MOUNTAIN CARIBOU SCIENCE TEAM

MODELING

Preliminary Calibration of a Habitat Supply Model for Mountain Caribou in British Columbia

Interim Progress Report

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ABSTRACT

An interim progress report is presented which updates progress on the development of a habitat supply model for mountain caribou in British Columbia. Modifications to alpha-level modeling were made to: (1) improve model structure where ecological relationships had previously been omitted and (2) refine conditional probabilities of relationships from the original application. Based on these primarily technical modifications the model was applied to 12 recovery planning areas and preliminary maps constructed for caribou seasonal ranges (4 seasons), non-caribou ungulate ranges (2 seasons and 4 species), a predator search rate adjustment (2 seasons), and background predation rates from grizzly bear and wolverine (2 seasons). A presentation of current model status was presented to the Mountain Caribou Science Team and 3 members of the team briefly reviewed range maps from 3 planning areas. Prior to map review, 3 members of the science team drafted a model testing protocol to guide map review and deter the possibility of confounding any future testing of the model. The review of maps revealed consistent and unintentional errors which were fixed prior to applying the model in a beta-level run, the results of which are summarized here. In anticipation of further refinement of the model, reviews are presented for wolf and cougar predation parameters and the climate data basis for several macro-climate codes used in the model.

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INTRODUCTION

The Mountain Caribou Science Team began development of a habitat supply model (HSM) to support decisions about recovery of mountain caribou (*Rangifer tarandus*) in British Columbia (SARCO 2005, McNay et al. 2006). The goal for the modeling was to provide transparent and consistent use of information about habitat values and anticipated threats to habitat. Emphasis for the modeling was therefore placed on developing clarity among functional ecological relationships and on linking changes in habitat with management. Work on the HSM occurred in two, five-month periods: December 2004 to March 2005 and May 2005 to September 2005. Results were documented (SARCO 2005, McNay et al. 2006) and a proof-of-concept (i.e., an alpha-level HSM) was presented to the science team in September 2005. Lack of funds precluded further work on the alpha-level HSM at that time. However, a portion of the science team developed a proposal to complete the HSM (McNay 2005[1]) and, as a partner on this application, the BC Ministry of Forests expedited continued development of selected model components.

Objectives

Objectives of the modeling team for this expedited portion of work were to: implement changes to the alpha-level model Bayesian Belief Networks, implement changes to the alpha-level mortality model, and produce a beta-level run of the modified BBNs based on current habitat conditions.

1. Implemented changes were to be consistent with meeting minutes from the September 7-8 meeting (see Table 1, BBN changes);
2. Reapplication of the model (see Table 1, Beta-level run) was to be made to all 12 recovery planning areas where these areas were described generally by McNay et al. (2006) and are listed for reference in Table 2;
3. Maps of seasonal range values for caribou and other ungulates were to be made available to the science team for review.
4. Results of the reapplication were to be made available for the science team meeting on February 08-09th, 2006.
5. Subsequent to that meeting, the required changes to the mortality model were to be made and implemented based on the beta-level BBN results.
6. Notes on all model changes were to be documented and data from beta-level BBNs and mortality model were to be summarized for each planning area.

Background

The HSM for mountain caribou is a suite of Bayesian Belief Networks (BBNs) that use ecological correlates to predict seasonal forage values at 1-ha resolution across the range of mountain caribou in BC. Detailed description of the BBNs was provided by McNay et al. (2006). Modeled forage values were based on key environmental correlates and modified by the extent to which caribou are able to access forage based

[1] McNay, R.S. 2005. Use of habitat supply modeling to support development of recovery options for woodland caribou in southeastern British Columbia. Unpubl. Proposal submitted to BC Forest Science Program. Wildlife Infometrics Inc., Mackenzie, BC

on the required energetic expenditures and/or disturbance factors. Seasonal range values for other ungulates were also predicted as a way to estimate the prey base for the main predators of caribou. The other ungulates modeled were elk (Cervus elaphus), moose (Alces alces), white-tailed deer (Odocoileus virginianus), and mule deer (Odocoileus hemiounus hemiounus). Predator effects were described in two ways. First, a background predation rate by grizzly bear (Ursus arctos) and wolverine (Gulu gulu) was estimated as a direct function of predicted habitat values (Adams and Lofroth 2004, Hamilton et al. 2004). Second, wolf and cougar numbers and spatial distribution were modeled directly as a function of prey habitat values from the BBNs using a multi-species predator-prey disc equation (McNay et al. 2006). As partial input to the disc equation, we modeled a landscape-level modifier of predator search rates with another BBN. In total, there were 7 individual BBNs producing 16 spatial layers as follows:

1. Carrying capacity for caribou in early winter;
2. Carrying capacity for caribou in late winter;
3. Carrying capacity for caribou in spring;
4. Carrying capacity for non-caribou ungulates in winter (four species);
5. Carrying capacity for ungulates in summer (five species);
6. Potential predation by grizzly and wolverine (two seasons); and
7. Potential predation search rate adjustment (two seasons).

A conceptual depiction of the relationship among these BBNs is presented in Figure 1.

Table 1. A detailed list of tasks necessary to advance alpha-level habitat supply modeling for mountain caribou in British Columbia.

Task	Description
BBN changes	Review Macro-climate codes
BBN changes	Finish reviewing CPT's
BBN changes	Organize BBN changes
BBN changes	Finish reviewing CPT's
BBN changes	MA node: new calibration, product of scales, and review
BBN changes	Build new NRGcost/permeabilty model
BBN changes	Alter pcd node with a nil state and sharpen curve
BBN changes	UWR model: check MA node changes
BBN changes	UWR model: allow moose in deep snow
BBN changes	UWR model: check MC changes (too much snow)
BBN changes	UWR model: mule deer shoud be 0.1 rather than 0.05
BBN changes	Add SUR to spread nc ungulates into summer range
BBN changes	Add thermal (3 spp groups: mo, wt/m, e/c) to SUR
BBN changes	PSR: set decrease of 50% parallel to increase
BBN changes	PSR: nonfrozen rivers (BEC) are refuge
Mortality model	Collect inputs from herd experts (small parameter list)
Mortality model	Review literature for ROA parameter estimates
Mortality model	Review literature for edible biomass parameter estimates
Mortality model	Modify spatial pre-processing to include new nil class in CC
Mortality model	Add option to invoke type 1 predator response
Mortality model	Recalculate parameters per wolf rather than per pack
Mortality model	Recalculate "natural search rate" by season
Mortality model	Construct output to explore density-dependent response
Mortality model	Change script to initiate model in summer rather than winter
Mortality review	Review changes
Beta-level run	Current habitat 12 units+mortality model
Beta-level run	Summarize results
Beta-level run	Review results

Table 2. Caribou recovery planning areas situated in southeastern 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

MODEL TESTING PROTOCOL

Early in the model building process, the science team recognized the need for clarity and structure around how the habitat supply model would be tested. This was introduced briefly by McNay (et al. 2006) but it became obvious prior to review of preliminary HSM results that the team required more clarity around what constituted model testing versus model construction. The priorities were amended to allow for development of a protocol for model testing in time to allow for preliminary map review to continue. The protocol was completed by members of the science team and, at the time of this report, was out for review under separate cover (Appendix B).

SPECIFIC MODEL CHANGES PRIOR TO MAP REVIEW

Energetic Cost of Movement / Landscape Permeability / Thermal Neutral

Alpha-level modeling: (1) included terrain steepness as a modifier of forage values directly in the forage BBN, (2) did not have any consideration for requirement of thermal cover by ungulates during summer, and (3) used a simple distance buffer around caribou herd areas to restrict the value of forage in areas where habitat was fragmented. Discussion with the science team led to the concept of constructing a spatial layer representing the cumulative effects of these three factors on energetic cost of movement – a cost surface that would be more spatially explicit and more responsive to topographic conditions than was the case within the alpha level models.

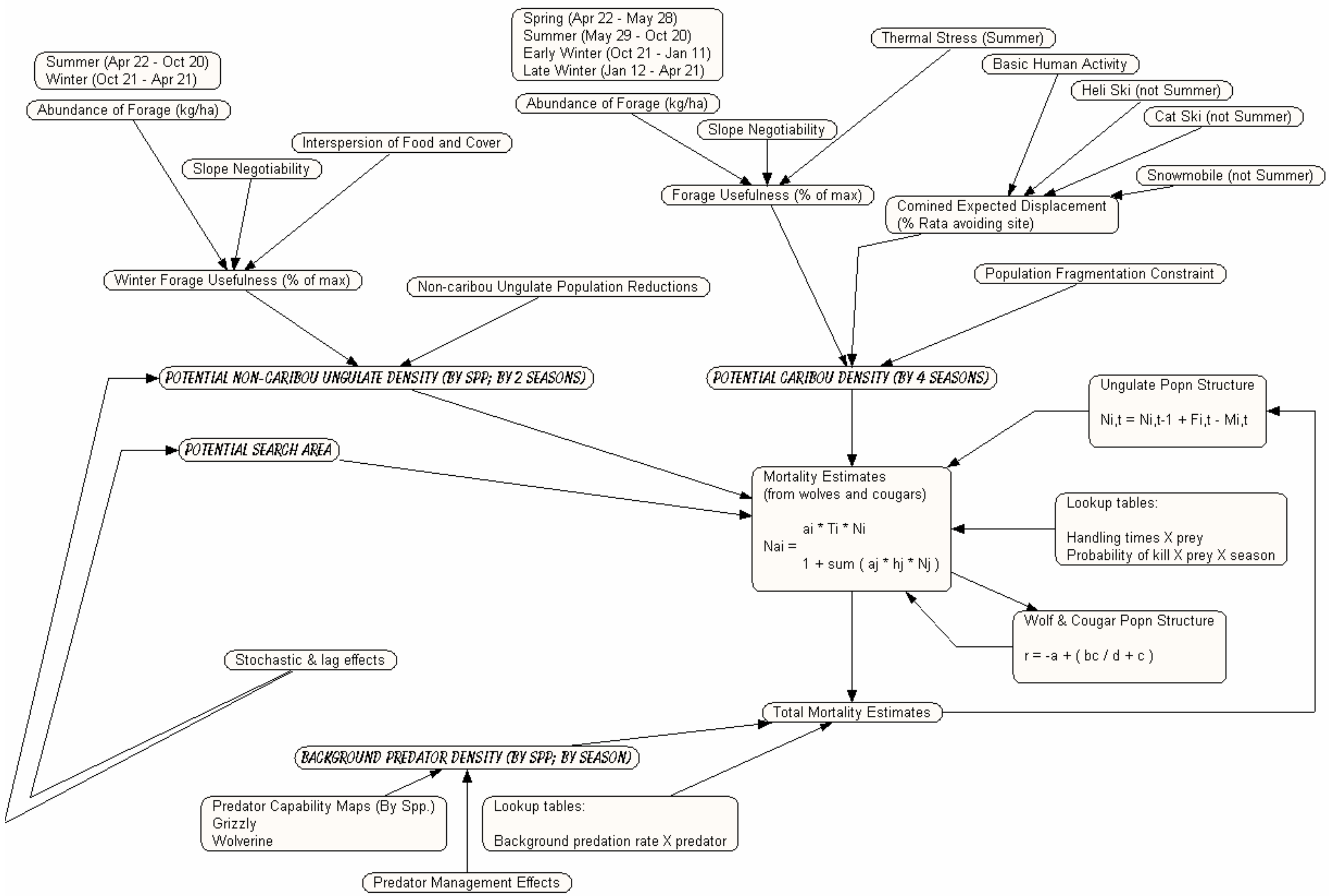

Figure 1. A conceptual model for general environmental factors influencing the spatial distribution and expected mortality rate of mountain caribou in southeastern British Columbia.

Movement cost (MC) was therefore modeled as a function of Terrain Steepness (TS), landscape Permeability (P) and species-specific needs for Thermal Regulation (TR) (Figure 2). Thermal regulation was primarily for moose which were considered to have a greater need for thermal cover than either elk or caribou. Deer were considered not to need thermal cover. The requirement for cover to maintain a thermal-neutral condition depended on Solar Radiation (SR) and the general climatic conditions of the Biogeoclimatic zone – Macro-Climate Temperature (MCT).

The general landscape was considered permeable if there were no barriers to movement by ungulates. Barriers were modeled to occur as: specific Inventory Type Groups (from Forest Cover) at specific forest ages, double-lane highways, and large water bodies.

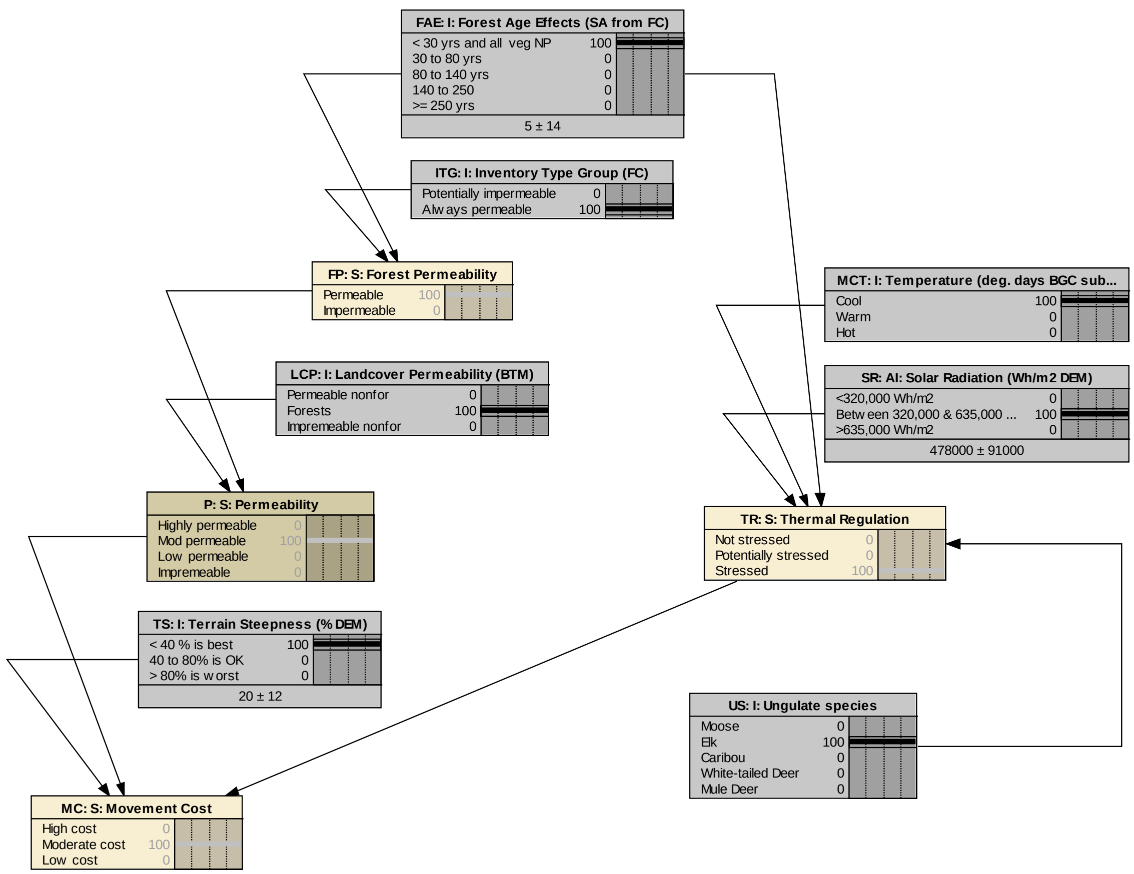

Figure 2. A Bayesian belief network used to predict the expected, relative energetic cost of movement for ungulates during summer in southeastern British Columbia.

This general expression of energetic cost was used to reduce the usefulness of available forage at the Seasonal Forage Usefulness node within each BBN (Appendix A). A spatial layer of the MC node was also used as a distance weight to express the likelihood of caribou moving away from, and therefore being able to access forage values outside the herd areas. Weighted-distance analysis calculates the minimum sum of cell costs between the herd area and every cell outside the herd area resulting in a map depicting the cumulative effect of movement cost away from the herd areas (Figure

3). We classified the resultant movement cost node as suitability values from 0 (Low Cost) through 0.5 (Moderate Cost) to 0.9 (High Cost) and calculated weighted distances as:

$$\left(CellSize*\left(\frac{100}{100*(1-S)}\right)\right)^2 \text{; where}$$

S was the suitability represented by the movement cost node. Others have used similar procedures to depict barriers to animal movements or movement corridors (Singleton et al. 2002). In our application, we found this to be a reasonable approach to depict the relative reduction in forage values outside caribou herd areas as a result of the spatially fragmented condition of mountain caribou habitat. The procedure may have additional merit in identifying spatial location of relative linkage areas among herds.

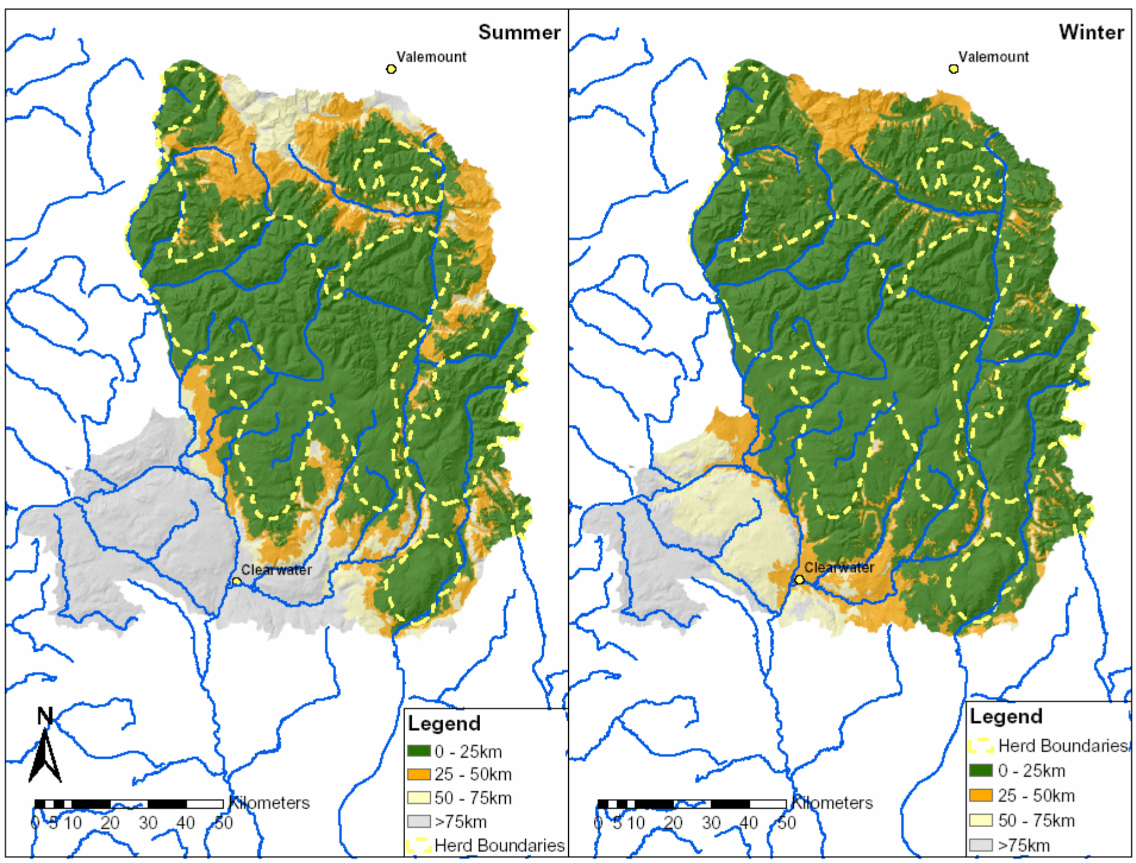

Figure 3. Weighted-distance analysis of potential movement areas external to caribou herd areas within the Wells Gray South recovery planning unit in southeastern British Columbia.

Moisture Regime

The moisture regime node was an input to most BBNs where an assessment of forage for ungulates was required (see Appendix A). We used this modeled input in the absence of actual information about forage types and condition such as would be available from detailed inventories. Flow accumulation calculated from a Digital Elevation Model is akin to slope position which we interpreted to be an index or correlate of soil moisture regime. According to expert opinion from the science team, our first attempt to model moisture regime over emphasized crest and upper-slope positions (or what we would have interpreted as xeric to sub-mesic soil conditions) (Figure 4A). Our last attempt (Figure 4B), was accomplished through a number of steps as follows:

1. We first smoothed a 25-m Digital Elevation Model using the mean of a 20-cell rectangle;
2. Next, output from an Arcview Hydrological Modeling Extension (ESRI, Redlands, California) was iteratively re-calibrated until results demonstrated the expected slope positions based on a “known" sites;
3. Finally, these results were aggregated to our standard 100-m cell size using the sum of a 4-cell rectangle.

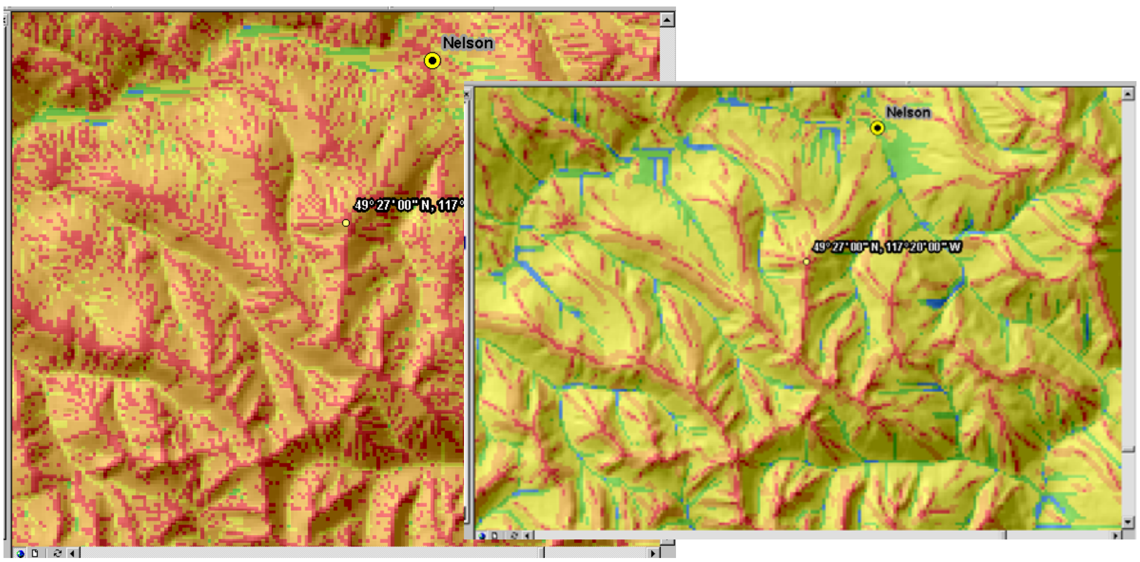

Figure 4. Modeled slope positions from alpha- (left) and beta-level (right) habitat supply models used to evaluate forage conditions for ungulates in southeastern British Columbia.

Carrying Capacity Node

The carrying capacity node was used in several BBNs to translate the seasonal forage usefulness into an expected density of animals (see models in Appendix A). In the alpha-level model, this node was called the expected caribou density and was calculated in a way that allowed for translation of the forage values at the Abundance of Available Forage (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 (McNay et al. 2006). The calibration of this node however, produced an unrealistic number of animals and so we re-calibrated to achieve lower densities (Figure 5).

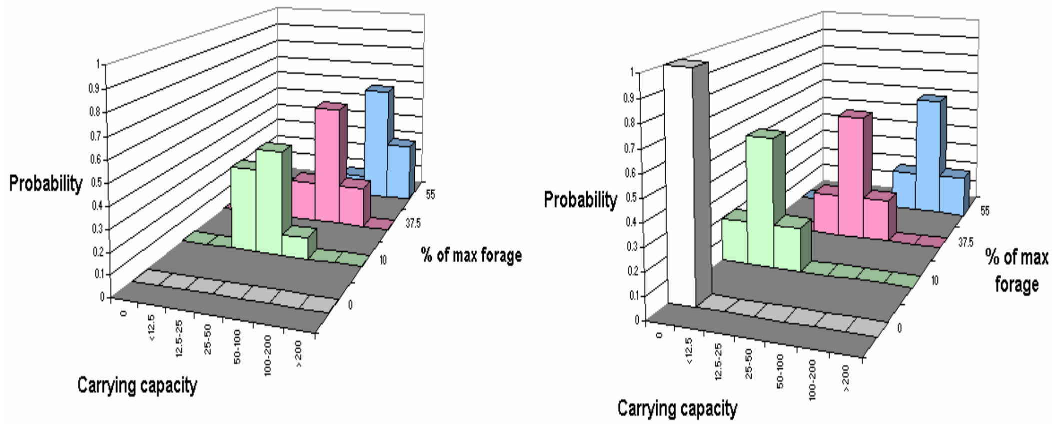

Figure 5. Conditional probability of observing specific carrying capacity states modeled in alpha- (left) and beta-level (right) habitat supply models as a function of forage conditions for ungulates in southeastern British Columbia.

Ungulate Summer Range

Alpha-level modeling included BBNs for caribou and non-caribou ungulates and we anticipated a more efficient approach in combining the two BBNs, both of which focused on forage values, energetic cost of movement, and potential for displacement by human activities (Figure 6).

Potential Search Rate Adjustment

We modified the BBN that was used to predict an adjustment to predator search rates because, in the alpha-level model, the BBN only allowed for an increase in search rates due to relatively high density of roads and linear corridors where ever that occurred. Double-lined rivers and other larger water bodies were also assumed to provide increased rates of travel for wolves during winter (McNay et al. 2006). However, it was noted by the science team that not all rivers freeze during winter and furthermore, open water can sometimes actually act as a refuge from predators. These adjustments were made by adding a macro-climate input allowing for rivers to freeze in colder climates only. We modified the model to allow for refuge areas adjacent to open water and in areas of deep snow.

Ungulate Winter Range

The alpha-level ungulate winter range model for non-caribou ungulates was judged by the science team as needing refinement in a number of places. The changes were required primarily due to ecological concepts that were not yet part of the model or where conditional probabilities of certain relationships were not what the team considered as appropriate. Our modifications can be summarized as: (1) conditional probability changes to modify how snow zones affected forage availability (Figure 7) and

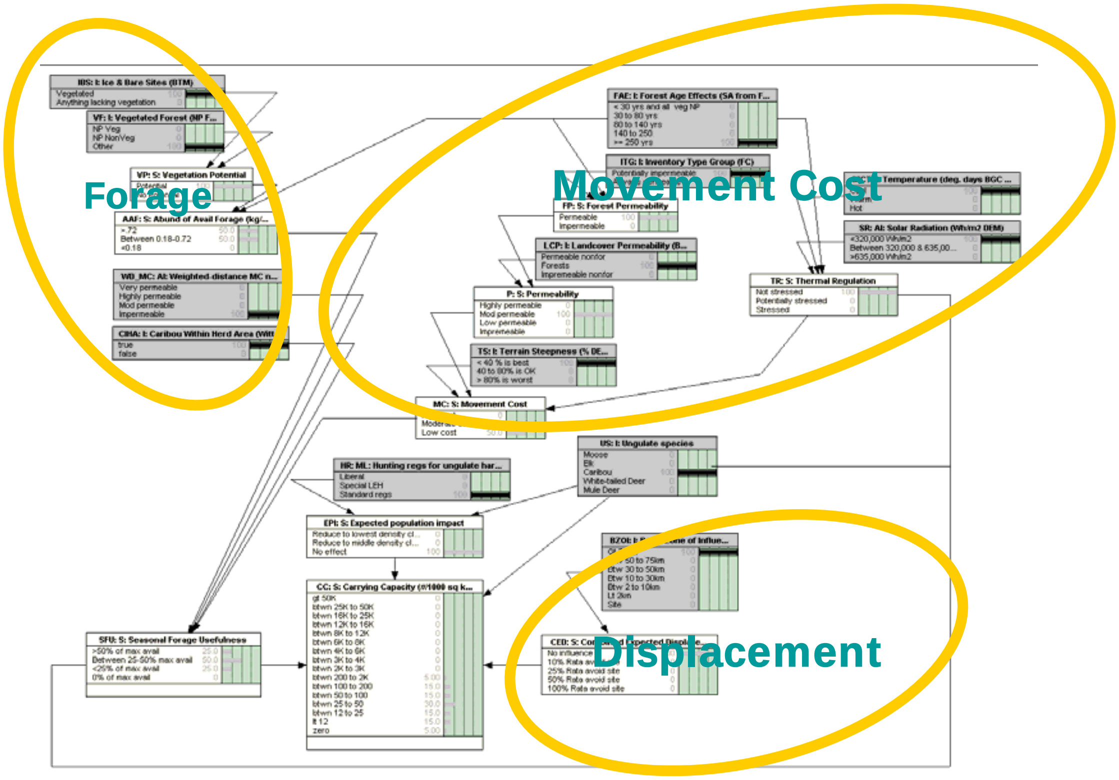

Figure 6. A generalized BBN for predicting carrying capacity of ungulate summer ranges in southeastern British Columbia where modeling focused on the relative value of forage resources, energetic cost of movement, and potential sources of human activity that could displace ungulates away from the range.

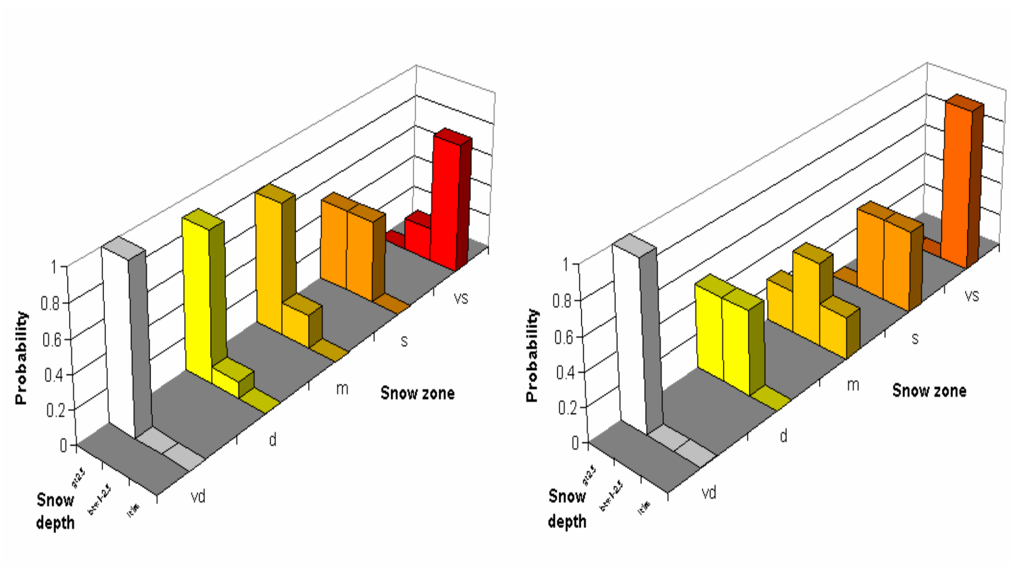

Figure 7. Conditional probability of observing specific snow depth states modeled in alpha- (left) and beta-level (right) habitat supply models as a function of broad snow zones in southeastern British Columbia.

use of deeper snow by moose and (2) new relationships for predicting forage potential and for restricting forage values based on distance from cover.

MODEL CHANGES BASED ON REVIEW OF SEASONAL RANGE MAPS

I held review sessions with 3 members of the science team to review seasonal range maps and although we touched on the Purcells (recovery planning area 1b) most of the review covered the Central Selkirks (recovery planning area 2b) and the Wells Gray South (recovery planning area 4a).

- Review of maps from caribou recovery planning area 4a, specifically the Caribou Late Winter Range, revealed that early seral types were ranked as high value when this was not expected. In theory, at least, there should be low forage availability at these sites since the modeled forage type for late winter is limited to Bryoria. I confirmed this error was consistent (i.e., a bias) in other study areas (e.g., 1b and 2b). This error was tracked to conditional probabilities in the Abundance of Available Forage (AAF) node. Bryoria abundance was ranked low at these sites but the low state condition did not allow for sufficient degradation at the AAF node. I added a new state of “Nil” to the Bryoria Abundance (BA) node to allow for an appropriate degradation of AAF within it’s CPT and now consider this problem fixed. In investigating this problem I noted that Bryoria was being down-graded fairly aggressively in the AAF node as the abundance changed from High through Medium to Low. I lessened this affect as long as Bryoria was available in the Bryoria Distribution (BD) node.
- Review of areas 4a, 2b, and 1b revealed that most non-caribou ungulate winter ranges were not being restricted enough in the deeper snow zones. I made adjustments in the Snow Accumulation (SA) node accordingly. Most critique from herd experts focused on the observation that there was too much spatial coverage of most ungulate winter range. However, we also noted that most of this area was actually ranked very low and likely is not of great consequence. By comparison, it may be possible the high areas are too few and therefore are not noticed on first inspection of the maps. On close inspection the high areas did occur within many of the already designated Ungulate Winter Ranges.
- Due to the change in the BA node, the model for Caribou Early Winter Range also required this adjustment which then precipitated changes to the AAF node.
- Review of area 2b Predator Search Rage Adjustment revealed that the adjustment appeared opposite to what it should have been (i.e., enhanced predation away from roads). This occurred because, for that one area, the spatial input for Density of Road was mistakenly coded wrong. This was fixed.
- Although it was not reviewed by herd experts, I noticed that the Vegetation Potential node within the ungulate summer range BBN was wrong in that conditional probabilities for the 30-80 and 80-140 seral states were reversed. This was fixed for the current application.

APPLICATION OF THE BETA-LEVEL BBNS

The changes listed above were made to the BBNs and the model was reapplied to the planning areas under conditions for both current and natural disturbance scenarios. Results were summarized as follows:

- The amount or area (ha) of land stratified by caribou recovery planning unit and relative levels of carrying capacity under current time conditions (Table 3) and under assumed conditions of natural disturbance (Table 4) and
- A similar presentation but using model results from the seasonal forage usefulness (SFU) node rather than carrying capacity (Table 5 and

Species	Range Type	Relative Range Quality	Caribou Recovery Planning Areas								
			South Selkirks	Purcells	Monashee	Central Selkirks	Central Rockies	Revelstoke	Wells Gray South	Mount Robson	North Cariboo
Caribou	Early Winter	High	353	878	0	624	588	2111	1813	0	2189
		Moderate	16153	62450	10371	43793	50771	101460	95883	0	206550
		Low	158300	243765	110838	370355	505277	440093	696874	0	629554
		Nil	881809	1041785	1132784	852288	527954	668615	597730	793251	528627
	Spring	High	229	208	487	5040	421	429	6871	0	2732
		Moderate	40326	45805	26682	156115	89602	124221	277105	0	194564
		Low	146474	286663	120500	318083	503959	392079	578996	0	623043
		Nil	869586	1016202	1106324	787822	490608	695550	529328	793251	546581
	Summer	High	15364	22094	2888	41441	54617	95674	98212	0	102531
		Moderate	48652	88995	19150	188558	232056	249312	357840	0	246411
		Low	57707	80814	17362	137361	195798	200421	278725	0	190469
		Nil	934892	1156975	1214593	899700	602119	666872	657523	793251	827509
	Late Winter	High	1897	4897	306	3004	1369	6407	9168	0	4107
		Moderate	48914	70893	15400	71749	47229	98722	153721	0	168808
		Low	142793	251091	107837	363954	507522	450706	667341	0	666035
		Nil	863011	1021997	1130450	828353	528470	656444	562070	793251	527970
Elk	Summer	High	92183	155323	143929	139808	146896	166018	179172	144694	281402
		Moderate	219044	292631	256801	379500	339006	337179	442841	278955	370460
		Low	361333	415680	440416	401087	399073	421790	491539	239799	565045
		Nil	384055	485244	412847	346665	199615	287292	278748	129803	150013
	Winter	High	9781	65666	11913	6660	0	5273	3614	96	453
		Moderate	224859	347995	368435	124116	57706	179663	183595	82152	73623
		Low	426179	434226	563051	418550	261585	515582	566561	297657	956751
		Nil	395796	500991	310594	717734	765299	511761	638530	413346	336093
Mule Deer	Summer	High	112230	182003	157988	189506	214012	201932	236306	209635	317125
		Moderate	201390	266926	248389	332335	273152	307620	389081	214180	334906
		Low	471644	567209	631721	483487	444862	510927	621436	281900	621157
		Nil	271351	332740	215895	261732	152564	191800	145477	87536	93732
	Winter	High	14713	64918	13153	6506	37	5109	3637	39	5
		Moderate	198913	309199	322889	103416	44522	154015	151482	57225	42737
		Low	245669	336132	376178	220768	119368	241379	310044	170934	563598
		Nil	597320	638629	541773	936370	920663	811776	927137	565053	760580
Moose	Summer	High	91713	154666	141513	137585	145514	161473	175389	143913	280324
		Moderate	201150	273283	239314	356328	325570	311482	411785	259308	286964
		Low	353736	404709	429104	413300	408505	433429	494629	237923	563292
		Nil	410016	516220	444062	359847	205001	305895	310497	152107	236340
	Winter	High	7009	13	13384	7257	414	1075	6167	2417	5695
		Moderate	258440	359128	502560	204372	111055	263405	342109	144661	506449
		Low	423578	526530	488382	423305	255485	510182	492241	275497	550384
		Nil	367588	463207	249667	632126	717636	437617	551783	370676	304392
White-tailed Deer	Summer	High	112230	182003	157988	189506	214012	201932	236306	209635	317125
		Moderate	201390	266926	248389	332335	273152	307620	389081	214180	334906
		Low	471644	567209	631721	483487	444862	510927	621436	281900	621157
		Nil	271351	332740	215895	261732	152564	191800	145477	87536	93732
	Winter	High	812	0	493	177	0	0	353	0	0
		Moderate	204095	290895	321181	100313	34129	123378	153291	47053	13727
		Low	236748	361629	377324	220354	126075	263635	307513	176700	588212
		Nil	614960	696354	554995	946216	924386	825266	931143	569498	764981

- Table 6).

I also summarized results for the area of each planning unit that was affected by relative levels of background predation from grizzly bears and wolverine (Table 7) and the area that might experience either higher or lower (than the average) predator search rates (Table 7).

REVIEW OF MACRO-CLIMATE CODES

Macro-climate codes were used at various places in the BBNs to obtain general climatic conditions as input to ecological relationships. A member of the science team (Greg Utzig) summarized climate data from available data sources[2][3][4] and compared our relative ranking of macro-climate for summer temperature, early winter snow depths, and spring snowmelt conditions (Appendix C). Greg noted that variation of snow depth within BEC subzones was substantial - climate was a continuous variable broken into classes (i.e. by BEC units) where the class limits may not have been focused on snow depth (in some cases more likely extreme temperatures or summer drought). Also, locations of climate stations likely never covered the full distribution of the variability within a BEC unit, so extensive interpolation was required. There was some uncertainty in the exact locations of some of the climate stations and which BEC unit they were located. Some climate stations covered only a few years of data, and any two stations may not have covered the same decades (hence the confounding errors of annual climate variability and climate change).

REVIEW OF PREDATION PARAMETERS

A portion of the HSM for caribou was structured to anticipate threats to caribou and their habitat. An over-riding threat was considered to be increased predation and this was

[2] Environment Canada - 1971-2000 Climate Normals on line:
http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html
[3] Environment Canada - Climate Data for Western Canada on CD:
http://www.climate.weatheroffice.ec.gc.ca/prods_servs/cdcd_iso_e.html
[4] BC Ministry of Environment - Historic Snow Survey Data:
http://www.env.gov.bc.ca/rfc/archive/historic.html

Table 3. Amount of seasonal range (Range Type) for ungulates (Species) distributed within caribou recovery planning areas in southeastern British Columbia as predicted by a habitat supply model applied under current landscape conditions.

Species	Range Type	Relative Range Quality	Caribou Recovery Planning Areas											
			South Selkirks	Purcells	Monashee	Central Selkirks	Central Rockies	Revelstoke	Wells Gray South	Mount Robson	North Cariboo	Wells Gray North	Hart Ranges North	Hart Ranges South
Caribou	Early Winter	High	4274	17162	1004	8566	12970	37312	30992	0	75017	58580	44244	7934
		Moderate	13337	35407	9872	28497	29921	41722	68015	0	91806	103680	71496	14373
		Low	29578	46457	23738	73215	87660	100414	146681	0	204354	195094	152885	13285
		Nil	1009426	1249852	1219379	1156782	954039	1032831	1146612	793251	995743	1262026	864886	1031536
	Spring	High	7705	433	6542	70350	7215	6445	112910	0	12250	15063	73038	11891
		Moderate	23748	32914	23368	94249	98227	93656	175756	0	160972	133787	104770	18289
		Low	53173	135773	35182	135461	245744	255772	306955	0	347923	425704	245037	31389
		Nil	971989	1179758	1188901	967000	733404	856406	796679	793251	845775	1044826	710666	1005559
	Summer	High	15107	19934	2713	51214	105681	100803	146561	0	109160	144844	109411	11748
		Moderate	27003	38960	7713	103356	120671	156555	217044	0	166362	202320	141123	15076
		Low	12456	28590	5107	44180	50435	48183	82523	0	87442	85651	61089	7422
		Nil	1002049	1261394	1238460	1068310	807803	906738	946172	793251	1003956	1186565	821888	1032882
	Late Winter	High	23567	33505	3053	32761	22609	61322	101995	0	122031	130718	60803	12870
		Moderate	13673	29825	8163	31497	18884	20100	36294	0	30751	64745	23981	12136
		Low	11619	22584	14335	33549	45000	56457	102447	0	104739	150049	142651	7961
		Nil	1007756	1262964	1228442	1169253	998097	1074400	1151564	793251	1109399	1273868	906076	1034161
Elk	Summer	High	52078	79509	91794	144848	214393	149708	198797	134025	197634	170395	103194	279773
		Low	87562	143638	144031	242426	221449	221488	292032	122379	190943	244810	122432	297142
		Nil	916975	1125731	1018168	879786	648748	841083	901471	536847	978343	1204175	907885	490213
	Winter	High	138760	321141	164029	54965	22978	88689	63378	22525	24334	173882	79	2429
		Low	143250	139510	346450	124549	66466	149273	230093	105875	247874	348778	188352	88135
		Nil	774605	888227	743514	1087546	995146	974317	1098829	664851	1094712	1096720	945080	976564
Mule Deer	Summer	High	51903	79436	91189	144077	212657	149106	198330	133894	197383	169212	102275	277316
		Low	87842	143856	145378	245133	226950	225221	295239	123448	195968	248908	127985	301189
		Nil	916870	1125586	1017426	877850	644983	837952	898731	535909	973569	1201260	903251	488623
	Winter	High	121243	276202	127446	40110	12866	70814	53230	8409	8365	10779	1	1227
		Low	131813	137542	302171	104724	49781	122306	156092	83668	64620	271058	8182	20326
		Nil	803559	935134	824376	1122226	1021943	1019159	1182978	701174	1293935	1337543	1125328	1045575
Moose	Summer	High	52314	80599	92166	154169	242043	153444	228268	138591	204064	192788	123631	312044
		Low	77953	132632	129688	218299	188664	199926	240955	109663	128161	189944	94546	248926
		Nil	926348	1135647	1032139	894592	653883	858909	923077	544997	1034695	1236648	915334	506158
	Winter	High	159423	159453	346664	152894	65918	147362	251072	98873	346730	207791	459823	135986
		Low	150322	336490	236143	111159	74204	177514	165045	124660	303402	480620	91292	68846
		Nil	746870	852935	671186	1003007	944468	887403	976183	569718	716788	930969	582396	862296
White-tailed Deer	Summer	High	51903	79436	91189	144077	212657	149106	198330	133894	197383	169212	102275	277316
		Low	87842	143856	145378	245133	226950	225221	295239	123448	195968	248908	127985	301189
		Nil	916870	1125586	1017426	877850	644983	837952	898731	535909	973569	1201260	903251	488623
	Winter	High	49807	67707	66275	23296	4099	14217	32166	5076	753	10779	1	954
		Low	175432	266698	340701	114106	54477	167474	161059	74896	43446	271058	11019	21344
		Nil	831376	1014473	847017	1129658	1026014	1030588	1199075	713279	1322721	1337543	1122491	1044830

Table 4. Amount of seasonal range (Range Type) for ungulates (Species) distributed within caribou recovery planning areas in southeastern British Columbia as predicted by a habitat supply model applied under assumed conditions of natural disturbance.

Species	Range Type	Relative Range Quality	Caribou Recovery Planning Areas											
			South Selkirks	Purcells	Monashee	Central Selkirks	Central Rockies	Revelstoke	Wells Gray South	Mount Robson	North Cariboo	Wells Gray North	Hart Ranges North	Hart Ranges South
Caribou	Early Winter	High	11851	33273	9842	23478	23383	44325	51001	0	81280	66160	43353	13783
		Moderate	30716	52642	23798	58067	43396	79353	134993	0	188748	178561	117754	13441
		Low	30992	64315	31219	58119	85804	108001	109233	0	221143	196771	139573	10041
		Nil	983050	1198644	1189085	1127357	932003	980536	1097050	793221	875645	1177785	832777	1029841
	Spring	High	12541	1304	11299	89003	8543	7668	128132	0	15886	18744	84578	12473
		Moderate	41184	75003	34681	107119	106781	117014	218436	0	187003	160481	109622	17890
		Low	98776	257179	62518	159736	280977	317798	365265	0	484697	572516	289616	31627
		Nil	904108	1015388	1145446	911163	688285	769735	680444	793221	679230	867536	649641	1005116
	Summer	High	32578	56289	11357	109054	149583	183473	214128	0	189263	197156	155343	21310
		Moderate	51021	85014	11170	116659	126562	153531	236113	0	149565	217700	126009	8297
		Low	15584	36586	8026	41691	46917	42742	80134	0	75844	70073	40234	3534
		Nil	957426	1170985	1223391	999617	761524	832469	861902	793221	952144	1134348	811871	1033965
	Late Winter	High	29615	52094	8857	41734	27807	71356	115934	0	141905	163650	52566	15883
		Moderate	18735	29740	14183	36447	23277	32195	46345	0	39817	93314	29642	8499
		Low	21227	48937	28584	43981	52702	66963	113443	0	206092	146866	164779	9830
		Nil	987032	1218103	1202320	1144859	980800	1041701	1116555	793221	979002	1215447	886470	1032894
Elk	Summer	High	142684	221189	183354	241082	243468	246118	267508	244182	321792	290437	308428	420201
		Low	272831	396741	355888	321836	238765	302811	401439	198039	371866	496868	339735	325824
		Nil	641094	730944	714702	704103	602353	663286	723330	351000	673158	831972	485294	321081
	Winter	High	139849	347189	170046	63463	29156	98238	66544	23500	27451	187848	36	2694
		Low	143552	148291	322606	118717	53941	129318	204744	97804	241912	299865	170730	87836
		Nil	773208	853394	761292	1084841	1001489	984659	1120989	671917	1097453	1131564	962691	976576
Mule Deer	Summer	High	139465	205017	173380	228183	237810	233059	258976	238611	289918	260350	293155	414337
		Low	294936	424973	386689	341100	246736	324473	417909	203593	402499	527148	354776	331345
		Nil	622208	718884	693875	697738	600040	654683	715392	351017	674399	831779	485526	321424
	Winter	High	120407	295806	120874	45949	12425	73441	49954	7958	11431	116579	1	878
		Low	132235	150577	292774	100990	50264	113989	138201	82657	60834	263348	5883	19792
		Nil	803967	902491	840296	1120082	1021897	1024785	1204122	702606	1294551	1239350	1127573	1046436
Moose	Summer	High	157080	269263	197520	307806	297884	279797	344677	310108	449474	434124	437988	431959
		Low	256244	345772	340651	251484	182496	266947	322592	131270	241868	351508	209566	313344
		Nil	643285	733839	715773	707731	604206	665471	725008	351843	675474	833645	485903	321803
	Winter	High	205090	214520	385134	167394	63428	157296	263331	96532	356409	225499	430494	147788
		Low	104481	322485	197345	109774	72764	161918	144690	118305	290743	426454	119619	51169
		Nil	747038	811869	671465	989853	948394	893001	984256	578384	719664	967324	583344	868149
White-tailed Deer	Summer	High	139465	205017	0	228183	237810	233059	258976	238611	289918	260350	293155	414337
		Low	294936	424973	0	341100	246736	324473	417909	203593	402499	527148	354776	331345
		Nil	622208	718884	1253944	697738	600040	654683	715392	351017	674399	831779	485526	321424
	Winter	High	70055	69773	70942	25445	3537	13051	30381	3862	846	12064	1	1010
		Low	168491	291840	332324	119741	53627	158428	154359	75214	44590	255490	8239	23019
		Nil	818063	987261	850678	1121835	1027422	1040736	1207537	714145	1321380	1351723	1125217	1043077

Table 5. Amount of seasonal range (Range Type) for ungulates (Species) distributed within caribou recovery planning areas in southeastern British Columbia as predicted by a habitat supply model applied under current landscape conditions.

Species	Range Type	Relative Range Quality	Caribou Recovery Planning Areas											
			South Selkirks	Purcells	Monashee	Central Selkirks	Central Rockies	Revelstoke	Wells Gray South	Mount Robson	North Cariboo	Wells Gray North	Hart Ranges North	Hart Ranges South
Caribou	Early Winter	High	353	878	0	624	588	2111	1813	0	2189	2070	821	136
		Moderate	16153	62450	10371	43793	50771	101460	95883	0	206550	173067	103006	17273
		Low	158300	243765	110838	370355	505277	440093	696874	0	629554	720799	465240	47770
		Nil	881809	1041785	1132784	852288	527954	668615	597730	793251	528627	723444	564444	1001949
	Spring	High	229	208	487	5040	421	429	6871	0	2732	1215	6348	203
		Moderate	40326	45805	26682	156115	89602	124221	277105	0	194564	161648	173228	20979
		Low	146474	286663	120500	318083	503959	392079	578996	0	623043	737471	402030	62099
		Nil	869586	1016202	1106324	787822	490608	695550	529328	793251	546581	719046	551905	983847
	Summer	High	15364	22094	2888	41441	54617	95674	98212	0	102531	90613	66242	1826
		Moderate	48652	88995	19150	188558	232056	249312	357840	0	246411	313767	196135	22077
		Low	57707	80814	17362	137361	195798	200421	278725	0	190469	262441	157091	13118
		Nil	934892	1156975	1214593	899700	602119	666872	657523	793251	827509	952559	714043	1030107
	Late Winter	High	1897	4897	306	3004	1369	6407	9168	0	4107	6481	3488	344
		Moderate	48914	70893	15400	71749	47229	98722	153721	0	168808	255215	90335	22065
		Low	142793	251091	107837	363954	507522	450706	667341	0	666035	676484	476774	42643
		Nil	863011	1021997	1130450	828353	528470	656444	562070	793251	527970	681200	562914	1002076
Elk	Summer	High	92183	155323	143929	139808	146896	166018	179172	144694	281402	246239	66242	177924
		Moderate	219044	292631	256801	379500	339006	337179	442841	278955	370460	420187	196135	455910
		Low	361333	415680	440416	401087	399073	421790	491539	239799	565045	586336	157091	322993
		Nil	384055	485244	412847	346665	199615	287292	278748	129803	150013	366618	714043	110301
	Winter	High	9781	65666	11913	6660	0	5273	3614	96	453	4907	0	0
		Moderate	224859	347995	368435	124116	57706	179663	183595	82152	73623	394072	10600	16731
		Low	426179	434226	563051	418550	261585	515582	566561	297657	956751	786503	873459	637155
		Nil	395796	500991	310594	717734	765299	511761	638530	413346	336093	433898	249452	413242
Mule Deer	Summer	High	112230	182003	157988	189506	214012	201932	236306	209635	317125	272415	85967	250078
		Moderate	201390	266926	248389	332335	273152	307620	389081	214180	334906	394241	177095	383893
		Low	471644	567209	631721	483487	444862	510927	621436	281900	621157	834438	165621	359627
		Nil	271351	332740	215895	261732	152564	191800	145477	87536	93732	118286	704828	73530
	Winter	High	14713	64918	13153	6506	37	5109	3637	39	5	0	0	0
		Moderate	198913	309199	322889	103416	44522	154015	151482	57225	42737	143766	307	8955
		Low	245669	336132	376178	220768	119368	241379	310044	170934	563598	591511	474956	191259
		Nil	597320	638629	541773	936370	920663	811776	927137	565053	760580	884103	658248	866914
Moose	Summer	High	91713	154666	141513	137585	145514	161473	175389	143913	280324	244336	65715	175972
		Moderate	201150	273283	239314	356328	325570	311482	411785	259308	286964	338879	164196	374732
		Low	353736	404709	429104	413300	408505	433429	494629	237923	563292	560738	180065	350583
		Nil	410016	516220	444062	359847	205001	305895	310497	152107	236340	475427	723535	165841
	Winter	High	7009	13	13384	7257	414	1075	6167	2417	5695	2430	7579	2250
		Moderate	258440	359128	502560	204372	111055	263405	342109	144661	506449	419242	518036	176102
		Low	423578	526530	488382	423305	255485	510182	492241	275497	550384	821789	390937	533011
		Nil	367588	463207	249667	632126	717636	437617	551783	370676	304392	375919	216959	355765
White-tailed Deer	Summer	High	112230	182003	157988	189506	214012	201932	236306	209635	317125	272415	85967	250078
		Moderate	201390	266926	248389	332335	273152	307620	389081	214180	334906	394241	177095	383893
		Low	471644	567209	631721	483487	444862	510927	621436	281900	621157	834438	165621	359627
		Nil	271351	332740	215895	261732	152564	191800	145477	87536	93732	118286	704828	73530
	Winter	High	812	0	493	177	0	0	353	0	0	0	0	0
		Moderate	204095	290895	321181	100313	34129	123378	153291	47053	13727	143766	1178	10890
		Low	236748	361629	377324	220354	126075	263635	307513	176700	588212	591511	479327	190414
		Nil	614960	696354	554995	946216	924386	825266	931143	569498	764981	884103	653006	865824

Table 6. Amount of seasonal range (Range Type) for ungulates (Species) distributed within caribou recovery planning areas in southeastern British Columbia as predicted by a habitat supply model applied under assumed conditions of natural disturbance.

Species	Range Type	Relative Range Quality	Caribou Recovery Planning Areas											
			South Selkirks	Purcells	Monashee	Central Selkirks	Central Rockies	Revelstoke	Wells Gray South	Mount Robson	North Cariboo	Wells Gray North	Hart Ranges North	Hart Ranges South
Caribou	Early Winter	High	1211	2829	351	1969	1367	3495	4957	0	5836	4056	750	390
		Moderate	21830	64895	20139	47927	53925	98114	95130	0	196332	147267	97816	18693
		Low	158531	272032	104846	361645	493348	439630	686622	0	605456	716869	442584	46374
		Nil	875037	1009118	1128608	855480	535946	670976	605568	793221	559192	751085	592307	1001649
	Spring	High	229	239	507	5004	421	436	6775	0	2717	1303	6284	203
		Moderate	41735	47298	26863	157945	87791	122865	280074	0	179593	154547	166476	20961
		Low	157427	355652	128413	321353	505379	404422	590122	0	656263	762580	407664	62115
		Nil	857218	945685	1098161	782719	490995	684492	515306	793221	528243	700847	553033	983827
	Summer	High	15811	20623	3177	40494	51678	90610	85138	0	68799	76549	54696	2201
		Moderate	66731	128877	23740	196144	237561	242670	368728	0	268026	329650	217738	29028
		Low	65835	92046	20963	158900	211512	226172	305185	0	239160	297816	163466	7568
		Nil	908232	1107328	1206064	871483	583835	652763	633226	793221	790831	915262	697557	1028309
	Late Winter	High	4682	11662	825	4283	2592	9940	21553	0	26889	21486	4470	745
		Moderate	40961	65368	18265	68173	50587	98164	145055	0	192267	235398	96855	20742
		Low	147948	280606	107099	355692	492066	444174	649178	0	593984	647220	443207	43564
		Nil	863018	991238	1127755	838873	539341	659937	576491	793221	553676	715173	588925	1002055
Elk	Summer	High	88847	147809	116937	135076	134086	142712	149360	145477	198045	178808	159952	182031
		Moderate	326668	470121	422305	427842	348147	406217	519587	296744	495613	608497	488211	563994
		Low	423680	447576	479330	452830	430110	465629	518782	248612	556686	614257	431391	254563
		Nil	217414	283368	235372	251273	172243	197657	204548	102388	116472	217715	53903	66518
	Winter	High	9618	67226	11739	7278	0	5241	3780	121	589	5829	0	0
		Moderate	216257	380446	346560	122039	56392	170488	157368	76199	77076	361872	12266	15777
		Low	425496	411476	579772	412492	257554	508143	582711	292945	926909	761400	858755	639627
		Nil	405238	489726	315873	725212	770640	528343	648418	423956	362242	490176	262436	411702
Mule Deer	Summer	High	111990	184172	139593	189360	204703	183205	210075	213747	239310	212526	216940	257912
		Moderate	307343	434842	403578	375694	278591	369771	463148	228655	454497	575197	431274	488151
		Low	456336	514319	545672	497729	464632	504731	571291	270744	584366	683393	438365	267380
		Nil	180940	215541	165101	204238	136660	154508	147763	80075	88643	148161	46878	53663
	Winter	High	13728	65928	12732	7182	53	5108	3633	73	118	4934	0	0
		Moderate	191359	343340	293848	101364	43396	136458	129043	51918	42928	287847	300	8748
		Low	244264	290612	404115	214845	113134	261680	334888	162699	605273	461806	458535	190416
		Nil	607258	648994	543249	943630	928003	808969	924713	578531	718497	864690	674622	867942
Moose	Summer	High	83870	140752	105832	128072	130117	128324	138060	140946	162183	151188	136970	169054
		Moderate	324219	466475	425826	425782	346219	409287	515673	293144	509497	610316	483104	555740
		Low	414946	437678	456861	451043	428810	450246	503140	246759	512505	582191	407488	256172
		Nil	233574	303969	265425	262124	179440	224358	235404	112372	182631	275582	105895	86140
	Winter	High	7095	20	16254	7708	415	1043	6746	3674	4451	2197	5549	2585
		Moderate	267853	401300	493411	218572	105888	255602	338734	144940	500999	436415	504734	178105
		Low	422777	510362	489435	404083	259670	518366	488170	271384	557854	786390	401537	524873
		Nil	358884	437192	254844	636658	718613	437204	558627	373223	303512	394275	221637	361543
White-tailed Deer	Summer	High	111990	184172	0	189360	204703	183205	210075	213747	239310	212526	216940	257912
		Moderate	307343	434842	527983	375694	278591	369771	463148	228655	454497	575197	431274	488151
		Low	456336	514319	504585	497729	464632	504731	571291	270744	584366	683393	438365	267380
		Nil	180940	215541	221376	204238	136660	154508	147763	80075	88643	148161	46878	53663
	Winter	High	287	0	329	164	0	0	295	0	0	0	0	0
		Moderate	205717	316111	307065	105839	34330	115228	134745	42615	16692	153837	897	10922
		Low	236722	343455	385723	210161	118218	274584	325839	165532	627959	567111	462939	187582
		Nil	613883	689308	560827	950857	932038	822403	931398	585074	722165	898329	669621	868602

Table 7. Amount of area distributed within caribou recovery planning areas in southeastern British Columbia predicted by a habitat supply model to be affected by varying levels of background predation and predator search rate adjustments under current landscape conditions and under assumed conditions of natural disturbance.

Scenario	Factor	Range Type	Relative Range Quality	Caribou Recovery Planning Areas											
				South Selkirks	Purcells	Monashee	Central Selkirks	Central Rockies	Revelstoke	Wells Gray South	Mount Robson	North Cariboo	Wells Gray North	Hart Ranges North	Hart Ranges South
Current	Back-ground Predation	Summer	High	1056615	1348878	1253993	1267060	1084590	1212279	1392300	793251	1366920	1619380	1133511	1067128
			Mod	0	0	0	0	0	0	0	0	0	0	0	0
			Low	0	0	0	0	0	0	0	0	0	0	0	0
		Winter	High	577770	835359	640841	1162747	928905	1031483	1241058	760226	1244999	1119091	1116461	1043515
			Mod	0	0	0	0	0	0	0	0	0	0	0	0
			Low	478845	513519	613152	104313	155685	180796	151242	33025	121921	500289	17050	23613
	Search Rate Adjustment	Summer	High	331227	494254	572626	985072	87524	381065	348550	85282	543374	623510	242153	102281
			None	671671	836806	618127	254341	942337	771682	986442	685467	773944	901338	837218	917156
			Low	53717	17818	63240	27647	54729	59532	57308	22502	49602	94532	54140	47691
		Winter	High	0	2999	1904	972	0	0	1092	12966	5970	13511	106	1723
			None	265316	402949	403724	123644	44861	168549	134538	82853	55931	271918	1376	13902
			Low	791299	942930	848365	1142444	1039729	1043730	1256670	697432	1305019	1333951	1132029	1051503
Natural Disturbance	Back-ground Predation	Summer	High	1056609	1348874	1253944	1267021	1084586	1212215	1392277	793221	1366816	1619277	1133457	1067106
			Mod	0	0	0	0	0	0	0	0	0	0	0	0
			Low	0	0	0	0	0	0	0	0	0	0	0	0
		Winter	High	0	835359	640840	1162712	928901	1031441	1241041	760206	1244929	1119016	1116416	1043497
			Mod	0	0	0	0	0	0	0	0	0	0	0	0
			Low	1056609	513515	613104	104309	155685	180774	151236	33015	121887	500261	17041	23609
	Search Rate Adjustment	Summer	High	0	0	0	0	0	0	0	0	0	0	0	0
			None	971696	1303419	1160994	1198147	1007873	1112536	1304769	750074	1283698	1483168	1052597	1005265
			Low	84913	45455	92950	68874	76713	99679	87508	43147	83118	136109	80860	61841
		Winter	High	0	0	0	0	0	0	0	0	0	0	0	0
			None	0	4728	2694	4049	0	0	3447	23984	10807	26680	596	5450
			Low	1056609	1344146	1251250	1262972	1084586	1212215	1388830	769237	1356009	1592597	1132861	1061656

thought to occur through increased coincidental kill of caribou while predators preyed on an increased prey base of non-caribou ungulates. This was the primary rationale for putting effort toward modeling the effects in a multi-species predator-prey disc equation (McNay et al. 2006). However, it was an opinion of the science team that there were many uncertain parameters under which this system needed to be modeled and that dedicated effort was required to arrive at the necessary parameters. In an attempt to meet this demand, I have presented the results of a literature review including over 100 published accounts of predation parameters concerning predation of caribou (see Appendix D). Presumably this review will form substantial support for selection of parameters to fulfill the needs of the disc equation.

CONSIDERATIONS FOR FURTHER IMPROVEMENTS OF THE HSM FOR MOUNTAIN CARIBOU

- Consider the suggested macro-climate changes as they effect spring snowmelt and early-winter snow interception and include thinking more about the balance between macro-climate and other factors in spring snowmelt.
- Review and, where necessary, revise the carrying capacity node (i.e., conditional probabilities, state values, calculation of the expected value, translation of seasonal forage usefulness, etc.) to achieve realistic outputs.
- Review and, where necessary, revise the effects of disturbance by humans (i.e., in which BBNs is it invoked and for what species, it's relative weight in down-grading forage values, etc.).
- Collect remaining information about potential disturbance factors.
- More effort should be placed on reviewing model output. Are there parts of the model that are not producing the results that we anticipate given the intended relationships?
- Full analysis of the model outputs with the intent to reveal potential inaccuracies. Ideally, this would occur within the framework provided by the model testing protocol and include available, already collected empirical information (e.g., census information, radio-telemetry information, etc.).
- Consider a simpler approach to the multi-species disc equation with the intent to focus on relative risk of predation.
- List the potential land-use policies that need to be addressed and confirm that the model is capable of asking questions regarding future changes to those policies. Where will the spatial data for the land-use policies come from and who will collected it?
- Begin using the model to ask questions associate with some relatively simple policy comparisons. Two examples that have been suggested are:
    - Compare current habitat with habitat conditions of 1980 forest composition. Do the differences agree with our general perceptions of increased number of non-caribou ungulates, increased predators, and decreased caribou populations?
    - Create a hypothetical scenario of future management for caribou recovery. What is the likelihood of success? Where is that success more likely to happen?
- Explore reduction (i.e., simplification) of the BBNs for application in management.

- Consider automating some of the modeling procedures and extending the BBNs and the input data for use by others.

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APPENDIX A. BAYESIAN BELIEF NETWORKS

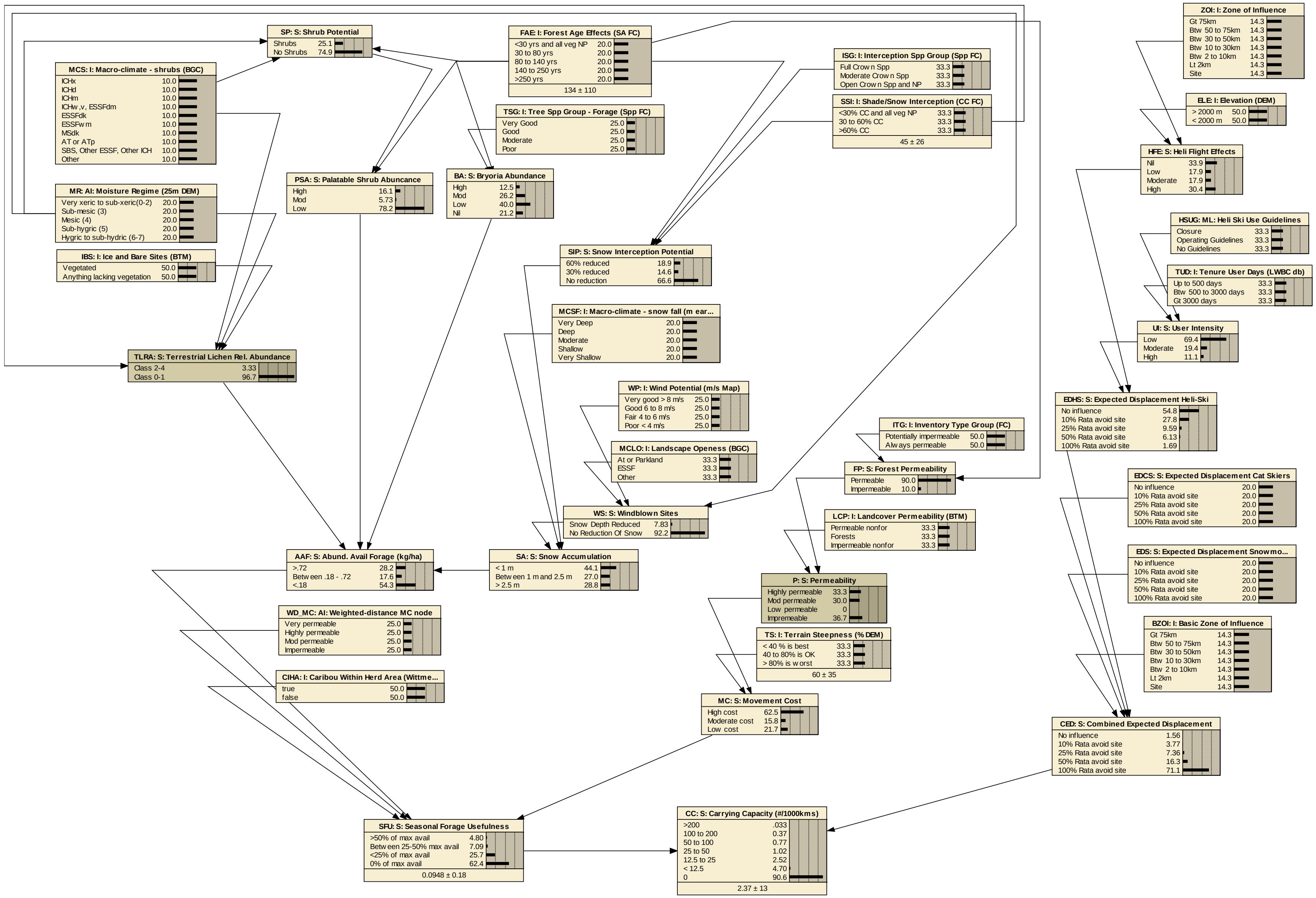

Figure 8. A Bayesian belief network used to predict the carrying capacity of mountain caribou range (prior to accounting for the potential effects of predation) during early winter in southeastern British Columbia.

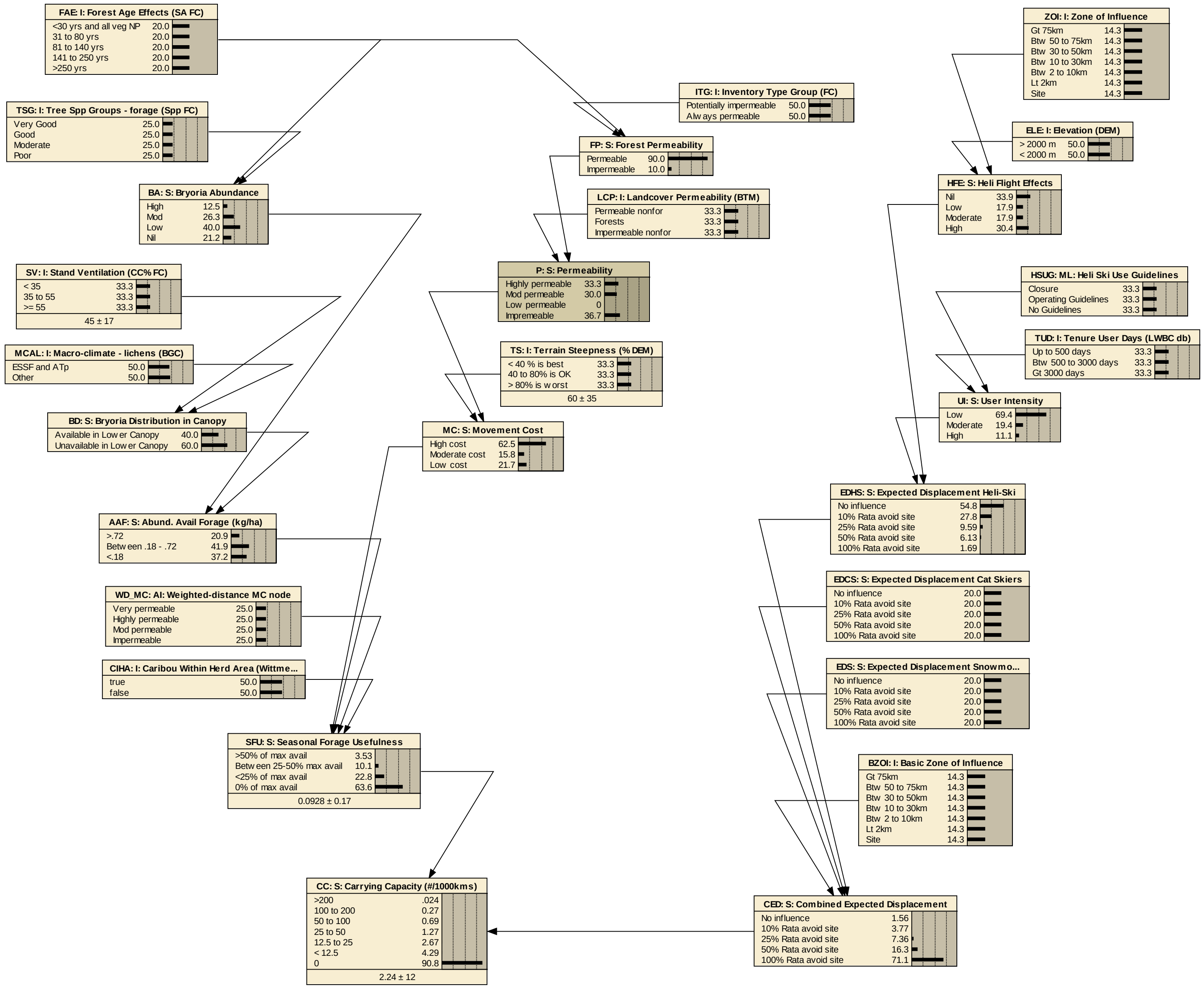

Figure 9. A Bayesian belief network used to predict the carrying capacity of mountain caribou range (prior to accounting for the potential effects of predation) during late winter in southeastern British Columbia.

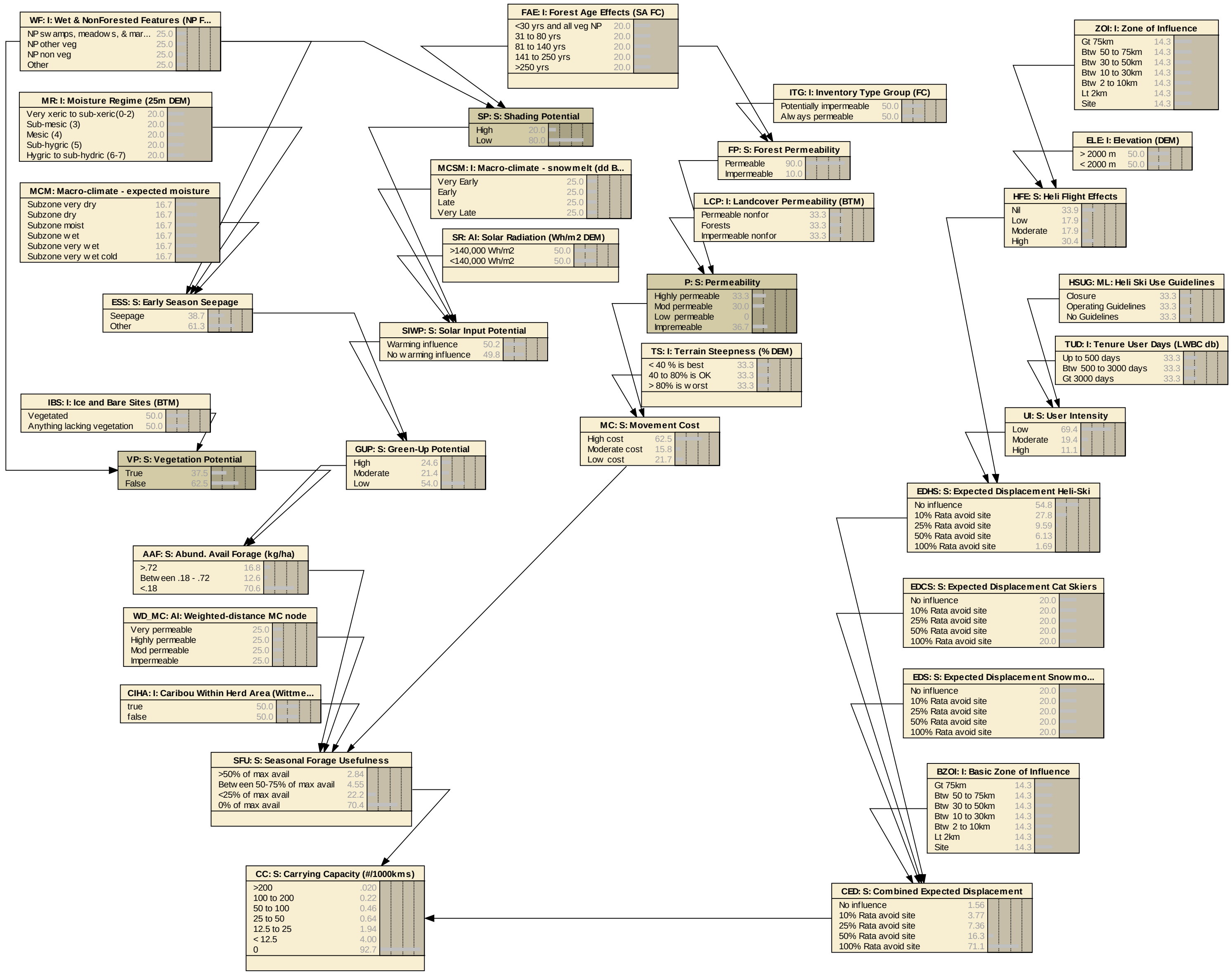

Figure 10. A Bayesian belief network used to predict the carrying capacity of mountain caribou range (prior to accounting for the potential effects of predation) during spring in southeastern British Columbia.

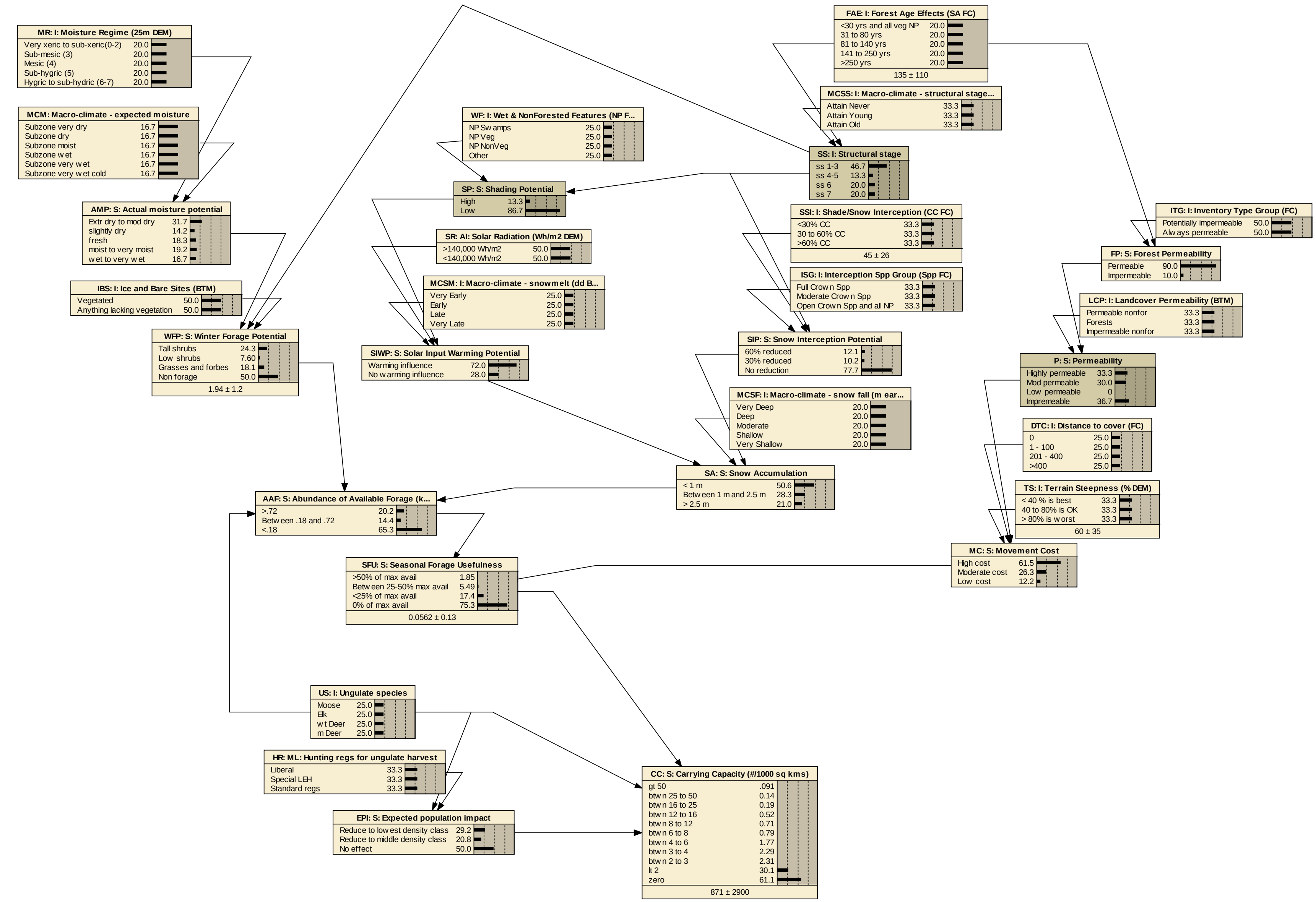

Figure 11. A Bayesian belief network used to predict the carrying capacity of range for selected ungulates (prior to accounting for the potential effects of predation) during winter in southeastern British Columbia.

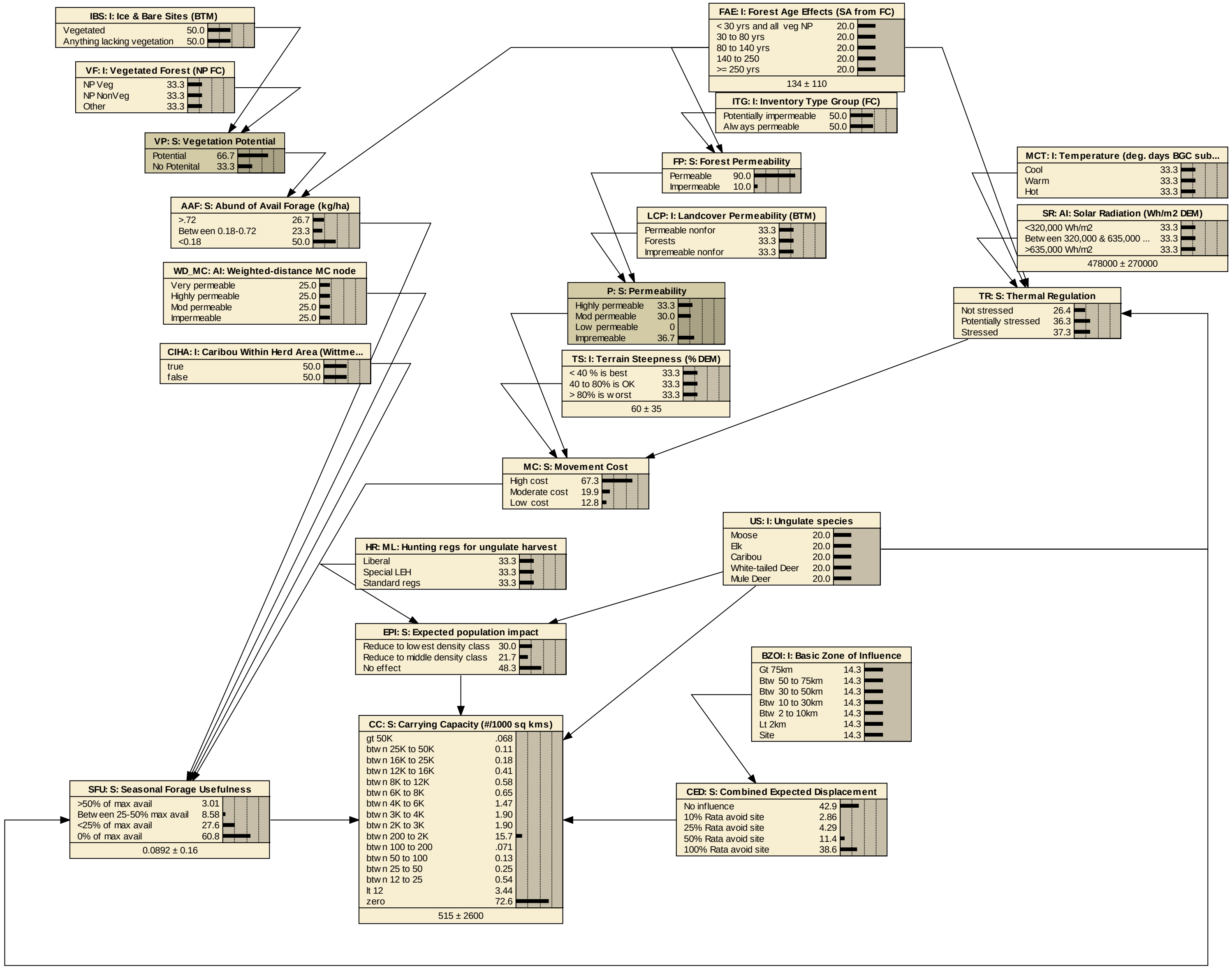

Figure 12. A Bayesian belief network used to predict the carrying capacity of range for selected ungulates (prior to accounting for the potential effects of predation) during summer in southeastern British Columbia.

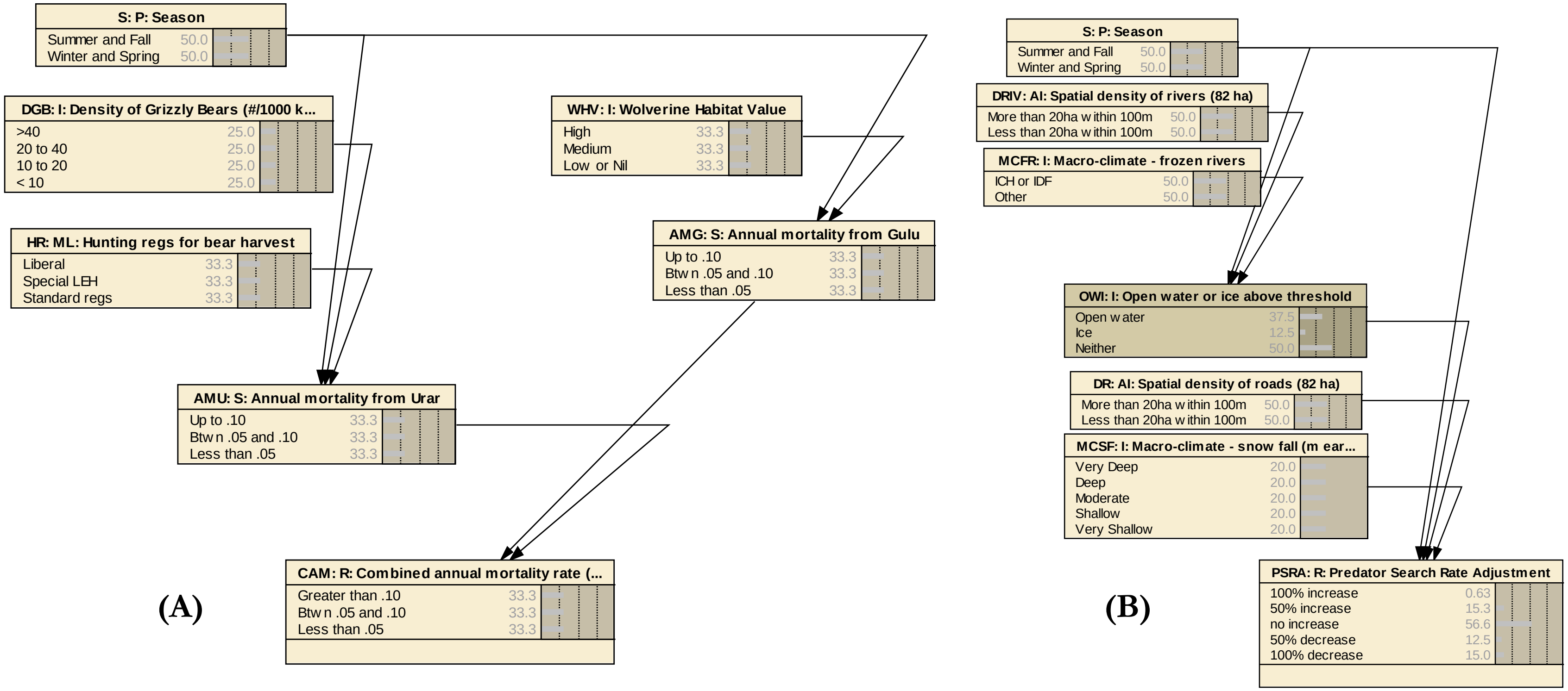

Figure 13. Bayesian belief networks used to predict (A) the annual mortality rate of mountain caribou due to the combined predation effects of grizzly bears and wolverine and (B) a predator search rate adjustment for wolves and cougar.

APPENDIX B: MOUNTAIN CARIBOU MODEL EVALUATION

A Review Draft authored by Steve Wilson, Clayton Apps, and Scott McNay

Rationale

Our objective is to establish a standard protocol for evaluating the mountain caribou habitat supply model. We expect the protocol to distinguish different types of, and time frames for, model evaluations. In addition to providing this guidance for individual researchers, we also expect other outcomes including: (1) a common language for the Science Team about model evaluation and, even more generally; (2) common expectations about what type of model evaluations will occur.

Models are representations of systems that can be used to aid explanation, prediction, or both. All models describe causal or correlative relationships among variables and can be built in a variety of different ways. Explanatory models are those that are intended only for inferring relationships among data already collected. For example, observations of canopy closure and snow depths might be fitted to a linear regression model in order to describe the relationship between the two variables observed within a certain study area during a particular sampling period.

In contrast, predictive models are those that are intended to forecast outcomes based on hypothetical circumstances. For example, if the regression model built with the canopy closure and snow depth data were to be used to predict snow depths under canopy conditions that differed in space or in time from the data we used to build the model, then our explanatory model would become predictive. Predictions are commonly derived through the inductive characterization of relationships between known outcomes and relevant predictor variables. Our confidence in a model's ability to explain and/or predict depends on its evaluation; however, appropriate methods depend on a model's intended use.

In general, evaluating an explanatory model involves model-fitting; that is, ensuring that the relationships and variables in the model adequately describe the dynamics of the system as we know it. Predictive models must meet a higher standard of evaluation because they will be used to forecast outcomes of circumstances that have not yet been encountered. As a result, predictive models must be tested in order to assess their robustness to new data.

The data requirements of model fitting may limit the information available for model testing, and visa versa. If the goal is to develop a purely explanatory model, then we would like to consider all information that contributes to our understanding in order to capture as much of the variation and dynamics of the system as possible. In contrast, if we are building a predictive model, we may want to consider only prior ecological understanding and use available data to test the robustness of the model across as broad a range of conditions as possible.

For models that describe functional relationships, evaluation occurs at three different levels. The first two levels apply to both explanatory and predictive models, while all three levels apply to evaluating predictive models.

First, models must be evaluated according to whether they encapsulate the relevant explanatory variables and associated causal relationships, and this is commonly based on our interpretation of past observations (e.g., is mule deer winter use correlated with Douglas-fir stands because those stands occur on low snow-loading sites or because they are associated with preferred forage?).

At the second level, a well-constructed functional model will generate testable hypotheses with which to evaluate individual relationships within the model. For example, a model of ungulate winter range might include our relationship between snow depth and canopy closure. The modelled relationship represents a falsifiable hypothesis that can be tested either retrospectively or with new data.

At the third level, any model intended for prediction should be evaluated with respect to goodness-of-fit to independent observations relative to predicted outcomes. Alone, this level of testing is not sufficient to evaluate the veracity of the functional relationships within the model, nor does it inform how a model and/or our associated ecological understanding may be failing. An appropriate design for characterizing a model's predictive ability must ensure that, to the extent practicable, independent observations represent the range of conditions to which extrapolation is intended (in time and/or space). Such a valid and objective evaluation requires that data used for evaluating a model be as independent as possible from any data or opinions used in the derivation of the original model.

Evaluating Bayesian Belief Networks

The habitat supply model developed by the provincial mountain caribou science team was intended to serve primarily as an explanatory model; that is, to tell the "story" of mountain caribou biology, as understood broadly by herd experts. Bayesian techniques were used to construct influence diagrams (i.e., Bayesian Belief Networks) of the ecological relationships depicting caribou ecology. BBNs were used rather than more standard statistical models because we needed to generalize our understanding across circumstances (e.g., temporal, spatial, ecological) where we knew empirical information would be lacking. Moreover, the Bayesian approach allowed us to use our knowledge and our opinion to develop a functional model with a structure and relationships that fully reflect our understanding of caribou ecology and associated limiting factors. The value in such a tool is not only in the representation of relevant ecological pathways and mechanisms, but in the potential for predicting consequences of future management actions. Consequently, the BBNs represent both a state-of-knowledge explanatory model that is also intended for use in prediction, both in space and time. Hence, model building and evaluation must balance the requirements of developing a tool that is both explanatory *and* that provides robust predictions.

Phase 1 Evaluating Functional Veracity

The first task in evaluating the mountain caribou habitat supply model is to ensure that it meets the expectations of herd experts with respect to the variables and relationships described. The goal of this evaluation phase is to build confidence among science team members in the model's ability to capture the state of our knowledge of mountain caribou ecology. As a result, herd experts should focus their evaluation on model variables and relationships to ensure that they are consistent with the experts' understanding of the system, based on professional experience and an understanding of available scientific literature and management information.

Models will be stratified into major subcomponents (seasonal forage, ungulate winter range, disturbance and predator displacement) for evaluation. Within these submodels, herd experts should examine the following:

1. **Overall submodel structure:** does the submodel capture the essential variables (nodes) and relationships (arrows) required to describe the system in a functional way?
2. **States:** do the classes (known as "states") associated with each node capture the essential variation in the system? Can the number of states be reduced?
3. **Summary nodes:** examine the effects of different combinations of states on

the state of summary nodes (a node receiving arrows from one or more other nodes). Do the summary nodes reflect our understanding (or lack thereof) of the relationships?

4. **Submodel output:** Use a “case study” approach to examine model output in specific areas. For example, to evaluate the deer winter range submodel, examine an area of the output map where you are personally familiar with winter range values and compare model output with your expectations. Then work back through nodes to diagnose potential sources of error.

Outstanding issues with the models should be documented, but no changes should be made to the model itself. The documentation from several herd experts will need to be collated and the model adjusted based on a collective reconciliation of the input.

This phase of evaluation should be considered an extension of the model building process itself. As long as evaluation avoids arbitrary changes to the model in order to better fit known patterns that reflect data that are otherwise independent and that may be used for subsequent testing, future tests of robustness will not be compromised.

Phase 2 Evaluating Relevant Hypotheses

The relationships among variables described in a Bayesian Belief Network are essentially hypotheses that can be tested. The importance of different relationships to the output of the model can be evaluated and ranked by conducting sensitivity analyses. The key nodes and relationships can then be tested, either with data already available (except where the nodes were expressly parameterized with the same data), or with new data collected to address knowledge gaps.

Relationships can be tested deductively by establishing falsifiable null hypotheses and alternate hypotheses, and adjusting model nodes according to observed effect sizes. Alternatively, subsequent to testing, nodes can be revised using Bayesian methods. Some view the Bayesian approach as unscientific, claiming that poor models are iteratively updated to fit data rather than being rejected. This misrepresents the Bayesian approach. In fact, models are typically abandoned or revised when the updating results in more uncertain output.

The Phase 2 evaluation involves the following steps:

1. **Sensitivity analyses**: rank nodes according to their contribution to model output. These nodes and associated relationships represent the critical hypotheses.
2. **Hypothesis testing:** use available data or design studies to collect data to test hypothetical relationships that have not been previously verified across the range of model application conditions.
3. **Update model:** update conditional probability tables based on hypothesis testing and observed effect sizes, or based on Bayesian methods. Revise model structure if output becomes too uncertain to be useful.

Phase 3

The final phase of model evaluation involves comparing model output to available independent and representative data sets. In the case of mountain caribou, this will include data such as telemetry locations. Because the model was built and evaluated using the results and conclusions of various studies conducted during different times over different spatial extents throughout the range of mountain caribou, arguably, there should be sufficient intellectual distance between the model and original data sets to consider such tests sufficiently independent to evaluate the robustness of the model.

Of course there is no substitute for independent data and these can be applied as collected in order to improve confidence.

Testing the goodness-of-fit of data to the model output should be considered a final step in development. As mentioned, goodness-of-fit statistics themselves provide no information regarding the veracity of modelled relationships, and such a test may quantify our confidence in model predictions but has limited diagnostic value. However, an information-theoretic approach (Burnham and Anderson 2002) can be used to consider whether the "weight of evidence" supports hypothetical combinations of submodels. For example, the relative contributions of the "forage usefulness", "displacement", "fragmentation", and "mortality risk" submodels in explaining current caribou distribution can be evaluated and compared to that reflected in the current model structure. It may be possible to move to the next level within the hierarchical model structure (e.g., "forage usefulness") and again evaluate the contribution of individual nodes relative to model structure. This approach represents an inductive analogue to the hypothesis testing described under Phase 2, above. Alternatively there are Bayesian model reduction techniques that also allow for more parsimonious approaches to prediction when ecological description is not the primary goal in using the model.

Ultimately, the question addressed through Phase 3 evaluation is whether the model is sufficiently "not wrong" to be useful in decision-support. While the model should of course perform better than a random guess, it may also need to perform better than the collective opinion of herd experts to justify its application in prediction. If the answer is "no", then the model should be either abandoned or wholly revisited.

Literature Cited

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information theoretic approach. Springer-Verlag, New York, New York, USA.

APPENDIX C: REVIEW OF MACRO-CLIMATE CODES[5]

Early Winter Snow Depths[6]

Est. ave. Nov-Jan Snow depth (cm)	
Very Deep	>100
Deep	61-100
Moderate	41-60
Shallow	20-40
Very Shallow	<20

Class	BGC unit
Very Deep	AT un
	AT unp
	ESSFvcp
	ESSFvvp
	ESSFwcp
	ESSFwkp
	ESSFwmp
	ESSFmvp
	ESSFmmp
	ESSFwmw
	ESSFwcw
	ESSFwc
	ESSFwm
	ESSFwk
	ESSFdkp
Deep	ESSFvv
	ESSFvc
	ESSFdmw
	ESSFmm
	ESSFdcp
	ESSFdmp
	ESSFdcw
	ESSFdkw
Moderate	ESSFdc
	ESSFdk
	ICH vk
	ICH wk
Shallow	ICHmw
	MS dm
	SBS mk 1
	SBS mc
	SBS wk
	SBS mm
	SBS mw
	SBS dw
	ICH mk
	IDF dk
	MS dk
	ESSFxc
	SBSdh
	SBS mh
	SBPSmk
	ICH mm
	ESSFmv
Very Shallow	ICHdw
	SBS vk
	SBS mh
	ICH dk
	ICH dm
	IDF dm
	IDF mw
	IDF xh
	PP dh
	ICH xw
	IDF un

Summer Temperatures[7]

Warmest Month Est. ave. Temp. (oC)	
Cool	<13
Warm	13-16
Hot	>16

Class	BGC unit
Cool Summer	AT un
	AT unp
	ESSFvvp
	ESSFmvp
	ESSFwcp
	ESSFwcw
	ESSFvv
	ESSFwc
	ESSFwkp
	ESSFmm
	ESSFmv
	ESSFwk
	ESSFdcp
	ESSFdcw
	ESSFvcp
	ESSFxc
	ESSFvc
	ESSFdc
	ESSFdk
	ESSFdkp
	ESSFdkw
	ESSFwmp
	ESSFmmp
	ESSFdmp
	ESSFdmw
	ESSFwmw
	ESSFdm
	ESSFwm
Warm Summer	SBS mc
	SBS mk 1
	SBPSmk
	SBS wk
	MS dm
	SBS mw
	SBS vk
	ICH vk
	ICH mm
	SBS mm
	SBS dw
	IDF dk
	ICH mk
	MS dk
	SBS dh
	ICH wk
	ICH dm
	ICH dk
Hot Summer	SBS mh
	IDF dm
	IDF mw
	ICH mw
	IDF un
	ICH dw
	IDF xh
	PP dh
	ICH xw

Spring Snowmelt[8]

	Est. ave. Snow depth (cm) Mar	April	May	June
Very Early	0-20	0-10	0	0
Early	20-50	0-50	0-20	0
Intermediate	50-100	50-100	10-50	0-10
Late	100-200	100-200	50-100	0-50
Very Late	>200	>200	>150	>50

Class	BGC unit
Very Early Snowfree	ICH xw
	IDF xh
	IDF mw
	IDF dm
	IDF un
	PP dh
	ICHdw
	ICH dk
	ICH dm
	SBS mh
	SBPSmk
	ICH mk
Early Snowfree	IDF dk
	SBS vk
	MS dk
	ESSFmv
	ICH mm
	SBSdh
	SBS dw
	SBS wk
	SBS mw
	SBS mm
	SBS mc
Intermediate Snowfree	MS dm
	ESSFxc
	SBS mk 1
	ICHmw
	ESSFdk
	ESSFdm
	ICH wk
	ICH vk
	ESSFmm
Late Snowfree	ESSFwk
	ESSFdmw
	ESSFdkw
	ESSFvc
	ESSFdc
Very Late Snowfree	ESSFmmp
	ESSFvv
	ESSFwm
	ESSFwc
	ESSFwm w
	ESSFdcw
	ESSFdmp
	ESSFdkp
	ESSFdcp
	ESSFwcw
	ESSFmvp
	ESSFwmp
	ESSFwkp
	ESSFwcp
	ESSFvcp
	ESSFvvp
	AT unp
	AT un

[5] Coloured BGC - no available data, classification based on subzone modifiers relative to BGC units with data; even BEC units with data often had only one or two stations and some with less than 15 years of data

[6] Early Winter Snow Depths - based on average Nov-Jan mean monthly snow depths; where unavailable based on mean annual winter precip and snowfall, number of months with snow and number of degree days < 0.

[7] Summer Temperatures - based on mean temp in warmest month and # of months with mean temps >10 degrees

[8] Spring Snowmelt - based on average Mar-June mean monthly snow depths; where unavailable based on mean annual snowfall, and number of frost free days, months with temperature <0 and degree days >5

APPENDIX C: COMILATION OF PREDATION PARAMETERS

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
Demographics	Mean Pack Size	mean pack size	6	wolf		Peterson et al in Carbyn 1983	mean pack size was 12 (early winter) but declined to 6 after 1980 after hunter harvesting increased- Alaska
	(pack size)	pack size	2-20 (average=10.8)	wolf		Smith et al 2004	based on 13-14 packs in Yellowstone:sizes of ind packs: 2,10,8,3?,12?,10,17,7,5,19,7,15,5?,15,20,17,2
		pack size	7 down to 5	wolf		Theberge 1998	1 wolfs pack over winter (PG 66)-Algonquin
		pack size	4	wolf		Theberge 1998	1 wolfs pack over winter (pg 86-87) Algonquin
		pack size	7	wolf		Theberge 1998	1 wolfs pack over winter (pg 86-87) Algonquin
		pack size	6	wolf		Theberge 1998	1 wolfs pack over winter (pg 86-87) Algonquin
		pack size	2-12 (avg=5.4) , 7-9 in early fall	wolf		Person et al 1996	SE Alaska
		pack size	from 3-11 (avg=6)	wolf		Ballard et al 1987	pack size numbers for up to 13 packs from 1975 through 1982 spring and fall counts - this is a hunted popltn-Alaska
		pack size	9.3	wolf		Gasaway et al 1983	average pack size during early winter -Alaska
		pack size	5-9	wolf		Fuller 1989	range of mean pack size Minnesota
		pack size	w	wolf		Fuller and Keith 1980	Alberta -
		pack size	7-12 in wint/5-9 adults and 7 pups in summer	wolf		Fuller and Keith 1980	Alberta -
		pack size	2 in winter/2 adults and 3 pups in sum	wolf		Fuller and Keith 1980	Alberta -
		pack size	5-8	wolf		Ministry of Env. 1985	"packs usually consist of 5-8 individuals…"
		pack size	2-20	wolf		Hayes 1995	mean pack size for 1990=4, 1991= 5, 1992=6, 1993=7, 1994= 7.8 for years after wolf control stopped
		pack size	6-8	wolf		Seip 1992	mean winter pack size
		mean pack size and principal prey size	mean prey size=5.66, prey deer/mps=6.49, pry moose/ mps=10.2 prey elk/ mps=9.05 prey elk	wolf	deer/moose/elk caribou	Fuller et al 2003	summary stats from data from mnay studies

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
Prey mortality	Summer Rate of Attack: mean and sd for probability of killing an adult given encounter, specified by prey species.	% of prey taken	0.7	wolf	moose	Ballard et al 1987	from April to April 70% of the observed kill was moose -Alaska
	(need # killed as well as number detected and thus % killed out of # that predators encounter)	note on kill rate	summer kill rate is 70% of winter kill rate	wolf	elk	Vucetich et al 2005	note comment
	(also look for stats on likliehood of predator taking one sp over another)	% of prey taken	0.38	wolf	moose	Ballard et al 1987	adult moose were most common prey May-Oct
		% of prey taken	0.21	wolf	caribou	Ballard et al 1987	2nd most important prey - Alaska
		note		wolf	caribou	Seip 1992	wolf kills of caribou happened in summer and early winter -SE BC
		overall selectivity of wolves for prey types by packs and season	graph - no # data	wolf	elk/moose/ deer	Huggard 1993	pg 134 and 135 by seasonBanff - in this study elk and deer were slected equally on a per individual basis and elk were prefered on a per encounter (herd) basis
		note on kill rate		wolf		Ballard et al 1987	estiamted that wolves killed approx the same prey biomass during summer and winter
		generalizations about vulnerabiltiy		wolf	various prey	Mech and Peterson 2003	young are most vulnerable in their first few weeks, and remain so for most of their 1st yr except caribou/ adult males most vulnerable just before, during and just after rut/ adult feamles most vulnerable in late winter
		% success	49% based on hunts/ 3% based on individuals	wolf	caribou	Mech and Peterson 2003	Haber 1977 in…. Alaska, also author notes that these results should be considered min. effort because Haber included prey that he thought wolves "tested"…
Prey mortality	Summer Rate of Attack: mean and sd for probability of killing a calf given encounter, specified by prey species.	% prey type	0.3	wolf	moose	Ballard et al 1987	during may and June 30% of moose killed were calves - thye composed 38-48% of the moose popltn

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
	(for ROA on calves also look for data on ratio of selection for calves)	% prey type	0.14	wolf	moose	Ballard et al 1987	Jul-Oct 14% of moose taken were calves - and they composed 12-20% of moose counted in Nov surveys.
		% prey type	0.4	wolf	moose	Ballard et al 1987	Nov-Apr calves were 40% of wolf kills -but were only 12-20% of moose poltn counted in Nov.
		% calves relative to popltn	approx 42% of kill but calves made up 20% of the poltn	wolf	moose	Fuller and Keith	Alberta
		% fawns taken	30%	cougar	mule deer	Ackerman et al	in summer (jul-sep) 30% of muloe deer kill was fawns, 20% adult males and 50% adult females -Utah
Prey mortality	Winter Rate of Attack for adults: mean and sd for probability of killing an adult given encounter, specified by prey species.	% prey type	55% moose, 12% caribou17% other prey, 26% empty	wolves	moose/caribou	Gassaway et al 1983	stmach contents - Alaska study btwn 1975-79 apopltns are approx 2500-3500 moose and caribou 1500-4000 with poltn of moose and caribou increasing in mid 70's after wolf control in some areas and remaining stable in others after wolf control
	(need # killed as well as number detected and thus % killed out of # that predators encounter)	% prey type	15 elk:1 moose - wolf diet	wolves	elk/moose/wt deer	Carbyn 1983	The elk moose popltn was 2.4 elk to every 1 moose but predation rate was 15 elk to 1 moose.
	(also look for stats on likliehood of predator taking one sp over another)	kill rate	7.9+/-0.7(SE) kg moose^{-1}day^{-1} compared to 2.5+/-0.6(SE) kg caribou wolf^{-1}day^{-1}	wolf	moose/caribou	Hayes 1995	caribou greatly outnumbered moose but packs killed more moose (40) then caribou(20).
		# successful attacks	out of 45 attempts - 37 were successful	cougar	prey?	Hornocker 1970	author notes the difficulty in calculating rate of successful attacks and further states that using tracks in snow - it would appear that most attacks are successful and if the final attack (meaning what you see with tracks in the snow) is considered the attempt.

Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
	note on prey selection by predator		wolf/cougar	WT deer/elk/ moose	Kunkel et al 1999	their prediction was that wolves would kill more vulnerable prey than cougars - proved false -WT deer was 83% of wolf kill and 87% of cougar kill, and elk and moose were a larger part of the wolf diet than cougar - wolves and cougars selected more old and young deeer and elk than hunters....deer more frequency of tracks than elk and elk than moose...
	%prey killed/ %prey available/ % prey encountered	83% of prey killed / prey availability 74.4% / prey encountered 89%	wolf	WT deer	Kunkel et al 2004	% killed is % of that prey species btwn deer, elk and moose - prey availability is based on tracks/km of that prey compared to other large ungulate prey, prey encountered is % of that prey spp tracks found along wolf travel routes- Montana study
	%prey killed/ %prey available/ % prey encountered	13.9% of prey killed / prey availability 16.1% / prey encountered 9.1%	wolf	elk	Kunkel et al 2004	% killed is % of that prey species btwn deer, elk and moose - prey availability is based on tracks/km of that prey compared to other large ungulate prey, prey encountered is % of that prey spp tracks found along wolf travel routes- Montana study
	%prey killed/ %prey available/ % prey encountered	3% of prey killed / prey availability 9.6% / prey encountered 1.9%	wolf	moose	Kunkel et al 2004	% killed is % of that prey species btwn deer, elk and moose - prey availability is based on tracks/km of that prey compared to other large ungulate prey, prey encountered is % of that prey spp tracks found along wolf travel routes- Montana study
	note on prey selection by predator		cougar	mule deer/elk	Anderson and Lindzey 2003	in this study female cougars killed more mule deer than other sp and male cougars killed more elk than other spp - Wyoming
	note on prey selection by predator		cougar	mule deer	Spalding and Lesowski 1971	mule deer were approx 74% of the cougars winter diet in the Okanogan - author notes that although WT deer were common, none found in stomachs
	note on prey selection by predator		cougar	moose/el k/deer	Cdn Wildlife Service 1990	in sw alberta moose calfs were 85% of winter prey for adult male, deer and elk were 79% of female diet in winter
	prey killed vs prey availability		wolf	moose/c aribou	Joly and Paterson 2003	presents data from various studies with density of prey vs preference by predator
	hunting success rate	10%	wolf	moose	Peterson 1977	wolves tended to kill less than 10% of the moose they encountered - Isle Royale
	hunting success rate	15%	wolf	caribou	Mech et al 1998	on avg wolves killed 15% of caribou they encountered - Alaska

Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
	encounter rate/% overlap of habitat use/% prey killed	encounter rates for pack 1: 5.76 (SE0.87), % overlap of elk with pack 77.2, and % of prey killed by this pack that were elk is 82.5%	wolf	elk	Huggard 1993	encounter rates for pack 2: 4.41 (SE1.11), % overlap of elk with pack 77.9, and % of prey killed by this pack that were elk is 61.5%
	encounter rate/% overlap of habitat use/% prey killed	encounter rates for pack 1: 1.35 (SE0.38), % overlap of deer with pack 75.7, and % of prey killed by this pack that weredeer is 9.5%	wolf	M and WT deer	Huggard 1993	encounter rates for pack 2: 1.52 (SE0.47), % overlap of deer with pack 84.3, and % of prey killed by this pack that were deer is 10.9%
	% overlap of habitat use with wolves/% prey killed	% overlap of moose with wolves for pack 1 was 55.2/ % of prey killed that were moose 4.4%	wolf	moose	Huggard 1993	% overlap of moose with wolves for pack 2 was 57.3/ % of prey killed that were moose 17.2%
	overall selectivity of wolves for prey types by packs and season	graph - no # data	wolf	elk/moose/ deer	Huggard 1993	pg 134 and 135 by seasonBanff - in this study elk and deer were slected equally on a per individual basis and elk were prefered on a per encounter (herd) basis
	success rate	46%	wolf	WT deer	Kolenosky 1972	of 35 chases reconstructed 46% were successful
	densities/pred rates	note	wolf	caribou/ moose	Lessard 2005	author sumarizes densities and pred rates for various studies
	proportion of prey encounters resulting in kills	50% caribou, 16% moose calves, 4% yrlng and adult moose	wolf	caribou/ moose	Walters et al 1981	data from Haber 1977 for their model
	% success	19-38% based on hunts/ 13-26% based on individuals	wolf	moose	Mech and Peterson 2003	Mech et al 1998 in… Denali, Alaska
	% success	46% based on individuals	wolf	deer	Mech and Peterson 2003	Kolenosky 1972 in ….. Ontario
	% success	20% basedon indiv.	wolf	deer	Mech and Peterson 2003	Nelson and Mech 1993 in…. Minnesota
	% success	56% basedon indiv.	wolf	caribou	Mech and Peterson 2003	Haber 1977 in….. Denali
	% success	15% based on hunts/ 1% basedon indiv.	wolf	caribou	Mech and Peterson 2003	Mech et al 1998 in… Denali, Alaska
	% success	21% based on hunts/ 1% basedon indiv.	wolf	elk	Mech and Peterson 2003	Mech et al 2001 in… Yellowstone
	% success	7.80%	wolf	moose	Peterson and Ciucci 2003	on Isle Royale from Mech 1966b in….

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
		% success	50%	wolf	caribou	Thomas 2003	Haber 1977 in….. Denali
		note on prey selection		cougar		www.hww.ca/hww2.asp?id=87	"Where different prey species are available the diets of male and female cougars may be significantly different. In winter in the Sheep River area of southwestern Alberta, moose calves made up about 85 percent of the winter prey of male cougars, whereas deer and elk represented 79 percent of the diet of female cougars."
Prey mortality	Winter Rate of Attack for calves: mean and sd for probability of killing a calf given encounter, specified by prey species.	% calves	27% of elk killed by wolves were calves	wolves	elk	Smith et al 2004	authors note: wolves selected calves in early winter, bulls in late winter and in summer elk as prey decreased and mule deer became part of the diet-Yellowstone
	(for ROA on calves also look for data on ratio of selection for calves)	% calves	32% of moose killed were calves	wolves	moose	Hayes et al 2000	in winter - authors found no relation to # of calvesin wolves diet and proportion in population - Yukon
		% fawns	40%	cougars	mule deer	Ackerman et al 1984	in winter 40% of mule deers killed were fawns, 40% adult males and 20% adult females - Jan-Mar Utah
		note on prey selection by predator		cougar	moose/elk/deer	Cdn Wildlife Service 1990	in sw alberta moose calfs were 85% of winter prey for adult male, deer and elk were 79% of female diet in winter
		ratio of selection for calves	6:1	wolves	moose	Burkholder 1959	for moose the wolves selected calves at a ratio of 6:1 - Alaska
		% calves	1.8% caribou calves (38% adult caribou)/ 10.1 % calf moose (25% adult moose)	wolves	caribou	Ballard et al 1997	authors note that wolves killed proportionally fewer caribou claves than adults in winter based on spring caribou counts - author noted that Ballard et al (1987) and Mech et al (1995) also found fewer calf caribou killed in winter. Calf moose were 17% of moose popltn, and 21% of kills
		% calves	Calves were 20% of moose popltn and 47% of kill	wolves	moose	Peterson et al 1984	Alaska

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
		% fawns	17% killed, 26% of popltn/ 34% killed, 33% of the popltn/ 30% killed, 35% of popltn/ 17% killed, 20% of popltn	wolves	WT deer	Vales and Peek 1995	data from various studies
		% calves	34% killed, 19% of the poltn	wolves	elk	Vales and Peek 1995	data from various studies
Prey mortality	Time spent handling adult prey (days/predator)	days/pack	3.3+/-0.19 days	wolves	moose	Hayes et al 2000	per small packs (2-3 wolves) for adult moose no significant diff between pack sizes - thus average handling time for this study is 2.9+/-0.17
		days/pack	3.1+/-0.5 days	wolves	moose	Hayes et al 2000	per med packs (4-9 wolves)
		days/pack	2.6+/-0.16 days	wolves	moose	Hayes et al 2000	per large pack (>10 wolves)
			1.3+/-0.1 days	wolves	caribou	Hayes et al 2000	authors note: saw some large packs consume caribou in a few hours making it difficult to accurately estimate caribou handling time
		days/pack	mean=3.8 range 2-5 days	wolves	moose	Ballard et al 1987	the longest avg stay at a kill recorded during this study was when a cow and a calf were killed.
		days/pack	mean 3.3 days	wolves	moose	Ballard et al 1987	9 wolves at an adult moose
		days/pack	average 2.7 days	wolves	moose	Ballard et al 1987	average length of time wolves remained at adult moose in this study- Alaska
		days/pack	mean of 2.5 days	wolves	moose	Ballard et al 1987	for a wolf pack of 9-10 in Alberta Fuller and Keith's study cited in...
		days/pack	average 2.3 days	wolves	caribou	Ballard et al 1987	Alaska 2 days each for a pack of 7 and a pack size of 8, 3 days were spent by a pack size of 4
		days/pack	<24hrs	wolves	WT Deer	Fuller 1989	no pack stayed at a deer kill longer than 24hrs - author notes that larger packs probably stayed less than 12hrs
		days/pack	2.5 days	wolves	moose	Fuller and Keith 1980	this is for a mean pack size of 9.8 wolves
		days/pack	1.4=/-0.1 days	wolves	elk	Carbyn 1983	time spent at elk cows - pack of 5 wolves?-Maniitoba
		predator handling time	0.01	wolves	moose	Stocker 1981	predator handling time for older moose..Denali, Alaska

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
		days/pack	2.9+/-0.17(SE) days	wolves	moose	Hayes 1995	mean handling time was the same for adult and calf moose - as well, mean handling time was not sig. diff. for small (3.3+/-0.19), med (3.1+/-0.5) and large (2.6+/-0.16) packs for adult kills - there was a sig diff btwn handling time of calves for diff size packs - note below -Yukon
		days/pack	1.3 +/-0.1 (SE) days	wolves	caribou	Hayes 1995	all packs spent an avg of 1.3 days except large packs could consume a caribou in a couple of hours so estiamtion of handling times was difficult.- Yukon
		days/predator	1-19 days	cougar	deer/elk	Seidensticker et al 1973	cougar remained in the vicinity of the prey for 1-19 days only leaving the prey for short periods until it was all consumed. - if it was not closely guarded it was quickly gotten by scavengers (raven, magpie, goldeneagle, coyote, other lion…)
		days/predator	3.4 nights on deer, 6.0 nights on elk	cougar	deer/elk	Andersonand Lindzey 2003	through GPS loctns-Wyoming
		days/predator	1.1-1.7 caribou/ 1.8-2 moose	wolves	moose/caribou	Ballard et al 1997	authors found no correlation btwn pack size and length of stay at either adult moose or adult caribou kills which was 1.1-1.7 days and 1.8-2 for moose - Alaska
		days/predator	avg 2.4 and 3.4 days for 2 males/ avg 4.3 days for 2 females	cougar	large prey	Mattson et al 2005	through GPS loctns-Arizona, females avgd 1.3 and 1.6 days for small prey
Prey mortality	Time spent handling calf prey (days/predator)	days/pack	2.6+/-0.22days	wolves	moose	Hayes et al 2000	NOTE: pg 87 of your rept - "assume calf handling times are 37% of adult handling times" - but Hayes et al states ..found no difference in hndling times btwn adult moose and calf moose..but ..adult handling time did not differ with pack size but calf handling time did...note following data
		days/pack	3.3=/-0.3	wolves	moose	Hayes et al 2000	per small packs (2-3 wolves
		days/pack	2.5=/-0.3	wolves	moose	Hayes et al 2000	per med packs (4-9 wolves)
		days/pack	2.0=/-0.3	wolves	moose	Hayes et al 2000	per large pack (>10 wolves)
		days/pack	mean 4 days	wolves	moose	Ballard et al 1987	authors note that there is considerable variation among packs - i.e. A pack of 2 stayed at a calf moose for mean of 4 days. -Alaska

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
		days/pack	mean of 2.5 days	wolves	moose	Ballard et al 1987	average time wolves spent on calf in this study mean 2 days:pack size of 9, mean of 3 days:pack size of 8, mean of 2 days:pack size of 4, mean of 4 days:pack size of 2
		days/pack	mean of 1.5	wolves	moose	Fuller and Keith 1980	average time wolves spent on calf with a mean pack size of 9.8 wolves
		days/pack	1.5=/-0.07 days	wolves	elk	Carbyn 1983	time spent at elk calves - pack of 5 wolves?- Maniitoba
		predator handling time	0.005	wolves	moose	Stocker 1981	predator handling time for calf moose..Denali, Alaska
		days/pack	2.6+/-0.22(SE)days	wolves	moose	Hayes 1995	note above under Hayes 1995 for moose -also, calf handling time for diff pack size were sig different: small pack: 3.3+/-0.3(SE)days, medium 2.5+/-0.3(SE) days, large 2.0+/-0.3 (SE)days.
Prey mortality	Edible Biomass corrected for scavengers: (wts of ungulates, % consumable biomass, and/or estimates of loss to scavengers per day spent handling)	weight (kg)	500kg (bull) ,300 kg (cow)		elk	Tweill and Ward 2002	under optimal condtns, mature elk from the widespread mtn ecotypes - states bulls may exceed 500 and cows may exceed 300kg.
		weight (kg)	450 kg (bull), 310kg (cow)		elk	Tweill and Ward 2002	typical mature wieight of Rocky Mtn Elk
		weight (kg)	100 -250 kg		caribou	COSEWIC	
		weight (kg)	38-51 kg		wt deer	Halls 1984	large variation in wt depending on food and popltn density -wts are from sth and east US - this is potentially a field dressed wt although not specifically said in book
		weight (kg)	304-401 (avg -353.5) males/168-311 (avg-245.5) females		elk	Shackleton 1999	Rocky Mtn Elk
		weight (kg)	33-519 (avg-437.3) males / 270-352 (avg-312.3) females		moose	Shackleton 1999	northwestern moose
		weight (kg)	avg 505 males/375 females		moose	Shackleton 1999	Alaskan moose
		weight (kg)	avg 54.5 male/45.7 female		mule deer	Shackleton 1999	black-tailed deer
		weight (kg)	avg 103.7 male/ 64.6 female		mule deer	Shackleton 1999	Rocky Mtn mule deer
		weight (kg)	88 male		wt deer	Shackleton 1999	Dakota wt deer

Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
	weight (kg)	77 male/ 61.6 female		wt deer	Shackleton 1999	Northwestern wt deer
	weight (kg)	181-272 male / 91-145 female		caribou	Shackleton 1999	
	edible biomass	0.68		elk	Willmers et al 2003b	edible biomass calculated from kills from data in Willmers et al 2003 - Yellowstone
	loss to scavengers	10-50%		moose/caribou	Hayes et al 2000/Hayes 1995	Modelers quote Promberger 1992 in Hayes to estimate loss to raven scavengers of ungulate ranges from 50% from a pair of wolves 33% from a pack of 6 to 10% for a pack of of 10 wolves: note in Hayes 1995 he reestimated his consumption rates to account fro raven loss - if these are needed look up Hayes 1995
	edible biomass	0.75		caribou	Hayes et al 2000	from Ballard et al 1987 in Hayes
	edible biomass	0.65		moose	Hayes et al 2000	estimate made bu their measuring moose carcasesses after wolves had abandoned them
	kg of edible biomass/adult	295 kg		moose	Vucetich and Peterson 2004	note comment
	loss to scavengers	note		elk	Willmers et al 2003b	Authors note that the amount of snow influences the amount of food left for scavengers - the deeper snow weakens ungulates making them easy prey for wolves therefore wolves opt to kill another prey for the more valuable food bits rather than protect a kill for the lower value food bits.
	active consumption rates for scavengers	comment		scavengers	Willmers et al 2003b	note comment
	weight (kg)	152		caribou	Hayes et al 2000	
	edible wts (kg)	159		elk	Paquet et al 2001	average edible wt from New Mexico study
	edible wts (kg)	36		wt deer	Paquet et al 2001	average edible wt from New Mexico study
	edible wts (kg)	55		mule deer	Paquet et al 2001	average edible wt from New Mexico study
	weight (kg)	47		mule deer	Person et al 1996	the avg wt of adult Sitka bt deer Alaska
	% consumed	0.74		mule deer	Person et al 1996	authors assumtion that 74% of adult deer carcases are consumed based on Ballard et al 1987 and Fuller 1989. -sitka bt deer Alaska
	% consmable wt	0.75		moose/elk	Carbyn 1983	assumption by author based on Peterson 1977.
	% consumed	0.56		elk	Carbyn 1983	based on carcass use during tracking feb-mar

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
		% consumed	0.4		moose	Carbyn 1983	based on carcass use during tracking feb-mar
		% consumable biomass	0.75		moose	Ballard et al 1987	from Peterson 1977 in..
		% consumable biomass	0.75		caribou	Ballard et al 1987	
		% consumed	0.75		WT deer	Carbyn 1983	average carcass use of deer
		weight (kg)+proportion inedible and/or wasted	232kg/286kg live wt-0.2 inedible		elk	Weaver 1979	live wt of elk cow was 232kg and bull was 286 kg and the proportion inedible or wasted was 0.2
		% loss to scavengers	up to 75% for small packs	wolf		Kaczensky et al 2005	author notes that amount taken by ravens is dependant on pack size -for a pack of 2 a raven can take up to 75% of the edible biomass while for a large pack a raven would get virtually none-Yukon
Prey mortality	Proportion of adult edible biomass for calves:	weight (kg)	16-23		wt der	Halls 1984	this wt is for ~.5 yr olds - sth and eastern US - may be field dressed wt
	(wts of young as compared to wts of adults or edible biomass)	weight (kg)	10-15		Rocky Mtn Elk	Shackleton 1999	this wt is for newborn calves
		weight (kg)	11-16		moose	Shackleton 1999	this is newborn wt
		weight (kg)	2-4		mule deer	Shackleton 1999	this is newborn wt
		weight (kg)	2-4		WT Deer	Shackleton 1999	this is newborn wt
		weight (kg)	5-12		caribou	Shackleton 1999	this is newborn wt
		weight (kg)	150		moose	Hayes et al 2000	
		weight (kg)	55kg		caribou	Skoog 1982 and Hayes et al 1991 in Hayes 2000	avg wt of caribou calf
		kg of edible biomass/calf	114 kg		moose	Vucetich and Peterson 2004	note comment above in adult edible biomass section - excerpt from Vucetich and Peterson 2004
		weight (kg)	19.5		mule deer	Person et al 1996	winter fawn wt (<1yr) -Sitka BT deer Alaska
		% consumed	0.88		mule deer	Person et al 1996	authors assumption based on Floyd et al 1978

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
		% consumable biomass	75% ?		moose	Ballard et al 1987	from Peterson 1977 in… used for adult and yearling moose
		% consumable biomass	0.9		caribou	Ballard et al 1987	assumtion by author: newborn wighs 13 kg and gains wt at a rate of 1.3 kg/day thereofre 15day old calf weighs 32 kg of which 90% is consumable…
		weight (kg)	39kg		WT Deer	Fuller 1989	this is fawn weight/adult weighing 78kg
		weight (kg)+proportion inedible and/or wasted	109kg live wt - 0.0 inedible		elk	Weaver 1979	live wt of elk plus the proportion of inedible and /or wasted was 0.0 for calf
		weight (lb)	62 lbs female 68lbs male fawn		mule deer	Hornocker 1970	
		weight (lb)	254 lbs male calf, 227 lbs femal calf		elk	Hornocker 1970	
Prey mortality	Maximum Area searched per day (km2/day):	distance traveled per day	1977 - avg of 9km btwn loctns, 5.7km in 1978	wolves		Fuller and Keith 1980	this is the average straight line distances btwn daily loctns -Alberta
		distance traveled btwn kills	avg 44km over an average of 4.5 days	wolves		Fuller and Keith 1980	avg dist btwn kills (cumulative straight line dist btwn successive loctns)range 11-81km) over an averageof 4.5 days (range 2-6) btween kills. These are probably underestimates because based on daily loctns
		distance traveled btwn kills	avg 25km over an average of 2.7 days	wolves		Fuller and Keith 1980	avg dist btwn kills (cumulative straight line dist btwn successive loctns)range 3-61 km) over an averageof 2.7 days (range 1-4) btween kills. These are probably underestimates because based on daily loctns
		km/day	30-40km/day	wolves		Min of Env 1985	"wolves often move 30-40 km per day in search of their prey…"
		km/day	0-15 km	wolves		Messier 1985	data only in graph - y - states cumulative relative frequency, x - daily distnce (km) Quebec
		km^2/day	23+/-5(SE)km^2day^{-1}	wolves		Hayes 1995/Hayes et al 2000	small packs (2-3) Yukon
		km^2/day	18+/-5(SE)km^2day^{-1}	wolves		Hayes 1995/Hayes et al 2000	medium packs (4-9wolves)-Yukon
		km^2/day	28+/-4(SE)km^2day^{-1}	wolves		Hayes 1995/Hayes et al 2000	large packs(>=10wolves) -Yukon
		km/day	10.9km winter/12.9 km summer	cougars		Seidensticker 1973	this is max distance between locations - straight line distances rather than total distances travelled.

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
		km/day	1.5-4.8 km/day	cougars		Hemker et al 1984	author noted that females with class 1 cubs moved the least and females with older cubs moved progressively greater distances as the cubs got older.-these are straight line distances btwn daily loctns - Utah
		miles/day	6, 45 miles/day	wolves		Burkholder 1959	on one occasion the wolf pack was noted to move 6 miles, on another 45 miles in one day. - Alaska
		km/day	4.2-8.9 km/day	wolves		Kolenosky 1972	average daily travel - Ontario
		km/day	56km overnight, up to 72km in 24 hrs - or an average of 50 km/day	wolves		Mech and Boitani 2003	Pulliainen 1965 caimed that wolves being hunted travelled 200km in a day, but author notes this may be an exageration, authors note that in winter packs can travel the rates noted - further, that during hunting a pack may travel an average of 50km/day. - they further suggest that it is probable taht they can travel further in summer becasuse of the lack of snow.
Ungulate recruitment	Ratio adult females to males:	male to female ratio	1.45		elk	Toweill and Ward 2002	male to female ratio for Rocky Mtn Elk
		male to female ratio	8.3-8.6		elk	Mathews and Krein 2001	mean bull:100 cow ratio for 1996-2000-Oregon
		male to female ratio	27:73 / 23:79		moose	Mytton and Keith 1981	ratio for winter 1975-76/ ratio for76-77 winter obtained on surveys in Rochester, Alberta - note follwing bull:cow ratio is from 1st darting flights then relocation flights
		male to female ratio	47:53 / 41:59		moose	Mytton and Keith 1981	note above - and darting flts were oct-dec 1975 and relocation flts were Jul-Nov
		male to female ratio	26:74 /33:67		moose	Mytton and Keith 1981	bull:cow ratios in northeastern Alberta for 1976 and 1977 (Hauge and Keith in…)
		male to female ratio	35:100 (Jan1976) 49:100 (Feb 1977) 77:100 (Dec 1977)		moose	Hauge and Keith 1981	difference btwn the jan 76 and dec77 - suspect different because differnce in relative visibility - Alberta
		male to female ratio	note		wt deer	Halls 1984	the sex ratio at birth should be approximately even -but wide variation is reported - also if the bucks are more heavily hunted then the ratio chnges relative to this -the sex ratio is different for each poltn because of the diff mortality factors.
		male to female ratio	note		wt deer	Degayner and Jordan 1987	state that sex ratio at birth is not always even - depends on poltn and other factors

Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
	male to female ratio	1994: 25f:7m (O unk) / 1995:5fem:3mal (16 unknown), / 1996 12F:10M (0 u)/ 199715f:23m (4 u)/ 1998 70f:18m (0u)/ 1999 78f:16m (o u)/ 2000 37f:8m (0u)		caribou	Larter and Nagy 2003	from caribou herds on Banks and Melville Isl from July surveys the aver works out to be 56 bulls:100cows
	male to female ratio	31:100, 35:100, 86:100, 76:100, 44:100, 36:100, 74:100, 45:100, 27:100, 32:100, 32:100		elk	Toweill and Ward 2002	from a herd in Arid Lands Ecology reserve Washington from 1983-1993 average over the years works out to be 47:100
	male to female ratio	15:78 (19% bulls)		elk	Toweill and Ward 2002	from a herd in western Wash 1976
	male to female ratio	1:100		mule deer	White 2001	colorado study
	male to female ratio	40:60		mule deer	Person et al 1996	Sitka black-tailed deer in Alaska
	male to female ratio	1:3		mule deer	Pierce et al 2004	California -
	male to female ratio	1:5-10		moose	Gasaway et al 1983	author notes that 1 bull for every 5-10 cows is needed for successful reproduction in certain popltns..Bishop and Rausch 1974 in..
	male to female ratio	>=30:100		moose	Boertje et al 1996	30 males to 100 females-this ratio was the minimum that they wanted during an intense wolf control and then wolf recovery program in Alaska - there was no harvest of female moose during this time
	male to female ratio	>=30:100		caribou	Boertje et al 1996	30 males to 100 females-this ratio was the minimum that they wanted during an intense wolf control and then wolf recovery program in Alaska - there were different harvest rates during this time as the herd was on the decline - they do not mention if they actually acheived this ratio
	male to female ratio	103:100		BT deer	Hatter and Janz 1994	avg observed sex ratio between 1975-77 VI deer
	male to female ratio	60:100		BT deer	Hatter and Janz 1994	avg observed sex ratio 1984 VI deer

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
		% bulls of adults	16.9%-35.6%		caribou	Bergerud and Elliot 1986	% of bulls of adults for 1978-1983: 16.9,17.6,29.9,33.1,35.6,24.3 - this areas also had wolf control from 1977-1982
		male to female ratio	50:50		sitka BT deer	Smith et al 1987	from nightcounts and heli surveys: data shows that adult se ratio is roughly 50:50 - authors note that Taber and Dasmann (1954) state that both sp of Odocoileus have this ratio under good range condtns and females dominate in food stressed herds.
		male to female ratio	28.7:100 up to 51.7:100 and 35.9:100 vs 21.1:100 and 59.2:100 vs 58:100		caribou	Hayes et al 2003	before wolf control was 28.7 bulls:100 cows - 3 yrs after wolf control 51.7:100. Areas without tratment did not have a change in ratio. 35:100 before, 21:100 after and other control herd was 59 before and 58 after
		male to female ratio	38% adult bulls		caribou	Fuller and Keith 1981	Kelsall (1968), Parker (1972) and Miller (1974) in ... found 30-40% bulls in areas with little or no hunting and Bergerud (1971 in..) found 28-42% bulls in hunted popltns
Ungulate recruitment	Maximum fecundity:	pregnancy rate	92.4%+/-2.24		caribou	Wittmer et al 2005	123 out 134 adult females - BC
	please note: The modelers used preg rates (out of Wittmer et al and the other cited papers) the same as maxfecundity (fetuses/cow) for elk and caribou because they only have 1 calf/cow (elk only have a 1% chance of twinning(Toweill and Thomas 2002), However, because deer and moose can have twins or more the max fecundity is based on fetuses/doe or cow.	pregnancy rate	0.83		caribou	Flaa and McLellan 2000	Revelstoke caribou
		pregnancy rate	0.93		caribou	Seip 1990	Wells Gray

Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
	fetuses/doe	1.5		mule deer	Wallmo 1981	fetuses/doe for Rocky Mtn Mule Deer - Montana
	fetuses/doe	1.72		mule deer	Wallmo 1981	fetuses/doe for Rocky Mtn Mule Deer - Colorado
	fetuses/doe	1.71		mule deer	Wallmo 1981	fetuses/doe for Rocky Mtn Mule Deer - California
	fetuses/doe	1.49		mule deer	Wallmo 1981	fetuses/doe for Rocky Mtn Mule Deer - Utah
	fetuses/doe	1.71		mule deer	Wallmo 1981	fetuses/doe for Rocky Mtn Mule Deer - Oregon
	fetuses/doe	1.51		mule deer	Wallmo 1981	fetuses/doe for Rocky Mtn Mule Deer - Washington
	fetuses/doe	1.38		mule deer	Wallmo 1981	fetuses/doe for Rocky Mtn Mule Deer - Colorado
	fetuses/doe	1.24		mule deer	Wallmo 1981	fetuses/doe for Rocky Mtn Mule Deer - California/Nevada
	fetuses/doe	1.24		Black-tailed deer	Wallmo 1981	fetuses/doe for California
	fetuses/doe	1.36		Black-tailed deer	Wallmo 1981	fetuses/doe for Washington
	pregnancy rate	0.54		Roosevelt Elk	Toweill and Thomas 2002	% of prime age lactating cows that were preganant -Oregon
	pregnancy rate	0.84		Roosevelt Elk	Toweill and Thomas 2002	% of prime age non-lactating cows that were preganant-Oregon
	fawns/doe	1.83		mule deer	Bender et al 2001	"adult does produced a min of 1.83 fawns…in 1999" in 2000=1.36 fawns/doe -Washington
	fetuses/doe	1.71		mule deer	Watkins et al 2001	mean fetal rate per adult doe -Colorado
	pregnancy rate	72,89%		elk	Zager and Gratson, 2001	preg rate in 2 management units in Idaho the lower preg rate is from a herd in poorer condtn
	pregnancy rate	61-96%		elk	Noyes et al 2001	range of preg rates given for 1993 and 95-98 - abstract only in proceedings - these rates were for a breeding trial in Oregon in a controlled area with acontrolled # of animals
	pregnancy rate	86-96%		elk	Noyes, Johnson et al 2001	a study on the effect of archery on preg rates - went down to 78% for year with archery season - Oregon
	pregnancy rate	40,92,73,100%		caribou	Thomas 1982	for Peel popltn of Peary caribou in 1974-77 Nth Cdn Islands -author found change in preg rate correlated with change in fat reserves and body wt.

Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
	pregnancy rate	7,7,6,88%		caribou	Thomas 1982	for Parry popltn of Peary caribou in 1974-77 Nth Cdn Islands -author found change in preg rate correlated with change in fat reserves and body wt.
	pregnancy rate	0.77		elk	Cook et al 2004	44 out of 57 were pregnant: data from captive herd of Rocky Mtn elk where nutrition was manipulated after prgnancy in Dec 95 - so subsequent years preg rates not noted here.
	fetuses/doe	1.7 SE=0.109		mule deer	Andelt et al 2004	Colorado
	twinning rate/preg rate	preg rate=0.89, twinning rate=0.63		moose	Bertram and Vivion 2002	for monitored cows in Eastern Alaska
	twinning rate/preg rate	preg rate=0.96, twinning rate=0.31		moose	Bertram and Vivion 2002	from low density moose popltns: NWT
	twinning rate/preg rate	preg rate=1.0, twinning rate=0.52		moose	Bertram and Vivion 2002	from low density moose popltns: Alaska
	twinning rate/preg rate	preg rate=0.84, twinning rate=0.28		moose	Bertram and Vivion 2002	from low density moose popltns: SthYukon
	fecundity	0.68		moose	Testa 2001	1994 parturation rate=63%, twinning rate= 9.1 % Alaska
	fecundity	0.97		moose	Testa 2001	1995 parturation rate=86%, twinning rate= 12.6 % Alaska
	fecundity	0.98		moose	Testa 2001	1996 parturation rate=86%, twinning rate= 14.4 % Alaska
	fecundity	1.06		moose	Testa 2001	1997 parturation rate=87%, twinning rate= 21.2 % Alaska
	fecundity	0.97		moose	Testa 2001	1998 parturation rate=78%, twinning rate= 24.4 % Alaska
	fecundity	1.07		moose	Testa 2001	1999 parturation rate=90%, twinning rate= 18 % Alaska
	fecundity	0.89		moose	Testa 2001	2000 parturation rate=76%, twinning rate= 16.9 % Alaska
	fecundity	0.97		moose	Testa 2001	total for Test 2001 parturation rate=82%, twinning rate= 16.6 % Nelchina study area Alaska
	fetuses/doe	1.83 SE=0.31		white-tailed deer	Robinson et al 2002	in this study there was no diff in fetal rates between wt deer and mule deer (rate below)- WT deer examined only in 2000 mule deer checked from 97 to 2000-southern BC
	fetuses/doe	1.78 SE=22		mule deer	Robinson et al 2002	note above note - BC

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
		twinning rate/preg rate	preg rate=0.81, twinning rate=0.38		moose	Ballard et al 1991	this is the average from the following rates: preg:88%,73,79,82,72 twinning rates for same years 23%,31,52,58,63 these rates are similar to others from Alaska and NAmerica note next row
		fetal counts	0.22, 1.27,0.14		moose	Schwartz and Hundertmark 1993	fetal counts for yrlngs, cows aged 2-15, and cows > 16 respectively
		fetuses/doe	0.5-1.55		white-tailed deer	Bunnell in Wemmer 1987	0.5 yrs=0.5, 1.5 yrs=1.55, >/==1.51
		fawns/doe	1.5		white-tailed deer	Jensen and Miller 2001	fawns produced/year/deer mi=1.5 where mi is the fecundity of age i deer
		pregnancy rate	0.925		caribou	Young and Freeman 2001	
		pregnancy rate	0.86		caribou	Bergerud and Elliot 1986	data for mainland canadian caribou…Bergerud 1980 in Bergerud 1986
		parturition rate	112 calves/100 females		moose	Bergerud and Elliot 1998	Larsen et al 1989a and Child pers comm in ...this is for moose in their study area - nthn BC
		parturition rate	84 calves/100 females		caribou	Bergerud and Elliot 1998	Bergerud and Elliot 1986 in…
		parturition rate	80 calves/100 females		elk	Bergerud and Elliot 1998	Bunnell 1987 and Brunt et al 1989 in…
Ungulate recruitment	Proportion of >1yr Adults breeding.	note			elk	Tweill and Ward 2002	Author states that puberty and conception strongly related to wt- 1/2 the elk cows in a herd will reach puberty when 70% of mature wt. In well nourished popltns 1st estrus in fall of 2nd yr - may be delayed 1 yr in undernourished popltn
		note			caribou	Adams and Dale 1998b	if when they start breeding and other reprod stuff in this publication
		pregnancy rate	46-90%		caribou	Fuller and Keith 1981	for 2 yrs or older barren ground caribou in canada and Alaska in various studies
		note above category - fecundity for other preg rates					
		pregnancy rate	71-90%		moose	Ballard et al 1991	preg rates ranged from 71-90% for other NA moose poltns (Blood 1974 in…)
		pregnancy rate	100%		WT deer	Halls 1984	for does more than one year of age in 1 area of Alberta

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
		pregnancy rate	varied from 67-100% avg 92%		Mule and BT deer	Wallmo 1981	for various areas in the US (Wash, Cal, Colorado, Texas,Utah,Oregon)
		reproductive rate	avg 0.81 SE0.037		moose	Testa 2001	avg annual reprod rate for >=4 yr old cows from 1994-2000 - Alaska
Predator recruitment	Maximum rate of decrease:	max sustainable mortality	note comment for data	wolf		Ballard et al 1987	authors note that with an overall mortality rate of 50% for all causes the wolf poltns could remain stable - a further note that excluding natural mortality (which accounted for approx 20%) human harvest in excess of 40% would cause a poltn decline - for individual packs this number would change depending on sex and age composition of the pack - Alaska
		max sustainable exploitation	0.38	wolf		Keith in Carbyn 1983	author notes that where human exploitation does not exceed 38% wolf densities adjust to available food -rates of increase decline to 0 as per capita food supply declines… based on info from many studies throughout NA (incl Alaska)
		max sustainable exploitation	23% and 38%	wolf		Keith in Carbyn 1983	the max sustainable harvest of 38% assumes harvest over a short period of time - author notes that a more conservative estimate is 23% - this was calculated using his estimate of rm of 0.304, an assumption of constant harvest over 5 months (Nov-Mar) and a reproductive coeficient of 2.3.
		harvest rate	0.3	wolf		Gasaway et al	author notes that harvest rates of >30% are required to reduce wolf numbers.
		max sustainable exploitation	nat mort=35%, harvest=28%	wolf		Fuller 1989	reanalysed Ballard et al and" using transformed values of finite rates of increase... as a regression variablewith percent overwinter mortality results to increase model fit…revised model suggests, on average, a stable poltn(lambda=1) with an overwinter mort rate of 35% and harvest rate of 28%. pers comm with Ballard by Fuller: 8 of 25 packs with >35% mort (28% harvbest) had rates of increase of >=1.00
		yearly mortality rate	0.5	wolf		Fuller and Keith 1980	Mech (1977) in Fuller and Keith states that a wolf popltn with an adequate prey base can sustain up to 50% yearly mort without reduction.

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
		max sustainable exploitation	25%	cougar		Oregon Fish and Wildlife 2006	…"Anderson and Lindzey (2005) found that cougar populations did not begin to decline until adult (3+) females comprised at least 25% of the harvest."
		max sustainable loss	50%	wolf		Peterson et al 1984	Mech 1970 in… determined total mortality (hunitng and natural) had to be no more than 50% in order to replace annual loss. - author also supports Keith (1983) that resilience of a wolf poltn will vary depending on avg litter size, nat mort rate and pack size.
		mort rate for stable pop rate	mort rate of 0.34+/-0.06SE or human caused rate 0.22+/-0.08 SE	wolf		Fuller et al 2003	for a wolf poltn to stabalize (r=.00 and lambda=1.00) these mort rates in late autumnare needed - from many studies - this chapter also discusses more specifically rates from other studies NOTED that there was large variation between studies for this rate important note made by authors -most critical factor that determines the annual percent that can be taken by humans without reducing the popltn is the poltns productivity
		note		cougar		Cougar Management Guidelines Working Group 2005	notes that dispersal is critical in maintainignpopltn - i.e. harvest in one area can be 30% but need adjacent popltns at lower levels to compensate…
		max sustainable exploitation	28%	cougar		Akenson et al 2005	Logan (2001) in… indicates that if harvest exceeds 28% the popltn will decline.
Predator recruitmen t	Upper limit of r (instantaneous rate of increase):	(wild) rate of increase	r_m=0.304 (maxlambda=1.36)	wolf		Keith in Carbyn 1983	best estimate for wolf popltns in the wild (found by calculating a survival-fecundity rate of increase from highest reproductive and survival rates in the wild - data from Mech 1970 and Rausch 1967)
	(theoretical and wild popltns)	theoretical rate of increase	0.833 (lambda=2.3)	wolf		Keith in Carbyn 1983	theoretical exponential rate given max reproduction, stable age distribution and no deaths
		(wild) rate of increase	0.326 (lambda=1.39)	wolf		Keith in Carbyn 1983	rate of increase from Isle Royale from 1952-59 - author notes that this rate probably approaches max or intrinsic rate for wolves.
		annual rate of increase	0.57-0.81	wolf		Ballard et al 1987	annual rate of increase during years of wolf control - note follwing data for same area w/o wolf control
		annual rate of increase	1.04-2.4	wolf		Ballard et al 1987	annual rate of increase for years after wolf control was stopped -Alasks

	Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
		mean annual rate of increase	1.02	wolf	WT deer	Fuller 1989	annual finite rate of increase varied from 0.88-1.33 -Minnisota study
		annual finite rate of increase	note	wolf		Fuller 1989	note : Fuller 1989 provides a summary of annual finite rates of increase for 9 studies including ones from Alaska and Alberta if this is needed
		finite rate of increase	1.21	wolf		Fuller and Keith 1980	Alberta study
		max rate of increas	0.5	wolf		Stocker 1981	where rmax is the max intrinsic rate of increase of wolf pack numbers.
		finite rate of increase	lambda=2.38	wolf		Hayes 1995	this is the finite rate of increase for the first year of recolonization after wolf control
		annual rate of increase	lambda=2.06-2.53	wolf		Hayes 1995	from Farnell et al (unpubl ms) in…
		spring finite rate of increase	0.34-1.22	wolf		Ballard et al 1997	finite rates of increase varied from 0.34 in 1991 and 1.22 in 1988 and also in 1990.Alaska
		fall finite rate of increase	0.62-1.43	wolf		Ballard et al 1997	finite rates of increase varied from 0.62 in 1991 and 1.43 in 1988
		finite rate of increase	0.42-1.49	wolf		Fuller et al 2003	finite rates of increase for vrious studies with references to primary prey spp.
Predator recruitment	Food Intake at half of maximum kill rate (kg/predator/day):	mean consumption rate	0.04kg of food per kg of wolf body wt per day	wolf	deer	Person et al 1996	authors state that this is what the mean consumtion rate of wolves is in other parts of NA where deer is the primary prey.
		consumption rate	2.72 kg/wolf/day	wolf	mule deer	Person et al 1996	based on the above using avg wolf wt on Prince of Wales Isl as 30.4kg - Alaska -Sitka BT deer
		consumption rate	2.9 kg/wolf/day	wolf	prey general	Holleman and Stephenson 1981	winter consumption Kolensky 1972 in …
		consumption rate	2.5kg/wolf/day	wolf	deer	Holleman and Stephenson 1981	winter consumption of deer Mech and Frenzel 1971 in …
		consumption rate	1.7-5.8 kg/day/wolf	wolf	prey general? Deer?	Holleman and Stephenson 1981	(probably deer as prey) this is based on a packs food consumption for 6 winters Mech 1977 in..
		consumption rate	4.9-6.1 kg/day/wolf	wolf	moose	Holleman and Stephenson 1981	T.Fuller and Keith (Alberta) - pers comm - a pack of 9-10 wolves during 2 winters
		consumption rate	1.7 kg/day/wolf	wolf	caribou	Holleman and Stephenson 1981	this is based on the assumption that all the radiocesium (the method used to determine prey eaten) was from caribou - the author then states that this is a safe assumption …
		consumption rate	0.81 kg/day/wolf	wolf	BT deer	Holleman and Stephenson 1981	based on radiocesium levels in stmachs - authors assumption that the body wt of deer is 40kg and that 50% was consumed Alaska

Model Parameter (in brackets are variables which make up the model parameter)	variables	data	Predator species	ungulate species	source	comments
	consumption rate	3.6 kg/day/wolf (3-3.4 kg/day/wolf)	wolf	prey general? Deer?	Ballard et al 1987	Mech 1977 in Ballard et al - noted a wolf pack remained stable at 3.6 but declined at 3-3.4 - note next note
	consumption rate	5.8 kg/wolf/day	wolf	prey general? Deer?	Ballard et al 1987	Mech 1977 in Ballard et al - noted a wolf pack increased at this consumption rate
	consumption rate	5.3 kg/wolf/day	wolf	prey general	Ballard et al 1987	Alaska
	consumption rate	4.5-8 kg/wolf/day	wolf	prey (mostly caribou/ moose)	Ballard et al 1987	this is the range of consumption rates -Alaska study
	consumption rate	4.9 and 6.1kg/wolf/day	wolf	mostly moose	Ballard et al 1987	for Fuller and Keith(1980) -Alberta cited in ...
	consumption rate	2kg/wolf/day	wolf	WT deer	Fuller 1989	winter consumption of WT deer - Minnesota study
	consumption rate	6.8 kg/wolf/day	wolf	elk	Fuller 1989	Carbyn 83 in… Manitoba
	consumption rate	5.5 kg/wolf/day	wolf	moose	Fuller 1989	Fuller and Keith 1980 in…Alberta
	consumption rate	6.1 kg/wolf/day in 1977 and 4.9 kg/wolf/day in 1978	wolf	moose	Fuller and Keith 1980	Alberta
	consumption rate	25-35 deer sized prey/yr; or up to 50 ungulates/yr	cougar	prey ungulates	Katnik 2002	Sth Selkirk Mtns - but these numbers from other sources in Katnik..
	consumption rate	5.2-7.5 kg/wolf/day	wolf	elk	Weaver 1979	
	consumption rate	7-8 lb/day	cougar	deer	Hornocker 1970	based on Robinette et al in Utah -1959 study
	consumption rate	2.6-3 kg/day/wolf	wolf	caribou	Holleman and Stephenson 1981	based on radiocesium levels in stmachs - authors assumption that the body wt of caribou is 75kg and that 50% was consumed Alaska
	consumption rate	approx 2.8kg/day/wolf	wolf	moose	Holleman and Stephenson 1981	based on radiocesium levels in stmachs - authors assumption that the body wt of moose is 300kg and that 50% was consumed Alaska
	consumption rate	4.1 and 6.4 kg/wolf/day	wolf	prey general	Hayes et al 2000	this is adjusted to account for scavengers - before adjustment consumption rate was 8.7 kg/wolf/day -

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