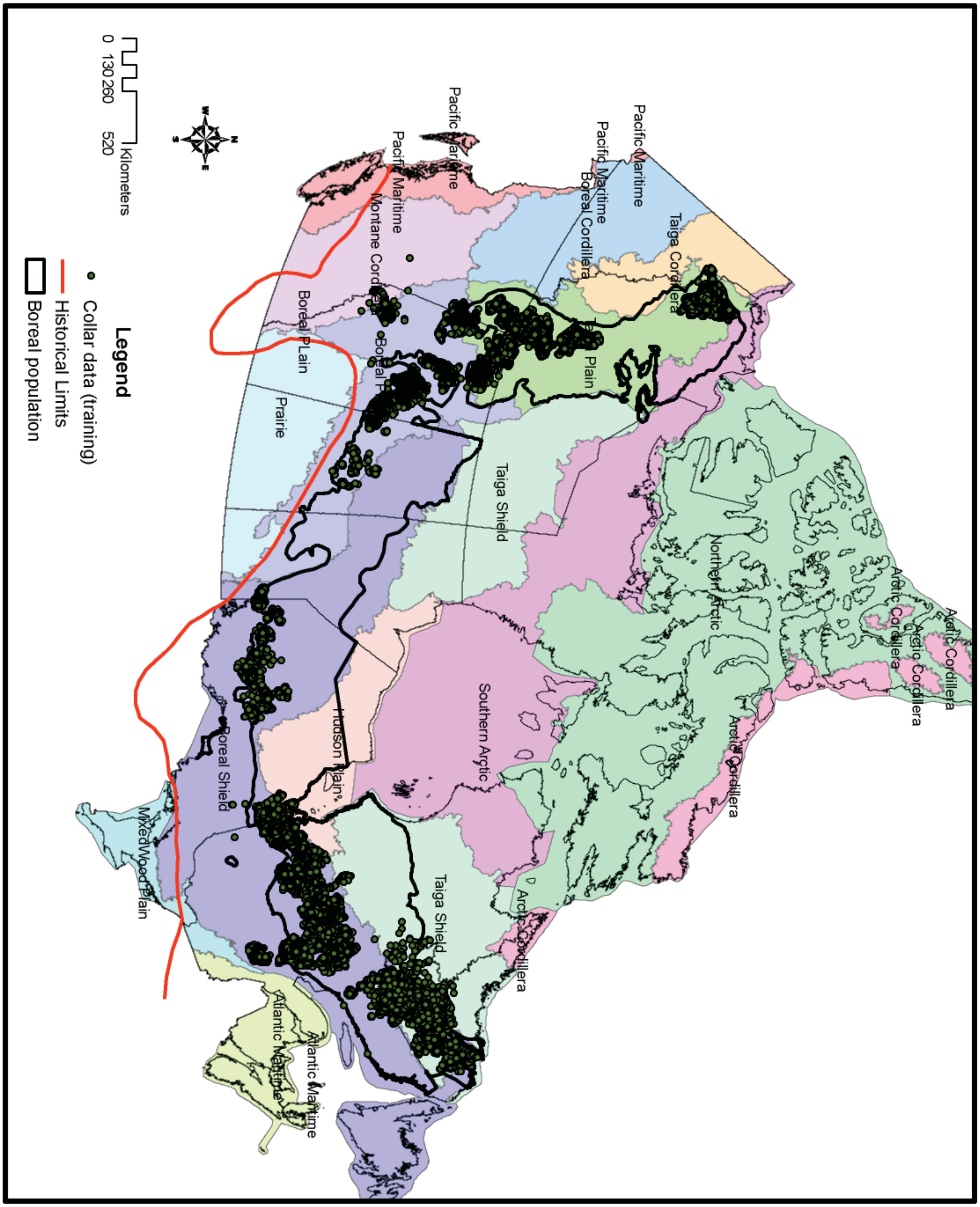
Methods

The boreal caribou is a forest-dwelling sedentary ecotype of woodland caribou with an extent of occurrence over approximately 2.4 million km^2, in eight provinces and territories, and occurring predominantly within five ecozones (Environment Canada 2007: Figure 1, Table 1). Often, boreal woodland caribou habitat is characterized as peatland complexes intermixed with mature to old pine, black spruce, and tamarack (e.g., Brown 2005) Forested peat complexes with abundant arboreal lichens and uplands dominated by mature conifers with dense ground lichens are typical of boreal caribou habitat, and are thought to provide for nutrient rich forage and as a refuge from higher predator densities associated with typical deer and moose habitat (e.g., deciduous/mixedwood, Thomas et al. 1996, McLoughlin 2003, 2005).

Occurrence Data

Geo-referenced boreal caribou observational location data were obtained from a variety of sources and consisted of various acquisition methods including: GPS (Global Positioning System) collar, ARGOS collar, VHF collar, aerial surveys, ground surveys, and incidental observations, ranging over time from the 1940’s to 2007. The database included over 1 million records of caribou observations. Two different datasets were used for niche modelling, to train and to validate the models, respectively. For the former, collared (GPS, ARGOS, VHF) data were used, whereas non-collared (surveys) data were held back for independent validation of outputs (Fielding and Bell 1997, Boyce et al. 2002).

To reduce spatial and temporal autocorrelation and minimize bias introduced by collar type, training data were limited to one location, per animal, per day by random selection where multiple daily acquisitions were captured (White and Garrott 1990). Because occurrence data frequently included location error, entries with uncertainty greater than 1 km were excluded for the study, regardless of acquisition method. The training dataset for current analyses consisted of over 217,000 points from collared animals, but the distribution of locations was



Appendix 6.4 - Figure 1. Ecozone map of Canada showing the current extent of occurrence of Boreal Caribou and the training (collar) data. The black line represents the current extent of occurrence for the boreal ecotype from the National Recovery Strategy and the red line is the historical southern extent of woodland caribou (Environment Canada 2007).

not uniform throughout the geographic range of boreal caribou (Table 1, Figure 1). Therefore, we stratified sampling to obtain datasets representative of the species-habitat variability in different ecozones across the extent of occurrence (Callaghan 2008). For modelling purposes, we produced ten subsets consisting of 10,000 points randomly selected from the 200,000 locations at the same ratio as the proportion of boreal caribou range represented by that ecozone (Boyce et al. 2002, Araujo and New 2006). Niche models are sensitive to sample size and to biases in the geographic distribution of the data (Peterson and Cohoon 1999, Stockwell and Peterson 2002). Statistical sampling designs outlined above have been suggested to limit these biases, while increasing model performance (Araujo and Guisan 2006). Although this balanced the coverage for ecozones, there were still considerable gaps in the geographic distribution of the occurrence data (Figure 1).

Appendix 6.4 - Table 1. Percent of Boreal caribou extent of occurrence in each ecozone and breakdown of collar locations used for training subsets input data.

Ecozone	Percent of Extent of Occurrence	Percent of fixes	Number of fixes
Boreal Plan	13.5	21.4	46561
Boreal Shield	41.1	43.5	94893
Hudson Plain	7.7	1.7	3809
Montane Cordillera	0.4	0.6	1207
Southern Arctic	2.2	0.1	134
Taiga Cordillera	0.1	0.0	29
Taiga Plain	19.6	26.7	58115
Taiga Shield	15.3	6.1	13227

Environmental Covariates

To predict the geographic extent of the boreal caribou environmental niche, we used abiotic and biotic variables including climate surfaces, topography, and biotic variables derived from satellite and existing vector data. Climate covariates were created using an interpolation technique based on thin-plate-smoothing splines (Hutchinson 1995). Biologically meaningful climate parameters (35 bioclimatic) were derived from monthly temperature and precipitation data that were averaged over two 30-year time periods: 1930 to 1960 and 1971 to 2000. Data were provided by the Canadian Forest Service at 30 arcseconds (~1 km) and 300 arcseconds (~10 km) resolutions (see McKenney et al. 2006). Potential variables were selected based on hypotheses developed from literature reviews of caribou and other northern ungulates (Table 2). Climatic variables have been shown to affect population dynamics in many large-bodied, northern ungulates through direct and indirect mechanisms at a variety of scales (Weladji et al. 2002). Indirect effects include for example, late winter precipitation and spring temperatures and precipitation on forage quality and its quantity in summer, and conditions of the summer range have shown associated effects on body size and reproductive success (Finstad et al. 2000). However, winter weather severity also has direct effects on population dynamics. Years with high snowfall may lead to increased winter calf mortality (Fancy and

Whitten 1991), decreased body mass of calves (Cederlund et al. 1991) and lighter yearlings (Adams and Dale 1998). To reduce collinear predictor variables, we randomly sampled 10,000 grid cells from the entire country and derived Pearson's correlation coefficients for 35 bioclimatic parameters and elevation. We excluded variables that had a coefficient of correlation >0.7 (Parra et al. 2004).

Appendix 5.4 - Table 2. Climate variables included in the abiotic environmental niche models together with elevation (from McKenney et al. 2006).

Variable	Hypothesis
Precipitation in driest period	High summer/fall forage availability – improved condition at breeding
Total precipitation for 3 months prior to start of growing season	Early green-up – improved calf survival
Growing degree days (gdd) above base temperature for 1st 6 weeks of growing season	Early green-up – improved calf survival
Precipitation of coldest quarter	Food limitation caused by crusting or snow depth
Gdd above base temperature 3 months prior to growing season	Snowy late winters lead to improved summer forage
Annual mean temperature	Range limit based on physiology
Maximum temperature of warmest period	Range limit based on physiology
Annual temperature range	Range limit based on physiology

Digital elevation models (DEM) were derived from the Shuttle Radar Topography Mission (SRTM) data and obtained from the WorldClim website (www.worldclim.org) at 1-km and 10-km grid cell resolution.

To model realized niche, we attempted to capture attributes related to competition (e.g., resource availability and predation) that may restrict the occupied niche or environmental space. To account for forage resources we included: MODIS derived cumulative annual fraction of Photosynthetically Active Radiation (fPAR) (Coops et al. 2007, Huete et al. , Zhao et al. 2005), minimum annual fPAR (Coops et al. 2007), landcover (Latifovich, unpub), and peatland presence (Tarnocai 2005). The fPAR data were derived from a physically-based model that describes the propagation of light in plant canopies (Tian 2000) together with MODIS spectral bands. The cumulative annual fPAR reflects the annual productivity of the site, whereas the minimum annual fPAR represents the minimum perennial cover of the site (Yang et al. 2006, Coops et al. 2007). Few studies incorporate information to account for predators or competitors directly in niche modelling, and those that have modelled the environmental niche of the predator or competitor and included them as a covariate (Peterson and Robbins 2003, Heikkinen et al. 2008). Few density data exist for the main predators of caribou across the boreal forest, yet predation by wolves and and black bears is the most frequently identified limiting factor of caribou populations (Bergerud and Elliot 1989, Johnson et al. 2004). However, the principal driving factor changing predator distributions at the southern limit of caribou range is hypothesized to be anthropogenic disturbance. Modern commercial forestry creates new early seral forest stands which benefit primary prey species, such as moose (*Alces alces*) and deer (*Odocoileus spp*), followed by wolves (Fuller 1981) resulting in increased predation rates on secondary prey such as caribou (Wittmer 2007). Human activities also include linear developments like roads, seismic exploration lines, pipelines, and utility corridors, all of which increase predation rates and efficiency of wolves preying on caribou (James and Stuart-Smith 2000, McKenzie 2006). Therefore, we approximated predation risk with: road density (calculated as the total distance of roads within 1-km pixel from the Updated Road Network (Geobase), the Statistics Canada Road Network (Statistics Canada) and the DMTI SpatialTM roads database GFWC 2007), disturbance (from GFWC anthropogenic footprint, GFWC 2007), mean forest patch size, number of forest patches, standard deviation forest patch size (derived from Earth Observation for Sustainable Development, calculated using (EOSD) gridded at 1 km, (Wulder et al. 2008).

Environmental Niche Modelling

Ecological niches of boreal caribou were modelled using Maximum Entropy (MaxEnt; Phillips et al. 2004, 2006). Maxent estimates the most uniform distribution (maximum entropy) of occurrence points across the study area, given the constraints that the expected value of each environmental variable under this estimated distribution matches its empirical average (Phillips et al. 2004, 2006). The raw output is a probability value (0-1) assigned to each map cell of the study area, which are then converted to a percentage of the cells with the highest probability value. This is termed the 'cumulative' output. Comparative studies using MaxEnt for species distribution modelling that used independent validation performance suggest that it is more accurate than other models (Elith et al. 2006, Hernandez et al. 2006) and does not require or incorporate known absences in the theoretical framework (Phillips et al. 2004). In MaxEnt, it is unnecessary to define the occupancy threshold *a priori*. In fact, the spatially explicit continuous probability output may be one of the most relevant advantages of MaxEnt for Critical Habitat Identification because it allows for the fine distinction of habitat suitability in different areas (Kirk 2007). We examined the continuous cumulative output to determine the potential to distinguish a continuum of habitat suitability in different areas.

For intrinsic model evaluation, the area under the receiver-operating characteristic (ROC) curve (AUC) provides a single measure of model performance, independent of any particular choice of threshold (Fielding and Bell 1997). The ROC curve is obtained by plotting sensitivity (fraction of all positive instances that are classified as positive or true positive rate) on the y-axis and 1-specificity (fraction of all negative instances that are classified as negative) for all possible thresholds. Since MaxEnt does not require or use absence data (negative), the program considers the problem of distinguishing presence from random, rather than presence from absence. Our ROC analysis used all the test localities as instances of presence and a sample of 10,000 random pixels drawn from the background as random instances (Phillips et al. 2006). A random prediction corresponds to an AUC of 0.5, the best discriminating model corresponds to an AUC of 1.0.

Model Scenarios

We produced environmental niche models for boreal caribou based on three independent environmental datasets to satisfy the objectives outlined above:

1) Potential distribution based on climate averages from 1971 to 2000 and elevation (current fundamental niche).
2) Potential distribution based on climate averages from 1930 to 1960 and elevation (historic fundamental niche).
3) Realized distribution based on biotic variables from recent satellite imagery (current realized niche).

If observed range contractions by caribou resulted, at least in part, from climate change, then we expected that the current fundamental niche should differ most from the historical fundamental niche at more southerly reaches and/or regions where caribou were present historically. Further, if biotic interactions exacerbated by anthropogenic disturbance account for range contractions, then we expected that the current realized niche should be smaller than the current fundamental niche.

All scenarios used the dataset derived from collared animals for training the models. Ten random subsets were run individually with MaxEnt (v3.1) and the cumulative distribution pixel values were averaged over the ten runs to produce a final map.

Results

Climate and Topography

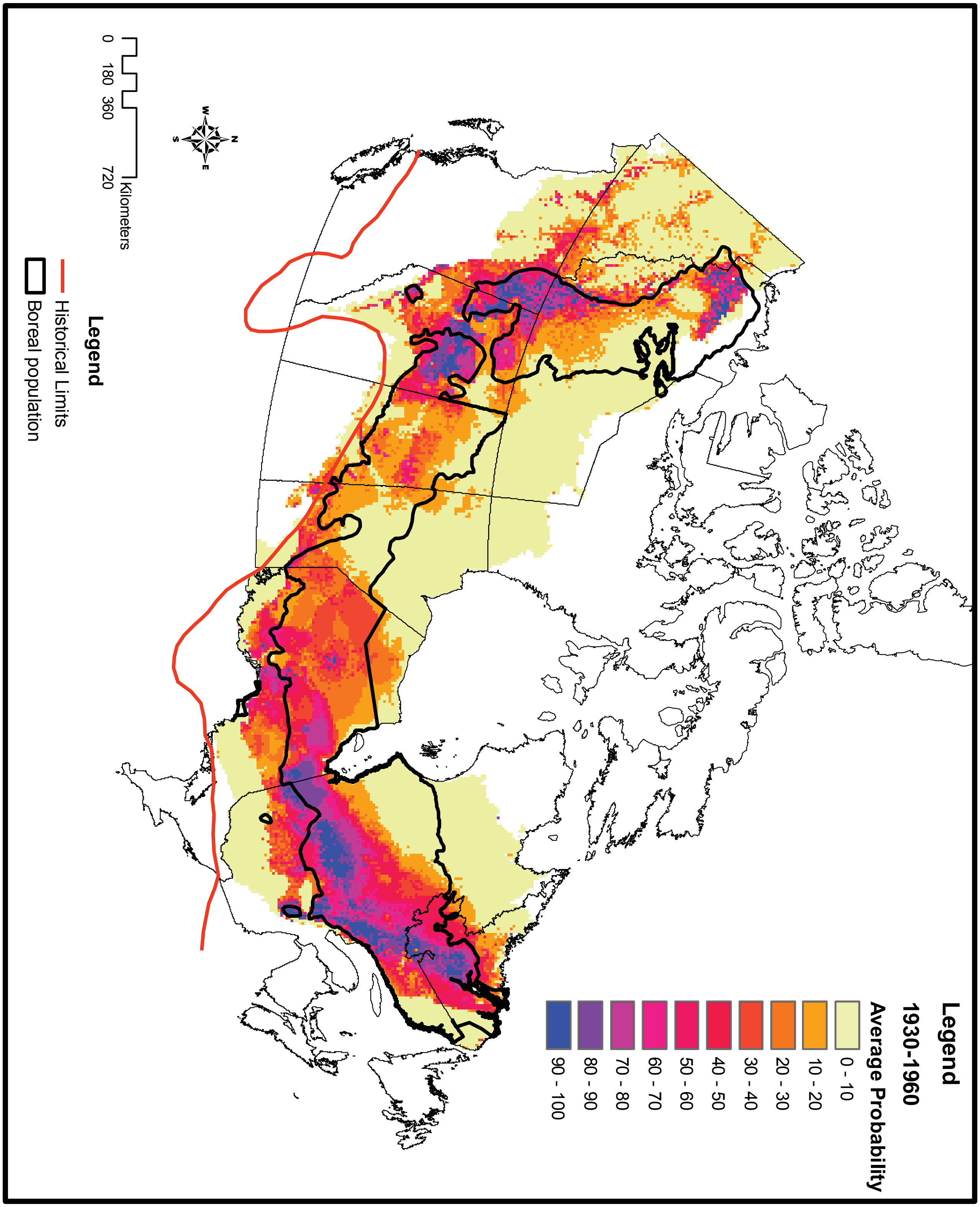
The final models included the variables listed in Table 2. Mean AUC scores among sub-samples was 0.95, indicating that the model output was significantly better than random. Figures 2 and 3 show the mean cumulative Maxent output for climate variables and topography niche models, from 1930 to 1960 and 1971 to 2000, respectively. Outputs showed that areas of highest probability in both maps correspond to areas where collar data were available to train the model (Figure 1). Similarly, areas with no training presence are not strongly predicted in either time period (e.g., areas in northern Manitoba). Visual inspection along the southern extent of the distribution suggested that the fundamental niche in Ontario and Quebec has not changed significantly over the two time periods. In Alberta, however, the potential distribution may have receded northward. The earlier distribution map suggested presence to the disjointed Little Smokey population, whereas the map from the later time period did not (Figures 2 and 3).

Appendix 6.4 - Table 3. Biotic covariates used in environmental niche models.

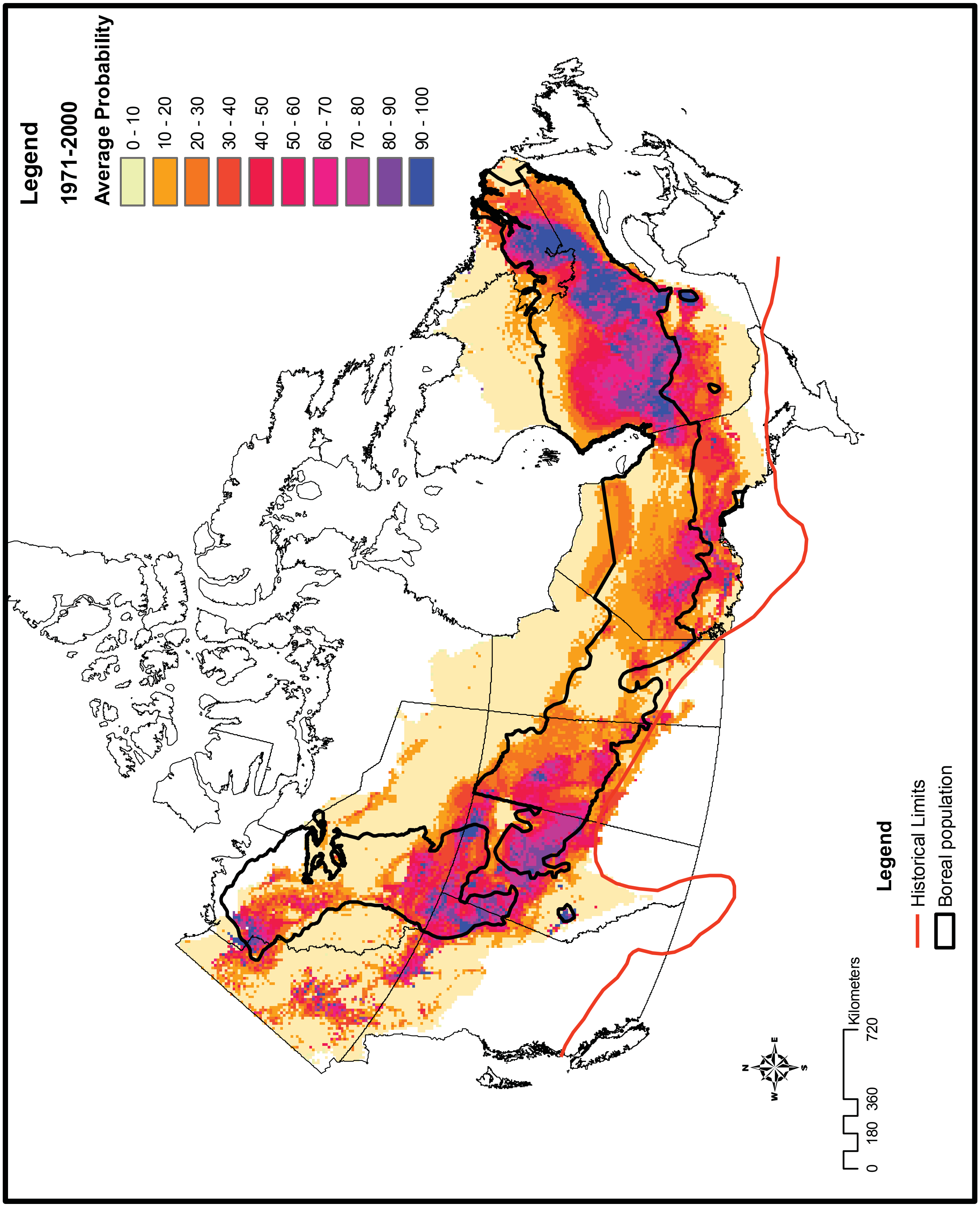
Cumulative Annual fPAR
Minimal Annual fPAR
Landcover
Peatland presence
Road Density
Anthropogenic disturbance
Mean forest patch size
Number of forest patches
Standard deviation of forest patch sizes
Elevation

Biotic Analysis

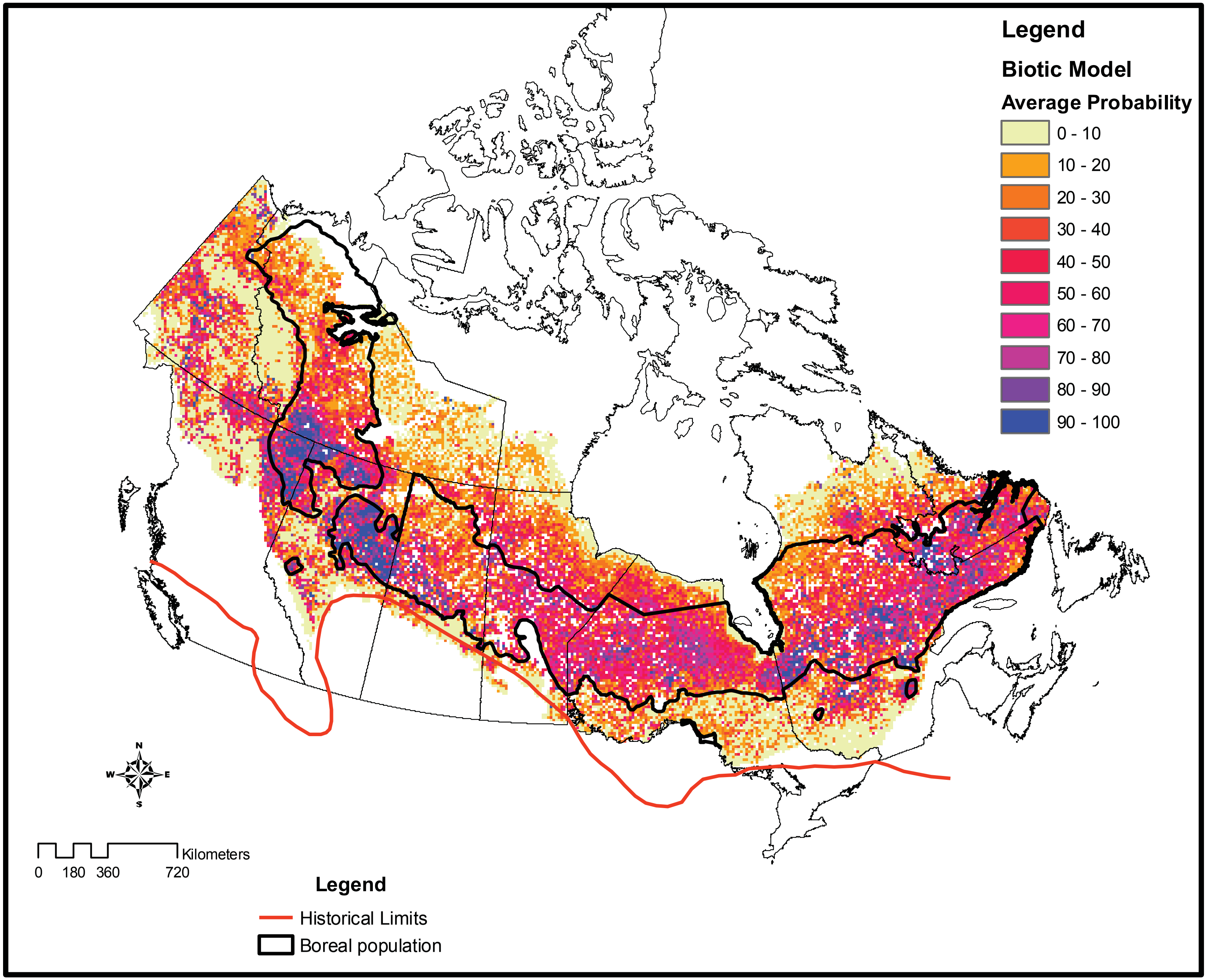
Covariates were screened for collinearity and variables included in the model are listed in Table 3. Mean AUC scores were 0.884 among the ten subsets. Figure 4 shows the cumulative MaxEnt output for the biotic models. Higher probabilities were associated with areas with high numbers of satellite collar fixes, but close examination of Alberta and British Columbia herds shows congruency with the 'Local Population' polygons in the National Recovery Strategy (Environment Canada 2007; Figure 5 a), where training data were not available. The model predicted a high probability of occurrence, consistent with the extent of occurrence across the range, with the exception of the distribution in northern Saskatchewan, northern NWT, and the northern part of the Quebec (Figures 4,5b).



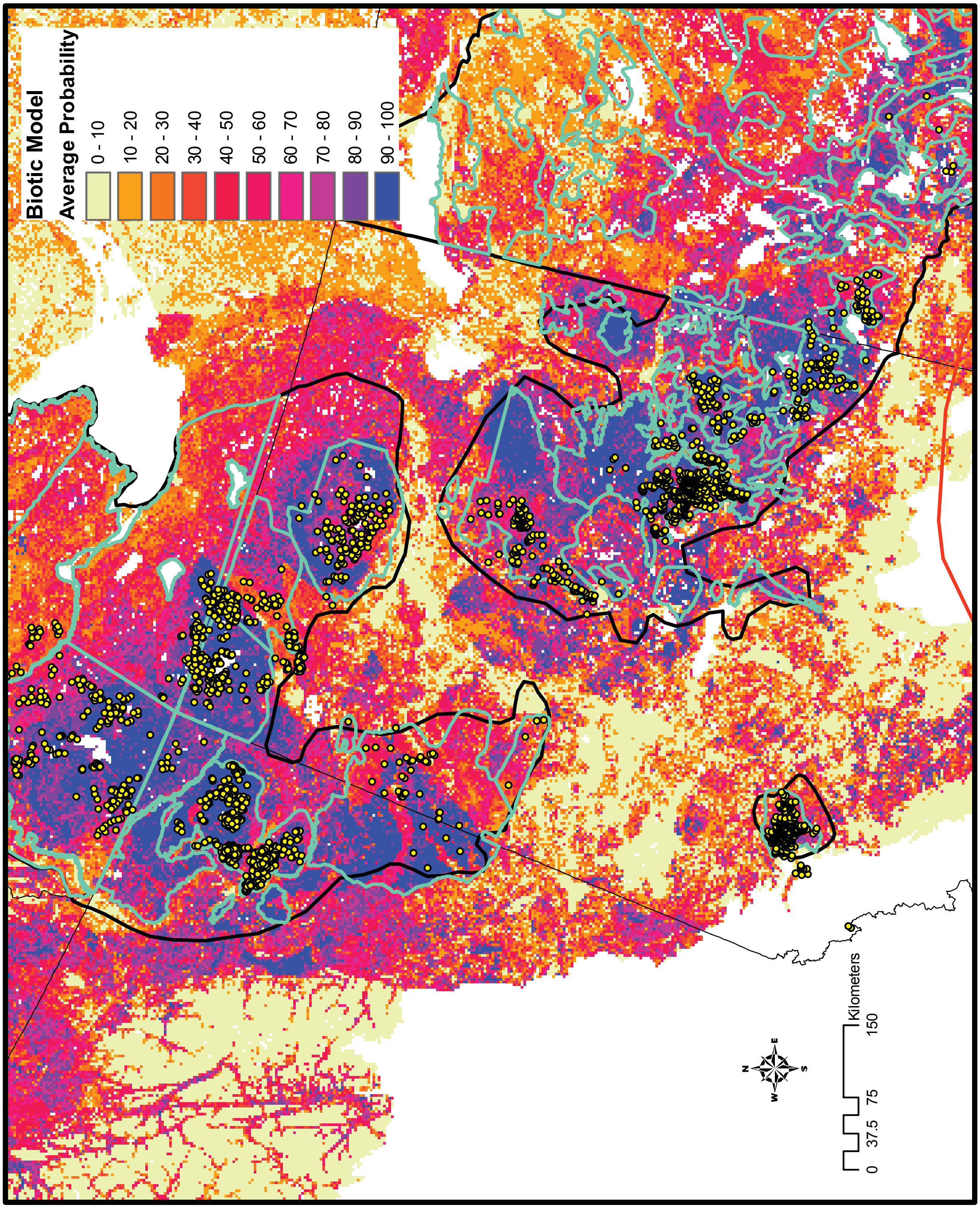
Appendix 6.4 - Figure 2. Cumulative output distributions based on climate variables from 1930-1960. Pixel values are averages from 10 sub-sample model runs.



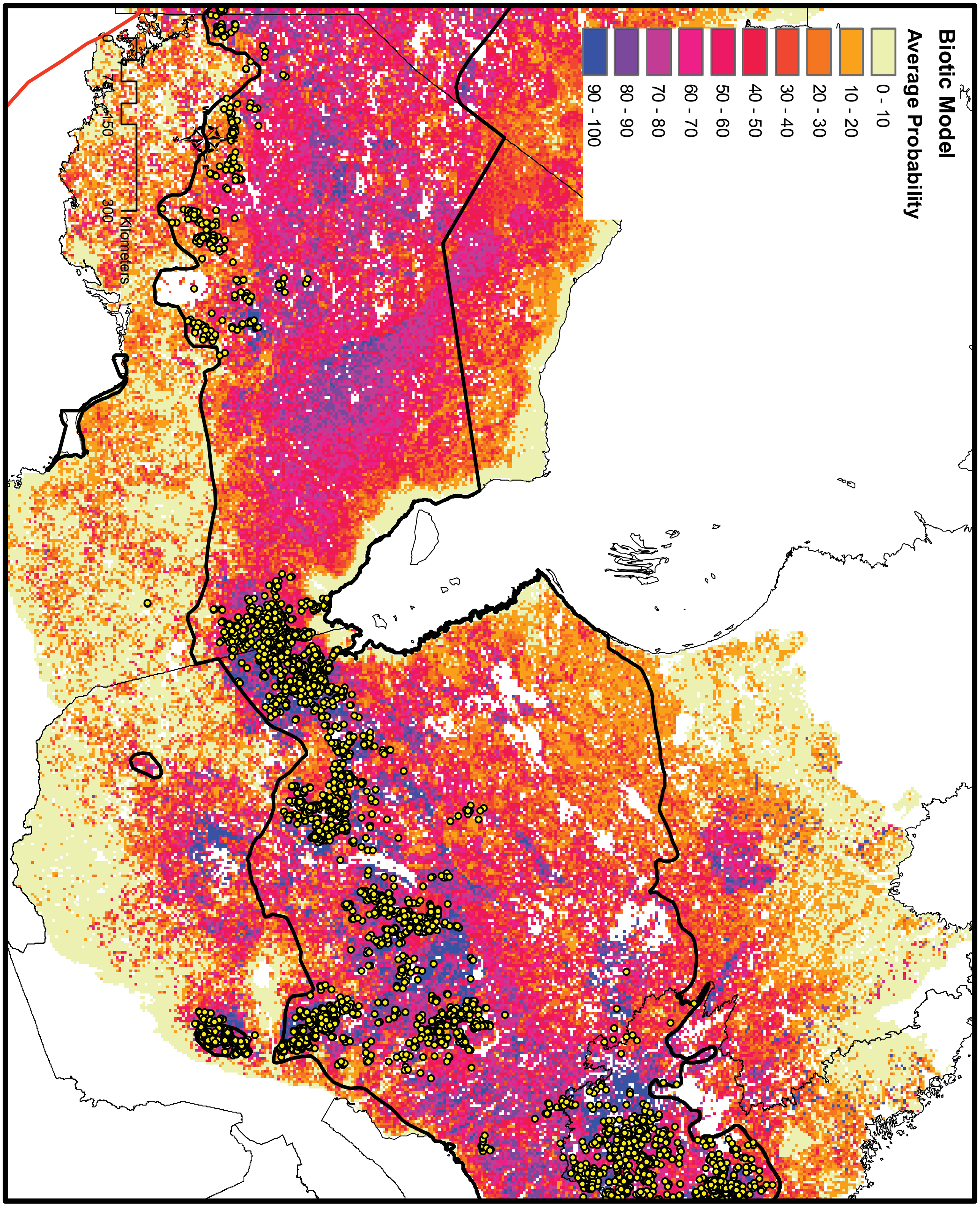
Appendix 6.4 - Figure 3. Cumulative output distributions based on climate variables from 1971-2000. Pixel values are averages from 10 sub-sample model runs.



Appendix 6.4 - Figure 4. Cumulative output from MaxEnt using biotic variables. Pixel values represent the average from 10 subset model runs.



Appendix 6.4 - Figure 5a. Biotic model output in western Canada. Light blue lines are the local population polygons from the respective jurisdictions and the yellow dots indicate collar location used for training data.



Appendix 6.4 - Figure 5b. Biotic model output in central Canada. Yellow dots indicate collar locations used for training data.

Discussion

We found support for our first hypothesis in part of the country but not everywhere. For example, the fundamental niche, or potential distribution, of woodland caribou may have contracted marginally along its southern frontier in Alberta and Saskatchewan. Thus, some minor range contraction may have occurred in these regions owing to climate change in the past 30 years. In Ontario and Quebec, however, the fundamental niche has remained relatively constant and, based on mid-20th century climate data, does not extend to the southern extent of the Boreal Shield Ecozone, as is suggested by the historical distribution of woodland caribou. Our study design called for training datasets to be compiled using radio-tagged animals owing to the large datasets available and the wide geographic distribution across the extent of occurrence, but these data did not exist for the entire time period. Improved estimates of the historical fundamental niche may come with inclusion of other types of locational data (e.g., not telemetry) consistent with the period, which may include animals outside (south) of the current distribution. It is possible that the more southerly habitats comprised a different biophysical fundamental niche space that is not captured in current distribution of animals.

Our second hypothesis that the realized niche is smaller that the fundamental niche was supported in some parts of the country. In Ontario, for example, Figure 3 shows continuous areas of potential habitat for caribou as far south as the entire north shore of Lake Superior, including Pukaskwa National Park. Figures 4 and 5b revealed that areas of potential continuous occupancy that should otherwise be suitable are restricted to some 200-300 km north of the lake, consistent with the current extent of occurrence. A remnant population of boreal caribou exists in Pukaskwa National Park, likely because conditions suitable for their survival continue to persist along the lakeshore, inside the Park. However, forest management of the landscape between the Park and the current more northerly extent of occurrence has eliminated other suitable habitats (Vors et al. 2007). Our results also suggested that some patches of potential habitat exist in this latter area and that movement of individuals between the present continuous extent and Pukaskwa Park may be possible. Refinement of these types of models may help to identify potential areas for connectivity and help determine priority areas for potential rehabilitation via landscape management.

Other studies have modelled population extirpations using niche models by combining climate variables and landcover data (Peterson et al. 2006). Climate, vegetation, and elevation datasets are often related (Hutchinson 1998). For example, in Canada, ‘greener’ areas get higher rainfall and also have higher temperatures (Ichii 2002). Elevation also shows a close relationship to temperature but the nature of this relationship is variable in space and time (Ichii 2002). Our analysis demonstrated correlation among many climate parameters used as predictor variables for caribou and the annual fraction of Photosythetically Active Radiation (fPAR) from MODIS, as expected. Inclusion of climate parameters (at 1-km resolution) in the ‘realized’ niche models effectively ‘washed out’ the precision of the predictions. In the climate surfaces, pixel values are interpolated from weather station data, whereas satellite-derived data are collected such that a systematic measurement is taken for each pixel. Based on consistent and recent coverage by remote sensing, 1-km biotic variables should reflect spatial and temporal variation at a higher resolution than the climate data and satellite based models will be more representative of current distribution boundaries (Parra et al. 2004). Within the range of a species, satellite-based models should have less over-prediction (commission error), or higher specificity, that is, higher probability of correctly predicting a cell as absent (Peterson et al. 2004, Parra et al. 2004). Further reduction of commission errors in the biotic models may come from exclusion of old locality records that reflect available habitat at a previous time, but which may have been recently altered. Our training dataset was limited to point locations from the last 20 years to be consistent with timelines used in other areas of the document (Environment Canada 2007), whereas the biotic variables were more recent (last 5 years). Industrial activities that are probably deleterious to caribou populations have increased drastically in some areas over the last 20 years (McKenzie 2006). Restricting location data to be temporally consistent may improve performance of the satellite-based models.

Somewhat unique to our realized niche models was the inclusion of data (disturbance, road density, fragmentation parameters) to account for top-down or predator interactions in limiting species distributions. Hutchinson's n-dimensional niche concept suggested that a species will occupy areas of the fundamental niche where the species is competitively dominant. However, interspecific competition also needs to be considered (Pulliam 2000). Evidence suggests that predation is a major factor in boreal caribou population dynamics and probability of persistence and thus should be considered when modelling caribou habitat occupancy (Sorenson 2008). Many recent satellite-based initiatives and worldwide efforts to maintain access to high quality space-based vegetation data ensure that the economic and timely availability of resource type information for modelling at broad geographic scales is secure (Yang et al. 2006). However deriving accurate and time-specific disturbance layers, such as linear feature density or other industrial activities at the scale required, is difficult and expensive. Improvement in the derivation and inferential capacity of these data and better relationships defining the spatial and temporal scale at which these top down predator interactions occur in caribou populations may improve the occupancy predictions.

A major limitation to any analysis, such as ours, is the geographic bias of locational data available to train the model (Peterson and Cahoon 1999, Johnson and Gillingham 2008, Phillips 2008). Our study design employed many protocols cited to improve model accuracy and reduce bias on model outcomes, including filtering of GPS collar data (Rettie and McLoughlin, Friar et al. 2004), random subsetting and multiple model runs (Araujo and New 2006), and ecological stratification (Reese et al. 2005, Aroujo and Guisan 2006). Nonetheless, despite the large contributions of locational data from across the country, the extent of occurrence as outlined in Environment Canada (2007) is not completely sampled (Figure 1). The location of sampling areas highlights another important bias demonstrated, in theory and practice, to affect the outcome of niche modelling. Most studies have been done on caribou populations at the southern end of the range, while other studies have been conducted on low and/or declining populations (Environment Canada 2007). Niche theory and studies performed using environmental niche models suggest that to improve accuracy of predictions, known sink populations should not be included since this habitat may represent marginal niche space (resources and conditions) for viable populations (Pulliam 2000, Soberon 2007). Sample selection bias due to sampling effort (accessibility) has been shown to dramatically reduce the predictive performance of presence-only models, such as MaxEnt (Phillips 2008). Improved sampling design to represent the entire geographic distribution and attempting to capture the entire niche space of boreal caribou would improve overall model performance and value of the outputs (Jimenez-Valverde and Lobo 2006).

In summary, preliminary results using environmental niche models to study the distribution of boreal caribou at broad scales are important to support Critical Habitat Identification. Species distribution models are increasingly used in conservation planning and management of rare or threatened species to understand the patterns and processes of occurrence on the landscape. The National Recovery Strategy delineates the extent of occurrence of boreal caribou and suggests that some portions of the shaded area (Figure 1) have higher probability of caribou occurrence than others (Environment Canada 2007). The strategy also considers local populations of boreal caribou to be the fundamental units of conservation and management for recovery and action planning. Further refinement and more rigorous validation of the models presented here would contribute to understanding the areas of occupancy and local population ranges within the larger extent of occurrence. The vital rates required for management and recovery of boreal caribou are difficult to obtain because of the large areas that the animals occupy and the low densities at which they exist and because the forested areas that they occupy are difficult to survey with traditional aerial techniques (Environment Canada 2007). Spatial predictions from niche-based distribution models may be used to stratify sampling to increase efficiency. The new data can then be used to improve the original model and performed repeatedly. Such an adaptive process would refine predictions and support management and recovery of local populations at a regional scale. A large range of techniques now exists to predict species distributions, and various studies have demonstrated the predictive capability and accuracy with various types of species and input data availability (e.g. Elith et al. 2006). Presence-only models, such as MaxEnt, may be the most appropriate for rare or threatened species, and caribou in particular, because absences are not likely actual absences but false negatives. Future analyses will focus on model comparisons and reducing data bias to accurately predict boreal caribou occupancy across its extent of occurrence.

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6.5 A National Meta-analysis of Boreal Caribou Demography and Range Disturbance

Preface

A key step in the critical habitat identification process is determining attributes of a caribou range that support or compromise population persistence (e.g. the ability of the range to support a self-sustaining population). This meta-analysis compiled demographic data from boreal caribou populations across Canada to evaluate the hypothesized relationship between caribou population parameters and levels of anthropogenic and/or natural (fire) disturbance on caribou ranges. Results from this work provide quantitative guidelines for one of the three assessment criteria (range disturbance) used in the evaluation of local populations for critical habitat identification.

Introduction

Woodland caribou (*Rangifer tarandus caribou*) are designated a species-at-risk nationally, and in most provinces and territories within their range, due to broad-scale range recession and population declines, in large part associated with human settlement and disturbance (Bergerud 1974, Mallory and Hillis 1998, Schaefer 2003, Vors et al. 2007). This species is closely associated with late-successional coniferous forests and peatlands (Rettie and Messier 2000). These forests are a source of lichens, which comprise the bulk of woodland caribou diet – particularly in winter – but lichen availability is generally not considered a limiting factor (Schaefer and Pruitt 1991, Joly et al. 2003, Courtois et al. 2007). More importantly, these forests provide refugia from predators and other ungulates (Bergerud and Elliott 1986). Many woodland caribou populations are in decline, and the proximate cause is thought to be increased predation. Logging and other disturbances that increase the amount of early seral-stage forest promote higher densities of prey species such as moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*), which support higher predator densities, especially wolves (*Canis lupus*) (Bergerud and Elliott 1986, Seip 1992, Stuart-Smith et al. 1997, Racey and Armstrong 2000, Wittmer et al. 2005, 2007). In addition, linear disturbances (e.g. roads, seismic lines) that accompany industrial development in the boreal forest facilitate greater predator mobility and hunting efficiency (James and Stuart-Smith 2000, Dyer et al. 2001, McLoughlin et al. 2003, James et al. 2004). Boreal caribou, an ecotype of woodland caribou, are declining throughout much of their North American range (McLoughlin et al. 2003). Given the increasing levels of industrial development in previously pristine areas, preventing or mitigating further population declines is increasingly the focus of management efforts.

In this study, a simple question is posed: is there a clear relationship between caribou demography and anthropogenic and/or natural (fire) disturbance levels on caribou ranges across the distribution of boreal caribou in Canada? We expected that adult survival, calf recruitment and overall population growth would be negatively related to changes that create favorable habitat for moose and deer, in keeping with the logic that increased primary prey increases predator density which contributes to caribou population decline. Caribou avoidance of industrial development (Bergerud 1974, Mallory and Hillis 1998, Dyer et al. 2001, Schaefer 2003) and recent burns (Schaefer and Pruitt 1991, Joly et al. 2003, Dunford et al. 2006) have been well documented; thus it is reasonable to postulate that these factors would negatively affect range condition with respect to the ability of an area to support a self-sustaining local population. Wittmer et al. (2007) found that the variation in adult female survival among 10 woodland caribou populations of the arboreal lichen-feeding ecotype was best explained by range condition. Further, in a review of 85 studies that examined impacts of human activity on caribou, Vistnes and Nellemann (2008) concluded that choice of spatial scale for examining impacts strongly influenced conclusions, recommending that accurate assessment required regional-scale studies. Finally, in a recent analysis of 6 boreal caribou populations in Alberta, Sorensen et al. (2008) demonstrated a negative relationship between range condition and population growth rate. Their 2 variable model, which included level of anthropogenic disturbance (%IND) and wildfire (%FIRE), explained 96% of the variation in caribou population growth rates. Hence, our selection of caribou range as the appropriate unit of analysis is justified.

The Sorensen et al. (2008) regression model represents a significant advance in our understanding of the effects of disturbance on caribou demography at the level of population ranges. However, the study was based on a small sample size and a limited range of values for anthropogenic disturbance (e.g. the minimum level of anthropogenic disturbance was 31.6%). As a result, while the data were sufficient to demonstrate significance in terms of a relationship between the dependent and independent variables, the model has limited scope for prediction beyond the geographic area and parameter space included in that study, and should be used cautiously within that region when predicting minimum levels at which negative effects on caribou population growth might occur. The objective here was to extend the Sorensen et al. (2008) analysis to populations of boreal caribou across Canada, in order to test whether the relationship documented was robust across a broader spectrum of range conditions, and guide evaluation of the ability of ranges to support self-sustaining populations. Original work on this study was initiated in 2006, as part of an independent effort to address this question. Augmentation and refinement of this effort was undertaken in conjunction with the Environment Canada scientific review of critical habitat for boreal caribou.

Methods

Data collection – caribou

Researchers and management agencies were approached to supply demographic information on woodland caribou populations that had been studied for a minimum of two years (the smallest interval included in Sorensen et al. 2008), and for which adult female survival (as determined by radio-telemetry monitoring) and/or calf recruitment (late winter calf/cow population surveys) had been measured. The intent was to assemble data that exhibited a broad range of variation with respect to geography and degree of anthropogenic change to population ranges. A tabular data survey with instructions was circulated to potential contributors. Information on 25 boreal populations from 7 provinces and 1 territory was acquired (Figure 1). There was considerable variability in the intensity and duration of sampling, and availability of ancillary information.

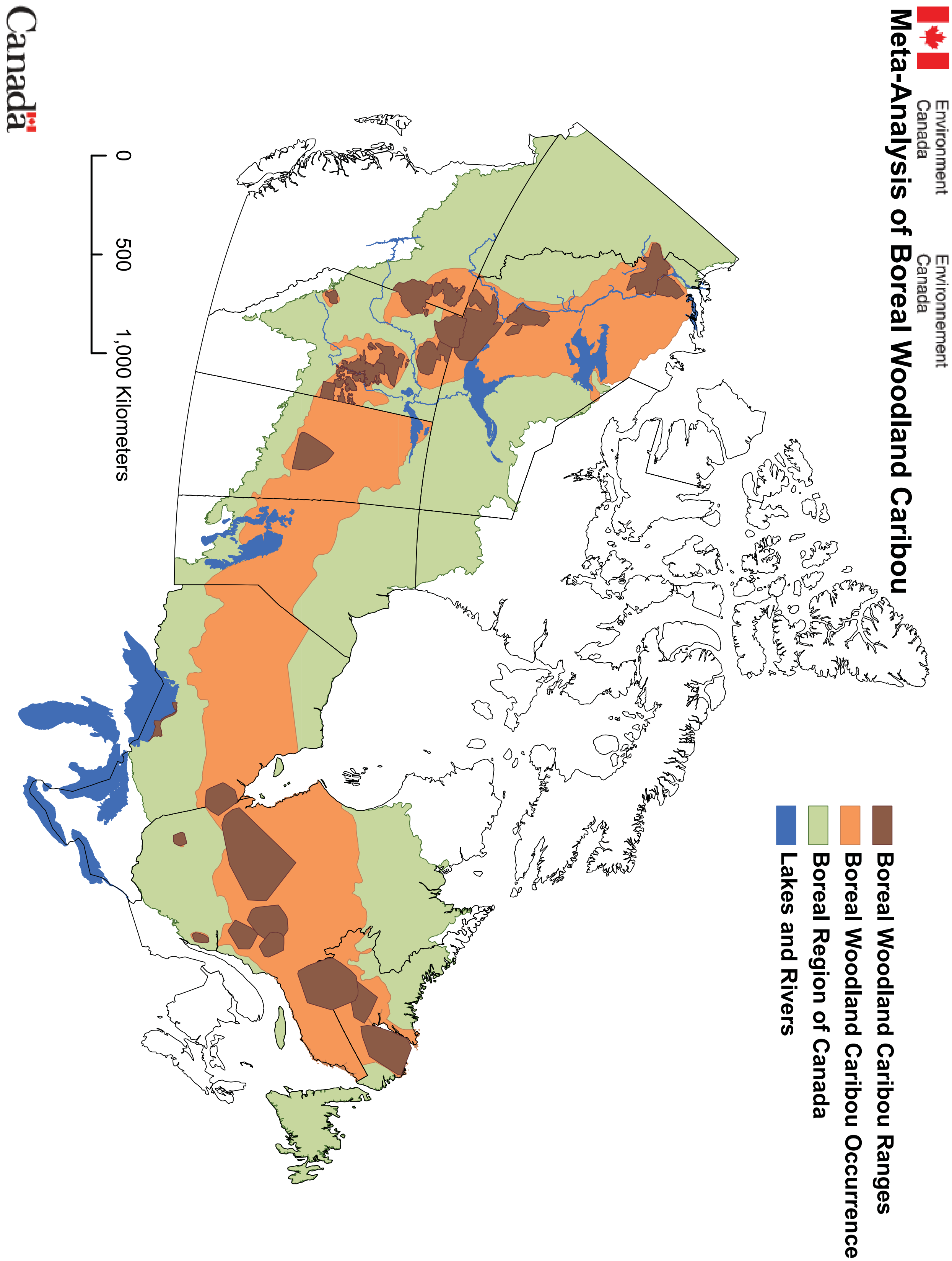
Estimates of population condition

Of the 25 populations included in this study, data for assessing female survival and therefore estimating population growth rates were available for 15 (Table 1). Some populations had only a small number of female caribou collared and concomitant high variability in estimated survival. Therefore, to maximize the number of populations available for analysis, estimates of recruitment rates, which were available for all populations, were used as a surrogate of ‘population condition’. Bergerud and Elliot (1986, 1998) demonstrated that recruitment was directly related to population rate-of-growth in caribou, as well as in other ungulates. Furthermore, recruitment may be a better short-term indicator of population condition in rapidly changing landscapes than either female survival or population growth rate, given that calves are more susceptible to predation than adults, and high adult survival could initially mask the negative effects of landscape change.

To test the relationship between recruitment and population growth, and the appropriateness of using recruitment as the response variable to range condition in the regression analysis, data from the subset of populations for which recruitment and survival were available were used to estimate population rate of change (λ) following Hatter and Bergerud (1991); see also McLoughlin et al. (2003) and Sorensen et al. (2008). However, because averages and not annual data were provided for some local populations, an arithmetic, rather than geometric mean (McLoughlin et al. 2003. Sorensen et al. 2008) was used to estimate average values for each parameter over the years of study included for each population (Table 1). Data for some populations were sub-sampled to be temporally consistent with available data on landscape change; in particular, to avoid inclusion of demographic data that potentially preceded the change. Also, some populations with long-term data exhibited trends suggesting that an average over the entire sampling interval was not representative of the current population condition. Where available, up to 4 years of most recent data, spanning a maximum sampling interval of 5 years, and with greatest temporal correspondence to the landscape change data, were used to estimate demographic parameters for analysis (Table 1). The 6 Alberta populations included in Sorensen et al. (2008) were also included in this study; however, the sampling intervals differed (1993-2001 vs. 2002-2006). Thus, it was possible to also evaluate the relationship between recruitment and population growth for a second subset of temporally non-overlapping data, based on Sorensen et al. (2008).

Delineation of population ranges

Range boundaries were provided by contributors for study populations, obtained from provincial or territorial sources for jurisdictionally-recognized population ranges, or generated from 100% minimum convex polygons (MCPs) of telemetry data provided by contributors. Delineation method is indicated in Table 1 and illustrated in Figure 1. Where a study population



Appendix 6.5 - Figure 1. Location of 25 boreal caribou populations included in this study.

corresponded closely to a jurisdictionally recognized range (e.g. ≥90% correspondence), the data were considered representative of the range, and the jurisdictional boundary was used for population delineation and characterization of range condition.

Characterization of range condition and model specification

Following Sorensen et al. (2008), the relationship between recruitment and range condition was evaluated by comparing three candidate models. Model 1 considered the percent of the range area burned within the past 50 years of the most recent recruitment data for each population. Fire data from the Canadian Large Fire Database, augmented by additional coverage for the Northwest Territories, that contained wildfires >200 ha (NRCan 2008, GNWT 2008) were used. Model 2 considered the percent of the range area affected by anthropogenic disturbance, based on GIS layers obtained from Global Forest Watch Canada (GFWC). GFWC have compiled the only available, nationally-consistent coverage of anthropogenic disturbance across forested regions of Canada. All visible linear and polygonal anthropogenic disturbances were digitized from Landsat images from the period 1985–2003, and combined with additional coverage of roads, reservoirs and mines from databases spanning the period 2002-2006. Linear disturbances included roads, railroads, seismic lines, pipelines, and utility corridors; polygonal features included recently anthropogenically-converted areas such as settlements, populated industrial areas, croplands (both new and abandoned), reservoirs, cutblocks, and mining activity. All features in the database were buffered by 500 m to create a “zone of influence”, and merged to create a non-overlapping coverage of all anthropogenic disturbances. Detailed methodology is available from Lee et al. (2006). Sorensen et al. (2008) used a 250-m buffer when quantifying human disturbance. However, we did not have access to the raw data used in the GFWC analysis, so could not select an alternate or varying buffer width. Nevertheless, in a review of reindeer and caribou response to human activity from regional-scale landscape studies, Vistnes and Nellemann (2008) report reduced use by caribou of areas within 5 km of infrastructure and human activity, thus the 500-m buffer is not unreasonable. Lastly, Model 3 considers the combined effect of fire and anthropogenic disturbance, herein termed total disturbance.

Characterization of total disturbance and modeling procedure

Sorensen et al. (2008) used a 2 variable model to characterize total disturbance (%FIRE and %IND); however, they found a relatively high correlation between these 2 variables (Pearson correlation of 0.69) which tends to produce least-squares estimates that are exaggerated in absolute value (Montgomery et al. 2001). Multi-colinearity between these 2 variables could also influence parameterization because of the likely non-linear relationship between the proportion of area disturbed and the level of spatial overlap. Specifically, at low levels of disturbance the spatial overlap is likely to be low whereas the likelihood of overlap should increase at higher levels of disturbance. Visual inspection of the data revealed such a pattern. Therefore, to describe total disturbance when testing the hypothesis of primary interest (e.g. the combined effects of fire and anthropogenic disturbance), the merged mapped of non-overlapping disturbances was used to derive a single measure of total disturbance. This

Appendix 6.5 - Table 1. Location, sampling duration, method of range delineation (J = jurisdiction; SA = study area), yearly ratio of calves per 100 cows (R), annual adult female survival (S), and rate of population change (λ) for 25 boreal caribou populations in Canada.

Local Population	Prov/Terr	Years Available	Sample	# Years	Years Used	Range	R	S	λ
Red Wine	NL	1981-1988, 1993-1997, 2001-2003	Y	3	2001-2003	J	45.4	n/a	n/a
Mealy Mountain	NL	1971, 1974-1975, 1977, 1981, 1985, 1987, 1994, 2002, 2005	Y	2	2002, 2005	J	50.3	89.0	1.19
Lac Joseph	NL	2000-2002, 2005, 2007, 2008	Y	4	2000-2002, 2005	J	34.3	n/a	n/a
Val-d'Or	QC	1987-1988, 1990-1991, 1995-2002, 2004-2005	Y	4	2001-2002, 2004-2005	J	15.3	87.0	0.94
Manicouagan	QC	1999-2001	N	3	1999-2001	J	50.5	75.0	1.00
Manouane	QC	1999-2001	N	3	1999-2001	J	28.1	86.0	1.00
Pipmuacan	QC	1999-2001	N	3	1999-2001	J	40.6	82.0	1.03
Charlevoix	QC	2000-2001,2004-2006	Y	4	2001,2004-2006	J	35.0	n/a	n/a
Jamesie	QC	2002-2003	N	2	2002-2003	SA	27.4	n/a	n/a
James Bay	ON	1998-2000	N	3	1998-2000	SA	21.3	79.0	0.88
Pukaskwa	ON	1973-1991, 1997, 1999, 2001	Y	3	1997, 1999, 2001	J	40.3	n/a	n/a
Smoothstone-Wapawekka	SK	1993-1995	N	3	1993-1995	SA	28.0	84.0	0.98
Caribou Mountain	AB	1995-2007	Y	4	2003-2006	J	17.4	75.0	0.82
ESAR	AB	1994-1997, 1999-2007	Y	4	2003-2006	J	13.4	86.6	0.93
Red Earth	AB	1995-1997, 1999-2007	Y	4	2003-2006	J	13.6	81.9	0.88
WSAR	AB	1994-2007	Y	4	2003-2006	J	20.9	84.2	0.94
Little Smoky	AB	2000-2007	Y	4	2003-2006	J	12.3	82.2	0.88
Cold Lake	AB	1999-2002, 2004-2007	Y	4	2002, 2004-2006	J	12.6	83.8	0.89
Chinchaga	AB	2002-2007	Y	4	2003-2006	J	13.9	87.0	0.93
Snake-Sahtaneh	BC	2004-2005	N	2	2004-2005	J	7.2	94.0	0.97
Cameron Hills	NWT	2006-2008	N	3	2006-2008	SA	16.4	n/a	n/a
Dehcho North	NWT	2006-2008	N	3	2006-2008	SA	20.7	n/a	n/a
Dehcho South	NWT	2006-2008	N	3	2006-2008	SA	32.3	n/a	n/a
GSA South	NWT	2004-2006	N	3	2004-2006	SA	28.9	n/a	n/a
GSA North	NWT	2005-2006	N	2	2005-2006	SA	45.4	n/a	n/a

method captured the required information from each variable while accounting for the spatial overlap, and increased the power of the test by reducing the number of variables in the model.

Linear regression and related diagnostics were used to test the relationship of recruitment to each measure of range condition specified by the three models. Similarly to Sorensen et al. (2008), herds were considered to be independent and Akaike's Information Criteria (AIC) with correction for small sample sizes (AICc) was used to test between the three candidate models (Burnham and Anderson 1998).

Results

Estimates of population condition

Recruitment was positively correlated with population rate of change for both the subset of data evaluated here ($r=0.75$; $p<0.01$) and the Sorensen et al. (2008) data ($r=0.63$; $p<0.01$). Regression analysis yielded very similar constants and coefficients (Table 2). Recruitment was not correlated with adult female survival in either data set. Exploratory analysis of the subset of 15 populations further revealed recruitment to be more sensitive to % anthropogenic disturbance and % total disturbance than either adult female survival or population growth rate. Use of recruitment as an index of population condition for subsequent analyses of main models therefore seems reasonable.

Appendix 6.5 - Table 2. Regression statistics for analysis of mean annual recruitment versus population growth rate for a 15 population subset of data compiled for this study and 6 Alberta populations included in Sorensen et al (2008).

Data Source	R^2	β0 intercept	SE	*P*	β_1 (X_1)	SE	P
15 population subject	0.56	0.84	0.030	<0.001	0.005	0.001	0.001
Sorenson et al. (2008)	0.40	0.84	0.033	<0.001	0.007	0.002	<0.001

Regression diagnostics and data selection for main models

For the full data set, outliers were examined visually and tested for leverage and influence (leverage versus normalized residual squared plots) with DFBETA (STATA 8.0), which assesses how the coefficient is affected by deleting each of the observation values (values exceeding 2/sqrt n = 0.4 are of concern). Only Charlevoix had a DFBETA value above the model cut-off in Model 3 (Charlevoix DFBETA = 0.70). Given that was the only data point that significantly affected estimation of the regression coefficient, and that it was also the sole reintroduced population, it was excluded from further analyses.

There was no evidence of heteroscedasticity in the residuals of any of the models (White's test and Breusch-Pagan test, STATA 8.0). Residuals from Models 1 and 2 met conditions of normality; however, residuals from Model 3 significantly deviated from normality (Shapiro-

Wilk test of normality, $P = 0.01$). Log transformations of the variable total disturbance were considered, as well as the addition of a squared term, to examine potential non-linear forms of the relationship. Neither of these options increased the fit of the model. Therefore, the linear form was retained due to ease of interpretation, and a lack of knowledge concerning the true form of the underlying distribution.

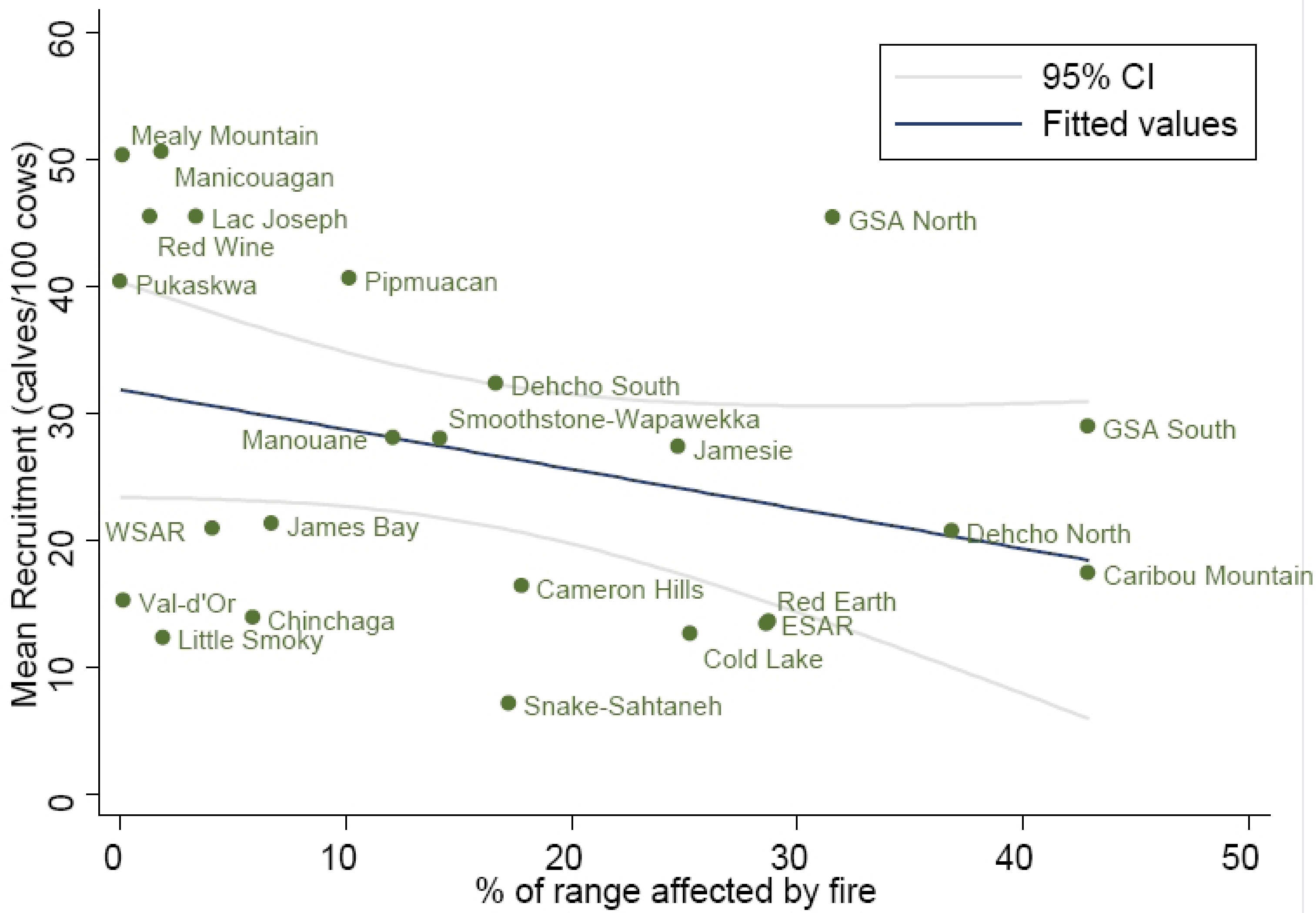
Regression results

There was no significant relationship between caribou recruitment rate and the percent area disturbed by fire alone ($F_{1,22} = 2.52$, $p = 0.13$; Model 1, Table 3; Figure 3). However, there were significant negative relationships between recruitment and the percent area affected by anthropogenic disturbance ($F_{1,22} = 20.21$, $p < 0.001$; Model 2, Table 3; Figure 4) and with the merged measure of total disturbance ($F_{1,22} = 34.59$, $p < 0.001$; Model 3, Table 3; Figure 5). Model 3, the measure of total disturbance, had the lowest AICc value and best fit with population recruitment rates (Table 3, Figure 5).

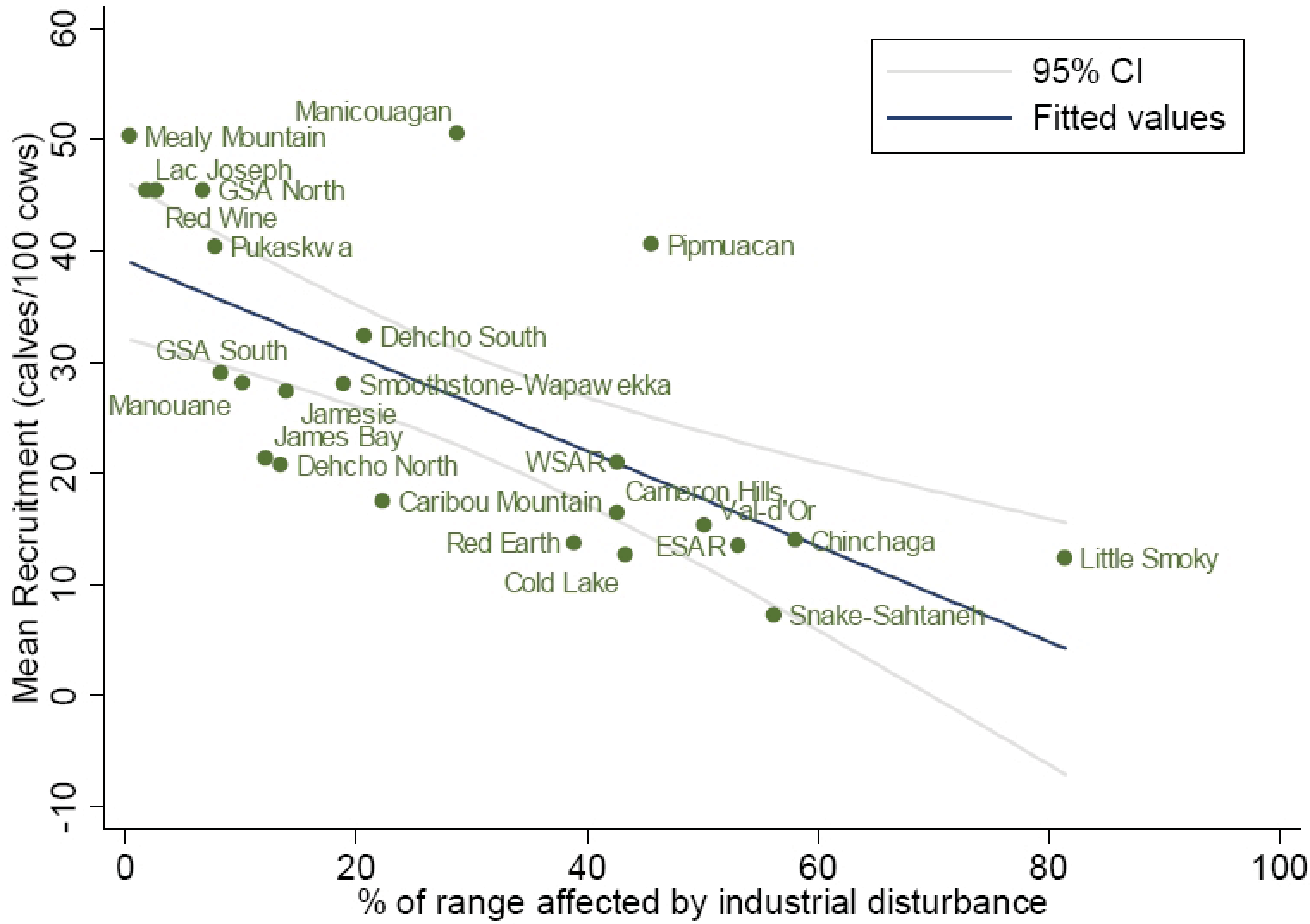
Appendix 6.5 - Table 3. Regression statistics for analysis of mean annual recruitment versus parameters of range disturbance for boreal caribou populations across Canada (n=24).

Model	R^2	β0 intercept	SE	*P*	β_1 (X_1)	SE	*P*	AIC_c
1 - % fire	0.10	31.86	4.10	<0.001	-0.31	0.20	0.13	54.81
2 - % anthropogenic	0.49	39.13	3.40	<0.001	-0.43	0.10	<0.001	49.15
3 - % total disturbance	0.61	46.37	3.75	<0.001	-0.49	0.08	<0.001	46.09

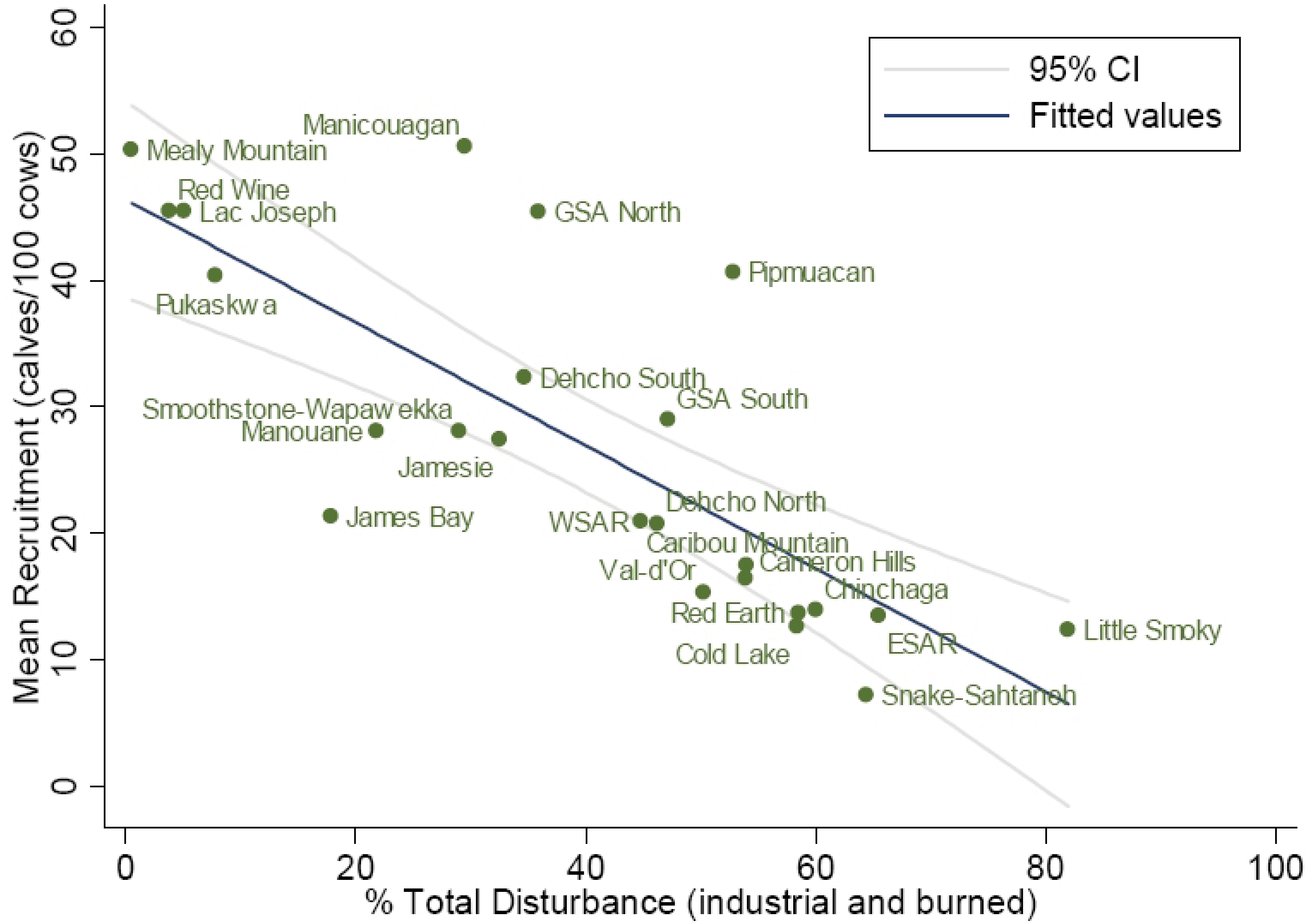
There was no clear pattern between the size of population ranges or study areas and the observed relationship between recruitment and total range disturbance (Figure 6).



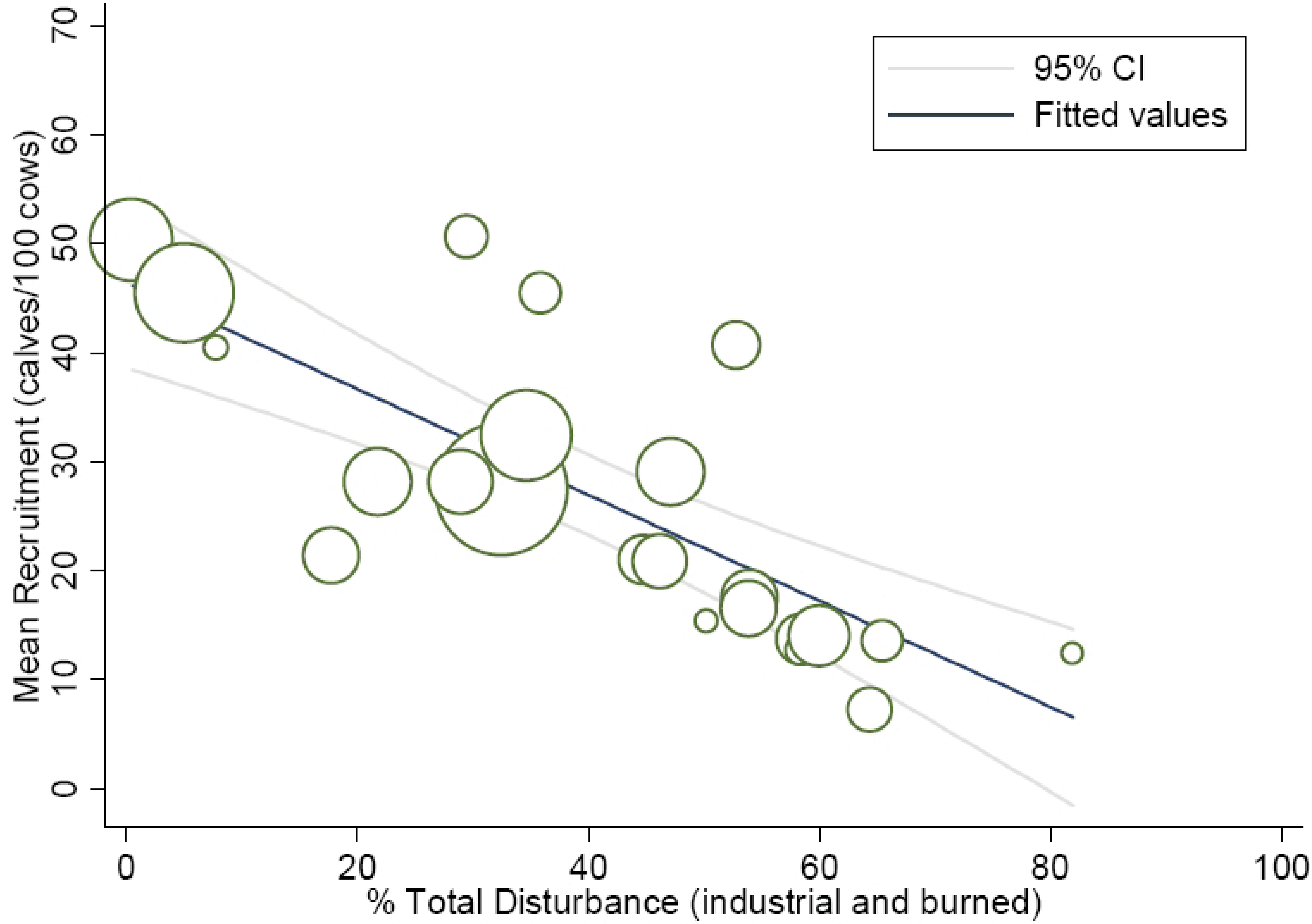
Appendix 6.5 - Figure 3. Linear regression of mean caribou recruitment versus the percent of range disturbed by fire within 50 years of the most recent demographic data (n = 24). The relationship is not significant (P=0.13).



Appendix 6.5 - Figure 4. Linear regression of mean caribou recruitment versus the percent of range affected by anthropogenic disturbance (n = 24).



Appendix 6.5 - Figure 5. Linear regression of mean caribou recruitment versus the percent of range affected by fire and anthropogenic disturbance, accounting for spatial overlap of the variables (n = 24).



Appendix 6.5 - Figure 6. Linear regression of mean caribou recruitment versus the percent of range disturbed by fire and anthropogenic disturbances, accounting for spatial overlap of the variables (n=24). The size of circles represents the relative size of individual ranges or study areas (see Table 1).

Discussion

This is the first analysis of caribou demography and range disturbance at the scale of the national distribution of boreal woodland caribou in Canada. We found a clear negative relationship between caribou recruitment, as measured by calf/cow ratios, and the level of disturbance within caribou ranges. Total disturbance (non-overlapping burn and anthropogenic disturbance) was the best predictor of boreal caribou recruitment rates. As in Sorensen et al. (2008), the extent of anthropogenic disturbance appeared to be the main driver of this relationship, also reflecting results from other studies where the level of anthropogenic disturbance influenced caribou distribution and persistence (Courtois et al. 2007, Schaefer and Mahoney 2007, Vors et al. 2007, Wittmer et al. 2007).

The relationship between recruitment rate and proportion of range disturbed by fire was less clear. The percent area burned within caribou ranges was not a significant predictor of recruitment rate by itself, but its merger with the anthropogenic disturbance layer did improve model fit. Similar to anthropogenic disturbances, fires affect the amount, composition and age structure of forest available to caribou, although the effect on configuration may be different; that is, disturbance by fire tends to be more aggregated and thus result in less fragmentation of remaining areas (e.g., Schmiegelow et al. 2004). Spatially, fires are represented as polygons of disturbance without consideration of severity; however, fires in boreal forests are highly variable, and often result in mosaics of burned and unburned patches within the mapped fire boundary (Smyth et al. 2005, Schmiegelow et al. 2006). This variability is likely to result in differential effects on habitat quality for caribou, dependent on their immediate effects on lichen and other forage, the post-disturbance trajectory of burned areas, and the indirect effects of disturbance by fire on habitat suitability and resultant numerical response by predators and apparent competitors. Nevertheless, the main question is how disturbance by fire differs from anthropogenic disturbances with respect to demographic response by caribou. In this regard, a conspicuous difference is the absence of linear features in naturally disturbed areas. As a result, fires are unlikely to elicit the functional response by predators attributed to increased travel and hunting efficiency in association with linear anthropogenic disturbances (James and Stuart-Smith 2000, James et al. 2004, Dyer et al. 2001, McLoughlin et al. 2003). They are many other aspects that could be examined, such as post-disturbance successional trajectories following fire or harvest, but comprehensive treatment is beyond the scope of the present exercise.

One methodological consideration is the 50-year window for quantifying disturbance by fire. The 50-year interval is consistent with Sorensen et al. (2008), and with the anticipated duration of effects on caribou from several studies (Klein 1982, Schaefer and Pruitt 1991, Dunford et al. 2006), but represents a discrete cut-off when extracting the disturbance data. For example, a large fire that burned 51 years before the last year for which demographic data were available would not have been included in the disturbance estimate for that local population range. Similarly, 49 year-old and 1 year-old fires were considered identical within a range, and no consideration was afforded across ranges to potential variability in the duration of impacts. Future analyses should consider a variable or moving window for measuring this disturbance at the level of individual ranges, and given the large geographic extent over which the species is distributed, where possible incorporate information on variability in post-fire regeneration and recovery.

Measures of both anthropogenic and natural disturbance in this study were arguably conservative, due to a requirement to use nationally-standardized data sets. The Global Forest Watch Canada data were restricted to detection of features readily identified from mid-resolution satellite imagery (1:40,000–1:50,000 scale; overall pixel resolution of 28.5 m), and the Canadian Large Fire Database includes only fires >200 ha in size. Thus, narrow and small disturbances were not captured. Furthermore, the most recent anthropogenic disturbance data included were to 2005, and some features were current only to 2003. Effort was made to match demographic data to the disturbance layers; however, data availability was a constraint. In ranges experiencing high rates of change, the level of disturbance may have been underestimated, particularly when demographic data were very recent. Regardless, the strength of our analyses includes the standardization of disturbance measures across ranges, and the repeatability of the procedure. Finally, while our analyses revealed some fundamental relationships with a parsimonious explanation, our disturbance measures captured only a subset of the attributes that affect range condition, and a better understanding of additional range attributes could help explain variation in the observed relationships at a national scale. It is also important to note that our measures of disturbance accounted only for conspicuous changes to forest cover that could be derived from national-scale data and mapped. Some caribou ranges in Canada experience other forms of disturbance that may compromise population condition and/or affect range use. For example, low level aircraft traffic can affect caribou reproduction (Luick et al. 1996, Maier et al. 1998) and calf survival (Harrington and Veitch 1992). Over-hunting can also drive populations into decline (Bergerud 1967, 1974).

Of the models evaluated, total disturbance, expressed as proportional amount of range affected, was the best predictor of observed recruitment levels in caribou, explaining 61% of the variation in this parameter. An assumption implicit in the use of a simple model is that areas within population ranges or study areas that are not burned or impacted by anthropogenic features are equally good for caribou, which may or may not be the case. Exploring the variability in response across ranges, closer examination of the specific conditions on individual ranges, and consultation with biologists familiar with local circumstances, could help to identify reasons underlying populations falling outside the confidence intervals of the regression, and generate additional hypotheses about measures affecting range condition for evaluation in future analyses. An obvious additional attribute of disturbance that could be quantified using existing data is the spatial configuration of disturbances within caribou ranges, and their effect on measures of connectivity and patch size. There exists both theoretical and empirical evidence to suggest that, at the same level of disturbance, a more dispersed spatial pattern would lead to greater fragmentation of the range, greater interspersion of high quality caribou habitat with that suitable for other species, increased accessibility of the range by predators, and thus an overall decrease in available refuge areas for caribou, leading to negative effects on population condition.

The measure of population condition employed in this study was recruitment, for which the most extensive data set was available. Exploratory analyses revealed good correspondence between recruitment and population growth for a subset of the available data. However, recruitment was not correlated with female survival, as suggested for caribou populations in previous studies (e.g., Bergerud 1988). We had earlier hypothesized that a disjunct might exist. Future analyses should explore the relationship between recruitment and other population parameters through empirical and simulation studies. To be of greatest utility to management, demographic analyses should focus on the co-variation between vital rates and habitat variables (Boyce et al. 2005), in this case measures of range condition. There are several important outcomes from such work. First, it would increase understanding of the relationship between the components of population growth and their interaction with range condition, and identify uncertainties that could become the focus of future adaptive management experiments. Second, it would inform monitoring schemes for caribou, such that the data collected represent the most cost-efficient and effective measures of population condition. The development of long-term, standardized monitoring programs and protocols would produce consistent estimates that maximize the information available for future analyses.

Previous work suggests that population response may lag behind landscape change by up to several decades, due to the proximate factors responsible (Vors et al. 2007). Effects on caribou populations mediated by changes in competitors and predators can take some time to emerge, as numerical response by these species is not be immediate. Our analyses did not address potential time lags in population response to changing range condition, as the Global Forest Watch Canada (GFWC) anthropogenic disturbance data could not be partitioned into time intervals. However, GFWC is presently completing a landscape change analysis, which quantifies anthropogenic changes over the time intervals 1990-2000, and 2001-2007. These data will facilitate investigation of caribou population dynamics relative to rates of change, as well as exploration of potential time lags in response.

A primary objective of the present study was to extend the Sorensen et al. (2008) analysis to a broader range of population and landscape conditions. The general model structure employed for each study was similar; however, different measures of both the independent and dependent variables were evaluated. Thus, it is not appropriate to quantitatively compare specific model outputs. Nevertheless, both studies posed the question: is there a relationship between human-caused disturbance and caribou population performance? The answer is affirmative. There is an increasing risk to caribou population persistence as the level of anthropogenic disturbance increases, and disturbance by fire interacts with this, such that the total disturbance on a caribou range must be considered when developing management guidelines. The results further suggest that it is possible to establish quantitative guidelines for disturbance thresholds relative to probability of population persistence, even though the mechanisms underlying the relationship may not be fully understood. Ultimately, the evaluation and management of habitat must be tied to demographic responses, like recruitment. Assembling and analyzing information from multiple populations – the product of many years of effort from many individuals - is one means to generate such vital knowledge.

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6.6 Non-Spatial Population Viability Analysis

Introduction

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed the boreal caribou ecotype as threatened in 2002 (Thomas and Gray 2002). Causes of the decline of boreal caribou populations include over-harvesting by humans and habitat alteration at the landscape scale that favours early seral stage forests and their associated prey species and predators (Environment Canada 2007). Key objectives of the national recovery strategy for boreal caribou are to prevent extirpation of local populations and to maintain or enhance habitat conditions to allow these populations to be self-sustaining (Environment Canada 2007). Concern about the long-term persistence of boreal caribou populations raises questions about the relative role of various vital rates and population size in maintaining populations of boreal caribou.

Deterministic and stochastic processes may cause populations to decline (Caughley 1994). Overharvesting, human-induced habitat loss and fragmentation, and predation are deterministic factors that may reduce population size (Diamond 1984, 1989). Once populations are small and isolated, they are vulnerable to demographic and environmental stochasticity, which may further reduce numbers and cause genetic isolation (Shaffer 1981, 1987, Lande 1988, 1993). The interaction of deterministic and stochastic factors may contribute further to endangerment, described as an extinction vortex (Gilpin and Soule1986). Stochastic factors may cause small populations to become extinct, even if habitat conditions are adequate and deterministic causes of decline are removed (Shaffer 1981). Catastrophes (such as large forest fires) are considered to be an extreme form of environmental stochasticity that cause major reductions in populations and thus have important implications for any size of population (Lande 1993).

Habitat conditions directly affect the demographics of boreal caribou populations. Habitat alteration at the landscape scale, favouring early seral-stage forests and their associated prey species and predators, can result in declines in survival rate in boreal caribou (Wittmer et al. 2007). Reduced adult survival and recruitment increases the risk of extinction. Exploring how boreal caribou life history and vital rates influence population persistence in different habitat situations aids in our understanding of habitat conditions that may allow boreal caribou populations to be self-sustaining.

The Boreal Caribou Critical Habitat Science Review pursued four analytical approaches to support the critical habitat decision framework; here we report on one of these, a non-spatial population viability analysis (PVA). The objective of this work was to use non-spatial models to assess how population persistence is affected by aspects of boreal caribou life history and population structure, using the range of population vital rates and their variance that have been recorded for boreal caribou across their distribution. This work informs the Critical Habitat decision analysis by assessing population sizes required for persistence under various demographic conditions and by providing a tool to investigate the effects of altered vital rates on the population dynamics of boreal caribou.

Using a Leslie Matrix Model, we assessed the effects of variation in boreal caribou vital rates on population dynamics and persistence. Specifically, we explored the following questions:

1) What is the critical population size that will ensure persistence under environmental and demographic stochasticity and various combinations of adult and calf survival rates reported in the literature?
2) Of adult female survival, calf survival and their coefficients of variation (CV), which parameter has the greatest relative contribution to the probability of extinction?
3) How do recruitment rates affect the relative risk of extinction under various population sizes and adult female survival scenarios?

Methods

We used a two-stage, female-only Leslie matrix model with pre-calving census to model the population dynamics of boreal caribou. The model, BWCSim1.0 (Boreal Woodland Caribou Simulator; J. Tews unpubl.), was developed using Borland C++ Builder 5.0 Professional. The calculated intrinsic growth rate (lambda) was based on a deterministic projection of the stage matrix (Caswell 2001). Density dependence was incorporated as a logistic Ricker equation assuming a maximum finite rate of population increase (lambda) of $\lambda = 1.3$. Density dependent population growth is affected when abundance reaches the carrying capacity (K); below K vital rates of the stage matrix are unchanged. Fecundity was modelled as recruitment of female calves to yearlings per adult female and calculated at t+1 as: parturition rate * sex ratio * survival rate (0 -1 yrs).

We used stage-specific (calf, yearling, and adult) demographic data for boreal caribou available from published literature to populate the model (Table 1). We calculated the mean, minimum, and maximum values for female calf and female adult survival and corresponding coefficients of variation (CV; Table 1). From each study, we calculated each individual CVs using one of three approaches: 1) for studies that reported SE or 95% confidence intervals (CI) that were symmetrical around the estimate, we calculated CV as SE/Parameter Estimate; 2) for studies reporting 95% CI that had been calculated using bootstrapping or other techniques (making the back-calculation of CVs impossible), we divided the CI by 4 to obtain a rough estimate of SE and then calculated the CV as above; or 3) for studies that reported a CI that was asymmetrical or its upper bound was truncated to 1 (e.g., survival rates), we determined the difference between the mean and the upper or lower CI bounds, whichever had the highest value. We then estimated the CI as equal to twice that value and then calculated the corresponding CV.

A number of additional parameters were necessary to run the models (Table 2). We assumed that: adults represented 70% of the population, females represented 61% of adults, yearlings were14% of the population, and calves were 16% of the population, and female adults and yearlings comprised 50% of the population[1], based on the means of values reported in the literature (Table 1). We set the proportion of calves that were female produced each year at 0.50 (Gustine et al. 2006) and, in the absence of published data for the proportion of female

1 Adults in population = Total population (100%) – Yearlings (14%) - Calves (16%) = 70%; Adult females = 70% * 61% = 42.7% of population; Yearling females = 50% sex ratio * 14% = 7% of Population; Adult females + yearling females = 42.7% + 7% = 49.7 or ≈ 50% of population.

yearlings, we also set this value at 0.50. The model generated a stable age distribution for the initial population (Ni) based on survival rates and Ni. We estimated that yearling females and adult females represented ~50% of population . Given that BWCSim1.0 predicts female abundance only (e.g., adults + yearlings), we doubled female abundance values predicted by the model to obtain total population sizes (including males, see footnote Table 1 for calculation). For all results, we reported total population size.

We set parturition rate for adults (>2 yrs old) at 0.76 based on the mean of values reported in the literature (Table 1). Caribou typically have their first calf at age 3, but earlier reproduction (as early as 2 yrs.) has been reported (Bergerud 1980). Consequently, we set the yearling parturition rate at 0. Although variations of parturition rate and calf sex ratio were not reported in the literature, we assigned a CV of 0.10 to both parameters under the assumption that they do vary.

We modelled simulated populations over 100 years, with 500 replicates. Carrying capacity was set at three times the initial female abundance (3Ni) to coincide with the widely accepted belief that boreal caribou populations occur at densities typically well below the carrying capacity of their habitat, likely because predation limits many North American caribou populations to levels below the density that food availability could sustain (Seip 1991, Bergerud 1996). BWCSim1.0 incorporates demographic stochasticity by using a random number generator to ascribe annual values for vital rates within the range of variation around mean values reported in the literature, thus simulating the variation in vital rates among individuals. Environmental stochasticity is simulated through the model replicates (e.g., generation of multiple Leslie matrices), which incorporate a range of survival and fecundity estimates derived from variation in vital rates.

BWCSim1.0 models the population demographics of single populations, whereby no immigration or emigration occurs between populations. Environmental catastrophes were not included in the model and there was neither maximum age nor maximum breeding age. To buffer against overly optimistic estimates of population persistence due to limitations of the model, we report quasi-extinction risk (risk of population dropping below 10 females) for critical population size assessment. For all other analysis, we reported predictions of extinction risk. The IUCN criterion for classifying species as Vulnerable (equivalent to COSEWIC's Threatened category) is a risk of extinction ≥10% over 100 yrs (SSC 2001). We therefore set the threshold of acceptable risk of extinction at <10% over 100 yrs.

Appendix 6.6 - Table 1. Mean, minimum, and maximum population parameter values for boreal caribou across Canada.

Jurisdiction	Year	% Adult Males	% Yearlings	% Calves	Adult Female Survival (S_{ad})	CV of Adult Female Survival ($S_{ad}CV$)[1]	Calf Survival (S_{calf})	CV Calf Survival (S_{calf} CV)	Parturition	Parturition CV	Study
QC	1999-2001	43.1%			0.75	0.11					Courtois et al. 2007
QC	1999-2001	37.3%			0.87	0.06					Courtois et al. 2007
QC	1999-2001	29.8%			0.82	0.07					Courtois et al. 2007
AB	1995	45.9%		9.0%	0.81						Stuart-Smith et al. 1997
AB	1976-78	46.0%		13.0%	0.85		0.25				Fuller and Keith 1981
NFLD	1995-97				0.88	0.09	0.46	0.46	1		Mahoney and Virgl 2003
NFLD	1994-97	43.2%									Mahoney and Virgl 2003
Sask	1993-96				0.80	0.12					Rettie and Messier 1998
Sask	1993-96				0.87	0.10					Rettie and Messier 1998
Sask	1993-96				0.79	0.13					Rettie and Messier 1998
Sask	1993-96				0.78	0.13					Rettie and Messier 1998
BC	2003-04				0.94	0.03			0.78		Culling et al.
AB	1993-2002				0.89	0.01					McLoughlin et al. 2003
AB	1993-2002				0.86	0.01					McLoughlin et al. 2003
AB	1995-2002				0.87	0.04					McLoughlin et al. 2003
AB	1995-2002				0.89	0.03					McLoughlin et al. 2003
AB	1998-2002				0.93	0.01					McLoughlin et al. 2003
AB	1998-2002				0.86	0.02					McLoughlin et al. 2003
Lab	1981-1988	38.9%		18.5%	0.80	0.07	0.38	0.12	0.74	0.10	Schaefer et al. 1999
Lab	1993-1997	28.6%		8.9%	0.70	0.07	0.17		0.71	0.09	Schaefer et al. 1999
ON	1976-1984	52.0%	15.7%	22.0%			0.67		0.81		Ferguson et al. 1998
AB	1999-2003	26.0%		10.9%	0.85	0.04	0.23				Smith 2004

[1] Coefficient of Variation

Appendix 6.6 - Table 1. Mean, minimum, and maximum population parameter values for boreal caribou across Canada.

Jurisdiction	Year	% Adult Males	% Yearlings	% Calves	Adult Female Survival (S_{ad})	CV of Adult Female Survival ($S_{ad}CV$)[1]	Calf Survival (S_{calf})	CV Calf Survival (S_{calf} CV)	Parturition	Parturition CV	Study
AB	1979-1984				0.75	0.14					Edmonds 1988
AB	1993-2001										Sorensen et al. 2008
AB	1993-2001										Sorensen et al. 2008
AB	1993-2001										Sorensen et al. 2008
AB	1993-2001										Sorensen et al. 2008
AB	1993-2001										Sorensen et al. 2008
AB	1993-2001										Sorensen et al. 2008
ON	2005			15.5%							Vors 2006
ON	2005			11.9%							Vors 2006
QC	1999			12.5%	0.73	0.22					Courtois et al. 2005
QC	2000				0.82	0.14					Courtois et al. 2005
QC	2001				0.85	0.12					Courtois et al. 2005
QC	2002			20.9%	0.79	0.15					Courtois et al. 2005
QC	2003			23.1%	0.94	0.06					Courtois et al. 2005
QC	2004			26.7%	0.87	0.10					Courtois et al. 2005
QC	2005			18.2%	0.93	0.07					Courtois et al. 2005
NFLD	1957-1967		10.3%	13.4%							Bergerud 1971
NFLD	1957-1967		15.4%	19.6%							Bergerud 1971
N. America		36.0%									Bergerud 1971
	Min	26%	10%	9%	0.70	0%	0.17	12%	0.71	9%	
	Mean	39%	14%	16%	0.85	8%	0.38	38%	0.76	10%	
	Max	52%	16%	27%	0.94	22%	0.67	64%	0.81	10%	

[1] Coefficient of Variation

Appendix 6.6 - Table 2. Model parameters used for the non-spatial boreal caribou PVA

Parameter	Value/Range	Source
Stage classes	2 (Adult female, Yearling female, Calf female)	
Carrying Capacity	3 times initial female abundance ($3N_i$)	
% Calf in population	16%	2,3,5,6,10,11,13,14
% Yearling in population	14%	2,5
% females among adults	61%	2,3,5,6,7,10,11,13
% females among calves	50%	
% females among yearlings	50%	
Parturition rate	0.76	5,10,15,16
Recruitment (of female calves)	parturition * sex ratio * calf survival	
Yearling female fecundity	0	
CV Yearling Female Fecundity	0	
Adult female survival	0.70, 0.85, 0.94	1,3,4,5,6,8,9,10,11,12,13
CV adult female survival	1%, 8%, 22%	1,3,4,5,6,8,9,10,11,12,13
Yearling female survival	0.70, 0.85, 0.94	1,3,4,5,6,8,9,10,11,12,13
CV yearling female survival	1%, 8%, 22%	1,3,4,5,6,8,9,10,11,12,13
Calf Survival	0.17, 0.38, 0.67	1,3,4,5,6,8,9,10,11,12,13
CV calf survival	12%, 38%, 64%	1,3,4,5,6,8,9,10,11,12,13

1 Edmonds 1988; 2 Bergerud 1971; 3 Courtois et al. 2007; 4 Courtois et al. 2005; 5 Ferguson et al. 1988; 6 Fuller and Keith 1981; 7 Gustine et al. 2006; 8 Mahoney and Virgl 2003; 9 McLoughlin et al. 2003; 10 Schaefer et al. 1999; 11 Smith 2004; 12 Sorenson et al. (2008); 13 Stuart Smith et al. 1997; 14 Vors 2006; 15 Rettie and Messier 1998; 16 Culling et al. (no date)

Critical Population Size Assessment

We modelled a combination of calf survival (S_{calf}) and adult female survival (S_{ad}) rates to assess the population size required to reduce the probability of quasi-extinction to <0.10 over 100 years. The values we used for low (L), medium (M), and high (H) survival and CV for calves and adult females, which were compiled from the mean and minimum and maximum of mean published values (Table 1). We assessed the following four combinations of vital rates:

i) Low S_{calf}, high CV of S_{calf}, mean S_{ad}, and mean CV of S_{ad} (LHMM);
ii) Mean S_{calf}, high CV of S_{calf}, mean S_{ad} and mean CV of S_{ad} (MHMM);
iii) Mean S_{calf}; High CV of S_{calf} ; Mean S_{ad}, High CV of S_{ad} (MHMH);
iv) Low S_{calf}, high CV of S_{calf}, high S_{ad} and mean CV of S_{ad} (LHHM);
v) 75th percentile of S_{calf}, CV of Scalf, S_{ad}, and CV of S_{ad} (75th percentile; Table 3).

We did not model a combination of high S_{calf} and low S_{ad} because we assumed this was unlikely to be observed in natural populations.

For each scenario, we increased initial female abundance until the risk of quasi-extinction was <10%. The risk of quasi-extinction was calculated as the average number of years, over 500 replicates, for which abundance was equal to less than 10 female caribou over 100 yrs.).

Appendix 6.6 - Table 3. Scenario parameter values to assess population size thresholds of boreal caribou, based on calf and adult female survival (S) and variation (CV = coefficient of variation).

Scenario	Description of Scenario	Calf Survival (S_{calf})	CV Calf Survival S_{calf} CV	Adult Female Survival (S_{ad})	CV Adult Female Survival (S_{ad} CV)
LHMM	Low S_{calf}; High CV of S_{calf}; Mid Sad, Mid CV of S_{ad}	0.17	64%	0.85	8%
LHHM	Low S_{calf}; High CV of S_{calf}; High S_{ad}, Mean CV of S_{ad}	0.17	64%	0.94	8%
MHMM	Mean S_{calf}; High CV of S_{calf} ; Mid S_{ad}, mean CV of S_{ad}	0.38	64%	0.85	8%
MHMH	Mean S_{calf}; High CV of S_{calf} ; Mean S_{ad}, High CV of S_{ad}	0.38	64%	0.85	22%
75th Percentile	75thP_S_{calf}, 75thP_CV of S_{calf}; 75thP_S_{ad}, 75thP_CV of S_{ad}	0.44	51%	0.88	15%

Population Trajectory Models

We modelled population trajectories using data from the only studies that reported both calf and adult female survival for four populations of boreal caribou (Table 1), including two study periods for a population in Labrador (for which vital rates differed substantially), for a total of five models (Table 4). We used mean survival rates and CVs of survival rates and population sizes reported in the studies. For the three studies that did not report variation in survival estimates, we used CVs compiled in Table 1 for the missing values. We assigned the Max CV (as reported in Table 1) to the missing Scalf CVs because because the corresponding Scalf rates for the missing values were below the overall mean of 0.38 and low survival estimates are associated with higher inter-annual variation and (Table 1). We used the mid-CV of 8% reported in Table 1 for the missing Sad CV because the corresponding Sad value was equal to the overall mean Sad compiled in Table 1. All studies reported estimates of population size. We used 50% of these estimates as the initial female abundance to be modelled; given that we calculated female adults and yearlings represented ~50% of the total population. We used values reported in Table 2 for parturition, proportion of yearlings in population and calf sex ratio.

Appendix 6.6 - Table 4. Parameter estimates used to model populations of boreal caribou.

Study	Population	Population Size	Ni*	S_{ad}	S_{ad} CV	S_{calf}	S_{calf} CV
Fuller and Keith 1981	Birch Mountains, AB 1976 – 78	59	30	0.85	8%**	0.25	64%
Mahoney and Virgl 2003	Corner Brook Lakes, NF 1994 - 97	584	292	0.88	6%	0.45	17%
Schaefer et al. 1999	Red Wine Mountains, Labr.1981 - 88	710	355	0.80	7%	0.38	12%
Schaefer et al. 1999	Red Wine Mountains, Labr. 1993 - 97	151	76	0.70	7%	0.17	64%
Smith 2004	Little Smokey, AB1993 - 2003	80	40	0.85	4%	0.23	64%

* Initial female abundances (Ni) were set to 50% of population estimates reported in the studies.
** Data in italics denotes values assigned from range of mean values in Table 1.

Sensitivity Analysis

We conducted sensitivity analyses to determine the relative importance of adult female survival (S_{ad}), calf survival (S_{calf}), and their coefficients of variation (S_{ad} CV and S_{calf} CV) to risk of extinction, by modeling the range of mean values for each parameter that we compiled from the literature (Table 1). We varied one parameter at a time, while keeping the other parameters at mean values (Table 5). We then calculated the percent risk of extinction for each scenario as the average number of times the population reached 0 in 100 yrs over 500 replications. We ran models with three initial female abundances (Ni) at 100, 200 and 400 individuals to investigate the potential effect of population size on extinction risk.

Appendix 6.6 – Table 5. Scenario parameter values to assess the relative importance of population parameters to risk of extinction for boreal caribou.

Parameter Varied	S_{calf}	S_{calf} CV	S_{ad}	S_{ad} CV
S_{ad}	0.38	38%	0.70-0.94	8%
S_{calf}	0.17-0.67	38%	0.85	8%
S_{ad} CV	0.38	38%	0.85	1-22%
S_{calf} CV	0.38	12-64%	0.85	8%

Recruitment Analysis

We modelled the effect of recruitment on risk of extinction under a variety of female survival rates (0.80, 0.84, 0.88) and initial female abundances of 200, 400, 600, and 800 (corresponding to population sizes of 400, 800, 1200 and1600 caribou; Table 5). We calculated corresponding calf survival rates from mean recruitment values taken from the National Meta-analysis of Boreal Caribou Demography and Range Disturbance (Table 6; see also Appendix 4.5). Given an assumed parturition rate of 0.76, calf survival was calculated as:

S_{calf} = (mean recruitment / 0.76) / 100

Appendix 6.6 - Table 6. Recruitment of boreal caribou and corresponding calf survival values.

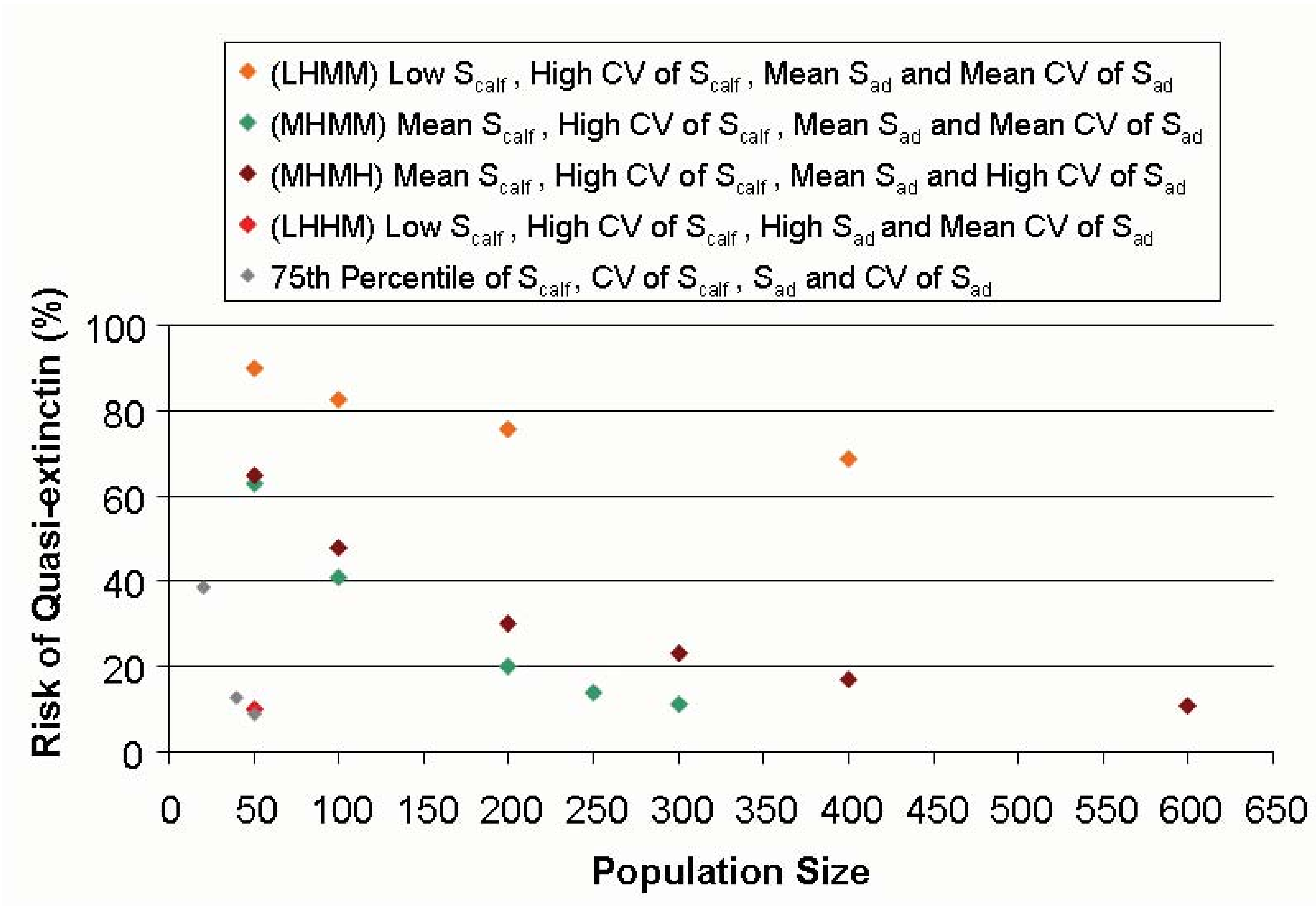
Recruitment (calves/100 cows)	calves/cow	S_{calf}[1]
7.15	0.072	0.09
12.30	0.123	0.16
12.60	0.126	0.17
13.40	0.134	0.18
13.60	0.136	0.18
13.90	0.139	0.18
15.25	0.153	0.20
16.38	0.164	0.22
17.40	0.174	0.23
20.71	0.207	0.27
20.90	0.209	0.28
21.30	0.213	0.28
27.35	0.274	0.36
28.00	0.280	0.37
28.05	0.281	0.37
28.94	0.289	0.38
32.28	0.323	0.42
40.33	0.403	0.53
40.58	0.406	0.53
45.37	0.454	0.60
45.40	0.454	0.60
45.40	0.454	0.60
50.25	0.503	0.66
50.54	0.505	0.67

[1]Calf survival calculated as S_{calf} = Recruitment/Parturition. Parturition rate assumed to be 0.76.

RESULTS

Critical Population Size Assessment

The results of the non-spatial PVA indicated that populations of boreal caribou with poor demographic conditions (e.g., low calf survival and moderate adult female survival) face a high risk of quasi-extinction regardless of population size (Figure 1; LHMM). Populations with medium calf survival (high CV) and medium adult female survival (mean CV) required a minimum of 300 individuals to reduce the risk of quasi-extinction to <10% (Figure 1; MHMM). Under the same mean survival rates but using high CVs for calf and adult female survival, a population size of 600 was required to offset the risk of quasi-extinction. Under conditions of low calf survival (high CV but high adult female survival and mean CV), however, a population of 50 animals had a quasi-extinction risk <10%, suggesting that high adult female survival compensated for low calf survival (Figure 1; LHHM). Under good demographic conditions (e.g., relatively high adult female and calf survival corresponding to 75th percentile of survival rates and CVs), a population size of 50 had a 10% chance of quasi extinction over 100 yrs (Figure 1; 75th Percentile).



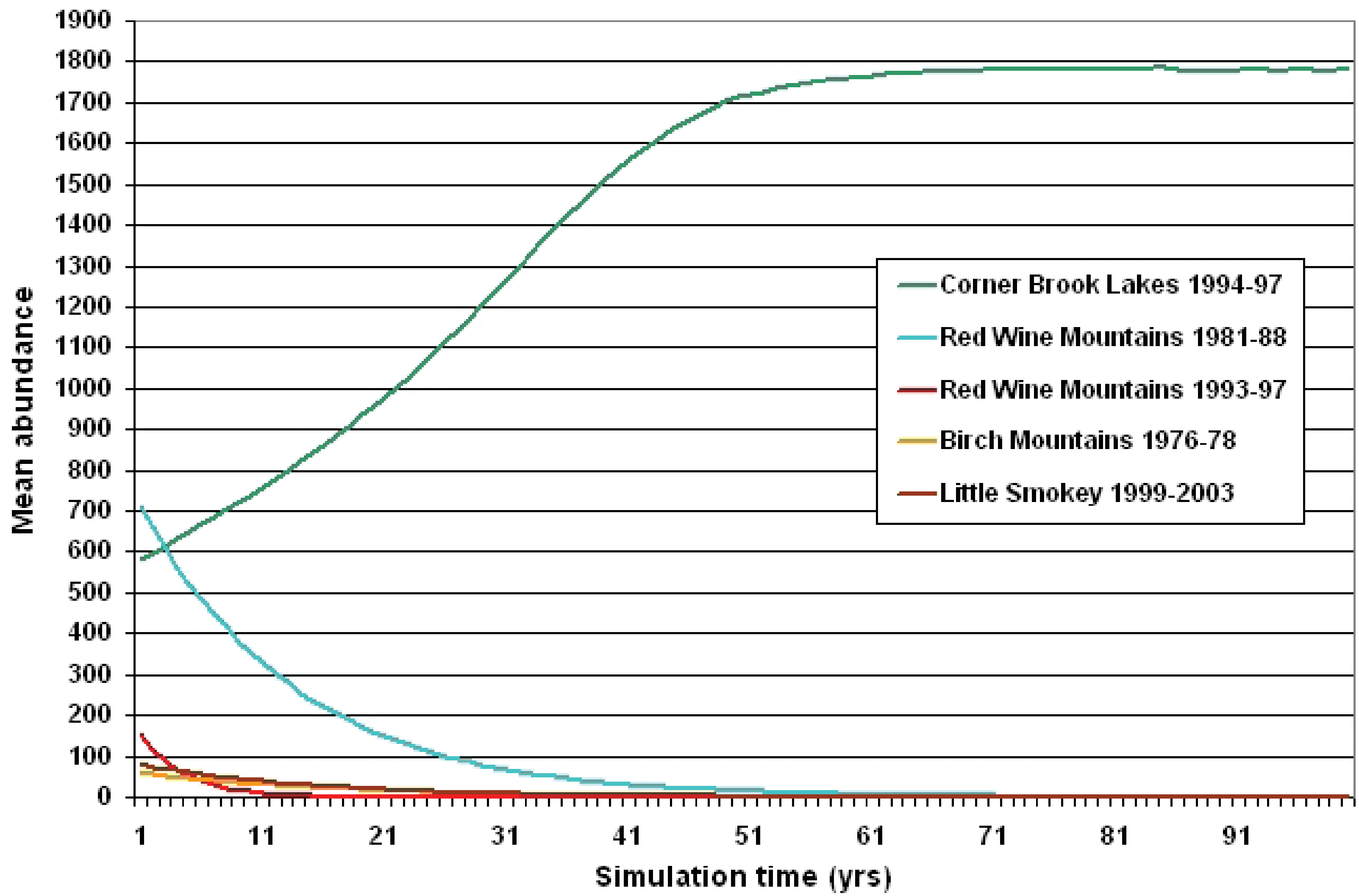
Appendix 6.6 - Figure 1. The effect of population size on risk of quasi-extinction for models combining various rates of calf survival, CV of calf survival, adult female survival, and CV of adult female survival. Quasi-extinction is defined as the risk of the population decreasing below 10 females over 100 yrs. See Table 3 for a description of the models.

Population Trajectory Models

All populations, except the Corner Brook Lakes population in Newfoundland (Mahoney and Virgl 2003), went extinct within 100 yrs, although the time to extinction varied among studies (Figure 2). The three populations with the poorest demographic conditions (Red Wine Mountains late period, Birch Mountains, and Little Smokey) declined to the quasi-extinction threshold of 10 females within 20 years, while the Red Wine Mountains early population declined at a slower rate. The risk of extinction P(e) and quasi-extinction P(qe) for all populations except the Corner Brook Lakes population was >10% (Table 7).

Appendix 6.6 - Table 7: Probabilities of extinction, P(e), and quasi-extinctions, P(qe), over 100 yrs for four boreal caribou study populations

Study Population	P(e)	P(qe)
Birch Mountains 1976-78	0.52	0.82
Corner Brook Lakes 1994-97	0.00	0.00
Red Wine Mountains 1981-88	0.30	0.55
Red Wine Mountains 1993-97	0.83	0.93
Little Smokey 1999-2003	0.53	0.80



Appendix 6.6 - Figure 2. Predicted changes in the mean total abundance of four populations of boreal caribou over 100 years, based on population size, mean adult female survival, calf survival, and their variance (CVs) reported in a demographic study for each population. We used mean values from 15 boreal caribou population studies to estimate parturition, proportion of yearlings in population and calf sex ratio.

Sensitivity Analysis

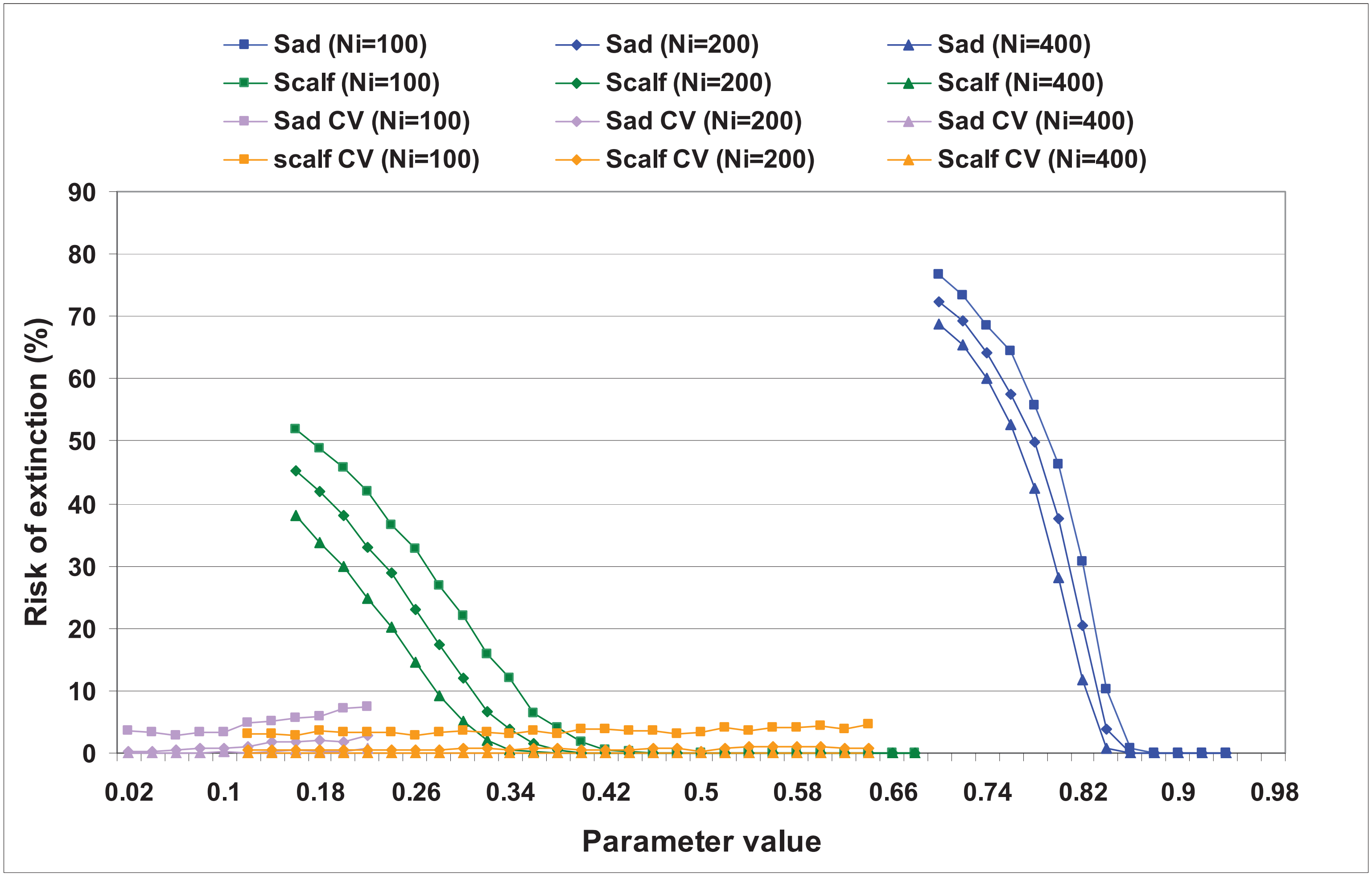
Of the vital rates that we tested, adult female survival and calf survival had the largest effect on probability of extinction (Figure 3). The CV of S_{ad} and the CV of S_{calf} had minor effects on probability of extinction, depending on the size of the population that was modelled (Figure 3). Relative to survival rates, population size in the range that we modelled (100 – 400 initial adult and yearling females) had little effect on the risk of extinction (Figure 3).

The cumulative percent change in risk of extinction was much greater with increasing adult female survival than it was with increasing calf survival (Figure 4). A change from mean to low S_{ad} increased the probability of extinction by 72%, while a change from mean to low S_{calf} increased the probability of extinction by 42%. In contrast, a change from mean to low CV of S_{calf} or S_{ad} did not change the probability of extinction more than 5%. Relative to survival rates, population size in the range that we modelled (100 – 400 initial adult and yearling females) had little effect on the risk of extinction (Figure 3).

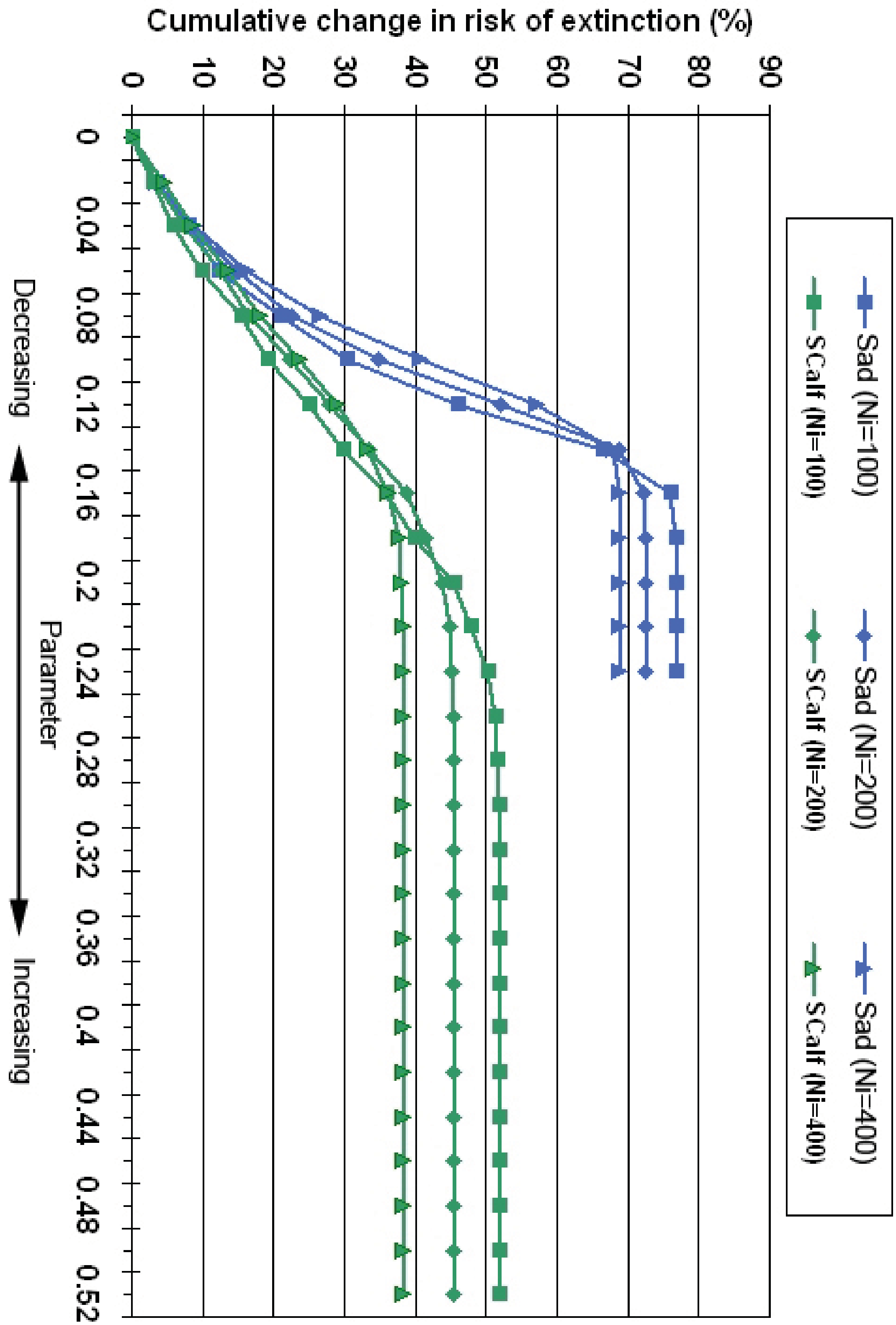
Although the range in modelled adult female survival was smaller (0.70 – 0.94) than the range in modelled calf survival (0.17 – 0.67), the cumulative change in risk of extinction was much higher for adult female survival (78%; Figure 4) than for calf survival (52%), suggesting the importance of adult female survival in boreal caribou population dynamics.

Recruitment

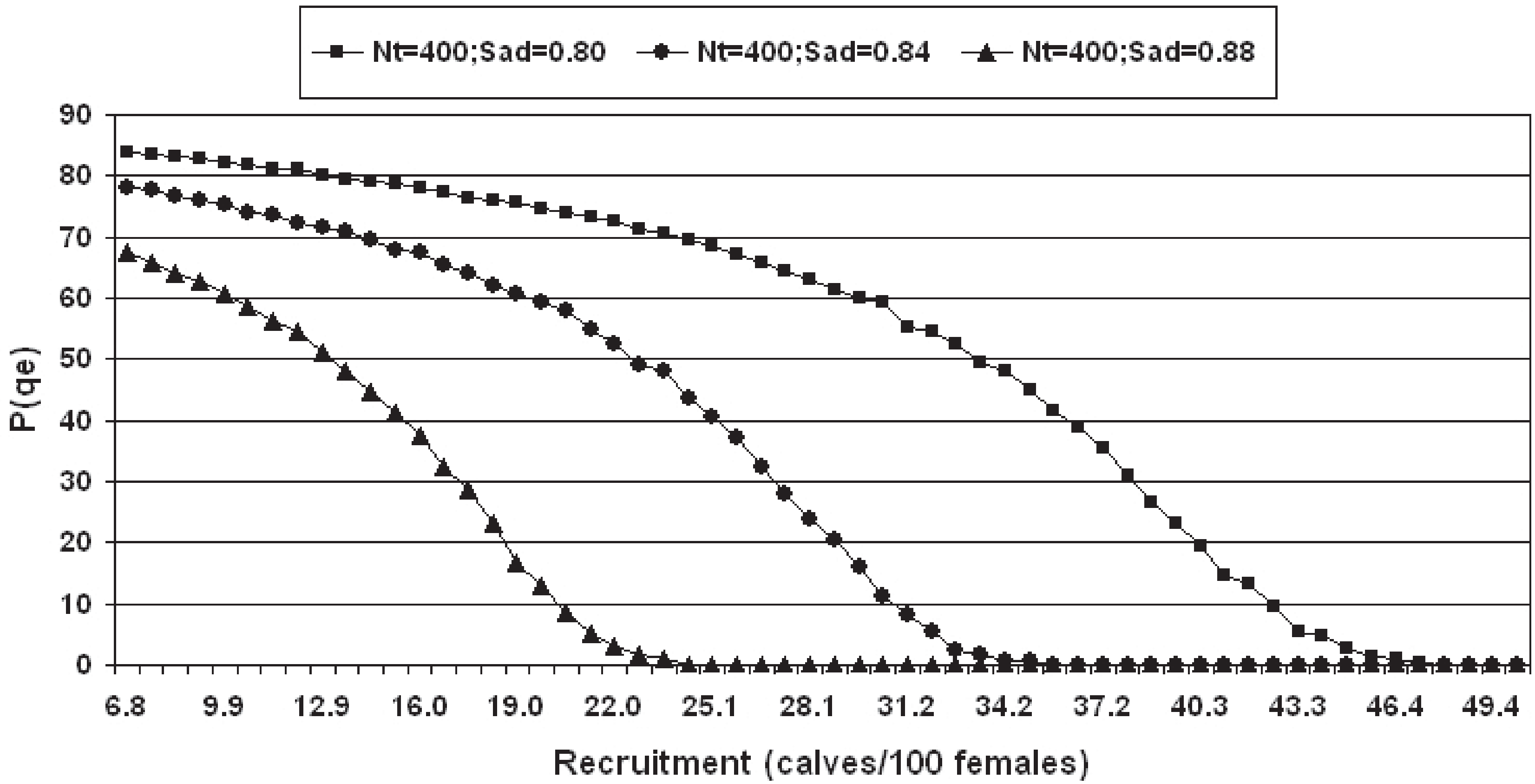
The probability of extinction decreased with increasing recruitment rates (Figure 5). Under conditions of relatively high adult female survival (0.88), populations of 400 individuals required a recruitment rate of 20 calves/100 cows to reduce the risk of quasi-extinction to <10% (Figure 1). Under lower adult female survival (0.80 – 0.84), populations of 400 individuals required a recruitment rate of 30 – 43 calves/100 cows to reduce the risk of quasi-extinction to <10% (Figure 5).



Appendix 6.6 - Figure 3. Change in risk of extinction (%) per unit increase in rates of the following parameters: adult female survival (S_{ad}) and female calf survival (S_{calf}), and unit increase of coefficients of variation (CV) of adult female survival (S_{ad} CV) and female calf survival (S_{calf} CV), under various population sizes (Ni; 100, 200, 400 females).



Appendix 6.6 - Figure 4. Cumulative change in risk of extinction due to change in adult femalesurvival and calf survival for boreal caribou. Parameter represents adult female survival (S_{ad}) or female calf survival (S_{calf}).



Appendix 6.6 - Figure 5. Effect of boreal caribou recruitment (calves per 100 females) on the probability of quasi-extinction as determined from a non-spatial population viability analysis. Quasi-extinction risk was measured as the mean number of years (across 500 replicates) the population reaches 10 females over 100 years (based on an initial population size of 400 females).

Discussion

Our models suggested that populations of boreal caribou with poor demographic conditions (e.g., low calf survival and moderate adult female survival) face a high risk of quasi-extinction at any population size. Under moderate demographic conditions (mean calf survival and mean adult female survival), population size plays an important factor in reducing risk of quasi-extinction. Under good demographic conditions (e.g., relatively high calf and adult female survival or high adult female survival and mean calf survival), when other factors that may increase the risk of extinction are absent, small populations of 50 individuals could persist for long periods of time. Of the 57 local populations of boreal caribou in Canada that are considered to be threatened, 46% are small (less than 300 animals), 28% are considered to be declining, and 19% have both conditions. Our models indicated that small, declining boreal caribou populations are in immediate need of enhanced management to improve their chance of persistence.

Our results indicated that adult female survival strongly influences boreal caribou population trajectory and that high adult female survival can buffer the effects of poor calf recruitment. This conclusion is supported by field studies that have demonstrated the strong influence of adult female survival on ungulate demographics (Nelson and Peek 1984, Eberhardt 1985, Hern et al. 1990. Walsh et al. 1995, Crête et al. 1995, Arthur et al. 2003, Wittmer et al. 2005). Our results also demonstrated the influence of calf survival on boreal caribou population trajectory, similar to Bergerud (1971), who showed a strong correlation between calf survival and population growth. Raithel et al. (2007) found that, despite calf survival having relatively low elasticity, the variation in calf survival explained most of the variation in lambda in an elk population.

Our models indicated that, given demographic conditions reported in the literature for four populations of boreal caribou, three have a high risk of extinction. Under relatively poor demographic conditions (e.g., relatively low adult female and calf survival), no population size can eliminate the risk of extinction, although larger populations would take longer to become extinct. The population experiencing good demographic conditions, on the island of Newfoundland (Mahoney and Virgl 2003), exists in the absence of wolves, a predator whose functional and numerical response increases with habitat disturbance (Seip 1991). It is unrealistic to expect that vital rates of boreal caribou remain unchanged over 100 years. For example, adult female survival in the Red Wine Mountains population increased from an average of 0.70 during 1993 - 1997 to 0.90 during 2000 - 2005 (Unpublished data, Wildlife Division, Government of Newfoundland and Labrador). This population has therefore not met the prediction of extinction in the PVA as a result of increasing adult female survival. Nonetheless, our results illustrated that moderate to low adult and calf survival rates increase the risk of extinction and that populations with poor demographic conditions decline rapidly regardless of their population size. Positive change in vital rates, however, particularly of adult female survivorship, can significantly change the outcome of the PVA predictions. Thus, models need to be re-evaluated as new data and new knowledge become available.

Our results demonstrated that the probability of extinction in boreal caribou populations decreases with increasing recruitment rates. Bergerud (1992) reported that 27.7 calves/100 cows yielded a finite rate of population increase (λ) value of 1, based on 32 population survey years of both barren-ground and woodland caribou. Our results indicated that this threshold can vary, depending on survival of adult females.

In our model, density dependence is incorporated as a logistic Ricker equation (scramble competition), assuming a maximum population growth rate (lambda) of Rmax=1.3. Population growth is affected when abundance reaches the carrying capacity K; below K vital rates of the stage matrix are unchanged (e.g., no density dependence). Although this suggests a ceiling form of density dependence, any form of density dependence below K would otherwise increase extinction risk and suggest an unrealistically high risk of extinction.

Linking carrying capacity with population size (e.g., K= 3Ni) likely introduced some density dependent bias, especially for large populations, that may result in an overestimation of growth rates for large populations. The importance of the CV of survival increases as population abundance approaches K because a high CV causes greater fluctuations in abundance and thus causes the population to approach or overshoot K more rapidly, when density dependence effects occur.

The primary limitations of our model were that no maximum age or maximum age of breeding were incorporated. These limitations resulted in optimistic projections of extinction risk and likely over-emphasized the importance of adult female survival to risk of extinction and under-estimated the critical population size. The addition of a multi-age matrix model with a maximum age and senescence components would address these issues and produce more realistic estimates of extinction risk relative to population size.

Future modeling efforts should investigate the relationship between the age structure of the initial population on population size and trend over time. Insight into the degree to which a population skewed toward females is able to moderate a decline due to the greater proportion of reproducing individuals and how the proportion of yearlings to adults can influence trends would help inform conservation management of boreal caribou. An investigation of the correlation between adult and calf survival would help elucidate the relative importance of these factors and inform the development of management strategies that affect these vital rates.

The recovery strategy for boreal caribou states the “need for large areas of boreal forest with adequate amounts of suitable habitat and low predation rates is a consistent requirement for the conservation of the boreal population of woodland caribou across Canada” (Environment Canada 2007). Given that population vital rates are affected by habitat alteration that favours alternate prey and their predators, the non-spatial PVA provided insight into the effects of a range of demographic conditions on population persistence and the recovery goal of self-sustaining boreal caribou populations.

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6.7 Spatial Population Viability Analysis Case Study

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Introduction

The overarching goal of the national recovery strategy for boreal caribou is to conserve and recover boreal caribou populations and their habitat; that is, prevent extirpation of local populations and maintain or enhance habitat condition to allow these populations to be self-sustaining (EC 2007). Thus the link between population viability and habitat amount and condition is an explicit part of the recovery goal. The question of "How much and what configuration of **habitat** is enough to achieve the goal of self-sustaining (viable) **populations**?" links the process of delineation of critical habitat designation with an analytical approach or suite of methods known as population viability analysis (PVA).

Population viability analysis often involves the use of analytical models to provide quantitative estimates of extinction times and probabilities. Most recent review papers on PVA have judged these metrics less than robust to model and data uncertainty (McCarthy et al. 2003). This type of PVA has also been criticized for limited relevance to real-world conservation planning contexts, due to its emphasis on "small population paradigm" factors (e.g., inbreeding depression) rather than more pressing "declining population paradigm" factors (e.g., habitat loss) (Caughley 1994). Here we use a broader definition of PVA that includes a range of methodologies to integrate existing knowledge and models of varying complexity in a structured way. The most valuable output of such PVA is often a better understanding of how trends in species distribution at larger spatial and longer temporal scales are linked to landscape change (development) trends, in a way that is difficult to assess without some form of modeling. This allows PVA to be used as a tool to rank alternative management scenarios rather than assign absolute persistence probabilities. There are significant challenges to application of such PVA modeling to boreal caribou, such as the species' relatively complex local population dynamics. A variety of specific analytic methods can be used, with the most appropriate method for boreal caribou depending on factors such as the spatial scale of the question and the nature of available input data. The critical habitat science review has pursued four complementary analytical approaches: environmental niche analysis, range-wide meta-analysis of demography-habitat relationships, non-spatial (heuristic) PVA, and spatial PVA. Here we review initial results from the spatial PVA. The timeline of the critical habitat science review did not allow for completion of a full PVA study. These results instead serve as a proof of concept to assess the relevance of spatial PVA to the boreal caribou critical habitat analysis and recovery process. Although spatial PVA modeling methods are more complex, time-consuming, and require greater levels of input data than other methods, their potential to inform critical habitat designation and planning may justify their use as a complement to other, less data-intensive decision support tools. The major questions addressed in this report include:

- Adequacy of spatial (habitat) data – What type and quality of spatial data are required for a PVA?
- Adequacy of demographic data – Is possible to estimate demographic rates in different habitats with a level of accuracy sufficient for a PVA?
- Relevance of results – Do results from a spatial PVA inform recovery planning in ways not possible with other methods?
- Integration with other tools – How are results from a spatial PVA best integrated in a decision support context with results from the other analysis methods used in the critical habitat science review (environmental niche analysis, meta-analysis, and heuristic PVA)?

Motivation

The boreal caribou critical habitat science review participants chose spatial PVA as one of four methodologies to evaluate during the science review process. In common with the environmental niche analysis, the PVA incorporates spatial data. Spatial models are essential supports to critical habitat analysis in that they provide a broad-scale summary of landscape condition. In contrast to the environmental niche analysis, which addresses habitat primarily at the broadest spatial scale, the spatial PVA focuses on aspects of habitat such as forest type and distance from roads that act at an intermediate spatial scale corresponding to the extent of the local population.

Given this scale of analysis, several approaches of varying levels of complexity could be implemented. The same habitat data used as input to the spatial PVA could also be appropriately used to develop a "static" habitat model (e.g., habitat suitability index (HSI) or resource selection function (RSF)). However, even if such static models are used in place of a dynamic population model, a PVA-type process may be useful to help structure range-wide meta-analysis of habitat data and consideration of how the habitat relationships translate up spatial scales from habitat patches to landscapes and from short-term temporal fluctuations to long-term trends and persistence thresholds.

The model used here ("HexSim"; (Schumaker et al. 2004; Schumaker in prep.)) is a spatially-explicit population model (SEPM; also termed an individual-based model) in which habitat quality affects individuals that are followed as they age, give birth, disperse, and die over time. Individuals may hold exclusive territories or live in social groups. To justify its additional complexity, a spatial PVA must provide insights not possible with a static habitat model. One benefit of a SEPM is that it can help incorporate landscape processes into conservation planning and thus facilitate evaluation of the effects of alternate future scenarios. Planners must consider multiple future landscape scenarios due to uncertainties as to the effects of climate change, inherent uncertainty in ecosystem processes such as fire, and alternate options for management processes that transform habitat.

Previous research applying SEPMs to threatened species recovery planning found that the models gave insights beyond those provided by static habitat models because they could assess area and connectivity effects (e.g., inter-population dynamics and source-sink dynamics) that strongly affected persistence of the species considered (Carroll et al. 2006). This may also be the case for boreal caribou. Alternatively, a caribou SEPM could provide similar conclusions to a simpler model such an HSI and thus the simpler model would be preferred. Or a caribou SEPM could potentially offer new insights but require spatial data or demographic parameters that are largely unavailable. Each of these three outcomes is likely true in different regions, and a case study such as the one described here can help planners assess when and where SEPM are an appropriate decision support tool. Even if the data in a particular portion of caribou range are inadequate for deriving SEPM-based predictions regarding quantitative persistence thresholds, SEPM may still be useful in a heuristic sense in offering insights as to emergent processes and effects of landscape condition and structure on caribou persistence.

Caribou SEPM can be expected to be more complex than those for species such as the spotted owl, where individuals defend exclusive territories. Because boreal caribou occur in social groups, local population dynamics should be added to the SEPM. Movement between seasonal habitats should be added to the model for local populations where this occurs. In addition, multi-species SEPM that can capture the interaction between predators and caribou, and indirectly with alternate prey species such as moose, should be possible and may reveal important insights. However, it is important to keep in mind a key guideline: what is the simplest model that effectively supports conservation planning, and what real-world complexities can be ignored in the model without qualitatively compromising results in terms of the questions at hand?

The spatial scale of the case studies presented here was determined somewhat opportunistically by the extent of the available spatial habitat data. Ideally, as was the case here, the spatial data used would encompass the larger landscape, rather than only areas currently occupied by caribou. This extent allows addressing questions such as “How does habitat condition in the larger landscape support or not support caribou occurrence?” But unlike methods that assess summary statistics on aggregate habitat amount within a local population’s range (e.g., the proportion of the landscape within a set buffer distance from roads), a SEPM also focuses on finer-scale habitat pattern and composition. At this scale, the model addresses “How does the arrangement of habitat patches within the extent of a local population influence its persistence and demography?”, e.g., by influencing within-range movement and consequent exposure to predation.

Relationship with other components of science review

The four components of the critical habitat science review form a spatial and analytical hierarchy of methods. Their output shows less generality and more complexity (or “biological realism”) as one descends the hierarchy. Environmental niche analysis and range-wide meta-analysis can be seen as top-level methods, followed by the heuristic PVA, and finally the spatial PVA. Results from top-level analyses reveal overarching constraints on processes examined at lower levels. This perspective allows a synthesis of the four components. Lower-level results suggest factors missing from the top-level analyses, and in turn the top-level analyses suggest the extent to which conclusions from e.g., the spatial PVA results may lack generality to some portions of range.

Environmental niche analysis (ENA) characterizes the distribution of boreal caribou by examining which abiotic factors (climate and topography) characterize the distribution of observed locations. These models may be especially relevant in predicting potential effects of climate change. In a second stage of ENA, broad-scale biotic variables (land cover and human impact levels) are added to further refine the models. However, these variables, because they are the lowest common denominator of detail available range-wide, lack the fine-scale habitat data possible in the spatial PVA. The second range-wide approach is a meta-analysis of relationships between demography and habitat. Both of these approaches, in contrast to the spatial PVA, can produce broadly general conclusions as to what abiotic and biotic conditions permit boreal caribou occurrence and persistence. However, neither approaches are mechanistic, in that they do not address the biotic mechanisms by which e.g., climate limits distribution. The heuristic PVA, in contrast, uses non-spatial models to assess how population persistence is affected by aspects of boreal caribou life history and population structure (e.g., age structure, age-specific survival and fecundity, environmental stochasticity, breeding structure, and density dependence). Because such a non-spatial PVA has far fewer parameters and computational demands than a SEPM, the heuristic PVA can more exhaustively explore the plausible parameter space for population dynamics and assess sensitivity of model results to chosen parameters. The spatial PVA explores only a subset of this parameter space but adds consideration of landscape structure and individual movement.

The spatial PVA is linked to the meta-analysis component, in that results of the meta-analysis can be used to inform, and to some extent validate, PVA results. The PVA can help in interpreting results of the meta-analysis in that the PVA may offer heuristic insights as to the mechanisms by which the ability of an area to support caribou scales up spatially from the patch to landscape. Additionally, spatial PVA tools allow simulation of longer-term trends and scenarios to extrapolate the relationships drawn from the meta-analysis to future landscapes.

Comparison of the heuristic and spatial PVA results helps assess 1) to what degree the spatial PVA model's behaviour is an artefact of particular assumptions as to parameters, 2) whether spatial effects produce qualitatively different results in terms of predictions of population persistence. An integrated assessment using the four approaches might begin with general conclusions as to what climatic conditions and broad-scale habitat characteristics are associated with boreal caribou occurrence (ENA) and persistence (meta-analysis), and refine these conclusions by assessment of what life history characteristics (heuristic PVA) and spatial population dynamics (minimum area requirements or dispersal limitation) may explain these patterns and further limit distribution and persistence.

Methods

Spatially-explicit population models (SEPM), like static HSI models, use input data on habitat factors that affect survival and fecundity of the species of concern. But SEPM then integrate additional information on characteristics such as demographic rates and dispersal behaviour. For example, social carnivores often require larger territories than solitary species of similar size, and may thus be more vulnerable to landscape fragmentation in a SEPM (Carroll et al. 2006). Unlike a simpler HSI model, a SEPM can provide insights on the effects of population size and connectivity on viability and identifying the locations of population sources and sinks.

HexSim, the SEPM used here, links the survival and fecundity of individual animals or groups to GIS data on mortality risk and habitat productivity (Schumaker et al. 2004, Schumaker in prep.). Individual territories or group ranges are allocated by intersecting the GIS data with an array of hexagonal cells. The different habitat types in the GIS maps are assigned weights based on the relative levels of fecundity and survival expected in those habitat classes. Base survival and reproductive rates, derived from published field studies, are then supplied to the model as a population projection matrix. The model scales these base matrix values based on the mean of the habitat weights within each hexagon, with lower means translating into lower survival rates or reproductive output. Each individual in the population is tracked through a yearly cycle of survival, fecundity, and dispersal events. Environmental stochasticity can be incorporated by drawing each year's base population matrix from a randomized set of matrices whose elements were drawn from a beta (survival) or normal (fecundity) distribution. Adult organisms are classified as either territorial or floaters. Floaters must always search for available breeding sites or existing groups to join. Movement decisions can be parameterized in a variety of ways, with varying proportions of randomness, correlation (tendency to continue in the direction of the last step), and attraction to higher quality habitat (Schumaker et al. 2004). Because it is difficult to parameterize movement rules directly from field data (but see Fryxell and Shuter 2008), it is important to assess the sensitivity of model results to a range of plausible movement parameters.

SEPM can produce a wide range of output in the form of both spatial data (maps) and summary statistics (e.g., population time series). This output can be used to assess an area in terms of the probability of occurrence of the species (similar to the output of a HSI model), the area's demographic role (source or sink) as well as give population-level predictions of long-term persistence or extirpation.

Because absolute estimates of risk from a SEPM are suspect due to uncertainty in data and models, SEPM output should instead be used to rank candidate recovery strategies in terms of viability (or extinction risk) and distribution (range expansion or contraction).

Spatial Data

Two case study areas were selected opportunistically for the SEPM analysis based on data availability. The first study area is located in northeastern Alberta on lands with forest tenure held by Alberta Pacific Forest Industries (ALPAC). This area encompasses the extent of the ESAR (eastside of Athabasca River) and WSAR (westside of Athabasca River) caribou herds (local populations). The area is predominantly a mixture of peatland and upland habitats with the predominant resource industries being timber extraction and oil and gas development. The second case study area is located in southeastern Manitoba, and encompasses the extent of the Owl Lake herd. The predominant resource industry in this area is timber extraction. Data for this study area was provided by the Eastern Manitoba Woodland Caribou Advisory Committee (EMWCAC). While the two case study areas obviously do not represent the full spectrum of landscape contexts encountered across the range of boreal caribou, they do show contrasts in habitat use and type of threats to population persistence. For example, a large expansion of linear features related to the energy sector is ongoing in the Alberta study area. The Manitoba case study allows examination of effects of timber harvest scenarios (as well as lower rates of expansion of linear features) on population persistence. Use of two contrasting case study areas allows more general assessment of what minimum level of habitat data (vegetation and linear features) is required for SEPM analysis.

In Alberta, data from the Alberta Vegetation Inventory (AVI) was classified into high, medium, and low quality caribou habitat. High quality habitat was defined as pure stands of black spruce, pure stands of larch, and mixed stands of black spruce and larch. Medium quality habitat was defined as black spruce and larch dominated-stands mixed with tree species other than larch and black spruce.

Low quality habitat was defined as all remaining areas. A second habitat layer was created from data on linear features. Areas within 250m of a roads or seismic lines were considered reduced in habitat suitability based on previous research (Dyer et al. 1999). The spatial data for the Manitoba study area was received later than the Alberta data and time constraints permitted only initial evaluation of its suitability for SEPM modeling. It is anticipated that spatial data predicting summer and winter habitat suitability (HSI model) will be the key input to the SEPM. Data on linear features (roads and transmission) lines are also available and may be buffered as in the Alberta case study.

Parameters

Survival rates were parameterized for the Alberta study area based on an expert workshop held with a subset of the Science Advisory Group (SAG) in Vancouver, BC, February 11-12, 2008. Rates were set to vary by habitat type and age class. Survival rates in high and medium quality habitat varied based on the proportion, averaged over a 10 km^2 moving window, of the area within 250m of linear disturbance. The equation for adult annual survival rate [S_a] in high and medium quality habitat was S_a = 0.98 – (proportion within buffer * 23)(Figure 1). The equation for calf annual survival rate [S_c] in high and medium quality habitat was:

S_c = 0.50 – (proportion within buffer * 40). Adult annual survival rate in poor quality (upland) habitat was set to 0.65 irrespective of proportion of linear disturbance buffer. Calf annual survival rate in poor quality (upland) habitat was set to zero irrespective of proportion of linear disturbance buffer. Fecundity rate was set constant across habitats as 0.5 female offspring/female/year. A range of values for the parameter for maximum movement distance have been assessed. The base value used in the simulations shown here is 112 km (total path length, not total net displacement). All of the parameters used above would be subject to further review, revision, and sensitivity analysis in the course of a complete PVA study in order to produce a credible decision support tool.

Results

This initial report focuses on qualitative patterns in the results because it is expected that quantitative predictions would change as initial exploratory simulations are subject to review and sensitivity analysis in a complete PVA study. In the initial simulations, areas of high predicted occupancy are relatively widespread across the Alberta study area when linear disturbance effects are not considered (Figure 2a). This may be conceptualized as representing a landscape state closer to historic (pre-development) condition. These areas are much reduced in extent under the simulations where survival rates are affected by linear disturbance buffer zones (Figure 2b). This may be conceptualized as assessing the current landscape condition. The ESAR herd is affected more heavily by linear disturbance than is the WSAR herd. According to our data, 63.0% of the ESAR range is within 250 meters of linear disturbance, versus 44.93% of the WSAR range. A comparison between the HexSim simulations with and without linear disturbance shows a decline in occupancy probability of 76.7% for the ESAR herd, versus 58.7% for the WSAR herd. Although neither local population has a high likelihood of extirpation (given no further habitat loss) in these initial simulations, more realistic assessment of persistence probabilities should await simulations that better incorporate group dynamics.

Occupancy rates shown above are drawn from the final decade of 200 year simulations, averaged over 10 simulation runs. Although the simulations are 200 years in length, the landscape does not change in the current analysis. Therefore, predictions show the equilibrium “carrying capacity” of the current landscape, not the future persistence probabilities of the population given landscape change. Both stochastic landscape change, such as driven by fire, and deterministic habitat trends, such as increases in linear disturbance, would alter current equilibrium carrying capacity. These aspects could be explored in future simulations.

Despite a static landscape, population levels show wide variation around carrying capacity. A plot of five population time series drawn from the Alberta simulations with linear disturbance (Figure 2b) is shown in Figure 3. Relatively large population fluctuations (~20%) over periods of several decades are evident although the longer-term trend is stable. These fluctuations are driven by both demographic stochasticity and habitat pattern. The potential of caribou life history structure and demographic stochasticity in relative small populations to cause long-term fluctuations should be evident in a non-spatial (heuristic) PVA model. However, a spatial model such as a SEPM allows habitat fragmentation and dispersal limitation to accentuate small population effects and increase the magnitude of fluctuations. The larger population inhabiting the "historic" landscape (Figure 2a) shows fluctuations of smaller magnitude due to both larger population size and lower levels of landscape fragmentation. The model output emphasizes that it is inherently challenging to interpret data from population monitoring programs for long-lived vertebrates, and SEPM simulations could be instructive in designing monitoring programs for more intact landscapes. However, deterministic habitat changes in the Alberta study area over the short-term will likely swamp the effects of demographic stochasticity.

Although HexSim simulations for the Manitoba study area were not possible within the timeframe of this study, the input habitat layers appear suitable for use in HexSim simulations. Figure 4 shows predictions from the EMWCAC HSI model (averaged over 100 km2 moving window) for the Manitoba study area for a) caribou summer habitat, and b) winter habitat, overlaid with linear features. Although HexSim does allow habitat value to change seasonally, there is relatively low contrast between winter and summer HSI values (correlation = 0.944). Although here the HSI values are averaged over a moving window to graphically display large-scale landscape pattern, the unaltered HSI values would be used as input to HexSim. Although density of linear features is much lower than in the Alberta study area, there is enough separation between blocks of high-quality habitat to suggest that a spatial model that incorporates effects of landscape structure may be informative.

Discussion

The HexSim model has been previously used in population viability analyses for species where individuals hold exclusive territories (Carroll et al. 2003, Schumaker et al. 2004). Boreal caribou are the first species with group, rather than individual, movement dynamics to which HexSim has been applied. The complexity of adapting the HexSim model to caribou life history and group dynamics has slowed initial progress in developing realistic simulations. However, despite these challenges, further effort invested in model development with HexSim is worthwhile due to the potential for HexSim to provide unique insights into the relationship between habitat and viability of boreal caribou populations.

Concurrently with the national critical habitat science review process, a spatial PVA of Ontario boreal caribou populations has been developed (Fryxell and Shuter 2008). This work extends previous caribou simulation models (e.g., Lessard 2005) in several areas, notably by parameterizing movement paths from statistical analysis of detailed movement data rather than by conceptual models (e.g., attraction to high quality habitat). The model of Fryxell and Shuter (2008) is not fully spatial or individual-based as demographic rates experienced by caribou are based on an analytical wolf-moose-caribou predator-prey model. The model is highly suited for exploration of the general types of demographic parameters and landscape conditions that support caribou persistence and thus falls into an intermediate level of complexity between the heuristic non-spatial PVA and the HexSim model. In contrast, the strengths of the HexSim model are that it is fully individual-based, and thus can evaluate relationships that emerge from spatial interactions between caribou, their predators (e.g., wolves), and alternate prey species (e.g., moose). A “canned” software application such as HexSim inevitably lacks the flexibility of a program developed specifically for a single species, but as a consequence offers the potential for greater standardization and comparability between study areas and between species than is possible with a custom-built program such as used in Fryxell and Shuter (2008).

Although a conclusive evaluation of the potential for SEPM as a decision support tool in the boreal caribou conservation planning process is not possible in this report, initial results do shed light on the four questions outlined in the introduction (adequacy of habitat and demography data, relevance compared to and integration with results from other methods). The spatial (habitat) data from the two case study areas appear adequate for conducting PVA simulations. However, although the habitat suitability model based on vegetation type and linear features generally matches observed caribou distribution in the Alberta study area, there are contrasts in some areas (high habitat quality with no herds observed) that needed to be further evaluated. The demographic data available for the Alberta study area also appear adequate for HexSim parameterization, as estimates of adult and calf survival by major habitat class in disturbed and undisturbed habitats can be derived from field data. Suggested methods for integrating spatial PVA results with those from the environmental niche analysis, meta-analysis, and heuristic PVA have been described above. Although it is not yet possible to conclusively evaluate whether SEPM tools will inform recovery planning in ways not possible with other methods, the potential benefits justify further model development as described above.

The boreal caribou conservation planning process has at least three stages: 1) the now-completed critical habitat science review, 2) assessment of what constitutes effective protection, to be completed over the coming months, and 3) longer-term conservation planning efforts at the provincial and federal level. In the shorter term of the first two stages of planning, it seems clear based on the challenges encountered so far in parameterizing the caribou HexSim model that the SEPM approach is best developed as a heuristic tool for illuminating area and connectivity effects in representative case study areas. This is due to limitations on available habitat data, but also as a strategy to concentrate effort on refinement of the SEPM model before application to a large number of study areas. Although initial predictions can be developed from a SEPM at a relatively early stage in the modeling process, they should not be used in a decision support context until exhaustive sensitivity analysis has been completed. In the interim, static habitat (HSI or RSF) models (e.g., Sorenson et al. 2008) should be developed and used to track amount and quality of habitat at local and range-wide scales, and perhaps refined through consideration of landscape structure (core area size, etc.) in addition to habitat amount. These static models are a foundation for and complementary to SEPM model development.

Over the longer term (stage 3), SEPM seems a promising approach for addressing issues that have arisen during the critical habitat science review. This is because SEPM output directly addresses the relative risk to population persistence of alternate conservation strategies and thus what constitutes effective protection. By evaluating persistence under scenarios where habitat is maintained, enhanced, or decreased, SEPM output supports placing populations within a framework of range adequacy and resiliency as developed in the critical habitat science review process. SEPM are also currently the best tool for rigorously assessing the importance of intra- and interpopulation connectivity for persistence of boreal caribou, as in cases where large-scale industrial development may fragment habitat of formerly continuous populations.

The next steps in SEPM development for the two case study areas described here fall into several categories. Initially, the focus will be on parameter refinement and sensitivity analysis under the current static landscape. Availability of seasonal HSI models as in Manitoba will allow the SEPM to incorporate seasonal ranges and movement between them. More complex population dynamics (e.g., Allee effects) will be incorporated in the simulations. Once a satisfactory parameter set for current landscapes has been developed, simulations will incorporate future scenarios, including threats from development and climate change, and simulation of landscape dynamics due to forest succession and fire. The value of the SEPM analysis will be enhanced by continued interaction and integration of the spatial PVA with the other three facets of the science review (environmental niche analysis, meta-analysis, and non-spatial PVA).

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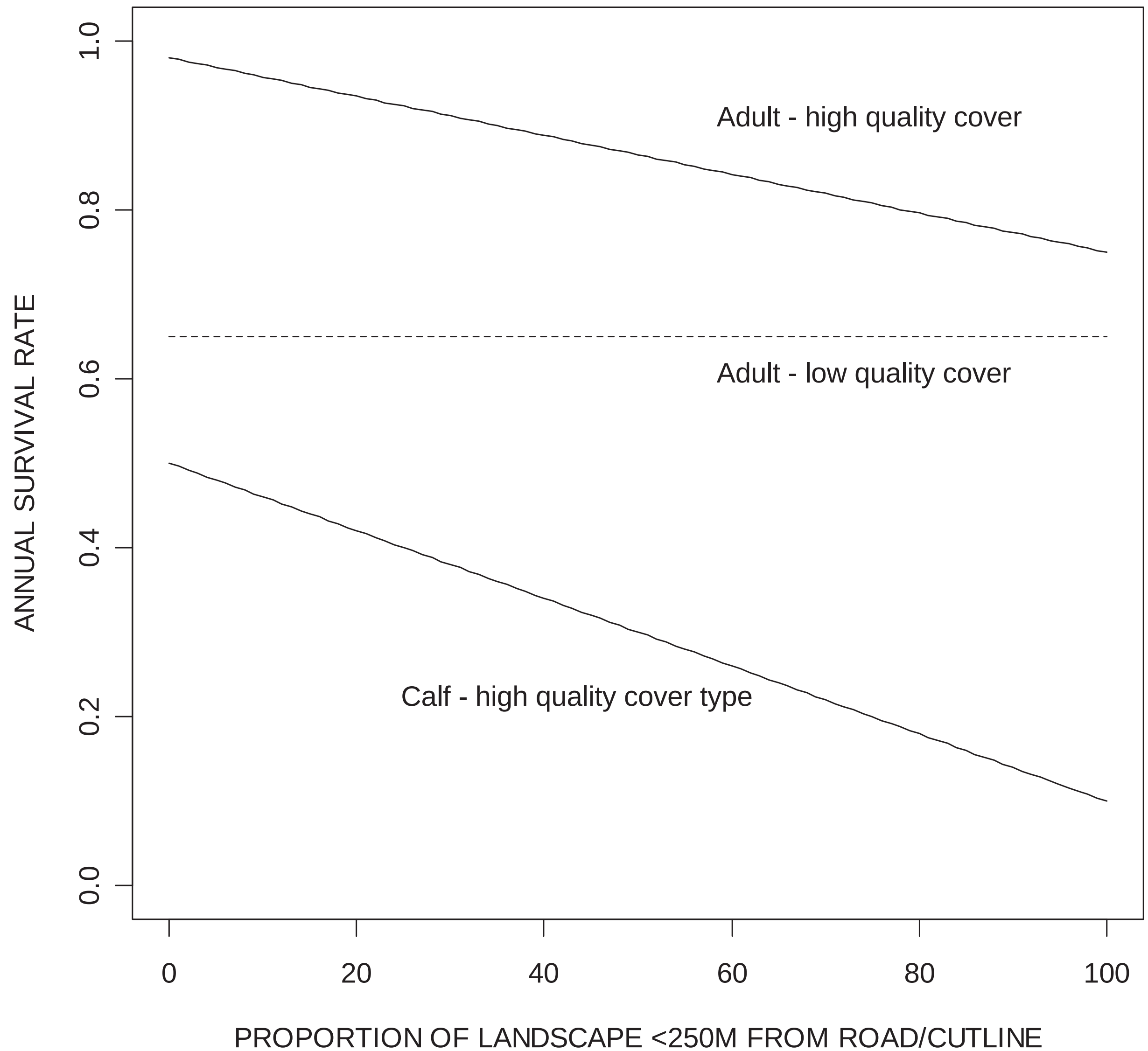
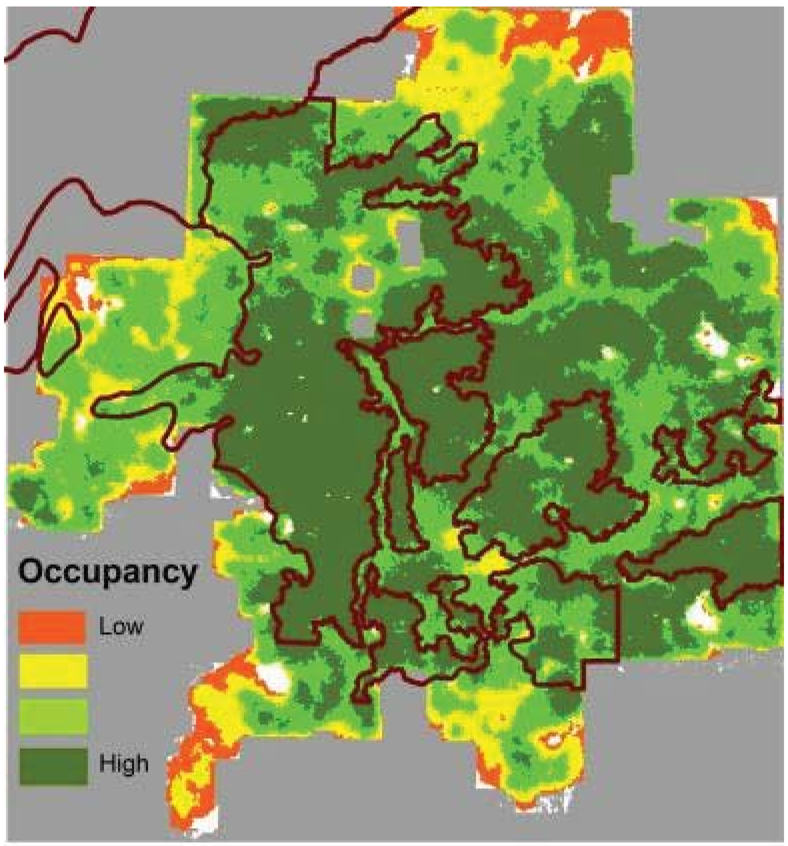
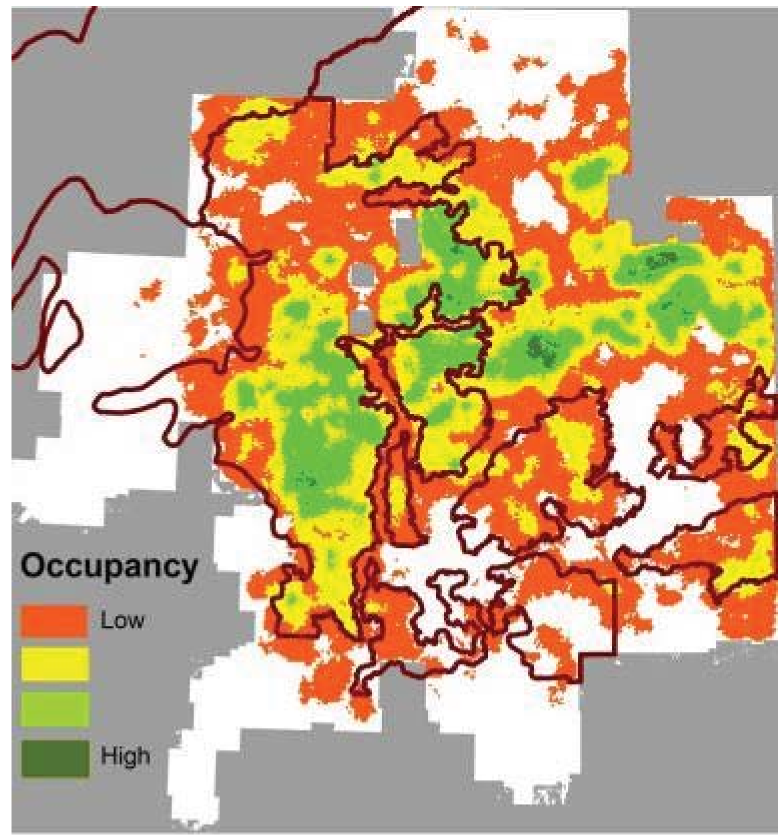
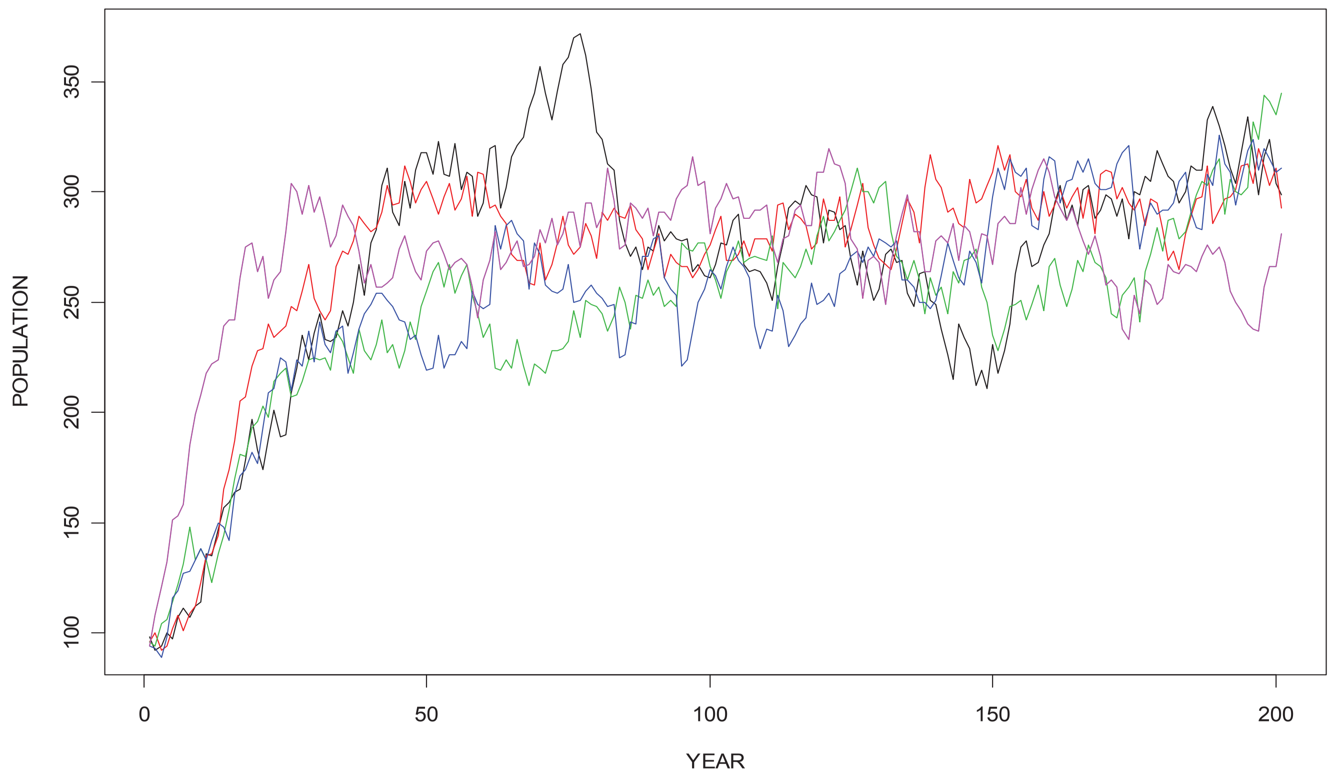


Appendix 6.7 - Figure 1. Initial parameterization for the Alberta study area of the relationship between caribou survival rate and proportion of landscape within 250 meters of linear disturbance features (roads and seismic lines).

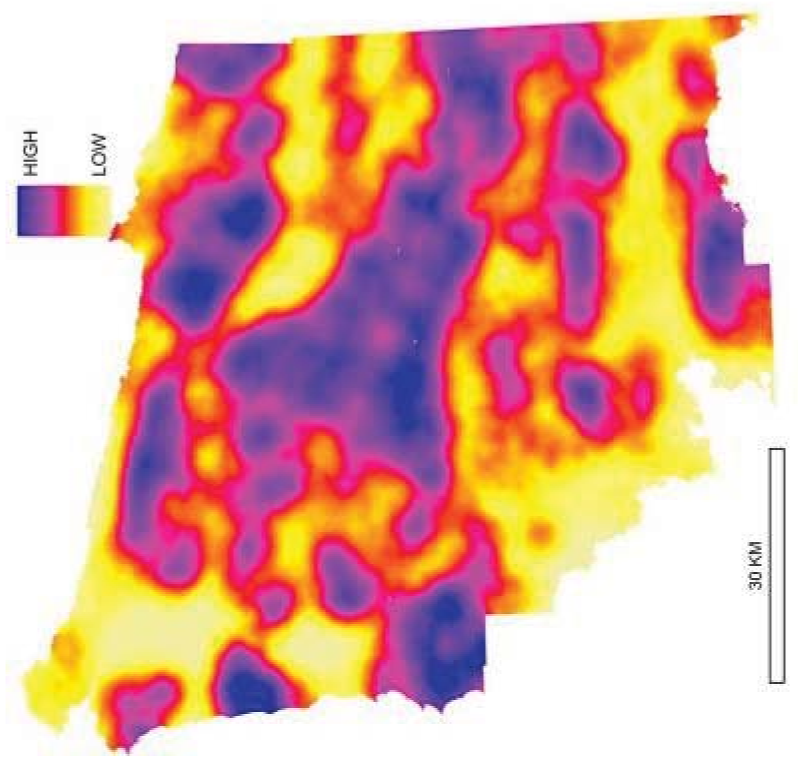


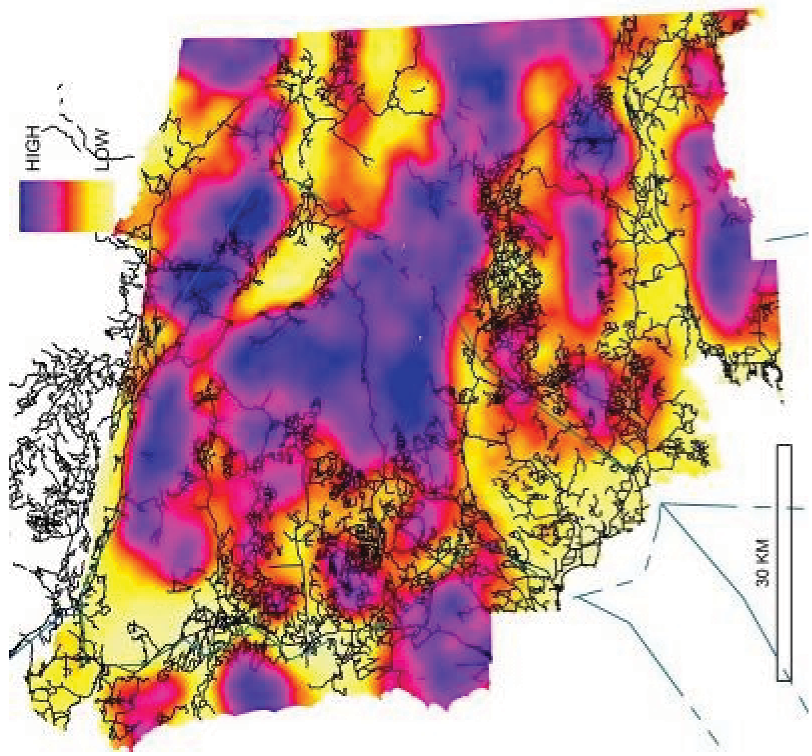


Appendix 6.7 - Figure 2. Results from initial HexSim simulations for the north/eastern Alberta case study area under a) habitat condition without effect of linear disturbance, b) habitat condition with effect of current linear disturbance levels.



Appendix 6.7 - Figure 3. Population time series from HexSim simulations for the north/eastern Alberta study area showing long term fluctuations around stable trend. These fluctuations are driven by a combination of demographic stochasticity and dispersal limitation related to habitat pattern.





Appendix 6.7 - Figure 4. Predictions from the EMWCAC HSI model (averaged over a 100 km2 moving window) for the Manitoba study area for a) caribou summer habitat, and b) winter habitat, overlaid with linear features.

6.8 Conditional Probability Table

The conditional probability table for the joint distribution of criteria states, with integrated prior probability assignments as referenced in Section 2.6.5. SS*f*R is the probability of a local population being self-sustaining, given present range and population conditions.

Trend	Size	Disturbance	SS*f*R	Range Assessment
Declining 0.1	Very Small 0.1	Very High 0.1	0.1	R_{NSS}
		High 0.3	0.2	R_{NSS}
		Moderate 0.5	0.2	R_{NSS}
		Low 0.7	0.3	R_{NSS}
		Very Low 0.9	0.4	R_{NSS}
Declining 0.1	Small 0.3	Very High 0.1	0.2	R_{NSS}
		High 0.3	0.2	R_{NSS}
		Moderate 0.5	0.3	R_{NSS}
		Low 0.7	0.4	R_{NSS}
		Very Low 0.9	0.4	R_{NSS}
Declining 0.1	Above Critical 0.5	Very High 0.1	0.2	R_{NSS}
		High 0.3	0.3	R_{NSS}
		Moderate 0.5	0.4	R_{NSS}
		Low 0.7	0.4	R_{NSS}
		Very Low 0.9	0.5	R_{SS}/R_{NSS}
Stable 0.7	Very Small 0.1	Very High 0.1	0.3	R_{NSS}
		High 0.3	0.4	R_{NSS}
		Moderate 0.5	0.4	R_{NSS}
		Low 0.7	0.5	R_{SS}/R_{NSS}
		Very Low 0.9	0.6	R_{SS}
Stable 0.7	Small 0.3	Very High 0.1	0.4	R_{NSS}
		High 0.3	0.4	R_{NSS}
		Moderate 0.5	0.5	R_{SS}/R_{NSS}
		Low 0.7	0.6	R_{SS}
		Very Low 0.9	0.6	R_{SS}
Stable 0.7	Above Critical 0.9	Very High 0.1	0.6	R_{SS}
		High 0.3	0.6	R_{SS}
		Moderate 0.5	0.7	R_{SS}
		Low 0.7	0.8	R_{SS}
		Very Low 0.9	0.8	R_{SS}
Increasing 0.9	Very Small 0.1	Very High 0.1	0.4	R_{NSS}
		High 0.3	0.4	R_{NSS}
		Moderate 0.5	0.5	R_{SS}/R_{NSS}
		Low 0.7	0.6	R_{SS}
		Very Low 0.9	0.6	R_{SS}
Increasing 0.9	Small 0.3	Very High 0.1	0.4	R_{NSS}

Trend	Size	Disturbance	SS*f*R	Range Assessment
		High 0.3	0.5	R_{SS}/R_{NSS}
		Moderate 0.5	0.6	R_{SS}
		Low 0.7	0.6	R_{SS}
		Very Low 0.9	0.7	R_{SS}
Increasing 0.9	Above Critical 0.9	Very High 0.1	0.6	R_{SS}
		High 0.3	0.7	R_{SS}
		Moderate 0.5	0.8	R_{SS}
		Low 0.7	0.8	R_{SS}
		Very Low 0.9	0.9	R_{SS}
Unknown 0.5	Very Small 0.1	Very High 0.1	0.2	R_{NSS}
		High 0.3	0.3	R_{NSS}
		Moderate 0.5	0.4	R_{NSS}
		Low 0.7	0.4	R_{NSS}
		Very Low 0.9	0.5	R_{SS}/R_{NSS}
Unknown 0.5	Small 0.3	Very High 0.1	0.3	R_{NSS}
		High 0.3	0.4	R_{NSS}
		Moderate 0.5	0.4	R_{NSS}
		Low 0.7	0.5	R_{SS}/R_{NSS}
		Very Low 0.9	0.6	R_{SS}
Unknown 0.5	Above Critical 0.5	Very High 0.1	0.4	R_{NSS}
		High 0.3	0.4	R_{NSS}
		Moderate 0.5	0.5	R_{SS}/R_{NSS}
		Low 0.7	0.6	R_{SS}
		Very Low 0.9	0.6	R_{SS}

6.9 Estimates of Numbers and Trends for the Boreal Population of Woodland Caribou Provided By Jurisdictions

Note: Caribou local population estimates in the following chart may not fully account for the movement of caribou between jurisdictions within trans-boundary ranges (e.g., some caribou that cross provincial/territorial borders may be represented more than once). Also, some of the local population size estimates and trend data are based primarily on professional judgement and limited data and not on rigorously collected field data.

Local Population refers to the 39 recognized discrete local populations; Unit of analysis refers to the remaining units of which 6 units in NWT are the results of sub-dividing a large area of relatively continuous habitat considered to be occupied by one large population into units of analysis. Eight units in Saskatchewan represent units of analysis for multiple local populations within an area of relatively continuous habitat. The 4 remaining units of analysis found in parts of Manitoba, Ontario, Quebec and Labrador include possible multiple local populations within a large area of relatively continuous habitat. In the absence of defined local populations and units of analysis for these areas, the extent of occurrence was considered to comprise the unit of analysis for these 4 units.

map #	Local Population or Unit of analysis	Year of Census	Extent of Survey Coverage	Local Population Size Estimate	Confidence Limits	Current Local Population Trend
Cross-Jurisdictional						
1	AB/BC Chinchaga	AB – Annual BC - 2004	AB – Prescise pop. Trend estimate only (AB does not enumerate caribou) BC - Incomplete	250-300 (includes former Hotchkiss Local Population)	AB- Size estimate based on professional judgement and available field data BC – Average based on several different extrapolations from partial inventory coverage	AB - Rapidly decline (Mean λ = 0.93 during 2002-2006; Range λ = 0.80-1.06) BC – Suspected Declining based on professional judgement
2	AB/NWT Bistcho	AB – 2005 NWT - unknown	AB – Prescise pop. Trend estimate only (AB does not enumerate caribou) NWT – Incomplete	300	AB- Size estimate based on professional judgement and available field data NWT – Estimates based on minimum numbers observed from flights	Suspected declining based on professional judgement agreed to by both jurisdictions
3	AB/NWT Steen River \ Yates	AB – 2005 NWT - unknown	AB – Prescise pop. Trend estimate only (AB does not enumerate caribou) NWT - unknown	300	AB- Size estimate based on professional judgement and available field data NWT – unknown	Unknown

LP map #	Local Population or Unit of analysis	Year of Census	Extent of Survey Coverage	Local Population Size Estimate	Confidence Limits	Current Local Population Trend
Northwest Territories Reported data: Estimates for the units representing continuously distributed local population were derived from density estimates surrounding collared animals, and then extrapolated to larger geographic areas, or for the North Slave region, a density estimate was developed from aerial surveys. Reported trends are expert opinion from NWT based on size estimates over time.						
4	NWT Inuvialuit	2005	Incomplete	Unknown	Unknown	Unknown
5	NWT Gwich'in	2005	Incomplete	500	The population estimate is based on extrapolation of densities from minimum numbers observed from other areas in NWT with collared animals	Increasing based on professional judgement
6	NWT Sahtu	2005	Incomplete	2000	The population estimate is based on extrapolation of densities from minimum numbers observed from other areas in NWT with collared animals	Unknown
7	NWT North Slave	2005	Incomplete	700	The population estimate is based on extrapolation of densities from minimum numbers observed from other areas in NWT with collared animals	Unknown
8	NWT Dehcho (N/SW)	2005	Incomplete	2000	The population estimate is based on extrapolation of densities from minimum numbers observed from other areas in NWT with collared animals	likely decline based on professional judgement
9	NWT South Slave/SE Dehcho	2005	Incomplete	600	The population estimate is based on extrapolation of densities from minimum numbers observed from other areas in NWT with collared animals	likely declining based on recruitment and cow survival–based on 5 years of trend data

LP map #	Local Population or Unit of analysis	Year of Census	Extent of Survey Coverage	Local Population Size Estimate	Confidence Limits	Current Local Population Trend
British Columbia						
10	BC Maxhamish	2004	Incomplete	306	Average based on several different extrapolations from partial inventory coverage	Unknown
11	BC Calendar	2004	Incomplete	291 (best estimate)	Average based on several different extrapolations from partial inventory coverage	Unknown
12	BC Snake Sahtaneh	2004	Incomplete	365 (best estimate)	Average based on several different extrapolations from partial inventory coverage	Suspected Declining Report for the Snake Satenah had 94% adult female survival and calf recruitment of 5-9 calves/100 cows which is essentially a lambda of 1, but the low calf recruitment concluded that the local population was suspected declining. However, the study was too short to make any firm conclusions.
13	BC Parker Core	2007	Incomplete	24 (best estimate)	Average based on several different extrapolations from partial inventory coverage	Unknown
14	BC Prophet Core	2004	Incomplete	54 (best estimate)	Average based on several different extrapolations from partial inventory coverage	Unknown
Alberta						
15	AB Deadwood	2005	Local population trend estimate (AB does not enumerate caribou)	40	Local population size estimate based on professional judgement and available field data	Suspect declining. Local population trend not measured.
16	AB Caribou Mountains	Annual	Local population trend estimate (AB does not enumerate caribou)	400-500	Local population size estimate based on professional judgement and available field data	Rapidly declining (mean λ = 0.92 during 1995 – 2007 Range λ = 0.73 – 1.14)

LP map #	Local Population or Unit of analysis	Year of Census	Extent of Survey Coverage	Local Population Size Estimate	Confidence Limits	Current Local Population Trend
17	AB Red Earth	Annual	Local population trend estimate (AB does not enumerate caribou)	250-350	Local population size estimate based on professional judgement and available field data	Rapidly declining (mean λ = 0.94 during 1995 – 2007 Range λ = 0.81 – 1.30)
18	AB West Side Athabasca River	Annual	Local population trend estimate (AB does not enumerate caribou)	300-400	Local population size estimate based on professional judgement and available field data	Declining (mean λ = 0.99 during 1993 – 2007; range λ = 0.83 – 1.14)
19	AB Richardson		Local population trend estimate (AB does not enumerate caribou)	<100	Local population size estimate based on professional judgement and available field data	Unknown. Local population trend not measured.
20	AB East Side Athabasca River	Annual	Local population trend estimate (AB does not enumerate caribou)	150-250	Local population size estimate based on professional judgement and available field data	Declining (mean λ = 0.95 during 1993 – 2007; range λ = 0.80 – 1.08)
21	AB Cold Lake Air Weapons Range	Annual	Local population trend estimate (AB does not enumerate caribou)	100-150	Local population size estimate based on professional judgement and available field data	Rapidly declining (mean λ = 0.93 during 1998 – 2007; range λ = 0.75 – 1.05)
22	AB Nipisi			60-70		Unknown
23	AB Slave Lake	Annual	Local population trend estimate (AB does not enumerate caribou)	75	Local population size estimate based on professional judgement and available field data	Unknown
24	AB Little Smoky	Annual	Local population trend estimate (AB does not enumerate caribou)	80	Local population size estimate based on professional judgement and available field data	Rapidly declining (mean λ = 0.89 during 1999 – 2007 Range λ = 0.77 – 1.04)

LP map #	Local Population or Unit of analysis	Year of Census	Extent of Survey Coverage	Local Population Size Estimate	Confidence Limits	Current Local Population Trend
Saskatchewan Data reported: The survey used by Saskatchewan Wildlife Branch in the 1980s and early 1990s was one developed by government staff based on advice from some caribou researchers at the time. Surveys were conducted in late November or early December (but were never successful for a variety of reasons). Staff then chose to fly as soon as possible after a fresh snowfall, conducting a transect survey each morning using tightly spaced lines to pick up fresh caribou signs and record. Each afternoon staff would return with a helicopter to search out the sign, locate, count and sex/age the animals. In a survey in 1992, a helicopter was used for everything and simply went off transect each time fresh caribou signs were encountered - following up the sign, recording it, and returning to transect. Sunny days with shadows to show up the tracks were preferrable in contrast to a typical moose survey. Staff also stratified survey areas for the southern ones that were off the shield. In retrospect minimum counts were obtained rather than total local population estimates, and no attempts were made to define confidence limits. (pers comm. T.Trottier)						
25	SK Davy-Athabasca	2006	N/A	310	Estimate based on habitat based on a density estimate of 0.031 (Al Arsenault pers. Comm.)	Unknown
26	SK Clearwater	2006	N/A	425	Estimate based on habitat based on density estimate of 0.036 (average of density estimates from two adjacent WCMUs)	Unknown
27	SK Highrock-Key	2006	Incomplete	1060	Estimate based on habitat surveys of portions of range based on density estimate of 0.041 (average of two surveys)	Unknown
28	SK Steephill-Foster	2006	Incomplete	1075	Estimate based on habitat and aerial surveys of portions of range and aerial survey in late 1980s based on density estimate of 0.033	Unknown

LP map #	Local Population or Unit of analysis	Year of Census	Extent of Survey Coverage	Local Population Size Estimate	Confidence Limits	Current Local Population Trend
29	SK Primrose-Cold Lake	2006	Incomplete	350	Estimate based on habitat and aerial surveys in early 1990s, and data collected by Alberta based on density estimate of 0.047(average of two surveys)	Unknown
30	SK Smoothstone-Wapawekka	2006	Incomplete	700	Estimate based on habitat and previous aerial surveys of portions of range in early 1990s, and documented range recession based on density estimate of 0.027 (average of three surveys)	Declining with habitat change based on professional judgement
31	SK Suggi-Amisk-Kississing	2006	Incomplete	430	Estimate based on habitat and previous aerial surveys of portions of range in late 1980s based on density estimate of 0. 055 (average of two surveys)	Unknown
32	SK Pasquia-Bog	2006	Incomplete	30	Estimate based on recent genetic work cooperative with Manitoba. Documented range recession. based on density estimate of 0.012 (Al Arsenault pers. Comm.)	Threat of decline based on professional judgement
Manitoba Data reported: Year of census (except for Owl Flinstone) and extent of survey coverage were not reported. Trend data is based on local population estimates carried out in the 70's and 80's and in recent years (2007 for Owl Flinstone), that reported similar estimates.						
33	MB Kississing	N/A (not available)	N/A	50-75	based on professional judgement and periodic local population counts	Stable based on professional judgement and periodic local population counts

LP map #	Local Population or Unit of analysis	Year of Census	Extent of Survey Coverage	Local Population Size Estimate	Confidence Limits	Current Local Population Trend
34	MB Naosap	N/A	N/A	100-200	based on professional judgement and periodic local population counts	Stable based on professional judgement and periodic local population counts
35	MB Reed	N/A	N/A	100-150	based on professional judgement and periodic local population counts	Stable based on professional judgement and periodic local population counts
39	MB William Lake	N/A	N/A	25-40	based on professional judgement and periodic local population counts	Stable based on professional judgement and periodic local population counts
37	MB Wapisu	N/A	N/A	100-125	based on professional judgement and periodic local population counts	Stable based on professional judgement and periodic local population counts
36	MB The Bog	N/A	N/A	50-75	based on professional judgement and periodic local population counts	Stable based on professional judgement and periodic local population counts
38	MB Wabowden	N/A	N/A	200-225	based on professional judgement and periodic local population counts	Stable based on professional judgement and periodic local population counts
40	MB North Interlake	N/A	N/A	50-75	based on professional judgement and periodic local population counts	Stable based on professional judgement and periodic local population counts
41	MB Atikaki-Berens	N/A	N/A	300-500	based on professional judgement and periodic local population counts	Stable based on professional judgement and periodic local population counts
42	MB Owl Flintstone	2007	N/A	71-85	based on professional judgement and periodic local population counts	Stable based on professional judgement and periodic local population counts

LP map #	Local Population or Unit of analysis	Year of Census	Extent of Survey Coverage	Local Population Size Estimate	Confidence Limits	Current Local Population Trend
43	Manitoba (Remainder of boreal caribou in MB)	N/A	N/A	775-1585	based on professional judgement and periodic local population counts	Stable based on professional judgement and periodic local population counts
Ontario						
44	ON North East Superior (includes Pukaskwa, Gargantua and Pic Islands)	N/A (not available)	N/A	42	estimate is based on compilation of expert opinions and varied survey techniques across the province	Decreasing based on expert opinion
45	ON Michipicoten	N/A	N/A	200	estimate is based on compilation of expert opinions and varied survey techniques across the province	Increasing based on expert opinion
46	ON Slate Islands	N/A	N/A	250	estimate is based on compilation of expert opinions and varied survey techniques across the province	unknown
47	Ontario (remainder of boreal caribou in Ontario)	1996 (questionnaire survey)	Incomplete	5000	estimate is based on compilation of expert opinions and varied survey techniques across the province	unknown
Quebec						
48	QC Val d'Or	N/A (not available)	Complete	30	Local population size estimate based on professional judgement and available field data	Declining based on professional judgement and available field data
49	QC Charlevoix	1998	Complete	75	Local population size estimate based on professional judgement and available field data	Stable based on professional judgement and available field data

LP map #	Local Population or Unit of analysis	Year of Census	Extent of Survey Coverage	Local Population Size Estimate	Confidence Limits	Current Local Population Trend
50	QC Pipmuacan	N/A	N/A	134	Local population size estimate based on professional judgement and available field data	Stable based on professional judgement and available field data
51	QC Manouane	N/A	N/A	358	Local population size estimate based on professional judgement and available field data	Stable based on professional judgement and available field data
52	QC Manicouagan	N/A	N/A	181	Local population size estimate based on professional judgement and available field data	Increasing based on professional judgement and available field data
53	Quebec (Remainder of boreal caribou in QC)	Incomplete	Incomplete	6000-12 000	Local population size estimate based on professional judgement and available inventory data for the southern part of the range extent	Suspected stable Supported by Quebec's Comité de rétablissement based on surveyed areas and data confirming that the range extent has not changed.

LP map #	Local Population or Unit of analysis	Year of Census	Extent of Survey Coverage	Local Population Size Estimate	Confidence Limits	Current Local Population Trend
Newfoundland and Labrador Data reported: No Newfoundland local populations are included in the 'threatened' designation. The following local populations occur in Labrador, not Newfoundland and there fore the abbreviation "LAB" has been used at the beginning of the local population's name. Lac Joseph - surveyed in 2000. Full Range (38 00 km2), using a mark-recapture method, Lincoln-peterson/joint hypergeometric maximum liklihood estimator. We have conducted late-winter classifications (March, best indicator of recruitment as calves are 9.5 months old) every year since 2000. Percent calves has ranged between 15 and 20% over that time period, and sex ratios of males/females indicate there are approximnately 50 adult males per 100 females (or about 33% males). Between 1999 and 2006 adult survival ranged between 0.788 to 0.913 with a mean value of .852 in this herd, and mean calf survival over the same period is 0.4. Collectively, these suggest that this herd is either stable or slightly declining. Calf recruitment is good, but adult female sruvival could be better. Red Wine Mountain: The survey in 2001 covered the full range of this herd, or 29 900 km2. The estimator used was also a maximum liklihood estimator (mark-recapture techique). The minimum count (number of unique animals observed) was 67, and revised to 87 in 2003 based on a partial sruvey of animals associated in groups with radio-collared females in 2003. Calf recruitment is similar to LJ, as is adult female survival. However, survival rates need to be adjusted to account for losses of adult animals due to illegal hunting. Mealy Mountain: Survey in 2005 covered an area of 62 000 km2 (full range). Type was a density-distribution survey (after Gasaway 1986). Survey repeated methods/extent of 2002 census and estimates of population size do not differ significantly (statistically speaking), which suggests that teh population is stable. This herd declined sharply from 2600 to 284 between 1958 and 1975, and has recovered to numbers in excess of 2000 since 2002. Calf recruitment in 2005 was 16%, and adult female survival averaged 89% between 2002 and 2006. The current rate of grwoth in this herd appears to be 0. However, observed parturition, recruitment, and survivorship schedules suggest this herd has the potential to increase. It is possible that any gains in recruitment are being offset by enhanced mortality of adult (uncollared) animals.						
54	LAB Lac Joseph	2000	Complete	1101	756-1933 ($\alpha = 0.10$)	Unknown
55	LAB Red Wine Mountain	2001	Complete	97	72-189 ($\alpha = 0.10$)	Declining based on professional judgement and available field data; declined from over 800 animals in 1997 to less than 100, and a corresponding change in range size/use has been documented
56	LAB Mealy Mountain	2005	Complete (high density offshore island not included ~ 300 caribou)	2106	765-3447 ($\alpha = 0.10$)	Stable based on professional judgement and available field data

LP map #	Local Population or Unit of analysis	Year of Census	Extent of Survey Coverage	Local Population Size Estimate	Confidence Limits	Current Local Population Trend
57	Labrador (remainder of boreal caribou in Labrador)	N/A	Incomplete	Unknown	N/A	Unknown

7.0

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