Northern Woodland Caribou – Habitat Models

Late winter, Calving and Summer Habitat Suitability Models

Morie and Lakes Forest Districts IFPA

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INTRODUCTION

This report describes the caribou winter, calving and summer habitat models developed for the Morice and Lakes Innovative Forest Practices Agreement (IFPA) eco-subgroup. The following report documents a species account for northern woodland caribou, outlines the logic used and assumptions made in the preparation of the model, describes the model and the relationships used to build the model, and outlines testing of model sensitivity and the level of validation.

NORTHERN WOODLAND CARIBOU

Common Name: Woodland Caribou (Northern ecotype)
Scientific Name: Rangifer tarandus caribou
Species Code: M-RATA
Status: The Provincial Tracking Lists of the British Columbia Conservation Data Centre designate Northern Woodland Caribou as a Blue (Bl) listed species which federally is defined as a species of “Special Concern” or a wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) classifies southern mountain populations as Threatened. They are protected as big game under the British Columbia Wildlife Act (1982).

SPECIES ACCOUNT AND HABITAT USE INFORMATION

Distribution

Provincial Range

All woodland caribou in British Columbia belong to the woodland subspecies (Rangifer tarandus caribou), but they can be further divided into two different ecotypes, the mountain caribou and the northern ecotype (Stevenson 1991). Mountain caribou live in southeastern BC and spend most of the year at high elevations in subalpine forests and alpine habitats. Mountain caribou winter in high elevation forested habitat and forage almost exclusively on arboreal lichen because deep snow prevents access to terrestrial lichens (Stevenson et al. 1994). Northern caribou live in the northern and west-central areas of British Columbia and in west-central Alberta. They generally inhabit mountainous areas in the summer and low elevation pine forests or windswept alpine areas during winter, however; the proportion of time spent in low elevation forests versus windswept alpine areas varies with individuals, populations and years (Cichowski 1993, Wood 1996). Northern caribou appear to forage primarily on terrestrial lichens in relatively young stands (Johnson 2000, Cichowski 1993), but they also use arboreal lichens depending on snow conditions and lichen abundance (Johnson 2000, Poole et al. 2000).

Elevational Range

Northern woodland caribou utilize habitats from low elevation pine stands and wetlands to high alpine habitat depending on the time of year and the presence of alternate prey, such as moose, and predators, particularly wolves. In mountainous terrain, pregnant caribou space away from wolves, alternate prey, and non-calving conspecifics to calve at high elevation (Bergerud and Page 1987) or on islands. Non-reproductive females and bulls will remain at lower elevations to feed on green vegetation in the late spring.

Provincial Context

The current population of caribou in British Columbia is estimated at 14,000 – 17,000 animals (Seip and Cichowski 1996) and is believed to be substantially reduced from historic populations (Bergerud 1978 from Seip and Cichowski 1996). Caribou have been eliminated from about 15% of their historic provincial range and some currently occupied habitats have experienced population declines (Seip and Cichowski...
1996). Bergerud (1974) and later Edmonds (1991) reported that the North American range of woodland caribou has shrunk gradually but substantially since settlement by Europeans.

**Distribution in Study Area**

Three herds are associated with the study area: Tweedsmuir – Entiako, Takla Lake herd (Sidney Williams sub herd) and the Telkwa caribou herd. The Tweedsmuir – Entiako caribou exhibit a seasonal migration between summer range in northern Tweedsmuir Park and winter range in the Entiako drainage southeast of Tetachuck Lake. Migration typically occurs along the Chelaslie River corridor, and in certain years, part of the herd may winter along this route rather than continuing on to the Entiako area (Lance and Mills 1996). The other two herds do not migrate between areas, but they do show an elevational shift downwards following vegetative phenology after the winter, in early spring.

**Ecology and Key Habitat Requirements**

**General**

The majority of habitat use information of caribou in British Columbia pertains to the mountain ecotype in southern BC with only a few well-documented studies on the northern ecotype. The combined influence of predators, habitat patch configuration, and corridors on the large scale movements of northern woodland caribou have not been quantified (Johnson 2000). Northern woodland caribou may require large tracts of contiguous suitable habitat to disperse widely and minimize predator encounters.

Woodland caribou require food and security habitat to ensure survival during the winter, spring, summer and calving seasons. The northern ecotype is non-migratory and active year-round. They utilize a spacing away strategy to avoid predators and thereby can exhibit a seasonal elevational migration. During summer and calving, the northern ecotype typically favours areas that are remote and spatially separated from alternate prey species, such as moose and from predator species, such as wolves and grizzly and black bears. Reproductive female northern woodland caribou often calve solitarily and then may join post-calving groups in late June (Cichowski 1993, Bergerud and Page 1987, vic Stronen 2000). Some animals may not join post-calving aggregations and will remain solitary or with a calf all summer. By October, woodland caribou have typically aggregated in alpine habitat for the rut (Cichowski 1993, vic Stronen 2000). Rutting groups were also found in meadows or forest/meadow complexes in the eastern part of Tweedsmuir Park.

Summer home ranges varied from 4.8 to 731.4 km² in the Tweedsmuir – Entiako area, and from 3.5 to 554.8 km² in the Itcha-Ilgachuz – Rainbow area. Cichowski (1993) reported that the summer home range of adult female caribou in the Tweedsmuir – Entiako and Itcha-Ilgachuz – Rainbow areas were larger than those reported for other woodland caribou populations. Poole et al. (2000) found that Takla Lake caribou had an average home range size of 151 km² with a range from 24 to 300 km².

Northern woodland caribou are herbivorous foragers and rely heavily on terrestrial and arboreal lichens for winter-feeding. Other than feeding on lichen, caribou will forage on most other green vegetation in the spring and growing season. The growing season is the most important season for determining the survival of caribou throughout the year (M. Williams pers. comm. 2000). Caribou require access to large quantities of nutritious vegetation for growth, to be in good reproductive condition for the rut and to amass enough fat stores to survive the lean winter.

Northern woodland caribou tend to use either high elevation windswept areas or low elevation mature pine stands during the winter (Cichowski 1993, Seip and Cichowski 1996, Poole et al. 2000). Poole (2000) suggests that the Takla Lake caribou were not typical of either mountain or northern caribou ecotypes, but that they have adapted to the food, topography, and cover types available to them in an area diminished from a historically larger range. In all seasons except spring, Takla Lake caribou avoided low elevation forests and selected mid to high elevation, open hybrid white – Engelmann spruce (Picea glauca x P. engelmannii) - subalpine fir (Abies lasiocarpa) (Poole et al. 2000, J. Vinnedge pers.comm. 2000). Poole et al. (2000) concluded that the caribou in this area were predominantly arboreal lichen feeders in the winter because in the forests that were occupied, terrestrial lichens were scarce and arboreal lichen loads were moderate to high. The northern ecotype in the Tweedsmuir – Entiako area typically overwintered in low elevation dry-pine sites with abundant terrestrial lichens (Cichowski 1993). If...
snow conditions made digging for or detecting terrestrial lichens difficult, such as in the late winter, then these caribou moved into stands that had more arboreal lichen loads. The Telkwa caribou typically spent the winter in high elevation alpine and subalpine areas (vic Stronen 2000) where they would presumably crater for terrestrial lichens. Some animals did move to lower elevations, however; telemetry locations of these caribou indicated that they were in low elevation forested wetlands and fringe forests rather than dry-pine lichen sites (D. Reid pers. comm. 2000). There are very few lichen dominated stands at low elevation in the Telkwa caribou range (Roberts 2001).

Habitat Use – Life Requisites

The life requisites that will be rated for northern woodland caribou are 1) Feeding – Winter, 2) Living – Growing and 3) Reproducing (Calving) - Spring. Living, which combines feeding, security and thermal habitats, was used because of the likelihood that all life requisites would be met within the same mapping polygon.

Feeding Habitat – Winter

Winter forage choices of northern woodland caribou are limited to terrestrial and arboreal lichens and depending on the snow conditions, browse from shrubs and herbaceous vegetation (Table 1).

<table>
<thead>
<tr>
<th>Latin name</th>
<th>Common name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cladina spp.</td>
<td>Reindeer Lichens</td>
</tr>
<tr>
<td>Stereocaulon spp.</td>
<td></td>
</tr>
<tr>
<td>Cetraria spp.</td>
<td></td>
</tr>
<tr>
<td>Cladonia spp.</td>
<td></td>
</tr>
<tr>
<td>Bryoria spp. and Alectoria sarmentosa</td>
<td>Hair Lichens</td>
</tr>
</tbody>
</table>

Early in the winter, vegetation may still be available to caribou on their winter range due to lack of snow accumulation. However, as the winter progresses, shrubs and herbaceous vegetation are buried and caribou become dependent on terrestrial and arboreal lichens. The proportion of terrestrial and arboreal lichens in the diet varies with herd location and winter conditions (Cichowski 1993, Wood 1996).

Terrestrial lichens are patchily distributed according to the availability of suitable growing sites, and accessibility may vary depending on snow conditions (Johnson 2000). Cratering facilitates feeding by caribou during winter and the energy cost of cratering depends on snow conditions. Increased snow hardness and density in combination with a thick crust influences the ability of caribou to detect terrestrial lichens and their mean energy expenditure to crater for lichens (Fancy and White 1985).

Arboreal lichens are used most heavily during years of heavy snowfall and later in the winter after melt/freeze conditions have impaired digging conditions (Cichowski 1993, Rominger et al. 1996).

During winter, the Tweedsmuir-Entiako herd made extensive use of low elevation, mature pine stands on low to poor quality growing sites (Cichowski 1993). In early to mid-winter (December to mid-March), both immature and mature stands of dry, terrestrial lichen dominated stands were used extensively and by late winter and early spring (mid-March – April) caribou had started to use moister forested sites in addition to the dry lichen sites. Cratering was the primary winter-feeding activity in pine forests whereas pine/spruce forests were predominantly used for arboreal feeding and spruce stands were used primarily for arboreal feeding. Cichowski (1993) found that craters made up 63% of winter-feeding site types. Feeding sites in wetlands, lakes and fescue-lichen meadows consisted mostly of cratering sites and arboreal lichen feeding was the predominant activity in forested wetlands. Arboreal feeding was more pronounced in stands on moister sites where arboreal lichens are more abundant than in stands on drier sites. Arboreal lichens were foraged most intensely in late winter, presumably after several melt/freeze weather episodes (Cichowski 1993).

At the scale of the feeding site of caribou in the Wolverine caribou herd caribou in the forest and alpine cratered at locations with lower snow depths and greater amounts of terrestrial lichens (Johnson 2000). In the forest, they selected Cladina mitis and Cladonia spp. and avoided mosses; in the alpine, they selected Cladina rangiferina, Cetraria cucullata, C. mitis, Thamnolia spp., and Stereocaulon alpinum and avoided sites with debris. Across both forested and alpine areas, caribou selected the most abundant, but not necessarily the most nutritious lichen species. Johnson (2000) also found that as the snow depth,
hardness, and density increased, caribou in the forest fed more frequently at trees with abundant arboreal lichens (Bryoria spp.).

The Takla Lake herd is within the range of the northern caribou ecotype. Poole *et al.* (2000) found that the foraging behaviour of Takla Lake caribou was not typical of either the northern or the mountain ecotype. Like northern caribou, Takla Lake caribou foraged on terrestrial lichen when in alpine areas, but when in forested areas they fed on arboreal lichens like mountain caribou. Terrestrial lichens are rarely found in the spruce – fir stands that were used by the caribou (Meidinger and Pojar 1991) and snow depth typically exceeded the maximum depth through which caribou will crater (Johnson 2000). Pine stands were uncommon in this area and rarely used (Poole *et al.* 2000).

**Living - Growing Season**

**Feeding Habitat**

Caribou habitat use during summer reflected abundant and nutritious forage available at the time. In early spring, forbs made up 20% of vegetation found in fecal samples collected from the Tweedsmuir-Entiako caribou (Cichowski 1993). In the summer, lichen use decreased and grasses, sedges, and forbs made up more than 50% of vegetation in fecal pellet groups.

Female Takla Lake caribou generally descended to low elevations in the spring, presumably to access new green vegetation (Poole *et al.* 2000). Radio-collared caribou in the Telkwa caribou herd also descended from alpine habitat to low elevation habitat in the spring (vic Stronen 2000).

**Security Cover**

Caribou will often occupy rugged, mountainous terrain, which keeps them spatially separated from wolves and moose (Bergerud and Page 1987). During summer, northern woodland caribou primarily use alpine and subalpine areas (Cichowski 1993, Poole *et al.* 2000).

**Reproducing (Calving) - Spring**

Dispersion in the mountains is considered to be an anti-predator strategy of woodland caribou (Bergerud and Page 1987). Adult female caribou often forego superior forage quality available at lower elevation to calve high in the mountains where they are spaced away from alternative prey such as moose, which occupy lower elevations at this time. This strategy of calving alone at high elevations also increases the predator searching time for calves, making it less profitable for predators to hunt reproductive caribou during calving (Bergerud and Page 1987). Bergerud and Page (1987) found that for caribou calving in Spatsizi Provincial Park, the calves of cows that moved to valley bottoms in June suffered greater wolf and bear predation than those that stayed at high elevation.

In northern Tweedsmuir Park, caribou were widely dispersed during calving, but only 30% were found above tree line and 50% were at low elevations. This was a similar finding to the caribou in Spatsizi Provincial Park, as they were also found below tree line (Cichowski 1993). Female caribou that calved at high elevations preceded the vegetative phenology and sacrificed higher forage quality found at lower elevations (Cichowski 1993). Takla Lake caribou moved to higher elevations in late May to calve but remained primarily within spruce – fir stands (Poole *et al.* 2000). Calving occurred at even higher elevations during a year of lower snowfall (Poole *et al.* 2000). A recent study of the Telkwa caribou herd found that calving occurred in early June, with reproductive females found at high elevations (vic Stronen 2000). Calving typically occurred in alpine or subalpine habitats (vic Stronen 2000).

**Seasons of Use**

Northern woodland caribou are year round residents of the study area. There are three northern woodland caribou herds with regional variations of habitat use partially determined by topography, alternate prey abundance, predator abundance and season. Ecosystem ratings for the northern woodland caribou ecotype are applied by the growing season (spring, summer, fall), winter, and reproducing (late spring). Figure 1 summarizes the seasonal life requisite requirements for woodland
caribou based on the seasons outlined in the Habitat Mapping Standards (Ministry of Environment, Lands and Parks 1999) for the Sub-Boreal Interior, Central Interior, and Coast and Mountains Ecoprovinces.

Figure 1. Woodland Caribou Living and Reproduction seasons for the biogeoclimatic subzones in the study area.

Habitat Requirements Summary

Exact habitat requirements of caribou in the Morice Forest District and in the SBS, ESSF, and CWH biogeoclimatic zones in this area have not been well documented. Habitat use of vegetation associations for the Tweedsmuir – Entiako herd has been studied and the results can be interpreted for the key habitat requirements. Habitat use for the other two herds is less known, however; habitat use of northern caribou in other parts of west-central British Columbia can be extrapolated to supplement the available information for these areas. Table 2 outlines habitat requirements for northern woodland caribou in the study area.

Table 2. Summary of habitat requirements for woodland caribou in the study area.

<table>
<thead>
<tr>
<th>Life Requisite</th>
<th>Season</th>
<th>Specific Attributes Required</th>
<th>Structural Stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeding - Terrestrial Lichens</td>
<td>Winter</td>
<td>-preference for low elevation pine or pine/spruce dominant sites</td>
<td>5 to 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-preference for windswept alpine and subalpine sites</td>
<td>2, 3a</td>
</tr>
<tr>
<td>Feeding – Arboreal Lichens</td>
<td>Winter</td>
<td>-sites with moderate to heavy Bryoria spp. loadings (&gt;class3)</td>
<td>5 to 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-minimum age 70 years, typically better arboreal lichens found in stands 90 years and older</td>
<td>5 to 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-preliminary trend of best arboreal sites adjacent to wetlands, ridge crests, established edges and in forested bogs</td>
<td>5 to 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-high elevation forest typically preferred, large areas of contiguous low elevation forest also used</td>
<td>5 to 7</td>
</tr>
</tbody>
</table>
### NORTHERN CARIBOU HABITAT MODELS

The output of seasonal caribou habitat models currently predict habitat suitability. In future revisions of the models, we intend to include other variables that modify habitat suitability and result in a prediction of habitat effectiveness. Examples of variables are predation risk (as a function of moose density), distance to roads, and winter recreation use. All of these examples result in downgrading affected habitat, and a revision of where better habitat is located. Habitat value will refer to the final model output once variables are added in that affect the habitat effectiveness.

| Northern Woodland Caribou Late Winter, Calving and Summer Habitat Models | Reproducing Spring | -high elevation mountainous sites; alpine or subalpine | 1 and 2  
| | | -relative close proximity to high elevation wetlands | 1 to 7  
| | | -high elevation spruce – fir forest (Sidney Williams) | 6 and 7  
| | | -some use of islands by the Entiako herd (all habitats) | 1 to 7  
| | Growing Living (Feeding, Security) | -open forests; low canopy closure, low stem density | 5 to 7  
| | | -sites with green vegetation early in the spring | 2, 3 and 5 to 7  
| | | -herbaceous sites, often high elevation. Avoid low elevation young cutblocks. | 2, 3 and 5 to 7 |
Figure 2. Flowchart illustrating potential process for running the northern caribou late winter habitat suitability model and mapping the output.

Application of Models

Geographic Area: This model has been developed for application in the forests of Morice and Lakes Forest Districts in west-central British Columbia, Canada.

Seasons: Late Winter, Calving, Summer

Habitat Areas: The following caribou herd areas are in the Morice and Lakes Forest Districts: Tweedsmuir – Entiako herd (not for winter), Telkwa Range Caribou herd, Sydney Williams herd (Takla caribou)

Model Output: Each model will produce a most probable habitat suitability value for caribou for that season (late winter, calving, summer) as well as a most probable habitat value with predation risk considered.

Verification Level: Verification of the model involved testing the belief net to ensure that the output is consistent with our expected output. The late winter model was reviewed internally as well as having a working review done by Debbie Cichowski (Caribou Ecological Consulting, Smithers). The terrestrial and arboreal lichen abundance and availability models were reviewed internally and a working review was done.
by Patrick Williston (Mnium Ecological Consulting, Smithers). Portions of the late winter model had working reviews done by George Schultz and Mark Williams (WLAP, Smithers). The calving and summer models were reviewed internally for consistency between model output and expected output.

Assumptions

The following section describes the logic and assumptions used to translate habitat element information for the caribou to the variables and equations used in the models. For assumptions in the terrestrial lichen or arboreal lichen abundance models, see the Appendix A and B respectively.

General Assumptions

1. Caribou can obtain water and mineral resources in areas that supply foraging and/or security habitat.
2. At the landscape (coarse) scale, caribou select habitats to address predation (limiting factor) and then continue to select for the required habitat attributes (such as those to satisfy forage requirements) at successively finer scales.

Late Winter Habitat Model

The following section describes the current late winter habitat suitability model (See Figure 3) and the assumptions used to define the relationships used in the model. The late winter habitat suitability rating at this stage is meant to be interpreted at the landscape level and not used as a stand management interpretation. It is intended that a future iteration of the model will include an evaluation of predation risk as a function of moose and wolf density. Predation risk will then be used to modify the value of the suitable habitat for caribou. Currently (December 2003), the model output that is used is an evaluation of the habitat suitability in late winter for northern woodland caribou.

Figure 3. Habitat variables and ecological relationships used to build the caribou late winter habitat suitability Bayesian belief model in the Netica© program.
Model Description
The late winter habitat suitability model for northern woodland caribou is largely dependent on the ability of the habitat to provide foraging opportunities. Foraging and security habitat are described using a set of elements from various map layers. The following section outlines the components of the late winter habitat suitability model for caribou in the Morice and Lakes Forest Districts and describes the relationships that were used to create the model.

Late Winter Habitat Model Assumptions
1. Structural stage 1 – 4 in all forests have minimal value for foraging in winter because both terrestrial and arboreal lichen loads are low.
2. Snow depth moderates the availability of both arboreal and terrestrial lichens. Deep snow (150 cm+) makes terrestrial lichens less available to caribou, whereas deep snow in winter can create lift for caribou to reach arboreal lichens.
3. Snow in the alpine and parkland biogeoclimatic zones are highly variable and difficult to predict on a coarse scale. Assume that there is equal probability of the snow being shallow, moderate, or deep.
4. Caribou do not use very steep sites in the winter.
5. Sites with available terrestrial and/or arboreal lichens are potentially suitable winter habitat for caribou in the winter. Northern woodland caribou utilize a mixed foraging strategy, in which they forage on both terrestrial and arboreal lichens during the winter.
6. Caribou avoid roads closer than 100m and partially avoid areas with roads closer than 500m.
7. The level of motorized recreation in the winter is generally higher in the Telkwa range than in the Whitesail area (Tweedsmuir herd) or the Takla herd area. This assumption was made due to proximity to urban areas.
8. Caribou can tolerate a certain level of “motorized recreation”, i.e. snowmobile activity, in their winter range by moving away from the activity but still using the range, however; a moderate to high level of this activity will result in abandonment of this range.
9. The risk of predation to caribou in the winter is mostly determined by the distribution and density of alternate prey (i.e. moose).

Description of Network Nodes

Late Winter Habitat Suitability
The late winter habitat suitability node summarizes the late winter forage value node in a conditional probability table (See Table 3).

Example Relationship: Conditional Probability Table
Variables:

| CWHS | caribou winter habitat suitability |
| WF | Late winter forage value |
Table 3. Conditional probabilities used within Netica to configure the relationship between late winter forage value in describing late winter habitat suitability for northern woodland caribou.

<table>
<thead>
<tr>
<th>Late Winter Forage value</th>
<th>Late Winter Habitat Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>0 - 0.2</td>
<td>100</td>
</tr>
<tr>
<td>0.2 - 0.4</td>
<td>70</td>
</tr>
<tr>
<td>0.4 - 0.6</td>
<td>0</td>
</tr>
<tr>
<td>0.6- 1</td>
<td>0</td>
</tr>
</tbody>
</table>

**Late Winter Forage Value**

The late winter forage value node is described as a function of the availability of arboreal lichens and the availability of terrestrial lichens. Caribou will also access evergreen shrubs where possible throughout the winter, however; the main source of forage in late winter are lichens, therefore we consider these as the critical components. Both arboreal lichen availability and terrestrial lichen availability are described by environmental conditions. The value of the habitat for forage is additive for availability of the two types of lichens, more of either lichen type increases the value of the habitat to a maximum quality of 1.

Example Relationship: $WF (ASD, TSD) = \text{clip}(0,1, (ASD+TSD))$

Where: $WF = \text{Late winter forage value}$

ASD = Arboreal lichen availability

TSD = Terrestrial lichen availability

**Arboreal Lichen Availability**

The arboreal lichen availability node predicts the availability of arboreal lichens for late winter foraging based on the abundance of arboreal lichens and the relative access to those lichens based on snow conditions and slope (See Table 4).

Example Relationship: **Conditional Probability Table**

<table>
<thead>
<tr>
<th>Arboreal Lichen Abundance</th>
<th>Effective Snow Depth</th>
<th>Slope (degrees)</th>
<th>Arboreal Lichen Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nil</td>
<td>Shallow</td>
<td>0 - 5</td>
<td>100 0 0 0</td>
</tr>
<tr>
<td>Nil</td>
<td>Shallow</td>
<td>5 - 30</td>
<td>100 0 0 0</td>
</tr>
<tr>
<td>Nil</td>
<td>Shallow</td>
<td>30 - 50</td>
<td>100 0 0 0</td>
</tr>
<tr>
<td>Nil</td>
<td>Shallow</td>
<td>&gt;=50</td>
<td>100 0 0 0</td>
</tr>
</tbody>
</table>

Table 4. Conditional probabilities used within Netica to configure the relationship between arboreal lichen abundance, snow conditions, and slope to predict arboreal lichen availability in late winter conditions.
<table>
<thead>
<tr>
<th>Nil</th>
<th>Moderate</th>
<th>0 - 5</th>
<th>100</th>
<th>0</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nil</td>
<td>Moderate</td>
<td>5 - 30</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nil</td>
<td>Moderate</td>
<td>30 - 50</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nil</td>
<td>Moderate</td>
<td>&gt;=50</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nil</td>
<td>Deep</td>
<td>0 - 5</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nil</td>
<td>Deep</td>
<td>5 - 30</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nil</td>
<td>Deep</td>
<td>30 - 50</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nil</td>
<td>Deep</td>
<td>&gt;=50</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>Shallow</td>
<td>0 - 5</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>Shallow</td>
<td>5 - 30</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>Shallow</td>
<td>30 - 50</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>Shallow</td>
<td>&gt;=50</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>Moderate</td>
<td>0 - 5</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>Moderate</td>
<td>5 - 30</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>Moderate</td>
<td>30 - 50</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>Moderate</td>
<td>&gt;=50</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>Deep</td>
<td>0 - 5</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>Deep</td>
<td>5 - 30</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>Deep</td>
<td>30 - 50</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>Deep</td>
<td>&gt;=50</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>Shallow</td>
<td>5 - 30</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
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<td>0</td>
<td>20</td>
<td>80</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>Shallow</td>
<td>&gt;=50</td>
<td>0</td>
<td>70</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
<td>0 - 5</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
<td>5 - 30</td>
<td>0</td>
<td>0</td>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
<td>30 - 50</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
<td>&gt;=50</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>Deep</td>
<td>0 - 5</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>Deep</td>
<td>5 - 30</td>
<td>0</td>
<td>0</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>Moderate</td>
<td>Deep</td>
<td>30 - 50</td>
<td>0</td>
<td>15</td>
<td>70</td>
<td>15</td>
</tr>
<tr>
<td>Moderate</td>
<td>Deep</td>
<td>&gt;=50</td>
<td>0</td>
<td>70</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>High</td>
<td>Shallow</td>
<td>0 - 5</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>High</td>
<td>Shallow</td>
<td>5 - 30</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td>High</td>
<td>Shallow</td>
<td>30 - 50</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td>High</td>
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<td>20</td>
<td>0</td>
</tr>
<tr>
<td>High</td>
<td>Moderate</td>
<td>5 - 30</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>
Terrestrial Lichen Availability

The terrestrial lichen availability node predicts the availability of terrestrial lichens for late winter foraging based on the abundance of terrestrial lichens and the relative access to those lichens based on snow conditions and site conditions for cratering (See Figure 4). Site conditions for cratering are predicted based on slope and snow depth (effective snow depth).

Example Relationship:

**Conditional Probability Table**

Variables:
- TSD = Terrestrial lichen availability
- TLQ = Terrestrial lichen abundance
- SITE = Site quality for cratering

Figure 4. Probabilities of terrestrial lichen availability based on terrestrial lichen abundance and the quality of the site for cratering by caribou.

Site Quality for Cratering

The site quality node predicts the quality of an area for cratering through snow based on slope and snow depth (See Figure 5). This node describes the access for cratering by caribou. For sites that are steeper than 50 % slope – consider the potential for terrestrial lichen sites to be poor.

Example Relationship:

**Conditional Probability Table**

Variables:
- SITE = Site quality for cratering for terrestrial lichens
- SLOPE = Slope
- ESD = Effective Snow Depth
Figure 5. Probabilities of cratering site quality by snow depths based on slope.

**Terrestrial Lichen Abundance**

The terrestrial lichen abundance node is a parent node whose value has been predicted in the Terrestrial lichen Netica model. This node has the potential values of high, moderate, low.

Variables: 

\[ TLQ = \text{Terrestrial lichen abundance} \]

**Arboreal Lichen Abundance**

The arboreal lichen abundance node is a parent node whose value has been predicted in the arboreal lichen Netica model. This node has the potential values of high, moderate, low.

Variables: 

\[ ARB = \text{Arboreal lichen abundance} \]

**Effective Snow Depth**

The effective snow depth node is used to account for the highly variable and currently unpredictable distribution of snow depth in the alpine and subalpine parkland zones. In these zones, snow depth can range from very deep to very shallow, therefore; we assumed that there was equal probability of shallow, moderate or deep snow occurring. If a polygon is in the alpine or parkland zones, then this node will modify the snow depth to reflect the uncertainty in our ability to predict snow depth in these zones; however, if a polygon lies outside these specific zones, then no modification will occur. This includes all other sites (forested or non-forested). Snow depth in the alpine and parkland can be extremely variable due to wind, which can result in scouring of some locations and deep accumulations in others.

Example Relationship: 

**Conditional Probability Table**

<table>
<thead>
<tr>
<th>Variables:</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESD = Effective Snow Depth</td>
</tr>
<tr>
<td>SNOW = Snow depth rating summarized by biogeoclimatic subzone</td>
</tr>
<tr>
<td>AT_P = Alpine or Parkland zones</td>
</tr>
</tbody>
</table>
Table 5. Conditional probabilities used within Netica to model effective snow depth by biogeoclimatic subzone.

<table>
<thead>
<tr>
<th>Snow Depth</th>
<th>Alpine or Parkland?</th>
<th>Effective Snow Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Shallow</td>
</tr>
<tr>
<td>Shallow</td>
<td>Yes</td>
<td>100</td>
</tr>
<tr>
<td>Shallow</td>
<td>No</td>
<td>100</td>
</tr>
<tr>
<td>Moderate</td>
<td>Yes</td>
<td>100</td>
</tr>
<tr>
<td>Moderate</td>
<td>No</td>
<td>100</td>
</tr>
<tr>
<td>Deep</td>
<td>Yes</td>
<td>33</td>
</tr>
<tr>
<td>Deep</td>
<td>No</td>
<td>100</td>
</tr>
</tbody>
</table>

**Snow Depth**

The snow depth node is a parent node whose value has been summarized from snow station data and BEC guidebook data into mean late winter snow depth by biogeoclimatic subzone. This node has the potential values of shallow (0 – 50cm), moderate (50 – 150cm), and deep (150+cm), based on our interpretation for both arboreal and terrestrial lichen access. Within forested stands, snow depth and snow density can be affected by various variables such as canopy closure, aspect, or elevation. These variables are not included in the estimation of snow depth due to the high level of uncertainty around these relationships.

Variables: \( SNOW = \) Snow Depth rating by BEC subzone

**Slope**

The slope node is a parent node whose value has been extracted from the digital elevation model (DEM) and is read into the node as a numerical value. Once in the node, the values are interpreted into one of 4 classes: 0 - 5 degrees, 5 – 30 degrees, 30 – 50 degrees, or 50+ degrees.

Variables: \( \text{Slope} = \) Slope from the DEM

**Calving Habitat Suitability Model**

The caribou calving habitat suitability model is applied across the three herd areas. Calving habitat suitability is the current output and it is intended that a future iteration will include an evaluation of predation risk and its influence on the value of the habitat for calving. Note that “other” in the model encompasses all polygons not specifically referred to in the other classes of the same node.
Calving Habitat Model Assumptions

1. During the calving season, caribou will forage primarily on graminoids, herbs and terrestrial lichens. Caribou do not browse on the woody portion of shrubs and if they forage on shrubs, they consume the green leaf portion.

2. Assume that the abundance of herbs and graminoids in the spring is not as abundant than during the summer.

3. Herbaceous growth in high elevation habitats is delayed compared to lower elevation areas in the spring.

4. Access to terrestrial lichens is not inhibited by snow during calving.

5. Slopes greater or equal to 50° are poor calving habitats.

6. Caribou prefer alpine tundra, open high elevation subalpine areas, or islands during calving.

7. Islands provide areas of lower predation risk than do adjacent mainland habitats.

8. Rivers and lakes do not provide any habitat value to caribou during calving.

9. Parturient females select calving areas first for security cover and secondly for forage during calving.

10. Female caribou have a high level of fidelity to calving areas.

Description of Network Nodes

Caribou Calving Habitat Suitability

The caribou calving habitat suitability is a rating of the location of the habitat in the landscape and then within that location, the relative abundance of forage (See Table 6). Rivers and lakes are identified as having very low suitability for calving and are labelled as site exceptions.

Example Relationship:  Conditional Probability Table
Variables:  
CCS = Caribou calving habitat suitability  
CT = Habitat location  
EXC = Exceptions to terrain, including all lakes, rivers and very steep terrain

Table 6. Conditional probabilities used within Netica to configure the relationship between location and forage in describing calving habitat suitability for northern woodland caribou.

<table>
<thead>
<tr>
<th>Site Exceptions</th>
<th>Forage Abundance</th>
<th>Habitat Location</th>
<th>Caribou Calving Habitat Suitability</th>
</tr>
</thead>
</table>
|                 | CCS = Caribou calving habitat suitability  
CT = Habitat location  
EXC = Exceptions to terrain, including all lakes, rivers and very steep terrain |
| YES            | Nil              | Poor             | 100 0 0 0                          |
| YES            | Nil              | Moderate         | 100 0 0 0                          |
| YES            | Nil              | Good             | 100 0 0 0                          |
| YES            | Low              | Poor             | 100 0 0 0                          |
| YES            | Low              | Moderate         | 100 0 0 0                          |
| YES            | Low              | Good             | 100 0 0 0                          |
| YES            | Moderate         | Poor             | 100 0 0 0                          |
| YES            | Moderate         | Moderate         | 100 0 0 0                          |
| YES            | Moderate         | Good             | 100 0 0 0                          |
| YES            | High             | Poor             | 100 0 0 0                          |
| YES            | High             | Moderate         | 100 0 0 0                          |
| YES            | High             | Good             | 100 0 0 0                          |
| NO             | Nil              | Poor             | 0 100 0 0                          |
| NO             | Nil              | Moderate         | 0 100 0 0                          |
| NO             | Nil              | Good             | 0 60 40 0                          |
| NO             | Low              | Poor             | 0 100 0 0                          |
| NO             | Low              | Moderate         | 0 70 30 0                          |
| NO             | Low              | Good             | 0 0 20 80                          |
| NO             | Moderate         | Poor             | 0 100 0 0                          |
| NO             | Moderate         | Moderate         | 0 30 70 0                          |
| NO             | Moderate         | Good             | 0 0 0 100                          |
| NO             | High             | Poor             | 0 35 65 0                          |
| NO             | High             | Moderate         | 0 0 100 0                          |
| NO             | High             | Good             | 0 0 0 100                          |

Calving Forage Abundance: Spring Forage and Terrestrial Lichen Abundance

Calving forage abundance is dependent on the abundance of forbs and graminoids and the abundance of terrestrial lichens. The value of the habitat for forage is dependent on the abundance, in spring, of either forage type. Spring forage is rated based on site series and structural stage. Important forage in spring consists of forbs and graminoids. The phenology of vegetation growth by biogeoclimatic subzone is considered during spring. Terrestrial lichen abundance is predicted from the terrestrial lichen model.
Example Relationship: \[ \text{Forage} (\text{RATA\_P\_Forg}, \text{TLQ}) = \max (\text{RATA\_P\_Forg}, \text{TLQ}) \]

Where:
- \text{Forage} = \text{Calving forage value}
- \text{RATA\_P\_Forg} = \text{Spring rating of forage abundance by ecosystem and structural stage}
- \text{TLQ} = \text{Terrestrial lichen abundance}

**Habitat Location: High Elevation Habitat and Islands**

The spatial location of calving habitat is important for security. Pregnant caribou tend to space away from conspecifics and from other ungulates during calving. High elevation sites are often used, perhaps because of better ability to detect potential predators due to longer sight lines. Islands may not necessarily provide better opportunity to detect predators as do high elevation habitats, however; islands may offer more isolation to calving caribou than adjacent mainland habitats and consequently these animals may suffer lower predation than if they were on the mainland (See Table 7).

Example Relationship: \textit{Conditional Probability Table}

Variables:
- \text{CT} = \text{Habitat location}
- \text{HIGH\_ELE} = \text{Rating by BGC subzone of habitat as potential for high elevation calving terrain}
- \text{Island} = \text{Island}

Table 7. Conditional probabilities used within Netica to describe the value of the spatial location of the habitat using high elevation types and islands.

<table>
<thead>
<tr>
<th>High Elevation Zone</th>
<th>Island</th>
<th>Habitat Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Poor</td>
</tr>
<tr>
<td>Poor</td>
<td>No</td>
<td>100</td>
</tr>
<tr>
<td>Poor</td>
<td>Yes</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>No</td>
<td>25</td>
</tr>
<tr>
<td>Moderate</td>
<td>Yes</td>
<td>0</td>
</tr>
<tr>
<td>Good</td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td>Good</td>
<td>Yes</td>
<td>0</td>
</tr>
</tbody>
</table>

**Site Exceptions: Steep Slopes and Ecosystems of No Value**

There are certain site types located throughout the landscape that have no potential to provide suitable caribou calving habitat. These are specifically identified by this node and include: sites with very steep slopes (greater than 50 degrees), lakes and rivers.

**Summer Habitat Model**

The caribou summer habitat model (See Figure 7) is applied across the three herd areas.
Summer Habitat Model Assumptions
1. Caribou habitat use in summer reflects abundant and nutritious forage available.
2. Caribou prefer to forage on grasses, sedges and forbs in the summer, but will also forage on mushrooms and lichens.
3. In general, caribou will use many habitat types in the summer and do not strictly use high elevation habitats; however, high elevation subalpine and alpine habitats are preferred.
4. Mobility restrictions from snow accumulation are not a factor in summer, therefore enabling alternate prey, such as moose, and predators to disperse across more of the landscape, which results in less localized predation risk.
5. Caribou tend to avoid low elevation young (less than approximately 40 years) cutblocks.
6. Slopes greater or equal to 50° are poor summer habitats.
7. Rivers, lakes, and talus slopes have low habitat suitability and value to caribou in the summer.
8. Glaciers provide some habitat value to caribou in the summer by supplying thermal cover and/or relief from insects.
9. Caribou do avoid roads in the three herd areas. The most marked avoidance is within the closest 100m to the road, and, to a lesser extent, the area 101 to 500m from a road. Habitat further than 500m from a road is not avoided.

Description of Network Nodes
Caribou Summer Habitat Suitability
The caribou calving habitat suitability is a rating of the location of the habitat in the landscape, and then, within that location, the relative abundance of forage. Rivers, lakes, rock, and talus (EXE) are identified as having very low suitability for calving.

Example Relationship: 
\[
CSS = \text{If EXC} = \text{Nil, then CSS} = \text{very low, otherwise} \\
((\text{Forage} \times 1.5) + \text{Terrain}) / 2.5
\]
Variables:

CSS = Caribou summer habitat suitability

Terrain = Habitat location on the landscape

EXC = Exceptions to terrain, including all lakes, rivers and very steep terrain

Summer Forage Abundance: Vascular forage, terrestrial lichen, and arboreal lichen abundance

Summer forage abundance is described as a function of the abundance of forbs and graminoids, the abundance of terrestrial lichens, and the abundance of arboreal lichens. Even though caribou forage on lichens in the summer, it was assumed that vascular forage is more influential than the abundance of terrestrial or arboreal lichens when rating habitats. Vascular forage is rated based on site series and structural stage. Important forage in summer consists mostly of forbs and graminoids. Vegetative phenology is considered to be fully available in the summer. Terrestrial lichen abundance is predicted from the terrestrial lichen model and arboreal lichen abundance is predicted from the arboreal lichen model.

Example Relationship: \[ \text{Forage} = \frac{(\max (\text{ARB}, \text{TLQ}) + \text{RATA}_S \_\text{Forg} \times 2)}{3} \]

Where:

Forage = Summer forage value for caribou

RATA_S_Forg = Rating of vascular forage abundance by ecosystem and structural stage for the summer season

TLQ = Terrestrial lichen abundance

ARB = Arboreal lichen abundance

Terrain Location

Terrain location is included as a rating of habitats where caribou are more likely to be located in the landscape. These include high elevation sites and islands.

Example Relationship: Conditional Probability Table

<table>
<thead>
<tr>
<th>Terrain Location</th>
<th>Poor</th>
<th>Moderate</th>
<th>Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor No</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Poor Yes</td>
<td>0</td>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>Moderate No</td>
<td>25</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Moderate Yes</td>
<td>0</td>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>Good No</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Good Yes</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 8. Conditional probabilities used within Netica to rate the location of the habitat on the landscape.
Site Type Exceptions

Some site types do not provide suitable habitat for caribou in summer regardless of where they are located on the landscape. These site type exceptions are rivers, lakes, and talus slopes. Rock and glaciers do provide some habitat value; however, their poor forage value supersede that value.

Example Relationship:  

**Conditional Probability Table**

Variables:  

- EXC = Site exceptions (no value habitat)
- SITEMC_S = Site types

Table 9. Conditional probabilities used within Netica to rate site type exceptions.

<table>
<thead>
<tr>
<th>Site Type Exceptions</th>
<th>Site Type Exceptions for Suitability Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nil</td>
</tr>
<tr>
<td>RI</td>
<td>100</td>
</tr>
<tr>
<td>RO</td>
<td>55</td>
</tr>
<tr>
<td>LA</td>
<td>100</td>
</tr>
<tr>
<td>GL</td>
<td>30</td>
</tr>
<tr>
<td>TA</td>
<td>100</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
</tr>
</tbody>
</table>

Elevation

This node is summarized by BEC subzone. Alpine and subalpine zones are rated good, higher elevation forested zones (i.e. ESSF and MH) are moderate, and mid and lower elevation zones are poor. This node is used to assess the value of the location of habitat on the landscape to caribou in summer. Higher elevation habitats tend to provide better terrain for predator avoidance and spacing out from conspecifics and from other ungulate prey species.

Variables:  

- HIGH_ELE = Elevation (by BEC subzone)

Seasonal Moose Range and Predation Risk (IFPA)

The risk of predation is not currently modifying the habitat suitability for caribou for any of the seasons modeled. Predation risk will be incorporated into future versions of the model.

Computing Output for Habitat Value

Non-spatial caribou habitat suitability will be the output from the model for each grid cell. An assessment of the spatial pattern, or configuration, of the habitat needs to be completed to be able to appropriately interpret habitat value for caribou in late winter, calving and summer. When evaluating the spatial habitat value for caribou by season, there are a few key points that need to be considered. Calving females tend to have high fidelity to calving sites from one year to the next. Caribou space away from conspecifics during calving and summer in an effort to minimize risk of predation. A spatial analysis of habitat value based on suitability should also address northern caribou’s requirement of large areas in which to disperse.

Caribou also have traditional ranges where there is use most years. In the interpretation of caribou habitats, these traditional areas should be regarded as moderate to high value.
**Sensitivity Analysis**

Caribou seasonal habitat models were examined to assess the sensitivity of findings of dependent nodes on input (parent) nodes. This test of sensitivity is conducted within Netica© and is a relative indication of the influence of parent nodes on the findings in the child or output node. The results of this testing allow us to evaluate whether the BBN is working how we expect it to and/or gives insight into relative weighting of variables. Depending on the type of nodes that are involved in each test, the sensitivity is either reported as the value ‘mutual info’ or as ‘variance reduction’. In both cases, the node reporting the largest value affects the output node that is being tested the greatest extent. The sensitivity values for the input nodes can be directly compared to assess the magnitude of their effect on the output node. For example, if node “A” and node “B” are measured for their influence on node “C” and node “A” reports a variance reduction of 0.100 and node “B” reports a value of 0.010, then we know that not only does node “A” have a greater influence on the output of node “C”, but that the magnitude of the influence is ten times greater than node “B”.

**Caribou Late Winter Habitat Suitability Model**

In the caribou late winter habitat suitability model, habitat suitability was mostly influenced by terrestrial and arboreal lichen abundance and then influenced to a much lesser extent by slope and snow depth.

**Caribou Calving Habitat Suitability Model**

The calving habitat suitability is most influenced by where the habitat is on the landscape and secondly by forage value.

**Caribou Summer Habitat Suitability Model**

In summer, the influences of forage abundance and terrain location on habitat suitability are approximately equal.

**Testing and Validation**

The models should be viewed as hypotheses of species-habitat relationships rather than statements of proven cause and effect relationships. Their value is to serve as a basis for improved decision making and increased understanding of habitat relationships because they specify hypotheses of habitat relationships that can be tested and improved. There are several levels at which the models should be validated. The first is an ongoing process during model development during which we have tested the model to ensure that it is acting in a manner that we want it to. The second level is to test the model assumptions and output through field-testing or verification.

Testing of the models relationships and output is an ongoing iterative process concurrent with the development of the BBNs. Development of the caribou habitat suitability models occurred within Ardea – with several working reviews. These reviews entailed testing the model for various scenarios, evaluating the relationships and ratings, testing the sensitivity of the model to habitat variables, and adjusting the equations and tables to reflect fine-tuning. A working review of the model and the model document was done in the winter of 2002-03 and suggested changes were incorporated into the model to create an explicit and transparent flow of information. Several reviews have occurred since this time to reassess the outputs and resulting maps.

**Research Needs for Model Verification**

The performance of a model should be tested against population data, preferably estimates of density or reproductive success, to translate the perception of habitat quality or suitability into differential use of habitat (Brooks 1997). The spatial configuration of habitat will affect the spatial spread and use of a population in a heterogeneous environment (Söndererath and Schröder 2002). The output of this model provides a habitat suitability value; however, the pattern and amount of the habitat with respect to caribou
use is not evaluated. The importance of the landscape structure varies according to the demographic characteristics of the population (Söndgerath and Schröeder 2002, With and King 1999).

Caribou late winter, calving, and summer habitat suitability models for the three herd areas can be partially tested using existing telemetry locations. As a start, location data may be able to confirm high use areas by season.

The following are proposed initiatives and research needs to verify portions of the caribou habitat models. Various levels of verification can occur to strengthen our confidence in the model output. The input data, ratings lookup tables, relationships, and output can all be improved. Model output would be most strengthened by verification of the following:

- Coarse filter validation by site series and structural stage of average values and range of:
  - Spring and summer vascular forage abundance
- Verification of the terrestrial lichen model
- Verification of the arboreal lichen model

Development of habitat effectiveness and spatial evaluation of these output values to reflect habitat value for caribou should be the next step. Layers and relationships that would be incorporated in this section are partially developed and would need extensive review. Because there is limited information regarding detailed habitat use, predation levels and demographic response to factors such as roads, recreational use, and habitat fragmentation, we would rely on what information there is as well as information from other areas that are more thoroughly studied until suitable local information can be collected.
NORTHERN WOODLAND CARIBOU REFERENCES


**Personal Communications:**


D. Reid. 2000. Ministry of Environment, Lands and Parks, Wildlife Section, Smithers, BC.

J. Vinnedge. 2001. Ministry of Environment, Lands and Parks, FES, Fort St. James, BC.


D. Cichowski. 2003. Consultant, Smithers, BC.
APPENDIX A – TERRESTRIAL LICHEN ABUNDANCE SUB-MODEL

Terrestrial Lichen Ecology

The distribution of terrestrial lichens in the Morice and Lakes forest districts is largely determined by the interactions among site characteristics (moisture and nutrients), disturbance history, reproduction and dispersion, and competition with other terrestrial species (Williston pers. comm., Williston and Cichowski 2002, Cichowski and Williston 2003).

Terrestrial lichen abundance is estimated in a belief net using Netica. A team of ecologists and a lichenologist developed the terrestrial lichen algorithm for the study area. The model is mainly based on predicting the abundance of terrestrial forage lichens preferred by woodland caribou that reside within the study area. Because of a lack of foraging data within the study area, we used the list of preferred terrestrial lichens provided by Lance and Eastland (1999) for caribou in the Fort St. James Forest District and cross-referenced by terrestrial lichen species that caribou preferentially consume in the Tweedsmuir area. Caribou will consume several genera of terrestrial lichen species; however, genera that are recorded as preferential are species of the genera *Cladina*, *Cladonia*, and *Stereocaulon*. *Cetraria* is utilized but is considered to be preferred to a lesser extent. These genera are all grouped together and modeled as caribou terrestrial forage lichens.

Most of these forage lichens have a broad tolerance for moisture conditions and can be found growing on dry, rapidly draining substrates such as sand, coarse gravel, or bedrock; or on wet substrates such as *Sphagnum* hummocks. Whether wet or dry, *Cladina* is most abundant in nutrient poor sites where the success of potential competitors is limited (Ahti 1961). Lichens are very poor competitors, in part because of their slow growth rate. Vascular plants and mosses grow much more rapidly and are able to quickly overgrow adjacent lichen colonies.

Modeling a prediction of terrestrial lichen abundance is a sub model of a model of late winter habitat value and of calving and summer habitat value of northern woodland caribou in the study area. An algorithm was created for predicting terrestrial lichens in the study area. Information incorporated into the algorithm stemmed from projects within the study area, from projects outside the study area but within similar ecotypes and from expert knowledge. The Bayesian belief nets were originally built according to the information in these algorithms. Habitat attributes that were considered important to predicting terrestrial lichen abundance were included in the algorithm and rated for importance against one another. This information is incorporated into the belief net in Netica©.

The output values of terrestrial lichen quality for each polygon were described in terms of forage function groups. The groups and the test ranges for each group (nil, low, moderate, high) are outlined in the following sections. Expectations of what each group will provide in terms of abundance and forage value is also described. Limits of each range will be adjusted to fit the expected utility of each group once the model is tested, validated, and verified.

Predicting terrestrial lichen abundance in the study area involves many sources of uncertainty because there are a lot of data gaps. Much of the knowledge that is synthesized is based on information from other project areas, or on data that was collected only in a portion of the biogeoclimatic subzone and site series, or, on relationships that are not clearly defined between abundance and habitat variables. However, terrestrial lichens have a relatively close-fitting relationship with site series (Banner *et al.* 1993) and with ecosystem variables that can be quantified from field data or from forest cover. Other habitat variables can be used to strengthen the abundance prediction; however, the good predictive relationship of terrestrial lichens with site series simplifies the model for predicting terrestrial lichen abundance.
Terrestrial Lichen Model Structure

Figure 8. Ecological factors and relationships characterizing terrestrial lichen abundance.

Terrestrial lichen availability is dependent on annual variation in snow conditions and ability to access a location (defined by slope); therefore, availability is assessed in seasonal models (late winter, calving, summer).

Terrestrial Lichen Model Assumptions

The assumptions that were made in the development of this habitat variable model are listed below:

1. Terrestrial lichens are never able to grow in lakes, rivers, glaciers, and developed (i.e. urban, road) habitats.

2. In alpine areas, terrestrial lichen abundance is predicted from the predictive ecosystem mapping (PEM) layer.

3. Not all potential lichen-bearing sites will be mapped (i.e. some of the smaller pockets of lichen habitat will not show up in the database) and some sites will be overestimated due to the current level of resolution in the mapping and database layers.

4. Terrestrial lichens are most abundant in forests 70 to 140 years of age. Because lichens are slow growing, prior to 70 years, they are considered low abundance. After approximately 140 years of age, mosses tend to out compete terrestrial lichens for space on the forest floor and all but the driest stands generally become moss dominated.

5. Terrestrial lichen abundance can be quite strongly predicted through site series predictions. Site series that are considered to be the best lichen producing stands are: SBPS/02,01b; SBSdk/02, 03; SBSmc2/02; ESSFmc/02; ESSFmk/02; sites that have moderate amounts of terrestrial lichen abundance are: SBPS/04, 01a; SBSdk/09, 01a; SBSmc2/01c; ESSFmc/03, CWHws2/02; sites that have moderate to low terrestrial lichen abundance are: SBPS/03; SBSdk/01b, 04, 05; SBSmc2/03; ESSFmc/04, 01, 31; and all other sites are considered very low terrestrial lichen abundance.

6. Stands with a very low site index (less than 13) have the best terrestrial lichen growth. As the site becomes richer, the terrestrial lichen abundance generally declines. Sites with richer site indices (greater than 25) are considered to have very low potential for growing terrestrial lichens.

7. Lodgepole pine leading stands have better terrestrial lichen growth and stands with lodgepole pine as the secondary species tend to have better terrestrial lichen growth than other stands that have no pine.

8. Stands with lower canopy closure (classes 1 - 3) have the best conditions for growing terrestrial lichens. Stands with canopy closure greater than class 3 are less likely to have high terrestrial lichen growth.
9. The following set of assumptions/predictions were made based on the work of Williston and Cichowski (2001-2). Stands with mountain pine beetle (MPB) killed trees are predicted to have some structural differences from stands disturbed from other agents or factors (Williston and Cichowski 2002). Stand changes that are expected to influence terrestrial lichens are:
   a. Reduction of evapotranspiration from canopy trees.
   b. Due to needle loss, there is a high influx of mulch on the forest floor, which may result in a short-term suffocation or suppression (predicted to last 3-5 years) due to burial from needle litter.
   c. A decrease in the canopy interception of precipitation.

   The predicted result of a, b, and c is that there will be an increase in the ground moisture/humidity that will result in an increase in the growth of feathermosses (on circum-mesic sites). On drier sites, there may not be much change in the cover.
   d. A fourth prediction is that the standing dead trees provide more thermal and light interception than in clearcut stands, especially while there are still branches on the snags.

   Overall, the factors from these predictions indicate that MPB stands are somewhat detrimental to terrestrial lichen abundance and to winter forage for caribou. The effect of MPB killed stands will be dependent on the extent of the killed stand and the portion of the stand that is lodgepole pine leading.

Terrestrial Lichen Quality Rating Interpretation

The terrestrial lichen model output will be considered a prediction of the abundance of terrestrial lichens. The abundance was stratified into ratings that are ecologically interpreted (See Table 10). This interpretation has not been verified.

<table>
<thead>
<tr>
<th>Quality</th>
<th>Netica Range</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nil</td>
<td>0</td>
<td>These sites are restricted to areas that do not have any potential to grow lichens, such as lakes, rivers, and development.</td>
</tr>
<tr>
<td>Low</td>
<td>&gt;0 – 0.33</td>
<td>These areas may have sporadically located, small patches of some forage lichens, but are not considered to be potential terrestrial feeding areas.</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt;0.33 – 0.66</td>
<td>These areas may have the occasional patch of terrestrial lichen, however only sometimes are these preferred forage lichens. These areas could be considered to be marginal areas, mostly not foraged in, however with the lack of information regarding foraging in the Telkwa herd and the Sydney Williams herd, it is difficult to state the extent that some of these habitats may be used in some years.</td>
</tr>
<tr>
<td>High</td>
<td>&gt;0.66 - 1</td>
<td>These areas have a predominance of terrestrial forage lichens over other ground cover. There should be medium to large size patches of terrestrial lichens in close proximity to one another. These are considered to be good potential terrestrial feeding areas (both lichen abundance). The very best of these sites are areas with large patches of deep terrestrial lichens and very low to no moss cover. These areas are probably going to be restricted to the SBPSmc in the Morice and Lakes forest districts due to the largely drier climate of this zone.</td>
</tr>
</tbody>
</table>
APPENDIX B – ARBOREAL LICHEN ABUNDANCE SUB-MODEL

Arboreal Forage Lichen Ecology

Arboreal lichens in the genera *Bryoria* and to a much lesser extent, *Alectoria*, are considered important forage genera for caribou. Because of the relative importance of *Bryoria* to caribou during the winter, this model can be interpreted essentially as a predictor of *Bryoria* abundance.

Based on observations in the ESSF (Goward 2000, Goward 1998), the distributional ecology of "hair lichens" in the genus *Bryoria* is examined. Seven microscale and mesoscale patterns are recognized:

1. A failure to successfully colonize branches occurring below the upper limit of the winter snowpack;
2. An occurrence in much lower abundance over the outer, foliated portions of branches than over the inner, defoliated portions of the same branches;
3. A tendency to periodic die-off in the outer, foliated branches, but not in the inner, defoliated branches;
4. A development of disproportionately heavier loadings over old, senescent trees than over young, vigorously growing trees of similar size;
5. An ability to colonize all levels of the forest canopy, including the upper crowns of trees;
6. An anomalously higher biomass in young stands growing in exposed sites than in young stands growing in sheltered sites; and
7. A development of considerable biomass in poorly illuminated stands that are nevertheless well ventilated.

It is suggested that the main features of *Bryoria* micro- and mesodistribution are controlled by a pronounced sensitivity to prolonged wetting (Goward and Arsenaault 2000). The vertical zonation of lichen communities is accompanied by distinct height and aspect related trends in canopy microclimate. Snowmelt events during the winter period account for most of lichen wetting. The attenuation of lichen wetting after precipitation events (both snowmelt and rainfall) is typically greatest in lower canopy exposures. The exception to this pattern is seen under midwinter conditions, when solar insolation is insufficient to sustain prolonged snowmelt activity. Differences in lichen wetting duration between upper and lower canopy locations were significant only for south-facing aspects during the summer period. For lichens from the *Bryoria* functional group, their peak of abundance in the upper canopy, notwithstanding exclusionary mechanisms preclude colonization and growth in the lower canopy. These may be based on substrate preference or physiological limits. In the later case, intolerance of periods of prolonged wetting would provide a mechanistic basis consistent with observed canopy microclimate gradients (Coxson and Coyle 2003).

Foliose lichens, though widely distributed on individual branches at all heights, show greatest total loading in the lower canopy. These distribution patterns are accentuated by the physical structuring of high elevation forests, with trees growing in clumps retaining significantly higher lichen loading on a per branch basis, compared to solitary trees.

Studies in the Coastal Western Hemlock Zone on the coast of Vancouver Island (Price et al. 1998) found that epiphytic lichen abundance, and the proportion of alectorioid lichens, increased with stand age, at least up to 120 years: young-mature stands contained about one-third of the lichen biomass of their old growth counterparts (33 ± 10%); old-mature stands contained similar amounts to their counterparts (124 ± 43%). Abundance and composition also varied with tree species and location. Relatively high elevation fir forests (> 400 m) had a high abundance of lichen dominated by cyanolichens; low elevation forests (< 200 m) had a high abundance dominated by alectorioids; mid elevation forests (300-400 m) had less lichen. It is important to note that the mature stands studied were all small (~0.5 ha), contained remnant structure and were surrounded by old growth. Hence, the results likely overestimate the level of lichen abundance that would exist in mature stands following standard forestry practices (Price 1987).
Partial cutting affects arboreal lichens in several ways. By making the stand more open, partial cutting alters the canopy microclimate. The changed microclimate can affect the physiological activity, the growth rates, and the fragmentation rates of the lichens in the canopy. Fragmentation reduces standing crop, but is also a mechanism by which lichen fragments disperse to colonize regenerating trees, and by which lichens become available to caribou as litterfall. High levels of timber removal can result in windthrow in the residual stand and excessive fragmentation of the lichens, depleting the standing crop (Stevenson 1991).

**Arboreal Lichen Model Structure**

The following provides documentation for how the arboreal lichen abundance belief model was developed.

Modeling a prediction of arboreal lichen abundance is a sub model of late winter habitat value of northern woodland caribou in the study area. An algorithm was created for predicting arboreal lichen abundance in the study area. Information incorporated into the algorithm stemmed from projects within the study area, from projects outside the study area but within similar ecotypes and from expert knowledge. The BBN’s were originally built according to the information in these algorithms. Habitat attributes that were considered important to predicting arboreal lichen abundance were included in the algorithm and rated for importance against one another. This information is incorporated into the belief net in Netica®.

The output values of arboreal lichen quality for each polygon were described in terms of forage function groups. The groups and the test ranges for each group (low, moderate, high) are outlined in the following sections. Expectations of what each group will provide in terms of abundance and forage value is also described. Limits of each range will be adjusted to fit the expected utility of each group once the model is tested and validated.

Predicting arboreal lichen abundance in the study area involves many sources of uncertainty because there are many data gaps. Also, much of the knowledge that is synthesized is based on information from other areas, data that was collected only in a portion of the biogeoclimatic subzone and sites, or on relationships that can be highly variable between abundance and habitat variables. Arboreal lichens do not appear to have a strongly predictive relationship with one particular habitat variable; therefore, the arboreal model does not have a variable that overrides all others in predicting arboreal lichen abundance. There are habitat variables that greatly improve the possibility that arboreal lichens will be present; however, there is a lot more variability surrounding this information.

Arboreal lichen abundance is estimated in a model using Netica®. As more information is collected regarding arboreal lichen abundance and stand attributes, we should be able to refine this model.
Arboreal Lichen Model Assumptions

The assumptions that were made in the development of this habitat variable model are listed below:

1. Arboreal lichens are more prominent in older forests. Below age 70 years, there are essentially no arboreal lichens. Age classes 6 to 8 (101 – 250 years) have the highest amounts of arboreal lichens. Age class 9 (>250 years) stands have slightly less total lichens than age class 8 due to gap dynamics in the old growth stand.

2. In general, trees that are situated near the edge of wetland openings, in relatively well ventilated (often open canopy) stands, along ridges, or in other locations that allow wind venting to occur, have greater amounts of *Bryoria* loading. We assumed that trees within a 20m buffer of wetland types (W5 and W1 type wetlands) and a 10m buffer along river types (S3 and S5) would have an advantage over other trees for growing arboreal lichens due to better stand venting. Forested polygons located along the subalpine-alpine tundra are also considered to be ecological edges that have a higher propensity for growing arboreal lichens; therefore, these sites were also identified as edges with good ventilation.

3. Stands with a relatively open canopy (less than 15% canopy closure) generally have the better conditions for growing arboreal lichens than denser stands. This is not always true because dense stands with good drying and venting conditions can have good growing conditions. The conditional probability table reflects the uncertainty in this information.

4. Assume that stands with a warm or flat aspect have an advantage over cool aspect stands because of preferred growing conditions for *Bryoria* (Goward 1998). *Bryoria* tends to prefer slightly drier micro conditions and we assume that on warm or flat aspects, snow will melt sooner from trees and result in better growing conditions for these lichens.

5. Assume that forest type (leading and secondary species) affects the abundance and growth of arboreal lichens. Black spruce leading stands typically have very good arboreal lichen growth; however, because of their tree form, the total amount of arboreal lichens is generally only abundance class 3 for high abundance black spruce trees. Abundance in pine, spruce, or subalpine fir stands is not easy to predict based on tree alone and can have low to high amounts of arboreal lichen.
abundance. We assumed that assigning a moderate rating to pine, spruce, or subalpine fir stands would be representative of lichen producing ability. Other stands (such as whitebark pine, hemlock, or deciduous) have low arboreal lichen growing ability in all conditions.

6. The growing season at lower elevation sites is longer and therefore better than at higher elevation sites; however, the higher elevation forests tend to be older than lower elevation forests.

7. Assume that arboreal lichens are completely removed when trees are removed by any agent (i.e. forestry or fire).

8. For partial cut stands, arboreal lichen growth in the regenerating stand will be greater than in similar aged clear-cut stands because of lichen colonization by fragmentation.

9. For MPB attacked stands, the affect of tree and/or stand mortality, adjacent stand mortality, needle, or needle loss on arboreal lichen growth is not quantified; however, it could be assumed that the more open stand structure will favour arboreal lichen growth.

10. Currently, there is no component to adjusting arboreal lichen growth after management.

**Arboreal Lichen Quality Rating Interpretation**

The arboreal lichen model output will be considered a prediction of the abundance of arboreal lichens. The abundance was stratified into ratings that are ecologically interpreted (See Table 11). This interpretation has not been verified.

<table>
<thead>
<tr>
<th>Quality</th>
<th>Netica Range</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nil</td>
<td>0</td>
<td>These sites are restricted to areas that do not have potential to grow lichens, such as lakes, rivers, and development.</td>
</tr>
<tr>
<td>Low</td>
<td>&gt;0 – 0.33</td>
<td>Nil to very low volume of arboreal lichens. Arboreal lichen foraging considered negligible. These stands are dominated by lichen class 1 and may also have the occasional lichen class 0 or lichen class 2 trees.</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt;0.33 – 0.66</td>
<td>These stands are characterized the widest range of possible lichen classes (0 to 3, and rarely lichen class 4). There will typically be a mixture of class 1, 2 and 3 with class 2 dominating. These stands can provide some arboreal forage for caribou; however, there is a higher energetic cost to foraging in these sites versus sites with higher loads due to more travel to forage.</td>
</tr>
<tr>
<td>High</td>
<td>&gt;0.66 - 1</td>
<td>High arboreal lichen ratings mean that there are mostly lichen class 3 and 4 trees, with some class 5. These sites are valuable forage areas because of the roving manner which caribou typically forage. Class 3 and 4 trees will have enough available lichen to be energetically favourable to foraging in these stands. The very best sites in this class will be dominated by class 4 and 5 trees and are considered very high potential for foraging.</td>
</tr>
</tbody>
</table>