ECOLOGY AND SEASONAL HABITAT SELECTION OF BOREAL CARIBOU IN THE SNAKE-SAHTANEH WATERSHED, BRITISH COLUMBIA

2000 to 2004

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SUMMARY

The boreal ecotype of woodland caribou (*Rangifer tarandus caribou*) is classified as *Threatened* by the *Committee on the Status of Endangered Wildlife in Canada* (COSEWIC 2002). Within British Columbia, the ecotype is restricted to the Boreal Plains and Taiga Plains ecoprovinces, in the northeastern corner of the province. Prior to 2000, little information was available on boreal caribou distribution and ecology within this area. This study was initiated in 1999-2000 as a joint project between BC Environment and Slocan Forest Products Ltd. – Fort Nelson (subsequently, Canadian Forest Products Ltd.), with the original objective of collecting baseline ecological information on boreal caribou in the Snake and Sahtaneh river watersheds and Kotcho Lake area (hereafter, the Snake-Sahtaneh herd), east of Fort Nelson, B.C. Interim telemetry results were used to delineate the larger *Snake-Sahtaneh Boreal Caribou Range* (BCTAC *in prep*, Culling *et al.* 2004), which ultimately defined the boundaries of the study area.

Between March 2000 and December 2004, 57 adult female Snake-Sahtaneh caribou were monitored using global positioning system (GPS) and very high frequency (VHF) radio-collars, resulting in the collection of 48 individual GPS data sets. GPS data was used to define the range of the Snake-Sahtaneh herd, identify key habitats and movement patterns, and describe seasonal habitat selection. Information on population dynamics was collected during spring and fall calf-survival surveys, late-winter composition surveys, and by monitoring pregnancy rates and mortality of radio-collared females.

GPS telemetry revealed the importance of 7 *core habitat areas* (cores) within the Snake-Sahtaneh range. Ninety-four percent of 96,645 3-dimensional GPS caribou locations collected fell within these cores, as well as 65 of 66 identified calving sites. Caribou activity was concentrated in the cores throughout the year, including the May-June calving and September-October rutting periods. Home ranges of individual caribou encompassed up to 5 of the 7 cores. Caribou typically made direct movements between cores while traveling throughout the range.

Adult female Snake-Sahtaneh caribou exhibited high pregnancy rates (96%), high parturition rates, and were found to be in good late winter condition, suggesting forage availability is not currently limiting. Peak calving was estimated at May 15, with peak conception back-calculated to September 30. Calf survival to 6 weeks was approximately 20% in 2002 and 2003, and 29% in 2004. Fall surveys indicated a further decline in calf survival to 12%, 13%, and 14% for 2002 to 2004, respectively. Late-winter composition surveys conducted in March 2003 and 2004 indicated low recruitment, with 5 calves:100 cows and 9 calves:100 cows, respectively. Standardized annual adult survival for 57 females during the 58 month study was estimated at 0.94 (95% CI = 0.89 to 0.99). Although adult female mortality was low, juvenile recruitment estimates fell significantly below the 15% (25 calves:100 cows) threshold believed necessary to maintain a stable population (Bergerud 1996). These surveys were not of sufficient duration to establish a long-term population trend; further investigations are required to confirm whether the Snake-Sahtaneh herd is in decline.

Results of resource selection function modeling indicated high probability of caribou use of the DU Earth Cover *Woodland Needleleaf* and *Open Needleleaf* habitat classes (i.e., black spruce peatlands with 10-25% and 26-60% crown closure, respectively), areas of extremely low gradient (0.0° to 0.30° slope), and lake clusters comprised of lakes between 5 and 50 hectares in size. Fine-scale slope modelling appears to have potential as a predictor of boreal caribou use throughout adjacent caribou ranges in northeastern British Columbia.

As early results indicated very low calf survival and recruitment, the study objectives were expanded to investigate the spatial overlap of wolves and black bears with Snake-Sahtaneh caribou during the May-June calving/post-calving period. A total of 31 wolves were monitored using a combination of GPS and

VHF telemetry between December 2002 and November 2004, resulting in the acquisition of 18 GPS data sets of an average duration of 6 months. A total of 9 black bears were fitted with GPS collars in May of 2003 and 2004, with collars retrieved each fall prior to the bears entering their winter dens. Eight GPS data sets of 4 to 5 months duration were collected.

The Snake-Sahtaneh study area contains a relatively high density of wolves (minimum estimate 6.3 wolves/1,000 km²) given the estimated moose biomass (0.08 moose/km²). Wolf capture activities in the winters of 2002-2003 and 2003-2004 resulted in the identification of 6 packs, 4 of which contained a minimum of 12 to 15 wolves. GPS data indicated the identified packs denned both within and adjacent to the Snake-Sahtaneh range, including multiple den sites within caribou core habitat areas. GPS data and observations made during the study indicated wolves were closely associated with beaver activity within the Snake-Sahtaneh caribou range from spring through fall. Several den sites were in abandoned beaver lodges and beaver accounted for the majority of items in 27 wolf scat samples collected at den sites. Scat samples also included ungulate calf (moose and caribou) and waterfowl remains. Beaver appear to be an important alternate prey species for wolves during the spring and summer, and may contribute to increased pup survival.

Analysis of GPS black bear data indicated that bear activity was strongly associated with deciduous-dominated upland and riparian habitats within the upland-peatland mosaic. Preference for early seral communities in cutblocks and along linear corridors was evident during the caribou neonatal period, however, limited forays into adjacent black spruce peatlands by some bears were noted.

While caribou used treed peatlands throughout the year and wolves and bears showed strongest selection for deciduous and mixedwood upland and riparian habitats, there was considerable overlap of use between the species during the May-June neonatal period. Fifty-four percent and 26% of caribou locations throughout the year were in the Open Needleleaf and Woodland Needleleaf habitat classes, respectively, with 81% of May-June locations in these 2 classes combined. Forty-nine percent of May-June wolf locations and 27% of May-June black bear locations also fell within the Open Needleleaf and Woodland Needleleaf classes combined. GPS wolf data analysis and field observations suggest that wolf predation is likely the primary cause of high calf mortality observed in the Snake-Sahtaneh caribou herd.

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1 INTRODUCTION

Within British Columbia, woodland caribou (*Rangifer tarandus caribou*) are classified into 3 ecotypes, based on characteristic ecology. The *mountain* and *northern* ecotypes occur throughout the mountainous regions of the province, displaying variable vertical and lateral seasonal migrations. In contrast, the sedentary *boreal* ecotype (*hereafter*, boreal caribou) is restricted to the lowlands of the Boreal Plains and Taiga Plains ecoprovinces of the Alberta Plateau physiographic region, in the northeastern corner of the province. These animals form part of a national meta-population, which spans the boreal forest from the Northwest Territories to Labrador. Within British Columbia, there is virtually no historical information on the distribution or abundance of boreal caribou (Spalding 2000).

Boreal caribou are classified as *Threatened* by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002), and blue-listed by the British Columbia Conservation Data Centre (BC CDC 2006). The ecotype is on *Schedule 1* of the *Species at Risk Act* (SARA 2003), which provides legal protection for critical habitats of all SARA-listed species.

Boreal caribou typically exhibit high pregnancy and parturition rates, but low productivity and recruitment (Bergerud 1978, Seip and Cichowski 1996, Dzus 2001, McLoughlin *et al.* 2003). Caribou calf mortality is generally highest in the first month following birth (Bergerud *et al*. 1984, Bergerud and Elliott 1986, Stuart-Smith *et al.* 1997, Dzus 2001). Adult survival is typically high; Dzus (2001) notes adult survival from a series of northern Alberta studies ranged from 74% to 100%, comparable to reports from other geographic areas of Canada. Wolf (*Canis lupus*) predation is considered the major cause of caribou mortality, with black bears (*Ursus americanus*), grizzly bears (*U. arctos*), lynx (*Lynx canadensis*), wolverine (*Gulo gulo*), coyote (*C. latrans*), and golden eagle (*Aquila chrysaetos*) contributing variable predation pressure across the geographic range (Thomas 1995, Bergerud and Elliott 1998, Edmonds 1998, Rettie and Messier 1998, Spalding 2000, Dzus 2001, Gustine 2005). Boreal caribou employ a strategy of dispersing at very low densities, referred to as “spacing out,” to reduce predation during the calving period (Bergerud 1996).

Boreal caribou typically select poorly-drained peatlands, including bogs and fens, and avoid uplands (Bradshaw *et al.* 1995, Hornbeck and Moyles 1995, Stuart-Smith *et al.* 1997, Anderson 1999, Schneider *et al.* 2000). While wildfires are considered detrimental to caribou lichen forage supply in the short-term (Joly *et al.* 2002), periodic burning may be necessary to rejuvenate older forests with declining lichen productivity (Bergerud 1978, Klein 1982). Caribou use of recently burned areas has been documented in northern Alberta (Dunford 2003) and the Northwest Territories (Nagy *et al.* 2005).

Wetlands and waterbodies play an important role in the ecology of woodland caribou. Caribou use shorelines, islands, and peninsulas during ice-free periods for refuge from predation throughout the calving and post-natal periods (Stardom 1977, Bergerud 1985, Cumming and Beange 1987, Edmonds 1988, Hillis *et al.* 1998). Groups of smaller lakes may provide additional escape opportunities for caribou as well as increasing search time for wolves (Carruthers *et al.* 1986 *in* Bergerud 1996). Use of lake margins and wetlands in fall and early winter has been attributed to foraging for “winter-green” vascular plants that offer high protein and phosphorus and high-digestibility (Klein 1982). Open habitats associated with waterbodies and shorelines also provide caribou with relief from insects (Darby and Duquette 1986). Extreme insect harassment can negatively affect energy expenditure and summer weight gain for both neonate calves and cows, which in turn, can influence future reproductive performance (Walsh *et al*. 1992).

Boreal caribou face increasing anthropogenic disturbance across their geographic range. As early as the 1970’s, Banfield (1974a) noted concern that the tendency of caribou to take the path of least resistance over frozen lakes and along gravel eskers during migration had been translated into travelling along cutlines, which might put them at increased risk of predation by wolves. Since that time, much has been learned about potential direct and indirect effects of industrial development within caribou range, including energetic costs associated with disturbance (Bradshaw *et al.* 1998), alteration of predator-prey dynamics (James 1999), and caribou avoidance of disturbed areas, including cutblocks, linear corridors, and oilfield infrastructure (Darby and Duquette 1986, Hillis *et al.* 1998, James and Stuart-Smith 2000, Smith *et al*. 2000, Dyer *et al.* 2001). Avoidance behaviour can result in functional habitat loss beyond that of the actual disturbance footprint.

Before 2000, little information was available on the status, distribution, and ecology of boreal caribou in BC. In 1999, a joint project was initiated between the British Columbia Ministry of Environment (BC Environment) and Slocan Forest Products Ltd. – Fort Nelson (subsequently, Canadian Forest Products Ltd. (Canfor)) to collect baseline ecological information on boreal caribou in the Snake and Sahtaneh river watersheds and Kotcho Lake area (hereafter, the Snake-Sahtaneh herd), approximately 50 km northeast of Fort Nelson, B.C. Interim telemetry results were incorporated in a planning process to delineate the larger *Snake-Sahtaneh Boreal Caribou Range* (BCTAC *in prep*, Culling *et al.* 2004), which ultimately defined the boundaries of the study area.

Snake-Sahtaneh caribou population demographics, movements, and seasonal habitat use were investigated between March 2000 and December 2004, using a combination of global positioning system (GPS) and very high frequency (VHF) telemetry and annual calf survival and recruitment surveys. To assess predator distribution during the caribou parturition and neonatal period, a total of 31 wolves and 9 black bears were monitored using a combination of GPS and VHF telemetry between December 2002 and November 2004.

2 STUDY AREA

The 11,980 km² Snake-Sahtaneh study area lies approximately 50 km northeast of Fort Nelson, British Columbia, between latitudes N 58° 17' and N 59° 42' and longitudes W 120° 26' to W 122° 40' (Fig. 1), and is synonymous with the *Snake-Sahtaneh boreal caribou range* (BCTAC *in prep*, Culling *et al.* 2004). It is roughly bounded by the Fontas and Petitot rivers to the south and north, respectively, and the Fort Nelson River to the west. An aspen-dominated escarpment, along the east edge of the Etsho Plateau, forms a band of upland habitat marking the eastern boundary of the study area. The Sahtaneh River, and its major tributary, the Snake River, drain the central portion of the area. Terrain is typically flat with occasional areas of gentle undulation. Elevation above sea level ranges from 412 m near Clarke Lake to 751 m on the Etsho Escarpment.

The climate is continental, characterized by long, cold winters and short, cool summers. Mean daily temperature at the Fort Nelson Airport is -21°C for January and +17°C for July (Environment Canada 2006). Annual precipitation is 451 mm, of which 319 mm falls as rain. Mean snow depth for March is 49 cm.

The study area lies within the Taiga Plains ecoprovince and is represented by a single biogeoclimatic zone and variant, BWBSmw2 (*Fort Nelson Boreal White and Black Spruce moist warm*). The landscape is typified by poorly-drained, organic peatlands, interspersed with deciduous and mixedwood upland and riparian habitats. Stunted black spruce (*Picea mariana*), with minor components of tamarack (*Larix larix*), is prevalent on poorly-drained, organic soils. White spruce (*P. glauca*), lodgepole pine (*Pinus contorta*), trembling aspen (*Populous tremuloides*), balsam poplar (*Populous balsamifera*), and paper birch (*Betula papyrifera*) are dominant on more well-drained mineral soils. On lowland sites, the understorey includes Labrador tea (*Ledum groenlandicum*), scrub birch (*B. glandulosa*), willow (*Salix*

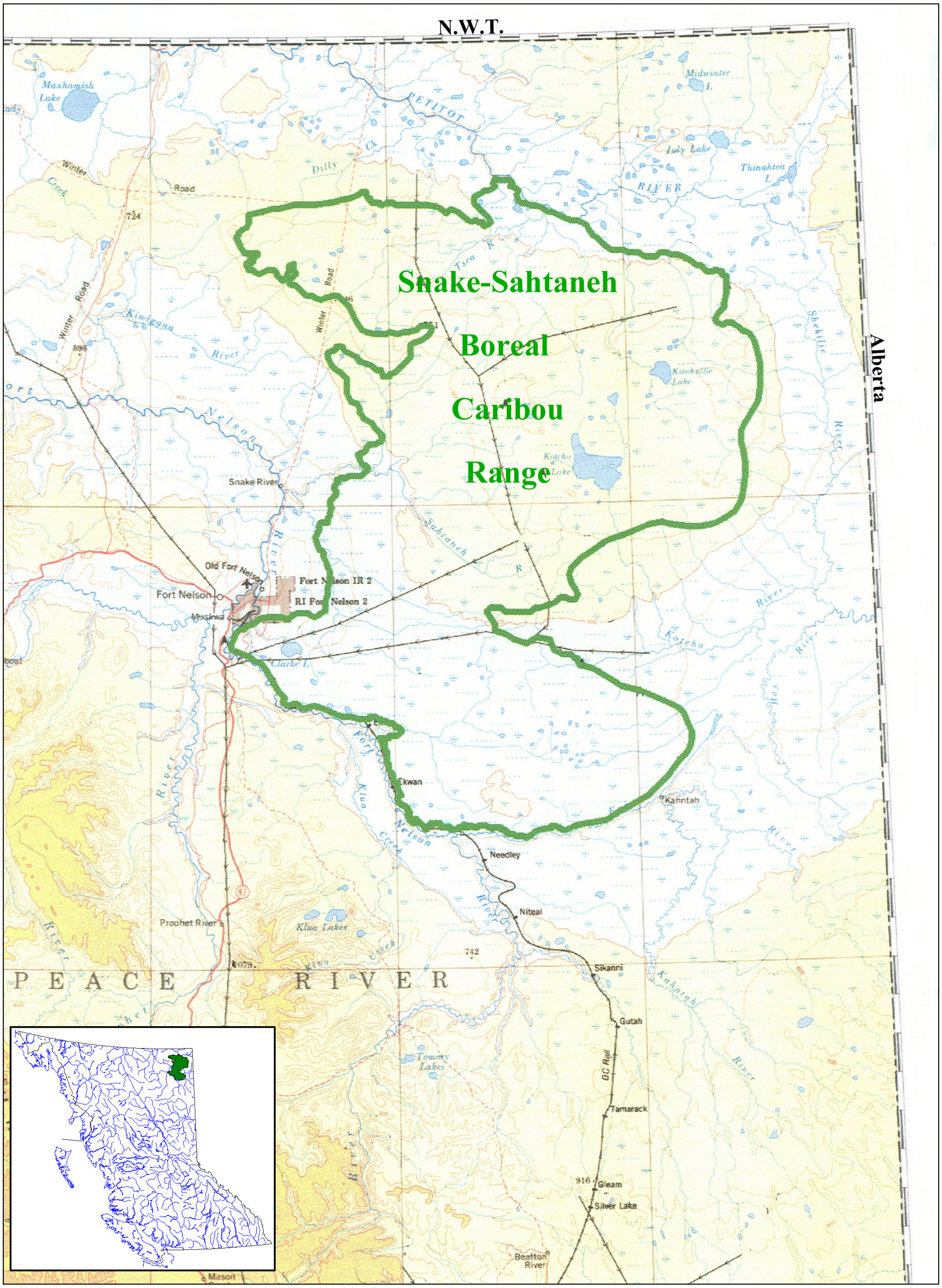

Figure 1. Location of Snake-Sahtaneh study area in northeastern British Columbia; 1:750,000.

spp.), and cloudberry (*Rubus chamaemorus*). Sphagnum mosses (*Sphagnum* spp.) and sedges (*Carex* spp.) are the principal groundcover in bogs and fens, respectively. Dominant terrestrial lichens include *Cladina* spp., *Cladonia* spp., and *Peltigera* spp., which are common and widespread. As is typical of the boreal forest, landscapes throughout the study area have been shaped by extensive fire history.

The area has an abundance of waterbodies, including 5,577 lakes, 4,101 (74%) of which are less than 1 ha in size (British Columbia Watershed Atlas, 1:50,000 NTS digital mapping). Only 4 lakes, Kotcho, Kwokullie, Clarke, and Outaanetdey, exceeded 400 ha in area.

Large herbivore fauna within the study area is limited to moose (*Alces alces*) and boreal caribou, although white-tailed deer (*Odocoileus virginianus*) are known to occur along the large river corridors to the south and west. Wolves, black bears, and lynx are common, while grizzly bears and wolverine are assumed present at very low densities. No evidence of coyotes was noted in the study area during the 58-month field component; however, this species may be currently undergoing range expansion from the west and south.

The Snake-Sahtaneh study area falls within the Etsho Resource Management Zone (RMZ) as defined by the Fort Nelson Land and Resource Management Plan (Fort Nelson LRMP 1997). The study area has been subject to intense petroleum industry activity since the 1950's, with additional activity resulting from forestry (hardwood and softwood). The Etsho RMZ falls within the "enhanced development" category in which industrial activity is promoted. The area is crossed by a number of all-weather and frozen access routes, including the Helmet-Desan, Clarke Lake, Sierra-Yoyo, Yoyo-Komie, and Elleh high-grade roads and the Kotcho winter road.

3 METHODS

3.1 Capture, Collaring, and Telemetry

Caribou

All wildlife capture and handling was conducted in accordance with British Columbia *Resources Inventory Committee* guidelines (RIC 1998a, RIC 1998b). Adult female woodland caribou were captured using a hand-held net-gun fired from a Bell 206B Jet Ranger helicopter. Blood, hair, and fecal samples were collected and standard morphometric measurements taken (RIC 1998a, RIC 1998b). A plastic or metal ear tag was affixed to one ear to allow for subsequent identification in the event of re-capture after collar detachment. Caribou were assigned to broad age classes (young adult, mature adult, old adult). Blood serum was sent to Prairie Diagnostic Services (University of Saskatchewan, Saskatoon, SK) for plasma progesterone analysis. Animals with progesterone levels greater than 2 ng/ml were deemed pregnant (S. Cook, pers. comm.).

Captured caribou were fitted with store-onboard Televilt POSREC C900, Televilt POSREC C600 (Televilt/TVP Positioning AB; Lindesberg, Sweden), or ATS G2000 (Advanced Telemetry Systems Inc.; Isanti, Minnesota) GPS radio-collars or Lotek VHF radio-collars (Lotek Wireless Inc.; Newmarket, Ontario). Caribou GPS collars were programmed to log positions at 4-hour intervals (7 days/week) and detach at the end of their estimated GPS receiver battery life (Televilt) or following detection of low main battery voltage (ATS). VHF recovery beacons operated for up to 120 days after activation of the drop-off mechanism. Collars were equipped with mortality sensors that transmitted a diagnostic pulse upon failing to detect motion for more than 2.5 hours. The objective was to maintain 20 active caribou collars through a rotation of recovery, refurbishment, and re-deployment of collars. Where possible, caribou were re-captured and re-collared before their anticipated collar release dates in order to collect multi-year data sets.

Based on initial study objectives, caribou capture effort was concentrated in the area of existing Terrestrial Ecosystem Mapping (TEM) coverage (Shearwater Mapping 1997); however, analysis of interim GPS caribou data resulted in expansion of the study area and search effort.

Predators

Wolves were captured and collared during the early to late winter period (November to March). During the winter of 2002-03, three bait stations were established within the Snake-Sahtaneh study area through the placement of road-killed moose, mule deer (*O. hemionus*), and white-tailed deer. Two bait stations were established during the following winter at locations suspected to fall between the territories of wolf packs identified during 2002-03. Bait stations were monitored twice weekly by fixed-wing aircraft. Following detection of wolf activity at a bait station, wolves were tracked by helicopter and immobilized with 3.0 mg of Telazol™ (Fort Dodge Animal Health, Fort Dodge, Iowa) delivered by aerial darting. Similar to James *et al*. (2004), capture effort for wolves was designed to ensure adjacent packs were monitored in the central portion of the caribou range.

Black bears were captured during May 2002 and 2003 following emergence from winter dens. Search effort was centred on black spruce peatlands associated with caribou core habitat areas; however, the scarcity of bears at these sites necessitated searching adjacent upland habitat. Bears were immobilized with 5 mg of Telazol delivered by aerial darting.

Wolves and black bears were fitted with Televilt POSREC C600 GPS collars. Collars were programmed to log fixes at 3-hour intervals for an estimated 234 days, with drop-off mechanisms set to activate at 240 days. Mortality sensors transmitted a diagnostic pulse upon failing to detect motion for more than 2.5 hours. Collars were located and picked up by helicopter after the 240-day drop-off date. In the event of drop-off failure, animals were re-captured by aerial darting. Both bears and wolves were fitted with numbered plastic ear tags to allow identification after collar release.

Additional wolves within each pack were captured and fitted with VHF radio-collars to allow identified packs to be located for subsequent collaring activities following detachment of deployed GPS collars.

Telemetry

Telemetry monitoring flights were flown monthly for all species to confirm collar status and detect VHF mortality signals; no attempt to attain visuals or record habitat attributes was made. Additional flights were made prior to capture sessions and during bait station operation. All fixed-wing flights were conducted with a Piper SuperCub.

GPS location precision was estimated for ATS and Televilt collars by examining data clusters from collars known to have remained stationary on the ground within the study area (i.e., detached collars or mortalities), as well as 4 ATS test collars placed in open black spruce bog (2) and closed black spruce forest (2). The centre of each data cluster was assumed to represent the actual location of the collar and the distance from the centre to each point in the cluster was measured to calculate mean error. GPS location precision of data logged in open black spruce bog habitat was compared to test data logged in black spruce forest habitat using the same method.

Wolf Scat Analysis

A limited number of wolf scat samples were collected at the Kyklo pack den site following abandonment. Fecal samples were analyzed to determine diet composition during the denning period.

3.2 Calf Survival, Recruitment, and Adult Mortality

Calf survival surveys were conducted by helicopter in late June and late October 2002 to 2004. Radio-collared females were located and presence or absence of calf-at-heel confirmed. All caribou associated with each collared animal were classified by sex and age (adult females, adult males, calves). Incidental observations of caribou not associated with collared females were also recorded. As interim results from the 2002 and 2003 spring surveys indicated low calf survival to late June, the 2004 spring survey was conducted in four replicates between May 25 and June 30 to confirm live-birth rates and gain additional insight into neonatal mortality rates.

Late-winter composition surveys were conducted by helicopter in March 2003 and 2004 to estimate annual juvenile recruitment. Radio-collared females were located and all caribou associated with collared and uncollared groups were classified by sex and age (adult females, adult males, calves). Recruitment was expressed as the number of calves alive at 10 months of age per 100 females in the population.

Site investigations were conducted as soon as possible following detection of a mortality signal to confirm the status of the animal and determine the apparent cause of death. Annual adult survival rates were estimated using the Kaplan-Meier method staggered entry design, with standard error calculated using Greenwood's formula (Pollock *et al*. 1989; Krebs 1999, Krebs 2003).

April through June GPS caribou data were examined to identify pre-calving movements, calving dates, and calving sites. Calving dates and locations were signified by marked periods of restricted movement.

3.3 GPS Data Analysis

The study commenced immediately before the removal of *selective availability* by the United States Department of Defence in May 2000; GPS data were not differentially corrected. Caribou, wolf, and black bear location coordinates were converted to Universal Transverse Mercator (UTM) projection (NAD 83 datum) and imported into ArcView (ESRI Inc., Redlands California). Individual raw data sets were screened for evidence of collar malfunction. Two-dimensional points (2D), extreme outliers, and obvious erroneous points were culled from each data set.

GPS data were subsampled using a multi-stage process to reduce spatial and temporal autocorrelation and potential satellite acquisition bias associated with canopy closure. For caribou, 1 of a possible six 3-dimensional (3D) daily locations was randomly selected from the total sample of 3D points (*oneperday data set*). The *oneperday* data set was systematically subsampled to select 1 location every third day (*final random data set*); if gaps occurred in the data, the next available location was selected. A similar process was used to subsample wolf and black bear GPS data. The final random data sets were used for caribou, wolf, and black bear home range estimation and resource selection analyses. GPS data were pooled between years, with the rationale that boreal caribou display similar patterns of habitat selection annually (Bradshaw *et al*. 1995, Mahoney and Virgl 2003). Limited wolf and black bear data necessitated pooling to provide more robust samples.

3.3.1 GIS Development

Availability was defined by generating approximately 12,000 random points within a 1,000 m grid overlain on the study area. As some contamination (i.e., overlap of used and available points) was evident, the available sample was further randomly subsampled by 66%. Used and available points were associated with GIS layers representing habitat, biophysical, and hydrological variables (Table 1) to describe habitat use and develop resource selection function (RSF) models (described in section 3.4).

Table 1. Habitat, biophysical, and hydrological variables used to describe habitat use and create resource selection models (RSF) for boreal caribou, wolves, and black bears in the Snake-Sahtaneh study area, 2000-2004.

RSF Model Class	Variable
Habitat Class:	
DU Earth Cover Classification Models:	Closed Needleleaf
	Open Needleleaf
	Woodland Needleleaf [Reference Category]
	Closed Mixed Needleleaf-Deciduous
	Open Mixed Needleleaf-Deciduous
	Tall Shrub
	Low Vegetation
	Wetlands and Waterbodies
	Burn Regeneration
	Cutblock
	Other
Vegetation Resources Inventory (VRI) Models:	
Leading Species:	Black Spruce-Tamarack [Reference Category]
	Lodgepole Pine
	Other
Crown Closure (CC)	Percent crown closure [continuous]
Biophysical Models:	
Slope Class:	SC1 (0.00-0.30°) [Reference Category]
	SC2 (0.31-0.60°)
	SC3 (0.61-0.90°)
	SC4 (0.91° +)
Hydrology Models:	
Waterbody Proximity:	
Distance to Nearest Stream	km [continuous]
Distance to Nearest Lake	km [continuous]
Distance to Nearest Cluster Lake	km [continuous]
Waterbody Characteristics (nearest lake):	
Lake Size:	<2 ha [Reference Category]
	2-5 ha
	5-10 ha
	10-50 ha
	50-100 ha
	>100 ha
Cluster Lake Size:	2-5 ha [Reference Category]
	5-10 ha
	10-50 ha
	50-100 ha
	> 100 ha

The primary vegetation cover analysis was based on Ducks Unlimited *Fort Nelson Earth Cover Classification* mapping (*hereafter*, Earth Cover) derived from Landsat TM7 imagery (DU 2003). Ninety-four percent (11,262 km²) of the 11,960 km² Snake-Sahtaneh range fell within the boundaries of the Fort Nelson Earth Cover project. The twenty-nine Earth Cover classes were amalgamated into 11 habitat classes (Table 2). To augment the Earth Cover imagery, shape files containing cutblock and wildfire polygons (< 50 years old) within the study area were acquired from the Canadian Forest Service, British Columbia Forest Service, BC Timber Sales (BCTS), and Canfor. As the Earth Cover did not differentiate between coniferous classes, habitat was also described using Vegetation Resources Inventory (VRI) data. Leading species and percent crown closure (%CC) attributes were extracted from the VRI.

Digital elevation model (DEM) data were interpolated to create a GIS layer initially consisting of 10 fine-scale slope classes (SC), ranging from SC1 (0.0-0.30°) to SC10 (4.5° and greater), which were collapsed into 4 final classes, SC1 (0.0-0.30°), SC2 (0.31-0.60°), SC3 (0.61-0.90°), and SC4 (0.91° and greater).

The British Columbia Watershed Atlas 1:50,000 NTS digital lake layer and 1:20,000 TRIM digital stream layer were imported into the GIS. Straight-line distances (m) from used and available points to the nearest stream, lake, and *clustered lake* (i.e., within a lake cluster) were measured. Lake clusters were defined as 2 or more lakes greater than 2 hectares in size, with overlapping 250 m buffers. To determine whether differential use was made of lakes of varying sizes, both lakes and clustered lakes were categorized by area (Table 1).

Seasonal Use Periods

Pooled GPS point data were associated with the 11 Earth Cover classes to summarize habitat use by week. Weekly habitat use was stratified into seasonal use periods using hierarchal cluster analysis (Ward's method; SPSS vers. 11.5). Four seasonal use periods were identified: Late Winter (LW; Feb 12 - April 8), Spring-Late Summer (SLS; April 9 - Sept 16), Fall-Early Winter (FEW: Sept 17 - Dec 16), and Mid-Winter (MW; Dec 17 - Feb 11). The SLS season spanned approximately 6 months, including the calving period; therefore, an additional period (Neonate; May 1 - June 30) was nested within it to describe caribou and predator habitat selection specific to this time.

3.3.2 Caribou Home Range, Movements, and Habitat Features

Annual and multi-annual home ranges (100% minimum convex polygon (MCP); Mohr 1947) were calculated for all caribou with greater than 11 consecutive months of location data, defined as 1 annual cycle, using the ArcView extension *Animal Movement* (Hooge and Eichenlaub 2000). GPS data were analyzed spatially to describe caribou movements, potential travel corridors, and seasonal patterns in habitat use, as well as to identify special habitat features (e.g., calving sites).

3.3.3 Predator Home Range and Movements

Multi-year pack territories (100% MCP) were delineated for wolves using the ArcView *Animal Movement* extension. Data points representing occasional, long distance movements beyond territory boundaries were excluded from the analysis. GPS data were analyzed spatially to identify wolf movements and describe seasonal patterns in habitat use during the Neonate and SLS periods.

Individual seasonal black bear home range polygons (100% MCP) were produced using the ArcView *Animal Movement* extension. GPS data were analyzed spatially to identify black bear movements and describe seasonal patterns in habitat use during SLS and the Neonate period.

Table 2: Description of 11 habitat classes derived from 29 DU Earth Cover classes within the Snake-Sahtaneh study area.

Habitat Class	DU Earth Cover Class	Description
Closed Needleleaf	Closed Needleleaf	At least 61% of the cover is trees and at least 75% of the trees are needleleaf species. Needleleaf classes include black spruce, white spruce, lodgepole pine, tamarack, and balsam fir. Comprises 10.92% of Snake-Sahtaneh study area.*
Open Needleleaf	Open Needleleaf, Open Needleleaf Moss	26-60% of the cover is trees and at least 75% of the trees are needleleaf species; includes black spruce bogs and transitional sites. Comprises 42.95% of Snake-Sahtaneh study area.
Woodland Needleleaf	Woodland Needleleaf, Woodland Needleleaf Lichen, Woodland Needleleaf Moss	10-25% of the cover is trees and at least 75% of the trees are needleleaf and > 1 m tall; understorey constituents often include a mosaic of moss and lichen (undifferentiated); typically includes black spruce bogs, transitional areas between open needleleaf and tall shrub, mixed pixel areas at the edge of open/closed needleleaf stands, and patches of burn regeneration. Comprises 14.3% of Snake-Sahtaneh study area.
Closed Mixed Needleleaf-Deciduous	Closed Deciduous, Closed Mixed Needleleaf/Deciduous	At least 61% of the cover is trees, with either deciduous dominant (> 75%) or mixedwood stands comprised of 26-75% deciduous. Deciduous stands (open and closed) are found in association with conifer forests, in regenerating burn areas, along well-drained south-facing slopes, and along the floodplains of major water courses. Mixed needleleaf/deciduous classes include mature stands, shorter stature stands in successional areas, and as sapling regrowth in recent burn scars. A variety of mixtures occur, including stands where conifers and deciduous trees are mixed tree by tree or in clumps of trees within the site. Comprises 17.46% of Snake-Sahtaneh study area.
Open Mixed Needleleaf-Deciduous	Open Deciduous, Open Mixed Needleleaf/Deciduous	From 26-60% of the cover is trees, with either deciduous dominant (> 75%) or mixedwood stands comprised of 26-75% deciduous. See description above. Comprises 3.02% of Snake-Sahtaneh study area.
Tall Shrub	Tall Shrub	Shrubs comprise 20-100% of the cover and shrub height is 2 m or greater. Includes some regenerating sites as well as areas with poorer soils not able to accommodate forested vegetation. Comprises 3.27% of Snake-Sahtaneh study area.
Low Vegetation	Low Shrub Other, Dwarf Shrub Moss, Moss, Wet Graminoid	Low strata vegetation, including low (< 2m) and dwarf shrubs, forbs, graminoids, and bryoids. DU Earth Cover Low Shrub class is predominantly found in wet areas interspersed with Wet Graminoid class and is typically representative of fens; areas often have standing water and small stands of tamarack also present. Comprises 2.92% of Snake-Sahtaneh study area.
Wetlands and Waterbodies	Aquatic Bed, Emergent Vegetation, Clear Water, Turbid Water,	Commonly found in and around lakes and ponds. Comprises 2.91% of Snake-Sahtaneh study area.
Burn Regeneration	Burn Regeneration	Includes DU Earth Cover Burn Regeneration class augmented by fire history polygons (< 50 years) derived from other sources. Comprises 1.38% of Snake-Sahtaneh study area.
Cutblock	Cutblock	Included DU Earth Cover Cutblock class by forest harvest polygons derived from other sources. Comprises 0.12% of Snake-Sahtaneh study area.
Other	Sparse Vegetation, Rock/Gravel, Non Vegetated Soil, Urban, Cloud/Contrail, Cloud/Contrail Shadow, Terrain Shadow, Other	Comprised 0.75% of Snake-Sahtaneh study area.

*Refers to the portion of the Snake-Sahtaneh range within the area encompassed by the DU Earth Cover project (~ 94%) .

3.4 Resource Selection Function (RSF) Models

Caribou Individual-level RSF Models

Caribou seasonal resource selection was evaluated at the third-order scale (Johnson 1980) following a design III approach (Thomas and Taylor 1990), where used and random available units are derived at the individual home range level (Manly *et al*. 2002, Nielsen *et al*. 2002). RSF models taking the form

$$w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + ...\beta_i x_i)$$

were developed to examine caribou resource selection, where $w(x)$ is defined as the relative probability of resource selection, β_i represents the selection coefficients, and x_i represents biological variables (Manly *et al.* 2002, Nielsen *et al.* 2004). Biological variables were grouped into habitat, biophysical, and hydrological classes as described in Table 2. To avoid colinearity issues among biological variables, continuous and categorical biological variables were analyzed independently. For each variable class, categorical variables were analyzed independently with the reference variable set to the most commonly used category (Nielsen *et al.* 2002).

Logistic regression conducted in JMP Version 6.0 (2005) estimated the coefficients for each of the biological variables. Evidence of resource selection was evaluated using log-likelihood chi-squared (-2LL) goodness-of-fit statistics (Manly *et al.* 2002). The Wald test was employed to test for significant coefficient estimates ($p < 0.05$) (Hosmer and Lemeshow 1980). Receiver operating characteristic (ROC) curves were employed to assess model performance. ROC scores greater than 0.7 were considered to indicate good model performance, while scores less than 0.7 were considered to indicate low model performance (Hosmer and Lemeshow 1980).

Following the construction of individual RSF models, coefficient estimates within each variable class were averaged across individuals to obtain individual-based average coefficient estimates. Individual-based average coefficient estimates were compared to individual coefficient estimates to contrast individual caribou resource selection characteristics.

Caribou Population-level RSF Models

Seasonal population RSF models were constructed at the third-order scale (Johnson 1980) following a *design II* approach (Thomas and Taylor 1990). Significant biological variables at the seasonal population-level, population selection dynamics between seasons, and selection dynamics between seasonal population-level models and individual-based averaged models were tested using 95% confidence intervals (Nielsen *et al.* 2002). Population-level RSF models made use of a robust clustering technique to account for pseudo-replication and unequal sample size between individual caribou (Hurlbert 1984).

Robust clustering techniques are analogous to fixed-effect logistic regression models where coefficient estimates, standard errors, and significance levels are corrected in accordance with variation attributed from individual caribou (Pendergast *et al.* 1996). Model testing and performance procedures at the population-level followed individual-level modelling strategies described above.

Predator Seasonal Population-level RSF Models

Spring-Late Summer and Neonate period RSF models were constructed at the third-order scale for wolves and black bears, as described above. While Mladenoff *et al.* (1999) suggests availability for wolves be measured at the individual pack level, small sample sizes necessitated pooling data between all individuals, with availability measured at the population level (i.e., combined 100% MCP of all wolves clipped to the study area boundaries).

4 RESULTS

4.1 Capture, Collaring, and Telemetry

Caribou

Fifty-four adult female caribou were fitted with GPS collars between March 2000 and March 2004 (Appendix 1). Three additional caribou were fitted with VHF collars in March 2004 to augment sample size for the 2004 late winter composition survey and final spring and fall calf survival surveys. GPS datasets were recovered for 48 caribou; no GPS data was collected for the remaining 6 animals due to collar failures. GPS receiver battery life varied from 6 months, at the commencement of the study, to up to 18 months by the end of the project, as collar design improved. Multiple datasets were acquired for 11 caribou through a rotation of collar recovery and redeployment, providing up to 4 years of data per individual animal. Two caribou (S21 and S42) were incidentally recaptured, identified by the presence of ear-tags, and re-collared, subsequent to the programmed release of their original collars. The 48 data sets represented a total of 22,885 GPS collar-days; the mean number of collar-days per caribou was 477 ± 52[1] (range 83 to 1,474).

A total of 117,829 GPS caribou locations were collected between March 2000 and December 2004. Following removal of all low precision (2D) locations, the dataset consisted of 96,645 3D points (Table 3). The mean number of 3D locations per caribou was 2,013 ± 232 (range 210 to 6,457; *n* = 48). The mean number of 3D locations per day for 48 caribou was 4.2 ± 0.1.

Table 3. Summary of total 3D locations collected per GPS-collared Snake-Sahtaneh caribou, March 2000-December 2004 (*n* = 96,645).

Caribou ID	Total 3D Locations	Caribou ID	Total 3D Locations	Caribou ID	Total 3D Locations
S1	921	S18	1,788	S39	712
S2	2,240	S19	1,304	S40	2,000
S3	5,796	S21	4,941	S41	1,485
S4	341	S22	830	S42	2,930
S5	6,457	S24	722	S43	1,581
S6	5,710	S26	736	S44	2,387
S7	665	S28	826	S45	1,634
S8	738	S29	4,165	S46	3,445
S9	597	S30	1,689	S47	2,315
S10	210	S31	1,241	S48	2,207
S11	628	S32	732	S49	1,257
S12	419	S33	1,516	S50	1,880
S14	1,981	S35	1,881	S51	1,531
S15	2,095	S36	1,742	S52	1,834
S16	6,370	S37	1,671	S53	1,808
S17	4,522	S38	1,394	S54	771

VHF locations collected during monthly telemetry flights were used to supplement GPS data in the event of collar failure or significant gaps in locations acquired for an individual caribou.

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[1] All means reported ± standard error (SE) unless otherwise specified.

Wolves

Between November 24, 2002 and March 29, 2004, 31 wolves were fitted with Televilt POSREC C600 GPS collars (19) and Lotek VHF collars (12), including 16 males and 15 females. GPS collars were deployed in 3 packs in the southern and central portions of the study area during the winter of 2002-2003 (Kyklo[2], Kotcho, and Snake packs). Two members of a smaller, fourth pack (Komie pack), active in the northwestern portion of the Snake-Sahtaneh range, were radio-marked with VHF collars in January 2003 to aid in delineating pack territories. During the following winter (2003-2004), GPS collars were re-deployed on the original 3 packs, and deployed on two additional packs (Gunnel and Clarke) identified between the territories described the previous year. In total, 7 wolves were collared in the Kyklo pack (5 GPS, 2 VHF), 6 in the Kotcho (4 GPS, 2 VHF), 7 in the Snake (5 GPS, 2 VHF), 4 in the Clarke (2 GPS, 2 VHF), 5 in the Gunnel (3 GPS, 2 VHF), and 2 VHF in the Komie pack. A total of 13,275 GPS locations (all fix types), representing 18 individual wolf data sets, were acquired during the 2002-2003 and 2003-2004 monitoring sessions, including 9,721 3D points (73%; Table 4). Wolves W7, W9, W11, and W30 collected limited location data due to collar malfunction resulting from bite damage to GPS antennae; W7 and W30 logged data consistently for approximately 1 month each prior to failing. These 4 animals were excluded from the statistical analyses. Mean number of total 3D locations for the remaining 14 wolves was 665 ± 69 (range 237 to 1,059), with the final random sample resulting in a mean of 64 ± 5 locations per wolf, representing 4 to 9 months of monitoring.

Table 4. Summary of total 3D locations collected per GPS-collared wolf in the Snake-Sahtaneh study area, December 2002-November 2004 (*n* = 9,721).

Wolf ID	Sex	Kotcho Pack	Kyklo Pack	Snake Pack	Clarke Pack	Gunnel Pack	Locations Per Wolf
W3	M		1,004				1,004
W4	F		418				418
W5	M		487				487
W6	F	725					725
W7	M	238*					238*
W8	M	961					961
W9	F			25*			25*
W11	F			36*			36*
W16	F			659			659
W18	F			697			697
W19	F	431					431
W20	F	237					237
W22	M		875				875
W25	F					1,059	1,059
W26	F				716		716
W27	M				307		307
W29	F					728	728
W30	F					118*	118*
Total		2,592	2,784	1,417	1,023	1,905	9,721
Mean locations per wolf (n = 18)							540
Standard Error							78

*W7, W9, W11, and W30 excluded from statistical analysis.

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[2] Wolf pack names were assigned based on nearest gazetted drainage.

Five wolf mortalities occurred during the study, including 1 Kyklo female (W2) shot 170 km east of the Kyklo pack territory, along the Chinchaga River near High Level, Alberta, and 1 Snake female (W18) caught in a trapper's snare 70 km northwest of the Snake pack territory. Two collared males (W15 and W27) and 1 collared female (W19) died of undetermined natural causes.

Black Bears

Nine black bears (5 females and 4 males) were captured and collared between May 13-22, 2003 and May 21-25, 2004 (Table 5). A total of 3,729 GPS locations (all fix types) were acquired, including 2,358 3D points (63%). Male SB4 slipped its collar less than a month after capture, but collected 53 3D locations between May 22 and June 17, 2003, providing information for a portion of the caribou calving period. Excluding male SB4, the mean number of 3D locations per bear was 288 ± 65 (range 103 to 662), with the final random sample resulting in a mean of 40 ± 3 locations per bear, representing 4 to 5 months of monitoring.

Table 5. Capture and GPS telemetry summary for 9 radio-collared black bears in the Snake-Sahtaneh study area, 2003-2004.

Bear ID	Sex	Capture Date	Data Start	Data End	Total 3D Locations	General Capture Location	Comments
SB1	M	13-May-03	13-May-03	15-Sep-03	103	Clarke Lake	
SB2	F	13-May-03	14-May-03	4-Oct-03	253	Sierra Gas Plant	2 yearling cubs present
SB3	F	22-May-03	22-May-03	30-Oct-03	662	Kotcho Lake	no cubs
SB4	M	22-May-03	22-May-03	17-Jun-03	53	Sextet Towers	
SB5	F	22-May-03	23-May-03	29-Oct-03	193	Hoffard Creek	no cubs
SB6	M	21-May-04	21-May-04	4-Oct-04	470	Sierra Gas Plant	
SB7	M	24-May-04	24-May-04	8-Oct-04	187	Clarke Lake	
SB8	F	24-May-04	24-May-04	30-Sep-04	199	Clarke Lake	no cubs present - physical condition suggests cub(s) lost previous to capture
SB9	F	25-May-04	25-May-04	30-Sep-04	238	Clarke Lake	no cubs; very fat

GPS Precision

Mean GPS precision for 2 ATS test collars (3D fixes[3]) positioned in open black spruce habitat was estimated at 3 ± 0.2 m (*n* = 312). Mean GPS precision for 5 Televilt collars (3D fixes) that lay on the ground in open habitat within the study area was estimated at 5 ± 1 m (*n* = 216). In comparison, the mean GPS precision for 2 ATS test collars positioned under black spruce forest canopy was 13 ± 1 m (*n* = 257). ATS test collars in open black spruce bog collected 100% of possible 3D hits for 26 consecutive days (i.e., six 3D locations per day), while ATS test collars mounted in dense black spruce forest collected 82% of possible 3D hits for 26 consecutive days (i.e., five 3D locations per day).

4.2 Caribou Population Characteristics

Pregnancy and Calving

Mean progesterone level for 43 blood serum samples testing positive was 7.9 ± 0.5 ng/ml (range 3.1 to 18.5 ng/ml), with an overall pregnancy rate of 95.6 % for the study period (43 of 45 females tested).

The caribou GPS data set encompassed 75 potential individual calving events, with 66 calving sites identified; 2 caribou were not pregnant and 7 calving sites were ambiguous. Calving sites were identified based on extended periods of restricted movement, with pregnant caribou remaining within a mean radius of 40 ± 4 m for an average of 47 ± 3 hrs. In comparison, the mean distance moved between paired,

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[3] The classification of GPS fix type varied slightly between ATS and Televilt collars, therefore, results are not directly comparable between manufacturers.

consecutive 4-hour locations for all caribou combined was calculated at 565 ± 114 m. Collared females calved between May 1 and June 2, with the peak of calving estimated at May 15 (*n* = 66; Fig. 2). Estimated peak conception was back-calculated to September 30, based on a 228-day gestation period (Shackleton 1999). The majority of females appeared to have been bred in the first estrous cycle.

Calf survival to the end of June was 20% for both 2002 and 2003 and 29% for 2004 (Table 6). In 2004, 4 consecutive spring surveys flights were conducted (May 25, June 4, June 12, and June 30) to confirm that females were producing live calves and track calf survival through the first month of life.

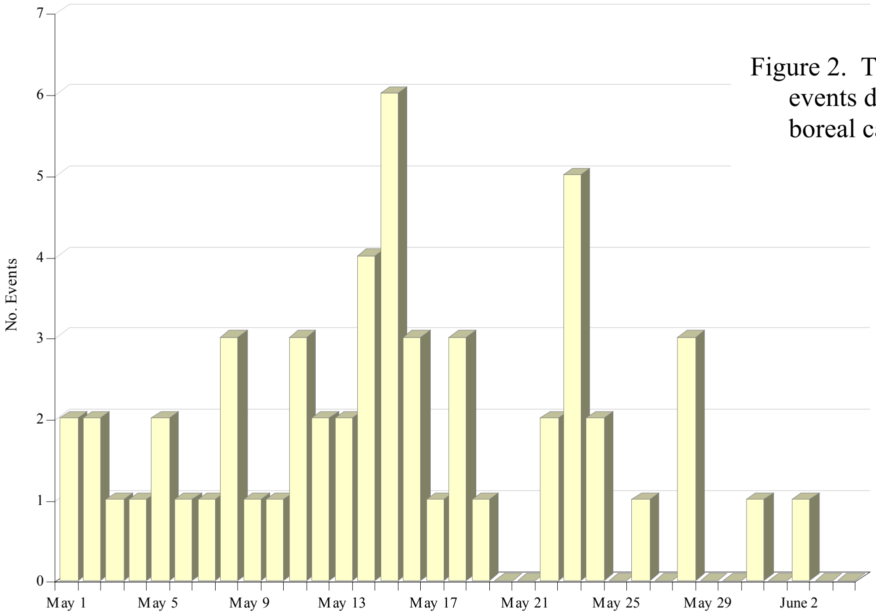

Figure 2. Timing of 66 identified calving events during the Snake-Sahtaneh boreal caribou study, 2000-2004.

Based on progesterone analysis and visual confirmation of calves, 23 of 24 collared cows monitored were pregnant in 2004. On May 25, calf status was confirmed for 22 of 23 pregnant females; 16 were accompanied by live calves. Subsequent analysis of GPS data indicated that of the 6 collared cows observed without calves, 2 had not yet calved and 3 had calved 9 to 24 days prior to the initial survey (May 1, 10, and 16) and had presumably lost their calves. By June 4, 6 of the 16 live calves had been lost and 2 additional calves had been born. By June 12, 2 more of the remaining 12 calves had been lost and by June 30, a further 6 had been lost. Interpretation of the GPS data and observations made during surveys indicated a minimum of 18 of the 23 pregnant females (78%) gave birth to live calves that accompanied them for a minimum of 5 days. If parturition success for the 3 females that lost calves before the May 25 survey followed a similar pattern, parturition and 5 day survival exceeded 90%. No GPS calving data was available for the remaining 2 cows whose calves were not observed during the spring survey period.

October calf survival surveys indicated a further drop in calf numbers to 12%, 13%, and 14% for 2002 to 2004, respectively (Table 6). Results of late winter composition surveys conducted on March 12, 2003 and March 24, 2004 indicated low recruitment, with 5.4 calves:100 cows and 8.9 calves:100 cows to 10 months, respectively.

While no systematic inventories were conducted during the study, 160 caribou were counted during the March 24, 2004 late winter composition survey (Table 6).

Table 6. Summary of spring and fall calf survival and late winter* composition surveys in the Snake-Sahtaneh study area, 2002-2004.

Survey Date	Total No.Groups	Total Caribou	Cows	Calves	Bulls	Calves:100 cows	Comments
26-Jun-2002	20	24	20	4	0	20.0	
27-Oct-2002	14	92	67	8	17	11.9	
12-Mar-2003*	17	82	74	4	4	5.4	
28-Jun-2003	15	18	15	3	0	20.0	
29-Oct-2003	12	76	60	8	8	13.3	
24-Mar-2004*	23	160	123	11	26	8.9	
25-May-2004	22	57	34	22	1	64.7	10 days after peak
4-Jun-2004	22	40	27	12	1	44.4	20 days after peak
12-Jun-2004	23	38	27	11	0	40.7	28 days after peak
30-Jun-2004	23	31	24	7	0	29.2	45 days after peak
24-Oct-2004	19	109	72	10	27	13.9	

Group Size

Seasonal changes in group size were observed, with females highly dispersed during the calving season (Table 7). The spacing out process appeared to be ongoing through the calving season, with smallest mean group size (1.0 ± 0.0, excluding neonate calves) not observed until the end of June. Telemetry locations indicated females remained widely dispersed throughout the summer months, forming small groups prior to the rut. Three groups of 7 to 9 caribou, with mature males in all groups, were observed on September 24, 2003. Regional weather patterns, characterized by dense fog and freezing rain throughout late September and early October, dictated that all 3 fall calf-survival surveys be conducted at the end of October. While surveys occurred approximately 1 month after the estimated peak of conception, the majority of caribou were still associated with rutting groups (Table 6).

Snake-Sahtaneh caribou remained in fluid aggregations throughout fall and winter. Mean group size for October and March surveys was 6.2 ± 0.7 (range 1-19) and 6.1 ± 0.5 (range 1-17), respectively (Table 7). Mean group size for 61 observations during capture sessions between September and March was 4.8 ± 0.3 (range 1-12). Group fidelity appeared low, with the size and composition of groups associated with radio-collared females shifting frequently. Males were typically in discrete groups in relatively close proximity to females, however mature males were also often found with groups of females throughout the winter.

Adult Mortality

Five of 57 radio-collared caribou were known to have died during the 58-month study period, including 2 cases of confirmed wolf predation, 1 case of suspected black bear predation, and 2 of undetermined cause. Both confirmed cases of wolf predation (S32 and S54) occurred on seismic lines. Mortalities occurred in April, June, July, August, and October. Standardized annual adult survival for 57 females over 58 months was estimated at 0.94 (95% CI = 0.89 to 0.99).

Table 7. Comparison of mean group size (± SE) of Snake-Sahtaneh caribou during spring (neonate calves excluded) and fall calf survival and late winter composition surveys, June 2002-October 2004.

Date	Survey Type	No. of Groups	Total Caribou/Survey	Mean Group Size	Range
26-Jun-02	Spring Calf	19	19	1.0 ± 0.0	1 - 1
28-Jun-03	Spring Calf	15	15	1.0 ± 0.0	1 - 1
25-May-04	Spring Calf	29	36	1.2 ± 0.1	1 - 3
4-Jun-04	Spring Calf	22	27	1.2 ± 0.1	1 - 3
12-Jun-04	Spring Calf	21	25	1.2 ± 0.1	1 - 3
30-Jun-04	Spring Calf	20	20	1.0 ± 0.0	1 - 1
Mean - All[a]	Spring Calf	-	-	1.1 ± 0.0	1 - 3
Mean - June[b]	Spring Calf	-	-	1.0 ± 0.0	1 - 1
27-Oct-02	Fall Calf	14	92	6.6 ± 1.1	2 - 19
29-Oct-03	Fall Calf	12	76	6.3 ± 1.6	1 - 18
24-Oct-04	Fall Calf	19	109	5.7 ± 1.0	1 - 18
Mean - Oct	Fall Calf	-	-	6.2 ± 0.7	1 - 19
12-Mar-03	Late Winter	17	82	4.8 ± 0.7	1 - 11
24-Mar-04	Late Winter	23	160	7.0 ± 0.7	1 - 17
Mean - March	Late Winter	-	-	6.1 ± 0.5	1 - 17

a includes 6 surveys between 25 May and 30 June, 2002 to 2004.

b includes only end of June surveys from 2002 to 2004.

4.3 GPS Data Analysis

4.3.1 Caribou Core Habitat Areas, Home Ranges, and Movement Patterns

Caribou Distribution and Core Habitat Areas

Of 96,645 3D caribou locations, only 7 points, representing 3 animals, fell outside the boundaries of the study area. S43 recorded three 3D locations west of the range between May 31 and June 2, 2003 while making a 35 km circuit through Open Needleleaf and mixedwood habitats before returning to her original departure point in the Paradise core habitat area. S16 took an indirect route during a 51 km movement between the Paradise and Clarke cores in late May 2002, logging two 3D locations roughly 2 km beyond the western boundary. In July 2001, S18 traveled approximately 14 km, in 4 hours, between the Komie Lake area and the Tsea core, crossing a mixedwood upland escarpment projecting into the northwest corner of the Snake-Sahtaneh range. Combined GPS and VHF data indicated S18 crossed through this area on at least 2 other occasions (June 2001 and April 2003).

GPS telemetry revealed the importance of several large patches of black spruce peatland within the Snake-Sahtaneh boreal caribou range. Using interim GPS data collected from 2000 through 2003 (approximately 65,000 data points), 7 *core habitat areas* were described based on a 95% fixed kernel estimator (Worton 1989), with boundaries adjusted to fit Earth Cover habitat polygons (Open and Woodland Needleleaf classes) and further refined through a series of reconnaissance flights (Culling *et al.* 2004). These 7 core habitat areas comprise approximately 31% of the Snake-Sahtaneh range and include the Clarke (1,381 km²), Paradise (403 km²), West Kotcho (362 km ²), North Kotcho (748 km²), East Kotcho (318 km²), Etsho (62 km²), and Tsea (472 km²) cores. Locations of the 7 core habitat areas within the range are shown in Appendix 2. Upon completion of the study, 94% of 96,645 3D GPS caribou locations collected fell within these cores (Fig. 3), as did 65 of 66 identified calving sites.

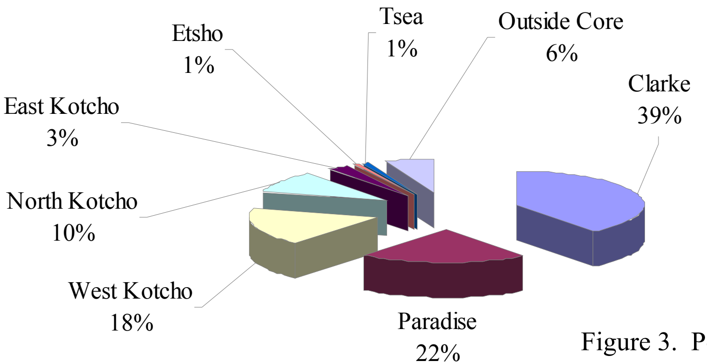

Figure 3. Percentage of Snake-Sahtaneh caribou locations within identified core habitat areas, 2000-2004 (*n* = 96,645 3D GPS points).

Figure 4 illustrates the distribution of collared Snake-Sahtaneh caribou within the study area during the 4 primary seasonal use periods, based on the final random sample (7,401 3D points) and 74 monthly VHF telemetry locations; the density of 3D locations within cores habitat areas necessitated presenting each seasonal use period separately. Caribou activity was concentrated in the cores throughout all seasons, including the May-June calving and September-October rutting periods (Fig. 5).

The majority of collared caribou activity occurred within the Paradise and Clarke cores and the complex formed by the West Kotcho and North Kotcho cores separated by Kotcho Lake (*hereafter*, the Kotcho complex). All collared caribou spent time in 1 or more of these 3 areas, with 20 of 48 animals using both the Clarke and Paradise cores, 8 using both the Kotcho complex and Paradise core, and 2 using all 3 cores. Clusters of locations recorded outside the cores were often the result of extended use of an area by a single collared animal.

Throughout the 3 winter seasons (Fig 4), collared caribou activity was generally concentrated within the Clarke and Paradise cores, and the Kotcho complex. Eight animals also logged winter locations in predominantly Open Needleleaf habitat south of the Clarke core.

Snake-Sahtaneh caribou were most dispersed during SLS (Fig. 4), with collared animals found in all 7 core areas, as well as on the peninsula of Open Needleleaf and Woodland Needleleaf habitat northwest of Komie Lake. Caribou made the greatest annual use of the northwestern portion of the study area during this season, with 4 animals spending time in the Etsho core (S17, S18, S24, S37), 3 in the Tsea core (S9, S18, S24), and 3 in the vicinity of Komie Lake (S18, S29, S35). Based on GPS telemetry alone, it would appear that the Tsea and Etsho core habitat areas were used solely during SLS; however, a review of VHF locations recorded for S18 in 2002-2003 (no GPS data available) indicated this caribou was in the Etsho core in August 2002, then moved to the Tsea core, where it remained from September 2002 to March 2003.

Caribou Home Range Size

Figure 6 depicts overlapping 100% MCP home range polygons for 48 individual adult female caribou including animals collared for less than 1 annual cycle and multi-annual polygons for animals with more than 2 annual cycles of GPS data. A summary of 100% MCP home range size for 33 adult female Snake-Sahtaneh caribou with greater than 11 months of location data is presented in Appendix 3. The mean annual home range size, adjusted for caribou with multi-year data, was 1,468 ± 128 km^2 (*n* = 33; range 375 to 3,592). Multi-annual home range size for 7 caribou with 2 to 3 full annual cycles was 2,408 ± 352 km^2 (range 1,426 to 3,975). Highest inter-year home range fidelity was shown by caribou S5 and S16, who consistently used both the Clarke and Paradise cores over 3-year periods. Mean distance between geographic centres of multiple annual 100% MCP polygons for these 2 animals was 7.3 km and 6.2 km, respectively.

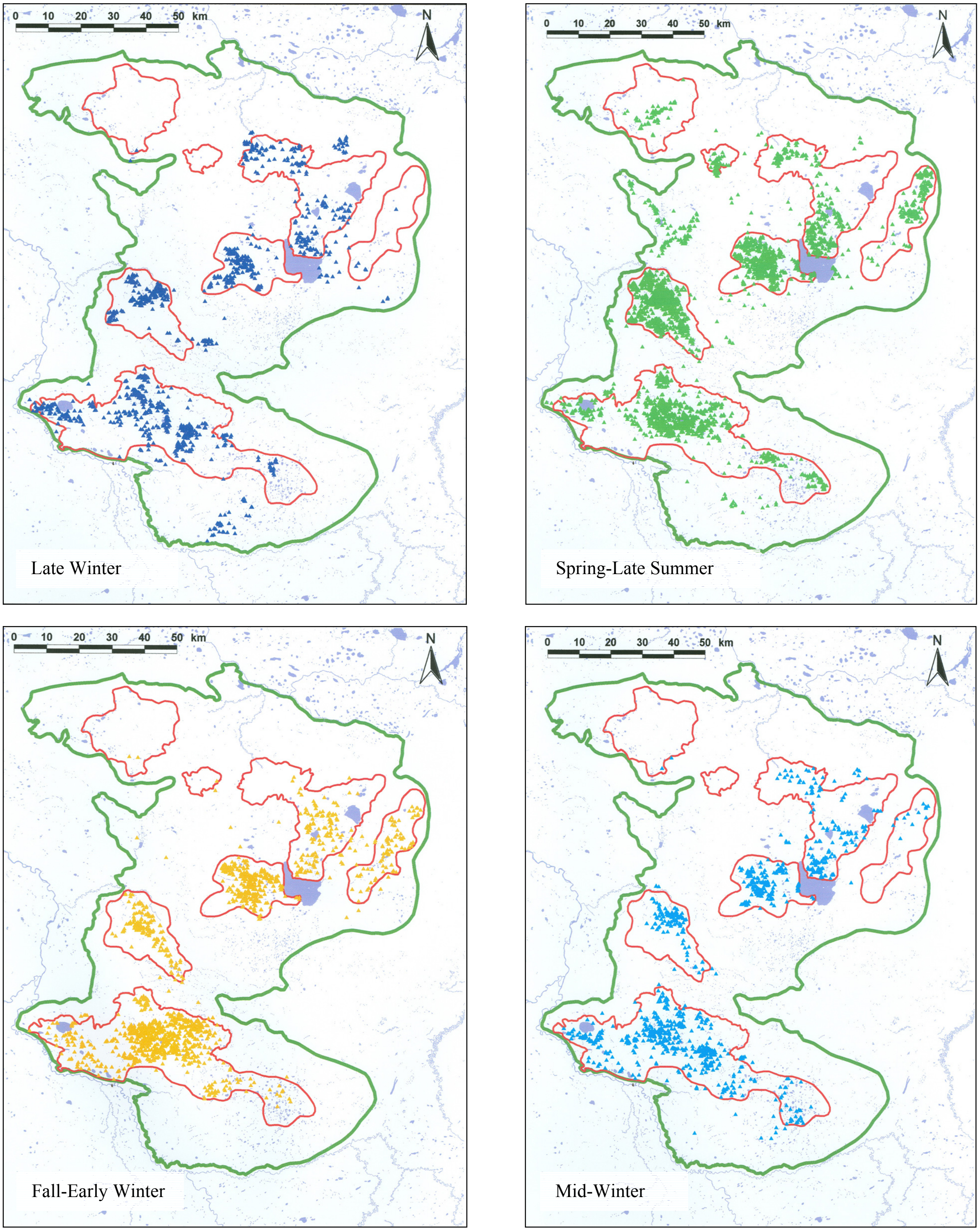

Figure 4. Distribution of 48 adult female Snake-Sahtaneh caribou during Late Winter (LW; Feb 12 – April 8); Spring-Late Summer (SLS; April 9 – Sept 16); Fall-Early Winter (FEW; Sept 17 – Dec 16); and Mid-Winter (MW; Dec 17 – Feb 11), March 2000-December 2004 (*n* = 7,475 GPS/VHF points).

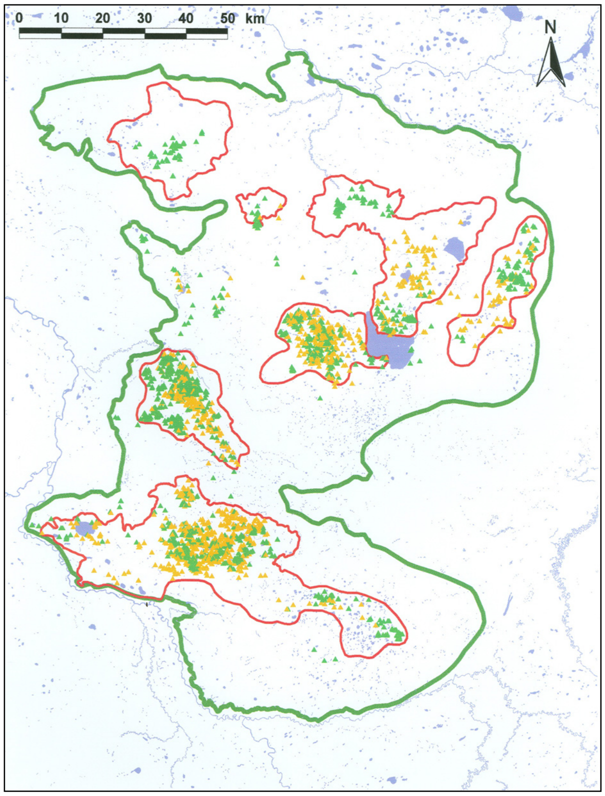

Figure 5. Distribution of 48 adult female Snake-Sahtaneh caribou during calving (▲ May – June) and the rut (▲ Sept – Oct), March 2000-December 2004 (*n* =2,577 GPS/VHF points).

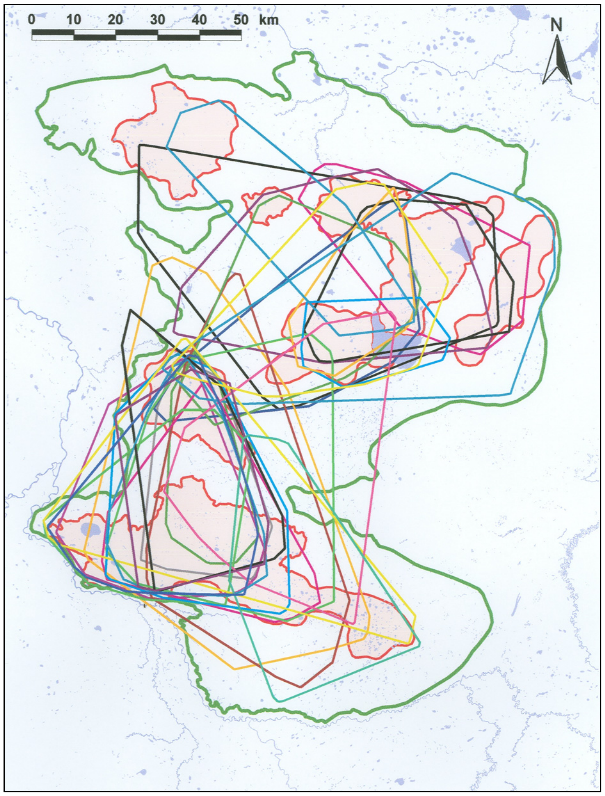

Figure 6. 100% MCP multi-annual home range polygons for 48 adult female Snake-Sahtaneh caribou, March 2000-December 2004 (*n* = 7,475 GPS/ VHF points).

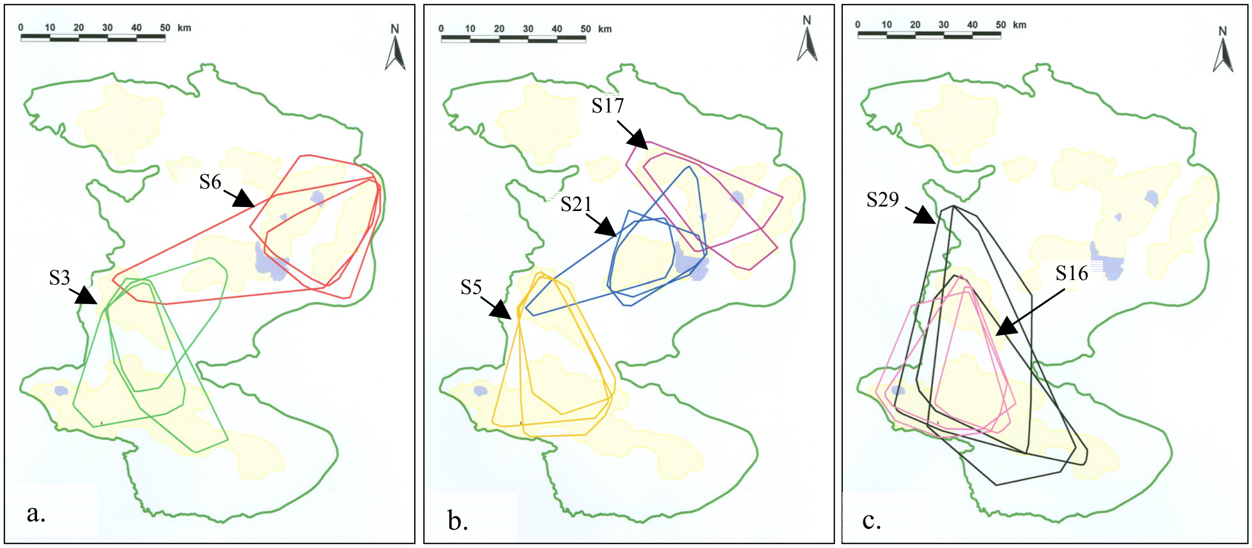

Figure 7. Overlap of annual 100% MCP polygons for 7 Snake-Sahtaneh caribou with multi-annual home ranges (a) S3 and S6, (b) S5, S17, and S21, and (c) S16 and S29, March 2000-December 2004.

The greatest variation in geographic centres of multiple annual home range polygons was shown by caribou S3, S6, and S21, with each animal spending time in a third core during one of 3 annual cycles. Mean distance between geographic centres of multiple annual 100% MCP polygons for these animals was 13.8 km, 16.1 km and 13.7 km, respectively. Mean inter-year shift in multiple annual home range centres for all 7 caribou was 10.6 ± 1.3 km (range 3.5 to 20.6 km).

Movement Patterns

Snake-Sahtaneh caribou are non-migratory. While some caribou showed evidence of seasonal patterns of use of individual core habitat areas, no unified movements were observed at the population level. Nine of 33 collared caribou with a minimum of 11 months of GPS data used a single core habitat area, while the remaining 24 used multiple cores, including 4 caribou that used 4 different cores and 2 caribou that used 5 cores.

While collared caribou were present in all core areas during all seasons, including calving and rutting, use of the Paradise core appeared to decline during the fall and early winter, when most collared animals shifted their activity to the Clarke core or Kotcho complex. Five caribou stayed within the Clarke core during their respective collar deployments and 4 remained within the Kotcho complex; however, of 20 caribou that used the Paradise core, none remained there for the duration of their respective monitoring periods, with all spending time in the Clarke core and/or Kotcho complex at some point. Fall movements from the Paradise core typically occurred between late August and early November, but most commonly took place during the last half of September. Conversely, the Paradise core appeared to receive increased use during the calving and post-calving periods. Several collared caribou wintering in the Clarke and Kotcho cores consistently made pre-calving movements to the Paradise core prior to mid-May and remained there through June and July. However, 2 collared caribou (S44 and S48) displayed opposing movement patterns, leaving the Paradise core to calve in the Clarke core.

Figure 8 shows the movements of 30 caribou that spent time in 2 or more cores during their respective GPS collar deployments. Twenty caribou travelled between the Clarke and Paradise cores, 6 moved between the Paradise core and Kotcho complex, and 3 moved between the Kotcho complex and Tsea core. Seven caribou moved between 3 or more cores, typically hop-scotching between adjacent cores as they travelled throughout the range. Movements between cores were generally rapid and direct.

The most concentrated inter-core movements occurred between Paradise and Clarke. Collared caribou entering and leaving the Clarke core typically did so from one of 2 points along the northern perimeter, one to the south of the existing Sierra-Yoyo high-grade road and another north of the road (Fig 9). Movements from the former typically occurred within a 3 km wide corridor of low-gradient upland with a significant deciduous component. The majority of caribou crossings of the Sierra-Yoyo high-grade occurred along a 2.6 km section of road centred at UTM 10.567229.6512490. The movements of caribou leaving the Clarke core from a patch of black spruce peatland north of the Sierra-Yoyo road were less distinct and tended to radiate outward, through similar upland habitat, to various points along the southern boundary of the Paradise core.

A number of Snake-Sahtaneh caribou made extensive, irregular movements within the study area. In April 2001, caribou S2 made a 74 km loop through the West Kotcho and Paradise cores, returning to within 700 m of her starting point in 4 days. Some movements observed by individual Snake-Sahtaneh caribou appeared to be associated with selection of seasonally available resources, such as wintergreen vascular plants found along lake margins. For example, while S2 was typically found in the central portion of the West Kotcho core, in early December 2000 she moved to the shoreline of Kotcho Lake and remained there for approximately 3 weeks.

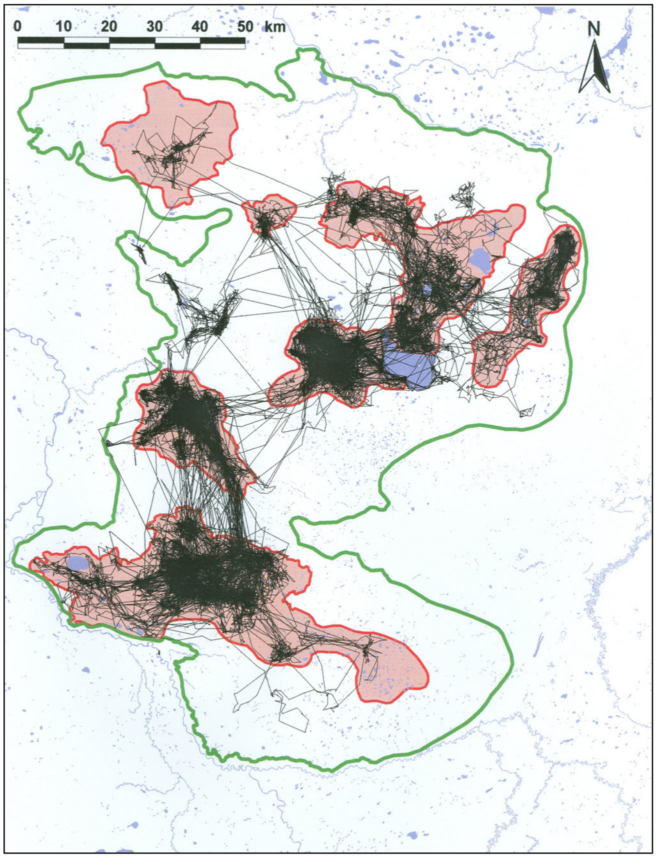

Figure 8. Movements of 30 adult female caribou through the Snake-Sahtaneh study area, showing significance of core habitat areas, 2000-2004 (*n*=73,383 3D GPS points).

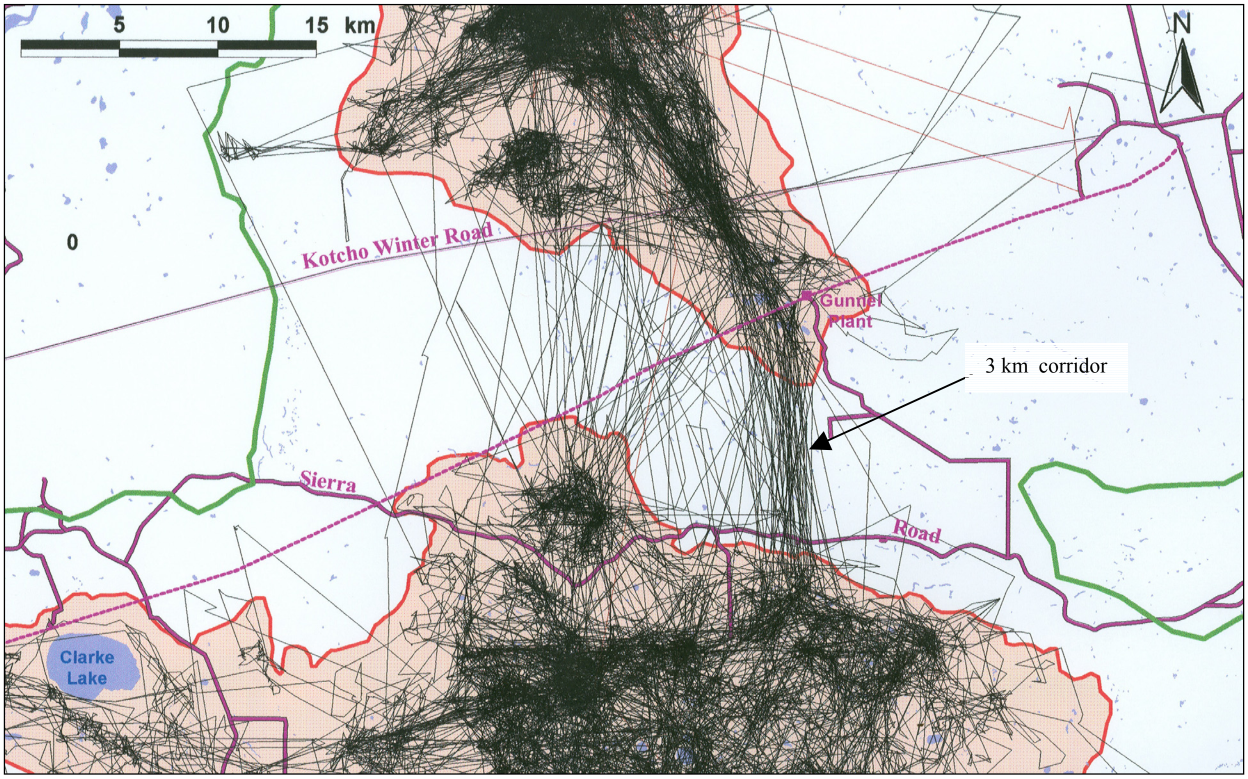

Figure 9. Movements of 20 GPS-collared Snake-Sahtaneh caribou between the Clarke and Paradise core habitat areas, illustrating concentrated use of 3-km wide corridor, March 2000-December 2004.

Caribou movements both within and outside core habitat areas in the Snake-Sahtaneh range were generally associated with extremely low gradient terrain, with 49% of locations recorded during movement between cores occurring in areas of less than 0.30° slope (SC1). Figure 10 depicts 3D caribou locations within and between the Kotcho complex, Etsho core, and Tsea core, as well as in the vicinity of Komie Lake, highlighting the proximity of caribou activity to extremely low gradient habitat.

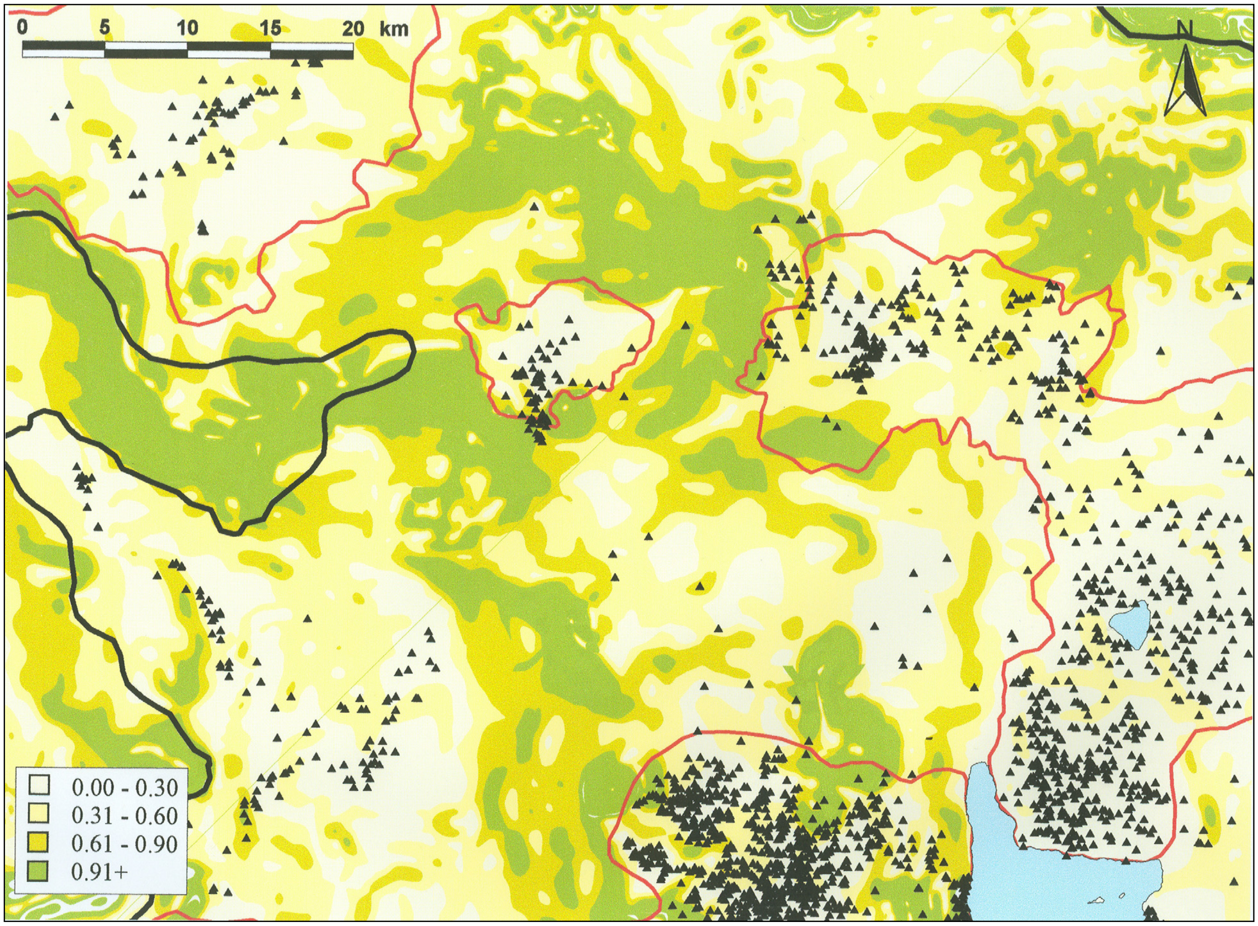

Figure 10. Snake-Sahtaneh caribou GPS locations (▲) in relation to slope class, illustrating the importance of areas of extremely low gradient terrain (SC1; 0.00 – 0.30°).

4.3.2 Seasonal Habitats

Calving Site Fidelity and Site Attributes

As previously mentioned, 65 of 66 identified caribou calving sites fell within the 7 core habitat areas, ranging from 1 site in the Etsho core to 26 sites in the Paradise core (Fig. 11; Appendix 4). Fourteen of 48 collared caribou collected GPS data through 2 or more identifiable calving events, with 7 animals monitored through 2 calvings, 4 through 3 calvings, 2 through 4 calvings and one animal (S5) through 5 consecutive calvings (Table 10). The multi-annual home ranges of all 14 caribou encompassed between 2 and 4 core habitat areas each, but with only one exception (S16), all caribou showed consistent calving fidelity to a single core. In May 2001, approximately 4 days before calving, S16 travelled 36 km from the Clarke to Paradise core. The animal repeated this movement in May 2002, travelling 30 km 1 day prior to calving roughly 1.5 km from the previous year's site. While no parturition site could be identified in 2003, the caribou moved from the Clarke to the Paradise core on June 4. S16 wintered in the

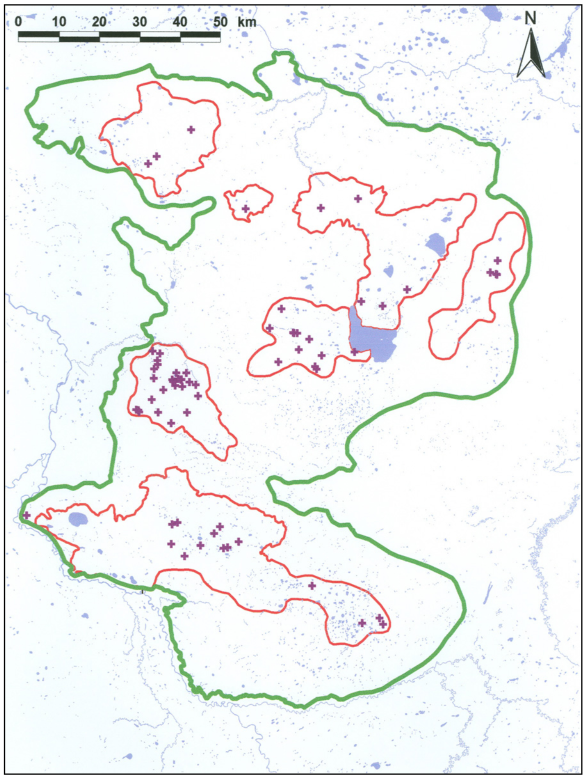

Figure 11. Location of 66 calving sites identified for GPS-collared caribou within the Snake-Sahtaneh study area, 2002-2004.

Table 10. Mean distance between consecutive calving sites for 14 Snake-Sahtaneh caribou, 2000-2004.

Caribou ID	No. of Calving Events	Distance Between Calving Sites (km)			Comments
		Min.	Max.	Mean	
S2	2	4.1	4.1	4.1	
S3	3	4.5	13.3	8.9	
S5	5	0.5	11.1	6.7	
S6	4	0.2	3.4	2.2	
S16	3	1.4	40.6	1.5	only cow that calved in 2 different cores: Paradise core (2), Clarke core (1)
S17	3	0.0	9.6	6.4	2003 site within 10 m of 2001 site
S21	4	1.0	8.4	6.4	
S29	3	2.2	4.4	3.0	
S42	2	8.2	8.2	8.2	
S43	2	6.3	6.3	6.3	
S44	2	1.7	1.7	1.7	
S45	2	2.4	2.4	2.4	
S46	2	0.7	0.7	0.7	
S49	2	14.5	14.5	14.5	

Clarke core again in 2003-2004, remaining there to calve in May 2004. In contrast, caribou S5 wintered in the Clarke core and traveled to the Paradise core to calve for 5 consecutive seasons. Collared caribou with multi-year data sets made pre-calving movements of up to 90 km to return to a previous general location within a maternal core. In 41 of 66 calving events identified, females displayed significant pre-calving movements between the beginning of April and mid-May, travelling a mean distance of 40.5 ± 3.7 km (range 12 to 119 km). Eleven caribou made pronounced movements immediately before calving, ranging from 4.5 km 1 day prior to giving birth, to 36 km 4 days prior to giving birth.

Fidelity to parturition sites varied both among animals and between consecutive years for individuals. With the exception of caribou S17, who returned to within 10 m of her 2001 calving site in 2003, fidelity appeared to be to a general location rather than a specific feature. Excluding S16's Clarke calving site, mean distance between multiple calving sites within the same core was 5.2 ± 1.0 km (range 180 m to 14.5 km; *n* = 14). The mean distance between multiple calving sites (5.2 km) equated to roughly 8% of the mean maximal distance across the 14 MCP multi-annual home ranges (68 ± 5 km; range 36 to 98 km). The maximum distance between multiple calving sites was 40.6 km, measured between caribou S16's Clarke and Paradise sites.

The 26 calving sites identified in the Paradise core represented 14 individual caribou, with 4 animals monitored through 2 calving events, 2 animals monitored through 3 calvings, and 1 caribou monitored through 5 calving seasons. In contrast, 14 calving sites identified in the Clarke core represented 13 individual caribou, with only 1 animal monitored for 2 calving events.

Habitat characteristics at calving and postpartum sites were variable. During spring calf surveys, females were located in small islands of mature black spruce forest or mixedwood habitat within surrounding peatlands, in old burns on the edge of wetlands, in alder thickets with abundant standing water, and along lakeshores.

Figure 12 illustrates the proportion of Earth Cover habitat classes at 66 identified parturition sites within the study area. The majority of calving sites were in coniferous habitats, with 46 sites in Open Needleleaf (70%), 10 sites in Woodland Needleleaf (15%), and 4 sites in Closed Needleleaf (6%). Three sites occurred in Burn Regeneration, 1 in Closed Mixed Needleleaf-Deciduous, 1 in Open Mixed Needleleaf-Deciduous, and 1 in Low Vegetation. VRI mapping indicated 58 of 66 sites (88%) were leading black spruce, with 56 sites (85%) in less than 45% crown closure. All 66 calving sites were characterized by very low gradients, with 30 (45%) and 29 (44%) of sites in SC1 and SC2, respectively.

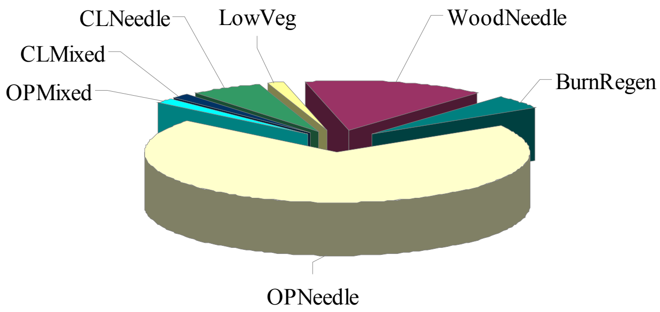

Figure 12. Earth Cover classes at 66 identified calving sites in the Snake-Sahtaneh study area, 2000-2004.

Both collared and uncollared caribou were frequently observed along lakeshores during spring calving surveys (2002-2004), including larger bodies, such as Clarke and Kotcho lakes, and small lakes and lake complexes. Kotcho Lake contains the only island (approximately 16 ha in area) within the Snake-Sahtaneh study area. Caribou were seen swimming the lake on 2 occasions, however no evidence of caribou use of the island was found.

Rutting Site Fidelity and Habitat

Snake-Sahtaneh caribou did not use a common rutting ground; similar to the calving season, rutting activity was distributed within core habitat areas throughout the study area. Fidelity to geographic areas by individuals during the rut was variable. Seven collared caribou logged GPS data for the September 29 to October 1 peak conception period during 2 or more years; the multi-annual home ranges of all 7 included 2 to 4 core habitat areas. Four of 7 animals exhibited relatively strong rutting fidelity to general areas within individual cores. The remaining 3 caribou spent alternate peak conception periods in the Paradise and Clarke cores and made movements between cores during the broader rutting season (mid-September to mid-October).

Within treed peatlands complexes, Snake-Sahtaneh caribou were found in relatively open habitats during the rut. Of 1,075 September and October 3D GPS locations, 41% were in Open Needleleaf, 37% in Woodland Needleleaf, 8% in Burn Regeneration, and 7% in Low Vegetation. Eighty-six percent of locations were in leading black spruce or tamarack polygons.

Burn Regeneration

In addition to fall use of the Burn Regeneration class, Snake-Sahtaneh caribou were observed within the perimeter of older fires, both in burned patches and in remnant unburned patches, on a number of occasions in the late spring and early summer months. Three collared caribou were located within burns during spring calf survival surveys; caribou S53 was repeatedly found in an old burn in the West Kotcho core during the spring 2004 surveys. GPS data revealed this burn was used by a number of collared caribou.

Other Habitats

Caribou were frequently observed on lakes and along lake margins from November through January. Site inspections revealed animals were foraging for wintergreen vascular plants, as well as pawing apart muskrat (*Ondatra zibethicus*) "push-ups" (i.e., domes of frozen aquatic vegetation covering breathing holes in the ice). On several lakes, caribou disturbance was evident at all push-ups. Snake-Sahtaneh caribou were also commonly found in fens during early winter, where forage items included sedges and cattail (*Typha latifolia*) rhizomes.

4.3.3 Predator Home Ranges and Seasonal Movements

Wolves

Four of 6 wolf packs identified (Table 11) had a minimum of 12 to 15 wolves per pack, including the Kotcho pack (15), Kyklo pack (15), Snake pack (14), and Gunnel pack (12). The Clarke and Komie packs were comprised of approximately 8 and 5 individuals, respectively. Excluding the Komie pack, for which only limited VHF data was collected, mean pack territory size was 2,190 ± 549 km^2, with a mean intra-territory density of 164 ± 31 km/wolf. Based on the minimum number of wolves known to be present in the area encompassed by contiguous pack territories, minimum wolf density within the Snake-Sahtaneh caribou range was estimated at 6.3 wolves/1,000 km^2. The distribution of GPS data indicated a vacant area between the Gunnel, Snake, Clarke and Kyklo pack territories (Fig. 13); anecdotal evidence suggests an additional pack, not identified during the study, was operating in this area, which encompasses a large proportion of the Clarke core. Wolves were found in the largest groups during the winter and in much smaller groups during the spring and summer, when individuals were often observed hunting alone.

All 5 wolf packs for which GPS data was acquired encompassed significant portions of caribou core habitat areas (Fig. 14). The Paradise and West Kotcho cores fell within zones of overlap between adjacent pack territories. Almost the entire West Kotcho core was located within the territories of both the Gunnel and Kotcho packs; the Kotcho pack territory also included 3 additional cores.

Table 11. Summary of wolf pack territory size and density in and adjacent to the Snake-Sahtaneh boreal caribou range, December 2002-November 2004.

Pack	MCP (km²)	No.of Wolves	km² per Wolf
Kyklo	2,834	15	188.9
Kotcho	3,860	15	257.3
Snake	1,283	14	91.6
Clarke	772	8	96.5
Gunnel	2,201	12	183.4
Komie	242	5	48.4

GPS data was used to identify den locations for each pack in both years of data collection, including 3 den sites in 2003 and 5 den sites in 2004. Six of 8 den sites fell within the Snake-Sahtaneh caribou range, with the remaining 2 situated within 3 km of the boundary. The Kotcho pack primary den site was located within the North Kotcho core in 2003 and the West Kotcho core in 2004. The den sites of the other 4 packs were located outside core areas by distances ranging from 500 m to 10.4 km (mean 5.8 ± 1.6 km).

Wolf activity at primary den sites typically began during the last week of April and continued into July. The movements of GPS-collared wolves radiated outward in all directions from den sites throughout the May and June caribou calving and postnatal period. Collared wolves typically hunted within a 16 to 25 km radius of their respective den sites. Kotcho female W20 hunted up to 48 km from the 2004 den site. Figure 15 depicts the movements of Kotcho female W19 between May 2 and June 26, 2004, radiating from the 2004 Kotcho pack den site, located within the West Kotcho core. Movements included frequent forays into the heart of the West Kotcho core and a 112 km circuit through the North Kotcho and East Kotcho cores from June 12 to 15. This figure represents the movements of 1 of approximately 15 wolves hunting within the same area during this period.

Den sites and SLS wolf locations were frequently associated with beaver activity. Several den sites were in abandoned beaver lodges on dewatered impoundments. Twenty-seven of 106 visual observations of wolves during fixed-wing telemetry monitoring flights in SLS were at beaver ponds. The majority of GPS wolf collars retrieved following successful activation of the programmed release mechanism were recovered at or near beaver impoundments. While a large proportion of wolf activity during the May-June calving period was associated with beaver activity, incidental observations of lone wolves traveling through undisturbed black spruce bogs within caribou cores were made on 3 separate occasions. This included a May 25 observation of an uncollared wolf on a recently killed caribou calf in the North Kotcho core, 10 km east of the 2004 Kotcho den site. Fresh wolf scat at the site contained the dew claws of a second, smaller caribou calf.

Figure 16 illustrates the relative frequency of occurrence of remains found in 27 scat samples collected at the primary Kyklo pack den site and a secondary (rendezvous) site in late summer 2003. Beaver accounted for over 80% of items identified, with waterfowl and neonate caribou and moose comprising secondary components.

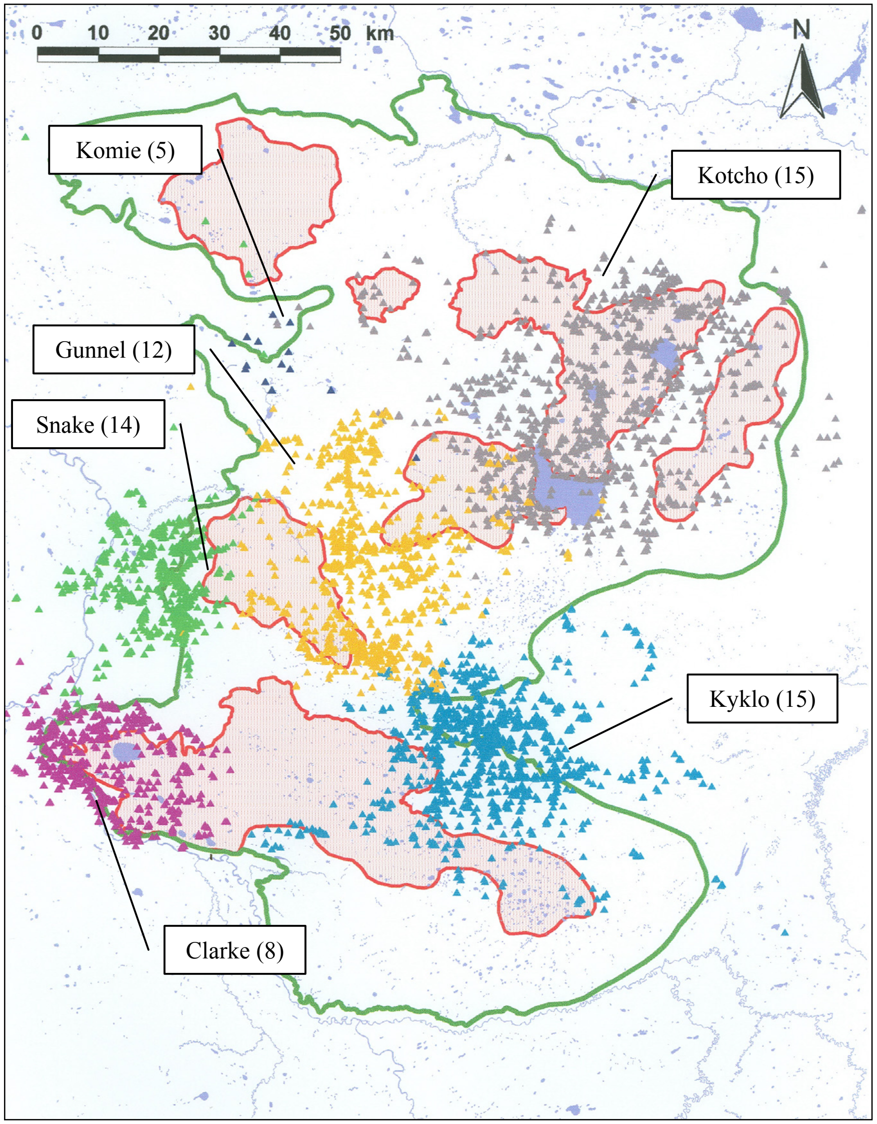

Figure 13. Distribution of 6 radio-collared wolf packs within the Snake-Sahtaneh caribou range (2002-2004) (*n* = 9,951 GPS/VHF points).

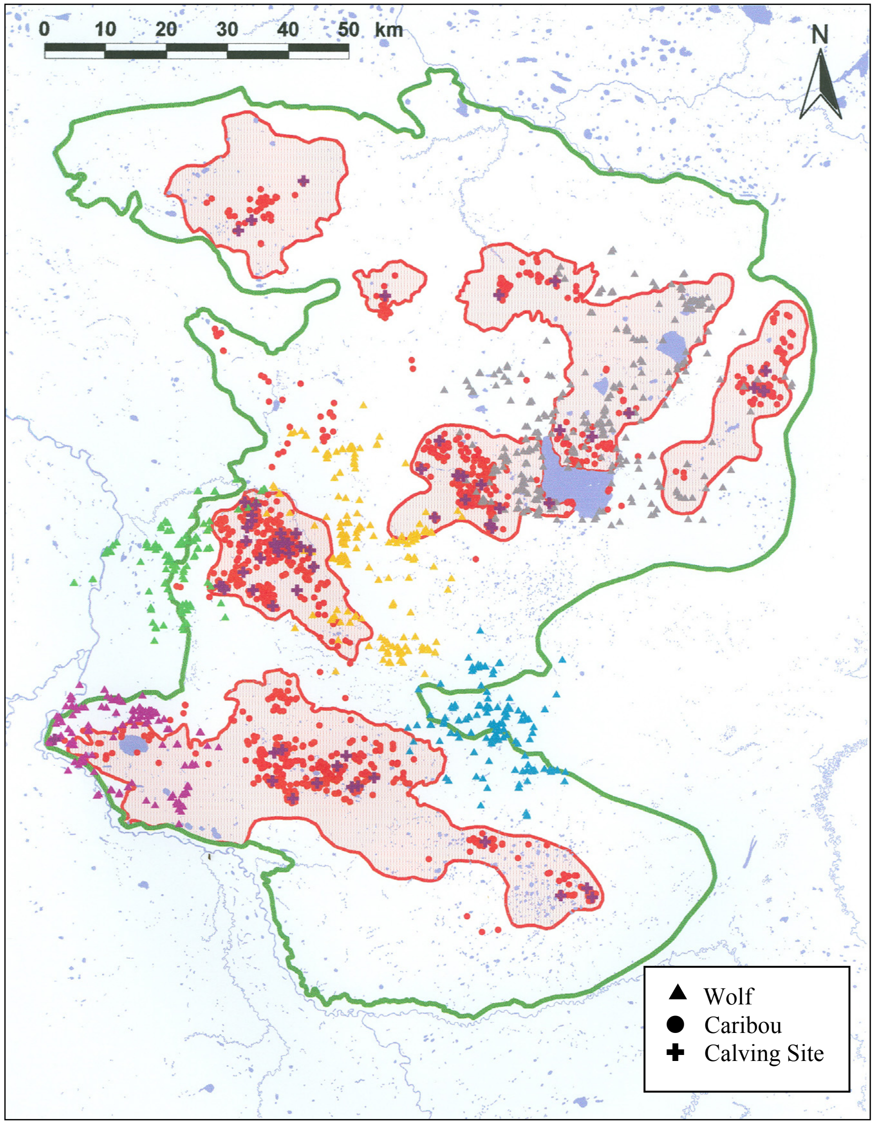

Figure 14. Distribution of 66 calving sites and May-June GPS locations of caribou and wolves showing potential spatial overlap, 2000-2004 (*n* = 7,401 caribou and 1,818 wolf locations).

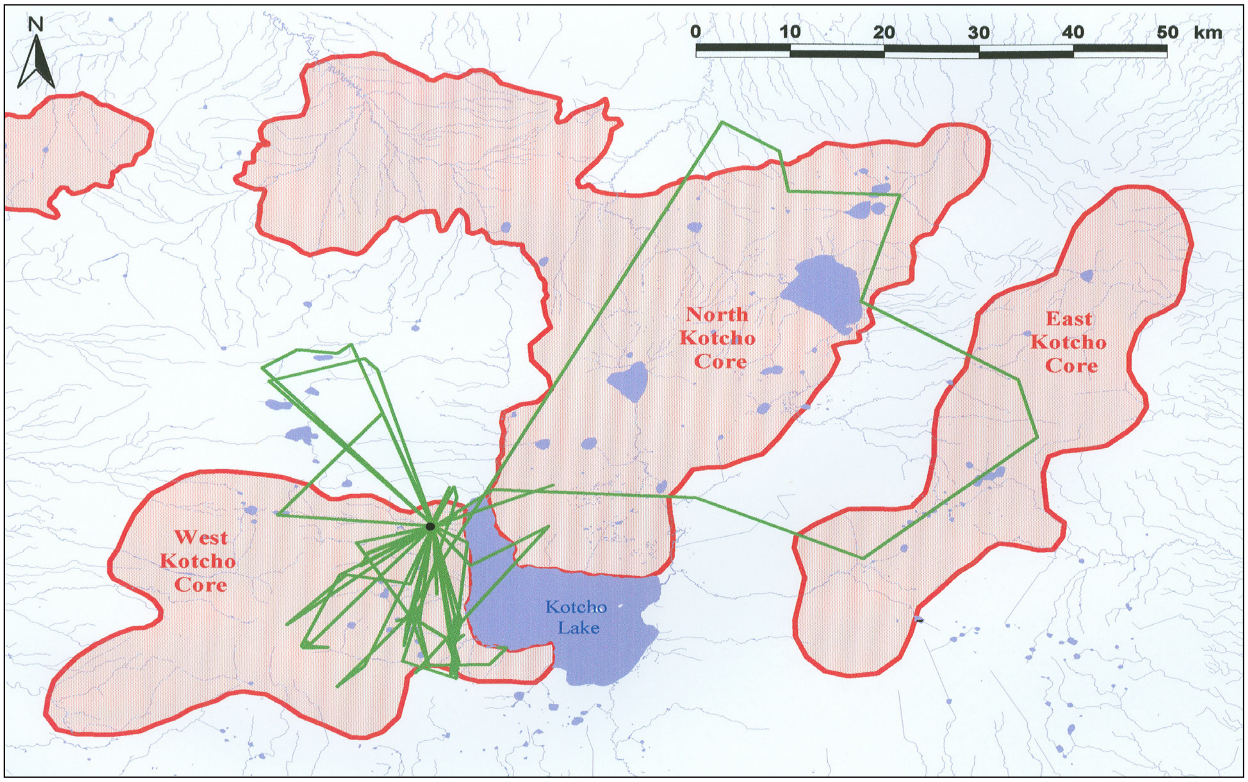

Figure 15. Movements of wolf W19 from the 2004 Kotcho pack den site between May 2 and June 26, 2004, including 112 km circuit through the North Kotcho and East Kotcho core habitat areas on June 12-15.

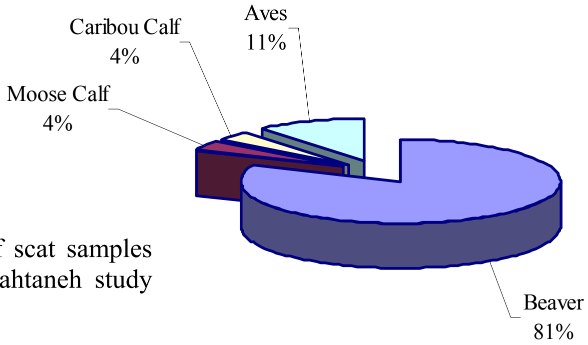

Figure 16. Relative frequency of remains in 27 wolf scat samples collected at Kyklo pack den sites in the Snake-Sahtaneh study area, August 2003.

Excluding mortality investigations of collared caribou, adult ungulate kill sites were examined on 14 occasions, either through random encounter, tracking of radio-collared wolves, or ground-truthing GPS wolf data clusters. Wolf-killed ungulate remains were identified as moose in all cases.

Although no formal moose surveys were conducted in conjunction with this study, the highest winter moose densities incidentally observed during the course of fieldwork were consistently recorded within the Snake River riparian corridor, along the west boundary of the Snake-Sahtaneh range. This area lies within the territory of the Snake pack, whose relative territory size was the smallest of the 4 large packs (96.5 km²/wolf). The other 3 large packs, whose territories included lower proportions of high suitability moose habitat, had relative home range sizes 100% to 180% larger (183 – 257 km²/wolf; Table 11).

Black Bears

Despite significant search effort during May capture sessions, no black bears were found in black spruce peatland habitats within caribou core areas, although bears were observed and captured in mixedwood upland habitat immediately adjacent to, or surrounded by, sparsely treed peatlands. In 2 cases, bears located in mature mixedwood upland were herded to suitable aerial darting locations in adjacent open peatland patches.

The 9 collared black bears spent varying amounts of time within the boundaries of the Snake-Sahtaneh caribou range (Fig. 17), including 2 females and male SB4 remaining within the range for their entire monitoring periods and 2 females and 2 males spending time both inside and outside the southwestern end of the range, in the vicinity of the Clarke core. Female SB2 and male SB6 were captured 1.8 km and 3.9 km outside the southeastern boundary of the range, respectively. While both bears recorded locations within the range, the majority of their activity occurred in well-drained mixedwood habitat on the adjacent escarpment.

Seasonal 100% MCP home ranges (May through October) varied greatly in size from 34 km² for female SB5 to 370 km² for male SB7, with male home ranges generally larger than those of females. Excluding SB4, as data was logged for less than 1 month, mean home range size was 116 ± 38 km² and 282 ± 84 km², for female and male black bears, respectively (Table 12). Activities of individual bears tended to be concentrated within 1 or 2 relatively small areas, with the largest MCP home ranges typically reflecting 2 distinct areas of activity with unused habitat between them. Three of 4 males and 2 of 5 females travelled between separate areas of activity; movements of the fourth male (SB4) are likely not representative due to the limited monitoring period. Four collared bears (2 males and 2 females) travelled between 20 and 35 km to spend portions of late July and August within riparian floodplain habitat at the confluence of the Fort Nelson and Muskwa rivers. Earth Cover mapping indicated bears were typically in closed canopy deciduous forests or cutblocks at this time. Similarly, the majority of locations for SB2 and SB6 were in closed canopy deciduous habitat adjacent to the eastern boundary of the Snake-Sahtaneh range.

Table 12. Summary of seasonal home range size (100% MCP) for 9 GPS-collared black bears, May-October 2003 and 2004.

Bear ID	Sex	100% MCP (km²)			Comments
		All	Males	Females	
SB1	M	363	363		
SB2	F	38		38	2 yearling cubs
SB3	F	111		111	no cubs
SB4	M	90	90		monitored for less than 1 month (lost collar); excluded from HR analysis
SB5	F	34		34	no cubs
SB6	M	114	114		
SB7	M	370	370		
SB8	F	231		231	no cubs
SB9	F	164		164	no cubs

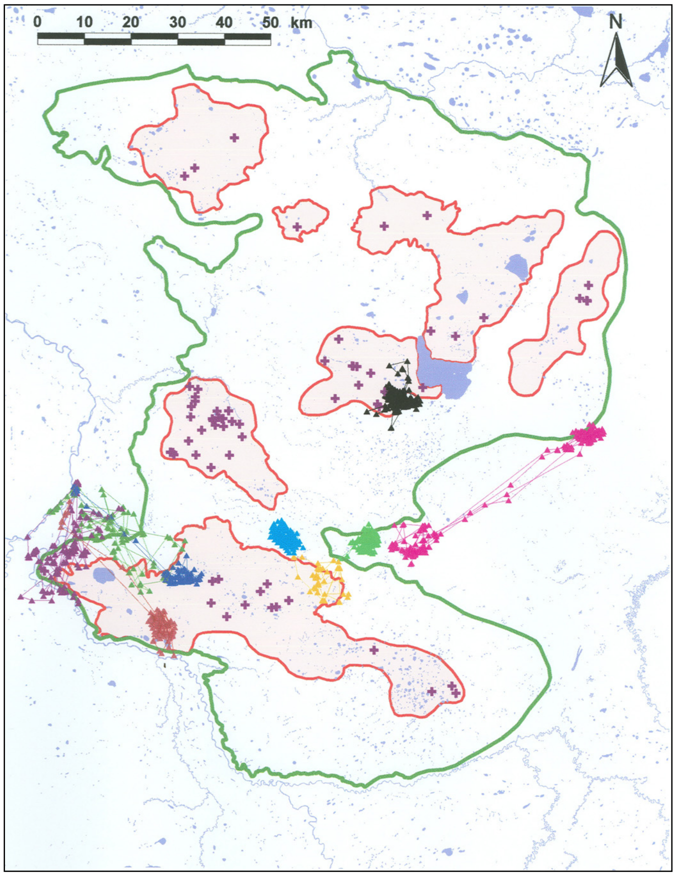

Figure 17. GPS locations (▲) and movements of 9 collared black bears, within and adjacent to the Snake-Sahtaneh study area, in relation to caribou core habitat areas and calving sites (✚), May-October 2003 and May-September 2004.

Five bears made significant use of caribou core habitat areas during the May-June caribou neonatal period. Within the cores, bear use was concentrated in aspen-dominated upland patches, along upland riparian zones, roads and pipelines, and in cutblocks. As with wolves, some collared black bears were commonly located near areas of beaver activity. Female SB5 remained active within an area of deciduous and mixedwood upland between the Clarke and Paradise cores from the time of capture, on May 22, 2003, until entering her den in late October. Although this bear collected GPS data points within 1.6 km and 2.5 km of the Clarke and Paradise cores, respectively, she did not venture into either core.

Figure 18 illustrates the interspersion of mixedwood and peatland habitats within the Clarke core habitat area in relation to GPS locations for 2 black bears (SB8 and SB9), as well as May and June caribou GPS locations (all years), and identified calving sites. Relative spatial separation between species is evident, with black bear locations strongly associated with mixedwood and deciduous habitats and cutblocks, while caribou locations and calving sites were typically within treed peatlands (Open and Woodland Needleleaf classes).

Of 5 collared caribou mortalities, 1 was suspected to have been the result of black bear predation. Caribou S4 calved in the Clarke core on May 13, 2000 and made localized movements within 300 m of a small lake until the late evening of June 3, when she began a rapid movement through the core to the northwest. Between 1:00 p.m. and 5:00 p.m. the following afternoon, she was killed on the edge of another small lake after moving 12.6 km. A site investigation revealed, bear scat, bear hair and evidence of a struggle. The mortality site was located at the interface between black spruce peatland and mixedwood upland habitat.

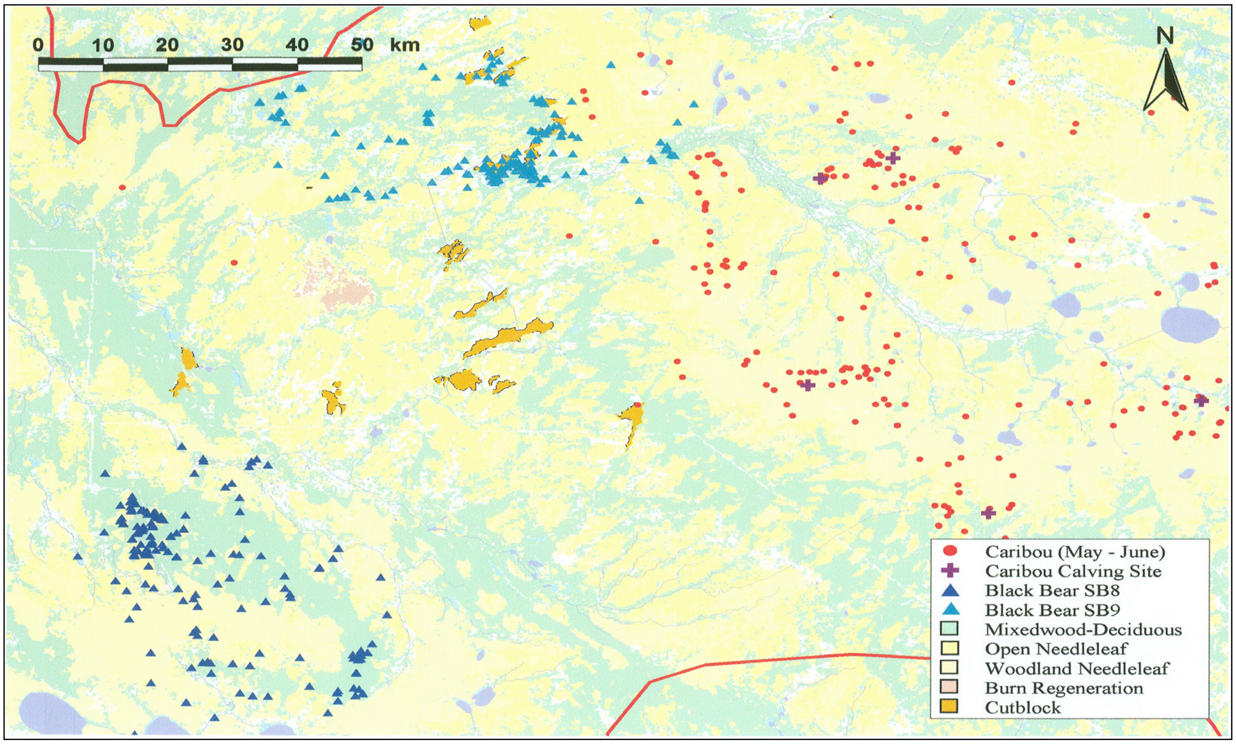

Figure 18. May to September locations of black bears SB8 and SB9 in the Clarke core habitat area, in relation to May and June caribou locations and identified calving sites.

4.4 Habitat Use and Resource Selection Function (RSF) Modeling

The Earth Cover mapping encompasses 94% of the Snake-Sahtaneh boreal caribou range. Needleleaf (i.e., conifer) habitat classes account for the majority (68%) of this area, with the predominantly black spruce Open Needleleaf (26-60% tree cover) and Woodland Needleleaf (10-25% tree cover) classes representing 43% and 14%, respectively (Table 13). The Closed Needleleaf class accounts for an additional 11% and consists of both well-drained (white spruce, lodgepole pine) and poorly-drained (black spruce) components. Closed and open canopy Mixed Needleleaf-Deciduous classes are interspersed throughout (21%). The Wetlands and Waterbodies, Burn Regeneration, and Cutblock classes comprise minor components (< 5% combined).

Figure 19 shows the proportion of GPS caribou locations (use) within each of the 11 Earth Cover classes compared to availability of each class for the 4 primary seasons. Figure 20 presents a comparison of use versus availability for the Neonate period and for all other months combined. Figures 21 and 22 compare GPS locations with availability of Earth Cover classes for wolves and black bears during the Neonate period, respectively. Predator locations occurring outside the study area boundary were excluded.

Caribou use of the Open Needleleaf class exceeded availability (43%) for all seasons except FEW (Fig. 19), with 54% of all locations falling within this class. Similarly, 26% of caribou locations (all seasons combined) were in the Woodland Needleleaf class, compared to 14% availability. With the exception of LW, when use and availability were comparable (~14%), caribou use of Woodland Needleleaf was roughly 2 to 3 times greater than availability. While use of the Closed Needleleaf class was consistently less than availability throughout the year, there was a relative increase in caribou use of closed canopy coniferous habitat during LW. Caribou were observed in the Low Vegetation class, which includes fens,

Table 13. Habitat composition of the Snake-Sahtaneh study area based on amalgamated *Earth Cover* classes.

DU Earth Cover Class Class	 Code	Area (ha)	Proportion (%)
Closed Needleleaf	CLNeedle	123,004	10.9
Open Needleleaf	OPNeedle	483,709	42.9
Woodland Needleleaf	WoodNeedle	161,102	14.3
Closed Mixedwood-Deciduous	CLMixed	196,641	17.5
Open Mixedwood-Deciduous	OPMixed	33,964	3.0
Tall Shrub	TallShrub	36,872	3.3
Low Vegetation	LowVeg	32,940	2.9
Wetlands and Waterbodies	Wetlands/Water	32,792	2.9
Burn Regeneneration	BurnRegen	15,516	1.4
Cutblock	Cutblock	1,304	0.1
Other	Other	8,426	0.7
Total Within Earth Cover Mapping Area		1,126,271	100.0

more than expected based on availability during SLS, FEW, and MW. Similarly, caribou were found in Burn Regeneration more often than expected in SLS, FEW, and MW, with use of this habitat class during FEW (7%) roughly 5 times availability (1.4%). While caribou use of the Cutblock class exceeded availability in SLS and FEW, these results are based a small number of GPS locations (5 of 7,401) found within a very rare habitat (0.1% of study area). All other Earth Cover classes were used less than expected based on availability.

The proportion of caribou use versus availability of Earth Cover classes was roughly comparable during the Neonate period and broader SLS season, with the Open Needleleaf, Woodland Needleleaf, Low Vegetation, and Burn Regeneration classes used more than expected (Fig. 20).

Wolf use of Open Needleleaf (33%) was less than expected based on availability (43%), with use of Woodland Needleleaf (16%) slightly greater than availability (14%). Forty-nine percent of May-June wolf locations were in the Open Needleleaf and Woodland Needleleaf classes combined (Fig. 21).

Approximately 6% of the study area is comprised of the Low Vegetation and Wetlands and Waterbodies classes combined. Wolf use of these habitats exceeded availability throughout the year (data not shown). During the Neonate period, wolves were found in Low Vegetation almost 3 times (8%) and Wetlands and Waterbodies over 5 times (16%) more than expected based on availability (3%).

Approximately 27% of May-June black bear locations were in Open Needleleaf and Woodland Needleleaf combined (Fig. 22), compared to 57% availability of these 2 classes. While use and availability were comparable (~14%) for the Woodland Needleleaf type, bears were observed in Open Needleleaf (13%) much less than expected based on availability (43%). Black bears used several habitat classes more than expected, including Closed Mixed Needleleaf-Deciduous, Open Mixed Needleleaf-Deciduous, Tall Shrub, Low Vegetation, Wetlands and Waterbodies, Cutblock, and Other. Of these, Tall Shrub and Low Vegetation were used approximately 4 and 3 times more than expected, respectively. Cutblock represents only 0.1% of the study area; however, 7% of black bear locations were within this class.

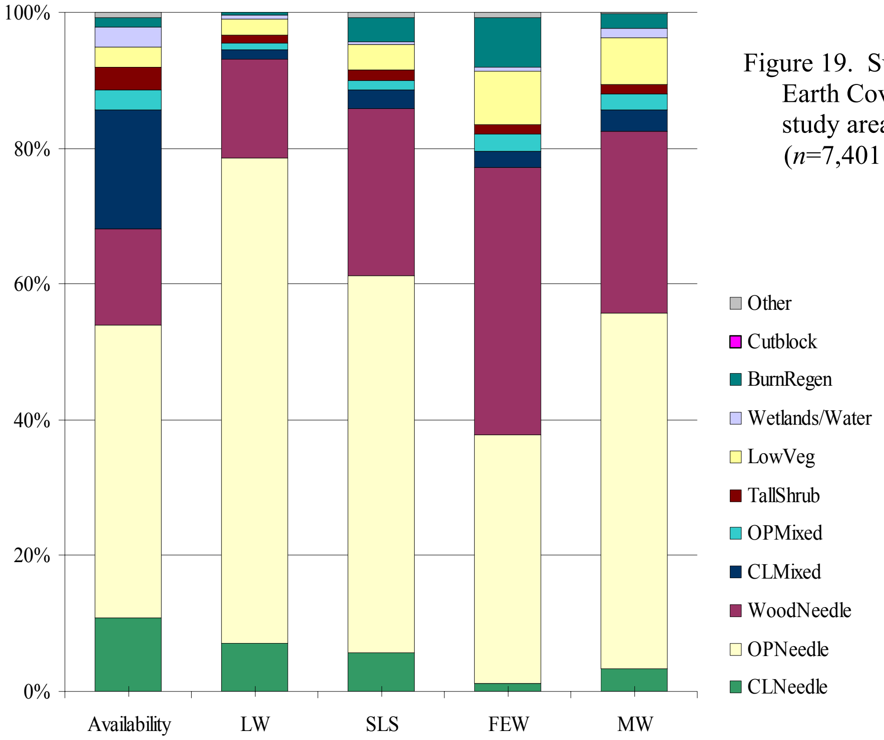

Figure 19. Summary of seasonal caribou use by Earth Cover class within the Snake-Sahtaneh study area, March 2000-December 2004 (*n*=7,401 GPS points).

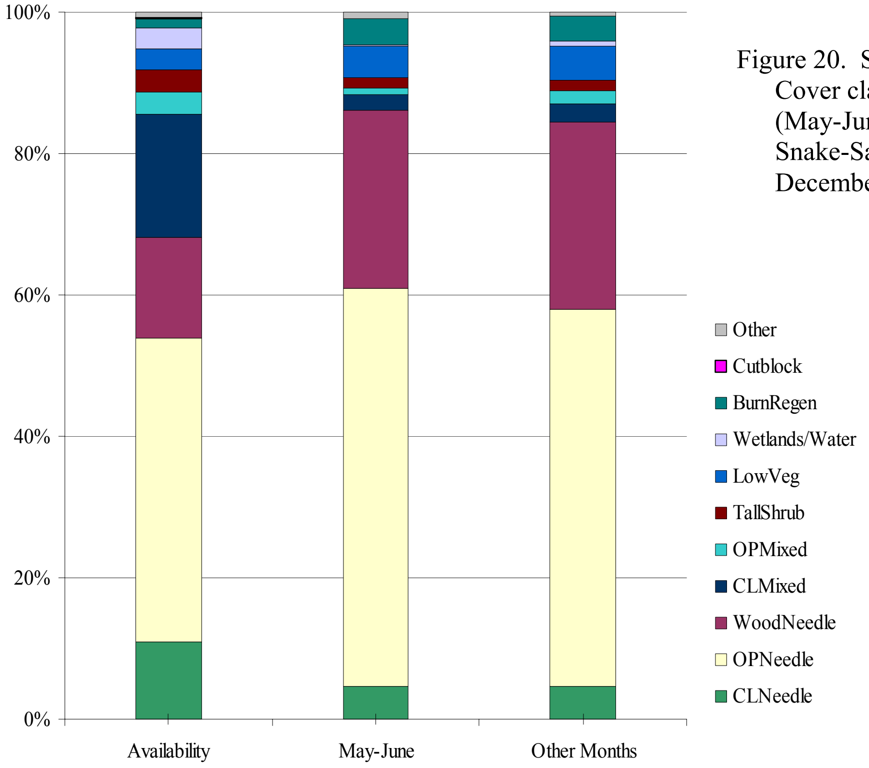

Figure 20. Summary of caribou use by Earth Cover class during the Neonate period (May-June) and Other Months within the Snake-Sahtaneh study area, March 2000-December 2004 (*n*=7,401 GPS points).

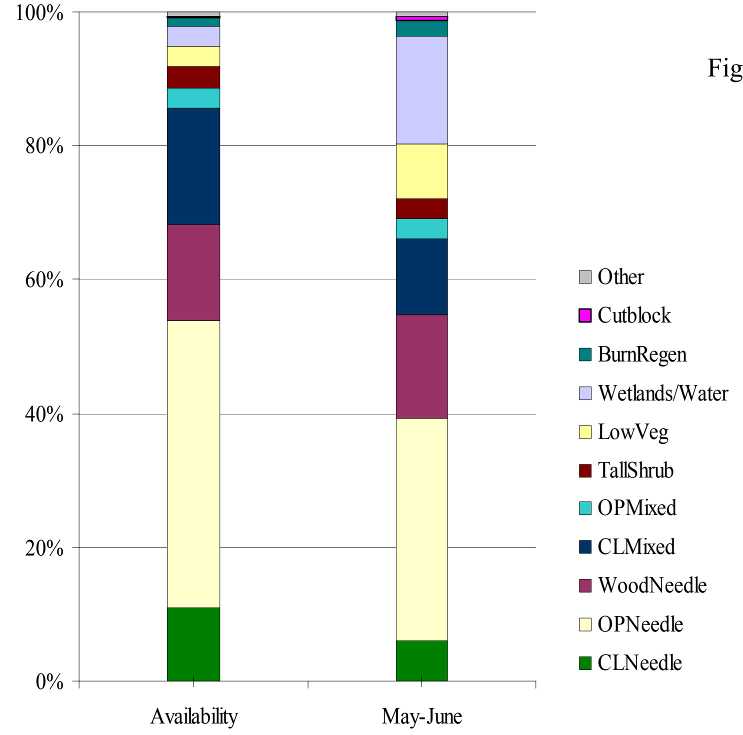

Figure 21. Summary of wolf use by Earth Cover class during the Neonate period (May-June) within the Snake-Sahtaneh study area, 2003-2004 (*n*=687 GPS points).

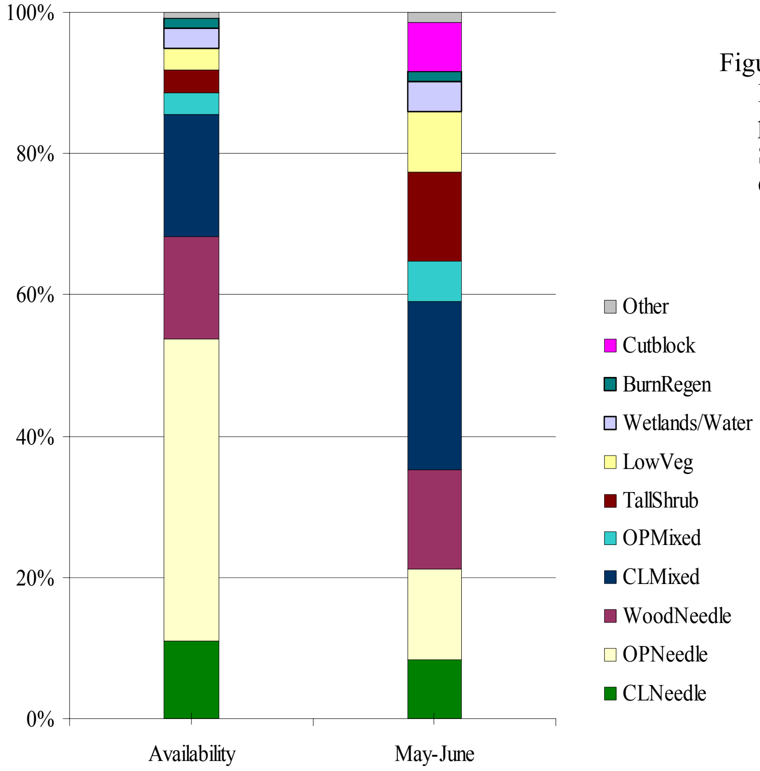

Figure 22. Summary of black bear use by Earth Cover class during the Neonate period (May-June) within the Snake-Sahtaneh study area, 2003-2004 (*n*=191 GPS points).

4.4.1 Resource Selection Function Models

Several coefficient estimates at the Design III level (i.e., individual level RSF models) were unstable due to small sample size and the limited occurrence of rare habitats within individual home ranges, therefore the primary analysis was based on Design II population-level models. As results of the 80% and 20% models were generally consistent with the 100% models, with overlapping 95% confidence intervals, only the latter are presented.

4.4.1.1 Caribou Seasonal Population-level RSF Models

Figures 23 to 29 illustrate the probability of seasonal use of various habitat parameters for caribou based on 100% Design II RSF models. Appendices 5a to 5e present a summary of coefficient estimates and 95% confidence intervals for seasonal caribou models. Coefficient estimates are ranked from highest probability of selection to lowest. Coefficient estimates were considered significant at $p < 0.05$.

Within the 100% Earth Cover models, ROC scores > 0.7 (indicating good model performance) occurred consistently for all 11 cover classes throughout all 5 seasons. Good performance (ROC > 0.7) for all Earth Cover models was generally consistent for the 80% models throughout all seasons, with the exception of Cutblock in MW and LW. Model performance was variable for the 20% models, particularly for the Cutblock, Wetlands and Waterbodies, Burn Regeneration, and Other (i.e., non-vegetated and undefined pixels) classes.

In LW, Open Needleleaf and Woodland Needleleaf ranked highest in probability of selection by Snake-Sahtaneh caribou, with the denser Open Needleleaf (26-60% CC) selected significantly ($\beta_i = 0.4728$, $p < 0.0001$) over the Woodland Needleleaf (10-25% CC) reference category (Fig. 23; Appendix 5a). While Closed Needleleaf ($\beta_i = -0.3510$, $p = 0.0160$) and Low Vegetation ($\beta_i = -0.4679$, $p = 0.0332$) were avoided relative to Woodland Needleleaf, the 2 classes represented almost 10% of all LW locations. Caribou showed relative avoidance of all other Earth Cover classes.

Burn Regeneration and Woodland Needleleaf ranked highest for probability of selection in both SLS and the Neonate period; however, the coefficient estimates for Burn Regeneration (SLS $\beta_i = 0.0795$, $p = 0.6042$; Neonate $\beta_i = 0.1148$, $p = 0.5424$) were not significantly different from the Woodland Needleleaf reference category (Appendices 5b and 5c). Caribou showed significant avoidance for all other classes, with Closed Mixed Needleleaf-Deciduous (SLS $\beta_i = -2.4009$, $p < 0.0001$; Neonate $\beta_i = -2.6306$, $p < 0.0001$) and Wetlands and Waterbodies (SLS $\beta_i = -2.8642$, $p < 0.0001$; Neonate $\beta_i = -3.7625$, $p < 0.0001$) most strongly avoided.

Burn Regeneration and Woodland Needleleaf also ranked highest for probability of selection in FEW (Appendix 5d), with the former showing significant probability of selection ($\beta_i = 0.3281$, $p = 0.0411$) over the Woodland Needleleaf reference category. Relative to the reference category, caribou showed avoidance of all other Earth Cover classes, with strong avoidance of *Other* ($\beta_i = -2.0064$, $p = 0.0002$), Wetlands and Water ($\beta_i = -2.7069$, $p < 0.0001$), Closed Mixed Needleleaf-Deciduous ($\beta_i = -3.0734$, $p < 0.0001$), and Closed Needleleaf ($\beta_i = -3.1197$, $p < 0.0001$). The latter 2 classes were the lowest ranked, indicating selection against closed canopy forests during this season.

The Woodland Needleleaf reference category ranked highest for probability of selection for MW (Appendix 5e). While the estimated coefficient for the Low Vegetation class, which included fens, was negative, it was not significantly different ($\beta_i = -0.0164$, $p = 0.9212$) from the reference category. Similar to FEW, closed canopy forests were strongly avoided during MW, with Closed Needleleaf ($\beta_i = -1.7067$, $p < 0.0001$) and Closed Mixed-Deciduous ($\beta_i = -2.3899$, $p < 0.0001$) the 2 lowest ranking Earth Cover classes.

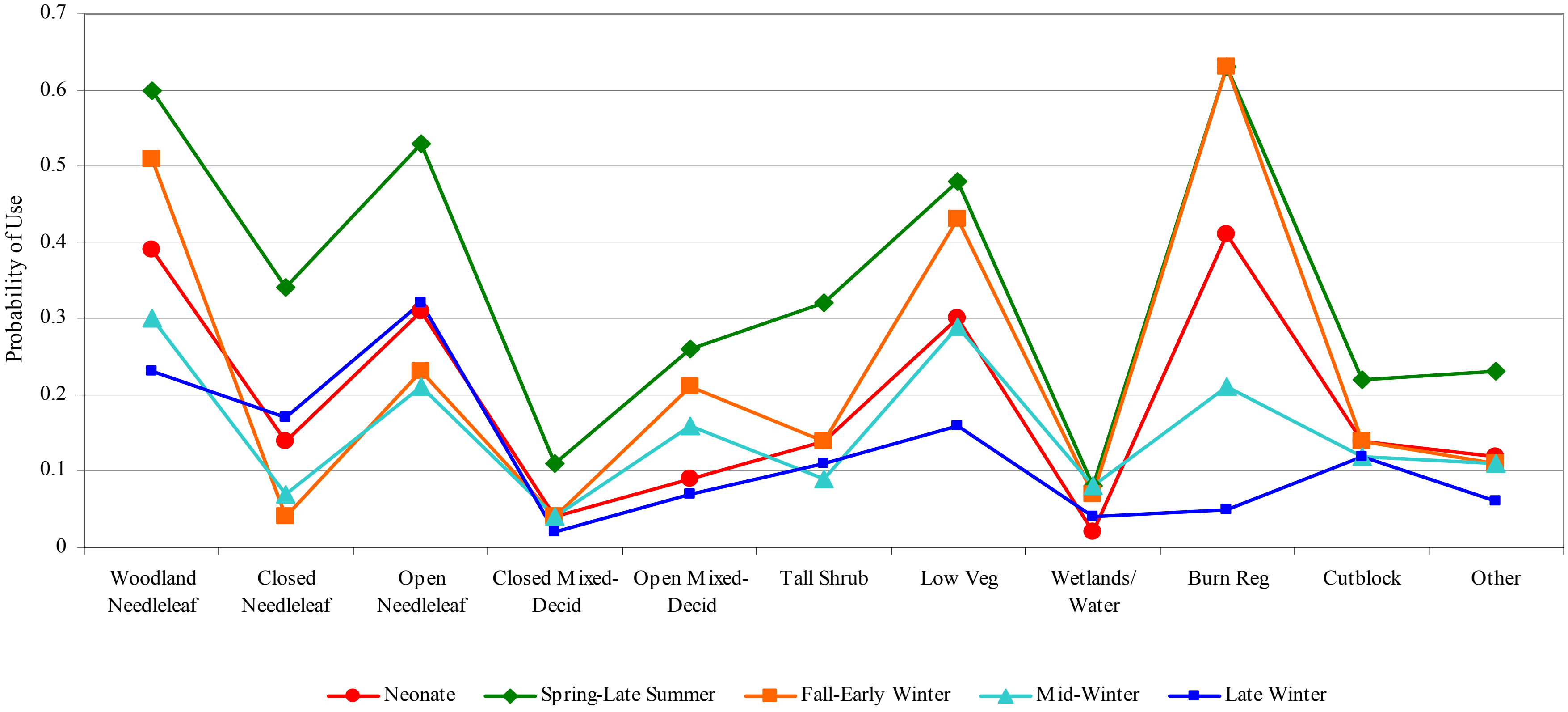

Figure 23. Probability of seasonal caribou use by Earth Cover class; Snake-Sahtaneh study area, 2000-2004, (*n* = 7,401 GPS points).

In comparison to the Earth Cover models, performance was generally lower for the VRI habitat models for caribou (ROC scores < 0.7). Within the VRI leading species models, caribou showed significant selection for Lodgepole Pine over the Black Spruce-Tamarack reference category in all 4 primary seasons, however selection for leading pine sites during the Neonate period was not significantly different (β_i=0.0999, p=0.6544) from the Black Spruce-Tamarack reference category. Caribou showed significant avoidance (β_i = -1.6448, $p < 0.0001$) for the *Other* category, which includes leading white spruce and deciduous species.

Negative coefficient estimates in the VRI crown closure models represent selection for more open habitats (i.e., the coefficient increases positively with increasing crown closure). While crown closure coefficient estimates were negative for all seasons, selection for open habitats was strongest in FEW, followed by MW, and relatively weaker during LW (Fig. 24).

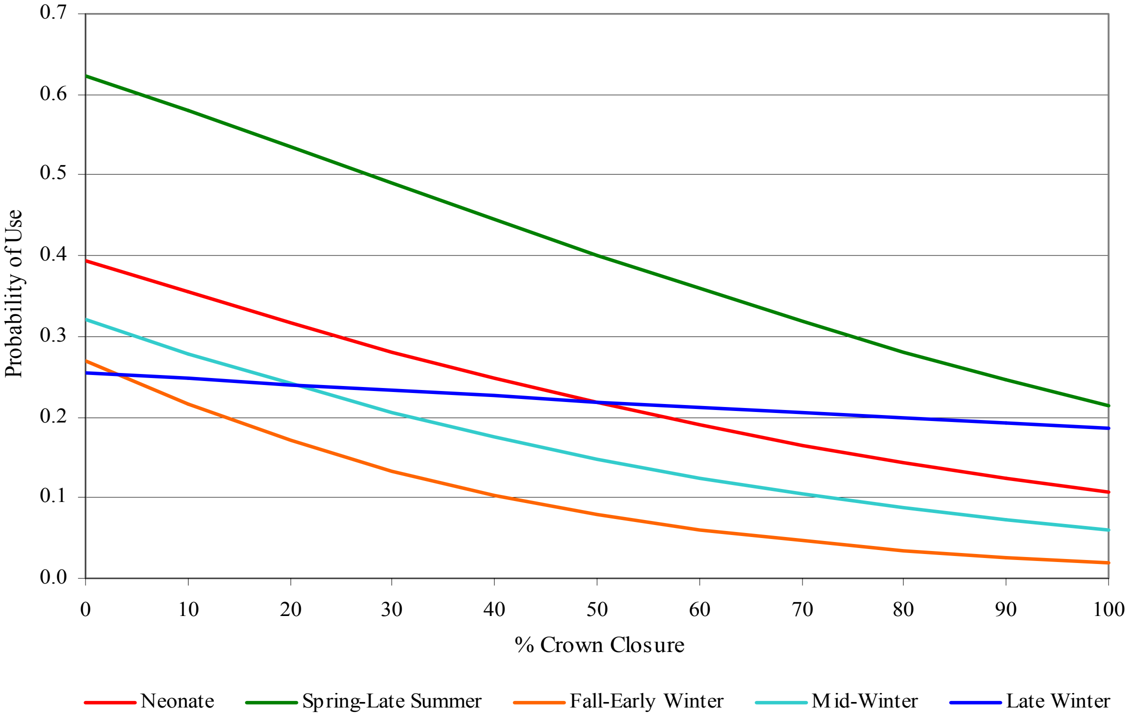

Figure 24. Probability of seasonal caribou use by Vegetation Resources Inventory (VRI) percent crown closure class; Snake-Sahtaneh study area, 2000-2004, (n = 7,401 GPS points).

Eighty-seven percent of caribou locations were on terrain of less than 0.60° slope, with 57% in SC1 (0.0-0.30°) and 29% in SC2 (0.31-0.60°). Caribou showed significant selection for extremely low gradients, with the SC1 reference category ranking above all other slope classes in all seasons. While the probability of caribou use declined with increasing gradient in SLS, the Neonate period, and FEW, the relationship was not as clear in MW and LW, with probability of use of SC3 slightly greater than SC2 (Fig.25).

Within the hydrology models based on continuous variables, negative coefficient estimates for distance to streams, lakes, or cluster lakes represent selection, with coefficients increasing positively with increasing distance to the feature. Caribou selection for streams and lakes varied with waterbody type and by season.

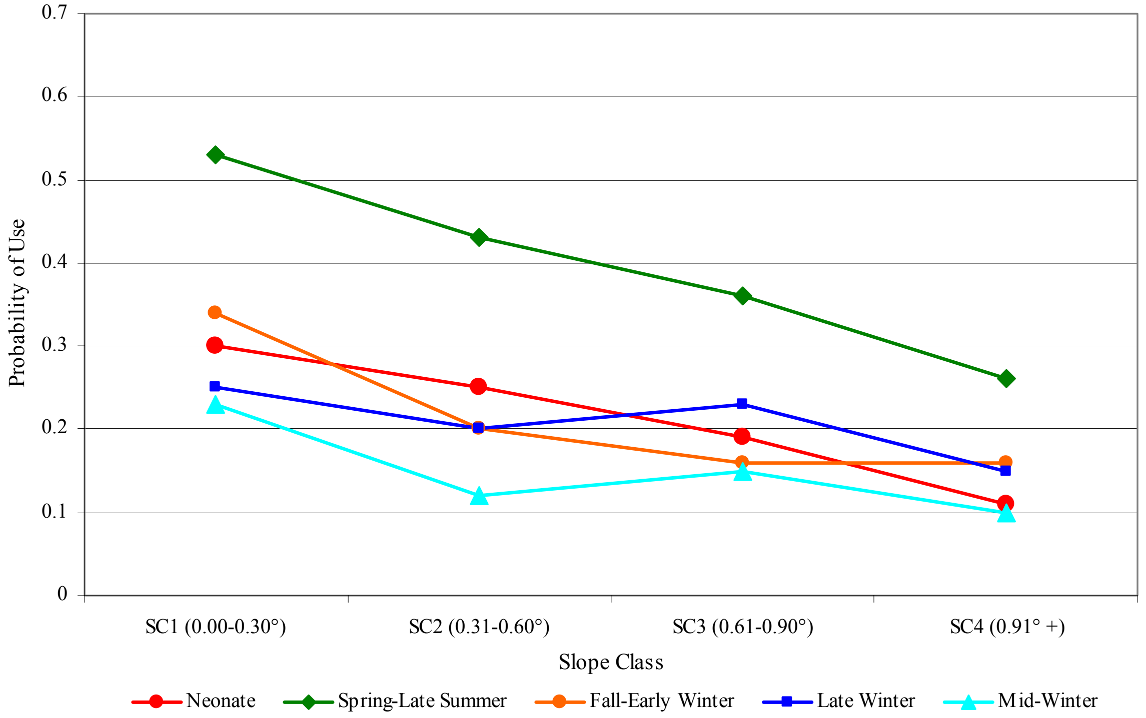

Figure 25. Probability of seasonal caribou use by slope class; Snake-Sahtaneh study area, 2000-2004, (*n* = 7,401 GPS points).

Caribou showed significant avoidance of streams in SLS ($\beta_i = 0.4671$, $p < 0.0001$), FEW ($\beta_i = 0.2516$, $p = 0.0178$), and the Neonate period ($\beta_i = 0.2673$, $p = 0.0115$), with probability of use increasing with increasing distance to streams. Chi-squared goodness of fit tests were non-significant (*NS*) for LW and MW models, indicating caribou neither selected nor avoided streams during these seasons. When all lakes in the study area were included (Fig. 26), Snake-Sahtaneh caribou showed avoidance during SLS ($\beta_i = 0.1747$, $p < 0.0001$) and the Neonate period ($\beta_i = 0.1995$, $p < 0.0001$), no evidence of selection (*NS*) in FEW and LW, and significant selection for lakes in MW ($\beta_i = -0.2747$, $p < 0.0001$). Running the models with lakes less than 2 ha in size excluded did not significantly alter results (data not shown). As described previously, lake clusters consisted of 2 or more lakes greater than 2 ha in area each, with overlapping 250 m buffers. When only those lakes falling within clusters were considered (Fig. 27), Snake-Sahtaneh caribou showed significant selection in all seasons, with ROC scores indicating good model performance (>0.7) for FEW ($\beta_i = -0.2226$, $p < 0.0001$) and MW ($\beta_i = -0.1233$, $p < 0.0001$). Mid-Winter was the only season in which caribou showed significant selection for both individual and cluster lakes.

For hydrology models used to describe probability of selection for individual and cluster lakes based on a range of lake sizes (i.e., categorical variables), positive coefficients represent selection. Rankings of estimated coefficients for size categories of lakes and cluster lakes varied within models and by season (Fig. 28 and 29), with highest overall probability of selection for lakes in the 5-10 ha and 10-50 ha range. Significant selection of individual lakes in the 2-5 ha range was also indicated for SLS ($\beta_i = 0.2591$, $p = 0.0004$), the Neonate period ($\beta_i = 0.2371$, $p = 0.0136$), and FEW ($\beta_i = 0.3953$, $p < 0.0001$). Both individual ($\beta_i = 0.4281$, $p = 0.0021$) and cluster lakes ($\beta_i = 0.6935$, $p < 0.0001$) in the 10-50 ha range ranked highest in probability of selection during MW.

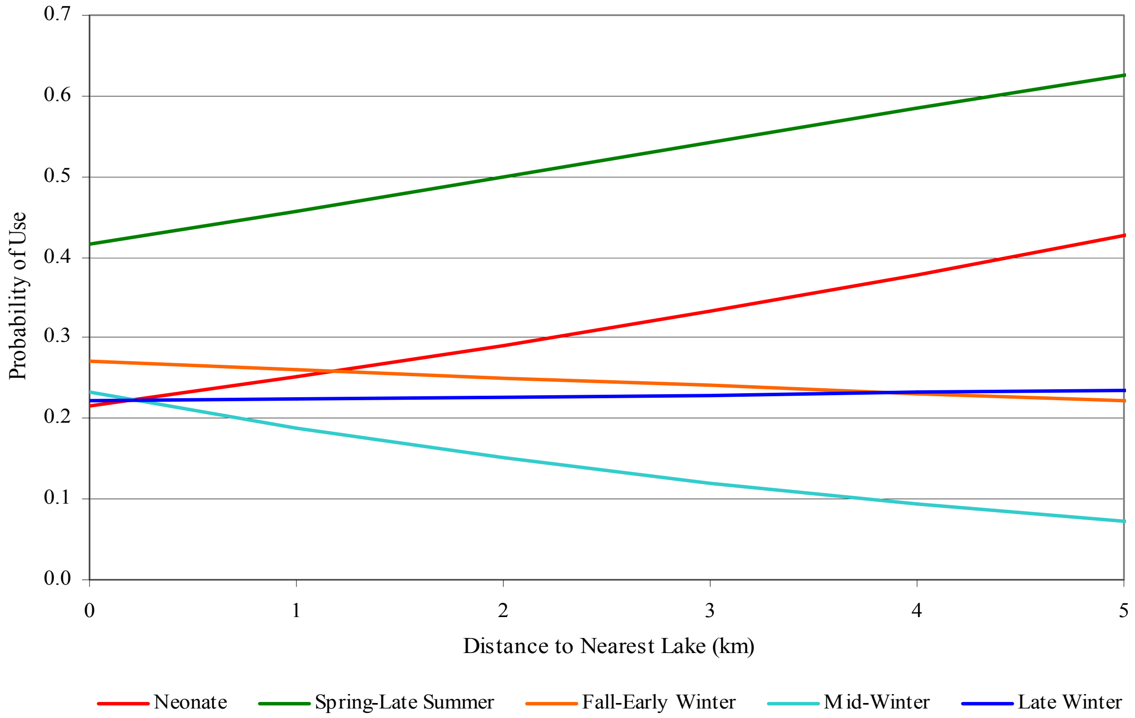

Figure 26. Probability of seasonal caribou use by distance to nearest lake; Snake-Sahtaneh study area, 2000-2004, (*n* = 7,401 GPS points).

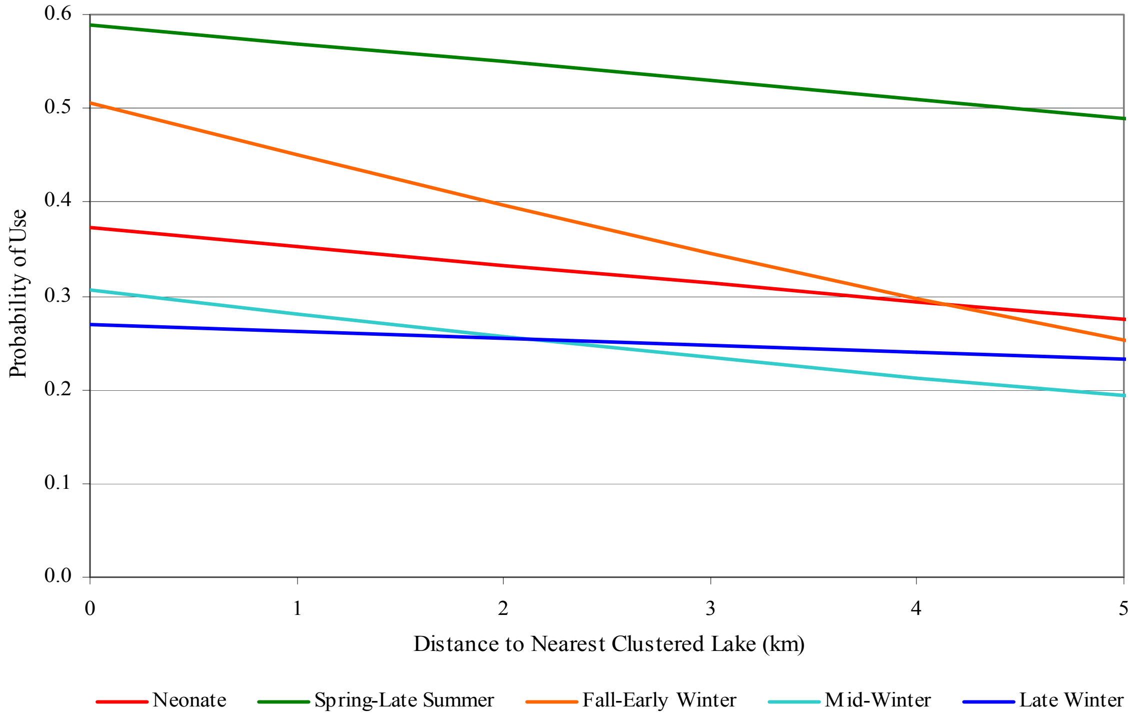

Figure 27. Probability of seasonal caribou use by distance to nearest clustered lake; Snake-Sahtaneh study area, 2000-2004, (*n* = 7,401 GPS points).

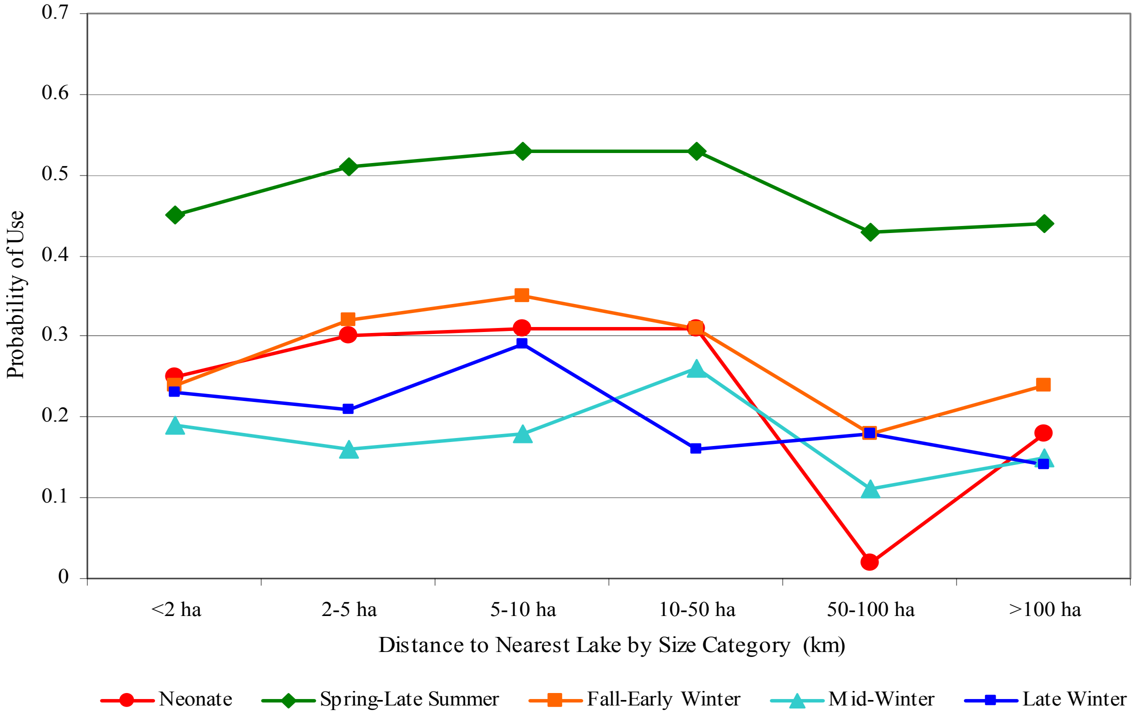

Figure 28. Probability of seasonal caribou use of lakes by size category; Snake-Sahtaneh study area, 2000-2004, (*n* = 7,401 GPS points).

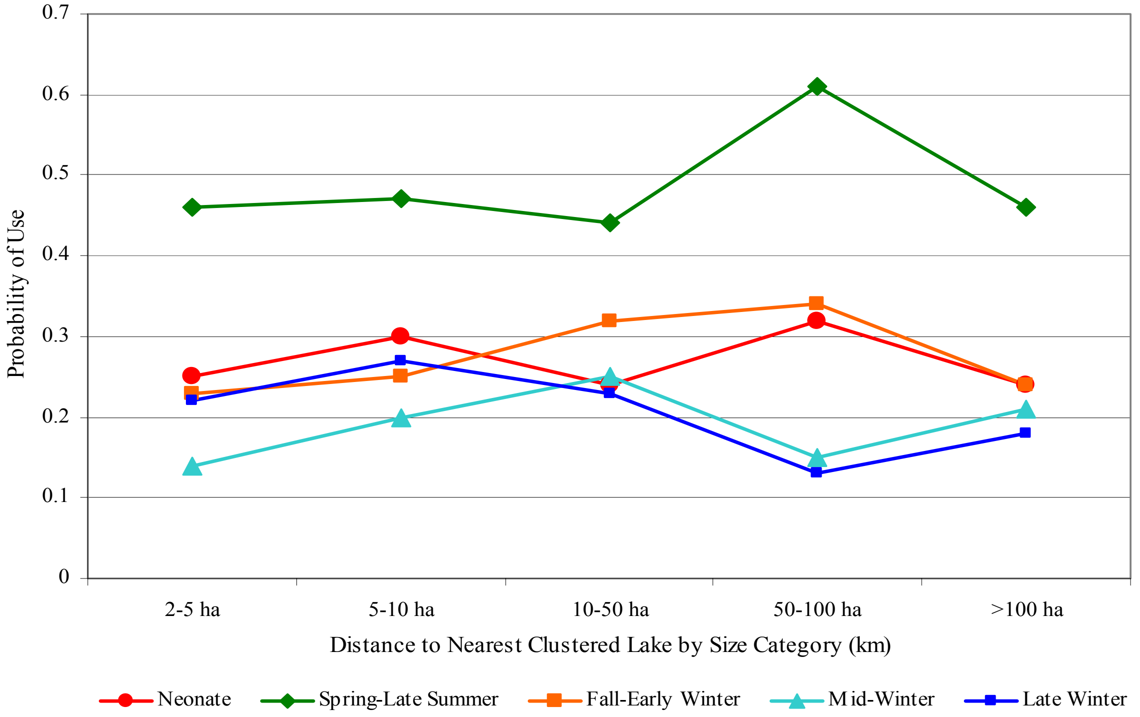

Figure 29. Probability of seasonal caribou use of clustered lakes by size category; Snake-Sahtaneh study area, 2000-2004, (*n* = 7,401 GPS points).

4.4.1.2 Predator Seasonal Population-level RSF Models

Wolves

Variable classes, parameters, and coefficient estimates for SLS and Neonate 100% RSF models (Design II) for wolves are presented in Appendices 6a and 6b, respectively. Coefficient estimates are ranked from highest probability of selection to lowest. Coefficient estimates were considered significant at $p < 0.05$.

Figure 30 illustrates the probability of use of Earth Cover classes by wolves during SLS and the Neonate period. In both seasons, wolves showed strong selection for Wetlands and Waterbodies (SLS $\beta_i = 1.5842$, $p < 0.0001$; Neonate $\beta_i = 1.5086$, $p < 0.0001$) and Low Vegetation (SLS $\beta_i = 0.6126$, $p = 0.0205$; Neonate $\beta_i = 0.7275$, $p = 0.0342$). Within the broader SLS season, Cutblock, Burn Regeneration, Open Mixed Needleleaf-Deciduous, and Tall Shrub classes also ranked higher than the Woodland Needleleaf reference category; however, coefficient estimates were not significant.

Based on the VRI habitat models, in both SLS and the Neonate period wolves showed significant selection for leading Lodgepole Pine (SLS $\beta_i = 1.2697$, $p < 0.0001$; Neonate $\beta_i = 1.3829$, $p = 0.0008$) and "Other" (i.e., deciduous and mixedwood types; SLS $\beta_i = 0.5229$, $p < 0.0001$; Neonate $\beta_i = 0.7696$, $p < 0.0001$) over the Black Spruce-Tamarack reference class.

While wolves showed selection ($\beta_i = -0.0216$, $p < 0.0001$) for open habitats during SLS, the chi-squared goodness of fit test for the percent crown closure model for the Neonate period was non-significant (*NS*), indicating no evidence of selection in May and June.

While the model for the Neonate period indicated weak selection ($\beta_i = 0.0790$, $p = 0.7610$) for SC4 (0.91° and greater), the SLS model indicated no evidence of selection for slope class by wolves (*NS*).

Wolves showed strong selection for streams during SLS ($\beta_i = -3.8476$, $p < 0.0001$) and the Neonate period ($\beta_i = -3.3749$, $p < 0.0001$), with ROC scores > 0.7 indicating good model accuracy for both seasons. Wolves showed significant selection for individual lakes in SLS ($\beta_i = -0.2367$, $p = 0.0003$) and the Neonate period ($\beta_i = -0.2225$, $p = 0.0216$). In contrast, wolves selected against clustered lakes during both periods (SLS $\beta_i = 0.0469$, $p < 0.0001$; Neonate $\beta_i = 0.0461$, $p = 0.0019$). Individual lakes in the 50-100 ha size range ranked highest in probability of selection for both SLS ($\beta_i = 0.6681$, $p = 0.0875$) and the Neonate period ($\beta_i = 1.4446$, $p = 0.0006$).

Black Bears

Variable classes, parameters, and coefficient estimates for SLS and Neonate 100% RSF models (Design II) for black bears are presented in Appendices 7a and 7b, respectively. Coefficient estimates are ranked from highest probability of selection to lowest. Coefficient estimates were considered significant at $p < 0.05$. Habitat models, including Earth Cover, VRI leading species, and crown closure, proved useful in describing black bear habitat selection. In particular, ROC curves indicated good model accuracy (ROC score > 0.7) for Earth Cover models in both seasonal periods. Chi-squared goodness of fit tests were generally non-significant ($p > 0.05$) for terrain (i.e., slope class) and hydrology models, indicating no evidence of selection for these variables.

Figure 31 illustrates the probability of use of Earth Cover classes by black bears during SLS and the Neonate season. Black bears showed strong selection for the Cutblock class ($\beta_i = 3.8986$; $p < 0.0001$) throughout the SLS season. Several other Earth Cover classes, including Other, Tall Shrub, Open Mixed Needleleaf- Deciduous, Burn Regeneration, Low Vegetation, and Closed Mixed Needleleaf-Deciduous, ranked higher in probability of selection compared to the Woodland Needleleaf reference category, however coefficient estimates were not significant. Bears showed significant avoidance of the Open

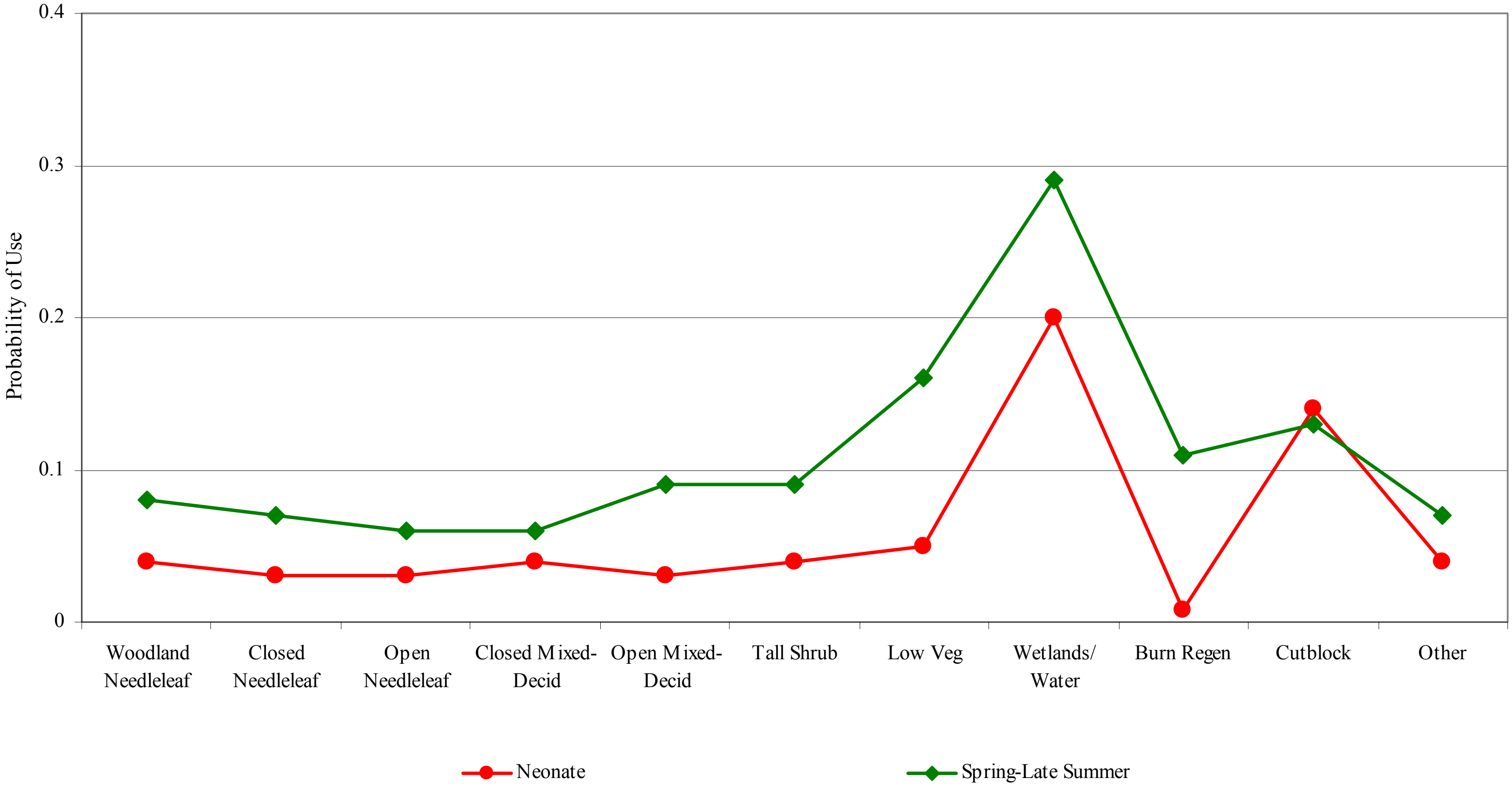

Figure 30. Probability of seasonal wolf use by Earth Cover class; Snake-Sahtaneh study area, April-September 2003 and 2004, (*n* = 687 GPS points).

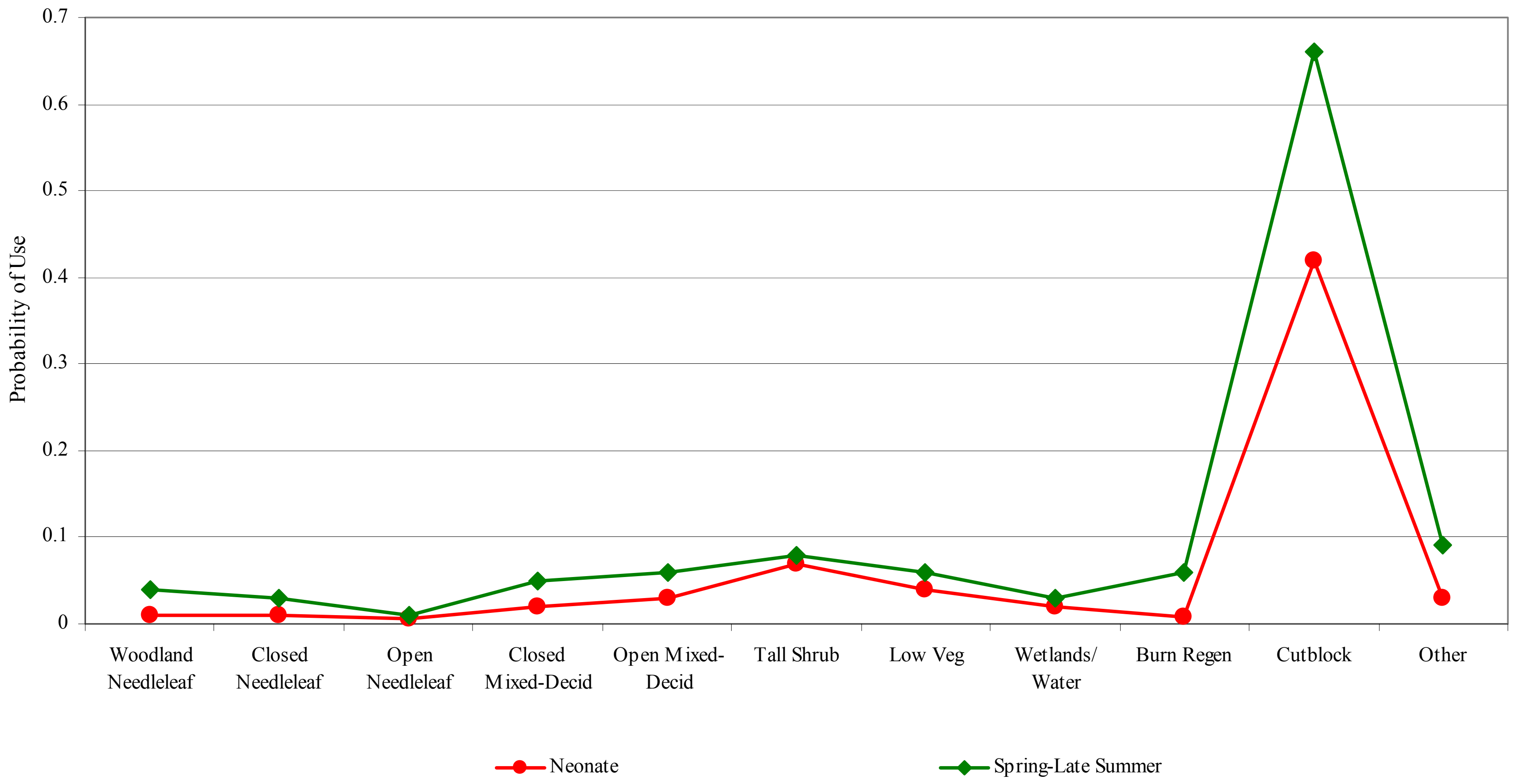

Figure 31. Probability of seasonal black bear use by Earth Cover class; Snake-Sahtaneh study area, May-September 2003 and 2004, (*n* = 187 GPS points).

Needleleaf class (β_i = -1.1081, p = 0.0001) during SLS. This pattern of selection for well-drained, mixedwood and deciduous habitats was generally consistent during the nested Neonate period of May and June, with significant selection for both Cutblock (β_i=3.7444, p<0.0001) and Tall Shrub (β_i=1.4261, p = 0.0023) and significant avoidance of Open Needleleaf (β_i=-1.2135, p=0.0086).

The VRI leading species models further supported black bear use of well-drained habitats, with significant selection for the composite Other category over both the reference Black Spruce-Tamarack category and Lodgepole Pine in both SLS (β_i=1.3117, p<0.0001) and the Neonate period (β_i=1.4258, p< 0.0001).

Negative coefficient estimates for VRI Crown Closure models in both SLS (β_i=-0.0195, p<0.0001) and the Neonate period (β_i=-0.0146, p = *0.0093*) indicate black bears selected for more open habitats, with probability of bear use decreasing as crown closure increased.

While SC4 ranked highest in probability of selection during SLS (β_i=0.4070, p = *0.0969*), the coefficient estimate was not significantly different from the reference category (SC1). Conversely, there was significant avoidance for the second steepest gradient class (SC3; β_i=-0.7278, p=0.0258). Slope class models for the Neonate period were non-significant (*NS*), suggesting black bears neither selected nor avoided habitats based on gradient.

With the exception of selection for clustered lakes in SLS (β_i = -0.0657, p = 0.0013), the hydrological models were non-significant (*NS*) based on chi-squared goodness of fit tests. No discernable pattern of black bear use was apparent within the range of clustered lake size categories, with 50-100 ha (β_i=1.6485, p < 0.0001) and 5-10 ha (β_i = 0.6560, p=0.0006) clustered lakes ranking significantly higher than the reference category, and lakes in the 10-50 ha range ranking significantly lower (β_i=-2.5115, p=0.0004).

5 DISCUSSION

This project represents the first formal study of boreal caribou in British Columbia. Results indicate seasonal habitat use and movements of Snake-Sahtaneh caribou are generally consistent with those reported across the geographic range of the ecotype. However, calf survival and recruitment rates observed during the study period were lower than those typically reported.

Population Characteristics

As the sparse distribution and low sightability of boreal caribou limits the effectiveness of conventional aerial inventory techniques in forested habitat (Stuart-Smith *et al.* 1997, Thomas and Gray 2002), no attempt was made to census the Snake-Sahtaneh population. Thomas (1998) suggests that if population surveys cannot be expected to produce accurate and precise results, funding is better directed to collecting information on demographic indices, such as pregnancy rates and calf survival, as well as ecological studies to identify habitat requirements.

The 96% pregnancy rate of Snake-Sahtaneh caribou is comparable to reports from boreal caribou populations elsewhere in Canada, including: 90-100% for 6 ranges in northeastern Alberta (McLoughlin *et al.* 2003), 94% in northern Saskatchewan (Rettie and Messier 1998), and 96% in Newfoundland (Mahoney and Virgl 2003). Boreal caribou parturition rates are frequently estimated at over 80% (Rettie and Messier 1998, Dzus 2001, McLoughlin 2003, Nagy *et al.* 2005). Based on the spring 2004 surveys, the minimum estimated parturition rate for Snake-Sahtaneh caribou was 78%, but may have exceeded 90%. Although the spring 2004 replicate surveys confirmed relatively high calf production, commencing the series prior to the peak of calving would have afforded a more accurate estimation of parturition rates.

Radio-collared Snake-Sahtaneh caribou calved over a 1-month period (May 1 to June 2), with peak calving activity estimated at May 15. These dates are consistent with research from northern Saskatchewan (peak May 15; Rettie and Messier 1998), northern Alberta (first 2 weeks of May; Dzus 2001), and the Mackenzie Valley (peak May 15 to 25; Nagy *et al.* 2005), although Brown *et al.* (1986) reported 4 boreal herds in Quebec and Labrador calved primarily during the first 2 weeks of June. In comparison, the estimated peak of calving for 2 northern ecotype herds in northeastern British Columbia was May 27 for the Graham herd (Culling *et al.* 2005) and May 28 for the Pink Mountain herd (Gustine 2005). These herds reside approximately 270 km south and 160 km southwest of the Snake-Sahtaneh study area, respectively. Thomas and Gray (2002) note that calving typically occurs 2-3 weeks earlier in boreal populations than mountain populations, attributing the difference to earlier green-up. Back-dating from estimated calving dates indicates Snake-Sahtaneh females conceived throughout the mid-September to mid-October rutting period considered typical for the ecotype (Arsenault 2003), with peak conception estimated at September 30.

The high pregnancy and parturition rates, and good late winter condition of female Snake-Sahtaneh caribou observed during capture activities suggest forage availability is not currently a limiting factor (Seip 1990, Rettie and Messier 1998). Although the structure of the adult component of the population was not estimated due to observation bias toward collared females, the high pregnancy rate and timing of peak parturition suggests the population currently supports an adequate number of mature bulls.

The sharply declining calf survival recorded during the four 2004 spring surveys is consistent with reports of highest calf mortality occurring in the first month of life (Bergerud *et al.* 1983, 1984; Bergerud and Elliott 1986, Stuart-Smith *et al.* 1997). While the June 30, 2004 calf survey showed higher survival than in the previous 2 years, inter-annual variation is not unusual. The winter of 2003-2004 was relatively mild, with early spring green-up. Decreased winter severity can result in improved maternal condition during late pregnancy, which may be reflected in corresponding higher birth weights and increased calf survival (Arsenault 2003).

The 10-month recruitment rates for Snake-Sahtaneh caribou of 5 calves:100 cows and 9 calves:100 cows in 2003 and 2004, respectively, are markedly lower than those reported elsewhere, including 28 calves:100 cows in Saskatchewan (Rettie and Messier 1998) and 18 calves:100 cows in northeastern Alberta (Stuart-Smith *et al.* 1997). McLoughlin (2003) reported calf recruitment to March averaged roughly 20 calves:100 cows throughout most Alberta boreal caribou ranges. During a documented decline of the Red Wine Mountains caribou herd in central Labrador, the proportion of calves in late winter was 9% (Schaefer *et al.* 1999). Bergerud (1996) suggests the minimum recruitment necessary to provide population stability is approximately 15% or 25 calves:100 cows.

The mean annual survival rate of adult female Snake-Sahtaneh caribou (0.94) was at the high end of the range of 0.84 to 0.95 reported in other studies (Bergerud 1980, Stuart-Smith *et al.* 1997, Rettie and Messier 1998, Dzus 2001, Mahoney and Virgl 2003). McLoughlin *et al.* (2003) reported a mean annual adult female survival rate of 0.88 (range 0.86 to 0.93) for 6 ranges in northeast Alberta monitored between 1993 and 2002. In 2003, the Alberta monitoring program was expanded to include caribou in the Chinchaga Hills, in the northwest portion of the province, approximately 180 km southeast of the Snake-Sahtaneh range. The 2003 adult female survival in Alberta herds ranged from 0.69 to 0.93 (McLoughlin 2003), including 0.79 in the Chinchaga range. In Labrador, Schaefer *et al.* (1999) reported the mean annual survival rate of Red Wine Mountains females fell from 0.80 between 1981 and 1988 to 0.70 between 1993 and 1997, during a documented population decline.

Results of the 2002-2004 calf survival and 2003-2004 late-winter composition surveys indicate juvenile recruitment within the Snake-Sahtaneh herd falls below the threshold necessary to maintain a stable population. Although low recruitment may be partially offset by high adult female survival, advancing mean age of reproductive females in the absence of sufficient recruitment may ultimately result in population collapse. Acknowledging the brief monitoring period, if current estimates of juvenile and adult female survival are an accurate reflection of long-term trends for the Snake-Sahtaneh caribou herd, demographics may not be sustainable over time. However, Thomas and Gray (2002) note that caribou populations are prone to wide fluctuations in numbers and suggest a 20-year span (3 generations) should be adopted as the standard for assessing trends.

All 5 mortalities of Snake-Sahtaneh radio-collared adult females occurred between April and October, consistent with reports of highest mortality from spring through fall (Rettie and Messier 1998, McLoughlin *et al*. 2003, Larter and Allaire 2005); however, Stuart-Smith *et al.* (1997) found no seasonal trend in adult mortalities attributed to wolves.

The small group size, typically consisting of cow-calf pairs or single cows, displayed by Snake-Sahtaneh caribou during the calving and postnatal period is consistent with research on other boreal populations (Racey *et al.* 1991, Stuart-Smith *et al*. 1997, Rettie and Messier 1998, Mahoney and Virgl 2003) and supports the anti-predator strategy of spacing out on the landscape (Bergerud 1996). Similarly, the observation of highest group sizes in fall and winter is consistent across boreal populations (Darby 1979, Stuart-Smith *et al*. 1997, Rettie and Messier 1998). The apparent lack of fidelity to social groups displayed by Snake-Sahtaneh caribou, with animals continually shifting between groups, has also been reported in the Northwest Territories (Larter and Allaire 2005). This behaviour was most obvious in the Clarke and West Kotcho cores during the fall and early winter months, when caribou were scattered in small, closely spaced groups throughout open bogs and fens.

Snake-Sahtaneh Caribou Distribution and Core Habitat Areas

Based on GPS telemetry, the vast majority of activity of the Snake-Sahtaneh caribou herd occurs within the recently defined range. In northeastern British Columbia, the 4 currently defined boreal caribou ranges (Culling *et al.* 2004) are separated by areas of upland and riparian habitat typically avoided by caribou. Research from elsewhere indicates little movement occurs between adjacent ranges (Brown *et al*. 1986, Mosnier *et al*. 2003). Despite earlier suggestions that boreal caribou historically had a continuous distribution across the boreal forest, Dzus (2001) argues that the current understanding of ecology and habitat requirements points to a discontinuous distribution.

An important outcome of this study was the delineation of 7 core habitat areas within the larger Snake-Sahtaneh range. Caribou cores were typically centred on the largest patches of treed peatlands, and were characterized by very low gradients (SC 1 and SC2; 0.0°– 0.60° slope) and Open Needleleaf and Woodland Needleleaf habitat classes. Within the Snake-Sahtaneh range, as elsewhere in the Boreal Plains and Taiga Plains ecoprovinces, these sites are commonly found at the headwaters of extremely low-gradient drainage systems. Extensive peatland complexes typically comprise the adjoining headwaters of several tributary systems, effectively encompassing the height of land between adjacent drainages. Surface hydrology is characterized by diffuse seepage and an absence of fluvial process, resulting in a low density of streams or the development of a series of small, shallow lakes lacking defined inlets and outlets (clustered lakes). The highest densities of caribou GPS points were associated with the height of land between the various tributary systems draining the Snake-Sahtaneh range. For example, the Clarke core encompasses the height of land between the Snake River, Elleh Creek, and Kyklo Creek drainages, while the West Kotcho core coincides with the height of land between the upper Sahtaneh River, Courvoisier Creek, and Kotcho Lake drainages.

The hydrological processes within these headwaters systems promote the development of nutrient-poor bogs, dominated by stunted black spruce, Labrador tea, and common brown sphagnum moss (*Sphagnum fuscum*), and limit the development of stream channels and more diverse riparian vegetation communities, resulting in relatively low suitability for moose and beaver. These black spruce bogs fall within the

BWBSmw2/08 (Sb - Labrador tea - Sphagnum) variant and site series, and are characterized by very poor to poor nutrient regime, hygric to subhydric soil moisture regime, and slope gradient of 0% (Delong *et al.* 1990). Throughout the year, Snake-Sahtaneh caribou showed significant selection for gradients of less than 0.30°, which likely represents a surrogate for bog habitats (D. James, pers. comm.).

Caribou Home Ranges and Movements
The mean annual home range size for Snake-Sahtaneh caribou (1,468 km^2) falls within the broad range reported across the distribution of the ecotype (Cumming and Beange 1987, Hornbeck and Moyles 1995, Stuart-Smith *et al.* 1997, Mahoney and Virgl 2003, Larter and Allaire 2005, Nagy *et al.* 2005). The 7 females with multi-annual data sets showed relative stability in home ranges between years. The greatest variability occurred when individual caribou moved temporarily to an additional core area during 1 of multiple annual cycles. Hornbeck and Moyles (1995) found inter-year home range stability was more variable in Alberta's Chinchaga herd, with individual caribou making significant shifts in their area of activity from year to year.

Snake-Sahtaneh caribou are considered sedentary, as they do not undergo wide-scale, unified migratory movements between seasonal ranges and females do not use a common calving ground, but space out from one another at calving to reduce predation risk (Bergerud 1996). Movements are best described in terms of seasonal expansion and contraction, as caribou spaced out during the calving and summer seasons, returning to a more concentrated distribution for the rut and winter months. The most significant long-range movements occurred in April and May, as individuals showing strong inter-year calving fidelity to specific core habitat areas made pre-calving movements of up to 90 km. Research from other boreal populations found a similar lack of common calving grounds, as well as extensive pre-calving movements and fidelity to familiar areas during calving (Brown *et al.* 1986, Racey *et al.* 1991, Hornbeck and Moyles 1995, Larter and Allaire 2005). Using definitions proposed by Bergerud (1974), Brown and Theberge (1985) described spring movements of female Red Wine Mountains caribou in terms of *homing*, with learning and tradition employed at the individual level, in contrast to *funnelling* through topographic features. The authors note that caribou travelled a mean distance of 50 km "through habitat that was apparently suitable for calving and similar to that finally reached." This statement applies equally well to pre-calving movements of collared Snake-Sahtaneh caribou, with pregnant females crossing paths as they moved between cores to reach their respective calving sites. In contrast to relatively rapid and direct pre-calving movements, the process of reaggregating occurred over the late summer and fall. This is consistent with reports of protracted fall movements for other woodland caribou populations (Edmonds and Bloomfield 1984, Cumming and Beange 1987, Racey *et al.* 1991, Culling *et al.* 2005).

At the population level, seasonal ranges overlapped significantly, with the largest core habitat areas used heavily throughout the year. The lack of distinct seasonal ranges and uniform movement patterns observed in Snake-Sahtaneh caribou has been reported for other boreal populations (Darby 1979, Hornbeck and Moyles 1995, Stuart-Smith *et al.* 1997).

Individual Snake-Sahtaneh caribou made occasional, sporadic movements both within and between core habitat areas. Hornbeck and Moyles (1995) reported similar irregular movements for caribou in the Chinchaga range of northwestern Alberta. While it is possible that these forays may be associated with the anti-predator strategy of being unpredictable on the landscape (Thomas 1995), GPS data associated with Snake-Sahtaneh predation mortalities suggest such movements may increase predation risk for caribou.

Given the flat to gently undulating terrain within the Snake-Sahtaneh range, caribou are not restricted to specific travel routes by topographic features or "pinch-points." Similar to observations by Cumming and

Beange (1987), movement routes were indistinct; however, Snake-Sahtaneh caribou frequently took the most direct path between core habitat areas.

Caribou Seasonal Habitat Selection

While pooling locations between individuals and years may conceal variability in behaviour of individual animals, Sather (2005) points out that management decisions are not typically made at the level of the individual, but rather must address general requirements of the population.

The Woodland Needleleaf, Open Needleleaf, Low Shrub, and Burn Regeneration Earth Cover classes had the highest overall probability of selection by caribou. Use of Woodland Needleleaf and Open Needleleaf throughout the year is consistent with the use of treed peatlands (Bradshaw *et al.* 1995, Stuart-Smith *et al.* 1997, Anderson 1999, Brown 2000, Dunford 2003). Within the broad peatland complexes comprising the core habitat areas, which include bogs and fens as well as patches of forested habitat, Snake-Sahtaneh caribou showed seasonal selection for variable canopy cover and availability of forage sources. Similar to research from northern Alberta (Schneider *et al.* 2000), the Woodland Needleleaf class, which represents black spruce bog, was selected over the Low Vegetation class, which represents fens.

While there was a higher probability of caribou selection of Woodland Needleleaf over Open Needleleaf, there is a high degree of interspersion of the 2 habitat classes. Similarly, while the lowest gradient sites showed the highest probability of selection, slope classes SC1 and SC2 are highly interspersed, with 30% of locations in SC2.

Snake-Sahtaneh caribou showed relative selection for burned habitats (< 50 years) during the snow-free months, with highest use during FEW. Burned habitats are likely under-represented in the Earth Cover mapping as several of the original 29 classes included small proportions of regenerating burned areas (DU 2003) and forestry mapping of burn polygons was relatively coarse. Caribou use of burned areas has been previously reported (Darby and Pruitt 1991, Dunford 2003, Nagy *et al*. 2005).

Consistent with reports from elsewhere (Brown *et al*. 2000, Schneider *et al.* 2000, Mahoney and Virgl 2003), Snake-Sahtaneh caribou displayed avoidance of upland mixedwood and deciduous habitats. Use of bog-fen complexes has been attributed to caribou seeking spatial separation from moose and wolves present on more well-drained sites (Stuart-Smith *et al*. 1997, James *et al*. 2004); however, mixedwood and deciduous habitats are interspersed within the larger peatland complexes that comprise the core habitat areas of the Snake-Sahtaneh range. Similarly, in northern Alberta, Schneider *et al.* (2000) found that although non-peat habitats were avoided, these types still constituted an average of 35% of caribou home ranges. Consistent with avoidance of recently logged areas and other early successional stands reported elsewhere (Cumming and Beange 1987, Smith *et al*. 2000, Mahoney and Virgl 2003), only 5 of 7,401 Snake-Sahtaneh caribou locations were recorded in cutblocks.

Snake-Sahtaneh caribou use of waterbodies, including streams, lakes, and lake clusters, varied by waterbody type and season. An inverse relationship was apparent between caribou and wolves in SLS and the Neonate period with respect to Wetlands and Waterbodies, with caribou showing significant selection against streams and lakes and significant selection for clustered lakes. Clusters of small lakes may provide more escape opportunities for caribou as well as increasing search time for wolves (Carruthers *et al*. 1986 *in* Bergerud 1996). As mentioned previously, lake clusters were commonly associated with areas of extremely low gradient, while single lakes were more likely to be associated with a stream network. A general selection for clustered lakes and avoidance of streams and individual lakes throughout the summer and calving period is consistent with reports by James *et al.* (2004) that caribou showed avoidance of well-drained habitats in all seasons, while wolves showed selection for well-drained habitats. Variability of caribou use of streams and lakes may also be influenced by the presence of open water, with significant selection or avoidance shown for all types of waterbodies throughout mid-April to mid-September, and relationships less consistent in the winter months when the function of some types of aquatic habitat features is altered by ice and snow cover.

Along with Open Needleleaf and Woodland Needleleaf, the Closed Needleleaf class ranked relatively high in LW. Snow cover characteristics are influenced by forest canopy, with coniferous cover reducing snow depth and hardness due to increased snow interception and shelter from wind and sun exposure (Schaefer 1996). Snow depths were typically between 25 and 50 cm throughout the study area and were lower than reports from other boreal caribou ranges (Brown and Theberge 1990, Nagy *et al* 2005). While Snake-Sahtaneh caribou are not usually constrained by snow pack, the selection of habitats with higher canopy cover in late winter may be associated with more efficient foraging during periods of highest snow accumulation. Similar use of patches of mature coniferous habitat in late winter has been previously reported (Darby and Pruitt 1984, Mahoney and Virgl 2003).

The Paradise core is the least typical of the 7 core habitat areas and, relative to the Clarke core and Kotcho complex, received lower collared caribou use during winter. The Clarke core and Kotcho complex contain a high proportion of open bogs and fens. These habitat types are more limited in the Paradise core, where marginally higher gradients result in slightly more productive peatlands, with higher crown closure. As well, the Snake River riparian corridor, located approximately 6 km west of the Paradise core, supports the highest winter densities of moose observed within the study area. Lower use of the Paradise core in winter may be partially due to the greater spatial separation from moose and wolves afforded by the Clarke and Kotcho cores.

Snake-Sahtaneh caribou showed relative selection for Burn Regeneration and Woodland Needleleaf over all other habitat classes in both SLS and the Neonate period. In northwestern Ontario, Hillis *et al.* (1998) found caribou avoided recent burns in all seasons, but frequently used older burns and cutblocks during spring. Nagy *et al.* (2005) reported similar use of burns from June through fall, suggesting these sites offer access to herbaceous vegetation and shrubs, insect relief, and predator avoidance.

Caribou use of waterbodies during calving has been frequently reported, including use of islands and lake shorelines (Cumming and Beange 1978, Brown *et al.* 1986, Racey *et al.* 1991, Bergerud 1995, 1996). In forested habitats in west-central Alberta, Edmonds (1988) noted frequent association of cows and calves with open muskegs containing "considerable amounts" of standing water. Despite the large number of lakes within the Snake-Sahtaneh study area, islands are not an available resource for caribou, with the exception being a single 16 ha island in Kotcho Lake. The variety of parturition sites selected by Snake-Sahtaneh caribou may be an anti-predator strategy, as plasticity in calving strategies may reduce predation risk (Thomas 1995, Gustine 2005).

Caution is warranted in interpreting the much greater proportion of calving sites within the Paradise core (26 of 66) versus the Clarke core (14 of 66). As these sites represented 14 and 13 individual females in Paradise and Clarke, respectively, the disparity is partially a function of monitoring period, with a larger number of caribou that used the Paradise core to calve being tracked for multiple calving seasons. Nevertheless, the Paradise core offers a higher proportion of closed canopy habitat, which may be preferred during calving (Mahoney and Virgl 2003). Observations during spring calf surveys suggest female Snake-Sahtaneh caribou used dense patches of black spruce within open bogs for security cover.

Snake-Sahtaneh caribou selected for open habitats during FEW, with the closed canopy classes significantly avoided. Boreal caribou use of sparsely treed and open upland areas, open muskeg swamplands, and herbaceous habitats during the fall rut has been previously reported (Fuller and Keith 1981, Hornbeck and Moyles 1995; Hillis *et al.* 1998; Metsaranta *et al.* 2003). Selection of open habitats, such as sedge meadows, during the rut may facilitate social display among caribou (Hornbeck and Moyles

1995). Many caribou moved from the Paradise core to the more open habitat of the Clarke core and Kotcho complex during this season; however, patterns of movement were not consistent for all caribou.

Similar to other boreal populations, Snake-Sahtaneh caribou did not appear to aggregate at specific rutting areas (Cumming and Beange 1987, Stuart-Smith *et al.* 1997), but were present in all core habitat areas.

Numerous observations were made of Snake-Sahtaneh caribou cratering along margins of small lakes and wetlands in early to mid-winter (November to January). Caribou foraging on lakes and wetlands during winter has been frequently reported (Russell and Martell 1984, Hillis *et al.* 1998, Barten *et al*. 2001, Nagy *et al.* 2003), with animals supplementing their diet of lichens with wintergreen vascular plants that supply higher levels of protein, nitrogen, and phosphorus (Klein 1982). The pawing of muskrat push-ups, as witnessed in Snake-Sahtaneh caribou, has been reported previously (Banfield 1974b, Nagy *et al.* 2003). The importance of this source of seasonal forage is highlighted by the fact that Banfield's *The Mammals of Canada* (1974b) specifically mentions caribou as a hazard to muskrat populations due to this behaviour. Secure, unimpeded access to lakes may have a direct bearing on caribou physiological condition throughout the winter months.

Contradictory results indicating significant caribou avoidance of the Wetlands and Waterbodies Earth Cover class during FEW and MW, despite hydrology models indicating significant selection for lakes and clustered lakes are due to the scale of analysis. The Earth Cover models were based on point data measured on 30 m^2 Landsat TM7 pixels; therefore, caribou use of a waterbody was only captured if the animal was standing on or immediately adjacent to the feature.

Predator Seasonal Distribution and Habitat Selection

While data collected during this study were insufficient to establish direct relationships between individual predator movements and caribou mortality, insight was gained on relative abundance of wolves, as well as wolf and black bear activity and habitat associations during the calving season.

Pooling data for individuals in the wolf and black bear analysis was necessary due to small sample sizes. While this is not the preferred analysis approach, the relatively uniform distribution of habitat types across the Snake-Sahtaneh study area partially compensated, as resources available within one portion of the area were generally available throughout. The major exception to this was the distribution and availability of lakes exceeding 400 ha; of the 4 large lakes in the Snake-Sahtaneh range, 3 occur within the territory of the Kotcho wolf pack.

As seasonal periods were delineated based on boreal caribou habitat use, variability in selection coefficients between SLS and the Neonate models for both wolves and bears may reflect ecological factors specific to these species that were not explored during this study.

RSF models indicating caribou showed relative avoidance of habitat types selected most strongly by wolves and bears (i.e., Wetlands and Waterbodies, Cutblock, Low Vegetation, and Tall Shrub) during SLS and the Neonate period are an apparent contradiction given the assumption that these predators are the major source of mortality of caribou calves. However, within the Snake-Sahtaneh study area, the juxtaposition of habitats frequently results in close association of peatland cover types (Open and Woodland Needleleaf) and upland and riparian habitats. This pattern of islands of well-drained habitat within larger peatland complexes is also common to the peatlands of northwestern Alberta (Vitt *et al.* 1998 *in* Schneider *et al.* 2000).

Wolf Telemetry

The predator telemetry component of the study revealed a relatively high density of wolves within and adjacent to the Snake-Sahtaneh range given the low moose biomass. Moose densities in Wildlife

Management Units 7-55 and 7-56, which encompass the Snake-Sahtaneh range, are approximately 0.08 moose km² (R. Backmeyer, pers. comm.), well below the threshold of 0.2 moose/km² where wolf reproductive success may decline (Messier 1987 *in* Potvin *et al.* 2004).

Similar to results of Merrill and Mech (2003), examination of wolf GPS data spatially showed spring and summer movements radiating outward from den and rendezvous sites in a spoke-like pattern as animals hunted and returned to the den repeatedly. Snake-Sahtaneh wolves typically hunted within a 16-25 km radius of their respective dens. In Alaska, Murie (1944 *in* Bergerud 1974) found wolves preying heavily on caribou calves would hunt and kill calves up to 20 miles (32 km) from the den site. In the Arctic, Frame *et al.* (2004) found a lactating female made numerous foraging bouts of up to 83 km from her den site. Wolves frequently travel in circuitous patterns (Carbyn 1974, Merrill and Mech 2003, Frame *et al.* 2004). Observations of collared wolves making circuits through multiple Snake-Sahtaneh core habitat areas, and their acknowledged capacity for learning (Carbyn 1974, Frame et al. 2004), suggest some wolves may be actively hunting caribou calves in areas where they have experienced previous success.

The high proportion of beaver remains in wolf scat samples analyzed must be interpreted in the context of the objective, which was to confirm that wolves denning near beaver impoundments were preying on beaver. Samples were acquired from the Kyklo pack den site, which was the most distant from the caribou cores. A thorough analysis of wolf food habits would require a much larger sample collected from a range of habitats throughout the study area, however Fuller and Keith (1980) found no significant difference in remains in summer adult scats collected at den and rendezvous sites and fresh scats collected on adjacent trails and cutlines. While interpretation of wolf prey consumption based on frequency of occurrence of items in scat samples can be biased by relative size of prey species (Fuller and Keith 1980, Weaver 1993), results of the scat analysis support the assumption that beaver are an important seasonal forage item, with wolves also preying on moose and caribou calves within the Snake-Sahtaneh range.

Earth Cover habitat and hydrology models proved most useful in describing probability of wolf use; however, slope class was not a useful predictor of wolf habitat selection. Wolves selected for Wetlands and Waterbodies over all other classes in spring and summer, with use during the Neonate period roughly 5 times more than expected based on availability. The Low Vegetation class (fens) was also heavily used by wolves during the calving season. In northeastern Alberta, Stuart-Smith *et al.* (1997) found wolves penetrated over 20 km into fen complexes. The authors suggest that during summer wolves may follow watercourses to gain access to fen complexes. The significant selection displayed by wolves for Wetlands and Waterbodies and Low Vegetation over all other Earth Cover classes in SLS and the Neonate period is consistent with their use of beaver as a spring and summer food source.

Black Bear Distribution and Seasonal Habitat Use

Throughout the SLS and Neonate periods, black bears used Closed Mixed Needleleaf-Deciduous, Open Mixed Needleleaf-Deciduous, Tall Shrub, Low Vegetation, Wetlands and Waterbodies, Cutblock, and Other more than expected. Bears showed strongest selection for Cutblock and relative avoidance of habitat classes selected by caribou. While GPS data indicated radio-collared black bears were most likely to be found in well-drained uplands and riparian areas, the proximity of these habitats to peatlands within the Snake-Sahtaneh range increases the probability of encounters with female caribou and their calves. Although black bears active within caribou core habitat areas occasionally used sparsely treed muskeg habitat adjacent to uplands or travelled through treed muskeg while moving between upland patches, there appeared to be no indication that collared bears targeted peatland habitat during SLS and the Neonate period.

Black bears commonly make long distance movements in summer and fall to access seasonally available forage sources (Samson and Huot 1998). Four bears made long distance excursions in mid-summer from the Clarke core to cutblocks along the Fort Nelson and Muskwa rivers, returning in late summer.

Results of the hydrology models indicated black bears were neither selecting nor avoiding streams during SLS and the Neonate period. This may be a function of the map base used, which included all orders of streams. Excluding first-order (i.e., headwater tributaries) streams from the analysis might prove more revealing regarding seasonal habitat selection of bears.

Predator-Prey Dynamics

The Snake-Sahtaneh herd is uniquely situated geographically in comparison to other boreal caribou populations. Commencing roughly 70 km west of the study area, the Rocky Mountain Foothills of northeastern British Columbia support complex predator-prey systems characterized by multiple ungulate species, including moose, Stone's sheep (*Ovis dalli stonei*), elk (*Cervus elaphus*), northern ecotype woodland caribou, mountain goat (*Oreamnos americanus*), bison (*Bos bison bison*), and white-tailed and mule deer. Bergerud and Elliott (1998) state that a program of actively managing wolf numbers in the Muskwa and Kechika watersheds resulted in the "greatest biomass of ungulates coexisting with wolves and bears that had so far been reported in North America." The authors estimated overall wolf densities at 22 wolves/1000 km² and 17.5 wolves/1000 km² for the Muskwa and Kechika study areas, respectively. Shortly after the cessation of wolf reduction activities by local outfitters, which had resulted in increased ungulate biomass, the wolf population in the Muskwa recovered to an estimated 39 wolves/1000 km². In contrast to this exceptionally high ungulate biomass and corresponding high wolf densities in the Muskwa and Kechika, a census in 1988 resulted in an estimate of 0.08 moose/km² and 4.1 wolves/1000 km² for a peatland study area (Bergerud and Elliot 1998), which overlaps the western portion of the currently defined Snake-Sahtaneh caribou range. Based on this moose density, Bergerud and Elliot used Fuller's regression formula (Fuller 1989) to calculate a predicted density of 5.2 wolves/1000 km². Results of a 2004 inventory indicate the current estimated moose density for wildlife management units encompassing the Snake-Sahtaneh study area is also 0.08 moose/km² (R. Backmeyer, pers. comm.). The estimate of 6.3 wolves/1000 km² for the Snake-Sahtaneh range is understood to represent a minimum density due to incomplete coverage of radio-marked packs across the study area. While this density is low compared to the Muskwa and Kechika, it exceeds Bergerud and Elliott's predicted and observed estimates for comparable ungulate biomass in their peatland study area. If dispersal is the primary mechanism driving wolf density (Fuller 1980, Bergerud and Elliott 1998), high wolf densities in the Muskwa and Kechika could potentially result in ingress into the adjacent Snake-Sahtaneh range, with high beaver densities contributing to the support of this sink population.

Wolf predation has been documented as the primary cause of adult mortality of woodland caribou (Edmonds 1988, Seip 1990, Stuart-Smith *et al.* 1997, Schaefer *et al.* 1999), with black bears also contributing to a proportion of adult deaths (Schaefer *et al.* 1999, Thomas and Gray 2002). Direct agents of calf mortality are more difficult to determine, particularly in the absence of studies specifically designed to monitor radio-collared neonates (Zimmerman *et al.* 2001, Gustine 2005) or intensively track predator activity (Young and McCabe 1997). In describing characteristics of grizzly bear predation of caribou calves in Alaska, Young and McCabe (1997) found bears spent an average of 14 minutes at a calf kill, which compares to the 2 to 3 days at an adult caribou kill reported by Boertje *et al.* (1988). This rapid consumption rate is just one of the difficulties encountered when attempting to confirm causes of mortality of neonate caribou in a multi-predator environment. Nevertheless, wolf predation is considered a major factor in caribou calf mortality (Bergerud and Elliot 1986, Seip 1990, Seip and Cichowski 1996), with black bears also contributing significant predation pressure on some populations (Rettie and Messier 1998, Mahoney and Virgl 2003).

Within mountainous areas, vulnerability to predation has been reported to vary with age of neonates and species of predator. Seip (1992) found survival of mountain ecotype calves was strongly associated with wolf abundance in southeastern British Columbia, however wolves did not appear to be a major source of early calf mortality. In the Besa-Prophet area of northeastern British Columbia, wolf-caused mortalities of northern ecotype calves did not occur until 18 days after birth (Gustine 2005). While Bergerud *et al.*

(1984) note that wolves continue to hunt calves throughout the summer, the period of relative vulnerability to bears is typically restricted to the first 2 weeks of life (Bergerud *et al*. 1984, Young and McCabe 1997, Mahoney and Virgl 2003). The 2004 spring surveys indicated that the period of highest Snake-Sahtaneh calf mortality occurred between 7 and 21 days of age. Decreasing rates of loss between 21 and 45 days of age coincide with significantly reduced density of remaining calves. October and late March composition surveys suggested that calf survival continued to decline from mid-summer through mid-winter.

Predatory behaviour also varies between individual predators. In Alaska, Boertje *et al*. (1988) found that while all radio-collared grizzly bears killed moose calves, 4 of 9 were responsible for 72% of calf mortalities. The observation of a wolf consuming a caribou calf, with evidence of recent consumption of a smaller calf, suggests that individual wolves may focus their predatory efforts on neonate caribou in peatland habitats within the Snake-Sahtaneh range.

Given their abundance and distribution within the study area, wolf predation appears to be the most likely factor in the high calf mortality observed in the Snake-Sahtaneh herd. While no evidence of black bear depredation of Snake-Sahtaneh caribou calves was found, bears are assumed to represent a secondary predator. Habitat associations revealed through GPS telemetry suggest black bear predation of calves is likely opportunistic and limited to peatland habitats in close proximity to mixedwood uplands. Lynx are common throughout the study area, however it is not known to what extent they contribute to calf mortality. Grizzly bears and wolverine occur at extremely low densities and are unlikely to exert significant predation pressure. An incidental observation of a golden eagle soaring in the general vicinity of caribou S52 and her calf, in the Clarke core during a June 2004 calf survey, raises questions about potential avian predators. Golden eagles are known to prey on caribou calves in mountainous regions (Young and McCabe 1997, Gustine 2005); however, they are rarely sighted in the Taiga Plains ecoprovince, and their ability to capture calves on flat, treed terrain is unknown.

The high calf mortality but relatively low adult mortality observed in the Snake-Sahtaneh study may be a function of wolf grouping behaviour and hunting strategy during the calving period. Over the course of the study, both collared and uncollared wolves were observed alone in peatland habitats during May and June. In Spatsizi Provincial Park, in northwestern British Columbia, Bergerud *et al.* (1984) found wolves were dispersed during the calving season, with 8 of 12 wolves observed hunting alone. The authors suggested wolves may employ this dispersion pattern when prey are widely scattered. Schmidt and Mech (1997) suggest that for packs preying on larger mammals, food acquisition per wolf decreases with increased pack size. During the spring and summer, wolves may realize a forage benefit by hunting alone, particularly when targeting smaller prey such as beaver or ungulate calves. Unlike moose, caribou cows do not defend their calves (Seip 1991); therefore, if a lone wolf initiates an attack on a calf, the female may retreat and survive.

Snake-Sahtaneh caribou occur within a multiple-prey system, with wolf densities primarily supported by moose, caribou, and beaver. Such situations can result in the development of a "predator pit", with predator numbers maintained at relatively high levels despite the decline of an individual prey species (Bergerud and Elliot 1986, Seip 1989). As predator numbers are sustained by multiple prey species, continued predation pressure can be exerted on the declining prey species, which may ultimately lead to extirpation. Page (1989) noted that a period of moose decline on Isle Royale corresponded to an increase in wolf numbers and an escalation of predation rate, especially of calves. As recruitment declined, the aging adult population also became increasingly vulnerable to predation by wolves.

While the relationship between wolves and moose is generally at the forefront of discussion of caribou population dynamics in multi-prey systems in western North America, the role of small mammal prey species, such as beaver and snowshoe hare is not well understood. Throughout the geographic range of wolves, beaver represent an important seasonal prey in areas where they occur in high densities, particularly when moose densities are low (Carbyn 1974, Page 1989, Potvin *et al.* 1991, Hayes 1995). While no formal beaver inventory has been conducted in the Snake-Sahtaneh study area, populations are high throughout northeastern British Columbia (Culling and Culling, pers. observ.). This readily available source of forage likely makes a significant contribution to wolf pup survival during the denning period. Potvin *et al*. (2004) found high variability in pup survival to 6 months. Farnell *et al.* (1996) suggest a decline in a woodland caribou herd in the southern Yukon might have been amplified by high pup survival associated with the peak of the snowshoe hare (*Lepus americanus*) cycle. For Snake-Sahtaneh caribou, the success of the avoidance strategy of spatially separating from other ungulate prey species may be confounded by wolf populations preying on abundant beaver within peatland complexes.

Caribou have co-existed with wolves and other predator and prey species over time (Dzus 2001, McLoughlin 2003). Bjorge and Gunson (1989) suggest additional factors have been involved in the majority of situations where declining prey populations were attributed to wolf predation. Caribou typically exhibit low fecundity and productivity, with survival and mortality finely balanced. Anthropogenic changes to the landscape, such as the development of linear corridors within boreal caribou ranges, may result in closer association of caribou, wolves, and moose, with a corresponding increase in incidental encounter rates between caribou and predators, as well as increased efficiency in predator travel and search time (James and Stuart-Smith 2000, James *et al.* 2004).

Fragmentation of habitat and caribou avoidance of disturbed areas may also result in animals being concentrated at higher densities, which could ultimately result in greater susceptibility to predators (Smith *et al.* 2000, Dyer *et al.* 2001). James and Stuart-Smith (2000) found increased hunting efficiency associated with predator use of linear corridors; however, the authors suggest wolves were not travelling into areas where they would otherwise not go. In the Snake-Sahtaneh range, observations of wolves hunting in undisturbed black spruce bogs during May and June support this assertion; however, wolf use of linear corridors was routinely witnessed. The incidental observation of a pack of wolves hunting a ploughed network of linear openings associated with a 3D seismic program, adjacent to the West Kotcho core, illustrates how effectively these predators may take advantage of anthropogenic changes to their environment. While tracking the pack from the air after fresh snow, it was apparent that wolves had systematically hunted a grid of source and receiver lines spaced at 500 m intervals. As the pack moved throughout the area, repeatedly splitting and rejoining at intersecting lines, it effectively created a dragnet, with no ungulate more than 250 m from a potential encounter. During their active season, both collared and uncollared black bears were also frequently observed using linear openings for travel and foraging. As over 80% of the Snake-Sahtaneh range is within 250 m of some form of disturbance, including wildfires and anthropogenic features such as linear corridors, oilfield facilities, and cutblocks (T. Antoniuk, pers. comm.), increased travel and search efficiency of predators likely influences boreal caribou survival. Wolf predation was confirmed as the cause of 2 adult caribou mortalities during the study period; both of which occurred on seismic lines.

5.1 Management Implications and Recommendations

As a part of the national Boreal population, listed on *Schedule 1* of the *Species at Risk Act* (SARA 2003), legal protection is provided for critical habitat of the Snake-Sahtaneh caribou herd. The following recommendations are suggested to refine the understanding of long-term Snake-Sahtaneh caribou population dynamics as well as to address immediate needs for habitat management within the caribou range.

Caribou Management Recommendations

Given the limited distribution of boreal caribou in British Columbia, and the intensity and acceleration of current industrial development within the Snake-Sahtaneh range, there is a need for further investigation of demographics and monitoring of long-term population trend indices, including calf survival and recruitment. Surveys conducted in this study are insufficient to determine long-term trends; periodic calf survival and recruitment surveys are necessary to confirm whether the Snake-Sahtaneh herd is stable or declining.

Low sightability and low density of boreal caribou has traditionally restricted the feasibility of collecting late winter recruitment information without the aid of radio-telemetry. However, given that Snake-Sahtaneh caribou are found in relatively open habitat in November and December, and the vast majority of activity is concentrated within the Clarke and Paradise cores and Kotcho complex at this time, the potential efficacy of periodic early winter index surveys focused on these cores should be investigated. Although such surveys will not provide information on population size or adult mortality, they may provide a long-term index to recruitment. Index surveys could incorporate a number of techniques, including conventional aerial census as well as newer technologies involving analysis of fecal DNA.

This study collected only incidental information on the adult male component of the Snake-Sahtaneh herd, with winter composition surveys primarily based on the relocation of collared females. Describing the adult population structure would provide additional information on the status of the herd. Caribou experience differential mortality between sexes, with low recruitment further biasing the sex ratio toward females (Bergerud and Elliott 1986). Future telemetry studies on the Snake-Sahtaneh herd should include the radio-collaring of adult males to provide this information as well as to identify potential movement and genetic exchange between adjacent caribou ranges.

If a long-term decline is confirmed, measures directed toward the management of predator and alternate prey populations may be required to avoid extirpation of the Snake-Sahtaneh herd. In addition to issues associated with inter-specific dynamics of caribou, wolves, and moose, the significance of beaver must be considered. Within the Snake-Sahtaneh boreal caribou range, relatively high wolf densities are being partially supported by beaver. In addition to mitigative measures aimed at preventing increased moose availability in caribou range, the feasibility of managing alternate prey populations may need to be explored.

If the current Snake-Sahtaneh boreal caribou range boundaries are re-drawn at a future date, the portion of upland escarpment currently excluded to the south of the Tsea core (centred on UTM 10.554939.6577174) should be captured, as it has been shown to provide connectivity between the Tsea core and suitable caribou habitat in the vicinity of Komie Lake.

Following the example of Nielsen *et al.* (2002), the RSF analysis was based on a full model design. This approach provided preliminary identification of ecological variables important to Snake-Sahtaneh caribou, which may be readily mapped. Variables identified as having strong predictive ability may be subsequently incorporated into more complex models that include both ecological and anthropogenic components. Results of the RSF modeling indicate areas of highest probability of caribou use include the Earth Cover Woodland Needleleaf habitat class (black spruce peatlands with 10-25% crown closure), extremely low gradient terrain between 0.0° and 0.30° slope (SC1), and lake clusters comprised of lakes between 5 and 50 hectares in area. In addition to these variables, a significant proportion of caribou GPS locations were collected in the Open Needleleaf (black spruce peatlands with 26-60% crown closure) habitat class and slope class SC2 (0.31-0.60°). Sites with these attributes are interspersed with the Woodland Needleleaf class and SC1, respectively, and should be incorporated into future caribou mapping in a manner that facilitates the creation of logical polygons.

The Earth Cover mapping proved superior to conventional forest cover (VRI) in predicting caribou habitat selection. As well, the *change detection* layer provided in the Ducks Unlimited Earth Cover imagery may be useful in the future to assess potential reductions in boreal caribou habitat capability due to anthropogenic disturbance and climate change. Opportunities to support additional projects that expand the coverage of this map base in northeastern British Columbia should be encouraged.

Industrial Land Use Implications and Recommendations

The significance of the 7 core habitat areas identified within the Snake-Sahtaneh boreal caribou range should not be underestimated. Past and ongoing anthropogenic changes to the landscape, driven by management directives that implicitly promote intensive industrial development within the Etsho RMZ, have resulted in a situation where critical habitats are already in a compromised state. Nevertheless, efforts should be made to minimize future impacts within these identified core habitat areas, while also supporting connectivity between core polygons. The following specific recommendations for core habitat areas are designed to avoid additional direct and indirect habitat loss and increased access for predators within caribou core habitat areas:

- do not develop additional all-weather roads within core habitat area polygons; minimize the extent and standard of temporary access, default to frozen-ground access, and decommission roads as soon as possible,
- do not locate industrial facilities (camps, plant sites, etc.) within core habitat area polygons,
- employ only low impact seismic (LIS) techniques within core habitat area polygons, including hand-cut, narrow-width mulchers (< 2.5 m), and meandering/avoidance cut, and
- avoid routing linear disturbances (i.e., pipelines, conventional seismic lines, etc.) through small lake complexes (i.e., comprised of 5-50 ha lakes) within core habitat area polygons.

Past forest inventories in northeastern British Columbia have focused on the description of merchantable stands, with attributes within the non-commercial habitats, such as black spruce peatland, often poorly described. While caution is necessary when interpreting inferences beyond the study area (Manly *et al.* 2002), in the absence of detailed wetland inventory, areas of less than 0.30° slope typed to black spruce or non-commercial forests may be a useful predictor of boreal caribou occurrence throughout the Taiga Plains and Boreal Plains ecoprovinces.

Lodgepole pine appears to be selected disproportionate to its low availability within the Snake-Sahtaneh range. VRI mapping lists lodgepole pine as the leading species in a 2,400 ha patch of coniferous forest used extensively by caribou in the West Kotcho core (UTM 10.589154.6549559). This polygon represents the most significant use of pine by Snake-Sahtaneh caribou. In the event that merchantable portions of this complex are targeted for future logging, caribou habitat values (i.e., lichen production) should be considered. Wherever possible, this area should also be avoided by other industrial activities.

Waterbodies serve a variety of functions important to boreal caribou throughout the year, therefore maintaining the habitat effectiveness of these sites is important. The creation of linear corridors through and immediately adjacent to lakes and lake complexes should be avoided. As well, potential impacts of altered hydrology, including effects on lichen productivity, should be considered when planning industrial development within core habitat areas.

Results of this study indicate current industrial timing restrictions for caribou described in the *Fish and Wildlife Timing Windows for Oil and Gas Development in Northeastern British Columbia* (OGC 2006) do not coincide with the peak calving and rutting periods for boreal caribou. The current calving window (May 15 to July 15) should be revised to April 15 to June 30 and the current rutting window (October 15 to November 15) should be revised to September 15 to October 15.

Measures should be taken to avoid increased moose production within and adjacent to the Snake-Sahtaneh boreal caribou range. Industrial land use practices should avoid increasing suitability of potential moose habitat. Additional measures aimed at limiting moose densities near caribou core habitat areas should be considered (e.g., increased human harvest).

The 3-km wide travel corridor identified between the Paradise and Clarke cores is important for connectivity. Proposed industrial development inconsistent with unimpeded movement of caribou should not be permitted.

6 REFERENCES CITED

Anderson, R.B. 1999. Peatland habitat use and selection by woodland caribou (*Rangifer tarandus caribou*) in northern Alberta. M.Sc. Thesis, University of Alberta, Edmonton, AB. 49pp.

Arsenault, A.A. 2003. Status and conservation management framework for woodland caribou (*Rangifer tarandus caribou*) in Saskatchewan. Fish and Wildlife Technical Report 2003-3. 40pp.

Banfield, A.W.F. 1974a. The relationship of caribou migration behaviour to pipeline construction. Pages 797-804. *In* V. Geist and F. Walther, eds. The behaviour of ungulates and its relation to management, vol. 2. IUCN New Ser. Publ. 24, Morges, Switzerland.

______________. 1974b. The mammals of Canada. Univ. Toronto Press, Toronto, ON. 438pp.

BC CDC (BC Conservation Data Centre). 2006. BC Species and Ecosystems Explorer. BC Ministry of Sustainable Resource Management. Victoria, BC. http://srmapps.gov.bc.ca/apps/eswp/

BC MWLAP (British Columbia Ministry of Water, Land and Air Protection). 2004. Caribou *in* Accounts and measures for managing identified wildlife. British Columbia Ministry of Water, Land and Air Protection, Victoria, BC. 52pp.

BCTAC (Boreal Caribou Technical Advisory Committee). *In prep*. A recovery strategy for boreal caribou in British Columbia. Ministry of Water, Land and Air Protection, Victoria, BC.

Bergerud, A.T. 1974. Decline of caribou in North America following settlement. J. Wildl. Manage. 38(4):757-770.

____________. 1978. Caribou. Pages 83-101 *in* Schmidt, J.L., and D.L. Gilbert (eds.). Big game of North America, ecology and management. Stackpole Press, Harrisburg, PA. 494pp.

____________. 1980. A review of the population dynamics of caribou and wild reindeer in North America. *In* Proceedings of the Second International Reindeer/Caribou Symposium, Roros, Norway. E. Reimers, E. Gaare, and S. Skjenneberg (eds.). Trondhein, Norway. pp556-581.

____________. 1985. Antipredator strategies of caribou: dispersion along shorelines. Can. J. Zool. 63:1324-1329.

____________. 1996. Evolving perspectives on caribou population dynamics, have we got it right yet? Rangifer, Spec. Issue. No. 9:95-116.

____________, H.E. Butler, and D.R. Miller. 1984. Antipredator tactics of calving caribou: dispersion in mountains. Can. J. Zool. 62:1566-1575.

____________, and J.P. Elliott. 1986. Dynamics of caribou and wolves in northern British Columbia. Can. J. Zool. 64:1515-1575.

____________, and _________. 1998. Wolf predation in a multiple-ungulate system in northern British Columbia. Can. J. Zool. 76:1551-1569.

____________, M.J. Nolan, K. Curnew, and W.E. Mercer. 1983. Growth of the Avalon Peninsula, Newfoundland caribou herd. J. Wildl. Manage. 47(4):989-998.

Bjorge, R.R., and J.R. Gunson. 1989. Wolf, *Canis lupus*, population characteristics and prey relationships near Simonette River, Alberta. Can. Field-Nat. 103(3):327-334.

Boertje, R.D., W.C. Gasaway, D.V. Grangaard, and D.G. Kelleyhouse. 1988. Predation on moose and caribou by radio-collared grizzly bears in east central Alaska. Can. J. Zool. 66:2492-2499.

Bradshaw, C.J.A., D.M. Hebert, A.B. Rippin, and S. Boutin. 1995. Winter peatland habitat selection by woodland caribou in northeastern Alberta. Can. J. Zool. Vol. 73:1567-1574.

______________, S. Boutin, and D.M. Hebert. 1998. Energetic implications of disturbance caused by petroleum exploration to woodland caribou. Can. J. Zool. Vol. 76:1319-1324.

Brown, W.K., and J.B. Theberge. 1985. The calving distribution and calving-area fidelity of a woodland caribou herd in central Labrador. Pages 57-67 *in* Proceedings of the Second North American Caribou Workshop. T.C. Meredith and A.M. Martell (eds.). McGill Subarctic Research Paper No. 40.

___________, W.J. Rettie, B. Wynes, and K. Morton. 2000. Wetland habitat selection by woodland caribou as characterized using the Alberta Wetland Inventory. Rangifer, Spec. Issue. No. 12: 153-157.

Carbyn, L.N. 1975. Wolf predation and behavioural interactions with elk and other ungulates in an area of high prey diversity. Ph.D. Thesis. Univ. Toronto. Toronto, ON. 213pp.

__________, S.H. Fritts, and D.R. Seip. 1995. Ecology and conservation of wolves in a changing world. Canadian Circumpolar Institute, Occasional Publication No. 35, 642 pp.

Carruthers, D.R., S.H. Ferguson, R.D. Jakimchuk, and L.G. Sopuck. 1986. Distribution and habitat use of the Bluenose caribou herd in mid-winter. Rangifer Spec. Issue 1:57-63.

COSEWIC. 2002. COSEWIC assessment and update status report on the woodland caribou *Rangifer tarandus caribou* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 98pp.

Culling, D., B. Culling, R. Backmeyer, and T. Antoniuk. 2004. Interim oil and gas industry guidelines for boreal caribou ranges in northeastern British Columbia. Prep. for BC Oil and Gas Commission, Fort St. John, BC. 31pp + Boreal Caribou Range Map.

_________, ________, and T. Raabis. 2005. Seasonal habitat use and movements of Graham caribou, 2001 to 2003. Prep. for Canadian Forest Products Ltd. and BC Ministry of Water, Land and Air Protection. Fort St. John, BC. 88pp.

Cumming, H.G., and D.B. Beange. 1987. Dispersion and movements of woodland caribou near Lake Nipigon, Ontario. J. Wildl. Manage. 51(1):68-79.

Dale, B.W., L.G. Adams, and R.T. Bower. 1995. Winter wolf predation in a multiple ungulate prey system, Gates of the Arctic National Park, Alaska. *In* Carbyn, L.N., S.H. Fritts, and D.R. Seip. 1995. Ecology and conservation of wolves in a changing world. Canadian Circumpolar Institute, Occasional Publication No. 35, 642 pp.

Darby, W.R. 1979. Seasonal movements, habitat utilization and population ecology of woodland caribou (*Rangifer tarandus caribou Gmelin*) in the Wallace-Aikens Lake region of southeastern Manitoba. M.Sc. Thesis, University of Manitoba, Winnipeg, MB. 189pp.

__________, and L.S. Duquette. 1986. Woodland caribou and forestry in Northern Ontario, Canada. Rangifer, Spec. Issue No. 1:87-93.

__________, and W.O. Pruitt, Jr. 1984. Habitat use, movements, and grouping behaviour of woodland caribou, *Rangifer tarandus caribou*, in southeastern Manitoba. Canadian Field-Nat. 98(2):184-190.

DeLong, C., A. MacKinnonn, and L. Jang. 1990. A field guide for identification and interpretation of ecosystems of the northeast portion of the Prince George Forest Region. Land Management Handbook Number 22. BC Ministry of Forests, Research Branch, Victoria, BC. 108pp.

DU (Ducks Unlimited Inc.). 2003. Fort Nelson, British Columbia earth cover classification user's guide. Prep. for: Ducks Unlimited Canada, Edmonton, AB; Slocan Forest Products Ltd., and British Columbia Ministry of Sustainable Resource Management through Forest Renewable British Columbia. Ducks Unlimited Inc., Rancho Cordova, CA. 77pp + digital mapping.

Dunford, J. 2003. Woodland caribou–wildfire relationships in northern Alberta. M.Sc Thesis, University of Alberta, Edmonton, AB. 113pp.

Dyer, S.J., J.P. O'Neill, S.M. Wasel, and S. Boutin. 2001. Avoidance of industrial development by woodland caribou. J. Wildl. Manage. 65(3):531-542.

Dzus, E. 2001. Status of the woodland caribou (*Rangifer tarandus caribou*) in Alberta. Alberta Environment, Fisheries and Wildlife Management Division, and Alberta Conservation Association, Wildlife Status Report No. 30, Edmonton, AB. 47pp.

Edmonds, E.J. 1988. Population status, distribution, and movements of woodland caribou in west central Alberta. Can. J. Zool. 66:817-826.

___________. 1998. Status of woodland caribou in Alberta. Rangifer, Spec. Issue No. 10:111-115.

___________, and M. Bloomfield. 1984. A study of woodland caribou (*Rangifer tarandus caribou*) in west central Alberta, 1979 to 1983. Alberta Energy and Natural Resources, Fish & Wildlife Div., Edmonton, AB. 203pp.

Environment Canada. 2006. Canadian Climate Normals 1971-2000. http://www.climate.weather office.ec.gc.ca/climatenormals.

ESRI (Environmental Systems Research Institutes Inc.). 2002. ArcView 8 (vers. 8.3) and ArcGIS Spatial Analyst extension. 380 New York Street, Redlands, CA.

Farnell, R., N. Baricello, K. Egli, and G. Kuzyk. 1996. Population ecology of two woodland caribou herds in the southern Yukon. Rangifer, Spec. Issue No. 9, 1996.

Fort Nelson LRMP. 1997. Fort Nelson Land and Resource Management Plan. Prep. by Fort Nelson LRMP Working Group, Fort Nelson, BC. 178 pp + map.

Frame, P.F., D.S. Hik, H.D. Cluff, and P.C. Paquet. 2004. Long foraging movement of a denning tundra wolf. Arctic 57(2):196-203.

Fuller, T.K. 1989. Population dynamics of wolves in north-central Minnesota. Wildl. Monogr. No. 105.

_________, and L.B. Keith. 1980. Wolf population dynamics and prey relationships in northeastern Alberta. J. Wildl. Manage. 44(3):583-602.

_________, and _________. 1981. Woodland caribou population dynamics in northeastern Alberta. J. Wildl. Manage. 45(1):197-213.

Hayes, R.D. 1995. Numerical and functional responses of wolves, and regulation of moose in the Yukon. M.Sc. Thesis, Simon Fraser Univ., Vancouver, BC. 132pp.

Hillis, T.L., F.F. Mallory, W.J. Dalton, and A.J. Smiegielski. 1998. Preliminary analysis of habitat utilization by woodland caribou in northwestern Ontario using satellite telemetry. Rangifer, Spec. Issue No. 10:195-202.

Hooge, P.N., and B. Eichenlaub. 2000. Animal movement extension to ArcView v. 2.2. Alaska Biological Science Center, U.S. Geological Survey, Anchorage, AK.

Hornbeck, G.E., and D.L.J. Moyles. 1995. Ecological aspects of woodland caribou in the Pedigree area of northwestern Alberta. Prep. for Pedigree Caribou Standing Committee: Wascana Energy Inc., Nova Corp. of Alberta, and Canadian Hunter Exploration Ltd. 40pp + append.

Hosmer, D.W., Jr., and S. Lemeshow. 1980. Goodness-of-fit tests for the multiple logistic regression model. Communications in Statistics A9:1043-1069.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 4:187–211.

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

___________, S. Boutin, D.M. Hebert, A.B. Rippin. 2004. Spatial separation of caribou from moose and its relation to predation by wolves. J. Wildl. Manage. 68(4):799-809.

___________, and A.K. Stuart-Smith. 2000. Distribution of caribou and wolves in relation to linear corridors. J. Wildl. Manage. 64(1):154-159.

JMP Version 6.0. 2005. Cary, NC, SAS Institute Inc.

Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology, 61(1):65-71.

Joly, K., B.W. Dale, W.B. Collins, and L.G. Adams. 2002. Evaluating the impacts of wildland fires on caribou in interior Alaska. Arctic Research of the United States 16:63-67. http://www.absg.vsgs.gov/research/caribou.

Klein, D.R. 1982. Fire, lichens, and caribou. J. Range Mgmt. 35(3):390-395.

Krebs, C.J. 1999. Ecological methodology. 2nd Edition. Addison-Wesley Educational Publishers, Inc., Menlo Park, CA. 620pp.

_________. 2003. Programs for ecological methodology, v 6.1.1, 2nd Ed. Harper & Row Publishers, New York, NY.

Kunkel, K., and D.H. Pletscher. 2001. Winter hunting patterns of wolves in and near Glacier National Park, Montana. J. Wildl. Manage. 65(3):520-530.

Larter, N.C., and D.G. Allaire. 2005. Trout Lake boreal caribou study progress report, February 2005. Resources, Wildlife and Economic Development, Fort Simpson, NT.

Mahoney, S.P., and J.A. Virgl. 2003. Habitat selection and demography of a nonmigratory woodland caribou population in Newfoundland. Can. J. Zool. 81:321-334.

Manly, B.F.J., L.L. McDonald, D.L. Thomas, T.L. McDonald, and W.P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. 2nd ed. Kluwer Academic Publishers, Norwell, MA. 221pp.

McLoughlin, P.D. 2003. Demographic monitoring. Ch. 2 *in* Dunford, J., J. Nolan, and P.D. McLaughlin (eds.). Boreal caribou research program, 2003 research summary. Boreal Caribou Committee. http://www.deer.rr.ualberta. ca/caribou/BRCP.htm.

_____________, E. Dzus, B. Wynes, and S. Boutin. 2003. Declines in populations of woodland caribou. J. Wildl. Manage. 67(4):755-761.

Mech, D.L. 2000. A record large wolf, *Canis lupus*, pack in Minnesota. Canadian Field-Naturalist 114(3):504-505.

Meidinger, D., and J. Pojar (eds.). 1991. Ecosystems of British Columbia. BC Min. For., Spec. Series No. 6, ISSN 0843-6452, Victoria, BC. 330pp.

Merrill, S.B., and L.D. Mech. 2003. The usefulness of GPS telemetry to study wolf circadian and social activity. Wildl. Soc. Bull. 31(4):947-960.

Messier, F. 1987. Physical condition and blood physiology of wolves in relation to moose density. Can. J. Zool. 65:91-95.

Metsaranta, J. M., F. F. Mallory, and D.W. Cross. 2003. Vegetation characteristics of forest stands used by woodland caribou and those disturbed by fire or logging in Manitoba. Rangifer, Spec. Issue No. 14.

Millspaugh, J.J., J.R. Skalski, B.J. Kernohan, K.J. Raedeke, G.C. Brundige, and A.B. Cooper. 1998. Some comments on spatial independence in studies of resource selection. Wildl. Soc. Bull. 26(2):232-238.

Mladenoff, D., T. Sickley, and A. Wydeven. 1999. Predicting gray wolf landscape recolonization: logistic regression models vs. new field data. Ecological Applications 9:37-44.

Mohr, C. 1947. Table of equivalent populations of North American small mammals. Am. Midl. Nat. 37:223-249.

Mosnier, A., J. Ouellet, L. Sirois, and N. Fournier. 2003. Habitat selection and home-range dynamics of the Gaspe´ caribou: a hierarchical analysis. Can. J. Zool. 81:1174-1184.

Murie, A. 1944. The wolves of Mount McKinley. U.S. Natl. Park Serv. Fauna Natl. Parks. U.S. Fauna Ser. 5. 238pp.

Nagy, J.A., D. Auriat, I. Ellsworth, W. Wright, and T. Slack. 2003. Ecology of boreal woodland caribou in the Lower Mackenzie Valley: work completed in the Inuvik Region 1 April 2002 to 31 March 2003 (Draft). Dept. Resources Wildlife and Economic Development (Inuvik and Sahtu Regions) and Gwich'in and Sahtu Renewable Resources Boards, Inuvik, NT. 62 pp.

__________________, W. Wright, Todd Slack, Ian Ellsworth, and Martin Kienzler. 2005. Ecology of boreal woodland caribou in the Lower Mackenzie Valley, NT: work completed in the Inuvik Region April 2003 to November 2004. Dept Resources, Wildlife and Economic Development, Inuvik, NT. 54 pp.

Nielsen, S.E., M.S. Boyce, G.B. Stenhouse, and R.H.M. Munro. 2002. Modeling grizzly bear habitats in the Yellowhead ecosystem of Alberta: Taking autocorrelation seriously. Ursus 13:45-56.

__________, __________, and _________. 2004. Grizzly bears and forestry I - selection of clearcuts by grizzly bears in west-central Alberta, Canada. Forest Ecology and Management 199:51-65.

Norris, D.R., M.T. Theberge, and J.B. Theberge. 2002. Forest composition around wolf (*Canis lupus*) dens in eastern Algonquin Provincial Park, Ontario. Can. J. Zool. 80:866-872.

OGC (British Columbia Oil and Gas Commission). 2006. Fish and wildlife timing windows for oil and gas development in northeastern British Columbia. www.ogc.gov.bc.ca.

Page, R. 1989. Impacts of wolf predation on Isle Royale moose populations. pp 43-56 *in* BC Environment. 1989. Wolf-prey dynamics and management – proceedings. Wildl. Working Rep. No. WR-40., BC Environment, Victoria, BC. 180pp.

Pendergast, J.F., S.J. Gange, M.A. Newton, M.J. Lindstrom, M. Palta, and M.R. Fisher. 1996. A survey of methods for analyzing clustered binary response data. International Statistics Review 64:89–118.

Pollock, K.H., S.R. Winterstein, C.M. Bunck, and P.D. Curtis. 1989. Survival analysis in telemetry studies: the staggered entry design. J. Wildl. Manage. 53(1):7-15.

Porter, W.F., and K.E. Church. 1987. Effects of environmental pattern on habitat preference analysis. J. Wild. Manage. 51(3):681-685.

Potvin, F., C. Pilion, and M. Macquart. 1991. Impact of an experimental wolf reduction on beaver in Papineau-Labelle reserve, Quebec. Can. J. Zool. 70:180-183.

Racey, G.D., K. Abraham, W.R. Darby, H.R. Timmermann, and Q. Day. 1991. Can woodland caribou and the forestry industry coexist: the Ontario scene. Rangifer, Spec. Issue No. 7:108-115.

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

_________, and _________. 2001. Range use and movement rates of woodland caribou in Saskatchewan. Can. J. Zool, 79:1933-1940.

RIC (Resources Inventory Committee). 1998a. Live animal capture and handling guidelines for wild mammals, birds, amphibians & reptiles. Standards for components of British Columbia's biodiversity No. 3. Version 2. Resources Inventory Branch, Ministry of Environment, Lands and Parks, Victoria, BC.

_________________________________. 1998b. Wildlife radio-telemetry. Standards for components of British Columbia's biodiversity No. 5. Version 2. Resources Inventory Branch, Ministry of Environment, Lands and Parks, Victoria, BC.

Rogers, L.L., L.D. Mech, K.D. Dawson, J.M. Peak, and M. Korb. 1980. Deer distribution in relation to wolf pack territory edges. J. Wildl. Manage. 44(1):253-258.

Russell, D.E., and A.M. Martell. 1984. Winter range ecology of caribou (*Rangifer tarandus*). In R. Olson, F. Geddes, and R. Hastings. 1984. Northern ecology and resource management. Univ. of Alberta Press. Edmonton, AB. 438pp.

Samson, C., and J. Huot. 1998. Movements of female black bears in relation to landscape vegetation type in southern Quebec. J. Wildl. Manage. 62(2):718-727.

SARA (Species at Risk Act Public Registry). 2003. Species at Risk Act: A Guide. www.sararegistry.gc.ca.

Sather, D.J. 2005. Woodland caribou habitat selection during winter and along migratory routes in west-central Alberta. M.Sc. Thesis, University of Alberta, Edmonton, AB. 125pp.

Schaefer, J. A. 1996. Canopy, snow, and lichens on woodland caribou range in southeastern Manitoba. Rangifer, Spec. Issue No 9:239-244.

Schmidt, P.A., and L.D. Mech. 1997. Wolf pack size and food acquisition. Am. Midl. Nat. 150:513-517.

Schneider, R.R., B. Wynes, S. Wasel, E. Dzus, and M. Hiltz. 2000. Habitat use by caribou in northern Alberta, Canada. Rangifer, 20(1):43-50.

Seip, D.R. 1989. An introduction to predator-prey interactions. Pages 1-12 *in* BC Environment. 1989. Wolf-prey dynamics and management – proceedings. Wildl. Working Rep. No. WR-40., BC Environment, Victoria, BC. 180 pp.

________. 1990. Ecology of woodland caribou in Wells Grey Provincial Park. B.C. Ministry of Environment, Wildlife Branch. Wildl. Working Rep. No. B-68. Victoria, BC. 43pp.

________. 1992. Factors limiting woodland caribou populations and their interrelationships with wolves and moose in southeastern British Columbia. Can. J. Zool. Vol. 70:1494-1503.

________, and D.B. Cichowski. 1996. Population ecology of caribou in British Columbia. Rangifer, Spec. Issue No. 9:73-80.

Shackleton, D.M. 1999. Hooved mammals of British Columbia. Royal British Columbia Museum handbook, the mammals of British Columbia, volume 3. UBC Press, Vancouver, BC. 268pp.

Shearwater Mapping Ltd. 1997. Snake/Sahtaneh Arc/Info digital map files and associated databases. Prep. for Slocan Forest Products Ltd.- Fort Nelson Division by Shearwater Mapping Ltd., Victoria, BC.

Smith, K.G., E.J. Fitch, D. Hobson, T.C. Sorensen, and D. Hervieux. 2000. Winter distribution of woodland caribou in relation to clear-cut logging in west-central Alberta. Can. J. Zool. 78:1433-1440.

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

Stuart-Smith, A.K., C.J.A. Bradshaw, S. Boutin, D.M. Hebert, A.B. Rippin. 1997. Woodland caribou relative to landscape patterns in northeastern Alberta. J. Wildl. Manage. 61(3):622-633.

Thomas, D.C. 1995. A review of wolf-caribou relationships and conservation implications in Canada. Pages 261-273 *in* Carbyn, L. N., S. H. Fritts, and D. R. Seip. 1995. Ecology and conservation of wolves in a changing world. Canadian Circumpolar Institute, Occasional Publication No. 35. 642pp.

___________. 1998. Needed: less counting of caribou and more ecology. Rangifer, Spec. Issue No. 10:15-23.

___________, and D.R. Gray. 2002. Update COSEWIC status report on the woodland caribou (*Rangifer tarandus caribou*) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 98pp.

Thomas, D.L., and E.J. Taylor. 1990. Study designs and tests for comparing resource use and availability. J. Wildl. Manage. 54(2):322-330.

Vitt, D.H., L.A. Halsey, M.N. Thormann, and T. Martin. 1998. Peatland Inventory of Alberta. Univ. of Alberta. Edmonton, AB.

Walsh, N.E., S.G. Fancy, T. R. McCabe, and L.F. Pank. 1992. Habitat use by the Porcupine Caribou herd during predicted insect harassment. J. Wildl. Manage. 56(3):465-473.

Weaver, J.L. 1993. Refining the equation for interpreting prey occurrence in gray wolf scats. J. Wildl. Manage. 57(3):534-538.

Worton, B.J. 1989. Kernel methods for estimating the utility distribution in home-range studies. Ecology 70:164-168.

Young, D.D., and T.R. McCabe. 1997. Grizzly bear predation rates on caribou calves in northeastern Alaska. J. Wildl. Manage. 61(4):1056-1066.

Zimmerman, K.L., R.S. McNay, L. Giguere, and J.B. Joy. 2001. Ecological factors affecting northern caribou in the Omineca Region, British Columbia – Year 3 (2000) inventory results. Prep. for Slocan Forest Products Ltd. and Abitibi Consolidated Inc., Mackenzie Forest District, BC. 95pp.

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APPENDICES 1 to 7

APPENDIX 1: Snake-Sahtaneh Caribou Telemetry Summary, March 2000 – December 2004.

Caribou ID	Collar Manuf.*	Start Data	End Data	No. Sessions	Total Points	3D Points	No. Days	3D Per Day	No. Calving Seasons	Comments
S1	A	1-Mar-2000	4-Oct-2000	1	1,177	921	217	4.2	1	retired
S2	A	2-Mar-2000	22-Aug-2001	2	2,819	2,240	538	4.4	2	retired
S3	A/T	1-Mar-2000	19-Nov-2004	4	6,966	5,796	1,416	4.1	4	gap 25 Dec 2001 to 29 Oct 2002; retired
S4	A	1-Mar-2000	4-Jun-2000	1	530	341	95	3.6	1	mortality (black bear)
S5	A	1-Mar-2000	23-Nov-2004	4	7,948	6,457	1,474	4.4	5	gap 28 May 2002 to 6 Feb 2003; retired
S6	A/T	29-Feb-2000	7-Sep-2003	3	6,734	5,710	1,201	4.6	4	gap 31 Aug 2002-24 Nov 2002; retired
S7	A	29-Mar-2000	9-Aug-2000	1	767	665	133	5.0	1	retired
S8	A	30-Mar-2000	5-Feb-2001	1	1,233	738	312	2.4	1	retired
S9	A	30-Mar-2000	1-Aug-2000	1	720	597	124	4.8	1	retired
S10	A	31-Mar-2000	29-Jun-2000	1	374	210	90	2.3	1	retired
S11	A	28-Mar-2000	1-Oct-2000	1	908	628	187	3.4	1	retired
S12	A	31-Mar-2000	22-Jun-2000	1	482	419	83	5.0	1	retired
S13	T	11-Mar-2001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	missing; not recovered
S14	T	11-Mar-2001	11-Apr-2002	1	2,204	1,981	396	5.0	1	recollared 11 April 2002, collar recovered 18 Dec 2003 - but no data logged; retired
S15	T	10-Mar-2001	22-Jul-2002	2	2,557	2,095	497	3.7	2	mortality (carcass intact; cause unknown)
S16	T	12-Mar-2001	15-Nov-2004	3	7,238	6,370	1,283	5.0	4	gap 12 Oct 2003 to 12 Dec 2003; retired
S17	T/A	10-Mar-2001	21-Sep-2004	2	5,251	4,522	1,100	4.0	3	no data logged May-Jun 2002; no collar 30 July 2003 to 6 Feb 2003; retired

APPENDIX 1 cont'd: Snake-Sahtaneh Caribou Telemetry Summary, March 2000 – December 2004.

Caribou ID	Collar Manuf.*	Start Data	End Data	No. Sessions	Total Points	3D Points	No. Days	3D Per Day	No. Calving Seasons	Comments
S18	T	11-Mar-2001	11-Apr-2002	1	1,951	1,788	396	4.5	1	recollared 11 April 2002; missing; not recovered; some VHF points aquired in second session
S19	T	11-Mar-2001	11-Apr-2002	1	1,530	1,304	396	3.3	1	recollared 11 April 2002; missing (heard intermittently to Dec 2003) -collar not recovered
S20	T	11-Mar-2001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	missing from Nov 2001; collar not recovered
S21	T	10-Mar-2001	15-Nov-2004	3	6,184	4,941	1,170	4.2	4	not collared from 18 June 2003 to 11 Dec 2003; retired
S22	T	11-Mar-2001	20-Aug-2001	1	947	830	162	5.1	1	mortality (carcass intact; cause unknown)
S23	T	11-Mar-2001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	missing since 6 March 2002; collar not recovered
S24	T	10-Mar-2001	13-Sep-2001	1	883	722	187	3.9	1	no data logged after Sept 2001; recollared 11 April 2002; last heard Dec 2002; collar not recovered
S25	T	11-Mar-2001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	missing since July 2002; collar not recovered
S26	A	12-Mar-2001	21-Nov-2001	1	1,357	736	254	2.9	1	retired
S27	A	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	collar malfunction
S28	A	8-Nov-2001	30-Mar-2002	1	852	826	142	5.8	0	retired
S29	A	8-Nov-2001	23-Nov-2004	3	5,388	4,165	1,012	4.0	3	gap 21 July 2002 to 28 Oct 2002; retired
S30	A	8-Nov-2001	19-Nov-2002	1	2,130	1,689	376	4.5	1	retired
S31	A	8-Nov-2001	10-Aug-2002	1	1,571	1,241	275	4.5	1	retired
S32	A	8-Nov-2001	10-Apr-2002	1	863	732	153	4.8	0	mortality (wolf kill); moved 10 km on day of death
S33	A	8-Nov-2001	9-Nov-2002	1	2,034	1,516	366	4.1	1	collar retired
S34	A	2-Dec-2003	n/a	n/a	n/a	n/a	n/a	n/a	n/a	collar recovered 24 Oct 2004, but no data logged; retired
S35	A	11-Dec-2003	2-Dec-2004	1	2,110	1,881	357	5.3	1	retired

APPENDIX 1 cont'd: Snake-Sahtaneh Caribou Telemetry Summary, March 2000 – December 2004.

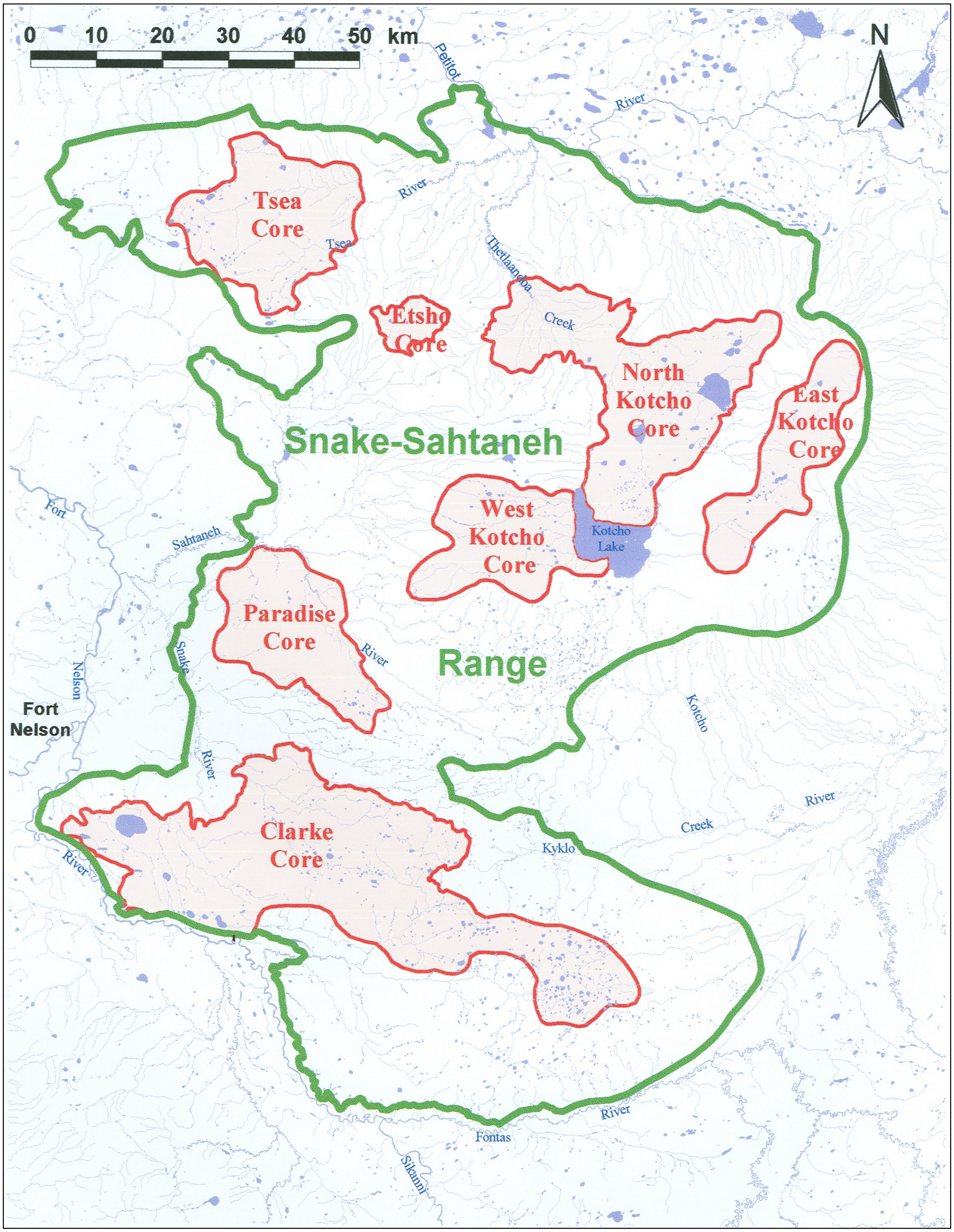
Caribou ID	Collar Manuf.*	Start Data	End Data	No. Sessions	Total Points	3D Points	No. Days	3D Per Day	No. Calving Seasons	Comments
S36	T	11-Dec-2003	15-Nov-2004	1	1,925	1,742	340	5.1	1	retired
S37	T	11-Dec-2003	27-Nov-2004	1	1,941	1,671	352	4.7	1	retired
S38	T	13-Dec-2003	10-Nov-2004	1	1,715	1,394	333	4.2	1	retired
S39	T	11-Dec-2003	20-Nov-2004	1	1,180	712	345	2.1	1	retired
S40	T	11-Apr-2002	1-Sep-2003	1	2,573	2,000	508	3.9	2	retired
S41	T	11-Apr-2002	7-Sep-2003	1	2,309	1,485	514	2.9	2	retired
S42	T/A	11-Apr-2002	2-Dec-2004	2	3,203	2,930	543	5.3	2	no data logged 3 Sept 2002 to 6 Jan 2003; no collar from 6 Jan 2003 to 30 Oct 2003; retired
S43	T	11-Apr-2002	31-Aug-2003	1	2,357	1,581	507	3.1	2	retired
S44	T	11-Apr-2002	5-Sep-2003	1	2,789	2,387	512	4.7	2	retired
S45	T	12-Apr-2002	10-Jun-2003	1	2,184	1,634	424	3.9	2	retired
S46	A	5-Feb-2003	24-Oct-2004	2	3,735	3,445	993	3.8	2	retired
S47	A	5-Feb-2003	29-Mar-2004	1	2,489	2,315	418	5.5	1	retired
S48	A	6-Feb-2003	27-Mar-2004	1	2,459	2,207	415	5.3	1	replaced 27 March 2004 with Lotek VHF collar; active at end of project
S49	T	12-Mar-2003	7-Oct-2004	1	2,122	1,257	575	2.2	1	retired
S50	A	12-Nov-2003	23-Nov-2004	1	2,202	1,880	377	5.0	1	retired
S51	T	12-Dec-2003	15-Nov-2004	1	1,704	1,531	339	4.5	1	retired
S52	T	12-Dec-2003	15-Nov-2004	1	1,975	1,834	339	5.4	1	retired
S53	T	12-Dec-2003	23-Nov-2004	1	1,981	1,808	347	5.2	1	retired
S54	T	13-Dec-2003	20-Oct-2004	1	1,278	771	312	2.5	1	mortality (wolf kill)

APPENDIX 1 cont'd: Snake-Sahtaneh Caribou Telemetry Summary, March 2000 – December 2004.

Caribou ID	Collar Manuf.*	Start Data	End Data	No. Sessions	Total Points	3D Points	No. Days	3D Per Day	No. Calving Seasons	Comments
S55	L	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	collared March 2004 -VHF collar on new caribou
S56	L	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	collared March 2004 -VHF collar on new caribou
S57	L	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	collared March 2004 -VHF collar on new caribou
Totals					**117,829**	**96,645**	**22,885**		**74**	

* T (Televilt GPS), A (ATS GPS), L (Lotek VHF; used to retain sample size of 20 cows during final year of study)

APPENDIX 2: Location of 7 identified core habitat areas within the Snake-Sahtaneh boreal caribou range.



APPENDIX 3: Summary of 100% MCP home range sizes for 33 adult female Snake-Sahtaneh caribou with greater than 11 months of location data, March 2000-December 2004.

Caribou ID	km²	Dates	Caribou ID	km²	Dates
S3	2,839	Mar 2000-Nov 2004	S38	1,679	Dec 2003-Nov 2004
S5	1,979	Mar 2000-Nov 2004	S39	1,376	Dec 2003-Nov 2004
S6	3,137	Mar 2000-Sept 2003	S40	1,535	April 2002-Aug 2003
S8	862	Mar 2000-Feb 2001	S41	1,182	April 2002-Sept 2003
S14	650	Mar 2001-April 2002	S42	580	April 2002-Dec 2004
S15	1,118	Mar 2001-July 2002	S43	1,553	April 2002-Aug 2003
S16	1,845	Mar 2001-Nov 2004	S44	2,824	April 2002-Sept 2003
S17	1,426	Mar 2001-Sept 2004	S45	1,406	April 2002-June 2003
S18	3,592	Mar 2001-April 2002	S46	2,521	Feb 2003-Oct 2004
S19	1,132	Mar 2001-April 2002	S47	1,997	Feb 2003-Mar 2004
S21	1,656	Mar 2001-Nov 2004	S48	1,633	Feb 2003-Mar 2004
S29	3,975	Nov 2001-Nov 2004	S49	1,419	Mar 2003-Oct 2004
S30	741	Nov 2001-Nov 2002	S50	1,953	Nov 2003-Nov 2004
S33	2,753	Nov 2001-Nov 2002	S51	1,760	Dec 2003-Nov 2004
S35	2,507	Dec 2003-Dec 2004	S52	375	Dec 2003-Nov 2004
S36	491	Dec 2003-Nov 2004	S53	781	Dec 2003-Nov 2004
S37	1,869	Dec 2003-Nov 2004			

APPENDIX 4: Distribution of calving sites within core habitat areas in the Snake-Sahtaneh boreal caribou range, 2000-2004 (*n* = 66).

Clarke (14)	Paradise (26)	West Kotcho (11)	East Kotcho (4)	North Kotcho (6)	Etsho (1)	Tsea (3)	Outside Core Areas (1)
S4-2000	S1-2000	S2-2000	S6-2000	S8-2000	S37-2004	S9-2000	S52-2004
S14-2001	S3-2000	S21-2001	S6-2001	S12-2000		S18-2001	
S15-2002	S3-2001	S21-2002	S6-2002	S17-2001		S24-2001	
S16-2004	S3-2003	S21-2003	S6-2003	S17-2003			
S19-2001	S5-2000	S21-2004		S17-2004			
S22-2001	S5-2001	S36-2004		S39-2004			
S31-2002	S5-2002	S42-2002					
S38-2004	S5-2003	S42-2004					
S41-2002	S5-2004	S46-2003					
S44-2002	S10-2000	S46-2004					
S44-2003	S11-2000	S53-2004					
S48-2003	S16-2001						
S50-2004	S16-2002						
S54-2004	S29-2002						
	S29-2003						
	S29-2004						
	S30-2002						
	S33-2002						
	S40-2002						
	S43-2002						
	S43-2003						
	S45-2002						
	S45-2003						
	S49-2003						
	S49-2004						
	S51-2004						

APPENDIX 5a:

Variable classes, parameters and coefficient estimates (βi) for Late Winter RSF models (Design II, 100% model) for boreal caribou in the Snake-Sahtaneh range, British Columbia (n = 42). Model fit evaluated with log likelihood (-2LL) statistics and receiver operating characteristic (ROC) curves.

	β_i	Lower C.I. (95%)	Upper C.I. (95%)	*P*
Earth Cover Model				
Open Needleleaf	0.4728	0.2885	0.6610	<0.0001*
Reference: Woodland Needleleaf	**reference**			
Closed Needleleaf	-0.3510	-0.6398	-0.0680	0.0160*
Low Vegetation	-0.4679	-0.9149	-0.0507	0.0332*
Cutblock	-0.7442	-3.6647	0.9918	0.4877*
Tall Shrub	-0.8777	-1.4590	-0.3599	0.0016*
Other	-1.5063	-3.3310	-0.2977	0.0405*
Open Mixed Needleleaf-Deciduous	-1.3399	-2.0676	-0.7235	0.0001*
Burn Regeneration	-1.7558	-2.9526	-0.8612	0.0007*
Wetlands and Waterbodies	-1.9192	-2.8677	-1.1694	<0.0001*
Closed Mixed Needleleaf-Deciduous	-2.5446	-3.0752	-2.0765	<0.0001*
Vegetation Resources Inventory Models				
Leading Species:				
Lodgepole Pine	0.6124	0.2106	1.0056	0.0025
Reference: Black Spruce-Tamarack	**reference**			
Other	-2.0996	-2.3821	-1.8367	<0.0001
Crown Closure (%)	-0.0046	-0.0078	-0.0015	0.0043
Terrain and Hydrology Models				
Slope Class:				
Reference: SC1 (0.00-0.30°)	**reference**			
SC3 (0.61-0.90°)	-0.1154	-0.3164	0.0815	0.2553
SC2 (0.31-0.60°)	-0.2486	-0.3930	-0.1042	0.0007
SC4 (0.91° +)	-0.6252	-0.9125	-0.3522	<0.0001
Distance to Nearest Stream (km)	*NS*	*NS*	*NS*	*NS*
Distance to Nearest Lake (km)	*NS*	*NS*	*NS*	*NS*
Distance to Nearest Cluster Lake (km)	-0.0396	-0.0541	-0.0253	<0.0001
Lake Size:				
5-10 ha	0.3530	0.0934	0.6051	0.0068
Reference: <2 ha	**reference**			
2-5 ha	-0.1360	-0.3638	0.0841	0.2336
50-100 ha	-0.2990	-1.0886	0.3794	0.4190
10-50 ha	-0.3875	-0.7312	-0.0659	0.0221
>100 ha	-0.6239	-1.0947	-0.1988	0.0061
Cluster Lake Size:				
5-10 ha	0.2828	0.1117	0.4538	0.0012
10-50 ha	0.0765	-0.0979	0.2482	0.3863
Reference: 2-5 ha	**reference**			
>100 ha	-0.2104	-0.4708	0.0394	0.1055
50-100 ha	**-0.5873**	**-1.1397**	**-0.0971**	**0.0263**

Bolded text indicate β estimate significance at $p < 0.05$

Dash (-) indicates perfect avoidance or selection, parameter estimate not available (approaches infinity)

Estimated β for distances to streams, lakes, clustered lakes measured in km and canopy cover % (negative coefficent represents selection).

NS results indicate non-significant ($p > 0.05$) Chi-squared goodness of fit tests (evidence of no selection)

* Indicates good model accuracy (ROC score >0.7)

APPENDIX 5b:

Variable classes, parameters and coefficient estimates (βi) for Spring-Late Summer RSF models (Design II, 100% model) for boreal caribou in the Snake-Sahtaneh range, British Columbia (n = 46). Model fit evaluated with log likelihood (-2LL) statistics and receiver operating characteristic (ROC) curves.

	β_i	Lower C.I. (95%)	Upper C.I. (95%)	*P*
Earth Cover Model				
Burn Regeneration	0.0795	-0.2211	0.3801	0.6042*
Reference: Woodland Needleleaf	**reference**			
Open Needleleaf	-0.3011	-0.4223	-0.1799	<0.0001*
Low Vegetation	-0.5318	-0.7829	-0.2807	<0.0001*
Closed Needleleaf	-1.1080	-1.3038	-0.9122	<0.0001*
Tall Shrub	-1.1942	-1.5235	-0.8752	<0.0001*
Open Mixed Needleleaf-Deciduous	-1.4740	-1.8387	-1.1263	<0.0001*
Other	-1.6405	-2.4514	-0.9287	<0.0001*
Cutblock	-1.6893	-3.5937	-0.2651	0.0355*
Closed Mixed Needleleaf-Deciduous	-2.4009	-2.6325	-2.1777	<0.0001*
Wetlands and Waterbodies	-2.8642	-3.5163	-2.3074	<0.0001*
Vegetation Resources Inventory Models				
Leading Species:				
Lodgepole Pine	0.4744	0.1581	0.7960	0.0033
Reference: Black Spruce-Tamarack	**reference**			
Other	-1.6552	-1.7964	-1.5142	<0.0001
Crown Closure (%)	-0.0182	-0.0206	-0.0158	<0.0001
Terrain and Hydrology Models				
Slope Class:				
Reference: SC1 (0.00-0.30°)	**reference**			
SC2 (0.31-0.60°)	-0.4091	-0.5081	-0.3101	<0.0001
SC3 (0.61-0.90°)	-0.7043	-0.8573	-0.5512	<0.0001
SC4 (0.91° +)	-1.1793	-1.3923	-0.9694	<0.0001
Distance to Nearest Stream (km)	0.4671	0.3034	0.6308	<0.0001
Distance to Nearest Lake (km)	0.1747	0.1270	0.2223	<0.0001
Distance to Nearest Cluster Lake (km)	-0.0861	-0.0970	-0.0752	<0.0001
Lake Size:				
10-50 ha	0.3231	0.1341	0.5121	0.0008
5-10 ha	0.3083	0.1175	0.4991	0.0015
2-5 ha	0.2591	0.1158	0.4024	0.0004
Reference: <2 ha	**reference**			
>100 ha	-0.0506	-0.3019	0.2007	0.6932
50-100 ha	-0.0808	-0.5573	0.3885	0.7357
Cluster Lake Size:				
50-100 ha	0.6162	0.3701	0.8623	<0.0001
5-10 ha	0.0241	-0.1028	0.1510	0.7096
>100 ha	0.0035	-0.1591	0.1660	0.9664
Reference: 2-5 ha	**reference**			
10-50 ha	**-0.0233**	**-0.1455**	**0.0988**	**0.7081**

Bolded text indicate β estimate significance at $p < 0.05$

Dash (-) indicates perfect avoidance or selection, parameter estimate not available (approaches infinity)

Estimated β for distances to streams, lakes, clustered lakes measured in km and canopy cover % (negative coefficent represents selection).

NS results indicate non-significant ($p > 0.05$) Chi-squared goodness of fit tests (evidence of no selection)

* Indicates good model accuracy (ROC score >0.7)

APPENDIX 5c:

Variable classes, parameters and coefficient estimates (βi) for the Neonate period (May-June) RSF models (Design II, 100% model) for boreal caribou in the Snake-Sahtaneh range, British Columbia (n = 46). Model fit evaluated with log likelihood (-2LL) statistics and receiver operating characteristic (ROC) curves.

	β_i	**Lower C.I. (95%)**	**Upper C.I. (95%)**	**P**
Earth Cover Model				
Burn Regeneration	0.1148	-0.2581	0.4841	0.5424*
Reference: Woodland Needleleaf	**reference**			
Open Needleleaf	-0.3118	-0.4648	-0.1587	**0.0001***
Low Vegetation	-0.3810	-0.7004	-0.0704	**0.0176***
Tall Shrub	-1.3097	-1.8047	-0.8595	**<0.0001***
Closed Needleleaf	-1.3188	-1.6095	-1.0399	**<0.0001***
Cutblock	-1.4946	-4.4139	0.2376	0.1629*
Other	-1.5636	-2.7830	-0.6244	**0.0036***
Open Mixed Needleleaf-Deciduous	-1.7539	-2.3638	-1.2217	**<0.0001***
Closed Mixed Needleleaf-Deciduous	-2.6306	-3.0095	-2.2822	**<0.0001***
Wetlands and Waterbodies	-3.7625	-5.5690	-2.6209	**<0.0001***
Vegetation Resources Inventory Models				
Leading Species:				
Lodgepole Pine	0.0999	-0.3489	0.5287	0.6544
Reference: Black Spruce-Tamarack	**reference**			
Other	-1.6448	-1.8552	-1.4440	**<0.0001**
Crown Closure (%)	-0.0176	-0.0206	-0.0145	**<0.0001**
Terrain and Hydrology Models				
Slope Class:				
Reference: SC1 (0.00-0.30°)	**reference**			
SC2 (0.31-0.60°)	-0.2757	-0.4061	-0.1454	**<0.0001**
SC3 (0.61-0.90°)	-0.6025	-0.8135	-0.3976	**<0.0001**
SC4 (0.91° +)	-1.3039	-1.6404	-0.9914	**<0.0001**
Distance to Nearest Stream (km)	0.2673	0.0582	0.4747	**0.0115**
Distance to Nearest Lake (km)	0.1995	0.1389	0.2602	**<0.0001**
Distance to Nearest Cluster Lake (km)	-0.0928	-0.1083	-0.0777	**<0.0001**
Lake Size:				
5-10 ha	0.3050	0.0538	0.5498	**0.0158**
10-50 ha	0.2811	0.0295	0.5261	**0.0264**
2-5 ha	0.2371	0.0470	0.4237	**0.0136**
Reference: <2 ha	**reference**			
>100 ha	-0.4258	-0.8313	-0.0507	**0.0319**
50-100 ha	-2.6279	-5.4904	-1.1026	**0.0094**
Cluster Lake Size:				
50-100 ha	0.3287	-0.0176	0.6628	0.0577
5-10 ha	0.2012	0.0388	0.3637	**0.0152**
Reference: 2-5 ha	**reference**			
10-50 ha	-0.0438	-0.2096	0.1220	0.6044
>100 ha	**-0.0485**	**-0.2745**	**0.1711**	**0.6691**

Bolded text indicate β estimate significance at $p < 0.05$

Dash (-) indicates perfect avoidance or selection, parameter estimate not available (approaches infinity)

Estimated β for distances to streams, lakes, clustered lakes measured in km and canopy cover % (negative coefficent represents selection).

NS results indicate non-significant ($p > 0.05$) Chi-squared goodness of fit tests (evidence of no selection)

* Indicates good model accuracy (ROC score >0.7)

APPENDIX 5d:

Variable classes, parameters and coefficient estimates (βi) for Fall-Early Winter RSF models (Design II, 100% model) for boreal caribou in the Snake-Sahtaneh range, British Columbia (n = 39). Model fit evaluated with log likelihood (-2LL) statistics and receiver operating characteristic (ROC) curves.

	β_i	Lower C.I. (95%)	Upper C.I. (95%)	*P*
Earth Cover Model				
Burn Regeneration	0.3281	0.0132	0.6454	**0.0411***
Reference: Woodland Needleleaf	**reference**			
Low Vegetation	-0.2663	-0.5324	-0.0002	**0.0498***
Open Needleleaf	-1.1934	-1.3428	-1.0441	**<0.0001***
Open Mixed Needleleaf-Deciduous	-1.2522	-1.6522	-0.8755	**<0.0001***
Tall Shrub	-1.7525	-2.2440	-1.3066	**<0.0001***
Cutblock	-1.9374	-4.8562	-0.2065	0.0704*
Other	-2.0064	-3.2245	-1.0693	**0.0002***
Wetlands and Waterbodies	-2.7069	-3.4644	-2.0800	**<0.0001***
Closed Mixed Needleleaf-Deciduous	-3.0734	-3.4477	-2.7306	**<0.0001***
Closed Needleleaf	-3.1197	-3.6405	-2.6637	**<0.0001***
Vegetation Resources Inventory Models				
Leading Species:				
Lodgepole Pine	0.4818	0.0836	0.8750	**0.0163**
Reference: Black Spruce-Tamarack	**reference**			
Other	-1.4460	-1.6422	-1.2576	**<0.0001**
Crown Closure (%)	-0.0294	-0.0326	-0.0262	**<0.0001**
Terrain and Hydrology Models				
Slope Class:				
Reference: SC1 (0.00-0.30°)	**reference**			
SC2 (0.31-0.60°)	-0.7205	-0.8581	-0.5829	**<0.0001**
SC4 (0.91° +)	-0.9869	-1.2619	-0.7254	**<0.0001**
SC3 (0.61-0.90°)	-0.9979	-1.2276	-0.7769	**<0.0001**
Distance to Nearest Stream (km)	0.2516	0.0417	0.4596	**0.0178**
Distance to Nearest Lake (km)	*NS*	*NS*	*NS*	*NS*
Distance to Nearest Cluster Lake (km)	-0.2226	-0.2439	-0.2020	**<0.0001***
Lake Size:				
5-10 ha	0.5259	0.2869	0.7603	**<0.0001**
2-5 ha	0.3953	0.2117	0.5789	**<0.0001**
10-50 ha	0.3537	0.1025	0.5984	**0.0051**
Reference: <2 ha	**reference**			
50-100 ha	-0.3687	-1.1582	0.3094	0.3189
>100 ha	-0.0449	-0.4002	0.2909	0.7983
Cluster Lake Size:				
50-100 ha	0.5201	0.1860	0.8446	**0.0019**
10-50 ha	0.3843	0.2317	0.5368	**<0.0001**
5-10 ha	0.0767	-0.0966	0.2500	0.3857
>100 ha	0.0252	-0.2023	0.2464	0.8257
Reference: 2-5 ha	**reference**			

Bolded text indicate β estimate significance at $p < 0.05$

Dash (-) indicates perfect avoidance or selection, parameter estimate not available (approaches infinity)

Estimated β for distances to streams, lakes, clustered lakes measured in km and canopy cover % (negative coefficent represents selection).

NS results indicate non-significant ($p > 0.05$) Chi-squared goodness of fit tests (evidence of no selection)

* Indicates good model accuracy (ROC score >0.7)

APPENDIX 5e:

Variable classes, parameters and coefficient estimates (βi) for Mid-Winter RSF models (Design II, 100% model) for boreal caribou in the Snake-Sahtaneh range, British Columbia (n = 38). Model fit evaluated with log likelihood (-2LL) statistics and receiver operating characteristic (ROC) curves.

	β_i	Lower C.I. (95%)	Upper C.I. (95%)	*P*
Earth Cover Model				
Reference: Woodland Needleleaf	**reference**			
Low Vegetation	-0.0164	-0.3461	0.3048	0.9212*
Open Needleleaf	-0.4389	-0.6164	-0.2614	**<0.0001***
Burn Regeneration	-0.4531	-0.9803	0.0334	0.0783*
Open Mixed Needleleaf-Deciduous	-0.8200	-1.3016	-0.3771	**0.0005***
Cutblock	-1.0997	-4.0195	0.6341	0.3048*
Other	-1.1687	-2.3898	-0.2265	0.0296*
Tall Shrub	-1.4409	-2.0765	-0.8888	**<0.0001***
Wetlands and Waterbodies	-1.5015	-2.1359	-0.9512	**<0.0001***
Closed Needleleaf	-1.7067	-2.1122	-1.3325	**<0.0001***
Closed Mixed Needleleaf-Deciduous	-2.3899	-2.8020	-2.0127	**<0.0001***
Vegetation Resources Inventory Models				
Leading Species:				
Lodgepole Pine	0.6285	0.1879	1.0518	**0.0042**
Reference: Black Spruce-Tamarack	**reference**			
Other	-1.5225	-1.7710	-1.2877	**<0.0001**
Crown Closure (%)	-0.0221	-0.0256	-0.0185	**<0.0001**
Terrain and Hydrology Models				
Slope Class:				
Reference: SC1 (0.00-0.30°)	**reference**			
SC3 (0.61-0.90°)	-0.6206	-0.8616	-0.3888	**<0.0001**
SC2 (0.31-0.60°)	-0.7907	-0.9599	-0.6244	**<0.0001**
SC4 (0.91° +)	-1.0501	-1.3960	-0.7290	**<0.0001**
Distance to Nearest Stream (km)	*NS*	*NS*	*NS*	*NS*
Distance to Nearest Lake (km)	-0.2747	-0.3644	-0.1876	**<0.0001**
Distance to Nearest Cluster Lake (km)	-0.1233	-0.1433	-0.1039	**<0.0001***
Lake Size:				
10-50 ha	0.4281	0.1496	0.6967	**0.0021**
Reference: <2 ha	**reference**			
5-10 ha	-0.0176	-0.3511	0.2964	0.9149
2-5 ha	-0.1923	-0.4535	0.0570	0.1393
>100 ha	-0.1944	-0.6334	0.2073	0.3627
50-100 ha	-0.6177	-1.6834	0.2205	0.1939
Cluster Lake Size:				
10-50 ha	0.6935	0.5170	0.8699	**<0.0001**
5-10 ha	0.4241	0.2249	0.6202	**<0.0001**
>100 ha	0.3974	0.1432	0.6437	**0.0018**
50-100 ha	0.0465	-0.4691	0.5119	0.8519
Reference: 2-5 ha	**reference**			

Bolded text indicate β estimate significance at $p < 0.05$

Dash (-) indicates perfect avoidance or selection, parameter estimate not available (approaches infinity)

Estimated β for distances to streams, lakes, clustered lakes measured in km and canopy cover % (negative coefficent represents selection).

NS results indicate non-significant (p>0.05) Chi-squared goodness of fit tests (evidence of no selection)

* Indicates good model accuracy (ROC score >0.7)

APPENDIX 6a:

Variable classes, parameters and coefficient estimates (βi) for Spring-Late Summer RSF models (Design II, 100% model) for wolves in the Snake-Sahtaneh boreal caribou range, British Columbia (n = 13). Model fit evaluated with log likelihood (-2LL) statistics and receiver operating characteristic (ROC) curves.

	β_i	**Lower C.I. (95%)**	**Upper C.I. (95%)**	***P***
Earth Cover Models				
Wetlands and Waterbodies	1.5842	1.1607	2.0113	**<0.0001**
Low Vegetation	0.6126	0.0804	1.1208	**0.0205**
Cutblock	0.5256	-2.4013	2.2801	0.6262
Burn Regeneration	0.2071	-0.6474	0.9389	0.6042
Open Mixed Needleleaf-Deciduous	0.1922	-0.4855	0.8036	0.5558
Tall Shrub	0.1044	-0.5968	0.7311	0.7560
Reference: Woodland Needleleaf	**reference**			
Closed Mixed Needleleaf-Deciduous	-0.0386	-0.4250	0.3523	0.8451
Open Needleleaf	-0.1298	-0.4613	0.2164	0.4518
Other	-0.2366	-2.0728	0.9989	0.7508
Closed Needleleaf	-0.3691	-0.8871	0.1229	0.1502
Vegetation Resources Inventory Models				
Leading Species:				
Lodgepole Pine	1.2697	0.6705	1.8133	**<0.0001**
Other	0.5229	0.3044	0.7393	**<0.0001**
Reference: Black Spruce-Tamarack	**reference**			
Crown Closure (%)	-0.0216	-0.0266	-0.0167	**<0.0001**
Terrain and Hydrology Models				
Slope Class:				
Reference: SC1 (0.00-0.30°)	**reference**			
SC2 (0.31-0.60°)	*NS*	*NS*	*NS*	*NS*
SC3 (0.61-0.90°)	*NS*	*NS*	*NS*	*NS*
SC4 (0.91° +)	*NS*	*NS*	*NS*	*NS*
Distance to Nearest Stream (km)	-3.8476	-4.6840	-3.0655	**<0.0001**
Distance to Nearest Lake (km)	-0.2367	-0.3677	-0.1128	**0.0003**
Distance to Nearest Cluster Lake (km)	0.0469	0.0267	0.0667	**<0.0001**
Lake Size:				
50-100 ha	0.6681	-0.1723	1.3809	0.0875
Reference: <2 ha	**reference**			
2-5 ha	-0.2675	-0.6629	0.0946	0.1649
>100 ha	-0.1896	-0.8422	0.3682	0.5357
10-50 ha	-1.0073	-1.8076	-0.3590	**0.0057**
5-10 ha	-1.1270	-1.9876	-0.4417	**0.0037**
Cluster Lake Size:				
>100 ha	0.9565	0.6334	1.2689	**<0.0001**
10-50 ha	0.6319	0.3552	0.9034	**<0.0001**
5-10 ha	0.5471	0.2500	0.8359	**0.0002**
50-100 ha	0.3449	-0.3851	0.9648	0.3116
Reference: 2-5 ha	**reference**			

Bolded text indicate β estimate significance at $p < 0.05$

Dash (-) indicates perfect avoidance or selection, parameter estimate not available (approaches infinity)

Estimated β for distances to streams, lakes, clustered lakes measured in km and canopy cover % (negative coefficent represents selection).

NS results indicate non-significant ($p > 0.05$) Chi-squared goodness of fit tests (evidence of no selection)

* Indicates good model accuracy (ROC score >0.7)

APPENDIX 6b:

Variable classes, parameters and coefficient estimates (βi) for Neonate season (May-June) RSF models (Design II, 100% model) for wolves in the Snake-Sahtaneh boreal caribou range, British Columbia (n = 12). Model fit evaluated with log likelihood (-2LL) statistics and receiver operating characteristic (ROC) curves.

	β_i	**Lower C.I. (95%)**	**Upper C.I. (95%)**	**P**
Earth Cover Models				
Wetlands and Waterbodies	1.5086	0.9372	2.0824	**<0.0001**
Cutblock	1.1795	-1.7672	2.9580	0.2782
Low Vegetation	0.7275	0.0290	1.3866	**0.0342**
Burn Regeneration	0.1679	-1.0712	1.1425	0.7604
Reference: Woodland Needleleaf	**reference**			
Open Mixed Needleleaf-Deciduous	-0.1093	-1.2074	0.7853	0.8262
Tall Shrub	-0.1172	-1.2152	0.7774	0.8140
Other	-0.2758	-3.1737	1.3270	0.7901
Open Needleleaf	-0.3409	-0.8045	0.1482	0.1590
Closed Mixed Needleleaf-Deciduous	-0.5674	-1.1816	0.0290	0.0643
Closed Needleleaf	-0.5906	-1.3777	0.1189	0.1178
Vegetation Resources Inventory Models				
Leading Species:				
Lodgepole Pine	1.3829	0.4833	2.1307	**0.0008**
Other	0.7696	0.4521	1.0858	**<0.0001**
Reference: Black Spruce-Tamarack	**reference**			
Crown Closure (%)	*NS*	*NS*	*NS*	*NS*
Terrain and Hydrology Models				
Slope Class:				
SC4 (0.91° +)	0.0790	-0.4583	0.5662	0.7610
Reference: SC1 (0.00-0.30°)	**reference**			
SC2 (0.31-0.60°)	-0.3043	-0.6564	0.0393	0.0858
SC3 (0.61-0.90°)	-1.0654	-1.8300	-0.4271	**0.0026**
Distance to Nearest Stream (km)	-3.3749	-4.5672	-2.2991	**<0.0001**
Distance to Nearest Lake (km)	-0.2225	-0.4201	-0.0404	**0.0216**
Distance to Nearest Cluster Lake (km)	0.0461	0.0164	0.0746	**0.0019**
Lake Size:				
50-100 ha	1.4446	0.5382	2.2045	**0.0006**
2-5 ha	0.2679	-0.2211	0.7108	0.2576
Reference: <2 ha	**reference**			
>100 ha	-0.1550	-1.2040	0.6518	0.7382
10-50 ha	-0.7905	-1.9769	0.0846	0.1230
5-10 ha	-1.4694	-3.2714	-0.3160	**0.0401**
Cluster Lake Size:				
>100 ha	1.2485	0.8010	1.6794	**0.0000**
10-50 ha	0.6761	0.2553	1.0846	**0.0013**
5-10 ha	0.6287	0.1815	1.0577	**0.0048**
50-100 ha	0.3350	-0.8691	1.2434	0.5237
Reference: 2-5 ha	**reference**			

Bolded text indicate β estimate significance at $p < 0.05$

Dash (-) indicates perfect avoidance or selection, parameter estimate not available (approaches infinity)

Estimated β for distances to streams, lakes, clustered lakes measured in km and canopy cover % (negative coefficent represents selection).

NS results indicate non-significant (p >0.05) Chi-squared goodness of fit tests (evidence of no selection)

* Indicates good model accuracy (ROC score >0.7)

APPENDIX 7a:

Variable classes, parameters and coefficient estimates (βi) for Spring-Late Summer RSF models (Design II, 100% model) for black bears in the Snake-Sahtaneh boreal caribou range, British Columbia (n = 7). Model fit evaluated with log likelihood (-2LL) statistics and receiver operating characteristic (ROC) curves.

	β_i	**Lower C.I (95%)**	**Upper C.I (95%)**	***P***
Earth Cover Models				
Cutblock	3.8986	2.9343	4.9493	**<0.0001***
Other	0.9029	-0.5704	2.0249	0.1585*
Tall Shrub	0.6560	-0.1495	1.3909	0.0915*
Open Mixed Needleleaf-Deciduous	0.5585	-0.2829	1.3152	0.1657*
Burn Regeneration	0.4711	-0.6392	1.3862	0.3521*
Low Vegetation	0.3657	-0.4727	1.1187	0.3619*
Closed Mixed Needleleaf-Deciduous	0.1791	-0.3393	0.7156	0.3445*
Reference: Woodland Needleleaf	**reference**			
Closed Needleleaf	-0.1741	-0.8694	0.4841	0.6111*
Wetlands and Waterbodies	-0.3209	-1.5565	0.6487	0.5584*
Open Needleleaf	-1.1081	-1.6851	-0.5312	**0.0001***
Vegetation Resources Inventory Models				
Leading Species:				
Other	1.3117	0.9819	1.6491	**<0.0001**
Reference: Black Spruce-Tamarack	**reference**			
Lodgepole Pine	-0.2098	-3.0892	1.3289	0.8366
Crown Closure (%)	-0.0195	-0.0272	-0.0119	**<0.0001**
Terrain and Hydrology Models				
Slope Class:				
SC4 (0.91° +)	0.4070	-0.0941	0.8714	0.0969
Reference: SC1 (0.00-0.30°)	**reference**			
SC2 (0.31-0.60°)	-0.3722	-0.7575	0.0014	0.0539
SC3 (0.61-0.90°)	-0.7278	-1.4231	-0.1307	**0.0258**
Distance to Nearest Stream (km)	*NS*	*NS*	*NS*	*NS*
Distance to Nearest Lake (km)	*NS*	*NS*	*NS*	*NS*
Distance to Nearest Cluster Lake (km)	-0.0657	-0.1072	-0.0269	**0.0013**
Lake Size:				
Reference: <2 ha	**reference**			
5-10 ha	-0.6087	-1.6533	0.1905	0.1864
2-5 ha	-1.4917	-2.6748	-0.6239	**0.0034**
10-50 ha	-1.5383	-3.3399	-0.3861	**0.0316**
>100 ha	-0.2101	-1.2583	0.5953	0.6500
50-100 ha	-	-	-	-
Cluster Lake Size:				
50-100 ha	1.6485	1.0928	2.1589	**<0.0001**
5-10 ha	0.6560	0.2713	1.0254	**0.0006**
Reference: <2 ha	**reference**			
10-50 ha	-2.5115	-4.3145	-1.3589	**0.0004**
>100 ha	-	-	-	-

Bolded text indicate β estimate significance at $p < 0.05$

Dash (-) indicates perfect avoidance or selection, parameter estimate not available (approaches infinity)

Estimated β for distances to streams, lakes, clustered lakes measured in km and canopy cover % (negative coefficent represents selection).

NS results indicate non-significant ($p > 0.05$) Chi-squared goodness of fit tests (evidence of no selection)

* Indicates good model accuracy (ROC score >0.7)

APPENDIX 7b:

Variable classes, parameters and coefficient estimates (βi) for Neonate season (May-June) RSF models (Design II, 100% model) for black bears in the Snake-Sahtaneh boreal caribou range, British Columbia (n = 7). Model fit evaluated with log likelihood (-2LL) statistics and receiver operating characteristic (ROC) curves.

	β_i	**Lower C.I. (95%)**	**Upper C.I. (95%)**	***P***
Earth Cover Models				
Cutblock	3.7444	2.3962	5.0603	**<0.0001***
Tall Shrub	1.4261	0.4849	2.3537	0.0023*
Open Mixed Needleleaf-Deciduous	0.6230	-0.6828	1.7355	0.2987*
Low Vegetation	0.8357	-0.2546	1.8421	0.1109*
Other	0.6797	-2.2459	2.3816	0.5234*
Closed Mixed Needleleaf-Deciduous	0.2769	-0.4949	1.1012	0.4912*
Wetlands and Waterbodies	0.2669	-1.2379	1.4669	0.6882*
Reference: Woodland Needleleaf	**reference**			
Burn Regeneration	-0.2629	-3.1791	1.4104	0.8033*
Closed Needleleaf	-0.1459	-1.2307	0.8526	0.7791*
Open Needleleaf	-1.2135	-2.1404	-0.3010	0.0086*
Vegetation Resources Inventory Models				
Leading Species:				
Other	1.4258	0.9465	1.9258	**<0.0001**
Reference: Black Spruce-Tamarack	**reference**			
Lodgepole Pine	-	-	-	-
Crown Closure (%)	-0.0146	-0.0258	-0.0037	**0.0093**
Terrain and Hydrology Models				
Slope Class:				
Reference: SC1 (0.00-0.30°)	**reference**			
SC2 (0.31-0.60°)	NS	NS	NS	NS
SC3 (0.61-0.90°)	NS	NS	NS	NS
SC4 (0.91° +)	NS	NS	NS	NS
Distance to Nearest Stream (km)	NS	NS	NS	NS
Distance to Nearest Lake (km)	NS	NS	NS	NS
Distance to Nearest Cluster Lake (km)	NS	NS	NS	NS
Lake Size:				
Reference: <2 ha	**reference**			
2-5 ha	NS	NS	NS	NS
5-10 ha	NS	NS	NS	NS
10-50 ha	NS	NS	NS	NS
50-100 ha	NS	NS	NS	NS
>100 ha	NS	NS	NS	NS
Cluster Lake Size:				
50-100 ha	1.3431	0.4382	2.1001	**0.0013**
5-10 ha	0.5019	-0.0758	1.0376	0.0754
Reference: 2-5 ha	**reference**			
10-50 ha	-2.5127	-5.3879	-0.9901	**0.0130**
> 100 ha	-	-	-	-

Bolded text indicate β estimate significance at $p < 0.05$

Dash (-) indicates perfect avoidance or selection, parameter estimate not available (approaches infinity)

Estimated β for distances to streams, lakes, clustered lakes measured in km and canopy cover % (negative coefficent represents selection).

NS results indicate non-significant (p >0.05) Chi-squared goodness of fit tests (evidence of no selection)

* Indicates good model accuracy (ROC score >0.7)