Caribou Habitat Assessment and Supply Estimator (CHASE):

Using Modeling and Adaptive Management to Assist Implementation of the Mackenzie LRMP in Strategic and Operational Forestry Planning

REVIEW DRAFT

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Omineca Northern Caribou Project

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Review Draft

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This project was conducted by a cooperative, multi-agency working group. Many contributed advice and information to the project. The following people were the key contributors in determining ecological relationships and developing the model.

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INTRODUCTION TO THE DOCUMENTATION OF CHASE

The documentation of the Caribou Habitat Assessment and Supply Estimator (CHASE) is composed of three main reports:

1. This report describes the overall model, ecological aspects of the model, and general types of management applications and interpretations.
2. The CHASE user's guide[1] describes the technical details of the model and the step-by-step procedure for running the model.
3. The application and results from 2003[2] are documented to describe the "to-date" results of the application of the model in the Mackenzie Timber Supply Area.

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[1] Doucette, A., R. McCann, A. Walton, A. Fall, and T. Barrett. In prep. The Caribou Habitat Assessment and Supply Estimator (CHASE) user guide. Draft documentation on file at Wildlife Infometrics, Inc., Mackenzie, B.C.

[2] McNay, S., A. Doucette, R. McCann, A. Fall, and R. Ellis. In prep. Results of applying the Caribou Habitat Assessment and Supply Estimator (CHASE) to the Wolverine Herd Area in north-central British Columbia: March 2003 application. Draft documentation on file at Wildlife Infometrics, Inc., Mackenzie, B.C.

EXECUTIVE SUMMARY

A strategic and operational planning framework has been developed for use in the management of caribou populations (*Rangifer tarandus caribou*) and their habitat in the Mackenzie Timber Supply Area (TSA). The Caribou Habitat Assessment and Supply Estimator (CHASE) links caribou and habitat information, predation risk factors, operational planning, and forest management activities to forecast the distributions of caribou habitat and timber supply through time.

This framework used to predict the ecological value of northern caribou ranges and follow-up adaptive management tests were developed through a series of consultative workshops involving industry, government, and academia. The range types considered were those most likely to be either limiting or important to caribou populations in the area: (1) calving and summer range; (2) pine–lichen winter range; (3) high-elevation winter range; and (4) movement corridors. Each range type was influenced by the risk of predation by wolves (*Canis lupus*), for which wolf density was estimated based on its relationship to moose (*Alces alces*) density. While consideration of individual range types was necessary, successful and significant management of caribou numbers or their habitats should ultimately be reflected in population parameters that characterize the whole herd: population size, age-specific mortality rates, and juvenile recruitment. This aspect of CHASE is currently being developed.

CHASE was designed for personnel within the planning departments of industrial stakeholders and for government agencies to compare the habitat distributions resulting from natural (wildfires) or managed (forest harvest) disturbances. The management scenarios considered for evaluation were based on the Mackenzie Land and Resource Management Plan (LRMP).

The LRMP management scenario was applied using geographical information organized and compiled with ArcView. Disturbances were forecasted with the disturbance simulator SELES. Results were analyzed with the modelling tool Netica to explore the location-specific interactions that affect caribou and moose habitat. The information required and procedures used to run each of these programs to generate the model results are described in detail. Results were displayed in posters for each range type, moose density, predation risk, and forest harvest information. The amount and spatial distribution of each range was compared with results obtained from model runs based on natural disturbance (fire size and return interval). Comparisons were also made to a hypothetical situation of no disturbance and no predation. The amount of subsistence hunting, and summer and winter habitat for moose were displayed to show the influence on summer and winter moose densities. These densities contributed to a prediction of the amount and spatial distribution of predation risk that caribou would experience through time. The forest harvest information results presented included the length (km) of roads built, area harvested, total volume harvested by tree species, class of diameter at breast height (dbh), and slope in each Landscape Unit over time. Interpretations about the results are intentionally focused on questions of interest to resource managers (e.g., how would patch-size distribution of the range types change over a three-pass forest rotation?).

Proposals for testing ecological relationships and validation of the model have been developed and this work will be conducted in the next phase of CHASE development. For example, CHASE was constructed to ensure that the results could be measured and monitored. Furthermore, data collection that occurred as part of the Omineca Northern Caribou Project was designed to contribute to testing

CHASE. The model is expected to be fully scrutinized to ensure that project goals are met effectively and efficiently. In this way, CHASE itself can become an accepted approach to habitat supply modelling for northern caribou.

The LRMP commits resource managers in the Mackenzie TSA to a “refined and adaptive caribou management direction” that will be modified over time to incorporate new information and improved practices. The Omineca Northern Caribou Project, through development of CHASE, has enabled this LRMP commitment. The Omineca Northern Caribou Project has further enabled that commitment through three adaptive management projects that are associated with CHASE:

1. **Terrestrial lichen responses to silviculture regimes.** The supply of terrestrial forage lichens is a critical aspect of winter habitat for caribou. Foresters and biologists are interested in the opportunities for maintaining or enhancing these lichens in managed forests. Ecologists recognize many uncertainties about lichen responses to forestry treatments, but there may be some potential to maintain quantities of forage lichens in logged areas under certain treatment conditions. These uncertainties will be explored through an active adaptive management program using a variety of timber harvesting and silviculture regimes.
2. **An adaptive approach to implementing the use of CHASE itself.** Under the direction of the Implementation and Monitoring Committees for the LRMP, CHASE will be continually updated with new policy scenarios and/or improved ecological understanding derived from testing and monitoring. This monitoring and amendment process could be conducted as an explicit adaptive management approach.
3. **Managing alternate prey as a technique for balancing resource objectives among moose, caribou, and timber.** This herd-level adaptive management trial isolates specific areas where caribou suffer high mortality due to predation by wolves and attempts to reduce risk to caribou by reducing numbers of moose. The trial offers potential solutions to recover caribou in areas of caribou habitat that are already highly fragmented by forest development and/or that suffer high predation by wolves.

The methods used in this project are transferable to other species, and/or issues, recognizing that species-specific ecological factors need to be determined.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 MANAGEMENT OF CARIBOU IN THE MACKENZIE TSA

Management of northern caribou[3] and forests is a major management issue in the Mackenzie Timber Supply Area (TSA). This importance is reflected in the development of a Caribou Management Strategy that formed part of the Mackenzie Land and Resource Management Plan (LRMP), led by the Land Use Coordination Office (LUCO).[4] The primary intent of this strategy (henceforth referred to as the LRMP Caribou Management Strategy) was to minimize interactions among caribou, moose, and wolves by concentrating logging into large, rather than dispersed, patches, and equally large patches of leave areas. In these areas, the caribou would presumably be less susceptible to predation. This strategy is thought to minimize areas influenced by road development and human-caused habitat fragmentation by more closely mimicking natural disturbance patterns (Seip 1998). These initiatives and LUCO's involvement demonstrate that caribou are important to both First Nations and other residents in the area.

Northern caribou within the Southern Mountain National Ecological Area have been deemed, by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2000), to be threatened of becoming endangered. Experience with mountain caribou suggests that management actions are required to prevent caribou populations from declining (MCTAC 2002). Given the planned logging activity in the area and the expected increase in hunting, poaching, and predation as road and cutblock networks are established, it was considered timely to evaluate potential impacts and solutions for integrated management of timber and caribou. A greater understanding of the relationships between caribou and their habitat, their response to habitat changes at both the individual and population level, and their interactions with other ungulate species and predators will assist in the design of effective policies and management practices. An approach that links field monitoring, ecological modelling, and adaptive management experiments was considered the best option for successful long-term management of habitat for northern caribou. To implement this approach, Slocan Forest Products, Abitibi-Consolidated, and British Columbia (B.C.) Ministry of Water, Land and Air Protection initiated the Omineca Northern Caribou Project in 1999.[5]

Managers must make decisions regarding the best patch size and distribution of clearcut logging to minimize impacts to northern caribou. Understanding the ecological factors that influence local caribou distribution and habitat use patterns can facilitate this decision-making. Biologists hypothesize that as logging occurs, moose move into young clearcuts where forage is abundant (Franzmann and Schwartz [editors] 1998). Wolves "follow" the moose, and caribou are subject to much greater predation rates where their distribution overlaps and where wolves have easier access via roads (James and Stuart-Smith 2000). The forests of the Mackenzie TSA are naturally disturbed by wildfire every 130–150 years (Delong and Tanner 1996), and the terrestrial lichen species preferred by caribou as forage are dominant in the lichen-bearing stands from about 70 to 140 years (Coxson and Marsh 1991). As these stands age and the canopy closes, lichens are replaced by moss, reducing the usability of the stand to caribou. Thus a silvicultural system that maintains preferred lichen species in stands is desired.

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[3] See Heard and Vagt (1998) for a description of different caribou ecotypes.

[4] See http://srmwww.gov.bc.ca/rmd/lrmp/mackenzi/final/maclrmp.pdf.

[5] Annual reports from the field monitoring project are on file at Slocan Forest Products and at Wildlife Infometrics Inc., Mackenzie, B.C.

Three aspects of these ecological interactions were considered to be of primary interest:

1. **Stand-level interaction.** What are the responses of preferred lichen species to alternative silvicultural system treatments?
2. **Landscape-level interaction.** What are the relationships of caribou, moose, and wolves to each other, and to clearcut logging patch size and distribution (including road networks)?
3. **Long-term interaction.** What is the long-term interaction of these two levels of interaction (i.e., how do silvicultural systems affect lichen abundance and caribou habitat quality) on patch size, predation, and succession?

Three caribou herd areas within the TSA, generally equivalent to the herd areas depicted by the Ministry of Sustainable Resource Management, were of interest: Akie/Ospika, Chase/Sustut, and Wolverine herds. Together, these herds range over approximately 25,503 km^2. Generally, all three areas are characterized by mountainous terrain with extensive alpine habitat, large river valleys, and dense coniferous forests. Much of the Engelmann Spruce–Subalpine Fir (ESSF) and Spruce–Willow–Birch (SWB) biogeoclimatic zones (Meidinger and Pojar 1991) of these study areas are characterized as ecosystems with infrequent stand-initiating events, such as wildfires, with a mean disturbance return interval of 200 years (Meidinger and Pojar 1991). By comparison, the Boreal White and Black Spruce (BWBS) and Sub-Boreal Spruce (SBS) zones are characterized as ecosystems with frequent stand-initiating events, with wildfires reaching tens of thousands of hectares, and a mean return interval of approximately 125 years. The resulting landscape is a mosaic of even-aged stands of different ages (Meidinger and Pojar 1991).

The current overall objectives regarding patch sizes for the three herd areas are specified in the LRMP Caribou Management Strategy. However, many options are available regarding how the patch-size criteria can be applied within a herd area. For example, the logging of a patch(es) could occur in habitat only used by caribou during a specific season, in an area that is currently good habitat, or in an area that is not currently good habitat but is predicted to be good habitat after logging and stand succession. The design of the location, patch size, and timing of logging will influence the resulting habitat for caribou, the costs of road development and logging, and the type/value of timber harvested. Consequently, it is important to develop a predictive model that would allow biologists and managers to explore the predicted effects of alternative scenarios of road development and logging on each of the caribou herd areas.

1.2 PROJECT OBJECTIVES

The project has the following seven objectives:

1. Structure a formal and agreed upon approach to implementing the LRMP Caribou Management Strategy so that the implementation incorporates adaptive management. This will likely include tests of a number of macro- (i.e., herd level or landscape level) and micro- (i.e., range level or stand level) factors via alternative logging and silviculture treatments.
2. Develop a common understanding among researchers and managers to aid in ongoing policy development and management of forests and wildlife, starting with caribou.
3. Develop analytical approaches that will incorporate and use fieldwork results effectively.
4. Develop modelling tools that will allow informed and testable predictions of caribou responses to managed and natural changes (i.e., disturbances) in the area. These predictions can then be tested through management trials and the results monitored.

5. Develop models that incorporate the spatial components of habitat selection by the animals linked to the successional change in the forests and forage species. In the future this may be linked to a model of the population dynamics of caribou.
6. Develop planning tools to be incorporated into the LRMP.
7. Make learning about how to improve management a key goal of forestry and wildlife programs in the area by:
    a. developing a shared understanding of the caribou–forestry issue and potential solutions;
    b. designing management alternatives that test the most promising solutions;
    c. implementing these alternatives in different areas through operational management programs;
    d. maximizing the value of monitoring dollars spent and field data collected in terms of ecological and managerial understanding gained; and
    e. evaluating outcomes of the management alternatives and using the resulting new knowledge to improve future management decisions.

1.3 MANAGEMENT APPLICATION

Results from applying CHASE will be used in two main ways. First, results that evaluate strategic effectiveness and alternatives to the current LRMP Caribou Management Strategy will be used to develop operational recommendations for implementing the strategy. The LRMP table, or a designated implementation committee, will then consider these recommendations, and other ecological and social factors in evaluating or revising the LRMP or in constructing herd-level management plans. Second, results will be used as a guide in road and cutblock placement in the preparation of operational development plans (e.g., Forest Stewardship Plans) that are consistent with the desired long-term management strategy.

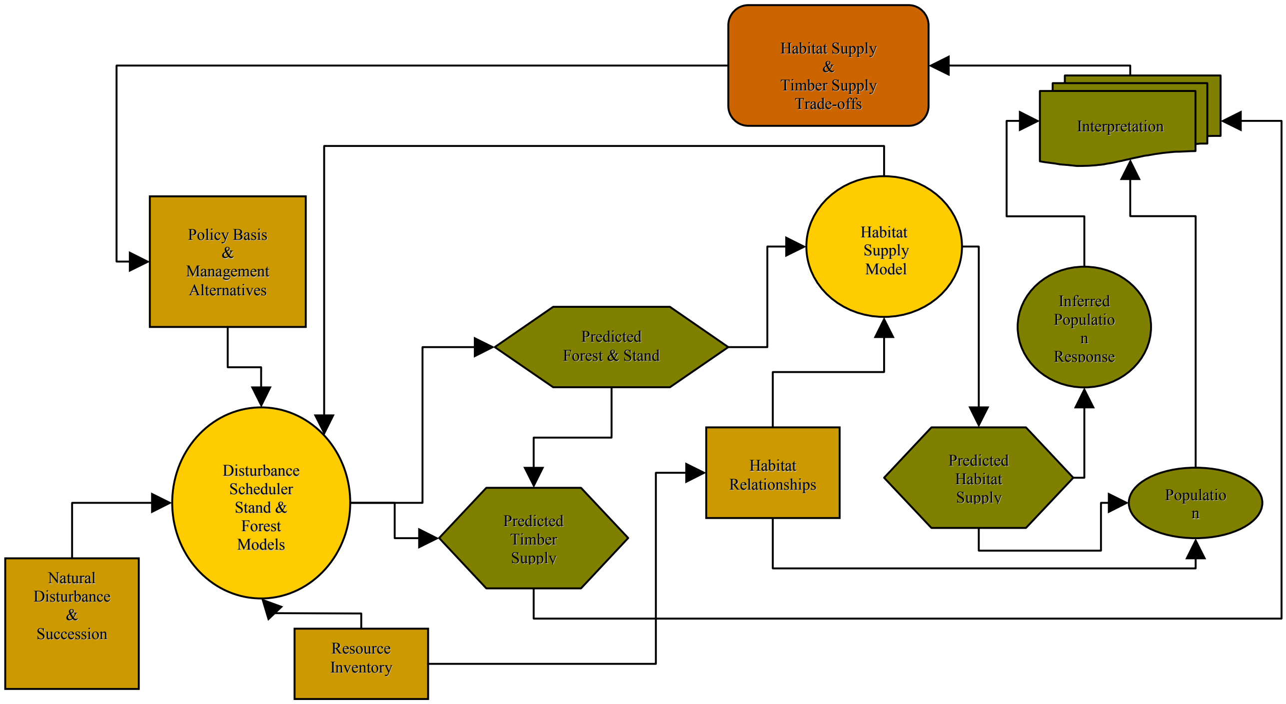
1.4 MODELLING APPROACH

CHASE is a habitat supply model. In the *Strategy for Habitat Supply Modelling for British Columbia* (Jones et al. 2002), six types of habitat supply models were identified. CHASE fits within the category of "Single Species, Large Area Home Range, All/Most Life Requisites." However, since it considers the interaction of moose, wolves, and caribou, CHASE is, in some ways, a multi-species model.

1.4.1 CHASE as a Type of Habitat Supply Model

CHASE can be represented graphically in a similar way to that presented by Jones et al. (2002). Figure 1.1 depicts CHASE in the overall context of modelling and management. In general, habitat supply models depend on expressions of habitat relationships which are typically based on resource inventory projects. Provided forecasts of predicted forest and stand conditions are available, these can then be translated into predicted habitat supply. Population response to habitat supply can then be modelled or inferred from the supply of habitat and interpretations made.

Habitat supply models are greatly enhanced if the predicted future conditions of the forest come from a disturbance scheduler or forest estate model because the estimates of habitat supply and timber supply can then be interpreted together to enable decisions about trade-offs. Understanding or asking questions about such trade-offs usually comes from introducing or implementing a policy or management alternative (i.e., to consider the implications of doing so). The policy information can be used as input to the disturbance simulator in scenario runs. Finally, a useful and often-requested



comparison in habitat supply analyses is a natural disturbance base case that can be simply input to the disturbance simulator and used in the habitat supply model to make predictions about habitat supply.

Figure 1.1. A general illustration depicting relationship among components of a habitat supply model (adapted from Jones et al. 2002).

1.4.2 CHASE Model Design

In developing a conceptual representation (i.e., a model) of an ecological and management system of the complexity known in this area, it is tempting to include all known factors and relationships in the model. This can lead to long model development time, an expensive and time-consuming product to use, and a loss of focus on developing a working management tool. To avoid this pitfall, the initial set of models includes only the “major” components of known ecological significance. These major factors were chosen because they were thought to have the most impact, are of key interest, have data available, and are currently within the realm of management action. In future model refinements, additional detail can be included, and other factors and relationships included as necessary.

1.4.2.1 Aspects of Caribou Ecology and Habitat Considered

Four range types used by caribou were modelled. These ranges were chosen since they are considered most likely to be either limiting or important to caribou populations in the area. Additional range types and ecological relationships that were considered but not included in the current models are described in Section 3. Four ranges were modelled:

1. Calving and Summer Range
2. Pine–Lichen Winter Range
3. Movement Corridors
4. High-Elevation Winter Range

In addition, since the risk of predation by wolves influences all range types, this factor was developed as a model component by estimating moose density as a surrogate for wolf density.

1.4.2.2 Underlying Philosophy Regarding Modelling

All modelling activities contain an inherent philosophy. In this project, the philosophy used is summarized in the following three general assumptions:

1. No model will be "the true or complete model." Therefore, formulate the model explicitly, incorporate empirical data and the recognition of uncertainty into the model, and adapt the model to new empirical information.
2. Alternatively, no finite amount of empirical data or science will form an exact characterization of the ecological situation or relationships. Therefore, develop a model that will bridge the gaps in the data and empirical understanding to create a more comprehensive and consistent, albeit theoretical, understanding of the ecological system.
3. No model will be readily implemented at the operations level. Therefore, incorporate an interpretive component into the overall project product.

An ideal model would be precise, general, and realistic; however, one of these elements must be sacrificed if the other two are to be met (Starfield and Bleloch 1986). This modelling approach is built upon a desire for generality and realism and, as such, it would:

- serve as a basis for communication regarding the causal relationships involved in the ecology of caribou, moose, wolves, and logging;
- consider operational management factors relevant to the area;
- incorporate First Nations concerns and knowledge;
- incorporate data from fieldwork;
- include a framework for analysis and decision-making;
- consist of an open architecture for the evaluation of results (rather than a "black box" approach); and
- provide a mechanism for the choice of alternative adaptive management experiments that includes the consideration of costs (monetary and social), uncertainty, sensitivity of the ecosystem, and likelihood of getting reliable results.

1.5 MODELLING TOOLS USED

To construct the overall modelling framework, a number of modelling tools were used to:

- represent the spatial aspects of the landscape (ArcView 3.2, ESRI Corp.);
- represent the ecological relationships involved in determining habitat value of caribou seasonal ranges (Netica, Norsys Corp.);
- simulate landscape disturbance over time (SELES, Gowland Technologies, Ltd.); and
- generate forest stand volumes for aging forests (VDYP, Heron Systems Management [1999]).

Additional data management that links modelling systems together and calculates timber flow and operational considerations was carried out using Access (Microsoft Inc.). These modelling tools are described in general in the following sections, and in detail by Doucette et al. (in prep.).[6]

A CHASE user's guide has been developed to provide an in-depth background to CHASE model tools, software, data requirements, "run" procedures, and step-by-step operating instructions. The 14 basic modelling steps (Figure 1.2) are as follows:

1. prepare spatial and tabular data for CHASE;
2. create pine–lichen winter range capability, and calving and summer range capability maps;

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[6] Doucette et al., in prep.

3. create disturbance schedules and dynamic roads;
4. create resultant A grid;
5. update resultant A with moose winter range habitat values and projected ages, and create forestry information;
6. create moose winter range and projected age grids;
7. create subsistence hunting grids;
8. create resultant B grids;
9. update resultant B with summer and winter moose density values;
10. create seasonal predation risk grids;
11. create resultant C grids;
12. update resultant C with caribou seasonal range habitat values;
13. create caribou seasonal ranges; and
14. create final products of results for interpretation and analysis.

1.5.1 Spatial Data Handling

All spatial data handling and processing for CHASE was performed using ArcView, either through custom computer programs (henceforth referred to as scripts) or the graphical user interface. ArcView is a desktop computer based geographic information system (GIS) developed by Environmental System Research Institute (ESRI). This particular system was chosen for its low cost, portability, existing widespread use, advanced analysis functions, and ability to handle vector and raster data types.

CHASE used primarily a raster data model to store and analyze the spatial data. The raster data model divided the study area into 1-ha pixels, the result of laying a grid of rows and columns over the landscape. The advantages of raster data are the simple data storage structure and ease in performing spatial overlays and analysis.

To perform most of the spatial data analysis, custom scripts were created using ArcView's proprietary macro language, Avenue. This object-orientated programming language accesses a wider array of spatial analysis functions and tools compared with the simple graphical user interface.

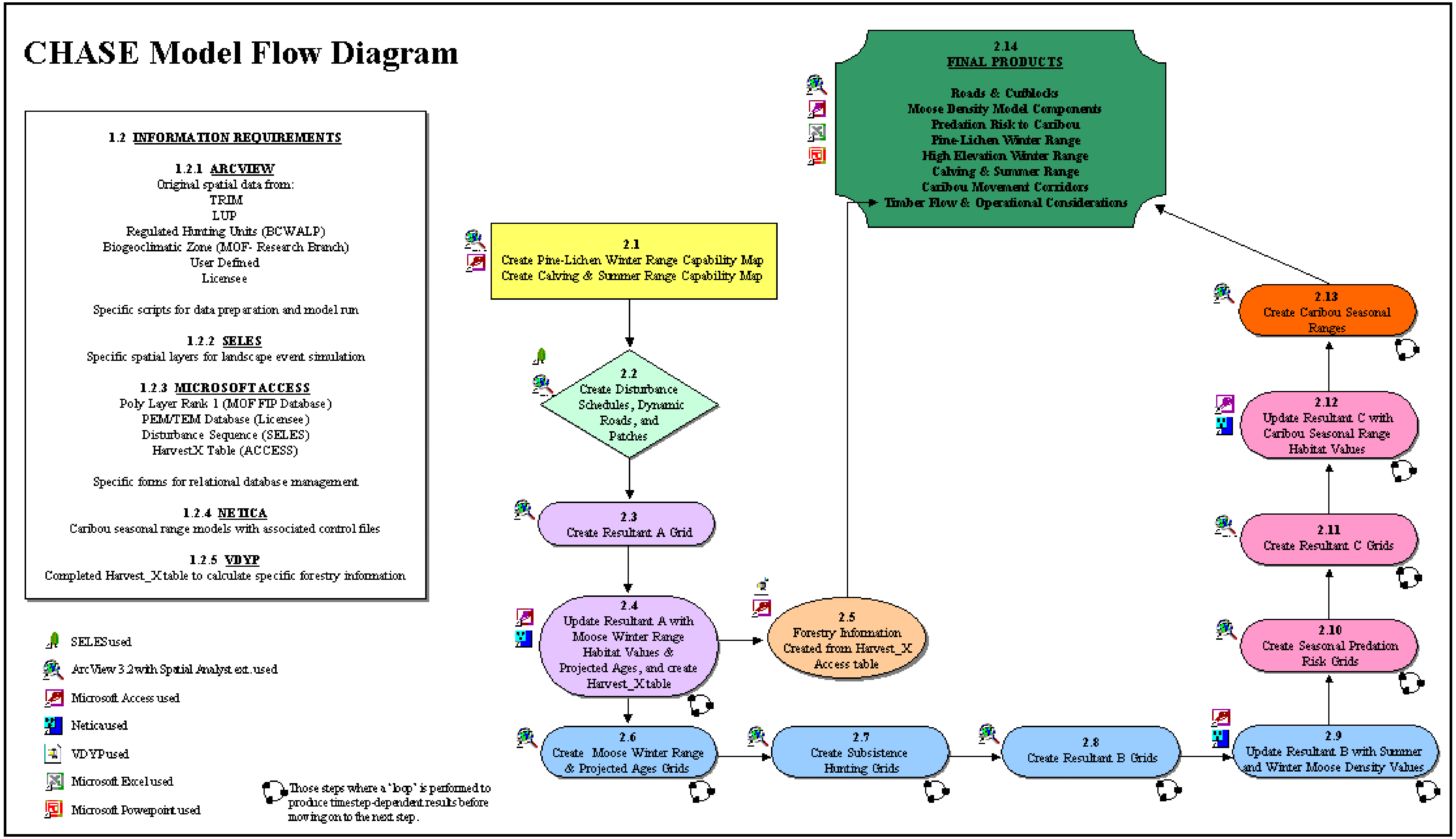

Figure 1.2. Flow diagram for implementing the Caribou Habitat Assessment and Supply Estimator (CHASE).

1.5.2 Ecological Relationships Network

One of the goals of the project was to represent the ecological relationships relative to caribou in a way that was transparent (the actual ecological factors and relations were shown), and allowed the incorporation of both professional judgement and data results. It was also important that the model could be built on a platform that was readily available, supported, and accessible to the modelling team (non-proprietary). In light of these criteria, alternative modelling platforms were evaluated and a Bayesian Belief Network (BBN) approach chosen. Of the BBN approaches available, Netica (Norsys Inc.) was chosen. This choice allowed close cooperation with researchers and managers working in Washington and Oregon, who are successfully using similar approaches (Marcot *et al.* 2001).

A BBN is a form of influence diagram which, as applied in ecology, depicts the logical or causal relations among ecological factors that influence the likelihood of outcome states of some parameter(s) of interest, such as forest condition or wildlife habitat. BBNs can be used to represent "causal webs" of major influences, such as factors that most affect population abundance and distribution. BBNs have been used in various ecology and forest management applications. For example, the Interior Columbia Basin Ecosystem Management Project of the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior Bureau of Land Management used numerous BBN models (B. Marcot, pers. comm., 2001).

BBNs also provided a useful communications medium that:

1. clearly displays major influences, and facilitates an explicit representation of how a system works;
2. combines categorical and continuous variables;
3. combines empirical data with expert judgement, often from multiple experts, and uses categorical, ordinal scale, and continuous data in the same model;
4. can be easily updated with new data and from expert review; and
5. expresses predicted outcomes as likelihoods for risk analysis and risk management (Marcot *et al*. 2001).

The BBN approach using Netica facilitated the effective development of habitat relationships in a workshop environment because it provided a relatively fast, interactive, and easily understood visual structure for exploring factors, and allowed professional expertise to be used to array factors into a causal web even if quantitative, statistically based information was lacking. Likewise, professional expertise was used to depict the probability structures of the degree to which various factors affect habitat or other variables of interest. In addition, relative sensitivity could be analyzed to determine the sensitivity of the outcome to various factors considered important. This approach allowed different types of uncertainty to be explicitly acknowledged and evaluated (B. Marcot, pers. Comm.; 2001).

Using the BBN/Netica approach entails (1) identifying important ecological factors that contribute to habitat value or other factor of interest; (2) developing a "causal web" model that depicts how the ecological factors and management options influence the potential distribution and abundance of the species of interest; and (3) developing a set of probabilities that quantify those factors that influence species.

The habitat models developed using Netica are described in Section 3.

1.5.3 Forest Simulation over Time

To determine the consequences of alternative management activities it was necessary to use a software tool that could simulate the change in the landscape over time as a result of alternative management scenarios (i.e., a landscape-level forest succession model). In addition, a natural disturbance scenario was required as a base case for comparison. SELES (Spatially Explicit Landscape Event Simulator) was chosen as the tool for building and running the landscape dynamics scenarios desired because it:

- combines discrete event simulation with a spatial database and a relatively simple modelling language to allow rapid development of landscape simulation;
- provides a means of specifying desired model behaviours ranging from management actions to natural disturbance and succession (Fall and Fall 1996);
- provides a relatively inexpensive and flexible mechanism for forest growth simulation using VDYP (Variable Density Yield Projection) growth curves (BCMOF 1999). This allowed the forest stand information to be built upon forest cover data and linked to other timber supply analyses such as the Timber Supply Review (TSR) II (e.g., BCMOF 2001);
- produced results that can be considered strategic representations of alternative management regimes, including natural factors such as wildfire; and
- is also well supported locally.

SELES allowed the project to meet three goals set for this component of the overall model: (1) accuracy in actual forest growth using accepted methods, and easily relatable to other forestry activities; (2) consistency of harvest with actual and planned roads and cutblocks using simple, realistic criteria without a large initial investment in long-term operational planning; and (3) reasonable cost of running simulations and data preparation required prior to runs.

1.5.4 Tracking Stand Ages and Estimating Harvested Volumes

The underlying forest simulation model upon which harvesting scenarios or natural disturbance scenarios were conducted was relatively simple. Primary assumptions were that forest succession did not occur (forest stands maintained the same species mix and percent composition through time) and that regenerating stands on harvested sites were identical in species mix and composition as the original stand that occupied the site prior to harvest. This reduced the nature of data that needed to be tracked through time to current stand age, age at harvest, area of each stand harvested in a harvest event, and timestep within which stands (or portions thereof) were harvested. All remaining stand-level information that was required to estimate volumes or characterize the stands was static and available in a Forest Inventory Planning (FIP) table that could be linked to timestep tables used to track the above variables.

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2.0 MODEL APPLICATION TO LAND USE PLANNING

The CHASE model was developed for two types of application: (1) to evaluate broad-based alternatives within the LRMP for the strategic management of caribou habitat; and (2) to prepare operational development plans. Each of these applications is described in subsequent sections and the anticipated users or audience for these applications are as follows:

- Forest industry: Planners, engineers, and professional foresters in the preparation of operational plans that comply with the LRMP Caribou Management Strategy or in site-level decision-making regarding road location, block location, harvesting season and equipment, and silviculture treatment of blocks.
- Statutory decision-makers: Forest district managers and designated environment officials who approve operational development plans.
- Third party "auditors": Auditors who investigate compliance or forest certification.
- Ad hoc committees: Biologist Technical Committee (Mackenzie LRMP), Recovery Action Groups (e.g., NCTAC[7]).
- Public: LRMP Monitoring Table.
- General public: Those viewing or reviewing the LRMP implementation plans or operational development plans.
- Scientific community/technical experts: Those interested in new methods and application of techniques.
- Educational: Extension or teaching (University of Northern B.C. or others).
- Federal/Provincial: Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2000) for species at risk reporting and recovery planning.

2.1 STRATEGIC PLANNING – LRMP

To evaluate and refine the LRMP Caribou Management Strategy it is useful to "test" the current ecological understanding and predicted response of caribou to alternative patch sizes and other management and natural activities using a model. The model can be used to evaluate the value of specific areas as seasonal habitat, and the ability of the overall landscape to support caribou populations for the three herds. Habitats can be compared within a herd area to assess the implications of management in different parts of a seasonal range. Herd areas can also be compared.

The strategic planning application of the model can accomplish the following:

- assess any area and describe its current habitat quality for caribou, and how this might change over time under alternative management scenarios;
- assess macro-level strategies of patch sizes (e.g., 60-ha vs. 1500-ha blocks) and distribution across a herd area (e.g., concentrate all management activities in a small area vs. dispersing activities over the whole herd area) to determine predicted impacts on caribou, moose, and wolves;
- quantify the relative impacts predicted for alternative policy choices, and "red flag" actions that have significant impacts on caribou;

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[7] Northern Caribou Technical Advisory Committee (NCTAC). In prep. A strategy for the recovery of Northern Caribou in the Southern Mountain National Ecological Area in British Columbia. Draft manuscript available from the chair of the Northern Caribou Technical Advisory Committee, B.C. Ministry of Water, Land and Air Protection, Biodiversity Branch, Victoria, B.C. 100 p.

- assess the relative importance of ecological relationships and management actions as opposed to the effects of background variation in the ecological system; and
- trigger a policy review, or monitoring activity, based on some predicted response of the model that has not been anticipated in LRMP planning.

The following types of questions could be evaluated:

- What is the overall risk/outlook for each herd?
- What type of habitat is limiting for each herd?
- Will a reduction or increase in a type of habitat likely lead to an increase or decrease in the number of caribou?
- What is the relationship between the number of caribou and the number of moose, number of wolves, and the amount of hunting?

In addition, the model can be used to refine understanding and contribute to communication and planning by:

- testing the understanding of relationships incorporated in the model using sensitivity testing, follow-up evaluation of the ecological causal links, and focused, efficient fieldwork;
- ensuring the efficient use of research and field data by providing a mechanism for incorporating and then using data to re-evaluate the causal links and overall ecological understanding of the management situation; and
- providing a common language for discussion among resource managers, stakeholders, and researchers.

2.2 FOREST DEVELOPMENT (FOREST STEWARDSHIP) PLANNING

At the strategic level, the LRMP Caribou Management Strategy describes the desired overall approach to forest development within the area. After this broad direction is established, industry foresters and engineers face numerous follow-up challenges such as: (1) locating roads and cutblocks in a design that supports the strategy; (2) providing the mills with the species and size of timber they desire; and (3) managing development and logging costs through equipment choice, seasonal timing, amount of road constructed, and silviculture treatment. The model was designed to assist operational planning in the following six ways:

1. On the broadest level, any operational plan can be used in the model to compare results with alternative development options. The actual location of roads and cutblocks will not likely match a scenario run; however, the result of the operational plans can be evaluated in terms of the amounts of the different types of caribou habitat of various values that result after implementation of the plan.
2. If a forest company wishes to use one of the scenario runs as a starting point for planning, they can evaluate the feasibility of building roads in locations that would allow the forest to be harvested in the sequence and distribution suggested by the scenario run. Thus the model runs could be used to guide the location of roads and cutblocks.
3. In any run of the model, the amount of road built and the volume of timber harvested by species is calculated. This information can be used to evaluate the timber flow and operational considerations of alternatives development options.
4. Within the model, a number of options are available regarding site-specific management. These options are included so that management activities (e.g., season of logging or type of site preparation) that are known to influence the value of caribou habitat can be considered in operational planning. The potential to manage habitat through harvesting methods and silviculture treatment can be considered, as well as the overall distribution and size of

cutblocks. The following management alternatives are included in the model and the implications of implementing them in forest development can be evaluated:
   a. stand removal method: whole-tree logging, cut-to-length logging, wildfire;
   b. removal (logging) season: summer or winter;
   c. site preparation: broadcast burning, pile and burn, scarification, or no treatment; and
   d. hunting pressure on moose (hunting regulation management): high, moderate, or low hunting pressure.
5. Other types of "gaming" (trying alternatives) can be conducted with the model to explore the implications of alternative forest management activities on caribou habitat and timber harvest flow and operational considerations. The extent to which gaming can be easily done, and the associated costs, are determined by the size of the area, the speed of the computers used, and the amount of special data preparation time required to run the model. The sequence could be (1) develop policy; (2) prepare road and logging plans in line with the policy; (3) run the modelling tool to predict results; (4) evaluate the predicted results (indicators) against available and compatible field monitoring data; (5) review and revise the development plan; and (6) repeat the cycle. Gaming could also be conducted where alternative timber volume flows and operational considerations are mandated and the resulting caribou habitat value is predicted. This would indicate whether caribou habitat value is sensitive to certain factors or not, and allow managers to only focus on the factors that matter.
6. The model could also be used to design adaptive management experiments to test alternative stand management activities and their implication to caribou habitat value. For example, Sulyma and Wawryszyn (2001) are currently studying lichen response to stand treatment.

In addition to the application of the tools to the Mackenzie study area, more generalized products such as guidebooks could be developed to transfer general landscape management guidelines derived from the model results to a broader geographic area. The overall modelling approach, or portions of it, is expected to be transferable to other areas, species, or management issues.

2.3 EVALUATION OF MANAGEMENT ALTERNATIVES

The model is designed to test alternative management scenarios of interest to managers and planners.

2.3.1 Starting Point for Scenarios

To have the model behave as realistically as possible, the starting point for all scenarios was the current landscape situation (roads and cutblocks) plus all roads and cutblocks that are approved in current plans. For simplicity, the approved roads and cutblocks were assumed to have been built and logged by year 2005, even though some blocks may not actually be logged until later.

2.3.2 Natural Disturbance Base Case

For comparison, a natural disturbance scenario was established to determine if the current pattern of habitat across the herd area would be sustained by the natural fire pattern and timing or whether the current pattern is an artifact of historic events.

The objective was to implement an empirical fire model driven by fire history information for the region, which consisted of fire return intervals and patch-size distributions (by forest area) stratified by biogeoclimatic variant.[8] Two different return times were provided for the analysis based on

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[8] See Meidinger and Pojar (1991) for descriptions of biogeoclimatic variant.

alternative research results. The fire model operated on an annual time step. Each year, and in each biogeoclimatic zone, the computed mean number of fires was initiated. For each fire, a fire size class was selected from the patch-size distribution using the frequencies as relative probabilities. A fire extent was selected for the size class from a uniform distribution. Fires were assumed to be stand-replacing, and so age was set to zero in burned cells. Fires spread from a burned cell to a random number of the eight neighbouring cells (including diagonals). Fires continued to spread until the chosen extent was burned (counting only forested cells, but spreading over non-forested cells). The fire model was run for 400 years with five replicates each. At the end of this time, the average amount and distribution of different types of caribou habitat were calculated. The results of the runs were averaged to produce an average amount of each type of habitat in the herd area based on long-term natural conditions.

2.3.3 Treatment of Omineca Park

For all management scenarios within the Wolverine herd area, Omineca Park (about 17% of the herd area) was excluded from forest harvesting activities. Since forest harvesting is the only disturbance type in the basic management scenario and forest succession does not occur in the model, it was felt that over time the Park would simply grow older (as would the rest of the non-contributing land base). Without more advanced disturbance scenarios where both harvesting and natural disturbance occurred simultaneously, it was decided a theoretically old condition of about 400 years old was appropriate to cease aging any undisturbed forest. A departure from this rule was taken in one scenario where a managed disturbance was allowed to occur within Omineca Park. The theoretical goal for this managed disturbance was to allow for maintenance of terrestrial lichens for caribou but the logistics for the disturbance were not defined.

2.3.4 Alternative Management Scenarios

Many alternative management scenarios could be applied to the Mackenzie TSA caribou herd areas. It is possible to evaluate policy such as that specified in the Forest Practices Code or to modify those regulations by additional recommendations proposed, for example, in the *Biodiversity Guidebook* (BCGovt 1995). The focus of the analysis applied, however, was the LRMP Caribou Management Strategy (BCGovt 2000). This strategy was based on the Forest Practices Code policy and recommends using *Biodiversity Guidebook* recommendations with some modifications to allow for larger patch-size targets within an identified Caribou Management Strategy (CMS) Zone 1. Furthermore, patch-size and early-seral targets were adjusted lower within an identified CMS Zone 2. Documentation and results of this application are available.[9]

Basic criteria needed to implement a policy-based disturbance with SELES included the following:

1. estimates of patch size and return intervals for unmanaged disturbances such as fire;
2. patch-size targets for managed disturbances;
3. seral-class targets for managed disturbances;
4. biodiversity emphasis options or resource management zone objectives;
5. timber harvesting objectives for sustainable flow of timber (e.g., minimum cutting ages, operability, a defined timber harvesting land base [THLB], and adjacency rules for controlling the spatial extent of harvesting).

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[9] McNay et al., in prep.

In addition to predicting the caribou range values resulting from the application of the LRMP scenario, the model was used to explore two interlinked questions within the scenario:[10]

1. Would the situation for caribou be improved if a “flow-control constraint” (i.e., maximum allowable harvest in winter ranges) was added to the LRMP strategy criteria listed above? The flow control that was tested would maintain 50% of the Pine–Lichen Winter Range in the optimum age range for caribou (70–140 years).
2. Would it more advantageous for caribou to apply the winter range management strategy (i.e., LRMP Caribou Management Strategy 1) to the LRMP Zone 1 within the herd areas or to the Ungulate Winter Range zones (Schmidt and McNay 2002)?

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[10] McNay et al., in prep.

3.0 CARIBOU ECOLOGY AND RANGE TYPES

This section describes the five models that were used to predict the ecological value of range types used by northern caribou in the Mackenzie TSA. Four of the models were based on range types considered most likely to be either limiting or important to caribou populations in the area. These included (1) Calving and Summer Range; (2) Pine–Lichen Winter Range; (3) High-Elevation Winter Range; and (4) Movement Corridors. The value of each range type to caribou was influenced by the risk of predation by wolves, which was estimated as a direct relationship to Moose Density, the fifth model.

Throughout these range-type models, reference is often made to habitat, as in "habitat value" or "habitat preference." Habitat was defined to include three commonly stated requisites for survival of a species or an individual: procurement of food, avoidance of predators, and the ability to undergo those activities without being displaced or excessively interrupted by human activity or management. Two of those elements, food and predators, are explicitly associated with each range model. One common resultant from each model is an estimate of habitat preference, which is intended to relate to the animal's ability to procure available forage with little to no risk of predation. Preference is deemed to occur any time an animal is located in a habitat type more frequently than would be expected from random locations (Chesson 1983). Another common resultant from each model is an estimate of habitat value, which incorporates both the elements of food procurement and predation risk. Generally, the resultant from each model is determined by factors and relationships depending on a variety of primary ecological inputs or ecological correlates (Marcot *et al*. 2001) that can be measured or estimated in land-based inventories.

During the calving and summer seasons, caribou herds tend to disperse and live at low densities primarily in alpine and subalpine areas. In the Calving and Summer Range model, habitat value was determined by the risk of predation and the preference that caribou likely exhibit for an area, where the ecological factors considered to have the greatest influence on habitat preference were percent slope, ecological unit,[11] and forest inventory type group.[12]

Pine–lichen woodlands provide foraging opportunities during winter when conditions allow northern caribou to dig or crater through snow to obtain terrestrial lichens. In the Pine–Lichen Winter Range model, the habitat value was influenced by the risk of predation and the preference that caribou exhibit for an area, where the ecological factors considered to have the greatest influence on habitat preference were stand age, percent lodgepole pine (*Pinus contorta*) in the stand, stocking level in the stand, method of stand removal, ecological unit, ecological variant, aspect, and elevation.

Caribou use high-elevation winter ranges in late winter, where they seek areas of exposed terrestrial lichens scoured free from snow by persistent winds. In the High-Elevation Winter Range model, habitat value was influenced by the risk of predation and the preference that caribou exhibit for an area, where the ecological factors considered to have the greatest influence on habitat preference were percent slope, elevation, stand age, inventory type group, ecological unit, and topographic curvature.

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[11] Ecological Unit used in this context is a specific grouping of site units (as described by Meidinger and Pojar 1991).

[12] Inventory Type Group used in this context is taken directly from the Forest Inventory Planning data used widely throughout the province of British Columbia and supported by the B.C. Ministry of Forests.

When snow conditions in pine–lichen winter ranges hinder caribou from detecting or accessing terrestrial lichens, caribou move to high-elevation winter ranges. Caribou also tend to move among segregated patches of high-elevation winter range and can move large distances between high-elevation winter ranges and sites used for calving. These movements typically occur along valley bottoms. In the Movement Corridor model, a panel of biologists mapped the potential and known corridor paths. The corridors included habitat within 200 m elevation and up to 1 km horizontal distance of the central path. Risk of predation was then applied to corridor areas to determine the mortality rates likely to occur in each movement corridor.

In these range models, a caribou's risk of predation was assumed to be directly related to the seasonal distribution of wolves across the landscape. Seasonal distribution of wolves was in turn determined by the density of moose and by the presence of roads. Moose density was estimated by considering the impact of regulated and subsistence hunting on the number of moose occupying moose habitat, where the ecological factors considered the greatest influence on habitat were season, elevation, stand age, and ecological unit.

The range models do not address two common observations about range use by caribou but the intent is to add such models in the future. The first observation concerns the aggregations of caribou that generally occur in fall after the mating season. These aggregations occur in pine–lichen forest types at high elevation, in areas characterized by an interspersion of wetlands. The second observation concerns an apparent use of specific areas in the spring before calving. These specific areas are usually characterized by mineral licks and/or by the "first flush" of perennial vegetation.

Another component of modelling concerns the interaction of amounts and spatial locations of the range types through time. Successful and significant management of caribou numbers and their habitats should be reflected in population parameters that characterize the whole herd: population size, age-specific mortality rates, and juvenile recruitment. A spatially explicit population model (Turner *et al*. 1995) for northern caribou will be added to future versions of CHASE.

3.1 MOOSE DENSITY AND PREDATION RISK

3.1.1 Introduction

The *Moose Winter/Summer Density (MD_WIN or MD_SUM)* model characterizes the factors that influence seasonal moose density, which is then used to predict wolf relative density seasonally, and thereby, seasonal predation risk to caribou.

Bergerud (1974) and Bergerud and Elliot (1986) suggest that the colonization of the B.C. Interior by moose during the 1900s has resulted in increased wolf populations and has led to higher predation rates and population declines in caribou. Seip (1992a) also found that the caribou populations in the Quesnel Highlands were declining primarily as a result of wolf predation, particularly in areas close to moose. During winter, caribou use high-elevation habitats where they are spatially separated from moose and wolves, which tend to remain in valley bottoms (Bergerud 1983; Seip 1992b). During summer, caribou, moose, and wolves can overlap, but caribou sustain low predation rates by predominantly using more rugged mountain terrain than wolves (Seip 1992b) or by existing at low densities, and therefore being more difficult for wolves to exploit. These tactics typically result in low adult mortality rates and relatively high calf survival rates.

3.1.2 Ecological Factors Considered

In the Mackenzie TSA, northern caribou spend part of the winter in low-elevation lodgepole pine (*Pinus contorta*) or black spruce (*Picea mariana*) forests where they feed primarily on terrestrial lichens (Wood 1996; Johnson 2000). These caribou also use low elevations while moving to their calving and summer range and their high-elevation winter range. Use of these low-elevation ranges has the potential to bring caribou in direct or proximal contact with wolves.

Messier (1995) found that wolf densities exhibit a direct numerical response to changing moose densities. Therefore, wolf abundance, and hence risk to caribou, can be directly based on the capability of an area to support moose. Increases in moose numbers are most apparent in young seral habitats (e.g., recently logged or recently burned areas) that provide abundant browse species (Franzmann and Schwartz [editors] 1998). This increase in moose (i.e., primary prey density) can lead to larger wolf populations and increased predation in areas used by caribou (i.e., secondary prey density). Wolves do not exhibit negative feedback (numerical response) to the resulting declining numbers of caribou (Bergerud et al. 1984; Seip 1989) because caribou are the secondary prey. According to Cumming (1996) and Seip (1990, 1992b), caribou experience sustainable levels of predation by wolves at distances between 5 and 10 km away from concentrations of moose and wolves but this predation becomes unsustainable at distances less than 5 km.

Recent studies in northeastern Alberta have also shown that linear corridors such as roads, pipelines, and seismic lines facilitate wolf movements and predation on boreal woodland caribou (Anderson 1999; Dyer 1999; James and Stuart-Smith 2000). Wolves occupy areas closer to linear corridors than random (James and Stuart-Smith 2000). Caribou killed by wolves occur closer to linear corridors while those caribou that survive occupy areas away from linear corridors, where the average displacement from random is about 100 m.

3.1.3 Description of Model Components

Moose Winter/Summer Density (MD_WIN or MD_SUM)

Seasonal Moose Winter/Summer Density (MD_WIN or MD_SUM) (e.g., during winter) was determined by the interaction of *Moose Winter Habitat Value* (*MW_VAL*) and the *Proportional Reduction of Moose (HUNT)* from hunting by humans (Figure 3.1). Hunting by humans was categorized into a *Subsistence Hunting Level (SUBS)* and *Regulated Hunting (REG)*, as per provincial legislation. *Moose Winter Habitat Value* was estimated based on whether the *Elevation (ELE)* of a site was considered too high, and the *Shrubby Forage Abundance (SFA)* of the site. *Ecological Unit (ECO)* and forest *Stand Age (SA)* were used to estimate the abundance of forage *in an area*. Moose Winter/Summer Density models were used to account for the differences in moose densities between the two seasons.

Proportional Reduction of Moose from Hunting (HUNT)

The *Proportional Reduction of Moose* node represents the total moose mortality resulting from both regulated and subsistence hunting.

Regulated Hunting (REG)

The Ministry of Water, Land and Air Protection regulates moose hunting in British Columbia (BCMWLAP 2001). Three possible levels of *Regulated Hunting* were identified: (1) the naturally regulated moose population size could be greatly reduced, through a high level of

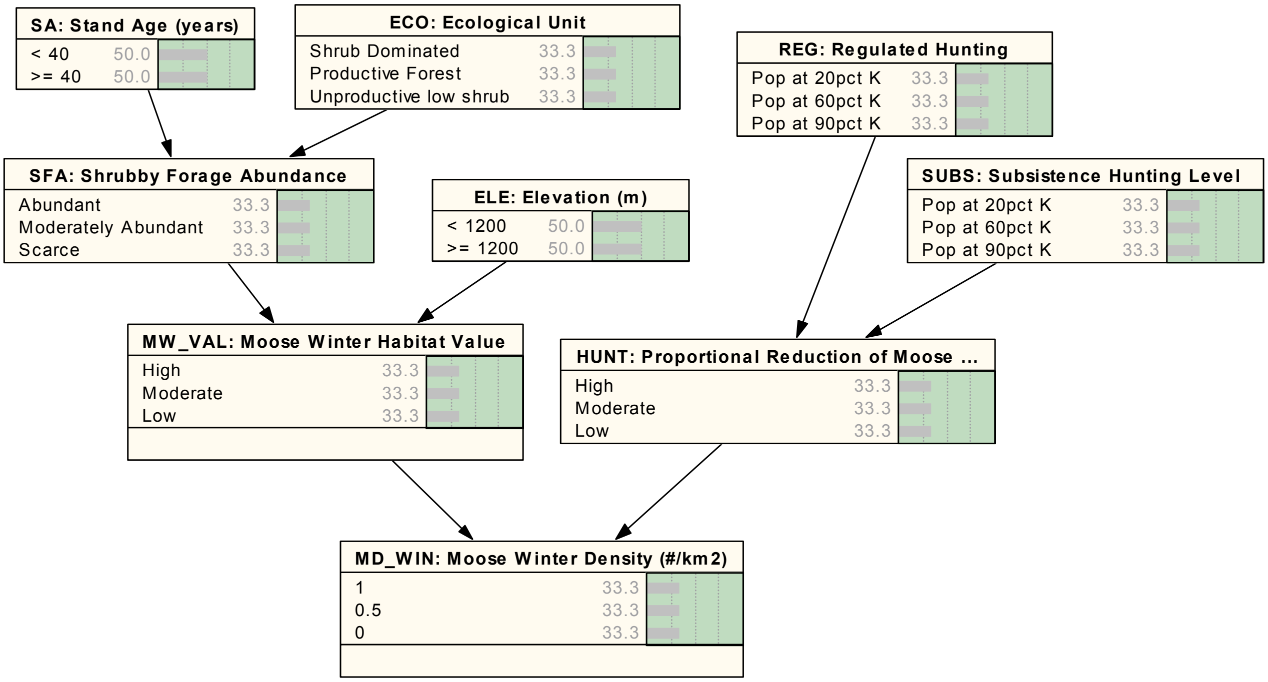

Figure 3.1. **Ecological factors and relationships characterizing the moose density during winter in north-central British Columbia.**

hunting, to only 20% of carrying capacity (“Pop at 20pct K”); (2) the naturally regulated population size could be reduced to 60% of carrying capacity (“Pop at 60pct K”), considered to be a moderate level of hunting; and (3) the naturally regulated population size could be reduced to 90% of carrying capacity (“Pop at 90pct K”), considered to be a low level of hunting. High regulated hunting could be accomplished by implementing an aggressively advertised open hunting season, moderate hunting could be accomplished by implementing an extended open hunting season, and low hunting represents the current level of regulated hunting.

Subsistence Hunting (SUBS)

The three *Subsistence Hunting Levels* identified were the same as the regulated hunting levels: “Pop at 20pct K,” “Pop at 60pct K,” and “Pop at 90pct K.” The level of subsistence hunting was estimated based on the amount of accessible moose winter range and its proximity to defined communities. In this model, only Tsay Keh Dene and Fort Ware were defined. *Subsistence Hunting Levels* were determined using the following equation:

$$y = \{m(p_1 * p_2) + [(1 - p_1) * p_3]\} * 100$$

Where: y = resultant subsistence hunting level, where y = 0–49 represented low hunting; 50–199 was moderate; and 200+ was high. The cut-points were chosen to reflect changes in moose winter range accessibility. The low cut-point (y = 50) is the point where all of the moose winter range is beyond 10 km of a town and only half of it is accessible, while the high cut-point (y = 200) is the point where 33% of the moose winter range is within 10 km of a town, and all of it is accessible. The remaining 67% of the moose winter range is beyond 10 km of a town, and 50% is accessible.

m = adjustment factor used to account for the higher level of subsistence hunting near towns. In the Mackenzie TSA, $m = 5$ because subsistence hunting was considered to be 5 times greater when within 10 km of a community.

p_1 = proportion of moose winter range within 10 km of a town.

p_2 = proportion of moose winter range within 10 km of a town that is accessible to hunters, where hunting can occur on or within 2 km of a road or major river, including the Kwadacha, Akie, Ingenika, and Finlay rivers.

$(1-p_1)$ = proportion of moose winter range beyond 10 km of a town.

p_3 = proportion of moose winter range beyond 10 km of a town that is accessible to hunters.

For example, if the proportion of winter range within 10 km of town was 0.3, half of that area was accessible to hunters, and the proportion of the winter range beyond 10 km of town that was accessible to hunters was 0.2, then the equation becomes: $\{[5 * (0.30 * 0.5)] + (0.70 * 0.2)\} * 100 = 89$. Subsistence hunting varied across all levels compared with regulated hunting, which was held constant at a low level given the current regulations, for the following reasons:

1. While regulated hunters shoot primarily male moose, subsistence hunters tend to shoot more female moose, thereby influencing recruitment rates. This reduces moose densities more than if the same number of males were shot.
2. Subsistence hunters can, and do, hunt in winter when moose are more concentrated and more easily shot, relative to any conceivable regulated hunting.

The conditional probabilities that were used to configure how *Subsistence Hunting* and *Regulated Hunting* relate to *Proportional Reduction of Moose* are presented in Table 3.1.

Table 3.1. Conditional probabilities used within Netica to configure the overall Proportional Reduction of Moose (High, Medium, or Low) resulting from Regulated Hunting and Subsistence Hunting (Pop at 20pct K represents moose population at 20% of carrying capacity, Pop at 60pct K represents moose population at 60% of carrying capacity, and Pop at 90pct K represents moose population at 90% of carrying capacity). Variable code names are in parentheses.

Regulated	Subsistence	Proportional Reduction of Moose (HUNT)		
Hunting (REG)	Hunting (SUBS)	High	Moderate	Low
Pop at 20pct K	Pop at 20pct K	90	10	0
Pop at 20pct K	Pop at 60pct K	80	20	0
Pop at 20pct K	Pop at 90pct K	70	30	0
Pop at 60pct K	Pop at 20pct K	80	20	0
Pop at 60pct K	Pop at 60pct K	20	60	20
Pop at 60pct K	Pop at 90pct K	10	45	45
Pop at 90pct K	Pop at 20pct K	70	30	0
Pop at 90pct K	Pop at 60pct K	10	45	45
Pop at 90pct K	Pop at 90pct K	0	10	90

Moose Winter/Summer Habitat Value (MW_VAL or MS_VAL)

The *Moose Winter/Summer Habitat Value* node represents the value of habitat to moose (and hence the likely number of moose) that would occur, during winter or summer, in a naturally regulated population in the absence of human hunting. "High" habitat value was considered to allow for 0.67–1.00 moose/km^2 in winter. The carrying capacity of summer habitat was adjusted to allow for winter densities of moose to fill the area of summer habitat (see "Seasonal Moose

Density Correction Factor" below). Carrying capacities of "Moderate" and "Low" habitat values were defined as 0.34–0.66 and 0.00–0.33 moose/km^2 in winter, respectively. The ecological factors influencing this naturally regulated abundance of moose include *Elevation* as a proxy for season and a summary variable characterizing *Shrubby Forage Abundance*.

Shrubby Forage Abundance (SFA)

Abundance of shrubby forage can be measured by basal diameter of stems taken from favored browse species and the amounts eaten projected using mass-diameter regressions (MacCracken and Van Ballenberghe (1993). Therefore, abundance of forage for moose, assumed to be measured by such a technique, was stratified into three states ("Abundant," "Moderately Abundant," and "Scarce") based on forest *Stand Age* and *Ecological Unit.*

Stand Age (SA)

A stand age of 40 years was used as the cut-off between young habitat that provides abundant shrubby forage for moose ("< 40") and older forest where browse production is less ("≥ 40"). This age criterion was based on aerial survey data for moose in the Prince George Forest District (Heard, D., Pers. Comm., 2001.). The age strata are appropriate for naturally regenerated areas but could be reduced if conifer canopy closure occured at a younger age.

Ecological Units as Moose Habitat (ECO)

Habitats dominated by shrubby forage were considered good areas for moose (Eastman 1977; Franzmann and Schwartz [editors] 1998). The highest rating was assigned to natural wetlands dominated by preferred browse species such as *Salix* spp., *Cornus stolonifera*, and *Betula papyrifera* ("Shrub-Dominated"). Moose also make extensive use of the browse available in young forests following disturbance by fire or logging, especially on more productive sites ("Productive Forests"). Old forests, and young stands on unproductive sites characterized by low browse availability, were assigned a low rating ("Unproductive-Low-Shrub"). The rating assigned to each ecological unit was based on professional opinions and is presented in Appendix A. For areas where ecological mapping was not available, ratings were based on available geographic and forest cover data (Appendix B).

Conditional probabilities used to configure the way in which *Stand Age* and *Ecological Unit* determined *Shrubby Forage Abundance* for moose are presented in Table 3.2.

Table 3.2. Conditional probabilities used within Netica to configure the relationship between Shrubby Forage Abundance (Abundant, Moderately Abundant, Scarce) and the ecological factors deemed to influence those values: Stand Age (< 40, ≥ 40) and Ecological Unit (Shrub-Dominated, Productive Forest, Unproductive-Low-Shrub). Variable codes are in parentheses.

Stand Age	Ecological Unit (ECO)	Shrubby Forage Abundance (SFA)		
(SA) (yr)		Abundant	Moderately Abundant	Scarce
< 40	Shrub-Dominated	90	10	0
< 40	Productive Forest	60	30	10
< 40	Unproductive-Low-Shrub	0	5	95
≥ 40	Shrub-Dominated	90	10	0
≥ 40	Productive Forest	10	30	60
≥ 40	Unproductive-Low-Shrub	0	0	10

Elevation (ELE)

Moose occur over a wide range of elevations in summer, but concentrate at lower elevations in winter. Consequently, moose habitat was stratified by winter and summer seasons based on elevations above 1200 m ("> 1200") and below 1200 m ("< 1200"). This elevation stratification was determined from moose locations during winter distribution surveys and existing telemetry information (Heard et al. 1999a, 1999b).

Moose Winter/Summer Habitat Value (MW_VAL or MS_VAL) Summary

The conditional probabilities that were used to configure how *Shrubby Forage Abundance* and *Elevation* relate to *Moose Winter Habitat Value* are presented in Table 3.3. A similar relationship is presented for *Moose Summer Habitat Value* in Table 3.4. In each case, the three possible states identified for *Moose Winter/Summer Habitat Value* are "High," "Moderate," and "Low" where these states are defined by densities as described previously.

Table 3.3. **Conditional probabilities used within Netica to configure the relationship between Moose Winter Habitat Value (High, Moderate, or Low) and the ecological factors deemed to influence those values: Shrubby Forage Abundance (Abundant, Moderately Abundant, and Scarce) and Elevation (< 1200 m, ≥ 1200 m). Variable code names are in parentheses.**

Elevation (ELE) (m)	Shrubby Forage Abundance (SFA)	Moose Winter Habitat Value (MW_VAL)		
		High	Moderate	Low
< 1200	Abundant	95	5	0
< 1200	Moderately Abundant	0	95	10
< 1200	Scarce	0	5	95
≥ 1200	Abundant	0	10	90
≥ 1200	Moderately Abundant	0	5	95
≥ 1200	Scarce	0	0	100

Table 3.4. **Conditional probabilities used within Netica to configure the relationship between Moose Summer Habitat Value (High, Moderate, or Low) and the ecological factors deemed to influence those values: Shrubby Forage Abundance (Abundant, Moderately Abundant, and Scarce) and Elevation (< 1200 m, ≥ 1200 m). Variable code names are in parentheses.**

Elevation (ELE)	Shrubby Forage Abundance (SFA)	Moose Summer Habitat Value (MS_VAL)		
(m)		High	Moderate	Low
< 1200	Abundant	90	10	0
< 1200	Moderately Abundant	0	90	10
< 1200	Scarce	0	5	95
≥ 1200	Abundant	90	10	0
≥ 1200	Moderately Abundant	10	70	20
≥ 1200	Scarce	5	10	85

Moose Winter/Summer Density (MD_WIN or MD_SUM) Summary

The *Proportional Reduction of Moose* from hunting was believed to have a relatively greater impact on *Moose Winter/Summer Density* than did *Moose Winter/Summer Habitat Value.* The impact of hunting became proportionately greater as habitat value declined, which was reflected in the structure of the conditional probability table (Table 3.5). That is, even in good habitats, high hunting impacts result in absolutely low moose densities ("0 moose/km^2") because: (1) there were no imposed/regulated limits to moose hunting; (2) the need or interest in having moose to hunt and eat is not likely to be easily satiated (i.e., no functional response by people); and (3) people will continue to go to areas where they can hunt moose during their pursuit of other activities, even as moose densities decline. Low hunting levels in high value habitats predominantly resulted in high moose densities ("1 moose/km^2" in winter and "0.62 moose/km^2" in summer), and moderate habitat or hunting levels resulted in moderate moose densities ("0.5 moose/km^2" in winter and "0.31 moose/km^2" in summer).

Table 3.5. Conditional probabilities used within Netica to configure the relationship between Moose Winter/Summer Density and the ecological factors deemed to represent those values: Moose Winter/Summer Habitat Value (High, Moderate, Low) and Proportional Reduction of Moose from hunting (High, Moderate, Low). Variable code names are in parentheses.

Moose Winter/Summer Habitat Value (MW_VAL or MS_VAL)	Proportional Reduction of Moose (HUNT)	Moose Winter/Summer Density (MD_WIN or MD_SUM)		
		1 moose/km^2 (winter) or 0.62 moose/km^2 (summer)	0.5 moose/km^2 (winter) or 0.31 moose/km^2 (summer)	0 moose/km^2 (winter and summer)
High	High	10	30	60
High	Moderate	30	50	20
High	Low	90	10	0
Moderate	High	5	40	55
Moderate	Moderate	5	60	35
Moderate	Low	5	80	15
Low	High	0	10	90
Low	Moderate	0	10	90
Low	Low	0	10	90

Seasonal Moose Density Correction Factor

Moose population size was expected to be essentially identical for the winter and summer seasons within any given year. The assumption was that the moose population was always at equilibrium with the ecological factors that influenced it (i.e., population-level factors such as recruitment and immigration or emigration were not explicitly considered). Also, the availability of winter range was expected to limit annual population sizes. Consequently, the moose densities corresponding to "High," "Moderate," and "Low" habitat values (1, 0.5, and 0 moose/km^2, respectively) assigned to the *Moose Winter Habitat Value* or the *Moose Winter Density* nodes of the winter model, when moose are concentrated at low elevations, were inappropriate if used for the same nodes of the summer model when the same population used a much larger area.

To calculate a density correction factor for the summer model, the winter and summer models were used to generate moose population estimates for the study area and examine the ratios of winter to summer populations. This analysis was conducted over an entire harvest rotation so as to incorporate the influence that any forest disturbance had on the availability of winter ranges, and hence, annual population size. Three levels of hunting mortality were included (by imposing state values of “High,” “Moderate,” and “Low” at the *Proportional Reduction of Moose* node) to confirm that the ratios of winter and summer population sizes were relatively stable across broadly differing levels of this ecological factor.

Winter and summer model generated population estimates for the study area are presented in Table 3.6. Over all years and across all levels of hunting mortality, the ratios of winter to summer population size ranged from 0.540 to 0.665, indicating that population estimates from the summer model were 50–85% larger than the corresponding winter population estimates. Within each level of hunting mortality, the mean ratio over years of winter to summer population size was calculated and determined to be similar (0.603–0.644).

Table 3.6. **Model-generated estimates of winter and summer moose populations (N) for the study area over a simulated forest harvest rotation and across levels of hunting mortality (Low, Medium, and High). For both winter and summer moose models, the Moose Density node was set to densities of 1, 0.5, and 0 moose/km^2.**

Years into Simulation	Low Hunting Mortality			Moderate Hunting Mortality			High Hunting Mortality		
	Winter N	Summer N	Winter N/ Summer N Ratio	Winter N	Summer N	Winter N/ Summer N Ratio	Winter N	Summer N	Winter N/ Summer N Ratio
0	1617	2993	0.540	1194	2135	0.559	853	1410	0.605
10	1722	3000	0.574	1253	2133	0.587	876	1404	0.624
20	1836	3014	0.609	1316	2135	0.616	902	1398	0.645
30	1872	3007	0.623	1337	2128	0.628	910	1392	0.654
40	1922	3006	0.639	1365	2124	0.643	922	1387	0.665
50	1908	3002	0.636	1357	2122	0.639	919	1386	0.663
60	1850	2979	0.621	1325	2109	0.628	906	1382	0.656
70	1811	2966	0.611	1303	2103	0.620	897	1379	0.650
80	1759	2948	0.597	1274	2093	0.609	886	1376	0.644
90	1734	2940	0.590	1260	2089	0.603	880	1375	0.640
100	1748	2947	0.593	1268	2093	0.606	883	1376	0.642
Means	1798	2982	0.603	1296	2115	0.613	894	1388	0.644

From Table 3.6, an average density correction factor of 0.62 was calculated for the summer model and used to adjust the moose densities assigned to the *Moose Summer Habitat Value* or *Moose Summer Density* nodes of the summer model accordingly (corrected densities were 0.62, 0.31, and 0.0 moose/km^2 for Low, Moderate, and High Hunting Mortality, respectively). To test the performance of the correction factor, winter and summer population estimates were evaluated over a subset of years and across combinations of regulated and subsistence hunting (Table 3.7). For the years examined, the summer population ranged from 6% less to 14% greater than the corresponding winter population.

3.1.4 Determining Risk of Predation

A caribou’s risk of predation was determined to be influenced by two factors: (1) the average density of wolves within 5 km of potential caribou habitat, which will be referred to as *Proximity Risk (PR);* and (2) the density of wolves directly within potential caribou habitat, which will be referred to as *Direct Risk (DR)*. The overall risk of predation was the maximum risk level between *Proximity Risk* and *Direct Risk*.

Proximity Risk (PR)

Proximity Risk is a caribou's risk of being killed by wolves that are occupying nearby moose habitat. As mentioned previously, Cumming (1996) and Seip (1990, 1992b) found that caribou can sustain levels of predation at distances between 5 and 10 km away from concentrations of moose and wolves, while levels of predation at distances less than 5 km are not sustainable. Thus, it can be assumed that the concentrations of moose and wolves within 5 km of potential caribou habitat will influence the level of predation risk associated with that habitat. Messier (1995) found that wolf densities dropped to very low levels when moose densities were less than 0.1 moose/km^2, were intermediate at 0.2 moose/km^2, and were high at and above 0.5 moose/km^2. A similar relationship was used in CHASE to reflect this numerical response. Given that moose densities average 1 moose/km^2 in suitable habitats in the absence of predation (Messier 1995), wolf densities were considered low when the average moose density within 5 km of caribou habitat was less than 0.1 moose/km^2. If the surrounding 5 km zone contained an average moose density between 0.1 and 0.2 moose/km^2, the value of the caribou habitat was reduced by 50%. If the average moose density in the surrounding 5 km zone exceeded 0.2 moose/km^2, the value of the caribou habitat was reduced by 90% (Seip and Heard, pers. comm., 2001) (Table 3.8).

Table 3.7. Performance of the density correction factor applied to the Summer Moose Density Model over a subset of simulation years and across combinations of Regulated (REG) and Subsistence (SUBS) Hunting levels. Population numbers (N) represent model-generated estimates for the study area.

Years into Simulation	Combinations of Regulated (REG) and Subsistence (SUBS) Hunting Levels											
	REG = 90% of K SUBS = 90% of K		REG = 60% of K SUBS = 90% of K		REG = 60% of K SUBS = 60% of K		REG = 20% of K SUBS = 90% of K		REG = 20% of K SUBS = 60% of K		REG = 20% of K SUBS = 20% of K	
	Winter N	Summer N	Winter N	Summer N	Winter N	Summer N	Winter N	Summer N	Winter N	Summer N	Winter N	Summer N
0	1575	1803	1350	1518	1211	1340	955	1009	921	964	887	919
20	1784	1814	1509	1523	1338	1341	1026	1004	985	958	943	913
40	1866	1809	1571	1517	1388	1335	1055	997	1010	951	966	905
60	1798	1793	1519	1505	1346	1325	1032	992	990	947	948	902
80	1710	1775	1453	1492	1293	1315	1002	986	963	942	924	897
100	1700	1774	1446	1492	1287	1315	999	987	960	942	922	898

Table 3.8. Relationship between area-specific moose density, wolf density, predation risk, and the influence on caribou habitat value reduction.

Proximal or direct moose density (moose/km^2)	Proximal or direct wolf density	Predation Risk	Caribou habitat value reduction (%)
< 0.1	Low	Low	0
0.1–0.2	Medium	Medium	50
> 0.2	High	High	90

Direct Risk

Direct Risk is a caribou's risk of being killed by wolves directly occupying either areas within 100 m of linear corridors, or areas of moose habitat. Regardless of habitat type, all areas within 100 m of roads were considered to have high predation risk (James and Stuart-Smith 2000), resulting in a habitat value reduction of 90%. The numerical response of wolf abundance to moose abundance used for determining proximity risk was also used for determining location specific direct risk (Table 3.5).

Overall Risk

Overall risk at any given location was the maximum risk value between *Proximity Risk* and *Direct Risk*. For example, if the location specific moose abundance was > 0.2 moose/km^2 (high predation risk), but only 15% of the area within 5 km of the location was in good moose habitat (medium predation risk), the overall risk was high.

3.1.5 Assumptions

- Wolves are the primary predators of caribou in the Mackenzie TSA.
- Wolf distribution and abundance are key ecological correlates with both moose and caribou abundance. Relative (qualitative) levels of wolf relative abundance can be estimated from moose density; however, wolf relative abundance cannot be predicted numerically from moose habitat quality or moose density since other factors may affect the actual numbers of wolves in an area.
- Wolves do not change their distribution as a result of direct interaction with humans.
- Roads are considered an entry/travel route for wolves, regardless of whether they are ploughed in winter.
- Wolves are shot and run over when on or close to roads (especially mainlines). This mortality has an impact on wolf numbers, but will not be considered explicitly in this sub-model.
- Roadkills (especially on mainlines) may be a source of food for wolves, and thereby may influence wolf distribution relative to mainline roads; however, this was incorporated in the proximity to roads factor of the predation risk calculation.
- Mainline roads remain open once they are created.
- Spur roads are deactivated 20 years after they are last used.
- Modelled spur roads are considered to be an approximation of future spur roads.
- Roads are static beyond the study area.
- The LRMP-identified areas of "high" moose habitat suitability index were used to define the boundaries of moose winter ranges.
- Moose summer range boundaries were delineated based on professional judgement (Glen Watts, B.C. MWLAP, pers. comm., 2001).
- Moose summer and winter ranges are static beyond the study area.
- Several site series or forest cover classes do not have an assigned age class (e.g., typically unforested areas such as alpine tundra, bogs, and fens). For this sub-model, these areas were classified as good age class (< 40 years old), since ecological unit will override age class. For example, alpine habitat ecological units are ranked as poor moose habitat, so even though the age-class rating has defaulted to good, the overall habitat rating will be poor.
- Management units will be used as boundaries for regulated hunting policies.
- Information on subsistence hunting is not readily available; however, based on local knowledge, hunting was assumed to be generally a microscale phenomenon, occurring within 10 km of a community, and within 2 km of open roads and the Kwadacha, Akie, Ingenika, and Finlay rivers.
- Most subsistence hunting occurs when moose are concentrated on valley bottom winter ranges; therefore, the spatial impact (or population reduction) was extended over the corresponding summer ranges.

3.1.6 Management Factors

Managers have three methods to potentially influence the model results: (1) regulated moose hunting policy, (2) the amount and spatial location of road development, and (3) the amount and spatial location of disturbance leading to reductions in forest stand age.

Regulated Moose Hunting

Moose hunting regulations that implement an extended open season would result in high mortality from regulated hunting, and could potentially reduce a caribou's risk of predation, while a closure on moose hunting would potentially increase a caribou's risk of predation.

Road Development

Road development influences two variables used in the calculation of predation risk: (1) potential for sustenance hunters to access moose winter range, and (2) wolf movement. A caribou's risk of predation by wolves was considered to be high within 100 m of any open road. Also, an increase in the amount of road built within 2 km of a moose population's winter range will increase the moose mortality attributed to subsistence hunting throughout the moose population area. In addition, roads built within 2 km of a moose population's winter range and within 10 km of communities with sustenance hunters will have a greater impact on moose population mortality than if the roads were built beyond 10 km of these communities.

Forest Age

Of the three management factors, changes in forest *Stand Age* have the most widespread implication on a caribou's risk of predation. At any given location, changes in forest age will potentially influence the abundance of moose, given that forest stands 40 years old and less support higher moose abundance in both the summer and winter than forest stands greater than 40 years old. In addition, changes in the amount of moose winter range either closer or further from communities with First Nations hunters and within 2 km of First Nations hunting access routes will change the impact of subsistence hunting within the entire moose population unit.

3.1.7 Summary and Anticipated Model Development

In this model, a caribou's risk of predation was controlled solely by the distribution of wolves across the landscape. This distribution of wolves was in turn determined by the abundance of moose across the landscape and the presence of roads. Moose abundance depended on the value of the range to moose and the impact of hunting.

Factors that may be considered in future models include:

- influence of snow depth and hardness on predator and prey movements;
- influence of herbicide-treated areas on moose habitat value;
- fire history of the stand; and
- predation on caribou by other species.

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3.2 CALVING AND SUMMER RANGE

3.2.1 Introduction

The *Calving and Summer Range* (C_SR) model characterizes habitat used by northern caribou in terms of the relative preference they demonstrate for specific conditions during the natal period and throughout summer. The “calving” and “summer” periods in this model were arbitrarily bounded in the spring (May-June), when cows usually make prenatal movements to seek individual sites for calving (Wood 1996), and in the fall (September-October), when northern caribou aggregate into large groups following mating (Bergerud 1982). By comparison to other ranges, calving and summer range is used at times when herds tend to be relatively dispersed geographically (Cichowski 1989, Seip 1990, Wood 1996,). Even with this dispersed use of habitat, northern caribou typically can be found at high elevations in the upper Engelmann Spruce–Subalpine Fir (ESSF) or Alpine Tundra (AT) biogeoclimatic zones (Meidinger and Pojar 1991). For example, Wood (1996) found most radio-collared caribou of the Wolverine herd at these relatively high elevations during calving and throughout the summer. Lance (2002) reported similar findings for the same herd and these findings have also been reported for other herds of northern caribou (Boonstra and Sinclair 1984; Cichowski 1989).

3.2.2 Ecological Factors Considered

The apparently common use of high-elevation ecosystems by northern caribou cows during calving is considered to be an anti-predator tactic (Bergerud et al. 1984). Evidence to support this premise has been reported extensively, usually as a conclusion from the combination of two general observations: (1) that wolves and caribou are spatially segregated during calving (Hatler and Cichowski 1990; Brown 1994); and (2) that caribou move into these high-elevation habitats of relatively poor foraging opportunity just prior to calving after having spent most of the spring using habitats of relatively better foraging opportunity (Cichowski 1989; Brown 1994). Snow conditions during spring are presumed to act as a barrier to movement by wolves but not to movement by caribou. Apparently the security for calves afforded by this barrier is more important than the opportunity for the cow to access high-quality forage. Bergerud and Page (1987) surmised that when snow does not form a barrier between wolves and caribou (i.e., after severe winters when snow at higher elevations is too deep even for caribou), caribou suffer higher calf losses to predation because they must calve at lower elevations. Caribou also disperse to low density when they move to calving habitats (Bergerud and Page 1987; Seip 1989; Brown 1994) where a patchy but deep snow cover provides cryptic cover for newborn calves (Adams et al. 1995). Both factors further support the notion that habitat selection during calving is primarily a function of predator avoidance.

Although northern caribou are known to aggregate in alpine areas after calving, this generally does not last long and caribou revert to highly dispersed locations throughout the summer (Cichowski 1989, Seip 1990), presumably to reduce the hunting efficiency of wolves (Bergerud and Page 1987). Open spaces offer an additional opportunity to increase vigilance while foraging, an anti-predation tactic considered basic to the evolutionary ecology of caribou. Complicating this preference shown by caribou for open, alpine habitats in summer is the complementary reduction in aggravation from flies that is made possible by the generally cooler temperatures and more wind-prone topographic positions. The importance of this benefit to caribou is unknown.

Avoidance of predators, either by using snow packs as barriers to predator movement, by herding in open spaces to increase vigilance, or by dispersing to low density to decrease detection by wolves, was therefore considered the most proximate life requisite for northern caribou to fulfill during the calving and summer periods. To achieve any one or all of these anti-predation tactics, use of large areas of open habitat at high-elevations that retained remnant snow packs in early summer encompassed the ecological factors of critical importance to the Calving and Summer Range model. Furthermore, the significance of anti-predator tactics on these range types was believed to affect habitat preferences so fundamental to caribou behaviour that the tactics would persist even when or where predators were reduced or, for other reasons, occurred naturally at low densities. In effect, even though calving could theoretically be achieved anywhere without predators, caribou will continue to select habitat according to the habitat factors that provide security from predators (i.e., large, open areas with snow packs that persist into early summer).

3.2.3 Description of Model Components

Calving and Summer Range Habitat Value (CSR_VAL)

To calculate *Calving and Summer Range Habitat Value (CSR_VAL)*, habitat preference for calving and summer ranges by caribou was estimated, then the *Habitat Value Reduction (RISK)* was determined according to potential risk of predation by wolves (see Section 3.1.4, "Determining Risk of Predation") (Figure 3.2). Overall *Calving and Summer Range Habitat Preference (CSR_PREF)* was established as a summary node to estimate usability for two range types:

Calving Range (CR) and *Summer Range (SR)*. Usability of *Calving Range* was estimated based on the steepness of the *Slope (SLP)* of a site, and the potential for snow packs to restrict access by predators. *Ecological Unit (ECO)* and forest *Inventory Type Group (ITG)* were used to estimate *Predator-Restrictive Snow Packs (PRSP)*. Usability of *Summer Range* was also influenced by *Slope*, as well as the *Terrestrial and Arboreal Lichen Forage Abundance (TA_LFA)* and whether an area was *Open and Cool (OC)*, as defined by *Ecological Unit*. Both *Ecological Unit* and forest *Inventory Type Group* were used to determine abundance of terrestrial and arboreal lichen forage types.

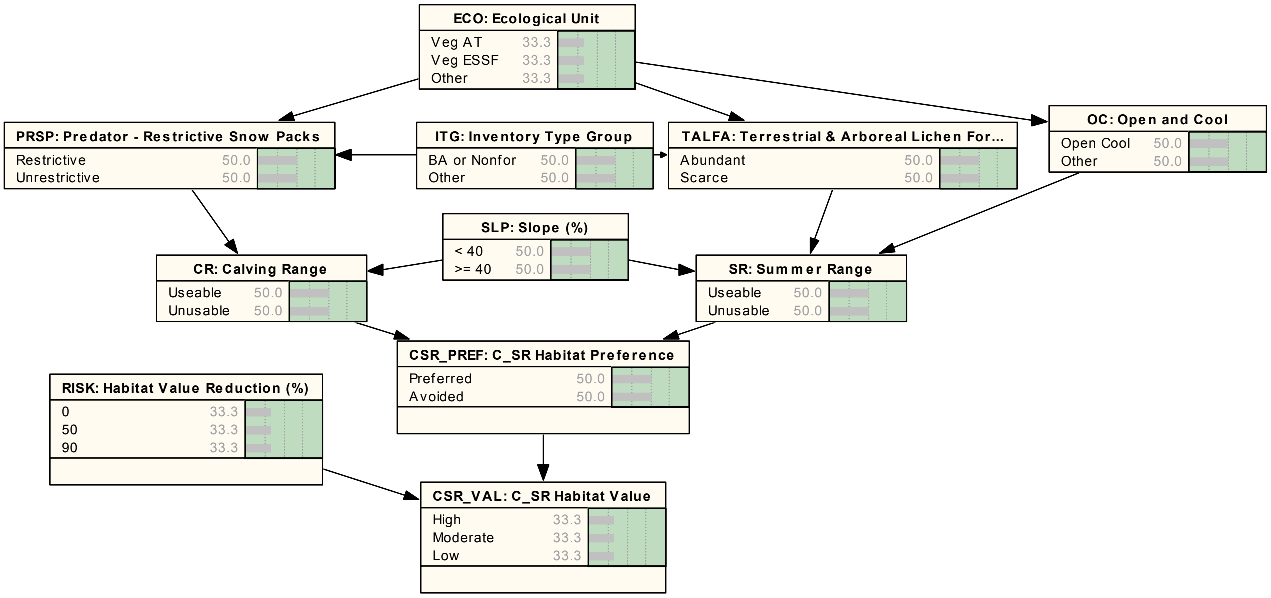

Figure 3.2. **Ecological factors and relationships characterizing preference for calving and summer range habitats by northern caribou in north-central British Columbia.**

Calving and Summer Range Habitat Preference (CSR_PREF)

The variables *Calving Range* and *Summer Range* were used to determine overall preference for calving and summer range habitats.

Calving Range (CR)

Usability of *Calving Range* was based on the potential of an area to develop a *Predator-Restrictive Snow Pack* that would persist into the calving season and whether the *Slope* was considered useable.

Predator-Restrictive Snow Pack (PRSP)

The potential of an area to develop a predator-restrictive snow pack that would persist into the calving season depends on the ecological factors *Ecological Unit* and *Forest Inventory Group*:

Ecological Unit (ECO)

The vegetated AT and parts of the ESSF (see *Inventory Type Group* below) biogeoclimatic zones ("Veg AT" and "Veg ESSF") were considered sufficient to represent the ecosystem conditions allowing caribou access to predator-restrictive snow packs that persist into the calving season (Appendix A). All other ecosystems within these zones (i.e., areas of talus, gravel, rock, rubble, bare soil, or cliffs), and those from other biogeoclimatic zones, were considered unlikely to provide suitable conditions ("Other").

Inventory Type Group (ITG)

Subalpine fir (*Abies lasiocarpa*) and/or non-forested areas within the ESSF are considered good indicators of cooler, moister ecosystems (MacKinnon et al. [editors] 1992), and are therefore areas that are more likely to retain snow longer into the summer period than those areas dominated by other tree species in this biogeoclimatic zone. Forest *Inventory Type Group* was used to distinguish "balsam" (i.e., subalpine fir) dominated forest types and non-forest types ("BA or Nonfor") and therefore refine the ESSF zone into useable areas of relatively more persistent snow compared with other unusable areas of the same zone ("Other").

The conditional probabilities that were used to configure how the ecological factors *Ecological Unit* and forest *Inventory Type Group* relate to *Predator-Restrictive Snow Pack* are presented in Table 3.9. If ecosystems were part of the AT zone then the potential for predator-restrictive snow packs ("Restrictive") was considered to always occur (P = 100%). If ecosystems were ESSF, then the potential for these snow packs was considered restrictive (P = 80%) only if the forest *Inventory Type Group* indicated the presence of balsam-dominated or non-forested habitat; otherwise the potential was "Unrestrictive" (P = 20%). In any of the remaining other conditions, if balsam-dominated or non-forested habitats occurred, the potential for predator-restrictive snow packs was essentially unknown (P = 50%) and considered unlikely at all if balsam was not present (P = 0%).

Table 3.9. Conditional probabilities (%) used within Netica to configure the relationship between Predator-Restrictive Snow Packs (Restrictive or Unrestrictive) and the ecological factors considered important in predicting where such snow packs could develop: Ecological Unit (Veg AT for vegetated alpine tundra, Veg ESSF for vegetated Engelmann Spruce–Subalpine Fir, or Other for all other ecosystems) and Inventory Type Group (BA or Nonfor for balsam-dominated forests and any non-forest type groups and Other for all other forest type groups). Variable code names are in parentheses.

Ecological Unit (ECO)	Inventory Type Group (ITG)	Predator-Restrictive Snow Packs (PRSP)	
		Restrictive	Unrestrictive
Veg AT	BA or Nonfor	100	0
Veg ESSF	BA or Nonfor	80	20
Other	BA or Nonfor	50	50
Veg AT	Other	100	0
Veg ESSF	Other	20	80
Other	Other	0	100

Slope (SLP)

Identified *Ecological Units* rated as "Useable" could have had high components of steep terrain that are not easily negotiated by caribou, and so *Slope* was used as a means to exclude these steep areas. Northern caribou from the Wolverine herd were found to predominantly use slopes less than 40% (Wood 1996) and so that point was used to distinguish useable slopes ("< 40%") from unusable slopes ("≥ 40%").

The conditional probabilities that were used to configure how the ecological factors *Predator-Restrictive Snow Pack* and *Slope* relate to *Calving Range* are presented in Table 3.10. If a *Predator-Restrictive Snow Pack* developed on slopes less than 40%, then *Calving Range* was certain to be "Useable" (P = 100%) but this certainty dropped significantly (P = 40%) if slope was greater than 40%. Conversely, when snow packs were determined to be unrestrictive to predators, the value of habitat with slopes greater than 40% was always "Unusable" (P = 100%) unless slopes were less than that, in which case the value of habitat for calving was essentially unknown (P = 50%).

Table 3.10. Conditional probabilities (%) used within Netica to configure the relationship between Calving Range Value (Useable or Unusable) and Predator-Restrictive Snow Packs (Restrictive or Unrestrictive) including modifying effects on the latter due to Slope (< 40% or ≥ 40%). Variable code names are in parentheses.

Predator-Restrictive Snow Packs	Slope	Calving Range Value (F)	
(PRSP)	(SLP)	Useable	Unusable
Restrictive	< 40 %	100	0
Restrictive	≥ 40 %	40	60
Unrestrictive	< 40 %	50	50
Unrestrictive	≥ 40 %	0	100

Summary Range (SR)

Summer Range was primarily based on an assessment of an area being able to provide relatively *Open and Cool* or windy climatic conditions, with *Lichen Forage Abundance*, on negotiable *Slopes*.

Open and Cool (OC)

Caribou likely seek ecosystem conditions that provide food, openness, and the cool temperatures and windy conditions necessary to reduce aggravation from flies. These conditions were determined by *Ecological Unit*.

Ecological Unit (ECO)

The AT and parts of the ESSF (see *Inventory Type Group* below) biogeoclimatic zones ("Veg AT" and "Veg ESSF") were considered sufficient to represent the ecosystem conditions sought by caribou that provide food and reduced aggravation from flies. Only the vegetated ecosystems within these zones were considered useable as foraging habitat with all other areas (e.g., rock or cliffs) being considered unusable ("Other"). Classification of *Ecological Units* according to the importance to caribou as summer range habitats is presented in Appendix A.

The conditional probabilities that were used to configure how *Ecological Unit* relates to *Open and Cool* are presented in Table 3.11. If ecosystems were part of the vegetated AT zone then the potential for open and cool habitat ("Open_Cool") was considered to always occur (P = 100%). If ecosystems were vegetated ESSF, then the potential for open and cool habitat was essentially unknown (P = 50%) and considered improbable in all other ecosystems (“Other”) (P = 0%).

Lichen Forage Abundance (LFA)

The potential of an area to provide terrestrial and arboreal lichen species preferred by caribou as forage was determined by the factors *Ecological Unit* and forest *Inventory Type Group*.

Ecological Unit (ECO)

The AT and parts of the ESSF (see *Inventory Type Group* below) biogeoclimatic zones (“Veg AT” and “Veg ESSF”) were considered sufficient to represent the ecosystem conditions sought by caribou that provide adequate forage. Only the vegetated ecosystems within these zones were considered useable with all other areas (e.g., rock or cliffs) being considered unusable (“Other”). Classification of ecological units according to the importance to caribou as summer range habitats is presented in Appendix A.

Inventory Type Group (ITG)

The cooler and moister ecosystems that generally characterize the “balsam”-dominated and/or non-forested areas of the ESSF (“BA or Nonfor”) tend to give rise to a greater abundance of arboreal lichens that are sometimes sought by caribou. By comparison, other parts of the ESSF are relatively devoid of forage (“Other”).

Table 3.11. Conditional probabilities (%) used within Netica to configure the relationship between Open and Cool (Open_Cool or Other) and Ecological Unit (Veg AT for vegetated alpine tundra, Veg ESSF for vegetated Engelmann Spruce–Subalpine Fir, and Other for all other ecosystems). Variable code names are in parentheses.

Ecological Unit	Open and Cool (OC)	
(ECO)	Open_Cool	Other
Veg AT	100	0
Veg ESSF	50	50
Other	0	100

The conditional probability table that was used to configure how the ecological factors *Ecological Unit* and forest *Inventory Type Group* relate to *Lichen Forage Abundance* is presented in Table 3.12. Low-elevation ecological units were generally considered to have some likelihood (P = 40%) of being able to support “Abundant” preferred terrestrial lichens for caribou unless these habitats had a component of balsam (P = 20%). High-elevation habitats by comparison were considered to always (P = 100%) provide abundant preferred terrestrial lichens for caribou unless they were characterized by ESSF ecosystems without balsam-dominated or non-forested *Inventory Type Groups* (P = 20%), such that forage abundance was “Scarce.”

Table 3.12. Conditional probabilities (%) used within Netica to configure the relationship between Lichen Forage Abundance (Abundant or Scarce) and the ecological factors considered important in predicting abundance of that forage: Ecological Unit (Veg AT for vegetated alpine tundra, Veg ESSF for vegetated Engelmann Spruce–Subalpine Fir, and Other for all other ecosystems) and Inventory Type Group (BA or Nonfor for balsam-dominated forests and any non-forest type groups and Other for all other forest type groups). Variable code names are in parentheses.

Ecological Unit (ECO)	Inventory Type Group (ITG)	Lichen Forage Abundance (LFA)	
		Abundant	Scarce
Veg AT	BA or Nonfor	100	0
Veg ESSF	BA or Nonfor	100	0
Other	BA or Nonfor	20	80
Veg AT	Other	100	0
Veg ESSF	Other	20	80
Other	Other	40	60

Slope (SLP)

Identified useable *Ecological Units* could have had high components of steep terrain that are not easily negotiated by caribou, and so *Slope* was used to exclude these steep areas. Northern caribou from the Wolverine herd were found to predominantly use slopes less than 40% (Wood 1996) and so that point was used to distinguish useable slopes ("< 40%") from unusable slopes ("≥ 40%").

The conditional probabilities that were used to configure how the ecological factors *Lichen Forage Abundance, Slope*, and *Open and Cool* relate to *Summer Range* are presented in Table 3.13. When slope exceeded 40%, *Summer Range* was considered "Unusable" (P = 100%) unless this condition existed in open and cool areas associated with AT where there was a small likelihood of the range being "Useable" (P = 20%). By comparison, when slope was less than 40%, forage was abundant, and in open and cool areas associated with AT habitat, the range was completely useable (P = 100%). If this latter condition existed other than in the AT, the likelihood of the habitat being useable dropped considerably (P = 40%). When slope was less than 40% in the AT but food was scarce, it was unlikely that the range was useable (P = 20%).

Table 3.13. Conditional probabilities (%) used within Netica to configure the relationship between Summer Range (Useable or Unusable) for northern caribou and the ecological factors deemed to represent that range: Lichen Forage Abundance (Abundant or Scarce), Percent Slope (< 40% or ≥ 40%), and habitats that were Open and Cool (Open Cool or Other). Variable code names are in parentheses.

Lichen Forage Abundance (LFA)	Slope (SLP)	Open and Cool (OC)	Summer Range (SR)	
			Useable	Unusable
Abundant	< 40 %	Open Cool	100	0
Abundant	< 40 %	Other	40	60
Scarce	< 40 %	Open Cool	20	80
Scarce	< 40 %	Other	0	100
Abundant	≥ 40 %	Open Cool	20	80
Abundant	≥ 40 %	Other	0	100
Scarce	≥ 40 %	Open Cool	0	100
Scarce	≥ 40 %	Other	0	100

Calving and Summer Range Habitat Preference (CSR_PREF) Summary

Calving and Summer Range Habitat Preference was used as a summary node to accumulate estimates of usability for *Calving Ranges* and *Summer Ranges*. The conditional probabilities used to configure preference for these two ranges were simple (Table 3.14). If both ranges were useable then *Calving and Summer Range Habitat Preference* was certain to be "Preferred" (P = 100%) and if both were unusable then the value was certain to be "Avoided" (P = 100%). If only one of the ranges was useable, habitat value was still considered likely to be preferred (P = 75%).

Calving and Summer Range Habitat Value (CSR_VAL) Summary

Preferred calving and summer range habitats had to exist within zones of relatively low risk of predation (see Section 3.1.4, "Determining Risk of Predation") for their value to remain "High" for caribou (Table 3.15). Although some predation occurs in these zones, it was assumed to have a natural, but relatively low-level, underlying effect on habitat value. Avoided habitats were always (P = 100%) "Low" value regardless of the risk of predation. Preferred habitats were always (P = 100%) "High" value under low predation risk conditions, but in the presence of high predation risk was considered to have lost 90% of its value resulting in a complete (P = 100%) "Low" habitat value. By comparison, it is likely that habitat value would be "Moderate" if the same preference was exhibited under a medium risk of predation.

Table 3.14. Conditional probabilities (%) used within Netica to configure the relationship between Calving and Summer Range Habitat Preference (Preferred or Avoided) exhibited by northern caribou as and the useability of the two range types deemed to represent those outcomes: Calving Range (Useable or Unusable) and Summer Range (Useable or Unusable). Variable code names are in parentheses.

Calving Range (CR)	Summer Range (SR)	Calving and Summer Range Habitat Preference (CSR_PREF)	
		Preferred	Avoided
Useable	Useable	100	0
Useable	Unusable	75	25
Unusable	Useable	75	25
Unusable	Unusable	0	100

Table 3.15. Conditional probabilities (%) used within Netica to configure the relationship between Calving and Summer Range Habitat Value (High, Moderate, Low) and the ecological factors deemed to represent those values: Calving and Summer Range Habitat Preference (Preferred or Avoided) and Habitat Value Reduction (No Reduced Value, 50% Reduced Value, or 90% Reduced Value). Variable code names are in parentheses.

Habitat Value Reduction (RISK)	Calving and Summer Range Habitat Preference (CSR_PREF)	Calving and Summer Range Habitat Value (CSR_VAL)		
		High	Moderate	Low
No Reduced Value	Preferred	100	0	0
No Reduced Value	Avoided	0	0	100
50% Reduced Value	Preferred	0	100	0
50% Reduced Value	Avoided	0	0	100
90% Reduced Value	Preferred	0	0	100
90% Reduced Value	Avoided	0	0	100

3.2.4 Assumptions

- Generally, there is some maximum slope beyond which caribou are unable to negotiate terrain easily; that maximum was arbitrarily chosen to be 40%.
- Anti-predator tactics dominate the selection of habitats by caribou during calving; as a result, the habitat feature of most importance at this time of year is predator-restrictive snow packs wherever these occur.

- Summer habitat is selected on the basis of both anti-predator tactics (open habitat to increase success of vigilance, dispersing to low density to decrease detection by wolves), abundance of preferred forage, and reduced potential for being harassed by bugs.
- Anti-predator tactics were assumed to prevail regardless of predator population dynamics.
- For this range type it was assumed that food is not limiting, these areas will not be logged, and the major factor in determining use of habitat is the risk of predation.

3.2.5 Management Factors and Options

Few opportunities or options for management of the ecological factors exist to determine habitat value as calving and summer range for northern caribou. Nevertheless, the spatial location and extent of these ranges have impact on the potential for successful management of other seasonal ranges (e.g., Pine–Lichen Winter Range). Exploration for, or development of, mining sites may remove some habitat directly, but usually this exploration occurs infrequently across the landscape. Successful mining sites, however, do eliminate significant amounts of calving and summer range locally.

More significant regional effects on calving and summer range occur indirectly from the increased predation risk through development of roads and/or logging adjacent to these habitat types.

3.2.6 Summary and Anticipated Model Development

During the spring calving season and summer, northern caribou are typically found at low densities in high elevations in the upper ESSF or AT biogeoclimatic zones, where the potential snow barrier reduces their risk of predation by wolves. This range type was characterized by the *Ecological Unit*, *Inventory Type Group*, and *Slope*, which in turn defined whether *Predator-Restrictive Snow Pack*, *Lichen Forage Abundance*, and *Open and Cool* areas were reducing aggravation from flies. As with all range types, the overall habitat value was reduced according to the level of predation risk present, determined from the Moose Winter/Summer Density model inputs for calculating *Habitat Value Reduction*.

One factor that may be considered in future models is a more sophisticated combination of the calving and summer range types.

3.2.7 Literature Cited

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3.3 PINE–LICHEN WINTER RANGE

3.3.1 Introduction

The Pine–Lichen Winter Range (PLWR) model characterizes habitat used by northern caribou in terms of the relative preference they demonstrate for specific conditions during winter. Pine–lichen woodlands provide important foraging opportunities when snow conditions are favourable. The lichens used in these stands are often referred to as reindeer lichens. In the north-central B.C., *Cladina mitis*, *Cladina rangiferina*, *Cladonia uncialis,* and *Cladonia ecmocyna* dominate the reindeer lichen functional group. The presence of these lichens within a vegetation complex is a product of vegetation succession on dry sites (Coxson et al. 1999). This succession trend is consistent with other lichen woodlands situated throughout Canada (Maikawa and Kershaw 1976; Carroll and Bliss 1982; Payette et al. 2000).

The presence of terrestrial lichens at a site is largely related to the absence of other vegetation, such as bryophytes and vascular plants. Unlike most other forms of vegetation, lichens do not have roots; rather, they gather resources from the atmosphere (Rowe 1984). To anchor, lichens simply require a suitable microsite as a growing substrate. Though lichens can survive with limited resources, their ability to compete is very poor (Grime 1977). If growing conditions can support competing plants, lichen presence quickly declines.

Crawley (1997) identified that a plant's distribution can be viewed as a refuge from competitors or enemies; it is not that a site provides the "ideal environmental conditions" for the plant to grow. This concept holds true for defining the ecological niche of terrestrial lichens. These lichens are generally present on a site not because they outcompete other forms of vegetation, but because other forms of vegetation cannot persist under the harsh environmental conditions. Due to the lack of a relationship with the growing substrate, and the poor competitive ability of lichens, their success is inversely related to the productivity of a site.

Much of the work that has been conducted on terrestrial lichen ecology has focused on identifying the successional trends of sites that have been influenced by wildfire (Maikawa and Kershaw 1976; Johnson 1981; Carroll and Bliss 1982; Morneau and Payette 1988; Bruelisauer et al. 1996; Coxson et al. 1999). The effects of mechanical disturbance on lichen development are poorly documented. In general, succession of lichens is attributed to changes in the wetting and drying events that occur at the forest floor, which result from corresponding changes in the forest overstorey stand dynamics. Older pine–lichen woodlands subsequently provide conditions that can support competing plants (Lesica et al. 1990; Bruelisauer et al. 1996). Changes in organic matter accumulation that occur at the forest floor are also important when considering the microsite features that are suitable for terrestrial lichens (Steijlen et al. 1994). In general, over time, more favourable microsite conditions are produced from organic matter accumulations providing opportunities for competing vegetation to become established.

3.3.2 Ecological Factors Considered

The Pine–Lichen Winter Range model was developed to predict the value of an area as pine–lichen winter range based on the ecological features of a site and the forestry treatments conducted there. The ecological features of this model are grouped into four core elements:

- **Capability of supporting terrestrial lichens.** This element is used to define the stand-level features required at a site to support a terrestrial lichen community. It is based on the terrain, vegetation community, and edatopic factors of the location.
- **Stand characteristics.** This element provides an avenue to present the relationship of solar radiation penetration through the forest overstorey and its corresponding effect on the succession of terrestrial lichen communities. This element considers the variable influence of crown development (closure) as it changes with aging stands.
- **Forest floor characteristics.** This element addresses the relationships of disturbance history and the influence that the growing medium has on the developing terrestrial lichen community. It considers the method and season of disturbance and the debris loading level caused by the event.
- **Utility of the stand for caribou use.** This element reflects on usability of lichen communities for caribou use. It considers the influence of both snow conditions and predation.

3.3.3 Description of Model Components

Pine–Lichen Winter Range Habitat Value (PLWR_VAL)

To calculate *Pine–Lichen Winter Range Habitat Value (PLWR_VAL)*, habitat preference for the range by caribou was estimated, then the *Habitat Value Reduction (RISK)* was determined according to the potential risk of predation by wolves (see Section 3.1.4, "Determining Risk of Predation") (Figure 3.3). *Pine–Lichen Winter Range Habitat Preference (PLWR_PREF)* was based on the *Terrestrial Lichen Forage Availability (PLWR_TLFA)* during winter where a *Habitat Availability Reduction (HAR)* from an original abundance estimate was implemented as potential for deep snow increased. In this model, both *Elevation (ELE)* and *Biogeoclimatic Variant (BGC)* were used as a proxy for deep snow (Bunnell *et al*. 1985, Meidinger and Pojar 1991). The abundance of terrestrial lichens as a forage resource for caribou was a function of *Terrestrial Lichen Habitat Capability (TLHC)* and the effects on *Stand Characteristics (SC)* and *Forest Floor Characteristics (FFC)* resulting from natural or managed disturbances to the site. *Aspect (ASP)*, the amount of lodgepole pine present at the site (*Stand Percent Pine [PINE]*), and *Ecological Unit (ECO)* were used to determine the capability of an area to support terrestrial lichens. *Stand Characteristics* were estimated based on the tree seedling *Stocking (STOK)* density at the site and the *Stand Age (SA)*, as older and denser forests tend to have closed canopies allowing for the establishment of mosses. *Forest Floor Characteristics* represent the ability of a site to support terrestrial lichens after a disturbance, as determined by *Stand Age (SA)*, *Debris Loading (DL),* and *Organic Matter Disturbance (OMD)*. Organic matter disturbance was a function of the type of *Stand Removal (REM)*, *Site Preparation (PREP)*, and *Season of Removal (RSEA)*.

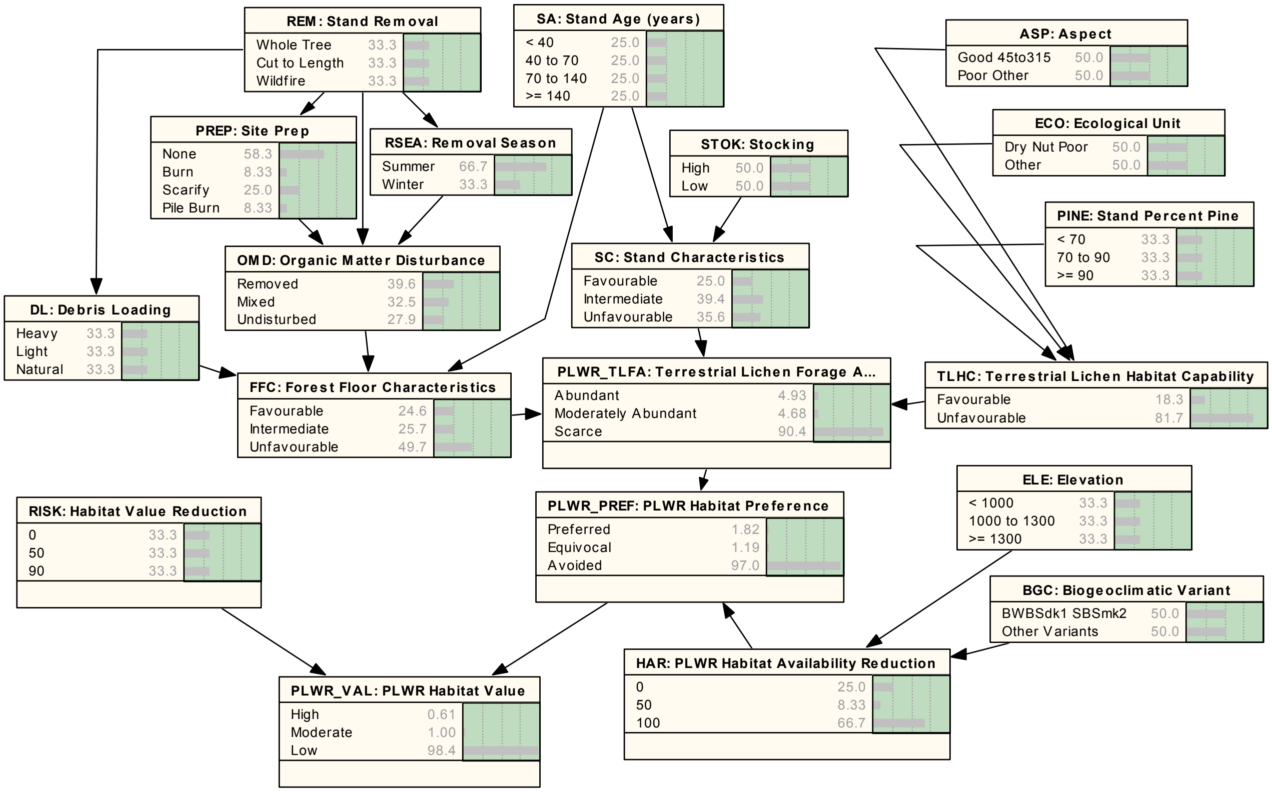

Figure 3.3. **Ecological factors and relationships characterizing preference for pine–lichen winter ranges by northern caribou in north-central British Columbia.**

Pine–Lichen Winter Range Habitat Preference (PLWR_PREF)

The *Pine–Lichen Winter Range Habitat Preference* exhibited by caribou for sites with differing states of *Terrestrial Lichen Forage Abundance* was modified based on availability of the forage lichens, where availability was considered to be restricted by deep snow conditions.

Terrestrial Lichen Forage Abundance (PLWR_TLFA)

The abundance of terrestrial lichen types used as forage by caribou was influenced by *Terrestrial Lichen Habitat Capability*, *Stand Characteristics*, and *Forest Floor Characteristics*.

Terrestrial Lichen Habitat Capability (TLHC)

Pine–lichen woodlands have distinct characteristics that can be used to identify their presence on the landscape. These characteristics are expressed as variables in several inventory databases and are used to identify the *Terrestrial Lichen Habitat Capability* of a site.

Reindeer lichens are commonly found on south or flat aspect sites that have xeric, nutrient poor soils, and forest overstoreys dominated by lodgepole pine (Ahti 1977; Johnson 1981; Rowe 1984; Stevenson 1991; Cichowski 1993).

Aspect (ASP)

Direct sunlight is an important factor related to the severity of drying events at a microsite. In a study of pine stands in the Omineca, lichen presence in pine stands had a strong association with south aspect sites (Sulyma and Coxson 2001). The digital elevation model from Terrain Resource Inventory Mapping (TRIM) data was used to identify the topography of polygons. Suitable sites had either an aspect between 45 and 315°, or another aspect but had a slope less than 5% ("Good 45to315"). All other conditions were considered to be unsuitable for caribou ("Poor Other").

Stand Percent Pine (PINE)

The tree species that dominates the overstorey is an important factor in identifying where terrestrial lichens will grow. In the Omineca, terrestrial lichens are typically associated with sites that have a percent composition of lodgepole pine that is greater than 94% (Sulyma 2001). Using this value as a threshold, forest cover and the associated attribute information were used to delineate pine sites from others. The threshold for the composition of lodgepole pine was therefore set at 90%, where stands with greater than 90% pine were considered optimal for supporting lichens ("≥ 90"), stands between 70 and 90% were moderate ("70–90"), and stands with less than 70% pine were poor ("< 70").

Ecological Unit (ECO)

Ecological Unit was used to classify Terrestrial Ecosystem Mapping (TEM) and Predictive Ecosystem Mapping (PEM) information based on site series. Pine–lichen woodlands are associated with sites that are drier and more nutrient-poor ("Dry Nutrient-Poor") than zonal sites for the biogeoclimatic zone they are in or other site series ("Other"). A panel of biologists coded source information into either of these states based on the position of the site series on the edatopic grid (Meidinger and Pojar 1991) and on the plant associations that are found with them. Classification of ecological units according to their importance to caribou as having lichen habitat capability is presented in Appendix A. For areas where TEM/PEM data were not available, decisions about ecological unit ratings were based on available geographic and forest cover data (Appendix B).

The conditional probabilities that were used to configure how the three ecological factors *Aspect, Ecological Unit,* and *Stand Percent Pine* relate to *Terrestrial Lichen Habitat Capability* are presented in Table 3.16. The resulting states in the model were either "Favourable" or "Unfavourable." The ecological unit was assigned the greatest influence in the determination of the values in the conditional probability table. Dry and nutrient-poor polygons were ranked higher than other ecological units. Likewise, sites with a good aspect were considered more likely to support a terrestrial lichen community than other aspect sites. Sites containing more than 90% lodgepole pine were purported to have more favourable conditions for lichen than those with less than 90% pines.

Within the conditional probability table, polygons identified with favourable attributes for all three variables were rated as favourable *Terrestrial Lichen Habitat Capability* (P = 90%). Polygons with unfavourable attributes for all three variables were rated as having a 100% likelihood of having an unfavourable *Terrestrial Lichen Habitat Capability*. Trends for the intermediate values were prepared based on the influence of each environmental factor as they are ranked in importance above.

Table 3.16. Conditional probabilities used within Netica to configure the relationship between Terrestrial Lichen Habitat Capability (Favourable or Unfavourable) and the ecological factors deemed to influence those values: Aspect (Good or Poor), Stand Percent Pine (< 70%, 70–90%, or > 90% lodgepole pine), and Ecological Unit (Dry-Nutrient Poor or Other). Variable code names are in parentheses.

Aspect	Stand Percent Pine	Ecological Unit	Terrestrial Lichen Habitat Capability (TLHC)	
(ASP)	(PINE)	(ECO)	Favourable	Unfavourable
Good	< 70	Dry Nut-Poor	0	100
Good	< 70	Other	0	100
Good	70–90	Dry Nut-Poor	50	50
Good	70–90	Other	10	90
Good	≥ 90	Dry Nut-Poor	90	10
Good	≥ 90	Other	20	80
Poor	< 70	Dry Nut-Poor	0	100
Poor	< 70	Other	0	100
Poor	70–90	Dry Nut-Poor	10	90
Poor	70–90	Other	0	100
Poor	≥ 90	Dry Nut-Poor	30	70
Poor	≥ 90	Other	10	90

Stand Characteristics (SC)

Stand Characteristics express the impacts of the forest overstorey on the microclimate conditions of a site. A primary factor that changes the structure of a lichen community is the moderation of drying events at a microsite (Sulyma and Coxson 2001). Large trees and high density stands are effective at intercepting solar radiation resulting in microclimate conditions that can support bryophytes and vascular plants. By contrast, the more open a stand and the shorter the trees within it, the greater the irradiance at the forest floor and the better the conditions for terrestrial lichens. *Stocking* and *Stand Age* determine these attributes.

> *Stocking (STOK)*
>
> The density of a stand has the potential to modify the presence of reindeer lichen species at a site. A very high stocking density can result in high levels of shading and litterfall, which are counterproductive for lichen development ("High"). Thus, stands managed to restrict full crown closure, or in other words, stands with a lower density and patchy stocking pattern will promote lichen growth over stands with a very high uniform density ("Low").
>
> *Stand Age (SA) as Related to Stand Characteristics*
>
> *Stand Age* represents the size of trees and the impacts of a maturing overstorey on lichen development. The age-class breakdown applied was based on the developmental phases of lichen woodlands for the Omineca Region, as identified by Coxson et al. (1999) and Coxson and Marsh (2001). Lichen woodland stands are typically less than 140 years old and have open overstoreys that do not promote the growth of vascular plants and bryophytes. In these stands, the small trees ("< 40 years") have very little influence on microsite environmental conditions. As trees age, changes in canopy architecture (specifically increases in tree canopy size) modify the microclimate at the forest floor (Sulyma and Coxson 2001). From 40 to 70 years ("40–70"), growing conditions for lichens are good, yet the site microclimate is sufficiently harsh that it precludes the development of bryophytes and vascular plants. These conditions persist until 140 years, with the optimal age class for lichen development in a stand being "70–140" years. As stands exceed 140 years of age ("≥ 140"), however, their increased size intercepts significant amounts of solar radiation and reduces the severity of drying events. This creates favourable conditions for competing vegetation and reduces the availability of terrestrial lichens.

The conditional probabilities that were used to configure how the ecological factors *Stocking* and *Stand Age* relate to *Stand Characteristics* are presented in Table 3.17. Stand age had a strong influence on the probability estimates, whereas the influence of the stocking node was relatively minor due to the present lack of information available to define both the influence and the threshold that should be applied in the definition of high versus low stocking. The values in the conditional probability table strongly reflect trends of the natural patterns of succession of terrestrial lichens. Young stands less than 40 years were ranked as "Unfavourable" to "Intermediate" in their ability to provide suitable *Stand Characteristics* for terrestrial lichen communities. As stands reached 70 to 140 years old, however, they were rated as providing the most "Favourable" conditions. Stands older than 140 years were rated as the most unfavourable.

Forest Floor Characteristics (FFC)

Forest Floor Characteristics provide an assessment of the suitability of the growing medium for lichen development. Suitability required a long-term view and may not be realized from one rotation to the next; however, changes would be noticed when assessed over several stand rotations. This node expressed the results of disturbance events to the forest floor organic layer (*Organic Matter Disturbance*), as well as the influence of *Debris Loading* and *Stand Age*.

Table 3.17. Conditional probabilities used within Netica to configure the relationship between Stand Characteristics (Favourable, Intermediate, or Unfavourable) and the ecological factors deemed to influence those values: Stocking (High or Low) and Stands Age (< 40 yr, 40–70 yr, 70–140 yr, or > 140 yr). Variable code names are in parentheses.

Stocking	Stand Age	Stand Characteristics (SC)		
(STOK)	(SA) (yr)	Favourable	Intermediate	Unfavourable
High	< 40	0	10	90
High	40–70	20	60	20
High	70–140	55	30	15
High	> 140	10	55	35
Low	< 40	0	20	80
Low	40–70	30	60	10
Low	70–140	70	20	10
Low	> 140	15	60	25

Organic Matter Disturbance (OMD)

Each disturbance state of the organic matter has a different influence on the suitability of the site for the establishment of vegetation communities. The suitability was influenced by three primary factors: the *Stand Removal* process, the type of *Site Preparation* conducted, and the *Removal Season* in which the harvesting occurred.

Stand Removal (REM)

Three *Stand Removal* methods were recognized: “Whole-Tree,” “Cut-to-Length,” and “Wildfire.” Each of these had dissimilar influences on the four different nodes that *Stand Removal* feeds into. Whole-tree and cut-to-length harvest methods refer to mechanical disturbance processes and indicate how logs are processed and removed from a cutblock. Wildfire was considered the natural stand disturbance process for pine–lichen woodlands.

With the whole-tree harvest system, the assumption was made that trees will be felled and skidded (dragged) to a roadside or landing, and then processed. This method has the potential to create the greatest level of forest floor disturbance relative to the other two processes, by creating a “Mixed” organic layer. In a cut-to-length system, trees are felled and processed on site. Logs are then forwarded (carried) to the roadside; thus, this method should result in less disturbance to the forest floor than the whole-tree method. Wildfire, on the other hand, reduces the accumulations of organic debris without mixing it into the mineral soil substrates, resulting in two possible states: organic matter “Removed” or organic matter “Undisturbed.”

Site Preparation (PREP)

Four *Site Preparation* treatments were considered as possible options for application in pine–lichen woodlands: “Burn,” “Scarify,” “Pile and Burn,” and “None” (no treatment). The *Stand Removal* process used in a polygon heavily influences which site preparation treatment is used. For example, it is not possible to pile and burn if a whole-tree stand removal system is used because the debris left after harvesting would not be considered adequate to support such a treatment. Within the conditional probability table that was used to configure how stand removal treatments relate to site preparation options, combinations that are impossible were assigned a null (X) value. The remaining treatments are assigned an equal likelihood of occurring (Table 3.18).

Table 3.18. Conditional probabilities used within Netica to configure the relationship between Site Preparation (None, Burn, Scarify, or Pile and Burn) and Stand Removal type (Whole-Tree, Cut-to-Length, or Wildfire). Variable code names are in parentheses.

Stand Removal	Site Preparation (PREP)			
(REM)	None	Burn	Scarify	Pile and Burn
Whole-Tree	50	X	50	X
Cut-to-Length	25	25	25	25
Wildfire	100	X	X	X

Removal Season (RSEA)

Removal Season modifies the impacts of the *Stand Removal* event, thus, influencing the outcome of the *Organic Matter Disturbance*. There is less disturbance from mechanical activities during “Winter,” when the snow pack protects the forest floor, than during “Summer.” Stand removal by wildfire was not considered an option for the winter state. The conditional probabilities that were used to configure how *Stand Removal* treatments relate to *Removal Season* are presented in Table 3.19.

Table 3.19. Conditional probabilities used within Netica to configure the relationship between Removal Season (Summer or Winter) and Stand Removal type (Whole-Tree, Cut-to-Length, or Wildfire). Variable code names are in parentheses.

Stand Removal	Removal Season (RSEA)	
(REM)	Summer	Winter
Whole-Tree	50	50
Cut-to-Length	50	50
Wildfire	100	X

The conditional probabilities that were used to configure how the ecological factors *Stand Age, Stand Removal, Site Preparation,* and *Removal Season* relate to the overall state of the *Organic Matter Disturbance* are presented in Table 3.20. The three states of organic matter expressed in this node are “Removed,” “Mixed,” or “Undisturbed,” each of which has a different impact on the development of terrestrial lichen communities.

Removing the organic matter from a microsite is considered the natural process. It can occur by burning off the accumulated organics on the forest floor, or it can be the outcome from a mechanical process (e.g., scalping by machines). Regardless of how it occurs, removal results in exposed mineral soil, creating conditions that should be favourable to support the natural development of plant and lichen communities within pine–lichen woodlands.

Mixing organic matter into the mineral soil substrates has the most detrimental impacts of the three states identified. Mixed (and decomposed) organic matter has the potential to enrich the nutrient regime and improve the moisture holding capacity of the mineral soil. This creates favourable conditions for vascular plants and bryophytes, which outcompete lichens. The undisturbed state of organic matter provides a neutral condition. Over one or two tree rotations, undisturbed organic matter may provide suitable conditions for lichen community development; however, as the organic matter accumulates over time, similar results as proposed for mixing may occur.

Debris Loading (DL)

Debris Loading was determined by the relationship between the slash accumulation and the stand removal process. A panel of professionals involved in an adaptive management project assessing forestry impacts on terrestrial lichen communities developed the relationships expressed in this node (Table 3.21). The whole-tree removal process was considered to create "Light" debris (slash) loading since trees were removed from the site to be processed, whereas cut-to-length harvesting resulted in "Heavy" loading because trees were processed directly on the site. Wildfire was considered to create "Natural" levels of loading, the lightest of the three states. On a lichen site, debris loading from a disturbance event is considered to have a detrimental impact on the lichen community, as lichens are buried under slash and cannot survive (Webb 1998; Miege et al. 2001).

Stand Age (SA) as Related to Forest Floor Characteristics

Stand Age is an important factor related to the rate of recovery of reindeer lichen communities. For example, in the Omineca after a mechanical disturbance, lichens may recover to a pre-disturbed state within 20 years (Webb 1998; Sulyma 2001). However, after a wildfire, recovery to a similar state may take as long as 70 years. Four states were identified for this node: "< 40," "40–70," "70–140," and "> 140" years of age, as described previously in the "Stand Age as Related to Forest Floor Characteristics" section. These categories were based on chronosequence information for the Omineca region (Coxson et al. 1999).

The conditional probabilities that were used to configure how the ecological factors *Organic Matter Disturbance, Stand Age,* and *Debris Loading* relate to the overall state of the *Forest Floor Characteristics* and its capability for the development of lichen communities are presented in Table 3.22. The values expressed for this node are "Favourable," "Intermediate," and "Unfavourable." Stand age was considered the most influential factor in this relationship. This is particularly important when considering the effects of the removed and undisturbed organic matter states. Removing organic matter results in a lichen community that develops in the same way as that found in natural disturbance regimes. In the Omineca, this means reindeer lichens are most dominant in 70- to 140-year-old stands. In contrast, sites that have little disturbance tend to have a high cover of reindeer lichens much sooner in the development of the stand. The mixed organic matter disturbance state has been identified to create the most detrimental condition for terrestrial lichens; likewise, debris loading is also considered to have strong negative impacts. With these corners defined, trends were applied to define the "Intermediate" variable combinations.

The integration of information about *Terrestrial Lichen Habitat Capability*, *Stand Characteristics,* and *Forest Floor Characteristics* provides an estimate of the value of a polygon as pine–lichen winter range habitat. The conditional probabilities that were used to configure how these three ecological factors relate to *Terrestrial Lichen Forage Abundance* are presented in Table 3.23. All combinations that include unfavourable lichen habitat capability were assigned 100% probability of having "Scarce" forage lichens. The optimal combination containing favourable values was assigned 100% probability of having "Abundant" forage lichens. With these corners defined, trends were applied to define the intermediary ("Moderately Abundant") variable combinations.

Table 3.20. **Conditional probabilities used within Netica to configure the relationship between Organic Matter Disturbance (Removed, Mixed, or Undisturbed) and Site Preparation (None, Burn, Scarify, or Pile And Burn), Stand Removal type (Whole-Tree, Cut-to-Length, or Wildfire) and Removal Season (Summer or Winter). Variable code names are in parentheses.**

Site Preparation (PREP)	Stand Removal (REM)	Removal Season (RSEA)	Organic Matter Disturbance (OMD)		
			Removed	Mixed	Undisturbed
None	Whole-Tree	Summer	0	40	60
None	Whole-Tree	Winter	0	10	90
None	Cut-to-Length	Summer	0	30	70
None	Cut-to-Length	Winter	0	10	90
None	Wildfire	Summer	90	0	10
None	Wildfire	Winter	X	X	X
Burn	Whole-Tree	Summer	X	X	X
Burn	Whole-Tree	Winter	X	X	X
Burn	Cut-to-Length	Summer	55	25	20
Burn	Cut-to-Length	Winter	75	5	20
Burn	Wildfire	Summer	X	X	X
Burn	Wildfire	Winter	X	X	X
Scarify	Whole-Tree	Summer	0	90	10
Scarify	Whole-Tree	Winter	0	90	10
Scarify	Cut-to-Length	Summer	0	90	10
Scarify	Cut-to-Length	Winter	0	90	10
Scarify	Wildfire	Summer	X	X	X
Scarify	Wildfire	Winter	X	X	X
Pile_Burn	Whole-Tree	Summer	X	X	X
Pile_Burn	Whole-Tree	Winter	X	X	X
Pile_Burn	Cut-to-Length	Summer	50	35	15
Pile_Burn	Cut-to-Length	Winter	50	35	15
Pile_Burn	Wildfire	Summer	X	X	X
Pile_Burn	Wildfire	Winter	X	X	X

Table 3.21. **Conditional probabilities used within Netica to configure the relationship between Debris Loading (Heavy, Light, or Natural) and Stand Removal type (Whole-Tree, Cut-to-Length, or Wildfire). Variable code names are in parentheses.**

Stand Removal (REM)	Debris Loading (DL)		
	Heavy	Light	Natural
Whole-Tree	0	100	0
Cut-to-Length	100	0	0
Wildfire	0	0	100

Table 3.22. Conditional probabilities used within Netica to configure the relationship between Forest Floor Characteristics (Favourable, Intermediate, or Unfavourable) and Organic Matter Disturbance (Removed, Mixed, Undisturbed), Stand Age (< 40, 40–70, 70–140, or > 140), and Debris Loading (Heavy, Light, or Natural). Variable code names are in parentheses.

Organic Matter Disturbance (OMD)	Stand Age (SA) (yr)	Debris Loading (DL)	Forest Floor Characteristics (FFC)		
			Favourable	Intermediate	Unfavourable
Removed	< 40	Heavy	0	0	100
Removed	< 40	Light	X	X	X
Removed	< 40	Natural	0	0	100
Removed	40–70	Heavy	0	40	60
Removed	40–70	Light	X	X	X
Removed	40–70	Natural	0	50	50
Removed	71–140	Heavy	60	15	25
Removed	71–140	Light	X	X	X
Removed	71–140	Natural	75	20	5
Removed	> 140	Heavy	15	35	50
Removed	> 140	Light	X	X	X
Removed	> 140	Natural	15	35	50
Removed	< 40	Heavy	5	25	70
Mixed	< 40	Light	15	25	60
Mixed	< 40	Natural	X	X	X
Mixed	40–70	Heavy	15	25	60
Mixed	40–70	Light	20	25	55
Mixed	40–70	Natural	X	X	X
Mixed	71–140	Heavy	20	20	60
Mixed	71–140	Light	25	25	50
Mixed	71–140	Natural	X	X	X
Mixed	> 140	Heavy	5	15	80
Mixed	> 140	Light	10	20	70
Mixed	> 140	Natural	X	X	X
Undisturbed	< 40	Heavy	30	25	45
Undisturbed	< 40	Light	35	30	35
Undisturbed	< 40	Natural	35	30	35
Undisturbed	40–70	Heavy	45	30	25
Undisturbed	40–70	Light	60	25	15
Undisturbed	40–70	Natural	60	25	15
Undisturbed	71–140	Heavy	45	35	20
Undisturbed	71–140	Light	65	25	10
Undisturbed	71–140	Natural	65	25	10
Undisturbed	> 140	Heavy	15	35	50
Undisturbed	> 140	Light	15	35	50
Undisturbed	> 140	Natural	15	35	50

Table 3.23. **Conditional probabilities used within Netica to configure the relationship between Terrestrial Lichen Forage Abundance (Abundant, Moderately Abundant, Scarce) and the ecological factors deemed to influence those values: Stand Characteristics (Favourable, Intermediate, or Unfavourable), Terrestrial Lichen Habitat Capability (Favourable, or Unfavourable), and Forest Floor Characteristics (Favourable, Intermediate, or Unfavourable). Variable code names are in parentheses.**

Stand Characteristics (SC)	Terrestrial Lichen Habitat Capability (TLHC)	Forest Floor Characteristics (FFC)	Terrestrial Lichen Forage Abundance (PLWR_TLFA)		
			Abundant	Moderately Abundant	Scarce
Favourable	Favourable	Favourable	100	0	0
Favourable	Favourable	Intermediate	35	40	25
Favourable	Favourable	Unfavourable	10	35	55
Favourable	Unfavourable	Favourable	0	0	100
Favourable	Unfavourable	Intermediate	0	0	100
Favourable	Unfavourable	Unfavourable	0	0	100
Intermediate	Favourable	Favourable	75	25	0
Intermediate	Favourable	Intermediate	20	50	30
Intermediate	Favourable	Unfavourable	0	20	80
Intermediate	Unfavourable	Favourable	0	0	100
Intermediate	Unfavourable	Intermediate	0	0	100
Intermediate	Unfavourable	Unfavourable	0	0	100
Unfavourable	Favourable	Favourable	65	35	0
Unfavourable	Favourable	Intermediate	15	50	35
Unfavourable	Favourable	Unfavourable	0	10	90
Unfavourable	Unfavourable	Favourable	0	0	100
Unfavourable	Unfavourable	Intermediate	0	0	100
Unfavourable	Unfavourable	Unfavourable	0	0	100

Pine–Lichen Winter Range Habitat Availability Reduction (HAR)

Deep snow can render forage lichens unavailable to caribou because the energetic cost of moving around to find the lichens and digging through the snow to access them exceeds the benefit from doing so. At these times, caribou seek abundant lichens that occur in areas of comparably shallower accumulations of snow. *Elevation* was used as a proxy variable to predict these areas because snow depths are generally directly related to increasing elevations (Bunnell *et al.* 1985); snowfall begins earlier in the winter at higher elevations due to colder temperatures. However, local variations due to topography make elevation incomplete as a proxy for snow conditions, and so *Biogeoclimatic Variant* was added to complete the prediction. Two variants in particular (i.e., BWBSdk1 and SBSmk2) have long-term records of generally having less snow than other surrounding variants (Meidinger and Pojar 1991).

Elevation (ELE)

The three elevation classes used to represent likelihood of different snow accumulations were "< 1000 m," "1000–1300 m," and "> 1300 m." High-elevation sites were expected to have greater accumulation of snow over the winter compared with low-elevation sites, thereby restricting caribou from accessing terrestrial lichens. When snow depths exceed 1 m, or as layers of ice accumulate through the snow profile, the ability for caribou to dig or crater for food is greatly reduced (Brown and Theberge 1990). It was assumed, therefore, that snow above 1300 m would completely restrict the availability of forage lichens for caribou (i.e., 100% reduction factor). By comparison, the area below 1000 m had no reduction factor placed on the availability of forage lichens.

Biogeoclimatic Variant (BGC)

The BWBSdk1 and SBSmk2 (“BSBSdk1 SBSmk2”) have been reported as two subzone variants with significantly milder winter weather and shallow snow accumulations relative to other ecological subzone variants in the area (Meidinger and Pojar 1991). All other subzone variants (“Other Variants”) were therefore determined to restrict the availability of terrestrial lichens to caribou, and therefore were “Avoided” by caribou, even if lichens were abundant.

The conditional probabilities that were used to configure how the ecological factors *Elevation* and *Biogeoclimatic Variant* relate to the overall *Pine–Lichen Winter Range Habitat Availability Reduction* are presented in Table 3.24.

Table 3.24. Conditional probabilities used within Netica to configure the relationship between percent Pine–Lichen Winter Range Habitat Availability Reduction (0, 50, 100) and the ecological factors determined to represent that reduction: Elevation (< 1000 m, 1000–1300 m, and > 1300 m) and Biogeoclimatic Variant (BWBSdk1 SBSmk2, Other Variants). Variable code names are in parentheses.

Biogeoclimatic Variant (BGC)	Elevation (ELE)	Pine–Lichen Winter Range Habitat Availability Reduction (HAR)		
		0	**50**	**100**
BWBSdk1 SBSmk2	< 1000 m	100	0	0
BWBSdk1 SBSmk2	1000–1300m	50	50	0
BWBSdk1 SBSmk2	≥ 1300 m	0	0	100
Other Variants	< 1000 m	0	0	100
Other Variants	1000–1300 m	0	0	100
Other Variants	≥ 1300 m	0	0	100

Pine–Lichen Winter Range Habitat Preference (PLWR_PREF) Summary

The preference that a caribou may exhibit for a site was modified by the *PLWR Habitat Availability Reduction* caused by snow conditions and the *Terrestrial Lichen Forage Abundance*. The conditional probabilities that were used to configure how these ecological factors relate to *PLWR Habitat Availability Reduction* are presented in Table 3.25. Where lichens were abundant and available, *PLWR Habitat Preference* was certain to be “Preferred” (P = 100%), and in all areas where availability was reduced by 100% or lichens were scarce, then habitat was certain to be “Avoided” (P = 100%). If availability was reduced by 50% and lichens were either abundant or moderately abundant, habitat was considered to be neither preferred nor avoided (“Equivocal”) (P = 100%).

Pine–Lichen Winter Range Habitat Value (PLWR_VAL) Summary

Preferred pine–lichen winter range habitats had to exist within zones of relatively low risk of predation to be of “High” value to northern caribou (Table 3.26). Avoided habitats were always (P = 100%) “Low” value regardless of the risk of predation. Likewise, all habitats in the presence of high predation risk were considered to have lost 90% of their value resulting in a complete (P = 100%) classification of “Low” habitat value. By comparison, northern caribou responded “Moderately” (P = 100%) to preferred habitats under a medium risk of predation, or to equivocal habitats with no risk of predation.

Table 3.25. **Conditional probabilities used within Netica to configure the relationship between PLWR Habitat Preference by northern caribou (Preferred, Equivocal, or Avoided) and the ecological factors deemed to influence those values: Terrestrial Lichen Forage Abundance (Abundant, Moderately Abundant, or Scare) and PLWR Habitat Availability Reduction to northern caribou (0%, 50%, or 100% reduction in habitat availability). Variable code names are in parentheses.**

Terrestrial Lichen Forage Abundance (TLFA)	PLWR Habitat Availability Reduction (HAR)	Pine–Lichen Winter Range Habitat Preference (PLWR_PREF)		
		Preferred	Equivocal	Avoided
Abundant	0% Reduced Availability	100	0	0
Abundant	50% Reduced Availability	0	100	0
Abundant	100% Reduced Availability	0	0	1000
Moderately Abundant	0% Reduced Availability	0	100	0
Moderately Abundant	50% Reduced Availability	0	0	100
Moderately Abundant	100% Reduced Availability	0	0	100
Scarce	0% Reduced Availability	0	0	100
Scarce	50% Reduced Availability	0	0	100
Scarce	100% Reduced Availability	0	0	100

Table 3.26. **Conditional probabilities used within Netica to configure the relationship between Pine–Lichen Winter Range Habitat Value (PLWR_VAL) (High, Moderate, or Low) and the ecological factors deemed to influence those values: PLWR Habitat Preference (Preferred, Equivocal, or Avoided) and Habitat Value Reduction (0%, 50%, or 90% reduction in habitat value due to wolf predation risk). Variable code names are in parentheses.**

PLWR Habitat Availability Reduction (PLWR_HAR)	Habitat Value Reduction (RISK)	PLWR Habitat Value (PLWR_VAL)		
		High	Moderate	Low
0	0% Reduced Value	100	0	0
0	50% Reduced Value	0	100	0
0	90% Reduced Value	0	0	100
50	0% Reduced Value	0	100	0
50	50% Reduced Value	0	0	100
50	90% Reduced Value	0	0	100
100	0% Reduced Value	0	0	100
100	50% Reduced Value	0	0	100
100	90% Reduced Value	0	0	100

3.3.4 Assumptions

- At the database levels currently available to us, not all potential lichen-bearing sites will be mapped (i.e., some of the smaller pockets of lichen habitat will not show up in the database).
- This habitat is most commonly, but not exclusively, used during early winter at low elevations.
- In the Netica model, two of the states for *Aspect* (southerly aspect and flat) are combined as both are considered to have high-value lichen-bearing potential.
- Dense stocking negatively influences terrestrial lichen development.
- Older stands in the existing database are the result of fire disturbance events; therefore, wildfire and natural regeneration are considered status quo.
- Lichen development follows patterns recognized by Coxson and Marsh (2001) and Coxson et al. (1999).

- Whole-tree harvesting refers to processing logs at a landing or roadside; cut-to-length refers to processing logs at the stump in the setting where they are felled.
- Whole-tree harvesting results in less debris scattered across a setting than cut-to-length, but more than wildfire.
- Whole-tree harvesting results in greater levels of organic matter mixing than cut-to-length harvesting systems.
- Winter as a *Removal Season* refers to adequate snow cover to protect the surface organic matter from disturbance.
- As a site preparation treatment, “Burn” refers to broadcast burning.
- Factors that influence organic matter accumulation are accounted for by factors that influence light at the ground (site index, basal area, stand age, and crown area).
- Stocking density and distribution will influence lichen presence. Open canopies are favourable for terrestrial lichen development, closed canopies favour bryophytes and vascular plants.
- Self-thinning occurs between 0 and 50 years.
- In pine–lichen woodlands, crowns close between 40 and 70 years.
- In younger stands (0–40 yr) that develop after wildfire, there tend to be fewer preferred species of lichens for caribou to forage.
- Season node relates only to logging (note that there could be some summer site prep for winter-logged blocks).
- A limiting factor to lichen growth is how well drained the soils are (i.e., need dry soils, otherwise moss will dominate). North aspects tend to have fine-textured soils; not many lichens grow on north aspects.
- The site preparation “Burn” refers to a broadcast burn across the site.
- The site preparation “Pile and Burn” can only occur after cut-to-length harvesting systems. Whole-tree harvesting does not leave adequate debris on the site to implement a pile and burn treatment.
- In whole-tree harvesting, trees are dragged across the ground therefore causing considerable organic mixing; branches are removed at the landing and burned.
- More debris is left on site with cut-to-length harvesting, but less organic mixing occurs.

3.3.5 Management Factors and Options

The management levers that were incorporated into this model focus strongly on the manipulation of stands through forest management activities. Implementation of different disturbance regimes have been allowed through the modification of the stand removal process, site preparation activity, and/or the season in which stand removal occurs. Various changes in this portion of the model result in modifications of the growing medium found at lichen sites. The option to adjust the stocking density also provides an avenue to manipulate the environment, or the light interception levels.

3.3.6 Summary and Anticipated Model Development

The value of a pine–lichen winter range is determined by assessing the availability of terrestrial lichens at a site and then modifying this value by both the cost of foraging through snow, and the risk of predation associated with using a site. A combination of ecological features and factors from disturbance regimes were used to determine the abundance of terrestrial lichens. Increases in elevation were applied as a surrogate to represent less desirable snow conditions for accessing the terrestrial lichen forage supply. Lastly, the predation risk identified in Section 3.1 was used to modify habitat preference and indicate an area's relative worth to caribou as pine–lichen winter range habitat.

The relationships expressed in this model were based on a combination of professional opinion and literature reviews. To strengthen our understanding, an adaptive management project assessing the impacts of forestry activities on the development of terrestrial lichen communities has been established. Treatment areas for field activities were installed in the summer of 2001. The PLWR model was an important tool used to develop hypotheses for the project. Once these are tested, findings will be fed back into the PLWR model, updating the relationships within it.

Through a combination of different workshops, many additional factors influencing the "value" and ecology of pine–lichen woodlands were recognized. The following factors may be considered in future models:

- amount of small wetlands containing sedges, arboreal lichen supply, or hummocks of terrestrial lichens close to pine–lichen woodlands;
- the influence of snow depth and hardness on lichen availability to caribou (ESSF in early winter has a predictable snow accumulation pattern);
- relationships of stand management practices (spacing or not);
- influence of stocking density on lichen development; and
- influence of silvicultural system (clearcut or partial cut) on lichen development.

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3.4 HIGH-ELEVATION WINTER RANGE

3.4.1 Introduction

The High-Elevation Winter Range (HEWR) model characterizes habitat used by northern caribou in terms of the relative preference they demonstrate for specific conditions that sometimes occur during the late winter (Wood 1996; Terry and Wood 1999). Use of this range type is not strongly defined seasonally because northern caribou's reliance on this range has extreme annual variation (comparing Wood 1996 with our own unpublished data). However, if use of the high-elevation winter range occurs, it tends to be strongest after January in late winter and before northern caribou make distinct movements to low-elevation habitat during spring. The high-elevation winter range is used at times when herds tend to be relatively concentrated geographically (wood 1996), seeking specific and localized areas free from snow due to scouring by persistent and strong winds. These wind-blown areas persist primarily along ridges within the Alpine Tundra (AT) biogeoclimatic zone (Meidinger and Pojar 1991) and selection of this habitat may be displayed strongly by some herds or strongly only in some years.

3.4.2 Ecological Factors Considered

Northern caribou leave pine–lichen winter ranges in search of high-elevation winter ranges presumably in response to the increasing difficulty they experience in negotiating snow at low elevations as snow packs increase in depth and density through the winter (Johnson 2000). Increasing depth of snow in late winter makes it difficult for caribou to crater for terrestrial lichens and, even though the abundance of terrestrial lichens exceeds that of the AT, availability may be greater in the AT where persistent winds can reduce snow depth to near nil. Ironically, snow packs that detract from the ability of caribou to crater for terrestrial lichens in pine–lichen winter range provide support. They allow caribou to forage on arboreal lichens high into tree canopies, where this type of lichen tends to be abundant. Arboreal lichens occur most abundantly in high-elevation ESSF ecosystems (Goward and Arsenault 1999), especially those where balsam is the dominant tree species. The attraction to high-elevation winter range, therefore, has been explained as a selection for foraging opportunity (Stevenson *et al.* 1999). However, others (Bergerud *et al*. 1984, Bergerud and Page 1987) have pointed out that by moving to high elevations in late winter, caribou also avoid predators. Predator avoidance is facilitated by deep snow acting as a barrier to wolves but not to caribou, the former tending to be restricted to extensive use of riparian areas along valley bottoms during late winter. Both tactics of predator avoidance, while increasing foraging opportunity, likely operate simultaneously. Use of high-elevation winter habitat seems to depend, therefore, on snow pack development at low- and mid-elevation ranges and the reduction of snow on wind-blown, high-elevation ridges. Hence extreme annual variation in use of high-elevation winter range could be expected.

Avoidance of predators and forage availability was considered the most proximate life requisite for northern caribou to fulfill during the late winter. Avoidance of wolves was deemed to occur by tactfully using the snow at low- and mid-elevations as a barrier to predator movement. Ease of access to forage was deemed to occur by seeking areas blown free of snow by persistent winds or by using deep snow packs to elevate themselves higher into tree canopies laden with arboreal lichens.

High-elevation areas capable of allowing caribou access to either terrestrial lichens or arboreal lichens were considered to encompass the ecological factors of critical importance to the High-Elevation Winter Range model (i.e., use of predator-resistant snow packs was deemed consistent with the foraging objective and so was not considered a factor required for modelling). Use of this range type, however, would also depend annually on the development of the right ecological conditions.

The conditions that cause caribou to seek high-elevation winter range also provide some of the best recreational use of snowmobiles; this use of snowmobiles is often adjacent to, or overlapping with, the same locations sought by caribou. Intense recreational use of these areas has apparently led to caribou abandoning their high-elevation winter range presumably to seek habitat of lesser value (e.g., see discussion in the Revelstoke Snowmobile Strategy[13]). Inclusion of the recreational use of snowmobiles as a factor to limit access to high-elevation winter range was recognized as important but, despite efforts to do so, could not be included successfully in this application.

3.4.3 Description of Model Components

High-Elevation Winter Range Habitat Value (HEWR_VAL)

To calculate *High-Elevation Winter Range Habitat Value (HEWR_VAL)*, the *Habitat Preference (HEWR_PREF)* for the range by caribou was estimated, and then the *Habitat Value Reduction (RISK)* were determined according to the potential risk of predation by wolves (see Section 3.1.4, “Determining Risk of Predation”) (Figure 3.4). *Habitat Preference* was reduced according to non-negotiable *Slopes (SLP)* and an *Elevation (ELE)* restriction, with preference being based on opportunities for foraging on both terrestrial and arboreal lichens. *Terrestrial Lichen Forage Abundance (TLFA)* was determined by *Ecological Unit (ECO)* and by *Topographic Curvature (CURV)*, an indicator for wind-scouring potential to reduce snow depths for easier access to the lichens. *Arboreal Lichen Forage Abundance (HEWR_ALFA)* was also determined by *Ecological Unit*, as well as forest *Inventory Type Group (ITG)* and *Stand Age (SA)*.

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[13] http://www.cityofrevelstoke.com/edc/snowmobile/toc.htm

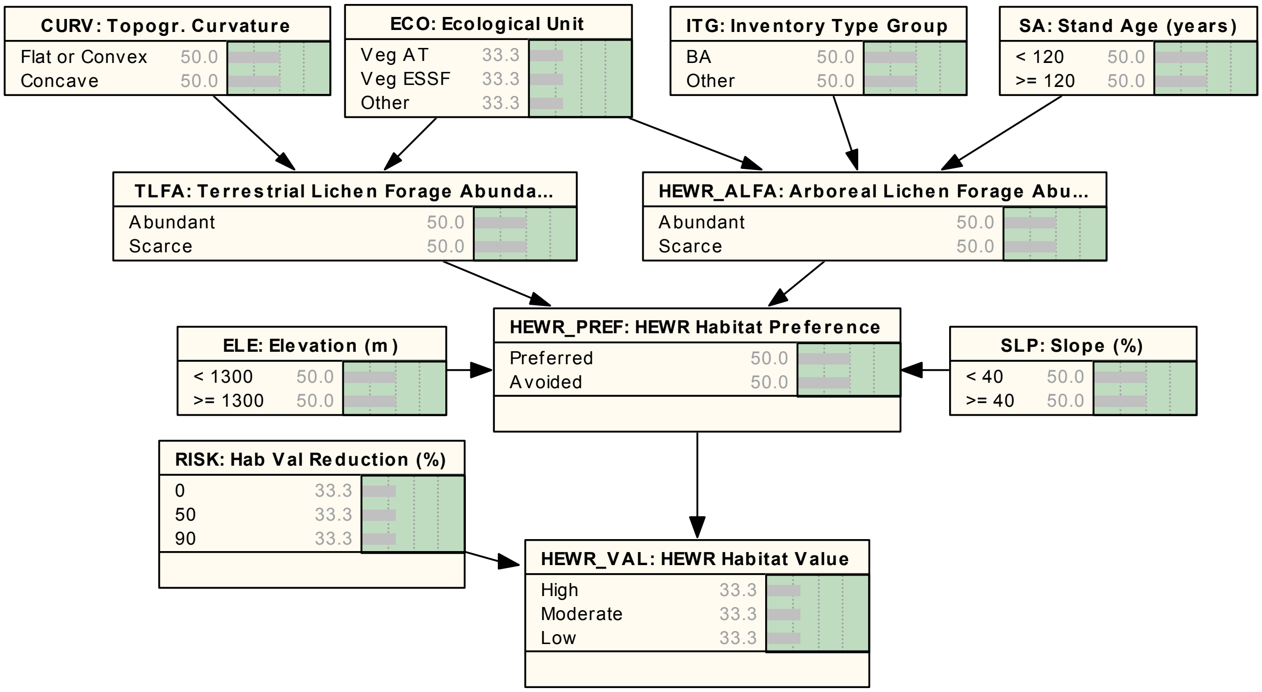

Figure 3.4. **Ecological factors and relationships characterizing preference for high-elevation winter range habitats by northern caribou in north-central British Columbia.**

High-Elevation Winter Range Habitat Preference (HEWR_PREF)

Habitat preference by caribou was estimated based on the interaction of *Elevation*, *Terrestrial Lichen Forage Abundance, Arboreal Lichen Forage Abundance,* and *Slope*.

Elevation (ELE)

Habitats less than 1300 m above sea level ("< 1300") were considered to be below the lower elevation limit to what is considered to be "high" elevation. Habitats at elevations greater than 1300 m ("> 1300") were considered capable of containing high-elevation winter ranges.

Terrestrial Lichen Forage Abundance (TLFA)

The abundance of terrestrial lichen forage was influenced by *Ecological Unit* and *Topographic Curvature*:

Ecological Unit (ECO)

The AT biogeoclimatic zone represented the elevations where terrestrial lichens would be abundant and available as a result of being exposed by wind scouring. Only vegetated ecosystems within this zone were considered to have abundant lichens ("Veg AT"). All other ecosystems within these zones (i.e., areas of talus, gravel, rock, rubble, bare soil, or cliffs), and those from other biogeoclimatic zones, were considered to only have scarce lichens ("Veg ESSF" and "Other"). "Veg ESSF" is only distinguished from "Other" here because it is a relevant category used to determine *Arboreal Lichen Forage Abundance* (described below). Classification of *Ecological Units* according to the importance to caribou as high-elevation winter range is presented in Appendix A.

Topographic Curvature (CURV)

Physical topographic shape, specifically curvature, was used to indicate the potential for prevailing winds to reduce snow depths in these areas of high elevation. Curvature was calculated as the surface shape at each geographic 1-ha cell centre by fitting a fourth-order polynomial through the cell and its eight neighbours. A positive curvature indicated that the surface was upwardly convex at that cell, while a negative curvature indicated that the surface was upwardly concave at that cell; a value of zero indicated that the surface was flat. "Flat or Convex" shapes at these high elevations were considered to be exposed and likely to have winds strong and persistent enough to scour, rather than accumulate, snow. These conditions were considered favourable to caribou seeking terrestrial lichens, whereas "Concave" conditions were considered unfavourable.

The conditional probabilities that were used to configure how the ecological factors of *Topographic Curvature* and *Ecological Unit* relate to *Terrestrial Lichen Forage Abundance* are presented in Table 3.27. If ecosystems were those other than vegetated AT, terrestrial lichens were considered to be predictably (P = 100%) "Scarce." Similarly, if ecosystems were vegetated AT but topographic curvature was "Concave," then habitat was considered to always (P = 100%) be scarce. Conversely, if the ecosystem was AT and topographic curvature was "Flat or Convex," then at least some useable terrestrial lichens were present: "Abundant" (P = 100%).

Table 3.27. Conditional probabilities (%) used within Netica to configure the relationship between Terrestrial Lichen Forage Abundance (Abundant or Scarce) and the ecological factors considered important in predicting availability: Ecological Unit (Veg AT for vegetated Alpine Tundra, Veg ESSF for vegetated Engelmann Spruce–Subalpine Fir, and Other for all other ecosystems) and Topographic Curvature (Flat or Convex, or Concave). Variable code names are in parentheses.

Ecological Unit	Topographic Curvature	Terrestrial Lichen Forage Abundance (TLFA)	
(ECO)	(CURV)	Abundant	Scarce
Veg AT	Flat or Convex	100	0
Veg ESSF	Flat or Convex	0	100
Other	Flat or Convex	0	100
Veg AT	Concave	0	100
Veg ESSF	Concave	0	100
Other	Concave	0	100

Arboreal Lichen Forage Abundance (HEWR_ALFA)

The abundance of arboreal lichen forage was influenced by *Ecological Unit*, forest *Inventory Type Group,* and *Stand Age*.

Ecological Unit (ECO)

Arboreal lichens were considered to be most abundant and available for caribou in the vegetated AT and parts of the ESSF (see *Inventory Type Group* below) biogeoclimatic zones ("Veg AT" and "Veg ESSF"). All "Other" *Ecological Units* were considered unlikely to support arboreal lichens. Classification of *Ecological Units* according to the importance to caribou as high-elevation winter range habitat is presented in Appendix A.

Inventory Type Group (ITG)

Forest *Inventory Type Group* was used to identify areas where balsam was the dominant tree species ("BA"), capable of supporting arboreal lichens. All other Inventory Type Groups ("Other") were considered unlikely to support arboreal lichens.

Stand Age (SA)

Forests that have tall trees accumulate greater abundance of arboreal lichens (Campbell 1998) and so *Stand Age* was used to modify the prediction of lichen availability. A stand age of 120 years old was considered the threshold between being likely to support arboreal lichens ("> 120 yr"), or not ("< 120 yr").

The conditional probabilities that were used to configure how *Ecological Unit, Inventory Type Group*, and *Stand Age* relate to *Arboreal Lichen Forage Abundance* are presented in Table 3.28. If older balsam-dominated forest conditions occurred in either the AT or the ESSF biogeoclimatic zones, then arboreal lichens were considered to have at least some useable lichens present: "Abundant" (P = 100%). Otherwise, for most other situations, lichens were "Scarce." The exception to this was for the remaining conditions within the ESSF where arboreal lichens could possibly (P = 30%) be abundant.

Table 3.28. Conditional probabilities used within Netica to configure the relationship between the Arboreal Lichen Forage Abundance (Abundant or Scarce) and the ecological factors deemed to represent those values: Ecological Unit (Veg AT for vegetated alpine tundra, Veg ESSF for vegetated Engelmann Spruce–Subalpine Fir, and Other for all other ecosystems), Inventory Type Group (BA for balsam-dominated forests, and Other for all other forest type groups), and Stand Age (< 120 for stands less than 120 years old and ≥ 120 for stands greater than 120 years old). Variable code names are in parentheses.

Ecological Unit	Inventory Type Group	Stand Age (yr)	Arboreal Lichen Habitat Capability (HEWR_ALHC)	
(ECO)	(ITG)	(S_AGE)	Abundant	Scarce
Veg AT	BA	< 120	0	100
Veg ESSF	BA	< 120	0	100
Other	BA	< 120	0	100
Veg AT	Other	< 120	0	100
Veg ESSF	Other	< 120	0	100
Other	Other	< 120	0	100
Veg AT	BA	≥ 120	100	0
Veg ESSF	BA	≥ 120	100	0
Other	BA	≥ 120	0	100
Veg AT	Other	≥ 120	0	100
Veg ESSF	Other	≥ 120	30	70
Other	Other	≥ 120	0	100

Slope (SLP)

While terrestrial and arboreal lichens may be considered available in an area, these high-elevation habitats can have large areas of steep terrain not typically used by caribou and so *Slope* was used to exclude these steep areas. Useable slopes ("< 40%") were distinguished from unusable slopes ("≥ 40%") on the basis of similar rationale developed for the Calving and Summer Range model (see Section 3.2, "Calving and Summer Range Model").

High-Elevation Winter Range Habitat Preference (HEWR_PREF) Summary

The *High-Elevation Winter Range Habitat Preference* was a summary node where values of *Arboreal* and *Terrestrial Lichen Forage Abundance* are accumulated and constrained by *Slope* and by *Elevation*. The conditional probabilities used to configure how these ecological factors interact are presented in Table 3.29. If either or both lichen types were available and sites were on slopes less than 40%, then high-elevation winter range habitat value was likely (P = 100%) to be "Preferred" unless the only lichen type available was arboreal lichens below 1300 m, in which case habitat was "Avoided" (P = 100%). By comparison, if neither lichen type was available, habitat was avoided (P = 100%) regardless of its topographic position. If both lichen types were available on sites exceeding 40% slope, there was some possibility of habitat being preferred (P = 30%) and if only terrestrial lichens were available on these sites, the possibility of habitat being preferred dropped considerably (P = 10%).

Table 3.29. Conditional probabilities (%) used within Netica to configure the relationship between High-Elevation Winter Range Habitat Preference (Preferred or Avoided) and the ecological factors deemed to influence those values: Terrestrial Lichen Forage Abundance (Abundant or Scarce), Arboreal Lichen Forage Abundance (Abundant or Scarce), Elevation (< 1300 for sites below 1300 m above sea level and ≥ 1300 for sites higher in elevation), and Slope (< 40% or ≥ 40%). Variable code names are in parentheses.

Terrestrial Lichen Forage Abundance (TLFA)	Arboreal Lichen Forage Abundance (HEWR_ALFA)	Elevation (m) (ELE)	Slope (SLP)	High-Elevation Winter Range Habitat Preference (HEWR_PREF)	
				Preferred	**Avoided**
Abundant	Abundant	< 1300	< 40%	100	0
Abundant	Abundant	≥ 1300	< 40%	100	0
Abundant	Scarce	< 1300	< 40%	100	0
Abundant	Scarce	≥ 1300	< 40%	100	0
Scarce	Abundant	< 1300	< 40%	0	100
Scarce	Abundant	≥ 1300	< 40%	100	0
Scarce	Scarce	< 1300	< 40%	0	100
Scarce	Scarce	≥ 1300	< 40%	0	100
Abundant	Abundant	< 1300	≥ 40%	30	70
Abundant	Abundant	≥ 1300	≥ 40%	30	70
Abundant	Scarce	< 1300	≥ 40%	10	90
Abundant	Scarce	≥ 1300	≥ 40%	10	90
Scarce	Abundant	< 1300	≥ 40%	0	100
Scarce	Abundant	≥ 1300	≥ 40%	10	90
Scarce	Scarce	< 1300	≥ 40%	0	100
Scarce	Scarce	≥ 1300	≥ 40%	0	100

High-Elevation Winter Range Habitat Value (HEWR_VAL) Summary

Preferred high-elevation winter range habitats had to exist within zones of relatively low risk of predation to be of "High" habitat value to northern caribou (Table 3.30). Avoided habitat was considered to always (P = 100%) be of "Low" habitat value regardless of the risk of predation. Preferred habitat, in the presence of high predation risk, was considered to have lost 90% of its value resulting in a complete (P = 100%) reduction to "Low" value habitat, while caribou would show a "Moderate" response to the same habitats under a medium risk of predation.

Table 3.30. Conditional probabilities (%) used within Netica to configure the relationship between High-Elevation Winter Range preference (Preferred, Equivocal, or Avoided) exhibited by northern caribou and the ecological factors deemed to represent those outcomes: High-Elevation Winter Range Habitat Value (Useable or Unusable) and Habitat Value Reduction (0% Reduced Value, 50% Reduced Value, or 90% Reduced Value). Variable code names are in parentheses.

High-Elevation Winter Range Habitat Preference (HEWR_PREF)	Habitat Value Reduction (RISK)	High-Elevation Winter Range Habitat Value (HEWR_VAL)		
		High	Moderate	Low
Preferred	0% Reduced Value	100	0	0
Preferred	50% Reduced Value	0	100	0
Preferred	90% Reduced Value	0	0	100
Avoided	0% Reduced Value	0	0	100
Avoided	50% Reduced Value	0	0	100
Avoided	90% Reduced Value	0	0	100

The usefulness of habitats would have been further modified by the likelihood of receiving recreational use of snowmobiles, but development of this modelling component proved problematic. In attempting to model the likelihood of snowmobile use according to environmental and/or behavioural variables, understanding about the presumed relationships was simply insufficient to set realistic parameters. Availability of high-elevation winter range for caribou became volatile (i.e., all available or none available) mostly due to the coarse resolution of the parameters set in attempting to model this component. For example, if high-elevation winter range existed within some distance limits of towns and/or roads, then it was presumed useless. Most habitats within the study area met this criterion and were therefore considered useless. In reality, the use of snowmobiles only exists regularly at a few locations and is not intense enough to cause caribou to vacate the area. A more thorough understanding about the relationship between snowmobile use and site characteristics is necessary before this factor can be modelled as a partial determinant of caribou's preference for high-elevation winter range.

3.4.4 Assumptions

- Predator avoidance by caribou in late winter is consistent with their need to seek available forage and hence can be modelled (i.e., represented) by the latter their need for forage.
- This habitat is predominantly in the upper Engelmann Spruce–Subalpine Fir (ESSF) and Spruce–Willow–Birch (SWB) parkland site series, and the AT. The upper forested ESSF and SWB areas are assumed to provide important forage habitat for arboreal lichens.

3.4.5 Management Factors and Options

There are few opportunities or options to manage high-elevation winter range other than access to sites for use of snowmobiles. Exploration for, or development of, mining sites may remove some habitat but usually these sites occur infrequently across the landscape. Successful mining sites, when they do occur, do eliminate significant amounts of high-elevation winter range locally.

More significant regional effects on high-elevation winter range occur indirectly from the increased predation risk through development of roads and/or logging adjacent to these habitat types.

3.4.6 Summary and Anticipated Model Development

Caribou tend to use high-elevation winter ranges after January in late winter, presumably in response to the increasing difficulty they experience in negotiating snow at low elevations as snow packs increase in depth and density through the winter. These high elevation areas provide specific and localized windswept snow-free areas, primarily along ridges within the AT biogeoclimatic zone, where caribou can forage on terrestrial lichens. In addition, snow packs that detract from the ability of caribou to crater for terrestrial lichens in pine–lichen winter range allow caribou to forage on arboreal lichens high into tree canopies. Arboreal lichens occur most abundantly in high-elevation ESSF ecosystems. In addition to these two foraging opportunities, moving to high elevations in late winter also allows caribou to avoid predators. This range type was characterized by topographic curvature, ecological unit, inventory type group, and stand age, which in turn defined the availability of terrestrial and arboreal lichens. Lichen availability was combined with elevation and slope to determine overall habitat preference, which was reduced according to the level of predation risk present, determined from the Moose Density model inputs for calculating Predation Risk.

Some discussion during model development focused on adding prevailing winds as a factor to provide more resolution to the prediction of useable habitat. The addition of prevailing winds will be considered in more depth during subsequent model development (e.g., macro-aspect, mountain range orientation). Also, it remains unclear if the fourth-order polynomial used to represent curvature is adequate in that it only considers, for each 1-ha grid cell, the topographic positions of the neighbouring eight cells.

Use of snowmobiles in high-elevation areas occupied by caribou is considered to have a significant detrimental impact on caribou and therefore presents a management conflict (e.g., City of Revelstoke[14], Youds *et al*. 2002) in many areas of British Columbia. A high priority should be placed on adding this factor to the current model even though the current situation in the Mackenzie TSA is unlikely to be a critical management issue.

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[14] http://www.cityofrevelstoke.com/edc/snowmobile/toc.htm

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3.5 MOVEMENT CORRIDORS

3.5.1 Introduction

Over a year, caribou often move from one seasonal range to another along distinct corridors. The Movement Corridor (MC) model characterizes the factors affecting the corridors that northern caribou use to move between pine–lichen winter ranges and high-elevation winter ranges in the Mackenzie TSA. As described in Section 3.3, caribou occupy dry, nutrient-poor pine–lichen winter ranges in early winter (Nov.-Jan.), when the conditions are suitable for caribou to crater through the snow to forage on terrestrial lichens. Telemetry locations of caribou in the TSA over several years show that caribou will often move to high-elevation winter ranges around late winter (late December to mid-January), where they forage on terrestrial lichens on windswept slopes, as described in Section 3.5. Movement corridors between these ranges are typically along valley bottoms, and mountaintops are avoided (Johnson 2000). These corridors are predominantly forested habitats with high timber values and relatively easy terrain to access. With the potential for interactions between forest harvesting practices and caribou habitat requirements, it is important to be able to model corridor locations to ensure these areas are managed appropriately.

3.5.2 Ecological Factors Considered

While the rationale for movements between range types is not fully understood, several researchers have proposed that caribou move up to alpine habitats when the snow conditions (increasing depth, hardness, and/or the formation of ice layers) in forested areas hinder caribou from detecting or accessing the terrestrial lichen forage supply (Edmonds and Bloomfield 1984; Hatler 1986; Wood 1996; Johnson 2000). Such conditions have been shown to dramatically increase the energy expenditures required for caribou to obtain forage (Fancy and White 1987). Other researchers suggest that caribou may move to high elevations to distance themselves from moose and thereby wolves, their primary predators (Bergerud 1983, Bergerud et al. 1984; Cumming and Beange 1987;

Seip 1992). In late winter the snow conditions often present a barrier to wolf movements at these high-elevation habitats, allowing caribou to exist in areas of low predation risk.

Caribou have also demonstrated a lack of fidelity to their winter ranges, presumably to allow range rotation to reduce grazing pressure on slow-growing terrestrial lichens (Bloomfield 1980). This result suggests that caribou continue to explore new areas, using new movement corridors throughout their lives (Simpson and Woods 1987).

Topographic position and predation risk were the ecological factors considered most important in influencing the selection of movement corridors. Unlike the other range types previously discussed, habitat type (e.g., ecological unit) does not appear to be an important factor in a caribou's decision to use an area as a movement corridor, and therefore has not been included in this model.

3.5.3 Description of Model Components

Movement Corridor Mortality Rate (MCMR)

The *Movement Corridor Mortality Rate* (MCMR) was influenced by two ecological factors: *Corridor Path (COR)* and *Habitat Value Reduction (RISK)* (see Section 3.1.4, "Determining Risk of Predation") (Figure 3.5).

Corridor Path (COR)

Potential and known *Corridor Paths* were manually delineated on a map by a panel of biologists that have studied the movements of caribou herds in the Mackenzie TSA. Corridors are primarily located along valley bottoms with reasonable passage to the next drainage in areas between identified seasonal ranges. The identified "Useable" corridor paths were digitized by delineating a single line down the centre of the corridor. A GIS algorithm was then used to include habitat within 200 m elevation, up to a maximum of 1 km horizontal distance of the line, to display the movement corridor area.

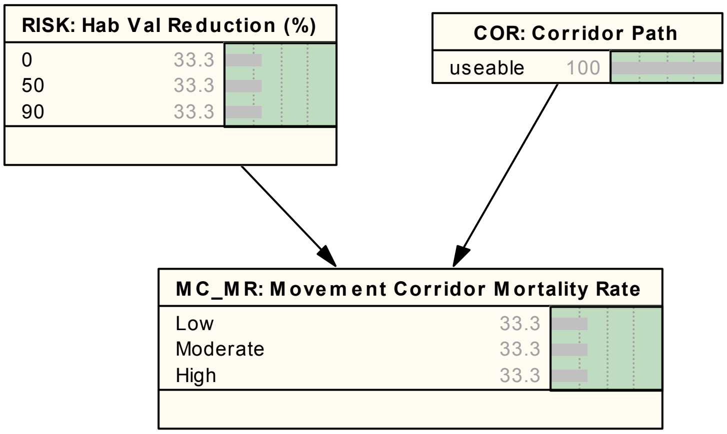

Figure 3.5. **Ecological factors and relationships characterizing northern caribou mortality rates along movement corridors in north-central British Columbia.**

Movement Corridor Mortality Rate (MCMR) Summary

The conditional probabilities that were used to configure how *Habitat Value Reduction* and *Corridor Paths* relate to the *Movement Corridor Mortality Rate* are presented in Table 3.31. A corridor path in the presence of high predation risk was considered to have lost 90% of its value always resulting in “High” mortality rates (P = 100%). By comparison, caribou likely experience “Moderate” mortality rates (P = 100%) in the same habitats under a medium risk of predation, under which 50% of its value was lost. Paths with no risk of predation were always considered to have “Low” caribou mortality rates (P = 100%).

Table 3.31. Conditional probabilities used within Netica to configure the relationship between northern caribou mortality rates along movement corridors (High, Moderate, or Low) and the ecological factors that influence those corridors: Corridor Path (Useable) and Habitat Value Reduction due to predation risk (0% Reduced Value, 50% Reduced Value, or 90% Reduced Value resulting from wolf predation)

Corridor Path (COR)	Habitat Value Reduction (RISK)	Movement Corridor Mortality Rate (MCMR)		
		Low	Moderate	High
Useable	0% Reduced Value	100	0	0
Useable	50% Reduced Value	0	100	0
Useable	90% Reduced Value	0	0	100

3.5.4 Assumptions

- Caribou will choose the path of least resistance to move between ranges (i.e., travel occurs along valley bottoms, not over mountains).
- Actual corridors locations were inferred from telemetry and incidental observations of caribou. These routes are not well known and animals appear to be somewhat flexible in their choice of corridors between years.
- Logging of these areas is not an impediment to caribou movement, but influences the level of predation risk.
- For this range type, food is not limiting, therefore the major factor of interest is the risk of predation.

3.5.5 Management Factors and Options

The most significant regional effects on movement corridors occur indirectly from the increased predation risk resulting from development of roads and forest harvesting in or adjacent to corridor paths. Logging within corridors was not considered a direct impediment to caribou movement. Once more complete information is available about the influence of stand-tending activities (e.g., thinning of dense second growth) and road placement, these activities could be considered in the next level of modelling.

3.5.6 Summary and Anticipated Model Development

The movement corridors that caribou use to travel between pine–lichen winter ranges and high-elevation winter ranges were influenced by topographic position and predation risk. Expert opinions were used to delineate corridor paths predominantly along valley bottoms between known seasonal ranges.

Once more complete information is available, this model could incorporate movement corridors between high-elevation winter ranges and calving/summer ranges, or between fall staging ranges and pine–lichen winter ranges. A habitat value factor could be included if areas of dense second growth are proven to be avoided by caribou. As well, a road density factor could be included in the model if caribou are proven to avoid crossing roads, depending on the density of traffic (James and Stuart-Smith 2000).

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3.6 OVERALL CARIBOU POPULATION RESPONSE

3.6.1 Caribou Response to Temporally and Spatially Varying Range Values

CHASE is used to calculate quality of seasonal ranges where that quality is then modified by risk of predation from wolves. The ultimate expression of habitat supply was presumed to be reflected in the total amount of range stratified by levels of range quality (i.e., High, Moderate, and Low). Caribou, however, cannot sustain all life requisites on any one range type; rather, they use all ranges in context of a composite set of tactics for avoiding death while producing healthy offspring. Establishing management objectives for single range types may lack context if other range conditions are not considered (e.g., how these other conditions either complement or detract from the single-range management goal). Ultimately, establishing management goals for caribou and monitoring of management results should be based in population parameters that characterize a herd: population size, age-specific mortality rates, and juvenile recruitment (McCullough 1992). However, the complex relationships between population parameters and the spatial configurations of an animal's habitat are rarely well understood. Density-dependent effects on population parameters, temporal lags in caribou's response to habitat change , and inter-range dependencies among other, even lesser understood factors, make any single prediction about population response to spatially and temporally dynamic habitat supply difficult (McCullough 1992). Nevertheless, setting appropriate and explicit goals for management, and monitoring results of management, depends on conquering those difficulties.

Spatially explicit population models are an attempt to bridge population dynamics with the spatial configuration of habitats (Pulliam and Dunning 1995). Although much of this modelling is in its infancy (Dunning et al. 1995), tools are commercially available to implement the necessary procedures to forecast predictions about populations based on spatially explicit habitat configurations (Akcakaya and Atwood 1997). These tools require two sources of input data (Figure 3.6): (1) geographic data upon which to calculate range value, and (2) range-based demographic parameters or vital statistics (e.g., births and death rates stratified by range type and quality) for the animal. The models also require rules for establishing value of range (denoted as "Range-specific Model Results" in Figure 3.6) and rules about how populations function to disperse among patches. Presumably these patches could be either seasonal ranges and/or spatially exclusive polygons of the same seasonal range. Construction of a spatially explicit population model for northern caribou is under development.[15]

3.6.2 Problems Associated with Estimating Range-specific Population Parameters

Predator Effects on the Use of Ranges and Range-specific Mortality Rate

Preference exhibited by caribou for ranges (i.e., Calving and Summer Range, Pine–Lichen Winter Range, High-Elevation Winter Range, and Movement Corridors) occurs as a result of balancing range value with risk of predation (Figures 3.2–3.4). There are two opposing interpretations of how risk of predation manifests itself in caribou populations. If caribou are omniscient and free to react to high predation risk instantaneously, then this response could be measured in terms of habitat preference. Alternatively, if fidelity to specific sites or any other behavioural factor (e.g., lack of knowledge about choices) constrains this freedom, then response to predation would likely be

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[15] Sutherland, G. and S. McNay. In prep. Preliminary development of a spatially explicit population model for northern caribou in north-central British Columbia: An extension of the Caribou Habitat Assessment and Supply Estimator. Draft report on file at Wildlife Infometrics Inc., Mackenzie, B.C.

measured by mortality or population change. In fact, a continuum likely exists between these opposing responses and the ultimate effect of predation risk is a combination of both.

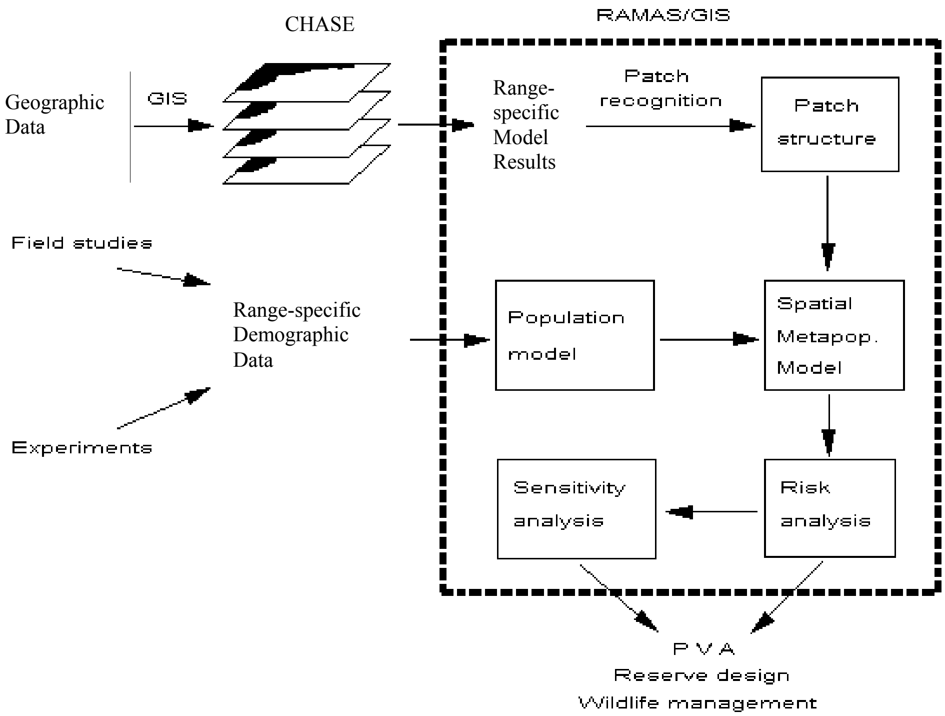

Figure 3.6. A schematic representation of a typical procedural framework used to implement a spatially explicit population model. This figure depicts how two primary sources of input data, geographic and demographic, interact through geographic information systems (GIS) to develop estimates of populations at specific locations. Adapted from RAMAS Web page http://Ramas.com.

To accommodate the multiple ways predation is likely to affect caribou, behavioural responses were assumed to predominate the expression of habitat preference. In fact, preference is a pooled estimate over a number of individual caribou faced with current choices about habitats characterized by, among other factors, varying risk of predation (Sections 3.2–3.4). Conversely, active predation would need to enter a spatially explicit population model as an age-specific mortality rate for each range type and be varied according to quality of range. Field data on mortality rates may provide general mortality rates associated with the different ranges but these estimates likely lack precision. Furthermore, refinement of the mortality rate estimates, by way of correlation with range quality, would be guided mostly by opinion without firm empirical support.

One method to estimate mortality rates is to first estimate range-specific carrying capacity or maximum that varies with range quality and predation level, then calculate the mortality rate necessary to obtain those population densities (Figure 3.6).

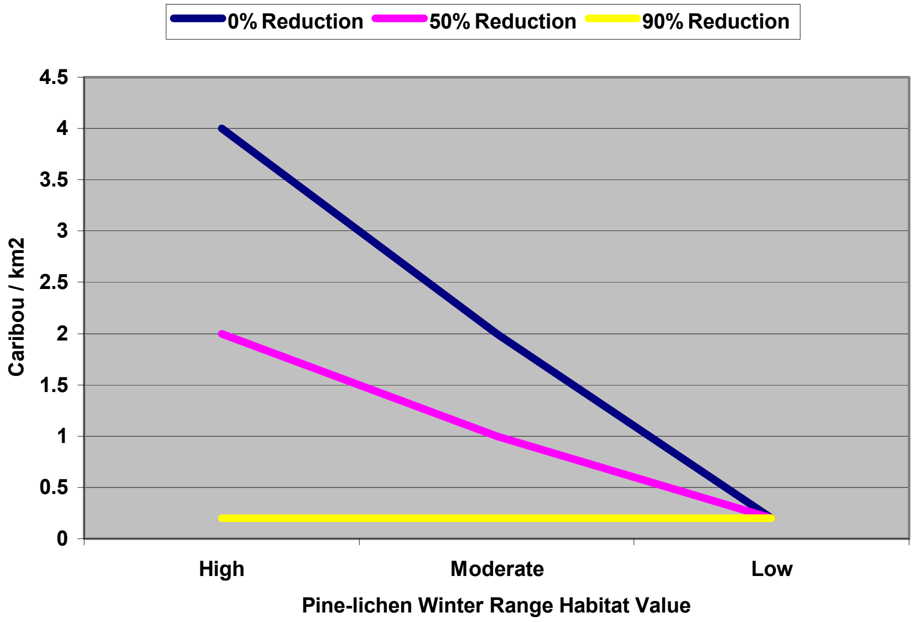

Figure 3.6. **A schematic representation of the hypothetical relationship among range-specific carrying capacity (caribou/km^2), Pine–Lichen Winter Range habitat value (High, Moderate, or Low), and predation level (0% Reduction, 50% Reduction, and 90% Reduction) from wolves.**

Estimating Natality and Recruitment Rate

Natality and juvenile recruitment occur on only one range type and so these estimates can be annual, or one-time estimates based again on field data. These estimates should be relatively easily collected and made available for modelling.

Estimating Range-specific Carrying Capacity

Obtaining estimates about the number of animals that an individual range is able to support at varying levels of habitat quality is problematic mostly from a simple lack of data, information, and knowledge. While the estimates for pine–lichen winter range were attempted (Figure 3.6), the modelling team was unwilling to make similar estimates for other range types.

3.6.3 Problems Associated with Identifying Spatial Meta-population Rules

The temporal rules about moving animals from calving and summer range to pine–lichen winter range are relatively known based on field data. By comparison, the relationship between use of pine–lichen winter range and high-elevation winter range is unknown (e.g., are these ranges compensatory or additive in value to caribou?). Also, it is unclear how caribou make decisions about movement corridors that vary in quality.

3.6.4 Literature Cited

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4.0 FORESTRY INFORMATION

A key aspect of the operational use of CHASE was to evaluate the effects of alternative caribou habitat management and forest development scenarios on timber flow and operational costs to the forest industry. Ideally, a measure of forestry operations profitability would have been developed and predicted as a model output. However, given the number of forest licensees operating in the area, their differences in logging and milling equipment, and the influence of the current timber valuation process on development costs, it was not possible to develop a simple profitability measure. Consequently, a number of simple measures associated with timber flow and operational costs were developed, including: volume harvested by tree species, dbh class, slope class, and length of road built. These factors were tracked by Landscape Unit to facilitate the interpretation of information for each individual forest company or division.

Each management scenario followed a set of predefined rules as described previously for patch size and distribution over the landscape. Within the constraints of any scenario the development of the road network and the sequence of harvesting of blocks was conducted (using the harvest simulation program SELES) such that blocks closest to existing roads were "harvested" first to minimize the amount of road built to access timber. Forest harvest was primarily dependent on there being forests of the correct age to harvest. These ages depended on Inventory Type Group, leading tree species, site index, and haul zone, which make up "analysis units" used in a typical Timber Supply Review (Table 4.1).

Table 4.1. Minimum harvest ages to be used in CHASE, as determined from the Mackenzie Timber Supply Review

Analysis unit no.	Lead species and productivity	Inventory Type Groups	Site index range	Minimum harvest ages (yr)					
				Near & mid-haul zone			Far haul zone		
				A1*	A2*	C*	A1*	A2*	C*
1	Balsam – Good	18–20	≥ 31	80	90	110	90	110	130
2	Balsam – Medium	18–20	≥ 01 & < 31	110	130	160	130	160	190
3	Balsam – Poor	18–20	< 10	150	190	230	190	230	250
4	Spruce – Good	21–26	≥ 61	70	80	90	80	90	100
5	Spruce – Medium	21–26	≥ 1 & < 61	90	110	120	110	120	140
6	Spruce – Poor	21–26	< 10	140	170	200	170	200	220
7	Pine – Good	28–31	> 17	60	70	80	65	80	90
8	Pine – Medium	28–31	≥ 41 & ≤ 71	80	90	110	80	100	120
9	Pine – Poor	28–31	< 14	100	120	140	110	140	190
10	Poplar – Good/Med	35, 36	> 18	60	N/A	N/A	N/A	N/A	N/A
11	Aspen – Good/Med	41, 42	> 18	60	N/A	N/A	N/A	N/A	N/A
12	Birch – Good/Med	40	> 18	60	N/A	N/A	N/A	N/A	N/A
99	Decid – Poor	35, 36, 40–42	< 18	n/a	N/A	N/A	N/A	N/A	N/A

* The three operability classes assigned in the Landscape Unit planning database are as follows:

- A1 = Conventional Ground Based Skidding, on slopes ≤ 30%, all soil types
- A2 = Conventional/Cable Based Skidding/Yarding, on slopes > 30% to < 55%, stable soils, non-lacustrine
- C = Cable Based Yarding System, on slopes > 30% to ≤ 100%, lacustrine soils and slopes > 55% to ≤ 100%, non-lacustrine soils

4.1 HARVESTED VOLUME AND FLOW

Three tree species are harvested in the area: lodgepole pine (*Pinus contorta*), spruce (*Picea* spp.), and subalpine fir (*Abies lasiocarpa*). The model tracked the volume harvested per hectare of each of these species. Because some pine stands are composed of small trees that are of marginal value, pine stands were further stratified into two size classes using diameter measures (12.5 to 20 cm dbh, and > 20 cm dbh).

Since the forest companies use two primary methods of logging (cable and ground), the volume per species was further subdivided according to the slope of the site it was harvested from. Two slope classes were used: < 40% slope (corresponding to ground harvest); and > 40% slope (corresponding to cable harvest).

Although season of logging is also of interest to the forest companies, this level of detail was not included in this analysis.

4.2 OPERATIONAL CONSIDERATIONS

The most important operational consideration is the cost of road construction. Consequently, the model tracked the length of road built. Other timber harvesting factors, such as hauling distance and road maintenance costs, were not included.

The model was designed to evaluate the use of alternative timber harvest and silviculture methods (see Chapter 3).

4.3 USE OF FORESTRY INFORMATION

A number of potential applications of this information are described in Sections 2.1 and 2.2. Some specific examples of the application of this information are described below.

For any scenario in strategic planning, comparisons can be made between (1) the impact of forestry operations on caribou directly (habitat logged) versus indirectly (habitat subject to higher predation due to wolf access via clearcuts and roads); (2) differences in volumes harvested and road built; and (3) the flow of tree species and volumes over time, and plans for mill upgrades and other changes in wood processing technology.

In operational planning, the timber volume and road length values in the model can be compared with those in a proposed operational plan. Any operational plan will likely differ from the model prediction since the model chooses one sequence of development for an area, whereas other sequences are likely to more closely meet the forest companies' short-term goals and be within the parameters of the overall management scenario. The implications of the use of an alternative logging method, season, or type of site preparation can also be evaluated.

4.4 ASSUMPTIONS

As with the caribou ecology components of the model, a number of assumptions are associated with the forestry component:

- All of the timber in the timber harvesting land base (THLB) has a probability of being logged. The entire profile will be logged over the time span of the model even though some stands in the THLB may not be economically viable now.

- All roads will be constructed to a summer haul standard as specified in road regulations. Harvest scenarios may place summer blocks behind winter blocks thus foregoing the option of lower standard winter roads.

5.0 RESULTS AND INTERPRETATIONS

As described in Chapter 2, the model can be used for strategic and operational planning in a number of ways. While specific questions about individual applications of CHASE may vary, a number of results will likely be of interest in most applications. These typical results have been developed into "standard" posters that depict the amount and spatial distribution of the range types (by habitat value classes) over time. These standard results are presented in Section 5.1. The types of questions to be assessed in the interpretation of results are presented in Section 5.2. The "standard" model results can be applied to typical management decision-making. Additional applications of the model are described in Section 5.3.

An example of results is presented to demonstrate the capability of the model. The complete results and interpretations of the model runs are presented elsewhere.[16]

5.1 PRESENTATION OF RESULTS

The results that have been presented to date use the LRMP Caribou Management Strategy for the Wolverine herd area. These results have been used to test the presentation format with several audiences to determine what information and format are most useful.

Two formats were used to present the model results:

1. Digital versions of the maps of the various ranges are available in 10-year timesteps for the entire duration of the model run. For demonstration, maps were generated for two specified timesteps (2005 and 2105) for each model and for predation risk. Capability[17] maps were also presented for comparisons. Maps were produced in ArcView then exported as an image in JPEG format. Each script that has an "Output" of a grid will export a JPEG (see Figure 5.1 for an example map product).
2. Graphs and tables of the area of the final output nodes of each model were produced by state value and patch size, in 10-year timesteps. Tables from Access were exported to Excel, where the graphs and tables were produced (see Figure 5.1 for examples of the tables and graphs).

Maps, graphs, and tables were compiled and posters produced for presentation. For each of the factors of interest in the model, a format for the presentation of results was developed. Sections 5.1.1 to 5.1.8 describe the material presented as results for each model.

An example of a poster in Figure 5.1 depicts results for a model run for the Calving and Summer Range Model.

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[16] Doucette et al., in prep.

[17] Capability was defined as a theoretical condition for each range where predation risk was controlled at 0% reduction and, in the case of the Pine–Lichen Winter Range, Stand Age was held at 70 to 140 years old.

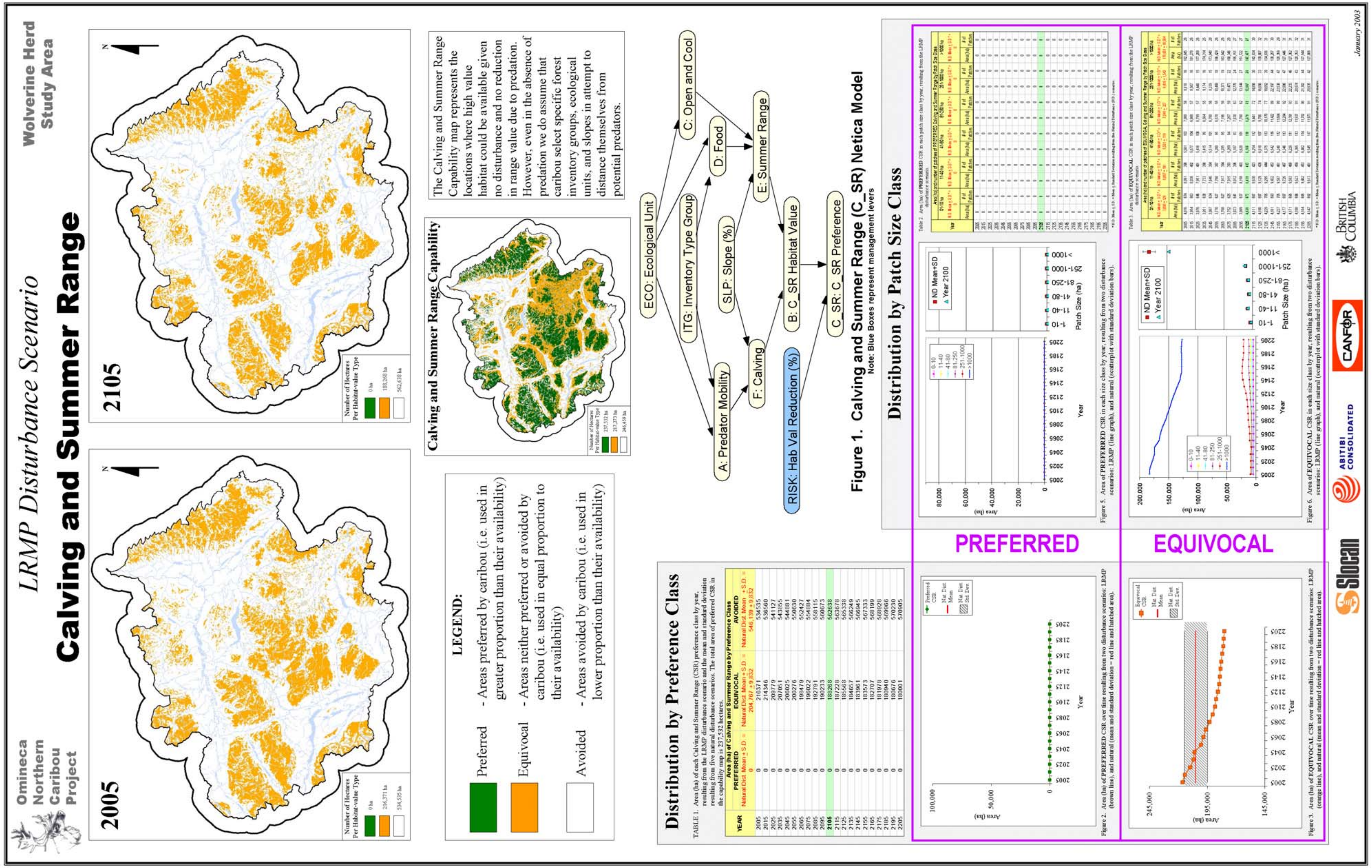

Figure 5.1. An example poster layout illustrating the generic products generated from a typical application of the Caribou Habitat Assessment and Supply Estimator (CHASE).

5.1.1 Moose Density and Predation Risk

Results presented for Moose Density included:

- Moose Density Netica model;
- graphic and equation describing factors influencing subsistence hunting;
- year 2005 and 2105 maps of subsistence hunting levels;
- year 2005 and 2105 maps of moose winter habitat values; and
- year 2005 and 2105 maps of moose winter densities.

Results presented for Predation Risk included:

- Predation Risk Netica Model and table showing relationship between moose density, wolf density, predation risk, and caribou habitat value reduction;
- text box describing Proximity Risk and Direct Risk;
- year 2005 and 2105 maps of winter predation risk levels;
- year 2005 and 2105 maps of summer predation risk levels;
- tables of the area of each predation risk class over time, for winter and summer; and
- graphs of the area of each predation risk class over time, for winter and summer.

5.1.2 Calving and Summer Range

Results presented for the Calving and Summer Range included:

- year 2005 and 2105 maps of calving and summer range habitat value classes;
- Calving and Summer Range Capability map with definition;
- Calving and Summer Range Netica model;
- table of the area of high- and moderate-habitat value class over time, with the mean and standard deviation of the natural disturbance scenarios;
- graphs of the area of high- and moderate-habitat value class over time, compared with the mean and standard deviation of the natural disturbance scenarios;
- table of the area of high- and moderate-habitat value class by patch-size class over time, with the mean and standard deviation of the natural disturbance scenarios. The patch-size categories used in all the models were 1–10, 11–40, 41–80, 81–125, 126–1000, > 1000 ha; and
- graphs of the area of high- and moderate-habitat value class by patch-size class over time, compared with the mean and standard deviation of the natural disturbance scenarios.

5.1.3 Pine–Lichen Winter Range

Results presented for the Pine–Lichen Winter Range included:

- year 2005 and 2105 maps of Pine–Lichen Winter Range habitat value classes;
- Pine–Lichen Winter Range Capability map with definition;
- Pine–Lichen Winter Range Netica model;
- table of the area of high- and moderate-habitat value class over time, with the mean and standard deviation of the natural disturbance scenarios;
- graphs of the area of high- and moderate-habitat value class over time, compared with the mean and standard deviation of the natural disturbance scenarios;
- table of the area of high- and moderate-habitat value class by patch-size class over time, with the mean and standard deviation of the natural disturbance scenarios; and
- graphs of the area of high- and moderate-habitat value class by patch-size class over time, compared with the mean and standard deviation of the natural disturbance scenarios.

5.1.4 High-Elevation Winter Range

Results presented for the High-Elevation Winter Range included:

- High-Elevation Winter Range (HEWR) habitat value classes and an overlay of the areas capable of supporting arboreal lichen;HEWR Capability map and arboreal lichen capability map with definitions;
- High-Elevation Winter Range Netica model;
- table of the area of high- and moderate-habitat value class over time, with the mean and standard deviation of the natural disturbance scenarios;
- graphs of the area of high- and moderate-habitat value class over time, compared with the mean and standard deviation of the natural disturbance scenarios;
- table of the area of high- and moderate-habitat value class by patch-size class over time, the mean and standard deviation of the natural disturbance scenarios; and
- graphs of the area of high- and moderate-habitat value class by patch-size class over time, compared with the mean and standard deviation of the natural disturbance scenarios.

5.1.5 Movement Corridors

Results presented for the Movement Corridors included:

- year 2005 and 2105 maps of Movement Corridor habitat value classes;
- capability map with definition;
- Movement Corridor Netica model;
- table of the area of high- and moderate-habitat value class over time, with the mean and standard deviation of the natural disturbance scenarios;
- graphs of the area of high- and moderate-habitat value class over time, compared with the mean and standard deviation of the natural disturbance scenarios;
- map showing the four distinct movement corridors named Omineca, Germansen, North Gillis, and South Gillis; and
- graph of road densities within the movement corridors over time.

5.1.6 Timber Flow and Operational Considerations

Results presented for Timber Flow and Operational Considerations included:

- map of the caribou herd area showing Landscape Unit boundaries;
- graphic displaying indicators of timber flow and operational considerations;graph display of length of new roads to be built across all Landscape Units over time;table of area harvested in Landscape Units over time;
- graph display of total area harvested in all Landscape Units over time;
- table of conifer volume (m^3) harvested, by tree species, diameter at breast height (cm), and by slope class, for all Landscape Units over time;
- graph display of conifer volume harvested by slope class for all Landscape Units over time; and
- graph display of volume harvested by tree species and dbh class for all Landscape Units over time.

5.1.7 Roads and Cutblocks

Results presented for Roads and Cutblocks included:

- map of current roads and cutblocks in the year 2005; and

- map of roads developed in the 20 years previous to 2105 and cutblocks developed in the previous 40 years, which represent the disturbance factors that influenced predation risk in 2105.

5.1.8 Landscape Disturbance Simulation

A flowchart was presented to describe the inputs, outputs, and management options for modelling the spatial and temporal distribution of disturbances resulting from forest harvesting and wildfires

5.2 POTENTIAL FOR EVALUATION AND INTERPRETATION OF MODEL RESULTS

5.2.1 General Evaluation and Interpretation Criteria

Questions of interest to resource managers guide model interpretations. The following nine questions were the focus of the general or overall model interpretations:

1. How much of each range type (by habitat value class–high, moderate, low) will there be in the herd area?
    1.1. This can be evaluated quantitatively from tables and graphs of the area (ha) of each habitat value class (where applicable) over time. In addition, this can be evaluated visually by looking at the 10-year timestep maps.
2. How have the amounts of each range type changed over the time horizon of the model?
    2.1. This can be evaluated by comparing the area of each range type (by habitat value class where applicable) over time using either the tables or graphs provided.
3. How has the overall spatial distribution of each range type changed across the herd area over time?
    3.1. Although distribution information can be presented in several statistical ways, at this time a visual scan of the maps available is considered the best evaluation technique (maps are available for each 10-year timestep of the model and can be run as a "movie" to see changes in distribution of habitats over time). Any areas of concern regarding distribution of habitat can be explored in more detail.
4. How has the patch-size distribution of the range types changed over the time horizon of the model?
    4.1. This can be evaluated by using tables of both the area in each patch-size category and the number of patches in each patch-size category (by habitat value class where applicable), or by using graphs depicting the area of habitat in each patch-size category over time. The patch-size categories used are based on those recommended in the LRMP.
5. How does the amount of habitat in each range type compare with the amount that would be present under a natural disturbance regime?
    5.1. The mean and standard deviation expected under a natural disturbance regime is portrayed in the tables and graphs. This expected amount of habitat (by habitat value class where applicable) under a natural disturbance regime is presented as a baseline for comparison and interpretation.
6. How does the amount of habitat in each range type compare with what might be possible under a management regime designed to optimize the amount of the range type?
    6.1. To evaluate the "capability" of the area for the various range types, a map of capability is presented. This map depicts the maximum amount of habitat (usually the high habitat value class) that would be available if habitat value due to predation risk or disturbance was not

reduced, and the age-class structure of the habitat was optimum. Although this amount of habitat is not likely to occur in reality, it does provide a base for comparing results.

7. As the amount of habitat in each range type changes, when should managers become concerned?
    - 7.1. The proposed approach to determining important or critical changes in habitat is via a set of "red flags"——a set of criteria that would indicate significant events in the predicted future supply of habitat. This raises the question: What magnitude of change constitutes a red flag? To answer this question completely, whole herd level population responses must be considered. The planned follow-up modelling regarding whole herd population response to habitat will address the question of the carrying capacities of the range types and consequently the linkage of habitat change to population change. However, in the short term, the following red flags are proposed:
        - 7.1.1. When the amount of the high habitat value class of any range type falls below the 25th percentile of the natural disturbance range (the 25th percentile is a soft target).
        - 7.1.2. When fluctuations in the amount of the high habitat value class of any range type become large (potentially leading to problems such as lag effects), measured as a 25% change in the amount of predicted habitat over 10 years (soft target).
        - 7.1.3. When the amount of high value habitat of any range type reaches 50% of its current amount.
        - 7.1.4. When the amount of the high value habitat of any range type falls below the minimum of the natural disturbance range (the minimum of the natural disturbance range is a "hard target")
        - 7.1.5. As interpretation continues, it is expected that other "hard targets" will be established for specific range types (e.g., PLWR may be the current limiting factor regarding caribou populations; or predation risk on movement corridors may be a limiting factor in the future)
8. Is the amount of one range type limiting the numbers of caribou (i.e., the limiting factor)? If so, which range type is limiting? If one range type is limiting and others are in "abundance," does this mean that the abundant range types can be managed "down" to levels that support the numbers of caribou supported by the limiting range type?
    - 8.1. It is likely that one range type is limiting population numbers; however, this has not been determined in the model as yet. It is likely that the number of caribou that can be supported by a hectare of habitat will vary with range type and the length of time during a year that the caribou depend on that range type. Thus, there is no direct correspondence in value to caribou between a hectare of one range type and a hectare of another. Since the area of all range types is dynamic over time, it is possible that at some point in the simulation the limiting range type will change. Specific interpretations for individual range types are further developed in Section 5.2.2.
9. How is the amount of habitat in each range type linked to the numbers of caribou?
    - 9.1. This question cannot be answered without considering whole herd level population responses. The follow-up modelling regarding whole herd population response to habitat will address the question of the carrying capacities of the range types and consequently the linkage of habitat change to population change.

5.2.2 Evaluation and Interpretation Criteria of Specific Model Results

The following model interpretations are based on the results of the specific range type models.

Moose and Wolf Relationship Model

1. What is the area under risk of predation?

    1.1. The area under risk of predation is depicted on the maps and in tables and is available for each timestep.
2. What is the distribution of the risk of predation areas?
    2.1. Although distribution information can be presented in several statistical ways, a visual scan of the maps available is considered the best evaluation technique now. Maps are available for each 10-year timestep of the model and can be examined for changes in distribution of area under risk of predation over time. Any areas of concern regarding distribution of the risk of predation can be explored in more detail.
3. Should road deactivation be considered as a tool to minimize the loss of caribou to subsistence hunting?
    3.1. At present this analysis is not a model product. However, the model could be adopted to allow road closures to be a management lever. Then it would be possible to compare the human harvest decrease on caribou due to road closures with the impact of the decrease in human hunting harvest of moose and the consequent increase that the increased numbers of moose would have on predation risk.
4. Can hunting of moose to low numbers be used as an indirect method of “wolf control” and consequently reduce predation risk to caribou?
    4.1. The model is designed to allow this option to be evaluated. Various levels of moose harvest can be implemented in the model to explore the effect of the possible reduction in predation risk.

Calving and Summer Range Model (CSR)

1. Is there a change in the patch-size distribution of CSR habitat?
    1.1. This can be evaluated using the graphs and tables of patch size available for each timestep.
2. Is the amount of the high habitat value class of CSR limiting to caribou?
    2.1. This question will be further explored using the population component of the model.

Pine–Lichen Winter Range (PLWR)

1. Can the amount of PLWR that currently exists be maintained over time?
    1.1. This can be evaluated using the graphs and tables of high value PLWR habitat. The dynamics of the change in high value PLWR habitat can be evaluated over time.
2. Is there a change in the patch-size distribution of high value PLWR habitat?
    2.1. This can be evaluated using the graphs and tables of patch size available for each timestep.
3. Is PLWR essential or can HEWR be a substitute?
    3.1. This is a question of caribou biology rather than model prediction; however, the current thinking is that caribou could persist without PLWR, but probably at significantly lower densities (e.g., Takla herd). Consequently, if the desire is to maintain the current “ecological situation” then the system of red flags described previously is relevant to PLWR.
4. Is the amount of the preferred class of PLWR limiting to caribou?
    4.1. This is commonly thought to be the case; however, this question will be further explored using the population component of the model.

High-Elevation Winter Range Model (HEWR)

1. Is the area of HEWR that provides arboreal lichens specified separately from other HEWR?
    1.1. The arboreal lichen areas are depicted as an overlay on the maps.
2. Is there a change in patch-size distribution of HEWR over time?
    2.1. This can be evaluated using the graphs and tables of patch size available for each timestep.
3. Is HEWR essential? Will this range type ever be limiting to caribou?

    3.1. This is a question of caribou biology rather than model prediction. However, the current thinking is that caribou require HEWR in times of high snow on PLWR areas. The ratio of the amounts of high value PLWR and HEWR can be evaluated using the model. This question will be further explored using the population component of the model to address the carrying capacities of the two range types and consequently the amounts of each needed to support any desired caribou population.

4. Can HEWR replace PLWR when it is unavailable, or are both range types essential?
    4.1. This is a question of the current understanding of caribou behaviour and biology. The model predicts the amount of both HEWR and PLWR habitat. This question will be further explored using the population component of the model. To explore this possibility for management, a single map depicting both HEWR and PLWR is planned for operational use.
5. How important is the juxtaposition of PLWR and HEWR and the corridors between them?
    5.1. The relationship between the two habitats is considered important, however no specific measures are provided in the model. Caribou are assumed to travel long distances between these range types and use the movement corridors. The movement corridor model portrays the potential barriers between ranges due to predation risk.

Movement Corridor Model

1. If movement corridors are areas where caribou are being preyed upon at significantly higher levels than other areas, then should there be special model interpretation techniques, or specific timber harvesting regimes for these areas?
    1.1. Movement corridors could become a “gauntlet” for caribou. The current model products depict the area of movement corridors and the density of roads (roads being the key to an increase in predation risk in the model). The loss of 50% of a corridor to high predation risk appears to have a significantly different impact on caribou numbers than the loss of 10% of all five corridors to high predation risk, even though the total area impacted would be about the same. At present, a number of specific interpretations are being considered for movement corridors, including:
        1.1.1. Use a different set of red flag thresholds—higher amounts of low predation risk area in movement corridors may be required for caribou to survive compared with other habitats
        1.1.2. Treat corridors individually to evaluate whether at least two low predation corridors are available to caribou at any one time. This may be translated into a constraint in the development of an area with respect to when and where roads and blocks are built in corridor areas.
        1.1.3. In addition, many biological questions could be addressed, such as: Will caribou go down a corridor regardless of predation risk? Can they determine predation risk in advance or is it simply a case of the ones who choose high predation risk corridors suffer a higher mortality rate? Do caribou choose the use of movement corridors according to any predictable criteria?
2. If movement corridors become areas of high predation risk, do they become limiting to caribou and consequently the amounts of other habitat are less important?
    2.1. The question of the impact of predation in movement corridors on caribou population and the link back to caribou density in other habitat types will be further explored using the population component of the model.

Forestry Information

1. Does the specific development plan used in the model have to be followed to get the result indicated for caribou, or are alternative development plans likely to have similar results for caribou?
    1.1. The model results depict only one stochastically generated development pattern within the constraints of the chosen scenario. Other development scenarios that may be better or worse for both caribou and the value of timber harvested are possible within the same scenario constraints. Additional runs (perhaps 10) will be conducted and the development "space" mapped out over time indicating the mean and standard deviation of the specified timber values and piece sizes at each timestep.
2. If the results of the model run indicate that this development scenario will result in an unfavourable mix of species and piece sizes harvested, what are the options to introduce a harvest pattern that is more favourable to mill profitability?
    2.1. The model is based on the assumption that the entire profile of timber used in the TSR will be logged. If this is the basis of concern, then the fundamental issue of what is in the THLB must be addressed. Any desired THLB can be specified for the model runs.
    2.2. If the pattern of development used in the model appears to be "unrealistic" from a timber harvesting perspective, several options are possible. The results of further modelling (as described briefly in question 1 above) will provide a range of values within which harvesting might occur. The model can also be used to evaluate any long-term development plan of roads and cutblocks designed by forest companies. The model will then predict the results for both caribou habitat and timber values.

5.3 OTHER MODEL APPLICATIONS

CHASE has a number of possible additional applications:

- stratify herd areas in the Mackenzie TSA by range classes, to conduct random stratified block censuses for both caribou and moose; and
- produce maps of Pine–Lichen Winter Range Habitat Value to guide Ungulate Winter Range designation and setting of legal objectives.

In addition, the model could be used to evaluate management options in Omineca Park.

6.0 MODEL TESTING

6.1 GENERAL APPROACH TO TESTING

Protocols for reporting, testing, and accrediting habitat supply models in British Columbia do not exist. This lack of procedure is likely in part due to philosophical debate about the proper use of models, and hence how testing might proceed. Testing should consider how the model is intended to be used. For example, a standard and accepted, or valid, modelling technique may be completely inappropriate when applied to a set of modelling goals that differ for the ones the model was designed to address. Most people using habitat supply models acknowledge the goal generally as an aid to making decisions about resource management, and not as a calculation to predict outcomes of management actions (i.e., strategic rather than operational). Hence, a general principle about assessing habitat supply models should simply be whether the model effectively achieves the overall goals. Using "effectiveness" as a part of model testing embraces the commonly expressed, general characteristic of models—no model is correct but some are useful (e.g., useful as an aid in making decisions about management as discussed in general by Thompson 1997).

Nevertheless, demand for more technical model testing remains strong (Nelson 2003). For example, the suite of models fundamental to the Timber Supply Review (TSR) in British Columbia (e.g., BCMOF 2001) forms the basis for a policy that has important and widespread economic implications on site-specific management around the province. It is proposed that CHASE be tested and reviewed to the extent that it achieves at least the same credibility as the TSR models. Presumably, a credible model is one that is judged to be effective and has strong technical merits (Starfield and Bleloch 1983). Technical testing of models has produced many terms that are sometimes used indiscriminately. The plan for testing CHASE focuses on the following:

- effectiveness, where the primary concern is whether applications are generally determined to be useful and advantageous;
- validation, where relationships used in the model are determined to have some empirical evidence to support or justify the use of the relationship; and
- calibration, where validated relationships are used in a way that is judged to be suitable for the specific application.

Some discussions regarding model testing refer to the terms "verification" or "veracity"; here, these terms are considered part of the processes of validation and calibration.

6.2 EFFECTIVENESS: DETERMINING THE DEGREE OF SUCCESS IN APPLYING CHASE

Fundamentally, the most important test of CHASE is whether the tool is determined to be effective or useful as an aid to managing forests in a manner that maintains the sustainable supply of habitat for caribou and if, by using the tool for that purpose, caribou populations remain healthy. Because this result cannot be measured quickly or precisely, effectiveness must be judged on other, more measurable results, some of which are technical (discussed in Section 6.3) and some of which are not. The non-technical results simply confirm that CHASE meets the following of the original goals:

- ➢ It is commonly accepted as addressing a high priority resource management issue.
- ➢ It provides the necessary functional links among inventory, policy, and management (i.e., has a functional feedback from management to policy, with appropriate indicators that are measurable through a monitoring protocol).
- ➢ It is adaptable (i.e., easy to update with new information about basic resources or relationships).

- ➢ The ecological relationships used and the associated assumptions are made explicit.
- ➢ It is used and is useable (i.e., gains a track-record) to address common problems like TSRs, Strategic Forest Management Plans, operational plans (Forest Stewardship Plans).
- ➢ It is relatively easy to run and interpret.

One key goal of CHASE, for example, was to make one common set of explicit rules for habitat management available to all stakeholders. If CHASE was effective at this, then management decisions would become easier to make and presumably, more consistent across jurisdictional boundaries and among resource managers.

6.3 VALIDATION AND CALIBRATION: DETERMINING THE DEGREE OF TECHNICAL MERIT

Future supply of habitat and the health of caribou herds is essentially a theoretical construct as far as monitoring is concerned. CHASE develops indicators of these constructs through modelling. These indicators are likely to be used at a strategic planning level rather than for monitoring results of management at an operational level. Indicators that are useful at the operational level are more likely to be those associated with individual relationships within specific caribou range models. For example, organic matter characteristics acts as an indicator for how stand removal method, site preparation, and removal season will affect the ability of terrestrial lichens to grow in areas of pine–lichen winter range (see Figure 3.3). For this reason, all ecological relationships within CHASE need to be valid and calibrated to the region of application. Validation should address at least the following two major assumptions:

1. Are the assumptions valid?
    1.1. An explicit list of assumptions and their implications should be available for review.
    1.2. Assumptions should not override applicability or usefulness of results.
2. Are the relationships measurable and accurate?
    2.1. Dependent and independent variables are defined in measurable units.
    2.2. Outputs are consistent with observations (i.e., > 50% of variance explained by the independent variables, 9 times out of 10).
    2.3. Outputs are tested against independent predictions (e.g., ancillary information supports the logic of primary predictions, predictions remain robust in new applications).

Validation on CHASE is planned as the next phase of model development. To the extent possible, data collected as part of the Omineca Northern Caribou Project will be used to assess the validity of ecological relationships.

6.3.1 Opportunities for Using Empirical Data to Update CHASE

CHASE was constructed so that both the model inputs and model results could be measured and monitored. Furthermore, although data collection associated with the Omineca Northern Caribou Project was independent of the modelling, it was designed to be a set of data that could be used to assess the model relationships. This association between modelling and fieldwork has been referred to as “model-motivated data collection” after Turchin (1998).

The general inventory objectives of the Omineca Northern Caribou Project were to:

- monitor annual population characteristics of caribou, moose, and wolves;
- monitor movements and distribution of caribou, moose, and wolves;
- assess characteristics of habitats used by caribou; and
- determine predation rates on caribou and causes of mortality (Zimmerman et al. 2002).

Four general techniques for data collection were implemented:

1. aerial population surveys of caribou, moose, and caribou calves;
2. remote monitoring of sample animals, including capture and radio-collaring of caribou, moose, and wolves with subsequent relocations by either VHF (very high frequency) telemetry and/or GPS (global positioning system) telemetry;
3. investigation of sites including those used by sample animals, those at which mortalities occurred, and those necessary to test ecosystem mapping; and
4. monitoring of weather conditions.

The data collected as part of the Omineca Northern Caribou Project can contribute substantially to the testing and validation of CHASE. As an example, in the High-Elevation Winter Range model, the two states identified for the variable *Slope* (< 40% = suitable caribou habitat, and > 40% = unsuitable habitat) could be tested by analyzing the percent slope of all VHF and GPS telemetry locations of caribou when they occur in high-elevation terrain during the winter.

6.3.2 Opportunities to Design Tests of CHASE: Adaptive Management

The LRMP commits to a "refined and adaptive caribou management direction" that will be modified over time to incorporate new information and improved practices. The Omineca Northern Caribou Project has been promoting that goal through adaptive management. Here "adaptive management" is defined to mean a systematic process for continually improving forestry policies and practices by learning from the outcomes of operational programs. The process typically includes the following six steps (Taylor and Nyberg 1999):

1. assessing the problem or opportunity to be investigated;
2. designing a management approach that achieves resource goals and also advances learning about how to improve management in the future;
3. implementing the management approach in operational, not research, settings;
4. monitoring the outcomes;
5. evaluating the results to determine if they match forecasts made at the design stage; and
6. adapting future management decisions to incorporate what was learned.

Adaptive management (AM) can take two forms: passive and active. In passive AM, a policy or prescription (e.g., LRMP Caribou Management Strategy) would be implemented, outcomes would be monitored and evaluated, and the policy would be modified as necessary to increase its future success. This cycle might be repeated numerous times. In the case of one of the Caribou Management Strategies, each iteration of the passive AM cycle would take many years, because large areas of habitat would have to be disturbed for effects to show.

In active AM, two or more policy alternatives (e.g., different harvesting and silviculture regimes at the stand level) would be implemented in different areas to compare their success. Again, results would be monitored and evaluated, and the preferred policy would be selected based on the results of the management experiment.[18]

The Omineca Northern Caribou Project offers several opportunities for both passive and active AM as explained below. CHASE and its sub-components will be useful for most or all of these adaptive management applications, including the following examples:

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[18] Throughout this section, "experiment" means a test of an unproven technique or policy and does not imply the use of the full rigour normally expected of scientific experiments. All policies and practices to be tested through AM are recognized as experiments in this broad sense, because their outcomes cannot be predicted with confidence.

- The LRMP implementation and monitoring committees could use the model to forecast outcomes of management policies.
- Researchers could use sensitivity analyses to prioritize fieldwork aimed at improving understanding of key relations.
- AM teams could do "gaming" with different policy options while designing projects.

For any AM application, the project team should ensure that an adaptive management project plan is written and made available to participants over the whole term of the project. The plan for the lichen–forestry project (see below) shows the recommended format for such projects.

Terrestrial Lichen Responses to Silviculture Regimes

The supply of terrestrial forage lichens—especially *Cladina* spp. and *Cladonia uncialis*—is a critical component of winter habitat for caribou. Foresters and biologists are interested in the opportunities for maintaining or enhancing these lichens in regenerating and managed forests of the Mackenzie and Vanderhoof forest districts. Ecologists have pointed out many uncertainties about lichen responses to forestry treatments, but there appears to be some potential to maintain significant quantities of forage lichens in logged areas under certain treatment conditions (Coxson and Marsh 2001). The uncertainties could be explored through an active adaptive management program, with replicated timber harvesting and silviculture treatments applied to cutblocks.

In collaboration with Slocan Forest Products and Abitibi-Consolidated, a project plan has been developed and implemented (Sulyma and Wawryszyn 2001) for an active adaptive management project focused on this issue The plan proposes to test 9 treatments in total, with 8 being applied in the Mackenzie Forest District, and 4 in the Vanderhoof Forest District. The treatments represent combinations of harvesting method (whole-tree and cut-to-length), harvesting season (summer and winter), site preparation method (none and drag scarifying), and regeneration method (natural and planting). Treatment units will be 12–25 ha, with 6–8 harvesting treatment units plus an unharvested control at each of 4 sites in the Mackenzie Forest District. Expected outcomes of the treatment have been forecast using the Pine–Lichen Winter Range model, and monitoring plans are being developed for each site. In general, monitoring will begin with pre-treatment sampling in the year before harvesting occurs and will continue in the summers of years 1, 2, 3, 5, and 7 after the treatment occurs. Later sampling may also be needed to confirm long-term responses.

Caribou and Habitat Responses to Management Strategies

Under the direction of the Implementation and Monitoring Committees for the LRMP, the plan will be amended based on the results of monitoring both its implementation and effectiveness. This monitoring and amendment process could be conducted as an explicit adaptive management approach if desired. This would require completion of several steps, including:

- carefully assessing uncertainties associated with various management policies or strategies;
- designing passive or active approaches that will generate new knowledge about the uncertainties, in addition to producing the resource commodities (e.g., timber) and services (e.g., recreation user-days) that are the current priorities of the plan;
- forecasting expected outcomes, using an explicit model that shows relations between actions (policies), system components, and indicators (outcomes); and
- evaluating the results of monitoring, including comparing actual to predicted outcomes.

Although the use of different caribou management strategies in different areas, as outlined in the LRMP and this report, might appear to be a management experiment that fits the active AM concept, there are several difficulties with this notion. The main problems arise from the size of the caribou herd areas and the differences among them. So few herds use such large areas that not enough "treatment units" (herds) are available to allow replication of treatments. In addition, each herd area has a unique combination of terrain, vegetation, and climate, making it unrealistic to consider the various areas as similar treatment units.

Passive adaptive management is the most likely approach for evaluating and improving the caribou management strategies. The LRMP committees could implement, monitor, and evaluate a given strategy in a particular herd area, recognizing it as a policy to be tested and improved over time using AM procedures.

The passive AM framework for evaluation of the overall caribou strategy in a herd area also allows opportunities to conduct additional "nested" management experiments. These nested experiments could be used to test other policy alternatives in sub-areas, in some cases using the active AM approach. Moose hunting policies, snowmobile access policies, predator management policies, and small-scale land management policies (e.g., silviculture regimes) are potential candidates for sub-area management experiments. One such test has already been proposed for the Wolverine herd area (Wilson *et al*. 2003)

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APPENDIX A. ECOLOGICAL UNIT (ECO) RATINGS

Table A.1. Ecological Unit Ratings for caribou calving and summer ranges (CSR), pine–lichen winter ranges (PLWR), high-elevation winter ranges (HEWR), and moose habitat (Moose) within the Wolverine and Chase/Sustut study areas of the Mackenzie Timber Supply Area. A panel of biologists assigned ratings.

Zone	Subzone/ Variant	Site series			C/SR *	PLWR **	HEWR ***	Moose ****
		Number	Code	Name				
AT	n	0	AA	Altai Fescue-Dwarf Willow (FW); Rubble (RU); Rock Outcrop (RO)	G	P	G	L
AT	n	0	BB	Mountain-Heather (MH); Talus Slope (TA); Rock Outcrop (RO)	G	P	G	L
AT	n	0	CC	Talus Slope (TA); Rock Outcrop (RO)	P	P	P	L
AT	n	0	CF	Cryptogam-Altai Fescue	G	P	G	L
AT	n	0	CL	Cliff	P	P	P	L
AT	n	0	DD	Bl-Krummholz (FK); Altai Fescue-Dwarf Willow (FW); Talus Slope (TA)	G	P	G	L
AT	n	0	FK	Bl-Krummholz	G	P	G	L
AT	n	0	FW	Altai Fescue-Dwarf Willow	G	P	G	L
AT	n	0	LA	Lake	P	P	G	M
AT	n	0	MH	Mountain-Heather-Leafy Liverwort Snowbed Community	G	P	G	L
AT	n	0	PD	Pond	P	P	G	M
AT	n	0	RO	Rock Outcrop	P	P	P	L
AT	n	0	RU	Rubble	P	P	P	L
AT	n	0	TA	Talus Slope	P	P	P	L
BWBS	dk1	0	AA	Sw-Wildrye-Toadflax; Sw-Knight's Plume-Step Moss (SM); Sw-Soopolallie-Twinflower (SS)	P	P	P	M
BWBS	dk1	1 & 4	BB	Sw-Knight's Plume-Step Moss (SM); Sb-Lingonberry-Knight's Plume (BL)	P	P	P	M
BWBS	dk1	7	BC	Sb-Lingonberry-Coltsfoot	P	G	P	M
BWBS	dk1	9	BH	Sb-Horsetail-Sphagnum	P	P	P	M
BWBS	dk1	8 & 7 & 0	CC	Sw-Currant-Horsetail (SC); Sb-Lingonberry-Coltsfoot (BC); Willow Birch Floodplain (Wf)	P	P	P	H
BWBS	dk1	0	CS	Cottongrass-Sphagnum Wetland	P	P	P	M
BWBS	dk1	0	DD	Cottongrass-Sphagnum Wetland (CS); Sedge-Fuzzy Fen Moss Fen (SF); Willow-Birch-Sedge Wetland (WB); Willow-Birch Floodplain (WF)	P	P	P	M
BWBS	dk1	0	EE	Talus Slope (TA); Rock Outcrop (RO)	P	P	P	L
BWBS	dk1	0	LA	Lake	P	P	P	M
BWBS	dk1	2	LL	Pl-Lingonberry-Feathermoss	P	G	P	L
BWBS	dk1	0	RI	River	P	P	P	L
BWBS	dk1	8	SC	Sw-Currant-Horsetail	P	P	P	M
BWBS	dk1	0	SF	Sedge-Fuzzy Fen Moss Fen	P	P	P	M
BWBS	dk1	1	SM	Sw-Knight's Plume-Step Moss	P	P	P	M
BWBS	dk1	6	SR	Sw-Scouring-Rush-Step Moss	P	P	P	M
BWBS	dk1	5	SS	Swpl-Soopolallie-Twinflower	P	P	P	M
BWBS	dk1	0	TC	Timothy-Sedge Herb Meadow	P	P	P	M
BWBS	dk1	0	WF	Willow-Birch Floodplain	P	P	P	H
ESSF	mv3	1 & 4	AA	Bl-Rhododendron-Feathermoss (FR); Bl-Oak Fern-Knight's Plume (FO)	G	P	G	M
ESSF	mv3	1 & 2	BB	Bl-Rhododendron-Feathermoss (FR); BlPl-Crowberry-Cladina (LC)	G	G	G	M

Zone	Subzone/ Variant	Site series			C/SR *	PLWR **	HEWR ***	Moose ****
		Number	Code	Name				
ESSF	mv3	0	BS	Sb-Sphagnum	G	P	G	M
ESSF	mv3	3	BT	BlSb-Labrador Tea	G	G	G	M
ESSF	mv3	4 & 7	CC	Bl-Oak Fern-Knight's Plume (FO); Bl-Horsetail-Feathermoss (FH)	G	P	G	M
ESSF	mv3	0	CF	Cryptogram-Altai Fescue	G	P	G	L
ESSF	mv3	0	CS	Cottongrass-Sphagnum Wetland	G	P	G	M
ESSF	mv3	7 & 4	DD	Bl-Horsetail-Feathermoss (FH); Bl-Oak Fern-Knight's Plume (FO)	G	P	G	M
ESSF	mv3	7 & 0	EE	Bl-Horsetail-Feathermoss (FH); Willow-Birch Floodplain (WF)	G	P	G	M
ESSF	mv3	0	ES	Exposed Soil	P	P	P	L
ESSF	mv3	0	FC	Bl-Crowberry	G	G	G	L
ESSF	mv3	5	FD	Bl-Devil's Club-Rhododendron	G	P	G	L
ESSF	mv3	0	FF	Cottongrass-Sphagnum Wetland (CS); Sedge-Fuzzy Fen Moss Fen (SF); Willow-Birch-Sedge Wetland (WB); Willow-Birch Floodplain (WF)	G	P	G	M
ESSF	mv3	7	FH	Bl-Horsetail-Feathermoss	G	P	G	M
ESSF	mv3	0	FK	Bl-Krummholz	G	P	G	L
ESSF	mv3	0	FM	Bl-White Mountain-Heather	G	P	G	L
ESSF	mv3	4	FO	Bl-Oak Fern-Knight's Plume	G	P	G	M
ESSF	mv3	1	FR	Bl-Rhododendron-Feathermoss	G	P	G	M
ESSF	mv3	0	FV	Bl-Valerian-Arnica	G	P	G	L
ESSF	mv3	0	FW	Altai Fescue-Dwarf Willow	G	P	G	L
ESSF	mv3	0	GB	Gravel Bar	P	P	P	M
ESSF	mv3	0	GG	Aspen	G	P	G	M
ESSF	mv3	0	HH	Bl-Crowberry (FC); Bl-Rhododendron-Feathermoss (FR)	G	G	G	L
ESSF	mv3	0	II	Bl-White Mountain-Heather (FM); Bl-Rhododendron-Feathermoss (FR)	G	P	G	M
ESSF	mv3	0	JJ	Altai Fescue-Dwarf Willow (FW); Rubble (RU); Rock Outcrop (RO)	G	P	G	L
ESSF	mv3	0	KK	Bl-Krummholz (FK); Talus Slope (TA); Rock Outcrop (RO)	G	P	G	L
ESSF	mv3	0	LA	Lake	P	P	G	M
ESSF	mv3	2	LC	BlPl-Crowberry-Cladina	G	G	G	L
ESSF	mv3	0	LL	Cryptogram-Altai Fescue (CF); Talus Slope (TA); Rock Outcrop (RO)	G	P	G	L
ESSF	mv3	0	MH	White Mountain Heather Heath	G	P	G	L
ESSF	mv3	0	OW	Open Water	P	P	G	M
ESSF	mv3	0	PD	Pond	P	P	G	M
ESSF	mv3	0	RI	River	P	P	P	L
ESSF	mv3	0	RO	Rock Outcrop	P	P	P	L
ESSF	mv3	0	RP	Road Surface	P	P	P	M
ESSF	mv3	0	RU	Rubble	P	P	P	L
ESSF	mv3	0	SB	Sedge-Buckbean Wetland	G	P	G	M
ESSF	mv3	0	SF	Sedge-Fuzzy Fen Moss Fen	G	P	G	M
ESSF	mv3	0	ST	SxwFd-Toad-Flax	G	P	G	M
ESSF	mv3	0	TA	Talus Slope	P	P	P	L
ESSF	mv3	0	TC	Timothy-Sedge Herb Meadow	G	P	G	M
ESSF	mv3	0	VG	Sitka Valerian-Arrow-Leaved Groundsel	G	P	G	L
ESSF	mv3	0	WB	Willow-Birch-Sedge Wetland	G	P	G	H
ESSF	mv3	0	WF	Willow-Birch Floodplain	G	P	G	H
ESSF	mvp3	0	AA	Bl-Crowberry (FC); Altai Fescue-Dwarf Willow (FW); Bl Krummholz (FK); Rubble (RU)	G	P	G	L
ESSF	mvp3	0	BB	Altai Fescue-Dwarf Willow (FW); Rubble (RU); Rock Outcrop (RO)	G	P	G	L
ESSF	mvp3	0	CC	Bl-White Mountain Heather (FM) White Mountain Heather Heath (MH); Bl Krummholz (FK)	G	P	G	M
ESSF	mvp3	0	CF	Cryptogram-Altai Fescue	G	P	G	L

Zone	Subzone/ Variant	Site series			C/SR *	PLWR **	HEWR ***	Moose ****
		Number	Code	Name				
ESSF	mvp3	0	CL	Cliff	P	P	P	L
ESSF	mvp3	0	CS	Cottongrass-Sphagnum Wetland	G	P	G	M
ESSF	mvp3	0	DD	Bl-White Mountain Heather (FM); Bl-Sitka Valerian (FV)	G	P	G	M
ESSF	mvp3	0	EE	Bl-Sitka Valerian (FV); Sitka Valerian-Arrow-Leaved Groundsel (VG)	G	P	G	M
ESSF	mvp3	0	FC	Bl-Crowberry	G	P	G	L
ESSF	mvp3	0	FF	Bl Krummholz (FK); Talus Slope (TA); Rock Outcrop (RO)	G	P	G	L
ESSF	mvp3	0	FK	Bl Krummholz	G	P	G	L
ESSF	mvp3	0	FM	Bl-White Mountain Heather	G	P	G	L
ESSF	mvp3	0	FV	Bl-Sitka Valerian	G	P	G	L
ESSF	mvp3	0	FW	Altai Fescue-Dwarf Willow	G	P	G	L
ESSF	mvp3	0	GG	Cryptogram-Altai Fescue (CF); Talus Slope (TA); Rock Outcrop (RO)	G	P	G	L
ESSF	mvp3	0	HH	Talus Slope (TA); Rock Outcrop (RO)	P	P	P	L
ESSF	mvp3	0	II	Cottongrass-Sphagnum Wetland (CS); Willow-Birch-Sedge Wetland (WB); Willow-Birch Floodplain (WF); Sitka Valerian-Arrow-Leaved Groundsel (VG)	G	P	G	M
ESSF	mvp3	0	LA	Lake	P	P	G	M
ESSF	mvp3	0	MH	White Mountain Heather Heath	G	P	G	L
ESSF	mvp3	0	OW	Open Water	P	P	G	M
ESSF	mvp3	0	RO	Rock Outcrop	P	P	P	L
ESSF	mvp3	0	RU	Rubble	P	P	P	L
ESSF	mvp3	0	TA	Talus Slope	P	P	P	L
ESSF	mvp3	0	VG	Sitka Valerian-Arrow-Leaved Groundsel Moist Meadow	G	P	G	L
SBS	mk1	7 & 8	AA	Sxw-Oak Fern (SO); Sxw-Devil’s Club (SD)	P	P	P	M
SBS	mk1	10	BB	Sb-Scrub Birch-Sedge	P	G	P	M
SBS	mk1	0	BE	Beach	P	P	P	L
SBS	mk1	6	BH	Sb-Huckleberry-Spiraea	P	G	P	M
SBS	mk1	0	BS	Scrub Birch-Sedge Poor Fen	P	P	P	M
SBS	mk1	9a	CC	Sx-Horsetail: Fluvial Phase	P	P	P	H
SBS	mk1	9b	DD	Sx-Horsetail: Organic Phase	P	P	P	M
SBS	mk1	0	ES	Exposed Soil	P	P	P	L
SBS	mk1	0	GB	Gravel Bar	P	P	P	M
SBS	mk1	0	LA	Lake	P	P	P	M
SBS	mk1	3	LC	Pl-Feathermoss-Cladina	P	G	P	L
SBS	mk1	1	LM	Pl-Cladina-Step Moss	P	G	P	L
SBS	mk1	0	OW	Open Water	P	P	P	M
SBS	mk1	0	PD	Pond	P	P	P	M
SBS	mk1	0	RI	River	P	P	P	L
SBS	mk1	0	RO	Rock Outcrop	P	P	P	L
SBS	mk1	0	RP	Road Surface	P	P	P	M
SBS	mk1	0	RR	Rural	P	P	P	M
SBS	mk1	1	SB	Sx-Huckleberry-Highbush-Cranberry	P	P	P	M
SBS	mk1	0	SD	Sxw-Devil’s Club	P	P	P	M
SBS	mk1	0	SF	Sedge-Fuzzy Fen Moss Fen	P	P	P	M
SBS	mk1	9	SH	Sxw-Horsetail	P	P	P	H
SBS	mk1	0	SM	Sedge-Moss Bog Wetland	P	P	P	L
SBS	mk1	7	SO	Sxw-Oak Fern	P	P	P	M
SBS	mk1	5	ST	SxwFd-Toad-Flax	P	P	P	M
SBS	mk1	0	TA	Talus Slope	P	P	P	L
SBS	mk1	0	TC	Timothy-Sedge Herb Meadow	P	P	P	M
SBS	mk1	0	WB	Willow-Bluejoint Floodplain	P	P	P	H

Zone	Subzone/ Variant	Site Series			C/SR *	PLWR **	HEWR ***	Moose ****
		Number	Code	Name				
SBS	mk2	3 & 1	AA	Sx-Huckleberry-Soopolallie (SS); Sx-Huckleberry-Highbush Cranberry (SB)	P	P	P	M
SBS	mk2	2 & 3	BB	Pl-Feathermoss-Cladina (LC); Sx-Huckleberry-Soopolallie (SS)	P	G	P	M
SBS	mk2	4	BH	Sb-Huckleberry-Soopolallie	P	G	P	L
SBS	mk2	0	IN	Inundated	P	P	P	L
SBS	mk2	0	LA	Lake	P	P	P	M
SBS	mk2	2	LC	Pl-Feathermoss-Cladina	P	G	P	L
SBS	mk2	0	RI	River	P	P	P	L
SBS	mk2	0	RO	Rock Outcrop	P	P	P	L
SBS	mk2	1	SB	Sx-Huckleberry-Highbush Cranberry	P	P	P	M
SBS	mk2	6	SH	Sx-Horsetail	P	P	P	H
SBS	mk2	5	SO	Hybrid White Spruce-Oak Fern	P	P	P	M
SBS	mk2	3	SS	Sx-Huckleberry-Soopolallie	P	P	P	M
SBS	mk2	0	WL	Generalised Wetland	P	P	P	M
SBS	wk2	2 & 3	AA	Pl-Huckleberry-Cladina (LH); Sx-Huckleberry-Highbush-Cranberry (SC)	P	G	P	L
SBS	wk2	4	BF	SbPl-Feathermoss	P	P	P	L
SBS	wk2	0	LA	Lake	P	P	P	M
SBS	wk2	2	LH	Pl-Huckleberry-Cladina	P	G	P	L
SBS	wk2	0	RI	River	P	P	P	L
SBS	wk2	0	RO	Rock Outcrop	P	P	P	L
SBS	wk2	3	SC	Sx-Huckleberry-Highbush-Cranberry	P	P	P	M
SBS	wk2	5	SD	Sx-Devil's Club	P	P	P	M
SBS	wk2	6	SH	Sx-Horsetail	P	P	P	H
SBS	wk2	1	SO	Sx-Oak Fern	P	P	P	M
SBS	wk2	0	WS	Willow–Sedge Fen	P	P	P	H

* C/SR = Caribou Calving and Summer RangeValues:
1 = Vegetated AT (useable caribou habitat). Note: includes lakes
2 = Vegetated ESSF (useable habitat). Note: includes lakes
3 = Other (unusable habitat)

** PLWR = Pine–Lichen Winter Range Values:
1 = Dry, Nutrient-Poor (useable caribou habitat)
2 = Other (unusable caribou habitat)

*** HEWR = High-Elevation Winter Range Values:
1 = Vegetated AT (useable caribou habitat). Note: includes lakes
2 = Vegetated ESSF (useable habitat). Note: includes lakes
3 = Other (unusable habitat)

**** Moose = Moose Habitat Values:
1 = Shrub-dominated (high-value moose habitat)
2 = Productive Forest (moderate-value moose habitat). Note: includes lakes and ponds
3 = Unproductive Forest (low-value moose habitat)

APPENDIX B. ASSIGNING ECOLOGICAL UNIT RATINGS IN THE ABSENCE OF TEM/PEM COVERAGE

A panel of biologists rated biogeoclimatic site series (ecological units) identified in Terrestrial/Predictive Ecosystem Mapping (TEM/PEM) for the Caribou Calving and Summer Range, High-Elevation Winter Range, and Pine–Lichen Winter Range models, and for the Moose Density model. TEM/PEM coverage was incomplete for the Wolverine study area (only 356,469 ha had TEM/PEM completed), therefore we used Forest Inventory Planning (FIP) data, Ministry of Forests biogeoclimatic ecosystem classification (BEC) zonation data, and Terrain Resource Inventory Mapping (TRIM)-based data as a substitute for TEM/PEM in assigning ecological unit (EU) ratings for the remaining portion of the study area (631,064 ha).

CALVING AND SUMMER RANGE

For the Calving and Summer Range model, the highest rating was assigned to vegetated EUs in the Alpine Tundra zone *(Veg AT)*, high to medium ratings were assigned to vegetated units in the Engelmann Spruce–Subalpine Fir zone *(Veg ESSF)*, and all other units were assigned a low rating (*Other*) (see Section 3.2.3 for further descriptions of EU ratings). Frozen lake surfaces were considered suitable habitat, and were therefore included in the *Veg AT* and *Veg ESSF* categories. In the absence of TEM/PEM data, the BEC zone and Non-productive Forest descriptor from the FIP data were used for assigning EU ratings (Table B.1).

Table B.1. The knowledge table rules to assign Ecological Unit ratings for calving and summer range habitat based on the biogeoclimatic ecosystem classification (BEC) zone and Non-productive Forest descriptor from the Forest Inventory Planning data

BEC zone	Non-productive Forest descriptor	Assigned Ecological Unit state
AT, ESSF, SWB	icefield, rock, gravel pit, sand, clay bank, lake, tidal flat, gravel bar, river, mud flat, roads, urban, non-applicable	Other
AT	null, alpine, alpine forest, non-productive brush, non-productive, non-productive forest, non-productive burn, swamp, clearing, hayfield, meadow, open range	Veg AT
ESSF, SWB	null, alpine, alpine forest, non-productive brush, non-productive, non-productive forest, non-productive burn, swamp, clearing, hayfield, meadow, open range	Veg ESSF
BWBS, SBS	any	Other

The two states of the Inventory Type Group node included “balsam”-dominated or non-forested (*BA or nonfor*) and *Other*. These states were defined based on the leading commercial tree species (Tree Species CD 1), Non-productive Forest descriptor, and Inventory Type Group number from the FIP data (Table B.2).

Table B.2. The knowledge table rules to assign Inventory Type Group states for calving and summer range habitat based on the leading commercial tree species (Tree Species CD 1), Non-productive Forest descriptor, and Inventory Type Group number from the FIP data

Trees Species CD 1	Non-productive Forest descriptor	Inventory Type Group number	Inventory Type Group state assigned
null	lake, river, non-applicable	any	Other
null	null, icefield, alpine, rock, gravel pit, sand, clay bank, alpine forest, non-productive brush, non-productive, non-productive forest, non-productive burn, tidal flat, gravel bar, mud flat, swamp, clearing, roads, urban, hayfield, meadow, open range	any	BA or Nonfor
not null	any	18, 19, 20	BA or Nonfor
not null	any	1–17, 21–42	Other

PINE–LICHEN WINTER RANGE

For the Pine–Lichen Winter Range model the highest habitat rating was assigned sites that were dry and nutrient-poor (*Dry Nut-Poor*), and all other units were assigned a low habitat rating (*Other*) (see Section 3.3.3 for further descriptions of Ecological Unit ratings). In the absence of TEM/PEM data, Site Index from the FIP data was used for assigning EU ratings. If the site index was between 1 and 14.49, the EU was rated *Dry Nut-Poor*, but if the site index was 0 or > 14.49 the rating was *Other.*

HIGH-ELEVATION WINTER RANGE

For the High-Elevation Winter Range model, the highest EU rating was assigned to vegetated units in the Alpine Tundra zone *(Veg AT)*, high to medium ratings were assigned to vegetated units in the Engelmann Spruce–Subalpine Fir zone *(Veg ESSF)*, and all other units were assigned a low rating (*Other*) (see Section 3.4.3 for further descriptions of Ecological Unit ratings). Frozen lake surfaces were considered suitable habitat, and were therefore included in the *Veg AT* and *Veg ESSF* categories. In the absence of TEM/PEM data, the BEC zone and Non-productive Forest descriptor from the FIP data was used for assigning EU ratings (Table B.3).

Table B.3. The knowledge table rules to assign Ecological Unit ratings for high-elevation winter range habitat based on the biogeoclimatic ecosystem classification (BEC) zone and Non-productive Forest descriptor from the Forest Inventory Planning data

BEC zone	Non-productive Forest descriptor	Assigned Ecological Unit state
AT ESSF SWB	icefield, rock, gravel pit, sand, clay bank, tidal flat, gravel bar, river, mud flat, roads, urban, non-applicable	Other
AT	null, alpine, alpine forest, non-productive brush, non-productive, non-productive forest, non-productive burn, lake, swamp, clearing, hayfield, meadow, open range	Veg AT
ESSF SWB	null, alpine, alpine forest, non-productive brush, non-productive, non-productive forest, non-productive burn, lake, swamp, clearing, hayfield, meadow, open range	Veg ESSF
BWBS SBS	any	Other

The two states of the Inventory Type Group node included “balsam”-dominated forest (*BA*) and *Other*. These states were defined based on the leading commercial tree species (Tree Species CD 1) and Inventory Type Group Number from the FIP data (Table B.4).

Table B.4. The knowledge table rules to assign Inventory Type Group states for high-elevation winter range habitat based on the leading commercial tree species (Tree Species CD 1) and Inventory Type Group Number from the Forest Inventory Planning data

Trees Species CD 1	Inventory Type Group Number	Assigned Inventory Type Group state
null	any	Other
not null	18, 19, 20	BA
not null	1–17, 21–42	Other

The two states of the Elevation node included < 1300 m and ≥ 1300 m. However, given that all Ecological Units assigned to the *Veg AT* state should not be influenced by the elevation node, all AT BEC zones were assigned an elevation of ≥ 1300 m. Note that the influence of elevation on the High-Elevation Winter Range Habitat Value node is constrained in two ways:

1. In the CP table of the HEWR Habitat Value node, elevation does not interact with terrestrial lichen availability. In other words, the probability of the HEWR Habitat Value does not change with elevation in those state combinations that have terrestrial lichens available. Since terrestrial lichens are only available in the AT zone, this is tantamount to allowing AT zonation to take precedence over elevation.
2. In keeping with point 1 that AT zonation takes precedence over elevation, the state assigned to the Elevation node was constrained as outlined in Table B.4. This constraint is redundant for state combinations in the HEWR Habitat Value node that have terrestrial lichens available (because of the CP table) but exerts its impact on those state combinations where terrestrial lichens are unavailable but arboreal lichens are available in the AT zone. In these cases, AT zonation takes precedence over elevation through recoding elevations < 1300 m as ≥ 1300 m if the zone is AT.

In combination, constraints 1 and 2 allow elevation to only influence HEWR Habitat Value if the zone is ESSF/SWB, in keeping with our objective of using elevation to differentiate between upper and lower portions of the ESSF.

MOOSE DENSITY

For the Moose Density model, the highest habitat rating was assigned to *Shrub-Dominated* units, a medium habitat rating was assigned to early seral forests on productive sites (*Productive Forests*), and older forest stands and early seral stands on unproductive sites were assigned a low habitat rating (*Unproductive-Low-Shrub*) (see Section 3.1.3 for further descriptions of Ecological Unit ratings). The general rules used for assigning EU ratings in the absence of TEM/PEM were derived in four steps. First, Non-productive Forest descriptors and Non-forest descriptors in the FIP database were categorized into those that were likely to denote shrubby sites and those that likely denoted non-shrubby or non-vegetated sites. Second, EU ratings assigned to TEM/PEM data (Appendix xx) were examined to establish broad patterns in ratings assigned to shrubby sites by BEC zone. Third, we examined the distributions of EU ratings based on TEM/PEM site series in the corresponding combinations of FIP-, BEC-, and TRIM-based data for the area of TEM/PEM coverage. Fourth, the results of steps 1–3 were used to construct a simple knowledge table that was used to translate FIP-, BEC-, and TRIM-based data into EU ratings over the portion of the study area without TEM/PEM coverage.

Table B.5 delineates the FIP Non-forest and Non-productive descriptors that, in the absence of lead forest species, were likely to be shrubby or non-shrubby/non-vegetated sites. Correspondence was low between the selection of FIP descriptors that denoted shrubby sites and TEM/PEM site series that were coded with an EU rating of *Shrub-Dominated*. Within the SBS, BWBS, and ESSF, only 36%, 25%, and 5%, respectively, of the area that was considered shrubby based on FIP descriptors was coded as *Shrub-Dominated* from TEM/PEM data (53%, 70%, and 37% of the area, respectively, was rated as *Productive Forest* from TEM/PEM data). The poor correspondence in the ESSF was due to most shrubby site series having been assigned a lower value to moose (*Productive Forest*) by the panel of biologists based on elevation (Table B.6). In spite of this low correspondence between the selected FIP descriptors and TEM/PEM site series data, the FIP descriptors were used in the knowledge table to define *Shrub-Dominated* sites in the SBS and BWBS, and *Productive Forest* sites in the ESSF, as this was the best information available over the portion of the study area without TEM/PEM coverage.

Table B.5. Partitioning of Forest Inventory Planning data based on Non-productive Forest and Non-forest descriptors

Shrubby sites	Non-shrubby/Non-vegetated sites	
non-productive brush	icefield	mud flat
non-commercial brush	alpine	roads
non-productive burn	rock	urban
non-productive[a]	gravel pit	hayfield
not sufficiently restocked[a]	sand	open range
swamp	clay bank	non-applicable
meadow	tidal flat	non typing available
clearing	gravel bar	lake[b]
	river	

[a] Without leading tree species.

[b] Lakes in the BWBS, SBS, and ESSF were assigned an EU rating of Productive Forest in the knowledge table to indicate moderate habitat value to moose in accordance with ratings assigned by the panel of biologists.

Table B.6. Percent of area in each Ecological Unit rating class for moose habitat by biogeoclimatic ecosystem classification (BEC) zone. Ecological Unit ratings were assigned to TEM/PEM site series by a panel of biologists.

BEC zone	Total area (ha)	Percent of area in each Ecological Unit rating class (%)		
		Shrub-Dominated	Productive Forest	Unproductive Low Shrub
AT	52,283	0.1	2.8	97.1
ESSF	214,759	0.8	10.1	89.1
SBS	53,615	8.0	65.1	26.9
BWBS	35,812	8.4	70.8	20.8

Although all TEM/PEM site series in the AT were coded as *Unproductive-Low Shrub* (Appendix xx), inconsistencies in zone boundaries between BEC data and TEM/PEM data (TEM and PEM both provided an independent assessment of BEC variants) resulted in some higher value moose habitat in the AT (Table B.6). Most (90%) of the BEC-defined AT at elevations < 1200 m was classified as BWBS in the TEM/PEM data. Similarly, 87% of the BEC-defined AT between 1200 and 1300 m was classified as ESSF in the TEM/PEM data. Therefore, in constructing the knowledge table, AT at elevations < 1200 m was treated similarly to the BWBS, while AT between 1200 and 1300 m was treated in similarly to the ESSF.

Relationships between TEM/PEM-based EU ratings and a suite of corresponding FIP-, BEC-, and TRIM-based variables were examined to define knowledge table rules for forested sites outside the area of TEM/PEM coverage. EU ratings assigned to TEM/PEM site series by the panel of biologists was at the BEC variant level. However, the BEC variant data available for the remainder of the study area did not fully delineate between ESSFmv3 and ESSFmv3 and also included an appreciable area (34,308 ha) of SBSwk3 for which the panel had assigned no EU ratings. As a consequence, the examination of relationships for these areas was at the BEC zone rather than variant level. FIP and BEC variables examined included BEC zone, Site Class 5 m (site index to the closest 5 m), Non-productive Forest descriptor, Non-forest descriptor, and Tree Species CD 1 (leading commercial species), which were subsequently grouped into Lead Species categories of None, Deciduous, Lodgepole Pine, Black Spruce, and Other Conifer. For the AT zone, we examined four elevation classes (1 = < 1000 m, 2 = ≥ 1000–< 1200 m, 3 = ≥ 1200–< 1300 m, and 4 = ≥ 1300 m) to verify our partitioning of the AT zone by elevation class. For the remaining zones, we explored two aspect classes (1 = ≤ 5% slope or aspects ≥ 45° and ≤ 315°, and 2 = > 5% slope and aspects > 315° and < 45°) to identify dry poor sites in class 1, which are unfavourable moose habitat.

EU ratings assigned to TEM/PEM site series did not correspond well with combinations of FIP, BEC, and TRIM variables. Many such combinations had more than one EU rating due to overlap with multiple site series (Table B.7). As an aid in formulating knowledge table rules, the area (ha) of each EU rating within combinations of FIP, BEC, and TRIM variables was totaled and a simple area-based majority rule was used in most cases. Exceptions to this majority rule occurred when a combination resulted in little area upon which to make a decision and the EU rating with the majority of the area was inconsistent with the majority EU rating in similar combinations (e.g., the combination of Non-productive and Other Conifer in Table B.7 was assigned an EU rating of *Productive Forest* in accordance with the Other Conifer category). With the exception of pine-leading sites on low site indexes in the SBS, aspect contributed little to the examination and was dropped for other zones and other Lead Species Categories.

Table B.7. An example of relationships between EU ratings assigned by the panel of biologists to TEM/PEM site series and a suite of FIP-, BEC-, and TRIM-based variables

BEC zone	Site class (5 m)	Non-productive or Non-forest descriptor	Lead species category	Aspect class	EU rating assigned by panel	Total area (ha)
SBS	5		Other Conifer		Shrub Dominated	6
SBS	5		Other Conifer		Unproductive Low Shrub	133
SBS	5		Other Conifer			297
SBS	5		Pine	1	Unproductive Low Shrub	50
SBS	5		Pine	1	Productive Forest	8
SBS	5		Pine	2	Shrub Dominated	1
SBS	5		Pine	2	Unproductive Low Shrub	3
SBS	5		Pine	2	Productive Forest	52
SBS	5	Non-productive	Black Spruce		Shrub Dominated	32
SBS	5	Non-productive	Black Spruce		Unproductive Low Shrub	16
SBS	5	Non-productive	Black Spruce		Productive Forest	131
SBS	5	Non-productive	Other Conifer		Shrub Dominated	3
SBS	5	Non-productive	Other Conifer		Unproductive Low Shrub	1

[a] EU ratings in shaded text represent the EU rating assigned to forested sites outside the area of TEM/PEM coverages based on the simple majority rule.

Upon completion of the area-majority rules for each combination of FIP, BEC, and TRIM variables, we examined and found that 1,324 ha (0.2%) of the study area had combinations that did not occur within the area coverage. For these combinations the EU rating assigned was based on similar combinations that did occur, or on general patterns of assignment within BEC zones. Finally, the combinations of FIP, BEC, and TRIM variables were collapsed by zone into the minimum number of mutually exclusive combinations required to represent the EU rating assignment rules and organized into a knowledge table (Table B.8).

Table B.8. The knowledge table rules to assign EU ratings based on FIP, BEC and TRIM-based variables for the portion of the study area without TEM/PEM coverage. Rows in the table represent combinations of the FIP-, BEC-, and TRIM-based variables and the EU rating assigned to the combination. The order of rules within BEC zones denotes the order the rule is applied in the decision process.

BEC zone	Elevation class (m)	Lead species category	Non-productive/ Non-forest descriptors	Site class (5 m)	Aspect class	EU rating assigned
AT	< 1200	None	Lake	Any	Any	Productive Forest
AT	< 1200	None	Non-productive brush, non-commercial brush, non-productive burn, non-productive, not sufficiently restocked, swamp, meadow, clearing	Any	Any	Shrub-Dominated
AT	< 1200	None	Any other descriptor	Any	Any	Unproductive Low Shrub
AT	< 1200	Any but None	Alpine forest	Any	Any	Unproductive Low Shrub
AT	< 1200	Any but None	Any other descriptor	Any	Any	Productive Forest

BEC zone	Elevation class (m)	Lead species category	Non-productive/ Non-forest descriptors	Site class (5 m)	Aspect class	EU rating assigned
AT	1200–1300	None	Lake, non-productive brush, non-commercial brush, non-productive burn, non-productive, not sufficiently restocked, swamp, meadow, clearing	Any	Any	Productive Forest
AT	1200–1300	None	Any other descriptor	Any	Any	Unproductive Low Shrub
AT	1200–1300	Deciduous	Any	Any	Any	Productive Forest
AT	1200–1300	Lodgepole Pine, Black Spruce, Other Conifer	Any	Any	Any	Unproductive Low Shrub
AT	≥ 1300	Any	Any	Any	Any	Unproductive Low Shrub
BWBS	Any	None	lake	Any	Any	Productive Forest
BWBS	Any	None	Non-productive brush, non-commercial brush, non-productive burn, non-productive, not sufficiently restocked, swamp, meadow, clearing	Any	Any	Shrub-Dominated
BWBS	Any	None	Any other descriptor	Any	Any	Unproductive Low Shrub
BWBS	Any	Lodgepole Pine	Any	≤ 5	Any	Unproductive Low Shrub
BWBS	Any	Any but None	Alpine forest	Any	Any	Unproductive Low Shrub
BWBS	Any	Any but None	Any other descriptor	Any	Any	Productive Forest
SBS	Any	None	Lake	Any	Any	Productive Forest
SBS	Any	None	Non-productive brush, non-commercial brush, non-productive burn, non-productive, not sufficiently restocked, swamp, meadow, clearing	Any	Any	Shrub-Dominated
SBS	Any	None	Any other descriptor	Any	Any	Unproductive Low Shrub
SBS	Any	Lodgepole Pine	Any	≤10	1	Unproductive Low Shrub
SBS	Any	Lodgepole Pine	Any	≤10	2	Productive Forest
SBS	Any	Any but None	Alpine forest	Any	Any	Unproductive Low Shrub
SBS	Any	Any but None	Any other descriptor	Any	Any	Productive Forest
ESSF SWB	Any	None	Lake, non-productive brush, non-commercial brush, non-productive burn, non-productive, not sufficiently restocked, swamp, meadow, clearing	Any	Any	Productive Forest
ESSF SWB	Any	None	Any other descriptor	Any	Any	Unproductive Low Shrub
ESSF SWB	Any	Deciduous	Any	Any	Any	Productive Forest

BEC zone	Elevation class (m)	Lead species category	Non-productive/ Non-forest descriptors	Site class (5 m)	Aspect class	EU rating assigned
ESSF SWB	Any	Black Spruce	Non-productive, non-productive forest	Any	Any	Productive Forest
ESSF SWB	Any	Black Spruce	Any other descriptor	Any	Any	Unproductive Low Shrub
ESSF SWB	Any	Lodgepole Pine, Other Confer	Any	Any	Any	Unproductive Low Shrub

As a simple performance test of the knowledge table, the EU rating assignment rules were applied to the portion of the study area with TEM/PEM coverage and percentage area by BEC zone and EU rating was tallied (Table B.9). In comparison with Table B.6, the knowledge table rules resulted in similar percent areas of the three EU ratings for the AT and the ESSF but tended to greatly overestimate the amount of *Productive Forest* and underestimate the amount of *Unproductive Low Shrub* in the SBS and BWBS. The results of applying the knowledge table to the portion of the study area without TEM/PEM coverage are presented in Table B.10.

Table B.9. Percent of area by BEC zone assigned to Ecological (EU) ratings of the Moose Density Model. EU ratings were assigned from BEC-, FIP-, and TRIM-based data applied to the area of TEM/PEM coverage.

BEC zone	Total area (ha)	Percent of area in each Ecological Unit rating class (%)		
		Shrub-Dominated	Productive Forest	Unproductive Low Shrub
AT	52,283	< 0.1	2.3	97.6
ESSF	214,759	0.0	5.6	94.4
SBS	53,615	5.4	90.6	4.0
BWBS	35,812	4.7	94.5	0.9

Table B.10. Percent of area by BEC zone assigned to EU ratings of the Moose Density Model. Ecological Unit (EU) ratings were assigned from BEC-, FIP-, and TRIM-based data applied to the portion of the study area without TEM/PEM coverage.

BEC zone	Total area (ha)	Percent of area in each Ecological Unit rating class (%)		
		Shrub-Dominated	Productive Forest	Unproductive Low Shrub
AT	63,669	< 0.1	1.3	98.7
ESSF	311,913	0.0	4.9	95.1
SBS	159,034	6.2	90.5	3.3
BWBS	96,448	7.2	90.7	2.1