Use of Habitat Supply Models to Establish Herd-based Recovery Targets for Threatened Mountain Caribou in British Columbia

Year 2 Progress Report

S. MCNAY[1], C. APPS[2], S. WILSON[3], T. KINLEY[4], D. O'BRIEN[5], AND G. SUTHERLAND[5]

NOVEMBER 30, 2005
REVISED JANUARY 16, 2006

[1]Wildlife Infometrics Inc., PO Box 308, Mackenzie, BC, V0J 2C0, scott.mcnay@wildlifeinfometrics.com
[2]Aspen Wildlife Research Inc., 2708 Cochrane Road N.W., Calgary, AB T2M 4H9, clayton.apps@telus.net
[3]Ecologic Research, 406 Hemlock Avenue, Gabriola Island, BC V0R 1X1, sfwilson@shaw.ca
[4]Sylvan Consulting Ltd., RR5, 3519 Toby Creek Road, Invermere, BC V0A 1K5, sylcon@telus.net
[5]Cortex Consultants, Suite2a – 1218 Langley Street, Victoria, BC V8W 1W2, dobrien@cortex.ca

Prepared for the Provincial Species at Risk Recovery Coordination Office

CITATION: McNay, R.S., C. Apps, S. Wilson, T. Kinley, D. O'Brien, and G. Sutherland. 2006. Use of habitat supply models to establish herd-based recovery targets for threatened mountain caribou in British Columbia: Year 2 Progress Report. Wildlife Infometrics Inc., Mackenzie, BC. Wildlife Infometrics Inc. Report No. 180. 92pp.

ABSTRACT

This progress report covers the second 6-month period (May-September 2005) of a project initiated to support the development of options to recover the declining population of mountain caribou in British Columbia (BC). Outcomes from the project apply specifically to Recovery Implementation Groups and to the Species At Risk Coordination Office (SARCO) by way of providing:

- Consistent interpretations of seasonal range values throughout the range of mountain caribou in BC;
- Simulation modeling and scenario planning to establish herd-based, relative seasonal range and relative population targets; and
- Standard procedures for defining survival and recovery habitats.

These outcomes are complementary to other initiatives on mountain caribou undertaken by SARCO including a situation analysis, a Delphic survey, and an information compilation process.

Specific objectives that were completed over the first six months (October 2004-March 2005) included:

- Selection of a recovery planning area;
- Construction of alpha-level models used to estimate seasonal range quality;
- Collection of sufficient geographic data to project seasonal range potential; and
- Application of the alpha-level models to two test areas for the purposes of assessing preliminary, non-calibrated predictions of seasonal range potential.

Specific objectives that were completed over the second six months included:

- Documented rationale for habitat supply modeling methods;
- Construction of models for non-caribou ungulate winter range;
- Transferred methods to a 25-m Digital Elevation Modeling environment;
- Completed hydrological modeling as input to predictions of ungulate forage;
- Completed caribou displacement models;
- Completed alpha-level caribou mortality modeling;
- Completed alpha-level, spatially-explicit, caribou population modeling;
- Reclassified and calibrated input nodes;
- Applied alpha-level model to all planning areas;
- Predicted mountain caribou range reference conditions based on planning scenarios for natural disturbance, potential, and current conditions;
- Delivered results of alpha-level modeling at a Science Team workshop;
- Collected review and suggestions contributing to beta-level modeling from the Science Team;
- Developed a model testing protocol;
- Continued documentation begun in phase 1 including but not limited to:
    - Revised model descriptions;
    - Description of new model components;
    - Description of model input requirements;
    - General summary of model implementation steps;
    - Summary of model results for the 12 recovery planning areas;
    - Description of beta-level model construction requirements;
- Documented the habitat supply model ecological rationale; and
- Participated in a web-based Delphic survey of recovery options.

Recovery planning for mountain caribou extends over more than 15M hectares of south-eastern BC in 12 planning cells that roughly relate to the spatial distribution of 13 herds of threatened mountain caribou. Four seasonal ranges were modeled: early winter; late winter; spring; and summer. Modeling was designed to provide transparent use of information from empirical studies and professional interpretation of those studies, as well as expert opinion about ecological relationships when specific information was not available. The models provide predictions about three functional levels of ecological relationships influencing caribou: life requisites such as forage resources or cover from extremes in ambient temperature; competition such as displacement through intensive interruption by human activity; and mortality from predators such as bears, cougars, wolverines, and wolves. Inherent range quality and interactions with factors that modify range quality were modeled to be spatially-explicit and responsive to scenario simulations of landscape disturbance. The likelihood of caribou mortality was in turn responsive to range quality dynamics, the occurrence of non-caribou ungulates, and the abundance of predators where these latter interactions were evaluated by use of a multi-species predator/prey model. Focus was placed on being able to evaluate resource development activities as they affect caribou recovery. Management effects that were modeled included: logging, roads, heli-ski operations, snowmobiling, cat ski operations, and basic displacement from point sources such as human settlement areas or recreation staging areas.

The alpha-level models were applied to the study area at 1 ha resolution as a means to demonstrate integrity of the modeling environment and to assess efficacy of model operation. We also used the results of this application to gather expert review of model components which we considered would lead to final recalibration as a beta-level model.

Results of our application proved the integrity of the modeling environment; with a modest amount of data preprocessing and preparation (1 week), a planning scenario simulation could be applied to the entire recovery planning area in one day using 12 computers and 3 staff. Through data testing and consultation with the Science Team we concluded that model implementation occurred as expected but some components of the model lacked expert input and did not perform as required. We developed data that depicted spatial outputs for 16 different characteristics of habitat considered to influence recovery of caribou. These data were summarized as examples of ways in which to compare and contrast recovery planning areas in terms of their current, potential, and natural disturbance conditions for seasonal range values. This summary was used to demonstrate the ability to contribute information relevant to making decisions about recovery of caribou. Some brief descriptions of data were made to demonstrate some potential avenues for verifying the HSM prior to use in decision making. Further analyses were not performed because we recognized results were from a preliminary, and as yet uncalibrated model.

Despite our successful application of the models to the entire recovery area, the Science Team was divided on utility of the alpha-level models. The division was primarily based on an uncomfortable level of risk associated with the remaining tasks in light of an imposed 2 week deadline before preparing recovery options for delivery to cabinet. The remaining tasks were outlined should the Science Team decide to pursue the HSM direction further.

ACKNOWLEDGEMENTS

This report is essentially a report from the entire Science Team derived through contributions made during multiple workshop sessions, in review comments, or by common communication among team members. Team members were: Kevin Jardine, Pat Field, Janice Shaw, Pearl Wilton, Ian Hatter, Clayton Apps, Wayne Wakkinen, Guy Woods, Trevor Kinley, Greg Utzig, Dennis Hamilton, Bruce McLellan, Rob Serrouya, Dale Seip, Jim Young, John Surgenor, Harold Armleder, Rick Ellis, Cindy Pearce, Mark Zacharias, Eric Valdal, Katheleen McGuinness, Viktor Brumovsky, Randy Sulyma, Line Giguere, Jackie Caldwell, Scott McNay, Steven Wilson, Glen Sutherland, and Dan O'Brien. In completing the report, the lead author needed to edit portions for consistency. Errors or omissions created as a result of this are obviously not the fault of the original authors.

We would like to acknowledge the leadership of Kevin Jardine and Pat Field in steering the project from conception to its current state. The initiative to co-ordinate mountain caribou recovery efforts, and to do so from a foundation of science-based, transparent decisions, is an ambitious step but one that will advance our current policy.

There was already significant work accomplished by individual Recovery Implementation Groups when this work began and we extend our appreciation to the individual members of RIGs for the support and solid foundation they have provided.

The project was funded through the Species at Risk Coordination Office.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DECISION-SUPPORT FOR RECOVERY OF MOUNTAIN CARIBOU -- *SCOTT MCNAY, DAN O'BRIEN, AND GLEN SUTHERLAND*

Caribou (*Rangifer tarandus*) are: extinct in some parts of British Columbia (BC), extirpated from a large part of their historic range (Spalding 2000), and currently at risk of extirpation in southern BC (MCTAC 2002, Wittmer 2004, Messier *et al.* 2004). Where they are at risk, woodland caribou (*Rangifer tarandus caribou*) have two distinct foraging behaviors used during winter, those seeking terrestrial lichens (northern caribou) and those seeking arboreal lichens (mountain caribou). Mountain caribou herds (Table 1) tend to occur in small isolated groups and are considered the most threatened ecotype in BC (Messier *et al.* 2004). Despite having Recovery Implementation Groups (RIGs) responsible for herd-specific recovery actions, Government requires more comprehensive and coordinated recovery options that address the complete geographic range of mountain caribou in a manner that is consistent, transparent, scientifically defensible, and socially acceptable.

Table 1. Estimates of population size, trend, density and conservation status of mountain caribou in British Columbia (from MCTAC 2002).

Local Population	**Herd Size**[1]		**Population Trend**[2]			**Reliability of trend**[3]			**Current Range (km^2)**[4]	**Potential Range (km^2)**[5]	**Density (Caribou/ 1000 km^2)**[6]
			LT	**ST**	**CT**	**LT**	**ST**	**CT**			
South Selkirks	35	H	S	D	S	L	H	H	1,500	3,456	23
South Purcells	20	H	D	D	S	L	H	H	2,962	6,829	7
Central Selkirks	130	H	D	D	D	L	H	H	4,813	5,706	27
Monashee	10	L	S	D	D	L	L	L	2,082	1,745	5
Revelstoke	225	H	S	D	D	L	H	H	7,863	8,560	29
Central Rockies	20	L	D	D	D	L	L	M	7,265	9,734	3
Wells Gray N.	200	H	S	D	S	L	H	M	6,346	7,654	32
Wells Gray S.	325	M	S	S	S	L	L	L	10,381	11,238	31
North Cariboo	350	M	S	S	D	L	L	L	5,910	6,690	59
Barkerville	50	H	I	S	S	L	M	M	1,509	2,535	20
George Mtn	5	M	D	D	D	L	M	L	440	442	11
Narrow Lake	65	H	I	S	S	L	M	M	431	432	151
Hart Ranges	450	M	S	S	S	L	L	L	10,260	21,970	44
Total	1905	H	D	D	D	L	M	M	62.788	85,965	Mean = 30

1. Numbers are estimated 2002 late winter population. Reliability is subjectively determined: High = comprehensive survey, usually with marked animals; Med = less comprehensive survey; Low = partial survey
2. Local Population Trend
    a. LT = long-term trend (>20% change in 20 yrs), declining (D), increasing (I) or ~ stable (S)
    b. ST = short-term trend (> 20% change in 7 yrs), decreasing (D), growing (G) or ~ stable (S)
    c. CT = current trend (> 10% change in last 2 years), down (D), up (U), or ~ stable (S)
3. Reliability of trend is subjectively determined H = high, M = moderate, L = low
4. Current range occupied by Mountain Caribou based on known or suspected occupancy
5. Potential range available for occupancy by Mountain Caribou based on habitat suitability and expert opinion
6. Density = (population size/current range) x 1000

Goals and Objectives

Our goal was to assist the BC Species at Risk Coordination Office (SARCO) by establishing science-based recovery targets for mountain caribou across their range and by developing an analytical approach to evaluating recovery options including probability of success. We proposed to address this goal using recently developed, habitat supply modeling (HSM) techniques (McNay 2004). Our specific goals in using HSM were to:

- Develop consistent interpretations of seasonal range values;
  - How should caribou range be evaluated?
  - Where are the places best suited for mountain caribou?
- Use simulation modeling and scenario planning to establish herd-based, relative seasonal range and relative population targets;
  - What relative population levels might be expected to occur in the future given the likely condition of the landscape?
  - How would that population likely be distributed among herds?
  - How would these relative sub-populations vary with alternate management conditions?
- Develop standard procedures for defining survival[1] and recovery[2] habitats;
  - What is the probability that the population will be self-sustaining (i.e., without regular intervention by humans)?
  - What is the probability of recovery for each sub-population?

Presumably, the outcome of pursuing these specific goals would:

- Provide a transparent, systematic, and science-based approach to decisions about recovery; including guidance for management of resource development considered to threaten caribou (e.g., commercial backcountry recreation [heli-skiing, cat-skiing, snowmobiling], mining, and logging);
- Provide for greater certainty around resource development and management plans including development of strategies to meet Forest Planning and Practices Regulation, Section 7.1.a and 7.1.c under the Forest and Range Practices Act3;
- Assist Government in meeting obligations under the Accord for the Protection of Species at Risk signed in 1996;
- Provide specific and standardized information about caribou habitats to RIGs; and
- Lead to sustainable herds of mountain caribou and recovery of the Southern Mountain Population.

These goals were targeted in 2 phases of activity, Phase 1 (November 2004 to March 2005) and Phase 2 (May 2005 to September 2005), by a Science Team formed by SARCO (Figure 1).

---

[1] ***Survival Habitat*** is the habitat needed to maintain the current population size (usually the habitat occupied by the species at the time it was assessed by COSEWIC) as defined by the National Recovery Working Group (2004).

[2] ***Recovery Habitat*** is the habitat needed by a species to achieve and maintain a population level that is self-sustaining and viable.

[3] see http://www.for.gov.bc.ca/tasb/legsregs/frpa/frparegs/forplanprac/fppr.htm#section7).

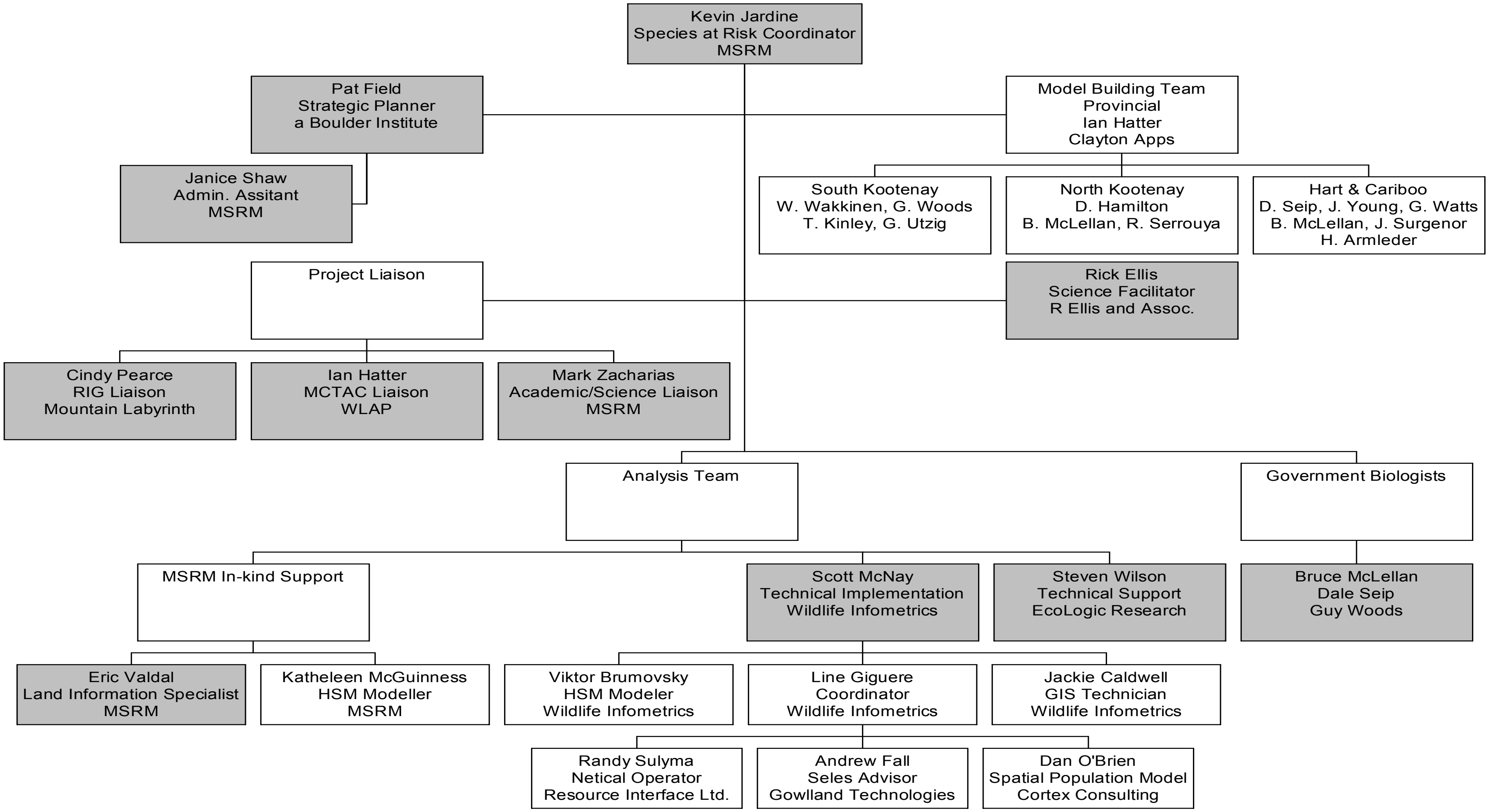

Figure 1. An organizational chart of personnel involved in development of a mountain caribou habitat supply model intended to inform recovery efforts in support of the Species At Risk Coordination Office for British Columbia. The boxes and names have changed since the election of 2005.

Specific objectives completed in Phase 1 included:

- Selection of a defined planning area;
- Construction of alpha-level Bayesian Belief Networks (BBNs) used to estimate seasonal range quality;
- Collection of basic data sufficient to project seasonal range potential; and
- Application of the models to two test areas for the purposes of assessing preliminary, non-calibrated predictions of seasonal range potential.

Specific objectives completed in Phase 2 included:

- Documented rationale for habitat supply modeling methods;
- Construction of models for non-caribou ungulate winter range;
- Transferred methods to a 25-m Digital Elevation Modeling environment;
- Completed hydrological modeling as input to predictions of ungulate forage;
- Completed caribou displacement models;
- Completed alpha-level caribou mortality modeling;
- Completed alpha-level, spatially-explicit, caribou population modeling;
- Reclassified and calibrated input nodes;
- Applied alpha-level model to all planning areas;
- Predicted mountain caribou range reference conditions based on planning scenarios for natural disturbance, potential, and current conditions;
- Delivered results of alpha-level modeling at a Science Team workshop;
- Collected review and suggestions contributing to beta-level modeling from the Science Team;
- Developed a model testing protocol;
- Continued documentation begun in phase 1 including but not limited to:
  - Revised model descriptions;
  - Description of new model components;
  - Description of model input requirements;
  - General summary of model implementation steps;
  - Summary of model results for the 12 recovery planning areas;
  - Description of beta-level model construction requirements;
- Documented the habitat supply model ecological rationale; and
- Participated in a web-based Delphic survey of recovery options.

Recovery Planning Area

Across the current range of mountain caribou, 18 herds were identified and considered by Wittmer (2004) to be isolated from each other with little to no interchange of animals. The herds currently occupy a number of Biogeoclimatic Zones (Alpine Tundra, Engelmann Spruce Subalpine Fir, Interior Cedar Hemlock, and minor components of the Montane Spruce and Sub Boreal Spruce; although the latter would have been more extensively used in historic times) and Ecoregions (Eastern Continental Ranges, Southern Rocky Mountain Trench, Columbia Mountains and Highlands, and Selkirk Bitteroot Foothills). The range in BC extends from headwaters of the Parsnip River, due east of Bear Lake in the north, to the border with the United States in the south, running in a southeasterly direction along the Rocky, Cariboo, Monashee, Purcell, and Selkirk Mountains. The recovery planning area (Figure 2, Table 2) was based on a combination of herd area information (Wittmer 2004; MCTAC 2002), resource management zones, and

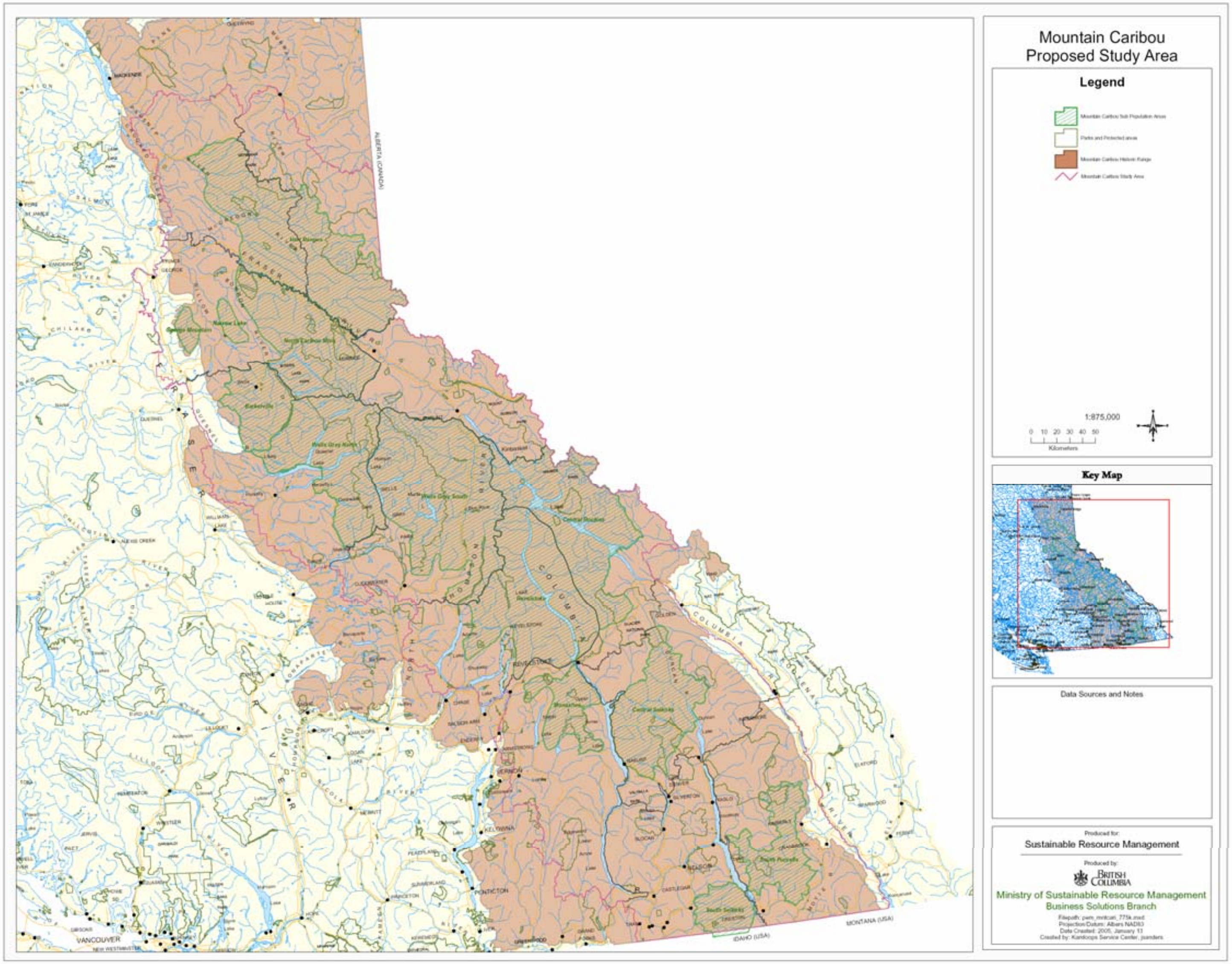

Figure 2. The planning area chosen as a basis for making decisions regarding recovery of mountain caribou (Rangifer tarandus caribou) subpopulations in south-western British Columbia.

expert opinion from the Science Team (i.e., in term of which resource management zones to include). In general, we wanted to include:

- The location of existing, known mountain caribou range and observed animal locations;
- The location of existing RIG planning area boundaries;
- Area assumed to be required for connectivity between existing ranges of mountain caribou herds; and
- The location of non-caribou ungulate populations and, by association, their predators that seasonally overlap or are otherwise adjacent to mountain caribou range.

We expect some minor modification to the recovery planning areas given that:

1. Some important areas of non-caribou ungulate winter ranges and other agriculture land are still not included in the study area; and
2. It remains unclear, the extent to which we'll be able to model the southern most area of the South Selkirks herd, which crosses the international boundary between Canada and the United States.

Table 2. Total area of analysis strata for the mountain caribou recovery planning area in southwestern British Columbia.

Recovery Area Code	***Recovery Area Name***	***Area (ha)***
1-A	South Selkirks	1,070,054.74
1-B	Purcells	1,208,912.72
2-A	Monashee	1,520,404.64
2-B	Central Selkirks	1,228,937.47
3-A	Central Rockies	1,006,268.50
3-B	Revelstoke	1,086,237.68
4-A	Wells Gray South	1,438,678.42
4-B	Mount Robson	903,337.44
5-A	North Cariboo	1,385,680.86
5-B	Wells Gray North	1,621,856.94
6-A	Hart Ranges North	1,591,216.87
6-B	Hart Ranges South	1,054,837.25
Grand Total		15,116,423.52

Modeling to Support Strategic Decisions

To inform strategic decisions about recovery of mountain caribou, we constructed an analytical framework based not on a single model but rather on a suite of integrated modeling approaches. Together, these models address mountain caribou range quality, competition for resources, likelihood of mortality, and ultimately, relative likelihood of population persistence. Information to guide recovery decisions comes from simulations of comparative management scenarios. The comparisons offer relative probabilities of implementing successful recovery actions (McNay 2004). For example, hypothetical base-case scenarios involving simulations of natural disturbance (Delong and Tanner 1996, Landres *et al.* 1999, Wong and Iverson 2004) have been used elsewhere to generate reference points that aid development of recovery actions for northern caribou in north-central BC (McNay *et al.* In prep[4].). We expect scenarios based on natural disturbances to be close approximations of habitat levels that would exist under unmanaged conditions giving rise to self-sustaining populations of mountain caribou. Results from this natural disturbance scenario were therefore used to operationally define recovery habitat. Similarly, projections of habitat under current conditions could approximate survival habitat for relatively smaller populations provided populations are above a minimum viable level. This analytical framework reflects recovery planning standards established under the Species at Risk Act (National Recovery Working Group 2004) and is consistent with standards for HSM in BC (Jones et al. 2002).

The modeling framework facilitated direct use of information from previously conducted studies of mountain caribou. Where there was important information lacking, we used expert opinion from those with experience conducting research, inventory, and management on mountain caribou. This opinion was taken to be sufficient for modeling since it is that same opinion which would be used to make decisions in the absence of a more formal approach. Explicit opinions can be formalized as hypotheses in HSM which we considered could be tested through application of the model and further data collection. In this way the HSM informs decisions and ranks research questions simultaneously.

Bayesian Belief Networks

Background

Information for model construction was collected using Netica (Norsys 1999) at 4 Science Team workshops. Netica is a software shell used for constructing Bayesian Belief Networks (BBNs) and Influence Diagrams. BBNs consist of nodes and linkages, where nodes represent environmental correlates, disturbance factors, and response conditions (Marcot et al. submitted[5]). All nodes are linked by probabilities. A Bayesian approach to modeling allows for combination of empirical data and opinion because BBNs are based on probability of occurrence (opinion and/or empirical information) rather than solely on frequency of occurrence (empirical information). Netica was chosen over other BBN modeling platforms because it:

- Handled both empirical data and opinion simultaneously;
- Provided a good graphical interface for easy editing of influence diagrams;
- Could be used for “real time” modeling during workshops; and

---

[4] McNay, S., R. Sulyma, and R. Ellis. In Prep. A recovery action plan for northern caribou herds in north-central BC. Wildlife Infometrics Report No. xxx. Wildlife Infometrics, Inc., Mackenzie, BC. xxpp

[5] Marcot, B.G., J.D. Steventon, G. Sutherland, and R.K. McCann. Submitted. Guidelines for developing and updating Bayesian Belief Networks for ecological modeling. Submitted to Can. J. For. Res.

- Was relatively inexpensive and readily available.

Bayesian approaches are particularly well suited to the problem of recovery planning. The threatened existence of an important resource has usually not been predetermined but rather has occurred from a lack of information and therefore, the solution to the problem is, by definition, uncertain. Also, resource management guidelines can change faster than our ability to learn from them so; our understanding is, by definition, challenged. Characterizing problem solutions is the objective held by normal statistics based on frequency of observations (Popper 1963). However, the case of rare species and uncertain causes of decline, the solution is usually one that cannot be characterized easily, if at all. Nevertheless, decisions must be made and such decisions are typically based on problem-solving probabilities rather than solution-characterization (Horvitz *et al.* 1988, Dagum *et al.* 1993). For example, it would be impossible to characterize recovery actions for low-elevation habitats based on observations of threatened caribou populations that now only exist in high-elevation habitats.

Bayesian approaches are not new and have proven useful in many other resource management issues: aspen (Haas 1991), wheat (Jensen and Jensen 1996), water quality (Reckhow 1999), sockeye salmon (Schnute et al. 2000), bull trout (Lee 2000), natural resource management generally (Cain 2001), fish and wildlife population viability (Marcot et al. 2001), sage grouse (Wisdom et al. 2002), wolverines (Rowland et al. 2003), marbled murrelet (Steventon et al. 2003), sport fisheries in general (Peterson and Evans 2003), spotted owl (Sutherland et al. 2004), and Eurasian black vulture (Poirazidis et al. 2004). A series of BBNs that have been used in BC is currently under review for publication where these include the following modeling applications: adaptive management, ecosystem mapping, northern caribou, marbled murrelet.

Construction of BBNs and workshop methods were influenced by, but not identical to, previous modeling efforts addressing habitat supply for sensitive wildlife species in north-central BC (McNay *et al.* in prep[6]., McNay *et al.* 2003, Hengeveld *et al.* 2004)). Methods adopted from previous work included a focus on the following:

- Sequential evaluation of caribou seasonal range quality from inherent capability based on life requisites (e.g., forage resources) through modifying factors due to competition for resources (e.g., displacement due to human recreation activities) and finally to modifying factors that cause mortality (e.g., predation);
- Spatial relationships were made explicit so that a pixel of caribou range would be enhanced or reduced by conditions in adjacent areas;
- An explicit identification of apparent and/or perceived threats to range quality so management of those threats were functional components (i.e., management levers) that could be simulated and forecasted both spatially and temporally; and
- Explicit linkage among range quality for caribou and expected population outcomes for other species as required.

---

[6] McNay, S., B. Marcot, R. Ellis, R. Sulyma, P. Hengeveld, and R. McCann. 2004. Developing forecasts of habitat supply to assist conservation management in north-central British Columbia. Wildlife Infometrics Report No. 099. Wildlife Infometrics, Inc., Mackenzie, BC.

Modeling and Analysis

Despite the apparent utility of using BBNs in our analytical framework, other habitat modeling approaches were evaluated. Habitat mapping in BC began 25 years ago with standard Habitat Suitability Index (HSI) modeling following methods of Hayes *et al.* (1981[7]) and evolved through more statistically advanced models to the now-popular Resource Selection Functions (RSF; Manly *et al.* 1993) and/or the expert based models advocated by BC Wildlife Habitat Relationships program[8]. Much, but not all, of the recovery planning area has been modeled through at least one of these approaches or another (e.g., Apps et al. 2001, Johnson et al. 2004).

The Science Team decided that these previous modeling attempts would not provide the range of information required for purposes of making decisions about caribou recovery. Individual habitat mapping projects were either difficult to retrieve, lacked consistent standards of interpretation, were not transparent in how habitats were evaluated, were sometimes limited to specific seasons or life-requisites, were sometimes limited to observations of caribou based only on radio-collared animals, and/or were incomplete in coverage of the recovery planning area. Nevertheless, some of this previous mapping and model documentation was collected, reviewed and, to the extent possible, resulting interpretations were used in a coarse-level situation analysis (SARCO 2005) and were helpful as references during construction of the BBNs.

BBNs were constructed by the Science Team in a series or workshops. Decisions made by the Science Team were recorded on flip-charts by a facilitator and distributed in workshop meeting minutes. Following completion of the alpha-level influence diagrams, conditional probability tables (CPTs) were used to express relationships among BBN nodes (Norsys 1999). The BBNs were then linked according to a conceptual image of the overall habitat supply model (Figure 3) resulting in final BBNs for potential caribou density by 4 seasons, potential non-caribou ungulate density by 2 seasons and species, and potential search rate of predators, background predator density by 2 seasons for bears and wolverine.

Alpha-level models were applied to the recovery planning areas by first calculating the amount of potential range (i.e., a theoretical construct where all input nodes were constrained to their optimal state for caribou). We then evaluated current range conditions followed by an evaluation of future range conditions based on simulated natural disturbance.

We used ArcView 3.2 (ESRI, Redlands, California) and Microsoft Access 2000 (Microsoft Corp., Redmond, Washington) to construct and manage case files of environmental correlates taken from 1-ha cells in the study area (15,116,423 ha). We used Netica in batch mode to process the case files before preparing the modeled results in Access for display in ArcView and analysis in SAS (SAS Inst. Inc., Cary, North Carolina). We displayed seasonal range values on raster maps as the expected value from the seasonal range nodes (i.e., the probability of a state multiplied by the state value, summed across all states). Raster maps were constructed for predicted range values under scenarios of potential, current, and natural disturbance by iteratively

---

[7] Or see http://www.nwrc.usgs.gov/wdb/pub/hsi/hsiintro.htm

[8] See http://srmwww.gov.bc.ca/wildlife/whr/index.html

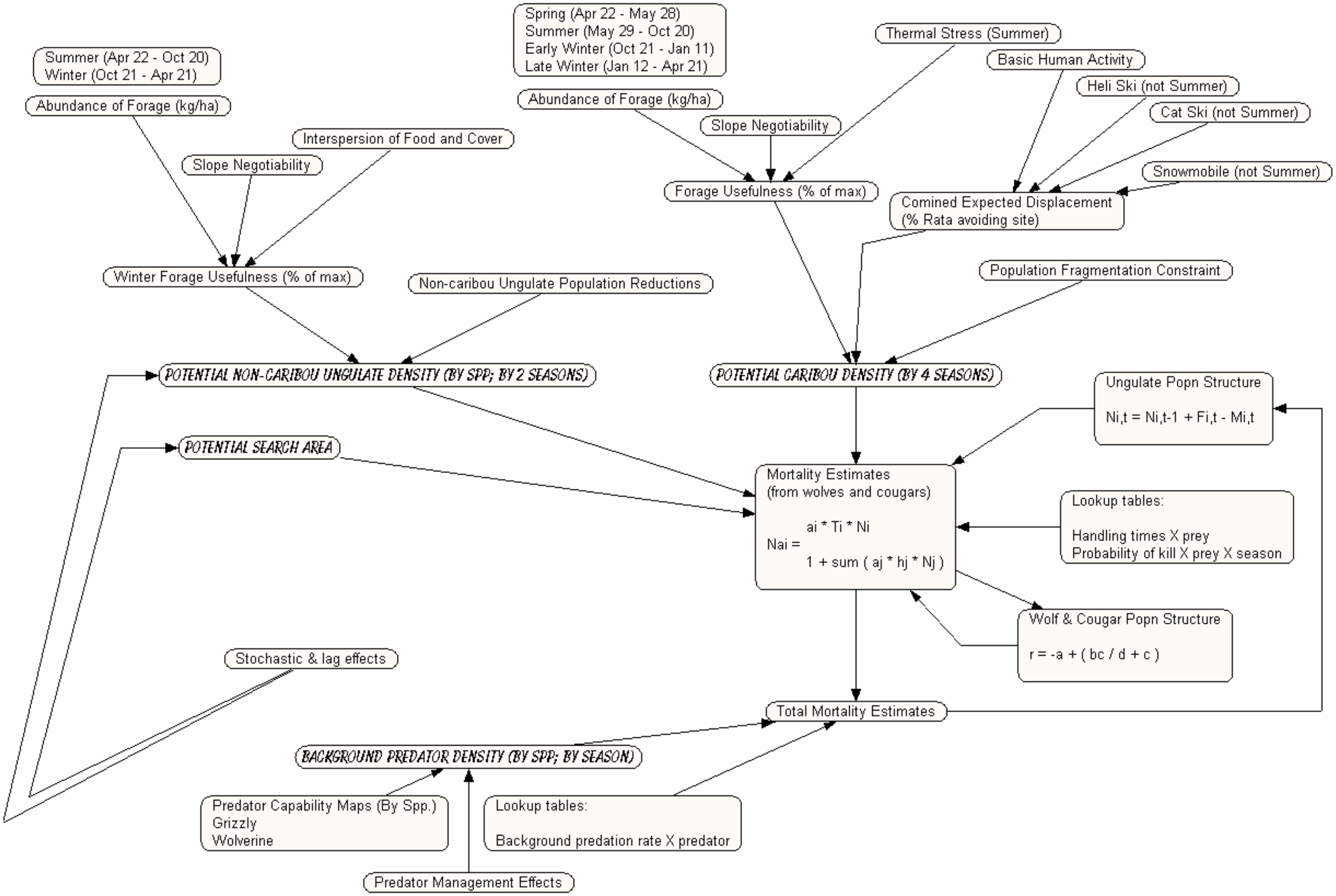

Figure 3. A conceptual model for general environmental factors influencing the spatial distribution and expected mortality rate of mountain caribou in southeastern British Columbia.

working through the model data flow (Figure 4), where estimated seasonal range values were for caribou, non-caribou ungulates, predation search rates, and background predation rates. In a few cases (e.g., solar radiation) raw information was preprocessed into the state values expected by Netica in order to decrease processing time needed to apply the model. However, this was usually accomplished using an Access script we refer to as Netica Manager. Prior to running Netica Manager, the spatial data were combined into a resultant theme and exported to Access. Netica Manager was then used to generate case files for BBN processing. Using Netica Manager, case files were processed and results imported back to Access where seasonal range values were then joined to the original resultant table. An Avenue script (ESRI, Redlands, California) was used to generate raster grids and ascii files of the seasonal range results.

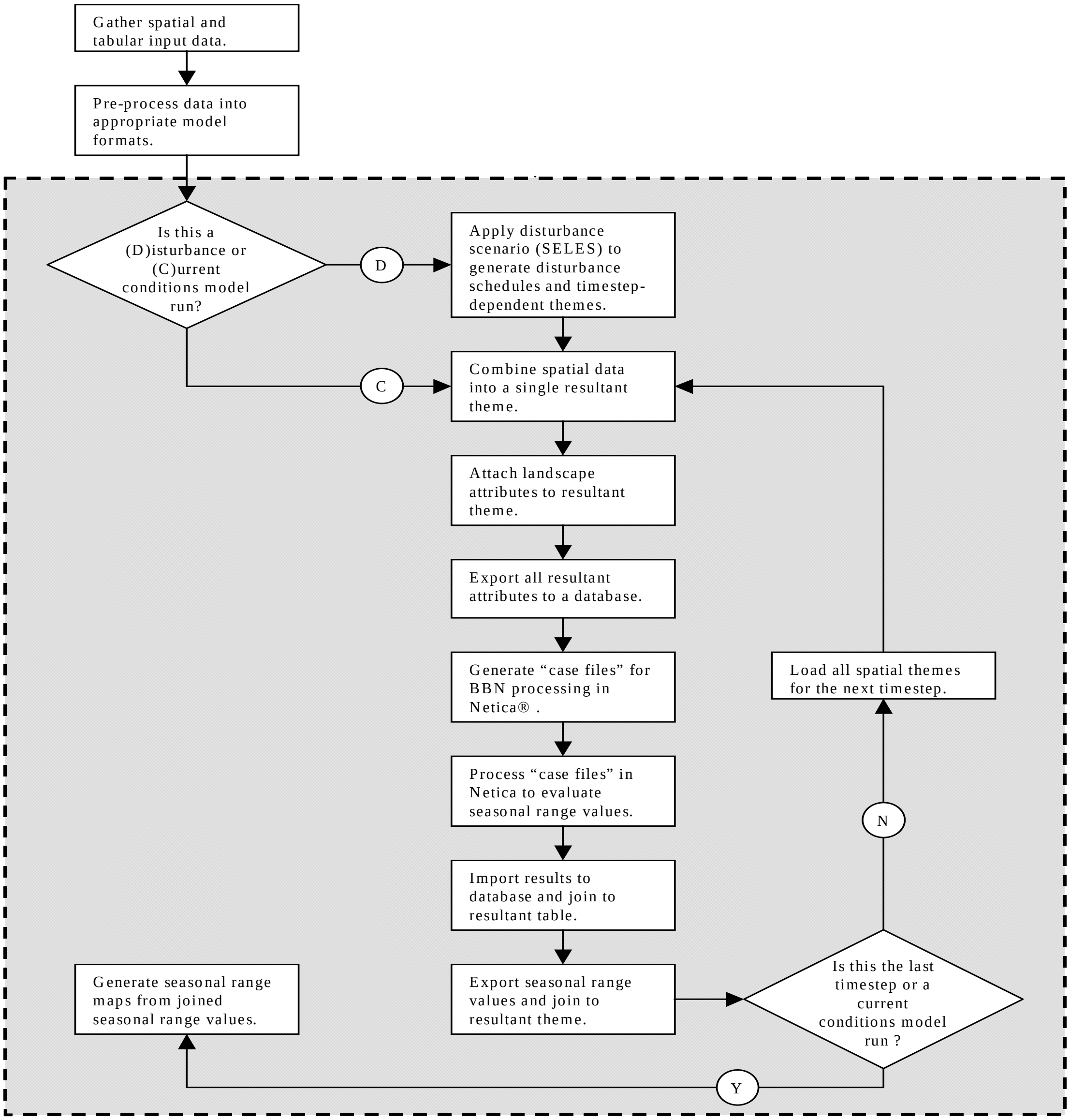

Figure 4. Depiction of model data flow in a habitat supply model used to aid decisions about recovery of caribou populations in southeastern British Columbia.

In planning scenarios that required repeated disturbance to the landscape, the disturbance schedule generated was processed by an Access script called the Cell Schedule Processor. This script parses the disturbance schedule into tables describing the time and type of disturbance encountered at each geographic location over the course of the simulation. These tables are then used to create raster maps of the disturbance times and types. The information parsed by the Cell Schedule Processor is passed to another Access script called the Time Step Disturbance Manager which uses it to update the model's forest cover data (i.e. stand age) for the desired time step. Since a natural disturbance scenario includes no harvesting or road-building and the other landscape factors (e.g. solar loading, slope, etc.) are static through time this gives a snapshot of the simulated landscape at a given point in the model application.

Forecasting Future Range Values From Simulated Landscape Disturbances

Landscape disturbance was simulated over 400 years in 10-year time steps from current conditions (year 2005) using the Spatially Explicit Landscape Event Simulator (SELES; Fall and Fall 2001). SELES is a modeling shell that simulates vegetation or environmental conditions across a landscape over time, given initial conditions and disturbances to, or succession dynamics of, each condition. In SELES, the user allocates defined disturbances to a geographic area based on rule sets applied to spatial cells. In our application, we mimicked natural disturbance as defined by patch sizes and disturbance return intervals based on Natural Disturbance Types (BC Environment 1995) using year 2400 as a sample of likely conditions under natural disturbance. We assumed that by that year, any footprint (i.e., start-up bias) from forest management would have been eliminated.

We used variable density yield prediction (VDYP) growth curves (BCMOF 1999) to determine post-disturbance forest conditions where forest stands were always completely replaced (i.e., stand age set to zero) by disturbance. We defined ecological successional stages solely by forest age classes (i.e., regenerating forest stands were identical in species mix and composition to original pre-disturbance conditions). Disturbances occurred in multiples of adjacent 20-ha cells where the size of each disturbance varied according to its type and intensity.

Under conditions of assumed natural disturbance, roads and human activities that cause displacement of caribou (see Expected Displacement Factors) were no longer present on the landbase. Also, we assumed there were no or relatively few factors constraining caribou from accessing seasonal ranges (see Landscape Level Considerations).

Linking Population Responses to Habitat Values

Previous Approaches

Weclaw and Hudson (2004) developed an aspatial model of woodland caribou population dynamics to help assess the cumulative effects of natural and human-caused disturbances (e.g., industrial forestry and oil and gas developments) on caribou populations in the boreal forest ecosystem. Although they briefly review previous simulation models of ungulate predator/prey dynamics, the focus of their study was to development their own model (REMUS) for assessing natural (i.e., fire, snow effects, predation, forage availability) and anthropogenic (i.e., hunting, habitat alteration or loss) factors that influence survival of caribou. The authors develop equations specifying functional (i.e., changes in numbers of prey consumed per predator) and numerical (i.e., changes in reproduction of predators) responses between predator (wolves, bears) and prey (caribou, moose) populations. Recruitment of prey was modeled as a function of forage availability and predator recruitment was a function of prey densities.

Earlier, a spatially-explicit, cumulative-effects model was developed by Rohner and Demarchi (2000), again focusing on caribou in the boreal forest of Alberta. This model simulates individual movements of caribou in response to primary determinants of habitat suitability, habitat alteration, and disturbances. The modeling approach is intended to explore the effect of different management scenarios on caribou population trends.

Lessard (2003) developed numerical/functional models to understanding interactions between caribou, moose, wolves, and anthropogenic factors in northern Alberta. The focus was to describe behavioral interactions between industrial activities, habitat, recruitment, mortality, predation and ungulate harvesting. These models predict cyclic behavior between wolves and moose (with approximately a 15-year cycle period). Lessard (2003) notes important difficulties in substantiating trophic relationships. His modeling approach was primarily aspatial and involved minimum parameters to effectively capture system dynamics. He used Monte-Carlo simulations to provide estimates of uncertainty in model parameters, and examined the range of uncertainty in estimates of extinction probabilities and rates of population decline.

The population modeling component of the CHASE model, used in north-central BC (O'Brien et al 2004), was a spatial population model designed to respond to changing patterns of habitat and predation risk. Mortality rates of caribou were assumed to be density dependent and respond to varying predation risk within caribou seasonal ranges. Linkages were developed between spatial maps produced by BBNs which allowed for rapid processing of time series output. Significant advances were made in linking population dynamics to a changing landscape and in rapidly processing time series output.

A Conceptual Model for the Mountain Caribou HSM

We used a multi-species disc equation (e.g. Walters 1986), modeled in SELES, to estimate ungulate prey mortality as a function of: predator densities (wolves, cougars), prey densities (caribou, moose, elk, white-tailed deer, mule deer), predator search rate modifiers, and a background predation rate (grizzly, wolverines). These factors were located spatially using time series outputs of BBNs (Figures 3 and 5). To complete the disc equation, projected maps of predator search rates were used to modify predation rates at each location. In the cycle of annual seasons, the population structure of predator and ungulate prey species was based on prior season estimates of: mortality, recruitment rates, and the incremental rates of increase for cougars and wolves. The modeling approach was spatial in that it explicitly represented the local densities of prey and predators within each herd range area using the expected density maps output by the BBNs. This modeling framework enabled evaluation of the potential interactions

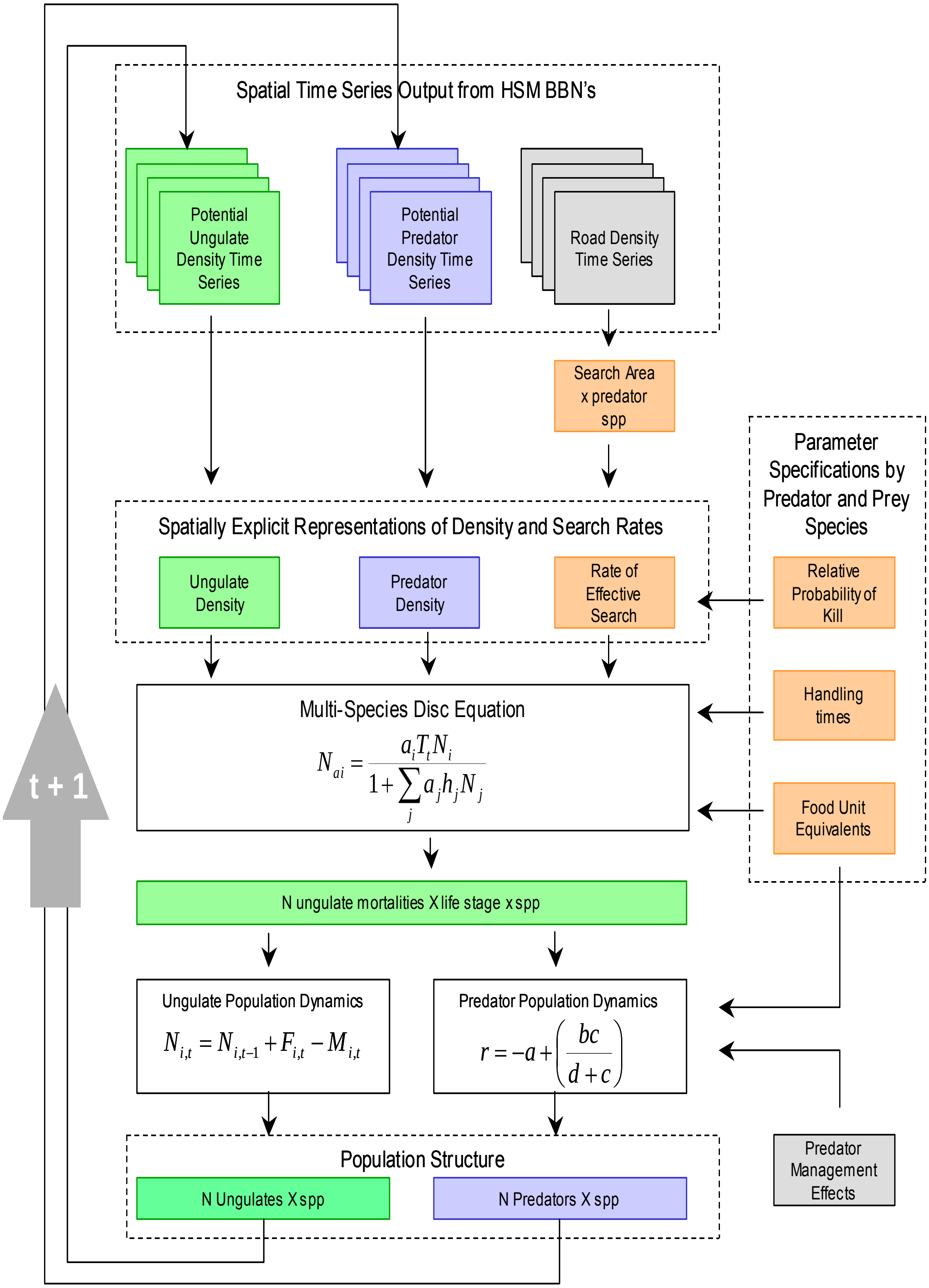

Figure 5. A conceptual model of the process for linking population responses to spatially-explicit outputs of habitat supply.

between the relative densities of predators and prey in response to projected land management scenarios and evaluation of the effects of predator management. The model provides the indicators specified in Table 5 which we consider necessary for effectively evaluating recovery options for mountain caribou, including, but not limited to: current and future ungulate population size and densities, predator population size and densities, and rates of population change. Subsequent phases of this project should include sensitivity analyses to measure uncertainties surrounding key model assumptions and parameter estimates and the generalization to a true spatial application.

Table 3. Quantitative ecological measures of predator – prey population status to be used to inform development of recovery options for mountain caribou in British Columbia.

Indicator	***Units***
Population size	N
MC Population density	#/1000km^2
Rate of MC Population change	Lambda (λ)
Probability of MC persistence	P(λ) >= 0^1
Rates of mortality	annual mortality / N x spp
Other Prey densities	#/1000km^2 x spp
Predator densities	#/1000km^2 x spp

The alpha-level SELES model used aspatial summaries of this information where prey are stratified into groups of spatially overlapping species. In beta- and higher-level models, we could divide BBN results into a grid of cells of species (prey and predator) density and predator search rates. Grid cell size could then be based on the mean extent of movements for predators during the model time step. The population of each species would be distributed into each of the cells within the herd area using the potential densities such that: $N_{ijt} = N_t * d_{ij} / \Sigma d_{ij}$, where d is the potential density for grid cell i j and N is the population size at time t. Regardless of the spatial detail used, for each season, the total number of mortalities for each species were then summed over the entire recovery planning area, and used to compute predator and prey population structures for the following time step. These population estimates are in turn used to determine spatial estimates of population densities using the potential density maps for the following time step, and the process repeats over the period of time defined for the simulation.

Geographic Data Collection

Once the context for modeling was established (i.e., study area and input variables), the basic data sources were collected for all land jurisdictions within the planning area (i.e., private, federal, provincial). Raster layers were constructed at 1 ha resolution using the BC Resource Inventory Committee standard Albers projection (NAD83 datum) for each data source. One hectare resolution should not be equated to data accuracy since each input layer varied in this regard. The 1-ha resolution was considered to be a required resolution for mapping the spatial location of threats to habitat value and resulting caribou range quality while still allowing for reasonably efficient processing of information. This conclusion was drawn after considering the potential use of 9 ha resolution information as a means to expedite medium resolution (i.e., compared to the coarse resolution situation analysis) recovery option development. The 9-ha resolution was abandoned when we realized it would be inadequate to define large scale information needs related to predict ungulate forage resources. Terrain Resource Information Management (TRIM) information was converted to a Digital Elevation Model (DEM) which then contributed to models of other environmental conditions (e.g., solar radiation, soil moisture accumulation, slope, elevation). We used previously assembled forest cover information because it was easily accessed and suited our needs for expediting modeling. However, this data source included information about stand ages from the Forest Inventory and Planning (FIP) database (Resources Inventory Branch 1995) only to the year 2000. Therefore, a subsequent collection of information regarding forest disturbance (i.e., industrial development and fires) since 2000 was used to update the FIP data. The Science Team anticipated assessing the completed HSM using historic forest cover data. For this reason, collection of forest cover information representing the year 1980 was begun and is ongoing. In 1980, mountain caribou were considered to have more stable population parameters. Collection of ecological mapping was focused on 1:50,000 scale Biogeoclimatic information rather than larger scale mapping due to the assumed effort required to organize the latter. This relatively coarse-level information was used to characterize broad climatic zones (e.g., snowfall, summer temperatures, snow melt, etc.). Information regarding human-caused disturbances other than industrial forestry was collected from Baseline Thematic Mapping (Geographic Data BC 2001). This source of information was also used to define some non-vegetated areas that were not classified in forest cover. Roads were collected from a central repository managed at that time by Land and Water BC Inc.. Finally, we required spatial representation for any policy guideline that would intersect our list of management levers (e.g., Ungulate Winter Ranges, Protected Areas, and various recreation tenures). Collection of that information was begun and is ongoing. A complete list of these data inputs is provided in Table 3.

Literature Cited

Apps, C.D. B.N. McLellan, T.A. Kinley, and J.P. Flaa. 2001. Scale-dependent habitat selection by mountain caribou, Columbia Mountains, British Columbia. J. Wildl. Manage. 65:65-77.

BC Environment. 1995. Biodiversity guidebook. British Columbia Min. of Environment, Victoria, BC 99pp.

Cain, J. 2001. Planning improvements in natural resources management: guidelines for using Bayesian networks to support the planning and management of development programmes in the water sector and beyond. Centre for Ecology & Hydrology, CrowmarshGifford, Wallingford, Oxon, U.K. 124 pp.

Dagum, P., A. Galper, E. Horvitz, and A. Seiver. 1993. Uncertain reasoning and forecasting. International Journal of Forecasting 11:73-87.

Delong, C. and D. Tanner. 1996. Managing the pattern of forest harvest: lessons from wildfire. Biodiversity and Conservation 5:1191-1205.

Fall, A. and J. Fall. 2001. A domain-specific language for models of landscape dynamics. Ecol. Modelling 141:1-18.

Table 4. Geographic data sources used as inputs to a habitat supply model for mountain caribou in southeastern British Columbia.

Data Source	***Key Ecological Correlate***	***Code***	***Habitat Supply Range Models***							
			Early Winterr	***Late Winter***	***Spring***	***Summer***	***Ungulate Winter***	***Ungulate Summer***	***Background Predation***	***Predator Search Rate***
BGC	Snow zones	MCSF	SA				SA			PSRA
	Temperature	MCT				TR		TR		
	Snow melt	MCSM			SIWP		SIWP			
	Moisture	MCM			ESS		WFP			
	Caribou forage	MCS, MCAL	TLRA, SP	BD						
	Age at mature structure	MCSS					SS			
	Landscape openness	LO	WS							
BTM	Non-productive	IBS	TLRA		VP	VP	WFP	VP		
FC	Age (n.b., recent cut blocks)	SSSI, SSI, SI	SP, PSA, BA, SIP	BA	SP	TR, AAF	SS	TR, AAF		
	NP codes	WF, VF			ESS, VP, SP	VP	SP	VP		
	Canopy closure	SSII, SV	TLRA, SIP	BD			SIP			
	Canopy fullness	ISG	SIP				SIP			
	Ability to grow lichens	TSG	BA	BA						
	Spatial density of waterbodies	DRIV								CDLF
DEM	Slope	NCM	SFU	SFU	SFU	SFU	SFU	SFU		
	Elevation	ELE	HFE	HFE	HFE					
	Moisture accumulation (soil)	MA	TLRA, SP, WS		ESS		WFP			
	Solar radiation	SR			SIWP	TR	SIWP	TR		
Roads	Spatial density of roads	DR								CDFL
Caribou herds	Buffers	PFC	PCD	PCD	PCD	PCD				
Predators	Grizzly density	DGB							AMU	
	Hunting regulations	HR							AMU	
	Wolverine habitat value	WHV							AMG	
Season	Season	S							AMU, AMG	CEDLF, PSRA
Ungulates	Species	US					EPI, URD	EPI, URD, TR		
	Hunting regulations	HR					EPI	EPI		
Basic human activity	Towns, industrial sites	BZOI	CED	CED	CED	CED				
Heli-ski activitiy	Base	ZOI	HFE	HFE	HFE					
	Tenure user days	TUD	UI	UI	UI					
	Guidelines	HSUG	UI	UI	UI					
Snowmobile activity		EDS	CED	CED	CED					
Cat-ski activiity		EDCS	CED	CED	CED					
Food/cover maps	Interspersion	IFC					SFU			
Wind maps	Wind potential	WP	WS							

Geographic Data BC. 2001. Baseline thematic mapping; present land use mapping at 1:250,000. British Columbia specifications and guidelines for geomatics, content series volume 6, part 1, release 2.1. Ministry of Sustainable Resource Management, Victoria, British Columbia, Canada.

Haas, T.C. 1991. A Bayesian belief network advisory system for aspen regeneration. Forest Science 37(2):627-654.

Hays, R.L., C. Summers, and W. Seitz. 1981. Estimating wildlife habitat variables. USDI Fish and Wildlife Service. FWS/OBS-81/47. 111 p.

Hengeveld, P. E., M. D. Wood, R. Ellis, R. S. McNay, and R. Lennox. 2004. Mountain goat habitat supply modeling in the Mackenzie Timber Supply Area, north-central British Columbia. Version 2.0 – March 2004. Wildlife Infometrics Report No. 109. Wildlife Infometrics Inc., Mackenzie, British Columbia, Canada.

Horvitz, E., J. Breese, and M. Henrion. 1988. Decision theory in expert systems and artificial intelligence. International Journal of Approximate Reasoning 2:247-302.

Hu, P. and P. Rich. 2000. The solar analyst 1.0 user manual. Helios Environmental Modeling Institute. 49pp.

Jensen, A.L., and F.V. Jensen. 1996. MIDAS - an influence diagram for management of mildew in winter wheat. In: E. Horvitz and F. Jensen (Ed.). Proceed. of 12th Conference on Uncertainty in AI. Morgan Kaufmann Publishers, San Francisco, CA. 349-356 pp.

Jones, K., R. Ellis, R. Holt, B. MacArthur, and G. Utzig. 2002. A strategy for habitat supply modeling for British Columbia. Unpubl. Report. Draft 1, Volume 1. Prepared for the Habitat Modeling Steering Committee, Victoria, BC. 265 pp.

Johnson, C., D. Seip, and M. Boyce. 2004. A quantitative approach to conservation planning: using resource selection functions to map distribution of mountain caribou at multiple spatial scales. J. Appl. Ecol. 41(2):238.

Landres, P.B., P. Morgan and F.J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9(4):1179-1188.

Lee, D.C. 2000. Assessing land-use impacts on bull trout using Bayesian belief networks. In: S. Ferson and M. Burgman, ed. Quantitative methods for conservation biology. Springer, New York. 127-147 pp.

Lessard, B. 2003. The empirical basis of modeling caribou population dynamics. University of Alberta Research News, Issue 7.

Manly, B, L. McDonald, and D. Thomas. 1993. Resource selection by animals: Statistical design and analysis for field studies. Chapman and Hall. London, UK. 177pp.

Marcot, B. G., R. S. Holthausen, M. G. Raphael, M. Rowland, and M. Wisdom. 2001. Using Bayesian belief networks to evaluate fish and wildlife population viability under land management alternatives from an environmental impact statement. Forest Ecology and Management 153(1-3):29-42.

McNay, R. S. 2004. Use of habitat supply models to establish herd-based recovery targets for threatened mountain caribou in British Columbia. Wildlife Infometrics Report No. 147. Wildlife Infometrics Inc., Mackenzie, BC 35pp.

_____, K. Zimmerman, and R. Ellis. 2003. 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. Wildlife Infometrics Report No. 055, Wildlife Infometrics Inc., Mackenzie, British Columbia. 113pp.

MCTAC. 2002. A strategy for the recovery of Mountain Caribou in British Columbia. British Columbia Min. of Water, Lands, and Air Protection, Biodiversity Branch, Victoria, BC.

Messier, F., S. Boutin, and D. Heard. 2004. Revelstoke mountain caribou recovery: An independent review of predator-prey-habitat interactions. Unpubl. Rep., Revelstoke Caribou Recovery Committee, Revelstoke, British Columbia. 12pp.

O'Brien, D., G. Sutherland, R. S. McNay. 2004. Caribou Habitat Assessment and Supply Estimator (CHASE) Modifications and Sensitivity Analysis for the CHASE Spatially Explicit Population Model for Northern Caribou. Wildlife Infometrics Inc. Report No. 130. Wildlife Infometrics Inc., Mackenzie, British Columbia, Canada.

National Recovery Working Group. 2004. Recovery Handbook. April 2004. Working Draft. Recovery of Nationally Endangered Wildlife, Ottawa, Ontario. 36 pp. plus appendices

Norsys. 1999. Netica: Application for belief networks and influence diagrams. User’s Guide version 1.05 for Windows. Norsys Software Corp., Vancouver, British Columbia. 82pp.

Peterson, J.T., and J.W. Evans. 2003. Quantitative decision analysis for sport fisheries management. Fisheries 28:10-21.

Poirazidis, K., V. Goutner, T. Skartsi, and G. Stamou. 2004. Modelling nesting habitat as a conservation tool for the Eurasian black vulture (Aegypius monachus) in Dadia Nature Reserve, northeastern Greece. Biol. Conser. 118:235-248.

Popper, K. 1963. Conjectures and refutations: the growth of scientific knowledge. Routledge Publishing, New York, NY.

Reckhow, K. 1999. Water quality prediction and probability network models. Can. J. Fish. Aquat. Sci. 56:1150-1158.

Resources Inventory Branch. 1995. Relational data dictionary (RDD) 2.0. British Columbia Ministry of Forests, Victoria, British Columbia, Canada.

Rohner, C., and D. A. Demarchi. 2000. Cumulative effects and Mountain Caribou in West-Central Alberta: an individual-based and spatially-explicit simulation model for conservation planning. Unpublsihed report prepared for the West-Central Alberta Caribou Standing Committee (WCACSC), Alberta Environment, Grande Prairie, AB.

Rowland, M.M., M.J. Wisdom, D.H. Johnson, B.C. Wales, J.P. Copeland, and F.B. Edelmann. 2003. Evaluation of landscape models for wolverines in the interior northwest, United States of America. Journal of Mammology 84(1):92-105.

SARCO. 2005. Mountain caribou situation analysis. Min. of Agriculture and Land, Species at Risk Coordination Office, Victoria, BC. 9pp+Appendix 28pp

Schnute, J.T., A. Cass, and L. Richards. 2000. A Bayesian decision analysis to set escapement goals for Fraser River sockeye salmon (Onchorhynchus nerka). Can J. Fish. Aquat. Sci. 57:962-979.

Spalding, D.J. 2000. The early history of woodland caribou (*Rangifer tarandus caribou*) in British Columbia. Wildl. Bull. No. B-100. British Columbia Min. of Environ., Lands, and Parks, Wildl. Br., Victoria, BC 61pp.

Steventon, D., G. Sutherland, and P. Arcese. 2003. Long-term risks to marbled murrelet (*Brachyramphus marmoratus*) populations: assessing alternative forest management policies in coastal British Columbia. Tech. Rep. 012, British Columbia Min. of Forests, Victoria, BC 51pp.

Sutherland, G., A. Fall, and D. O’Brien. 2004. A framework for assessing consequences of alternative management scenarios on spotted owl habitat and prospects for population recovery in British Columbia. Pp. 23-25 *In* Zimmerman, K. K. Welstead, E. Williams, and J. Turner (eds) Northern spotted owl workshop proceedings. January 21-22, 2004, Vancouver, British Columbia. FORREX, Kamloops, BC

Walters, C.J. 1986. Adaptive Management of Renewable Resources. MacMillan Publishing Company, New York, NY, USA.

Weclaw, P. and R.J. Hudson. 2004. Simulation of conservation and management of woodland caribou. Ecological Modelling, 177:75-94.

Wisdom, M.J., M.M. Rowland, B.C. Wales, M.A. Hemstrom, W.J. Hann, M.G. Raphael, R.S. Holthausen, R.A. Gravenmier, and T.D. Rich. 2002. Modeled effects of sagebrush-steppe restoration on Greater Sage-grouse in the interior Columbia Basin, U.S.A. Conservation Biology 16(5):1223-1231.

Wittmer, H.U. 2004. Mechanisms underlying the decline of mountain caribou (*Rangifer tarandus caribou*) in British Columbia. Ph.D. thesis, University of British Columbia, Vancouver, BC

Wong, C. and K. Iverson. 2004. Range of natural variability: Applying the concept to forest management in central British Columbia. BC J. Ecosystems and Management 4. www.forrex.org

INHERENT RANGE QUALITY -- *CLAYTON APPS*

Mountain Caribou Seasons

For many if not most subpopulations, mountain caribou ecology and range use patterns exhibit distinct seasonal differences, and these are usually characterized by marked shifts in elevation. Seasonal patterns relate to the different requirements of, and constraints on, mountain caribou as seasons change. Seasonal differences in range use and foraging strategies are largely related to snow conditions, and general patterns are usually summarized specific to Early Winter, Late Winter, Spring, and Summer seasons. The calving period is encompassed within the latter part of the spring and early part of the summer seasons. Generic seasonal cut-dates have been defined (Stevenson et al. 2001); however actual dates will vary with conditions among regions and years. Two studies have defined local cut dates by analyzing multi-year elevation shifts (Apps et al. 2001, Kinley and Apps 2005).

Studies of Mountain Caribou Habitat Relationships

Radiolocation data collected for virtually every mountain caribou subpopulation have been analyzed for stand- and/or landscape-level habitat relationships, and/or have facilitated foraging studies based on snow-trailing. These studies generally correspond to all or parts of the following (MCTAC 2002) herds: Hart Ranges, North Cariboo Mountains, George Mountain, and Narrow Lake subpopulations (Apps and Kinley 2000a, Terry et al. 2000, Johnson et al. 2004), Wells Gray North and South (Seip 1990, Seip 1992, Apps and Kinley 2000b), Revelstoke and Central Rockies (Apps et al. 2001), Central Selkirks (Hamilton et al. 2000), Southern Purcells (Apps and Kinley 1998, Apps and Kinley 2000c, Kinley et al. 2003), and South Selkirks (Rominger and Oldemeyer 1989, Servheen and Lyon 1989, Kinley and Apps 2005). The more recent of these studies have employed a scale-dependent analysis design that accounts for the influence of spatial scale in understanding and predicting habitat relationships and avoids subjective decisions of habitat “availability” that can influence results. This approach also better addresses the potential importance of habitat density and dispersion in defining landscape suitability. These analyses typically considered 4 spatial scales comparing, for example, 95 km^2 used and available landscapes separated by 14 km at the broadest scale, down to 38 ha used and available landscapes separated by 900 m at the finest scale (Apps et al. 2001). Results from these studies are largely comparable due to consistency in methods, allowing variation in habitat selection strategies among subpopulations to be characterized. Such variation is particularly apparent during the early-winter season.

Seasonal Habitat Summaries and Correlates

Below, I provide a brief overview of mountain caribou habitat ecology during each season that builds on existing summaries (Stevenson et al. 2001, MCTAC 2002). I also provide a description of functional models reflecting inherent seasonal range quality for mountain caribou. Variation in early-winter range selection strategies among regions is primarily related to climatic and physiographic conditions as they pertain to snow conditions, human-caused disturbances to the range, and patterns of human occupation and activity particularly in low-elevation areas. Summer range use may also vary depending on the availability of alpine conditions. Differences in ranges among regions are likely to be most apparent in comparing the steep, rugged and very wet North Columbia Mountains, the more subdued and considerably drier southern Purcell Mountains, and the rolling and moderately wet Quesnel Highland. In describing the ecological factors that may influence mountain caribou, I explicitly avoid considerations related to predation and human activity as these modifying factors are considered by Wilson (Displacement Factors) and by Kinley (Mortality Factors) later.

Early Winter (November to mid-January):

Compared to conditions in other seasons, mountain caribou are expected to experience the poorest mobility and food availability during early winter due to typically unconsolidated snow. As snow accumulates, autumn foods of sedges and forbs become buried, while the snowpack is not deep or supportive enough for caribou to reach arboreal lichens (mainly *Bryoria* spp.) that characterize late-winter habitats. Arboreal lichens are typically absent from the lower 2-4 m of subalpine trees due to effects of the late-winter snowpack. Therefore, in the rugged and high-snowfall North Columbia Mountains, caribou typically move to lower elevations associated with the Interior Cedar - Hemlock (ICH) or lower Englemann Spruce – Subalpine Fir (ESSF) biogeoclimatic zones (Apps et al. 2001). The shallower snow in these biogeoclimatic zones allows continued foraging on forbs and shrubs such as falsebox (*Pachistima myrsinites*) as well as on lichens from litterfall and on windthrown trees. In the drier and more subdued southern Purcell Mountains, caribou seldom move to significantly lower elevations during early winter (Apps and Kinley 2000), and feed largely on grouseberry (*Vaccinium scoparium*), terrestrial lichen (*Cladonia* spp.), and arboreal lichen, with the latter becoming more important, especially from downed trees, as snow depths increase (i.e., ≥ 62 cm; Kinley et al. 2003, Rominger and Oldemeyer 1990). In this drier ecosystem, lichen on standing trees can be available lower in the canopy, and it is sometimes used during early winter (ibid). Snow interception provided by a coniferous canopy cover may be particularly important during early winter in minimizing the energetic cost of movement and in facilitating access to ground forage (Servheen and Lyon 1989).

Relative to conditions in the larger landscape, early winter range selection by mountain caribou in the North Columbia Mountains (Apps et al. 2001) is associated with relatively low elevations, gentle slopes, and little terrain complexity. As described, the value of low elevation areas is likely a function of energetics and food availability. The gentle slopes and minimal terrain complexity may be partially dictated by movement costs and associations with forest stand conditions preferred by caribou. Southerly aspects have been selected at a relatively fine spatial resolution, but this preference is superseded by overstory conditions at the finest resolution. Due to the typically greater forest harvesting at lower elevations, broad landscapes are often an interspersion of young and old forests, but stands >140 years of high canopy closure have been highly selected across scales. Overstory composition has been primarily western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), and Douglas-fir (*Pseudotsuga menziesii*). Associations with lodgepole pine (*Pinus contorta*) and deciduous stands in the larger landscape are presumably spurious.

In contrast to the North Columbia Mountains, caribou in the southern Purcell Mountains (Apps and Kinley 2000) rarely descend to significantly lower elevations and remain in the ESSF during early winter. Preferred range is associated with old, relatively high elevation forests of subalpine fir (*Abies lasiocarpa*), alpine larch (*Larix lyalii*), and whitebark pine (*Pinus albicaulis*) within the subalpine parkland (forest-alpine ecotone), typical of late winter range for most subpopulations. Selection for other terrain and stand attributes is similar to the North Columbia Mountains, especially at finer spatial resolution. Most other mountain caribou subpopulations show range selection patterns that are intermediate between that reported for the North Columbia and southern Purcell subpopulations. Disparate early-winter range selection strategies are sometimes apparent within a given year and subpopulation. For example, in the Quesnel Highland, while the majority of animals may shift to lower elevations, a significant proportion of the population will often remain at high elevations where they forage for terrestrial lichens on windswept ridges (H. Armleder, BC Ministry of Forests, personal communication).

1. Modeling Seasonal Forage Usefulness for early-winter (SFU)

As described above, seasonal forage usefulness (SFU) for mountain caribou during early-winter is a function of the energetic cost of movement (NCM) and abundance of available forage (AAF) (Figure 5).

1.1. Energetic Cost of Movement (NCM)

In addition to movement barriers and proximity among suitable foraging patches, the NCM to caribou is assumed to be determined primarily by slope (SLP) conditions, with movement potential being best (<40%), OK (40-80%) or worst (>80%).

1.2. Abundance of Available Forage (AAF)

Forage accessibility is a function of site potential to provide mountain caribou foods (Simpson et al. 1985, Antifeau 1987, Rominger and Oldemeyer 1990, Rominger et al. 1996, Rominger et al. 2000, Terry et al. 2000, Kinley et al. 2003, H. Armleder, BC Ministry of Forests, *pers. comm.*) without being excessively buried by snow accumulations (SA). Arboreal lichen (BA; mostly *Bryoria* spp. from downed trees) is the most important of these foods, especially during years of rapid snow accumulation. However, as noted above, caribou will also feed on shrubs extending above the snow (palatable shrubs abundance; PSA) and, where available, animals in some subpopulations will seek out terrestrial lichens (terrestrial lichen relative abundance; TLRA) on windswept ridges.

1.2.1. Bryoria Abundance (BA)

Among the arboreal lichen species, hair-lichens of the *Bryoria* genus are preferred by caribou due to their relatively high crude protein levels (Rominger et al. 1996, Rominger et al. 2000). As snow depths increase during early winter, these lichens are an important food source for mountain caribou and are mostly obtained from litter fall and downed trees (Rominger and Oldemeyer 1990, Kinley et al. 2003). *Bryoria* lichens benefit from a moist climate and can be widespread within the interior wet-belt of British Columbia where there is sufficient rainfall. We considered that this condition could be approximated using tree species groups (TSG) as an ecological correlate for BA. These

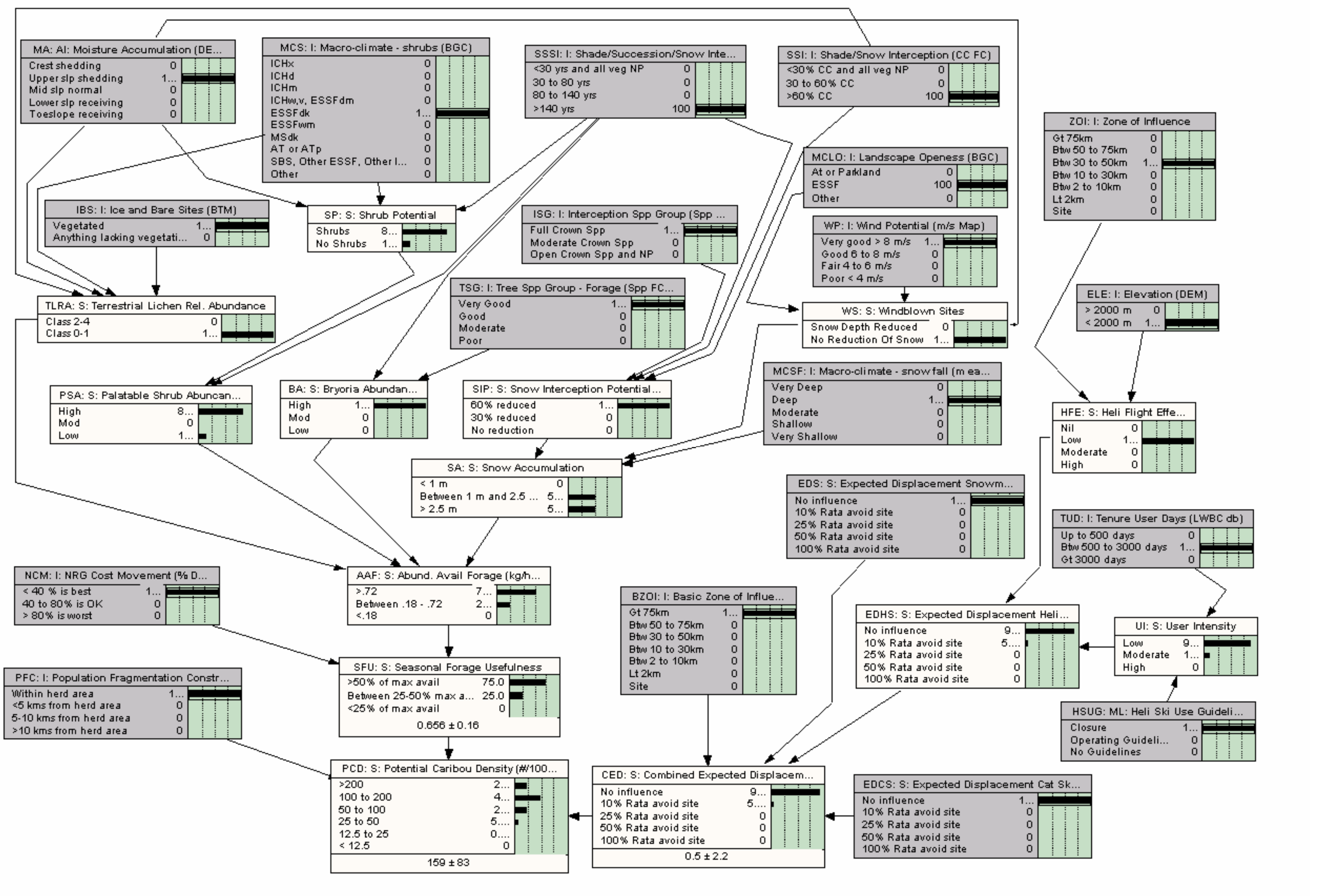

Figure 6. A Bayesian belief network used to predict the expected density of mountain caribou during early winter in southeastern British Columbia.

lichens also grow slowly and therefore their abundance can also be related to stand age (shade/succession/snow interception; SSSI)

1.2.1.1. Shade/Succession/Snow Interception (SSSI)

Potential is assumed to be highest in old (>140 year) stands that are common in this ecosystem undernatural disturbance cycles (Armleder and Stevenson 1996). Potential was assumed to be moderate in mid-aged (80-140 years) stands and lowest in younger (<80 years) stands. Input for this node was stand age taken from the FIP database.

1.2.1.2. Tree Species Group (TSG)

Due to differences in branching structure, a stand's overall potential to carry arboreal lichen varies with tree species, with potential being very high in subalpine fir and whitebark pine stands, high in spruce, hemlock, and Douglas-fir stands, lowest in deciduous stands, and moderate in all other stands. The relative abundance and distribution of *Bryoria* within a given tree will vary with macro- and micro-climate (see 2.1.1). However, because caribou do not rely on standing trees for a significant amount of *Bryoria* during early winter, the accessibility of lichen on the tree is *not* a modeling consideration for this season.

Based on information from the forest cover data base, TSG classes are determined by the stand species/composition combinations described below:

Very Good:	Combination of subalpine fir and whitebark pine is at least 70%.
Good:	Combination of subalpine fir, whitebark pine, douglas fir, and hemlock is at least 50% OR if the stand is atleast 50% spruce with the combination of subalpine fir, whitebark pine, douglas fir, and hemlock is between 25% and 50%.
Moderate:	Combination of subalpine fir, whitebark pine, douglas fir, and hemlock is between 25% and 50% OR if the stand is at least 50% spruce with the combination of subalpine fir, whitebark pine, douglas fir, and hemlock is between 10% and 25%.
Poor:	All other species/composition combinations.

1.2.2. Palatable Shrub Abundance (PSA)

While mountain caribou will feed on a variety of shrubs such as willows (*Salix* spp.) and *Vaccinium* spp., their preferred shrub forage is primarily falsebox (*Pachistima myrsinites*) and grouseberry (*Vaccinium scoparium)* (Simpson et al. 1985, Rominger and Oldemeyer 1990, Terry et al. 2000, Kinley et al. 2003) both of which are relatively common within the ecosystems that define mountain caribou range. However, the palatability of these species, particularly *Pachistima*, is apparently influenced by secondary plant compounds that relate to overstory conditions (Rominger et al. 2000). Therefore, PSA at a given site is a function of both shrub potential (SP) and the likelihood of secondary plant compounds inferred from stand succession conditions (shade/succession/snow interception; SSSI)

1.2.2.1. Shrub Potenial (SP)

Of the two main shrubs species preferred by mountain caribou, *Pachistima* generally occurs at low to mid elevations in coniferous forests, rocky openings and clearings, while *V. scoparium* is common at mid to high elevations in moist, open coniferous forests, often forming dense ground cover near treeline (Parish et al. 1996). Their potential for growth is therefore influenced by <u>macro-climate-shrubs </u>(MCS), <u>moisture accumulation</u> (MA) and shade/succession/snow interception (SSSI).

1.2.2.1.1. Macro-climate Shrubs (MCS)

The MCS input is derived from the biogeoclimatic ecosystem classification (Meidinger and Pojar 1991). Depending on MA (described below), Pachistima can occur in ICHx, ICHd, ICHm, ICHw, and ICHv. Again, depending on MA, V. scoparium was considered to occur in ESSFdm, ESSFdk, ESSFwm, and MSdk. Other ecological units, regardless of MA or age were considered not to have potential for these shrubby forage species.

1.2.2.1.2. Moisture Accumulation (MA)

A DEM was used with the Arcview Hydrological Modeling Extension (ESRI, Redlands, California) to determine the most likely flow direction of water from any given 1-ha pixel in the landscape. Cumulative water flow (one can easily imagine that this number grows as one moves down slope) was calculated for each pixel. Results were initially heavily skewed to the low end of the range of flow accumulation values. We re-applied the algorithm to an area centered on 49º 27' N, 117º 20' W, within the planning area 1A – South Selkirks, but allowed for greater resolution at the low end of the resultant. This then allowed us to reclassify the resultant into those pixel groupings which we felt would provide at least a preliminary estimate of slope position and hence moisture accumulation for our BBNs[9]. Crest shedding slope positions were intended to represent very xeric, xeric, and subxeric moisture regimes; upper slope shedding positions represented submesic and mesic sites, mid-slope normal positions represented subhygric sites, lower slope receiving postions represented hygric sites, and toe slope positions represented subhydric sites.

1.2.2.2. Shade/Succession/Snow Interception (SSSI)

Secondary plant compounds, such as tannins, have an inhibitory influence on the ability of ruminants to digest protein and dry matter (Robbins et al. 1987a, b). Such compounds are more common in plants growing in early seral openings than in the shaded understory of older stands (Van Horne et al. 1988). Thus, the potential for palatable shrub forage is expected to be highest in old (>140 years) stands, moderate in mid-aged (80-140 years) stands, and lowest in younger (<80 years) stands.

1.2.3. Terrestrial Lichen Relative Abundance (TLRA)

As previously noted, mountain caribou in some subpopulations will remain at high elevations during early winter provided terrestrial lichens are available on windswept ridges (H. Armleder, BC Ministry of Forests, *pers. comm.*). These lichens are mostly *Cladonia* spp. but may also include *Cladina* and *Mitella* spp. Potential for TLRA is

---

[9] Note that this classification of MA was one of the primary recalibration activities undertaken at the 5th workshop having review and recalibration by G. Utzig.

influenced by macro-climatic-shrubs (MCS), the occurrence of “crest-shedding” terrain defined by the moisture accumulation (MA) node, shade/snow interception (SSI), and whether the site has potential for vegetation which was indexed by ice and/or bare sites (IBS).

1.2.3.1. Macro-climate-shrubs (MCS)

Terrestrial lichen abundance within the range of mountain caribou was limited to higher-elevation ecosystems characterized by ICH, ESSF, and AT biogeoclimatic zones.

1.2.3.2. Moisture Accumulation (MA)

Well-drained, coarse textured soils give rise to conditions where lichens can survive better than most forbs and shrubs. We used the crest-shedding state from the hydrologic modeling to approximate this condition.

1.2.3.3. Shade/snow Interception (SSI)

Terrestrial lichens need relatively open (i.e., <30% crown closure) conditions where micro-climate conditions are prone to frequent cycles of wetting and drying. Crown closure data input to this node was taken from the FIP database.

1.2.3.4. Ice and/or Bare Sites (IBS)

This node was used to eliminate sites that had no potential to grow vegetation.using Baseline Thematic Mapping (BTM) available from Geographic Data BC (2001)

1.2.4. Snow Accumulation (SA)

Accumulation of snow mediates the relative importance and accessibility of food sources to mountain caribou. Snow accumulation can be considered a function of actual snowfall as determined by macro-climate-snowfall (MCSF; Meidinger and Pojar 1991), snow interception potential (SIP), and windblown sites (WS).

1.2.4.1. Macro-climate Snowfall (MCSF)

Basic climate information was classified, and subzone/variants were ranked according to the potential for snowfall and snowfall accumulation in early winter. Rankings were for very deep, deep, moderate, shallow, and very shallow (Appendix A).

1.2.4.2. Snow Interception Potential (SIP)

A forest stand’s ability to intercept snowfall, facilitate sublimation, and thereby decrease snow accumulation on the ground is related to attributes of stand structure (McNay et al. 1988, Pomeroy et al. 1998). Snow interception is greater with increasing canopy closure which we referred to as shade/snow interception (SSI), increasing stand age which we referred to as shade/succession/snow interception (SSSI), and species-specific structural characteristics of the tree crown which we referred to as interception species group (ISG).

1.2.4.2.1. Shade/Snow Interception(SSI)

Compared to open sites with no canopy closure, forests with >60% canopy closure were considered to be capable of reducing snow pack accumulation by 60%. Canopy closures ranging between 30-60% were capable of reducing snow pack accumulation by 30% and canopy closures <30% were incapable of reducing snow packs.

1.2.4.2.2. Shade/Succession/Snow Interception (SSSI)

Relatively young sites (<30 years old) and all non-forested sites were considered unlikely to intercept snow, hence would not reduce snow pack accumulations. By comparison, sites >140 yrs were considered more likely to intercept snow depending on canopy closure.

1.2.4.2.3. Interception Species Group (ISG))

For the latter component, full-crowned species with low interception potential included all deciduous species and larch; moderately developed crowns and interception included subalpine fir and all pine species; and all remaining species were considered to be full-crowned with high interception potential.

1.2.4.3. Windblown Sites (WS)

The availability of windblown sites is considered to be a function of the moisture accumulation (MA) model, macro-climate-landscape openness (MCLO), and wind potential (WP). ,

1.2.4.3.1. Moisture Accumulation (MA)

Derivation of the MA component is as previously described (1.2.2.1.2) with the potential for wind-scouring being highest on ridge crests (i.e., “crest-shedding”) and upper slopes, moderate on mid-slopes, low on lower slopes, and very low at the toe of slopes and in depression sites.

1.2.4.3.2. Macro-climate Landscape Openness (MCLO)

The MCLO component was determined from biogeoclimatic zones, with wind-scouring potential being high in the AT and ESSF-parkland zones, moderate in the ESSF, and low in all other biogeoclimatic zones (Appendix A).

1.2.4.3.3. Windblown Sites (WS)

The WP component has not been implemented but was intended to be obtained from a BC Hydro map of predicted wind speed. In the absence of applied wind speed data, all sites were assumed to possess the optimal state for this component (i.e. very good > 8m/s).

Late Winter (mid-January to mid-April)

As winter progresses, snowpacks within the range of mountain caribou typically deepens and consolidates. As this snow pack consolidation occurs, mountain caribou generally move to or remain at relatively high elevations, with the supportive snowpack facilitating access to arboreal lichens (*Bryoria* spp.). This low-protein but highly digestible energy source is the only food available to mountain caribou during late winter, and caribou rely almost exclusively on it (Rominger et al. 1996). Preferred range is generally associated with subalpine parkland - typically open, often stunted, old subalpine fir-dominated stands associated with the forest-alpine ecotone, and trees within these stands usually carry abundant loads of *Bryoria* lichen. In most years, the snowpack provides a platform that allows mountain caribou to be highly mobile and able to access the typically abundant arboreal lichen food source. However, food availability can be a problem during years of unusually shallow or unconsolidated snow. During these rare years, range use may continue to resemble the early-winter pattern. The climatic and forest conditions that characterize late-winter mountain caribou range is often associated with larger landscapes that are relatively rugged, and a consistent association with gentle slopes is apparent among studies, especially at finer scales. Range selection strategies are relatively consistent among subpopulations during late winter.

2. Modeling Seasonal Forage Usefulness for late winter (SFU)

As described above, SFU for mountain caribou during late-winter is a function of the energetic cost of movement (ECM; see 1.1) and the abundance of available forage (AAF; see 1.2) but, in this season AAF is simplified to Bryoria abundance (BA; see 1.2.1, 1.2.1.1, and 1.2.1.2) and Bryoria distribution (BD) in the tree canopy (Figure 6).

2.1. Bryoria Distribution (BD)

The primary mountain caribou forage during late winter is arboreal lichen (*Bryoria* spp. primarily from standing trees). The height at which arboreal lichen is available on standing trees depends on the snow pack of previous years. Thus, snow depths that are typical for a given site during late winter (assuming relatively low variation in snow pack among years) and that provide a supportive base for caribou are important. The time period in which the necessary snow accumulation and consolidation occurs is what allows caribou to shift their foraging to an almost exclusive dependence on arboreal lichen on standing trees, and this functionally defines the late-winter mountain caribou season. During late winter, Bryoria is accessible to caribou if its distribution includes the lower portion of the canopy. Within stands, the distribution of the arboreal lichen community varies along a vertical gradient in the canopy due differences in sun exposure, moisture, and air movement (Coxson et al. 1984). Although *Bryoria* lichens benefit from frequent, short-duration wetting, they are relatively intolerant to prolonged wetting (Goward 1998). Thus, the within-tree distribution of lichen depends on the macro-climate (MC) and stand ventilation (SV).

2.1.1.1. Macro-Climatic-Arboreal Lichens (MCAL)

Within the interior wet-belt, Bryoria lichens favor the wetter climate of higher elevations (Goward 1998). Such higher elevations may also receive greater sun exposure that may help to facilitate the frequent drying that *Bryoria* requires. Hence, trees within landscapes typical of the ATp and ESSF wet and very wet subzones may support *Bryoria* lower in the canopy.

2.1.1.2. Stand Ventilation (SV)

Due to its need for frequent drying, *Bryoria* lichen tends to be more abundant higher in the canopy where there is greater air-flow, and less abundant lower on the tree where it is restricted to either dead branches or the defoliated portions of live branches (Goward 1998). Given a suitable macro-climate, old stands with appropriate branching structure are also more likely to support an abundance of *Bryoria* low in the canopy if those stands are relatively open. This condition allows the air flow necessary to facilitate frequent

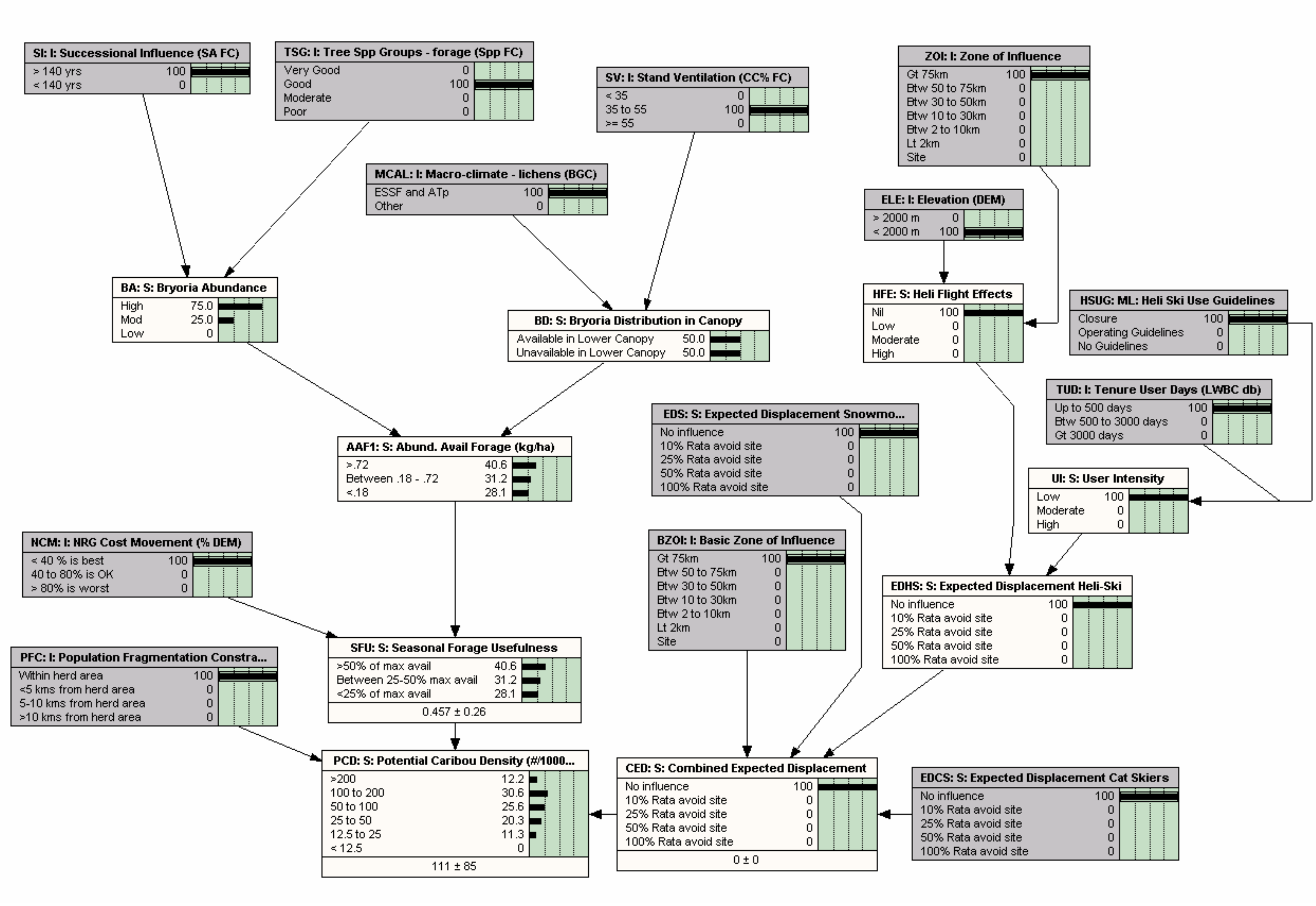

Figure 7. A Bayesian belief network used to predict the expected density of mountain caribou during late winter in southeastern British Columbia.

drying of lichen and the dispersal of lichen propagules. However, wind-scouring and dessication may reduce existing lichens and limit new growth as trees become too isolated (Campbell and Coxon 2001). The relative availability of Bryoria is thus assumed to be high where canopy closure is >35%, moderate where it is between 35% and 55% and low where canopy closure is at least 60%.

Spring (mid-April to May)

In spring, mountain caribou will often move to take advantage of snow-free sites and emergent green vegetation high in digestible energy and protein. These sites are usually found at lower elevations and warmer aspects, and sometimes include cutblocks, roadsides, powerlines, and natural forest openings. However, they are usually within larger landscapes dominated by old forests of relatively high canopy closure (perhaps due to proximity to both late winter and summer habitats). In the North Columbia Mountains, where a notable shift to lower elevations occurs, spring landscapes are associated with western redcedar and western hemlock. However, such an elevation shift to the ICH zone is not apparent in many other regions (may relate to predation risk), though some movement to lower elevations is not uncommon. Despite their need for abundant, nutritious early spring food, the overriding factor influencing range selection by pregnant females may be security from predators, and these animals will often move to steeper, rugged and rocky terrain later in the spring season. Among other animals, gentle slopes are generally preferred, presumably for ease of movement.

3. Modeling Seasonal Forage Usefulness for spring (SFU)

As described above, SFU for mountain caribou during spring is a function of the energetic cost of movement (ECM; see 1.1) and the abundance of available forage (AAF; see 1.2) but, in this season AAF is a function of a site's vegetation potential (VP), and green-up potential (GUP) reflecting the early availability of emergent forage (Figure 7)..

3.1 Vegetation Potential (VP)

Most sites were considered to have potential for some from of vegetation. Sites that did not have potential were those associated with alpine ice and bare sites (IBS; see 1.2.3.4) and wet and non-forested features (WF) from forest cover information.

3.1.1 Wet and Non-forested Features (WF)

The following "non-productive" designations of the FIP database: "rock", "icefield", "sand", "gravel", "clay bank", "lake", "gravel bar", "river", "mud", and "urban".

3.2 Green-Up Potential (GUP)

A site's potential for early season green-up, hence providing emergent forbs for caribou during spring, was assumed to be a function of solar input potential (SIP) and the occurrence of early-season seepage (ESS) sites on the landbase.

3.2.1 Solar Input Potential (SIP)

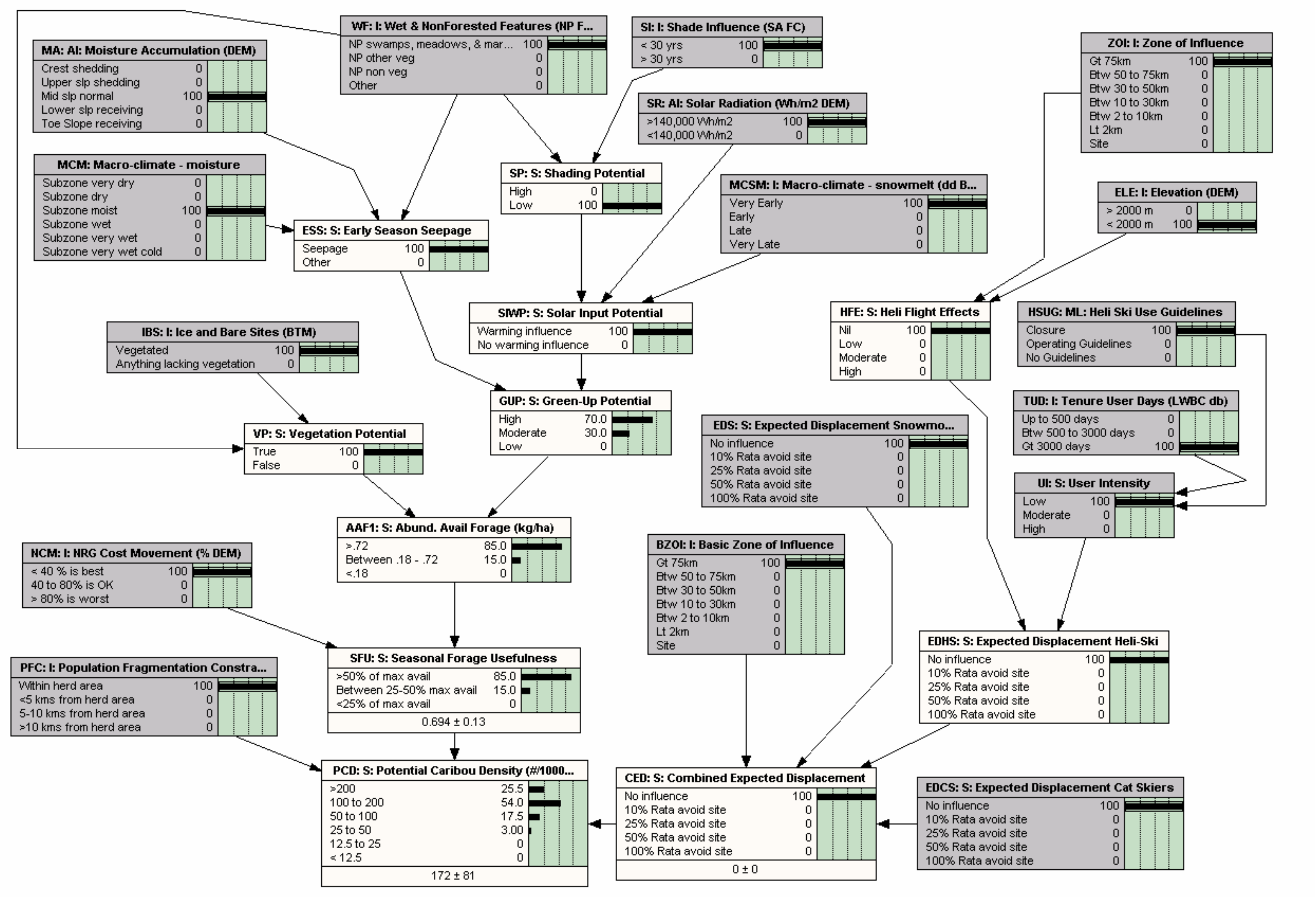

Figure 8. A Bayesian belief network used to predict the expected density of mountain caribou during spring in southeastern British Columbia.

A site's potential for solar input is assumed to be determined by received solar radiation (SR) given terrain conditions, macro-climate-snowmelt (MCSM), and shading potential (SP) given forest conditions.

3.2.1.1 Solar Radiation (SR)

The SR of a site is directly inferred from the maximum kilojoules of radiant energy that it may receive given topographic variation (slope and aspect), and slope position relative to sun angle at specific times of the year and terrain shading (Kumar et al. 1997). Specifically, SR potential was assumed for sites receiving >175,000 Wh/m^2 during the. spring season, and low SR potential is assumed for all other sites. Solar radiation was calculated for map areas using cumulative seasonal direct, and diffuse, solar radiation (Wh/m2) based on horizon angles within a topographical view shed and solar position where the latter depends on time of year and latitude (Hu and Rich 2000). Preliminary calibration was set to establish spring relatively hot zones and summer relatively cool zones based simply on a visual inspection of model results applied to the planning area 6a – Wells Gray South.

3.2.1.2 Macro-climate-snowmelt (MCSM)

The MCSM component was determined from biogeoclimatic zones having potential to be relatively warm early in the spring season (Appendix A).

3.2.1.3 Shading Potential (SP)

Shade potential of a site was determined by whether the site was a wet or non-forested feature (WF; see 3.1.1) and if not, then the age of forest as this was expected to correlate to shade influence (SI) of the forest canopy.

3.2.1.3.1 Shade Influence (SI)

For the purposes of determining potential for early season snowmelt, shade that would lower this potential was considered to be from any forest >30 years old. Otherwise, the site was considered not to be shaded.

3.2.2 Early-Season Seepage (ESS)

A site's potential for the hydrological runoff and seepage that is expected to facilitate accelerated snow-melt was determined from wet and non-forested features (WF; see 3.1.1), the moisture accumulation (MA; see 1.2.2.1.2) model, and a modifier to scale MA for the amount of moisture potential as derived from macro-climate-moisture (MCM) . In the MA component, highest seepage potential is assumed to occur at the toe of slopes and in depression sites, moderate on mid- and low-slope positions, and low on upper slopes and ridge crests.

3.2.2.1 Macro-climate-moisture (MCM)

For the purposes of scaling the MA node, biogeoclimatic subzone/variants were ranked according to the relative potential of moisture to occur as runoff (Appendix A).

Summer (June to October)

If movements to lower elevations have been made during spring, mountain caribou will gradually move back to higher elevations as snow-melt progresses. Summer ranges are generally associated with the mid to upper ESSF and ESSF-parkland near to the alpine. Food is not expected to be limiting during this season, and a variety of graminoids, forbs and shrubs are eaten throughout the summer, in addition to lichens. Hence, summer ranges vary in characteristics. General preferences are for high elevation forest stands dominated by subalpine fir. Landscapes and stands normally associated with cooler conditions, including north and east aspects and relatively closed canopies, are generally selected perhaps because caribou are more susceptible to heat stress during the summer. Associations with canopy cover generally vary from neutral to positive at finer scales. Like other seasons, gentle slopes are also preferred at successively finer scales. Calving occurs in early summer, from late May through June, near treeline in subalpine forests or in the alpine.

4. Modeling Seasonal Forage Usefulness for Summer (SFU)

As described above for other seasons, SFU for mountain caribou during summer is a function of the energetic cost of movement (ECM; see 1.1) and the abundance of available forage (AAF; see 1.2) but, in this season AAF is simply a function of vegetation potential (VP; see 3.1). SFU is modified by a site's potential to facilitate cooling thermoregulation (TR).(Figure 8).

4.1. Cooling Thermoregulation (CT)

Habitat conditions that can help to minimize heat stress are determined by macro-climate-temperature (MCT), solar radiation (SR: see 3.2.1.1 except calibration was best if <320,000 Wh/m^2, worst if >635,000 Wh/m^2, and moderate if between those levels), and shade/succession influences (SSI; see 1.2.4.2.2 except older stands were considered best given their ability to provide shade).

4.1.1. Macro-climate Temperature (MCT)

Derived from the biogeoclimatic ecosystem classification (Meidinger and Pojar 1991), MCT provides low cooling value where "hot", moderate cooling where "warm", and high cooling where "cool" (Appendix A).

Literature Cited

Antifeau, T. D. 1987. The significance of snow and arboreal lichen in the winter ecology of mountain caribou (*Rangifer tarandus caribou*) in the north Thompson watershed of British Columbia. Thesis. University of British Columbia, Vancouver, British Columbia, Canada.

Apps, C. D., and T. A. Kinley. 1998. Development of a preliminary habitat assessment and planning tool for mountain caribou in southeast British Columbia. Rangifer, Special Issue 10:61-72.

_____, and T. A. Kinley. 2000. Multi-scale habitat associations of mountain caribou in the southern Purcell Mountains, British Columbia. Prepared for East Kootenay

Environmental Society and Crestbrook Forest Industries. Aspen Wildlife Research, Calgary, Alberta, Canada.

_____, and T. A. Kinley. 2000. Scale-dependent habitat modeling for mountain caribou in the Quesnel Highlands, British Columbia. Ministry of Environment, Lands and Parks, Williams Lake, British Columbia.

_____, and T. A. Kinley. 2000. Mountain caribou habitat use, movements, and factors associated with GPS location bias in the Robson Valley, British Columbia. Columbia Basin Fish and Wildlife Compensation Program, Nelson, British Columbia, Canada. Apps, C. D., B. N. McLellan, T. A. Kinley, and J. P. Flaa. 2001. Scale-dependent habitat selection by mountain caribou, Columbia Mountains, British Columbia. Journal of Wildlife Management 65:65-77.

_____, B.N. McLellan, T.A. Kinley, and J.P. Flaa. 2001. Scale-dependent habitat selection by mountain caribou, Columbia Mountains, British Columbia. J. Wildl. Manage. 65:65-77.

Armleder, H. M., and S. K. Stevenson. 1996. Using alternative silviculture systems to integrate mountain caribou and timber management in British Columbia. Rangifer Special Issue 9:141-149.

Campbell, J., and D. S. Coxson. 2001. Canopy microclimate and arboreal lichen loading in a subalpine-fir forest. Canadian Journal of Botany.

Coxson, D. S., M. R. Webber, and K. A. Kershaw. 1984. The thermal operating environment of corticolous and pendulous tree lichens. The Bryologist 87:197-202.

Geographic Data BC. 2001. Baseline thematic mapping; present land use mapping at 1:250,000. British Columbia specifications and guidelines for geomatics, content series volume 6, part 1, release 2.1. Ministry of Sustainable Resource Management, Victoria, British Columbia, Canada.

Goward, T. 1998. Observations on the ecology of the lichen genus Bryoria in high elevation conifer forests. Canadian Field Naturalist 112:496-501.

Hamilton, D., S. F. Wilson, and G. Smith. 2000. Mountain caribou habitat use and population characteristics for the central Selkirks caribou inventory project. Nanuq Consulting Ltd., Nelson, BC, Canada. Hedstrom, N. R., and J. W. Pomeroy. 1998. Measuring and modeling of snow interception in the boreal forest. Hydrological Processes 12:1611-1625.

Hu, P. and P. Rich. 2000. The solar analyst 1.0 user manual. Helios Environmental Modeling Institute. 49pp.

Johnson, C. J., D. R. Seip, and M. S. Boyce. 2004. A quantitative approach to conservation planning: using resource selection functions to identify important habitats for mountain caribou. Journal of Applied Ecology 41:238-251.

Kinley, T. A., and C. D. Apps. 2005. Caribou habitat assessment for the Priest Lake endowment lands: volume1 habitat modeling for the South Selkirk Ecosystem. Sylvan Consulting, Invermere, British Columbia, Canada.

_____, J. Bergenske, J. Davies, and D. Quinn. 2003. Characteristics of early-winter caribou, *Rangifer tarandus caribou*, feeding sites in the southern Purcell Mountains, British Columbia. Canadian Field Naturalist 117:352-359.

Kumar, L., A. K. Skidmore, and E. Knowles. 1997. Modeling topographic variation in solar radiation in a GIS environment. International Journal of Geographic Information Science 11:475-497.

McNay, R. S., L. D. Peterson, and J. B. Nyberg. 1988. The influence of forest stand characteristics on snow interception in the coastal forests of British Columbia. Canadian Journal of Forest Research 18:566-573.

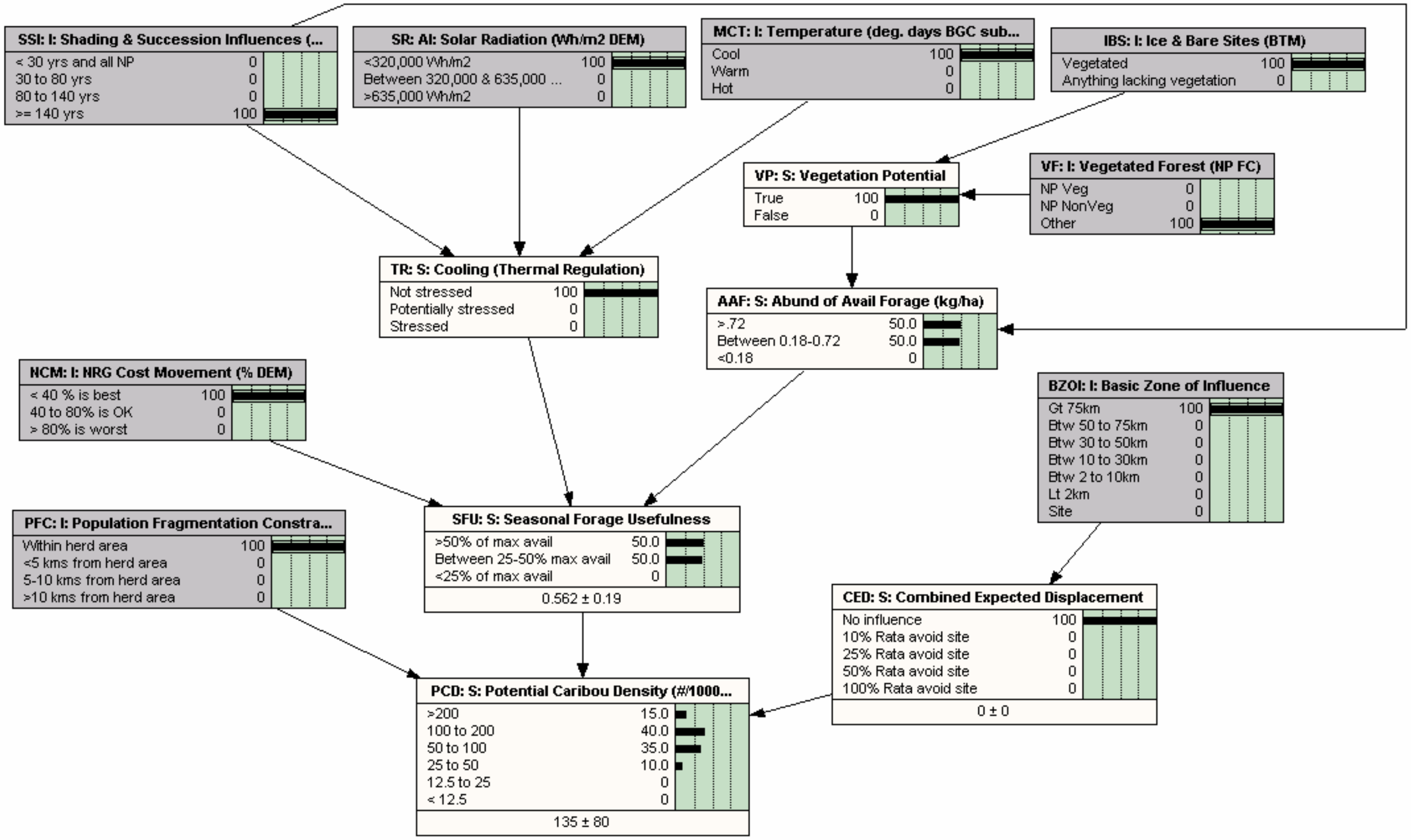

Figure 9. A Bayesian belief network used to predict the expected density of mountain caribou during summer in southeastern British Columbia.

MCTAC (Mountain Caribou Technical Advisory Committee). 2002. A strategy for the recovery of mountain caribou in British Columbia. Ministry of Water, Land and Air Protection, Victoria, British Columbia, Canada.

Meidinger, D. V., and J. Pojar. 1991. Ecosystems of British Columbia. British Columbia Ministry of Forests Special Report Series 4.

Parish, R., R. Coupe, and D. Lloyd, editors. 1996. Plants of southern interior British Columbia. Lone Pine Publishing, Vancouver, British Columbia, Canada.

Pomeroy, J. W., J. Parviainen, N. Hedstrom, and D. M. Gray. 1998. Coupled modelling of forest snow interception and sublimation. Hydrological Processes 12:2317-2337.

Robbins, C. T., T. A. Hanley, A. E. Hagerman, O. F. Hjeljord, D. L. Baker, C. C. Schwartz, and W. W. Mautz. 1987a. Role of tannins in defending plants against ruminants: reduction in protein availability. Ecology 68:98-107.

_____, T. A. Hanley, A. E. Hagerman, O. F. Hjeljord, D. L. Baker, C. C. Schwartz, and W. W. Mautz. 1987b. Role of tannins in defending plants against ruminants: reduction in dry matter digestion. Ecology 68:1608-1616.

Rominger, E. M., and J. L. Oldemeyer. 1989. Early-winter habitat of woodland caribou, Selkirk Mountain, British Columbia. Journal of Wildlife Management 53:238-243.

_____, and J. L. Oldemeyer. 1990. Early-winter diet of woodland caribou in relation to snow accumulation. Canadian Journal of Zoology 68:2691-2694..

_____, C. T. Robbins, and M. A. Evans. 1996. Winter foraging ecology of woodland caribou in northeastern Washington. Journal of Wildlife Management 60:719-728.

_____, C. T. Robbins, and M. A. Evans, and D. J. Pierce. 2000. Autumn foraging dynamics of woodland caribou in experimentally manipulated habitats, northeastern Washington, USA. Journal of Wildlife Management 64:160-167.

Seip, D. R. 1990. Ecology of woodland caribou in Wells Gray Provincial Park. British Columbia Ministry of Environment Wildlife Bulletin B-68.

_____. 1992. Habitat use and population status of woodland caribou in the Quesnel Highlands, British Columbia. British Columbia Ministry of Environment Wildlife Bulletin B-71.

Servheen, G., and L. J. Lyon. 1989. Habitat use by woodland caribou in the Selkirk Mountains. Journal of Wildlife Management 53:230-237.

Simpson, K., G. P. Woods, and K. P. Hebert. 1985. Critical habitats of caribou (*Rangifer tarandus caribou*) in the mountains of southern British Columbia. Pages 177-191 in T. C. Meredith and A. M. Martel, editors. Proceedings of the second North American caribou workshop. McGill University, Montreal, Quebec, Canada.

Stevenson, S. K, H. M. Armleder, M. J. Jull, D. G. King, B. N. McLellan, and D. S. Coxson. 2001. Mountain caribou in managed forests: recommendations for managers, second edition. Ministry of Environment, Lands and Parks, Wildlife Report No. R-26. Victoria, Canada.

Terry, E. L., B. N. McLellan, and G. S. Watts. 2000. Winter habitat ecology of mountain caribou in relation to forest management. Journal of Applied Ecology 37:589-602.

Van Horne, B., T. A. Hanley, R. G. Cates, J. D. McKendrick, and J. D. Horner. 1988. Influence of seral stage and season on leaf chemistry of southeastern Alaska deer forage. Canadian Journal of Forestry Research 18:90-99.

LANDSCAPE-LEVEL CONSIDERATIONS -- CLAYTON APPS

The amount of suitable habitat in the larger landscape necessary to support mountain caribou may be much greater than the minimal amount required to provide sufficient forage. Opportunities for spacing to achieve low overall densities may be important to minimize predation risk, and it is likely that caribou vulnerability to predation will increase as populations become more concentrated within smaller and more isolated patches of seasonal ranges (Stevenson et al. 2001, MCTAC 2002). Thus, the density and dispersion of range conditions is an important consideration in the suitability of larger landscapes. In their evaluation, modification and application of a mountain caribou habitat suitability index (HSI) model, Apps and Kinley (1998) considered habitat distribution at 2 scales (250 and 5000 ha), the larger roughly corresponding to the average core caribou home range within their study area. Kinley and Apps (2005) similarly considered broad-scale habitat aggregation and connectivity in their delineation of ecosystem-level habitat priority areas for the South Selkirk Mountains.

The suitability of areas interstitial to seasonal ranges may be another important consideration at the landscape level. Mountain caribou need to move within and among seasonal ranges, and these movements may involve significant traverses of valley bottoms and ridges. Some terrain conditions may restrict movement options, but densely stocked, immature forests (e.g., lodgepole pine, <80 years, >80% canopy closure) may also function as movement barriers. Areas with structural attributes that minimize physical obstruction and visual obscurity (the latter related to predation risk) can be assumed to increase landscape suitability, especially were associated with terrain conditions that also facilitate movement. Additional considerations for these areas relate to their potential to attract alternate ungulate prey species and resulting predation risk to caribou (see Expected Mortality Factors).

Although recognizing the importance of these factors associated with scale and landscape permeability, we were unable to dedicate sufficient discussion to identify a modeling approach. Instead we created a simple index to modify the seasonal forage usefulness (SFU) by a population fragmentation constraint (PFC; see Figures 5-8). This was accomplished by establishing consecutive spatial buffers around current caribou herd areas (Wittmer 2004) at 5 and 10 kms. Range within the herd area was not modified but range between 5-10kms was reduced in value, and range >10 was further reduced in value.

Literature Cited

Apps, C. D., and T. A. Kinley. 1998. Development of a preliminary habitat assessment and planning tool for mountain caribou in southeast British Columbia. Rangifer, Special Issue 10:61-72.

Kinley, T. A., and C. D. Apps. 2005. Caribou habitat assessment for the Priest Lake endowment lands: volume1 habitat modeling for the South Selkirk Ecosystem. Sylvan Consulting, Invermere, British Columbia, Canada.

MCTAC (Mountain Caribou Technical Advisory Committee). 2002. A strategy for the recovery of mountain caribou in British Columbia. Ministry of Water, Land and Air Protection, Victoria, British Columbia, Canada.

Stevenson, S. K, H. M. Armleder, M. J. Jull, D. G. King, B. N. McLellan, and D. S. Coxson. 2001. Mountain caribou in managed forests: recommendations for managers, second edition. Ministry of Environment, Lands and Parks, Wildlife Report No. R-26. Victoria, Canada.

Wittmer, H.U. 2004. Mechanisms underlying the decline of mountain caribou (*Rangifer tarandus caribou*) in British Columbia. Ph.D. thesis, University of British Columbia, Vancouver, BC

EXPECTED DISPLACEMENT FACTORS -- *STEVE WILSON*

Rationale

Disturbance of wildlife by human-related activities can have a variety of detrimental effects (Joslin and Youman 1999). In general, these effects can be categorized as (Wilson and Shackleton 2001):

1. Short-term acute: obvious, immediate changes in behavior in response to a stimulus.
2. Medium-term chronic: changes in behavior (over days to months) that minimize the probability of encountering the stimulus in the future. This is manifested in temporary or permanent changes in range use.
3. Long-term demographic: changes in behavior that lead to declines in populations. These can be behaviors that make animals more susceptible to predators, that reduce opportunities for mating, or that adversely affect the viability of offspring.

Short-term, acute responses have been the focus of most studies of mountain caribou and other ungulates and are best understood. Behavioral responses by woodland caribou to human foot traffic are relatively minor; resulting in moderate changes to time spent foraging (Duchesne et al. 2000). Responses to snowmobiles also result in moderate changes to behavior and energy expenditure (Simpson 1987, Tyler 1991, Mahoney at al. 2001). Studies of behavioral responses to civilian aircraft in Dall's sheep (Frid 2003), bighorn sheep (MacAurthur et al. 1982, Krausmann and Hervert 1983, Bleich et al. 1994) and mountain goats (Foster and Rahs 1983, Côté 1996) have suggested that behavioural responses to aircraft vary considerably, but that helicopter activity is associated with higher frequencies of alarm responses than fixed-wing aircraft. Caribou have been shown to change their behavior in response to low-level military over-flights (Harrington and Veitch 1991, Maier et al. 1998).

Displacement from range as a result of human-caused disturbance has been studied in caribou and other ungulates. Kinley (2003) found evidence of changes in range use by mountain caribou with recent increases in snowmobiling activity in the Kootenay region. Similarly, a study of heli-skiing activity within the range of the Central Selkirk mountain caribou subpopulation found that use of areas by mountain caribou was lower during months and years when skiing activity was highest, although the effect was weak (Wilson and Hamilton 2003). Reindeer in Norway avoided areas <5 km from alpine resorts, despite similar lichen availability and snow conditions (Nellemann et al. 2001). Although displacement has been demonstrated, there is no evidence that caribou have been displaced into poorer habitat as a result of these activities. Still, displacement by human-related activities from preferred range into areas where snow conditions might be poor and/or forage availability might be lower, or where mountain caribou may be more susceptible to avalanches or predation, remains a compelling hypothesis.

Only one study has demonstrated a direct effect of disturbance on woodland caribou demographics; Harrington and Veitch (1992) found that calving success was lower among woodland caribou subjected to military over-flights in Labrador.

In summary, many studies have demonstrated short-term, acute behavior changes in response to a variety of disturbances, but far fewer have identified range abandonment or demographic declines in response to disturbance. There have been no studies that have linked short-term, acute behavior changes to longer-term consequences. Displacement of mountain caribou from otherwise suitable range into less suitable areas that might be associated with lower survival (i.e., from higher rates of predation or accidents, or in association with higher metabolic costs due to poor snow conditions or lower forage availability) remains the potential effect of most concern.

Heli-skiing, snowcat skiing and backcountry touring are most often cited as the human-related activities that have the greatest potential to displace mountain caribou from preferred habitat (Simpson and Terry 2000, MCTAC 2002). Backcountry resorts are also a concern because of the Province's intention to increase substantially the number of such resorts in BC. Although the focus of most studies has been on winter recreation and activities, backcountry activity in the summer might result in similar effects. Of particular concern are commercial recreation operations or resource industries that use helicopters.

Model Structure

The seasonal displacement models are based on a series of activity submodels that predict displacement of caribou by cat-based skiing, snowmobiling, helicopter-based skiing, and a basic zone of disturbance around towns, industrial sites, or recreational staging areas. The structure of submodels is consistent among seasons but the set of submodels and/or their relative effect differ among seasons. Each activity submodel is comprised of four components:

1. A summary node and one or more input nodes that estimate the capability of the land base for an activity;
2. An input node that expresses the intensity of an activity;
3. An input node that expresses the effect of guidelines and mitigative behaviors by users engaged in the activity; and
4. A summary node that expresses the expected displacement associated with an activity where states are either no influence or displacement of 10%, 25%, 50% or 100% of the caribou that would normally occupy the site.

The combined expected displacement (CED; see Figures 5-8) was a function that added displacement effects from the activity-based submodels described below and served to modify the seasonal forage usefulness (SFU) of a specific site.

Activity-based Submodels

1. Modeling Basic Zone of Influence (BZOI))

Staging areas are points on the landscape where different recreational or industrial activities are centered. The intensity of the activity is assumed to decay with the square of the distance from the staging area. Sites associated with a number of activities that have the potential to displace mountain caribou are considered including:

1. Mechanized recreation activities (e.g., trailhead or cabin associated with snowmobile use);
2. Resort areas (e.g., ski hills and related infrastructure);

3. Industrial sites (e.g., mines);
4. Heli-skiing staging areas (either a lodge located within commercial tenure or entry point to tenure); and
5. Towns (location of towns is used to modify the potential use of areas).

2. Modeling Expected Displacement by Snowmobiling (EDS)

Snowmobiling was not currently invoked in the habitat supply model due primarily to the logistics of collecting data to predict areas suitable for the activity (i.e., primarily trails and access points) or estimate the intensity of use. For this reason, EDS appears in the seasonal range models as a single node with no inputs (Figure 10). We have left the documentation here simply to capture ideas that may be added to in the future if the decision is made to continue modeling EDS. As indicated above, EDS would be a function of <u>snowmobiling capability</u> (SC), <u>snowmobile user guidelines</u> (SUG), and an estimate of user days based on an <u>industry growth factor</u> (IGF).

2.1. Snowmobiling Capability (SC)

The capability of the landscape to support snowmobiling is defined by ease of the terrain or <u>site openness</u> (SO), <u>slope</u> (SLP), and <u>proximity to staging areas</u> (PSA):

2.1.1. Site Openness (SO)

The capability of the landscape to support snowmobiling is first a function of the openness of the terrain. In general, snowmobilers prefer subalpine and alpine areas. BEC subzones and perhaps forest cover will be used to defined site openness.

2.1.2. Slope (SLP)

Snowmobiling activities are largely restricted to areas with ≤80% slope.

2.1.3. Proximity to Staging Areas (PSA)

The intensity of potential snowmobiling activity is a function of distance from towns and the location of motorized recreation staging areas.

2.2. Snowmobile User Guidelines (SUG)

Snowmobile user guidelines outline desired behaviors for users in the backcountry in caribou habitat. When followed, these behaviors are expected to reduce the displacement effects of snowmobiles on mountain caribou.

2.3. Industry Growth Factor (IGF)

This node is used to estimate the number of seasonal user-days by snowmobilers.

3. Modeling Expected Displacement by Heli-skiing (EDHS)

Although helicopter-based skiing activity is invoked in the model, the logistics of locating data limited its functionality. We did not try to model the capability of areas for heli-skiing but rather determined these sites based on known tenures and staging areas.

Therefore, where heli-ski tenures exist, EDHS was a function of heli-ski flight effects (HFE) and user intensity (UI).

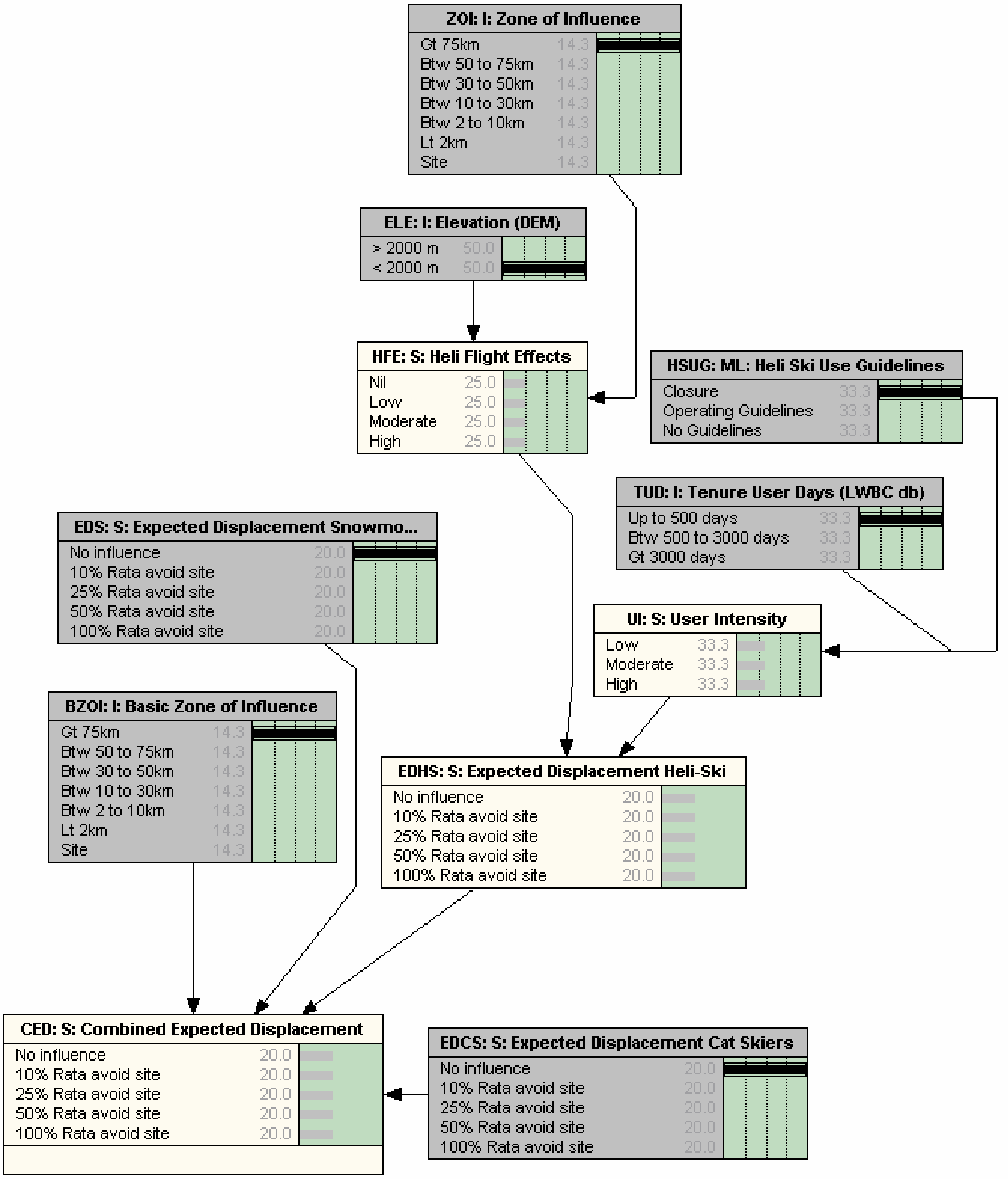

Figure 10. A Bayesian belief network used to predict the expected displacement of mountain caribou away from their seasonal ranges as a result of disturbance by humans undertaking a variety of activities.

3.1. Heli-ski Flight Effects (HFE)

Heli-ski flight effects can be characterized on the basis of a zone of influence (ZOI) around flight lines and the elevation (ELE) of the flight line.

3.1.1. Zone of Influence (ZOI)

The potential displacing effects of helicopters was considered to have its greatest effects up to 2 km away from a flight line with effects dissipating gradually out to 30 kms where the effects were considered low. There was no effect beyond 50 kms.

3.1.2. Elevation (ELE)

Helicopter activity within tenures is expected to be driven largely by the need to minimize fuel; therefore, flight activity >2000 m is assumed to occur at half the frequency of activity <2000 m.

3.2. User Intensity (UI)

The intensity with which an area is used was assumed to be based on regulated or self-imposed heli-ski use guidelines (HSUG) and the number of tenure user days (TUD).

3.2.1. Heli-ski Use Guidelines (HSUG)

Heli-ski user guidelines outline desired behaviors for operators in caribou habitat. When followed, these behaviors are expected to reduce the displacement effects of helicopters on mountain caribou.

3.2.2. Tenure User Days (TUD)

This node is used to estimate the number of seasonal user-days by heli-ski tenure.

4. Expected Displacement by Cat-skiing (EDCS)

Cat-skiing was not currently invoked in the habitat supply model due primarily to the logistics of collecting data to predict areas suitable for the activity (i.e., availability of local operators and/or access points) or estimate the intensity of use. For this reason, EDCS appears in the seasonal range models as a single node with no inputs. We have left the documentation here simply to capture ideas that may be added to in the future if the decision is made to continue modeling EDCS. As indicated above, EDCS would be a function of Cat-ski capability (CSC), cat-ski user guidelines (CSUG), and tenure user days (TUD).

4.1. Cat-ski Capability (CSC)

The capability of the landscape to support cat-skiing activities is defined by the following node:

4.2. Cat-ski Use Guidelines (CSUG)

Cat-ski user guidelines outline desired behaviors for operators in caribou habitat. When followed, these behaviors are expected to reduce the displacement effects of cat-skiing activities on mountain caribou.

4.3. Tenure User Days (TUD)

This node is used to estimate the number of seasonal user-days by cat-ski tenure.

Literature Cited

Bleich, V. C., R. T. Bowyer, A. M. Pauli, M. C. Nicholson, and R. W. Anthes. 1994. Mountain sheep Ovis canadensis and helicopter surveys: ramifications for the conservation of large mammals. Biological Conservation 70:1-7.

Côté, S. D. 1996. Mountain goat responses to helicopter disturbances. Wildlife Society Bulletin 24:681-685.

Duchesne, M., S. D. Côté, and C. Barrette. Responses of woodland caribou to winter ecotourism in the Charlevoix Biosphere Reserve, Canada. Biological Conservation 96:311-317.

Foster, B. R., and E. Y. Rahs. 1983. Mountain goat response to hydroelectric exploration in northwestern British Columbia. Environmental Management 7:189-197.

Frid, A. 2003. Dall's sheep responses to overflights by helicopter and fixed-wings aircraft. Biological Conservation 110:387-399.

Harrington, F. H., and A. M. Veitch. 1991. Short-term impacts of low-level jet fighter training on caribou in Labrador. Arctic 44:318-328.

_____, and A. M. Veitch. 1992. Calving success of woodland caribou exposed to low-level jet fighter overflights. Arctic 45:213-218.

Kinley, T. 2003. Snowmobile-mountain caribou interactions: a summary of perceptions and an analysis of trends in caribou distribution. Prepared for: BC Ministry of Water, Land and Air Protection, Victoria.

Krausman, P. R., and J. J. Hervert. 1983. Mountain sheep responses to aerial surveys. Wildlife Society Bulletin 11:372-375.

Joslin, G., and H. Youmans [Coordinators]. 1999. Effects of recreation on Rocky Mountain wildlife: a review for Montana. Committee on Effects of Recreation on Wildlife, Montana Chapter of The Wildlife Society.

Mahoney, S. P., K. Mawhinney, C. McCarthy, D. Anions, and S. Taylor. 2001. Caribou reactions to provocation by snowmachines in Newfoundland. Rangifer 21:35-43.

MCTAC. 2002. A strategy for the recovery of mountain caribou in British Columbia. BC Ministry of Water, Land and Air Protection, Victoria.

MacArthur, R. A., V. Geist, and R. H. Johnston. 1982. Cardiac and behavioral responses of mountain sheep to human disturbance. Journal of Wildlife Management 46:351-358.

Maier, J. A. K., S. M. Murphy, R. G. White, and M. D. Smith. 1998. Responses of caribou to overflights by low-altitude jet aircraft. Journal of Wildlife Management 62:752-766.

Nellemann, C., P. Jordhøy, O. G. Støen, and O. Strand. 2001. Cumulative impacts of tourist resorts on wild reindeer (*Rangifer tarandus tarandus*) during winter. Arctic 53:9-17.

Simpson, K. 1987. The effects of snowmobiling on winter range use by mountain caribou. BC Ministry of Environment, Lands and Parks, Wildlife Working Report WR-25.

_____, and E. Terry. 2000. Impacts of backcountry recreation activities on mountain caribou. Wildlife Working Report No. WR-99, BC Ministry of Environment, Lands and Parks, Victoria.

Tyler, N. J. C. 1991. Short-term behavioural responses of Svalbard reindeer *Rangifer tarandus platyrhychus* to direct provocation by a snowmobile. Biological Conservation 56:179-194.

Wilson, S. F., and D. Hamilton. 2003. Cumulative effects of habitat change and backcountry recreation on mountain caribou in the Central Selkirk Mountains. Prepared for: BC Ministry of Sustainable Resource Management, Nelson, Canadian Mountain Holidays, Banff, AB, and Pope & Talbot Ltd., Nakusp, BC.

_____, and D. M. Shackleton. 2001. Backcountry recreation and mountain goats: a proposed research and adaptive management plan. BC Ministry of Environment, Lands and Parks Wildlife Bulletin B-103.

EXPECTED MORTALITY FACTORS -- *TREVOR KINLEY*

Predation

Across the range of mountain caribou, predation has accounted for 63% of known-cause radio-collared adult mortality (Table 5). As discussed below, it is probable that human impacts on ecosystem processes have recently had, and continue to have, an important role in exacerbating natural predation levels. However, management actions exist that can reduce predation, potentially to rates lower than the "natural" baseline.

A key consideration in modeling predation is that mountain caribou typically make up a minor proportion of the food available to predators within any ecosystem. Mountain caribou live in areas that contain moose, mule deer, white-tailed deer, elk and mountain goats, along with non-ungulate prey species and, in the case of bears, plant food sources. Mountain caribou density in 2002 varied by subpopulation from 1 animal per 6 km^2 to 1 per 333 km^2 (MCTAC 2002). The total biomass of other species far exceeds that of caribou, and depending on the subpopulation and season, some individual ungulate species have local densities nearly 100 times greater than caribou. In relation to more readily available prey, the search effort required to specifically locate caribou and the minor food value they represent at such low densities almost certainly make it rare for predators to tailor their hunting strategies explicitly to caribou (Thomas and Gray 2002). Rather, it is probably more typical for mountain caribou to be encountered and killed incidentally by predators hunting other species or seeking other food types. Katnik (2002) found that some cougars in the southern Selkirk Mountains overlapped extensively with caribou during summer, but even those could not be considered caribou specialists as the total population of caribou in the ecosystem would only equate to half a year's food for 1 cougar. Thus, search effort and predation rates on mountain caribou under recent demographic conditions would be expected to be influenced little by caribou density. Wittmer (2004) reported no reduction in mortality rate among lower-density mountain caribou populations. Instead, caribou predation is presumably driven largely by their incidental encounter rate with predators, which in turn relates to predator numbers and their degree of overlap with caribou (e.g. Seip 1992).

In relation to other ungulates, caribou appear to be particularly susceptible to wolf predation (Seip 1991, Thomas 1995) but they may be even more vulnerable to cougars. Caribou primarily evolved in the presence of wolves, a cursorial predator, so they may not be well adapted to avoiding predation by stalking predators such as cougars. This vulnerability to predation, combined with the lack of a negative feedback on predator numbers as caribou populations decline (due to the presence of other prey species), results in caribou being susceptible to sustained population depression or even localized extirpation if they encounter predators with sufficient regularity (Bergerud 1978, Seip 1992, Rettie and Messier 1998, 2000).

Predator Numbers

The main factors influencing predator density appear to be the supply of ungulates or other food sources and the number of predators killed by humans. The weight of historical evidence regarding ungulate distribution in southeastern and east-central

Table 5. Reported mortality causes for mountain caribou, except legal hunting[1]. Data span 1967-2004. For footnotes relating to unpublished data, subpopulations follow nomenclature of Wittmer (2004).

Cause	**Data From Radiocollared Caribou**						**Data From Non-Collared Caribou[5]**					
	Simpson & Woods (1987)	Compton et al. (1995)[2]	Almack (2000)[3]	Wittmer (2004)[4]	Unpubl. Data	Subtotal	Stevenson & Hatler (1985)[6]	Johnson (1985)	Simpson & Woods (1987)	Other Reports	Subtotal	**All Data**
Bears		2	1	19	2[7]	24				2[8]	2	26
Cougars		5	7	12	2[9]	26					0	26
Wolves				18	1[10]	19	1			3[11]	4	23
Wolverines				6		6			1		1	7
Unknown Predator				3	3[12]	6					0	6
Predation Total		7	8	58	8	81	1		1	5	7	88
Illegal Shooting	1	1	2	2		6	30	21	3	1[13]	55	61
Vehicle Collisions	1			2		3	4	7		16[14]	27	30
Train Collisions						0	18[15]			1[16]	19	19
Fence Entanglement						0				1	1[17]	1
Research-Related		1		2		3				3[18]	3	6
Human-Caused Total	2	2	2	6		12	52	28	3	22	105	117
Falls/Avalanches	4		1	20	1[19]	26			4	3[20]	7	33
Locked Antlers	1					1			1		1	2
Malnutrit./Condition		3[21]		10	2[22]	15			1	1[23]	2	17
Calving		1				1					0	1
(Total Known-Cause)	*(7)*	*(13)*	*(11)*	*(94)*	*(11)*	*(136)*	*(53)*	*(28)*	*(10)*	*(31)*	*(122)*	*(258)*
Unknown Cause		14[24]	18	61	6[25]	99	3	0	3	3[26]	9	108
TOTAL ALL CAUSES	7	27	29	155	17	235	56	28	13	34	131	366

[1] hunting no longer causes mortality so is not included; past open seasons likely contributed to declines (e.g. legal, reported harvest alone in Purcells-South was >11 annually during 1964-1971, including 40% females – Russell et al. 1982)
[2] translocated caribou in South Selkirks, 1987-1992; excludes losses to emigration listed in cited paper
[3] translocated caribou in South Selkirks, 1996-2000; excludes loss to failed radiocollar listed in cited paper
[4] all subpopulations except South Selkirks (some results reported elsewhere by other authors)
[5] results from non-collared animals presumably biased to more readily detectable, human-caused mortality sources; Stevenson and Hatler (1985) include entire mountain caribou range, 1970-1982; Johnson (1985) based on Purcells-South and South Selkirks, 1967-1983
[6] excludes data listed in cited paper that is also reported in Johnson (1985), and data from legal hunts
[7] both grizzly kills, 1 each in Columbia-North and Columbia-South (R. Serrouya, consultant, unpubl. data)
[8] 1 calf each in Wells Gray (Furk 2003) and Hart Ranges or North Cariboo Mountains (D. Hamilton Nanuq Consulting Ltd., pers. comm.: attributed to D. King, formerly MWLAP)
[9] Columbia-North and Wells Gray (R. Serrouya, consultant, unpubl. data)
[10] Wells Gray; R. Serrouya, consultant, unpubl. data
[11] 2 from Hart Ranges (D. King, formerly MWLAP, pers. comm.; M. Nash, backcountry skier/reporter, pers. comm.) and 1 from Wells Gray (J. Surgenor, MWLAP, pers. comm.; Furk 2003)
[12] all in Wells Gray (R. Serrouya, consultant, unpubl. data)
[13] Barkerville subpopulation, 2002 (J. Young, MWLAP, pers. comm.)
[14] 3 from Highway 16 including Hart Ranges in 1994 (WARS) and North Cariboo Mountains in 1992 (WARS) and about 1999 (G. Watts, MWLAP, pers. comm); 1 in 2003 from Highway 26 in Barkerville (J. Young, MWLAP, pers. comm.); 1 from Highway 5 in Wells Gray subpopulation in 2002 (WARS); 4 from Columbia-South in 1992, 1994, 1996 and 2004 on highways 23 (2) and 1 (2), of which 1 was a calf and 1 was in poor body condition (J. Flaa, Parks Canada, pers. comm.; WARS); 5 on Highway 23 from Nakusp including 3 hit by transport truck in 1997 (D. Hamilton, Nanuq Consulting Ltd, pers. comm.) and 2 hit in 1996 (WARS); 2 from South Selkirks hit on Highway 3 including 1 in 1994 (WARS) and 1 in 2003 (G. Woods, MWLAP, pers. comm.) *WARS = Ministry of Transportation Wildlife Accident Reporting System, © 2005 Province of British Columbia*
[15] some of these killed by snowplow, but not clear whether plow mounted on train or truck (along railway tracks so assumed to be train); also up to 6-8 more noted as being absent after train collision, but no specific collision identified
[16] Columbia-South subpopulation in 1998 (J. Flaa, Parks Canada, pers. comm.)
[17] South Selkirks about 1997; antler caught in smooth-wire fence (W. Wakkinen, Idaho Dept. Fish and Game, pers. comm.)
[18] Almack (2000)
[19] fall in steep, rocky terrain in Groundhog (J. Flaa, Parks Canada, pers. comm.); was also in very poor condition (H. Schwantje, MWLAP, pers. comm.)
[20] avalanche: 2 in Wells Gray (D. Seip, MOF, pers. comm.); 1 in Nakusp (D. Hamilton Nanuq Consulting Ltd., pers. comm.)
[21] 1 of these also had severe parasitic infection (*Sarcocystis*)
[22] 1 in Groundhog (R. Serrouya, consultant, unpubl. data); 1 from Hart Ranges associated with an injury (D. Seip, MOF, unpubl. data)
[23] eartagged caribou translocated to Monashees-South but died in Columbia-South (J. Flaa, Parks Canada, pers. comm.)
[24] 0-11 of these due to predation; 0-3 due to malnutrition
[25] 1 suspected wolf predation in Hart Ranges (D. Seip, MOF, unpubl. data); 2 possible grizzly predation in Columbia-North and Columbia-South (R. Serrouya, consultant, unpubl. data); 1 each in Columbia-North, Frisby-Boulder and Wells Gray (R. Serrouya, consultant, unpubl. data)
[26] 1 in South Selkirks (J. Almack, Washington Department of Fish and Wildlife, pers. comm.); 2 in Purcells-Central (L. Ingham, Columbia Basin Fish & Wildlife Compensation Program, pers. comm.; J. Bergenske, Wildsight, pers. comm.) of which body condition may have contributed to 1 (H. Schwantje, MWLAP, pers. comm.)

BC indicates that densities and in some cases distributions of ungulates present within mountain caribou range have changed substantially from the mid 1800's to the present. Patterns in the mid 1800's may not have been consistent with those of even half a century prior (e.g. Spalding 1992). However, using the mid 1800's as a benchmark, elk, mule deer, white-tailed deer and moose all appear to have increased geographically, numerically, or both within mountain caribou range (Hatter 1950, Spalding 1990, 1992, 2000, MacDonald 1996, Demarchi 1999, Kinley 2002). Reasons likely vary among species and regions, but climatic change, natural or human-induced expansion of early-seral habitats, game-management laws and predator control up to the mid 1900's may have played roles. Regardless of the causes, obligate ungulate predators have almost certainly expanded their distributions or numbers as a result, including wolves (Seip 1992) and cougars.

Elk, moose and deer numbers also vary at much finer spatial and temporal scales. They can be influenced by hunting regulations and habitat quality, which can be altered substantially. For example, fires associated with early resource extraction and railroad construction dramatically increased early-seral habitat (MacDonald 1996). More recently, the great increase in logged areas within former old forests adjacent to Lake Revelstoke has been largely responsible for an increase in moose numbers from historic times to the present (Poole and Serrouya 2003) of perhaps 4 times (Messier et al. 2004) or greater (R. Serrouya, pers. comm.). Rempel et al. (1997) reported increasing moose populations where logging occurred but road densities did not increase sufficiently to enhance hunter access. Wallmo (1969) found mule deer to preferentially use cutblocks rather than mature subalpine forest. Thomas et al. (1979) considered landscapes with 60% foraging areas and only 40% cover to be optimal for deer and elk. Rettie and Messier (1998) attributed high predation among populations of the boreal ecotype of caribou to forest harvesting that enhanced habitat for moose, white-tailed deer, black bears and wolves. To the extent that resource management increases early-seral habitat, it can be expected that elk, moose and deer, and the wolves and cougars preying upon them, will benefit. Bears, with their more diverse diets, likely do not experience the same degree of benefit from enhanced ungulate numbers except where increased early-seral forest provides more plants eaten by bears. Wolverines probably also benefit less from higher ungulate numbers, as winter-killed or weakened ungulates generally occur in valley bottoms and are thus closer to human settlement, where wolverines are less common (Banci 1994, p. 100). This effect likely relates to the effect of trapping. Predation, hunting, and food limitations in relation to winter weather normally have more impact on ungulate populations than do potential summer food limitations (Bleich and Taylor 1998, Loison and Langvatn 1998, McCorquodale 1999, Bender et al. 2004). Thus, a greater numerical response is likely where early-seral conditions expand within ungulate winter range rather than summer range. Summer-range enhancement is more likely to result in shifts in distribution. As detrimental as high numbers of other prey may be to caribou, reductions in them may result in even higher short-term caribou predation rates. A rapid decline in the availability of prey other than caribou may increase individual foraging effort of predators and therefore their relative encounter rate with caribou, leading to increased caribou mortality (Rettie and Messier 1998) until predator numbers also adjust downward.

Predator hunting and trapping, as managed through harvest regulations, are the most common tools to directly regulate predator numbers ("predator management"). "Predator control", i.e. the killing of predators by government employees or contractors or via a bounty system to achieve immediate reductions in predator populations, is another tool, though rarely used. In practice, there are often significant limitations to increasing harvest or introducing predator control.

Wolves are the major predator of woodland caribou across Canada (Thomas 1995). This holds true within the northern portion of mountain caribou range (Wittmer 2004). Overall, 25% of known-species predation among collared caribou has been by wolves (Table 5). Predation by wolves has been particularly noted as contributing to caribou predation in the Quesnel Highlands (Hebert 1987, Seip 1992, Youds and Roorda 2001). Concern has been raised over apparently large recent increases in wolf numbers in the Revelstoke area, and liberalizing the wolf seasons there has been recommended (Messier et al. 2004). However, wolf hunting bag limits already vary regionally from 2 to 3 and trapping seasons extend for the entire winter throughout mountain caribou range. There is some evidence to suggest that there is not sufficient opportunity or interest for such actions to significantly reduce wolf numbers except where wolves become concentrated during winter in areas where hunters are abundant, as in the southern Rocky Mountain Trench (G. Woods, MWLAP, pers. comm.). Control of wolves through sterilization and killing has been undertaken in several situations, most recently in the Quesnel Highlands (Youds and Roorda 2001). In that case, concern over public reaction resulted in modifications to the control program, and lack of funding eventually ended it.

Cougar predation has been most significant at the southern end of mountain caribou range (Kinley and Apps 2001, Katnik 2002, Wittmer 2004) and has accounted for 35% of known-species predation of collared caribou (Table 5). This figure may not be representative of mountain caribou as a whole due to the longer history of monitoring in the South Selkirks subpopulation, where most cougar mortalities have been reported. It appears that unsustainable levels of caribou mortality were associated with a spike in cougar numbers in the South Selkirks and South Purcells subpopulations during the 1990’s, which may have been at least partly related to the introduction of a female quota in 1986. The reduction in cougar numbers at the end of the 1990’s (Figure 11) corresponded to the stabilization of the South Purcells subpopulation (Kinley 2002; Kinley 2004), although a conclusive cause-and-effect relationship has not been established. While the amplitude of cougar population change may not be as great as that of non-hunting cougar kills, Figure 11 does indicate that dramatic changes in cougar populations can occur over short periods. The decline in cougar numbers appears to have been achieved through relatively liberal hunting regulations and in conjunction with declining populations of elk and deer. Except at the northern fringe of cougar range, 2004/2005 bag limits in regions where cougars and caribou overlap are 1 to 2 cougars (plus a total female quota of 20 in the East Kootenay). There is no trapping season for cougars. Hunting has been an effective tool for cougar population reduction in the southern Kootenays, where there is a long tradition of hunting them with hounds, public land on ungulate winter ranges is widespread, and road access for hunters is good. However, this combination of factors may not be in place elsewhere, particularly as cougar distribution has spread northward into areas where they were formerly rare, such as Revelstoke (B. McLellan, MOF, pers. comm.) and the Robson Valley (G. Watts, MWLAP, pers. comm.).

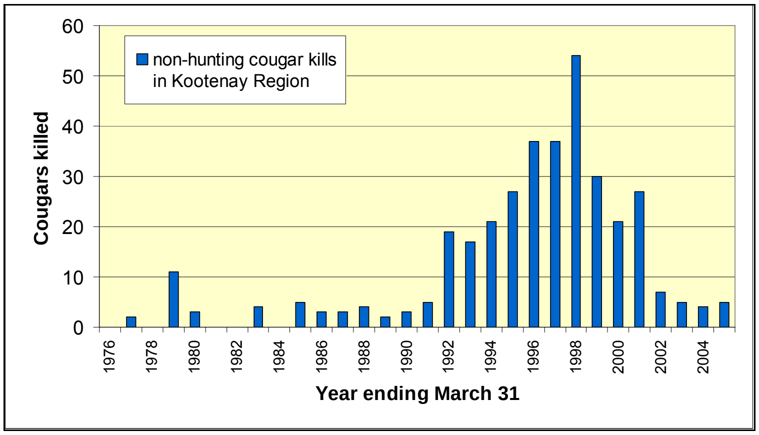

Figure 11. NonNon-hunting cougar kills (mainly problem animal control) in the Kootenay region as an index of total cougar population. These data are assumed to not be influenced within any given year by hunting regulations or hunter effort. (Data source: MWLAP)

Wolverines have killed 8% of collared mountain caribou whose predator was known (Table 5), with all recorded kills in the southern end of mountain caribou range (Wittmer 2004). It is almost certain that kills also occur nearer the northern limit of mountain caribou, because wolverines have been recorded as predators of the northern ecotype of caribou (G. Mowat, Aurora Wildlife Research, pers. comm.). Wolverines appear to have declined due to human impacts, particularly in the south (Weir 2004), so there is no evidence to suggest that their effect on mountain caribou is greater now than historically. Within mountain caribou range, there is no wolverine hunting season in the Cariboo or Thompson regions, and there is a bag limit of 1 elsewhere. Trapping is legal throughout the range. Options to increase wolverine trapping through longer seasons would be strongly limited by the species' blue-listed status in British Columbia.

Bears (black and grizzly) have been the identified predator in 32% of collared mountain caribou kills where the predator species was known (Table 5) with no obvious difference between northern and southern portions of caribou range (Wittmer 2004). These species are combined as it is not always possible to distinguish evidence of one from the other at kill sites. As with wolverines, grizzlies are thought to have similar to lower populations relative to historic times (Demarchi 1999) and are blue listed, so management aimed at reducing their densities would be unlikely. Currently, there is no trapping season for grizzlies and hunting is on a limited-entry basis. In contrast, black bears are abundant and widespread, and within the Southern Interior Mountains ecoprovince have increased since historical times (Demarchi 1999). The current black bear hunting bag limit within mountain caribou range is 2, and there is also a trapping season in the Cariboo and Omineca regions. The impediments to potentially limiting black bear numbers are not rarity but their ecological resilience and the limited number of bear hunters.

Other ecotypes or subspecies of caribou have been killed by golden eagles, (Adams et al. 1995, Crete and Desrosiers 1995, Valkenburg et al. 2004), lynx (Bergerud 1971, Valkenburg et al. 2004) and coyotes (Crete and Desrosiers 1995, Valkenburg et al. 2004). Bobcats overlap with mountain caribou in the south and occasionally occur in the subalpine (Kinley 1992, Apps 1996). As generalist predators similar in size to lynx, they may occasionally kill caribou calves as well. The relative importance to mountain caribou conservation of each of these species' is not known.

Spatial and Temporal Overlap of Predators with Caribou

Caribou predation rates depend not only on raw predator numbers but also on the spatio-temporal overlap of caribou and predators. Mountain caribou behavior may be driven to a larger extent by a need to occur where predators are scarce than by the pressure to maximize foraging opportunities. At an evolutionary scale, the adaptation to a lichen diet allows caribou to live where other ungulates are rare (Thomas 1995). In the case of mountain caribou, this places them during late winter in subalpine forests, when elk, deer and moose are generally located in valley bottoms. The short duration or complete lack of time spent by mountain caribou at low elevations, even where spring or early-winter forage may be best there, likely reflects the importance to caribou of being separated from more abundant ungulates and their predators. Woodland caribou diminish their overlap with predators during calving by using habitats not favored by other ungulates, including rugged mountains, shorelines, island and wetlands, or simply dispersing over wide areas (summary in Cumming et al. 1996 pp. 81-82). Cumming et al. (1996) found caribou in Ontario to have an inverse winter distribution to that of moose, even in the face of moose distribution shifting annually. McLoughlin et al. (2005) noted a higher mortality rate for boreal caribou selecting uplands, where the primary prey for wolves is more common, rather than peatlands. They also found that almost all caribou avoided uplands despite the food sources there. James and Stuart-Smith (2000) found every wolf-killed caribou died closer to a linear corridor than its mean live-location distance from those corridors. In the Purcell Mountains, caribou mortality sites occurred disproportionately in landscapes with abundant roads, logged areas and young forest, relative to locations of live animals (Kinley and Apps 2001; T. Kinley, Sylvan Consulting Ltd., unpublished data). This was true for broad through fine spatial scales. Kuzyk (2002) found wolves to select cutblocks over forest. Rettie and Messier (2000, 2001) noted that broad-scale movements and habitat selection of caribou appeared to result from an avoidance of disturbed areas having high predation risk, whereas finer-scale selection reflected a focus on forage. Smith et al. (2000) and Cumming and Beange (1993) noted avoidance of logged areas. Oberg (2001) recorded avoidance of areas adjacent to streams and roads and found caribou more likely to be near older than younger seismic lines. Smith (2004) found populations with expanding logging and oil and gas exploration activity to be in decline and attributed this in part to enhanced predation rates caused by the activities. Weclaw and Hudson (2004) predicted significant caribou declines in boreal forest with industry-caused forest fragmentation, both due to predation and independent of it.

At broad scales (home ranges, herd ranges, possibly historic ecotype ranges) it is evident that (a) caribou predation risk is higher when they overlap with predators, (b) caribou populations overlapping more with predators tend to decline, and (c) caribou distribute themselves to avoid high-predation risk areas (either by intent or as the default of variable predation rates). What is not clear is whether there is a lower limit to the scale at which avoidance of predator-dense areas is effective in minimizing predation risk. Given the mobility of predators, the question is "how small can low-prey patches be and still allow caribou to reduce their mortality risk by selecting them"? This question has significance for predicting the effect of forest management strategies. Forage for elk, moose and deer can be enhanced for years to decades by logging old subalpine forest, and this enhancement has the potential to significantly shift the distribution of those species. For example, Wallmo (1969) showed a tripling of mule deer activity in subalpine cutblocks relative to adjacent old forest. Ungulates that depend primarily on early-seral conditions do occur in old forests, but at a lower density than in disturbed, forage-rich areas (such as cutblocks, burns, avalanche paths and meadows). Presumably there is a gradient when moving from forage sources into intact older forest along which the density of early-seral ungulates declines. Optimal foraging theory suggests that predators dependent on those ungulates would also occur predominantly near them and therefore be less common in older forest, particularly portions of it farther from disturbed sites. This would therefore make areas farther from disturbances safer for caribou. Blocks of old forest at the scale of tens to hundreds of km^2 separated from heavily disturbed areas by tens of km undoubtedly provide relatively low-predation-risk refugia for caribou. However, when a landscape is a fine-grained mosaic of old forest, cutblocks and natural disturbances, the refuge provided to caribou by old forest patches may be minimal in light of the use (albeit less than in cutblocks) by elk, deer, moose and their predators of those forests and the occasional forays of caribou into disturbed sites. For example, Katnik (2002) investigated cougar predation in a relatively fragmented ecosystem in which caribou formed only a minor portion of the total prey biomass. Those cougars that were selective of habitat at a patch scale chose deer habitat and selected neither for nor against caribou habitat, yet cougars selected caribou habitat (along with that of deer) at a landscape scale. Wittmer (2004) found caribou demography to be more influenced by amount, rather than distribution, of forest age classes. Future analyses may more clearly indicate the variability in predation risk in relation to the scale of separation between cutblocks and old-forest caribou habitat, but estimates of the effect size of manipulating “grain size” through forest management practices currently depend upon professional judgment. At present, it can only be said that any disturbances within mountain caribou range that enhance forage for other ungulates are likely to have an incrementally negative effect on caribou survivorship, and the more uniformly these are distributed throughout caribou range, the fewer the opportunities for caribou to occur within low-risk patches and the smaller the benefit of occurring within them.

Key Ecological Correlates Relating to Predation Risk

Based on the above, measurable variables that influence or index the likelihood of caribou predation risk include:

- number of wolves, cougars, wolverines, black bears and grizzly bears within mountain caribou range, if known
- habitat suitability (or lacking that, capability) of those predators for which it is mapped (grizzly bears, black bears)
- harvest levels on predators, including hunting for wolves, cougars, wolverines, black bears and grizzly bears and trapping for wolves, wolverines and black bears
- number of moose, elk, white-tailed deer and mule deer within mountain caribou range, if known
- habitat suitability (or lacking that, capability) for moose, elk, white-tailed deer and mule deer within or adjacent to mountain caribou range; may be partially defined by winter range map designations
- degree of spatial and temporal overlap between caribou habitat and that of moose, elk, white-tailed deer and mule deer, particularly as influenced by the presence of early-seral forage in cutblocks, burns, avalanche paths and meadows

- number of linear corridors (including cutblock edges) providing enhanced predator hunting ability
- mortality of moose, elk, white-tailed deer and mule deer from hunting and winter conditions.

Other Mortality Causes

While predation is the single greatest known cause of mortality among collared mountain caribou, 17% of known-cause mortalities were attributed to falls and avalanches, 12% to poor body condition (malnutrition), 4% to shootings, 2% to research-related causes, 2% to vehicle collisions, and 1% to calving complications (Table 5). In addition, there are many reports from non-collared animals of illegal shooting, apparently both intentionally and as mistaken-identity killings (particularly up to 1983), and vehicle or train collisions, as well as a few deaths from each of unknown causes, predation, falls or avalanches, research-related causes, and malnutrition (Table 5). The low predation rate reported for animals without collars no doubt relates to the low likelihood of such animals being detected. No mortalities were directly attributed to disease or parasites, but they may have contributed to some. Though there are historic reports of mountain caribou dying from what may have been disease (Spalding 2000), there do not presently appear to be any significant mortality threats from parasites and disease (Cichowski et al. 2004).

Key correlates to these factors are not always clear. It is possible that some portion of accidents is the result of displacement of caribou from preferred habitat on gentle ground to steeper, more avalanche-prone terrain due to recreational activities (Simpson and Terry 2000). If this is the case, such mortality should be correlated to recreational activities such as snowmobiling, heli-skiing, cat-skiing and backcountry skiing. However, research has yet to confirm a clear short-term impact of such activities, much less identify particular patterns that might lead to displacement or demonstrate accidents that actually occur from it. Therefore, it can only be speculated that direct harassment of caribou may lead to a somewhat heightened risk of death through avalanches or perhaps falling in snow wells, and that risk levels would relate in a general way to levels of recreational activity to which caribou were not habituated. Avalanche kills also depend upon the presence of steep, avalanche-prone terrain adjacent to caribou early-winter, late-winter or spring habitat.

Vehicle collisions clearly are correlated to the presence of roads, and train collisions to the presence of railways. Where railways and major highways cross caribou ranges, such as portions of highways 1, 3, 5, 16 and 23, and adjacent railways. Roadkills have also occurred on forestry roads (Johnson 1985, Kinley and Apps 2001). Beyond the presence of roads and railways, correlates to mortality risk likely include traffic volume, use of salt on roads (caribou habitually lick salt on Highway 3 at Kootenay Pass), speed limits, and road alignment. The exact manner by which such factors can be used to predict mortality is unknown.

Illegal shooting can probably be best correlated to access (road density) within summer and early-winter habitat. The number of hunters is likely also a factor, and in turn is probably best correlated to number of ungulates, particularly elk and mule deer which are the most similar in appearance to caribou.

It is not known which factors have led to reported cases of mortality caused by malnutrition. It is generally believed that mountain caribou densities are far below forage carrying capacity for any season, and caribou are highly mobile so should be able to reach available food sources. It is possible that many reported cases relate to abnormal snow conditions, old age, diseases, injuries or parasitism, none of which are factors that can be readily predicted and modeled spatially. Weclaw and Hudson (2004) predicted significant reductions in forage-based caribou carrying capacity in Alberta due to displacement by industrial activity.

Deaths due to research activities are obviously best predicted by whether research is occurring within a subpopulation.

Modeling Caribou Mortality

1. Modeling Predator-prey Mortality Rates for Multiple Species

Prey mortality was estimated using the following multi-species disc equation:

$$N_{ai} = \frac{a_i T_t N_i}{1 + \sum_j a_j h_j N_j},$$

Equation 1

where

N_{ai} = the number of successful attacks per unit time period (e.g., day) for prey type i

$a_{i=}$ rate of effective search for prey type i. (area searched per day * probability of recognizing and successful killing each prey encountered)

T_i = amount of time/day spent searching (sum of searching time and handling time)

N_i = average prey density of prey type i in the area searched.

h_j = handling time for prey species i (mean time for handling each prey item, e.g., pursuit, capture, manipulation, rest when gut is full).

Initiating the disc equation requires the combination of a number of aspatial parameter estimates, a predator search rate adjustment (PSRA), combined annual mortality (CAM) from grizzly and wolverine, expected caribou density (ECD), and ungulate range density (URD).

1.1. Aspatial Parameter Estimation

Specification of aspatial parameters (i.e., search rate and density of prey are estimated by spatially-explicit BBNs) are provided in Appendix B. Given the large body of literature on ecology of wolf-ungulate population dynamics, estimates for most of the required parameters were available for wolves. Parameter estimates for other predator species were estimated based on best available information primarily through consultation with experts. Each parameter was associated with a variance so that sensitivity analysis could be conducted to evaluate effects of parameter uncertainty on model results.

The probability of successful attack was estimated from reported rates of successful attack. For example, wolves killed 6 of 131 moose detected on Isle Royale where moose were the primary prey (Mech 1970); which translates into a probability that a kill will occur given an encounter of 0.046 for moose hunted by wolves (n.b., this is only an example where actual parameters were based on a review by the Science Team). If we assume wolves are 4 times more likely to successfully attack a deer than a moose, and 6 times more likely to attack and kill a caribou, then kill rates for deer and caribou can be computed relative to moose (e.g., 0.183 and 0.275, respectively). Values vary by season in some cases.

Food Units: This is the amount of food (kg) provided by each prey species, base on an average-sized individual of an "average" age and sex class.

Handling Time: The food units for each prey species are divided by the amount of food consumed daily by an individual of each predator species after making a kill. Thus, handling time is a function of both prey species and predator species. When the handling time is completed, it is assumed that predators immediately begin searching for more prey.

Stochastic Effects on Prey Density: Snow conditions within a "normal" range of variability are assumed to have no impact on ungulate numbers. However, there are periodically years when snow accumulation patterns have a particularly strong impact on the ability of caribou to obtain forage, and in which it is assumed that caribou survivorship is affected. The frequency of such winters is assumed be normally distributed around a mean interval. The model therefore periodically selects a winter in which to decrease prey survivorship by a set percentage, independent of the effects of other mortality sources.

Background Food Availability: All predators have sources of food other than the ungulates listed in the model. Among other things, these include other species of ungulates, berries, roots, fish, rodents and hares, depending on the predator species. For each planning area, each predator is assigned a constant food-unit equivalent from such sources, which acts to dampen the effect of changes in densities of moose, caribou, deer and elk.

1.2. Predator Search Rate Adjustment (PSRA)

Rate of effective search (i.e., ai in Equation 1) was the product of area searched per day and the probability of successful attack (rates of attack). Area searched per day was estimated from the product of predator movement rates (km/day) and search path width or detection distances. For example if we assume a search path width of 0.15 km in forested areas, and that wolves travel 12 km/day when hunting (James 1999), we obtain a daily search area of 1.8 km2. The default parameter (Appendix B) was varied according to a combined density of linear features (CDLF), season (S), and macro-climate-snowfall (MCSF; see Inherent Range Quality 1.2.4.1); the latter being the same node as used elsewhere in the inherent range BBNs (Figure 12).

1.2.1. Combined Density of Linear Features (CDLF))

This summary node was influenced by the spatial density of roads (DR) and, during winter, spatial density of rivers (DRIV)

1.2.1.1. Density of Roads (DR)

Areas with higher densities of the linear features were presumed to allow predators, especially wolves, to search larger areas. We placed a 100m buffer on all roads, including logging spur roads, and then used a 82 ha nearest neighbor analysis to summarize the amount of area within 100m of a road. We considered predation search rates to be enhanced if >20 of the 82 ha was within 100m of a road.

1.2.1.2. Density of Rivers (DRIV)

In winter when rivers are frozen, predators can use these areas to enhance their search rates in a similar fashion as roads. We preformed a similar analysis of rivers (as was done with roads) and rated areas with >20 ha of the 82-ha analysis window within 100m of river as higher search rates adjustment.

1.2.2. Season (S)

Season was just a switch between summer and winter to modify the availability of frozen rivers for predators to travel on.

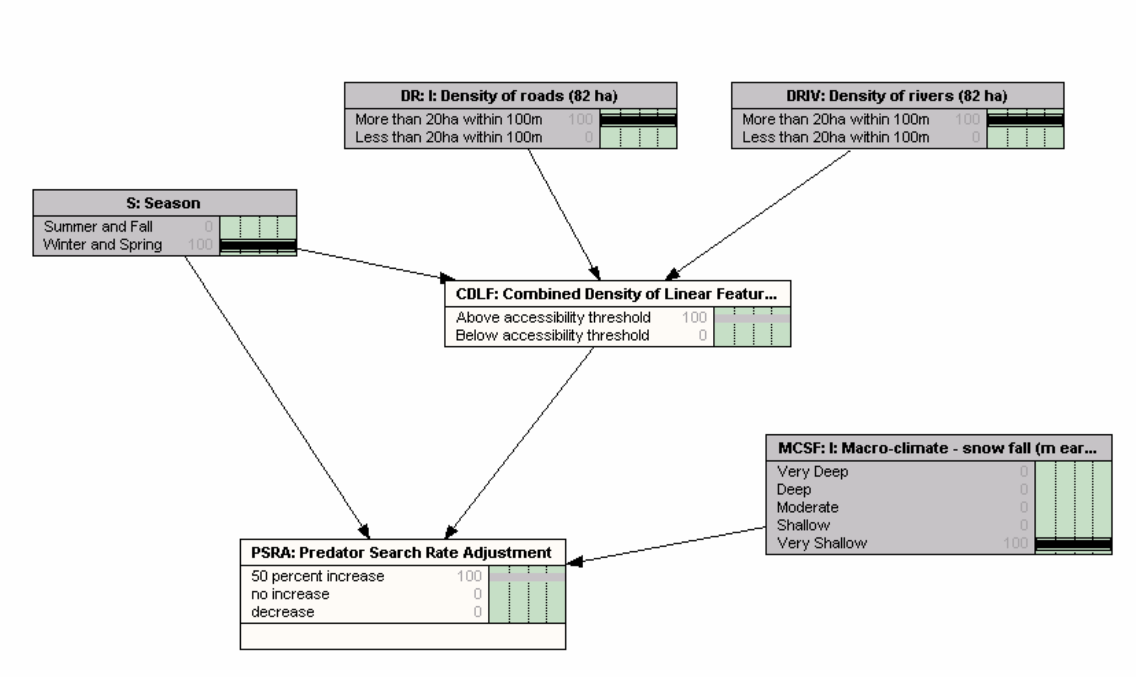

Figure 12. A Bayesian belief network used to predict a predator search rate adjustment for predators (cougars and wolves) seeking prey in southeastern British Columbia.

1.3. Combined Annual Mortality (CAM) From Grizzly and Wolverine

While mortality from wolves and cougars was modeled within the multi-species disc equation, we did not add this level of dynamics in the case of bears and wolverine. Many factors other than caribou, or ungulates generally, influence population status of bears and wolverine. Rather for these species we established a combined annual mortality rate (CAM) due annual mortality from Urar (AMU) and annual mortality from Gulu (AMG) (Figure 13).

1.3.1. Annual Mortality From Urar (AMU)

The annual mortality rate for caribou due to predation by grizzly was assumed to range from less than 5% to as high as 10% depending on density of grizzly bears (DGB) estimated for provincial bear population units, season (S), and status of hunting regulations (HE).

1.3.1.1. Density of Grizzly Bears (DGB)

We used estimates of habitat capability density (Hamilton et al. 2004) as an index to the likelihood of caribou being encountered and killed by grizzly bears.

1.3.1.2. Hunting Regulations (HR)

Hunting regulations was a management lever to allow for management of bear predation should that option become useful. For our model runs this lever was set to a state of standard regulations which was considered to have no effect on bear populations.

1.3.1.3. Season (S)

Season was used to allow grizzly bears to be more active predators during summer and fall while wolverine were more active predators during winter and spring.

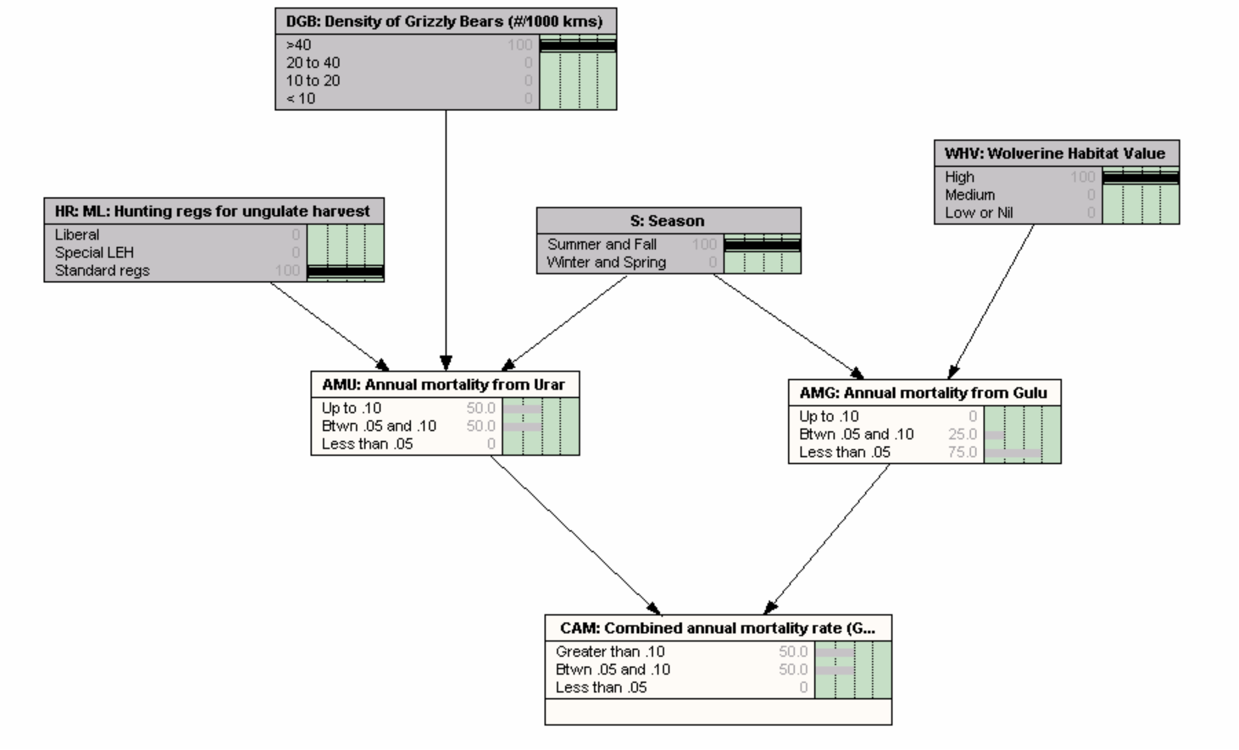

Figure 13. A Bayesian belief network used to predict the expected combined annual mortality rate on caribou due to grizzly bears and wolveries in southeastern British Columbia.

1.3.2. Annual Mortality From Gugu (AMG)

Annual mortality from wolverine was estimated based on <u>wolverine habitat value</u> (WHV) and <u>season</u> (S; see 1.3.1.3).

1.3.2.1. Wolverine Habitat Value (WHV)

Wolverine habitat value was mapped by Adams and Lofroth (2004). Their ratings of high, medium, or low (and nil) were used as a direct correlate of the likelihood of caribou being encountered and killed by wolverines.

1.4. Expected Caribou Density (ECD)

The ECD, in each of the 3 seasons modeled, was based on <u>seasonal forage usefulness</u> (SFU; see Inherent Range Quality 1., 2., 3., 4.) modified by the <u>population fragmentation constraint</u> (PFC; see Landscape Level Considerations) and by the <u>combined expected displacement</u> (CED; see Expected Displacement Factors) (Figures 3-8). The expected caribou density was calculated in a way that allowed for translation of the forage values at the AAF node into the expected number of animals/1000 km^2. We assumed animal proportional unit months (AUMs) for each species where forage for a full AUM was 360 kg on a range being used for 4 months and with forage being 50% utilized (Table 6).

Table 6. Estimated gross forage requirements assumed to support varying densities of selected ungulates in southeastern British Columbia.

Species	*Population Rating*	*Density/km2*	*Number per 1000km2*	*Animal Unit Months*	*Required Forage[a] (kg/ha)*	*Gross Forage[b] (kg/ha)*
Deer	High	50	50000	0.05	36	72
	Moderate	25	25000	0.05	18	36
	Moderate	12.5	12500	0.05	9	18
	Low	6.25	6250	0.05	5	9
Elk	High	16	16000	0.33	76	152
	Moderate	8	8000	0.33	38	76
	Moderate	4	4000	0.33	19	38
	Low	2	2000	0.33	10	19
Moose	High	12	12000	0.4	69	138
	Moderate	6	6000	0.4	35	69
	Moderate	3	3000	0.4	17	35
	Low	1.5	1500	0.4	9	17
Caribou	High	0.2	200	0.25	0.72	1.44
	Moderate	0.1	100	0.25	0.36	0.72
	Moderate	0.05	50	0.25	0.18	0.36
	Moderate	0.025	25	0.25	0.09	0.18
	Low	0.0125	12.5	0.25	0.05	0.09

a - Assuming forage per AUM = 360 kg and time on range is 4 months

b - Assuming forage is accessible and 50% utilization.

1.5. Ungulate Range Density (URD)

The Ungulate Range Density (URD) was based on <u>ungulate species</u> (US), the <u>expected population impact</u> (EPI) from hunting regulations and the <u>seasonal forage</u>

usefulness (SFU) (Figure 14) where, similar to ECD (see 1.4), the density calculation was a translation of forage values (Table 6).

1.5.1. Expected Population Impact (EPI)

The EPI was essentially a management lever allowing for the implementation of hunting regulations (HR) by ungulate species (US).

1.5.1.1. Hunting regulations (HR)

Under normal conditions where hunting is permitted on ungulates the goal is to allow a harvestable surplus with little to no impact on the overall population. Hunting has also been recognized as an important, although recently controversial; tool to manage ungulate populations to desired levels. This node allows for the opportunity to hunt ungulate populations although in our model runs we assumed “standard regulations” and no effect.

1.5.1.2. Ungulate Species (US)

Here we allow for regulated hunting to effect population sizes of moose, elk, white-tailed deer, and mule deer.

1.5.2. Seasonal Forage Usefulness (SFU)

The SFU for non-caribou ungulates in summer was modeled in essentially the same format as caribou (see Inherent Range Quality 4.; Figure 15). The SFU for non-caribou ungulates in winter was related to the energy cost of movement (NCM; see Inherent Range Quality 1.1), the interspersion of food and cover (IFC), and the abundance of available forage (AAF).

1.5.2.1. Interspersion of Food and Cover (IFC)

This node was not implemented in the current model run although the intent would be to modify forage values, increasing their value if close to cover.

1.5.2.2. Abundance of Available Forage (AAF)

The AAF was related to winter forage potential (WFP), snow accumulation (SA), and ungulate species (US; see 1.5.1.2).

1.5.2.2.1. Winter Forage Potential (WFP)

We classified winter forage into broad classes that can be generally related to preference by different ungulates. For example, we assumed moose generally tend to prefer tall shrubs compared to other ungulates. Similarly, although elk will and do forage on shrubs, they prefer and choose habitats based on a high component of grasses and forbs. Deer were assumed to prefer low shrubs and grasses. This is obviously a coarse classification but the resolution of the input data to describe understory vegetation was also coarse. Also, we considered this level of resolution adequate given our primary focus on estimating the effects that non-caribou ungulates would have on predators and ultimately predation rates on caribou. WFP was related to some of the same

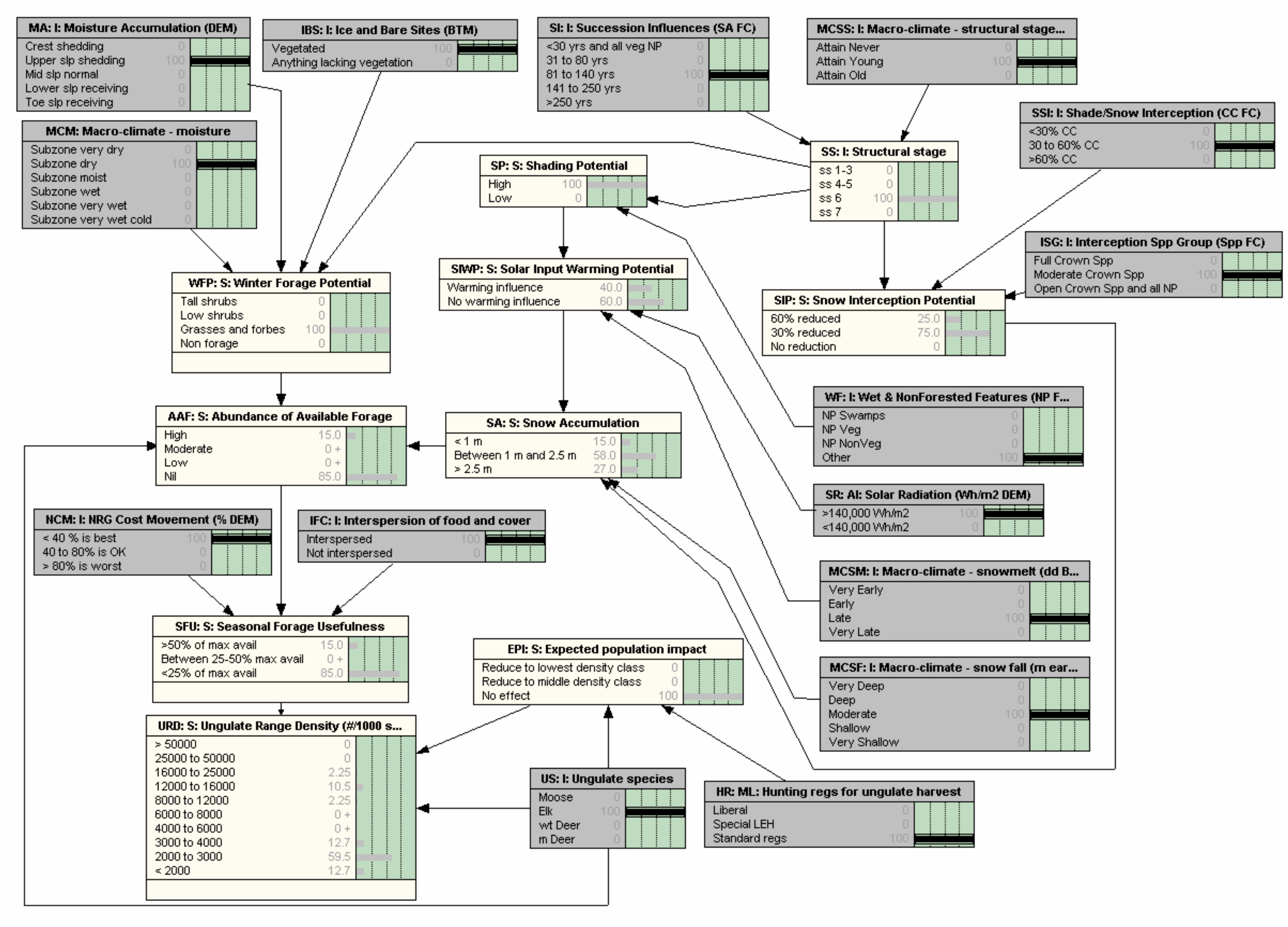

Figure 14. A Bayesian belief network used to predict the ungulate range density during winter for selected ungulates in southeastern British Columbia.

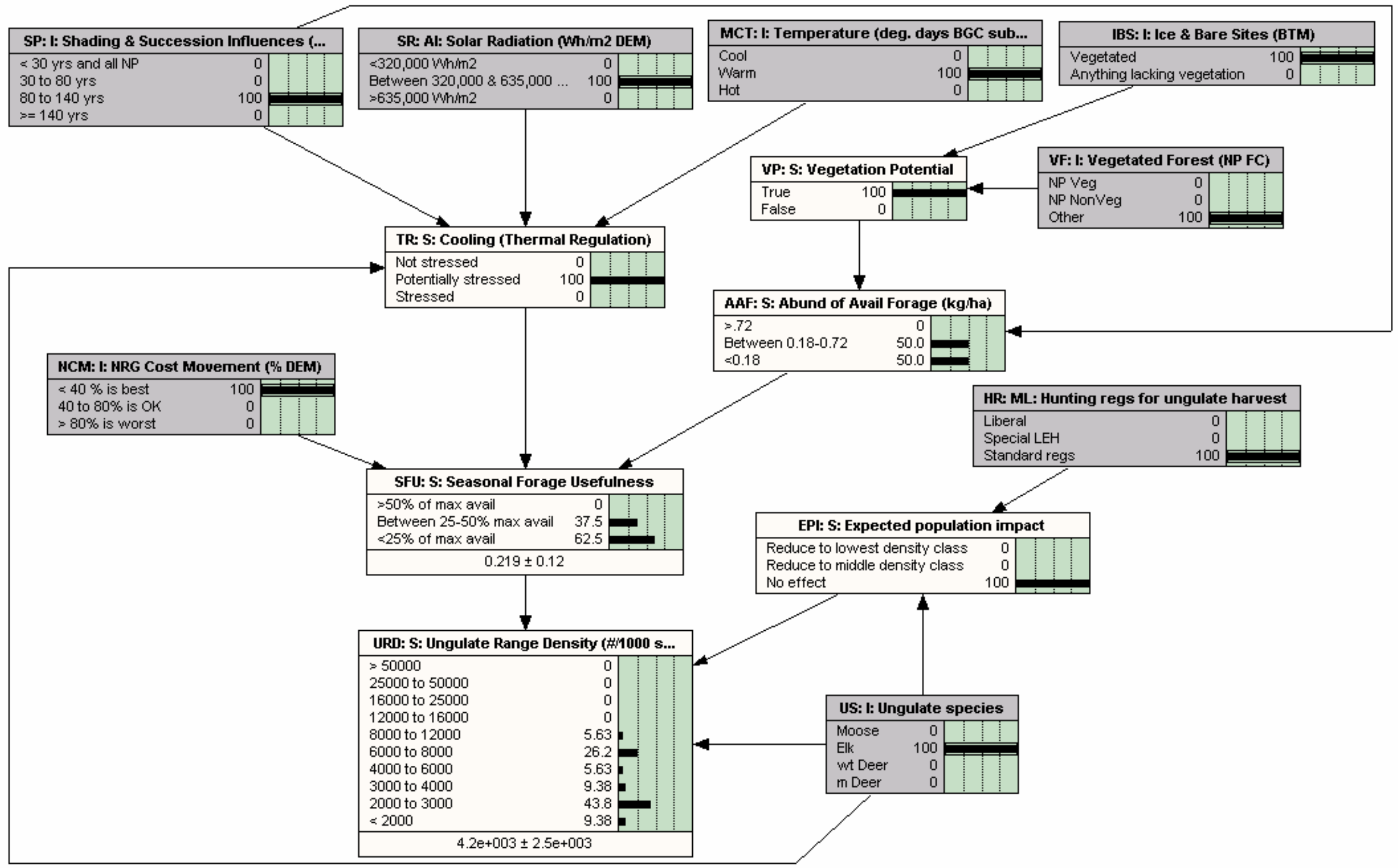

Figure 15. A Bayesian belief network used to predict the ungulate range density during summer for selected ungulates in southeastern British Columbia.

nodes used to establish forage potential for caribou: macro-climate-moisture (MCM; see Inherent Range quality 3.2.2.1), moisture accumulation (MA: see Inherent Range Quality 1.2.2.1.2), and ice and bare sites (IBS: see Inherent Range Quality 1.2.3.4). In this case we also included a new node structural stage (SS) to help differentiate forage for the different ungulate species.

1.5.2.2.1.1. Structural Stage (SS)

Structural stage was intended to capture the effects that forest structure has on potential for understory vegetation to occur in the broad states associated with the WFP node. SS was assumed to respond to forest age as characterized by the successional influences (SI: see Inherent Range Quality 1.2.1.1) node and macro-climate-structural stage (MCSS).

1.5.2.2.1.1.1. Macro-climate-Structural Stage

Biogeoclimatic zone/variants were rating according to the age at which they attained a multi-layered structure characteristic of old forests (Appendix A).

1.5.2.3. Snow Accumulation (SA)

Snow accumulation was used to reduce the abundance of different forage types from the WFP node depending on the ungulate species under consideration. Again, the resolution was kept fairly coarse in that we wanted to locate broad zones where snow accumulations would be relatively shallow (< 1m) where most forage types would be available and fairly deep (>2.5m) where most forage types would not be available. The SA node was influenced by macro-climate snowfall (MCSF; see Inherent Range Quality 1.2.4.1), solar input warming potential (SIWP), and snow interception potential (SIP).

1.5.2.3.1. Solar Input Warming Potential (SIWP)

SIWP was a summary node expressing the potential for physical factors to reduce snow accumulations through a climatic warming influence. The warming influence derived from macro-climate-snowmelt (MCSM: see Inherent Range Quality 3.2.1.2), solar radiation (SR: see Inherent Range Quality 3.2.1.1), and shading potential (SP).

1.5.2.3.1.1. Shading Potential (SP)

Shade potential served to reduce solar radiation as an input to climatic warming potential and was determined as a function of structural stage (SS: see 1.5.2.2.1.1) and vegetation class obtained from the wet and nonforested features (WF: see Inherent Range Quality 3.1.1) node.

1.5.2.3.2. Snow Interception Potential (SIP)

Snow interception to reduce snow accumulation was largely a function of the forest overstory characterized by structural stage (SS: see 1.5.2.2.1.1), shade/snow interception (SSI: see Inherent Range Qualty 1.2.3.3), and interception species group (ISG: see Inherent Range Quality 1.2.4.2.3)

2. Landscape Considerations for Non-caribou Ungulates

As with caribou, there are considerations of scale and landscape that must be taken into account for non-caribou ungulates. We did not want to model this level of detail as finely as for caribou so we simply allowed for non-caribou ungulates to migrate away from winter ranges in an idea-free manner (Fretwell 1972) and disperse themselves among summer range within the confines of the management unit.

3. Modeling Ungulate Population Dynamics

Annual recruitment for each ungulate prey species was computed as a function of recruitment (fecundity) and rates of mortality for each life stage of the species (provided as output from the disc equation) such that:

$$N_{i,t} = N_{i,t-1} + F_{i,t} - M_{i,t}$$

Equation 3

where

N is the total population size for prey species i at time t.

F is the number calves for prey species i produced at time t (number of adult females multiplied by maximum fecundity)

M is the total number of mortalities in all life stages for each prey species i at time t

4. Modeling Wolf and Cougar Populations

The start-of-season wolf and cougar density begins at model initiation with an estimate for each planning unit, and varies thereafter based on the results of the multi-species population model. Depending on species, predator management may include hunting, trapping and direct control activities. Predator management values are either determined on the basis of "occurring" (predator population is reduced to less than a predetermined cap for that season, currently < 5/1000km^2 for wolves) versus "not occurring" (no effect), or to vary along a gradient of hunting permits or regulations. It may vary spatially, with kill rates higher in areas with greater road densities. The densities of each prey species are as determined by the "above.

Wolf and cougar populations were assumed to increase linearly with increasing ungulate biomass. However with increasing prey densities, these predators undergo a functional response as the number of prey killed per individual increases with increasing rates of encounter (Fuller 1989; Seip 1995). Messier (1995) showed that wolf numbers follow a type 2 numerical response to increasing prey densities, and postulates that territorial behaviour of wolves may impose an upper limit on wolf numbers. We modeled predator population dynamics as a function of the annual incremental rate of increase and mortality rates output from the disc equation (converted to ungulate biomass). The model of annual incremental rates of increase in the predator population *r* is adapted from Weclaw and Hudson 2004, which was originally derived from Caughley and Sinclair 1994:

$$r = -a + \left(\frac{bc}{d + c} \right)$$

Equation 4

where

a is the maximum rate of decrease (value of r at zero food units)

b is the upper limit of r
c is ungulate biomass (kg biomass / km^2)
d is the level of food unit equivalents equal to half the asymptotic kill rate (kg/km^2)

Literature Cited

Adams, I., and E. Lofroth. 2004. Wolverine habitat capability mapping in British Columbia. British Columbia Ministry of Water, Land, and Air Protection, Victoria, BC 22pp.

Adams, L. G., F. J. Singer, and B. W. Dale. 1995. Caribou calf mortality in Denali National Park, Alaska. Journal of Wildlife Management 59:584-594.

Almack, J. A. 2000. Mountain caribou recovery in the southern Selkirk Mountains of Washington, Idaho, and British Columbia. Progress report October 1998 – March 2000. Washington Department of Fish and Wildlife, Olympia, Washington.

Apps, C. D. 1996. Bobcat (*Lynx rufus*) habitat selection and suitability assessment in southeast British Columbia. Thesis, University of Calgary, Calgary, Alberta.

Banci, V. 1994. Wolverine. Pages 99-127 *in*: L. F. Ruggiero, K. B. Aubrey, S. W. Buskirk, L. J. Lyon, and W. J. Zielinski, technical editors. The scientific basis for conserving forest carnivores American marten, fisher, lynx and wolverine in the western United States. General Technical Report RM-254, Rocky Mountain Range and Experiment Station, USDA Forest Service, Fort Collins, Colorado.

Bender, L. C., G. A. Schirato, R. D. Spencer, K. R. McAllister, and B. L. Murphie. 2004. Survival, cause-specific mortality, and harvesting of male black-tailed deer in Washington. Journal of Wildlife Management 68:870-878.

Bergerud, A. T. 1971. The population dynamics of Newfoundland caribou. Wildlife Monographs 25.

_____, 1978. The natural population control of caribou. Pages 14-61 *in*: F. L. Bunnell, D. S. Eastman, and J. M. Peek, editors. Symposium on natural regulation of wildlife populations. Proceedings No. 14, Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow, Idaho.

Bleich, V. C., and T. J. Taylor. 1998. Survivorship and cause-specific mortality in five populations of mule deer. Great Basin Naturalist 58:265-272.

Caughley, G., and A.R.E. Sinclair. 1994. Wildlife Ecology and Management. Blackwell Science. 305 pp.

Cichowski, D., T. Kinley, and B. Churchill. 2004. Caribou *Rangifer tarandus*. In: Accounts and measures for managing identified wildlife – accounts V. 2004. Ministry of Water, Land and Air Protection, Victoria, British Columbia.

Compton, B. B., P. Zager, and G. Servheen. 1995. Survival and mortality of translocated woodland caribou. Wildlife Society Bulletin 23:490-496.

Crete, M., and A. Desrosiers. 1995. Range expansion of coyotes, *Canis latrans*, threatens a remnant herd of caribou, *Rangifer tarandus*, in southeastern Quebec. Canadian Field-Naturalist 109:227-235.

Cumming, H. G., and D. B. Beange. 1993. Survival of woodland caribou in commercial forests of northern Ontario. The Forestry Chronicle 69:579-588.

_____, D. B. Beange, and G. Lavoie. 1996. Habitat partitioning between woodland caribou and moose in Ontario: the potential role of shared predation risk. Rangifer Special Issue 9:81-94.

Demarchi, D. N. 1999. Population trends of the big game species in British Columbia. Draft. British Columbia Wildlife Federation, Surrey, British Columbia, and British Columbia Conservation Foundation, Surrey, British Columbia.

Fretwell, S.D. 1972. Populations in a seasonal environment. Princeton Univ. Press, Princeton, N.J. 217pp.

Fuller, T.K. 1989. Population dynamics of wolves in north-central Minnesota. Wildlife Monographs 105: 41 pp.

Furk, K. 2003. North Thompson Caribou Project. Survival rates and sources of mortality for mountain caribou in the Clearwater forest district: preliminary report from telemetry data. Ministry of Water, Land and Air Protection, Kamloops, British Columbia.

Hatter, J. 1950. The moose of central British Columbia. Dissertation, State College of Washington, Pullman, Washington.

Hamilton, A.N., D.C. Heard, M.A. Austin. 2004. British Columbia grizzly bear (Ursus arctos) population estimate 2004. British Columbia Min. of Water, Land, and Air Protection, Victoria, BC 7pp.

Hebert, D. 1987. Quesnel Highlands wolf control project. Wildlife Working Report WR-26, Ministry of Environment and Parks, Williams Lake, British Columbia.

James, A.R.C. 1999. Effects of industrial development on the predator-prey relationship between wolves and caribou in northeastern Alberta. Ph.D. Thesis, University of Alberta, Edmonton Alberta. 70 pp.

James, A. R. C., and A. K. Stuart-Smith. 2000. Distribution of caribou and wolves in relation to linear corridors. Journal of Wildlife Management 64:154-159.

Johnson, D. R. 1985. Man-caused deaths of mountain caribou, *Rangifer tarandus*, in southeastern British Columbia. Canadian Field-Naturalist 99:542-544.

Katnik, D. D. 2002. Predation and habitat ecology of mountain lions (*Puma concolor*) in the southern Selkirk Mountains. Dissertation, Washington State University, Pullman, Washington.

Kinley, T. A. 1992. Ecology & management of bobcats (*Lynx rufus*) in the East Kootenay district of British Columbia. Thesis, University of Calgary, Calgary, Alberta.

_____. 2002. Background information for public consultation regarding the proposed translocation of caribou from the Itcha-Ilgachuz Mountains to the southern Purcell Mountains. Prepared by Sylvan Consulting, Ltd., Invermere, British Columbia. Columbia Basin Fish and Wildlife Compensation Program, Nelson, British Columbia, and Ministry of Water, Land and Air Protection, Nelson, British Columbia.

_____. 2004. 2004 population survey for the South Purcell subpopulation of mountain caribou. Prepared by Sylvan Consulting Ltd., Invermere, British Columbia. Columbia Basin Fish and Wildlife Compensation Program, Invermere, British Columbia.

_____, and C. D. Apps. 2001. Mortality patterns in a subpopulation of endangered mountain caribou. Wildlife Society Bulletin 29:158-164.

Kuzyk, G. W. 2002. Wolf distribution and movements on caribou ranges in west-central Alberta. Thesis, University of Alberta, Edmonton, Alberta.

Loison, A., and R. Langvatn. 1998. Short- and long-term effects of winter and spring weather on growth and survival of red deer in Norway. Oecologia 116:489-500.

MacDonald, G. A. 1996. Caribou and human agency in the Columbia Mountains. Parks Canada, Calgary, Alberta.

McCorquodale, S. M. 1999. Movements, survival, and mortality of black-tailed deer in the Klickitat Basin of Washington. Journal of Wildlife Management 63:861-871.

McLoughlin, P. D., J. S. Dunford, and S. Boutin. 2005. Relating predation mortality to broad-scale habitat selection. Journal of Animal Ecology 74:701-707.

Mech, L.D. 1970. Wolf Ecology and Management of an Endangered Species. University of Minnesota Press. 384 pp.

Messier, F. 1985. Solitary living and extraterritorial movements of wolves in relation to social status and prey abundance. Can. J. Zool., 63: 239-245.

_____, S. Boutin, and D. Heard. 2004. Revelstoke mountain caribou recovery: an independent review of predator-prey-habitat interactions. Revelstoke Caribou Recovery Committee, Revelstoke, British Columbia.

MCTAC. 2002. A strategy for the recovery of mountain caribou in British Columbia, version 1.0. Ministry of Water, Land and Air Protection, Victoria, British Columbia.

Oberg, P. R. 2001. Responses of mountain caribou to linear features in a west-central Alberta landscape. Thesis, University of Alberta, Edmonton, Alberta.

Poole, K. G., and R. Serrouya. 2003. Moose population monitoring in the Lake Revelstoke valley, 2002-2003. Prepared by Aurora Wildlife Research, Nelson British Columbia. Downie Street Sawmills Ltd., Revelstoke, Wood River Forest Inc., Revelstoke, Joe Kozek Sawmills Ltd., Revelstoke, Columbia Basin Fish and Wildlife Compensation Program, Nelson, and Mount Revelstoke and Glacier National Parks, Revelstoke, British Columbia.

Rempel, R. S., P. C. Elkie, A. R. Rodgers, and M. J. Gluck. 1997. Timber-management and natural-disturbance effects on moose habitat: landscape evaluation. Journal of Wildlife Management 61:517-524.

Rettie, W. J., and F. Messier. 1998. Dynamics of woodland caribou populations at the southern limit of their range in Saskatchewan. Canadian Journal of Zoology 76:251-259.

_____, and F. Messier. 2000. Hierarchical habitat selection by woodland caribou: its relationship to limiting factors. Ecography 23:466-478.

_____, and F. Messier. 2001. Range use and movement rates of woodland caribou in Saskatchewan. Canadian Journal of Zoology 79:1933-1940.

Russell, J., R. A. Demarchi, and H. R. Jamieson. 1982. Mountain caribou in the Kootenay region. Ministry of Environment, Cranbrook, British Columbia.

Seip, D. 1991. Predation and caribou populations. Rangifer Special Issue 7:46-52.

_____. 1992. Factors limiting woodland caribou populations and their interrelationships with wolves and moose in southeastern British Columbia. Canadian Journal of Zoology 70:1494-1503.

_____. 1995. Introduction to Wolf-Prey Interactions. Ecology and conservation of wolves in a changing world. L. N. Carbyn, S. H. Fritts, D. R. Seip, eds. Canadian Circumpolar Institute, University of Alberta. 620 pp.

Simpson, K., and E. Terry. 2000. Impacts of backcountry recreation activities on mountain caribou. Wildlife Working Report No. WR-99, Ministry of Environment, Lands and Parks, Victoria, British Columbia.

Smith, K. G. 2004. Woodland caribou demography and persistence relative to landscape change in west-central Alberta. Thesis, University of Alberta, Edmonton, Alberta.

_____, E. J. Ficht, D. Hobson, T. C. Sorensen, and D. Hervieux. 2000. Winter distribution of woodland caribou in relation to clear-cut logging in west-central Alberta. Canadian Journal of Zoology 78:1433-1440.

Spalding, D. J. 1990. The early history of moose (*Alces alces*): distribution and relative abundance in British Columbia. Contributions to Natural Science No. 11, The Royal British Columbia Museum, Victoria, British Columbia.

_____. 1992. The history of elk (*Cervus elaphus*) in British Columbia. Contributions to Natural Science No. 18, The Royal British Columbia Museum, Victoria, British Columbia.

_____. 2000. The early history of woodland caribou (*Rangifer tarandus caribou*) in British Columbia. Wildlife Bulletin No. B-100, Ministry of Environment, Lands and Parks, Victoria, British Columbia.

Stevenson, S. K., and D. F. Hatler. 1985. Woodland caribou and their habitat in southern and central British Columbia. Land Management Report No. 23, Ministry of Forests, Victoria, British Columbia.

Thomas, D. C. 1995. A review of wolf-caribou relationships and conservation implications in Canada. Pages 261-273 *in*: L. N. Carbyn, S. H. Fritts, and D. R. Seip, editors. Ecology and conservation of wolves in a changing world. Proceedings of the Second North American Symposium on Wolves, Edmonton, Alberta, 25-27 August 1992. Occasional Paper No. 35, Canadian Circumpolar Institute, Edmonton, Alberta.

Thomas, D. C., and D. R. Gray. 2002. Update COSEWIC status report on the woodland caribou *Rangifer tarandus caribou* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, Ontario.

Thomas, J. W., H. Black Jr., R. J. Scherzinger, and R. J. Pederson. 1979. Deer and elk. Pages 104-127 *in*: J. W. Thomas, technical editor. Wildlife habitats in managed forests. The Blue Mountains of Oregon and Washington. USDA Forest Service Agriculture Handbook No. 553.

Valkenburg, P., M. E. McNay, and B. W. Dale. 2004. Calf mortality and population growth in the Delta caribou herd after wolf control. Wildlife Society Bulletin 32:746-756.

Wallmo, O. C. 1969. Response of deer to alternate-strip clearcutting of lodgepole pine and spruce-fir timber in Colorado. USDA Forest Service Research Note RM-141.

Weclaw, P., and R. J. Hudson. 2004. Simulation of conservation and management of woodland caribou. Ecological Modelling 177:75-94.

Weir, R. D. 2004. Wolverine *Gulo gulo*. In: Accounts and measures for managing identified wildlife – accounts V. 2004. Ministry of Water, Land and Air Protection, Victoria, British Columbia.

Wittmer, H. U. 2004. Mechanisms underlying the decline of mountain caribou (*Rangifer tarandus caribou*) in British Columbia. Dissertation, University of British Columbia, Vancouver, British Columbia.

Youds, J., and L. Roorda. 2001. Proposal to temporarily reduce wolf population density in the Quesnel Highland-Cariboo Mountains, Cariboo region: a project to aid in the recovery of the red-listed mountain caribou. Ministry of Water, Land and Air Protection, Williams Lake, British Columbia.

STATUS OF MODELING – SCOTT MCNAY

The complete HSM for mountain caribou was run during August 2005 as a trial to test integrity of the modeling framework and to provide data for the Science Team to review. This was an alpha-level run of the model with some linkages among nodes defined without Science Team input (i.e., uncalibrated).

Logistics

For this test run, we used one simulation of three disturbance scenarios (i.e., conditions under assumed patterns of natural disturbance, potential range, and current range) for each of the 16 BBNs (i.e., four caribou seasonal ranges, two seasonal ranges for each of the four non-caribou ungulates, two seasonal predator search rate adjustments, and two seasonal background predation rates). This provided 48 data sets for each of the two parameters tracked (i.e., expected value and standard deviation of the expected value) or 96 data sets for each of the 12 planning areas (i.e., 1056 total output files). Application of the modeling process was conducted on 12 different computers each having their own data structure. We found this organization crucial to maintaining efficient operations and insuring integrity of the output datasets. Once all input data files were processed, we found that one complete scenario could be run through a single simulation in a day with three staff facilitating the process. These data were then available for analysis in SAS or as input to the mortality modeling component. Insuring scripts were correct for the specific application (i.e., Cell Schedule Manager, Time Step Disturbance Manager, and Netica Manager); that all input data are preprocessed (i.e., disturbance schedules, forest cover age updates, roads); and that directory structures are organized in preparation for a run can take up to a week or more for one staff depending on the type and degree of changes in model structure[10]. Once these logistics are accomplished however, we consider the one-day turn around on a run to be within our expectation. Data on range statistics are relatively easier to analyze and results can usually be obtained in part of a day. Moving the data into the mortality model took us about a day per recovery planning area but rerunning and/or gaming with the results from that point takes a matter of hours.

Example Results

Since the alpha-level BBNs did not all have adequate input from Science Team members we consider the HSM to be uncalibrated. For this reason we present only example results here to demonstrate the type of information that the HSM can supply. One of the first and maybe most relevant pieces of information is the spatial product which, in our example (Figure 16), identifies expected density of caribou prior to mortality by predators but after considering all modification to inherent range quality from displacement factors (e.g., heli-skiing) and landscape-level considerations (e.g., inability to locate high-valued range because populations are currently fragmented). Similar products are available for any of the 16 BBN runs. Some benefits in this product over historic mapping are:

- The complete range of mountain caribou is represented in a standard modeling approach;

---

[10] Note that these time estimates do not include collecting raw input data.

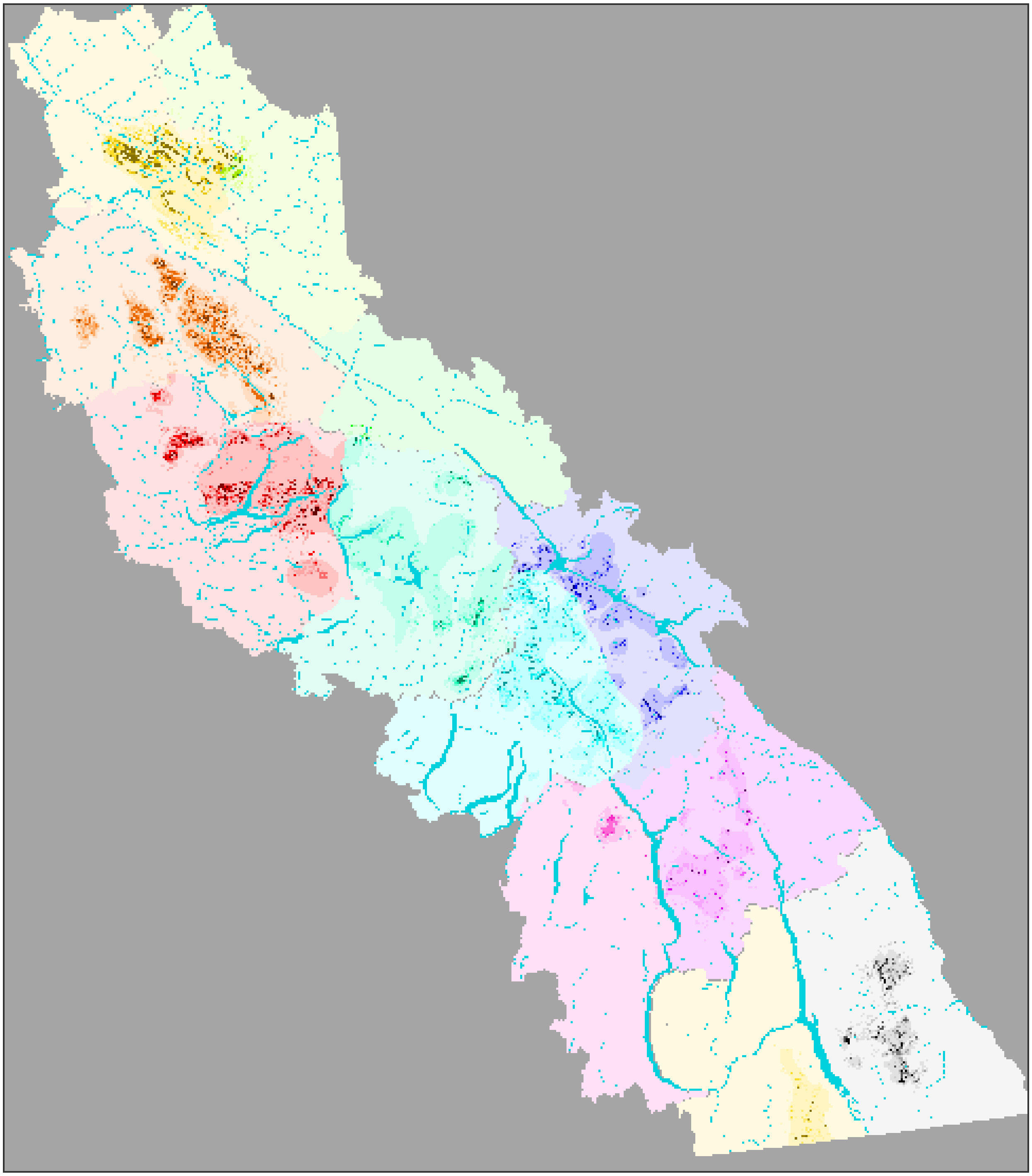

Figure 16. An example of output from a habitat supply model that was used to forecast late-winter range value for mountain caribou in southeastern British Columbia (darker colors are higher valued range; different colors represent the 12 recovery planning areas).

- Spatial resolution is relatively fine; and
- Results can be segregated or dissected to investigate importance of individual modifying factors (i.e., any key ecological correlate or management lever).

Another type of data available is the actual expected densities of caribou per planning area. In Figure 17, again for example purposes only, we show levels of caribou within each planning area, under the three disturbance scenarios, for each of the four seasonal ranges. Again, these data are for population estimates prior to considering predation effects.

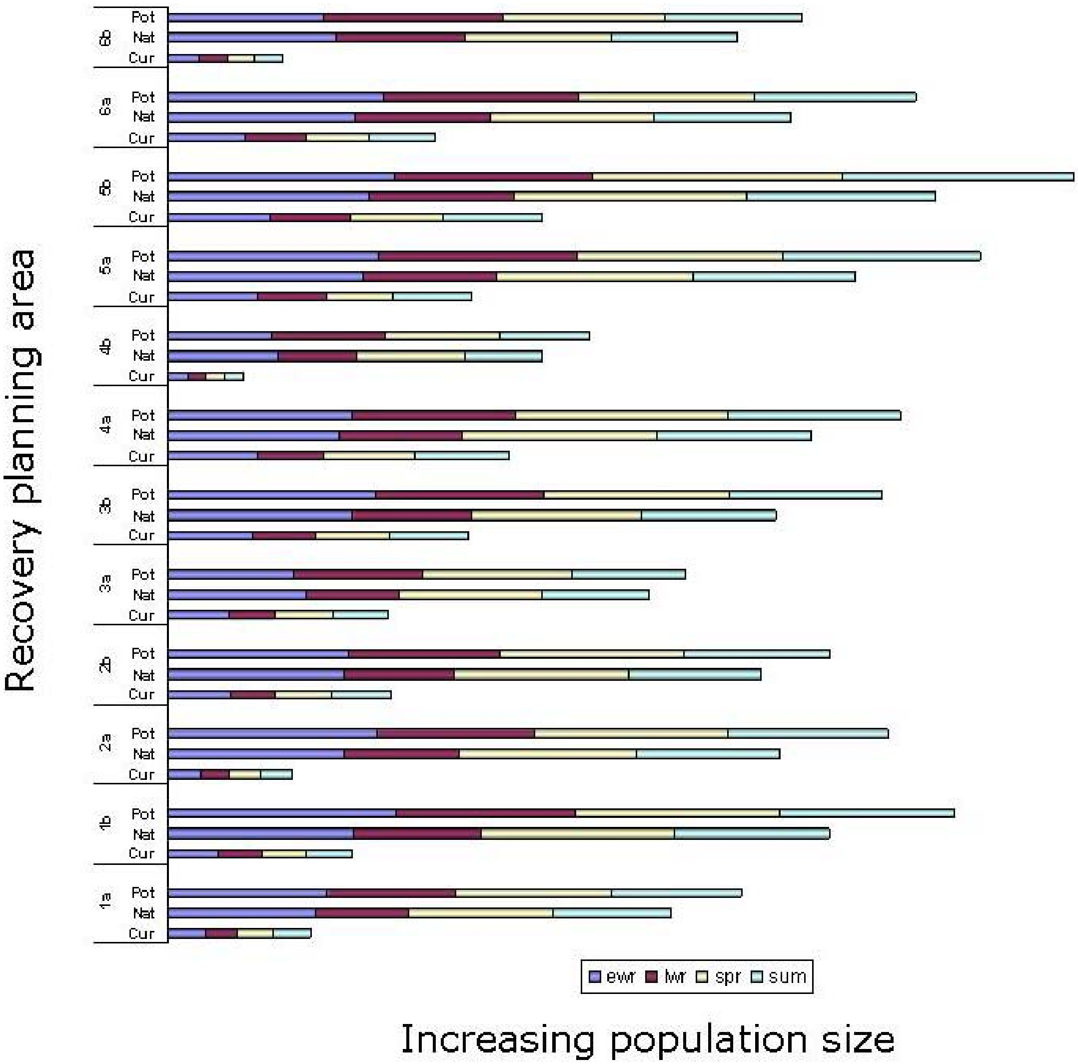

Figure 17. Expected relative population sizes of mountain caribou herds within recovery planning areas estimated for four seasonal ranges (ewr – early winter, lwr – late winter, spr – spring, and sum – summer) influenced by three landscape disturbance scenarios (pot – potential, nat – natural, and cur – current).

Data of this type, assuming that accuracy has been assessed, can provide the basis for informative analyses to address broad comparisons among planning areas, between levels of range under current or natural disturbance conditions, and among ranges within planning areas.

Development of Recovery Options

Tasks To Complete Beta- and Gamma-level Modeling

Testing Protocol

Verification and testing of a model like the mountain caribou HSM will be daunting task that will require a structured, strategic approach with at minimum, an established standard for deriving priorities. We don't know of any standard protocol already in existence so the thoughts from here are simply suggested approaches until the Science Team establishes confirmation for a particular methodology.

First, it should be recognized that the HSM is a tool to aid decisions about recovery of caribou; it supports strategic thinking by way of relative scenario comparisons, it does not characterize solutions to the ecological problem. Second, due to the combined use of data and opinion to generate probabilities of outcomes, the HSM is a research tool; it produces hypotheses in a hierarchical set. I use these two points as a way to stratify evaluation and verification of the HSM.

As a Decision Tool

We have run the model once to answer questions about the logistics of model flow. This is essentially the first in a series of questions that can verify the model operation for use in planning as follows:

1. Do the mechanics (scripts and other software) of the modeling process work as they should?
2. Are the variables (input nodes and states) and relationships (conditional probabilities) how we want to describe the system?
3. Do the model outputs meet with our expectation (spatial location, spatial amount, value)?
4. When we move management levers, do they produce the change in results that we'd expect (direction of change, magnitude of change)?
5. Does the model provide results that other professionals consider to be an accurate representation of their ecological knowledge and expectations?

While this may not be a complete list of questions, I consider questions like theses to be sufficient for verifying the model as a useful decision tool. This is because it is our own understanding and opinion of the ecological system that forms our basis for decisions in when formal process like modeling are not available. In our case we have essentially asked the first question with our alpha-level application of the HSM and have begun to compile a list of changes that address the second question. We propose to recalibrate and adjust model nodes based on our compiled list to derive a beta-level model.

Following this, and to add a level of independent assessment, it was suggested by the Science Team that we apply the beta-level model to six of the 12 recovery planning areas and review the output for consistency with our expectations (i.e., question three but only for half the area). Presumably then by moving on to the fourth question right away, we'll likely derive more adaptation to the model. We would then apply this gamma-level model to the entire planning area and reassess the third and forth questions prior to seeking external review (i.e., question five).

There are other comparative approaches that could be taken throughout this process to support model refinement. We took the expected density of caribou from the limiting range type in each planning area and compared it with actual census results (Figure 18).

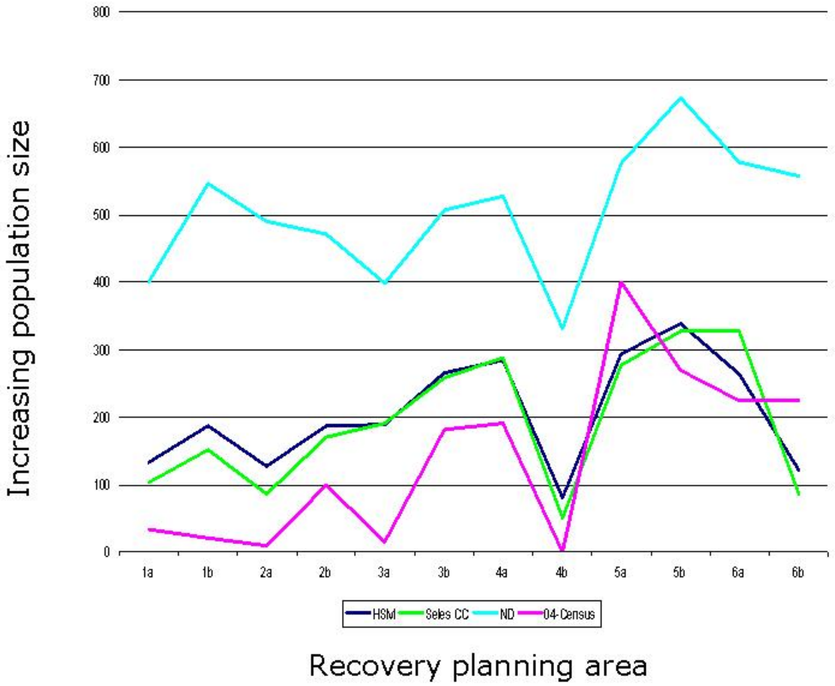

Figure 18. A comparison of expected population size of mountain caribou herds within recovery planning areas estimated using a habitat supply model under potential habitat conditions (HSM), a linked population model under conditions assuming carrying capacity (Seles CC), using the habitat supply model under conditions of natural disturbance (ND), and based on the census of herd areas in 2004 (o4 census).

Comparisons like this can provide area specific indicators of problems to guide investigations around poor performance. As another example, we compared a spatial output of ungulate winter range versus the ungulate winter range policy (Figure 19) for an area northwest of Williams Lake. In the area of overlap within the recovery planning area, there is some degree of spatial concordance but it is not perfect. Investigations of this HSM project at the pixcel level can often reveal ways to improve the agreement;

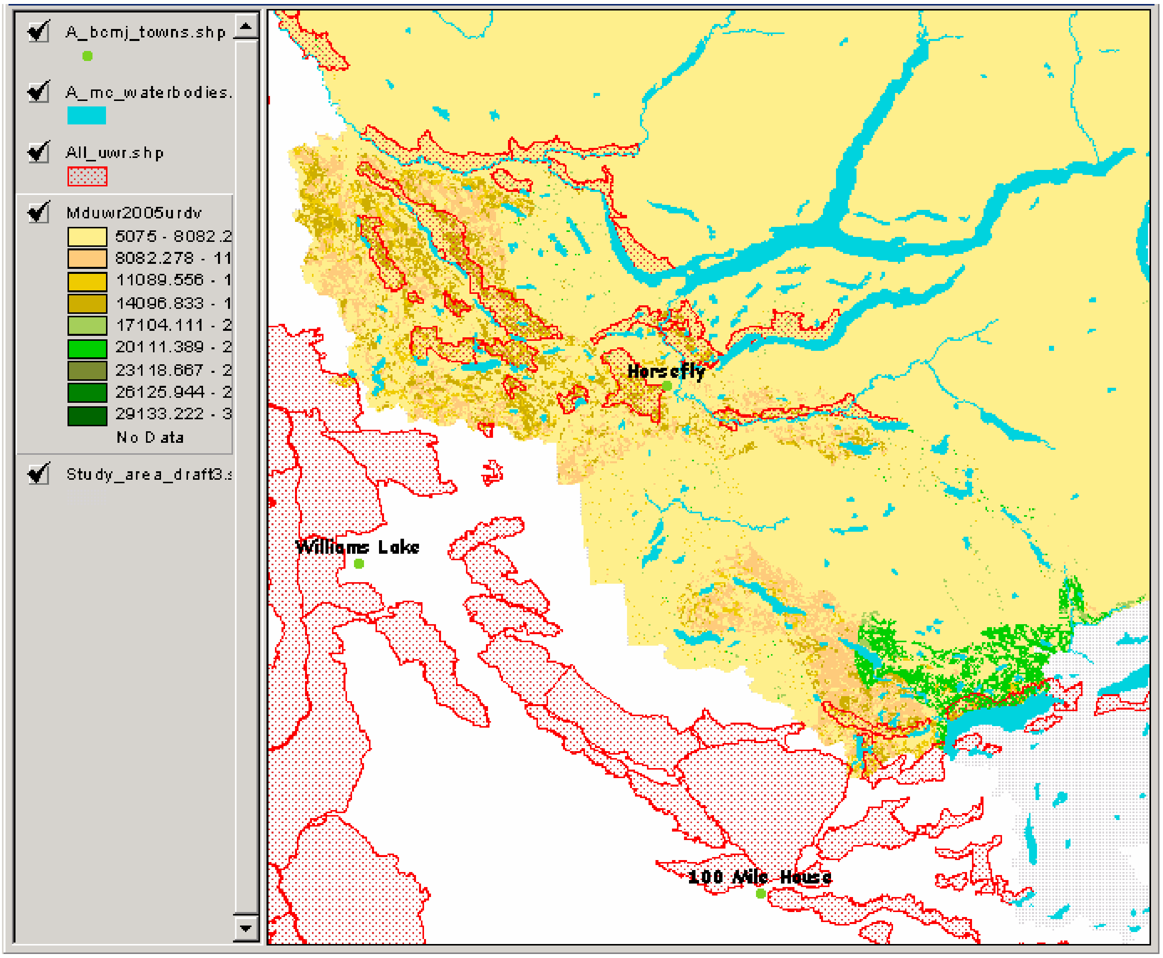

Figure 19. A spatial comparison of ungulate winter range for mule deer estimated from a habitat supply model (Mduwr2005urdv) and from policy (All_uwr.shp).

recognizing though that the policy level ungulate winter ranges may not cover the full range of high quality habitat for social or economic reasons.

As a Research Tool

There are many hypotheses that can be stated explicitly within the HSM; the most obvious are those associated with each conditional probability table or linkage among BBN nodes. We recommend beginning this test by thoroughly understanding the sensitivity of the outcome to the relationships within each node. This would involve formal sensitivity testing and an evaluation of the degree of uncertainty. Having this information would then allow for a priority assessment using criteria associated with the sensitivity results, uncertainty in relationships, and importance from the perspective of perceived social and/or economic constraints.

We anticipate that some of the high priority research questions may be at least partially addressed using data that have already been collected on previous research projects. To the extent possible we should give priority to those questions. For example, there has already been the suggestion from the Science Team, that the model could be applied to a landscape from the year 1980 to compare predictions of caribou habitat (i.e., amount, quality, and spatial distribution) with those of today. Given that use of the range by caribou and the number of caribou have changed dramatically over the past 25 years, the HSM should be able to detect that.

Finally, we have undertaken a number of field evaluations of BBNs and, using this experience, could develop a standard approach for collecting new data and recalibrating conditional probability tables using a Netica function referred to as “learn from cases”.

Proposed Activities

Activities proposed for the future generally address (Table 7):

- completing data collection to the extent possible (especially for industry-based recreation tenures);
- recalibrating the BBNs based on input already received from the Science Team;
- editing scripts and procedures associated with model implementation;
- running and assessing beta-level model runs on half the recovery area,
- making any necessary changes to the beta-level models; and
- applying the gamma-level model to all the recovery planning areas under specific planning scenarios for conditions of natural disturbance, current conditions, a scenario designed to assess model results (i.e., the 1980 test described earlier); and a scenario designed to test provide information to assist development of recovery options.

The proposed activity to apply the HSM using a specific scenario to assist development of recovery options is based on the following:

- Create a management scenario as follows:
    - Apply a constraint of no logging in areas that currently function as early- and late-winter ranges;
    - Manage area adjacent to these ranges so that early seral habitats are balance with the amount expected under a condition of natural disturbance; Acknowledge adjacent agricultural land as continuing to function in that manner (i.e., will be a continuing source of deer and elk);
    - Turn off any source of potential displacement;
- Run a simulation for enough time steps to create the desired (as above) conditions for each herd area (note: allow early- and late- winter range areas to grow from current if possible, up to the potential or at least 2X current);
- Set all populations to a theoretical 100 animals and investigate the population response to the created landscape in each planning area.

Running this hypothetical scenario is expected to provide information to address questions about recovery options including but not limited to, the amount and kind of effort that will be required to reach recovery.

The general activities proposed and the specific tasks outlined in Table 6 were forward during the last meeting of the Science Team. We also propose to have an iteration of this report with the co-authors, a full review of the final report by the Science Team, and a professional edit to standardize the use of some terms.

Table 7. Activity areas and specific tasks associated with developing a gamma-level run of a habitat supply model to aid decisions about recovery of mountain caribou in southeastern British Columbia.

Activity Area	***Task List***	
Base data	Add adjacent agriculture lands	Collect cat-ski tenures
	Investigate Ba coding issues	Collect heli-ski use data
	Collect wolf/cougar data	Review disturbance inputs
BBN changes	Review macro-climate codes	Allow moose in deep snow
	Finish reviewing CPTs	Check MC nodes in UWR
	Fix MA node input calibration	Add USR
	Build new BBN for NRG	Fix PSR decrease
	Add nil state to ECD	Allow for nonfrozen rivers
	Check new MA in UWR	
Model process	Build NRG into Netica	Amend output file syntax
	Allow for interspersion	Review changes
Mortality	Collect parameter list	Parameters / wolf
	Review literature: ROA	Natural search rate
	Review literature: biomass	Output density dependent
	Allow for nil class	Initiate in summer
	Option for type 1	Review changes
Analysis	Script to provide Delphic	
Beta-level run	Current habitat 6 units	Rules for 1980
	Review 6 units	Rules for recovery
	CPT changes	Review
Gamma run	Run current	Run recovery
	Run 1980	Analysis and presentation
	Run ND	

APPENDIX A: CLASSIFICATION OF MACRO-CLIMATE NODES

BGC Class	Macro-climate snowfall	Macro-climate temperature	Macro-climate snowmelt	Macro-climate UWRshrubs	Macro-climate structure
ATun	very deep	cool	very late	Subzone_very_wet_cold	0
ATunp	very deep	cool	very late	Subzone_very_wet_cold	0
BWBSmw	moderate	warm	early	Subzone_moist	250+
BWBSwk	moderate	warm	early	Subzone_moist	141+
ESSFdc	deep	cool	late	Subzone_moist	141+
ESSFdcp	very deep	cool	very late	Subzone_wet	141+
ESSFdcw	very deep	cool	very late	Subzone_wet	141+
ESSFdk	deep	cool	late	Subzone_moist	141+
ESSFdkp	very deep	cool	very late	Subzone_wet	141+
ESSFdkw	deep	cool	late	Subzone_moist	141+
ESSFdm	deep	cool	late	Subzone_moist	250+
ESSFdmp	very deep	cool	very late	Subzone_wet	250+
ESSFdmw	deep	cool	late	Subzone_moist	250+
ESSFmm	deep	cool	late	Subzone_moist	250+
ESSFmmp	very deep	cool	very late	Subzone_very_wet	250+
ESSFmv	very deep	cool	late	Subzone_very_wet	250+
ESSFmvp	very deep	cool	very late	Subzone_very_wet	250+
ESSFvc	very deep	cool	late	Subzone_very_wet	250+
ESSFvcp	very deep	cool	very late	Subzone_very_wet	250+
ESSFvv	very deep	cool	very late	Subzone_very_wet	250+
ESSFvvp	very deep	cool	very late	Subzone_very_wet	250+
ESSFwc	very deep	cool	late	Subzone_very_wet	250+
ESSFwcp	very deep	cool	very late	Subzone_very_wet	250+
ESSFwcw	very deep	cool	very late	Subzone_very_wet	250+
ESSFwk	very deep	cool	late	Subzone_very_wet	250+
ESSFwkp	very deep	cool	very late	Subzone_very_wet	250+
ESSFwm	very deep	cool	late	Subzone_very_wet	250+
ESSFwmp	very deep	cool	very late	Subzone_very_wet	250+
ESSFwmw	very deep	cool	very late	Subzone_very_wet	250+
ESSFxc	moderate	cool	late	Subzone_dry	141+
ICHdk	shallow	warm	very early	Subzone_dry	141+
ICHdm	shallow	warm	very early	Subzone_dry	250+
ICHdw	shallow	hot	very early	Subzone_dry	250+
ICHmk	moderate	warm	early	Subzone_moist	141+
ICHmm	moderate	warm	early	Subzone_moist	250+
ICHmw	moderate	hot	very early	Subzone_moist	141+
ICHvk	deep	warm	early	Subzone_wet	250+
ICHwk	deep	warm	early	Subzone_wet	250+
ICHxw	shallow	hot	very early	Subzone_very_dry	250+
IDFdk	moderate	warm	early	Subzone_dry	250+
IDFdm	shallow	hot	very early	Subzone_very_dry	250+
IDFmw	shallow	hot	very early	Subzone_very_dry	250+
IDFun	shallow	hot	very early	Subzone_very_dry	250+
IDFxh	shallow	hot	very early	Subzone_very_dry	250+
MSdk	moderate	warm	early	Subzone_dry	141+
MSdm	moderate	warm	early	Subzone_dry	141+
PPdh	shallow	hot	very early	Subzone_very_dry	250+
SBPSmk	moderate	warm	early	Subzone_moist	141+
SBSdh	moderate	warm	early	Subzone_dry	141+
SBSdw	moderate	warm	early	Subzone_dry	141+
SBSmc	deep	warm	early	Subzone_wet	141+
SBSmh	moderate	hot	very early	Subzone_moist	141+
SBSmk 1	deep	warm	early	Subzone_wet	141+
SBSmm	deep	warm	early	Subzone_wet	141+
SBSmw	deep	warm	early	Subzone_moist	141+
SBSvk	deep	warm	early	Subzone_very wet	250+
SBSwk	deep	warm	early	Subzone_very wet	141+

APPENDIX B: PARAMETER SPECIFICATION FOR MULTI-SPECIES A PREDATOR/PREY MODEL

Demographics					***Comments***
numDaysPerSeason	n				Number of Days Per Season
spring	37				Calculated based on the seasons identified in the MC-HSM Conceptual BBN
summer	145				no changes necessary
eWinter	83				
lWinter	100				
initPreyPopnSize	N				Initial Prey Population Size
caribou	17				Values are for area 1a (MOE best estimates 1994-2004)
moose	83				these values will be based on MOE estimates for each PU
elk	949				
wtDeer	5966				
mDeer	3707				
initPropClvs	mean	sd			Initial Proportion of Population as Calves
caribou	0.12	0			Source Value: MEAN 11.57 SE1.5 (Wittmer et al. 2005)
moose	0.12	0			Rationale for estimated parameters: assume values for moose, elk are equal to caribou, and double for deer.
elk	0.12	0			these values were deemed acceptable
wtDeer	0.24	0			
mDeer	0.24	0			
initPredPopnSize	N				Initial Size of Predator Population:Values for wolf and cougar are unknown and were estimated
wolf	10				Rationale for estimated parameters: cougar predation greater in South than North (Wittmer et al. 2005)
cougar	30				predator numbers will be estimated from a calibrated Type1 numerical response function.
	wolf		cougar		
packSize	p1_mean	p1_sd	p2_mean	p2_sd	Mean Pack Size
spring	3	0	1	0	Source Value: Mean pack size increased from 4.4 in 1990, to 7.8 in 1994, to 9 by 1996 (Hayes et al. 2000)
summer	3	0	1	0	Rationale for parameter estimates: pack sizes are smaller in south, and smaller during summer months.
eWinter	5	0	1	0	parameters will be specified per predator, parameter estimates are available per predator in Hayes et al. 2000.
lWinter	5	0	1	0	Hayes et al. 2000 is an acceptable+G81 source for parameter estimates

Mortality					**Comments**
	wolf		cougar		
smAdltROA	p1_mean	p1_sd	p2_mean	p2_sd	Summer Adult Rate of Attack: mean and sd for probability of killing an adult given encounter, specified by prey species.
caribou	0.4	0	0.35	0	Source Value: pKill given moose encounter observed to be 0.0458 for Wolves (Mech 1970)
moose	0.1	0	0.025	0	Rationale: Wolves in Isle Royale are smaller than wolves in our study area, therefore ROA will be higher (approx 2 times higher)
elk	0.2	0	0.05	0	Estimates for summer and winter ROA based on best guesses of D.Seip, T.Kinley, B.McLellan, I. Hatter
wtDeer	0.3	0	0.4	0	
mDeer	0.3	0	0.3	0	
	wolf		cougar		
smClvROA	p1_mean	p1_sd	p2_mean	p2_sd	Summer Calf Rate of Attack: mean and sd for probability of killing a calf given encounter, specified by prey species.
caribou					should be based on ratios of selection for calves (Boyd et al ????)
moose					
elk					
wtDeer					
mDeer					
	wolf		cougar		
wtAdltROA	p1_mean	p1_sd	p2_mean	p2_sd	Winter Rate of Attack for adults: mean and sd for probability of killing an adult given encounter, specified by prey species.
caribou	0.1	0	0.1	0	
moose	0.1	0	0.025	0	Estimates for summer and winter ROA based on best guesses of D.Seip, T.Kinley, B.McLellan, I. Hatter
elk	0.2	0	0.05	0	
wtDeer	0.5	0	0.4	0	
mDeer	0.5	0	0.3	0	
	wolf		cougar		
wtClvROA	p1_mean	p1_sd	p2_mean	p2_sd	Winter Rate of Attack for calves: mean and sd for probability of killing a calf given encounter, specified by prey species.
caribou					should be based on ratios of selection for calves (Boyd et al ????)
moose					
elk					
wtDeer					
mDeer					

Mortality (continued)					***Comments***
	wolf		cougar		Time spent handling adult prey (days/predator)
adltHandlingTime	p1_mean	p1_sd	p2_mean	p2_sd	Source Values:
caribou	5.2	0	5.2	0	Moose: 2.6 days / pack (Mean for all pack sizes, Hayes et al. 2000). Assume mean pack size of 4
moose	10.4	0	10.4	0	Caribou: 1.3 (SE 0.1) days/pack, Hayes et al. 2000.
elk	8	0	8	0	Elk: assume 85% of moose, because elk are 85% of mass
wtDeer	5.2	0	5.2	0	wt/m Deer: assume equal to caribou, because rougley equal mass.
mDeer	5.2	0	5.2	0	We assume equal handling times for cougar, and divide wolf per pack handling times by a mean pack size of 4.
					These assumptions are reasonable. Hayes et al. 2000 is an acceptable source for these estimates.
					Will want to check against Fuller's moose equivalents for ungulates.
	wolf		cougar		
clvHandlingTime	p1_mean	p1_sd	p2_mean	p2_sd	Time spent handling calf prey (days/predator)
caribou	1.924	0	1.924	0	Source Values: Moose calf 150kg (37.5% adult mass), Caribou calf is 55 kg (36% of adult mass)
moose	3.848	0	3.848	0	Rationale: Assume calf handling times are 37% of adult handling times.
elk	2.96	0	2.96	0	
wtDeer	1.924	0	1.924	0	These assumptions are reasonable
mDeer	1.924	0	1.924	0	
	wolf		cougar		Edible Biomass corrected for scavengers:
edibleBiomass	p1_mean	p1_sd	p2_mean	p2_sd	Source values: Moose are 400kg, 65% consumable biomass (Hayes et al. 2000).
caribou	54.72	0	54.72	0	Caribou are 152kg, with 75% consumable biomass (Hayes et al. 2000)
moose	65	0	65	0	Elk are 230 to 450 kg, with 75% consumable biomass
elk	63.75	0	63.75	0	Assume edible biomass for deer is equal to caribou. Assume edible biomass is equal for cougars
wtDeer	54.72	0	54.72	0	We estimate 10% loss to scavengers per day spent handling, to max of 75% (Based on Promberger 1992, cited in Hayes et al. 2000)
mDeer	54.72	0	54.72	0	These estimates are reasonable. Will want to check against Fuller's moose equivalents for ungulates.
	wolf		cougar		
clvPropBiomass	p1_mean	p1_sd	p2_mean	p2_sd	Proportion of adult edible biomass for calves:
caribou	0.37	0	0.37	0	Source Values: Moose calf 150kg (37.5% adult mass), Caribou calf is 55 kg (36% of adult mass) (Hayes et al. 2000)
moose	0.37	0	0.37	0	Rationale: Assume calf edible biomass is 37% of adult biomass.
elk	0.37	0	0.37	0	
wtDeer	0.37	0	0.37	0	These assumptions are reasonable
mDeer	0.37	0	0.37	0	
searchArea	mean	sd			Area searched per day under natural conditions (km2/day):
wolf	6	0			Source Value: Wolves travel 0.5km/h in forest (James 1999). Assume 1km detection distance, and 12 hours/day spent searching => 6km2/day under natural conditions
cougar	3	0			Estimate cougars cover half this area 3km2/day
					These assumptions are reasonable

Ungulate Recruitment			***Comments***
sexRatio	mean	sd	Ratio adult females to males:
caribou	0.53	0	Caribou: 0.53 (Stuart-Smith et al. 1997)
moose	0.5	0	Other species are estimates
elk	0.5	0	
wtDeer	0.5	0	These assumptions are reasonable
mDeer	0.5	0	
maxFecundity	mean	sd	Maximum fecundity:
caribou	0.915	0	Source Values:
moose	2	0	Caribou: 0.915 (Range: 0.83 - 1.0; Flaa and McLellan 2000, Stuart-Smith et al. 1997, Seip 1992, Wittmer et al. 2005)
elk	0.725	0	Moose: 2 (Estimate)
wtDeer	1.83	0	Elk: 0.725 (Range: 0.6-0.85; Houston 1982)
mDeer	1.78	0	Moose too high. Check Shakleton for moose fecundity estimate
pAdltBreeding	mean	sd	Proportion of >1yr Adults breeding.
caribou	0.83	0	Rationale: Yearling deer more likely to breed than other species.
moose	0.83	0	
elk	0.83	0	Will want to initiate model in summer season, therefore proportion of popn that are calves can be based on fecundity, prior to calf mortality.
wtDeer	0.75	0	
mDeer	0.75	0	

Predator Recruitment			***Comments***
maxRateDecrease	mean	sd	Maximum rate of decrease:
wolf	0.55	0	Estimated Value at 0.55
cougar	0.55	0	
upperLimitR	mean	sd	Upper limit of r (instantaneous rate of increase):
wolf	0.88	0	Source Value: for Wolves maxLambda = 2.4, r = 0.875 (Weclaw and Hudson 2004)
cougar	0.88	0	Assume max rate of increase for cougars is the same
foodIntakeAtHalfMax	mean	sd	Food Intake at half of maximum kill rate (kg/predator/day):
wolf	3.9195	0	Source Value: Kill rates 0.0336 moose/wolf/day (Messier 1994), 0.045 (0.004) moose/wolf/day (Hayes et al. 2000).
cougar	3.9195	0	Estimated Value: 4.522 kg/wolf/day Rationale: Moose are 400kg (Hayes et al. 2000). 65% consumable biomass, 33% lost to scavengers (Hayes et al. 2000). Results in max consumption rate of 7.839 kg/wolf/day. Hayes et al. (2000) report mean consumption rate of 8.7kg/wolf/day, adjusted for scavengers 4.1-6.4 kg/wolf/day. Assume max comsumption rate for cougars is the same.
predatorControl	prop		Predator Control
wolf	0		predator management option - applies an annual % reduction in predator propulation.
cougar	0		
			Predator numbers will be modeled as a type 1 numerical response to prey densities. Therefore, these parameters are redundent, although we may still want to compute r, in order to compare with the observed rates of increase in the predator popns.

Literature Cited

Anderson, C.R. and F.G. Lindzey. 2003. Estimating cougar predation rates from GPS location clusters. Journal of Wildlife Management 67: 307-316.

Ballard, W. B., J. S. Whitman and C.L. Gardner. 1987. Ecology of an exploited wolf population in south-central Alaska. Wildlife Monographs 114: 49 pp.

Beissinger, S.R., and M.I. Westphal. 1998. On the use of demographic models of population viability in endangered species management. J. Wildl. Manage. 62: 821-841.

Bergerud, A.T. and J. Elliot. 1986. Dynamics of caribou and wolves in northern British Columbia. Can. J. Zool., 64:1515-1529.

Boyce, M.S., B.M. Blanchard, R.R. Knight, and A. Servheen. 2001. Population viability for grizzly bears: a critical review. International Association of Bear Research and Management. Monograph Series No. 4: 9 – 12.

Caughley, G., and A.R.E. Sinclair. 1994. Wildlife Ecology and Management. Blackwell Science. 305 pp.

Flaa, J.P, and B.N. McLellan. 2000. Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., 15 - 19 Feb.,1999. Volume Two. B.C. Ministry of Environment, Lands and Parks, Victoria, B.C. and University College of the Cariboo, Kamloops, B.C. 520pp.

Fuller, T.K. 1989. Population dynamics of wolves in north-central Minnesota. Wildlife Monographs 105: 41 pp.

_____ and L.B. Keith. 1980. Wolf population dynamics and prey relationships in northeastern Alberta. J. Wild. Mgmt., 44: 583-602.

Grimm, V. and C. Wissel. 2004. The intrinsic mean time to extinction: a unifying approach to analysing persistence and viability of populations. Oikos 105: 501-511.

Hayes R.D., A.M. Baer, U. Wotschikowsky and A.S. Harestad. 2000. Kill rate by wolves on moose in the Yukon. Can. J. Zool., 78: 49-59.

Horoshi, H., Y. Iwasa, and J. Nakanishi. 2000. Comparing risk factors for population extinction. J. Theor. Biol. 204: 327-336.

James, A.R.C. 1999. Effects of industrial development on the predator-prey relationship between wolves and caribou in northeastern Alberta. Ph.D. Thesis, University of Alberta, Edmonton Alberta. 70 pp.

_____ and A.K. Stuart-Smith. 2000. Distribution of caribou and wolves in relation to linear corridors. J. Wild. Mgmt.,, 64: 154-159.

Jeschke, J.M., M. Kopp, and R. Tollrian. 2002. Predator functional responses: discriminating between handling and digesting prey. Ecological Monographs, 72: 95-112.

Kinley, T.A. and C.D. Apps. 2001. Mortality patterns in a sub-population of endangered Mountain Caribou. Wildl. Soc. Bull. 29:158-164.

Kunkel, K.E., D.H. Pletscher, D.K. Boyd, R.R. Ream, and M.W. Fairchild. 2004. Factors correlated with foraging behavior of wolves in and near Glacier National Park, Montana. J. Wild. Mgmt, 68: 167-178.

Kuzyk, G.W. 2002. Wolf distributions and movements on caribou ranges in west-central Alberta. PhD Dissertation, University of Alberta, Edmonton, AB, Canada.

Lessard, B. 2003. The empirical basis of modeling caribou population dynamics. University of Alberta Research News, Issue 7.

Mace, P. 1983. Predator-prey functional responses and predation by staghorn sculpins (Leptocottus armatus) on chum salmon fry (*Onchorhynchus keta*). PhD Dissertation, University of British Columbia, Vancouver, B.C., Canada.

McCarthy, M.A., S.J. Andelman, and H.P. Possingham. 2002. Reliability of relative predictions in population viability analysis. Cons. Biol. 17: 982-989.

Mech, L.D. 1966. The Wolves of Isle Royale. Fauna of National Parks of the U.S. Govt. Printing Office: Faunal Series Number 7. 210 pp.

_____. 1970. Wolf Ecology and Management of an Endangered Species. University of Minnesota Press. 384 pp.

_____, L.G. Adams, T.J. Meier, J.W. Burch and B.W. Dale. 1998. The Wolves of Denali. University of Minnesota Press. 225 pp.

Messier, F. 1985. Solitary living and extraterritorial movements of wolves in relation to social status and prey abundance. Can. J. Zool., 63: 239-245.

_____. 1994. Ungulate population models with predation: a case study with North American moose. Ecology, 75: 478-488.

_____. 1995. On the functional and numerical response of wolves to changing prey densities. L. N. Carbyn, S. H. Fritts, D. R. Seip, eds. Canadian Circumpolar Institute, University of Alberta. 620 pp.

Mountain Caribou Technical Advisory Committee. 2002. A strategy for the recovery of mountain caribou in British Columbia, version 1.0. Ministry of Water, Land and Air Protection, Victoria, British Columbia.

Musiani, M, H. Okarma and W. Jedrzejewski. 1998. Speed and actual distances traveled by radiocollared wolves in Bialowieza Primeval Forest (Poland). Acta Theriologica, 43: 409-416.

O'Brien, D., G. Sutherland, and S. McNay. 2005. A Model for Assessment of Northern Caribou Population Response to Projections of Seasonal Range Conditions and Predation Risk. Unpublished Report Prepared for the Chase Modeling Team Report.

Peterson, R.O. 1977. Wolf ecology and prey relationships on Isle Royale. U.S. National Park Series Science Monograph Series, No. 11, 210 pp.

Reed, D.H., J.J. O'Grady, B.W. Brook, J.D. Ballou, R. Frankham. 2003. Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. Biol. Con. 113: 23-34.

Robinson, H.S., R.B. Wielgus and J.C. Gwilliam. 2002. Cougar predation and population growth of sympatric mule deer and white-tailed deer. Can. J. Zool., 80: 556-568

Rohner, C., and D. A. Demarchi. 2000. Cumulative effects and Mountain Caribou in West-Central Alberta: an individual-based and spatially-explicit simulation model for conservation planning. Unpublsihed report prepared for the West-Central Alberta Caribou Standing Committee (WCACSC), Alberta Environment, Grande Prairie, AB.

SARCO. 2005. Use of habitat supply models to establish herd-based recovery targets for threatened mountain caribou in British Columbia: Year 1 Progress Report. Internal Rep., Wildlife Infometrics, Inc., No. 164. 100pp.

Seip, D.R. 1995. Introduction to Wolf-Prey Interactions. Ecology and conservation of wolves in a changing world. L. N. Carbyn, S. H. Fritts, D. R. Seip, eds. Canadian Circumpolar Institute, University of Alberta. 620 pp.

Stuart-Smith, A.K., C.J. Bradshaw, S. Boutin, D.M. Hebert and A.B. Rippin. 1997. Woodland caribou in relation to landscape patterns in northeastern Alberta. Journal of Wildlife Management, 61: 622-633.

Sutherland, G.D, M. Eng, and A. Fall. 2004. Effects of uncertainties about stand-replacing natural disturbances on forest management projections. BC Journal of Ecosystems and Management, URL: http://www.forrex.org/jem/2004/vol4/no2/art5.pdf

Thurber, J.M., and R.O. Peterson. 1993. Effects of population-density and pack size on the foraging ecology of gray wolves. Journal of Mammalogy, 74: 879-889

Walters, C.J. 1986. Adaptive Management of Renewable Resources. MacMillan Publishing Company, New York, NY, USA.

Weclaw, P. and R.J. Hudson. 2004. Simulation of conservation and management of woodland caribou. Ecological Modelling, 177:75-94.

Wilmers, C.C. and W.M. Getz. 2004. Simulating the effects of wolf-elk population dynamics on resource flow to scavengers. Ecological Modelling, 177:193-208.

Wittmer, H.U, B.N. McLellan, D.R. Seip, J.A. Young, T.A. Kinley, G.S. Watts, and D. Hamilton. 2005. Population dynamics of the endangered mountain ecotype of woodland caribou (*Rangifer tarandus caribou*) in British Columbia, Canada. Can. J. Zool. 83: 407 – 418.