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Assessing Spatial Factors Affecting Predation Risk to Boreal Caribou Calves: Implications for Management

2011 Annual Report

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EXECUTIVE SUMMARY

Boreal caribou (*Rangifer tarandus caribou*) are federally listed as *Threatened* due to population declines across much of their distribution. Low rates of calf recruitment (defined here as survival to one year of age) is a primary demographic factor influencing declines in many boreal caribou herds. In partnership with industry, government and conservation organizations, we initiated this project to assess spatial factors affecting predation risk to calves of boreal caribou in north-eastern British Columbia. For the project's first year, our primary objectives were to correlate female movement patterns to calving events, evaluate calving habitat selection and follow calf survival through the neonate period (six weeks of age).

We deployed GPS radio-collars on 25 female caribou in four caribou ranges near Fort Nelson, BC in areas that capture the range of landscape variation within the study area. Beginning May 7, 2011, we performed weekly aerial surveys of these caribou, visually observing each female at least three times during the calving season (last survey July 17th, 2011). Through movement and GIS analyses, we identified calving events and located calving sites. By the end of the calving season, we documented 20 calving events with the first calving event occurring April 29 and the last on June 2, 2011. Five calving sites were located outside of current boundaries delineating boreal caribou range.

We assessed fine-scale vegetation characteristics at a subset of calving sites and developed resource selection functions at a landscape scale to evaluate whether female caribou select calving habitat to reduce predation risk or optimize forage quality. Calving sites were predominantly located in tree bogs or nutrient-poor fens with relatively open canopies compared to winter locations. The overall low abundance of forage plants at calving sites suggests that forage quality and availability are not important attributes in calving site selection. During the calving season, caribou generally exhibited increased avoidance of uplands and anthropogenic disturbance, supporting the hypothesis that caribou select calving habitat to reduce predation risk. This pattern of avoidance, however, was not exclusive to females with calves as barren cows showed similar behavior. Surprisingly, the avoidance behavior was limited to proximity to disturbed areas and not the density of disturbance within a patch as caribou showed apparent selection for areas of high linear feature density during the calving season.

Of the 20 calves born, we estimated seven to have survived to the last survey on July 17, 2011, yielding a calf: cow ratio of 28 calves:100 cows for the study area. Seven calves were lost prior to reaching four weeks of age. Calf survival through the neonate period was positively correlated with pre-calving movement, supporting the hypothesis that female caribou become highly dispersed at calving to reduce predation risk. Maternal selection of habitat had no discernible effect on the probability calf survival through the neonate period, though this finding is likely confounded by the low statistical power of our preliminary data from the project's first year.

From a management perspective, our first year results suggest that: i) the boundaries of the Parker and Prophet ranges may need to be revised to included potentially important calving areas; ii) female boreal caribou require large patches of treed bogs or nutrient-poor fens during the calving season; ii) these patches should have large interior core areas with minimal to no disturbance; iii) identifying movement corridors between winter ranges and highly used calving areas should be a priority; and iv) the apparent inability of caribou to perceive variation in linear feature density may confound management strategies that seek to set aside protected areas within caribou ranges.

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INTRODUCTION

Boreal caribou, an ecotype of woodland caribou, are federally listed as *Threatened* under Schedule 1 of the Species at Risk Act due to population declines across much of their distribution (EC 2011). For many populations, a low rate of calf recruitment is a key demographic factor contributing to population declines, primarily caused by elevated predation rates of calves ((Stuart-Smith *et al.*, 1997); McLoughlin *et al*., 2003; EC 2008). While predation is the proximate cause of calf mortality, increased predation rates of caribou have been ultimately linked to increasing levels of landscape alteration within caribou ranges (James & Stuart-Smith, 2000; Courtois *et al*. , 2007; EC 2008; BCCDC 2010). With increasing landscape disturbance, predator numbers increase in response to increasing populations of other ungulates (e.g., moose (*Alces alces*)) that are in turn facilitated by an increasing extent of early seral forest. The positive numeric response of predators, in combination with enhanced hunting efficiency created by linear feature disturbance within caribou ranges (James & Stuart-Smith, 2000; Whittington *et al*., 2011), increases the probability of predator-caribou encounter and consequently leads to increased predation of caribou.

In British Columbia, boreal caribou ranges have been impacted by activities related to natural resource extraction (Thiessen 2009, Culling & Cichowski 2010). Sustained low rates of calf recruitment have been reported for most ranges with a significant proportion of calf morality occurring during the neonate period (0-6 weeks old; Culling & Cichowski 2010). In many years, exceedingly high rates of neonate mortality cause cow-calf ratios to fall below thresholds associated with population stability by the end of June (e.g. < ~29 calves:100 cows; EC 2008, Culling & Cichowski 2010), indicating that neonate period plays an important role in caribou population dynamics.

We initiated this project as a collaborative effort among industry, government, academia, and non-governmental organizations to evaluate spatial factors thought to influence predation risk to caribou calves in northeastern BC. With a three-year timeline, our overall objectives are to identify key characteristics of caribou calving habitat, assess predator habitat use during the critical neonate time period, and determine the relative importance of biotic and abiotic factors influencing neonate calf survival. Results from these analyses will be used to develop novel and comprehensive management strategies for reducing predation risk to caribou by taking into account the spatial requirements of caribou during the calving season.

For the project's initial year, we first assessed a method for identifying calving events based on female movement patterns then evaluated calving habitat selection. Because calf survival is tightly linked to maternal choices of habitat, management strategies to increase calf survival rates in human-altered landscapes will require an understanding of the selection and use of habitat by females during the calving season. To maximize reproductive success, maternal selection of calving habitat frequently involves a trade-off between reducing predation risk and finding sufficient forage to meet maternal nutritional demands (Berger, 1991; Rachlow & Bowyer, 1998; Bowyer *et al*. 1999; Gustine *et al*., 2006). Female boreal caribou are hypothesized to use a "spacing out" strategy to reduce predation risk to their calves, becoming over-dispersed at calving to reduce encounter rates with predators (Bergerud & Page, 1987). Within this strategy, however, it is not well understood whether females select calving sites and ranges that further reduce predation risk (predation risk hypothesis) or if they move into habitats of higher forage quality to meet maternal demands (forage quality hypothesis). Because the primary winter forage of boreal caribou – lichen – is relatively protein-poor (Parker *et al*., 2005), females enter the calving season at a protein deficit. Consequently, parturient females may be forced to select calving habitat with slightly higher forage quality (e.g. moving from bogs to nutrient-rich fens; Richardson *et al*. 1978) – and potentially increased predation risk – to meet the additional protein demands of lactation (Parker *et al*. 2009).

We assessed calving habitat selection by determining the relative influence of the predation risk and forage quality hypotheses. Because habitat selection is a hierarchical process (Johnson 1980) – and because neonate survival is not limited to only calving site selection *per se*, we assessed these competing hypotheses at two spatial scales: the calving site and the calving range. We predicted that if reducing prediction risk was more influential in calving habitat selection, then: i) calving sites would be located in areas of high forest cover within large patches of black spruce bogs, which provide a relative refuge from predators (Latham 2009); ii) calving ranges would be comprised of predominantly black spruce bogs; iii) calving site and range locations would be situated further away from natural or anthropogenic disturbance than random locations; and iv) calving ranges would have an overall low density of disturbance. Conversely, if female caribou were selecting for higher forage quality to meet maternal nutritional demands, we predicted that: i) calving sites and ranges would have higher forage quality and abundances than winter locations; and ii) calving sites and ranges would have higher forage quality and abundances compared to locations used by barren females during the calving season.

Management strategies based on resource selection are most effective when resource selection is linked to demographic performance (McLoughlin *et al*. 2007, 2010; Dzialak *et al*., 2011). We therefore evaluated the impact of maternal selection of calving habitat on the probability of calf survival through the neonate period. Because of accumulated evolutionary pressures, maternal selection of calving habitat in intact landscapes should reflect conditions that optimize calf survival (McLoughlin *et al*., 2007); however, if landscape alteration is a key driver in elevated predation rates of caribou calves, then female caribou may have not yet adapted to perceive those habitat features that are now most influential in determining calf survival. Consequently, we predicted that the habitat features most important in predicting neonate calf survival would differ from those features most important in determining maternal selection of calving habitat by female boreal caribou in northeastern BC.

METHODS

Study Area
Boreal caribou occur in the extreme northeast corner of British Columbia, an area bounded by the northern Rocky Mountains to the west, the Alberta border to the east, the Northwest Territories to the north, and to the south by the agricultural zone that extends northward from Fort St. John, BC. This distribution encompasses six recognized caribou ranges – Calendar, Chinchaga, Maxhamish, Parker, Prophet and Snake-Sahtaneh (Culling *et al*., 2006, Culling & Cichowski, 2010). Within each range, caribou predominantly use core habitat areas, identified as areas of high caribou use (e.g. >90% of locations from radio-collared animals fall within these core areas; Culling *et al*. 2004). Our study area includes the entirety of the Parker and Prophet ranges as well as three core areas within the Maxhamish range (Capot Blanc, Fortune, and Kiwigana) and two core areas in the Snake-Sahtaneh range (Clarke and Paradise; Appendix 1).

The study area is comprised of a single biogeoclimatic zone, Boreal White and Black Spruce, and lies within the Taiga Plains ecoprovince (DeLong *et al*., 1991). Terrain is predominantly flat to undulating, with elevation varying from 410 m in Fort Nelson to 700 m on the Etsho Plateau (Ferbey *et al*., 2005). Climate is northern continental, characterized by long, cold winters and short summers (EC 2010). The landscape is a mosaic of deciduous and mixed-wood uplands, poorly drained low-lying peatlands, and riparian areas (DeLong *et al*., 1991). Common upland tree species include white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*), trembling aspen (*Populous tremuloides*), and paper birch (*Betula papyrifera*). Low-lying peatlands are characterized by black spruce (*Picea mariana*) intermixed with stands of tamarack (*Larix laricina*). Forest fire is a frequent form of natural disturbance on the Taiga Plains with a mean fire interval of ~30-65 years (Bothwell *et al*., 2004).

The study area is further notable because it contains portions of the Horn River Basin (HRB), a geologic formation that holds the largest natural gas shale field in Canada (EMPR, 2007). Centered approximately 55 km northeast of Fort Nelson, BC, the HRB is a triangular-shaped area of ~ 7107 km^2. It spans parts of the Maxhamish, Parker and Snake-Sahtaneh ranges and contains significant parts of six caribou core areas (Fortune, Kiwigana, Paradise, Parker, Tsea and West Kotcho cores). With recent advances in hydraulic fracturing technology now making shale gas extraction feasible and economical, the HRB has been impacted to varying degrees by anthropogenic disturbance related to oil and gas exploration (Thiessen, 2009). Moreover, the area could see an even greater increase in oil and gas development in the next few years as record sales of oil and gas land rights were recently granted (EMPR 2007, 2010).

Caribou Capturing
To track female caribou movements during the calving season, we captured and affixed Iridium GPS radio-collars (Advanced Telemetry Systems, Model #G2110E) to female caribou distributed throughout the study area. The Iridium technology allows the radio-collared animals to be followed remotely as GPS location data is transmitted by email via satellite. Collars were pre-programmed for a fix-rate of every two hours during the calving season (April 15 – July 15) and

once per day otherwise, a schedule that allows for the collars to be operating through an estimated three calving seasons.

Within the study area, we focused capture efforts on the Capot Blanc, Clarke, Kiwigana, Parker, and Prophet core areas because (i) these cores are representative of the range of variation in landscape alteration within northeastern BC; and (ii) the proximity of these cores to Ft. Nelson will reduce overall flying time and therefore limit project expenses. To capture caribou, we used a fixed-wing aircraft on the first day to scout the five core areas to locate previously collared caribou (collars deployed by BC Ministry of Forests, Lands, and Natural Resource Operations) and look for fresh caribou tracks. On subsequent days, we used a Bell 206 Jet Ranger helicopter to fly to previously located caribou and individual females were captured using a net gun fired from the helicopter. For each captured animal, we collected hair, blood and fecal samples in addition to attaching the radio-collar. The capture team consisted of C. Thiessen (net-gunner), C. DeMars and M. Koloff, a helicopter pilot from Qwest Helicopters. All animals were captured and handled in accordance with approved provincial and institutional animal care protocols (BC RIC 1998; University of Alberta Animal Use protocol # 748/02/12).

Calf Surveys

We conducted weekly aerial surveys from May 7 to June 30, 2011 to assess calving rates, identify calving sites and determine neonate calf survival. One additional survey was flown on July 17, 2011 to determine survival of those remaining calves that had not yet reached six weeks of age as of June 30, 2011. The initial survey (May 7th) was conducted in a fixed-wing aircraft; however, because we were unable to visually locate any of the collared caribou from the fixed-wing, we used a Bell 206 Jet Ranger helicopter for all subsequent surveys. Prior to each survey, we established a survey priority list using location data from the Iridium GPS collars fitted on each cow. We graphically assessed average daily movement rates (m/hour) and gave the highest priority to those cows exhibiting significant changes in daily movement patterns. During each survey, we recorded the geographic location of each cow, the time of observation, and visually determined calf presence or absence. We also recorded the dominant habitat type of the location (based on Culling *et al*. 2006), the percent forest cover and snow cover in a 100-m radius, and the geographic coordinates of all beaver lodges in a 1-km radius. We attempted to locate all cows at least twice during the calving season. For cows with apparently lost calves (e.g., calf present on one survey then absent on the next survey), we confirmed calf absence by re-locating these animals on 1-2 subsequent surveys. To confirm pregnancy status of cows not seen with a calf during the calving season, we submitted blood samples taken from each animal during capture for progesterone analyses (analyses performed by Prairie Diagnostic Services, Saskatoon, SK). Animals with progesterone levels of ≥2.0 ng/ml were considered to be pregnant.

Calving Habitat Selection

We assessed calving habitat selection by female caribou at two scales: fine-scale selection of calving sites and broader-scale selection of calving ranges. At both scales, we evaluated whether caribou select calving habitat to reduce predation risk or optimize forage quality. At the fine-scale, we collected habitat data at all calving sites that we could reasonably reach by foot or helicopter. For each calving site sampled, we collected the same data from a winter site (e.g., GPS location between March 15 and April 15, 2011) used by the same animal. Because of the inaccessibility of some caribou locations, winter sites were randomly selected from the subset of sites that we could reasonably reach by foot or helicopter. Using data from the Iridium GPS collars, we identified calving events as periods where female movement rates dropped below 50-m/hour for at least 48 hours (Culling *et al.* 2006) and recorded the geographic location of such events. Calving sites were only accessed after the cow had moved at least 1-km from the site. In the field, we identified calving sites by a circular depression in the substrate that was frequently accompanied by caribou scat (Appendix 2). At each site, we recorded the dominant habitat type and the leading tree species. To assess habitat structure, we calculated tree basal area (m^2/ha) using angle gauges and estimated percent crown closure by averaging measurements taken at 5-m intervals along a 50-m transect (see below) centred on the site. We also assessed concealment cover using a 2-m cover pole (Bowyer *et al.* 1999), averaging the number of 10-cm segments covered by vegetation or topographic features when viewed from a distance of 10-m in four cardinal directions. To assess relative forage abundance, we measured shrub cover, ground cover and arboreal lichen cover. For shrub and ground cover, we used the line transect method (Bowyer *et al*., 1999; Canfield, 1941), placing a 50-m transect centred on the site. At each 1-m interval, we recorded the dominant ground cover (bare ground, dwarf shrub, graminoid, forb, lichen, moss, water, or wood debris) and any shrub species contacting the line. To evaluate forage quality, we collected vegetation samples by clipping all graminoids, forbs and shrub leaves from 0.25 m^2 quadrats placed at 5- and 20-m away from the site along the transect (4 total samples per site). Because boreal caribou also forage on arboreal lichen, we visually estimated arboreal lichen cover by averaging the extent of lichen cover up to 2.5-m in height of the five trees closest to the site centre that had a diameter-at-breast height of >5-cm (Armleder *et al*., 1992). To assess the relative importance of potential forage species to caribou during the calving season, we collected scat samples opportunistically from calving sites for subsequent dietary analysis and comparison to scat collected from these animals during their winter capture (samples analyzed by Washington State University Wildlife Habitat Nutrition Lab).

At the calving range scale, we developed resource selection functions (RSFs; Manly *et al.* 2002) in a GIS framework to assess calving habitat selection. We estimated RSFs of the form

$$\omega(x_i) = \exp(\beta_1 x_1 + \beta_2 x_{2\,+} \ldots \beta_n x_n) \qquad \text{Eqn. 1}$$

where $\omega(x_i)$ is the relative probability of use of a sample unit (or pixel) in category *i* as a function of *a priori* covariates thought to influence selection and their estimated coefficients (β) from logistic regression. To account for heterogeneity in selection among individual caribou, we used generalized linear mixed-effects models (Zuur *et al.* 2009) to estimate RSFs, assigning individual caribou as a random effect and thereby creating a random intercept for each caribou. To assess how caribou are selecting calving habitat within the study area, we evaluated selection at the third-order or home range scale (Johnson 1980) in a use-availability design where availability is defined for each individual caribou (Manly *et al.* 2002). For those caribou that calved, we delineated availability for each caribou by generating minimum convex polygons (MCPs) around GPS locations from three distinct movement periods: late winter (Mar 15 – Apr 14), pre-calving (Apr 15 to estimated calving date) and calving (calving date to four weeks post-calving or estimated date of calf loss – see *Calf Survival Analyses* below). For each movement period, we calculated the mean step length (distance travelled between successive GPS locations) for each individual, buffered the relevant MCP by this amount then merged the three buffered MCPs into one polygon. Within each of these larger polygons, we characterized availability by generating random points equal to twice the number of used locations for each individual (range: 70-672 random points per individual).

We also estimated two latent selection difference functions (LSDs; Latham *et al.* 2011) to assess whether parturient caribou shift to an identifiable calving habitat during the calving season. LSDs take the same form as RSFs (Equation 1 above) however in LSDs the estimated β coefficients are now interpreted as relative selection differences between the predefined categories of the response variable. We used generalized linear mixed effects models to estimate the two LSDs with individual caribou modelled as a random effect. For the first LSD, we compared winter locations (Mar 15 – Apr 14; coded as 0) to calving range locations (calving date to four weeks post-calving or estimated date of calf loss; coded as 1) to assess for potential selection differences between the two time periods. Because the GPS fix schedule differed between the two periods (once per day for winter, 12 times per day for calving), we selected only one location per day during the calving period, resulting in an equal number of winter and calving locations for each caribou. For the second LSD, we compared locations of cows with calves to cows without calves to determine whether shifts in habitat selection between late winter and spring are seasonal (e.g. all female caribou shift to spring habitats) or driven by pregnancy status (only cows with calves shift to identifiable calving habitat). For cows without calves, we used locations from May 15 (estimated peak calving date; Culling *et al.* 2006) to June 14. We used results of these LSD analyses in combination with the fine-scale calving site data to explicitly evaluate whether caribou were selecting calving habitats to further reduce predation risk or optimize forage quality.

For each RSF and LSD analysis, we evaluated three categories of models – a Land Cover model, a Forest Structure model, and a suite of Landscape Pattern models – using explanatory variables derived from a variety of data sources. For the Land Cover Model, we used Enhanced Wetlands Classification (EWC) GIS data developed by Ducks Unlimited Canada (DU 2010; Appendix 6). The EWC data has a resolution of 30-m and contains 25 classes of vegetation cover that were developed from Landsat 5 Thematic Mapper and Landsat 7 Enhanced Thematic Mapper Plus imagery. Because some of the 25 categories were rare on the landscape (<2%) and by themselves were not biologically meaningful to caribou, we collapsed the EWC data into 13 categories of vegetation cover (Table 1). For the Forest Structure model, we extracted the leading tree species and percent crown cover from Vegetation Resource Inventory data available from the BC Ministry of Forests, Lands and Natural Resource Operations (see Appendix 6). Based on the tree species occurring in the study area, we collapsed the leading tree species data into eight broad categories (Table 2).

Table 1: Classification of land cover types used to model resource selection by boreal caribou in northeastern BC. Land cover types were developed from Ducks Unlimited Enhanced Wetlands Classification data clipped to the distribution of boreal caribou within BC (see Appendix 6).

Land cover	EWC Class	Description
Treed bog	Treed bog	Black spruce dominated bogs (25-60% tree cover) with no hydrodynamic flow. Areal coverage: ~13%
Open bog	Open bog, Shrubby bog	*Spaghnum* moss dominated bogs with <25% tree cover. Areal coverage: ~3%
Nutrient poor fen	Graminoid poor fen, Shrubby poor fen, Treed poor fen	Low nutrient peatland soils influenced by groundwater flows. Treed poor fens dominate, comprised of black spruce, tamarack and bog birch (25-60% tree cover). Areal coverage: ~20%
Nutrient rich fen	Graminoid rich fen, Shrubby rich fen, Treed rich fen	Low nutrient peatland soils influenced by groundwater flows. Shrubby fens dominate, comprised of bog birch, willow and alder. Areal coverage: ~4%
Conifer swamp	Conifer swamp	Tree cover >60% dominated by black or white spruce. Occur on peatland or mineral soils. Areal coverage: ~8%
Hardwood swamp	Shrub swamp, Hardwood swamp, Mixedwood swamp	Mineral soils with pools of water often present. Dominant tree species include paper birch and balsam poplar. Dominant shrubs: alder and willow. Areal coverage: ~11%
Upland conifer	Upland conifer	Mineral soils with tree cover >25%. Dominant tree species: black spruce, white spruce and pine. Areal coverage: ~12%
Upland mixedwood	Upland mixedwood	Mineral soils with tree cover >25%. Mix of conifer and deciduous tree species. Areal coverage: ~8%
Upland deciduous	Upland deciduous	Mineral soils with tree cover >25% and >75% of trees are deciduous. Dominant tree species: aspen and paper birch. Areal coverage: ~14%
Aquatic	Open water, Aquatic bed, Mudflats, Emergent marsh, Meadow marsh	Includes a continuum of aquatic classes from low turbidity lakes to emergent marshes where aquatic vegetation is >20% of the cover. Areal coverage: ~2%
Burn	Burn	Recent burns where vegetation is limited or covered by burn litter. Areal coverage: ~2%
Anthropogenic	Anthropogenic	Urban areas, houses, roads and cut blocks. Areal coverage: ~2%
Other	Upland other, Cloud shadow	For uplands, mineral soils with tree cover <25%. Areal coverage: ~1% (Cloud shadow <0.5%)

Table 2: Classes of leading tree species used to model resource selection by boreal caribou in northeastern BC. Classes were developed from Vegetation Resource Inventory data (see Appendix 6) clipped to the distribution of boreal caribou within BC.

Leading Tree Species Class	VRI Tree Species
Black spruce	Black spruce (*Picea mariana*)
Tamarack	Tamarack (*Larix larix*)
White spruce	White spruce (*Picea glauca*), Spruce (*Picea* sp.), Spruce hybrid (*Picea* x sp.)
Pine	Lodgepole pine (*Pinus contorta*)
Fir	Alpine fir (Abies *lasiocarpa*), True fir (*Abies* sp.), Cedar (*Thuja plicata*), Yew (*Taxus brevifolia*)
Aspen	Aspen (*Populus tremuloides*)
Balsam poplar	Balsam poplar (*Populus balsamifera*)
Birch	Paper birch (*Betula papyrifera*), Willow (*Salix* sp.)
None	No tree cover

For Landscape Pattern models, we used data from multiple resources (Table 3; Appendix 6). We obtained forest cut block and fire data as well as geophysical feature data (rivers, lakes, forestry roads and major roads) from the BC Geographic Data Discovery Service, which is a service of the BC Integrated Land Management Bureau. From the BC Oil and Gas Commission, we obtained shapefiles describing well sites, pipelines, seismic lines (1996 to present) and secondary petroleum development roads. To further assess the impact of linear features (seismic lines, pipelines, roads, etc.) on the landscape, we used a shapefile obtained from BC Terrain Resources Information Management data. This shapefile represents all linear features visible on the landscape from 1992 aerial photos but does not classify a particular linear feature by type or age. Because of the potential overlap between the OGC and TRIM line data, we conducted separate analyses with each of these data sets. We used the above data to calculate the relative distance of caribou locations to natural and anthropogenic features compared to random points. We also developed patch-scale models to assess whether caribou were responding to the relative size of a habitat patch – with patch boundaries based on the Land Cover categories used above – and the density of linear features within a particular patch. We included interaction terms between patch type (binary variable with calving habitat coded as 1 and defined by the Land Cover model above) and area and between patch type and linear feature density per patch to specifically assess caribou response within habitats used during the spring calving season. Because our analyses in the first year of the project are exploratory in nature, we assessed a suite of Landscape Pattern models in order to evaluate caribou response to all landscape pattern variables rather than one global model where collinearity among variables would force one or more variables to be dropped from the analysis.

Table 3: Landscape pattern variables used to model resource selection by boreal caribou in northeastern BC (see Appendix 6 for data sources).

Variable	Description
Dist. To Upland	Euclidean distance from caribou GPS location to upland habitat
Dist. To River	Euclidean distance from caribou GPS location to nearest river or stream
Dist. To Lake	Euclidean distance from caribou GPS location to nearest lake
Dist. To Fire pre59	Euclidean distance from caribou GPS location to forest fires occurring before 1959
Dist. To Fire 60-99	Euclidean distance from caribou GPS location to forest fires occurring between 1960 and 1999
Dist. To Fire 00-10	Euclidean distance from caribou GPS location to forest fires occurring between 2000 and 2010
Dist. To Cut block	Euclidean distance from caribou GPS location to nearest forest cut block
Dist. To Pipeline	Euclidean distance from caribou GPS location to nearest pipeline polygon
Dist. To Seis. Line 06	Euclidean distance from caribou GPS location to nearest seismic line created between 2006-10
Dist. To Seis. Line 01	Euclidean distance from caribou GPS location to nearest seismic line created between 2001-05
Dist. To Seis. Line 96	Euclidean distance from caribou GPS location to nearest seismic line created between 1996-2000
Dist. To Roads	Euclidean distance from caribou GPS location to nearest road
Dist. To All OGC Lines	Euclidean distance from caribou GPS location to nearest linear feature. Combines Dist. To Roads and all three Dist. To Seis Line variables
Dist. To TRIM Lines	Euclidean distance from caribou GPS location to nearest linear feature regardless of age or type
Dist. To All Wells	Euclidean distance from caribou GPS location to nearest well site (active or retired)
Dist. To Active Wells	Euclidean distance from caribou GPS location to nearest active well site
Patch Area	Area of a land cover patch as defined by vegetation boundaries
Patch Type	Land cover class (see Table 1) of patch
OGC Line Density	Line density per patch using OGC data to define linear feature footprint
TRIM Line Density	Line density per patch using TRIM data to define linear feature footprint.

Calf Survival Analyses

To assess how maternal selection of calving habitat affects neonate calf survival, we evaluated the same suite of models – Land Cover, Forest Structure and Landscape Pattern models – in a Cox proportional hazards framework (Cox 1972). The Cox model typically takes the form

$$h_i(t) = h_0(t)\exp(\beta_1 x_{i1} + \beta_2 x_{ik} + \ldots\ldots + \beta_k x_{ik}) \qquad \text{Eqn. 2}$$

where $h_i(t)$ is the hazard function for individual *i* at time *t*, $h_0(t)$ is an unspecified baseline hazard function and the *x*'s are explanatory covariates. In this formulation, the exponentiated β coefficients are interpretable as hazard ratios and, in our context, ratios >1.0 indicate an increasing risk of mortality with increasing values of the associated covariate. We used a time-to-event approach and therefore considered all GPS locations from the estimated calving event until the estimated time of calf loss or, if the calf survived, until the last survey date. We estimated the time of calf loss by evaluating female movement patterns, focusing specifically within the interval between the date when the calf was last seen alive and the following survey when the calf was absent (Fig. 1). We inferred calf loss as the time interval where female movement rates showed a sharp increase from baseline with-calf movement rates (mean = 142 m/hr) to rates at or above pre-calving levels (mean = 415 m/hr) that were sustained for >1 day. We did not explicitly model the probability of calf detection as we had no instances where a cow with an apparently lost calf was observed with a calf on a subsequent survey (see *Results* below).

Because survival probabilities can be affected by multiple factors, we also considered a model that included variables representing heterogeneity in individual movement behaviour and time since the first calving event. For each cow, we calculated the Euclidean distance (m) travelled two weeks prior to calving. After calving, we estimated the mean daily movement rate (m/hr) of the cow-calf pair and the Euclidean distance (m) the pair had travelled from the calving site at the end of each day.

Data Analyses

All statistical analyses were performed in R, version 2.13 (R Development Core Team, 2011). To assess for differences in fine-scale characteristics between winter sites and calving sites, we used paired two-sample *t*-tests and, where the data violated the assumption of normality, permutation tests. We used the R package 'lme4' (Bates *et al.*, 2011) for estimating RSFs and LSDs with generalized linear mixed-effects models. Cox proportional hazards models were implemented using the R package 'survival' (Therneau & Lumley 2011). Prior to modelling, all continuous variables were standardized to improve model convergence.

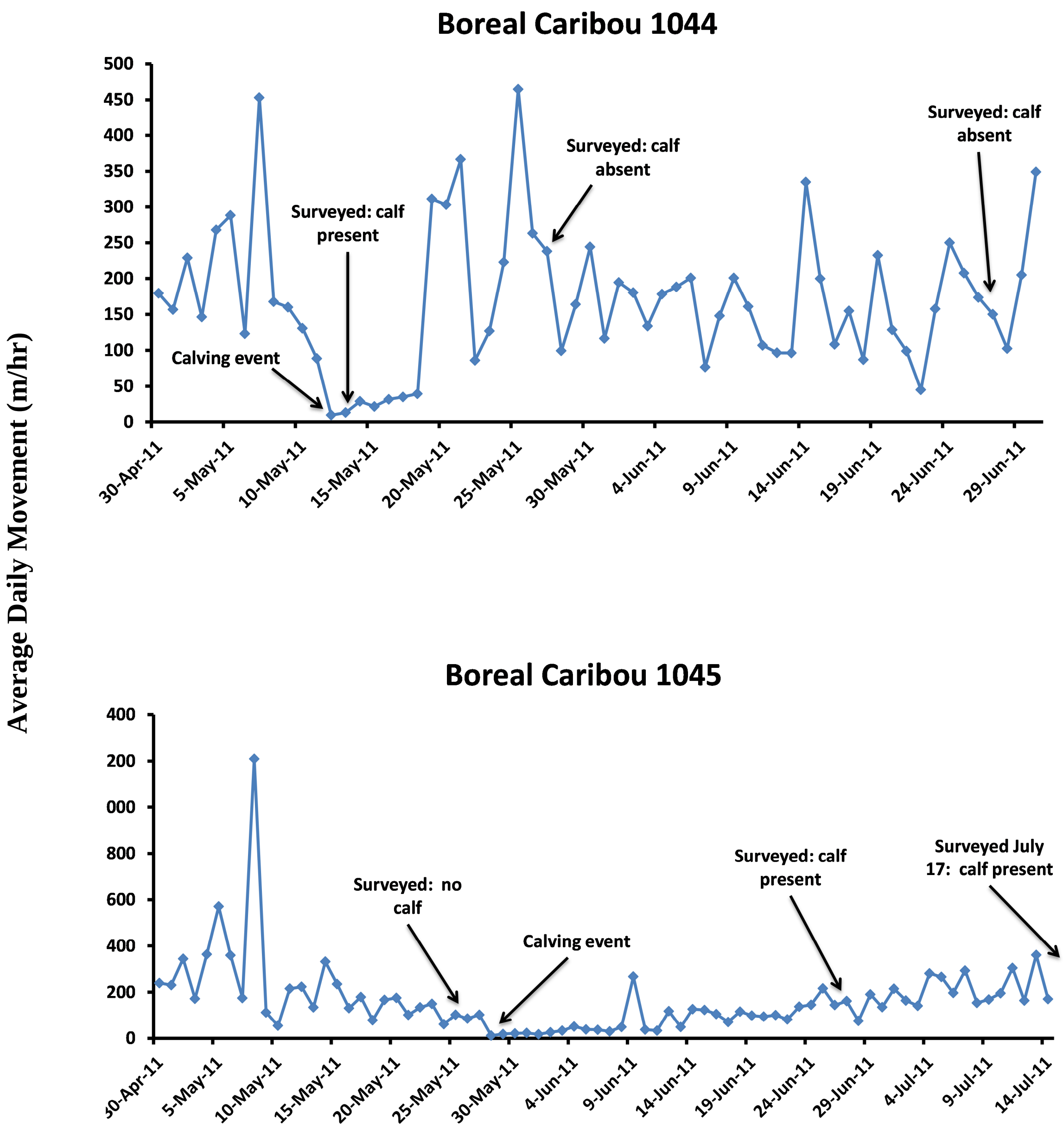

Figure 1: Daily movement patterns of two female caribou in the Prophet range during the 2011 calving season. Calving events are identified by movement rates of <50-m hr for at least 48 hours.

RESULTS

Caribou Capturing

Caribou capture and collaring occurred from February 23rd to March 2nd, 2011. We successfully captured and collared 25 female caribou in seven days of capture effort (including the first day of scouting with the fixed-wing aircraft). We deployed four collars in Capot Blanc, four in Clarke, five in Kiwigana, five in Parker, six in Prophet and one in a new area situated just north of Fort Nelson (Appendix 3). All animals were captured and processed safely with no injuries or mortalities to any animals. As of Oct. 30th, 2011, all collars were functioning properly and no mortalities have been recorded.

Calf Surveys

We visually confirmed calves with 19 of the 25 collared females. As expected, probable calving events identified on pre-survey movement analyses correlated with visually confirming calf presence (Fig. 1). In five instances, we were able to survey calves less than three days old. The average movement rate of cows for the first 48 hours following a calving event was 10-m/hour. In comparison, female caribou averaged 209-m/hour for the last two weeks in April prior to calving. Based on movement and progesterone analyses, one other cow is suspected of having calved but was never seen with a calf during any aerial survey. Five cows had progesterone levels <2.0 ng/ml indicating that they were not pregnant and none of these animals exhibited a movement pattern suggestive of a calving event.

A number of females made significant pre-calving movements (Table 4). Two females moved into different core areas just prior to calving, including one cow that travelled 85-km from the south-western part of the Kiwigana core to calve in the Fortune core just south of Maxhamish Lake (Appendix 4). These movements resulted in females being more highly dispersed at calving. For example, the mean distance between the six Prophet females on March 30, 2011 was 8.7-km whereas the mean distance between these same animals on May 15, 2011 was 32.8-km.

The first calving event occurred on April 29, 2011 with the peak calving date estimated to be approximately May 15th (Fig. 2). Six of the calving sites were located outside of core areas currently established for boreal caribou (Appendix 5). Of these six sites, five were outside current boundaries of caribou ranges with four belonging to Prophet animals.

On the final aerial survey conducted July 17, 2011, six female caribou were confirmed to still have a calf. We were unable to confirm calf status on one other cow after her calf had reached four weeks of age as we could not visually locate this cow on two subsequent survey attempts, possibly due to a weak VHF signal from her radio-collar. Assuming this calf to still be alive, the estimated calf-to-cow ratio across the study area as of July 17, 2011 is 28 calves per 100 cows. At the range level, four of the remaining calves were in the Prophet range, two were in the Maxhamish range, one in the Snake-Sahtaneh while none of the Parker animals retained their calves. Calf detectability was high as we had no instances where a cow having calved was seen without a calf then observed with a calf on a subsequent survey. Female behaviour at the time of survey was also indicative of calf status, with calf-less cows running quickly away from the helicopter while those with calves either standing still or walking slowly with the calf at heel.

Of the 13 apparently lost calves, seven were lost before reaching four weeks of age. Although causes of calf loss cannot be discerned at this time, wolf (*Canis lupus*) scat and tracks were encountered on multiple occasions while hiking into caribou calving sites. On one instance, black bear (*Ursus americanus*) scat was encountered; however, the age of the scat indicated that it was likely scat from the previous fall.

Table 4: Pre-calving movement patterns of female caribou in north-eastern BC during 2011. Distances are calculated as the straight-line distance between the calving site and caribou locations one and two weeks prior to calving.

Animal ID	Euclidean Distance (km) to Calving Site	
	1 week pre-calving	2 weeks pre-calving
BC1038	2.3	2.0
BC1061	3.0	3.2
BC1040	0.5	2.6
BC1054	10.6	40.8
BC1062	1.8	2.3
BC1052	2.1	2.5
BC1043	40.5	63.9
BC1044	9.8	11.8
BC1053	0.8	14.7
BC1056	1.7	11.2
BC1042	9.7	12.0
BC1039	1.5	30.2
BC1060	2.9	27.9
BC1048	0.7	7.1
BC1045	1.6	3.7
BC1058	27.6	11.6
BC1047	1.3	2.2
BC1050	36.8	51.8
BC1049	2.2	9.7
BC1059	1.1	12.6
Average	7.9	16.2

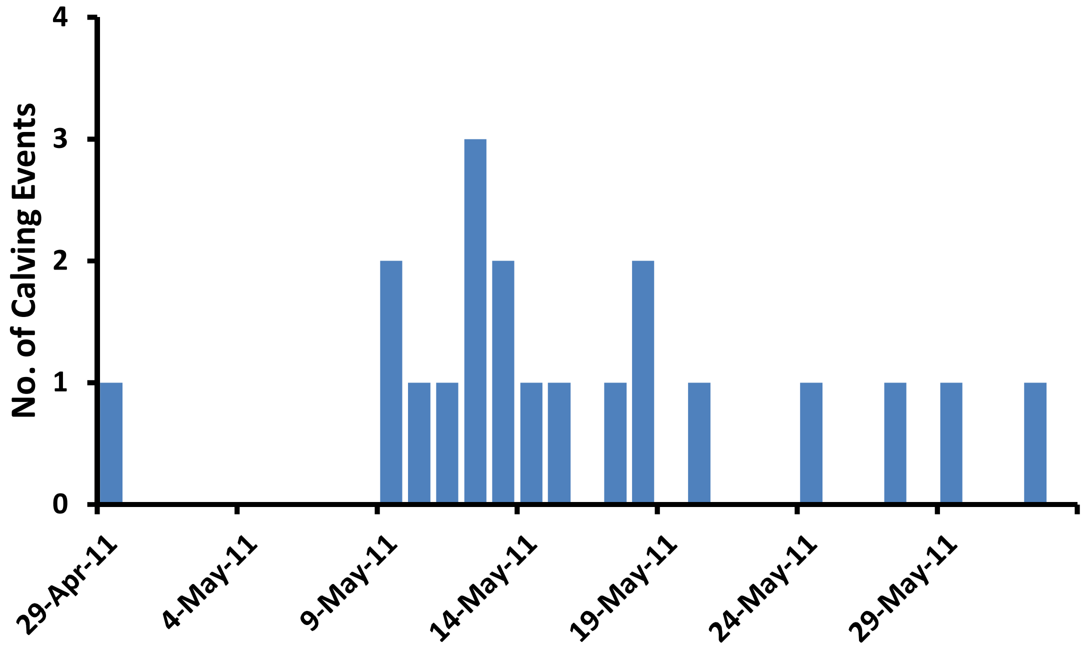

Figure 2: Distribution of calving events for boreal caribou collared in the Maxhamish, Parker, Prophet, and Snake-Sahtaneh ranges during 2011.

Calving Habitat Selection

Nineteen of the 20 calving sites were located in either treed bogs (*n* = 11) or nutrient-poor fens (*n* = 8) while the other remaining site was situated in upland conifer. We sampled 11 calving sites and correspondingly paired winter sites. All sampled calving sites were situated in black spruce (*Picea mariana*) and tamarack (*Larix larix*) peatlands characterized by a relatively open canopy and an understory dominated by moss (*Sphagnum* sp.) and Labrador tea (*Ledum groenlandicum*; Table 5). Comparing potential forage abundances between the two site types, calving sites had slightly higher relative abundances of graminoid cover but lower relative abundances of forbs and terrestrial lichen than winter sites. Dietary analyses of scat samples are still pending; however, we noted that spring green-up did not occur until ~ June 1 so it is likely that caribou diet during the peak calving period will be similar to the winter diet with terrestrial lichens being an important food item.

At the larger scale of the study area, caribou showed relative selection for nutrient-poor fens during the spring calving season in comparison to treed bogs (reference category; Table 5). All other land cover categories were relatively avoided with caribou showing the strongest avoidance of hardwood-associated land covers. Compared to winter sites, selection of nutrient-poor fens increased during the spring while avoidance of rich fens and conifer swamps relatively decreased. Caribou response to forest structure was similar with tamarack selected relative to black spruce and all other tree species avoided. The effect of crown cover was overall weak although the inclusion of a quadratic term suggests that in comparison to the landscape caribou selected for either relatively open or relatively dense forest habitats but more open forests were favored during the spring compared to winter.

When assessing the effects of landscape pattern, caribou continued to show strong avoidance of upland habitats. In comparison to the landscape, caribou were further away from upland edges than random points and this response was greater during the spring. During the calving season, caribou also moved further away from lakes and burns, although regenerating burns in the 10-50 years old range were weakly selected when comparing calving habitat to the landscape in general.

Caribou generally avoided anthropogenic habitats with this response becoming more evident in the spring (Table 5). There are, however, some notable discrepancies to this pattern. First, caribou appeared to be closer to active well sites than random points although an avoidance pattern is suggested when all well sites are considered. A second discrepancy arises when looking at relative distances to seismic lines. Caribou response appears to differ depending on line age and by the type of data used to define the overall linear feature footprint (BC OGC data versus BC TRIM data). Post-hoc analyses, however, reveal that this finding is not a change in caribou response *per se* but a function of the difference in the spatial patterns of lines between the two data sets and how availability in constructing RSF models is defined (Fig. 3). The OGC data is highly clumped with high density seismic grids interspersed with large areas of little to no seismic lines. Consequently, if a caribou spent the late winter in an area of low linear feature density then travelled into a high density seismic grid in the spring – which occurred in a number of instances, the resulting RSF suggests that caribou are closer to lines than random because sampling of random points from an MCP created from both winter and spring GPS locations has many random points falling outside of the high density seismic grid (Fig. 3a). When availability is constrained to only those caribou locations within the high density seismic grid, the estimated RSF in this instance reaffirms caribou avoidance of linear features, at least in terms of Euclidean distance away from lines (Fig. 3c). Surprisingly, this post-hoc analysis also suggests that caribou do not necessarily avoid areas of high linear feature density, a finding corroborated when looking at the patch-scale model. Analyses with both the OGC data and the TRIM data suggest that caribou actually selected calving habitat patches that were higher in linear feature density than available calving habitat patches. In general, caribou selected for larger patches of treed bogs and/or nutrient poor fens in comparison to those available on the landscape but that the patches used in the spring were smaller than treed bog / poor fen patches used during the winter.

Resource selection between cows with calves and those without calves did not differ during the spring calving season. All parameter estimates had p-values > 0.9 for variables within models of Land Cover, Forest Structure, and Landscape Pattern (individual parameter estimates not shown).

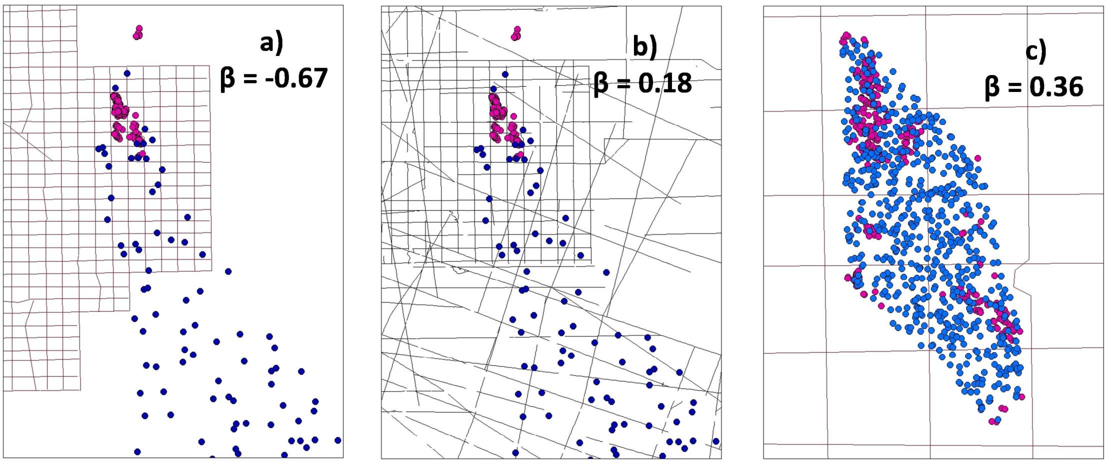

Figure 3: Differences in spatial pattern of linear feature data used in RSF analyses of caribou response to linear disturbance: *a*) caribou calving range locations (pink) in a seismic grid (OGC data) appear to be closer to lines than random points (blue), resulting in a negative β coefficient indicative of relative selection for linear features; *b*) TRIM lines are more uniform in distribution resulting in a positive β coefficient indicative of avoidance; *c*) when random locations are restricted to the calving range within the grid, caribou again show avoidance in terms of proximity to lines.

Table 5: Fixed effect estimates (β) from models of resource selection (Calving v. Landscape) and latent selection differences (Calving v. Winter) for boreal caribou in northeastern BC (SE = standard error; *p* = *p*-value). Variables grouped together were included in the same model.

Model	Variable	Calving v Landscape β	SE	*p*	Calving v Winter β	SE	*p*
Land Cover	Reference: Treed bog						
	Open bog	-0.29	0.08	<0.001	0.06	0.26	0.82
	Poor fen	0.38	0.04	<0.001	1	0.16	<0.001
	Rich fen	-0.37	0.09	<0.001	1.4	0.4	<0.001
	Conifer swamp	-0.4	0.07	<0.001	0.78	0.3	0.009
	Hardwood swamp	-1.32	0.08	<0.001	0.45	0.32	0.17
	Upland conifer	-0.85	0.1	<0.001	-0.1	0.33	0.76
	Upland mixed	-1.78	0.15	<0.001	1.88	1.18	0.11
	Upland deciduous	-3.08	0.21	<0.001	1.33	0.88	0.13
Forest Structure	Reference: Black spruce						
	Tamarack	0.61	0.04	<0.001	0.88	0.18	<0.001
	White spruce	-0.96	0.09	<0.001	-0.49	0.42	0.05
	Pine	-0.79	0.20	<0.001	0.44	0.79	0.08
	Fir	-10.16	69.30	0.88			
	Aspen	-0.82	0.09	<0.001	-0.50	0.36	0.07
	Balsam	-1.37	0.23	<0.001	0.51	0.81	0.03
	Birch	-1.30	0.13	<0.001	0.24	0.57	0.08
	Crown cover	0.10	0.00	<0.001	-0.04	0.02	0.01
	Crown cover^2	-1.4e-3	5.7e-5	<0.001	5.6e-4	2.4e-4	0.01
Landscape Pattern	Dist. To Upland	0.66	0.02	<0.001	1.18	0.13	<0.001
	Dist. To River	-0.02	0.02	0.28	-0.01	0.13	0.96
	Dist. To Lake	0.17	0.02	<0.001	0.49	0.12	<0.001
	Dist. To Fire pre59	0.22	0.04	<0.001	0.26	0.29	0.36
	Dist. To Fire 60-99	-0.12	0.02	<0.001	1.57	0.19	<0.001
	Dist. To Fire 00-10	0.89	0.03	<0.001	2.93	0.25	<0.001
	Dist. To Cut block	0.50	0.02	<0.001	1.98	0.14	<0.001
	Dist. To Pipeline	0.52	0.03	<0.001	0.55	0.08	<0.001
	Dist. To Seis. Line 06	-0.12	0.03	<0.001	-0.79	0.11	<0.001
	Dist. To Seis. Line 01	0.24	0.03	<0.001	-0.15	0.13	0.25
	Dist. To Seis. Line 96	-0.67	0.03	<0.001	-0.82	0.11	<0.001
	Dist. To Roads	0.27	0.02	<0.001	0.31	0.08	<0.001

Cont'd

Model	Variable	Calving v Landscape β	SE	*p*	Calving v Winter β	SE	*p*
Landscape Pattern							
	Dist. To All OGC Lines	0.20	0.02	<0.001	-0.27	0.07	<0.001
	Dist. To TRIM Lines	0.18	0.02	<0.001	0.34	0.07	<0.001
	Dist. To All Wells	0.12	0.02	<0.001	0.15	0.08	0.06
	Dist. To Active Wells	-0.53	0.03	<0.001	-0.31	0.08	<0.001
	Patch Area	-2.00	1.13	0.08	61.68	25.37	0.02
	Patch Type	1.96	0.34	<0.001	-18.29	7.60	0.02
	OGC Line Density	-1.07	0.09	<0.001	-0.56	0.25	0.03
	P. Area * P. Type	2.17	1.13	0.06	-61.16	25.37	0.02
	OGC Line Dens * P. Type	0.54	0.10	<0.001	0.19	0.27	0.50
	Patch Area	-1.47	1.10	0.18	65.79	28.13	0.02
	Patch Type	1.58	0.32	<0.001	-19.47	8.41	0.02
	TRIM Line Density	-0.05	0.03	<0.001	-0.75	0.16	<0.001
	P. Area * P. Type	1.60	1.10	0.15	-65.20	28.13	0.02
	TRIM Line Dens * P. Type	0.19	0.04	<0.001	0.24	0.19	0.22

Calf Survival

Neonate calf survival did not significantly differ among ranges and was generally unaffected by variables within all models considered (e.g., most confidence intervals (CI) of estimated hazard ratios overlap 1.0; Table 6). The large confidence intervals of most estimates indicates that the lack of effects may be attributable to the small sample size (n = 20; 13 mortality events) resulting from only one year of data. There were, however, three variables that did affect calf survival despite the small sample size. The probability of calf mortality increased with increasing distance from a lake (95% CI of hazard ratio: 1.31, 3.88) and weakly decreased with increasing linear feature density (95% CI of hazard ratio: 1.3e-4, 0.54). The pre-calving distance travelled by a cow also seemed to affect the probability of neonate calf survival. For every 18.6 km (one standard deviation) travelled by a cow in the two weeks prior to calving, the relative probability of the calf dying during the neonate period declined by 72% (95% CI: 8-91).

Table 6: Fixed effect estimates (β) and the resulting hazard ratio (exp(β)) for Cox proportional hazard models assessing neonate calf survival of boreal caribou in northeastern BC (SE = standard error; *p* = *p*-value). Variables grouped together were included in the same model.

Model	Explanatory Variable	β	SE	*p*	exp(β)	95% CI exp(β)
Range[1]						
	Parker	0.79	0.73	0.28	2.21	0.52, 9.29
	Prophet	-1.10	0.84	0.20	0.33	0.06, 1.75
	Snake-Sahtaneh	-0.64	0.85	0.45	0.53	0.10, 2.78
Land Cover[2]						
	Poor fen	-0.48	0.62	0.56	0.62	0.12, 3.11
	All else	0.89	2.43	0.21	2.43	0.61, 9.71
Forest Structure[3]						
	Black spruce/tamarack	-0.97	0.83	0.24	0.38	0.07, 1.93
	Crown cover	1.3e-4	0.02	0.99	1.00	0.97, 1.04
Landscape Pattern[4]						
	Dist. To Upland	0.23	0.32	0.47	1.26	0.67, 2.36
	Dist. To River	-0.47	0.45	0.30	0.63	0.26, 1.51
	Dist. To Lake	0.81	0.28	3.4e-3	2.25	1.31, 3.88
	Dist. To Fire pre59	0.25	0.37	0.50	1.28	0.62, 2.63
	Dist. To Fire 60-99	-0.44	0.36	0.22	0.64	0.32, 1.29
	Dist. To Fire 00-10	0.19	0.24	0.44	1.21	0.75, 1.95
	Dist. To Cut block	0.15	0.31	0.62	1.17	0.64, 2.13
	Dist. To Pipe	0.48	0.33	0.15	1.61	0.84, 3.08
	Dist. To Lines	-0.02	0.30	0.94	0.98	0.54, 1.76
	Dist. To All wells	1.7e-4	9.6e-5	0.07	1.00	1.00, 1.00
	Line Density	0.17	0.29	0.54	1.19	0.68, 2.08
	Patch Type	-2.98	1.30	0.02	0.05	3.9e-3, 0.65
	Line Dens* P.Type	-4.79	2.13	0.02	0.01	1.3e-4, 0.54
Individual Movement						
	Days since 1st calving	-0.07	0.04	0.09	0.93	0.86, 1.01
	Mean daily dist. moved	-0.60	0.54	0.27	0.55	0.19, 1.58
	Daily dist. to calving site	-0.51	0.43	0.24	0.60	0.26, 1.41
	Pre-calving movement	-1.28	0.60	0.03	0.28	0.09, 0.91

[1]Reference category is the Maxhamish range
[2]Reference category is treed bog
[3]Reference category is non-black spruce / tamarack tree species
[4]Model assessing response to patch area did not converge and is not shown

DISCUSSION

Through movement analyses and directed aerial surveys, we documented calving events of 20 female boreal caribou, assessed calving habitat selection and followed subsequent calf survival through the neonatal time period. Calving events were highly correlated with sudden decreases in female movement rates and this movement pattern differed markedly from movements of non-gravid females. The majority of calving sites were located in treed bogs or nutrient-poor fens. Importantly, six of the 20 confirmed calving sites were situated outside of current boundaries delineating core habitat areas. Moreover, five calving sites were outside of current caribou range, suggesting that existing boundaries of the Prophet and Maxhamish ranges may need to be revised to include these potentially important calving habitats.

Calf-to-cow ratios by the end of the spring calving season were slightly below those associated with population stability (annual recruitment of ~29 calves: 100 cows; EC 2008). Although this low ratio may be partly due to a relatively low pregnancy rate (80% vs. 95.6% reported by Culling *et al*. 2006), our data still suggests that boreal caribou in northeastern BC are incurring high calf losses during the spring calving season. Surprisingly, we recorded few calf mortalities during the first week of life when calf vulnerability is presumed to be highest. We were not able to confirm cause of death of any calves; however, the timing of mortalities can be indicative of the potential effects of individual predator species. Six of the thirteen mortalities occurred after calves had reached four weeks old, an age where calf mobility increases to a level where vulnerability to bear predation is thought to decrease significantly (Zager & Beecham, 2006; Barber-Meyer et al., 2008). We will more fully evaluate the relative contribution of wolves and black bears to overall calf survival rates after the project's second and third years when predator space use patterns are analyzed.

For many female caribou, pre-calving behaviour included large-scale movements from late-winter locations to calving areas. Three caribou moved out of the cores in which they were captured to adjacent cores just prior to the calving season. One female moved from the Kiwigana core to the Fortune core to calve while two caribou from the Clarke core made long distance movements into the Paradise core. Observations from oil and gas industry workers suggest that caribou are seldom seen in Fortune during the winter yet seem to become more noticeable in the spring, perhaps indicating higher use of Fortune during the calving period. The Paradise core has been previously identified as an area of high use during the calving season for Snake-Sahtaneh caribou (Culling *et al*., 2006). Thus, maintaining functional movement corridors for caribou between core areas –as recommended by Culling *et al*. (2006) – may be particularly important during the pre-calving period (mid-April to mid-May) when caribou movement rates are highest as a result of females making directed movements toward suitable calving areas (Ferguson & Elkie, 2004). The potential importance of pre-calving movement behavior is underscored by its influence on neonatal calf survival. Large-scale movement by a portion of the female population facilitates the spacing out strategy used by boreal caribou to reduce predator encounter rates (Bergerud & Page, 1987). Pre-calving movement may also reduce spatial predictability (Panzacchi *et al*., 2009) and moving long distances quickly can reduce detection by olfactory-oriented predators (Conover, 2007).

When choosing calving areas, female caribou generally selected for large patches of treed bogs and nutrient-poor fens, habitats hypothesized to reduce predation risk to caribou (James *et al.*, 2004; McLoughlin *et al*., 2005). At a finer scale within these patches, females selected calving sites in areas with relatively open canopies compared to winter locations. The low abundances of grasses, forbs and shrubs – combined with the observation that spring green-up is after the peak calving period – suggests that forage quality and availability are not important attributes in calving site selection. Rather, the low abundance of herbaceous forage at calving sites supports the hypothesis that caribou select calving sites to further reduce predation risk by selecting areas generally unsuitable to other ungulates (e.g. moose). To more fully assess the importance of forage to caribou at the calving site scale, the results of dietary analyses will need to be evaluated to determine the specific forage items important to caribou during this time period (results of analyses still pending). Further, our preliminary results are limited to the calving site and fine-scale forage attributes may become more important at later post-calving sites due to increasing lactation demands during the first month postpartum (Oftedal, 1985; Parker *et al*., 2009).

When evaluating the predation risk and forage quality hypotheses at the calving range scale, our data suggests that female caribou predominantly use strategies to further reduce predation risk but may also make subtle trade-offs to optimize forage quality. Within bog and fen complexes used during the spring, female caribou seemed to restrict themselves to the interior of these patches to further space themselves away from upland forests, habitats that present an increased predation risk to caribou (McLoughlin *et al*., 2005). While avoidance of uplands remained consistent from winter to spring, caribou avoidance of other habitats with higher abundances of herbaceous forage (e.g. mineral soil based habitats; Mitsch & Gosselink, 2007) decreased in the spring, suggesting that female caribou make occasional trade-offs to optimize forage quality. Nutrient-rich fens and swamps in particular show decreased avoidance by caribou during the calving season, perhaps indicating a form of functional response to resource selection dictated not by resource availability (*sensu* Mysterud & Ims, 1998) but by maternal nutritional demands.

Support for the predation risk hypothesis was also evident in caribou response to open habitats and anthropogenic features. Female caribou generally spaced further away from cut blocks, regenerating burns and linear features during the calving season, likely in response to the elevated predation risk that these areas represent. Cut blocks and regenerating burns are preferred habitat for moose (Maier *et al*., 2005; Bjørneraas *et al*., 2011) and consequently wolves (Kuzyk *et al*., 2004). Wolves are also hypothesized to highly use linear features for travel, particularly within caribou habitat (James & Stuart-Smith, 2000; Whittington et al., 2011). Our findings of avoidance are consistent with those of Nagy (2011) who found seasonal variation in caribou response to linear features with southern boreal populations showing strongest avoidance during the spring.

Female caribou did deviate from the general pattern of avoidance of anthropogenic features in two instances. First, caribou were relatively closer to active well sites during the calving season. This finding could occur if the current spatial pattern of active wells is correlated with habitats used by caribou in the spring and if the disturbance created by wells is not sufficient to deter potential fidelity of caribou to these areas. Alternatively, the areas immediately surrounding active well sites may provide a form of predator refuge (Hebblewhite *et al*., 2005; Muhly *et al*., 2011). The former hypothesis will be evaluated when calving site fidelity is assessed during the second and third years of the project. The predator refuge hypothesis will also be more fully evaluated when predator movement is analyzed next year; however, based on our first year data, there is no evidence to suggest that calves residing in close proximity to active wells had a higher probability of survival.

The other instance where caribou deviated from an avoidance pattern of anthropogenic features was their response to linear feature density. A number of female caribou moved from winter locations with relatively low linear feature density to calve in high density seismic grids. Within in these grids, caribou still exhibited avoidance in terms of proximity to lines; nevertheless, the overall density of lines did not seem to deter caribou use at the patch scale. This result suggests that while caribou may perceive linear features as a predation risk, the relative risk is not sufficient for caribou to shift their range use accordingly. The lack of caribou response to line density could be interpreted as maladaptive (Hollander *et al.* , 2011) given the hypothesized link between linear features and their facilitation of predator hunting efficiency (James & Stuart-Smith, 2000; Whittington et al., 2011). Interestingly, high linear feature density did not correlate to an increased risk of calf mortality in our survival analysis, a finding likely confounded by the lack of statistical power associated with our preliminary data (see below). If subsequent survival analyses show similar results, however, this does not necessarily indicate a lack of effect of line density on calf survival. Rather, the relationship between linear feature density and calf survival could be non-linear with the threshold at which line density impacts calf survival being quite low (e.g. a sharply increasing Type II functional response in predation; Holling, 1959; Messier, 1994; McCutchen, 2007). If much of our study area exceeds this potential threshold, then variation in line density in our study area will have minimal impact on calf survival. The potential for a low threshold of line density at the patch scale is supported by Nagy's (2011) finding that an important range characteristic of caribou populations that are stable is the availability of large patches of undisturbed habitat (e.g., > 500 km^2 with 0% linear disturbance). However, similar to our results, Nagy (2011) also found that caribou use of large, intact habitat patches declines when the availability of such patches declines, suggesting that caribou perception of line density diminishes with increasing linear feature disturbance at the range scale.

Overall, maternal selection of habitat had little to no influence on the probability of calf survival through the neonate period. This lack of influence is likely affected by our small sample size resulting from only one year of data. Detecting the relative influence of maternal habitat selection on the probability of calf survival will require an increase in statistical power – to be gained in the project's second and third years – because calf survival is likely affected by a multitude of other factors, including those that directly cause mortality (e.g. disease, Whitten *et al*., 1992) and those that indirectly interact with predation (e.g. climate, Adams *et al*., 1995; Post & Klein, 1999). Our preliminary results indicate that individual movement behaviors, specifically pre-calving movement, can influence calf survival and its impact may be as important as maternal selection of habitat.

Identifying habitat as important for calving implies that habitat selection by parturient females differs from other members of the population during the calving season. This difference in selection is presumed to be a result of calf vulnerability to predation *(*Berger, 1991; Adams *et al*., 1995; Carstensen *et al*., 2009). In many studies of calving habitat selection, this assumption of differential selection between gravid and non-gravid females is not explicitly tested (e.g., Bowyer *et al*. 1999; Briand *et al*. 2009; Brook 2010; but see Berger 1991; Barten & Bowyer 2001). For boreal caribou, our results indicate habitat selection by females during the spring does not depend on whether a female has a calf or not, a finding similar to Barten & Bowyer (2001) who reported no difference in habitat use between gravid and non-gravid females in the Mentasta caribou herd of Alaska. This finding may indicate that female caribou are genetically hard-wired to avoid open habitats during the calving season regardless of calf status. An alternative explanation is that increased avoidance of open habitats – including linear features – by caribou in the spring may be due to a seasonal change in the use of these features by predators (Latham *et al*., *in press*). This latter hypothesis will be directly evaluated when predator radio-collar data is analyzed after the project's second year.

Management Implications:

Boreal caribou operate at large spatial scales and consequently management is necessarily focused at the range scale (EC 2008, 2011). Complementary to this approach is identifying habitats within the range, such as calving, that influence important demographic parameters. Because boreal caribou employ a spacing-out strategy to calve, potential calving habitats will likely include multiple areas within a range. An assessment of fidelity to calving areas will also be necessary prior to designating areas as important calving habitat. Assessing site fidelity, validating current RSF models, and constructing probability maps of calving use will be primary objectives in the project's second and third years. However, based on our exploratory analyses from the project's first year, we can make the following recommendations:

1. Boundaries of the Prophet and Maxhamish ranges need to be revised to include calving areas used by caribou within these herds.
2. Pre-calving movement is an important aspect of the dispersion strategy used by boreal caribou to decrease predation risk at calving. Identifying travel corridors linking winter ranges to highly used calving areas should be a priority.
3. Female caribou require large patches of treed bogs and nutrient-poor fens during the calving season.
4. Caribou attempt to reduce predation risk during the spring calving season by spacing further away from upland and anthropogenic habitats. Ideal calving habitat should therefore have large core areas with minimal to no anthropogenic disturbance ; however,
5. The setting aside of areas of low density disturbance ostensibly for caribou conservation may be problematic if caribou do not perceive variation in the density of linear

disturbances and do not preferentially move to and use minimally impacted areas within in their range.

PROJECT YEAR 2 (2012) OUTLOOK

One of the primary objectives of the project's second year is the deployment of radio-collars on wolves and black bears, the two primary predators of caribou calves. Wolf capture and collaring activities are tentatively scheduled for January or February of 2012. For black bears, deployment of collars will be done during the end of April to early May of 2012. Because of the success of the Iridium GPS collars on caribou, we now recommend using the same collars on predators. The costs of the Iridium collars are slightly higher and have associated satellite data transfer fees but the Iridium collars offer significant advantages. First, the Iridium collars would transmit near real-time data during the calving season, offering the ability to combine investigation of kill sites with previously scheduled aerial surveys. Second, the Iridium collars provide a form of insurance against data loss from potential difficulties in retrieving collars, which would be necessary with store-on-board devices. Third, data analyses of predator movement patterns, habitat use and caribou-predator interactions could be initiated after the next calving season (2012) instead of waiting for collar retrieval at the end of the 2013 calving as would happen with store-on-board devices.

Other project objectives for 2012 include:

1. Continuation of calf survival surveys in the spring.
2. Continuation of vegetation sampling of caribou winter range and calving range sites.
3. Preliminary analyses of predator movement patterns during the caribou calving season.
4. Continued data analyses of calving habitat selection and neonate calf survival.

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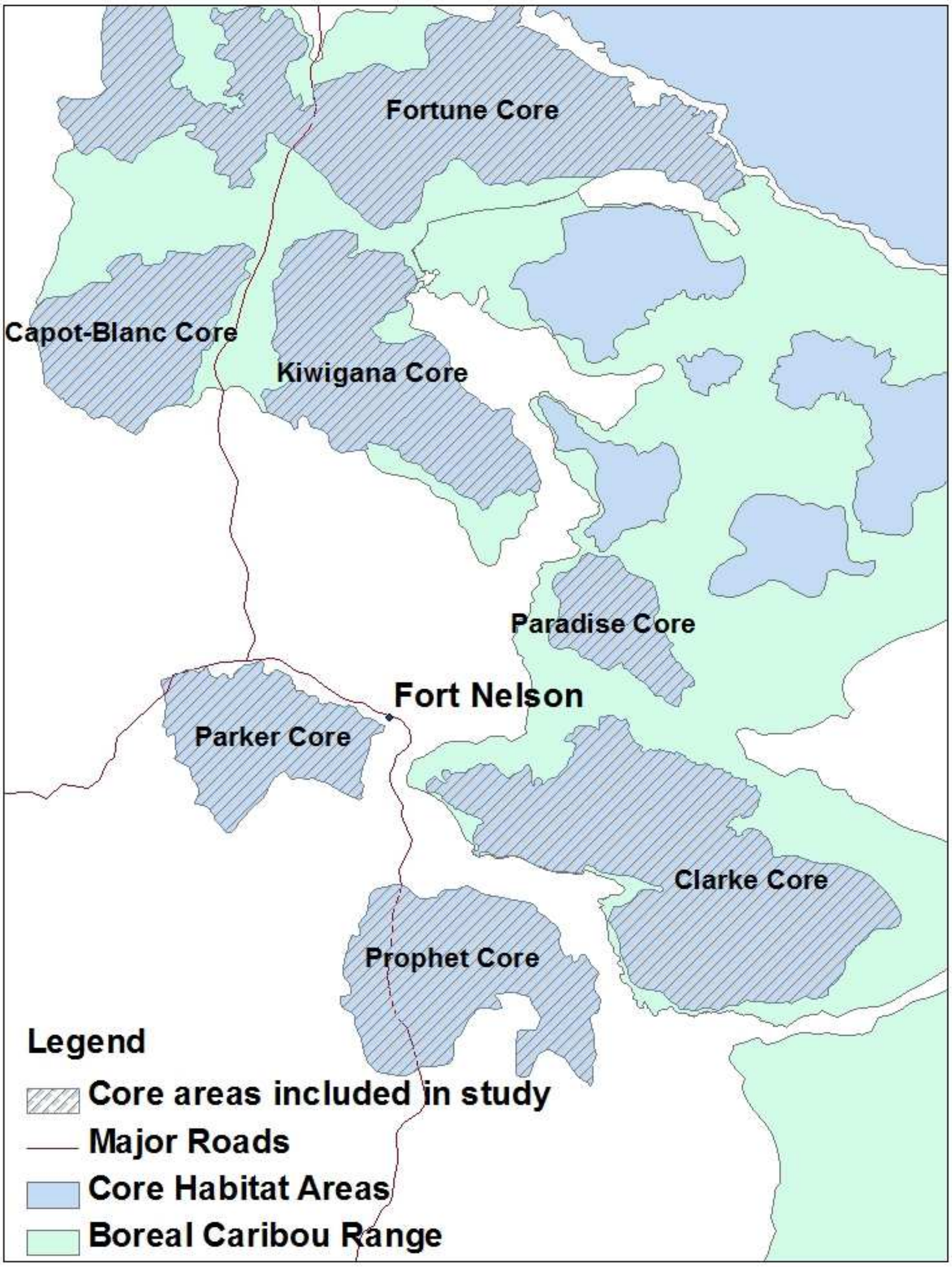
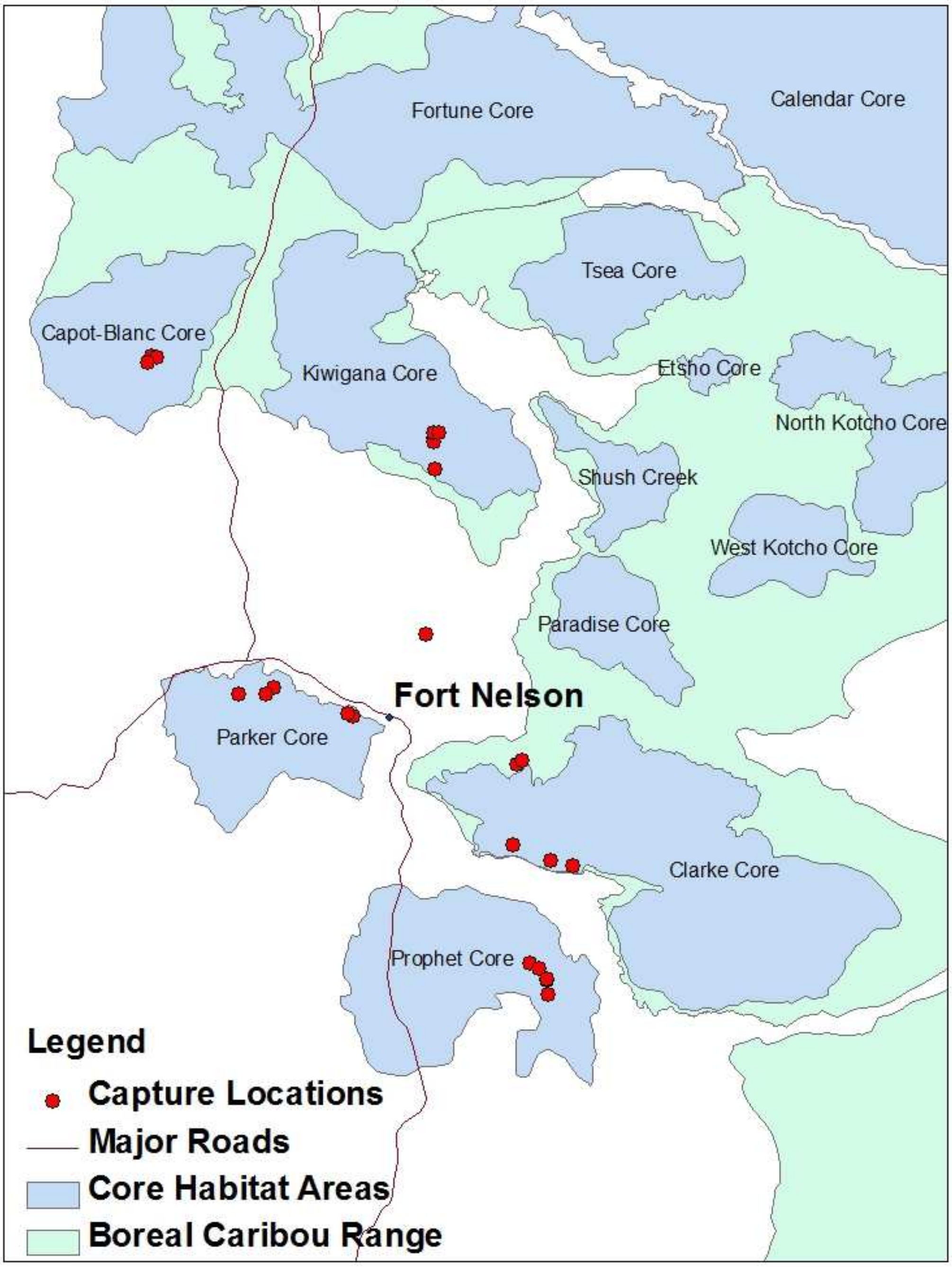
APPENDICES

APPENDIX 1:
Extent of study area in northeastern BC, including core areas used by radio-collared caribou during 2011 (hatching).

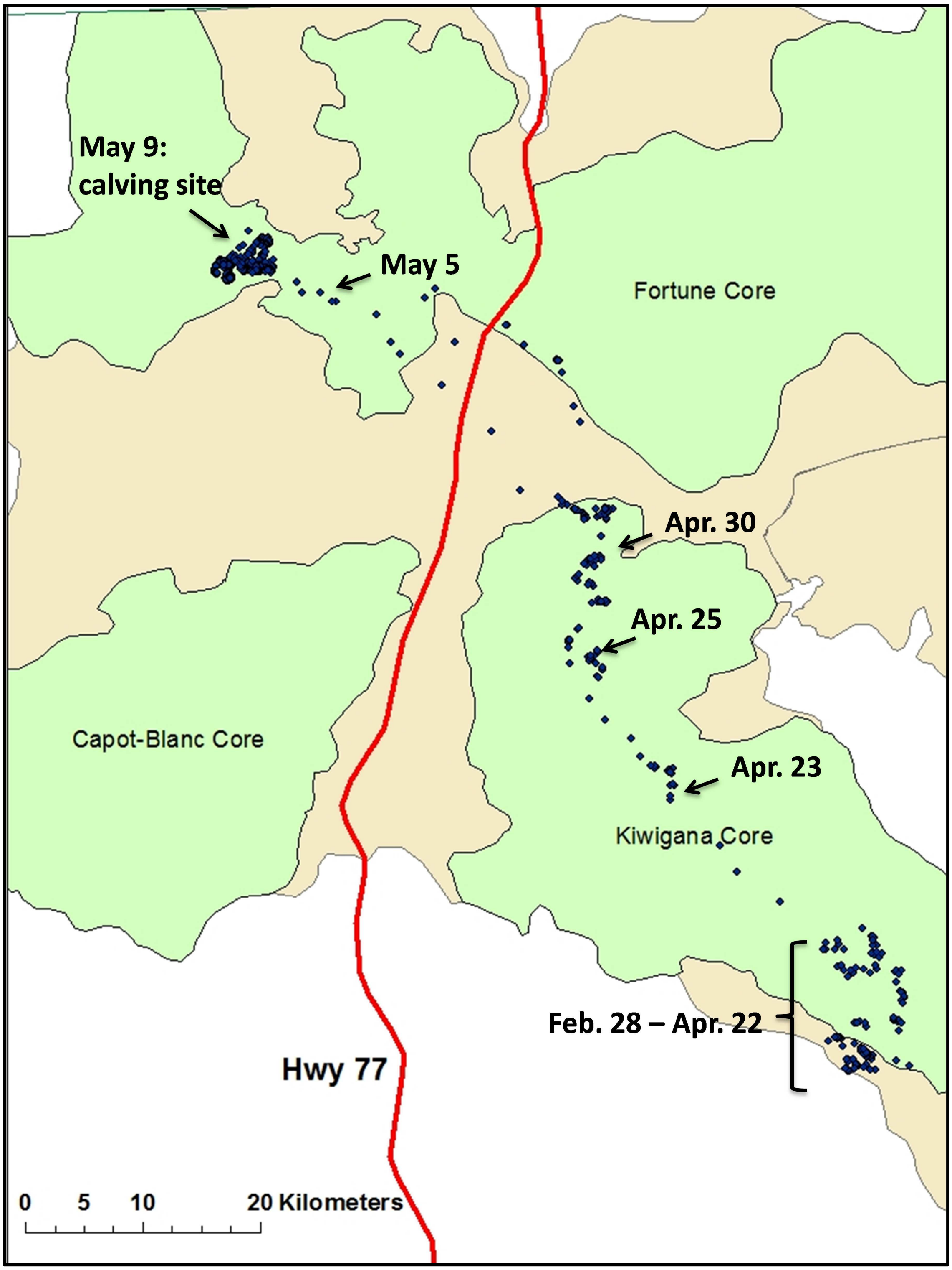


APPENDIX 2:
Calving site depression created during the 2011 calving season by a female boreal caribou in the Prophet range of north-eastern BC.

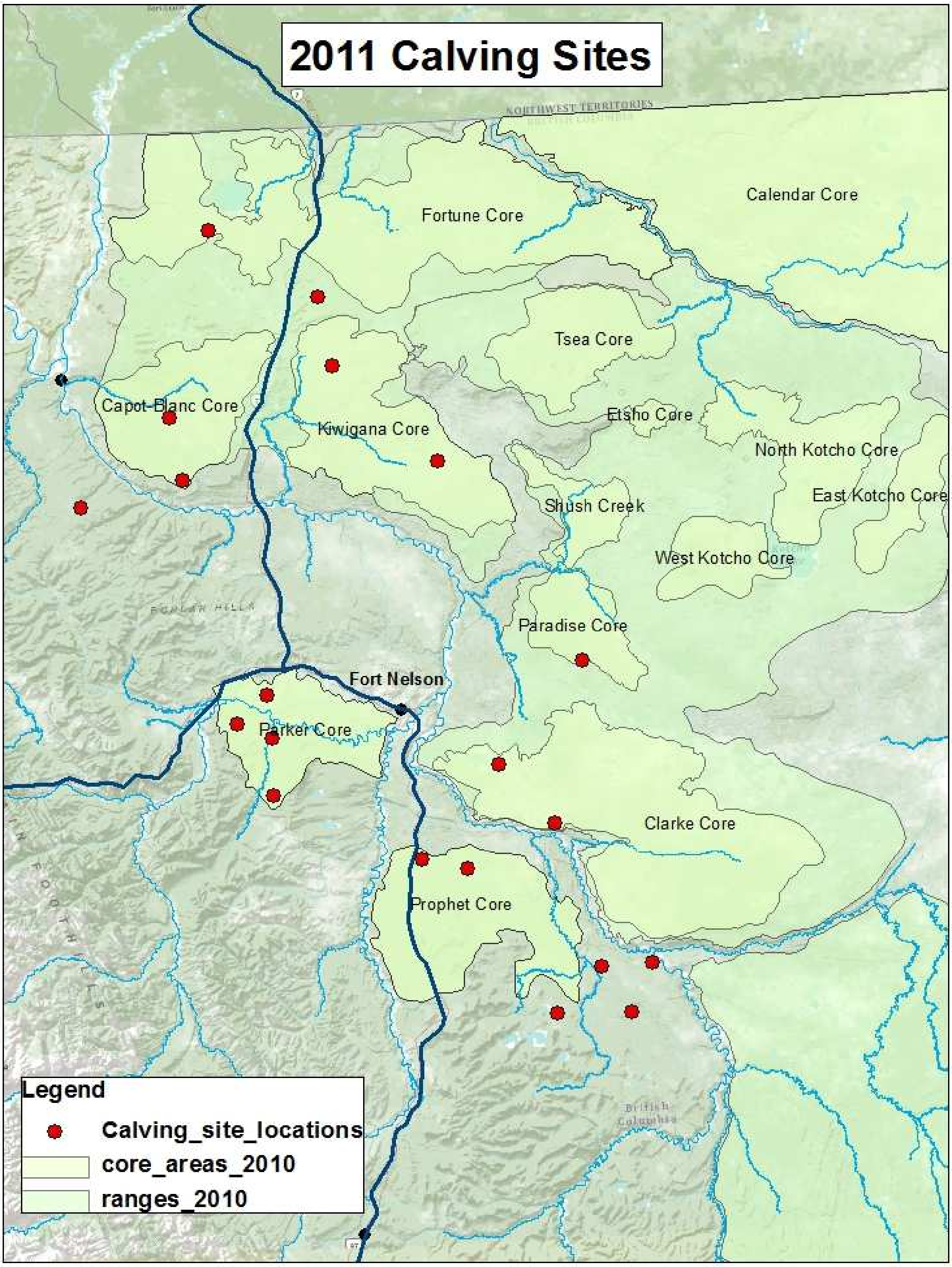
APPENDIX 3:
Locations of caribou captures during February and March 2011 near Fort Nelson, BC.



APPENDIX 4:
Pre-calving movements of a female boreal caribou during the late winter and early spring of 2011. This individual was originally captured in the southwest corner of the Kiwigana core area.



APPENDIX 5:
Distribution of calving sites used by 20 female boreal caribou in north-eastern BC during the 2011 calving season.



APPENDIX 6:

Data sources used to develop GIS variables to model resource selection by female boreal caribou in northeastern BC.

Variable	Source	Access Information
Land Cover	Ducks Unlimited Canada	Ducks Unlimited Canada 100, 17958 106 Ave, Edmonton, AB T5S 1V4
Forest Structure	Vegetation Resource Inventory, BC Ministry of Forests, Lands and Natural Resource Operations	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=47574&recordSet=ISO19115
Rivers, Lakes	Digital Baseline Mapping, BC Integrated Land Management Bureau, Geographic Data Discovery Service	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=3679&recordSet=ISO19115
Forest Fire History	Fire Perimeters – Historical, , BC Integrated Land Management Bureau, Geographic Data Discovery Service	http://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=57060&recordSet=ISO19115
Cut Blocks	Forest Tenure Cut Block Polygons, BC Ministry of Forests, Lands and Natural Resource Operations	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50580&recordSet=ISO19115
Pipelines	BC Oil and Gas Commission	ftp://www.bcogc.ca/outgoing/OGC_Data/Pipelines/
OGC Seismic Lines	BC Oil and Gas Commission	ftp://www.bcogc.ca/outgoing/OGC_Data/Geophysical/
Major Roads	Digital Baseline Mapping, BC Integrated Land Management Bureau, Geographic Data Discovery Service	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=3679&recordSet=ISO19115
Forestry Roads	Forest Tenure As-Built Roads, BCGOV FOR Resource Tenures and Engineering	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=45694&recordSet=ISO19115
Other Secondary Roads	BC Oil and Gas Commission	ftp://www.bcogc.ca/outgoing/OGC_Data/Roads/
Well Sites	BC Oil and Gas Commission	ftp://www.bcogc.ca/outgoing/OGC_Data/Wells/
TRIM Lines	TRIM miscellaneous annotation, BC Integrated Land Management Bureau, Geographic Data Discovery Service	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=4105&recordSet=ISO19115