Evaluation of Tools Available for Cumulative Effects Assessment for the Northwest Territories

Literature Reviews

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Government of the Northwest Territories
Department of Environment and Natural Resources
Wildlife Research and Management, Wildlife Division
Department of Environment and Natural Resources
Government of the Northwest Territories
P.O. Box 1320
Yellowknife, NT X1A 2L9

By:

ESSA Technologies Ltd.

77 Angelica Avenue
Richmond Hill, ON L4S 2C9

Suite 600, 2695 Granville St.
Vancouver, BC V6H 3H4
http://www.essa.com

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1.0 Introduction

Caribou in Canada's north are iconic animals and representative of a several aspects of the interrelation between humans and the environment. Caribou are symbols of the wild north– vast herds of migrating caribou are used to portray wilderness, and ecological integrity in many media. Caribou are also symbolic of a long-standing sustainable relationship between wildlife and humans as caribou traditionally have been the key in providing food, clothing, and sustenance for many indigenous peoples. Caribou are also symbols of the fragility of natural systems, as, over the last decades many populations have suffered tremendous declines. These declines highlight not only their susceptibility to a broad range of influences, but also the tenuous state of our understanding as we struggle to understand the impacts of natural and anthropomorphic effects.

Caribou management in the NWT is complicated by several factors: 1) There are many government agencies, co-management boards, organizations, and industrial forces which contribute to caribou management. While this is positive in that a wide range of expertise is brought to bear, it also brings tremendous complexity as management direction is subject to differing objectives, and overlapping expertise and jurisdictional responsibility. 2) There is no single factor, acting in isolation which drives caribou population dynamics. Fluctuations are caused by long-term natural forces interacting with both anthropogenic and other natural effects which likely operate in synergistic, additive, and other manners to affect populations. Further, different populations are not subject to the same forces and may not react in the same manner given the various environmental contexts in which they exist. 3) Our understanding of the manner in which anthropogenic and natural forces interact to affect caribou is incomplete. Although there is good quality information from both the scientific and traditional knowledge realms, it is obvious that much related to caribou population drivers remains unknown. 4) There is incomplete data on caribou. As is apparent from the results of this project, there are relatively few data on most caribou populations/ecotypes which can be used to develop comprehensive insights into cause: effect relationships driving caribou populations. 5) There are no comprehensive tools which provide the means to develop deep insight into caribou dynamics.

The sum of the above factors is the vexing conclusion that caribou are subject to cumulative effects of a variety of natural and anthropogenic forces and there is no obvious tool available for integrating the effects and providing direction on monitoring needs and management priorities. This conclusion led the NWT Department of Environment and Natural Resources (ENR) to sponsor this project. The Terms of Reference for this project include: 1) gather and synthesize information on the tools that are available to assess Cumulative Effects (CE), and the ways in which CE can be monitored and managed, 2) provide an assessment which will support the selection of tools with the greatest utility, and 3) provide an implementation plan for the implementation of the tools.

The project's objectives are addressed in the following three sections of this report. In Section 2, we have provided a review of twelve models which may have the capacity to assist in the consideration of cumulative effects. We assessed each of the twelve models according to 13 criteria. From that analysis we have identified models with the greatest potential, but it is apparent that none acting by themselves have to potential to address all, or even most of the potential factors contributing to cumulative effects. In Section 3, we provide a comprehensive literature review of the variety of factors contributing to cumulative effects on the four caribou ecotypes in the NWT. The literature review was based on a series of hypotheses used to construct conceptual models of each of the four ecotypes. Based on the literature review, each hypothesis was categorized according to a risk profile, and data and monitoring needs for each were identified. Monitoring needs are synthesized across ecotypes according to the risk categorization, providing direction on basic and refined monitoring needs. The synthesis of the undertaking, provided in Section 4 identifies a number of recommendations related to monitoring, modelling and collaborative efforts.

2.0 Review of Potential Cumulative Effects Modelling Tools

Numerous models have been created, used, or suggested for looking at caribou in the NWT, and the number of possibilities makes it difficult to decide which model, or models, should be utilized. The purpose of this Section is to evaluate models based on key aspects related to their use, and to provide insights on which may be most suitable for addressing caribou and cumulative effects-related concerns in an NWT context.

Seven models were selected as part of a primary list in order to focus the assessment: SLEDSS, ALCES, MARXAN, SELES, TELSA, Burn-P3, and the CARMA model. Seven additional models viewed as potentially applicable were also included on a secondary list: LANDIS II, Spatial Woodstock, Stanley, Patchworks, Neptune, MGM and the caribou model used by DeBeers. Each of these models was reviewed briefly, and the ones that were potentially most applicable to modelling the issues were reviewed in more depth.

The models can generally be classified into three categories: 1) those that are modelling the landscape or the habitat, 2) those that model caribou populations directly, and 3) those that analyze the landscape at a given point in time. There are many finer distinctions within each of these categories.

The majority of the models fit into the first category, and include both spatial and non-spatial models. Each model is good at modelling some part of the change in the vegetation or the patterns on the landscape. For example, ALCES, while non-spatial, is designed to account for habitat fragmentation that is created from oil and gas developments, roads, and other human-created impacts. SLEDSS is similar, but is a spatial model. Both these models, along with others such as TELSA, LANDIS-II, and Burn-P3 use various methods for accounting for changes in the landscape from disturbances. Models such as MGM, Patchworks, Stanley and Woodstock, also are vegetation change models, accounting primarily for forest management.

Of the models evaluated, there are only two models that focus directly on: the CARMA model and the Golder model developed for DeBeers. The ALCES model and the SLEDSS model are not primarily caribou models, but have incorporated some functionality to help the user do analyses related to caribou. These four models, with the addition of Patchworks, are also the models that have been used in the NWT in the past.

The third category of models analyzes the landscape in a given year only and does not address changes over time. For these models, which include MARXAN and NEPTUNE, the user provides sets of maps as well as other criteria and the model will give results based on those maps. The process needs to be repeated for different years or scenarios.

The remainder of this section provides more detailed information about the different models.

Overview

There are many different models that could be used to provide more information and understanding about cumulative impacts on the landscape and on caribou habitat. We have not attempted in this document to pick the *best* model. While this in part depends on data availability and ease of use, it also depends on the questions to be answered or the decisions that need to be made. For example, the questions “where should we preserve land to reserve the best caribou habitat?”, “what is the landscape vegetation pattern likely to look like after 100 years?", "how will the landscape change under climate change?" and "what is the energetics consequence to caribou from climate change?" may all lead to a different choice of model.

As a secondary consideration, if impacts on caribou are primarily related to habitat availability, then models such as TELSA or LANDS-II, that specifically and only look at vegetation change may be able to be used, and in forested areas, other models such as Patchworks or Woodstock may also be useful. Conversely, if impacts on caribou require knowledge about the energetics or population dynamics of caribou, then a caribou-specific model will be needed, although they tend to require large amounts of data, and may not be applicable to all caribou herds or capture the total impacts from fragmentation. At this point, only the CARMA model, the ALCES model, the SLEDSS model and the DeBeers model include any form of caribou modelling.

The four models that simulate caribou differ widely in availability, ease of use, and approach. In terms of availability and ease of use, the DeBeers model is primarily an in-house model that was developed for a particular purpose and, while all components are based on published research or third-party tools, the overall system may not be readily accessible to outside users. The different tools that make up the model are each relatively easy to use, and have good interfaces, but the linkage between them are manual. The CARMA model is a very detailed research model that has been widely used, but again is not easily accessible to others. Currently, the data entry is not easy, and output must be analysed and graphed before presentation to others. Users can hire the developers of the SLEDSS model and use it for the cost of their time as they help in the project. This model makes all the assumptions used in the simulations explicit to the user, facilitating understanding of the model. There is no front end interface for entering rules or data. Unlike the other three models, the ALCES model has a user interface, a detailed user's guide, training sessions and is available for a fee. This model may, however, also be the most complicated to use because it has a very large number of (non-caribou) possible options that can be included in any simulation.

From a caribou modeling perspective, the CARMA model contains the most detailed and scientifically valid energetics model. Its developers are in the process of linking the energetics model to a population model. It is therefore, very data intensive for highly specific caribou related data. The ALCES model has a basic population model, and is doing a test project which includes caribou energetics and will also therefore be very data intensive. . The DeBeers model contains a basic energetics model, and uses another company's population modelling software to model the population dynamics. It was based on existing available data, and is therefore less data-hungry than the others. The SLEDSS model is between the others. It is mostly a population model that relates changes in habitat to population levels. As such its data requirements are less.

The background to this review did not pose specific management questions and it is possible that the best strategy to address questions related to cumulative effects on caribou in the NWT will be a multi-tool/model approach that combines as necessary the best elements of models appropriate to a specific question. For example, the fire model Burn-P3 can give good fire information to other models such as ALCES or TELSA. Marxan or Neptune can be used to analyze maps output from other models to see if its choice of reserves or the spatial metrics have varied over time. Analyses done with the CARMA model could be used to provide the basis for creating a less detailed/data demanding caribou model in something like SLEDSS or ALCES (replacing or adding to the caribou model that is already there) or TELSA. Woodstock or Patchworks can provide harvest streams or patterns for input into other models as well.

The key consideration is to carefully review the questions that need to be answered, the people who will be trying to answer those questions and the capabilities and strengths of the models vis-à-vis the specific questions to be addressed.

Scope of the Model Reviews

The review of each model addresses nine questions:

A: Ease of Use: What is the extent of user knowledge required? Is there an interface, User's Guide, training session, support network? Is the model freely available or must it be purchased?

B: Output / interpretation of results : What are outputs?, How accessible are they? Do they require extra processing? How clear is the information to the general public?

C: What are the strengths and weaknesses of the model?

D: What is the primary use of the model? This includes examples of some of the types of projects that the model has been used for.

E: Data Needs: How data hungry is the model? What types of data are needed? What steps are taken if data do not exist?

F: Data Types: Does the model use only scientific data (i.e., maps, published data or data collected in a scientific manner) or can local or traditional knowledge also be incorporated?

G: What is the relationship between data needs and to available data?

H: What is the reasonable scale for this model? What is the timeframe?

I: Validation / Publications, including links to websites where this information is stored.

We answered these questions primarily by reviewing model documentation and papers. In some cases, we also spoke with developers or users. Differing amounts of information were available for the models. In some cases, the model web site was very detailed, we were able to look directly at the model or users guide, or speak with a developer or user. In other cases we had personal knowledge and experience with the model. For some models, the web site was not as informative, and there were few papers available on-line. We attempted to gather more detailed information for those models that directly model caribou, rather than those that would only be useful to be part of a larger modelling process. The varying level of detail available to our review does not necessarily reflect on the quality of the model.

Models are listed in alphabetical order both in the summary table and in the longer descriptions that follow.

Model Summary Table

Table 1 (on the following page) summarizes a subset of some of the key characteristics of the different models. Below is a key which defines the different rows in Table 1, the abbreviations that are used, and, if applicable, which of the review questions the row addresses.: In all cases, more detail is in the longer descriptions about each model.

Row	Definition	Question
1. Spatial	Is the model a spatial model?	n/a
2. Primary goal	What is the primary goal of the model? • 'LS' = a model that is simulating changes in the landscape based on many different factors such as growth, disturbances, and management. • 'FM' = Forest management	D
3. Caribou	Does the model simulate caribou? • Habitat = a model that can simulate or calculate changes in caribou habitat, but not populations	D
4. Dists	Does the model simulate disturbances? • F = fires • O = other natural disturbances such as insects, wind, disease, floods, etc. • M = forest management • A = other anthropogenic such as seismic lines, roads, wells, urban areas, etc.	n/a
5. Strength	What is the key strength of this model?	C
6. Weakness	What is the primary weakness of this model?	C
7. Regional Scale	Is the model capable of simulating at the regional scale? • Note that in some cases the answer may depend on the size of the cells being simulated.	H
8. Time scale	How long can the model simulate outwards?	H
9. Data Types	What types of data does the model use? • S = scientific • L = local knowledge • TK = traditional knowledge	F
10. Local?	Is the model *currently* parameterized for local or NWT conditions, or has it already been used in the NWT? • "*" are models that can be parameterized by the user (i.e., they require no code changes to use in the NWT).	n/a
11. UI	Is there a User Interface for the model?	A
12. UG, etc.	Is there a User's Guide? Is there support or training?	A
13. Free?	Is the model free?	n/a

Table 1 Model Summary Table

	ALCES	Burn-P3	CARMA	Golder	LANDIS	MARXAN	MGM	NEPTUNE	Patch-works	SLEDSS	TELSA	Wood-stock
1. Spatial?	no	yes	no	yes	yes	yes	no	yes	yes	yes	yes	yes
2. Primary Goal	LS	Fire	Caribou	Caribou	LS	Zonal optimization	FM	Dist. patterns	FM	LS	LS	FM
3. Caribou	partial	habitat	Yes	Yes	habitat	no	habitat	no	habitat	partial	habitat	habitat
4. Dists.	FOMA	F	indirect	no	FOM	no	M	Maps of disturbance	M	FOMA	FOMA	M
5. Regional Scale?	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	sub	yes
6. Strength	Fast, Detailed	Fire	Caribou	Caribou	Climate Sensitive	Defining Zones	Stand mgmt.	Dist Patterns	Flexible	Flexible	Non-grid Polygons	FM
7. Weakness	Non-spatial complex	Only fire	Difficult to use	Separate pieces	Data Intensive	Single year	Non-spatial	Single year	Learning curve	No docs.	Slow	Non-spatial
8. Time scale	any	1-year	40-years	Any	any	none	any	none	any	any	any	any
9. Data types	S, L, TK	S, (L)	S,L,TK	S,(L,TK)	S	S,(L,TK)	S	S	S	S,L,TK	S, L, TK	S
10. Local	yes	no	yes	yes	no	no	no	no	yes	yes	no	no
11. UI	yes	yes	no	no	no	yes	yes	yes	yes	no	yes	yes
12. UG, etc	yes	yes	no	no	yes	yes	yes	yes	yes	yes	yes	yes
13. Free?	no	yes	Not available	no	yes	yes	yes	no	no	no	yes	no

Abbreviations for Primary Goal (2):
FM = Forest Management,
LS = Landscape model

Abbreviations for Disturbance (4):
F = Fires,
O = Other natural disturbances,
M = forest Management,
A = other Anthropogenic disturbances

Abbreviations for Data Types:
L = Local knowledge,
S = Scientific
TK = traditional knowledge

More detailed information about each of the models is given in the following sections.

ALCES

ALCES ("A Landscape Cumulative Effects Simulator") is a non-spatial simulation model that is designed to represent the impacts of different processes on a wide range of environmental, economic and social indicators. While non-spatial, the model does track area, length and quantity of different features within separate spatial strata. ALCES represents many different functions including development (energy, mining, urban), harvesting, natural disturbances, and other ecological processes. The model also includes sub-sections that can track and report on a host of different types of variables such as carbon, water, transportation, farming, climate change, commodities, and many others. The model can simulate almost any type of landscape including forests, grasslands, and different types of non-forest areas.

There is work currently in progress to link information about caribou population and energetics into ALCES to allow users to use it for exploring cumulative impacts on caribou.

The model has been in use since the 1990s, and has been used for a wide variety of projects in various locations around the world.

A: Ease of Use

The model can be purchased and run independently (i.e., without needing to hire the developers) on the user's computer. Note that the government of NWT already holds an ALCES license. The user must also have a license for STELLA (http://www.iseesystems.com/), the tool using which ALCES was built.

The model contains a good and well documented User Interface.

The User's Guide is very detailed and includes a description of how ALCES can be used in a consensus building workshop setting with key stakeholders. Five day training sessions are available. The model is complex enough that, while training is not required, it is recommended.

Data and other information are entered into tables in the interface or into a linked table in Excel.

B: Output

At a minimum, the model produces output about the state of the landscape at various points in time, showing area in different vegetation or habitat classes, as well as areas disturbed. Each of the sub-sections of the model (e.g., natural disturbances, energy, mining, water, wildlife etc.) contains a host of other indicators any of which can be output from the model. Examples include numbers of active wells, amount of active roads, population levels of wildlife, and area or volume harvested. The model contains many pre-defined graphs of the most commonly requested indicators, but the user can customize graphs of other indicators.

The interface shows tables and graphs. Some of these are quite clear (e.g., area by seral stage) while others may look quite complex if many variables or simulations are being run, and if current and future conditions are being compared to historic information.

Results can be exported to other graphing programs. Output can be mapped using an additional add-on tool.

C: Strengths/Weaknesses

Strengths: The model is designed to allow users to quickly assess impacts of change on a landscape. It is designed to be used in a group setting to allow for collaboration and cooperation among the different stakeholders. The model runs quite quickly and has a large amount of capability built into it.

Weaknesses: The model is non-spatial, although it contains spatial metrics and some spatial functions such as buffering. As a consequence from this lack of specific spatial knowledge, some relationships that depend on spatial location (e.g., fire spread, green-up or buffering constraints) cannot adequately be simulated. Output can be mapped and the same model result could be mapped many different ways (which can help show potential stakeholders the range of meanings behind something such asnumber of small patches or seismic lines). Note that there is now a spatial version of the model, which gains this advantage, but gives up the advantage of speed. The model is costly, especially compared to some of the others evaluated (but the Government of the NWT already has a license, which will reduce the cost). The multiple capabilities of the model means that ALCES can do cumulative effects and interactions well, but that quantity of information that is require can be daunting, and the interactions between the different components may not be obvious, well understood by the user, or easy to interpret in the output.

D: Primary Uses of the Model

This model is designed to simulate the cumulative impacts of multiple events (natural and human caused disturbances) in landscapes over time. It was originally developed to address issues of the impact from oil and gas development in Alberta, and is used widely in the province as part of the regional planning.

The model has been used to explore effects of development. In one study, simulations were done for northeastern Alberta and southern NWT, comparing the impact of a business as usual scenario with a conservation scenario. The study looked at forest age classes, wildlife habitat (different species, including boreal caribou), and oil and gas production.

In another study in Alberta, the model was used to provide projections of future boreal caribou populations and habitat under different assumptions about the changing landscape, and to provide management options for helping to sustain population levels.

In the Yukon, the model was used to explore possible implications of different oil and gas scenarios. It was used to show land use issues, and potential levels of change in the landscape, socio economics and environmental impacts. The results supported the management recommendations from the local land use plan.

Besides use in Canada, the model has been used in various projects around the world. For example, the model was used in Paraguay as part of a land use planning process. The model was used to look at different agricultural and forestry practices, including protection, and compared impacts on land cover, carbon, and the income of local residents.

A common theme, and goal, in the ALCES modelling in Canada or abroad is to aid stakeholders in understanding the issues and trade-offs in planning.

E: Data Needs

ALCES is a complex model with numerous parts to it. A list of all the data needs would be immense. Few studies or uses of the model will require all parts of ALCES to be active, and the model is more efficient if not all sections are used. Therefore, only a subset of the data requirements are listed in this section to give a sense of the quantity and type of data that are required.

The initial state of the landscape needed as a series of summary tables that give the amount of the landscape in different categories (e.g., mixedwood forest, lake, prairie grassland, tundra, etc.) as well as the proportion of different industrial categories (e.g. roads, pipelines, well sites, cities, etc.). Forest age class structure is also needed. Users must supply growth and yield curves for the forests, and information about the dynamics of range or grasslands.

There are two different places where wildlife could be simulated. One is in the wildlife section of the model. Here, users must define general information such as the wildlife species being simulated as well as the habitat value of the different types of the landscape, and the response curve between changes in levels of habitat and wildlife. For the new NWT barren-ground caribou energetics portion of the model, some very specific data will be required. These include information about the proportion of time spent by an animal in different types of activities (foraging, lying, standing, walking, and running), seasons, detailed plant information (moss, lichens, mushrooms, horesetails, graminoids, deciduous shrubs, evergreen shrubs, forbs, standing dead, and eriophorum heads), snow levels, green-up, activity budgets, initial conditions of the animals, etc.

There are many other aspects of ALCES that, if used, require additional information. For example, ALCES contains a meteorological sub-model which into which the user must enter precipitation, temperature, water hydrology related data, and other such information. A climate change section allows users to enter tread data or modifier parameters. Natural Disturbances require information about the disturbance type (e.g., fire, insects, etc), the average frequency and the frequency distribution of disturbance on different landbases types, size classes of disturbances, impact of the disturbance on different seral stages, etc. The energy and mining sectors need information about unproven and proven reserves, well drilling trajectories, and size, lifespan, etc of various footprints. Other sub-models, such as transportation, hunting, first nations etc. require other types of data or information.

F: Data Types

The model uses scientific data primarily. However, some of the data is very specialized or localized and would need to draw upon local and traditional knowledge. This is especially true for the caribou sections of the model, which require detailed information about the caribou (see above).

G: Relationship to Available Data

Vegetation maps are available for much of the NWT for both forested and non-forested vegetation. Maps of industrial or other anthropogenic activity are difficult to find and may need to be created. It is hard to judge the availability of other data without knowing which modules of ALCES are to be run. Some of the information can be derived from workshop settings from talking with stakeholders. ALCES has been used in a pilot project in the NWT, so progress will have been made in finding necessary information.

H: Scale

The model is best used at the landscape scale.

The model works on annual time steps.

I: Validation / Publications

Two papers that are specific to modelling Barren-ground caribou in the NWT are:

Nishi, J.S., Antoniuk, T and Stelfox, J.B. 2009. Review of land cover data and suitability of Alces for evaluating cumulative effects on boreal caribou in the Dehcho Region. Manuscript Report No. 182. *(available from the authors)*

Gunn, A., Johnson, C.J., Nishi, J.S., Daniel, C.J., Russell, D.E., Carlson, M., Adamczewski, J.Z. 2011. Understanding the Cumulative Effects of Human Activities on Barren- Ground Caribou. In: *Cumulative effects in wildlife management : impact mitigation* / editors: P.R. Krausman and L.K. Harris pp113-133.

A list of other publications can be found on the website: http://www.alces.ca/publications

J: Source

Information for this section came from reports available on the ALCES website, provided by the GNWT and provided by a developer. Also, some information came from interviews with users and a developer.

Burn-P3

Burn-P3 (Parisien et al. 2005) is a spatial model designed to simulate the ignition and growth of large fires in Canada. It contains three modules: ignition, conditions, and growth.

The model is supplied with a rasterised landscape map containing fuel information. The model performs several iterations. In each iteration, it draws ignition and size information from a probability distribution based on local fire regime information, and grid cells are burned. At the end of the run, the burn area grid is summarized into an overall map of wildfire susceptibility over a wide area. This is a very detailed model for fire, and is a valuable tool for helping to predict fire locations and sizes in parts of Canada, but has not yet been parameterised for the North.

A: Ease of Use

The model can be downloaded without a fee and run on a user's computer. The User's Guide is detailed and users are able to use it to set-up their own run. No training sessions are offered.

B: Output

The outputs of the model are entirely about fire. Output includes both tables and maps. Tables give information about every simulated fire including fire intensity, location, season, duration, and area burned in each fuel type. Maps contain information about the burn probability of each grid cell, and maps of fire perimeters.

C: Strengths/Weaknesses

Strengths: This model is very strong at simulating fire on the landscape and will produce good maps of the areas of high and low probability of fire on the landscape. Information from runs of this model could be used to derive inputs on fire probabilities for other models.

Weaknesses: For the purpose of this report, the key weakness of the model is the same as its strength: the model looks at fire only. Also, it is not currently parameterized for the North.

D: Primary Uses of the Model

This model is designed to simulate fires and to show, given conditions on the landscape and the historical fire information, the probability that different areas will burn.

One use of the model was in BC where it was used as part of a larger analysis to compare the fire susceptibility under four conditions: historic, current and two scenarios of future climate. In another case, the model was used as part of the fire risk assessment in a TSA analysis. In Nova Scotia, the model is used for wildfire management.

E: Data Needs

The model needs detailed fire information, most specifically high-resolution maps of fuel types, and will not run without these maps. Ideally, it is also provided with daily weather data for the study area. The model also uses information about number of escaped fires, ignition locations, fire break maps, and elevation maps, but these are not critical to a simulation run.

F: Data Types

The model relies on scientific data and maps. Local knowledge could be used to refine some of the scientific data, such as helping create the maps, or information about local historic fire conditions.

G: Relationship to Available Data

Historical fire data about size of large fires is available, as are elevation maps. Weather predictions also exist to some degree, but may need to be downscaled from global climate models. Few, if any, local fuel maps are available, although the Canadian Forest Service does have coarse scale maps that cover the entire country, as well as some weather data (see http://cwfis.cfs.nrcan.gc.ca/en_CA/background/dsm/fbp). If this model were to be used, it would be necessary to contact the Canadian Forest Service for more information about the fire information that is available for the NWT, especially since they run a number of controlled burns in the territory each summer.

H: Scale

The model is best used at the landscape scale, defined in this case as an ecoregion or land management unit. The resolution within the model is a daily time step.

I: Validation / Publications

The key publication is:

Parisien, M.A.; Kafka, V.G.; Hirsch, K.G.; Todd, J.B.; Lavoie, S.G.; Maczek, P.D. 2005. Mapping wildfire susceptibility with the BURN-P3 simulation model. Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-405.

Some other publications which describe the model and its uses include:

Beverly, J.L., Herd, E.P.K., Conner, J.C.R. 2009. Modeling fire susceptibility in west central Alberta, Canada. Forest Ecology and Management 258:1465-78.

Braun,W.J., Jones, B.L., Lee, J.S.W., Woolford,D.G., and Wotton, B.M. 2010 Forest fire risk assessment: an illustrative example from Ontario, Canada. J. Probability & Statistics, Article ID 823018, 26 pp,

Parisien, M.A.; Kafka, V.G.; Todd, J.B.; Hirsch, K.G.; Lavoie, S.G.; The peripheral reduction in burn probability around recent burns in the boreal forest. (*found at: https://ams.confex.com/ams/pdfpapers/65569.pdf)*

Williamson, T.B.; Price, D.T.; Beverly, J.L.; Bothwell, P.M.; Frenkel, B.; Park, J.; Patriquin, M.N. 2008. Assessing potential biophysical and socioeconomic impacts of climate change on forest-based communities: a methodological case study. Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB. Inf. Rep. NOR-X-415E.

J: Source

Information for this section came from the website and reports available on-line.

CARMA MODEL

The “CARMA” (CircumArctic Rangifer Monitoring and Assessment) model is a non-spatial model that was originally built as an energy-based model using the understanding of forage intake, ruminant physiology, biochemistry and nutrition to simulate a female caribou driven by environmental variables measured in the range of the Porcupine Caribou Herd (PCH). The resultant PCH Energy model was driven by an intake sub-model that produced metabolizable energy input to drive an energy allocation sub-model that accounted for expenditures associated with maintenance and deposition in body reserves, gestation and lactation.

Later, the original energy model was modified and expanded to integrate protein. The current model now simulates separate but coordinated partitioning of energy and protein-nitrogen and consists of three sub-models; 1. Forage Intake (diet selection, logistic controls over eating rate, time allocation), 2. Metabolic Transactions (rumen/post-ruminal digestion and absorption to predict daily intake of metabolizable protein-N in parallel with metabolizable energy), and 3. Energy and Protein Allocation (partition metabolic nitrogen and energy to meet the animal’s protein-N and energy requirements for maintenance, growth and reproduction).

The model has been in development since the 1980s. The developers are currently working on linking output from this model to a population model that will project impacts at the population level.

A: Ease of Use

There is no User Guide for this model, but documentation exists for the energy model, and is in draft form for the energy-protein model. However, little training would be required to learn how to run the model.

There currently is no user-friendly way of generating the data input components as each application requires a unique setup depending on data available and application purpose. The developers are working on a spreadsheet format for entering the data.

B: Output

The model tracks up to 100 model indicators and the model platform is designed to either output variables in Microsoft Access or as user-defined graphs. The user has control over what variables are plotted. Output is not always easy to interpret, especially for a user unfamiliar with the model.

C: Strengths/Weaknesses

Strengths: The primary objectives of the Energy/Protein Model is to help guide research priorities and direction and to better support "what-if" scenario analyses applicable to assessment of cumulative effects of climate change and industrial development. The model's strength is its complexity and its incorporation of scientific knowledge about caribou metabolism. This allows users to explore mechanistic explanations for caribou responses to outside stimulus. Further because the model tracks numerous intermediate variables, at many stages the model output can be validated and sensitivity of variables assessed. The model can not only be used as a predictive tool, but also as a research tool (new research results easily incorporated), a monitoring tool (model can be used to assess the relative importance of indicators measured in the field), as a basis of data gap analysis, and as an adaptive management tool (can explore quantitative impacts of mitigation and management actions). Strengths also include the ability to include traditional knowledge. This was done in the habitat model for the Bathurst herd.

Weaknesses: Although complexity has positive implications, it also has drawbacks, especially 1) ease of use, 2) output interpretation, 3) data requirements and 4) accessibility. Further in its current state model outputs need to be manually interpreted to assess impacts at the population level, although this drawback is being addressed with linkage to a population model.

D: Primary Uses of the Model

The model is currently used to project effects of environmental changes including industrial development on caribou and to explore caribou ecology. Components of the model have been verified through applications that emphasize energy expenditure such as energy consequences of low flying fighter jet aircraft (Delta Caribou Herd), road and pipeline effects at Prudhoe Bay (Central Arctic Herd (CAH)); integration of nutritional components to determine responses to climate change (PCH); effects of climate change (PCH, CAH); summer range assessment (George River Herd,) and full integration of components for application to development (e.g., environmental assessment of Diavik mine-Bathurst Herd; cumulative effects pilot project-Bathurst Herd, and potential energetic impacts of the Baffinland mine in north Baffin Island).

The model is currently being used to assess vulnerability of Peary caribou populations to climate change and development (Nunavut General Monitoring Program) and to assess impacts of the Izok Mine proposal in central NWT

E: Data Needs

This model is very data hungry. To apply the model to any specific population, the model requires information on caribou activity and range and includes information such as: activity budgets (Foraging, lying, standing, walking, running, pawing intensity, eating intensity), diet (by plant group), and forage information (amount, fiber, nitrogen content, digestibility). It is obvious that few populations have all these data in sufficient detail. Recognizing these limitations the model developers have assimilated a tremendous number of studies to 'generate" data where no site-specific data exists. For example, for the north, CCRS has produced a number of broad scale products that map vegetation communities. Thus these data can be downloaded and applied to specific herd ranges. Many of the seasonal dynamics in vegetation have been assessed in a number of localles. For example studies in Alaska have documented the weather requirements of most key plant groups and specific relationships have been developed to predict growth rate, changes in nitrogen and plant quality and senescence from growing degree days (GDD). Thus to apply those dynamics to other regions and other herds, CARMA has developed 32 year climate database (Russell et al. in press), that is available to all mainland and Island herds in the world (except boreal and mountain caribou). This dataset has been used to generate most of the variable required to populate the model.

The modellers have also generated a "diet algorithm" incorporating knowledge of caribou seasonal nutrient requirements balanced with nutrient and biomass availability. This algorithm can generate diet from forage data described above, which can be over written should seasonally and herd specific data exist.

F: Data Types

The model development is heavily dependent upon scientific knowledge for its structure and functional relationships. However, local knowledge can play an important role in generating scenarios, providing local knowledge of caribou movements and providing observations on caribou behaviour under severe or unusual weather conditions. This knowledge can then be used to "move" caribou around in the model, or alter input data on activity etc.

G: Relationship to Available Data

See Section E above.

H: Scale

The model can be used from a very site specific scale to a global scale if comparative assessment within subspecies populations or among different subspecies.

I: Validation / Publications

Note that many other models have a publication page which we have linked to. For this model, we have listed the publications here.

Gunn, A., Johnson, C.J., Nishi, J.S., Daniel, C.J., Carlson, M., Russell, D.E. & Adamczewski, J.Z. 2011. Addressing Cumulative Effects in the Canadian Central Arctic – Understanding the Impacts of Human Activities on Barren-ground Caribou. Chapter 8. In eds. P. R. Krausman and L. K. Harris. Cumulative Effects in Wildlife Management: A Critical Aspect of Impact Mitigation. Taylor and Francis. 274pp.

Gunn, A. and Russell, D. E. submitted. Insights into integrating cumulative effects and collaborative co-management for migratory tundra caribou herds, NWT, Canada. Paper submitted to Environment and Society, February 2012.

Gunn, A., Russell, D.E., Daniel, C.J., White, R.G. & Kofinas, G.P. In press. CARMA's approach for collaborative assessment of cumulative effects. – Rangifer Special Issue

Kruse, J.A., White, R.G., Epstein, H.E., Archie, B., Berman, M., Braund, S.R., Chapin III, F.S., Charlie Sr., J., Daniel, C.J., Eamer, J., Flanders, N., Griffith, B., Haley, S., Huskey, L., Joseph, B., Klein, D.R., Kofinas, G.P., Martin, S.M., Murphy, S.M., Nebesky, W., Nicolson, C., Russell, D.E., Tetlichi, J., Tussing, A., Walker, M.D. & Young, O.R. 2004. Modeling sustainability of arctic communities: An interdisciplinary collaboration of researchers and local knowledge holders. – Ecosystems 7:815-828.

Luick, B.R., J.A. Kitchens, R.G. White & S.M. Murphy. 1994. Modelling energy and reproductive costs in caribou exposed to low flying military jet aircraft. Rangifer Spec. Issue 9: 209-212

Manseau, M. 1996. Relation réciproque entre les caribous et la végétation des aires d'estivage: Le cas du troupeau de caribous de la Rivière George. Ph.D thesis, Université Laval, Ste-Foy. 185pp.

Murphy, S.M., Russell, D. E., & White, R.G. 2000. Modeling energetic and demographic consequences of caribou interactions with oil development in the Arctic. – Rangifer, Special Issue No. 12: 107-109.

Russell, D.E., Martell, A.M., & Nixon, W.A.C. 1993. The range ecology of the Porcupine Caribou Herd in Canada. – Rangifer Special Issue No. 8, 168pp.

Russell, D. E. 2011. Energy–protein modelling of the North Baffin Caribou in relation to the Mary River mine project. Project completion report for EDI Environmental Dynamics, Inc. Whitehorse, Yukon. 48 pp.

Russell, D. E., & White, R.G. 2000. Surviving in the north- a conceptual model of reproductive strategies in arctic caribou. Proc. 8th North American Caribou Workshop. 23-25 April 1998. Whitehorse, YT, Canada. – Rangifer, Special Issue No. 12: 67.

Russell, D.E., White, R.G., & Daniel, C.J. 2005. Energetics of the Porcupine Caribou Herd: A computer simulation model. Technical Report series No. 431. Canadian Wildlife Service. Ottawa, Ontario, 64pp.

Russell, D. E., Whitfield, P. H., Cai, J., Gunn, A. & White, R.G. in press. CARMA's MERRA-based Caribou Range Climate database. Rangifer Special Issue.

Russell, D.E., van de Wetering, D., White, R.G., & Gerhart, K. L. 1996. Oil and the Porcupine Caribou Herd--Can we quantify the impacts? – Rangifer Special Issue 9:255-257.

White, R.G., Russell, D.E. & Daniel, C.J. In press. Modeling energy and protein reserves in support of gestation and lactation: glucose as a limiting metabolite in caribou and reindeer. – Rangifer Special Issue

J: Source

Information for this section was provided by the developer.

GOLDER CARIBOU MODEL

This model is a set of models that operate together within a spatial context. They were designed as part of an Environmental Impact Statement (EIS, DeBeers 2010), to help give a sense of the relative cumulative impact of different factors or events on barren-ground caribou. It is made up of three parts: 1) a habitat model which combines landcover classification, maps of development sites buffered by the footprint and zones of influence (sensory disturbance), and resource selection functions and uses this information to look at changes in habitat loss (both direct and indirect) and fragmentation; 2) an energetics model that looks at the energetic cost to caribou for encountering development (defined as being within a zone of influence), or from exposure to high levels of insects (based on weather). This cost is related to loss of reproductive ability; and 3) a population model which uses the change in habitat and the changes in reproduction and survival, combined with hunting or catastrophic events to predict relative changes in population levels from these effects.

A: Ease of Use

This model is a set of tools, each with differing levels of ease of use. A key requirement is that a project manager understand what information is required as input or output from each tool, so that the appropriate information can be obtained.

The habitat modelling can done in any GIS package as it primarily involves overlaying maps to gather the required information. An experienced GIS analyst should need no additional training for this, simply appropriate instructions. A different analyst would be required to define the resource selection function required for defining caribou habitat, if they are different from those already defined for the Bathurst caribou herd.

The energetics modelling is done in an Excel spreadsheet that has various defined macros. The key here would be having an understanding of information required in the different cells.

Population is done using a population viability model packaged in RAMAS-GIS, a population modelling software package. The information that is output from the first two tools (GIS and Excel) is manually input into the population model. Some training would be required for the novice user of this tool.

There is no specific manual or training program set-up for teaching others how to use this suite of tools together. This was not designed as a set of tools that would be distributed to others. There is, however, a user-interface and a user guide for the population model RAMAS. Knowledge of caribou ecology and limitations/constraints of modelling are essential to producing credible results that provide robust and meaningful predictions.

B: Output

The output from the habitat section includes any variables that would normally be available from a GIS analysis, with the addition of the information specific to this application: zones of influence, number of times caribou encounter these zones, etc.

The output from the energetics part of the model includes information about the energy cost to caribou and consequent decrease in parturition rate due to contact with the zones of influence or insect levels.

The output from the population model includes graphs and tables that summarize information about population levels and risk curves for different effects scenarios

C: Strengths/Weaknesses

Strengths: This model combines habitat, energetics and population dynamics. It uses three easily available tools, two of which (GIS and Excel) are very familiar to most analysts. Because of this, any defined function or relationship is easily explained.

Weaknesses: This model was not originally intended to be something that would be marketed or sent to others, and is not a cohesive, single package. The energetic model is simple and does not include variations in energy input (for example, if the caribou foraging was displaced into poor quality habitat). While the PVA approach to population models is a well-known tool developed for projecting population persistence over long-time scales (decades to centuries) it was not designed for the ‘management’ scale of population dynamics.

D: Primary Uses of the Model

This model was designed to be used for the EIS, for looking at cumulative impacts on caribou and for determining the sensitivity of the caribou to different human and natural disturbance events.

E: Data Needs

The models needs maps of vegetation, and development areas. For the EIS, data on where the caribou were at different key times of the year and their movement paths (such as migration routes, calving, summer and wintering areas, etc.) were also used. The energetic model requires a relationship between parturition rate and body mass. Changes in body mass from disturbance events (i.e., encountering zones of influence on the landscape) and insect harassment must also be estimated. Estimates of potential insect harassment days also require meteorological data for the region(s). Population metrics, including birth and mortality rates and harvest levels are also needed. This data is all required, and the model will not be able to be used in its absence.

F: Data Types

The model uses scientific data, primarily based on maps. Data from caribou collars were very important.

G: Relationship to Available Data

This model was created and used only with available data such as vegetation maps, development area maps, population levels of the relevant caribou herds, collar data for those herds, etc. Land cover data is available in many forms and scales of resolution, but some did not cover the entire caribou range, and computation time for small scale resolution (e.g., 30 m pixels) became a constraint for the size of the study area (about 300,000 km^2). The estimated zones of influence and disturbance coefficients for different types of development were based on best information available, and will likely be improved as further studies provide more precise estimates. The most challenging set of data were the maps of development areas. The largest constraint was collecting accurate and precise information on the type and areas of different developments from federal, territorial, provincial, and industrial sources. The physical footprints of many developments were not available and assumptions had to be made for this missing information. Similarly, the duration of exploration programs was assumed to extend throughout the entire five-year land use permit because these data were also not available.

H: Scale

The model can be used at any landscape scale. It makes the most sense, however, to use it at the scale of the caribou population that is being assessed.

I: Validation / Publications

Boertje R.D. 1985. An Energy Model for Adult Female Caribou of the Denali Herd, Alaska. Journal of Range Management 38:468-473.

De Beers Canada Inc. 2010. Gahcho Kué Project: Environmental Impact Statement: Volume 2, Section 7 (Key Line of Inquiry: Caribou).

This document can be found at:

http://reviewboard.ca/registry/project_detail.php?project_id=37&doc_stage=5

Information about the population modelling software, RAMAS can be found in

Akçakaya, H.R. 2005. RAMAS GIS: Linking Spatial Data with Population Viability Analysis (version 5). Applied Biomathematics, Setauket, NY.

and at http://www.ramas.com/ramas.htm#gis

J: Source

Information in this section came from the document listed above and the model developer.

LANDIS-II

The LANDIS-II model (Scheller et al. 2007) is a spatial model that simulates forest vegetation change in a landscape over time. Vegetation is simulated as cohorts (i.e, groups of the same age) of different species. Vegetation types and amounts change based on ecological processes such as succession (a function in part of shade tolerance, longevity, and sexual maturity), sprouting, and seed dispersal. Additional modules have been created for the model to allow users to simulate impacts of climate change, various types of management and disturbances such as wind, insects, and fire. This model is designed to work well for predicting vegetation succession, and can include impacts of climate change. It does, however, lack an interface and it requires detailed information about each tree species. Impacts on caribou would need to be inferred based on vegetation.

A: Ease of Use

This model can be freely downloaded (http://www.landis-ii.org/) and run on a user's PC. The model is run from the command line, and interacts with text files.

The first use of the model in a new area, such as the NWT, will require a significant set-up time, due to gathering all required species parameters. Subsequent model runs with the same types of vegetation will require much less set-up time.

There is no user interface to aid in model parameterization or for exploring results, although a free third-party mapping tool that can read the LANDIS output files is available (LandisView, https://mywebspace.wisc.edu/wxi3/web/landisview.html). Thus, model output needs to be manipulated and mapped or graphed before users or the public can see or understand the results.

Documentation in the form of a User's Guide and a Model Description exist, and are enough to get a user able to run the model. One-week training sessions are held periodically, and there is an on-line forum for asking questions. Model developers are also good about answering tougher questions.

B: Output

Output can be in the form of tables or files that can be mapped in other software. Variables that are output are mostly related to the vegetation on a site, and include various statistics about amounts or ages of one or more species on a site. Maps of disturbed cells are also produced. As mentioned above, there is no built-in interface for the output, but the output files can be read by other mapping tools. No landscape summary graphs are produced, but the output tables that are printed can be imported into another program such as Excel for further analysis, summary, or graphing.

C: Strengths/Weaknesses

Strengths: LANDIS-II has the ability to simulate cohorts of species on the landscape. Unlike most of the other landscape models, it has the ability to simulate changes in vegetation over time due to climate change, given appropriate input variables. It also contains the most detail about the structure of the vegetation in each cell in the landscape.

Weaknesses: The key weakness, for use in the NWT, is that there is no current ability in the model to simulate oil and gas activities (e.g., roads, wells and seismic lines) and their impact on the landscape. It may be possible to work with the developers to determine how to use the harvest module to address this issue, but it would not be ideal. A second weakness, which is more easily overcome, is that this model is purely a vegetation model, and primarily a forest model. All inferences about caribou would need to be done as a habitat post-processor.

D: Primary Uses of the Model

LANDIS-II is a landscape forest change model. Because it tracks individual cohorts, and can be sensitive to climate, it can be used to look at trees species and structure and how the composition of these change in cells over time, with or without disturbances such as management, fire, wind, or insects. It is not a population model. If this were to be used for caribou, it would be as a post-processor to relate the output vegetation to habitat.

The model has been used in area around the world, including the US, Canada, Mexico, Chili, and the Czech Republic. The model has been used to assess carbon cycling or balance in forests, examine the urban wildfire interface, look at impacts of Spruce Budworm, simulated changing land-use patterns, and predict how forests might change under climate change, to mention a few examples. While not yet used in the NWT, it has been used in southern boreal forests in Canada and in boreal forests in Siberia.

E: Data Needs

LANDIS needs maps of the initial conditions of the vegetation by species and age class. If forest management is to be simulated, then it also needs maps of any management zones. Detailed species information is needed (such as shade tolerance, longevity, sexual maturity, sprouting, and seed dispersal), and the model will not run without it. This information needs to be reasonably accurate as the values are used for calculating growth, mortality and succession.

F: Data Types

The model needs scientific data. Local knowledge would only be used to refine some of the data from the literature (e.g., if the literature gave a value for longevity but locals knew that the area they were working with had trees with a shorter lifespan).

G: Relationship to Available Data

Vegetation maps are available for much of the NWT for forested areas. Some data about boreal species are available. Since the model has been used in boreal forests, it is likely that many of the parameters necessary to run the model can be found in the scientific literature or from the authors of those projects.

H: Scale

The model is best used at the landscape scale.

The model works on variable, user-defined time steps.

I: Validation / Publications

The key publication for the LANDIS-II model is:

Scheller, R.M., J.B. Domingo, B.R. Sturtevant, J.S. Williams, A. Rudy, D.J. Mladenoff, and E.J. Gustafson. 2007. Introducing LANDIS-II: design and development of a collaborative landscape simulation model with flexible spatial and temporal scales. Ecological Modelling 201 (3-4): 409-419.

A list of publications can be found at: http://www.landis-ii.org/documentation/PublicationsPage

J: Source

Information for this section came from personal experience (ESSA Technologies developed one of the LANDIS-II extensions and has attended several LANDIS-II meetings and presentations), and various reports.

MARXAN

MARXAN (Game and Grantham 2007) is a spatial tool that is designed to identify areas that will meet a suite of user-defined targets, for the least possible cost (social, ecological or monetary). Users enter text-based summaries of maps and information about different species, habitats, management areas and other planning zones, as well as biodiversity targets or other constraints for the different areas or zones, and any associated costs. MARXAN will then provide one or more results that fulfill the planning requirements. This tool would be most useful if managers were trying to define one or more protected areas or regions for extra development.

A: Ease of Use

The model runs on a user’s PC, from a command line. There are various free add-on interfaces that can help a user prepare the required text-based input files. If no interface is used, then it is more difficult to prepare the input files, and knowledge of GIS would be required. The amount of time it requires to set-up a model run will depend on the questions being asked and the availability of the data, but the time requirement could be substantial and would need to be repeated for each new area analyzed. A detailed User's Guide is available and provides a good level of information to allow a novice user to run the model. Two-day training courses are available, held in various locations around the world.

One of the most difficult things to learn about this model is how to effectively use the relative weighting and cost functionality that is used for the model to determine some of the optimum answers. The User's Guide gives some useful descriptions of how these should be used and how to decide on the relative values.

B: Output

Output is written to several different text files. The main results are in two different files: a summary file which states the overall score, cost, and number of cells that are in the final zones, as well as a file that explicitly lists each cell that is in the final zone and that is in a format that can be used in various mapping programs. Some of the add-on interfaces allow users to map the results, but users familiar with mapping programs could import this file to their own GIS system as well.

C: Strengths/Weaknesses

Strengths: A key strength of this model is its ability to find optimal solutions to conservation area problems with different trade-offs and costs. The model is able to produce multiple answers, so that planners can see a range of potential options.

Weaknesses: This model is static. To be used over time, a second model would need to be run to generate maps for different timesteps. Then, either Marxan could be used for each set of output, or the output from the second model could be analyzed and summarized to get the various trade-off parameters. The model also requires significant set-up time.

D: Primary Uses of the Model

This model is primarily used to look at possible areas for conservation or other purposes. It is also used to help develop regional plans. It could be used for analyzing potential prime caribou habitat.

In one Canadian example in Southern Alberta, Marxan was used to help develop a regional plan. The model was given a summary of the overlay of maps of conservation areas and current land-uses such as agriculture, forestry, industry, energy, and recreation. Weightings were placed on different key desired features, and maps were produced which showed outcomes of the Marxan results. Based on these results, summary proposed land-use maps were drawn by planners. A second Canadian example was a Parks Canada study to help define different protected areas around Haida Gwaii. Marxan was given information about the habitats of different key species, as well as existing zones with different levels of protections. Marxan did not given a definitive answer, but provided important information for the planning process.

E: Data Needs

There is a fair amount of data that are required to run the model. Most of these data are specific to the sites being analyzed and will need to be redone for every location. The data include items such as planning zones (i.e., the grid or polygons that the landscape is divided into), the conservation features (e.g., species of interest) and target representation (e.g., how much of the area needs to have the species of interest), and information about how the zones and features interact. Complex information about costs, weightings and importance are also included, and are less tangible. Because these weighting factors cannot easily be determined prior to the first run of the model, the user is expected to run several different scenarios to search for reasonable values.

F: Data Types

Data are primarily scientific (e.g., the conservation features). Local knowledge could be used to help determine weighting factors, presence of features that may not be in the scientific literature (e.g., local forage areas) and local data accuracy.

G: Relationship to Available Data

Maps that cover the area of interest are needed by the model. Maps that contain key human disturbed areas generally exist, although their accuracy is variable. Vegetation maps also exist. Maps can be created that show key caribou habitat or ranges, and some of these already exist.

H: Scale

The model must be used at the landscape scale. The model is constrained by the number of units that the landscape is divided into, not the size of the units.

There is no time dimension in this model. It looks at a static collection of defined information.

I: Validation / Publications

Marxan was originally developed in 2000 in Australia. Development has continued since that time, and it has been used for a wide variety of applications, both terrestrial and marine. There are a large number of publications on Marxan and its various applications, listed on the following web sites:

Marxan publications: http://www.uq.edu.au/marxan/index.html?page=80365&p=1.1.6.3

Publications and presentations; http://pacmara.org/tikiwiki/tiki-index.php?page=Marxan+Resources+and+Training

Game, E. T. and H. S. Grantham. 2008. Marxan User Manual: For Marxan version 1.8.10. University of Queensland, St. Lucia, Queensland, Australia, and Pacific Marine Analysis and Research Association, Vancouver, British Columbia, Canada.

J: Source

Information for this section came from the website, publications and presentations available on-line and the User Manual.

MGM

The Mixedwood Growth Model (MGM) is a deterministic, distance-independent (i.e., aspatial), individual tree stand growth model. Trees are grown individually and separate equations are used for juvenile tree growth, height growth, diameter growth, and mortality. Various types of complex management can be simulated. Stands can be a single species, or combinations of the four species allowed in the model: white spruce, aspen, lodgepole pine, and black spruce. Outputs include both tree and stand level characteristics.

Unlike the other models reviewed here, this is a stand-level model, not a landscape-level model, although a landscape could be simulated non-spatially by performing multiple simulations with individual stands. Also note that this model, while it is for the boreal forest, has not yet been parameterised for the NWT.

A: Ease of Use

The model operates in an Excel environment, using a set of four Excel spreadsheets. The spreadsheets have a customized tool bar which allows users to navigate to the different required components and aids in entering the information.

A detailed help file is available which gives information about the different steps in setting up and executing a simulation.

The model is non-intuitive to use, and will require some time to understand the terms and how to interact with the different components.

B: Output

The output indicators are tree and stand-level characteristics such as volume/ha, diameter at breast height (dbh), density, basal area, and average stand height. Graphs are automatically generated at the completion of run.

C: Strengths/Weaknesses

Strengths: This is a good model for growing multispecies, multiage stands. It allows complex stands to be effectively simulated, and can model partial disturbances. Habitat values that depend on structure as well as species can therefore be predicted.

Weaknesses: There are three key weaknesses for the purposes of modelling caribou in the NWT. 1) This model is a stand-level model, so, while groups of stands can be modelled, they are simulated independently from each other. 2) Impacts of natural disturbances or climate change are not included. Because it is an aspatial model, the impact of seismic lines or other development is also not included. 3) It has been calibrated for use in Alberta, BC, Manitoba, and Saskatchewan, not the NWT. Calibrating it for the NWT is a significant undertaking, but the Alberta version could be used as a starting position to test the usefulness of the model, if desired.

D: Primary Uses of the Model

This is primarily a tool to assess the impacts of different stand management prescriptions on a single stand. In the US Forest Service, the model on which MGM was originally based (see below) is used to run hundreds of stands in the national forests to create their forest plans. In BC, this same US model has been used for various analyses including investigating the impacts of Mountain Pine Beetle or root disease on stand dynamics, and looking at the impacts of partial cutting. In BC, the results from this stand-level model is used to help inform models that are used for planning across larger areas.

E: Data Needs

The key data requirements are tree details. At a minimum, the model needs at least one tree record containing species, size, density and age. Information about stand location can also be used. Further information about prior growth increments or damage can also be used if available.

Analyses can be run with pseudo stands – representative stands that are created by the user, if necessary and if sufficient information about the forest can be estimated. A landscape would be simulated by repeating several of these example stands.

F: Data Types

The model uses scientific information from local plots only. No traditional knowledge is included.

G: Relationship to Available Data

It is unclear how much tree or stand-level data are available to run this model, but there is likely very little data, given that forestry is not pervasive across the NWT, and that, where trees are present, stand and tree data are not often collected.

H: Scale

The model is can only be used at the stand level.

I: Validation / Publications

Further information about the model, including downloading it, can be found at: http://www.rr.ualberta.ca/Research/MixedwoodGrowthModel.aspx

A list of publications about the model can also be found on the website at:
http://www.rr.ualberta.ca/en/Research/MixedwoodGrowthModel/TheModel/References.aspx

This model is originally derived from, and has similar characteristics to the Forest Vegetation Simulator (FVS). This is a model that is used widely across the US Forest Service, with variants that are calibrated for each different region. Variants of FVS also exist in BC (called PrognosisBC) and Ontario. FVS is a well-researched and well documented model, and has an extremely powerful user interface, regular training sessions, available support, and the ability to simulate a wide range of forest management, carbon, and some natural disturbances (most notably fire). Further information about FVS can be found at:

USFS: http://www.fs.fed.us/fmsc/fvs/

Ontario: http://www.fvsontario.ca/home_index.htm

BC: http://www.for.gov.bc.ca/hre/gymodels/progbc/

J: Source

Information for this section came from the website, exploration with a downloaded version of the model and our extensive knowledge of FVS. (ESSA Technologies has been working with and creating variants and extensions for FVS since the 1980s.)

NEPTUNE

The Novel Emulation Pattern Tool for Understanding Natural Events (NEPTUNE) is a spatial tool that converts maps of mortality (e.g., fires or large-scale insect disturbances) into disturbance events. It then looks for patterns and produces information about event sizes, shapes, and undisturbed areas in islands or remnants. It is designed to compare the given mortality maps to information about the historic natural range of variation. Thus, users can use this information to see how human disturbances combined with natural disturbances vary from historic conditions. It can also be used to analyze the impact of potential events (e.g., a large development) on landscape pattern. This model would only be useful in the analysis of caribou habitat if one were interested in comparing the historic patterns of the locations of caribou habitat with current or potential future habitat.

A: Ease of Use

The model is available for a fee, which may include a training session.

The model is accessed over the web, and is being used by several companies in Alberta and Saskatchewan.

B: Output

The model produces output tables that summarize information about the patterns on the landscape. The summary information includes the size, shapes, and number of events, percent of area in matrix or island remnants, and the natural range of variation of these indicators.

C: Strengths/Weaknesses

Strengths: This model gives users a good sense of the disturbance patterns on the landscape, and how they are similar or different to historic disturbance patterns, a requirement that is very important in some jurisdictions. The model also allows for assessments of potential disturbances (linear, harvesting, or fire) to see how they will impact the distribution of disturbed areas on the landscape.

Weaknesses: This model does not predict how patches or disturbed area will change over time. Users must, for any time period of interest, analyze a new set of maps. Thus, this model, if used, would not be used independently from another model that can predict changes in the landscape.

NEPTUNE is currently calibrated for the boreal plains of Alberta and Saskatchewan and would need to be calibrated, by the developers, for the NWT.

D: Primary Uses of the Model

The model's primary use is to answer questions about patch sizes of disturbed area on the landscape. A key use of the model is to compare current or proposed management and disturbance regimes with historic natural disturbance patterns on the same landscape.

One specific example of this is an analysis that was done in a forest management agreement area in Alberta that contained disturbances from energy exploration, mining and harvest. NEPTUNE was used to determine spatial metrics that could then be compared to those from historic wildfire patterns in Alberta. The human-induced disturbances were found to produce smaller and more frequent patches, but larger events. The results from this study can then be fed into any future planning that wants to increase ecosystem functioning.

E: Data Needs

The model requires input maps (shape files) of "mortality events" or any other areas that the user wishes to use to create patches on the landscape.

F: Data Types

The input data are maps. These maps can come from any source, including local knowledge.

G: Relationship to Available Data

This model needs disturbance maps as input. Maps of fires may be available. Maps of human disturbances are more difficult to find and may need to be created prior to using the model.

H: Scale

The model must be used at the landscape scale.

The model has no time dimension.

I: Validation / Publications

http://foothillsri.ca/resource/neptune

http://issuu.com/FoothillsResearchInstitute/docs/hlp_2012_05_rpt_characterisinganthropogenicdisturb/19

J: Source

Information for this section came from the website.

PATCHWORKS

Patchworks is a spatial explicit forest management optimization and planning model. The model allows users to set various objectives which can be non-spatial such as total harvest, or total area of old growth, or spatial such as adjacency constraints or patch size distributions. Each target has an associated user-defined weighting function which Patchworks uses as it searches for solutions. Patchworks allows users to look at various sensitivity or trade-off analyses, and is capable of solving complex spatial problems. It is primarily used for creating forest management plans, and does this very effectively.

A: Ease of Use

The model is exceedingly complex, but very powerful. There is a steep learning curve. The user interacts with the model using files which contain all the information about the various zones, vegetation, adjacencies and distances between blocks, etc. Much of the setup is done by the user prior to use of the model, so requires GIS skills. The model provides a rudimentary interface for aiding in the creation of the input files.

The model must be purchased, and support contracts are also available.

Two-day training sessions are held periodically.

B: Output

The reporting module is strong and allows users to customize reports with their desired output. The model produces information about the current state of each polygon in the landscape at every time step.

C: Strengths/Weaknesses

Strengths: The model is extremely powerful, with the ability to tweak many different aspects of a scenario. It is able to produce realistic answers to complex questions and trade-offs about forest management and planning.

Weaknesses: Depending on the complexity of the questions being asked, the model can be slow. Also, because of the various targets that it tries to resolve, clear answers to sensitivity questions can be difficult to understand. Natural disturbances, if desired, are entered as mortality events and are not explicitly simulated.

D: Primary Uses of the Model

The model is primarily a forest planning tool to help forest managers.

The model can be used in many different aspects of the planning process. In BC, for example, Patchworks is often used by different companies as a key tool in doing the timber supply review for many of the different Timber Supply Areas (TSA) in the Province. In Ontario, the model was used to test proposed landscape management guidelines prior to release. In Manitoba, it was used as part of a forest planning exercise.

Note that this model has been used for a project in the NWT.

E: Data Needs

The model needs data layers that contain the information necessary to solve the requested problems. At a minimum, there must be some measure of the location and type of vegetation with links to some type of growth curves, typically generated from stand-level models. Any information about location of management or protected zones enhances the utility of the model, as does more detailed vegetation information (e.g., adding snag or C information).

F: Data Types

Data are scientific. Local or traditional knowledge could potentially be used in assigning some of the weighting values used in the model, but are not a key part of the data requirements.

G: Relationship to Available Data

Since Patchworks has been used in NWT, most of the necessary growth curves are likely available (although they may need tweaking for the specific area of interest). Vegetation maps exist, but will need to be correlated appropriately with the growth curves. Maps of management areas and protected zones will need to be created for the study area.

H: Scale

The model must be used at the landscape scale.

The model works on user defined time steps, usually 5-10 year steps.

I: Validation / Publications

More information about the model can be found at: http://www.spatial.ca/

The paper upon which the first version of Patchworks was based is:

Lockwood, C.G.; Moore, T.G.E. 1993. Harvest scheduling with spatial constraints: a simulated annealing approach. Canadian Journal of Forest Research 23: 468-478.

Other sample papers or presentations that describe how Patchworks has been used:

Donnelly, M and Van Damme, L. 2010. Forest Landscape Design: Fundamentals and Applications. Proceedings of a national workshop in Winnipeg, Manitoba April 2008. 47pp.

ForSite. 2010. Mid Coast TSR3 Timber Supply Analysis Report. 145pp

Moore, T and Tink, G. 2008. Technical considerations in the design of core habitat patches in forest management: A case study using the Patchworks spatial model. Forestry Chronicle. Vol. 84:731-740.

Rouillard, D and Moore, T. 2008. Patching together the future of forest modelling: Implementing a spatial model in the 2009 Romeo Malette Forest Management Plan Forestry Chronicle. Vol. 84:719-730.

Timberline Natural Resources. 2009. Carbon Budget Modelling and Optimization Analysis on the Boundary TSA. Draft Report.

J: Source

Information for this section came from interviews with users and the website.

SLEDDS / SELES

The Spatial Landscape Evaluation and Decision Support Simulator (SLEDSS) is a spatial tool that is designed to simulate how forested landscapes change over time in response to human and natural activities and the resulting cumulative impacts on the landscape. The model tracks dominant vegetation at the ¼ ha to 1 ha cell level, with the vegetation following yield curves input by the user. It can simulate disturbances such as timber harvest, fire, insects, and development following deterministic, stochastic, or planned (i.e., off of maps provided by the user) processes. The model operates in a spatial raster map, and can therefore incorporate spatial considerations such as adjacency or size constraints.

SLEDSS was designed using the SELES modelling framework. This framework provides a powerful and flexible language which users use to tell the model what to do. The developers of SLEDSS have created customized data and management systems, modules, and outputs to help users with applications specific to cumulative effects. If one wanted to use this model in Alberta or the NWT, it makes more sense to start with SLEDSS than to build a new SELES model from scratch. Unless otherwise specified, all discussion below relates to SLEDSS.

A: Ease of Use

SELES is designed for a user to download and use on their desktop. Designing a run that looks at cumulative impacts of oil and gas exploration on the landscape or on caribou would be time consuming and challenging for the novice user, as all relationships and impacts must be defined by the user. With many key aspects to this type of analysis already customized, SLEDSS has made this easier, but there is no user interface for entering data.

There are no user manuals or formal training sessions specifically for the SLEDSS model. If this model is to be used for a project, the developers would likely be hired to help run the model, including setting up and defining the various relationships that need to be entered. Use of this model is expected to be a collaborative process involving many of the stakeholders so that all share a common understanding of the model and the proposed simulations.

Training sessions are offered periodically for SELES, and self-directed tutorials are under development.

B: Output

The model produces a huge quantity of different outputs, including vegetation types, seral stages, age class, areas disturbed, habitat, air quality, risk indicators, and impact indicators. Output of the last four indicators depends on the type of analysis that is being done and whether the model has included the rules to calculate these indicators.

Output is available as graphs or maps, some of which can be shown on the screen in real-time as the model runs.

C: Strengths/Weaknesses

Strengths: The model is spatial and simulates over landscapes. Because it was developed using SELES, it has the capability to be expanded to add extra indicators. The model is used in a group setting, so that all parties get understanding of how the model works and what is being put into the model. This also allows the model users to be able to interpret things like traditional knowledge into language that the model will understand.

Weaknesses: This model is not available for use by individuals on their own. FORCORP must be hired to help a group of stakeholders develop the understanding and particular models for their situation. While SELES was started in the mid-1990s and has been used and developed since that time,, the specific application of SLEDSS is relatively new and there is little documentation about it.

D: Primary Uses of the Model

This model is designed to be used for regional planning. It is primarily a vegetation model and as such can be used to model changes in habitat for different species, including caribou. Internally, the model currently ranks caribou habitat based on a federal model for caribou habitat.

SELES has been used throughout Canada for a wide variety of projects, including use in forest planning, mountain pine beetle analysis, researching impacts of different types of land planning, and even used as a platform for a cross-scale analysis of other models.

E: Data Needs

The model is able to use many types of data. Primarily, the model needs data layers: most importantly maps of vegetation. The scale of the map just needs to be enough to map a grid cell on the ground to a corresponding yield curve, so more accurate maps (e.g., from a vegetation inventory) have more accurate vegetation predictions, but predictions are possible with relatively coarse scale data (e.g., from remote sensing). The model is able to import exact development plans, if available.

F: Data Types

Data types can include all three: scientific, local and traditional knowledge. For the local and traditional knowledge, the only caveat is that this information must be translated into rules that can be entered into the model.

G: Relationship to Available Data

Vegetation maps exist. Yield curves for forested areas are also likely available, given that Patchworks has been used in the NWT. Development areas are not well mapped.

H: Scale

The model is best used at the landscape scale.

The model works on annual time steps.

I: Validation / Publications

There are no publications specifically on this model. Model development only started two years ago, which is insufficient time to publish in the peer-reviewed literature. Some project reports exist, as does a publication about an earlier precursor to the SLEDSS model, while it was considered an application of SELES.

Papers about SELES can be found at located at (note that both sites do not have some of the more recent publications):

http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/fall_andrew/fall.html
http://www.gowlland.ca/about_gowlland/publications.html

A few other publication that use SELES include:

Michael J. Papaik, M.J. Fall, A., Sturtevant, B., Kneeshaw, D. Messier, C. Fortin, M-J. and Simon, N. 2010. Forest processes from stands to landscapes: exploring model forecast uncertainties using cross-scale model comparison. Can. J. For. Res. 40: 2345–2359

Cote, P., Tittler, R., Messier, C., Kneeshaw, D., Fall, A., Fortin, M-J. 2010. Comparing different forest zoning options for landscape-scale management of the boreal forest: Possible benefits of the TRIAD. Forest Ecology and Management 259 (2010) 418–427

J: Source

Information for this section was provided by one of the developers, with further information about SELES from the SELES website and other publications available on the web.

TELSA

The Tool for Exploratory Landscape Scenario Analyses (TELSA) is a spatially explicit, landscape-level model for simulating terrestrial ecosystem dynamics. It helps resource managers and planners assess the consequences of alternative scenarios of management and natural disturbances on species composition and structure. The model simulates vegetation as different state classes, while disturbances, succession, and management are defined as pathways between these different classes. Because all state classes are defined by the user, the model can be used for any type of terrestrial landscape, including both forests and grasslands. The types of pathways are also defined by the user, so the model can simulate impacts of a wide variety of disturbances, whether natural or human-induced. Note that often, pathways and their probabilities are created based on local knowledge rather than scientific data. Indicators include areas disturbed or managed annual as well as maps and graphs of the distribution of different state classes. A non-spatial version of the model, the Vegetation Dynamics Development Tool (VDDT, now PATH) is also available.

A: Ease of Use

This model can be freely downloaded and run on a user's computer. While the documentation is enough to get a user able to run the model, a training session or support contract would be useful. It is essential that the user understand the concept of State Classes and transition pathways to be able to use this model effectively.

The first use of the model in a new area, such as the NWT, will require a significant set-up time, due to the necessity of setting up all the states and pathways. After the first set-up, however, subsequent model scenarios will proceed much more quickly.

Defining additional attributes which are carried and used during a model run is possible, but cumbersome. However, any post-processing analysis that requires only the knowledge about the state of the vegetation is straight-forward, as all information is stored in an Access Database.

Documentation in the form of a User's Guide and a Model Description exist. One-week training sessions are held periodically.

B: Output

At a minimum, the model prints the state of each polygon in the landscape at user-defined intervals. The state information includes the class (a measure of cover type and structural stage), age and volume. In addition, if the user has defined additional attributes these are available as well. Information about timing, size and location of all disturbance events (natural disturbances and management) are saved every year.

Output is stored in an Access database. One interface allows viewing of tables and graphs when all model runs are complete, and a second customized ArcView program allows viewing of maps. Other analyses are possible for those users with Access skills.

C: Strengths/Weaknesses

Strengths: Unlike most of the other spatial models, TELSA operates on a polygon basis rather than a grid basis. This allows the model to explicitly retain small, important, characteristics such as riparian buffer zones or seismic lines. State classes are extremely flexible and can be used to represent a wide variety of vegetation types including forest, grasslands, and non-vegetated states.

It also allows users to easily simulate almost any type of management or natural disturbance that can change the state of a polygon.

Output is stored in a database, so additional information can easily be derived from any scenario after the runs are complete.

Weaknesses: Because this model defines the landscape using polygons rather than grids or raster data, it is relatively slow compared to some of the other landscape models. Internal attributes (calculated additional values carried by each polygon) that could be used can be cumbersome to add to a scenario and costly (time- and memory-wise) to use. Linear disturbances can be done, but to be effective the potential location (even if they are not yet active) should be determined prior to the beginning of the model.

D: Primary Uses of the Model

This is primarily a landscape vegetation change model, and as such can be used for answering many types of vegetation, landscape pattern, and habitat questions. It is not a population model.

This model has been used since 1995 in various locations in the US, BC, and Alberta, for a variety of ecosystem types from forest to grasslands. For example, a grasslands study in Arizona examined what level of resources was required to prevent bufflegrass spread and how these should be allocated among inventory, treatment and maintenance. Results from the model affected management practices. Another study in Idaho examined the effects of differing fire regimes and management on aspen habitat. In BC, the model was used to examine impact of different management scenarios on wildlife habitat, fuels, understory productivity, timber yields and costs.

Caribou or other wildlife populations are not currently in the model. The simplest way would be to simply relate the caribou to the different state classes (i.e., habitat). A more detailed approach would be to create attributes which are a function of particular cells or states and that can be affected by disturbances or succession. The rules would need to be complex in order to capture caribou dynamics. Note, however, that discussions are currently underway to include caribou in the new PATH model.

E: Data Needs

The model is able to use many types of data. The model needs maps of vegetation (at a pretty general scale for turning into state classes), natural disturbance probabilities, and some knowledge of how states change over time.

F: Data Types

Traditionally, model simulations include data derived from scientific literature and personal knowledge. Usually information about how the vegetation changes from one state to another, impacts of natural disturbances, and their state-based probability are not available in the literature and rely on knowledge from local experts, which could include traditional knowledge.

G: Relationship to Available Data

Vegetation maps are available for many areas. Some disturbance probabilities can be calculated from existing knowledge. State class pathway diagrams for the north do not exist and would need to be developed in a workshop setting with local vegetation and disturbance experts.

H: Scale

The model is best used on small (e.g., watershed) landscapes.

The model works on annual time steps.

I: Validation / Publications

The key reference for this model is:

ESSA Technologies Ltd. 2008. TELSA: Tool for Exploratory Landscape Scenario Analyses, Model Description, Version 3.6. Vancouver, BC. 64 pp.

Other references can be found at: http://essa.com/tools/telsa/reports/

More recently, a model called PATH has been developed which allows users to run VDDT and a TELSA-like model from the same interface. This interface is easier to use, especially for users wishing to do many scenarios or to look at the impacts of climate change. The spatial engine in PATH is gradually being moved from TELSA to a grid-based model that operates much faster. There are also preliminary discussions underway to incorporate caribou into PATH. The website for PATH is:

http://www.apexrms.com/projects/path-lm

More publications (which include PATH, VDDT and TELSA publications) are also available on:

http://wiki.pathmodel.com/index.php?title=Publications

J: Source

Information for this section came from personal knowledge as the original developer of the model.

WOODSTOCK & STANLEY

Woodstock is a forest modelling platform designed to create optimization models to solve landscape planning issues. The basic version is aspatial, but a spatial version also exists that allows users to include adjacency and proximity relationships. Users have almost complete control over the description of the types of forest on the landscape, the activities and the outputs. The tool is quite flexible and can incorporate many strata and activities at the same time, but is most often used for forest planning and wood supply.

Stanley is a model that is designed to be used with Woodstock. It is a spatial harvest scheduling tool that helps create and schedule harvest blocks on a map. The tool combines the plan created by Woodstock with other user-defined spatial constraints to create these harvest units.

A: Ease of Use

Woodstock has a good user interface for entering and linking data. User's Guides and training sessions are available.

Woodstock is available for purchase.

B: Output

Outputs include the state of the landscape over time and the best solution given the entered constraints.

C: Strengths/Weaknesses

Strengths: Woodstock is very flexible and has been used to address a wide variety of forest ecosystems and optimization issues. Output harvest schedules can be used by other models such as the Carbon Budget Model (CBM-CFS3) to calculate additional information.

Weaknesses: The model produces the optimal solution which is not always the most realistic solution. Woodstock is aspatial, and its optimal solution does not always translate into a workable spatial solution (i.,e., when the aspatial solution is entered into Stanley, some of the targets may not be met). Stochastic natural disturbances cannot be included.

D: Primary Uses of the Model

This is primarily a forest planning model to help forest managers. It is an optimization model that includes economics variables as well as specific targets.

It has been used and applied quite widely around the world. In one Canadian example, the model was used in an area in British Columbia. The analysis included harvest cost, price projections, and target seral stage and wildlife considerations. Results, as harvest level by stand type, age and watershed, were provided to the engineers. In Alberta the model has been used to general the amount, and location, of harvest given various ecological constraints, mixed wood types, and the desire for an even harvest flow. In New Brunswick, Woodstock, is used by all the crown licensees in developing their management plans and by the government in its review of the plans. Many more examples are summarized on the company's web site.

This tool has been used in conjunction with other models, including Patchworks (e.g., Millar Western Forest Management Plan) or the CBM-CFS3.

E: Data Needs

The model requires information about the state of the landscape, with links to the appropriate growth curves. Targets and constraints must also be added.

F: Data Types

The model uses scientific data. Local data is not likely to be necessary, but could be used to add extra constraints or to adjust targets.

G: Relationship to Available Data

Vegetation maps exist, as do growth curves although these may need to be linked. Targets and constraints are defined on an as-needed basis.

H: Scale

The model is used at the landscape scale.

The model works on annual time steps.

I: Validation / Publications

The key publication about Woodstock is:

Cosgswell, A., and Feunekes, U. 1997. A Hierarchical approach to spatial forest planning. International Symposium on System Analysis and Management Decisions in Forestry.

J: Source

Information for this section came from the website and reports available on-line.

Descriptions of many projects that use Woodstock/Stanley can be found at:
http://www.remsoft.com/caseStudies.php

3.0 Monitoring and Management – Literature Review B

3.1 Summary

To facilitate this review a series of conceptual models were developed, identifying hypotheses of effect for each of the four caribou ecotypes. The hypotheses describe pathways linking natural or anthropogenic impacts (e.g. climate change, industrial activity) to end-points of indicators of caribou populations or key factors related to effects on caribou (e.g. health, predation). A risk categorization was undertaken, based on a review of scientific literature discussions with experts and our understanding of ecotype dynamics. Risk was defined as the combination of probability and severity of impacts. Twenty of the 47 hypotheses evaluated were considered to be high risk. Many pathways identified in the models were similar across ecotype models, however because of different ecological circumstances, similar hypotheses were not always ranked in the same risk category.

Basic and Refined monitoring needs were identified for each hypothesis and summarized across ecotypes. Although population trend and some vital rate data are available or extractable from existing sources for some caribou herds/populations (particularly some Migratory Tundra herds), in general, existing data do not meet the Basic or Refined requirements so as to conduct *a posteriori* review of hypothesis. Therefore, going forward, the exiting monitoring programs are not sufficient to address monitoring of most relationships illustrated in the hypotheses.

In developing a monitoring program, the following points should be considered:

1. Priority should be given to addressing monitoring requirements for hypotheses ranked high, however there may be rationale for monitoring hypotheses in other risk categories too.
2. Risks associated with different herds/populations may be different depending on their ecological circumstances, such as cycle of abundance. This should be considered in monitoring program design
3. It is not necessary (or practical) to monitor all (or even most) herds/populations should it be evident that they are susceptible to the same effects. Cost considerations would also preclude this.
4. There is a s skewed distribution of the frequency with which different metrics appear in the monitoring requirements for the hypothesis, suggesting that it should be possible to build efficiencies into the monitoring program design.
5. Economic considerations will obviously be important in monitoring program design. A cost-benefit framework should be developed to facilitate further selection of monitoring priorities.
6. The results of monitoring absolutely must be brought back into the decision-making process so that management of herds incorporates up-to-date information on stressors and ecological relationships.

3.2 METHODS

The literature review focusses on identification of impacts which may play an important role in contributing to cumulative effects, identification of data required for monitoring, and considerations in the development of monitoring programs.
There are 3 broad components to this part of the undertaking:

1. Effects on caribou are reviewed using a series of conceptual models to identify the relative risk associated with each effect.
2. Monitoring needs (focussing on high-risk effects) are identified and compared with existing data. This allows identification of additional data needs.
3. Aspects of potential monitoring programs for the caribou ecotypes are identified, based on an analysis of the monitoring needs identified in 2). above.

3.2.1 Development and Review of Effects Hypotheses

As all biota, caribou may be affected by a large number of impacts with a host of causes and dynamics. Some impacts are individually serious and pose substantial risks to maintaining populations, and other impacts are individually less signficant from a population perspective, but they may be additive, compensatory, or synergistic. It is not practical to incorporate all potential impacts into monitoring programs and so it's important to identify those with the greatest potential to contribute to cumulative effects and focus monitoring and management efforts on them.

To identify the most appropriate impacts for monitoring and management, we evaluated the effects pathways within a series of conceptual models (one for each caribou ecotype). The models are essentially illustrations summarizing a series of interconnected hypotheses which represent the ways in which caribou populations may be impacted by natural and anthropogenic stresses or disturbances. (Figures 2-5). All hypotheses ulitmate lead to the model core which representation the relationship that four key processes (births, deaths, immigation, emmigration) have on distribution and abundance.

To provide additional structure, the models are loosely divided into four quadrants – predation, habitat, climate, and human access/development, representing four key sources of pressure on caribou populations. The models' pathways illustrate the interrelation between the pressures. For example, for boreal caribou, one chain of hypotheses leads from climate change to habitat (influence of increased fire frequency on seral communities) to predation (increases in other ungulates as a result of changes in seral communities leading to increased predator populations causing increased predation on caribou).

The models were developed based on initial literature scans, discussions with experts, and our existing understanding of ecotype dynamics. We screenedpotential hypotheses in the development of the models and excluded those which were mentioned in the literature only once (or very few times), /or which had the potential to affect only a small segment of the population or did not have implications at the population-level. Each pathway within the models was assessed as part of the literature review. As is apparent from the complexity of the models, it was not practical to conduct a detailed review of each pathway; such a level of effort was beyond the scope of this undertaking. Rather, the intent was to establish the associated risk to caribou with each pathway.

3.2.2 Incorporating Risk

Risk in the context of our evaluations is defined as the potential of a given model pathway to lead to signficant long-term population impacts. Risk is the primary consideration upon which decisions about the allocation of monitoring and management effort should be based. In order to facilitate that, after considering the evidence for each hypotheses, we ranked them according to risk.

Risk has two components: probability and severity. As defined by Canada's Privy Council Office (PCO 2002) it is "*a function of the probability (chance, likelihood) of an adverse or unwanted event, and the severity or magnitude of the consequences of that event.*" Because this analysis did not have the luxury of working with large amounts of data for each hypothesized effect, we used somewhat subjective interpretations of 'severity' and 'probability'. A severe effect is one which would would cause a population to decline notably due to changes in vital rates. The effect could manifest itself progressively over a number of years (e.g. by increased rates of predation) or by catastrophic individual events (e.g. by severe icing inhibiting access to vegetation and causing wide-spread starvation in a single winter). Probability was interpreted to be the the likelihood of the effect occurring continuously (i.e. over several consecutive years) or repeatedly (i.e. several times within a reasonable span of years).

An important point is that probability and severity are largely independent – a low probability event does not necessarily equate to a low consequence event. It is the combination of probability and consequence that assist in determining what is accepatable risk and allow decision makers to develop appropriate strategies to identify *a priori* situations which must be avoided and design mitigation and consequence minimization strategies for those which are not avoidable.

We assessed the risk associated with each hypothesized effect and ranked it in one of four risk categories (Figure 1), based on our interpretation of the literature and professional opinion. In a small number of cases, we felt there was inadequate information to categorize the risk into one of the four categories and noted the risk as 'unknown'.

Obviously most attention should be paid to those pathways which are considered to be high risk and those that pose moderate risk to caribou habitat and caribou.

Two issues complicate the development of the conceptual models and the assignment of risk categories to the hypotheses. Firstly, there is variability in the ecologies of herds and populations within ecotypes, and relatedly herds may be differentially susceptible to stresses depending on the state of their population. A robust population can withstand stresses better (i.e. without significant viablity repercussions) than can a population which is already vulnerable.

The models address the four ecotypes, however it is well known that is considerable intra-ecotype variability. This is perhaps most evidently the case for migratory tundra caribou, where certain pressures (e.g. human development, hunting) more strongly affect some herds than others. It was not practical, within the scope of this undertaking, to develop herd-specific models, or develop herd-specific risk categorizations so the risk categorizations provided here represent a generic assessment. Before development of research and management programs on specific populations or herds, it would obviously be necessary to review the specific aspects of their ecologies and ensure that the risk profile provided here is appropriate.

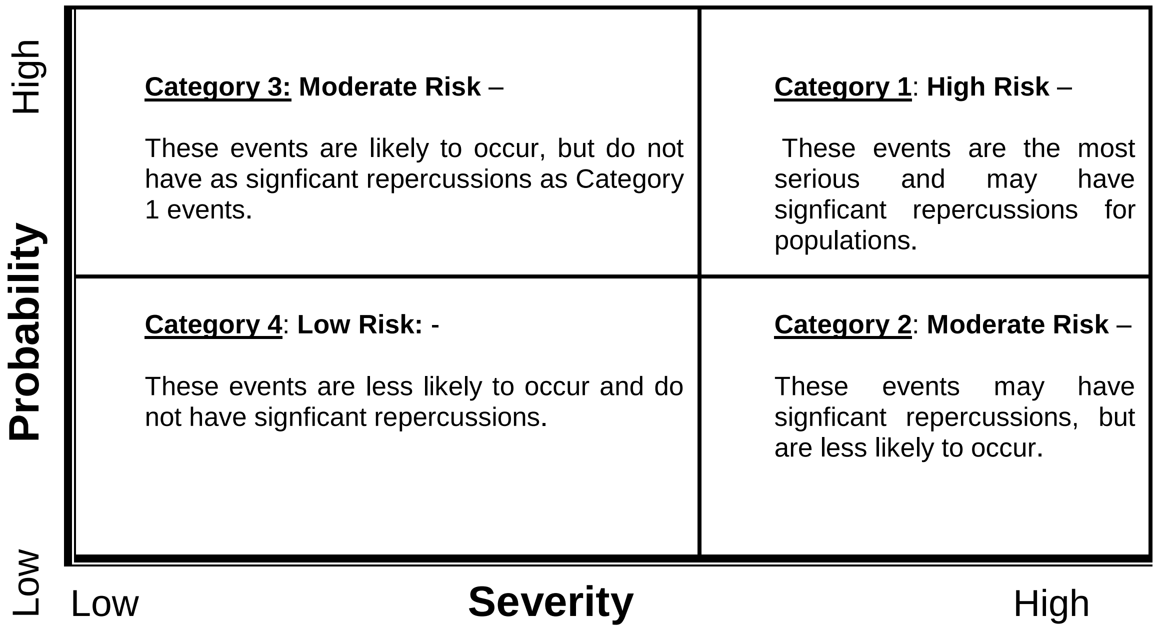

Figure 1. Categories used in describing Risk of individual effects in conceptual models.

Obviously most attention should be paid to those pathways which are considered to be high risk and those that pose moderate risk to caribou habitat and caribou.

One issue which complicated the development of the conceptual models and the assignment of risk categories to the hypotheses is that there is variability in the ecologies of herds and populations within ecotypes. The models address the four ecotypes, however it is well known that is considerable intra-ecotype variability. This is perhaps most evidently the case for migratory tundra caribou, where certain pressures (e.g. human development, hunting) more strongly affect some herds than others. It was not practical, within the scope of this undertaking, to develop herd-specific models, or develop herd-specific risk categorizations so the risk categorizations provided here represent a generic assessment. Before development of research and management programs on specific populations or herds, it would obviously be necessary to review the specific aspects of their ecologies and ensure that the risk profile provided here is appropriate.

Several hypotheses occur in more than one model, representing similar aspects of the ecotypes' ecologies and similar concerns. However, in a number of cases the hypotheses are not considered to have the same level of risk for all ecotypes. For example, the hypothesis linking climate change to the frequency of icing in the winter, restricting access to food occurs in the hypotheses of all four ecotypes, but is considered high risk only for Peary caribou (moderate risk for the others). Although the concern is identified in the literature for all ecotypes, documented evidence of a very signficant effect exists only for Peary caribou.

3.3 Analysis of Conceptual Models

The conceptual models are presented below accompanied by synopses of the hypotheses of effect. Appendix 1 presents the detailed tabular analysis undertaken for each hypothesis of effect and conclusions regarding risk categorization.

In total, 47 hypotheses were evaluated. The distribution of the assessed risk categories is provided in Table 2. Twenty of the hypotheses were considered to be high risk and only 9 assessed as low risk.

Table 2. Distribution of assessed risk categories by ecotype.

Ecotype	High Risk	Mod. Risk	Less Risk	Low Risk	Unknown	Total
Peary	4	3		1	1	9
Boreal	6	2	1	2	0	11
Mountain	6	3	1	3	1	14
Migratory Tundra	4	4	1	3	1	13
Total	20	12	3	9	3	47

3.3.1 Peary Caribou

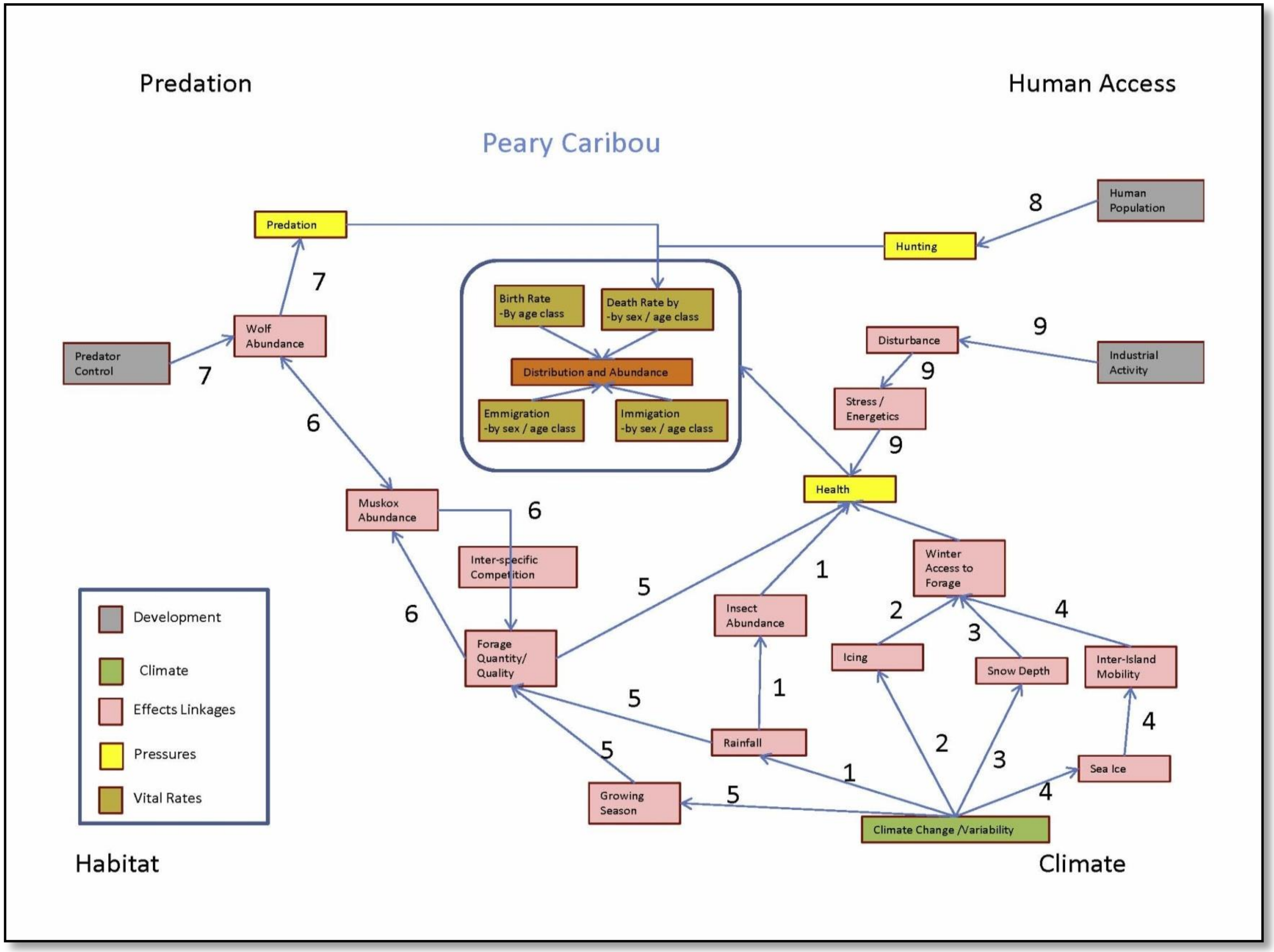

Figure 2. Conceptual model of Peary Caribou ecology. The numbers next to the arrows relate to the hypotheses documented in Table A1-1.

For Peary caribou, we identified nine hypothesis of effect, with a disproportionate number relating to climate change/variability. Detailed analyses of the hypotheses is presentedin Table A1-1 in Appendix 1. Literature available on Peary caribou focusses on the impacts of severe winter conditions, particularly icing, and the concomititant rise in muskox populations in areas that they co-inhabit with Peary caribou. Based on the literature review, we identified the following hypotheses as high risk:

- No. 2 - The frequency of winter icing events will change as a result of climate change. Icing events restrict access to winter forage;
- No. 4 - Warming climate will decrease the extent, stability and duration of sea ice restricting the ability of caribou to move between islands and ultimate limiting their access to winter forage;
- No. 6 - Changes in forage quality and quantity increase the abundance of muskox, providing more prey for wolves and leading to increased wolf populations. Muskox abundance will reduce the quality and quantity of forest available for caribou; and
- No. 7 - Predator control reduces wolf populations. Changes in wolf populations result in changes in predation.

Hypotheses considered to be moderate risk were No. 3 (impact of snow depth on access to forage), No. 8 (effect of changes in human population on hunting) and No. 9 (disturbance caused by human industrial activity will lead increased stress) were considered to be moderate risk, whereas Hypothesis No. 1 (changes in insect abundance related to climate change) was considered to be low risk. We were unable to make a risk determination for Hypothesis No. 5 and considered the risk for it to be uncertain.

3.3.2 Boreal Caribou

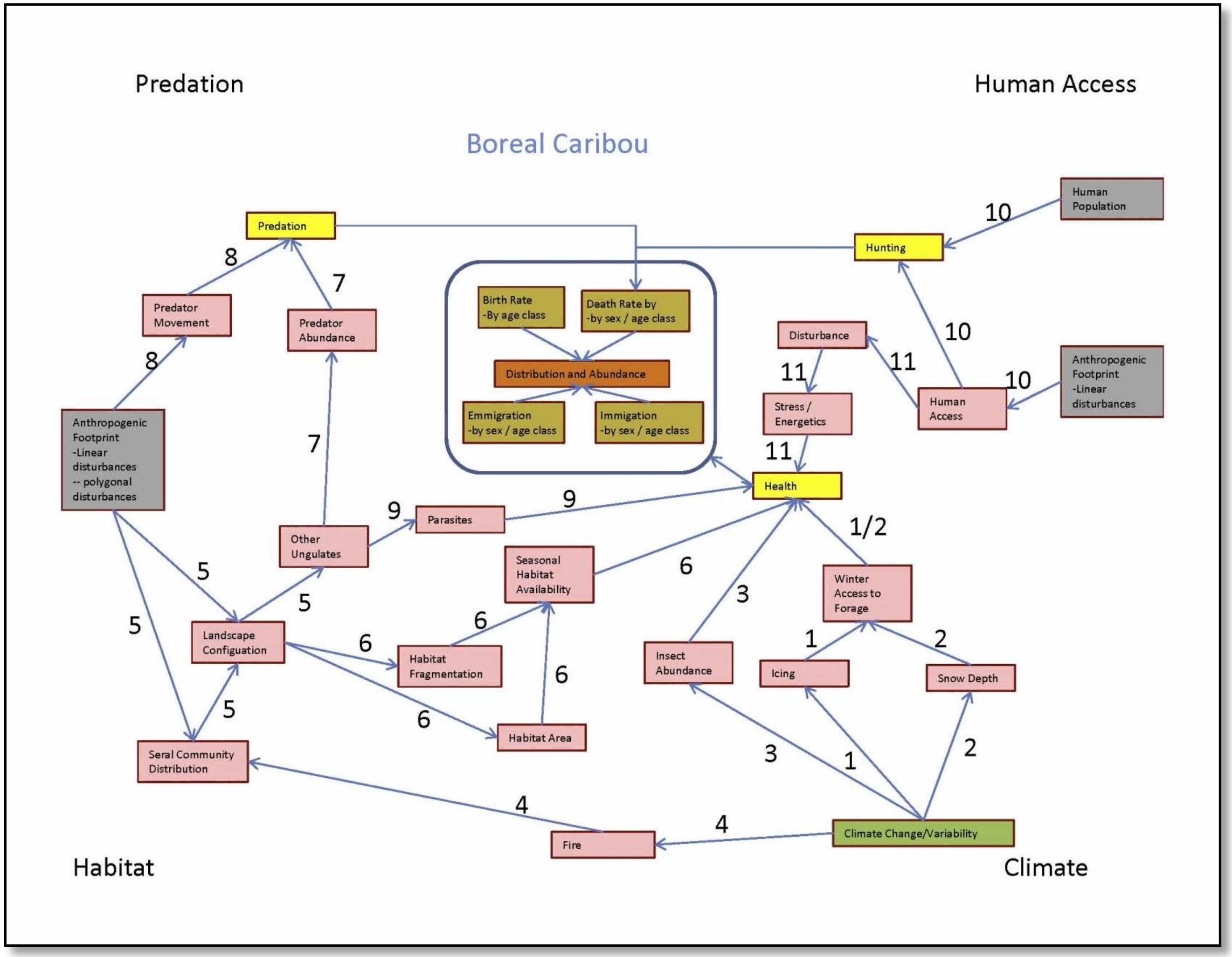

Figure 3. Conceptual model of Boreal Caribou dynamics The numbers next to the arrows relate to the hypotheses documented in Table A1-2.

The Boreal caribou model is somewhat more complex that the Peary caribou model. The ecologies of the two ecotypes are obviously very distinct, although there are some similar concerns related to climate change. For boreal caribou, the dynamics around apparent competition (which relates to prey abundance), habitat fragmentation, and loss of seasonally important habitats have recieved the lion's share of attention in the literature over recent years.

For Boreal caribou, we identified eleven hypotheses of effect. Detailed analyses of the hypotheses is presented in Table A1- 2 in Appendix 1. Based on the literature review and discussions with experts, we identified the following hypotheses as high risk:

- No.4 - Climate change will affect seral community distribution through the frequency of fire;
- No. 5 - The abundance and distribution of other ungulates will increase as a result of landscape changes brought about through anthropogenic changes to the landscape and climate change;
- No. 6 - Changes in landscape configuration will affect seasonal habitat availability via fragmentation and changes in habitat area. Changes in seasonal habitat availability lead to changes in the health of individuals;
- No. 7 - Changes the amount and distribution of other ungulates will lead to increased predator abundance which will cause increase predation on caribou;
- No. 8 - Anthropogenic changes in the landscape will facilitate predator movement increasing predation on caribou; and
- No. 11 - Increased human access and industrial development causes disturbances which increase stress on caribou.

Hypotheses 1(winter icing restricting access to food), 2 (snow depth restricting access to food), 10 (impacts of linear disturbances) were considered to be moderate risk, whereas hypotheses 4 (increased insect harassment due to climate change), and 9 (spread of parasites from other ungulates), were considered to be low risk.

3.3.3 Mountain Caribou

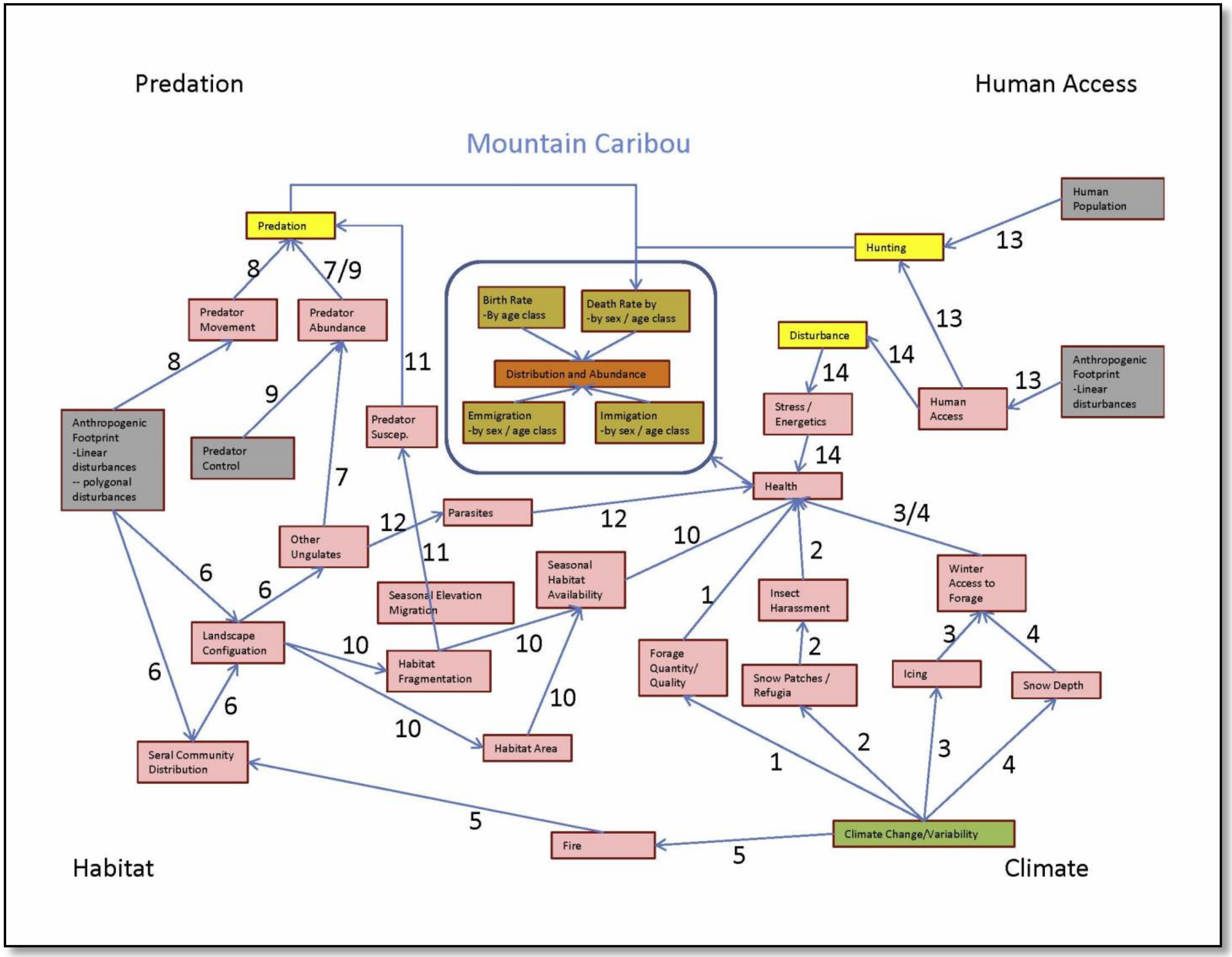

Figure 4. Conceptual model of Mountain Caribou dynamics. The numbers next to the arrows relate to the hypotheses documented in Table A1-3.

The Mountain caribou model is very similar to that for Boreal caribou, except it incorporates aspects of the elevation migration, possible impact of climate change on forage quality, use of snow patches, and the dynamic of predator control. For Mountain caribou, much literature in recent years has focussed on the fragmented nature of their habitats, dwindling populations, and potential utility of predator control.

For Mountain caribou, we identified fourteeen hypotheses of effect. Detailed analyses of the hypotheses is presented in Table A1- 3 in Appendix 1. Based on the literature review and discussions with experts, we identified the following hypotheses as high risk:

- No. 5 - Climate change will affect seral community distribution through the frequency of fire;
- No. 6 - The abundance and distribution of other ungulates will increase as a result of landscape changes brought about through anthropogenic changes to the landscape and climate change;
- No. 7 - Changes the amount and distribution of other ungulates will lead to increased predator abundance which will cause increase predation on caribou;
- No 9 – Predator control decreases predator abundance and predation ;
- No. 10 - Changes in seasonal habitat availability lead to changes in the health of individuals. Changes in landscape configuration will affect seasonal habitat availability via fragmentation and changes in habitat area;
- No. 14 - Increased human access and industrial development causes disturbances which increase stress on caribou

With the exception of No. 9 (predator control) these high risk hypotheses are the same as for Boreal Caribou (although the numbers are different).

Hypothesis considered to be moderate risk were: No. 2 (icing effects on forage access), No 3 (snow depth effect on forage access); No. 8 (landscape facilitated predator movement); and No. 13 (increase in hunting caused by linear access). Low risk hypotheses were No 1. (climate change effects on forage quality), No. 2 (climate change, snow patches, and insect harassement) and No. 12 (spread of parasites from other ungulates). We felt we did not have adequate information to make a risk assessment of Hypothesis 11 (impacts of fragmentation on vertical migration), and so considered the risk on that hypothesis to be unknown.

3.3.4 Migratory Tundra Caribou

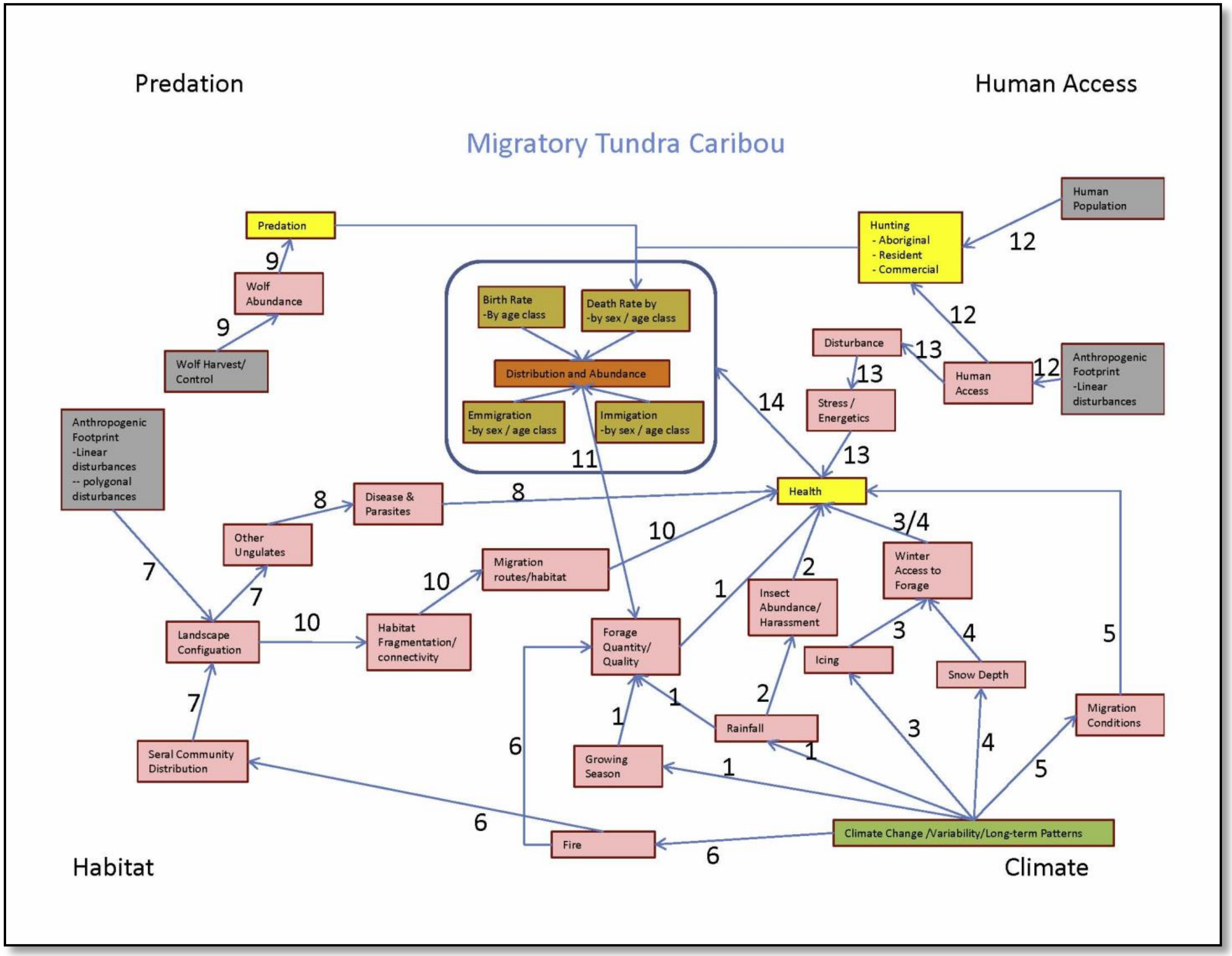

Figure 5. Conceptual model of Migratory Tundra Caribou dynamics. The numbers next to the arrows relate to the hypotheses documented in Table A1-4.

The model for Migratory Tundra caribou differs from the previous models largely through incorporation of pathways related to migration, both as affected by climate change, and as affected by althropogenic impacts on the landscape. Probably more than any other ecotype, there may be signficant differences in the ecologies of different herds or populations of Migratory Tundra caribou. There are at least eight herds in the NWT, some of the signficant differences between herds include:

- habitat variability –the Beverly herd in particular may migrate south of the tree-line, whereas most others spend their entire existence on the tundra;
- degree of human encroachment – some herds, in particular the Bathurst herd, exist in areas of more intense human activity ;
- population – all caribou herds fluctuate in abundance. At present, three are stable at a very low population size while two are increasing (Bluenose East and Porcupine).

For Migratory Tundra caribou, we identified fourteeen hypotheses of effect. Detailed analyses of the hypotheses is presented in Table A1- 4 in Appendix 1. Based on the literature review and discussions with experts, we identified the following hypotheses as high risk:

- No. 2 - Insect abundance will increase as a result of climate change, partially as a result of increased rainfall. Increased insect harassment of caribou will cause adverse health effects.
- No. 6 - Climate change will affect seral community distribution directly, such as an increase in shrubs on the tundra, and through the frequency of fire. Fire frequency intensity and area will affect the quality and quantity of forage available;
- No. 12 - Increased human populations and access created by linear disturbances increases hunting; and
- No. 13 – Increased human access and industrial development causes disturbances which increase stress on caribou.

Hypothesis considered to be moderate risk were: No. 3 (icing effects on forage access), No 4 (snow depth effect on forage access); No. 5 (climate change and migration); No. 7 (increase in other ungulates as a result of landscape changes); and No 10 (migration routes affected by changes in landscape coniguration). Low risk hypotheses were No.4 (changes in forage quality), No. 8 (risk of increased parasitism from other ungulates), and No. 11 (negative feedback of population abundance on forage). We felt that the risk associated with Hypothesis 9 was uncertain.

3.4 Monitoring Needs

At the core of each of the four conceptual models is a component which represents the four vital rates (Figure 6) and their impact on distribution and abundance. This aspect is central to all notions of monitoring – in order to determine the effect of any disturbance or perturbation, the fundamental piece of information is population, specifically the trend – rate of increase or decrease. A useful synopsis of monitoring for migratory tundra caribou is provided by CARMA's manual on monitoring caribou herds by Gunn et al. (2008), and that document is used as a basis for much of the following discussion. Gunn et al. (2008) identify three levels of population trend monitoring which can be used depending on the objective. The most basic level involves determination of herd abundance measured directly or indirectly using expert opinion. The second level includes mechanisms for determining vital rates, and the third, most detailed, level is used for 'Reference Herds' and is intended to provide more detailed information, such as that needed to "*..fine-tune our understanding of the mechanisms responsible for changes in demographic trends, such as disturbance and age-specific rates of fecundity or mortality...Reference herds may also provide opportunities to propose and test relationships between demographic and body condition...*".

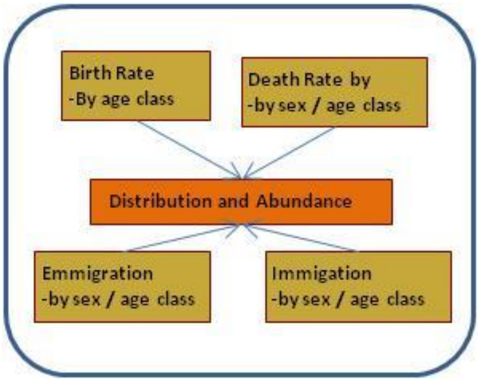

Figure 6. The core of each conceptual model

Table 3, taken from Gunn et al. (2008), summarizes the three sampling levels.

Table 3. The three sampling levels and their indicators for demographic monitoring.

Indicator	Level 1	Level 2	Level 3 (Reference Herd)
Abundance (direct)	• Trend in herd size	• Trend in herd size	• Trend in herd size
Abundance (indirect)	• Trend in herd size		• Long-term trend and climate change patterns
Vital Rates		• birth rate • annual calf survival • mortality-adult • recruitment • sex ratio • harvest rates	• age-specific fecundity • seasonal calf mortality • mortality – age specific • recruitment • sex ratio • harvest rates • predation rates
Dispersal		• natal breeding and dispersal	• natal breeding and dispersal

The focus of the report of Gunn et al. (2008) is in providing support for standardization of collection of population dynamics data. As identified above, those data are, by necessity, the core of monitoring programs as they provide information on the state of the caribou populations. In order to infer cause or develop an understanding of cumulative effects, they are necessary, but not sufficient. Demographic information cannot inform about the cause of a change in a population`s status. For example, in order to determine whether an increase in the population of other ungulates has led to the decline in caribou populations, as has been hypothesized for boreal, mountain, and Peary caribou, one must also collect information on the state of the population of other ungulates, predator populations, predation rates, etc. For most of the effects hypothesized in the ecotypes' conceptual models, at least some information from Level 2 of the sampling levels identified by Gunn et al. (2008) is necessary, and additional information regarding the stressor/environmental perturbation is also required.

To design an efficient monitoring program, its best to take stock of existing data collection efforts, or data in hand and reconcile that information with the identified monitoring/data collection needs. To create a synthesized account information needs, we reviewed the monitoring requirements associated with each hypothesis, and summarized across the ecotypes (Table 4). We divided the data needs into Basic, and Refined depending on sophistication of analyses on wished to conduct with the monitoring information..

In the subsequent step, we reviewed the data available from a wide variety number of sources for the Basic data needs; summarized in Table 5. A number of significant observations are apparent from that exercise:

- Considerably more survey data are available for Migratory Tundra Caribou than for other ecotypes, although within the Migratory Tundra Caribou some herds are far more data-rich than others.
- The precise caribou metrics related to vital rates needed to monitor some of the hypothesized effects (e.g. calf winter mortality) are extractable from some of the recent surveys;
- Although data required for a number of the other metrics (e.g. extent and nature of anthropogenic disturbances, density of linear features) may exist, they are not available in 'off the shelf" format, variable amounts of processing would be required to extract the desired metrics from existing data.
- For a number of metrics, there does not seem to be (we could not locate) any data or information sources. Although the data may exist from other sources it does not, from our assessment appear to be readily available.

Our Investigations of the data/information requirements identified as Refined confirmed that the same issues exist with those as with the Basic requirements; existing data necessary to develop many of the identified metrics are sparse or would require either a considerable amount of processing or development of new monitoring initiatives.

From the observation above, several broad conclusions are evident. Although data are available to track populations and extract vital rates for some Migratory Tundra herds, existing data are not sufficient to address even the basic monitoring associated with the full requirements for most hypotheses. This precludes, to a large extent, thorough *a posterior* examination of the dynamics of most hypotheses. The implications are that, in the future, considerable effort (and expense) will likely be necessary to do a reasonable job of monitoring to gather sufficient data so as to address even the Basic monitoring requirements. In the assessment of the hypotheses (Tables A1-1 to A1-4) we used research findings from the scientific literature, and published expert and traditional knowledge. Although this information was sufficient to categorize the risk associated with the hypotheses for this exercise, the obvious requirements going forward are for continued structured data gathering to validate or refute the risk and assess population implications. The present monitoring systems are not sufficient to address this requirement, although population and vital rate information are available for some Migratory Tundra herds.

Obviously it is not possible to conduct extensive monitoring so as to confirm risks for all herds or populations. Such a level of effort would not be possible (or necessary). As noted earlier, the risk categorizations derived in Tables A1-1 – A1-4 are generic within the four ecotypes; different populations within the ecotypes are likely subject to variable levels of risk even for distinct hypotheses. Therefore, in identifying monitoring priorities a finer exercise should be conducted in which the risk categorizations are examined for specific herds/populations. Based on that, a more efficient allocation of monitoring resources can be determined.

Figure 7 shows the frequency with which different monitoring/information requirements were identified for both Basic and Refined data needs. Not surprisingly information on population trend and several metrics associated with Level 2 of Gunn et al. (2008) (**Error! Reference ource not found.**) are most commonly represented. We identified 48 distinct monitoring data needs (Table 4). However, of those, 33 were identified only once or twice. This strongly implies that the detailed monitoring program should incorporate this set of monitoring requirements that can serve a number of different hypotheses. This set is comprised mostly of population and vital rate information, so it is no surprise that those data are considered to be the most vital. However, to truly get a sense of cause-and-effect, monitoring of demographics is necessary, but not sufficient. Beyond those data requirements , a number of less common monitoring requirements are key components of hypotheses categorized as high risk, and so for programs to facilitate understanding of cause-effect dynamics, monitoring cannot solely focus on demographic and vital rate parameters.

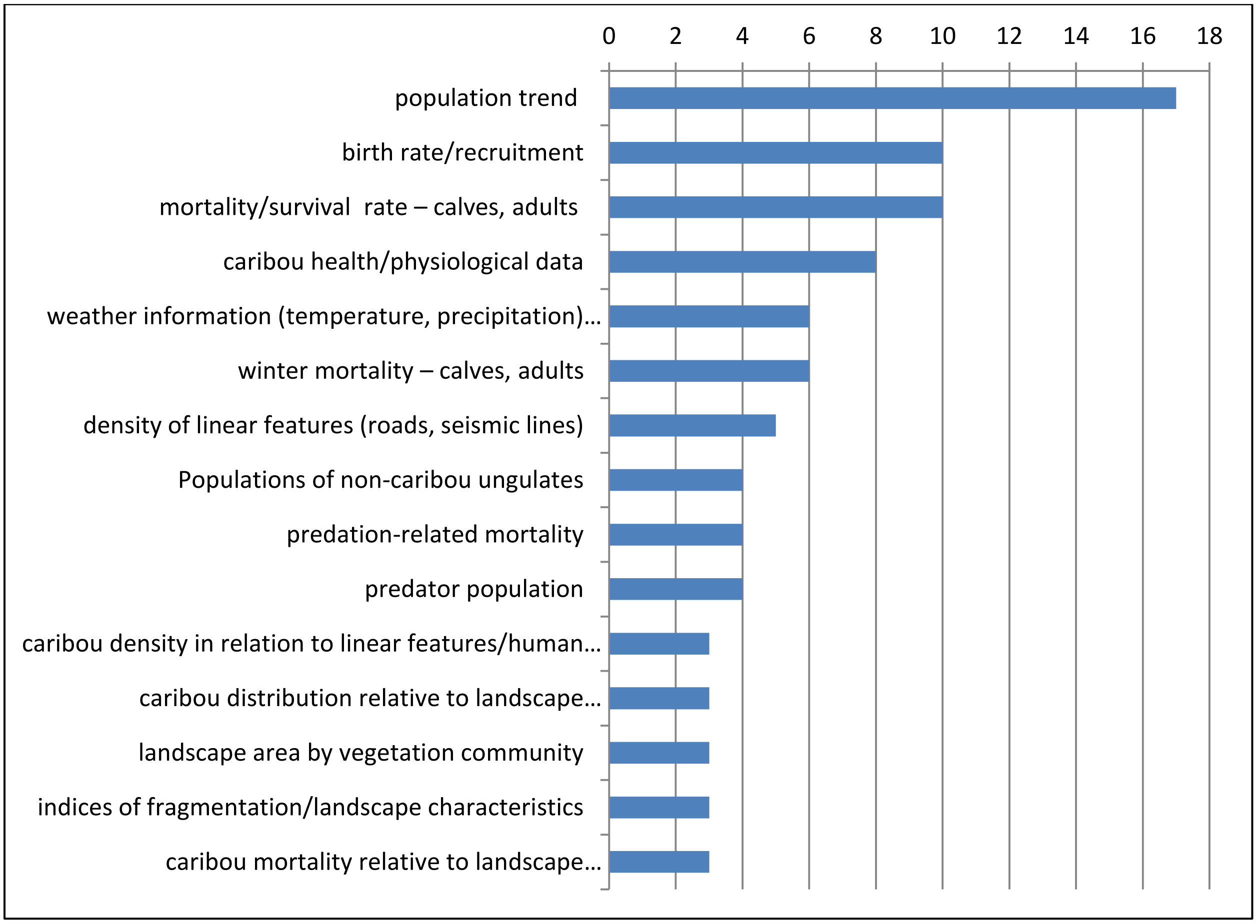

Figure 7. Basic and Refined data/information requirements, by frequency. Only those requirements identified for three or more hypothesis are shown.

In the design of an overall program, priority should obviously be given to monitoring requirements for hypotheses ranked high risk. Through the evaluation, these hypotheses were determined to have the highest likelihood of leading to population-level repercussions. However, there may be good rationale for monitoring hypotheses in other risk categories too , including: incremental effort may be negligible for some, emerging evidence may suggest that risk categorization is inaccurate, or there may be synergies between hypotheses, which when taken into account raise the potential importance of lesser-ranked hypotheses. In a comparable manner, it may not be necessary to monitoring all hypotheses considered high risk if upon close examination, there are significant similarities across hypotheses.

Table 4. Data needs for Monitoring and Management of Cumulative Effects Hypotheses for Four Caribou Eco-types in the NWT

Effect Hypothesis	Eco-type Risk Category				Monitoring& Management / Data Needs
	Boreal	Mountain	Migratory	Peary	
Climate change will affect seral community distribution directly and through the frequency of fire. (Fire frequency intensity and area will affect the quality and quantity of forage available.)	1	1	1		**Basic**: • fire frequency by size • landscape area by vegetation community • vegetation community age-class distribution **Refined:** • fragmentation / connectivity information • forage biomass after fires • forage quality after fires
Warming climate will decrease the extent, stability and duration of sea ice restricting the ability of caribou to move between islands and ultimate limiting their access to winter forage.				1	**Basic**: • population trend • winter mortality – calves, adults • birth rate/recruitment • sea-ice coverage **Refined**: • caribou inter-island/mainland movement • winter mortality, by cause
Climate change can affect weather and terrain conditions during migration which can affect caribou health.			2		**Basic:** • population trend • migration routes • climate/weather trends (e.g. snowmelt/snow free dates) • weather information (temperature, precipitation) long-term monthly/weekly averages through winter **Refined:** • arrival dates on calving grounds • recruitment • calf survival • physiological information
The frequency of winter icing events will change as a result of climate change. Icing events restrict access to winter forage.	3	3	3	1	**Basic:** • population trend

Effect Hypothesis	Eco-type Risk Category				Monitoring& Management / Data Needs
	Boreal	Mountain	Migratory	Peary	
					• winter mortality- calves, adults • birth rate/recruitment • icing events/snow depth/conditions **Refined:** • icing-related mortality –calves, adults • weather information (temperature, precipitation) long-term monthly/weekly averages through winter
Snow depth will change/vary as a result of climate change and variability. Snow depth affects access to winter forage.	2	2	2	2	**Basic:** • population trend • winter mortality- calves, adults • birth rate/recruitment • snow depth/condition information **Refined:** • icing/snow depth related mortality –calves, adults • weather information (temperature, precipitation) long-term monthly/weekly averages through winter
The extent of snow patches will change with climate change, increasing insect harassment and affecting caribou health.		4			**Basic** • population trend • indices of insect harassment of caribou over time • trend extent of snow patches • trend in caribou use of snow patches • weather information (temperature, precipitation) long-term monthly/weekly averages
The distribution and abundance of caribou can affect the amount and distribution of forage through negative feedback mechanisms.			4		**Basic:** • population trend • birth rate/recruitment • mortality rate • Indices of forage abundance • caribou health/physiological data **Refined** • indices on proportions of available forage consumed • mortality rate by cause (ie.starvation) • information on geographic distributional patterns/changes

Effect Hypothesis	Eco-type Risk Category				Monitoring& Management / Data Needs
	Boreal	Mountain	Migratory	Peary	
Forage quality and quantity is affected by climate change / variability affecting caribou health.		4	4	U	**Basic** • Population trend • birth rate/recruitment • calf/adult survival • forage quality/quantity • weather information (temperature, precipitation) long-term monthly/weekly averages through growing season
Changes in forage quality and quantity increase the abundance of muskox, providing more prey for wolves and leading to increased wolf populations. Muskox abundance will reduce the quality and quantity of forest available for caribou.					**Basic**: • population trend • birth rate/recruitment • mortality rate – calves, adults • predation-related mortality • muskox population trend **Refined**: • comparable caribou data in areas without muskox (if any)
Changes in seasonal habitat availability lead to changes in the health of individuals. Changes in landscape configuration will affect seasonal habitat availability via fragmentation and changes in habitat area.		1			**Basic:** • population trend • mortality rate – calves, adults • landscape characteristics/metrics • caribou distribution relative to landscape vegetation communities **Refined:** • caribou physiological information
Insect abundance will increase as a result of climate change, partially as a result of increased rainfall. Increased insect harassment of caribou will cause adverse health effects.			1	4	**Basic** • population trend • birth rate/recruitment • insect abundance over time • indices of insect harassment of caribou over time **Refined**: • caribou health indicators in periods of intense/less insect harassment • caribou productivity in years of intense/less insect harassment • weather information (temperature, precipitation) long-term

Effect Hypothesis	Eco-type Risk Category				Monitoring& Management / Data Needs
	Boreal	Mountain	Migratory	Peary	
					monthly/weekly averages through winter
Habitat fragmentation, particularly in relation to migratory elevation patterns, increases susceptibility to predation.		U			**Basic:** • Population trend • predation-related mortality rates • caribou mortality relative to landscape characteristics (primarily linear corridors) • caribou distribution relative to landscape vegetation communities • indices of fragmentation **Refined:** • predator population • density of linear features (roads, seismic lines, etc) • index of predator use of linear features compared to broader landscape
Changes in landscape configuration will affect seasonal habitat availability via fragmentation and changes in habitat area. Changes in seasonal habitat availability lead to changes in the health of individuals.	1				**Basic:** • caribou distribution relative to landscape vegetation communities • caribou physiology information calves/adults **Refined** • caribou physiological information
Anthropogenic changes in the landscape will facilitate predator movement increasing predation on caribou	1	2			**Basic:** • density of linear features (roads, seismic lines, etc) • index of predator use of linear features compared to broader landscape • caribou predation mortality relative to linear features **Refined:** • caribou habitat use relative to linear features
Migratory routes may be interrupted by changes in landscape configuration, ultimately affecting caribou health.			2		**Basic:** • population trend • migration route • density of linear features (roads, seismic lines, etc) • landscape area by vegetation community • extent and nature of anthropogenic disturbances

Effect Hypothesis	Eco-type Risk Category				Monitoring& Management / Data Needs
	Boreal	Mountain	Migratory	Peary	
					Refined: • arrival dates on calving grounds • birth rate • calf survival • physiological information
Increased industrial activity and human access causes disturbances which increase stress on caribou.	1	1	1		**Basic:** • population trend • density of linear features (roads, seismic lines, etc) • trends in human use of linear features • caribou density in relation to linear features • caribou response to human use by type of use **Refined:** • recruitment • calf/adult mortality • caribou physiological data
Increased human populations (and access created by linear disturbances increases hunting).	2	2	1	2	**Basic:** • population trend • harvest by sex/age • human population • density of linear features (roads, seismic lines) **Refined:** • trends in human use of linear features
Increased human/industrial activity will disturb caribou leading to increased stress and poorer health.				2	**Basic:** • population trend • birth rate/recruitment • mortality rate – calves, adults **Refined:** • caribou distribution relative to human/industrial activity • caribou physiological data

Effect Hypothesis	Eco-type Risk Category				Monitoring& Management / Data Needs
	Boreal	Mountain	Migratory	Peary	
The abundance and distribution of other ungulates will increase as a result of landscape changes brought about through anthropogenic changes to the landscape and climate change.	1	1	2		**Basic:** • landscape area by vegetation community • vegetation community age-class distribution • extent and nature of anthropogenic disturbances • Populations of non-caribou ungulates • **Refined:** • birth-rates of non-caribou ungulates • distribution of caribou and non-caribou ungulates
Changes the amount and distribution of other ungulates will lead to increased predator abundance which will cause increase predation on caribou.	1	1			**Basic:** • caribou populations trend (calves, adults) • caribou predation mortality (calves adults) • predator populations/trends • populations of non-caribou ungulates **Refined**: • caribou birth rate • non-predation mortality rate • predation mortality for non-caribou ungulates
Changes the amount and distribution of other ungulates will lead to increased parasitism of caribou leading to effects on health.	4	4	4		**Basic**: • Population trend from areas with/without other ungulates • populations of other ungulates • parasite infestation load in areas with/without other ungulates
Predator control decreases predator abundance and predation.		1	U	1	**Basic:** • population trend • mortality rate – calves, adults • predation-related mortality rates • predator population trend **Refined:** • predator mortality rate • predator fecundity • predator control effort • no. predators killed

Table 5. Basic Data Needs for Caribou Cumulative Effects Modeling and Management

<table>
<tr><th>Data Needs</th><th>Data Available / Source</th></tr>
<tr><td colspan="2">Caribou metrics - Population/vital rates etc.</td></tr>
<tr><td>Caribou populations trend (calves, adults)</td><td rowspan="5">Data for these metrics may be extracted or derived from the following surveys, which are in WMIS:
• Barren-ground Caribou Reconnaissance surveys:
o Inuvik 2005
o Bluenose West 2005
o North-Slave March 2010, Dec, Jan 2010, Aug 2010, Jan 2012
• Barren-ground Caribou Recruitment Survey
o Inuvik 2007
• Caribou Spring Composition Surveys:
o Bathurst 2001, 2002, 2003, 2004, 2006, 2007, 2008, 2009, 2010, 2011, 2012
o Bluenose East 2011, 2012
o Bluenose West 2009
o Cape Bathurst, Tuk Pen, 2010
o Inuvik 2009
o Beverly/Ahiak 1982, 2008, 2009, 2010
• Caribou Spring Surveys
o Inuvik Region 2004, Bluenose East 2004, 2005, 2006, 2009
• Caribou Fall Composition Surveys:
o Bathurst 2000, 2001, 2004, 2006, 2007, 2008, 2011, 2012
o Bluenose East 2008, 2009
• Caribou Classification Surveys
o Inuvik spring 1983-2001
o Bluenose spring 1988, 1989, 1991
o Peary spring 1998, 1999
o Bluenose East July 2007
o Beverly fall 1980, 1981, 1982
o Beverly spring 1993-95
• Calving Ground Surveys, 2007
o Tuktoyaktuk Peninsula, Cape Bathurst, Bluenose-West, Bluenose-East, Bathurst, Beverly, Ahiak, Qamanirjuaq
• Peary caribou surveys Banks, Melville and NW Victoria Islands 1998, 1999
• Peary Caribou and Muskox survey Western Queen Elizabeth Islands 1997
• Banks Island Peary Caribou and Muskox Surveys intermittently from 1991-2010
• Dehcho boreal caribou woodland GPS locations 2004-present
• Inuvik boreal caribou telemetry locations 2002-2009
• Sahtu boreal caribou GPS locations – 2003-present
• Sahtu Mountain caribou telemetry locatons 2006-2006
• Sahtu Mountain caribou surveys 2003-2005
• South Slave Boreal caribou satellite locations 2005 - present</td></tr>
<tr><td>Birth rate/recruitment</td></tr>
<tr><td>Mortality rate – calves, adults</td></tr>
<tr><td>Winter mortality - calves, adults</td></tr>
<tr><td>Population trend from areas with/without other ungulates</td></tr>
<tr><td>Harvest by sex/age</td><td>• Inuvialuit, SahtuTlicho have had studies compiling harvest information and reports are available. Currently several herds have harvest restrictions and informal monitoring of harvest levels. Data available as GNWT reports for Peary and barren-ground caribou
• Detailed survey of information available not undertaken
o Some information available through WMIS, additional info available through co-management and wildlife management boards</td></tr>
<tr><td>Caribou predation mortality (calves adults)</td><td>• Data are not routinely available, may be collected as part of individual studies</td></tr>
<tr><td>Caribou predation mortality relative to linear features</td><td>• Data are not routinely available, may be collected as part of individual studies</td></tr>
<tr><td>Caribou health/physiological data</td><td>• Data are not routinely available, may be collected as part of individual studies</td></tr>
</table>

Data Needs	Data Available / Source
Parasite infestation load in areas with/without other ungulate	• Data are not routinely available, may be collected as part of individual studies
Caribou distribution information	
Caribou density in relation to linear features	• Data are not routinely available, may be collected as part of individual studies
Caribou distribution relative to landscape vegetation communities	• Vegetation mapping, biomass estimates, compiled NDVI are available for Bathurst calving ground
Caribou mortality relative to landscape characteristics (primarily linear corridors)	• Data are not routinely available, may be collected as part of individual studies
Caribou response to human use by type of use	• Data are not routinely available, may be collected as part of individual studies
Migration routes	• Information is available/extractable from some surveys described above
Trend in caribou use of snow patches	• Data are not routinely available, may be collected as part of individual studies
Weather/climate/environmental conditions	
Climate/weather trends (e.g. Snowmelt/snow free dates)	**NDVI** • As part of the climate change research, data from the SPOT/VEGETATION instrument were systematically corrected for period 1998-2005 and provided in the following archive http://geogratis.cgdi.gc.ca/download/EO_Data/Spot_Veget/VGT_Canada_Metadata.html • NDVI data are used in land cover and climate change studies to generate various high-level products such as Fraction of Photosynthetically Active Radiation (FPAR) and Leaf Area Index (LAI). • NDVI data may not provide all information required for these data needs **Environment Canada Meteorological information** • Environment Canada weather station data and MERRA data. ○ This data is limited to about the 35 communities in the NWT. Ekati has reported conditions for the last 10 years or so. There is also weather data for the Tundra Ecosystem research station located just west of Ekati.
Weather information (temperature, precipitation) long-term monthly/weekly averages through winter	
Weather information (temperature, precipitation) long-term monthly/weekly averages	
Icing events/snow depth/conditions	• Records of past snow cover are derived using both satellite and surface-based (in situ) observations. Satellite data on snow-covered area is available over Northern Hemisphere land areas since the early 1970's and for snow depth or snow water equivalent since the late 1970's. The Canadian observing network is biased toward southern Canada and lower elevations in mountainous regions. http://www.ccin.ca/home/ccw/snow/past • Retroactive data are available at the scale of seasonal ranges from CARMA (MERRA data)
Snow depth/condition information	• MERRA and EC is developing use of satellite data
Trend in extent of snow patches (?)	• Uncertain; not collected on a routine basis anywhere, although MERRA may provide some utility.
Sea-ice coverage	• There are a variety of historical and current sea ice sensors and data available. http://www.ec.gc.ca/glaces-ice/
Landscape information	
Density of linear features (roads, seismic lines, etc)	• Some data on very old cut (> 30 yr old) lines available from NTS maps. Forest Management has some data.

Data Needs	Data Available / Source
	• NEB has pipeline data and possibly more recent exploration cutline data, however data does not include width, or cut method • The Dehcho region had cut lines digitized from 5-metre IRS satellite imagery; ENR Forest Management has this data. • Information on most secondary roads in all areas available from Gobies ○ However, this does not include snowmobile, boat, or quad access
Extent and nature of anthropogenic disturbances	**Land Use Permits** • Significant land development activities require land use permits. The permit applications are reviewed by the regional Land and Water Boards. Each board has different thresholds for a permit and has different abilities to provide data to the public/government. A couple of recent developments that may impact this is the Feds recently reduced funding to the Mackenzie Valley Land and Water Board; there are efforts underway to provide more consistent access to the boards. ○ http://mvlwb.ca/Boards/mv/SitePages/registry.aspx ○ http://mvlwb.com/ • Land use permits for the NWT archipelago and mainland north of Inuvik are under the jurisdiction of the Inuvialuit Settlement Region – Inuvialuit Land Administration ○ http://www.exdocs.net/ila/lamps/ila/launch/login.jsp;time=1362279696114 • There is no comprehensive dataset of land developments, past, present or planned. ○ A point-data set is available indicating a proponent's coordinates **Mining** • The NWT Mining Recorders office publishes the active and inactive mineral tenure status. This data shows mineral claims, mineral leases and exploration permits areas. The data also has the years the tenures were in effect. ○ This data is downloadable. at http://ntgeoviewer.aandc.gc.ca/geoviewer/Default.aspx?Map=NTMINTEN and http://nwt-tno.inac-ainc.gc.ca/ism-sid/minftplogin_e.asp ○ The data show the property extents of the various land titles, it does not directly indicate the level of activity that occurs on the land. Significant activity would still require a Land use Permit **Oil and Gas Leases** • Digital boundaries for existing exploration licences, significant discovery licences, production licences, former permits, former leases and the Norman Wells Proven Area are available for download. The digital boundaries provided have been generalized and may contain errors. ○ The data show the property extents of the various land titles, it does not directly indicate the level of activity that occurs on the land.http://www.aadnc-aandc.gc.ca/eng/1100100036298/1100100036301 • Although the information is not published, the diamond mines each monitor their footprint and can provide a shape file. **Water Licenses** • Significant water development activities require water licenses. These are administered by the 4 Mackenzie valley LWBs and the NWT Water Board; may provide information about project footprints.
Fire frequency by size class	• Fire history data containing polygon/spatial information and year is available from Forest Management branch/division. ○ These data are not complete for non-forest ecosystems
Index of predator use of linear features compared to broader landscape	• Data are not routinely available, may be collected as part of individual studies
Indices of forage abundance	• Monitoring data are available although not currently reported: MERRA data from NOAA are available from CARMA for spatial snow measurements at the scale of seasonal caribou ranges; Chen et al. (in press)Developed several parameters from meteorological data

Data Needs	Data Available / Source
Indices of fragmentation	• While not monitored, fragmentation is described in some mine environmental assessments. However, as it is a GIS routine, it can be produced from vegetation mapping
Landscape area by vegetation community	**Forest Inventory** • Forest inventory information available from http://www.enr.gov.nt.ca/_live/pages/wpPages/Forest_Inventory_Maps.aspxhttp://www.enr.gov.nt.ca/_live/pages/wpPages/inventory_and_analysis.aspx • Detailed forest inventories are available for some of the southern areas. A satellite based “reconnaissance level” inventory is complete for all the NWT. • GNWT Ecosystem Classification was completed over the last 10 years. It includes level 4 habitat description and delimitation. ENR is currently converting that to a spatial layer. o available a t http://www.enr.gov.nt.ca/_live/pages/wpPages/Ecosystem_Classification.aspx **NDVI** • As part of the climate change research, data from the SPOT/VEGETATION instrument were systematically corrected for period 1998-2005 and provided in the following archive http://geogratis.cgdi.gc.ca/download/EO_Data/Spot_Veget/VGT_Canada_Metadata.html • NDVI data are used in land cover and climate change studies to generate various high-level products such as Fraction of Photosynthetically Active Radiation (FPAR) and Leaf Area Index (LAI).
Other	
Human population	• Statistics Canada and GNWT
Trends in human use of linear features	• Data are not routinely available, may be collected as part of individual studies
Indices of insect harassment of caribou over time	• Data are not routinely available, may be collected as part of individual studies
Insect abundance over time	• Uncertain
Muskox population trend	• Monitoring trends of abundance for geographic areas (management units) is sporadic. Data are available as reports and WMIS
Populations of other ungulates	• Sample of Surveys available through WHMIS: o Dall’s Sheep Mackenzie Mountains 2003 o Dehcho historical Dall sheep 1981-87 o Dehco historical moose surveys 1978-87 o Dehco moose monitoring survey 2003-present o Dehco various Nahanni wood bison surveys 1999-present o Inuvik Muskox surveys; various years 1980 – 1997 o Peary caribou surveys Banks, Melville and NW Victoria Islands 1998, 1999 o Peary Caribou and Muskox survey Western Queen Elizabeth Islands 1997 o Banks Island Peary Caribou and Muskox Surveys intermittently from 1991-2010 o
Predator populations/trends	**Black bear:** • Populations not monitored **Grizzly bear** • Whmis central barrens grizzly bear tracking 1988-2004 • Whmis inuvik grizzly bear tracking 2001-2009 • Population trends are monitored through regional sampling coordinated with the diamond mines. • Data available through gnwt and mine

Data Needs	Data Available / Source
	Wolves • Whmis central barrens - historical wolf den sites 1946-1992 • Population trends are not specifically monitored. • Indexes are fur harvest database, export licences.

4.0 Moving toward Implementation

Here we provide advice in regard to three considerations, stipulated in the terms of reference for this study, for developing a plan for implementing model based advice to support cumulative effects monitoring and management:

- ♦ Justification for the selection and utilization of specific CE tools;
- ♦ How to achieve multi-party agreement on the selection and utilization of CE tools; and
- ♦ How to achieve multi-party agreement on data collection methods to support the application of CE tools.

As will be seen from the discussion that follows, these three considerations are inter-related, especially the first two, which are discussed together. First, we provide some context for thinking about such implementation questions.

Context for Thinking About Implementation

Consistent with the NWT management strategy for barren-ground caribou (NWT Environment and Natural Resources, 2011) this discussion takes as its starting point the basic objective of managing caribou populations in the Northwest Territories at the herd level to achieve their long term sustainability within the natural range of abundance. Given the current status of many of the herds together with the recognition that increased levels of human activity are virtually certain to occur, this means searching for and identifying patterns of activity on the landscape that are consistent with sustaining caribou populations within the range of historical abundance. Given the strong migratory nature of some caribou ecotypes this will require collaborative efforts among the various territories within the NWT, but also with neighbouring jurisdictions, in particular Nunavut.

Collaboration is required not just due to the spatial scope of the territories of caribou herds, but also to due governance structures that affect the management of different types of stresses (e.g. hunting, activities on the landscape that may disturb caribou, and activities that physically transform the landscape) within different management agencies.

A few points are key to understanding, modeling, monitoring and managing the cumulative effects on caribou:

1. ***Caribou are integrator of stress***. Within the ecosystem caribou exist at the end of various impact pathways (Figures 2 – 5 in Section 3, Figure 8 below) that cumulatively determine their condition. Caribou are themselves the integrators of the various stresses that affect them. While some stresses will undoubtedly have a stronger influence, due either to the nature of their impact or their prevalence (reflected in this report in the categorical risk ratings assigned to the various effects hypotheses in Section 3 and Appendix 1), it is the overall cumulative stress on caribou from all sources that will determine their condition.

2. ***Effects are cumulative, but agency responsibilities are not aligned with assessing cumulative effects***. The accumulation of impacts can be estimated at various points along a chain of ecological pathways that translate physical or chemical environmental changes resulting from human activities or natural environmental drivers (e.g. fire, climate) into eventual impacts on caribou. For example, cumulative impacts can be

characterized in terms of the cumulative change in landscape fragmentation, the cumulative increase in hunting from different peoples within the range of a herd, the cumulative change in quality of forage, etc. Such estimations are consistent with providing information for management decisions to agencies responsible for managing the stresses that cause them.

However, the significance of such changes in regard to "managing" caribou can only be evaluated in the context of the overall cumulative impact on the caribou themselves. Agencies mandated to manage a particular type of stress, but with no explicit responsibility for caribou condition can thus be functionally isolated from the key determinant of significance – unless their decision making protocols are explicitly linked to estimates of impacts on caribou. The linkage to caribou may be facilitated by a model that reflects the full suite of impacts (not just those that an agency is mandated to manage) or through quantitative management objectives that are predetermined in the context of caribou response and the potential impacts managed by other agencies.

3. ***Models should simulate long term dynamics***. For a species such as caribou that exhibit natural population cycles over decades, the significance of the caribou response to cumulative impacts resulting from development activities may only be fully understood in the context of the natural cycles. Impacts may be observed differently at times of high and low abundance and their full significance may not be fully understood without longer term monitoring to validate model predictions.

   Thus the ability to effectively manage risk associated with development may well be inversely related to the pace of development. Consequently, analyses will need to be conducted with models that are capable of addressing the processes which cause natural cycling of caribou populations. What is essential for this is model formulations that simulate the functioning of the ecological processes that determine caribou condition. The structure of the CARMA model exemplifies this modelling approach.

4. ***Not all stresses can be managed by agencies in the NWT***. Several of the pathways (hypotheses) in Figures 2 – 5, and Figure 8 originate with natural drivers, (climate, fire) are to a large degree beyond the scope of management. Understanding Point 1 above, that caribou condition will be determined by the aggregation of all stresses, the impacts of these natural pathways determine the residual capacity to absorb additional stress from human activity. Accounting for them in any cumulative effects modeling is a fundamental requirement for achieving the management objectives – even though they are not directly managed.

5. ***Monitoring needs will evolve as knowledge advances***. Although impacts on caribou need to be managed to achieve the objective of sustaining caribou populations within the historical range of abundance, it is important to recognize that understanding and predicting cumulative effects remains to a large degree a matter of research. Consequently, it must be expected that requirements, for data collection, information management and analysis with evolve.

Figure 8 presents a consolidated overview of the effects hypotheses summarized in Table 2 (p. 34) for the four caribou ecotypes found within the NWT. While cumulative effects analysis must be based on the specific pathways and risks relevant to each ecotype the purpose of Figure 8, together with Table 1Table 6 is simply to provide an overview of the scope of the models assessed in our review (Section 2) relative to the cumulative effects hypotheses identified for the four caribou ecotypes (Section 3). The numbering of the various pathway linkages in Figure 8 provides a reference for mapping the scope of the models presented in Table 6.

As can be seen from Table 6 only four of the models reviewed CARMA, DeBeers, ALCES and SLEDSS, address in any way the potential response of caribou to cumulative changes in other environmental components. The various landscape models reviewed, with the exception of the Marxan model, have relevance to specific aspects of the overall cumulative effects analysis. Several of the landscape models are dynamic, simulating change over time, while static models assess potential environment condition at a single point in time. While the overall cumulative effects analysis will need to deal with dynamic changes in the landscape, static models may still play an important role. For example, the specialized analysis provided by the Burn-P3 model may well be valuable in developing future scenarios of potential natural change on the landscape – by using multiple Burn-P3 analyses to estimate fire probabilities under different conditions.

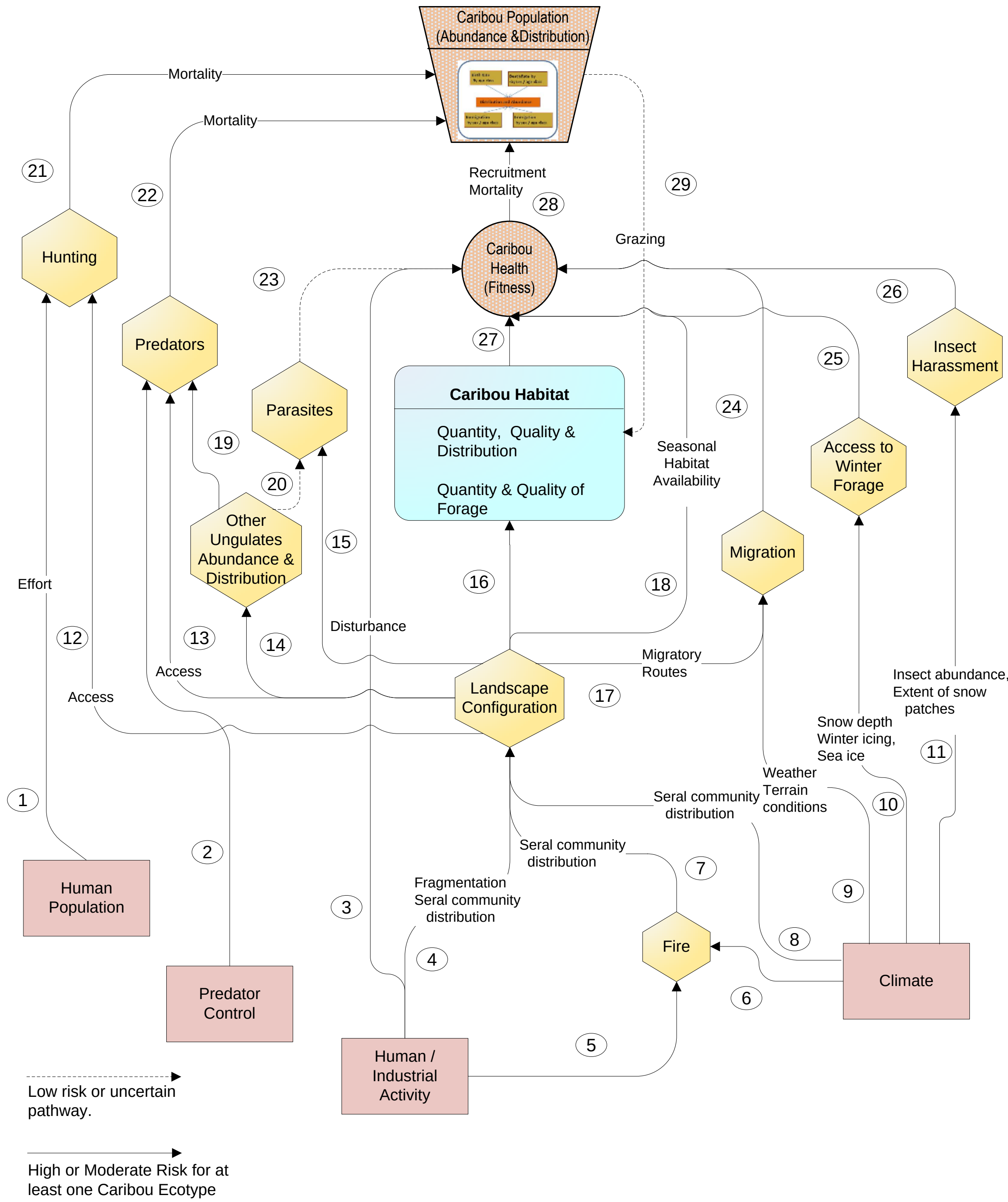

Figure 8 Overview of Cumulative Effects Pathways

Table 6 Linkages in Figure 8 addressed by the models reviewed.

	Caribou Models											
			Landscape Models									
			Dynamic							Static		
Figure 8 Link #	CARMA	DeBeers	ALCES	SLEDSS	LANDIS	MGM **	Patch-works	TELSA	Wood-stock	Burn-P3	MARXAN	NEPTUNE
29	o	X										
28	o	X	X									
27	X		?									
26	X	X										
25	?											
24												
23	X											
22	X	X	X									
21	X	X	X	?								
20												
19												
18												
17												
16			X		A	A	A	A	A			
15												
14												
13												
12												
11	X	X	?									
10	X		?									
9	X											
8					X			X				
7			X	X	X		X	X		X		
6								X				
5	X		X	X				X		X		X
4	X		X	X				X				X
3	x	X	X	X								
2	A	A	A									
1	X	X	X									

Footnotes:

A – Not explicitly part of the model, but could be derived from model output.
? – Needs further examination.
** – Landscape would need to be modelled as multiple runs of individual stands.
o – Under active development.

JUSTIFYING AND REACHING AGREEMENT ON THE SELECTION OF CUMULATIVE EFFECTS TOOLS

As discussed above, cumulative effects assessment requires consideration of all of the stresses that affect a valued environmental component such as caribou. This requires the integration and analysis of information (e.g. activity levels, environmental response) that is held in different formats by different management agencies. The simple amalgamation of data from different sources and the subsequent analysis of effects requires tools for data aggregation, analysis and reporting of results. Without tools to support these functions cumulative, effects analysis simply cannot be done.

In addition to the criteria identified for inclusion in our review of the various models (Section 2), the primary criteria for selecting a cumulative effects tool, or set of tools, are:

- The structure of the cumulative effects management process / strategy within which the tool will be applied;
- How it will be integrated within the management process; and importantly
- What primary question / function is the tool intended to answer / support? and How well does it address this need?

If there is consensus on the characteristics of the requirement for a modeling tool, namely:

- the key points discussed above in the context for thinking about implementation;
- the structure of the management process/strategy;
- the specific questions to be addressed with the tool; and
- how it will serve management decision making by agencies with differing mandates

then reaching agreement on tool selection should be relatively straight forward. It becomes a matter of choosing the tool that meets the requirements to effectively address the primary question(s) while optimizing its implementation, in consideration of cost, ease of use, training, support, etc.

If however there is not a consensus on the characteristics of the requirement for a modeling tool, especially if the relevance of the outputs of the tool to facilitate decisions made by different management agencies is in question, then analyses regarding implementation optimization are unlikely to be helpful in reaching agreement. Regulators can quite naturally be expected to want tools that are directly relevant to the decisions that they must make. That it, the relevance of the results provided by a model or models to management decisions must be clear.

In is important to note the recent completion of a demonstration project for the Bathurst herd in which a resource selection model was linked with a caribou energetics model to provide outputs that can be linked to a population dynamics model developed within ALCES (Nishi and Gunn, 2012). The preliminary analytical results obtained clearly demonstrate the feasibility of linking multiple models for cumulative effects analysis. Whether the results of the analysis are provided by a single integrated model, or by multiple linked models is not a primary concern. What is important is that supporting systems must be in place to make the resulting information available to decision makers, when needed and in an easily interpreted format.

Understanding that there will be an ongoing need to update / revise and expand the scope of models over time, in addition to the criteria already addressed in this review, we recommend that consideration be given to the ease of customization of a selected tool. Customization will be needed to support analysis to address each of the four caribou ecotypes. This means, either model variants that address cumulative effects that may be unique to an ecotype, built around a common core model, or a multi-function model in which particular eco-type components can be invoked as needed. Also, revision of models will be needed to reflect new understanding gained through the comparison over time of model predictions with observed outcomes.

STEPS TOWARD IMPLEMENTATION

We interpret the interest in multi-party agreements on selection and use of CE tools and data collection broadly to encompass not just data collection methods, but more generally data requirements. The key consideration is that the required data are those needed to enable the analysis of cumulative effects and this will be a function of the modelling/analytical strategy. For example, the data needed as input to ALCES to drive the model of predation on caribou are not currently available for the NWT, and would need to be obtained to enable that analysis. Similarly the CARMA model requires detailed data on caribou activities with which to estimate the energy costs and caribou condition.

With insightful analysis, modelling strategies may be able to be developed that employ highly detailed data to develop model components with less intensive data requirements across the landscape to support analysis with simplified versions of the more detailed models. The feasibility of such an approach can only be assessed in the context of specific relationships within a chosen model and the predictions may need ongoing periodic validation.

Given the regulatory commitment in NWT to adopt a regional cumulative effects assessment and management framework, the NWT Environmental Stewardship Framework, we presume that the modeling tools that NWT will acquire or develop may be used to support:

- regional scale assessments that anticipate potential cumulative effects under different development scenarios;
- analyses, to support setting quantitative management objectives for cumulative impacts measured at various intermediate points within the overall cumulative effects pathways (e.g. limits on stress such as disturbance, harvest, landscape fragmentation, etc.; and
- analyses to assess the resulting change in the overall cumulative effect associated with the addition of select (large) development projects.

It is notable that initiatives needed to pursue a model informed cumulative effects assessment and management framework have already been initiated, for example the identification of quantitative management objectives (Antoniuk et. al. 2009a, 2009b) and demonstration of a model based approach to cumulative effects assessment for the Bathurst herd (Nishi and Gunn 2012).

While this effort has made substantial progress towards identifying hypothesis and related data collection priorities, we note that additional review will strengthen the rational for engaging in data robust data collection programs.

Nishi and Gunn (2012) make several recommendations in regard to data integration, web accessibility which we support. We observe that the GNWT Geomatics Centre could serve as the locus for this. While much data is available, only some is in readily accessible formats and a substantial effort will be needed to make all of the necessary data available. While the data needed to estimate vital rates for the various herds are mostly available in WMIS, analysis will be needed to derive the rates for input to models. Prioritization of the data integration work might be approached in terms of the relative urgency to address impacts for different herds, and the estimated risk associated with different impact hypotheses.

The following steps are recommended for further implementation of cumulative effects tools to support the NWT's regional cumulative effects assessment and management framework:

Refining Monitoring/Data Collection Priorities

1. Review and adjust as needed the draft set of hypotheses for cumulative effects on the four caribou ecotypes presented in Section 3 of this report;
2. Review the data and management needs identified in Table 4 in concert with a review of the risk characterizations of the hypothesis. Following that, identify the critical data collection needs.
3. Develop a monitoring strategy which addresses the critical data collection needs, based on collaboration between agencies and governments
4. Begin the consolidation of databases of impact information needed as input to the models and make them available through a single web based portal to facilitate access to regulators, project proponents and the public throughout the NWT. We note that the need for this is already clearly recognized and that NWT CIMP has recently issued a call for participation in the inventory of Landscape Change. In addition to consolidation of existing data, what is also needed is the establishment of ongoing procedures to update this information as new developments are approved.

Modelling

5. In addition to modeling tools to assess impacts to caribou, attention should also be given to other tools for presenting information to decision makers. For example, as reflected in the CIMP call for participation noted above, is it generally not possible at the present time for regulators to view the current state of the landscape when faced with proposals for further development. If management objectives are to be of any value to decision makers it is essential that decisions are made with a sound understanding of the current state of the system.
6. Understanding that models are simply helpful quantitative representations of our current understanding of how various stresses may combine to create a cumulative impact on caribou an adaptive management approach is warranted in which model predictions are evaluated over time against the results that unfold across the landscape. Ongoing data collection to support this should come not just from government assessment programs but also from follow-up studies for private sector developments, i.e. the requirements fo follow-up should be consistent with supporting the ongoing modeling strategy.
7. Finally, we support the adoption of resilience of caribou as the endpoint of cumulative effects analysis adopted by Gunn et. al. (2012), and have recommended this previously in other contexts. It is in our view, the logical endpoint for cumulative effects analysis.

Collaborative Efforts

As noted at several points in this report, responsibility for managing caribou, and activities which contribute to cumulative effects on caribou is spread across many agencies. Therefore without collaboration significant progress on dealing with cumulative effects will not be possible.

8. Review with cumulative effects regulators the operational basis for decision making and how their decisions can/will be informed with modeling / data integration tools;
9. Develop protocols for integration/coordination of monitoring efforts across the agencies and territorial government;
10. Review and adjust if necessary protocols for collaborative decision making in regard to activities that will contribute to cumulative effects; and
11. Conduct periodic on-going reviews of the of how well the collaborative decision making protocols are working in providing for well informed decisions. Such reviews could be timed to correspond with periodic assessments of the condition of caribou herds within the NWT.

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Appendix 1: Detailed Literature Reviews of Eco-type Conceptual Models

Table A1- 1 Summary of evidence for hypothesized effects for Peary Caribou.

No.	Description	Literature/ Evidence	Conclusion
1	Climate change/variability affects rainfall which influences insect abundance. Insect abundance/ harassment has an effect on caribou health	• COSEWIC 2004 notes that Peary caribou are found in small groups compared to barren-ground caribou which likely reflects foraging strategies, relatively low caribou densities, and the absence of intense insect harassment • In discussing uncertainties beyond their modelling exercise, Tews et al. (2007) speculate that Peary caribou may suffer from increased insect harassment if summer precipitation and temperature increase as a result of climate change.	• Relatively little evidence of a significant effect • Category 4: Low Risk
2	The frequency of winter icing events will change as a result of climate change. Icing events restrict access to winter forage	• Climate projections suggest that the high Arctic will have warmer temperatures and greater precipitation (Rinke and Dethloff 2008in FestaBianchet), leading to more frequent icing events and die-offs of Peary caribou (Festa-Bianchet et al. 2011) • Klein (1999) notes that global climate change will increase the extent and seasonal duration of open water in the arctic seas and that icing events can, therefore be expected to increase • Three successive winters (1997-1997) of heavy snow and icing events resulted in a 98% decline of Peary caribou on Bathurst Island (Miller and Gunn 2003a) • Nagy and Gunn (2006, in Gunn et al. 2011) suggest that ice events in 2002/2003 and 2003/04 affected Banks Island and Norwest Victoria Island Peary caribou • The NWT Species at Risk Committee (2012) discusses distribution changes of Peary caribou likely in response to icing events in the 1950's and notes that the lowest calf:cow ratio followed the winter of 1993/94 which had increased snow hardness and icing. • The NWT Species at Risk Committee (2012) makes numerous additional references to effects of icing including that of Gunn and Dragon (2002) who described a die-off of 30% on the western Queen Elizabeth Islands following deep snow and icing in 1996-97 • Miller et al. (2005) note: "*It is most unlikely that the concepts of 'carrying capacity' and 'sustained yield' have any real application to Peary caribou on the QEI. To date, everything suggests that the caribou on the QEI function in a 'nonequilibrium grazing system' where abiotic factors, mainly snow and ice, control their fate through infrequently occurring, sporadic and unpredictable 'exceptionally hard weather years' (Caughley&*Gunn, 1993; *Behnke, 2000; Miller & Gunn, 2003a, b). At such times, extremely unfavorable snow and ice conditions prevent the animals from getting to food or cause caribou to use more energy accessing it than they recover in forage intake. In years when such snow and ice conditions are prolonged and widespread, a large number of caribou (and muskoxen) will die from starvation*."	• Severe impacts associated with icing are well documented • Occurs with sufficient frequency so as to pose significant concern • Category 1: High Risk
3	Snow depth will change/vary as a result of climate change and variability. Snow depth	• Three successive winters (1997-1997) of heavy snow and icing events resulted in a 98% decline of Peary caribou on Bathurst Island (Miller and Gunn 2003a)	• Impact of snow depth, in concert with icing has been significant

No.	Description	Literature/ Evidence	Conclusion
	affects access to winter forage		• Unclear if snow depth by itself is a significant factor • Category 2: Moderate Risk
4	Warming climate will decrease the extent, stability and duration of sea ice restricting the ability of caribou to move between islands and ultimate limiting their access to winter forage	• Movement of Peary caribou across sea ice presumably to get to better forage is reasonably well established (Nagy 1996, COSEWIC 2004, GNWT SAR Committee 2012,), and Instances of starvation on the ice (McEwan 1952 in GNWT SAR Committee 2012) and drowning (GNWT SAR Committee 2012, Kassam 2009) have been reported . • Miller et al. (2005) conducted an extensive analysis based on 805 trails found on sea ice between Prince of Wales Island, Somerset Island and Boothia Peninsula and hypothesize that movement is a mechanism which reduces overwinter grazing pressure on forage plants on their island ranges. They and Miller et al. (2007) speculate that climate change could seriously alter the timing and, perhaps, the opportunity for seasonal migrations across the sea ice, impacting access to winter forage. • GNWT Species at Risk Committee (2012) draw and Riedlinger's (2001) observations from Sach's Harbour residents of lesser sea ice to speculate that less secure sea ice would likely inhibit caribou movement between islands and possibly restrict access to forage. • Nagy et al. (1996) describes that residents of Sachs Harbour on Banks Island reported large numbers of caribou travelling on the sea ice south of Banks island in 1951 and that this movement appears to have occurred when available forage was low (Urquhart 1973) and that "*large scale movements from Banks Island may be driven by reduced forage availability during episodes of severe winter weather*".	• Caribou crossing between arctic islands is well established, as is potential implication of access restriction. • Although event might not occur every year, intermittent occurrence may be sufficient to pose a significant threat. • Category 1 High Risk
5	Climate change mediated changes in rainfall and growing season will affect the quality and quantity of forage	• GNWTSpecies at Risk Committee (2012) notes that increasing forage productivity which is occurring because of climate change "*may promote increased fattening and improved condition of animals prior to the winter...which may have a positive impact on calf survival and possibly adult survival.*." • Miller (1991) found no evidence that either winter or summer habitats were limiting factors in terms of absolute forage availability for Peary caribou, however COSEWIC (2004) notes that many researchers are careful to distinguish between absolute forage availability and relative or seasonal availability when limited by winter snow and ice. • COSEWIC (2004) reports that Greg Henry of UBC experimentally increased summer growing season temperatures by 1°C to 3°C in open-top chambers on Ellesmere Island . There was an increase in the abundance of non-woody (herbaceous) plants (graminoids and forbs) in all 7 plant communities he examined and concluded that climate warming should increase the abundance of some Peary caribou food species and cause earlier flowering of those species. • Epstein et al. (2000) developed a vegetation simulation model and predicted about a 50% increase in aboveground biomass for the High Arcticover the next 100 years.	• There is a reasonable basis for concluding that the amount of forage will increase (although it may not be directly because of rainfall). • Implications for health of caribou are unclear as it is not clear that forage is a limiting factor • Category; Uncertain

No.	Description	Literature/ Evidence	Conclusion
		• Tewset al. (2007) used the model of Epstein et al. (2000) as a basis for predicting that climate change-based increase in primary production could increase the amount of forage available for caribou	
6	Changes in forage quality and quantity increase the abundance of muskox, providing more prey for wolves and leading to increased wolf populations. Muskox abundance will reduce the quality and quantity of forest available for caribou	• Gunn et al. (2011) note: "*Muskox trends in abundance tend to differ from Peary caribou, although this is area specific. Muskox increases relative to Peary caribou decreases have raised the question of competition. The role of intra- or inter-specific competition for forage is conjectural as diet and habitat selection differ considerably between caribou and muskoxen (Gunn and Dragon, 2002). On Banks Island, however, there was overlap in the use of some plants, such as willow, by Peary caribou and muskoxen (Larter and Nagy, 2004), which suggests that a competitive relationship could occur*." • Nagy et al. (1996) note that "*Although, competition between muskox and caribou has been considered unlikely in the past ...., reconsideration of caribou and muskox ecology and recent research indicates they may in fact compete for forage resources especially during winter or when muskox densities are high...*" • Nagy et al. 1996 suggest that the relationship between Peary caribou and Muskoxen on Banks Island may be similar to that described for places where moose and caribou are sympatric, where a high biomass of muskoxen supports an increasing wolf population. • GNWT Species at Risk Committee (2012) note that traditional knowledge is that on Banks Island, especially, competition with Muskoxen is important as may compete with caribou for forage at times, and trample vegetation. • GNWT Species at Risk Committee (2012) note that, from a scientific perspective, "*the debate about whether muskoxen and Peary caribou compete for food or space dates back to the 1970s and is largely unresolved. However, the two species do show overlap in dietary components.*" • GNWT Species at Risk Committee (2012) notes that scientific knowledge is that wolf and muskox numbers have increased in most Peary caribou subpopulation ranges and that increased muskoxen could be "subsidizing" predation rates on Peary caribou.	• The opposite population trajectories for muskox and Peary caribou strongly suggest an interaction. • The distinct roles of competition for food and increased predation are not clear. • Category 1: High risk
7	Predator control reduces wolf populations. Changes in wolf populations result in changes in predation	• GNWT Species at Risk Committee (2012) note that traditional knowledge is that wolves are described as a threat to caribou on Banks Island, and that a past wolf control program in the late 1950's has been linked to growth of the muskox population. • Nagy et al. (1996) provide a brief numerical analysis showing that even a low wolf population can have a high relative impact on caribou on Banks Island, and infers that wolf population control in the 1950's likely had a beneficial effect on caribou.	• Specific information for Peary Caribou are relatively sparse, however given the strong relationship between predation and caribou populations noted for other ecotypes, the probability of an impact is high. • Category 1: High risk
8	Changes in human population	• Festa-Bianchet et al. note that: Since the 1970s, however, the human population in	• Hunting, facilitated by

No.	Description	Literature/ Evidence	Conclusion
	result in changes in hunting pressure	the Arctic and subarctic has doubled, reaching about 107 200 people in 2006. Changing socio-economic conditions and technology are influencingcaribou harvesting patterns. • In a discussion on northern caribou in general, Gunn et al. (2011) note that "*The increasing number of people, a shift to wage-earning, and changing technologies for hunting (snowmobiles, ATVs, aircraft, winter roads, and rapid communications) have likely altered hunting effort and made finding and harvesting caribou more efficient*." • However Gunn et al. (2011) also note that the relationship between hunting effort and harvest levels, is largely unknown and unquantified and this limits understanding of the effects of hunting. • GNWT (2012a) note that : "*In the 1970s, caribou hunting became a practice undertaken with skidoos rather than dogsleds during the winter.... Skidoos made hunting faster and easier, and caribou would not be as likely to run away as they had been when hunters used dog-teams (Condon 1996). Hunters could also cover a greater distance searching for caribou, thus increasing the effectiveness of their search effort (Condon 1996).* " • GNWT 2012a also note that "*A key influence that likely halted the decline of Peary caribou in the 1990s was the restriction of hunting, especially of female caribou.* " •	efficient means of transportation, has the potential to detrimentally affect caribou populations, although the impact is managed with present restrictions. As it is presently restricted, potential is diminished. • Category 2: Moderate
9	Increased human/industrial activity will disturb caribou leading to increased stress and poorer health	• GNWT Species at Risk Committee (2012) note that traditional knowledge holds concerns about the negative effects of resource development on Peary caribou. "*Specific concerns pertain to low-flying helicopters, increasing interest in coal exploration, a proposed Melville Island gas pipeline, offshore oil and gas exploration, and potentially increased offshore marine traffic*. " • Bergerud et al. (1984) concluded that caribou productivity does not suffer because of industrial development, but none of the eight populations they studied were Peary caribou.	• Sparse indications of impact. • Impact could be high, but would be localized given area of potential development relative to caribou occurrence. • Category 2: Moderate Risk

Table A1- 2. Summary of evidence for hypothesized effects for Boreal Caribou.

No.	Description	Literature/ Evidence	Conclusion
1	The frequency of winter icing events will change as a result of climate change. Icing events restrict access to winter forage	• GNWT Species at Risk Committee (2012) reported that community meetings held in 2007 identified icing events as potentially lethal for boreal caribou • Johnson et al. (2004) studied northern woodland caribou habitat use in northern B.C. during winter and found that snow limits movements and foraging efficiency. Caribou selected feeding sites where snow depth, density and/or hardness were least. During late winter caribou may have abandoned southern portions of their range because snow was too deep, dense and/or hard.	• Icing and deep snow can restrict movement, but lack of concern raised in literature suggests severe impacts do not occur frequently, Lack of concern regarding future impact may reflect uncertainty as to future potential impact. • Category 3: Less Risk
2	Snow depth will change/vary as a result of climate change and variability. Snow depth affects access to winter forage	• GNWT Species at Risk Committee (2012) reported that community meetings held in 2007 identified that deep snow is difficult for caribou and influences where they range. • Johnson et al. (2004) studied northern woodland caribou habitat use in northern B.C. during winter and found that snow limits movements and foraging efficiency. Caribou selected feeding sites where snow depth, density and/or hardness were least. During late winter caribou may have abandoned southern portions of their range because snow was too deep, dense and/or hard.	• Impact of snow depth, may be exacerbated or act in concert with icing • Category 2: Moderate Risk
3	Insects will increase in abundance due to climate change, affecting caribou health	• GNWT Species at Risk Committee (2012) notes that "*Biting insects are most active during periods of warm temperatures (Russell et al. 1993), thus longer warmer summers may lead to longer periods of insect harassment and, as a result, reduced body condition for boreal caribou. These conditions may occur with greater frequency in the future*"	• Rationale exists, but not consistently identified • Category 4 Low Risk
4	Climate change will affect seral community distribution through the frequency of fire.	• Racey (2005) parameterized a forest projection model based on literature assessments of climate change impacts on fire frequency and hypothesized that increases fire frequency and intensity would lead to reduced area in large patches of old, conifer dominated forest and reduced ability of caribou to separate themselves spatially and temporally from predators in northwestern Ontario. • Rupp et al. (2006) simulated changes in fire regime under climate change scenarios on the range of the Nelchina caribou herd in Alaska and found that simulations with more frequent fires produced a relatively immature forest age structure compared to the present, with few stands older than 100 years, and speculated that changes in fire regime due to climate warming could substantially alter the winter habitat of caribou and lead to changes in winter range use and population dynamics. • In its assessment of scientific knowledge, GNWT Species at Risk Committee (2012) notes: "*The likelihood of post-fire regeneration to lichen-bearing old growth stands is determined, in part, by the average fire-return interval or fire cycle (Thomas and Gray 2002); fire frequency in the Mackenzie River Basin is predicted to increase with climate warming (Cohen 1996). If the fire cycle is shorter than the regeneration time then areas that have been disturbed by fire may be held at earlier seral stages. Early*	• Reasonable body of simulated/modeling evidence of likely increase in fire and change in seral communities (primarily less old growth) • Category 1:High Risk

No.	Description	Literature/ Evidence	Conclusion
		seral habitats are favoured by moose (Alcesalces), bison (Bison bison), deer (Odocoileusvirginianus), elk (Cervuscanadensis), and black bears (Ursusamericanus) and, as a result, predator-prey dynamics may be altered for extended time periods in boreal caribou ranges that are frequently disturbed by fire (Latham et al. 2011a)."	
5	The abundance and distribution of other ungulates will increase as a result of landscape changes brought about through anthropogenic changes to the landscape and climate change	• In its assessment of scientific knowledge, GNWT Species at Risk Committee (2012) notes: "*The likelihood of post-fire regeneration to lichen-bearing old growth stands is determined, in part, by the average fire-return interval or fire cycle (Thomas and Gray 2002); fire frequency in the Mackenzie River Basin is predicted to increase with climate warming (Cohen 1996). If the fire cycle is shorter than the regeneration time then areas that have been disturbed by fire may be held at earlier seral stages. Early seral habitats are favoured by moose (Alcesalces), bison (Bison bison), deer (Odocoileusvirginianus), elk (Cervuscanadensis), and black bears (Ursusamericanus) and, as a result, predator-prey dynamics may be altered for extended time periods in boreal caribou ranges that are frequently disturbed by fire (Latham et al. 2011a).*" • Callaghan et al. (2011) cite the work of Bergerud and Elliot, (1986), Seip, (1992), Stuart-Smith et al., (1997), Racey and Armstrong (2000), Wittmer et al., (2005), Wittmer et al., (2007), Vors et al., (2007), and Vors and Boyce (2009) in noting "*Although wolves (Canis lupus)were very scarce or absent throughout most of the original distribution of woodland caribou (Cringan, 1956), logging and other industrial disturbances have increased the amount of early seral-stage forest and promoted higher densities of prey species such as moose (Alcesalces) and white-tailed deer (Odocoileusvirginianus), which support higher predator densities, especially wolves*" • Increase in moose density as a result of forest management and other changes in landscape configuration which cause younger and less contiguous old forest is well established (Crête 1988, Rempel et al. 1997, Voigt et al. 2000).	• Habitat needs of moose, deer, and elk are well known; they generally favour/use less contiguous old forest than caribou; changes in landscape which reduce old forest and increase younger seral communities will cause an increase in other ungulates. Dynamic will likely vary depending on latitude and range of other ungulates • Category 1: High Risk
6	Changes in landscape configuration will affect seasonal habitat availability via fragmentation and changes in habitat area.Changes in seasonal habitat availability lead to changes in the health of individuals.	• One of the key findings from Environment Canada's (2011) assessment of critical woodland caribou habitat was that "*Nearly 70% of the variation in caribou recruitment across twenty-four study areas spanning the full range of boreal caribou distribution and range condition in Canada was explained by a single composite measure of total disturbance (fire + buffered anthropogenic), most of which could be attributed to the negative effects of anthropogenic disturbance*." Although this finding is not precisely indicative of this link in our model, it is sufficiently related so as to establish a basis that disturbance of all sorts are a major impact on caribou habitat. • EC also noted that "*Little statistical support was found for distinguishing different types of anthropogenic disturbances (e.g., linear and polygonal types). However, supporting analyses of a range of buffer widths demonstrated that a 500 m buffer on anthropogenic disturbance provided an appropriate, minimum approximation of the zone of influence of these features on caribou demography*." • Sorensen et al (2008) monitored > 300 female caribou in six populations in northern Alberta examining functional habitat loss. They found both anthropogenic and natural disturbance were key factors in explaining habitat loss and concluded that "*population growth rates of boreal caribou in northern Alberta have a plausible dependency on functional habitat loss resulting from wildfire or industrial development*"	• There is a strong basis, based on an extensive body of work, to conclude that habitat configuration is an important element in the distribution and health of boreal caribou • Category 1: High Risk

No.	Description	Literature/ Evidence	Conclusion
		• In Québec, Courtois et al. (2007) compared the use of disturbed and undisturbed landscapes by collared caribou and found that "*In DLs [disturbed landscapes], caribou increased home range sizes and reduced fidelity to seasonal and annual home ranges, probably to avoid disturbed habitats. In response, the probably of surviving decreased with the extent of DL within home ranges.*" • GNWT Species at Risk Committee (2012) summarized the work of Dyer et al. (2002, Latham et al. 2011, and Nagy 2011) to conclude that caribou behavioural responses to seismic lines and other anthropogenic linear features result in functional habitat loss.	
7	Changes the amount and distribution of other ungulates will lead to increased predator abundance which will cause increase predation on caribou	• 'Apparent Competition' hypothesis (relating to impact of additional predation from increased in alternate prey) is the subject of considerable study. • Wittmer et al. (2005) concluded from work on > 300 collared caribou , that the decline woodland caribou in the absence of resources competition in southern B.C. is due to apparent competition • Bergerud et al. (2007) conclude from comparisons of survival rates and abundance of Slate Islands populations and proximal Ontario mainland population that "*predation is limiting caribou in the boreal forest*" • Rettie and Messier (2000) documented caribou selection of habitats at both seasonal and daily scales consistent with predator avoidance and explained this on the basis of avoiding greater wolf densities in areas with higher prey • GNWT Species at Risk Committee (2012b) note that traditional knowledge holds that moose, muskoxen, wood bison and even barren-ground caribou can affect the extent of predation on woodland caribou caused by increasing prey for wolves and therefore increasing impact on woodland caribou. • Environment Canada (2012b) concludes that: "*The primary threat to most boreal caribou local populations is unnaturally high predation rates as a result of human-caused and natural habitat loss, degradation, and fragmentation. These habitat alterations support conditions that favour higher alternate prey densities (e.g. moose (Alcesalces), deer (Odocoileusspp.)), resulting in increased predator populations (e.g. wolf (Canis lupus), bear (Ursus spp.)) that in turn increase the risk of predation to boreal caribou.....*"	• Apparent competition/alternative prey is established as a dominant mechanism of caribou mortality in anthropogenically altered landscapes • Category 1: High Risk
8	Anthropogenic changes in the landscape will facilitate predator movement increasing predation on caribou	• Courbin et al (2009) examined habitat selection of sympatric caribou and wolves in old-growth boreal forests in Québec. Among the findings was that caribou avoided roads for most of the year while wolves selected for them. • In a telemetry study in northeastern Alberta James and Stuart-Smith (2000) found that wolf locations and caribou mortalities attributed to predation were disproportionately close to linear corridors. • Thurber et al. (1994) found wolves used lightly travelled (by humans) roads extensively, but avoided more heavily travelled roads in southeast Alaska • Houle et al. (2009)found that wolf use of roads was strongest and disproportionately high when road density on the landscape was low in Quebec. An increase in road density decreased their selection and use of the surrounding area by wolves. • Pinard et al. (2012) suggest that caribou select calving sites in southwestern Québec	• Wolf use of roads is well established and the role of predation on caribou is also well established. • Category 1: High Risk

No.	Description	Literature/ Evidence	Conclusion
		in areas distal from human activities to avoid predation from wolves which use roads and areas of high road density in their study area during their denning period (Houle et al. 2009). • GNWT Species at Risk Committee (2012) reports that "*Dehcho harvesters know that seismic lines and other linear disturbances open up corridors for wolves, which can lead to increased predation of boreal caribou*" and that "*SambaaK'e harvesters indicated that wolf populations hare higher along linear distances such as seismic lines, resulting in lower caribou populations*".	
9	Changes the amount and distribution of other ungulates will lead to increased parasitism of caribou leading to effects on health.	• GNWT Species at Risk Committee (2012b) notes that muskox are being recorded farther south and implies there may be a competitive relationship with boreal caribou. In addition, citing Zimmer (2002), they note: "*Some participants felt that muskoxen may cause boreal caribou to leave areas due to hair, noise or parasites. Others said that they have seen boreal caribou and muskoxen feeding on the same plants, in the same places, without evidence of competition or exclusion (Zimmer et al. 2002)*". • In summarizing traditional and community knowledge GNWT Species at Risk Committee (2012b) note that "*parasites and disease are known to occur but are generally not a cause for concern*"; a similar sentiment is expressed in the summary of scientific knowledge although it does note that there is a possibility of introduction of *Parelaphostrongylustenuis* and Chronic Wasting Diseases as white-tailed deer expand their range in to the NWT. • Environment Canada (2012b) notes that parasites are not thought to be one of the major threats affecting boreal caribou at the national level. • Callaghan et al (2011) note that "*although little evidence exists of disease or parasites impacting boreal caribou populations (Jordan et al., 2003), broad scale climate and habitat change may play a role in increasing therisk of disease transmission from white-tailed deer to caribou. For example, caribou are susceptible to a parasitic nematode, the brain or meningeal worm (Parelaphostrongylustenuis)carried by white-tailed deer.*	• Literature indicates little cause for concern at present although uncertainty about future • Category 4: Low Risk
10	Increased human populations and access created by linear disturbances increases hunting	• Festa-Bianchet et al. note that: Since the 1970s, however, the human population in the Arctic and subarctic has doubled, reaching about 107 200 people in 2006. Changing socio-economic conditions and technology are influencingcaribou harvesting patterns. • In a discussion on northern caribou in general, Gunn et al. (2011) note that "*The increasing number of people, a shift to wage-earning, and changing technologies for hunting (snowmobiles, ATVs, aircraft, winter roads, and rapid communications) have likely altered hunting effort and made finding and harvesting caribou more efficient*." • However Gunn et al. (2011) also note that the relationship between hunting effort and harvest levels, is largely unknown and unquantified and this limits understanding of the effects of hunting. • Effect may be high on individual groups of boreal caribou which are proximal to more highly disturbed areas (B. Tracz GNWT pers comm..)	• Although human population and linear development are increasing, the precise role in hunting mortality seems unclear • Category 2: Moderate Risk
11	Increased human access and industrial development causes	• One of the key findings from Environment Canada's (2011) assessment of critical woodland caribou habitat was that "*Nearly 70% of the variation in caribou recruitment*	• Caribou avoidance of linear features is well established

No.	Description	Literature/ Evidence	Conclusion
	disturbances which increase stress on caribou	*across twenty-four study areas spanning the full range of boreal caribou distribution and range condition in Canada was explained by a single composite measure of total disturbance (fire + buffered anthropogenic), most of which could be attributed to the negative effects of anthropogenic disturbance*." Although this finding is not precisely indicative of this link in our model, it is sufficiently related so as to establish a basis that disturbance of all sorts are a major impact on caribou habitat. • EC also noted that Little statistical support was found for distinguishing different types of anthropogenic disturbances (e.g., linear and polygonal types). However, supporting analyses of a range of buffer widths demonstrated that a 500 m buffer on anthropogenic disturbance provided an appropriate, minimum approximation of the zone of influence of these features on caribou demography. • Bowman et al. (2010) conducted aerial track surveys over a 60,000 km2 area in northwestern Ontario and found that caribou's strong associations were for conifer communities and negative for wolf tracks and road density. Authors note that survey results are consistent with the hypothesis that distribution of caribou is limited by human activities. • Dyer et al. (2001) found that caribou avoided human development in northeastern Alberta and that the level of avoidance was related to the level of activity. Maximum recorded avoidance distances were 1,000 m (wells) and 250 m (roads and seismic lines) • Sorensen et al (2008) monitored > 300 female caribou in six populations in northern Alberta examining functional habitat loss. They found both anthropogenic and natural disturbance were key factors in explaining habitat loss and concluded that *"population growth rates of boreal caribou in northern Alberta have a plausible dependency on functional habitat loss resulting from wildfire or industrial development*"	and appears to be caused both by habitat limitations of those features and avoidance of human disturbance • Category 1: High Risk

Table A1- 3. Summary of evidence for hypothesized effects for Mountain Caribou

No.	Description	Literature/ Evidence	Conclusion
1	Forage quality and quantity is affected by climate change/variability and this affects caribou health	• Weladji et al. (2002) reviewed the comparative response of ungulates to climatic variability. They conclude that yearly variation in forage quality is strongly influenced by weather and that snow cover and depth affect length of the growing season and hence forage quality • Finstad et al (2000) showed a relationship between that late winter precipitation and spring temperatures and precipitation on forage quality and its quantity in summer, and conditions on the Seward Peninsula in Alaska. • In describing the habitat needs of mountain caribou in northern B.C. Environment Canada (2012a) notes that “for all populations of woodland caribou, forage quality and availability directly affects the body condition of female caribou and in turn calf survivorship (Reimers 1983)	• Evidence that forage affects health and productivity exists, but direct relation to climate change remains somewhat speculative. • The relative importance of this effect is also uncertain • Category 4: Low Risk
2	The extent of snow patches will change with climate change, increasing insect harassment and affecting caribou health	• Bergerud et al. (2008) describe the mechanisms by which caribou in the mountains use snow patches as refugia. • Reindeer in Norway exhibited lower carcass weight, decreased summer growth rate, and reduced levels of lactation in the presence of insect harassment, likely due to increased energy expenditure and reduced grazing timein an effort to escape (Weladji et al., 2003). • Kuzyk (1999) notes that alpinesnow patches are being reduced in size and infers that this could lead to increased stress caused by insect harassment.	• Mountain caribou use of snow patches is well established. Increase in insect harassment due to climate change related to potential decline in snow patches is somewhat speculative • The relative importance is also uncertain • Category 4 Low Risk
3	The frequency of winter icing events will change as a result of climate change. Icing events restrict access to winter forage	• In its synopsis of traditional and community knowledge GNWT (2012b) described “that icing can kill boreal caribou, as they can’t get to their food” • Johnson et al. (2004) studied northern woodland caribou habitat use in northern B.C. during winter and found that snow limits movements and foraging efficiency. Caribou selected feeding sites where snow depth, density and/or hardness were least. During late winter caribou may have abandoned southern portions of their range because snow was too deep, dense and/or hard.	• Icing and deep snow can restrict movement, but lack of concern raised in literature suggests severe impacts do not occur frequently. • Category 3: Less Risk
4	Snow depth will change/vary as a result of climate change and variability. Snow depth affects access to winter forage	• Environment Canada (2012a) hypothesizes that Increased snowfall may reduce winter survival of caribou by increasing energeticdemands or by reducing forage availability. • Johnson et al. (2004) studied northern woodland caribou habitat use in northern B.C. during winter and found that snow limits movements and foraging efficiency. Caribou selected feeding sites where snow depth, density and/or hardness were least. During late winter caribou may have abandoned southern portions of their range because snow was too deep, dense and/or hard. • Kuzyk et al (1999a) and Oberg (2001) attributed mountain caribou use of mature forest during winter to partly to snow interception which allows for relative ease of	• Impact of snow depth, may be exacerbated or act in concert with icing • Caribou movement and habitat use may be affected by snow depth, but impact on health is uncertain • Category 2: Moderate Risk

No.	Description	Literature/ Evidence	Conclusion
		movement.	
5	Climate change will affect seral community distribution directly and through the frequency of fire	• Racey (2005) parameterized a forest projection model based on literature assessments of climate change impacts on fire frequency and hypothesized that increases fire frequency and intensity would lead to reduced area in large patches of old, conifer dominated forest in northwestern Ontario. • Rupp et al. (2006) simulated changes in fire regime under climate change scenarios on the range of the Nelchina caribou herd in Alaska and found that simulations with more frequent fires produced a relatively immature forest age structure compared to the present, with few stands older than 100 years, and speculated that changes in fire regime due to climate warming could substantially alter the winter habitat of caribou and lead to changes in winter range use and population dynamics. • In its assessment of scientific knowledge, GNWT Species at Risk Committee (2012) notes: "*The likelihood of post-fire regeneration to lichen-bearing old growth stands is determined, in part, by the average fire-return interval or fire cycle (Thomas and Gray 2002); fire frequency in the Mackenzie River Basin is predicted to increase with climate warming (Cohen 1996). If the fire cycle is shorter than the regeneration time then areas that have been disturbed by fire may be held at earlier seral stages. Early seral habitats are favoured by moose (Alcesalces), bison (Bison bison), deer (Odocoileusvirginianus), elk (Cervuscanadensis), and black bears (Ursusamericanus) and, as a result, predator-prey dynamics may be altered for extended time periods in boreal caribou ranges that are frequently disturbed by fire (Latham et al. 2011a)*."	• Reasonable body of simulated/modeling evidence of likely increase in fire and change in seral communities (primarily less old growth • Category 1:High Risk
6	The abundance and distribution of other ungulates will increase as a result of landscape changes brought about through anthropogenic changes to the landscape and climate change	• Bergerud and Elliot (1986) and Wittmer et al. (2005) describe mechanisms through which landscape activities, such as clearcut logging or forest fires, will increase the population of other species such as moose, and thereby increase predator populations causing predation on caribou • Environment Canada (2012a) hypothesizes that " climate-induced changes in populations of other species, such as moose.. deer (white-tailed [Odocoileusvirginianus], mule deer [Odocoileushemionus]) may affect woodland [mountain] caribou" • Callaghan et al. (2011) cite the work of Bergerud and Elliot, (1986), Seip, (1992), Stuart-Smith et al., (1997), Racey and Armstrong (2000), Wittmer et al., (2005), Wittmer et al., (2007), Vors et al., (2007), and Vors and Boyce (2009) in noting "Although wolves (*Canis lupus*)were very scarce or absent throughout most of the original distribution of woodland caribou (Cringan, 1956), logging and other industrial disturbances have increased the amount of early seral-stage forest and promoted higher densities of prey species such as moose (*Alcesalces*) and white-tailed deer (*Odocoileusvirginianus*), which support higher predator densities, especially wolves.	• More evidence is available for boreal caribou than mountain caribou, but ecologies and ranges are sufficiently similar to conclude. • Category 1: High Risk
7	Changes the amount and distribution of other ungulates will lead to increased predator abundance which will cause increase predation on caribou	• Johnson (2004) noted that apparent competition was less of a factor in alpine habits than in forested ones, but still affects caribou • Wittmer et al. (2005) concluded from work on > 300 collared caribou , that the decline woodland caribou in the absence of resources competition in southern B.C. is due to apparent competition; Wittmer et al (2007) found that variation in adult female survival rates amount 10 subpopulations was best explained by the amount of early seral	• Apparent competition is established as a dominant mechanism of boreal caribou mortality in anthropogenically altered landscapes

No.	Description	Literature/ Evidence	Conclusion
		stands, consistent with the apparent competition hypothesis • Environment Canada (2012b) concludes that: "The primary threat to most boreal caribou local populations is unnaturally high predation rates as a result of human-caused and natural habitat loss, degradation, and fragmentation. These habitat alterations support conditions that favour higher alternate prey densities (e.g. moose (Alcesalces), deer (Odocoileus spp.)), resulting in increased predator populations (e.g. wolf (Canis lupus), bear (Ursus spp.)) that in turn increase the risk of predation to boreal caribou....."	• Category 1: High Risk
8	Anthropogenic changes in the landscape will facilitate predator movement increasing predation on caribou	• Whittington et al. (2011) used time-to-event models parameterized by radio-telemetry data in studies in Banff and Jasper National Parks and found that wolf-caribou encounter rates increase with proximity to linear features. • Considerable evidence of this for Boreal caribou	• More evidence exists for boreal caribou than mountain caribou, but given similar ecologies effect likely exists • Category 2: Moderate Risk
9	Predator control decreases predator abundance and predation	• Farnell (2009) summarized Yukon experience in lethal predator control in the vicinity of the Finlayson caribou herd (1983-89) and lethal and non-lethal control in the vicinity of Aishihk herd (1993-97) and found very significant growth of caribou populations. • Environment Canada (2012 a) summarizes wolf control experience as: Wolf control was successful, in the short term, in increasing caribou recruitment (although not adult survival) in the Aishihik herd when combined with reduced hunting (Hayes et al. 2003) and in increasing the growth rate of Alaska's Delta caribou herd (Boertje et al. 1996)....Limited success of wolf control was also documented in the Nelchina herd in south-central Alaska from 1950-1981 (Van Ballenberghe 1985). Documented cases of predation causing a herd's long-term decline or extirpation in the absence of any anthropogenic activity are rare, but there are numerous cases in which human activities can be shown to exacerbate predation pressures and precipitate population declines. • Bergerud (2007) emphatically states, as a conclusion to his analysis on predation rates in the face of fragmented caribou populations and increasing density of other ungulates: " *The Southern Mountain and Boreal Woodland Caribou are facing extinction from increased predation, predominantly wolves (Canis lupus) and coyotes (Canislatrans). These predators are increasing as moose (Alcesalces) and deer (Odocoileusspp). expand their range north with climate change. Mitigation endeavors will not be sufficient; there are too many predators. ....Without predator management these woodland caribou will go extinct in our life time."*	• Strong evidence that Predator control decreases predation, likely more so in anthropogenically altered landscapes • Category 1: High Risk
10	Changes in seasonal habitat availability lead to changes in the health of individuals. Changes in landscape configuration will affect seasonal habitat availability	• Apps and McLellan (2006) found a negative association between caribou occupancy and linear disturbance densities across 13 subpopulations of mountain caribou in southern Alberta and B.C. They found that, notwithstanding climatic conditions, subpopulation range occupancy conforms to the distribution of remaining old growth (age >140 yr) forests and are characterized by landscapes remote from human activity, with relatively low road densities and motorized recreational access.	• Strong evidence of this effect in boreal caribou and given similar habitat requirements for old contiguous forest for at least part of the year,

No.	Description	Literature/ Evidence	Conclusion
	via fragmentation and changes in habitat area.	• Considerable evidence of this effect in boreal caribou	impact likely exists for mountain caribou too. Also strong independent evidence of this for mountain caribou. Category 1: High Risk
11	Habitat fragmentation, particularly in relation to migratory elevation patterns, increases susceptibility to predation	• Apps and McLellan (2006) also hypothesize that interruptions in movement across "complex topography" (i.e. elevational migration) is akin to interruptions in more linear movements for other ecotypes	• Although intuitively logical, little direct evidence of this. • Category: Uncertain
12	Changes the amount and distribution of other ungulates will lead to increased parasitism of caribou leading to effects on health.	• Callaghan et al(2011) note: *Although little evidence exists of disease or parasites impacting boreal caribou populations (Jordan et al. 2003), broad scale climate and habitat change may play a role in increasing the risk of disease transmission from white-tailed deer to caribou. For example, caribou are susceptible to a parasitic nematode, the brain or meningeal worm Parelaphostrongylustenuis) carried by white-tailed deer* • Festa-Bianchet et al. (2011) describe that parasitism spread by other ungulates in mountain (and boreal) caribou may be one of a host of anthropogenically-induced impacts. • Environment Canada (2012b) notes that parasites are not thought to be one of the major threats affecting boreal caribou at the national level.	• Literature indicates little cause for concern at present although uncertainty about future • Category 4: Low Risk
13	Increased human populations and access created by linear disturbances increases hunting	• Festa-Bianchet et al. note that: Since the 1970s, however, the human population in the Arctic and subarctic has doubled, reaching about 107 200 people in 2006. Changing socio-economic conditions and technology are influencingcaribou harvesting patterns. • Gunn et al. (2011) note that "*The increasing number of people, a shift to wage-earning, and changing technologies for hunting (snowmobiles, ATVs, aircraft, winter roads, and rapid communications) have likely altered hunting effort and made finding and harvesting caribou more efficient*." • However Gunn et al. (2011) also note that the relationship between hunting effort and harvest levels, is largely unknown and unquantified and this limits understanding of the effects of hunting.	• Although human population and linear development are increasing, the precise role in hunting mortality seems unclear • Hunting regulations may also mitigate the effect. • Impact, if it exists, would be range/population specific • Category 2: Moderate Risk
14	Increased human access and industrial development causes disturbances which increase stress on caribou	• In a telemetry study of mountain caribou in western Alberta Oberg (2001) found that caribou avoided roads to a maximum distance of 500 m and were more likely to occur around older seismic lines than newer ones. • In discussing the Ibex herd of mountain caribou, Environment Canada (2012) notes "*The herd's range has been reduced by the activities and developments (e.g. housing, road building and agriculture) associated with Whitehorse's significant*	• Strong evidence of significant impact • Category 1: High Risk

No.	Description	Literature/ Evidence	Conclusion
		human population. Recently, off-road vehicle traffic and recreational activity (e.g. snowmobile and dog mushing activities) have increased within the range." • Polfus et al. (2011) estimated zone of influence of infrastructure on mountain caribou in northern B.C. and found avoidance ranging from 1.5 km to 9 km for cabins, roads, town, etc. They estimated cumulative functional loss of 8% and 2% of high quality habitat in winter and summer respectively. • Farnell (2009) implicates human disturbance in the decline of several populations of mountain caribou in the southern Yukon • Apps and McLellan (2006) found a negative association between caribou occupancy and linear disturbance densities across 13 subpopulations of mountain caribou in southern Alberta and B.C. They found that, notwithstanding climatic conditions, subpopulation range occupancy conforms to the distribution of remaining old growth (age >140 yr) forests and are characterized by landscapes remote from human activity, with relatively low road densities and motorized recreational access.	

Table A1- 4. Summary of hypothesized effects for Migratory Tundra Caribou

No.	Description	Literature/ Evidence	Conclusion
1	Forage quality and quantity is affected by climate change/variability and this affects caribou health	• Weladji et al. (2002) reviewed the comparative response of ungulates to climatic variability. They conclude that yearly variation in forage quality is strongly influenced by weather and that snow cover and depth affect length of the growing season and hence forage quality • Epstein et al. (2000) developed a vegetation simulation model and predicted large effects on low arctic biomass and variable response among low arctic flora, with substantial increases in deciduous and evergreen shrubs, and lichens' sedges and grasses declined. • Interpreting results of their modelling study on impacts of climate change on Quebec and Labrador caribou herds, Sharma et al (2009) note that" *a longer growing season and increased primary production could increase the amount of plant biomass and thus, available forage for caribou (Tews et al., 2007), [*and that*] an increase in forage production would likely decreases calf abortion, improve the birth mass of calves (Couturier et al., 2009), and increase parturition rates (Tews et al., 2007), thereby increasing the survival and fecundity of migratory caribou. Increased plant productivity may also reduce the dependency of caribou on lichens.*	• Evidence that forage affects health and productivity exists, but direct relation to climate change remains somewhat speculative. • The relative importance of this effect is also uncertain • Category 4: Low Risk
2	Insect abundance will increase as a result of climate change, partially as a result of increased rainfall. Increased insect harassment of caribou will cause adverse health effects.	• Bergerud et al. 2008 provide much discussion of intense harassment of migratory caribou by mosquitoes, oestrids, and tabanids • Roby (1978, in Trimper and Chubbs 2003) report that relief from insect harassment is a primary determinant for summer range as less time feeding and more time avoiding insects). • In a study of simulated predictions of impacts of climate change on migratory caribou in northern Quebec, Sharma et al. (2009) noted that future climate scenarios with warmer summers would increase the intensity and duration of caribou harassment by insects. • Reindeer in Norway exhibited lower carcass weight, decreased summer growth rate, and reduced levels of lactation in the presence of insect harassment, likely due to increased energy expenditure and reduced grazing timein an effort to escape (Weladji et al., 2003). • Gunn et al. (2011) cite Gunn and Poole (2009) in noting that the trend between 1957 and 2009 is for an increase in the index of suitable weather and a longer season for warble fly harassment for the summer range of the Bathurst herd. • Adamczewski et al. (2008) and Gunn (2012 et al.) in considering cumulative effects on barren-ground caribou note that insect harassment can reduce the resilience of individual caribou. • Anderson et al. (2002) suggest that insect harassment is not a major factor in caribou population ecology: "*Insect infestation may influence calf mortality in woodland and barren ground animals (Kelsall 1968 in Klein 1992) and insects have also been shown to alter caribou behaviour (Downes et al. 1986; Noel et al. 1998), which may have energetic implications. It is unlikely, however, that insect harassment alone*	• With the exception of Anderson et al. (2002) most authors suggest that effects of insect harassment can be significant • Category 1: High Risk

No.	Description	Literature/ Evidence	Conclusion
		could cause major declines in population rate of change. Instead, the influence of insects is likely cumulative with other factors and models have suggested that heavy insect levels may compound the effect of disturbance on caribou populations (Murphy et al. 2000). • In a review of the response of caribou to climatic variability Weladji et al. (2002) conclude that: "*insect harassment appears to be a key climate-related factor for the ecology of reindeer/caribou that has been overlooked in the literature of climatic effects on large herbivores."*	
3	The frequency of winter icing events will change as a result of climate change. Icing events restrict access to winter forage	• Identified as a likely impact on habitat and survival by (Gunn et al. 2011) • Campbell (2006, in Gunn et al. 2011) suggests that limited access to grasses as a result of fall icing in 1998 and 2005 may have affected body condition • Mentioned as a concern for herds in the Sahtu Settlement Area, but no population impact data provided (Antoniuk et al. 2009b)	• Basis for concern exists, in concert with snow depth but evidence is not as strong as for Peary caribou • Category 3: Less Risk
4	Snow depth will change/vary as a result of climate change and variability. Snow depth affects access to winter forage	• Dau (2005) analyzed events leading to caribou mortality events in Northwest Alaska in 1994-95 and 1999-2000 and concluded that the weather in 1994-95, which was colder, windier and had more snow contributed to significant die-off (20-30% of 10,000 caribou which wintered there). • Adamcewski et al. (1988) concluded that snow depth and hardness on Coats Island significantly restricted caribou access to winter forage and had a significant impact on calf survival. • In their review of cumulative effects on barren ground caribou Gunn et al. (2012) conclude that : *snow cover (i.e. depth, hardness, and duration) and freeze thaw cycles reduce access to forage and may limit nutritional intake of caribou during winter"* and link the impacts to climate variability.	• Basis for concern exists, in concert with snow depth but evidence is not as strong as for Peary caribou • Category 2: Moderate Risk
5	Climate change can affect weather and terrain conditions during migration which can affect caribou health	• Gunn et al. (2011) note that the trends of climate change are evident for the Porcupine herd: "*Spring strongly warmed over the last three decades. During late spring, after calving, this has resulted in early snowmelt and more food available for nursing mothers. As a consequence early calf survival had improved (Griffith et al., 2002). In early spring, however, when the herd is on migration, warmer weather has resulted in more freeze-thaw cycles... The greater difficulty in traveling and feeding through ice crusts would result in higher energetic costs....* • Sharma et al. (2009) hypothesize that "*Spring migration may also be affected under climate change scenarios as plant phenology occurs earlier resulting in a mismatch for reproducing caribou between the timing of increased resource demands andresource availability*	• Basis for concern exists, somewhat speculative, but potential implications are high • Category 2: Moderate Risk
6	Climate change will affect seral community distribution directly and through the frequency of fire. Fire frequency intensity and area will affect the quality and quantity of forage available.	• Gustine et al. (2006) describe that Thomas (1998) found that caribou in the Beverly herd did not use burned areas until approximately 40-60 years post-burn • Impact particularly relevant for herds which have a portion of their range south of the tree line. • Explained well by Gunn et al. (2011): "*Results from the Canadian Climate Centre General Circulation Model scenarios suggest a further increase in fire occurrence*	• Basis for concern is well founded, based on empirical information and likely implications of climate change

No.	Description	Literature/ Evidence	Conclusion
		across Canada of 25% by 2030 and 75% by the end of the century, with the average area burned expected to approximately double from the beginning to the end of the 21st century (Wotton et al., 2010). The magnitude of the changes in fire regimes is projected to be greater at northern latitudes (Flannigan et al., 2005). Trends toward an increase in forest fire intensity and frequency will affect caribou winter range (Russell et al., 1993; Thomas, 1998) as caribou shift their distribution in response to the pattern of recently burnt areas, as well as in response to snow conditions (Thomas and Kiliaan, 1998; Joly et al., 2003; Barrier, 2011). An increase in forest fires may have additional, long-term effects on lichens. On the tundra-boreal forest ranges of the Western Arctic Caribou Herd in Alaska, lichens have decreased from the combined effects of forest fires, grazing, and possibly the warmer temperatures (Joly et al., 2009; Joly et al., 2010). As lichens decreased, shrubs and grasses increased – a trend also seen elsewhere in the Arctic (Cornelissen et al., 2001)."	• Category 1: High Risk
7	The abundance and distribution of other ungulates will increase as a result of landscape changes brought about through anthropogenic changes to the landscape and climate change	• This may be relevant for migratory herds which use area south of the tree line for part of their southern range; dynamics associated with increasing moose populations as a result of seral stage changes, described above for boreal caribou, would be relevant. • In its assessment of scientific knowledge, GNWT Species at Risk Committee (2012) notes: "*The likelihood of post-fire regeneration to lichen-bearing old growth stands is determined, in part, by the average fire-return interval or fire cycle (Thomas and Gray 2002); fire frequency in the Mackenzie River Basin is predicted to increase with climate warming (Cohen 1996). If the fire cycle is shorter than the regeneration time then areas that have been disturbed by fire may be held at earlier seral stages. Early seral habitats are favoured by moose (Alcesalces), bison (Bison bison), deer (Odocoileusvirginianus), elk (Cervuscanadensis), and black bears (Ursusamericanus) and, as a result, predator-prey dynamics may be altered for extended time periods in boreal caribou ranges that are frequently disturbed by fire (Latham et al. 2011a)*." • Callaghan et al. (2011) cite the work of Bergerud and Elliot, (1986), Seip, (1992), Stuart-Smith et al., (1997), Racey and Armstrong (2000), Wittmer et al., (2005), Wittmer et al., (2007), Vors et al., (2007), and Vors and Boyce (2009) in noting "Although wolves (*Canis lupus*)were very scarce or absent throughout most of the original distribution of woodland caribou (Cringan, 1956), logging and other industrial disturbances have increased the amount of early seral-stage forest and promoted higher densities of prey species such as moose (*Alcesalces*) and white-tailed deer (*Odocoileusvirginianus*), which support higher predator densities, especially wolves	• This effect will be relevant for some herds depending on the extent to which they use areas south of tree line. • Category 2:Moderate Risk
8	Changes in the amount and distribution of other ungulates will lead to increased parasitism of caribou leading to effects on health.	• Although parasites can be important detrimental factors in caribou health they are not generally cited as a driving force of mortality (Bergerud et al. 2009) • Festa-Bianchet et al. (2009)express concern that "*changes in moose distribution and abundance may also increase the prevalence of Echinococcus*" and that this may affect migratory tundra caribou • Gunn et al. (2011) hypothesize that caribou in the southern part of their range may be susceptible to parasite infestation from other ungulates,	• Some basis for concern exists, however little evidence suggests risk from parasites of other ungulates is high • Category 4: Low Risk
9	Predator control decreases predator abundance and	• The Advisory Committee for the Cooperation on Wildlife Management (2011) notes that: "*Experience in Alaska, Yukon, NWT and Nunavut in the 1960s, have shown that*	• Although the topic is much-discussed and advocated

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	predation leading to higher caribou populations.	*predator control can be a tool for short term recovery in caribou populations in some situations. However, there is little evidence of wolf control programs being effective over the long term.*" However, it also recommends including incentives for harvest of predators as a means of predator control • Virtually all discussion of predator control as a means of managing caribou populations has been in the context of woodland and mountain caribou, although apparently is was also undertaken for Peary caribou in the 1950's (GNWT Species at Risk Committee 2012a) • Bergerud et al. (2009) argue in their expansive book about the George River Herd: "*If major arctic herds are to persist...it is important that biologists and environmentalists abandon the protectionist attitude toward wolf management that has already resulted in the extinction of so many woodland caribou populations.*	for other caribou ecotypes, its potential role for migratory tundra caribou is less clear • Category: Uncertain
10	Migratory routes may be interrupted by changes in landscape configuration, ultimately affecting caribou health	• Gunn et al. (2011) express concerns about impacts of roads and linear corridors on movements of the Beverly, Qamanirjuaq, and Porcupine Herds • Similar concerns about impediments to migration identified by Festa-Bianchet et al. (2011) • Bergerud et al. (1984) examined movement patterns of eight caribou populations in B.C., NWT, Yukon, Alaska, and Newfoundland concluded that the obstructions may deflect caribou movement, but "*there is no evidence that disturbance activities or habitat alteration have affected productivity*".	• Basis for concern exists, but somewhat disputed by the findings of Bergerud et al. of a similar • Category 2: Moderate Risk
11	The distribution and abundance of caribou can affect the amount and distribution of forage through negative feedback mechanisms	• In their expansive analysis of the George River Caribou Herd, Bergerud et al. (2009) conclude that the decline of the Herd was due to exceeding the carrying capacity of its summer habitat, but also note that it is the only instance of its kind to be documented for a mainland caribou herd since the commencement of scientific studies in the 1940's; similarly Messier et al. (1988) expressed a concern that "*the possible deterioration of foraging habitats at high caribou densities may pose a threat to the George River caribou herd*."	• No examples of negative feedback are apparent so it seems the possibility of range deterioration by overpopulation is low • Category 4: Low Risk
12	Increased human populations and access created by linear disturbances increases hunting	• Festa-Bianchet et al. note that: Since the 1970s, however, the human population in the Arctic and subarctic has doubled, reaching about 107 200 people in 2006. Changing socio-economic conditions and technology are influencing caribou harvesting patterns. • In a discussion on northern caribou in general, Gunn et al. (2011) note that "The increasing number of people, a shift to wage-earning, and changing technologies for hunting (snowmobiles, ATVs, aircraft, winter roads, and rapid communications) have likely altered hunting effort and made finding and harvesting caribou more efficient." • However Gunn et al. (2011) also note that the relationship between hunting effort and harvest levels, is largely unknown and unquantified and this limits understanding of the effects of hunting.	• Although human population and linear development are increasing, the precise role in hunting mortality seems unclear. This impact is potentially larger for some herds, and in general potentially larger for Migratory Tundra caribou than for other ecotypes. • Category 1:High Risk
13	Increased human access and industrial activities cause disturbances which increase stress on caribou	• Boulanger et al (2012) calculated a zone of influence of two diamond mines on caribou of the Bathurst herd of 14 km, affecting almost 7% of the core range. • Gunn et al. (2011) discuss concerns related to impacts of disturbance of mining and	• Conclusions by different authors are somewhat inconsistent; Although the findings of Bergerud et al.

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		oil and gas exploration, roads and transmission lines, and hydro-electric development, noting that "*Caribou behavioural responses to human activities, especially those associated with industrial exploration and development are quite well known (Wolfe et al. 2000, Stankowich 2008*)" • Wolfe et al. (2000) conducted a literature survey of caribou and reindeer responses to human activities and concluded that they*:" l) move away from point sources of disturbance; 2) increase activity and energy expenditure near disturbance; 3) delay crossing or fail to cross linear structures; 4) shift away from areas of extensive and intensive development; and 5) are killed by collisions with vehicles and by hunting along roads.*", but that the population-level effects of disturbance are not clear. • Olson and Chocolate. (2012) notes that elders from the Thchǫ Nation expressed concerns of caribou changing migration routes because of mining-related noise • Curatolo and Murphy (1986) examined the frequency of caribou crossings of roads, and pipelines on the Arctic Coastal Plain in Alaska. They found that the animals crossed roads and pipelines as frequently as control sites , however, where a pipeline paralleled a road with traffic, crossing frequencies were significantly less than expectedsuggesting that they acted in a that roads and pipelines act in a synergistic fashion. • Bergerud et al. (1984) examined movement patterns of eight caribou populations in B.C., NWT, Yukon, Alaska, and Newfoundland concluded that the obstructions may deflect caribou movement, but "*there is no evidence that disturbance activities or habitat alteration have affected productivity*".	imply less impact, the potential for impact based on other findings is high. • Category 1: High Risk.