# TECHNICAL REPORT

# Identification of Designated Areas for the Ongoing Management of Liard Plateau Woodland Caribou (*Rangifer tarandus caribou*) in British Columbia

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## ABSTRACT

The Liard Plateau herd of woodland caribou (*Rangifer tarandus caribou*) is a relatively small and isolated herd in northern British Columbia with a small portion of its range in southern Yukon. The herd is part of the threatened Northern Mountain population and, until recently, has been isolated from industrial disturbance. The recent threat of increased disturbance within the herd range led to the need for more advanced information about the status of the herd and for the development of measures to protect and conserve habitat. Our objectives were to report results of recent data collection and to use those data as the basis for: 1) a biological rationale for desired habitat conditions for the herd, 2) recommendations for the location of legally designated conservation areas (i.e., Ungulate Winter Ranges and Wildlife Habitat Areas), and 3) recommendations for herd and habitat management. Data about the caribou herd were available from surveys to estimate population size and structure, surveys to track radio-collared caribou, regular downloads of caribou locations from collars equipped with global positioning system technology, kill-site investigations, and blood samples from captured caribou. With these data we describe seasonal movements, home range sizes, population estimates, pregnancy and parturition rates, adult and calf survival rates and mortality causes, and habitat use. We used both Bayesian methods and Resource Selection Functions (RSF) to map seasonal ranges. The RSF seasonal ranges were judged to provide the best characterization of seasonal range use and were therefore recommended as the basis for depicting designated areas. Desired habitat conditions were described and specific considerations were provided for monitoring, research, population management, access, harvesting and silviculture, use of pesticides, and recreation.

## ACKNOWLEDGEMENTS

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# INTRODUCTION

## Background

The Liard Plateau population of woodland caribou (*Rangifer tarandus caribou*), henceforth the Liard Plateau herd (or the herd), is one of 31 herds of the northern ecotype of woodland caribou in British Columbia (Heard and Vagt 1998). The northern ecotype occupies 23 million ha of land in British Columbia (BC) and the Liard Plateau herd specifically is somewhat unique in occupying the most northeastern portion of this ecotypes distribution in BC. The herd is also trans-boundary with some of its occupied range existing in Yukon where it is known as the Crow River herd (EC 2011). The northern ecotype of caribou in BC, accounts for about 17,500 individuals or approximately 36-42% of the North American population and is generally associated with mountainous areas and adjacent low-lying plateaus found in the west-central and northern parts of the province. Range use by northern caribou is generally characterized by individual caribou having distinct seasonal migrations from low-elevation winter ranges in early winter to higher-elevation ranges in late winter and by their diets being primarily composed of terrestrial forage lichens (*Cladina* and *Cladonia* spp.).

In 2010, McNay and Hamilton (2010) characterized the Liard Plateau herd as having 141 individual caribou although at that time it had been 5 years since a population survey was conducted. The herd was assumed to be a relatively stable population with a range of 5,069 ha and a population density of 28 animals/1,000 $km^2$. The herd is located within the Northern Mountain Population (NMP) of northern caribou which was assessed by the Committee on the Status of Endangered Wildlife in Canada, as a zone within which caribou are considered to be a species of special concern. This population, and the Liard Plateau herd specifically, was therefore listed as a species at risk under the Species at Risk Act in 2005. A management plan was prepared for the NMP (EC 2011), and although the plan does not address management actions for the Liard Plateau herd specifically it does provide guidelines for developing management direction. The primary goal of the NMP plan is to prevent the caribou in the NMP from becoming threatened or endangered by maintaining herd populations within the natural range of variability and by maintaining the ecological integrity of key habitats, both goals to be achieved through a set of higher-level objectives as follows (EC 2011):

1. Determine herd status and trends;
2. Manage harvest for sustainable use;
3. Assess health risks;
4. Increase understanding of predator-prey systems and potential competition from other herbivores;
5. Identify and assess quality, quantity, and distribution of important habitats;
6. Manage and conserve important habitats;
7. Promote conservation through environmental and cumulative effects assessments; and
8. Foster opportunities to share knowledge.

Northern caribou herds were Blue-listed by the BC Conservation Data Center which means the herds are considered of “special concern” and in need of special management to ensure their survival. Under the BC Conservation Framework[1], northern caribou are considered priority 2 as a species that contributes to Goal 2 “to prevent species and ecosystems from becoming at risk”.

[1] See http://www.env.gov.bc.ca/conservationframework/ (Accessed April 27, 2010)

These herds, along with all other caribou in BC are also considered to be "Identified Wildlife" under the *Forest and Range Practices Act* (FRPA). FRPA regulations have been provided for the "protection of species at risk" and for the "overwinter survival of ungulates". This legal mechanism allows for the identification of designated areas within which management measures may be specified for protection and conservation of habitat for the species[2].

Although the Liard Plateau herd is located in a relatively remote area, there is potential for oil and gas development and associated concerns about increasing access to the area (EC 2011). According to EC (2011), the herd is considered vulnerable to this threat primarily due its relative isolation from other caribou herds and due to the fact that it is a relatively small herd restricted geographically to a very small plateau; the area being essentially the most easterly occurrence of higher elevation prior to the relatively continuous low-elevation landscape of the boreal forest. The herd is therefore a candidate for the identification of designated areas under FRPA on the basis of:

1. The potential threat from industrial development,
2. The herds legal "at risk" status,
3. Caribou being legally identified as "an ungulate species" under FRPA, and
4. The herd's contribution to strategic planning which is focused on maintaining NMP population levels.

## Objectives

Our objectives were to report results of recent data collection and to use those data as the basis for: 1) a biological rationale for desired habitat conditions for the herd, 2) recommendations for the location of legally designated conservation areas (i.e., Ungulate Winter Ranges and Wildlife Habitat Areas), and 3) recommendations for herd and habitat management.

## Site Description

The Liard Plateau caribou herd area, as delineated by the provincial government, is located entirely within the Fort Nelson forest district and encompasses an area of ~477,000 ha bounded approximately by the provincial border in the north, the Liard River in the east and south, and the Coal River in the west (Figure 1). The area contains all of the Redpott landscape unit and portions of the Crow, Graybank, Grayling, Liard Hot Springs, Moule, Scatter, and Smith landscape units. The area is mostly unroaded and is best accessed by traveling to the southern boundary of the herd area along the Alaska Highway to the communities of Muncho Lake or Liard River. From there, helicopter access is required to enter the interior of the herd area with the exception of a forest road that provides north-south access through the western portion of the area between the highway and a settlement at Smith River.

Topographically, the herd area is centred on the Caribou Range which constitutes the last significant mountain range before one descends into the boreal plain in the eastern third of the area. The western portions are generally mountainous or rolling. Surface elevation in the area ranges between 514 m and 1705 m with the lowest elevations found in the Smith River valley and the highest in the Caribou Range. Major drainages within the study area include the Smith, Grayling, and Crow Rivers, as well as Scatter, Vizer, and Moule Creeks. Also of note are numerous geothermal hotsprings in and around the study area such as those on the Liard, Grayling, and Deer Rivers.

[2] See http://www.env.gov.bc.ca/wld/frpa/species.html (accessed September 29, 2013)

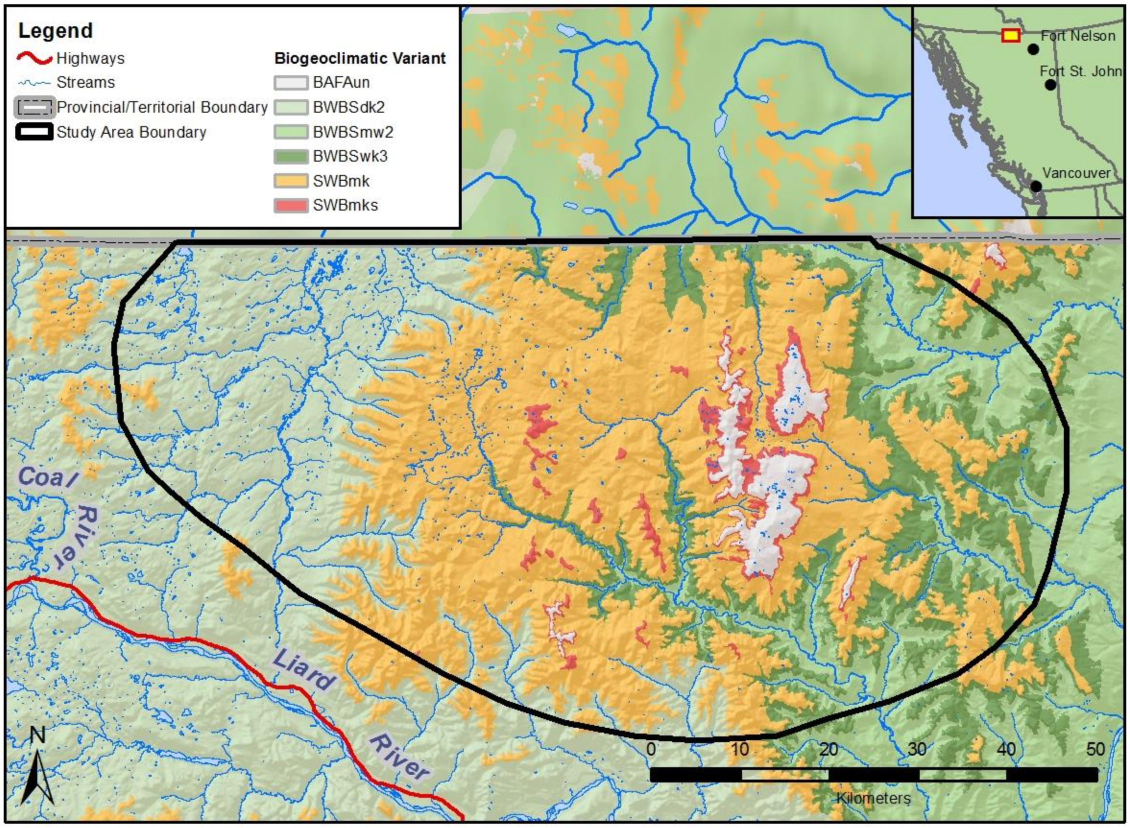


*Figure 1. The location of, and biogeoclimatic zones associated with, the Liard Plateau caribou herd in northern British Columbia.*

Lower elevations are dominated by the Boreal White and Black Spruce (BWBS) Biogeoclimatic zone with western areas containing dry subzones and eastern areas containing moist and wet subzones (Figure 1). Higher elevations are almost exclusively in moist, cool variants of the Spruce Willow Birch (SWB) zone. Alpine (BAFA) landscapes are confined to the Caribou Range at elevations generally over 1400m. Historically, this area has not seen intensive development or human-use. Most activity has been focused on subsistence and commercial hunting, fishing, and trapping by Aboriginal people, guide outfitters, and local residents. Recently, there has been interest in industrial development in the area for resource extraction (e.g. oil and gas interests, quartzite mining for frac sand).

# GENERAL ASSESSMENT METHODS

## Historic Studies

Information about the Liard Plateau herd has generally been sparse until recently. During the broadly conducted Canada Land Inventory[3], the surveyors were able to enumerate caribou in this herd in 1975 for the first recorded information about the herd (Pers. Comm.; July 18, 2011; A. Stewart (retired); British Columbia Min. of Environment, Victoria, BC). In April 2002, Yukon Dept. of Environment deployed GPS[4] instrumented collars on three caribou; the collars set to

[3] See http://sis.agr.gc.ca/cansis/nsdb/cli/ (accessed March 26,2013)
[4] GPS – Global Positioning System

deliver a geographic position once every 5 days for 2.5 years. A total-count population survey was conducted by Yukon Dept. of Environment for the first time in 2005 (Powel 2006) and again by the BC Min. of Environment in 2010 (Thiessen 2010). In March 2011, a detailed study of the herd was initiated by Stikine Energy Corp. as a component of baseline studies for a pending Environmental Impact Assessment that was associated with a proposed mine to develop frac sand for the nearby shale gas industry. Metadata for these studies are summarized in Table 1.

## Methods to Assess Baseline Conditions - Biological Rationale

### *Animal Captures and Data Collection*

Baseline environmental conditions for the Liard Plateau herd were characterized largely on the basis of collared animals fitted with instrumentation that was either: a) capable of communicating with the Iridium satellite system (SAT) or b) capable of emitting Very High Frequency (VHF) radio signals to enable location (and other) observations based on remote telemetry. The SAT communication facilitated remote transmission of animal locations via internet-based email. Caribou to be collared were caught using a net propelled by a .308 caliber rifle, fired while hovering above the animal in a rotary-wing aircraft. Caribou were blindfolded, hobbled, and manually restrained without the use of drugs while fitting collars. Collars were fit to minimize disturbance to the animal. Remote collection of SAT data from collared caribou was attempted once every 5 days or once every 6 hours for YK and Stikine animals, respectively. We also determined locations of collared animals more directly using a Cessna 185 fixed-wing aircraft and standard VHF receivers (SRX 400, Lotek Engineering Ltd.,

*Table 1. List of previously collected data available for characterizing baseline ecological conditions for the Liard Plateau caribou herd in northern British Columbia.*

| Survey | Data | Observations |
|---|---|---|
| Census – Late winter | Feb 1975 | 1 survey, 3 locations |
| Capture/mortality | Apr 2002 | 3 GPS |
| Satellite | Apr 2002 - Oct 2004 | 3 animals, 318 locations |
| Census – Fall | Sep 2005 | 1 survey, 28 locations |
| Census – Late winter | Feb 2010 | 1 survey, 28 locations |
| Census – Calving | Jun 2010 | 1 survey, 28 locations |
| Census – Fall | Oct 2010 | 1 survey, 26 locations |
| Capture/mortality | Dec 2010 | 20 VHF |
| Capture/mortality | Mar 2011 | 15 SAT |
| Census - Late winter | Mar 2011 | 1 survey, 13 locations |
| Census - Calving | May 2011 - Jul 2011 | 6 surveys, 202 locations |
| Census – Fall | Oct 2011 | 1 survey, 33 locations |
| Census - Late winter | Mar 2012 | 1 survey, 26 locations |
| Satellite | Dec 2010 - Nov 2012 | 15 animals, 24539 locations |
| Telemetry | Feb 2011 - Mar 2012 | 13 surveys for 318 locations |
| Pregnancy | Dec 2011 - Mar 2012 | 34 samples |

Newmarket, Ont.). Some relocations were obtained during other surveys using a Bell 206 B Jet Ranger helicopter. For each adult female encountered (marked or unmarked), we recorded: session number; date and time; weather conditions at the start and end of the flight; animal ID# and VHF frequency of the radio-collar being monitored; group number; total animals in the group; number of animals by gender and age class; activity class; visual location code; spatial UTM coordinates and zone; habitat type; estimate of animal sinking depth in snow; estimate of snow depth; identification of other marked animals in the vicinity; a photo of the site; and identification of the general location by name. We collected spatial coordinates for each animal observation using a Global Positioning System receiver and classed the accuracy of individual locations as follows: Visual ~100-m radius; Fix ~200-m radius; General ~4-km radius; and Heard ~30-km radius. We also recorded the presence/absence of calves. In addition, we recorded weather conditions every hour during each survey flight. Data were entered into a relational database (WIMS; Biodata - Wildlife Information Management Software, © 2002, Terra Cognita Software Systems Inc., Prince George, BC) and exported to ArcView (Environmental Systems Research Institute, Redlands, California) to check visually for spatial errors against notes recorded on maps while doing fieldwork.

### *Analytical Methods*

#### *Identification of Seasonal Movements*

Assessment of movements for the purpose of identifying individual-level response to seasonal environmental change was initiated by first inspecting movement segments; the latter being derived by calculating the distance between successive geographic locations (remote SAT downloads only). When unidirectional movement segments were easily detected, they were joined to form one longer movement. This was a manual task accomplished using ArcView GIS3.2a (ESRI, Redlands, California) with Extension Animal Movement SA v2.02 beta version. Point locations for each caribou and for each year were sequentially linked using "Create Polyline From Point File" and saved as a separate shape file. Each shape file was then "animated" using the "Animal Movement Path" extension and color codes were set to differ on a bi-monthly basis to help visual identification of movement patterns. As the movement path from one point to the next took place, the "active movement" was stopped when a series of unidirectional (i.e., never exceeding $90^0$ turns, >100m) moves were encountered. The location point representing the start of the move was labelled "start", subsequent points were labelled "enroute", and the last point of the movement was labelled "end". Single movements that exceeded 3,000m were labelled "start-end". "Enroute" segments were removed from the database and the resulting data were used to create a cumulative frequency distribution (*cfd*) of movement distances. Infrequent and "long" movements were then redefined as moves that exceeded the $95^{th}$ percentile of the *cfd*. Relatively more frequent and "short" moves were those that were less than the $90^{th}$ percentile of the *cfd* and the remaining moves were "intermediate".

When possible, movement behavior of each individual was used to delineate seasonal periods. Movements away from ranges that were used in late winter generally occurred in May and were distinguished by unusually long moves (e.g., > 20,000m). By comparison, calving in late May could often be distinguished by a series of unusually short moves (e.g., <50m). The start of the summer season was considered to occur when movements >1,000m became a regular event after caribou had spent the post-calving period in a relative stationary location. Rut was identified by a short series (i.e., n = 1 to 3) of long movements followed by two to three days of unusually short, unidirectional movements (i.e., <500m). Movements made by caribou to change range location within the winter season (i.e., early winter to late winter) were identified by a long move to a spatially distinct part of their range; the latter being determined from a visual comparison of the movement path shapefiles. Once seasonal start dates were determined for the obvious cases, averages of the dates and distances were used to define seasons for those animals and times when there were no obvious indications of behavioral response to seasonal changes.

### ***Home Range Use***

We calculated the total, annual, seasonal, and annual-by-season home ranges using SAS software (SAS Institute©; Cary, North Carolina) and an algorithm to calculate minimum convex polygon (MCP) home ranges (White and Garrott 1990). The MCP algorithm joins the outer animal locations to form a convex polygon for which home range area was calculated in $km^2$. Both SAT and VHF locations were used for the analysis. Seasons were defined based on methods described above (i.e., *Identification of Seasonal Movements*). We assumed ≥5 temporally independent relocations within each distinct seasonal range were required in order to adequately describe spatial use of seasonal range (Johnson 1980). We assumed relocations were temporally independent if separated by an 8-day interval. Home ranges were calculated for animals with > 5 locations within a stratification (i.e., annual, seasonal, or annual-by-season). For the MCP home range calculation to be valid, we assumed relocation data were uniformly distributed. Following the methods of Samuel and Garton (1985), we therefore tested that assumption by comparing the actual distribution of relocations with those from an expected bivariate uniform distribution using Cramer-von Mises statistic ($W^2$). For each home range calculated, we rejected the null hypothesis of a bivariate uniform distribution of caribou locations where the goodness of fit probability was less than 95%.

We assumed that fidelity to ranges was indicated by annual variation in the mean of spatial coordinates of relocations for a particular season. Fidelity was therefore measured as the straight-line distance between centers of annually successive seasonal ranges for each caribou.

We assessed all data distributions using techniques in PROC UNIVARIATE (SAS). We used Bartlett's test to assess homogeneity of variance after checking normality of data distributions (Zar 1974). Difference in parameters was assessed using a Kruskall-Wallis test (Zar 1974) when unequal variances were encountered. If data were normal and homoscedastic (or could be transformed so), we used an F-test.

### ***Survival Rates and Mortality Causes***

Survival rates were determined by inspecting downloaded SAT information for mortality notes associated with individual collared animals and by periodically (i.e., at least quarterly) checking the status of animals collared with VHF transmitters. For the purposes of this analysis we assumed VHF collar end was the same date as majority of Sat collar failure (September 10, 2012) and mean monthly survival rate over the length of the study was calculated as a Kaplan-Meier estimate in SAS.

Site investigations were conducted as soon as possible after first monitoring mortality signals. Site investigations included determination of the time of death as well as cause of death. Time of death, was subjectively determined by the investigator according to evidence at the site (e.g., a qualitative assessment of relative moisture content of the remains) or by investigating patterns in the radio-telemetry data leading up to the first observation of a mortality signal. When sufficient remains occurred at the site, we conducted partial necropsies, took photos for subsequent inspection, and collected any evidence of the source of mortality. Death was classified as: 1) accident/nutrition (including incidents involving vehicles, avalanches, starvation- and disease-related mechanisms), 2) human (including hunting and capture myopothy), 3) predation (including wolf, wolverine, or grizzly bear), or 4) unknown. Kills made by wolverine were generally recognized by substantial head and/or neck injury and by feeding signs consisting of burrowing into the carcass. Kills made by wolves were generally scattered in a wide area around the site while remains of caribou killed by bears were buried. Other evidence at the site, or lack of evidence, was used to help substantiate cause of death such as track patterns, condition of surrounding vegetation, and hair and scat samples. Malnutrition was identified by examination of the bone marrow; red, gelatinous bone marrow indicating malnutrition (Cheatum 1949)

### ***Population Estimates***

Population surveys were conducted using a Bell 206 helicopter with an experienced pilot, experienced or well-trained navigator, and two trained observers. The surveys were completed in May/June (Neonatal survey), in October or November (Post Summer survey), and in February/March (Late-winter survey) using techniques and data collection protocols which adhered to BC Resource Inventory Standards Committee guidelines for aerial ungulate inventories (BCMSRM 2002). The navigator used a lap top computer with ArcView® and a DNR Garmin ArcView extension[5] to navigate during the survey and record flight lines. This allowed us to ascertain our exact position inside each sample unit, insure full coverage of the unit, avoid erroneous duplication of area, and to provide a means for estimating sampling effort.

Aerial radio-telemetry, for marked animals in the survey areas, was conducted from a fixed-wing aircraft prior to the survey, confirming general locations for the marked animals. The information provided guidance to the navigator improving the efficiency of the rotary wing aerial survey. The alpine and parkland range of each sample unit were surveyed following contour-based flight lines working upwards in elevation from tree-line unless unfavourable winds were encountered. In relatively gentle terrain with very good visibility, we increased the distance between flight lines (500-800 m) otherwise, in conditions of steeper slopes or lower visibility; flight lines were between 100 and 400 m. Aircraft speed varied from 40-100 mph depending on relative visibility and terrain of each flight line. Height-above-ground ranged from 50-200 m and depended on openness, tree density, and safety of the crew. Subalpine areas were not always surveyed even though we knew animals occupied that habitat. The relatively closed-canopy nature of subalpine areas rendered the likelihood of detecting caribou insufficient to conduct a useful or statistically robust survey. Rather, when we observed use of that habitat through telemetry of radio-collared caribou, we sought out their locations, and recorded observations of accompanying animals as best we could. The low elevation portions of each sample unit was surveyed for the most part by following lakes, pine lichen winter ranges[6], black spruce wetlands[5]/meadows, and rivers normally occupied by caribou in an attempt to verify their absence based on lack of fresh tracks or foraging signs. If caribou or fresh caribou tracks were detected, we then began data collection in those areas. Data collection involved flying systematic transects, spaced 250 - 350 m apart, over the survey polygon. If tracks were encountered prior to animals, they were followed until the animal(s) was sighted.

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[5] http://www.dnr.state.mn.us/mis/gis/tools/arcview/extensions/DNRGarmin/DNRGarmin.html

[6] These range types were delineated using the Caribou Habitat Assessment and Supply Estimator (CHASE) model (McNay et al. 2006). See also section on *Methods for Identifying Designated Areas*.

Within all range types, once animals were sighted, the pilot attempted to hover in close proximity but only long enough so animals could be counted and classified with minimal harassment. Animals were classified according to the level two classifications standards (BCMSRM 2002). Where multiple groups were located in close proximity to each other, they were considered to be separate if they were at least 150 m apart, occurred in different habitats, or displayed different group characteristics or behaviours. Marked animals (i.e., ear-tags or collars) were noted and identified in each group. After completing the sample unit, radio telemetry was used to determine if any radio-collared caribou within the survey unit were missed by the observers.

The navigator recorded each observation of caribou along with ancillary information including: study area surveyed, crew names, aircraft type and speed, survey and census type, date, start and end time for each flight line, UTM coordinate at start and end for each flight line, general location and description of the sample unit, general weather conditions, observation time, UTM co-ordinates, animal identification if marked, marking descriptions (e.g., radio-collar color, ear tag number and color), approximate sinking depth in the snow, and status of detection (whether marked animals were observed or missed during the survey). One of the observers recorded the detailed count and classification for each group of animals observed, including species, group size, gender (if possible), and age class. The second observer recorded habitat features, including slope, aspect, elevation, habitat type, tree species, and forest crown closure.

All data were entered into WIMS. Data summaries providing basic statistics for population parameters were prepared using SAS. An alpha (α) of 0.05 was used for all analysis.

Statistical analysis, which included the calculation of typical group sizes and total population estimates followed procedures applied by McNay and Giguere (2008). Recruitment of calves into the subsequent age class was assumed to be represented by the sum of percent of calves observed (calves / total number of caribou) in each group (Bergerud 1983). Variance of recruitment was calculated from the binomial distribution using the Proc Survey Means procedure of SAS.

### *Habitat Use*

Habitat use for the herd was characterized for each seasonal range using attributed caribou locations (SAT and VHF). Relocations were attributed with vegetative and geographical variables from available 1:20,000 scale landscape information using ArcMap 10 (ESRI, Redlands, California). The sources of information used were the British Columbia Vegetation Resources Inventory[7], the British Columbia Terrain Resource Information Management program[8], and Baseline Thematic Mapping (BTM; Geographic Data BC 2001)[9]. Forest conditions were characterized by site index (average height of trees at 50 years old), average stand height (m), percentage canopy closure, tree stem density (number per ha), and the most common (i.e., leading) tree species. Geographical setting was characterized by slope (degrees), elevation (m), and aspect (0 –360$^0$). These latter variables were derived from a digital elevation model and were subsequently used to express a landform position roughly equivalent to slope position using an ArcView Hydrological Modeling Extension. Using this extension we determined the most likely flow direction of water from any given 1-ha pixel in the

[7] See http://www.for.gov.bc.ca/hts/vri/ accessed 130930
[8] See http://geobc.gov.bc.ca/trim.html accessed 130930
[9] See https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=43171&recordSet=ISO19115 accessed 130930

landscape. Crest shedding slope positions were intended to represent very xeric, xeric, and subxeric moisture regimes; upper slope shedding positions represented submesic and mesic sites, mid-slope normal positions represented subhygric sites, lower slope receiving positions represented hygric sites, and toe slope positions represented subhydric sites.

We ensured relocations of each animal contributed equally to the analyses of habitat use and preference despite sample size differences among animals and seasons following methods described by Apps and McLellan (2006). Because we assumed an interval of 8 days was required for independence of locations (see *Home Range Use* above), we set a relocation weight X to 1 if ≥8 days had elapsed since the previous relocation; otherwise X was the proportion of 8 days that had elapsed. We also ensured that the temporal representation of data for each animal was balanced seasonally by establishing a relocation weight Y as the proportion of the total relocations represented by the seasonal locations (i.e., (total relocations / number of seasons) / number of season-specific relocations) observed for each animal in each season and a relocation weight Z as the proportion of the year represented by the season (i.e., (period length / number of seasons) / season length). Sample schedules for each animal were then standardized by applying a total weight ([X * Y * Z]/sum [X * Y * Z]) to each relocation. We assessed habitat data distributions using techniques in PROC UNIVARIATE (SAS, SAS Institute, Cary, North Carolina). We used Bartlett's test to assess homogeneity of variance after checking normality of data distributions (Zar 1974). Difference in parameters was assessed using a Kruskall-Wallis test (Zar 1974) when unequal variances were encountered. If data were normal and homoscedastic (or could be transformed so), we used an F-test.

## Methods for Identifying Designated Areas

### *Bayesian and Resource Selection Function Models*

Baysian Belief Networks belong to a deductive (reason based) modelling approach which consist of nodes and linkages, where nodes represent environmental correlates, disturbance factors, and response conditions (Marcot et al. 2006). All nodes are linked by probabilities. Input nodes (the environmental variables) contain marginal ("prior") probabilities of their states determined from actual or simulated conditions on the landscape; intermediate nodes (e.g., describing attributes of caribou range) contain tables of conditional probabilities. These probabilities can be based on empirical studies and/or expert judgment. Output nodes (caribou range values) were calculated as posterior probabilities. Some input nodes, which we refer to as "management levers", can represent environmental correlates that are dynamic either through unmanaged (natural) or managed disturbances. Where feasible, these nodes are the focus of best management practices or general wildlife measures. Management levers can be adjusted, and their effects forecasted, based on simulations to estimate the effects of best management practices during BBN applications. BBNs for seasonal ranges were constructed as influence diagrams, using the modeling shell Netica (version 2.17, Norsys Systems Corp., Vancouver, British Columbia), expanding these into BBN models in which the node states and probabilities were parameterized mostly from expert judgment. The BBNs we created were used to predict the condition of seasonal ranges for caribou given the conditions of the environmental inputs. The final output from each seasonal range BBN took on values set to range from -1 (low range value), through 0 (moderate), to +1 (high). We displayed resulting seasonal range values on maps as the expected value from the seasonal range node (i.e., the probability of a seasonal range state multiplied by the state value, summed across all possible states) classified into the 3 outcomes of low, moderate, or high based on equidistant intervals of the observed seasonal range values. We used ArcView and Microsoft Access 2007 (Microsoft

Corp., Redmond, Washington) to construct and manage case files of environmental inputs taken from 1.0 ha cells in the Liard Plateau caribou herd area. The environmental inputs that we used came primarily from the BC Forest Inventory Planning attribute database and the BC Terrain Resource Information Management program (Table 2). Case files (i.e., 1 file for each seasonal range BBN) were lists of records (i.e., 1 record for each cell in the study area) containing columns (i.e., 1 column for each input node) specifying the existing condition or state of the environmental correlates represented by input nodes.

Resource selection functions (RSF) belong to an inductive (data based) modelling approach popularized by Manley et al. (1993) where resource selection is modeled by a function of resource unit attributes – the RSF value being proportional to the probability of a resource unit being used. The resource units used were the same as those used for the BBN modeling approach (Table 2). We used logistic regression to form a generalized linear model with a binomial (used and random – latter assumed not used) response and link logit. The binomial logit took the regular form:

$$P\,(y|x) = \frac{1}{1 + \sum\,(\exp(-1^{*}\beta x))_{F_1\text{-}F_{(i)}}} \quad ;\ \text{Eqn. (1)}$$

where, P (y|x) is the probability *y* of a resource unit *x* being used given the *F* state characteristics of the unit and *β* is the vector of estimated coefficients (one for each *F* state) determining the shape of the relationship.

Modeling of this nature has come under scrutiny from failure to address statistical assumptions, particularly those concerning independence of animals, independence of locations for each animal, and the definition of availability and inherent relevance (or lack thereof) to “not used” habitats (Strickland and MacDonald 2006, Gillingham and Parker 2008, Koper and Manseau 2012). In this application concerning designated areas, we assumed population-level responses were most important and so defined the study area as the pooled availability of resource units based on a paired random sample for each use location and pooled observations of use from individuals – essentially what has become known as design 2 in habitat use studies (Thomas and Taylor 1990). Caribou are highly mobile and we argue could easily have reached any location within the study area within a day or part of a day. We also argue that our methods for weighting individual relocations (see *Habitat Use* above), while not completely resolving the problem of dependence, significantly lessens the statistical bias associated with it. Further, while recognizing the population-level nature of designated areas, we addressed the potential importance of individual variation in preference of habitats while simultaneously testing model resultants (see *Model Tests* below). We used an information-theoretic approach (Burnham and Anderson 2002) to develop and select the most efficient model describing seasonal habitat use by the population of collared (SAT only) caribou. The first model addressed UWR and involved the following mixed (categorical and continuous) factors: 1) S - season (early winter [EW], late winter [LW]), 2) G - forest age (continuous), 3) F - forest condition (deciduous [D1], heavy canopied coniferous [C1], light canopied coniferous [C2], and nonforested [NP]), and 4) elevation (continuous). C1 forests were most spruce species (*Picea*) or fir (*Abies*) while C2 forests were primarily lodgepole pine, black spruce (*Pinus banksiana*), and larch (*Larix*). The second model addressed WHA and involved the same four factors described above except that the seasonal factor states were rut (R) and calving (C). All seasons were defined as described in *Identification of Seasonal Movements*.

*Table 2. A list of data inputs contributing to case files used by Netica in processing Bayesian Belief Network models of seasonal range value for caribou in the Liard Plateau caribou herd in northern British Columbia.*

| Case File Input | Description | Data Source |
|---|---|---|
| Aspect | Landscape aspect in degrees | DEM[d] |
| Alpine and Rocks | Alpine and rock non-forest codes | FIP[c] |
| Bare Areas | Unvegetated terrain | BTM[g] |
| BGC Subzone | Biogeoclimatic (BGC) subzone classification | BEC[f] |
| Ecological Unit | Plant community present at a given site | FIP[c], TEM[e], BEC[f] |
| Elevation | Elevation in metres above sea level | DEM[d] |
| Inventory Type Group | Forest type based on species composition | FIP[c] |
| Lead Tree Species | Dominant tree species in a stand | FIP[c] |
| Non-productive Type | Non-productive forest types on the landscape | FIP[c] |
| % Comp. Lead Species | Portion of a stand composed of the leading species | FIP[c] |
| Precipitation As Snow | Amount of precipitation that falls annually as snow | DEM[d][1] |
| Roughness | Rate of change in topographic slope | DEM[d] |
| Site Index | Stand site index | FIP[c] |
| Slope | Landscape slope in degrees | DEM[d] |
| Solar Loading | Global radiation budget in $Wh/M^2$ | DEM[d] |
| Stand Age | Age of a stand at a given time | FIP[c] |
| Stand % Pine | Percentage pine composition of a stand | FIP[c] |
| Stand Removal | Method of harvest or natural disturbance | User-defined[b] |
| Stocking | Stand stocking level (high/low) | User-defined[b] |
| Topographic Curvature | Local slope concavity/convexity | DEM[d] |
| Tree Height | Height of the dominant species in a stand | FIP[c] |

We considered candidate models representing all possible combinations of the independent variables. In the most general model, all factors contributed to P (y|x). We compared this model (the null hypothesis) with simpler nested models, or subsets of the main factors (alternative hypotheses). We used the Akaike's Information Criterion with small-sample bias adjustment (AICc) to help identify a suite of parsimonious models explaining our data best among the possible combinations of variables (Burnham and Anderson 2002). Further, we calculated the relative probability of each model being best as (Anderson et al. 2000):

$$W_m = \frac{\exp\left(-.5\Delta_n\right)}{\sum_{n=1}^{N}\exp\left(-.5\Delta_n\right)}\text{; Eqn. (2)}$$

Where N is the total number of models compared and $\Delta_n = \left(AICc_n - \min\left(AICc\right)\right)$.

[1] Topographic information from DEM, climate data from ClimateWNA application: http://www.genetics.forestry.ubc.ca/cfcg/ClimateWNA/ClimateWNA.html

### *Generation of Operational Maps*

In the Bayesian approach to mapping, we combined results from three independent BBNs (i.e., pine-lichen winter range [top two classes], black spruce swamp complexes [top class only], and high-elevation winter range [top two classes]) to form a composite of UWR. In a similar way we combined results from two independent BBNs (i.e., calving summer range [top two classes] and rutt range [top two classes]) to form a composite WHA. Cells were then selected from the composite rasters and subjected to a two-step process to smooth their boundaries. The smoothing essentially addressed ragged polygon boundaries influenced by surface topography, eliminated small polygons assumed to be of little value to caribou, and filled small voids in polygons of otherwise high likelihood of use. First a 1-cell circular maximum filter was applied to highlight areas of high likelihood of animal use, then a 3-cell circular majority filter was applied to 'clump' concentrations of high-value habitat into rasterized polygons. These rasterized polygons were then converted into vector polygons (shapefiles) and processed to remove small polygons deemed to be of lesser value (<150ha for UWRs, and <400ha for WHAs). As a final step, voids in the UWR and WHA polygons that were <250ha in size were filled in to create continuous polygons. All of the spatial processing was performing using ArcGIS Desktop Basic v10.0 with Spatial Analyst (ESRI, Redlands, California, USA).

Maps depicting UWR and WHA as predicted from RSFs were generating in ArcMap using the factor coefficients of the top models and the factor state conditions that existed within the Liard Plateau area to calculate a probability of use for each 100m pixel. The resultant array of probabilities was then classified into five equal classes from low (i.e, 0.0) to high (i.e., 1.0) probability of use. We arbitrarily represented UWR/WHA as the top 2 of the 5 classes (i.e., probability of use >0.6). The same smoothing process was used for the resulting RSF maps as was described above for the BBN maps.

We made a final assessment of operational map results by contrasting: 1) the proportion of caribou locations that fell within each designated area and 2) the proportion of the herd area that was designated area. The goal in this assessment was to achieve a high proportion coverage of caribou locations using the least amount of designated area.

## BIOLOGICAL RATIONALE

### Caribou Capture and Relocations

VHF collars deployment resulted in twenty adult female caribou being captured and collared during December 17-21, 2010 and all but two of those collars were assumed to still be functioning at the time of analysis although we chose to censor the data from the VHF collars on October 20, 2012 for the purposes all analyses. SAT collars were deployed on adult female caribou April 01, 2002 (n = 3) and March 22-23, 2011 (n = 15) with collars from the first deployment lasting to the fall of 2004 and from the second deployment to the fall of 2012, with the exception of two mortalities. Cumulative monitoring time was 9,607 days and 12,562 days for SAT and VHF collars, respectively. The weighted average fix rate for the SAT collars was 90% (Table 3).

*Table 3. Fix rate and duration of operation for SAT collars deployed on adult female woodland caribou. SAT collars were capable of communicating with the Iridium satellite system (SAT) and were programed to obtain fixes four times per day (caribou codes ending in N) or once every 5 days (caribou codes ending in Y).*

| Caribou | Number of Fixes | Duration | Potential Fixes | Fix Rate |
|---|---|---|---|---|
| C021N | 1924 | 537 | 2148 | 0.90 |
| C022N | 1737 | 536 | 2144 | 0.81 |
| C023N | 1226 | 340 | 1360 | 0.90 |
| C024N | 578 | 161 | 644 | 0.90 |
| C025N | 2021 | 537 | 2148 | 0.94 |
| C026N | 1961 | 537 | 2148 | 0.91 |
| C027N | 1899 | 537 | 2148 | 0.88 |
| C028N | 1994 | 538 | 2152 | 0.93 |
| C029N | 2006 | 537 | 2148 | 0.93 |
| C030N | 1917 | 537 | 2148 | 0.89 |
| C031N | 872 | 241 | 964 | 0.90 |
| C032N | 1675 | 451 | 1804 | 0.93 |
| C033N | 916 | 241 | 964 | 0.95 |
| C034N | 1939 | 536 | 2144 | 0.90 |
| C035N | 1874 | 536 | 2144 | 0.87 |
| C025Y | 157 | 895 | 179 | 0.88 |
| C026Y | 146 | 915 | 183 | 0.80 |
| C027Y | 15 | 85 | 17 | 0.88 |
| Totals | 24857 | 8697 | 27587 | |
| Weighted average | | | | 0.90 |

## Movement Patterns and Seasonal Ranges

A total of 24,857 locations from SAT collars yielded 24,839 distance measures and resulted in a *cfd* fit to a negative exponential of the form (Figure 2):

$$Frequency = 1{,}514 + 22{,}892 * (1 - e^{(-0.0013 * Distance)}).; \quad \text{Eqn. (4)}$$

Inflection points on this curve at the 90$^{th}$ and 95$^{th}$ percentiles, 2,250m and 4,000m respectively, resulted in us being able to distinguish relatively frequent and short moves from relatively infrequent and longer moves. In general, the proportion of long moves in each month was normally distributed with most of the long moves occurring in June and July, shoulder periods of April/May and August/September, and low proportions of long moves occurring October through Mar (Figure 3 A). The proportion of long to short moves was about 0.056 but varied through the year with a low of 0.013 in March to above 0.085 through June, July, September, and November (Figure 3 B).

We identified 10 times when caribou clearly shifted to distinctly different places within their range in late winter (Table 4). These were generally long moves between 12 to 19 kms and occurred around the end of February through to the end of March. Moves to migrate to new

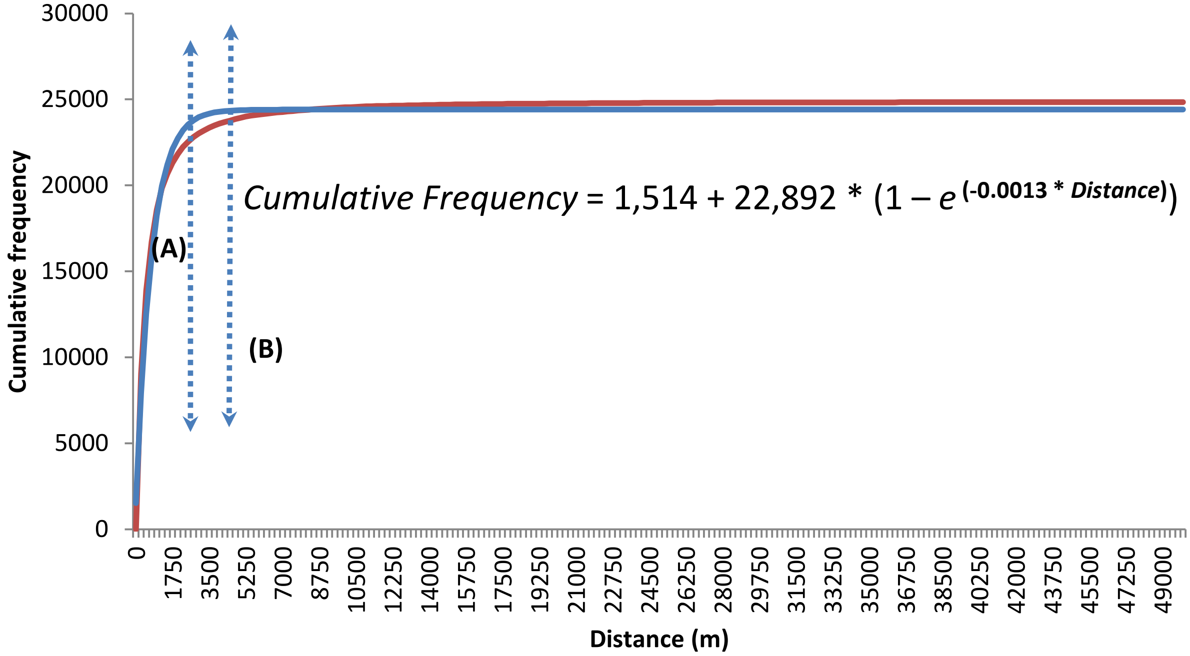


*Figure 2. The cumulative frequency of distances (m) moved by radio-collared caribou in a study of movement patterns of the Liard Caribou herd in northern British Columbia, 2002-2004 and 2011-2012.*

*A negative exponential (blue line) characterizes the general shape of the observed data (red line) and inflections distinguish relatively frequent and short movements (A) below the 90th percentile (2,250m) from relatively less frequent and longer moves (B) above the 95th percentile (4,000m).*

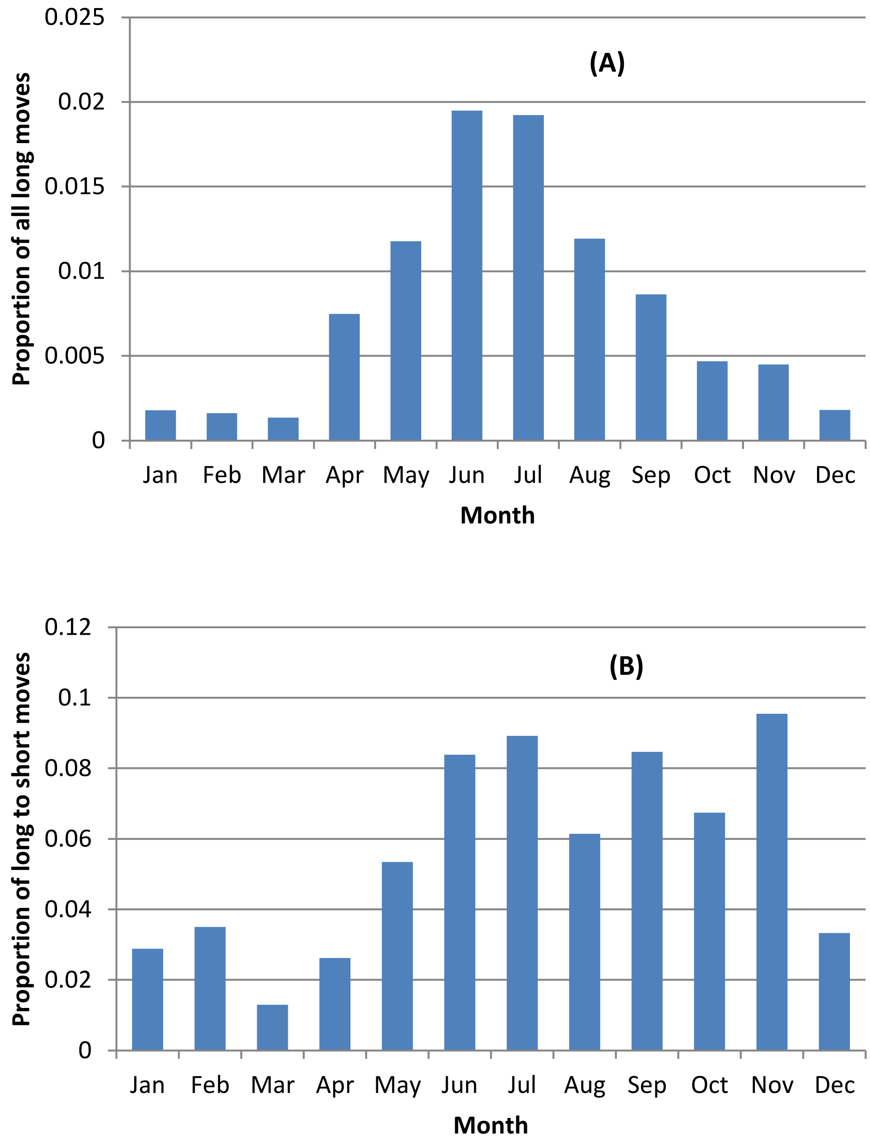


*Figure 3. The proportion of all long movements made by radio-collared caribou in each month (a) and the proportion of long to short moves made by radio-collared caribou in each month in a study of movement patterns of the Liard Caribou herd in northern British Columbia, 2002-2004 and 2011-2012.*

*Table 4. Statistics describing the timing (dates/days) and distances of relatively long movements (see text) made by radio-collared caribou as the basis for classifying seasons in a study of the Liard Caribou herd in northern British Columbia, 2002-2004 and 2011-2012.*

| | Seasons | | | | | | |
|---|---|---|---|---|---|---|---|
| Statistics[1] | Late winter | Pre-Calving | Calving | Summer | Rut | Fall | Early Winter |
| Dates (mm-dd) & number of days | | | | | | | |
| $\bar{x}$ | 03 - 12 | 05 - 11 | 05 - 27 | 06 - 11 | 09 - 21 | 11 - 02 | 11 - 25 |
| n (caribou) | 10 | 33 | 23 | 30 | 14 | 13 | 11 |
| SD (days) | 26.49 | 7.27 | 6.08 | 9.79 | 6.30 | 11.68 | 16.38 |
| SE (days) | 8.83 | 1.29 | 1.30 | 1.82 | 1.75 | 3.37 | 5.18 |
| LCI | 02 - 23 | 05 - 08 | 05 – 24 | 06 - 08 | 09 - 18 | 10 - 26 | 11 - 16 |
| UCI | 03 - 28 | 05 - 13 | 05 - 29 | 06 - 15 | 09 - 24 | 11 - 08 | 12 - 05 |
| Distances (m) | | | | | | | |
| $\bar{x}$ | 15,324.25 | 21,876.23 | 28.90 | 9,377.69 | 5,100.11 | 21,950.32 | 14,605.55 |
| n (caribou) | 10 | 33 | 23 | 30 | 14 | 13 | 11 |
| SD | 5,640.24 | 11,702.90 | 42.78 | 7,982.26 | 4,089.38 | 6,648.95 | 5,921.82 |
| SE | 1,880.08 | 2,068.80 | 9.12 | 1,482.27 | 1,134.19 | 1,919.39 | 1,872.64 |
| LCI | 11,828.46 | 17,883.37 | 11.41 | 6,521.33 | 2,958.00 | 18,335.98 | 11,106.04 |
| UCI | 18,820.04 | 25,869.10 | 46.38 | 12,234.05 | 7,242.22 | 25,564.66 | 18,105.05 |
| Season Definitions | | | | | | | |
| Start (mm-dd)<br>End (mm-dd) | 02 – 23<br>05 – 07 | 05 – 08<br>05 – 23 | 05 – 24<br>06 – 15 | 06 – 16<br>09 - 17 | 09 – 18<br>10 – 25 | 10 – 26<br>12 - 05 | 12 – 06<br>02 - 22 |
| Duration (days) | 79 | 16 | 21 | 93 | 38 | 39 | 79 |

*1 – where statistics are average date ($\bar{X}$ ), sample size (n), standard deviation in days (SD), standard error of the sample in days (SE), lower 95% confidence interval of the date (LCI), and upper 95% confidence interval of the date.*

ranges tended to be the longest moves between 18 and 26 kms or about 22 kms on average and occurred in early May (pre-calving) and late October to early November (fall migration) (Table 4). We defined the calving season based the period when female caribou were most sedentary with moves averaging less than 30m. The period tended to occur on average near the end of May (LCI May 24th) through to mid-June (UCI June 15th) when movements around the summer range were regularly composed of moves in excess of a kilometer and were clearly less sedentary compared to the calving season. The rut season appeared to occur near the third week of September (Table 4).

## Home Range

Home range sizes tended to be largest in the summer and early winter periods but varied widest in summer (Figure 4). The radio-collared caribou tended to follow a pattern of decreasing home range size prior to calving, moving little during calving, then expanding across the landscape in summer prior to decreasing range sizes again during the rut. The home range sizes ranged on average from near 100km$^2$ to highs around 400km$^2$ which is fairly typical of woodland caribou in northern BC (Terry and Wood 1999, Wood and Terry 1999, Poole et al. 2000).

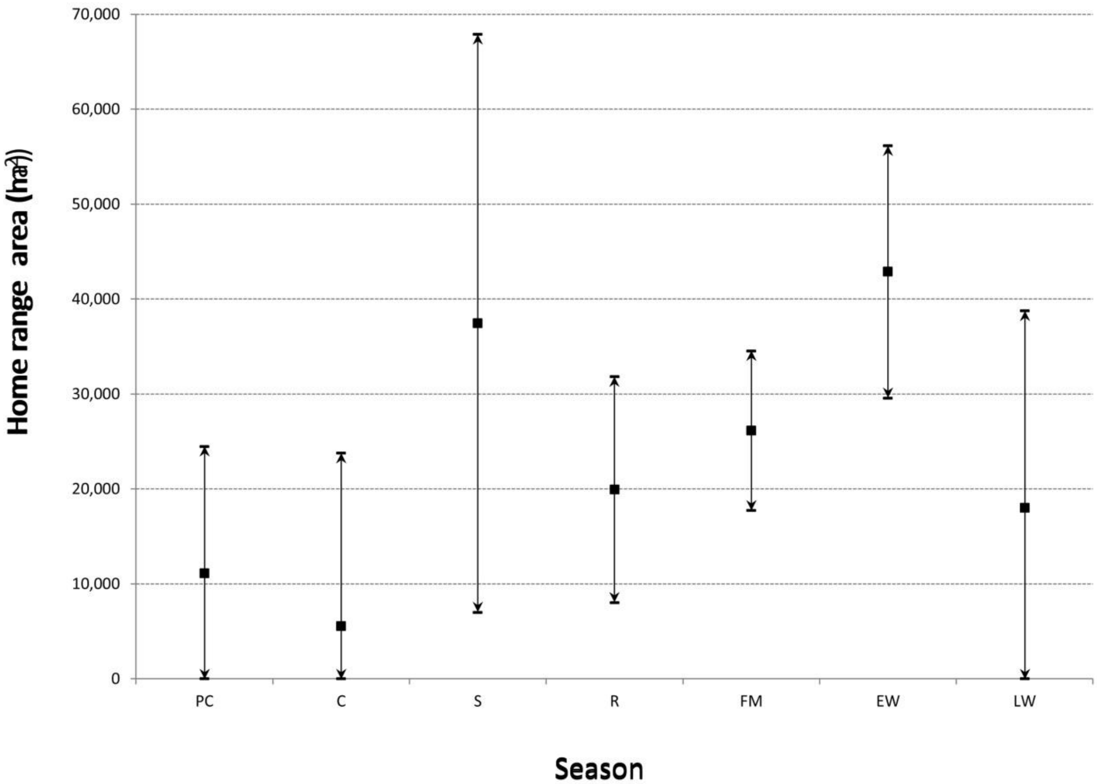


*Figure 4. Average (filled box) and ± 1 standard deviation of seasonal (PC – precalving, C – calving, S – summer, R – rut, FM – fall migration, EW – early winter, and LW – late winter) home range sizes of radio-collared woodland caribou from the Liard Plateau caribou herd in northern British Columbia.*

## Survival and Mortality

During the length of the study, only 4 radio-caribou died – 2 with vhf collars and 2 with sat collars. All deaths were by predation: 3 by wolf and 1 by bear. Two kills were made by wolves near the middle of June during the calving season and the other two kills were made at the end of August and early October basically coinciding with the start and end of the rut period. The collars were deployed and active on live caribou for a total of 19,114 collar days out of a possible 20,335 days representing a 94% survival rate for the collared caribou. Over the 22 month period the estimated average monthly survival rate for the collared caribou decayed to 88% (Figure 5).

## Population Estimates

The population for the Liard herd was originally noted as 425 (Pers. Comm.; July 18, 2011; A. Stewart (retired); British Columbia Min. of Environment, Victoria, BC) but populations of that size have not been recorded since (Figure 6, Table 5). Wolf control in the 1970's (EC 2011) may

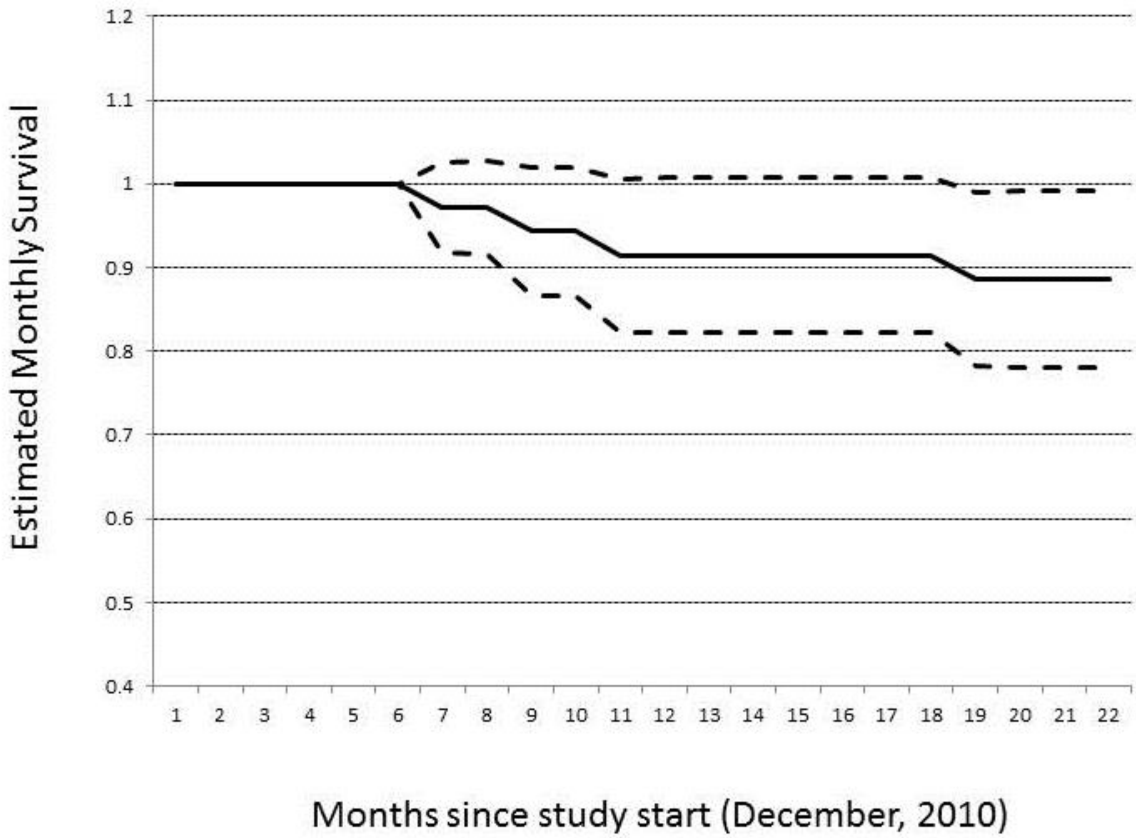


*Figure 5. Estimated mean monthly survival and upper and lower confidence limits (dashed lines), for radio-collared woodland caribou in the Liard Plateau caribou herd area of northern British Columbia, December 2010 to September 2012).*

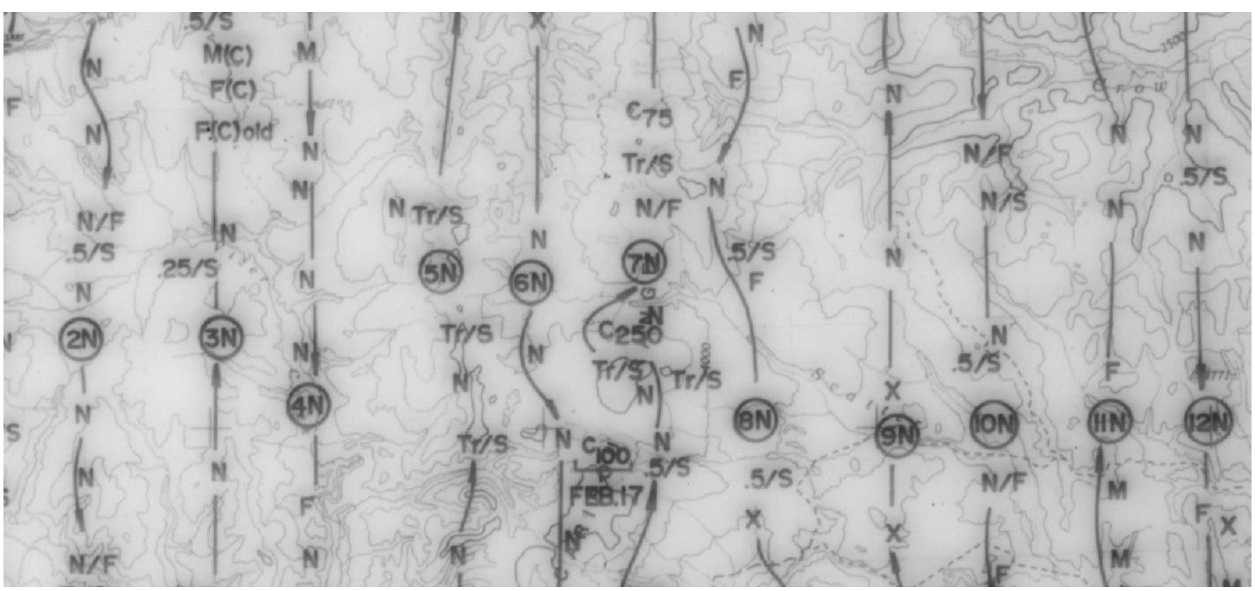


*Figure 6. Data collected during a Canada Land Inventory reconnaissance flight (linear transects) showing three observations of woodland caribou ($C_{75}$, $C_{250}$, $C_{100}$) on the Liard Plateau, British Columbia – February 17, 1975.*

*Table 5. Results of surveys conducted to enumerate woodland caribou within the Liard Plateau caribou herd area in northern British Columbia.*

| Date | Total number of caribou seen or estimated | Bulls as percent of adult cow population | Calves as percent of adult cow population | Calves as % of total population | References |
|---|---|---|---|---|---|
| Feb 1975 | 425[a] | | | | Pers. Comm.[b] |
| Sep 2005 | 141 | 26 | 20 | 13 | Powell (2006) |
| Sep 2008 | >160 | | | | Pers. Comm.[c] |
| Feb 2010 | 81 | 9.9 | 4.2 | 4 | Thiessen (2010) |
| Jun 2010 | 94 | | | 12 | WII[d] |
| Oct 2010 | 173 | 37 | 10 | 7 | WII[d] |
| Mar 2011 | 159 | 24 | 10 | 7 | WII[d] |
| Jul 2011 | 117 | 18 | 24 | 17 | WII[d] |
| Oct 2011 | 120 | 37 | 7 | 5 | WII[d] |

a – Estimated with 50 animal margin of error.
b – July 18, 2011; A. Stewart (retired); British Columbia Min. of Environment, Victoria, BC
c – July 20, 2011; Chris Shipmann, Guide Outfitter; Fort St. John, British Columbia
d – Unpubl. data; Wildlife Infometrics Inc.; Mackenzie, British Columbia

have led to a population that was larger than is estimated today. The largest count in recent times was from a survey conducted in the fall of 2010 with 173 animals and a reasonable bull ratio (37:100 cows). The percent of calves in the population however has never been strong (Table 5), and the most recent survey revealed only 5% calves which is far below the 15% that is considered necessary for population stability (Bergerud 2007).gerud

In a series of 5 periodic surveys conducted over 6 weeks during the 2011 calving season, we determined that, of the 25 radio collared cows observed:

- 4 were not pregnant (from blood progesterone levels) and 3 cows never showed any signs of being pregnant (total non-pregnant of the sample – 28%);
- 18 calves were produced or 34.8% of population (assuming 35 bulls/100cows); and
- 10 calves were still alive at end of June or 22.9% calves (assuming 35 bulls/100cows);

In the survey at the beginning of July, including all animals counted, there were 117 caribou and 20 calves or 17.2 % of population. However, this promising situation soon dissipated to only 5% calves in the population when we returned for a survey in October of the same year. Note that the bull count in these surveys and in particular the July count would be low as we were relocating female collared caribou and would have been biased to maternal groups of caribou.

## Habitat Modelling and Model Results

### *BBN*

Description of the four models used to depict caribou range as the basis for recommending designated areas (i.e., UWR and WHA) were first presented by McNay et al. (2006) where details on the modeling assumptions and logic can be found. The pine-lichen winter range and rut range models were similar (Appendix A) differing only in the more restricted extent of elevations that would be available in early winter as increasing snow depths at that time of year would cause caribou to abandon their rut range and move to lower elevations. However, in the Liard area, these ranges are essentially in the same location and are most predominant in the western plateau that exists adjacent to the main ridge of Caribou Range. This model depends on inputs of aspect, slope, stand percent pine, ecological site, site index, and stand age. These inputs are used to identify areas that would have an abundance of terrestrial lichens. Other inputs of elevation, solar radiation during winter, biogeoclimatic subzone and season are used to distinguish between winter range and rut range (Appendix A).

The black spruce swamp complex BBN is a relatively simple model based on stand age, tree species, and non-productive forest descriptor (Appendix A). Basically, the intent with this model was to identify spruce bogs that caribou tend to occupy during early winter where they forage on arboreal lichen.

The final model contributing to UWR was the high-elevation winter range BBN (Appendix A). This model was relatively more complex than others – while it is easy to define winter range at high elevations by an elevation contour there are many sheltered areas that accumulate snow or areas of rugged terrain that cannot provide adequate foraging opportunities for caribou. This model uses an index of terrain roughness, curvature, and elevation to help isolate areas where snow can be blown away leaving terrestrial lichens to be available as forage. Caribou also tend to forage on arboreal lichens at tree line and so the model also uses tree species, tree height, forest age, and other forest factors to help isolate habitat with abundant arboreal forage lichens (Appendix A). The resulting calving range model that was used was another relatively simple model that depended on ecological unit, forest inventory type group, and slope. These factors basically isolated habitat at relatively high elevations (slightly below tree line and above) as areas where caribou are likely to have calves. At this time of year individual caribou tend to disperse across the landscape and can be found almost anywhere that affords some form of protection from predators. Remnant snow packs can sometimes be used as a barrier for predator movements and the resulting low density of caribou due to dispersion is also considered to be one element of protection. Application of the resulting BBNs was used to identify 127,760 ha of UWR (Figure 7) and 79,982 ha of WHA (Figure 8). The two designated areas overlapped each other by 59% for a total area of designated range for caribou of 130,327 ha.

### *RSF*

The top ranked RSF model of winter range use was based on season, forest age, forest type, and elevation (Table 6). However, all models performed well except season alone and of the two variable models, elevation and forest age (Figure 10) was the best performer. Caribou tend to use elevations that are above the average available in the area (Figure 9) with a seasonal pattern indicating moves from higher-elevations in summer to lower elevation in early winter and back to higher elevations in late winter. There was a correspondingly similar use of age classes moving from older forest conditions to young and then back to older forests during the same time periods – possible with some correlation between elevation and age of forests although there is little in the way of forest disturbance within the Liard Plateau caribou herd area other than natural wildfire. Results for the use of calving and rut areas were very similar (Table 7) but in general the calving and rut model showed a slightly better fit statistically (

Table 8).

Application of the resulting RSF models was used to identify 244,657 ha of UWR (Figure 11) and 213,190 ha of WHA (Figure 12). The two designated areas overlapped each other by 78% for a total area of designated range for caribou of 287,770 ha.

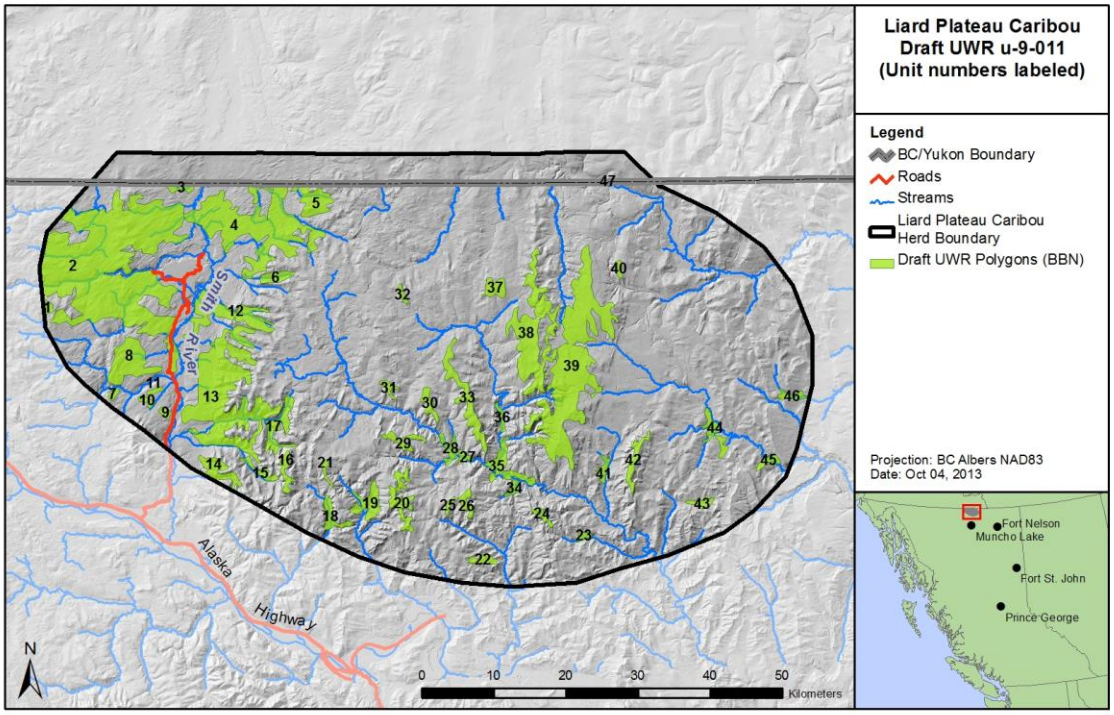


*Figure 7. The locations of Ungulate Winter Range polygons (modelled using a Bayesian Belief Network) proposed as designated areas for the protection and conservation of winter-habitats for the Liard Plateau caribou herd in British Columbia.*

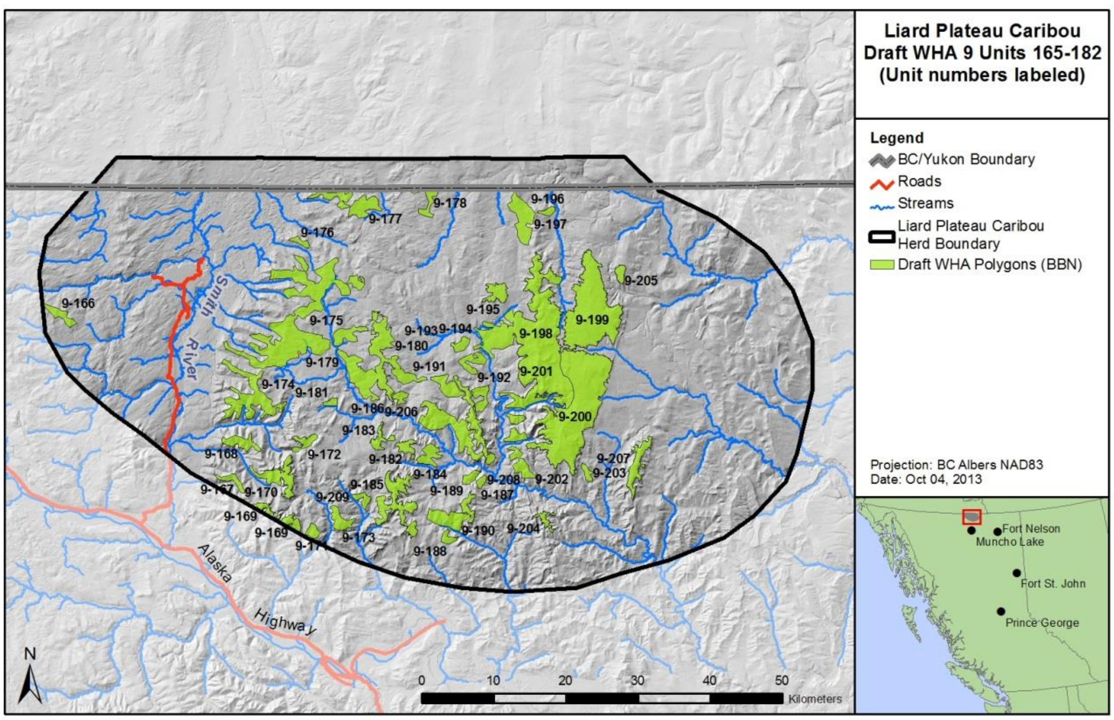


*Figure 8. The locations of Wildlife Habitat Area polygons (modelled using a Bayesian Belief Network) proposed as designated areas for the protection and conservation of rut and calving habitats for the Liard Plateau caribou herd in British Columbia.*

*Table 6. Comparison of the 19 highest ranked logistic regressions used to model the probability of habitat use during early and late winter (see text) by radio-collared, caribou from the Liard Plateau caribou herd in northern British Columbia. Decreasing model rank was assessed using Akaike's information criterion for small sample sizes (AICc), AICc difference from the model with lowest AICc (delta $\Delta_n$ ), AIC weight (Wm), area under the receiver operating characteristics curve (AUC), Wald $\chi^2$ , and number of independent parameters estimated (df). Models of all possible combinations of five non-correlated independent variables were assessed: S – season, G – forest age, F – forest type, A – aspect, and E – elevation.*

| Model | AIC | Delta | $W_m$ | AUC | Wald | df | P |
|---|---|---|---|---|---|---|---|
| SGFA | 8471.1 | 395.3 | <.0001 | 0.691 | 707.7 | 6 | <.0001 |
| GFAE | 8139.8 | 64.0 | <.0001 | 0.749 | 933.2 | 6 | <.0001 |
| SGAE | 8099.3 | 23.5 | <.0001 | 0.750 | 955.3 | 4 | <.0001 |
| SFEA | 8311.4 | 235.6 | <.0001 | 0.734 | 804.2 | 6 | <.0001 |
| SGFE | 8075.8 | 0.0 | 1.0000 | 0.747 | 963.3 | 6 | <.0001 |
| SGF | 8538.5 | 462.7 | <.0001 | 0.673 | 666.6 | 5 | <.0001 |
| SGE | 8137.5 | 61.7 | <.0001 | 0.742 | 928.1 | 3 | <.0001 |
| SFE | 8349.1 | 273.3 | <.0001 | 0.725 | 778.9 | 5 | <.0001 |
| GFE | 8180.2 | 104.4 | <.0001 | 0.739 | 908.0 | 5 | <.0001 |
| SG | 8578.4 | 502.6 | <.0001 | 0.664 | 613.4 | 2 | <.0001 |
| SF | 8848.4 | 772.6 | <.0001 | 0.646 | 418.6 | 4 | <.0001 |
| SE | 8381.6 | 305.8 | <.0001 | 0.722 | 747.0 | 2 | <.0001 |
| GF | 8563.3 | 487.5 | <.0001 | 0.68 | 649.9 | 4 | <.0001 |
| GE | 8235.6 | 159.8 | <.0001 | 0.737 | 868.0 | 2 | <.0001 |
| FE | 8427.8 | 352.0 | <.0001 | 0.71 | 720.2 | 4 | <.0001 |
| S | 9284.0 | 1208.2 | <.0001 | 0.529 | 0.0 | 1 | 0.8669 |
| F | 8860.6 | 784.8 | <.0001 | 0.65 | 406.9 | 3 | <.0001 |
| E | 8458.0 | 382.2 | <.0001 | 0.709 | 691.9 | 1 | <.0001 |
| G | 8600.8 | 525.0 | <.0001 | 0.673 | 599.1 | 1 | <.0001 |

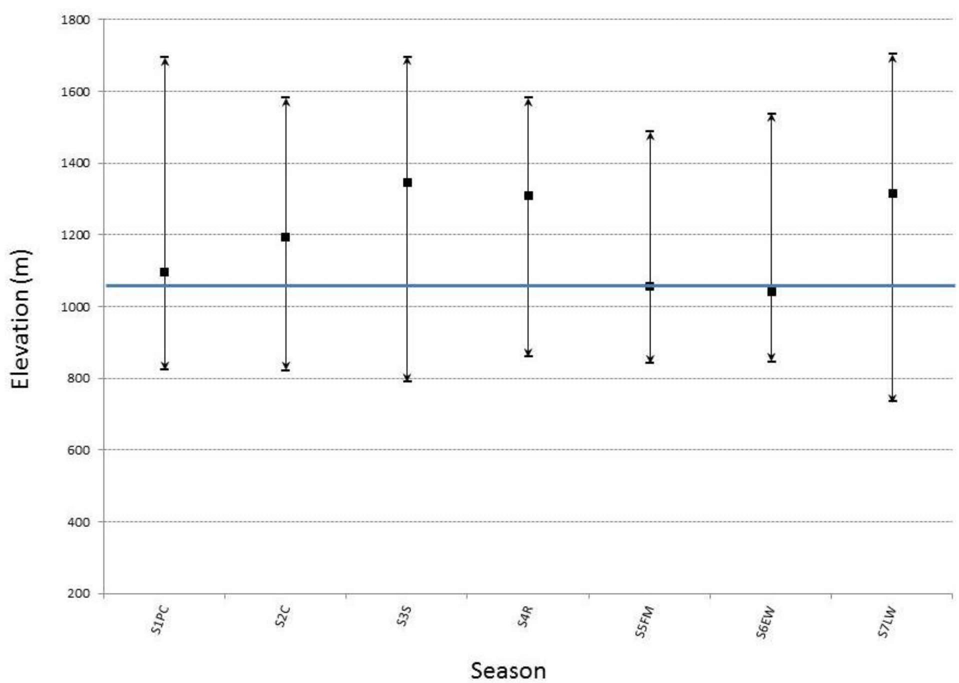


*Figure 9. Average (filled box) and maximum and minimum use of elevation by radio-collared caribou from the Liard Plateau caribou herd in northern British Columbia. Average elevation is 1,050 m (blue line). Seasons are: PC – precalving, C – calving, S – summer, R – rut, FM – fall migration, EW – early winter, and LW – late winter.*

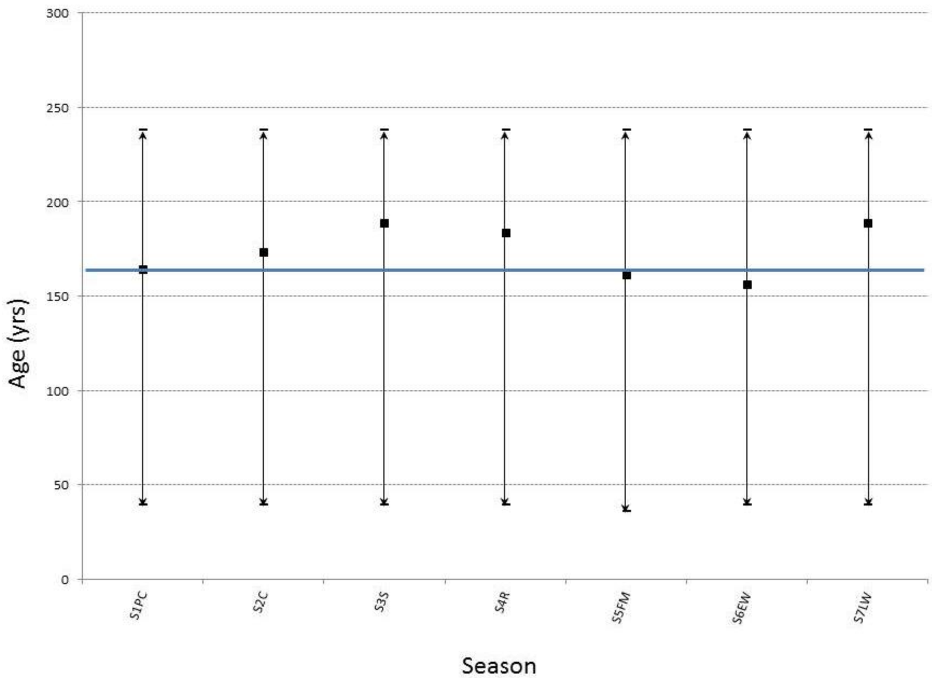


*Figure 10. Average (filled box) and maximum and minimum use of forest age by radio-collared caribou from the Liard Plateau caribou herd in northern British Columbia. Average age is 175 (blue line). Seasons are: PC – precalving, C – calving, S – summer, R – rut, FM – fall migration, EW – early winter, and LW – late winter.*

*Table 7. Comparison of the 19 highest ranked logistic regressions used to model the probability of habitat use during rut and calvi ng (see text) by radio-collared, caribou from the Liard Plateau caribou herd in northern British Columbia. Decreasing model rank was assessed using Akaike's information criterion for small sample sizes (AICc), AICc difference from the model with lowest AICc (delta $\Delta_n$), AIC weight (Wm), area under the receiver operating characteristics curve (AUC), Wald $\chi^2$, and number of independent parameters estimated (df). Models of all possible combinations of five non-correlated independent variables were assessed: S – season, G – forest age, F – forest type, A – aspect, and E – elevation.*

| Model | AIC | Delta | $W_m$ | AUC | Wald | df | P |
|---|---|---|---|---|---|---|---|
| SGFA | 18506.4 | 2679.0 | <.0001 | 0.696 | 1200.0 | 6 | <.0001 |
| GFAE | 15930.7 | 103.3 | <.0001 | 0.810 | 2832.2 | 6 | <.0001 |
| SGAE | 15934.6 | 107.2 | <.0001 | 0.802 | 2825.7 | 4 | <.0001 |
| SFEA | 16092.1 | 264.7 | <.0001 | 0.796 | 2667.5 | 6 | <.0001 |
| SGFE | 15827.4 | 0.0 | 1.0000 | 0.803 | 2896.0 | 6 | <.0001 |
| SGF | 18564.5 | 2737.1 | <.0001 | 0.691 | 1244.9 | 5 | <.0001 |
| SGE | 15933.5 | 106.1 | <.0001 | 0.802 | 2826.7 | 3 | <.0001 |
| SFE | 16118.7 | 291.3 | <.0001 | 0.796 | 2704.5 | 5 | <.0001 |
| GFE | 15931.7 | 104.3 | <.0001 | 0.811 | 2881.5 | 5 | <.0001 |
| SG | 18634.1 | 2806.7 | <.0001 | 0.684 | 1165.9 | 2 | <.0001 |
| SF | 19314.2 | 3486.8 | <.0001 | 0.630 | 624.2 | 4 | <.0001 |
| SE | 16122.1 | 294.7 | <.0001 | 0.795 | 2701.2 | 2 | <.0001 |
| GF | 18572.3 | 2744.9 | <.0001 | 0.713 | 1236.5 | 4 | <.0001 |
| GE | 16048 | 220.6 | <.0001 | 0.810 | 2796.5 | 2 | <.0001 |
| FE | 16240.7 | 413.3 | <.0001 | 0.804 | 2667.3 | 4 | <.0001 |
| S | 19958.2 | 4130.8 | <.0001 | 0.000 | 0.0 | 1 | 0.9105 |
| F | 19329.8 | 3502.4 | <.0001 | 0.648 | 609.1 | 3 | <.0001 |
| E | 16238.3 | 410.9 | <.0001 | 0.804 | 2664.7 | 1 | <.0001 |
| G | 18637.3 | 2809.9 | <.0001 | 0.705 | 1164.0 | 1 | <.0001 |

*Table 8. Logistic regression models estimating the probability of range selection (UWR – ungulate winter range, WHA – wildlife habitat areas) due to season, forest condition, forest age, and elevation for marked, adult woodland caribou in the Liard caribou herd of northern British Columbia. See text for range and variable descriptions.*

| Model | Factor | Intercept | Estimate | Standard Error | Chi Square | P |
|---|---|---|---|---|---|---|
| UWR | | Intercept | | Reference | | |
| | | | -5.932 | 0.242 | 600.6 | <0.001 |
| | **Season** | Late winter | | Reference | | |
| | | Early winter | 0.297 | 0.029 | 102.7 | <0.001 |
| | **Forest condition** | Non-forested | | Reference | | |
| | | Light canopy | 0.057 | 0.109 | 0.2 | 0.600 |
| | | Heavy canopy | 0.656 | 0.117 | 31.3 | <0.001 |
| | | Deciduous | -0.445 | 0.308 | 2.1 | 0.148 |
| | **Age** | | 0.015 | 0.0009 | 243.0 | <0.001 |
| | **Elevation** | | 0.003 | 0.0001 | 409.3 | <0.001 |
| WHA | | Intercept | | Reference | | |
| | | | -8.933 | 0.255 | 1231.2 | <0.001 |
| | **Season** | Late winter | | Reference | | |
| | | Early winter | 0.212 | 0.021 | 102.1 | <0.001 |
| | **Tree class** | Non-forested | | Reference | | |
| | | Light canopy | 0..433 | 0.197 | 4.8 | 0.027 |
| | | Heavy canopy | 0.949 | 0.198 | 22.9 | <0.001 |
| | | Deciduous | -1.602 | 0.584 | 7.5 | 0.006 |
| | **Age** | | 0.009 | 0.0006 | 247.9 | <0.001 |
| | **Elevation** | | 0.006 | 0.0001 | 2064.8 | <0.001 |

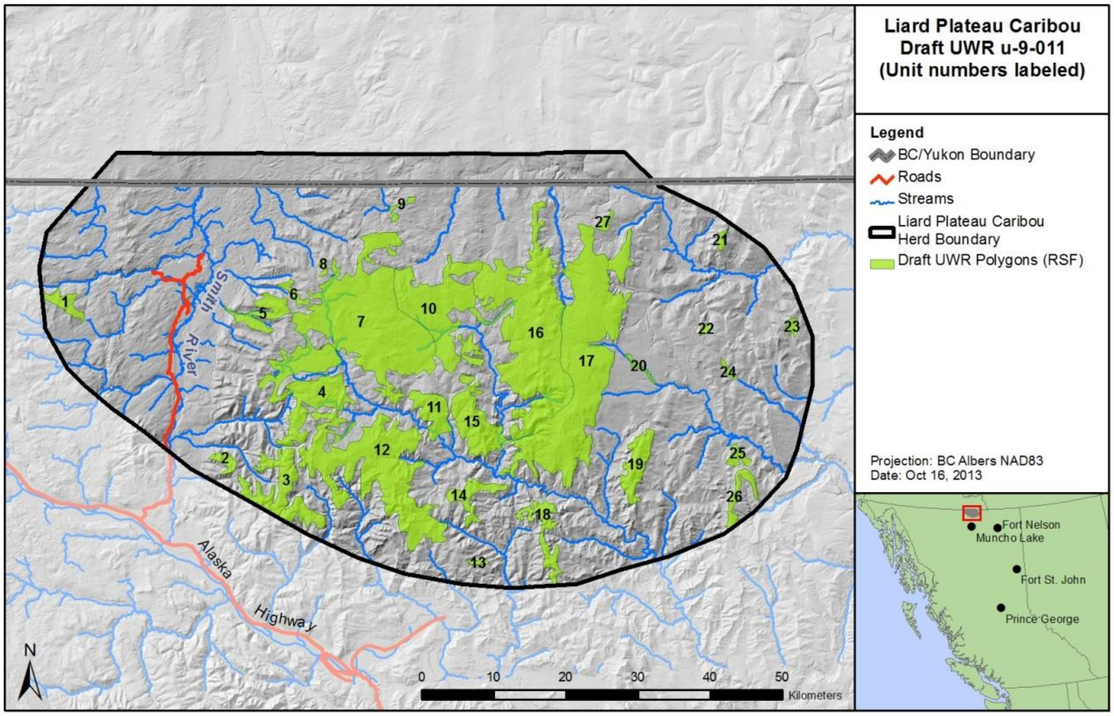


*Figure 11. The locations of Ungulate Winter Range polygons (modelled using a Resource Selection Function) proposed as designated areas for the protection and conservation of winter-habitats for the Liard Plateau caribou herd in British Columbia.*

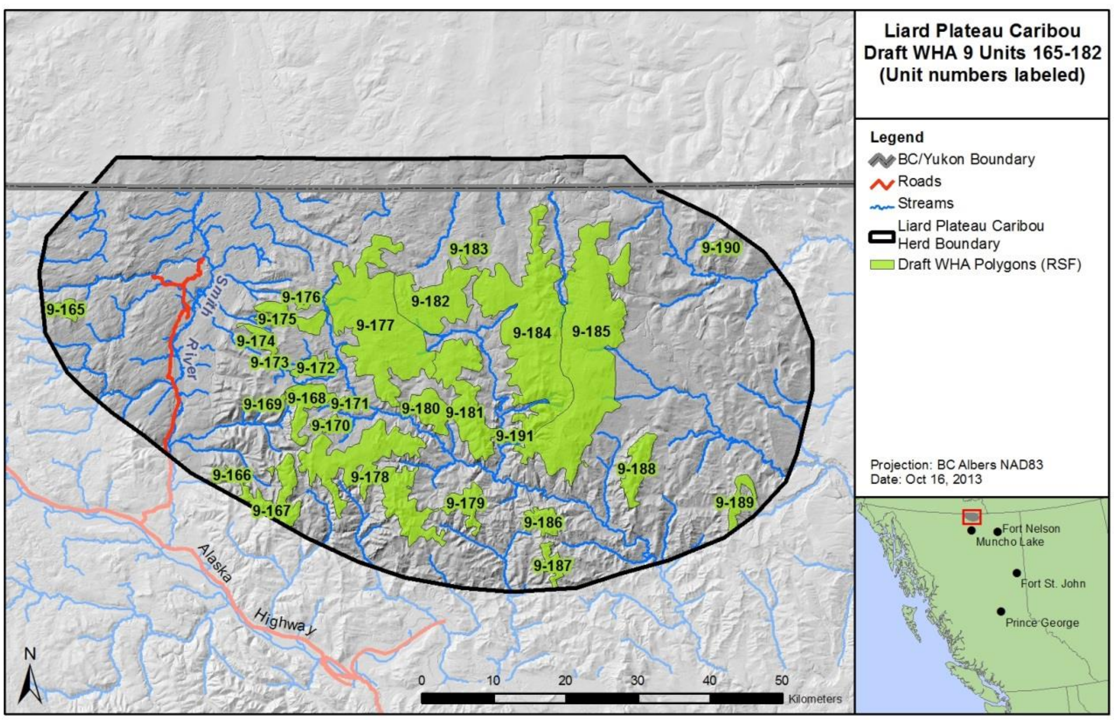


*Figure 12. The locations of Wildlife Habitat Area polygons (modelled using a Resource Selection Function) proposed as designated areas for the protection and conservation of rut and calving habitats for the Liard Plateau caribou herd in British Columbia.*

## Use of Proposed Designated Areas

The RSF mapped designated areas (both UWR and WHA together) appeared to have higher use by radio-collared caribou than was apparent in the case of the BBN designated areas (Figure 13). For example, if we considered 0.40 as threshold criteria for the proportion of use in the designated area by caribou, then 70% of the radio-collared caribou would meet that threshold in the RSF modeled area. By comparison, only about 20% of the radio-collared caribou would achieve that threshold in the BBN approach. For this reason, we recommend that the RSF mapped areas be considered as the designated areas for the Liard Plateau caribou herd.

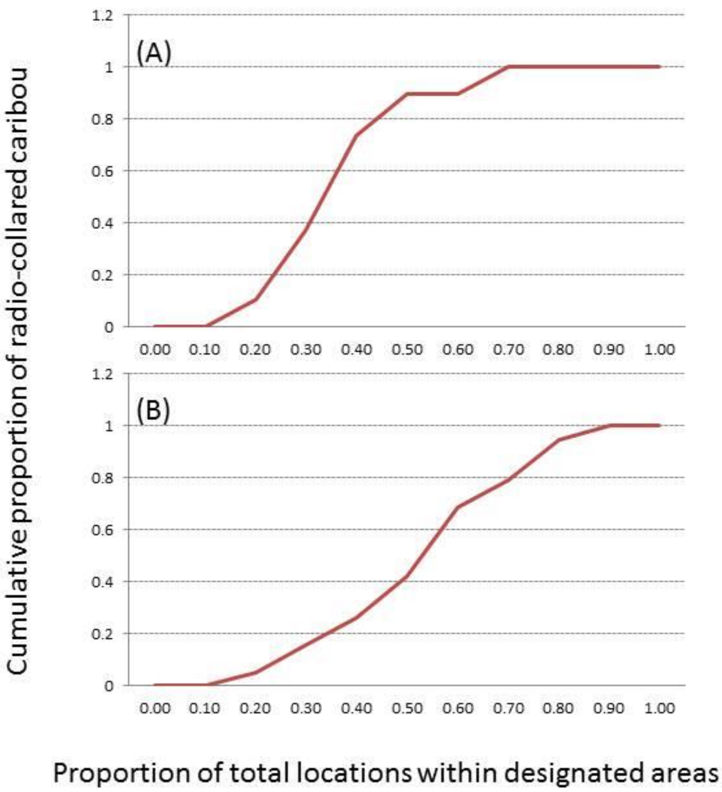


*Figure 13. A comparison of use of proposed designated areas (Ungulate Wiinter Range and Wildlife Habitat Areas) by radio-collared caribou from the Liard Plateau caribou herd in northern British Columbia. Designated areas were modeled using a Bayesian Belief Network (A) and a Resource Selection Function (B).*

# DESIRED HABITAT CONDITION AND MANAGEMENT CONSIDERATIONS

## Desired Habitat Conditions

Desired habitat conditions include extensive, undistrurbed and unfragmented areas of old forest and alpine. Caribou use almost all habitat within their range. Although they are herd animals, sometimes occurring in larger groups, their overall population density tends to be low compared to other ungulates and their dispersion across a large space (as individuals during calving or in groups at other times) is in itself considered to be an anti-predator tactic. Therefore, the large size of their undisturbed range is considered to be a desired habitat condition. This overarching habitat condition also helps to maintain other desired habitat conditions such as abundant forage, either as arboreal or terrestrial lichens, and less risk of predation than would otherwise occur in more fragmented and disturbed landscapes. Large areas of intact range, abundant forage, and low risk of predation are the most significant desired habitat conditions. Cover from extreme weather events (cold or heat) is an important habitat condition but is considered less important and is usually not considered to be a significant condition.

Until such time as additional or new information is available, disturbance (natural and anthropogenic) within the designated herd area should remain below the threshold level (35%) established by Environment Canada for boreal caribou populations (EC 2012). Habitat that is interstitial to designated WHA and UWR should be considered to be matrix range and be managed accordingly (see below). Caribou are known to use matrix range for travel and foraging.

## Management Considerations

1. Monitoring:
    a. Conduct sufficient population surveys to reliably track juvenile recruitment, bull to cow ratios, and population numbers.
    b. Consider conducting investigations that will allow for a refined designated herd boundary.
    c. Maintain a spatial inventory of all disturbance features.
2. Research:
    a. Depending on monitoring results (above), consider investigating the proximate cause of apparent low juvenile recruitment. This may include an investigation of pregnancy rates as, parturition in the herd appears to be significantly lower than normal.
    b. Investigate opportunities for designating matrix range as a Specified Area with appropriate management measures. For example:
        i. Industrial or agricultural activities that occur within matrix range should be restricted to west of WHA polygon 9-174 and east of WHA polygon 9-185 (or west of UWR polygon 5 and east of UWR polygon 17).
        ii. Aggregate new disturbance in time and space.
        iii. Coordinate different industrial disturbances to minimize the need for development of new roads.
        iv. Construct new roads to the lowest standard possible.
        v. Reduce sight lines along roads when possible.
        vi. Deactivate roads as soon as possible (berms, planting, recruit coarse woody debris).

    vii. Avoid disturbance to edaphic lichen-bearing sites.
    viii. Avoid creating forage for moose, elk, and deer.
    ix. Use vegetation management to reduce forage for moose, elk, and deer.

3. Population management:
    a. Assess the potential influence of current hunting regulations on the long-term sustainability of the herd.
    b. Depending on monitoring and research results (above), consider management actions to recover the herd to a sustainable population size.
4. Access:
    a. Industrial activities will not result in the construction of roads or trails except as regulated by authorized permits (e.g., Guide Outfitting).
    b. Prohibit all motorized access December through June.
5. Harvesting and silviculture
    a. Industrial activities (except Guide Outfitting) will not result in the removal of forest cover.
    b. Industrial or agricultural activities will not result in the use of domestic sheep or goats.
6. Pesticides
    a. Industrial activities will not result in the use of pesticides.
7. Recreation:
    a. Industrial activities will not result in the development of recreation sites or trails except as regulated by authorized permits (e.g., Guide Outfitting).

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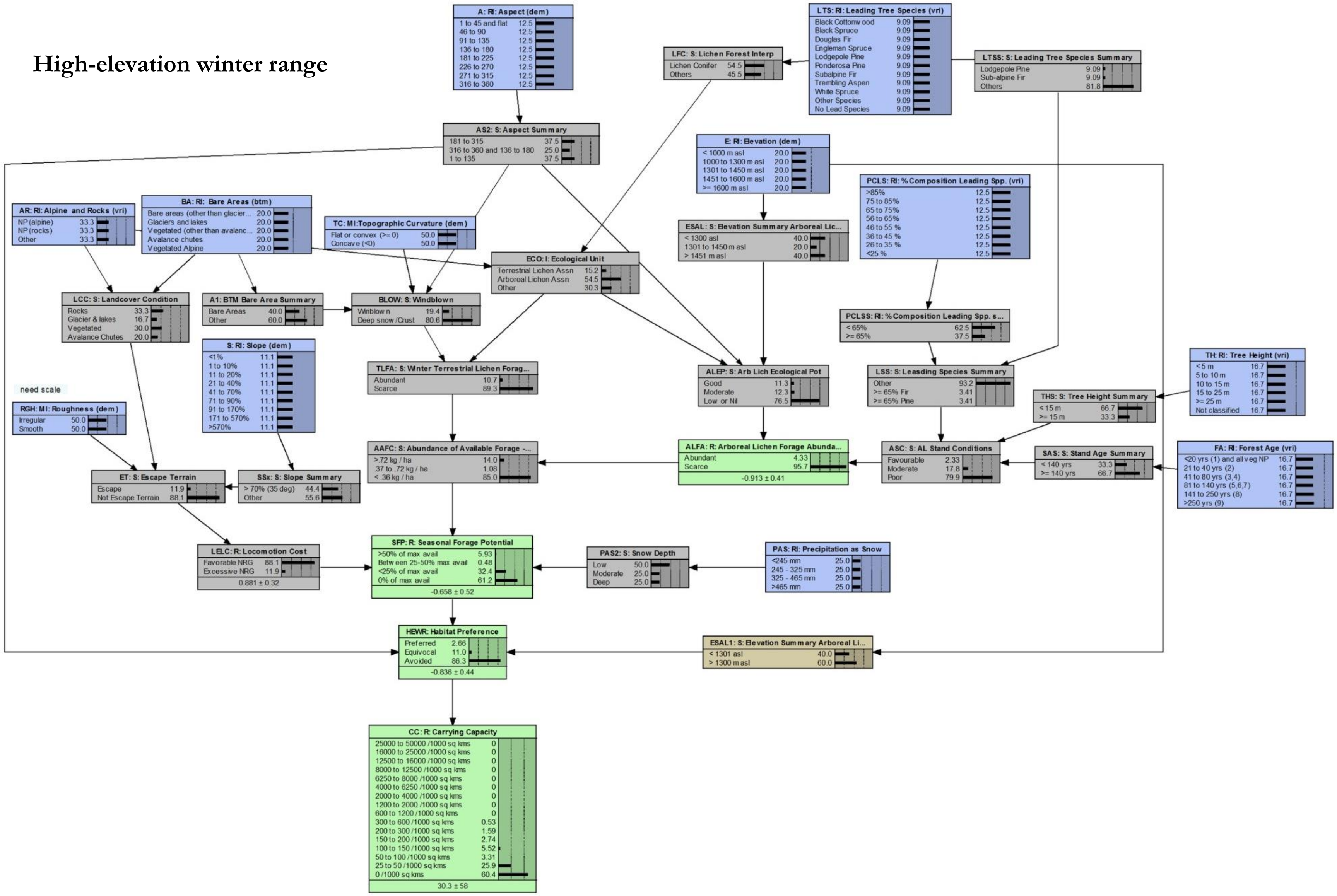
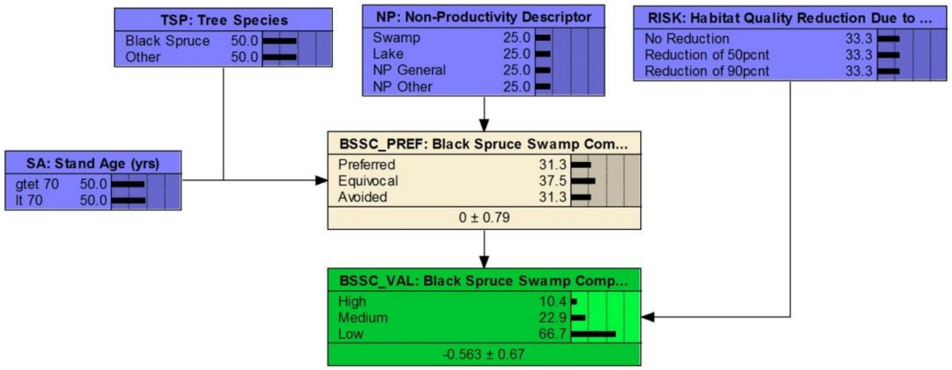
# APPENDIX A: BAYESIAN BELIEF NETWORK MODELS FOR CARIBOU SEASONAL RANGES

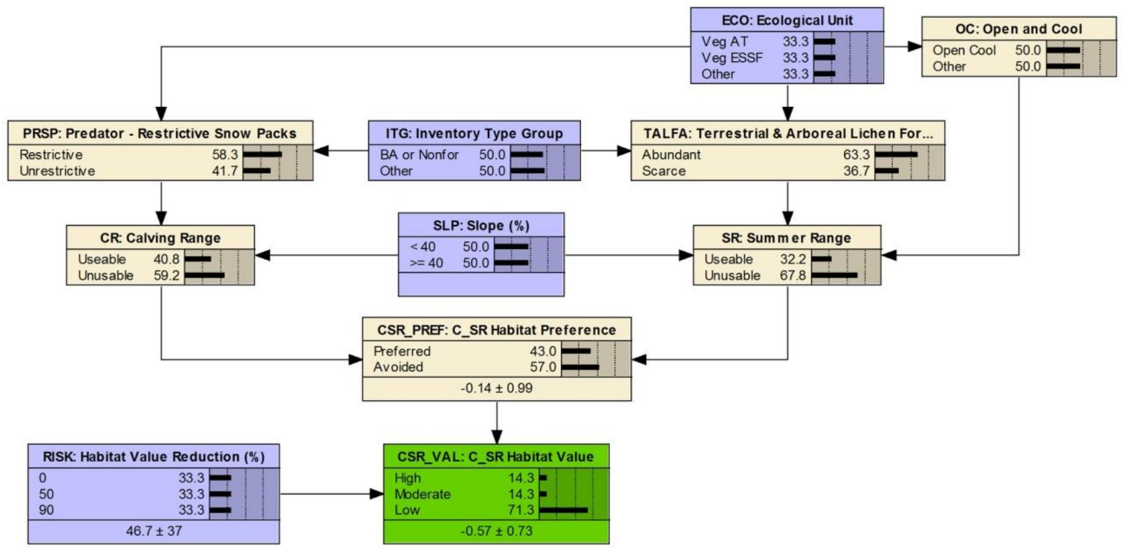
## High-elevation winter range

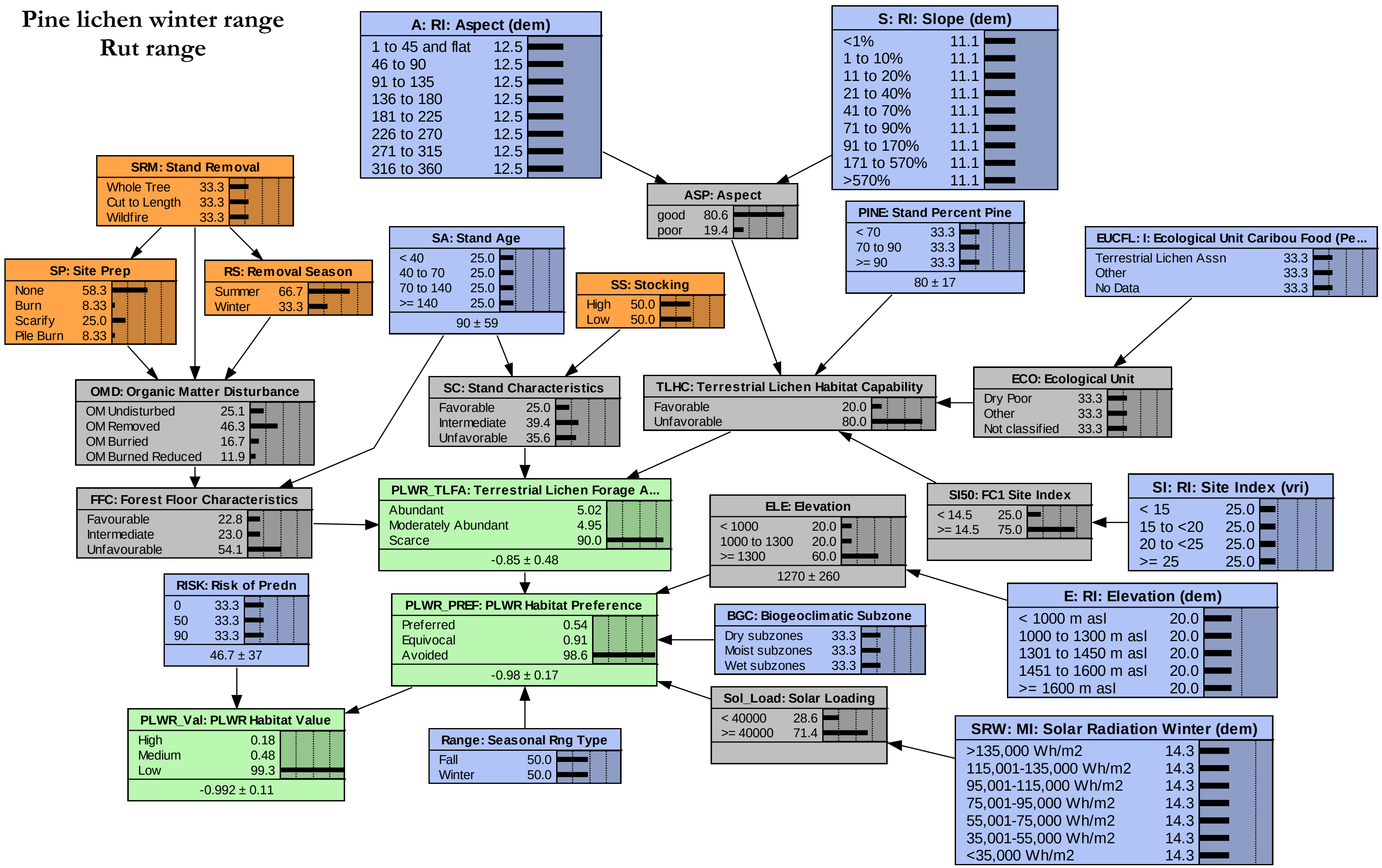


Black spruce swamp complex




Calving and summer range




Pine lichen winter range
Rut range
A: RI: Aspect (dem)
1 to 45 and flat 12.5
46 to 90 12.5
91 to 135 12.5
136 to 180 12.5
181 to 225 12.5
226 to 270 12.5
271 to 315 12.5
316 to 360 12.5
S: RI: Slope (dem)
<1% 11.1
1 to 10% 11.1
11 to 20% 11.1
21 to 40% 11.1
41 to 70% 11.1
71 to 90% 11.1
91 to 170% 11.1
171 to 570% 11.1
>570% 11.1
SRM: Stand Removal
Whole Tree 33.3
Cut to Length 33.3
Wildfire 33.3
ASP: Aspect
good 80.6
poor 19.4
PINE: Stand Percent Pine
< 70 33.3
70 to 90 33.3
>= 90 33.3
80 ± 17
SA: Stand Age
< 40 25.0
40 to 70 25.0
70 to 140 25.0
>= 140 25.0
90 ± 59
EUCFL: I: Ecological Unit Caribou Food (Pe...
Terrestrial Lichen Assn 33.3
Other 33.3
No Data 33.3
SP: Site Prep
None 58.3
Burn 8.33
Scarify 25.0
Pile Burn 8.33
RS: Removal Season
Summer 66.7
Winter 33.3
SS: Stocking
High 50.0
Low 50.0
OMD: Organic Matter Disturbance
OM Undisturbed 25.1
OM Removed 46.3
OM Burried 16.7
OM Burned Reduced 11.9
SC: Stand Characteristics
Favorable 25.0
Intermediate 39.4
Unfavorable 35.6
TLHC: Terrestrial Lichen Habitat Capability
Favorable 20.0
Unfavorable 80.0
ECO: Ecological Unit
Dry Poor 33.3
Other 33.3
Not classified 33.3
FFC: Forest Floor Characteristics
Favourable 22.8
Intermediate 23.0
Unfavourable 54.1
PLWR_TLFA: Terrestrial Lichen Forage A...
Abundant 5.02
Moderately Abundant 4.95
Scarce 90.0
-0.85 ± 0.48
ELE: Elevation
< 1000 20.0
1000 to 1300 20.0
>= 1300 60.0
1270 ± 260
SI50: FC1 Site Index
< 14.5 25.0
>= 14.5 75.0
SI: RI: Site Index (vri)
< 15 25.0
15 to <20 25.0
20 to <25 25.0
>= 25 25.0
RISK: Risk of Predn
0 33.3
50 33.3
90 33.3
46.7 ± 37
PLWR_PREF: PLWR Habitat Preference
Preferred 0.54
Equivocal 0.91
Avoided 98.6
-0.98 ± 0.17
BGC: Biogeoclimatic Subzone
Dry subzones 33.3
Moist subzones 33.3
Wet subzones 33.3
E: RI: Elevation (dem)
< 1000 m asl 20.0
1000 to 1300 m asl 20.0
1301 to 1450 m asl 20.0
1451 to 1600 m asl 20.0
>= 1600 m asl 20.0
Sol_Load: Solar Loading
< 40000 28.6
>= 40000 71.4
PLWR_Val: PLWR Habitat Value
High 0.18
Medium 0.48
Low 99.3
-0.992 ± 0.11
Range: Seasonal Rng Type
Fall 50.0
Winter 50.0
SRW: MI: Solar Radiation Winter (dem)
>135,000 Wh/m2 14.3
115,001-135,000 Wh/m2 14.3
95,001-115,000 Wh/m2 14.3
75,001-95,000 Wh/m2 14.3
55,001-75,000 Wh/m2 14.3
35,001-55,000 Wh/m2 14.3
<35,000 Wh/m2 14.3