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Assessing Spatial Factors Affecting Predation Risk to Boreal Caribou Calves

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Final Report

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FORWARD

This final report is a compilation and synthesis of recently completed analyses, status and annual reports from 2011 – 2013, and published or submitted manuscripts based on project data. These reports and manuscripts include:

Annual Reports

DeMars, C., Thiessen, C. & Boutin, S. (2011). Assessing spatial factors affecting predation risk to boreal caribou calves: implications for management. 2011 annual report. University of Alberta, Edmonton, AB. 41p.

DeMars, C., Leowinata, D., Thiessen, C. & Boutin, S. (2012). Assessing spatial factors affecting predation risk to boreal caribou calves: implications for management. 2012 annual report. University of Alberta, Edmonton, AB. 54p.

DeMars, C., & Boutin, S. (2013). Assessing spatial factors affecting predation risk to boreal caribou calves: implications for management. 2013 annual report. University of Alberta, Edmonton, AB. 60p.

Manuscripts

DeMars, C.A., Breed, G.A., Potts, J.R. & Boutin, S. (2014). Spatial patterning of prey at reproduction to reduce predation risk: what drives dispersion from groups? *The American Naturalist* (in review).

DeMars, C.A., & Boutin, S. (2014). An individual-based, comparative approach to identify calving habitat for a threatened forest ungulate. *Ecological Applications* (in review).

DeMars, C.A., Auger-Méthé, M., Schlägel, U.E. & Boutin, S. (2013). Inferring parturition and neonate survival from movement patterns of female ungulates: a case study using woodland caribou. *Ecology and Evolution*, **3**, 4149–4160.

EXECUTIVE SUMMARY

The boreal ecotype of woodland caribou (*Rangifer tarandus caribou*) is federally listed as *Threatened* and provincially designated as *Red-listed* in British Columbia due to population declines throughout much of its distribution. High rates of calf mortality due to predation are a key demographic factor contributing to population declines and increasing predation of caribou has been linked to landscape disturbance within and adjacent to caribou range. Developing effective management strategies for sustaining caribou populations in multi-use landscapes therefore requires an understanding of the spatial dynamics of caribou and their predators during the calving season.

In 2011, we initiated a four-year project to evaluate spatial factors influencing predation risk to boreal caribou calves in northeast British Columbia. The project was a collaborative effort among government, industry, non-governmental organizations, First Nations and academia. The two primary objectives of the project were to: *i*) identify key attributes of calving habitat and determine whether calving habitat constituted a discrete, identifiable habitat within caribou range; and *ii*) evaluate spatial factors influencing survival of neonate calves (< 4 weeks old). The latter objective required an assessment of space use by wolves (*Canis lupus*) and black bears (*Ursus americanus*), the two main predators of caribou calves.

Over the project's three years of data collection, boreal caribou continued to sustain high rates of neonate mortality. We also documented relatively low rates of parturition. Collectively, these results translated to calf-to-cow ratios that dropped below 30 calves: 100 cows by mid-July. While our findings of high rates of neonate mortality are consistent with the predation-mediated hypothesis for caribou population declines, the low rates of caribou productivity (fecundity and calf survival) may also suggest declining winter and/or summer range conditions.

Using GPS data from 56 radio-collared female caribou, we identified calving habitat in a multi-scale framework that also assessed whether females were selecting calving habitat to reduce predation risk or to access higher forage quantity and/or quality to meet maternal nutritional demands. Across all scales, reducing predation risk was a dominant factor driving calving habitat selection by females. At the finest scale, calving sites were predominantly situated in treed bogs and nutrient-poor fens – land covers considered to be predator refugia – and forage attributes of calving sites did not differ from winter locations used by the same animals. Females continued to select for treed bogs and nutrient-poor fens when moving within calving areas, defined as those areas used by females with neonate calves. Females generally avoided locations within high densities of linear features and showed weak selection for locations with higher forage productivity.

Our largest scale of analysis focused on female selection of calving areas within caribou range. We used an individual-based, comparative approach that assessed for selection differences based on season and maternal status (e.g. with calf versus barren). In general, females moved from winter ranges dominated by treed bogs to calving areas situated in landscapes mosaics with a high proportion of nutrient-poor fen. This shift may indicate a forage-risk trade off because fens are more productive than bogs but provide less of a predator refuge. Within these mosaics, females situated calving areas away from rivers, lakes and anthropogenic disturbance. Comparisons based on maternal status suggested that the presence of a neonate calf intensified selection behaviours associated with reducing predation risk.

We conducted similar multi-scale analyses of predator habitat selection. During the calving season, wolves were not confined to specific areas within caribou range; rather, pack territories were tightly spaced and overlapped significantly with caribou range and core areas. At a finer scale, wolves were closely associated with aquatic areas, showing selection for nutrient-rich fens and being closer to rivers and lakes than expected. This association is consistent with the hypothesis that wolves switch to beaver (*Castor canadensis*) as primary prey during the spring and supports previous studies highlighting the importance of water to wolves during the denning period. Wolf response to disturbance was counter to expectations as early seral vegetation and areas of high linear feature density were generally avoided. We further assessed wolf response to linear features by determining whether wolves preferentially select certain linear features over others. Of the two factors assessed, our results suggest that wolves select lines that increase movement efficiency and, secondarily, sightability.

In contrast to wolves, black bears were more predictable at larger spatial scales, favouring landscapes dominated by upland deciduous forest. Areas used by bears were also closer to early seral vegetation and had higher densities of linear features. Across all scales, bear were closer to aquatic features than expected and showed strong selection for rich fens when in caribou range. In general, selection patterns by bears suggested a preference for habitats associated with higher grass and forb abundance, which are important food sources for bears in the early spring.

We assessed the influence of spatial factors on the probability of calf survival by evaluating four hypotheses that described impacts from disturbance, refuge effects from lakes and peatlands, and predation risk from bears and wolves. We assessed each hypothesis at multiple scales and related calf survival to spatial factors using two metrics: exposure and maternal selection of habitat. The probability of calf survival was best predicted by a model representing predation risk from bears. Specifically, the model suggested that calf survival depended on the density of high quality bear habitat surrounding locations selected by females within the calving area. All other hypotheses were generally unsupported and we found no evidence to suggest that any

one specific landscape feature contributed disproportionately to the probability of calf survival. This lack of support may suggest that: *i*) the degree of disturbance within caribou range has exceeded thresholds where differences in neonate survival may be detected; and/or, *ii*) neonate survival may be driven by predator densities more than variation in spatial factors.

Results from this project highlight the challenges of managing calving habitat for caribou in multi-use landscapes. Management actions will need to be conducted at large spatial scales because caribou are at their most dispersed at calving and small-scale actions will likely be ineffective at improving rates of neonate survival. Targeting potential management actions toward large fen complexes may be most effective because of their importance to calving caribou. For rapidly declining populations residing in ranges highly impacted by disturbance, habitat conservation and restoration initiatives may need to be augmented by more intensive actions (e.g. maternal penning, predator management) to improve calf survival rates in the short-term.

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1. INTRODUCTION

Boreal caribou, an ecotype of woodland caribou, are *Red-listed* in British Columbia and federally designated as *Threatened* due to population declines and range retraction throughout much of their distribution (Environment Canada 2012). Predation is considered to be the proximate cause of population declines and increasing predation rates are thought to be facilitated by landscape disturbance within and adjacent to caribou range (McLoughlin *et al.* 2003; Sorensen *et al.* 2008; Festa-Bianchet *et al.* 2011). Climate change may also interact with disturbance to further alter caribou-predator dynamics (Latham *et al*. 2013b; Dawe *et al*. 2014). For most populations, increasing predation results in low rates of calf recruitment, a key determinant of caribou population dynamics (DeCesare *et al.* 2012a). Predation is particularly high on neonate calves (0-4 weeks old; Stuart-Smith *et al.* 1997; Pinard *et al.* 2012) with calf-to-cow ratios in many herds dropping below levels associated with population stability by the end of the neonate period (e.g. ~29 calves: 100 cows; Environment Canada 2008).

In British Columbia, high rates of neonate mortality are considered to be an important demographic factor driving suspected population declines within the province's six boreal caribou ranges (Culling & Cichowski 2010). To inform management strategies for improving rates of calf survival, we initiated a four-year project in 2011 to assess caribou-predator spatial dynamics during the calving season in northeast BC. The project, which encompassed data from all six caribou ranges, represented a collaborative effort among government, industry, non-governmental organizations, First Nations and academia.

The project had two primary objectives. The first was to determine whether calving habitat constituted a discrete, identifiable habitat within caribou range. Effectively discriminating calving areas from others has direct implications for management strategies aimed at habitat conservation and restoration. Critical habitat for boreal caribou has been designated as a herd's range (Environment Canada 2008) and the federal *Recovery Strategy* specifies habitat restoration as a key management lever for stabilizing or recovering populations in decline (Environment Canada 2012). Most caribou ranges, however, have a wide geographic extent, necessitating that areas within ranges be prioritized for any potential conservation or restoration actions. Key to such prioritization strategies is discriminating demographically important areas from others at scales that are both amenable to management and biologically relevant to caribou.

To identify key attributes of calving habitat, we used a multi-scale approach to reflect the hierarchical process of habitat selection (Johnson 1980). We focused much of our analyses on the identification of calving areas, defined as those areas used by females with neonate calves. We discriminated calving areas from others by using multiple individual-based comparisons that assessed for: *i*) differences between calving areas and other seasonal areas; *ii*) differences in habitat selection between females with calves and barren females; and *iii*) changes in habitat selection after females lost their calves. The latter two comparisons provide a rigorous test for determining whether calving areas are a discrete habitat within caribou range.

Across all scales, we further evaluated whether female caribou selected calving habitat to reduce predation risk to vulnerable calves (Bergerud 1985; Bergerud & Page 1987) or to access higher forage quality and/or abundance to meet maternal nutritional demands (Parker *et al.* 2009). This trade-off is one confronted by most female ungulates at calving (Festa-Bianchet 1988; Rachlow & Bowyer 1998; Panzacchi *et al.* 2010). For boreal caribou, previous research has suggested that females select calving sites to reduce predation risk (Bergerud *et al.* 1990; Pinard *et al.* 2012; Leclerc *et al.* 2012); however, it is unclear how females manage this trade-off as the calving period progresses and whether, as theory predicts, predation-averse behaviour is reflected at larger spatial scales (Rettie & Messier 2000). Compared to many other ungulates, caribou are unique because they enter the calving season with a protein deficit due to a winter diet consisting mostly of lichen (Barboza & Parker 2008). Thus, females may be forced to trade-off increasing predation risk to access higher forage quality to meet increasing lactation demands associated with calf growth (Parker *et al.* 2009).

Our second objective was to evaluate spatial factors influencing survival of neonate calves. Such analyses provide an index of calving habitat quality, which can further inform prioritizing areas for conservation or restoration within caribou range. To assess the influence of specific spatial factors, we discriminated among four hypotheses. The first – the disturbance hypothesis – suggests that landscape disturbance facilitates increasing spatial overlap between caribou, other ungulates, and their predators, resulting in increased caribou predation rates (James & Stuart-Smith 2000; Latham *et al*. 2011b; Peters *et al*. 2013). Under this hypothesis, calf survival is predicted to be negatively correlated with increasing landscape disturbance. The second hypothesis – the lake refuge hypothesis – suggests that lakeshores provide escape habitat and thus a predation refuge for female caribou with neonate calves (Bergerud 1985; Carr *et al.* 2011); consequently, increasing proximity to lakes should equate to an increased probability of calf survival. The third hypothesis suggests a similar refuge effect for peatlands (e.g. fens and bogs) where calf survival should increase as the proportion of peatlands in the landscape increases (peatland refuge hypothesis; McLoughlin *et al.* 2005). The fourth hypothesis predicts that calf survival will be negatively correlated to the proximity to – or density of – habitats favoured by wolves and/or black bears, the two main predators of caribou calves (predation risk hypothesis; Gustine *et al.* 2006). We evaluated each hypothesis using metrics of exposure and maternal selection of calving habitat. The former measures the landscape attribute directly and any relationship to survival – and thus habitat quality – is contingent on the absolute value of these measurements (e.g. Apps *et al.* 2013). Selection, on the other hand, is the ratio of the measured attributed relative to its availability at a larger, pre-defined scale; thus, habitat quality in this sense is also contingent on habitat availability (e.g. Dussault *et al.* 2012; DeCesare *et al.* 2014).

To evaluate the predation risk hypothesis – and to understand predator space use during the calving season, we conducted multi-scale analyses of habitats selected by wolves and black bears. In intact boreal forest landscapes, habitat selection by caribou and their predators are expected to be divergent, consistent with the spatial separation strategy used by caribou to lower predation rates (Seip 1992; James *et al.* 2004). Increasing landscape disturbance within caribou range, however, has decreased this separation by indirectly increasing predator numbers and/or facilitating predator movements into caribou range (James & Stuart-Smith 2000; McCutchen 2007; Latham *et al.* 2011b; c; Tigner *et al.* 2014). Here, we focused on this latter mechanism by evaluating caribou-predator spatial overlap with a specific emphasis on predator response to disturbance features.

For wolves, we further focused on their relationship to linear features, which are hypothesized to increase wolf hunting efficiency and facilitate wolf movement into caribou range (James & Stuart-Smith 2000; Latham *et al.* 2011b; McKenzie *et al.* 2012). In 2012, we conducted a small study to determine whether wolves preferentially select lines with attributes that either increase movement efficiency or sightability. By understanding potential mechanisms driving wolf use of linear features, this analysis has a direct impact on management strategies directed toward de-activating lines to decrease predation rates on caribou.

Collectively, the analyses contained in this final report represent the culmination of three years of data collection and field work to help understand caribou-predator spatial dynamics during the calving season. We anticipate that results from this project will support key objectives outlined in the BC Boreal Caribou Implementation Plan; specifically, those that target protecting sufficient habitat to sustain and/or recover populations in all six caribou ranges and those that manage and mitigate the industrial footprint to conserve habitat and minimize predation rates on caribou (BC Ministry of Environment 2011).

2. METHODS

2.1. Study Area

During the project's first year, our study area was confined to four caribou ranges (Maxhamish, Parker, Prophet, and Snake-Sahtaneh); however, by project end the study area expanded to include all six recognized boreal caribou ranges within BC (Appendix 1). These ranges are situated within the Boreal and Taiga Plains ecoprovinces in the extreme northeast corner of the province. The landscape in this region 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*). Terrain is predominantly flat to undulating (elevation range: 214-1084 m) and the climate is northern continental, characterized by long, cold winters and short summers (Environment Canada 2010). Forest fire is a frequent form of natural disturbance on the Taiga Plains with a mean fire interval of ~100 years (Johnstone *et al.* 2010). The study area is further notable because it contains some of the largest deposits of natural gas shale in Canada. Consequently, oil and gas extraction activities are the dominant form of anthropogenic disturbance within caribou range (Thiessen 2009).

2.2. Wildlife Capture and Collaring

To assess seasonal space use and movement patterns of caribou, wolves and black bears, we deployed Iridium GPS radio-collars on a sample of individuals within each species. We used radio-collars (hereafter, collars) from two manufacturers: Advanced Telemetry Systems (ATS; Isanti, MN; model #2110E) and Lotek Wireless Inc. (Newmarket, ON; model IridiumTrackM 2D). Each collar was equipped with a release mechanism that either released the collar on remote command or low battery (ATS) or by a timed blow-off device (Lotek).

All caribou were captured by net-gunning from a helicopter and physically restrained during collar deployment. All wolves and black bears were captured by aerial darting from a helicopter. Targeted wolves and bears were chemically immobilized using Telazol (4.0 mg/kg) delivered by an appropriate sized aerial dart. For all captured animals, we collected blood and hair samples as well as fecal samples from caribou. All capture and handling procedures followed approved governmental and institutional animal care protocols (BC RIC 1998; BC Wildlife Act Permits FJ12-76949 and FJ12-80090; University of Alberta Animal Use protocol # 748/02/13).

2.2.1. Caribou

For caribou, our objective was to maintain a sample of at least 25 collared females for each calving season. We targeted reproductive-aged females (≥ 3 years old) and all captured females were fitted with Iridium GPS collars from ATS. In 2011 and 2012, capture efforts were confined to the Parker, Prophet, Maxhamish and Snake-Sahtaneh ranges. For the latter two ranges, we focused capture efforts on the Capot Blanc, Clarke and Kiwigana core areas to obtain a sample of caribou residing in areas representative of the range of landscape disturbance levels in northeast BC (Thiessen 2009). Collars deployed in 2011 and 2012 were programmed to obtain a GPS location (or fix) every two hours during the calving season (April 15 – July 15) and once per day otherwise. At this fix rate, collars were expected to be operational for 30 months. In 2013, capture efforts expanded to include all six caribou ranges in northeast BC as part of the caribou monitoring program initiated by the Research Effectiveness and Monitoring Board. Collars deployed between December 2012 and March 2013 were programmed for a fix rate of every four hours during the calving season and every eight hours otherwise.

2.2.2. Wolves

For wolves, our objective was to deploy 20 Iridium GPS collars on individuals occurring within or adjacent to caribou range. For each wolf pack located, we attempted to deploy 1-4 GPS radio-collars per pack. Capture efforts were initiated in 2012 and we targeted areas that overlapped with the distribution of collared female caribou. For wolves captured in 2012, we used Iridium GPS collars from ATS. In 2013, wolf capture efforts expanded to include all six caribou ranges and we used Iridium GPS collars from Lotek. We further deployed 1-2 VHF collars (Lotek) per pack in 2013 to facilitate relocating packs in the event of GPS collar failure (VHF collars provided by BC Ministry of Forests, Lands, and Natural Resource Operations). We programmed all wolf GPS collars for a fix-rate of every 15 minutes from May 1 to June 30 and once per day otherwise. At this fix rate, wolf collars were expected to remain operational for one year (ATS) to 18 months (Lotek).

2.2.3. Black Bear

We had a similar objective for capturing and collaring black bears as for wolves; that is, to deploy 20 Iridium GPS collars (ATS) on individuals captured within or adjacent to caribou range. We targeted large, mature bears and avoided young animals or females with cubs. Capture efforts were initiated in 2012 and focused on the Maxhamish, Parker, Prophet and Snake-Sahtaneh ranges as well as the Fort Nelson caribou core area. All bear collars were programmed for a fix-rate of every 30 minutes from May 1 to June 30 and once per day otherwise, equating to an estimated battery life of 18 months.

2.3. Screening of Spatial Data

Prior to data analyses, we applied the following general and species-specific screening procedures to the GPS location data. For all data sets, we first removed all locations with low positional accuracy (e.g. < three-dimensional [3D] fixes; Lewis *et al.* 2007). For the retained 3D fixes, the mean horizontal measurement error was estimated to be ± 7.7 m for the ATS collars (C. DeMars, *unpublished data*) while the error associated with the Lotek collars was unknown. We then excluded outlying locations that were beyond the range of biologically possible movement using the methods described in Bjørneraas *et al.* (2010). For caribou and wolves, we further removed the first two weeks of GPS locations post-capture to reduce the effects of captured-related behavioural alterations (Morellet *et al.* 2009). We did not apply this screening procedure to the bear data because none of the individual bear data sets began before May 1 and we wanted to preserve all bear locations during the critical neonate period when caribou calves are most vulnerable to bear predation (Zager & Beecham 2006). Specific to caribou, we also removed locations from 10:00 to 18:00 hrs on dates of aerial surveys (see below) to reduce behavioural effects associated with helicopter disturbance. For wolves, we removed locations from the same time interval (10:00-18:00 hrs) during the calving season as all individuals had generally low movement rates (<100 m/hr) within this interval, presumably due to the animals bedding down to avoid warm daytime temperatures. We also excluded all locations within 200-m of suspected den sites. We did not exclude specific time intervals from bear data sets as most individuals did not display a consistent daily period of inactivity.

2.4. Estimating Caribou Parturition Status and Neonate Survival

We estimated parturition status of female caribou and survival of neonate calves across the project's three years using the movement-based methods (MBMs) of DeMars *et al.* (2013) corroborated by aerial survey data. In addition to status, the MBMs yield predictions of parturition date and calf loss date, where appropriate. The MBMs were developed using project data from 2011 then tested against 2012 data and data from 10 females captured in 2004 (Culling *et al.* 2006). To augment MBM development, we established the pregnancy status of all females in 2011, two females in 2012, and all females in 2013 (data courtesy D. Culling) by testing progesterone levels in blood serum samples taken upon capture (pregnancy: ≥ 2.0 ng progesterone/ml; Prairie Diagnostic Services, Saskatoon, SK). We further confirmed parturition events and established calf survival to four weeks of age by conducting weekly aerial surveys during the calving seasons of 2011 and 2012. After MBM development, we decreased the frequency of calf surveys in 2013 to where the majority of females were surveyed only once during the calving season to determine calf survival at four weeks of age.

We predicted parturition status using the population-based MBM, which identifies parturition events when the three-day average movement rate (m/hr) of a female drops below an *a priori* threshold. We used the same parturition threshold of 15.3 m/h as DeMars *et al*. (2013). For females predicted to have calved, we estimated calf survival status to four weeks of age by conducting an aerial survey of each female four weeks after the predicted parturition date and compared the survey status to MBM predictions. For the population-based MBM, which predicts calf loss when a female's three-day average movement exceeds the maximum expected rate of females with neonate calves, we used the 178.6m/hr threshold specified in DeMars *et al*. (2013). We also generated calf survival predictions using the individual-based MBM, which predicts calf loss by evaluating for an abrupt change – or break point – in the distribution of step lengths (the distance between successive GPS locations) of an individual female post-calving. If model predictions differed, we used the prediction which matched the status (e.g. calf presence / absence) on aerial survey. In one instance, we truncated the post-calving data to the date the calf was last observed as the predicted date of calf loss fell before the aerial survey, which was conducted prior to four weeks post-calving. For females with differing model predictions and no aerial survey data (*n* = 5), we used the predictions of the individual-based MBM to assign calf survival status as this method has a higher accuracy rate.

2.5. Fine-scale Analyses of Calving Site Selection by Caribou

We evaluated calving site selection by female caribou by comparing structural attributes of calving sites to sites used during the winter (January 1 – March 15). Calving dates were derived from the MBMs described above and we collected structural data from all calving sites that could reasonably reach by foot or helicopter. Calving sites were only accessed after the female 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). For each calving site sampled, we collected the same data from a winter site used by the same animal. Because of the inaccessibility of many caribou locations, winter sites were randomly selected from the subset of sites that we could reasonably reach by foot or helicopter. At each calving or winter site, we recorded the dominant habitat type and the leading tree species. To assess forest structure, we calculated tree basal area (m^2/ha) using angle gauges and estimated percent crown closure by averaging measurements from a moosehorn estimator (Garrison 1949) taken at 5-m intervals along a 50-m transect centred on the site. We 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 and ground cover using the line transect method (Canfield 1941; Bowyer *et al.* 1999), 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 woody debris) and any shrub species contacting the line.

To compare structural and forage attributes of calving sites to winter sites, we used paired *t*-tests and, where the data deviated from normality, zero-inflated mixed-effect regression models in a univariate analytical framework that specified individual caribou as the random effect (Zuur *et al.* 2009).

To assess the relative importance of forage species to caribou during calving, we collected scat samples opportunistically from calving sites for subsequent dietary analysis. These samples were compared to analyses conducted on scat collected from these animals during their winter capture (samples analyzed by Washington State University Wildlife Habitat Nutrition Lab).

2.6. Analyses of Resource Selection by Caribou and Predators

To assess larger scale habitat selection by caribou and predators during the calving season and other seasonal time periods, we developed resource selection functions (RSFs), a widely used modelling approach that compares environmental attributes associated with GPS (or “used”) locations to environmental attributes of random (or “available”) locations generated within the spatial scale of interest (Manly *et al.* 2002; DeCesare *et al.* 2012b). For both caribou and predators, we developed RSFs at multiple spatial scales. From a management perspective, a key output of RSFs is explicit spatial predictions of species-specific habitat within a designated study area (Boyce 2006).

2.6.1. *Caribou Resource Selection*

We estimated RSFs for caribou at second- and third-order scales (*sensu* Johnson 1980; Fig.1). For identifying calving areas within caribou range, we primarily focus on inferences derived from second-order analyses. Compared to finer scales of selection (e.g. third- or fourth-order), inferences at a second-order scale are likely more informative for guiding potential management decisions, particularly for wide-ranging species like caribou (Boyce 2006). Moreover, this scale likely reflects the primary selective decision of female caribou as many individuals undertake long distance, migratory-type movements just prior to calving, indicating that selection is occurring at large spatial scales (Schaefer *et al.* 2000; Faille *et al.* 2010). A further advantage to second-order analyses is that the comparison of selection differences is more straightforward because the scale of availability is constant for large groups of individuals.

To specifically assess how calving areas differed from other areas within a herd's range, we used an individual-based, comparative approach that contrasted RSFs developed for females with neonate calves to RSFs developed for other seasonal periods (see below) and to RSFs developed for barren cows during the calving season (DeMars and Boutin 2014, *in review*). We further assessed resource selection pre- and post-calf loss for females losing calves prior four week of age.

We evaluated for seasonal differences in resource selection by partitioning the screened GPS data into calving, fall, and winter seasons. For calving RSFs, we used GPS locations starting from the estimated parturition date to the estimated date of calf loss or four weeks post-calving, whichever came first. For females predicted to be barren, we used GPS locations starting from May 15 – the peak of calving in our study area – to June 12. To assess resource selection outside of the calving season, we followed Nagy's (2011) delineation of seasonal activity periods for boreal caribou and estimated RSFs for late summer (August 13 – September 12), late fall (October 21 – November 30) and midwinter (January 26 – March 15).

To assess whether maternal status influenced resource selection, we focused on females losing calves prior to four weeks of age and compared RSFs estimated from with-calf locations to RSFs estimated from post-loss locations. For each female, we used an equal number of with-calf and post-loss GPS locations. To exclude behavioural alterations potentially related to the calf loss event, we allowed two days between the estimated time of calf loss and the start of data for the post-loss period (e.g., for a female losing her calf at 10 days post-calving, we used locations from days 2-12 post loss).

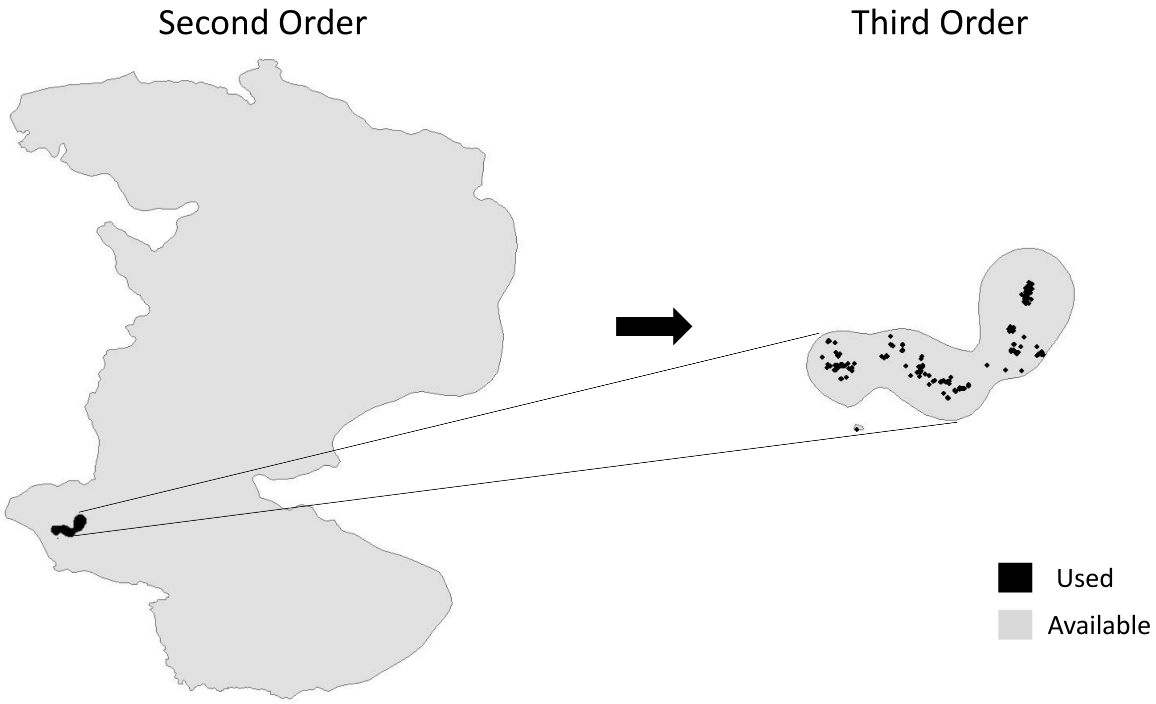


Figure 1: Scales of resource selection analyzed to identify calving habitat of female boreal caribou in northeast British Columbia. For second-order selection (left), environmental attributes of calving areas were compared to environmental attributes within caribou range (here, the Snake-Sahtaneh range). Calving areas were estimated from utilization distributions derived at the 80% isopleth (see main text). For third-order selection (right), environmental attributes associated with GPS locations of females were compared to environmental attributes within the calving area (modified from DeCesare *et al*. [2012b]).

For each seasonal and maternal status analysis, we estimated the extent of the area used by constructing 80% utilization distributions (UDs) from the GPS location data. UDs derived from the 80% isopleth provide a better estimate of home or seasonal range size than minimum convex polygons (MCPs) for non-territorial species (Börger et al. 2006). Within each UD, we generated enough random points to accurately represent the area. To determine the number of random points required, we conducted a sensitivity analysis on the largest UD, plotting the mean of each covariate against the number of random points used to calculate the mean (Appendix 3). We selected the number of random points where the mean of each covariate changed < 1%. For our data, we used 10,000 points. We repeated these analyses to determine the number of points necessary to adequately represent a herd's range (here, 20,000 points). Second-order RSF analyses thus entailed a comparison between UD random points and herd range random points. Because home range estimators like UDs can be sensitive to insufficient sampling (Börger et al. 2006), we excluded individuals with <80% fix rates within a particular seasonal period from the corresponding RSF analysis. For seasonal comparisons of selection, we used a paired design where non-calving season RSFs were estimated with all available individuals (i.e. those with >80% fix rates) and compared to calving season RSFs estimated with the same set of individuals.

To estimate third-order RSFs, we compared the GPS locations of females with neonate calves to the random points generated within the calving area UD. Because the exact location of the calving area changes year to year, we specified each animal-year as the random grouping factor (see *Section 2.6.4* below). Third-order RSFs were restricted to the calving season because the unique spatial extent of each seasonal area equates to changing resource availability across individuals and seasons, making comparison of selection differences problematic (Beyer *et al.* 2010). Similarly, we did not consider third-order analyses based on maternal status (e.g. with-calf versus post-loss).

2.6.2. Predator Resource Selection

To model resource selection of wolves and black bears, we used a similar sampling framework as for caribou, developing RSFs at second- and third-order scales (Fig. 2). We recognize that assessing second-order selection for predators is complicated by the fact that home range selection is influenced by territoriality in addition to environmental resources. We maintained this scale of analysis, however, because we constrained predator RSF analyses to the caribou calving season; consequently, predators may show preferential use of areas within their annual home ranges that may not be entirely constrained by territoriality and may be more reflective of seasonal resource selection. To account for the relatively strong territoriality of wolves, we delineated areas used by individual packs using MCPs, which are likely more reflective of actual home range boundaries for territorial species than UDs (Boyle *et al.* 2009). For black bears, we delineated used areas with 80% UDs as was done for caribou because many of the radio-collared bears in our study had overlapping areas of use during the caribou calving season, indicating a low degree of territoriality. For all second-order predator RSFs, we defined the scale of availability as the distribution of boreal caribou in BC rather than individual caribou ranges because both predators had individuals moving into and out of caribou range. To adequately characterize availability at this scale, we generated 100,000 random points. Predator UDs and MCPs were characterized by generating 10,000 random points. For wolves, we used pack-level MCPs for second-order analyses whereas bear used individual UDs. Third-order analyses for both predators compared the actual GPS locations of individuals to the UD or MCP random points.

We considered a further RSF framework for predators because a primary objective of modelling predator resource selection was to determine areas of high predation risk for caribou neonate calves (see section *2.8. Spatial Factors Affecting Calf Survival* below). For these analyses, we assessed the resources selected by bears and wolves when each predator specifically occurred in caribou range. To do so, we compared predator GPS locations falling within caribou range to available points drawn within the same range (20,000 random points / range as per caribou). These analyses may represent a more accurate depiction of predation risk to caribou calves because the majority of calving GPS locations are confined to caribou ranges (>82% based on 2010 range delineations).

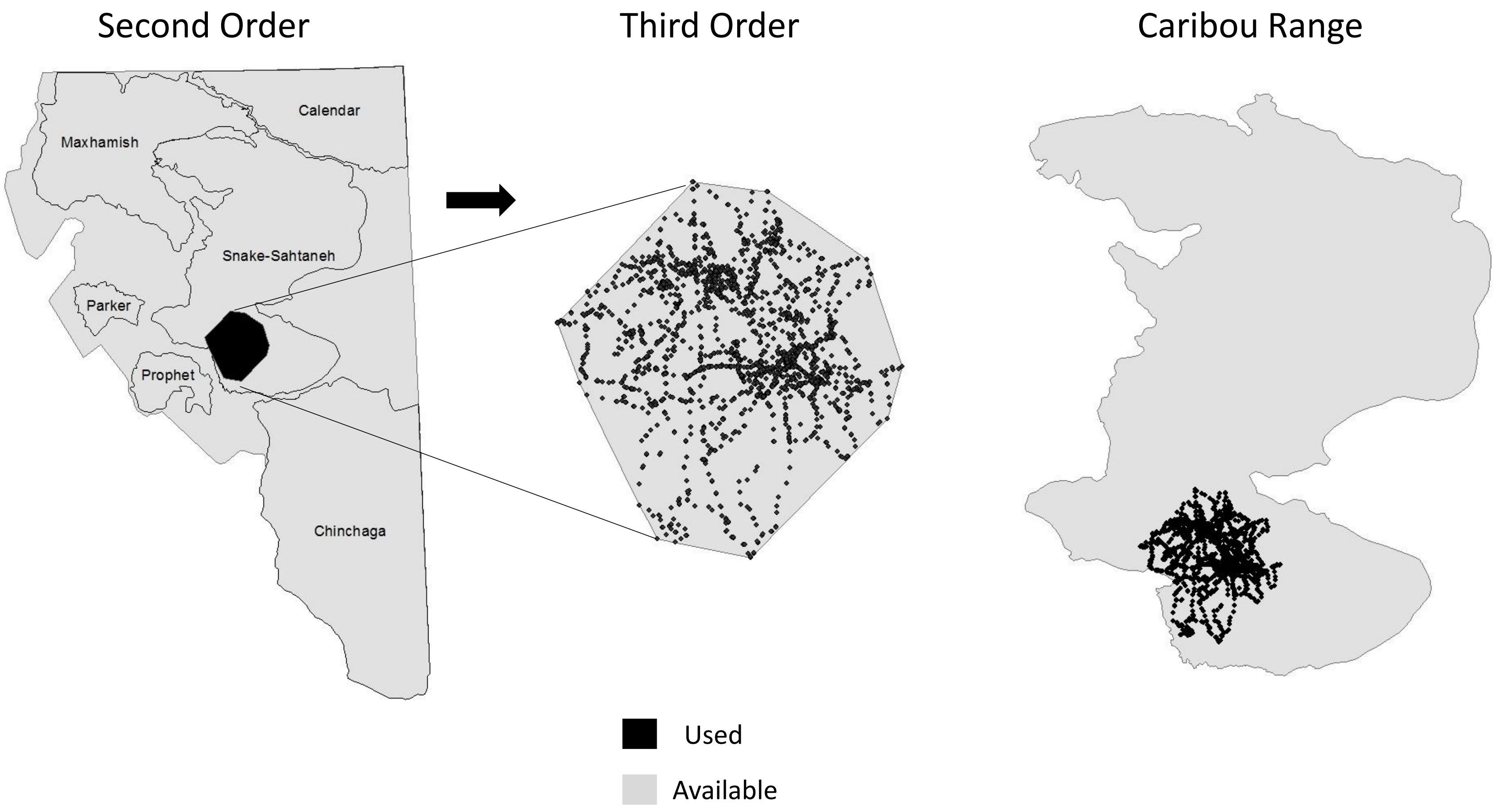


Figure 2: Scales of resource selection analyzed for wolves and black bears during the calving season of boreal caribou in northeast British Columbia. For second-order selection (left), environmental attributes of areas used during the calving season (May 1 – June 30) were compared to environmental attributes within the distribution of boreal caribou. For wolves, areas were delineated using minimum convex polygons (MCP) for each pack while 80% utilization distributions (UD) were used for individual bears. For third-order selection (center), environmental attributes associated with GPS locations of each individual wolf or bear were compared to environmental attributes within each MCP or UD. We also analyzed resource selection by predators when in caribou range (right) by comparing environmental attributes of only those GPS locations situated within caribou range to environmental attributes of the range itself (here, the Snake-Sahtaneh range; modified from DeCesare *et al.* [2012b]).

2.6.3. Environmental Variables For Modelling Resource Selection

We modelled caribou and predator RSFs using explanatory variables representing vegetation characteristics (cover type and normalized difference vegetation index [NDVI]), slope, natural features and anthropogenic disturbance (see Appendix 4 for list of data sources). For characterizing land cover type, we used Enhanced Wetlands Classification (EWC) GIS data (30-m pixel resolution) developed by Ducks Unlimited Canada, which we collapsed into eight categories that were biologically meaningful to caribou (Table 1; Appendix 5). For third-order caribou RSFs, we further collapsed deciduous swamp and deciduous upland into one category (deciduous forest) as many individual caribou had no representation of either deciduous swamp or deciduous upland in their calving UDs. For all analyses, we set treed bog as the reference category by omitting it from RSF models; thus, all land cover rankings derived from model estimates are relative to treed bog.

We modelled forage productivity using NDVI data, an index that has been used in other caribou studies (Gustine *et al.* 2006; DeCesare *et al.* 2012b). NDVI is correlated with above-ground net primary productivity and NDVI values in forested habitats are significantly influenced by forest floor greenness (Suzuki *et al.* 2011). We kept NDVI as a variable for all wolf and black bear RSF analyses because wolves may track forage quality as an index of ungulate prey density (Kunkel & Pletscher 2001) and because bears as omnivores may track green vegetation in the spring (Mosnier *et al.* 2008b). We obtained yearly NDVI data (250-m pixel resolution) for our study area from the U.S. National Aeronautics and Space Administration MODIS database. The NDVI data is derived from MODIS images spanning a 16-day window. For each year of our study and all RSF models, we used NDVI data spanning the calving season only (end-April to mid-July) and calculated an average NDVI value for each pixel during this time period. By using NDVI data only from the calving season, we could more directly evaluate the forage quality hypothesis by concurrently comparing NDVI values of calving areas with other seasonal areas.

We calculated slope in a GIS framework using a digital elevation model obtained from BC Terrain Resources Information Management data. For rivers, lakes, major roads and forestry data (fires, cut blocks, and forestry roads), we used data sets from the BC Geographic Data Discovery Service. We combined cut blocks and forest fires < 50 years old to create a unified variable describing early seral vegetation, which has been shown to be important in caribou habitat modelling (Sorensen *et al.* 2008; Hins *et al.* 2009). For well sites, pipelines, seismic lines (1996 to present) and petroleum development roads, we accessed data sets from the BC Oil and Gas Commission. We also used linear feature data from BC Terrain Resources Information Management, specifically a shapefile representing all linear features visible on the landscape, regardless of type or age, from 1992 aerial photos. To create a parsimonious linear feature data set for the study area, we merged all major roads, forestry roads, petroleum development roads, and seismic lines into one file then integrated the resulting data set at a scale of 10-m to eliminate redundancies among the original data sets.

We conducted preliminary analyses to determine the most predictive scale for each of the explanatory covariates (Levin 1992; Leblond *et al.* 2011). For each analysis, we pooled the data across individuals and conducted univariate logistic regression analyses at each spatial scale. We selected the scale with the lowest Akaike's Information Criterion (AIC) score as the scale to be included in further RSF modelling. While the most predictive scale can vary across seasons (Leblond *et al.* 2011), for caribou we conducted these analyses on the calving data only and kept the scale of each covariate constant across seasonal analyses to facilitate more direct comparison of seasonal selection coefficients (see below). For second-order analyses, we estimated the proportion of each cover type in a moving window analysis with radii varying from 400-m to 6000-m, the radius of our largest calving area MCP (100-m increments from 400- to 1000-m, 500-m increments thereafter). We assessed the density of lakes, rivers, early seral vegetation and well sites at the same scales and further evaluated whether distance-to measures were better than density measures. For lakes, we also assessed distance-to lake clusters, defined as lakes > 2 ha within 500-m of each other (Culling *et al.* 2006). All distance-to measures were transformed using an exponential decay function (1 - $\exp^{\alpha * \text{distance}}$; Nielsen *et al.* 2009) where the scaling parameter (α) was set using the 95% percentile of distance-to measures calculated for a particular covariate. This transformation erodes the importance of larger distance-to values and emphasizes values that are close to the feature itself. For linear features, we assessed density only as we were specifically interested in caribou response to changes in linear feature density. We kept NDVI and slope at the scale of the original data (250-m and 30-m, respectively) as we did not want to obscure fine-scale heterogeneity in these variables. For third order RSFs, we used a similar approach to determine the most predictive scales for each covariate except for land cover, which was maintained at its original resolution (30-m pixel).

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 study area (DU 2010).

Land cover	EWC Class	Description
Treed bog	Treed bog, Open bog, Shrubby bog	Black spruce and *Spaghnum* moss dominated bogs with no hydrodynamic flow. Areal coverage: ~20%
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: ~22%
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: ~5%
Conifer swamp	Conifer swamp	Tree cover >60% dominated by black or white spruce. Occur on peatland or mineral soils. Areal coverage: ~9%
Deciduous swamp	Shrub swamp, Hardwood swamp	Mineral soils with pools of water often present. At least 25% of tree cover is deciduous (paper birch and balsam poplar). Areal coverage: ~12%
Upland conifer	Upland conifer	Mineral soils with tree cover >25%. Dominant tree species: black spruce, white spruce and pine. Areal coverage: ~9%
Upland deciduous	Upland deciduous	Mineral soils with tree cover >25% and >25% deciduous trees Dominant tree species: aspen and paper birch. Areal coverage: ~17%
Other	Upland other, Cloud shadow, Anthropogenic, Burn, Aquatic	Uplands: mineral soils with tree cover <25%. Anthropogenic: urban areas, houses, roads and cut blocks. Burns: recent burns where vegetation is limited or covered by burn Aquatic: includes a continuum of aquatic classes from low turbidity lakes to emergent marshes where aquatic vegetation is >20% of the cover. Total areal coverage: ~6% (Cloud shadow <0.5%)

2.6.4. Statistical Framework for Estimating Resource Selection Functions

For all analyses, we visually assessed univariate relationships between used and available resources using either box plots (second-order analyses) or histograms (third-order analyses; Appendix 6). We estimated all RSFs using generalized linear mixed effect models (GLMMs; Zuur *et al.* 2009), which account for the hierarchical structure inherent in GPS location data. In all GLMMs, we assigned the individual animal as a random grouping effect, which creates a random intercept for each individual. These random-intercept GLMMs thus took the form

$$ln\left[\frac{\pi(y_i=1)}{1-\pi(y_i=1)}\right] = \beta_0 + \beta_1 x_{1ijk} + \ldots + \beta_n x_{nijk} + \gamma_{0j} + \gamma_{0jk} \qquad \text{(Eqn. 1; Gillies } et\ al. \text{ 2006)}$$

where the left-hand side of the equation is the logit transformation for location y_i, β_0 is the fixed-effect – or population mean – intercept, β_n is the fixed-effect coefficient for covariate x_n, and γ_{0j} is the random intercept for animal j. For caribou and wolf GLMMs, we extended the model to include two random grouping effects. For caribou, we used these two-factor GLMMs to test for functional responses in selection – an effect where selection strength changes as a function of availability (Mysterud & Ims 1998) – by nesting individual caribou within herd range, the second random grouping effect. These GLMMs explicitly test whether range-specific RSF models provide a better fit to the data. For third-order wolf GLMMs, we nested individual wolf within its pack to account for the often correlated movements of individuals within a pack. These two-factor GLMMs therefore take the form

$$ln\left[\frac{\pi(y_i=1)}{1-\pi(y_i=1)}\right] = \beta_0 + \beta_1 x_{1ijk} + \ldots + \beta_n x_{nijk} + \gamma_{0j} + \gamma_{0jk} \qquad \text{(Eqn. 2)}$$

where the extra parameter, γ_{0jk}, is the random intercept for herd range k (caribou GLMMs) or wolf pack k (wolf GLMMs).

The fixed-effects, or marginal, coefficients of GLMMs yield population-level inferences that can be interpreted within the classic use-availability design of

$$\omega(x_i) = \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots \beta_n x_n) \qquad \text{(Eqn. 3; Manly \textit{et al.} 2002)}$$

where $\omega(x_i)$ is the relative selection value of a sample unit (or pixel) in category i as a function of the explanatory covariates (x_n) and their estimated coefficients (β_n). For all predator and second-order RSF models, the fixed-effects component of the model stayed the same, specifically:

Land cover + slope + NDVI + river + lake + early seral + well site + line density

For third-order caribou RSFs, we excluded river, lake, early seral, and well sites because the majority of calving UDs did not contain these features. Within these model structures, none of the explanatory variables were found to be correlated (i.e., $r < 0.7$).

For predator RSFs, we only estimated random-intercept GLMMs as our interest was in quantifying population-level resource selection to derive spatial predictions of predation risk to caribou. For caribou, we estimated a suite of random-slope GLMMs because we were interested in variation among individual caribou to particular explanatory covariates and ultimately relating selection variation to calf survival. Random-slope GLMMs are an extension of the random-intercept GLMM (eqn.1) and take the form

$$ln\left[\frac{\pi(y_i=1)}{1-\pi(y_i=1)}\right] = \beta_0 + \beta_1 x_{1ijk} + \ldots + \beta_n x_{nijk} + \gamma_{0j} + \gamma_{nij} x_{nij}$$

(Eqn. 4; Gillies *et al.* 2006)

where the added parameter in Equation 4, γ_n, is the random slope (or coefficient) of covariate x_n for caribou *j*. Note that γ_n represents the difference of caribou *j* from the population mean, β_n. By estimating random slope coefficients for each individual, we explicitly maintained individual caribou as the sampling unit when evaluating caribou response to particular covariates (DeMars and Boutin 2014, *in review*). This approach is similar to two-stage RSF models where RSFs are estimated for each individual then population-level coefficients are generated by averaging across individuals (Fieberg *et al.* 2010). Two-stage RSF approaches, however, can be hampered when certain model coefficients cannot be estimated for all individuals (i.e. models fail to converge). GLMMs, on the other hand, can borrow information from the population to estimate coefficients for individuals where data is limited (Zuur *et al*. 2009). Statistical software and computing limitations constrain the number of random slopes that can be estimated in a given GLMM. We therefore estimated a suite of calving RSF models as follows, all with random intercepts for individual caribou and ranges:

i. A null model with no fixed-effects;
ii. A random-intercept only model with only fixed-effects specified;
iii. A Disturbance model where distance to early seral vegetation, distance to active well site, and linear feature density were specified as random slopes;
iv. A Water model where distance to river and distance to lake were specified as random slopes;
v. A Forage Quality model where NDVI was specified as the random slope;
vi. Three Landscape Context models where the following land cover types were specified as random slopes:
    a. Upland conifer and conifer swamp
    b. Poor fen and rich fen
    c. Upland deciduous and deciduous swamp

For third-order RSFs, we did not evaluate a Water model and excluded well sites and early seral from the Disturbance model because few calving UDs contained these features.

For seasonal analyses outside of the calving season and for comparisons based on maternal status, we estimated the Disturbance, Water, Forage, and Landscape Context models only. From these models, we used the random slope coefficients in a paired design to evaluate relative differences in selection at the individual level. For seasonal comparisons, we determined the number of individuals whose selection coefficient either increased or decreased during calving compared to selection coefficients estimated for the same set of individuals during other seasonal periods. Similarly, for females losing calves prior to four week of age, we determined the number whose selection coefficient was higher pre-loss versus post-loss. We could not use a paired design for evaluating differences between barren females and calving females because of the individual data sets spanning 2 calving seasons, most individuals calved in both seasons. We therefore compared the distributions of individual selection coefficients between calving and barren females and conducted Mann-Whitney U tests to determine whether selection differed between the two groups.

We evaluated RSF model performance using Akaike's Information Criterion (AIC) scores and two validation procedures. For caribou, we estimated all second-order RSFs using data from individuals in the Calendar, Maxhamish, Parker, Prophet, and Snake-Sahtaneh ranges. To initially evaluate predictive performance of these models, we used *k*-fold cross-validation (Boyce *et al.* 2002). To do so, we randomly partitioned the data by individual caribou into five folds (or subsets), using four folds for model training then testing model prediction on the withheld individuals. For each test, we used the fixed-effects output from the training data to predict values for both the random locations generated within each range and the locations of the withheld caribou. We partitioned the predicted values of the range random points into 10 ordinal bins of equal number (i.e. 10th percentiles) then assessed model prediction by comparing the frequency of predicted values for withheld caribou falling within a bin to bin rank using Spearman's correlation coefficient (r_S; DeCesare *et al.* 2012b)). We repeated this process three times, generating 15 total tests. The 15 tests were held constant for all models evaluated (e.g. the groups of individual caribou used for training and testing was constant for each model evaluated). We calculated the mean r_s for each model with higher $\bar{r}_S$ values indicating better predictive performance.

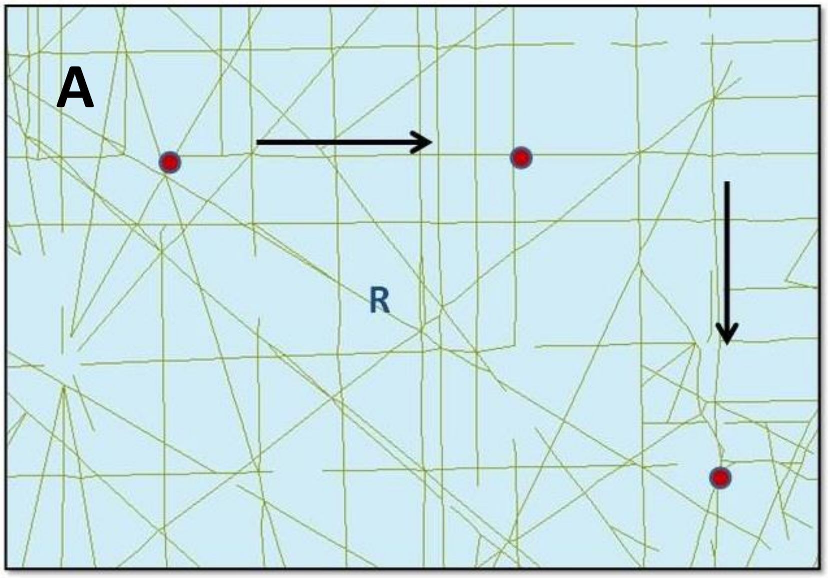
To explicitly assess how well model predictions of second-order caribou RSFs extrapolate through space, we further tested predictive performance using withheld data from four females in the Chinchaga range. For this test, we used a similar validation process where r_s was calculated after model outputs of the calving RSF were used to predict values of GPS locations of the four females as well as random points (20,000) generated with the Chinchaga range.

For third-order caribou RSF models and all predator models, we evaluated predictive performance using the *k*-fold cross-validation procedure described above. We did not evaluate the performance of seasonal RSF models for caribou outside of the calving season as our motivation was not to develop predictive models outside of calving *per se* but rather to determine how individual- and population-level selection differed from calving.

2.7. Wolf Selection of Linear Features

In 2012, we conducted a one-year study to evaluate whether wolves preferentially select certain linear features over others. For this analysis, we used GPS data collected during the 2012 calving season from two individuals in separate packs, one in the Prophet range and one centered within the Kiwigana core area. We used a paired sampling design where each line used by a wolf was matched to a line assumed to be unused, at least within the calving season of May 1 to June 30. We considered a line to be used if least two sequential wolf locations were situated on the same line and were within 10 m of the line itself to account for GPS location error. To select an unused line for comparison, we used one of two methods depending on the wolf's movement trajectory. If the wolf's movement trajectory involved a turn onto another line, we selected and sampled an unused line that represented the shortest distance between the start and end points of the trajectory (shortest path lines; Fig. 1a). If this movement pattern was not evident, we randomly selected a line within a 1 km radius of the used line that was perpendicular to the wolf's direction of travel and had no wolf GPS locations during our temporal window of sampling (parallel lines; Fig. 1b).

At each sampled line, we established three plots placed 200-m apart. For lines used by wolves, the center plot was placed at the mid-point between the two GPS locations. For unused lines, the center plot was placed midway along the line for shortest path lines or, for parallel lines, at a similar easting or northing (United Transverse Mercator units) location as the paired used line. For all lines, we noted the habitat type in which the line was located (e.g., bog, fen, upland conifer, upland deciduous), the orientation of the line, whether the line was straight or tortuous, and calculated the average line width from measurements taken at all three plots. For line width, we subsequently assigned lines to one of three types (Latham *et al.* 2011b): low-impact seismic lines (> 0-5m), traditional seismic lines (6-10m) and pipelines and secondary roads (>10m).



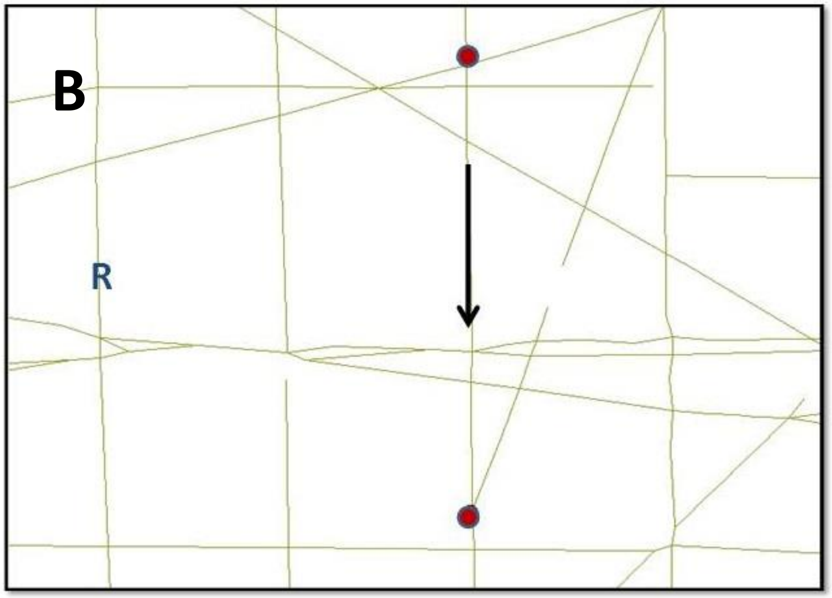


Figure 3: Selection of random lines with respect to wolf movement trajectories. Red circles represent wolf GPS locations, solid arrows represent direction of wolf travel and **R** represents unused lines selected for sampling. In A, the selected unused line represents the shortest path between the initial and final GPS location. In B, the selected unused line is parallel to the direction of travel.

To specifically describe line sightability, we recorded the maximum distance a white 40-cm diameter disk affixed to a 1.5-m pole could be seen way from the center plot in each direction down the line. For line characteristics associated with movement efficiency, we calculated indices of shrub density, substrate hardness and coarse woody debris (CWD). For the shrub density index, we multiplied average shrub height by the averaged percent shrub cover for each line. We calculated average shrub height by measuring shrub height at the center of the line and at 1-m in from each line edge at each plot. Shrub height measures were then grouped into six ordinal bins (1 = lowest shrub height values; 6 = highest shrub height values) based on the distribution of all heights recorded. Similarly, we created a six bin index for average percent cover, based on the methods of Daubenmire (1959), by estimating percent shrub cover in a 1-m wide transect extending from line edge to line edge and oriented through the plot center. For substrate hardness, we used the following index: 3 = dry ground; 2 = squishy (e.g. moss covered); 1 = squishy with water; and 0 = water visible on surface. For coarse woody debris, we recorded the number of downed woody debris with a diameter > 10 cm along a central 400-m transect connecting the end plots then created a five-level index based on the distribution of recorded counts. A score of five indicated little to no CWD while a score of one indicated lines with CWD counts > 30, a threshold selected because it approached the upper limit of the data and accounted for counting error in areas of high densities of CWD. To create an overall mobility score for each line, we summed the scores of the line width, shrub density, substrate hardness and CWD indices.

We used logistic regression to assess the relative effects of line mobility and sightability on the probability of wolf use of linear features. Because the addition of CWD to linear features has previously been considered as a management option for impeding wolf movements (Neufeld 2006), we also evaluated the effects of CWD independent of the overall mobility score. We assessed both univariate and bivariate models and used AIC, corrected for small sizes, to evaluate model performance. Prior to model fitting, we assessed for correlation among covariates by calculating Pearson correlation coefficients (r_p) and we excluded bivariate models that had variables with $|r_p| > 0.70$. For all analyses, we pooled the data across both wolves.

2.8. Spatial Factors Affecting Calf Survival

We assessed the effects of spatial factors on calf survival using two metrics: resource selection and exposure. For the first metric, we related calf survival to individual variation in maternal selection of resources. We considered both second- and third-order scales of selection, using the individual coefficients from random-slope calving GLMMs as explanatory covariates in calf survival models. Note that we did not combine different scales of selection in the same survival models. For the second metric, we related calf survival to measurements of exposure, or habitat use. In these analyses, we used the same suite of explanatory covariates used in RSF models; however, for each covariate we used the mean value of the “used” locations calculated at varying spatial scales. We considered the following scales:

i. Local or pixel scale
ii. 500-m buffer around each GPS location
iii. 1000-m buffer around each GPS location
iv. 1500-m buffer around each GPS location
v. 2000-m buffer around each GPS location
vi. Calving area (i.e. 80% UD random points)
vii. Range (i.e. range random points)

Distance-to measures were only contained in models at the local scale. For density measures, we considered buffers extending to 2000-m, which is likely near the maximum distance a predator might reasonably detect a female caribou and calf (Mech & Boitani 2003). As with survival models containing selection covariates, we did not consider models that included exposure covariates calculated at different scales.

To specifically test the predation risk hypothesis, we used explanatory covariates describing either the distance to high quality bear or wolf habitat or the density of high quality bear or wolf habitat. For these analyses, we defined high quality predator habitat as those areas with RSF values > 75th percentile and we only used predator GLMMs that had $\bar{r}_s$ validation values of > 0.70. To develop predation risk covariates for survival models, we followed the same framework, estimating individual selection coefficients at second- and third-order scales and exposure variables calculated as the mean values in the same buffer sizes as above. Selection coefficients were derived using univariate random-slope GLMMs and we evaluated the density of high quality predator habitat in radii of 500-m to 2000-m in 500-m increments to determine the most predictive scale of response (see Appendix 9).

We used Cox proportional hazard models to relate variation in either selection or exposure to the probability of neonate calf survival. To account for females calving in multiple years, we calculated year-specific selection and exposure covariates and used mixed-effects Cox models of the form

$$h_{ij}(t) = h_0(t)\exp(\beta_1 x_{i1} + \beta_2 x_{i2} + \ldots\ldots. + \beta_k x_{ik} + \Upsilon_j) \qquad \text{(Therneau 2012)}$$

where $h_{ij}(t)$ is the hazard function for individual calf i with female j at time t, $h_0(t)$ is an unspecified baseline hazard function, the x’s are explanatory covariates and Υ_j is the random effect attributable to female j. Cox models are time-to-event analyses and the event in our formulation is calf loss. We estimated the date of calf loss using the MBM approach described previously. Positive model coefficients are interpreted as an increasing risk of calf mortality with an increase in the associated covariate.

To test the four hypotheses relating spatial risk factors to calf survival, we ran the following models:

i. Disturbance hypothesis
Calf survival = distance to well site + distance to early seral + linear feature density

ii. Lake refuge hypothesis
Calf survival = distance to lake

iii. Peatland refuge hypothesis
Calf survival = proportion of poor fen + proportion of treed bog

iv. Predation risk hypotheses
Calf survival = distance to high quality bear habitat
Calf survival = density of high quality bear habitat
Calf survival = distance to high quality wolf habitat
Calf survival = density to high quality wolf habitat

We did not test the lake refuge hypothesis at third-order selection because few calving UD's contained lakes (*n* = 15) and thus this hypothesis was better evaluated at a second-order scale. We discriminated among models using AIC, first selecting the best model for explaining each hypothesis then selecting a top overall model. Relative model fit was also assessed by comparing AIC values to the value estimated from a null (or random expectation) model. For the top model(s) considered for inference, we tested the assumption of proportional hazards by assessing for linearity and a zero slope of the scaled Schoenfeld residuals (Therneau & Grambsch 2001). We furthered assessed the influence of maternal effects in the top model(s) by computing a chi-square goodness-of-fit statistic to compare Cox models with and without the random term for individual female. Model prediction was evaluated using Harrell's concordance index, which provides a measure of discriminatory power similar to the area under a receiver operating curve (ROC) used in logistic regression (Harrell *et al.* 1996).

2.9. Data Analyses

All statistical analyses were performed in R, version 3.0.2 (R Core Team, 2013). We used the R packages 'adehabitatHR' (Calenge 2006) to estimate UDs and 'lme4' (Bates *et al*., 2013) to estimate GLMMs. Mixed-effects Cox proportional hazards models were implemented using the R package 'coxme' (Therneau 2012).

3. RESULTS

3.1. Caribou Collaring and Spatial Data

In 2011, we deployed collars on 25 female caribou distributed among the Maxhamish (*n* = 9), Parker (*n* = 5), Prophet (*n* = 6) and Snake-Sahtaneh ranges (*n* = 4) and the Fort Nelson core area (*n* = 1; Appendix 7). By November 2011, three of these collars – two in Maxhamish and one in Prophet – ceased functioning due to low batteries. In March 2012, we relocated one of the Maxhamish collars still affixed to a female and this animal was re-captured and fitted with a VHF collar provided by BC MFLNRO. The other two collars were not recovered although the other Maxhamish collar was localized to an area without caribou sign (e.g. tracks or snow cratering), indicating the collar either released or the animal was deceased. During these relocation efforts, we deployed replacement Iridium GPS collars on two females in the Kiwigana core area. Through the spring and summer of 2012, three other collars ceased functioning and were not recovered. In addition, one of Kiwigana females with a replacement collar died in November. Because the mortality was not from predation, this animal was airlifted back to Fort Nelson for subsequent necropsy, which suggested poor nutrition as a likely cause (H. Schwantje, *personal communication*). By December 2012, the remainder of the collars deployed in 2011 ceased transmitting GPS data. From December 2012 through March 2013, these animals were re-captured and fitted with VHF collars as part of the REMB caribou monitoring program.

For 2013, we used GPS data from 30 female caribou, one of which was the remaining Kiwigana female captured in March 2012. The other 29 females were captured and fitted with Iridium GPS collars as part of the REMB monitoring program initiated in late 2012 / early 2013. In mid-June 2013, one female in the Chinchaga range was predated by wolves.

Overall, we obtained data from 56 individual female caribou. For collars deployed in 2011 and 2012, the mean per-collar data collection period was 542 days (range: 254, 647) with 19 collars remaining operational through two calving seasons. For collars deployed in late 2012 and early 2013, we used data up to September 12, 2013, resulting in a mean per-collar data collection period of 226 days (range: 192, 268). Following our data screening procedures, the mean per-collar fix rate during the calving season was 98.5% (range: 94.3 – 100) for 2011, 98.4% (95.4 – 99.9) for 2012 and 87.8% (69.8-96.3) for 2013. Outside of the calving season, mean per-collar fix rates were 87.9% (60.6, 97.8) for 2011, 90.0% (55.4-97.9) for 2012 and 94.7% (84.2-1.0) for 2013.

3.2. Predator Collaring and Spatial Data

3.2.1. Wolves

We initiated wolf collaring efforts in March 2012. During this time, we deployed Iridium GPS collars (ATS) on 10 wolves distributed among five packs (Appendix 8). Three packs were located in the Maxhamish range, one in the Snake-Sahtaneh and one in Prophet. Pack size varied from two to 14 individuals with three of the packs consisting of six individuals each. Shortly after deployment, many of these wolf collars began to fail. By the end of April 2012, only three were still transmitting GPS location data. These three collars continued to transmit data through June 30 but then all stopped transmitting during the first part of July. Only one collar from this initial cohort was recovered (see below).

In January 2013, we resumed wolf collaring efforts, capturing a total of 23 wolves distributed among eight packs (Appendix 8). Three packs were found in the Snake-Sahtaneh range while one pack was collared in each of the Parker, Prophet, and Chinchaga ranges. Packs were also collared in the proposed Fort Nelson core area and in an area near the Fort Nelson town site situated between the Parker and Snake-Sahtaneh ranges. Although we ultimately deployed only 22 collars (15 GPS and 7 VHF), the additional wolf was due to a mortality in the Prophet pack occurring shortly after collar deployment. This wolf was found with another deceased member of the Prophet pack and this latter individual was still wearing one of the non-functioning ATS collars deployed on this same pack in 2012. Cause of death was suspected to be inter-pack aggression (B. Culling, *personal communication*). We re-deployed the still-functioning Lotek collar on an individual in the Snake pack. Twelve of the 15 Lotek Iridium GPS collars transmitted data through the 2013 calving season. Of these, two individuals dispersed from their packs during the calving season and we therefore excluded these individual from RSF analyses. The other three collars ceased transmitting prior to April 2013.

Collectively, collar deployments in 2012 and 2013 resulted in packs being collared in all six caribou ranges. For 2012, per-collar fix rates during the calving season (May 1 – June 30) were 82.0%, 60.3%, and 49.3%. For 2013 (n = 10 collars), the mean per-collar fix rate during calving was 66.1% (range: 37.9, 95.2).

3.2.2. Black Bears

We began black bear capture efforts in May 2012. During three days of capture effort, we collared four bears, all clustered along the southern edge of the Clarke core area in the Snake-Sahtaneh range (Appendix 8). Further capture efforts in 2012 were not possible as wildlife capture activities in northeast BC were temporarily halted due to legal issues between government and First Nations. Of the four collars deployed, only one remained operation through the calving season although this collar also ceased functioning by early July. Two collars released prematurely in June while one bear was struck by a train and killed.

We resumed bear capture efforts in 2013 and from May 24 – 26, we collared 15 bears distributed within or near three caribou ranges and the Fort Nelson core area (Appendix 8). Of the 15 bears captured, 12 were males. Most bears were captured either within well sites or along roadsides. Two bears were caught within 2 km of carcasses of collared caribou that appeared to have been scavenged by bears. In general, bears seemed to be in good condition and on average were larger than individuals captured in 2012. Eight of the 15 collars remained operational through the calving season. Five non-functioning collars were recovered and all were premature releases. By October 2013, only three collars were still transmitting Iridium messages and of these three, only one appeared to be collecting GPS data. Because we did not want these remaining collars to fail during the winter denning period, we remotely blew-off these remaining collars. All three failed to transmit location data after their release and were not recovered.

For 2012 collars (*n* = 4), the per-collar data collection intervals during the calving season were 7.7, 19.0, 31.9, and 43.1 days and fix rates within these intervals were 51.3%, 77.0%, 83.1% and 78.5%, respectively. For 2013 collars (*n* = 15), the mean data collection interval per collar was 23.2 days (range: 3.9, 37.3) and the mean per-collar fix rate was 77.2% (range: 58.1, 87.0)

3.3. Caribou Parturition Rates and Neonate Survival

Based on our movement modelling and aerial surveys, we predicted parturition rates of 80% for 2011 and 74% for 2012. Parturition rates for 2011 were equal to pregnancy rates based on progesterone testing of blood serum taken from captured animals that year. For 2013, we estimated a parturition rate between 60 – 77%, a range resulting from five females having equivocal model predictions. Inspection of the raw movement data suggested that four of these females lost their calves within 48 hours, a scenario which may cause our modelling methods to miss calving events (DeMars *et al*. 2013). The other individual underwent a long-distance migration (~120 km) into the mountains southwest of the Parker range and likely calved in an alpine area. Progesterone testing of blood serum taken from females captured in 2013 revealed a pregnancy rate of 77%. Mean calving dates were similar in 2011 (May 15; range: April 29, June 1) and 2012 (May 13; range: April 22, June 21); however, in 2013 the mean calving date was approximately one week later (May 22; range: May 9, June 15; Fig. 2).

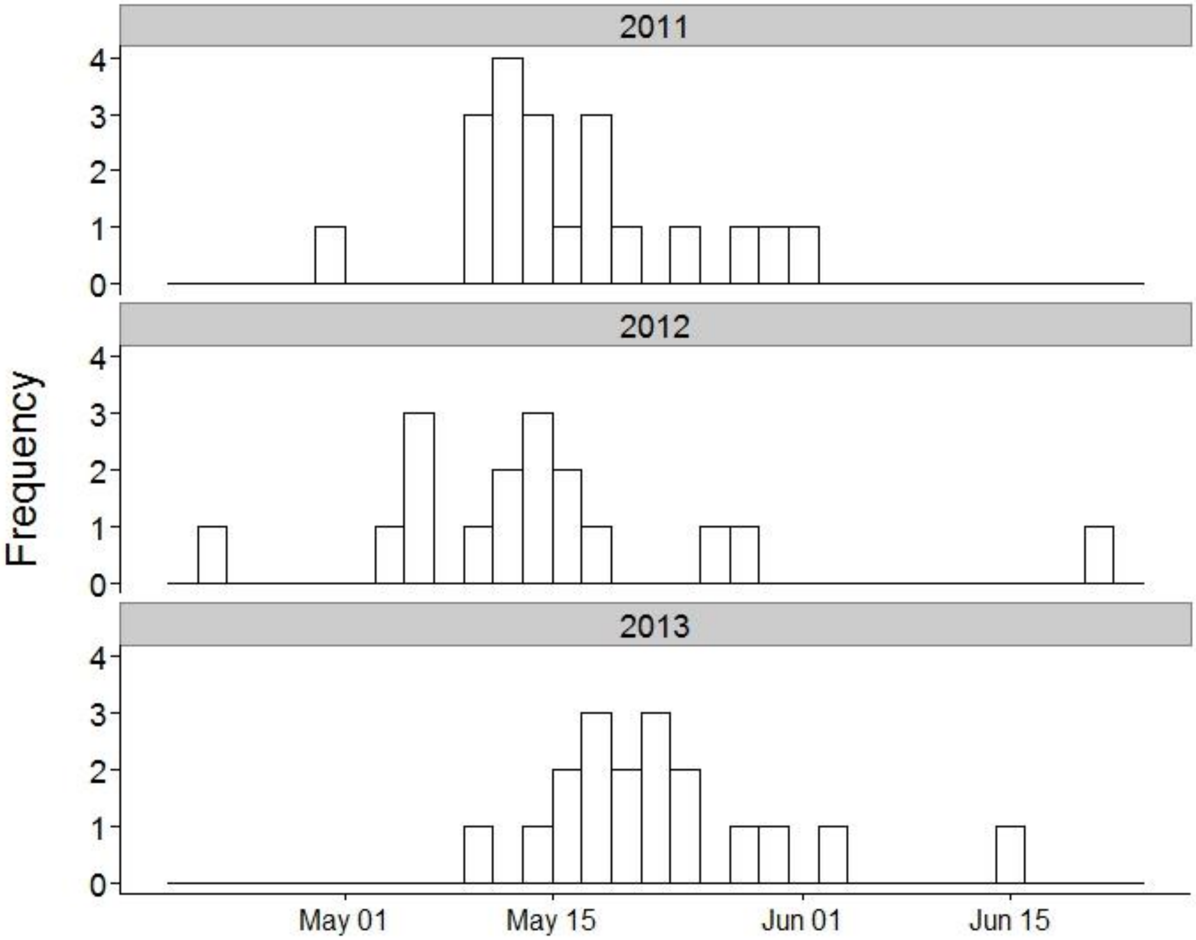


Figure 4: Distribution of estimated calving dates for female boreal caribou in northeast British Columbia across the study's three years.

In 2011, we predicted 13 of 20 calves to have survived to four weeks of age, equating to a 65% survival rate. Predicted survival was considerably lower in 2012 (6/17 calves; 35% survival rate). For 2013, we estimated eight calves to have survived to four weeks, which equates to a calf survival rate ranging between 35-44% after taking into account the uncertainty associated with our estimated parturition rate. Factoring in yearly parturition rates, estimated calf: cow ratios at the end of the neonate period were 52:100 in 2011, 26:100 in 2012 and 27:100 in 2013.

3.4. Fine-scale Analyses of Calving Site Selection by Caribou

The majority of calving sites were situated in treed bogs (*n*= 26) and poor fens (*n* = 15; Fig. 3). To a lesser degree, female caribou also used conifer swamp, upland conifer, rich fen, mixed-wood swamp and open bog as calving sites. Eighteen calving sites were located outside of delineated core habitat areas and, of these, 13 were outside of current range boundaries (Appendix 7).

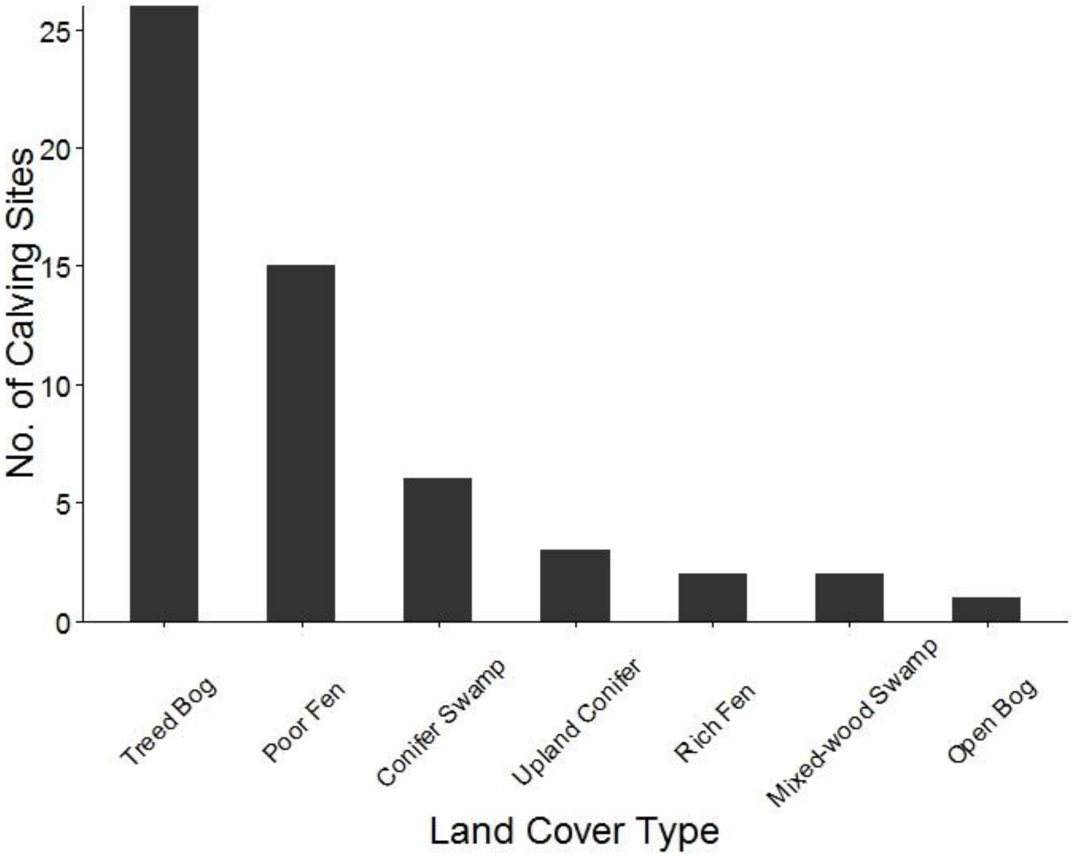


Figure 5: Distribution of land cover types used as calving sites by female boreal caribou during the calving seasons of 2011, 2012 and 2013 in northeast British Columbia.

We collected fine-scale data from 24 calving sites paired with 24 winter sites over the project's three years. In general, females selected calving sites with slightly higher concealment cover (*p* = 0.07 from a paired t-test) and less lichen cover compared to winter locations (Table 2).

Table 2: Comparison of structural and forage attributes between calving and winter sites used by female boreal caribou in northeast British Columbia from 2011 -13. We used paired t-tests for normally distributed data (A) and zero-inflated mixed-effect regression models for non-normal data (B). For regression models, we show the winter coefficient (β), which is the relative difference of winter compared to calving.

A

Variable	Calving Mean	Winter Mean	*t*	*p*
Arboreal Lichen	2.06	2.03	0.11	0.91
Concealment Cover	11.22	8.94	1.89	0.07
Moss Cover	54.83	46.25	1.54	0.14
Shrub Volume	2.22	1.61	1.42	0.17

B

	Winter β			
Variable	Estimate	SE	*z*	*p*
Basal Area	0.03	0.20	0.16	0.87
Canopy Cover	0.34	0.23	1.48	0.14
Lichen Cover	0.87	0.29	2.98	<0.01
Forb / Graminoid Cover	0.03	0.09	0.36	0.72

We collected scat samples from seven calving sites for dietary analysis (Table 3). We could only pair five of these samples with winter samples due to contamination of many winter samples (a freezer failure). We did, however, analyze two additional winter samples from other animals, allowing for the analysis of seven samples from each season. Due to these small sample sizes, we present only the raw data and the calculated seasonal means. In general, dietary composition appears similar between the two seasons.

Table 3: Percentage of major plant groups found in scat collected from female boreal caribou during the winter and at calving sites in northeast British Columbia.

Season	Caribou ID	Lichen	Moss	Grass	Sedge/Rush	Equisetum	Shrubs	Conifer
Calving	D030311	66.2	16.2	1.1	3.6	8.0	4.9	0.0
	D030312	72.7	15.4	0.0	5.9	0.3	5.1	0.6
	D030314	47.6	21.8	5.7	13.6	6.9	3.6	0.8
	D030315	29.7	34.6	0.8	13.9	14.8	6.2	0.0
	D030316	61.2	12.4	0.0	2.1	20.2	2.8	1.3
	D030320	54.1	23.2	0.0	5.8	11.8	4.0	1.1
	D030332	59.2	24.7	0.3	8.5	1.5	5.2	0.6
	Mean	55.8	21.2	1.1	7.6	9.1	4.5	0.6
Winter	D030309	62.3	24.0	4.1	3.9	1.2	4.1	0.4
	D030312	52.6	29.5	1.9	9.0	0.0	4.3	2.7
	D030314	47.2	22.9	0.9	2.7	19.9	5.2	1.2
	D030315	66.7	14.4	0.7	3.5	9.8	3.3	1.6
	D030316	50.8	22.6	0.0	21.4	0.0	4.1	1.1
	D030320	53.7	26.8	0.0	13.0	0.0	5.9	0.6
	D030331	52.0	24.3	0.6	11.2	0.5	8.6	2.8
	Mean	55.0	23.5	1.2	9.2	4.5	5.1	1.5

3.5. Caribou Resource Selection

3.5.1. Second-Order

For assessing selection of calving areas within caribou range, we used data from 35 females, twelve of which calved in two seasons. The most predictive scale of response for second-order selection varied among explanatory covariates (Appendix 9). For land cover, caribou selection was strongest at a radius of 1500-m. For linear feature density, the best scale was 400-m. For all other explanatory covariates, distance-to measures were stronger than density measures. For caribou response to lakes, distance to lake had better prediction than distance to lake cluster.

Female caribou did not show a functional response in selection of calving areas as two-factor GLMMs, which are indicative of range-level differences, were ranked lower than one-factor models (Table 4). We therefore consider only one-factor models for inference. We were unable to estimate a Forage model using calving season data as this model would not statistically converge. Also, we dropped upland conifer as a random slope variable from the Conifer model as the model would not converge with upland conifer specified as a random slope because a large portion of caribou (*n* = 17) had < 1% upland conifer within their calving UDs.

Table 4: Performance of RSF models for assessing calving area selection of female boreal caribou in northeast BC from 2011-13. Akaike's Information Criterion (AIC) measures model parsimony while mean Spearman's rank correlation ($\overline{r_s}$) measures model predictive performance. Two-factor RSFs refer to models where herd range and individual caribou were specified as random intercepts while one-factor RSFs specified only individual caribou as a random intercept. Predictive performance ($\overline{r_s}$) was evaluated for one-factor RSF models only.

Model	One-factor RSF AIC	Two-factor RSF AIC	$\overline{r_s}$ [1]
Null	2606237	2606239	n/a
Random Intercept	2046717	2046719	0.77
Disturbance	1186310	1186330	0.51
Forage	did not converge	did not converge	n/a
Water	1531568	1531579	0.75
Conifer	1576912	1576917	0.61
Fen	1292386	1292397	0.37
Deciduous	1715288	1715301	0.79

[1] $\overline{r_s}$ for each model calculated from 30 tests (6 iterations of 5 folds) except for Deciduous (n=28) where 2 training sets failed to converge

Among one factor GLMMs, the top-ranked model by AIC was Disturbance and all random-slope GLMMs were ranked higher than the model specifying a random intercept only. The Disturbance model, however, was not the top model for prediction, ranking fifth out of six models ($\overline{r_s}$ = 0.51) in *k*-fold cross-validation testing. The best models using this prediction test were the Deciduous ($\overline{r_s}$ = 0.79) and the Random Intercept ($\overline{r_s}$ = 0.77). These two models, though, had relatively poor predictive power when extrapolated to the Chinchaga range ($\overline{r_s}$ = -0.25, and -0.24, respectively), primarily due to a lack of validation points in the top two RSF bins.

We used the random-slope RSF models to specifically assess caribou response to individual covariates (Table 5). In general, caribou strongly avoided upland deciduous forests and situated their calving areas away from well sites, early seral vegetation, rivers and lakes. Caribou also avoided areas with high densities of linear features. Poor fen was the land cover most strongly selected while rich fen was selected at a rate similar to the reference category, treed bog. All other land covers were relatively avoided. Overall, female caribou showed considerable variation in calving area selection as many coefficients had 95% confidence intervals overlapping zero, although most intervals were directionally skewed toward either selection or avoidance. We further note that the magnitude of the population-level coefficient did not always correlate with the number of individuals associated with the direction of the coefficient. For example, the population-level coefficient for upland forest had the highest magnitude for avoidance (β = -5.20) yet four females had positive coefficients; conversely, the population-level coefficient for deciduous swamp showed a much lower magnitude of avoidance (β = -0.62) yet all females had negative coefficients.

Table 5: Fixed-effect coefficients, their 95% confidence intervals and the number of females with positive coefficients for the variables specified as random slopes in the suite of one-factor, random-slope GLMMs estimated for the calving season. Random slopes explicitly maintain the individual as the sampling unit and give a better representation of individual variability within the population.

Model	Variable	β Estimate	95% CI	Females (*n*=35) with Positive β 's
Disturbance	Dist. to early seral	1.42	-0.08, 2.92	26
	Dist. to well site	1.91	0.08, 3.74	33
	Line density (400-m)	-0.86	-1.79, 0.08	9
Water	Dist. to river	0.77	0.19, 1.36	32
	Dist. to lake	0.94	-0.09, 1.96	31
Conifer	Conifer swamp	-0.96	-2.03, 0.12	10
Fen	Poor fen	1.31	-0.38, 3.00	26
	Rich fen	0.05	-1.49, 1.59	16
Deciduous	Upland deciduous	-5.20	-11.25, 0.85	4
	Deciduous swamp	-0.62	-1.20, -0.04	0

Inferences gained from our analyses of individual random-slope covariates across model sets differed somewhat to inferences derived from the fixed-effect coefficients of the top AIC and predictive models (Table 6). First, effect sizes for a given variable were generally higher when it was specified as a random slope compared to models specifying it as a fixed-effect only. Second, 95% confidence intervals for random slope variables were considerably wider than the 95% confidence intervals for variables specified as fixed-effects only. Third, the coefficient direction (i.e., selection versus avoidance) changed for a few variables depending on the specifications of random-effects within the model. For land cover variables, a directional change equates to a change in the variables ranking relative to treed bog, the reference category.

Table 6: Fixed-effect parameter estimates and their 95% confidence intervals (in brackets) for three one-factor GLMMs for evaluating calving habitat selection by female boreal caribou evaluating calving habitat selection by female boreal caribou in northeast British Columbia. The Disturbance model was the top model selected by AIC while the Deciduous model had the highest predictive power (see Table 4).

	Model		
Variable	Disturbance	Random Intercept	Deciduous
Conifer swamp	0.03	-0.11	0.19
	(0.02, 0.04)	(-0.11, -0.10)	(0.19, 0.2)
Deciduous swamp	-0.39	-0.50	-0.62
	(-0.39, -0.38)	(-0.51, -0.50)	(-1.20, -0.04)
Other	-0.55	-0.47	-0.50
	-0.56, -0.55)	(-0.47, -0.46)	(-0.51, -0.50)
Poor fen	-0.22	-0.10	0.33
	(-0.23, -0.21)	(-0.10, -0.09)	(0.32, 0.34)
Rich fen	0.53	0.56	0.84
	(0.52, 0.54)	(0.56, 0.57)	(0.83, 0.84)
Upland conifer	0.42	0.42	0.33
	(0.41, 0.43)	(0.42, 0.43)	(0.32, 0.34)
Upland deciduous	-1.14	-1.05	-5.20
	(-1.15, -1.13)	(-1.06, -1.04)	(-11.24, 0.84)
Slope	-0.24	-0.16	-0.10
	(-0.25, -0.24)	(-0.16, -0.15)	(-0.10, -0.09)
NDVI	-0.02	0.11	0.15
	(-0.03, -0.01)	(0.11, 0.12)	(0.14, 0.15)
Dist. to river	0.24	0.33	0.32
	(0.24, 0.25)	(0.32, 0.33)	(0.32, 0.33)
Dist. To lake	0.25	0.16	-0.01
	(0.25, 0.26)	(0.15, 0.16)	(-0.02, -0.01)
Dist. To early seral	1.42	-0.20	-0.25
	(-0.08, 2.92)	(-0.20, -0.20)	(-0.26, -0.25)
Dist. To well	1.91	0.19	0.25
	(0.08, 3.74)	(0.18, 0.19)	(0.24, 0.25)
Line density	-0.86	-0.12	-0.06
	(-1.79, 0.08)	(-0.12, -0.11)	(-0.07, -0.06)

3.5.2. Second-Order Seasonal Comparisons

We compared calving area selection to the selection of other seasonal areas using 24 females for each comparison (Table 7, Appendix 10), a number reduced from the 35 above due to our criterion of excluding animals with seasonal fix rates <80% and because of differences in the timing of collar deployments and life spans of collar batteries. These factors also resulted in the set of 24 females differing for each comparison (i.e., the set of 24 used to compare calving to mid-winter was different than the set used to compare calving to late summer). Across all seasonal comparisons, the most consistent characteristics defining calving areas were relatively higher proportions of poor fens and lower densities of linear features. The relative selection or avoidance of other variables depended on the seasonal comparison. Comparing calving to mid-winter, female caribou showed relative selection for poor fens (23/24 individuals, $p < 0.001$ from binomial exact test) and moved into areas that were relatively lower in linear feature density (19/24, $p = 0.007$), higher in forage quality (20/24, $p = 0.002$) and closer to lakes (21/24, $p < 0.001$). Compared to late summer, calving females relatively selected both poor (19/24, $p = 0.007$) and rich fens (20/24, $p = 0.002$), were closer to lakes (23/24, $p < 0.001$) and avoided conifer swamps (18/24, $p = 0.02$), upland deciduous forests (24/24, $p < 0.001$) and areas higher in linear feature density (23/24, $p < 0.001$). Relative to late fall, females selected calving areas that had higher proportions of poor fens (22/24, $p < 0.001$), were lower in linear feature density (19/24, $p = 0.007$), and were situated farther from lakes (23/24, $p < 0.001$) and rivers (24/24, $p < 0.001$). Calving areas were also situated relatively closer to well sites (22/24, $p < 0.001$) and had lower proportions of upland deciduous forests (19/24, $p = 0.007$), conifer swamps (18/24, $p = 0.02$) and deciduous swamps (24/24, $p < 0.001$) than late fall areas.

Table 7: Relative seasonal differences in habitat selection by female boreal caribou in northeast British Columbia. Conditional coefficients of random-slope variables from calving RSF models were compared to coefficients derived from the same set of models estimated during other seasonal time periods. Listed numbers refer to the number of females that had a higher variable coefficient (i.e. relative selection) during calving compared to the other seasonal periods. Bold numbers refer to comparative differences where $p < 0.05$ from a binomial exact test.

		No. of Females with Relative Selection at Calving Versus:		
Model	Variable	Mid Winter ($n = 24$)	Late Summer ($n = 24$)	Late Fall ($n = 24$)
Disturbance	Dist. to early seral [1]	9	7	8
	Dist. to well site	10	17	**2**
	Line density (400-m)	**5**	**1**	**5**
Water	Dist. to river	15	10	**24**
	Dist. to lake	**3**	**1**	**23**
Forage	NDVI	**20**	17	9
Conifer	Conifer swamp	12	**6**	**6**
Fen	Poor fen	**23**	**19**	**22**
	Rich fen	9	**20**	9
Deciduous	Upland deciduous	17	**0**	**5**
	Deciduous swamp	13	8	**0**

[1] For distance-to variables, numbers refer to the number of individuals that were further way from the habitat element compared to the other time periods.

3.5.3. Second-Order Comparisons of Maternal Status

The presence of a dependent calf also influenced female habitat selection during the calving season (Table 8, Appendix 10). Comparing areas used by females with calves ($n = 22$) to areas used by the same females after calf loss, the presence of a calf resulted in females selecting areas that were further away from early seral vegetation (21/22 individuals, $p < 0.001$ from binomial exact test), well sites (17/22, $p < 0.02$), rivers (17/22, $p < 0.02$) and lakes (20/22, $p < 0.001$). Females with calves also relatively avoided rich fens (20/22, $p < 0.001$), upland deciduous forests (20/22, $p < 0.001$), and deciduous swamps (22/22, $p < 0.001$). Compared to barren females ($n = 11$; Table 9), calving females ($n = 35$) selected for areas higher in proportion of poor and rich fens ($p < 0.002$ and $p < 0.01$, respectively, from Mann Whitney U tests), lower in linear feature density ($p < 0.004$) and that were situated further away from early seral vegetation ($p = 0.03$), well sites ($p < 0.001$), rivers ($p < 0.007$) and lakes ($p < 0.004$). Calving females also showed relatively stronger avoidance of upland deciduous forests ($p < 0.001$).

Table 8: Relative differences in habitat selection by female caribou based on calf status. Conditional coefficients of random-slope variables are compared from RSF models calculated pre- and post-calf loss for females losing calves prior to four weeks of age. Bold numbers refer to comparative differences where p < 0.05 from a binomial exact test.

Model	Variable	No. of Females ($n = 22$) with Relative Selection Pre- versus Post-Calf Loss
Disturbance	Dist. to early seral	**21**
	Dist. to well site	**17**
	Line density (400-m)	12
Water	Dist. to river	**17**
	Dist. to lake	**20**
Forage	NDVI	14
Conifer	Conifer swamp	5
Fen	Poor fen	6
	Rich fen	**2**
Deciduous	Upland deciduous	**2**[1]
	Deciduous swamp	**0**

[1] For upland hardwood, the sample size is 19 female caribou. Because of non-convergence with the original sample of 22, we removed three females that did not have upland hardwood in their utilization distributions.

Table 9: Relative differences in habitat selection between female boreal caribou with calves and barren females during the calving season in northeast British Columbia. The distributions of individual selection coefficients for covariates specified as random-effects in generalized linear mixed-effects models were compared between the two groups using Mann-Whitney U tests. The median coefficient value (β) for each group is presented for each covariate.

		Median β		
Model	Variable	Calving (*n* = 35)	Barren (*n* = 11)	*p*
Disturbance	Dist. to early seral	1.52	0.05	0.03
	Dist. to well site	2.30	0.51	0.001
	Line density (400-m)	-1.82	0.22	0.004
Water	Dist. to river	1.07	0.17	0.007
	Dist. to lake	1.26	-0.03	0.004
Conifer	Conifer swamp	-1.79	-1.25	0.86
Fen	Poor fen	2.29	-0.75	0.002
	Rich fen	-0.15	-1.90	0.01
Deciduous	Upland deciduous	-6.39	-1.58	< 0.001
	Deciduous swamp	-0.83	-1.29	0.19

3.5.4. Third-Order

Female selection of resources was more variable within calving areas. At this scale, the top-ranked model by AIC was the Forage model, which was also the best for prediction although predictive power was relatively low (Table 10). Using the Forage model for inference, females selected treed bogs and poor fens at a similar rate while all other land covers were relatively avoided (Table 11). Females also avoided areas with high linear feature density. Female response to forage productivity – as indexed by NDVI – was weak though directionally skewed toward selection.

Table 10: Performance of RSF models for assessing resource selection within calving areas by female boreal caribou in northeast BC from 2011-13. Akaike's Information Criterion (AIC) measures model parsimony while mean Spearman's rank correlation ($\overline{r_s}$) measures model predictive performance.

Model	AIC	$\overline{r_s}$
Forage	982852	0.44
Disturbance	983151	0.18
Fen	987365	0.05
Hardwood	988380	0.30
Conifer Swamp	992245	0.25
Random Intercept	1000006	0.23
Null	1015329	n/a

Table 11: Parameter estimates (β) and 95% confidence intervals for the top-ranked RSF model evaluating third-order selection by female boreal caribou in northeast British Columbia.

Variable	β	95% CI
Conifer Swamp	-0.50	(-0.52, -0.48)
Upland Hardwood	-0.70	(-0.72, -0.68)
Other	-0.76	(-0.83, -0.69)
Poor Fen	0.00	(-0.01, 0.01)
Rich Fen	-0.09	(-0.11, -0.07)
Upland Conifer	-0.82	(-0.86, -0.79)
Slope	0.02	(0.02, 0.03)
NDVI	0.20	(-0.09, 0.49)
Line Density	-0.31	(-0.33, -0.30)

3.6. Predator Resource Selection

3.6.1. Wolves

Across the three scales of selection assessed for wolves, third-order RSF models had relatively good predictive power ($\overline{r_s}$ = 0.74) while second-order and caribou range models performed relatively poorly ($\overline{r_s}$, = -0.12 and 0.43, respectively). We focus on third-order models for inference into wolf resource selection during calving (Table 12). At this scale, wolf response to land cover was best discriminated by calculating proportions in a 400-m radius. The highest ranked land covers were "other" (i.e. anthropogenic features, recent burns, and aquatic habitats), rich fen and deciduous swamp. Treed bog and poor fen were the lowest ranked land covers. In general, wolves selected low slope areas and were closer to rivers and lakes and further away from early seral habitat than random locations. Wolves also weakly avoided areas of high linear feature density (6000-m radius) and areas with high NDVI values.

Table 12: Parameter estimates (β) and their 95% confidence intervals (in brackets) from resource selection functions estimated at three spatial scales for wolves during the calving season of caribou in northeast British Columbia. For Caribou Range analyses, wolf GPS locations falling within caribou range were compared to random locations within the same caribou range. Of the three scales, the third-order model had the highest predictive power.

	β		
Variable [a]	2nd Order	3rd Order	Caribou Range
Conifer Swamp	-0.17	0.10	-0.10
	(-0.17, -0.16)	(0.09, 0.11)	(-0.11, -0.09)
Deciduous Swamp	0.17	0.18	-0.27
	(0.17, 0.18)	(0.17, 0.19)	-0.28, -0.26)
Other	-0.17	0.54	-0.58
	(-0.17, -0.16)	(0.53, 0.54)	(-0.59, -0.57)
Poor Fen	0.12	0.05	-0.22
	(0.11, 0.12)	(0.04, 0.05)	(-0.23, -0.21)
Rich Fen	-0.08	0.26	0.68
	(-0.08, -0.08)	(0.25, 0.26)	(0.66, 0.68)
Upland Conifer	0.09	0.13	0.03
	(0.09, 0.10)	(0.12, 0.13)	(0.02, 0.04)
Upland Deciduous	-0.08	0.15	0.15
	(-0.09, -0.08)	(0.14, 0.17)	(0.14, 0.16)
Slope	0.02	-0.09	-0.16
	(0.01, 0.02)	(-0.10, -0.08)	(-0.17, -0.15)
NDVI	0.13	-0.11	0.06
	(0.13, 0.13)	(-0.13, -0.10)	(0.05, 0.07)
Dist. to river	-0.04	-0.16	-0.36
	(-0.05, -0.04)	(-0.17, -0.15)	(-0.37, -0.36)
Dist. to lake	0.00	-0.20	-0.28
	(0.00, 0.00)	(-0.21, -0.19)	(-0.28, -0.27)
Dist. to early seral	-0.28	0.33	0.19
	(-0.29, -0.28)	(0.32, 0.34)	(0.18, 0.20)
Dist. to well	0.42	0.00	0.24
	(0.41, 0.42)	(-0.01, 0.01)	(0.23, 0.24)
Line density	0.66	-0.07	0.61
	(0.66, 0.67)	(-0.09, -0.06)	(0.60, 0.62)

[a] Land cover proportions were calculated in 6000-m radius for 2nd and Caribou Range analyses and at a 400-m radius for 2nd order analyses. Line density was calculated at a 6000-m radius for all scales.

3.6.2. Black Bears

Resource selection by black bears during the calving season was better predicted at larger spatial scales (2^{nd} order $\bar{r}_s$= 0.87; Caribou Range $\bar{r}_s$= 0.71) than at a finer third-order scale ($\bar{r}_s$ = 0.45). As with wolves, we focus inference on models with $\bar{r}_s > 0.70$ (Table 13). For both second-order and caribou range analyses, selection was best discriminated by using a 6000-m radius to calculate land cover proportions and linear feature density. At a second-order scale, bears selected for upland deciduous forest, deciduous swamp, and poor fen while upland conifer, rich fen, and conifer swamp were avoided compared to treed bog. When specifically in caribou range, black bears strongly selected for upland deciduous forests and rich fens while deciduous swamp was the only land cover that was avoided relative to treed bog. At both scales, bears generally selected areas with high linear feature density, weakly selected for areas with increasing slope and were closer to water sources, particularly lakes, relative to random locations. Bears were also closer to early seral vegetation with this effect strongest at the second-order scale. Response to NDVI differed between scales as bears selected areas with higher NDVI values at a second-order scale but avoided these areas while in caribou range. Response to well sites was only evident when bears were in caribou range with generally closer to these features than expected.

Table 13: Parameter estimates (β) and their 95% confidence intervals (in brackets) from resource selection functions (RSF) estimated at three spatial scales for black bears during the calving season of caribou in northeast British Columbia. RSF models had better prediction at larger scales (2nd order $\overline{r_s}$= 0.87; Caribou Range $\overline{r_s}$= 0.71) than finer scales ($\overline{r_s}$ = 0.45).

	β		
Variable [a]	2nd Order	3rd Order	Caribou Range
Conifer Swamp	-0.51	0.01	0.16
	(-0.51, -0.51)	(0.00, 0.02)	(0.14, 0.17)
Deciduous Swamp	0.74	0.10	-0.10
	(0.74, 0.75)	(0.09, 0.11)	(-0.11, -0.09)
Other	0.00	0.19	0.30
	(-0.01, 0.00)	(0.18, 0.20)	(0.29, 0.32)
Poor Fen	0.36	0.06	0.04
	(0.35, 0.36)	(0.04, 0.07)	(0.02. 0.06)
Rich Fen	-0.42	0.13	0.62
	(-0.43, -0.42)	(0.12, 0.14)	(0.60, 0.64)
Upland Conifer	-0.35	0.14	0.02
	(-0.36, -0.34)	(0.13, 0.15)	(0.00, 0.03)
Upland Deciduous	0.82	0.40	0.86
	(0.82, 0.83)	(0.39, 0.42)	(0.84, 0.87)
Slope	0.02	-0.05	0.03
	(0.02, 0.03)	(-0.05, -0.04)	(0.02, 0.04)
NDVI	0.17	-0.21	-0.14
	(0.17, 0.17)	(-0.22, -0.20)	(-0.15, -0.13)
Dist. to river	-0.06	-0.05	-0.30
	(-0.06, -0.06)	(-0.06, -0.04)	(-0.31, -0.29)
Dist. to lake	-0.48	-0.13	-0.50
	(-0.45, -0.48)	(-0.14, -0.12)	(-0.51, -0.49)
Dist. to early seral	-1.06	-0.10	-0.25
	(-1.06, -1.06)	(-0.12, -0.09)	(-0.26, -0.24)
Dist. to well	0.00	-0.18	-0.38
	(-0.01, 0.00)	(-0.19, -0.17)	(-0.39, -0.37)
Line density	0.79	-0.18	0.55
	(0.79, 0.80)	(-0.19, -0.16)	(0.54, 0.55)

[a] Land cover proportions and linear feature density were calculated in 6000-m radius for 2nd and Caribou Range analyses. For 3rd order analyses, land cover proportion was estimated in a 400-m radius and linear featured density in a 2000-m radius.

3.7. *Wolf Use of Linear Features*

We sampled 23 lines used by wolves and 25 lines that were assumed to be unused during the 2012 calving season. The univariate model containing CWD was the top-ranked model although models with sightability included as a variable were all within one AIC_c unit (Table 14). CWD seemed to more parsimoniously explain the relative ease of movement on a given line rather than our overall mobility index. From the top-ranked model, the probability of wolves using linear features decreased with higher amounts of coarse woody debris ($\beta = -0.07$, SE = 0.03, $p = 0.05$; Fig. 4). The univariate model for sightability suggested that line use increased with increasing sightability ($\beta = 0.01$, SE = 0.003, $p = 0.02$; Fig. 5). Sightability had lower correlation with CWD ($r_p = -0.41$) than with the mobility index ($r_p = 0.69$.)

Table 14: Model selection results assessing the relative influence of sightability, coarse woody debris (CWD) and the overall mobility index score on the probability of wolf use of linear features in northeast British Columbia. We discriminated among models using Akaike's Information Criterion corrected for small sample sizes (AIC_c)

Model	AIC_c	Log-Likelihood	df [a]
Line use ~ CWD	64.17	-29.95	2
Line use ~ CWD + sightability	64.21	-28.83	3
Line use ~ Sightability	64.72	-30.24	2
Line use ~ Mobility	65.79	-30.76	2
Line use ~ Mobility + sightability	66.41	-29.93	3

[a] degrees of freedom

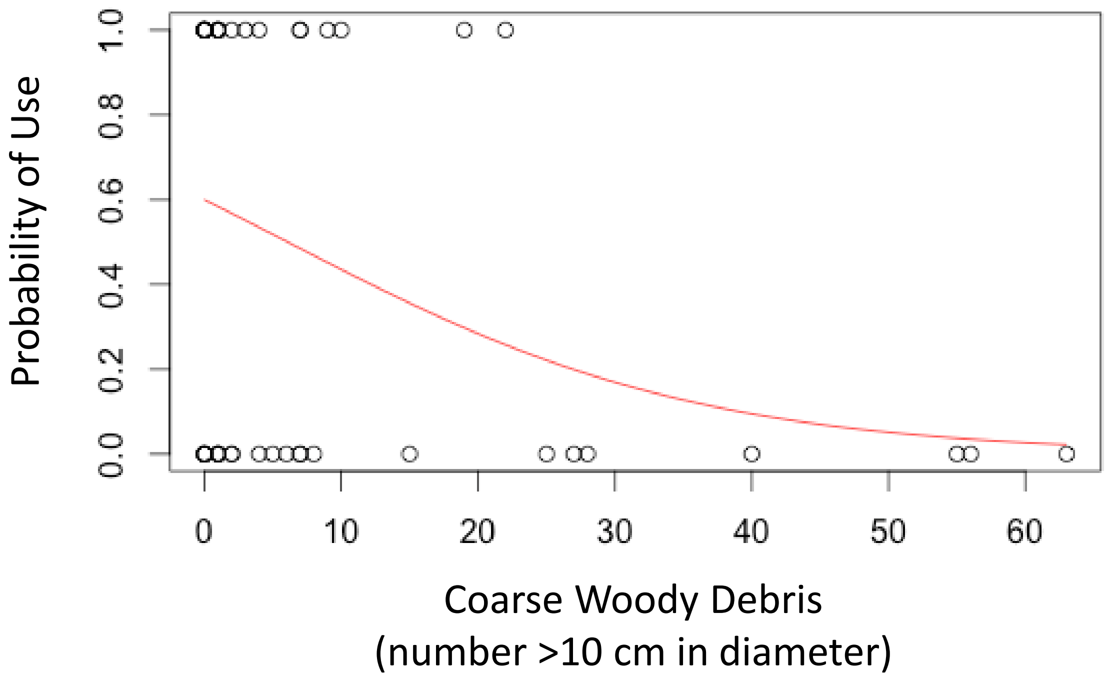


Figure 6: The effect of increasing coarse woody debris (CWD) on probability of line use by wolves in northeast British Columbia. Line use significantly decreases with increasing CWD (*p* = 0.05).

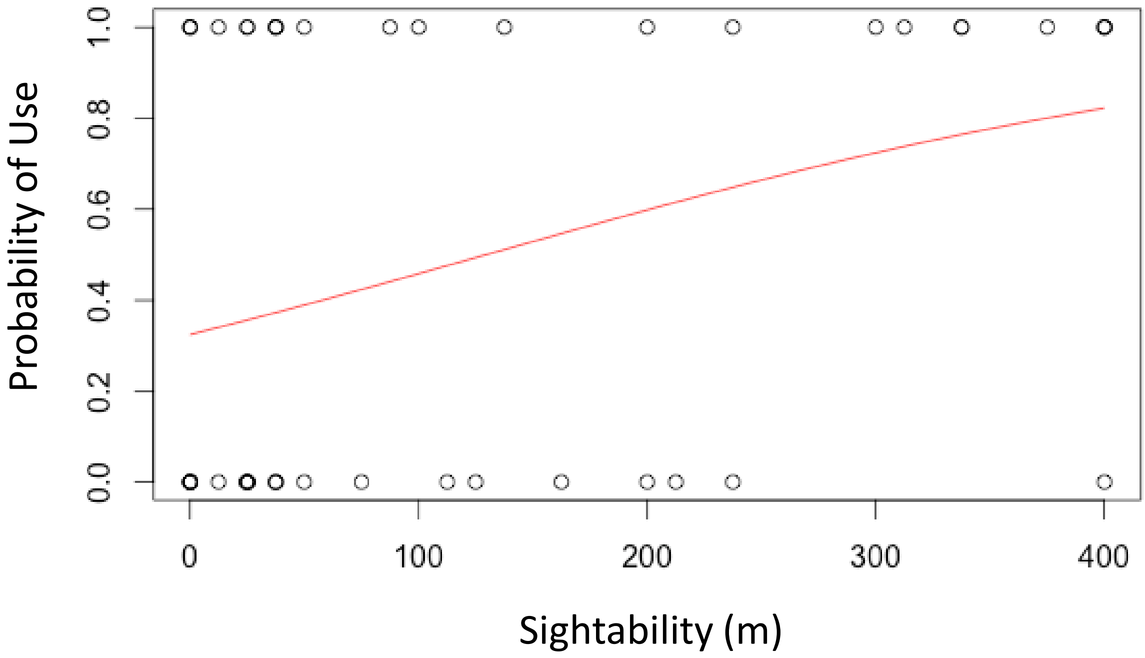


Figure 7: The effect of sightability on probability of line use by wolves in northeast British Columbia. Line use significantly increases with sightability (*p* = 0.01).

3.8. Spatial Factors Affecting Calf Survival

To assess spatial factors affecting survival of neonate calves, we evaluated multiple model sets, each falling under our four *a priori* hypotheses describing disturbance levels, lake refuge effects, peatland refuge effects and predation risk (Appendix 11). Among these models, neonate calf survival was best predicted by a predation risk model that described the third-order selective response of female caribou to predation risk from bears (Table 15). For this model, bear predation risk was represented as the density of high quality bear habitat within a 500-m radius and bear habitat was estimated from RSF models developed at the caribou range scale. We focus inference on the formulation of this model without random terms as maternal effects were weak ($X^2 = 0.16$, df = 1, $p = 0.68$). Model output suggests that the risk of neonate mortality increases by 59% (95% CI: 28, 98) for every one unit increase in maternal selection of local areas (500-m radius) containing higher proportions of high quality bear habitat. The model's estimated survival function shows that the highest rates of calf mortality occur during the first three weeks of life (Fig. 6). Model discriminatory power was good (Harrell's concordance = 0.78) and the assumption of proportional hazards was generally supported as there was no evidence for a non-zero linear trend in the scaled Schoenfeld residuals ($\rho = -0.362$, $X^2 = 1.91$, $p = 0.17$).

The bear predation model had clear separation from all other models considered, being seven AIC units lower than the next best model (Appendix 11). Models representing the other three hypotheses performed poorly, having AIC values similar to the null or random expectation model (Table 15). In general, models using selection metrics performed better than exposure metrics. For predation risk models, variables describing the density of predator habitat performed better than distance-to variables, particularly those calculated within smaller radii (≤ 1000-m).

Table 15: Top-ranked mixed-effect Cox proportional hazard models for each of four hypotheses evaluated for explaining the probability of survival of boreal caribou calves in northeast British Columbia. Analyses were restricted to the neonate period (< 4 weeks old). Models were developed at multiple scales and used two different metrics: selection and exposure (see main text). Models were ranked using Akaike's Information Criterion (AIC) and parameter estimates (β) with their 95% confidence intervals are presented for the top model within each hypothesis.

Hypothesis	Metric	Scale	Model Variables	β (95% CI)	AIC
Predation Risk	Selection	3rd Order	Density of high quality bear habitat [1]	0.50 (0.27, 0.73)	175
Disturbance	Selection	2nd Order	Dist. to early seral	0.09 (0.02, 0.16)	186
			Dist. to well	0.00 (-0.06, 0.06)	
			Line density	-0.10 (-0.21, 0.00)	
Random Expectation	-	-	Null (intercept–only) model	-	187
Lake Refuge	Selection	2nd Order	Dist. to lake	0.05 (-0.02, 0.12)	188
Peatland Refuge	Exposure	Local	Treed bog [2]	-1.45 (-3.14, 0.24)	188
			Poor fen	-0.54 (-2.21, 1.13)	

[1] High quality bear habitat defined as areas with >75% RSF values estimated from a black bear RSF model developed at the caribou range scale.

[2] Proportion of GPS locations falling within treed bogs or poor fens

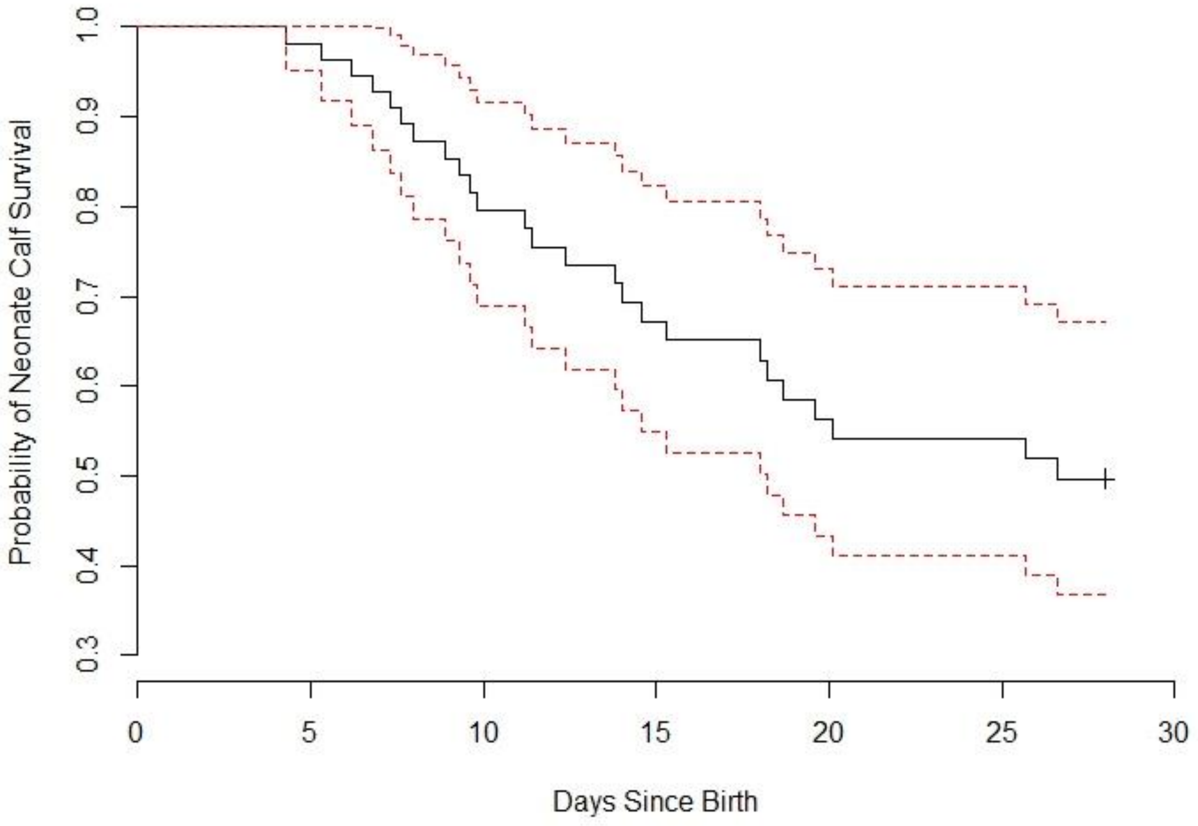


Figure 8: Estimated survival function (black line; red dashed lines = 95% confidence interval) of the top-ranked model for predicting survival of boreal caribou calves ≤ 4 weeks old in northeast British Columbia. The model related survival as function of maternal selection of local areas (500-m radius) that varied in the density of high quality black bear habitat.

4. DISCUSSION

Using a multi-scale, comparative approach, we documented discrete patterns of resource selection by female caribou with neonate calves, indicating that calving areas constitute distinct habitats within caribou range. Across scales, females with calves selected locations and areas for reducing predation risk. Yet, despite this selection tendency, caribou continued to sustain high rates of calf mortality. Patterns of resource selection by predators generally diverged from caribou except for potential overlap in landscapes containing rich fens. Survival of neonate calves, however, was not influenced by any specific landscape feature; rather, neonate survival was best predicted by predation risk from black bears.

4.1. Caribou Parturition and Neonate Survival

Across the project's three years, our estimated parturition rates (2011: 80%; 2012: 73%; 2013: 60-77%) were low compared to rates recorded for caribou in other studies (85%, Stuart-Smith *et al.* 1997; 86%, Rettie & Messier 1998; 78-90%, Culling *et al.* 2006; 79%, Pinard *et al.* 2012). For 2013, low rates of calving may have been influenced by severe winter conditions that lasted until the end of April (DeMars & Boutin 2013). Severe late winter conditions have been known to delay parturition in caribou (Skogland 1984) or cause embryonic mortality (Russell *et al.* 1998). The former effect likely contributed to the peak calving period being delayed by approximately one week in 2013 compared to 2011 and 2012. The reasoning for low rates of parturition the previous two years, however, is less clear (see below) and it is uncertain whether these rates reflect decreases in pregnancy rates or an increase in embryonic mortality. Although our overall parturition rates were similar to pregnancy rates, pregnancy testing was conducted on blood taken from animals in mid-winter and some pregnancies may have been terminated prior to capture.

Rates of neonate survival showed a similar pattern to parturition. In 2011, 65% of calves survived to four weeks of age while rates were considerably lower in 2012 (35%) and 2013 (35-44%). While this constitutes a large discrepancy in survival between the project's first and last two years, we note that in 2011 aerial surveys were continued until six weeks of age and survival had dropped to 35% by mid-July. Combining neonate survival with parturition, annual calf-to-cow ratios were 28: 100 in 2011 (at six weeks of age), 26: 100 in 2012 and 27: 100 in 2013. These results indicate that boreal caribou in northeast BC are continuing to incur high rates of neonate mortality. Moreover, these ratios are below annual calf-cow recruitment ratios associated with caribou population stability (~30 calves: 100 cows; Environment Canada 2012) although such analyses of stability should also include estimates of adult female survival (DeCesare *et al.* 2012a). For example, given an assumed 50-50 ratio of female to male calves, a calf-to-cow ratio of 28:100 would equate to 14 female calves at the end of the neonate period. Because recent estimates of survival rates for adult females range from 78-91% (Hervieux *et al*. 2013), the number of surviving female calves may be insufficient to replace adult mortalities.

Further, calves surviving the neonate period are likely to sustain further mortalities prior to reaching reproductive maturity (Seip 1992, Stuart-Smith *et al*. 1997), thereby decreasing the likelihood that juvenile recruitment will be sufficient to maintain stable caribou populations.

The primary cause of calf mortality in most caribou populations is predation (Adams *et al.* 1995; Gustine *et al.* 2006; Pinard *et al.* 2012) and given the low rates of neonate survival we recorded over the project's three years, our results are consistent with the predation-mediated hypothesis for population declines of caribou (Festa-Bianchet *et al.* 2011). Our low rates of parturition, however, suggest the potential for other interacting factors. Eberhardt (1977) proposed that that density dependent effects will affect fitness components in a predictable order: first juvenile survival, then fecundity, then adult survival. While there has been little evidence thus far to suggest that caribou populations are declining due to density dependent effects (Festa-Bianchet *et al.* 2011; McLellan *et al.* 2012), our low rates of parturition may indicate declining summer and/or winter range conditions that are density-independent (Russell *et al.* 1998; Parker *et al.* 2009). This line of reasoning is also supported by our dietary analyses, which found that moss constituted >20% of the winter and early spring diet and increasing rates of moss intake may correlate with declining range conditions (Ihl 2010). Such declines in winter range condition could result from climate-induced changes (Gunn 2003) or from decades of fire-suppression changing the distribution, abundance and quality of terrestrial lichen (Cumming 2005; Dunford *et al.* 2006), which constitutes a larger proportion of the diet. Quantifying range conditions over large scales for boreal caribou is difficult; however, given the hypothesis that range-mediated effects on caribou productivity (fecundity and calf survival; Parker *et al*. 2009) may cause caribou populations to cycle (Gunn 2003), the issue of range condition may warrant further investigation.

4.2. Calving Habitat Selection by Female Caribou

We used a multi-scale approach to evaluate calving habitat selection by female boreal caribou. In general, females selected habitats to reduce predation risk although the intensity of this response varied across scales. Predation risk has been suggested to be an important driver of caribou behaviour during reproduction (Bergerud *et al.* 1984; Bergerud 1992) with boreal caribou dispersing – or 'spacing out' (*sensu* Bergerud & Page 1987) to avoid predator encounters. Within this dispersion strategy, our results indicate that females select calving habitat that further reduces the probability of predator encounter.

At a fine-scale, females predominantly situated calving sites in treed bogs (*n* = 26 out of 55) and nutrient-poor fens (*n* = 15). These land covers are considered to be predator refugia for caribou (McLoughlin *et al.* 2005; Latham *et al.* 2011a, 2013a), a finding generally supported by our fine-scale analyses of predator habitat selection (see below). Females also selected calving sites with relatively high concealment cover, a result that contrasts with calving site selection by boreal caribou in eastern ranges where calving sites were situated in more open habitats

(Pinard *et al.* 2012; Leclerc *et al.* 2012). This discrepancy reflects equivocal results in other ungulate species (e.g. moose [*Alces alces*]: Bowyer *et al.* 1999; Poole *et al.* 2007; elk [*Cervus elaphus*]: Barbknecht *et al.* 2011; Rearden *et al.* 2011) and may be indicative of specific environmental conditions. For example, in more open forests where early visual detection of predators is possible, more open calving sites may be favoured; conversely, in relatively dense boreal forests such as those in northeast BC, concealment cover may be favoured because visual detection of predators from long distances is limited (DeMars *et al*. 2014, *in review*).

Forage quantity and/or quality appeared to have a limited role in calving site selection. Lichen abundance was lower at calving sites versus winter sites and there was no difference between the two in shrub, forb and graminoid cover. Moreover, composition analyses from collected scat at the two site types suggests that caribou diet at calving is similar to the winter, a finding likely influenced by the peak of calving (~ May 15) occurring before spring green-up (~ June 1) in northeast BC. The role of forage quality or quantity, however, may become evident later in the neonate period when new plant growth emerges and lactation demands increase with calf growth (Parker *et al*. 2009). We further note that results of our fine-scale analyses should be interpreted with caution because of our relatively small sample sizes and non-probabilistic sampling framework whereby we only sampled those calving and winter sites that could reasonably be reached by foot or helicopter.

Resource selection by females within calving areas also reflected predation averse behaviour. At this third-order scale, females generally favoured treed bogs and fens and avoided locations with high linear feature density. Females also showed weak selection for locations with higher NDVI values, an index of forage productivity. Although this forage signal contrasts with results from the calving site scale, it is consistent with the hypothesis that female nutritional requirements will increase as the calving season progresses due to increasing lactation demands (Parker *et al.* 2009).

Third-order RSF models had relatively low predictive power, perhaps indicative of high variability in selection among individuals at this scale. This variability, however, could also result from differences in resource availability among calving areas (Beyer *et al.* 2010). Indeed, variability in calving area composition was evident in second-order RSF models (see below). While modelling approaches accounting for differential resource availability have recently been developed (i.e. functional response models: Matthiopoulos *et al.* 2011; Moreau *et al.* 2012), we did not use these models because their interpretation for comparing individual differences is not straightforward and their translation to explicit spatial predictions is problematic. Despite the relatively low predictive performance of third-order RSFs, overall inferences remained similar across all models evaluated; that is, bogs and fens were the top-ranked land covers and areas of high linear feature density were avoided. For these covariates, models only differed in the magnitude of their coefficients (e.g. β range for linear feature density: -0.29, -0.75; mean = -.0.38).

To best inform landscape-level management strategies for boreal caribou, we focused a majority of our analyses on female selection of calving areas. Similar to results at finer scales, reducing predation risk was a dominant factor driving calving area selection. Across most seasonal and maternal status comparisons, females with neonate calves consistently avoided landscapes associated with increasing predation risk, such as upland deciduous forests (McLoughlin *et al.* 2005) and areas of natural and anthropogenic disturbance (Rettie & Messier 1998; Courtois *et al.* 2007). The response of calving females was particularly strong for upland deciduous forests. Effect sizes for this variable were consistently among the highest within the top calving RSF models (Table 6) and there was a large difference in the strength of avoidance between calving and barren females. Only when comparing winter ranges to calving did a majority of females show relative selection for this habitat type. This seasonal difference in selection, however, is likely a result of females shifting from winter ranges dominated by large peatland complexes to more mosaic-type landscapes in the spring and we note that within this seasonal comparison no females showed absolute selection (i.e., a positive coefficient) for upland deciduous forest during calving (Appendix 10).

The avoidance of areas representing increased predation risk was also evident in female response to anthropogenic features. Females generally avoided well sites and areas of high linear feature density. Caribou avoidance of anthropogenic features has previously been documented (Dyer *et al.* 2001; DeCesare *et al.* 2012b; Leblond *et al.* 2013) and females have been shown to select calving sites away from roads and cut blocks (Leclerc *et al.* 2012). Based on our comparative analyses, avoidance of these features intensifies when a female is accompanied by a neonate calf. This avoidance results in a functional loss of calving habitat (Dyer *et al*. 2001). Moreover, in highly modified landscapes, this avoidance response could negatively impact the spatial dispersion strategy of calving females (Bergerud & Page 1987), potentially resulting in females becoming increasingly clumped, and hence more predictable to predators (Fortin *et al.* 2013). Maintaining functional calving habitat within caribou range will therefore require management strategies that focus on restoring highly impacted areas in addition to conserving existing low-impact areas.

Females generally situated calving areas away from rivers and lakes, a further strategy for reducing predation risk given that both wolves and black bears selected for these features during the calving season (see below). Avoidance of lakes was particularly strong with < 7% of GPS locations for females with neonate calves falling within 500-m of a lake and < 20% were within 1-km (C. DeMars, unpublished data). The avoidance of lakes contrasts with other studies from eastern Canada where caribou used lakeshores and islands at calving, presumably because these habitats provided escape terrain from predators (Bergerud 1985; Carr *et al.* 2011; Dupont 2014). In northeast BC, however, the effectiveness of lakes as escape terrain may be limited because shorelines are marshy unlike the rocky shores of lakes situated in the Canadian Shield.

Further, the majority of lakes are devoid of islands and relatively shallow (e.g. < 10-m mean depth; Prepas *et al.* 2001).

While our analyses indicate that predation risk is an important driver of calving area selection, forage quality and/or quantity may still factor into female selection of calving areas. Females appeared to shift from winter ranges comprised of lichen-rich bogs to landscapes with a higher proportion of poor fens at calving and the selective response for poor fens was consistent across other seasonal and maternal status comparisons. Relative to bogs, poor fens have higher primary productivity due to a higher abundance of sedges and shrubs (Thormann & Bayley 1997). This shift from bogs to fens likely accounted for the high number of females showing selection for calving areas with higher NDVI values relative to winter ranges. As noted earlier, shifting to areas with higher forage quality (i.e. vegetation with higher caloric and protein values) may be necessary for females to meet maternal nutritional demands (Barboza & Parker 2008; Parker *et al*. 2009). By making this shift, females may be trading off an increase in predation risk to access higher quality forage because fens provide less of a predator refuge than bogs (Latham *et al.* 2011a, 2013a). Increasing predation rates of caribou in the snow-free season have been linked to increasing spatial overlap between caribou and predators during this time period (Latham *et al.* 2011a, 2013b). This hypothesis has been primarily based upon studies assessing seasonal habitat shifts of predators. Our results suggest that increasing spatial overlap between caribou and predators may also be driven by a habitat shift by caribou, at least during the calving season.

Across the population, however, females displayed considerable variation in calving area selection as reflected by the relatively wide 95% confidence intervals of the random-slope variables – with a few overlapping zero – and the predictive performance of the calving RSF models. This variation is consistent with studies of calving habitat selection by boreal caribou in eastern Canada – where calving RSF models yielded r_s values < 0.80 (Dussault *et al.* 2012; Leclerc *et al.* 2012) – and for the northern ecotype of woodland caribou in northeast British Columbia (Gustine *et al.* 2006). Individual variation in the selection of calving areas may be a further life history strategy of caribou for reducing predator encounters. By preventing predators from associating calving areas with certain habitat types, behavioural plasticity in calving area selection may make females and their calves more unpredictable to predators (Mitchell & Lima 2002; Miner *et al.* 2005).

4.3. Predator Habitat Selection during the Calving Season

Similar to caribou, we also used a multi-scale approach to assess predator space use during the caribou calving season. Interestingly, this approach yielded contrasting results for each predator. Wolf resource selection was best predicted at finer spatial scales (i.e. third-order selection) whereas resource selection by black bears was better predicted at larger, range-level scales. This discrepancy likely reflects differences in life history strategies. As a generalist predator, wolves can occupy a variety of habitats and territory occurrence is likely indicative of territoriality more than ideal resource selection *per se*, particularly at high population densities. As such, pack size may be a better index of habitat (or territory) quality for wolves than second-order resource selection unless wolf packs are collared in proportion to pack size or analyses are weighted by pack size, which were unknown in our study area. Nevertheless, we tested resource selection at this scale to assess spatial separation of wolves and caribou (Bergerud 1974; James *et al.* 2004). The high variability in habitat composition among wolf packs suggests that wolves are not confined to specific areas within the distribution of boreal caribou in northeast BC. Moreover, a visual inspection of wolf GPS locations (Appendix 8) suggests that pack territories are tightly spaced and overlap significantly with caribou range and core areas. Taken together, these findings parallel those of Latham *et al*. (2011c), which showed a high degree of large-scale spatial overlap between wolves and caribou in Alberta ranges.

While overall territory composition varied among packs, wolves were more predictable in resources selected at a third-order scale. In general, wolves had a strong association with aquatic habitats. The highest ranked land covers were rich fens and "other", which includes a continuum of aquatic features such as marshes and riparian areas. Wolves were also closer to rivers and lakes than expected. Aquatic habitats may be important for wolves during spring for a number of reasons. First, spring constitutes the denning period and wolves are known to situate dens near water sources so reproductive females have sufficient water to meet lactation demands (Trapp *et al.* 2008; Person & Russell 2009). Second, wolves are known to use rivers as travel corridors (Latham *et al.* 2011b). Third, many aquatic areas in our study area were occupied by beaver, which become a primary prey item of wolves in the spring and summer (Culling *et al.* 2006; Latham *et al.* 2013b). Beaver may play a key role in creating increased spatial overlap over wolves and caribou in the spring. Both wolves and caribou showed relative selection for rich fens during the calving season (Tables 5, 12) and beavers have been shown to select areas with high proportions of rich fens (Thiessen & DeMars 2012).

Wolf response to landscape disturbance was counter to expectations. Wolves generally avoided early seral vegetation and showed no response to well sites. Previous studies have suggested that wolves select for early seral vegetation because it is a preferred habitat of their primary prey, moose (Seip 1992; Courbin *et al.* 2009; Houle *et al.* 2010). Our results may differ because of our focus on the spring, a time when wolves may be switching from moose to beaver (Latham *et al.* 2013b). Surprisingly, wolves also avoided areas of high linear feature density although the overall effect size was small. This avoidance may have occurred if high line density is correlated with higher levels of human activity (Houle *et al.* 2010; Zimmermann *et al.* 2014). A further explanation is that wolves may have a curvilinear or quadratic response to line density, selecting areas of medium density and avoiding areas with low and high densities. We elected to not assess for quadratic relationships of RSF covariates to allow for more straightforward comparisons both within and among species. Nevertheless, even if a quadratic relationship was evident, it is likely that wolves would still show avoidance of areas with high line density. This result has implications for management actions aimed at restoring or de-activating lines, indicating that restoration efforts may be best directed toward areas with low to medium densities of linear features.

Black bears were more predictable at larger spatial scales than wolves, likely due to their lower territoriality. In general, bears selected landscapes dominated by upland deciduous forest and were closer to disturbed areas than expected. This selection pattern is consistent with bears favouring habitats associated with higher grass and forb abundance, which dominate the early spring diet of bears living in northern forests (Raine & Kansas 1990; Mosnier *et al.* 2008b; Bastille-Rousseau *et al.* 2011). In our study area, upland forest and disturbed areas are also the first areas to green-up in the spring (C. DeMars*, personal observation*). When specifically in caribou range, bears showed strong selection for rich fens, further supporting the importance of graminoids in bear spring diets (Mosnier *et al.* 2008b) and again suggesting that rich fens may be an area of spatial overlap between caribou and predators at calving. Bears in caribou range were also closely associated with rivers and lakes, which combined with a similar response in wolves, provides further reasoning as to why these aquatic features were avoided by calving caribou.

At a finer, third-order scale, bears were more variable in resource use. This finding is consistent with other studies assessing selection patterns of black bears in boreal forests (Latham *et al.* 2011a; Bastille-Rousseau *et al.* 2011). This variation may stem from at least two sources. First, green vegetation is patchy during May and early June in our study area. Variation in patch quality and distribution could create variation in patch residency times and inter-patch movements, which would also create variability in resource selection due to the time-dependency of these analyses (Bastille-Rousseau *et al.* 2011). Second, the omnivorous diet of bears could create variability in resource selection (Edwards *et al.* 2010). For example, during 2013 investigations of caribou mortalities, we found at least two winter-killed caribou that had been scavenged by bears in treed bog complexes during the spring. In this situation, RSFs for these bears could differ from other individuals that are foraging primarily on vegetation in upland forests.

4.4. Wolf Selection of Linear Features

Increased hunting efficiency attributed to wolves using linear features has been implicated as a primary mechanism for increasing predation rates of caribou (James & Stuart-Smith 2000; McKenzie *et al.* 2012). To date, little research has been conducted as to whether all linear features function equally in this respect. We documented wolves preferentially selecting linear features that further enhance mobility and, secondarily, sightability. Wolf selection of lines was best explained by the amount of coarse woody debris (CWD), a finding that contradicts a previous study in Alberta that found no effect on wolf use of lines that were blocked by fallen trees (Neufeld 2006). This discrepancy is likely due to differences in study design. Neufeld

(2006) used an experimental approach that compared wolf use in treated versus control areas and although wolf use was lower in treated areas, the effect was not statistically significant. Our study, on the other hand, used an observational approach that evaluated line use by wolves as a continuum. Fundamentally, our results do not suggest that high amounts of CWD will prevent wolves from using lines; rather, wolves will select lines that offer increased ease of movement as indexed by the amount of CWD. This inference, though, still has implications for the development of management actions to limit wolf use of lines within caribou range. Linear features are thought to enhance hunting efficiency by increasing wolf search rate (i.e. movement speed) and potentially the amount of area searched, thereby leading to an increase in caribou-wolf encounters (McKenzie *et al.* 2012). Management strategies, therefore, do not necessarily need to keep wolves off lines *per se*, but instead can be focused on slowing wolves down. Our results suggest that wolf movement efficiency is lowered on lines with higher amounts of CWD although a more rigorous test would involve correlating wolf speed to CWD, which we were unable do because of the coarse temporal resolution of the GPS data. Nevertheless, further research may be warranted to determine the amount and scale at which CWD should be deployed to effectively lower wolf speed on lines and whether such action equates to a lowering of kill rates by wolves. For such an analysis, we recommend a GPS fix rate of every five minutes on wolf collars to effectively measure wolf speed on lines.

4.5. Spatial Factors Affecting Calf Survival

We used a multi-scale, metric-dependent approach to evaluate four hypotheses that related sets of spatial factors to the probability of neonate survival. Among these hypotheses, predation risk from black bears was the best predictor of neonate survival. Outputs from this model were also consistent with patterns of black bear predation from other systems; that is, that calf mortality is highest during the first 3-4 weeks of life then lessens as calves gain sufficient mobility to elude bears (Fig. 6; Zager & Beecham 2006). In eastern ranges of boreal caribou, black bears have been identified as the dominant predator of caribou calves (Pinard *et al.* 2012). Moreover, in many multi-predator systems, bear predation is often the primary cause of offspring mortality for many ungulate species (Zager & Beecham 2006; Barber-Meyer *et al.* 2008; White *et al.* 2010; Griffin *et al.* 2011). Our results here are the first to explicitly link calf survival to black bear predation in western ranges of boreal caribou.

The relatively strong influence of bear predation risk on neonate survival should be viewed cautiously given our analytical framework. We modelled predation risk for wolves and bears using the top 25% of values from predator-specific RSF models. This framework only considers habitat and does not take into account differences in search rate, search radius and abundances between the two species. These three factors would necessarily influence the relative risk that each species represents to caribou (Lima & Dill 1990; Hebblewhite & Merrill 2007). Thus, a pixel with a 75th percentile value from an RSF developed for bears may not equate to the same predation risk as pixel with a 75th percentile value from a wolf RSF. Nevertheless, our results suggest that bear predation is a likely factor in the mortality rates of neonate calves and, similar to conclusions drawn from eastern caribou ranges, may be driven by high bear densities (Bastille-Rousseau *et al.* 2011; Pinard *et al.* 2012).

Predation risk from bears occurred at relatively small spatial scales, which was perhaps counter to expectations. Rettie & Messier (2000) suggested that large-scale patterns of habitat selection should reflect the primary limiting factor(s) of animal populations, which for caribou is predation. Variation in large-scale habitat selection or exposure patterns, therefore, should equate to variation in predation rates. At our largest scale of analysis, we detected no differences among caribou ranges in rates of neonate survival. Similarly, variation in female selection of calving areas within ranges did not correlate to variation in neonate survival. Combined with the realized high rates of neonate mortality, these findings suggest that (*i*) spatial factors thought to influence the predation process have exceeded thresholds where variation in predation is detectable (see below), at least at large scales; and, (ii) that female caribou cannot effectively space away from predators within northeast BC landscapes. Apps *et al*. (2013) reported similar results for mountain caribou where landscape disturbance indices had minimal effect on female survival. They suggested, however, that their scale of analysis was not sufficiently broad to encompass highly disturbed areas outside of caribou range, a factor likely to be unimportant in our study area given the wide distribution of disturbance within and outside of boreal caribou ranges in northeast BC (Thiessen 2009).

We found little support for the other three hypotheses linking spatial factors to the probability of neonate survival. Unlike the predation risk hypothesis which was tested using predator-specific RSF models encompassing multiple spatial factors, the disturbance, lake refuge and peatland refuge hypotheses were specified as univariate or bivariate models representing specific landscape attributes. Our results suggest that no specific landscape feature contributes disproportionately to the high mortality rates of neonate calves in northeast BC. A number of explanations may account for our lack of findings. First, neonate mortality may be driven more by predator density (i.e. the numeric response) than by variation in spatial factors potentially influencing the predation process (i.e. the functional response; Holling 1959; McCutchen 2007). Predator density is thought to be driven by increased densities of other ungulate species (e.g. moose), which respond favourably to the early seral conditions that follow disturbance (Seip 1992; Festa-Bianchet *et al.* 2011). This relationship, however, may not hold across northeast BC caribou ranges. For example, in the Calendar range calf recruitment has been higher than in other ranges despite high levels of landscape disturbance (Thiessen 2009; Culling & Culling 2013). In this case, predator densities – and thus calf mortality rates – may be unrelated to landscape disturbance because moose density is also low in Calendar (Thiessen 2010). Predator densities may further explain why there was no support for the peatland refuge hypothesis.

Historically, peatlands are thought to have provided caribou a spatial refuge from predators (McLoughlin *et al.* 2005) and our results suggest that caribou are selecting peatland-dominated areas for calving. Yet, caribou calves are still incurring high rates of mortality within these refugia. This lack of a refuge effect is consistent with the apparent competition hypothesis whereby increasing predator densities will result in higher numbers of predators “spilling over” into the spatial refugia of the victim prey (Holt & Lawton 1994).

Specific to the disturbance hypothesis, our lack of findings may indicate that the degree of disturbance within caribou range has exceeded thresholds where differences in neonate survival may be detected. McCutchen (2007) suggested that any enhancement to wolf hunting efficiency (i.e. the functional response) provided by linear features asymptotes at a line density of 1 km/km^2. When measured on a per kilometre basis, this threshold is exceeded in large portions of our study area (mean = 3.6 km/km^{2,} range: 0 - 22.73; see Thiessen 2009); however, it is unclear over what spatial scale that such a threshold might apply. Linking disturbance levels to caribou demographic performance has been integral to informing management strategies for sustaining and/or recovering caribou populations in multi-use landscapes (Environment Canada 2008; Sorensen *et al.* 2008). From the standpoint of the federal recovery strategy, disturbance is measured at the range scale; yet, caribou ranges can differ in size by an order of magnitude (Environment Canada 2012). We did not detect disturbance effects at the range scale, perhaps due to of our small sample size of ranges (*n* = 6), their relatively high levels of disturbance and the small variation among them (57-83%; Thiessen 2009; Environment Canada 2012). We also did not detect disturbance effects at small spatial scales (< 6 km radii), despite 13 females having calving areas with line densities < 1 km/km^2. This finding indicates that caribou calving habitat cannot be managed by disturbance indices at small spatial scales. Nagy (2011) suggests that caribou require 500 km^2 of intact space (0% disturbance) to effectively reduce predation risk although his observational findings were limited by a small sample size (*n* = 6) and did not explicitly test the interaction between disturbance levels and the space over which they are measured. In our study, we could not test Nagy’s (2011) hypothesis because this level of intactness is rare to non-existent. Testing this space-disturbance interaction, however, will be critical to understanding the spatial requirements of caribou and ultimately inform management strategies for sustaining caribou populations in multi-use landscapes.

4.6. Conclusions / Recommendations

Managing calving habitat for boreal caribou in multi-use landscapes presents a number of challenges. First and foremost is the issue of spatial scale. Management actions aimed at improving the quality of calving habitat will need to be conducted at large spatial scales because (*i*) compared to other seasons, boreal caribou are at their most dispersed during calving; and (*ii*) management actions employed at small spatial scales (e.g. the calving area scale) will be ineffective at improving rates of neonate survival. Because many female caribou migrate to landscape mosaics dominated by nutrient-poor fens, we suggest that potential management actions are best targeted toward large fen complexes. While we cannot provide specific recommendations on the most appropriate spatial scale for management actions, such scales may need to exceed 100 km^2 – the approximate size of our largest calving area – and that larger scales are likely better.

The link of caribou population declines to landscape disturbance dictates that management actions will need to address habitat restoration (Environment Canada 2012). Such actions, however, are necessarily long-term; for example, seismic lines in lowland black spruce forests can take > 60 years to recover (Lee & Boutin 2006; Schneider *et al.* 2010). For some caribou herds, current population trends point to extirpation before the effects of habitat restoration are realized (Schneider *et al.* 2010). For such herds where calf recruitment is a limiting factor, short-term actions such as maternal penning (Chisana Caribou Recovery Team 2010) or predator control (Mosnier *et al.* 2008a; Hervieux *et al.* 2014) may be necessary to augment habitat restoration. For the latter option, our results highlight the need to understand the specific predator(s) contributing disproportionately to calf mortality rates. In addition to these options, ongoing initiatives assessing line de-activation techniques (e.g. fencing, coarse woody debris) may hold promise but their efficacy in reducing predation rates is currently unknown.

To further build upon the findings of this study, we also suggest the following:

1. Updating predictive maps of calving areas as further GPS radio-collar data as accumulated.

   We used a relatively short-term data set to develop a predictive map of calving areas in northeast BC. Predictive power of such maps may improve as further data is accumulated. Further, our results suggest a range-specific map for Chinchaga may be warranted, which will require additional GPS radio-collar data from this range.

2. Effectively managing for caribou calving habitat requires understanding the full continuum of calving behaviour. To that end, we recommend:
   a. An assessment of female fidelity to calving areas, particularly if potential management actions include the protection of predicted calving areas within caribou range.
   b. Identifying and maintaining important movement corridors for females travelling from winter ranges to calving areas.

3. Understanding factors influencing low rates of parturition.

   The relatively low rate of parturition we documented over the study's three years suggests that other factors unrelated to predation may be influencing low rates of calf recruitment. For example, nutrition-related factors due to declining range conditions may result in low rates of pregnancy and/or high rates of embryonic mortality (Russell *et al.* 1998; Parker *et al.* 2009).

4. The role of bear predation in population declines of boreal caribou in western ranges requires further investigation.

   Hypotheses for population declines in the western distribution of boreal caribou have primarily focused on the role of wolf predation and its link to landscape disturbance. Our results suggest that black bear predation may be an important factor in the low rates of calf recruitment currently being documented in many western ranges of boreal caribou. The degree to which bear predation influences population growth rates of caribou, however, remains unclear. Moreover, mechanistic hypotheses linking bear predation to caribou population declines are less developed. Black bears have been shown to favour early seral vegetation following disturbance (Brodeur *et al.* 2008; Mosnier *et al.* 2008b; Latham *et al.* 2011a) but it is uncertain as to whether disturbance facilitates an increase in bear abundance (but see Schwartz & Franzmann 1991). The effects of linear features in facilitating caribou-bear spatial and enhancing bear movement rates also requires further investigation, particularly given recent research suggesting relatively high use of seismic lines by black bears in northeast BC (Tigner *et al.* 2014).

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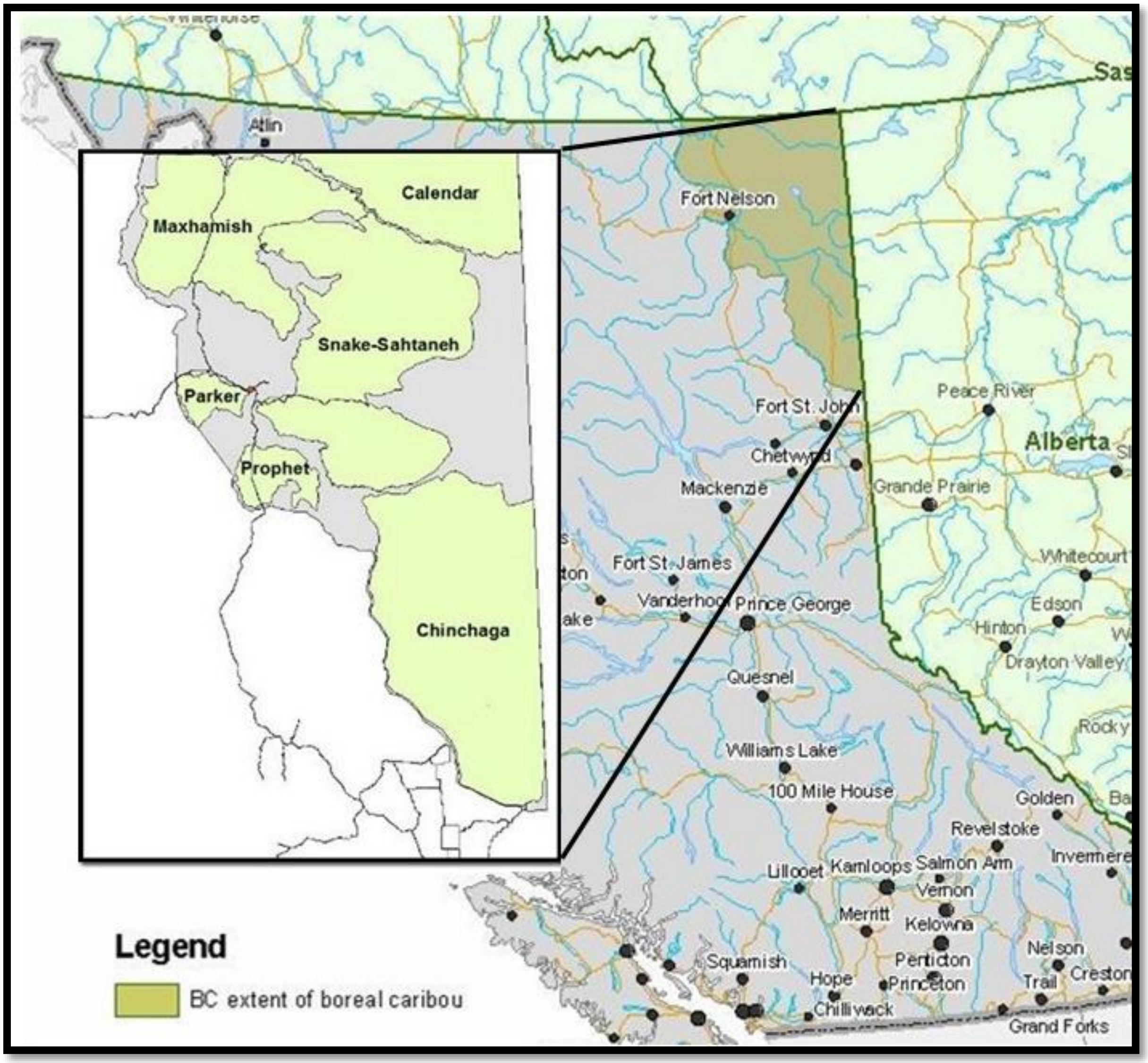
APPENDICES

APPENDIX 1: *Study Area Map*

Boreal caribou distribution and ranges within British Columbia. By the end of the project's three years of data collection, the study area had expanded to included radio-collared caribou in all six caribou ranges (yellow).

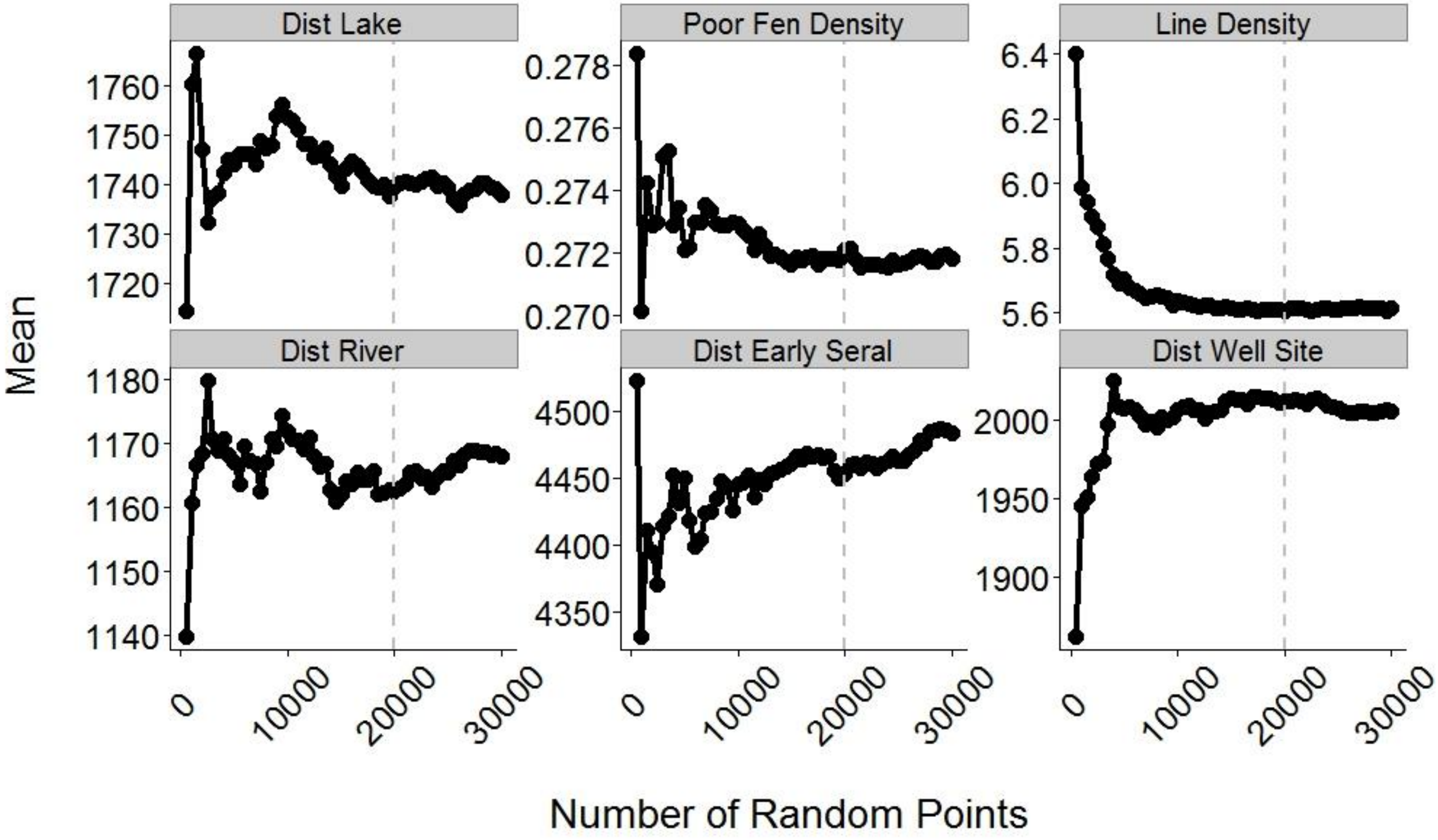


APPENDIX 2: *Boreal Caribou Calving Site*

Calving site depression created during the 2011 calving season by a female boreal caribou in the Prophet range of northeast British Columbia.

APPENDIX 3: *Random Point Sensitivity Analysis*

We conducted sensitivity analyses to determine the number of random points to adequately characterize availability for each covariate at the both the calving area and range scale. Below, we show analyses to determine the number of random points at the range scale. We used 20,000 random points because the mean of most covariates stabilized with this sample size (grey dashed line).



APPENDIX 4: *GIS Data Sources*

GIS data sources used to model resource selection functions.

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 (ILMB), 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 ILMB, 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
NDVI	U.S. National Aeronautics and Space Administration MODIS database	http://modis.gsfc.nasa.gov/data/dataprod/dataproducts.php?MOD_NUMBER=13

APPENDIX 5: *Land Cover Types Used to Model Resource Selection*

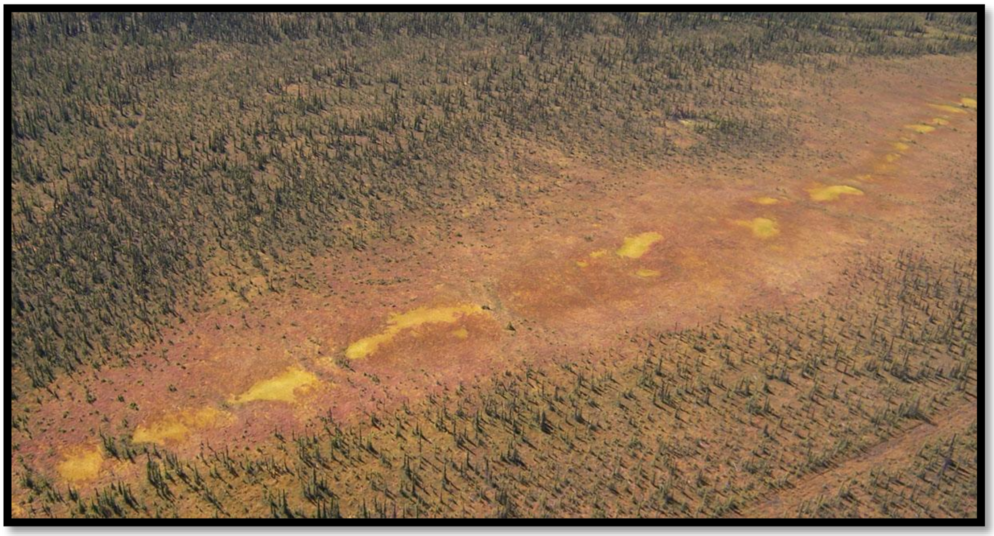
We modelled land cover in all resource selection models using Enhanced Wetlands Classification (EWC) GIS data (30-m pixel resolution) developed by Ducks Unlimited Canada (DU 2010). This data, which encompassed the entire study area, partitioned the landscape into 26 classes. We collapsed the data down to eight classes that were biologically meaningful to caribou. Here, we show visual representations of each of these eight classes. All photographs are from Ducks Unlimited Canada (2010).

Treed Bog

Black spruce (*Picea mariana*) is the leading tree species and generally is < 8 m tall. Ground cover is dominated by sphagnum moss (*Sphagnum* spp.; >20%) and, secondarily, lichen (*Cladonia* and *Cladina* spp.). This category includes open bogs and shrubby bogs (tree cover < 25%). Areal coverage ~ 20%.

Nutrient Poor Fen

Black spruce is the dominant tree species; however, fen indictaors such as larch (*Larix laricina*), bog-birch (*Betula glandulosa*), willow (*Salix* spp.) and alder (*Alnus* spp.) are present. Ground cover is predominantly spaghnum moss (> 20%) but also includes sedges (*Carex* spp.). This category includes shrubby and graminoid poor fens. Areal coverage ~ 22%.



Nutrient Rich Fen

This land cover is characterized by fen indicators such as larch, bog-birch, willow, alder, sedges and buckbean (*Menyanthes trifoliata*). Sphagnum cover is < 20%. This category includes shrubby and graminoid rich fens. Areal coverage ~ 5%.

Conifer Swamp

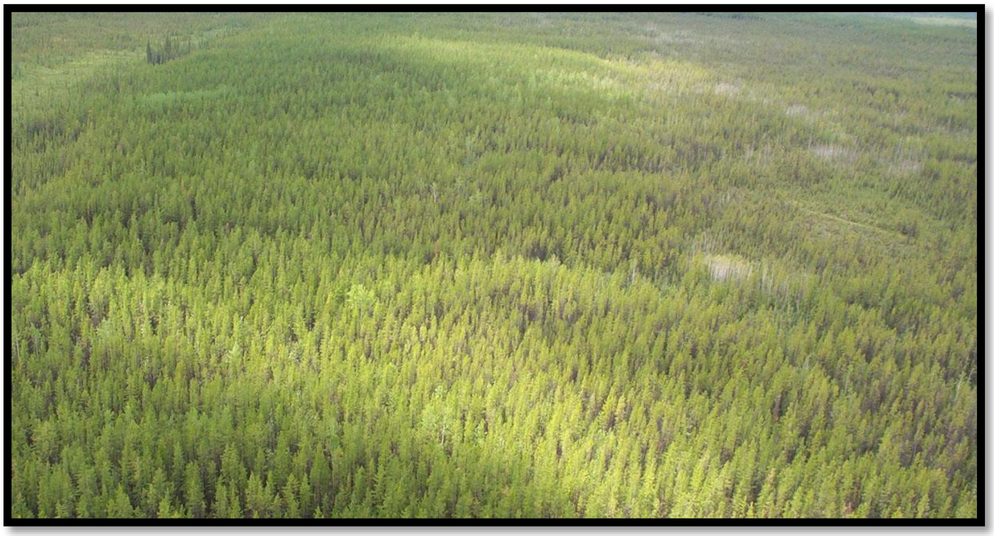
Black spruce is the dominant tree species with white spruce (*Picea glauca*) also present. Tree height is generally > 8 m. Characterized by pools of water although sphagnum moss cover may be > 20%. Areal coverage ~ 9%.

Deciduous Swamp

Characterized by pools of water and the presence of paper birch (*Betula papyrifera*) and balsam popular (*Populus balsamifera*) although conifers may be present. Understory includes shrub layer of willow and alder. Includes mixed-wood swamps and thicket swamp. Areal coverage ~ 12%.

Upland Conifer

Characterized by mineral soils. Tree species include black spruce, white spruce and pine (*Pinus banksiana*) and tree height is generally > 8 m. Areal coverage ~ 9%.



Upland Deciduous

Leading tree species is apsen (*Populus tremuloides*) although paper birch may be present. Mineral soils. Areal coverage ~ 17%.

Other

Composite category that includes anthropogenic disturbance, burns, and aquatic classes such low turbidity lakes and emergent marshes. Areal coverage ~ 6%.

Literature Cited:

[DU] Ducks Unlimited, Inc. (2010). Fort Nelson Project Enhanced Wetlands Classification User's Guide. 63 pp. Ducks Unlimited, Inc., Rancho Cordova, California. Prepared for: Ducks Unlimited Canada; Encana; The PEW Charitable Trusts; U.S. Forest Service; U.S. Fish and Wildlife Service (NAWCA); Imperial Oil, Devon Energy Corporation, and the Canadian Boreal Initiative.

APPENDIX 6: *Univariate Analyses of Caribou Used Locations versus Availability*

Prior to fitting resource selection function (RSF) models, we graphically assessed univariate relationships between “used” resources and “available” resources at second- and third-order scales for caribou, wolves, and black bears.

Caribou Second Order Selection

Second-order selection analyses for caribou entailed a comparison between random points generated within calving areas (“used” locations) and random points generated within caribou range (“available” locations). Figures A6.1 – A6.8 depict boxplots comparing average values of used versus available locations for each variable used in RSFs. Summaries are partitioned by caribou range. Circles of “used” locations represent the average value calculated for each individual caribou. Circles of “available” locations are the average or expected values calculated per range. Each caribou value has a corresponding available value. Available values per range are identical but the circles have been “jittered” for graphical purposes.

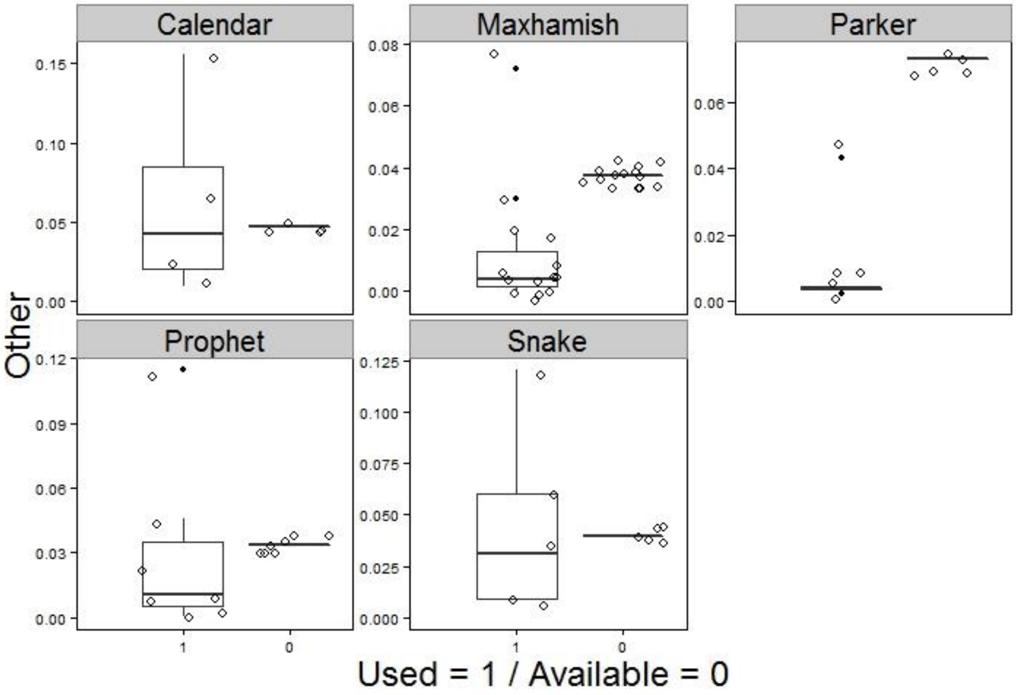


Figure A6.1: Mean proportion of the land cover class “other” in caribou calving areas (“used” locations) compared to the mean proportion in caribou range (“available” locations). “Other” includes recent forest fires, anthropogenic disturbance and aquatic areas. Land cover proportions were calculated in a moving window analysis with a 1500-m radius.

Caribou Second Order Selection (cont'd)

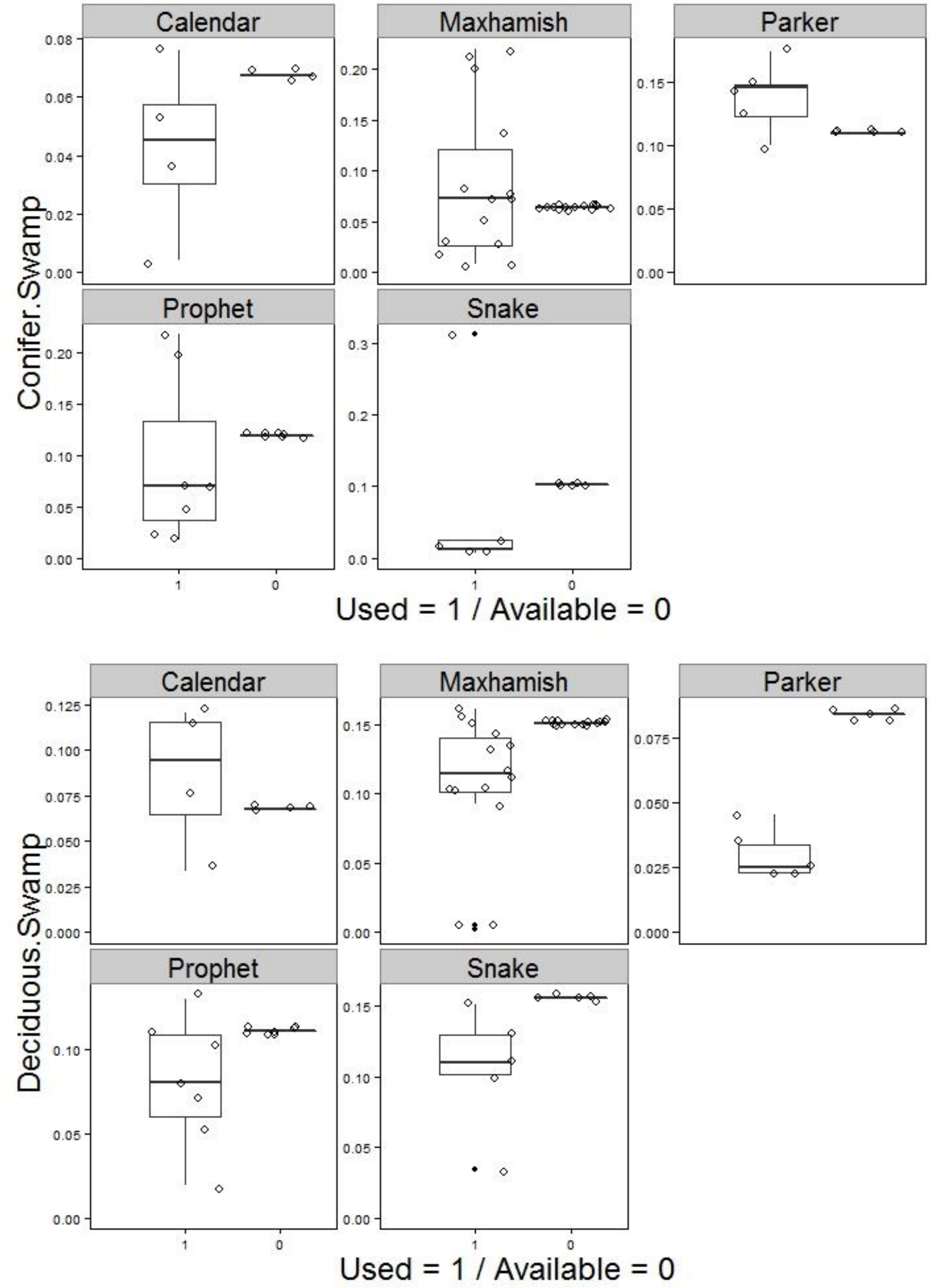


Figure A6.2: Mean proportion of conifer swamp and deciduous swamp in caribou calving areas ("used" locations) compared to the mean proportion in caribou range ("available" locations). Land cover proportions were calculated in a moving window analysis with a 1500-m radius.

Caribou Second Order Selection (cont'd)

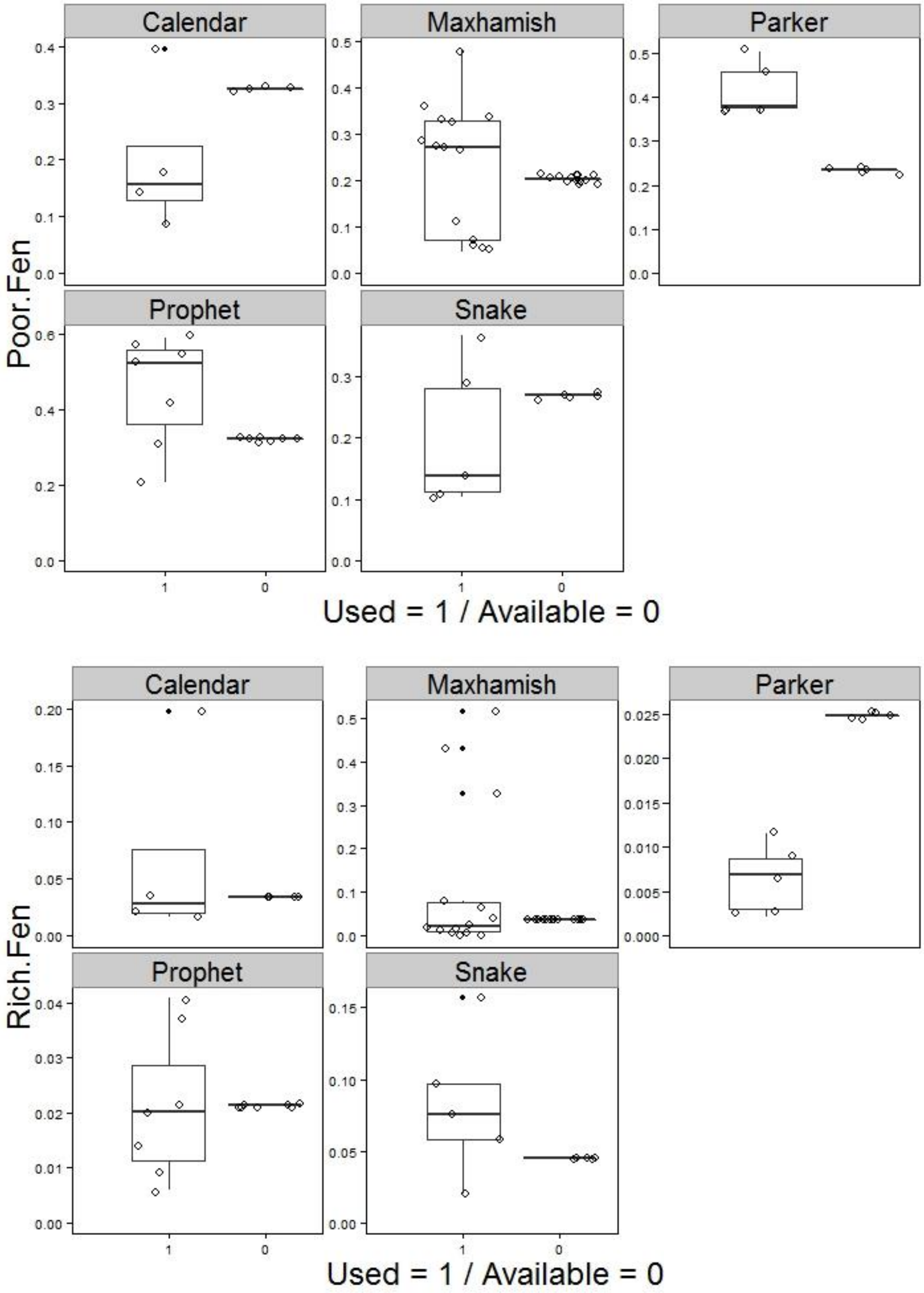


Figure A6.3: Mean proportion of nutrient poor fen and nutrient rich fen in caribou calving areas ("used" locations) compared to the mean proportion in caribou range ("available" locations). Land cover proportions were calculated in a moving window analysis with a 1500-m radius.

Caribou Second Order Selection (cont’d)

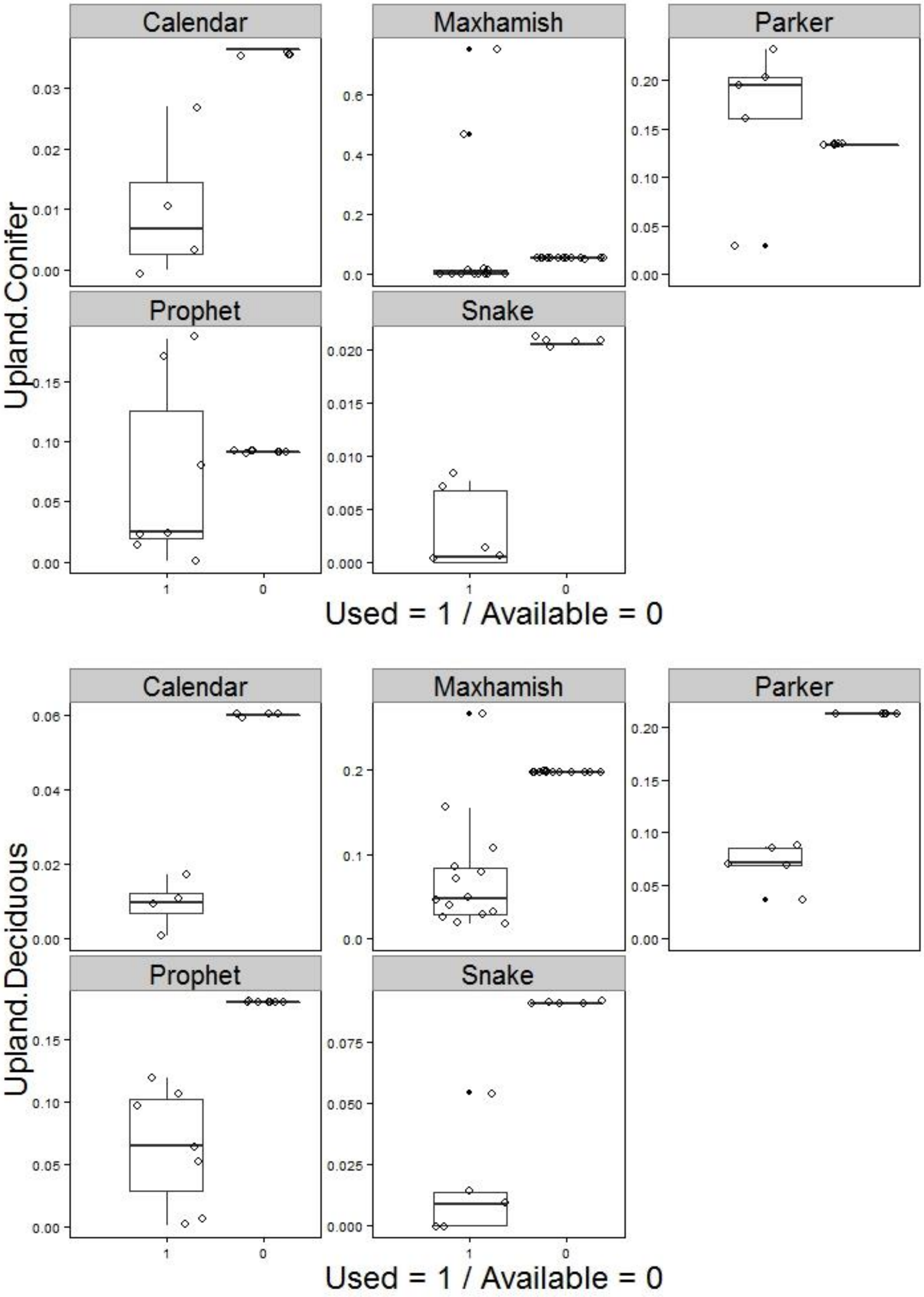


Figure A6.4: Mean proportion of upland conifer and upland deciduous forests in caribou calving areas (“used” locations) compared to the mean proportion in caribou range (“available” locations). Land cover proportions were calculated in a moving window analysis with a 1500-m radius.

Caribou Second Order Selection (cont'd)

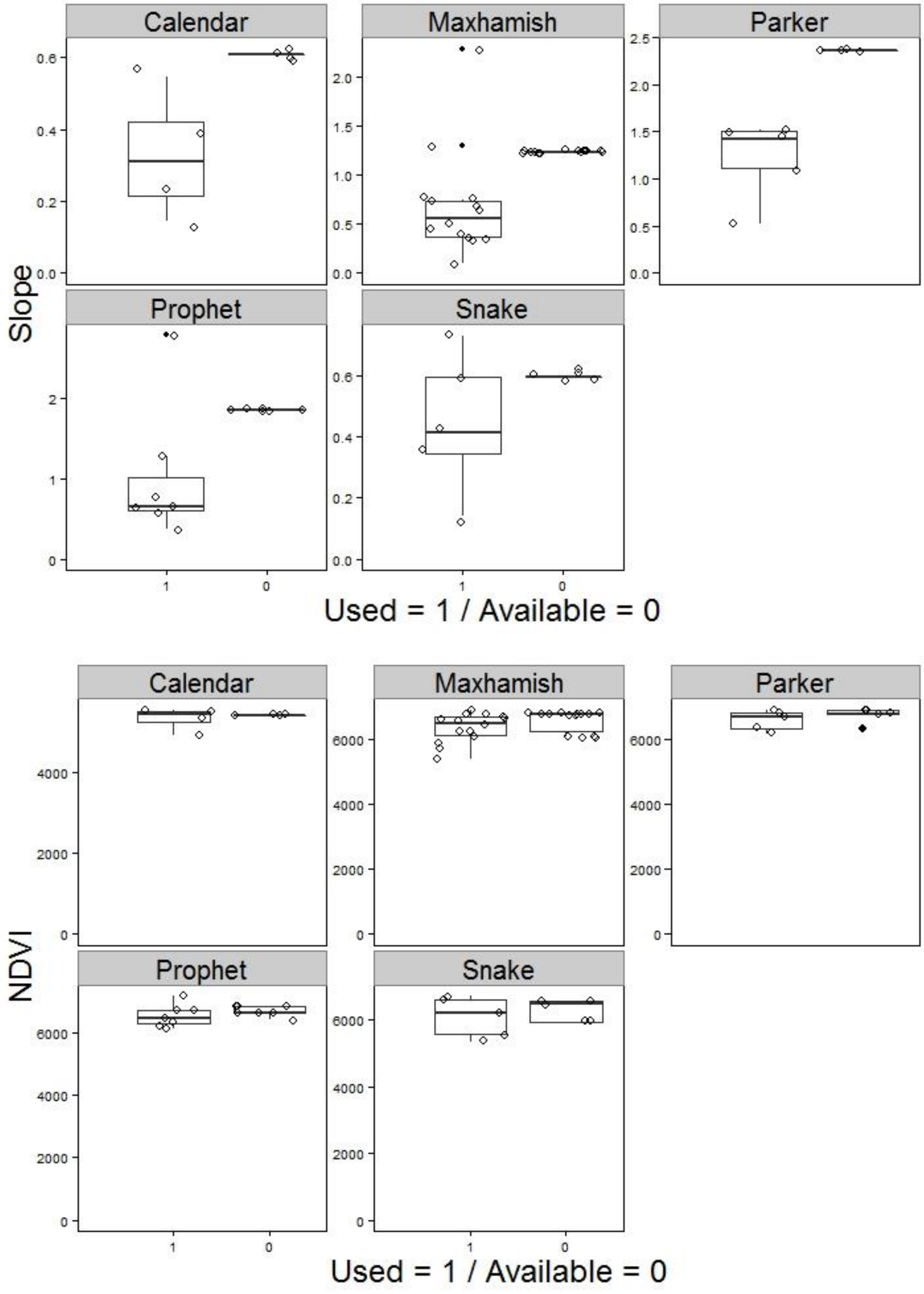


Figure A6.5: Mean values of slope and normalized vegetation difference index (NDVI) in caribou calving areas ("used" locations) compared to the mean values in caribou range ("available" locations). Both variables were calculated at a 30-m scale.

Caribou Second Order Selection (cont'd)

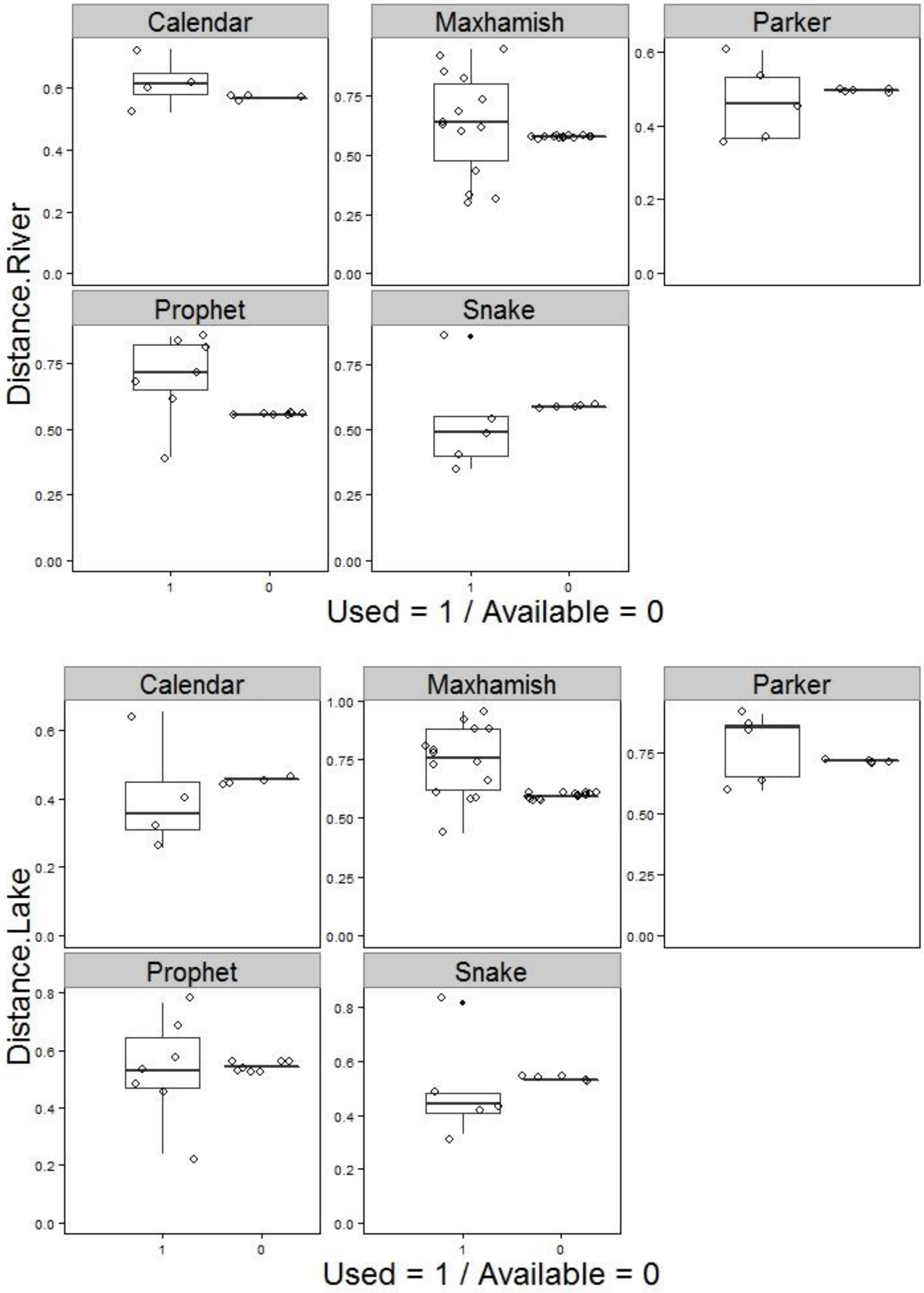


Figure A6.6: Mean distances to nearest river and lake for caribou calving areas ("used" locations) compared to the mean distances in caribou range ("available" locations). Both variables were transformed using an exponential decay function (see main text *Section 2.6.3*).

Caribou Second Order Selection (cont'd)

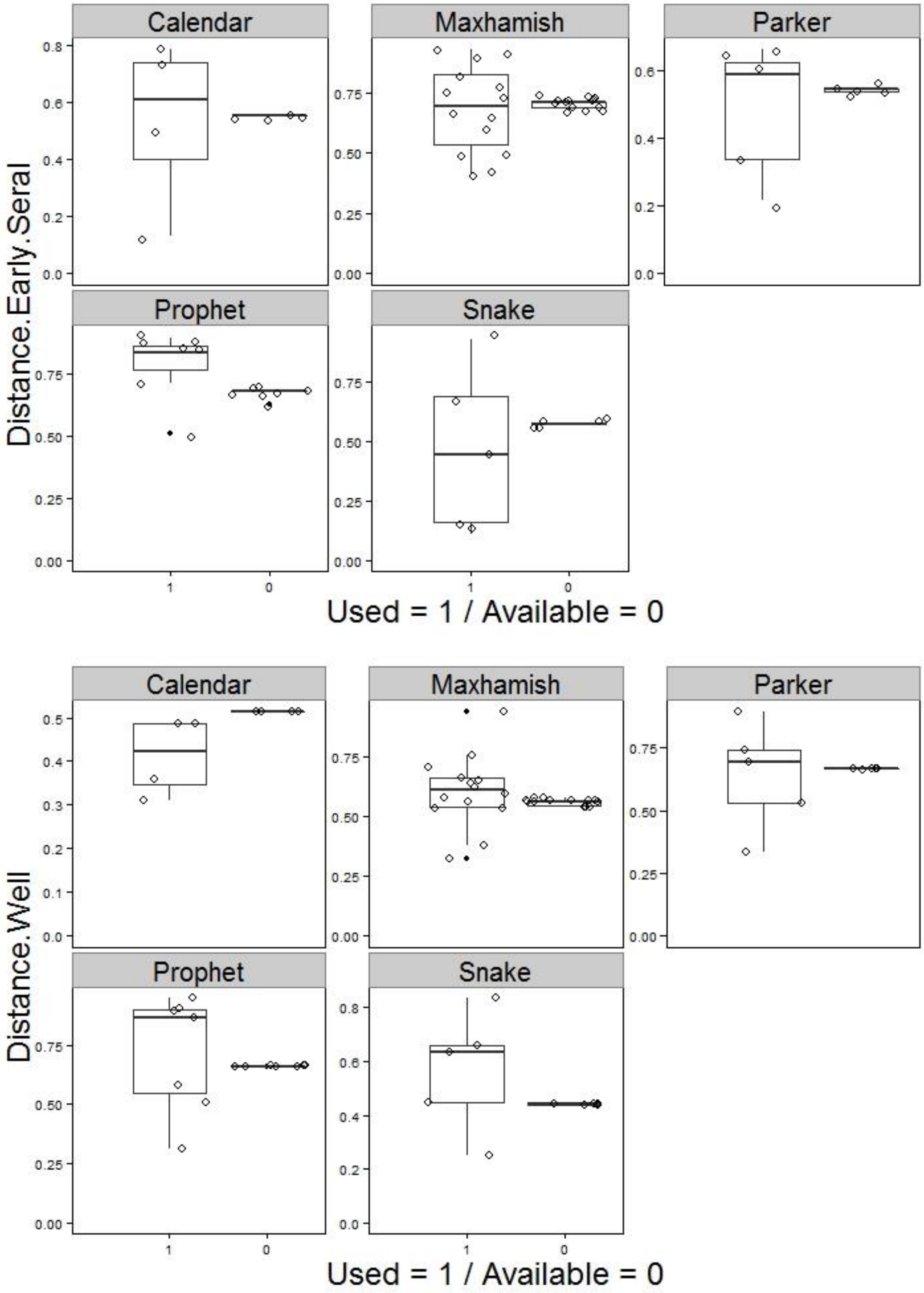


Figure A6.7: Mean distances to nearest patch of early seral vegetation and well site for caribou calving areas ("used" locations) compared to the mean distances in caribou range ("available" locations). Both variables were transformed using an exponential decay function (see main text *Section 2.6.3*).

Caribou Second Order Selection (cont'd)

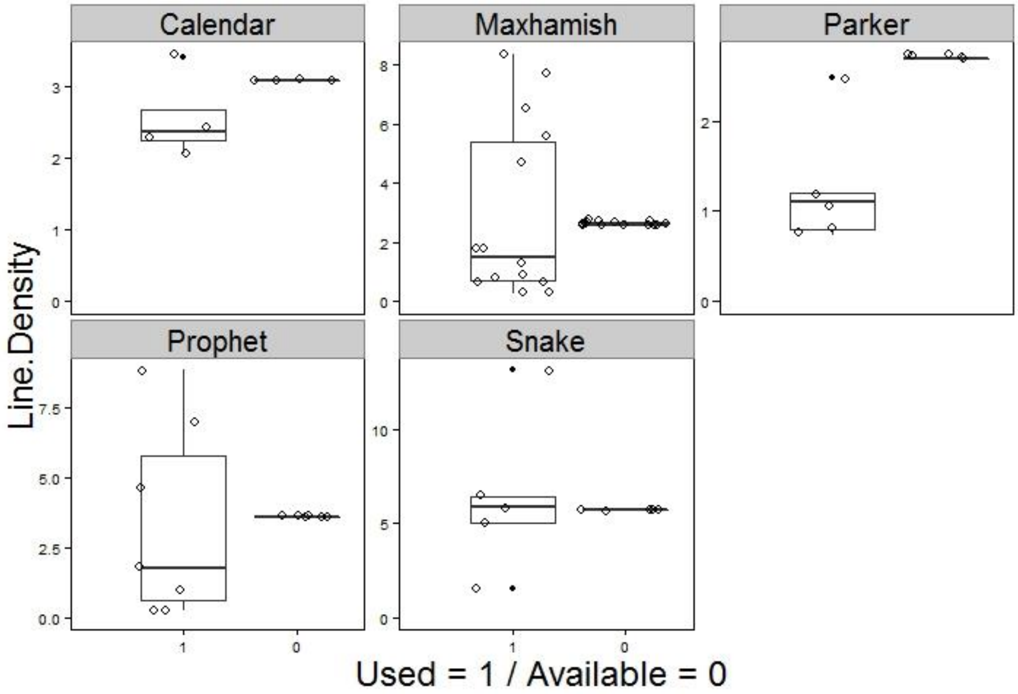


Figure A6.8: Mean density of linear features in a 400-m radius for caribou calving areas ("used" locations) compared to the mean distances in caribou range ("available" locations). Both variables were transformed using an exponential decay function (see main text *Section 2.6.3*).

Caribou Third Order Selection

Third-order selection analyses for caribou entailed a comparison between radio-collar GPS locations ("used" locations) and random points generated within calving areas ("available" locations). Because availability varied by individual caribou, we used bar charts to compare mean values of used and available resources for each caribou-year (Figs. A6.9 – A6. 18).

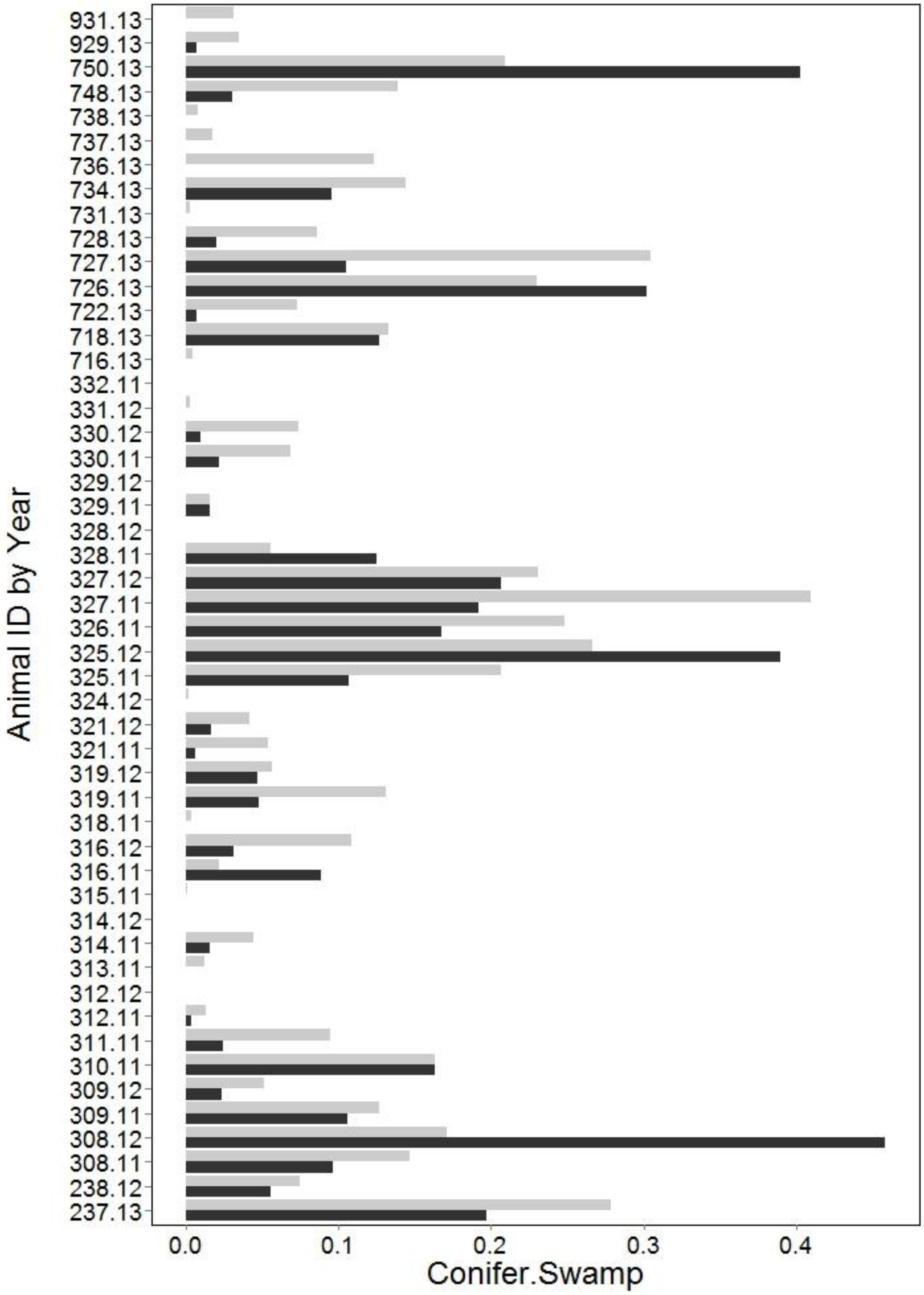


Figure A6.9: Mean proportion of conifer swamp for caribou GPS locations (black bars) compared to the mean proportion in calving areas (grey bars). Conifer swamp was measured at the 30-m pixel scale. Comparisons are for each individual caribou in each calving season (2011-2013 calving seasons).

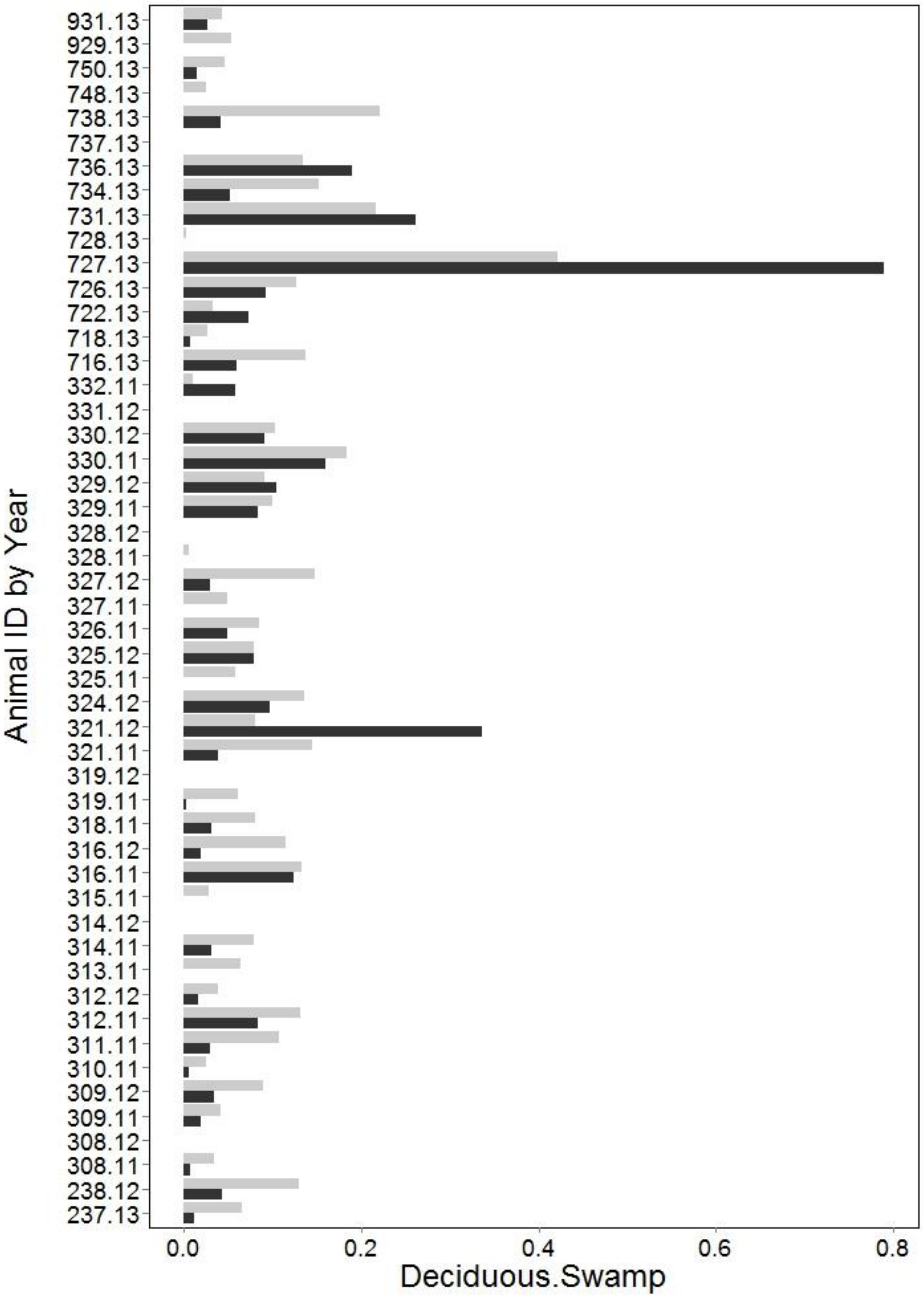


Figure A6.10: Mean proportion of deciduous swamp for caribou GPS locations (black bars) compared to the mean proportion in calving areas (grey bars). Deciduous swamp was measured at the 30-m pixel scale. Comparisons are for each individual caribou in each calving season (2011-2013 calving seasons).

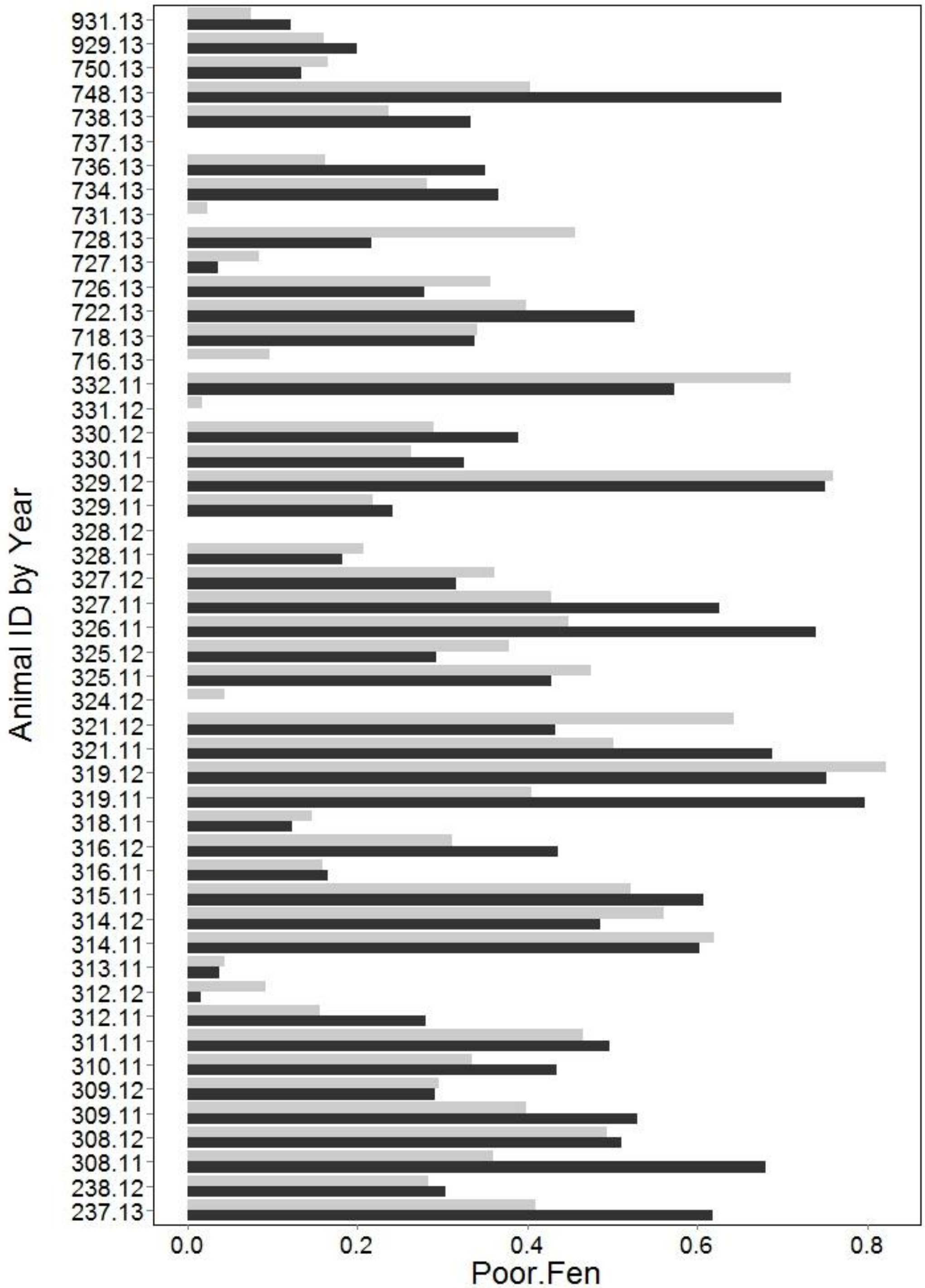


Figure A6.11: Mean proportion of nutrient poor fen for caribou GPS locations (black bars) compared to the mean proportion in calving areas (grey bars). Nutrient poor fen was measured at the 30-m pixel scale. Comparisons are for each individual caribou in each calving season (2011-2013 calving seasons).

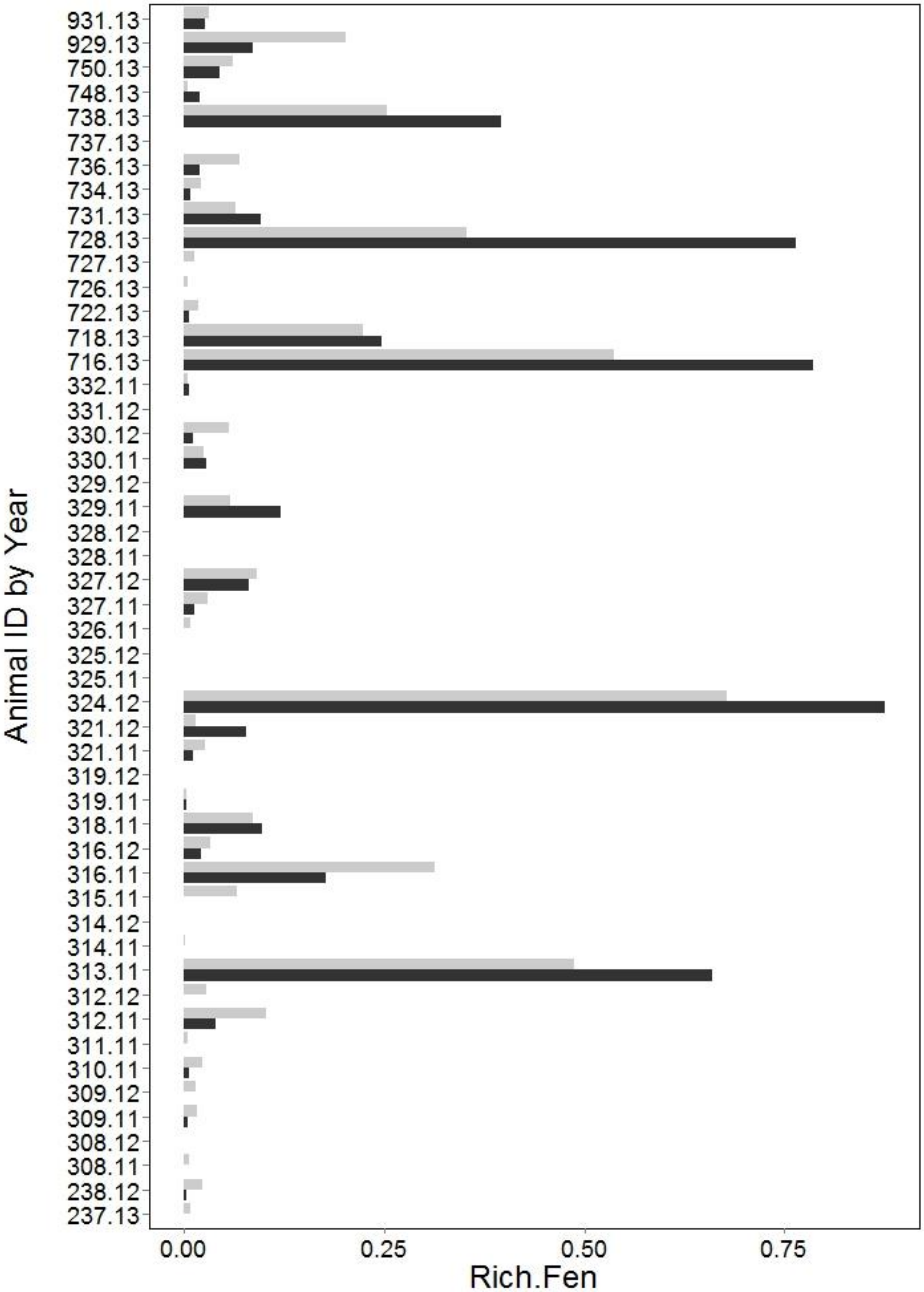


Figure A6.12: Mean proportion of nutrient rich fen for caribou GPS locations (black bars) compared to the mean proportion in calving areas (grey bars). Nutrient rich fen was measured at the 30-m pixel scale. Comparisons are for each individual caribou in each calving season (2011-2013 calving seasons). Absence of both bars indicates that nutrient rich fen was not contained in the female's calving area.

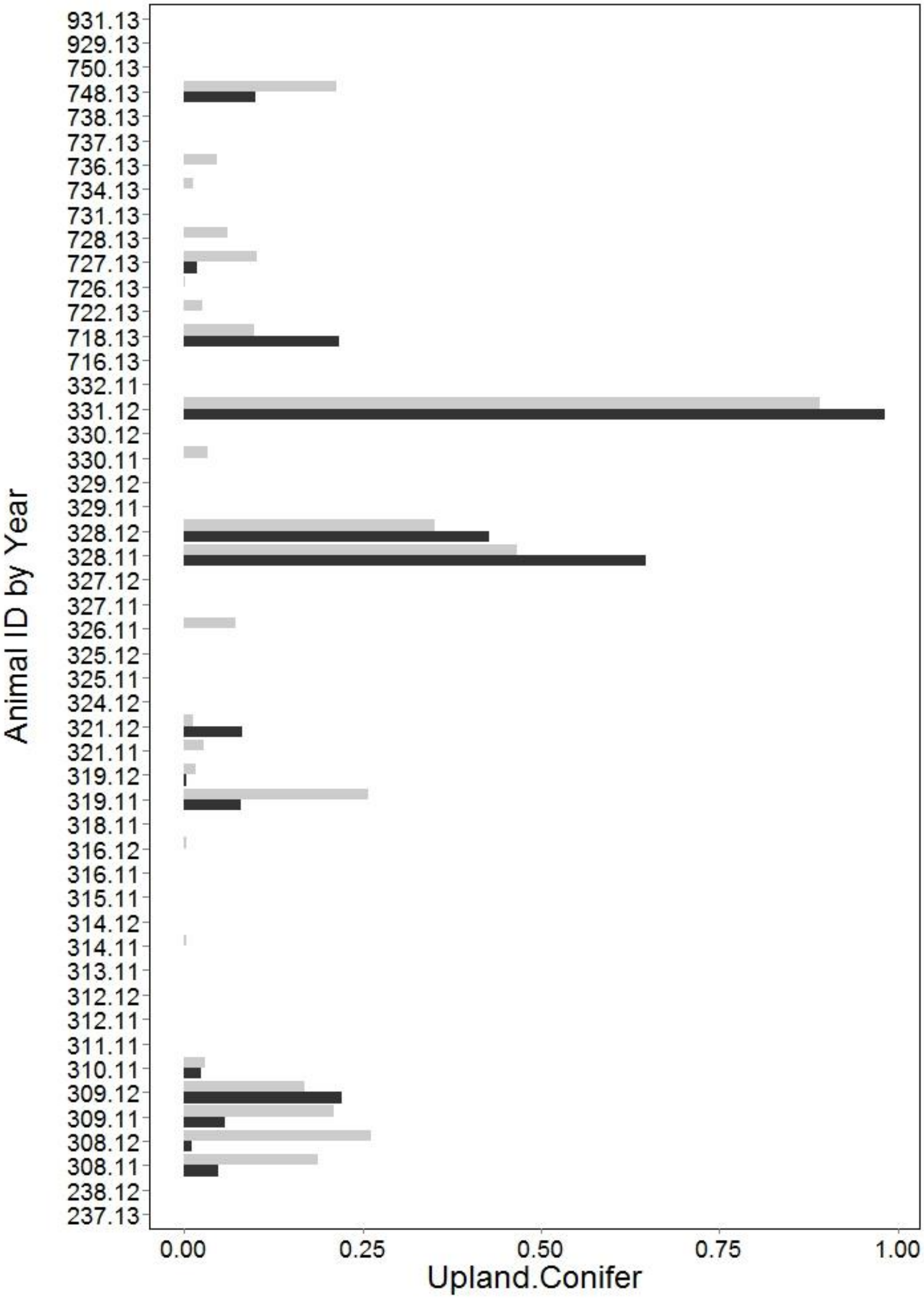


Figure A6.13: Mean proportion of upland conifer for caribou GPS locations (black bars) compared to the mean proportion in calving areas (grey bars). Upland conifer was measured at the 30-m pixel scale. Comparisons are for each individual caribou in each calving season (2011-2013 calving seasons). Absence of both bars indicates that upland conifer was not contained in the female's calving area.

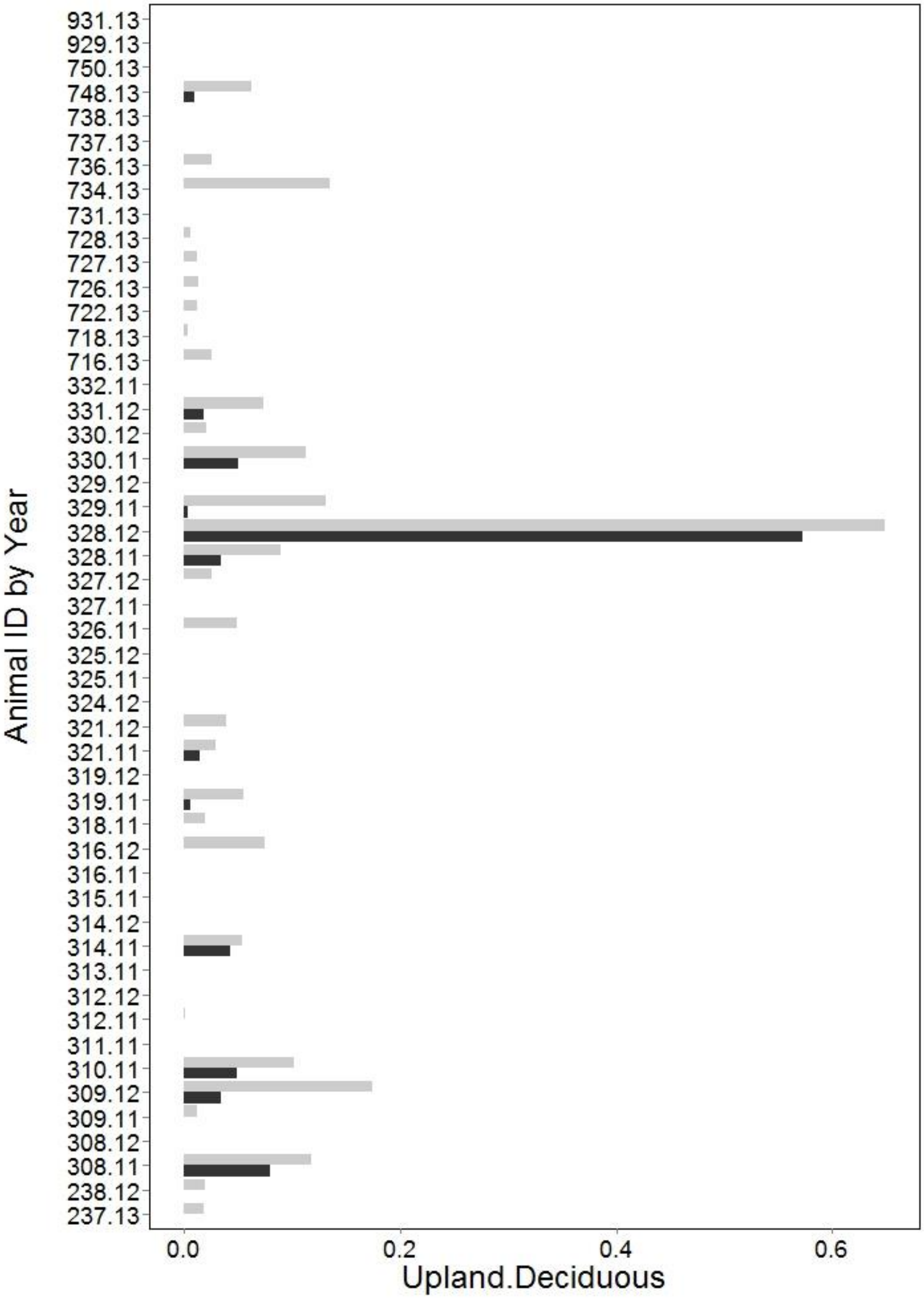


Figure A6.14: Mean proportion of upland deciduous for caribou GPS locations (black bars) compared to the mean proportion in calving areas (grey bars). Upland deciduous was measured at the 30-m pixel scale. Comparisons are for each individual caribou in each calving season (2011-2013 calving seasons). Absence of both bars indicates that upland conifer was not contained in the female's calving area.

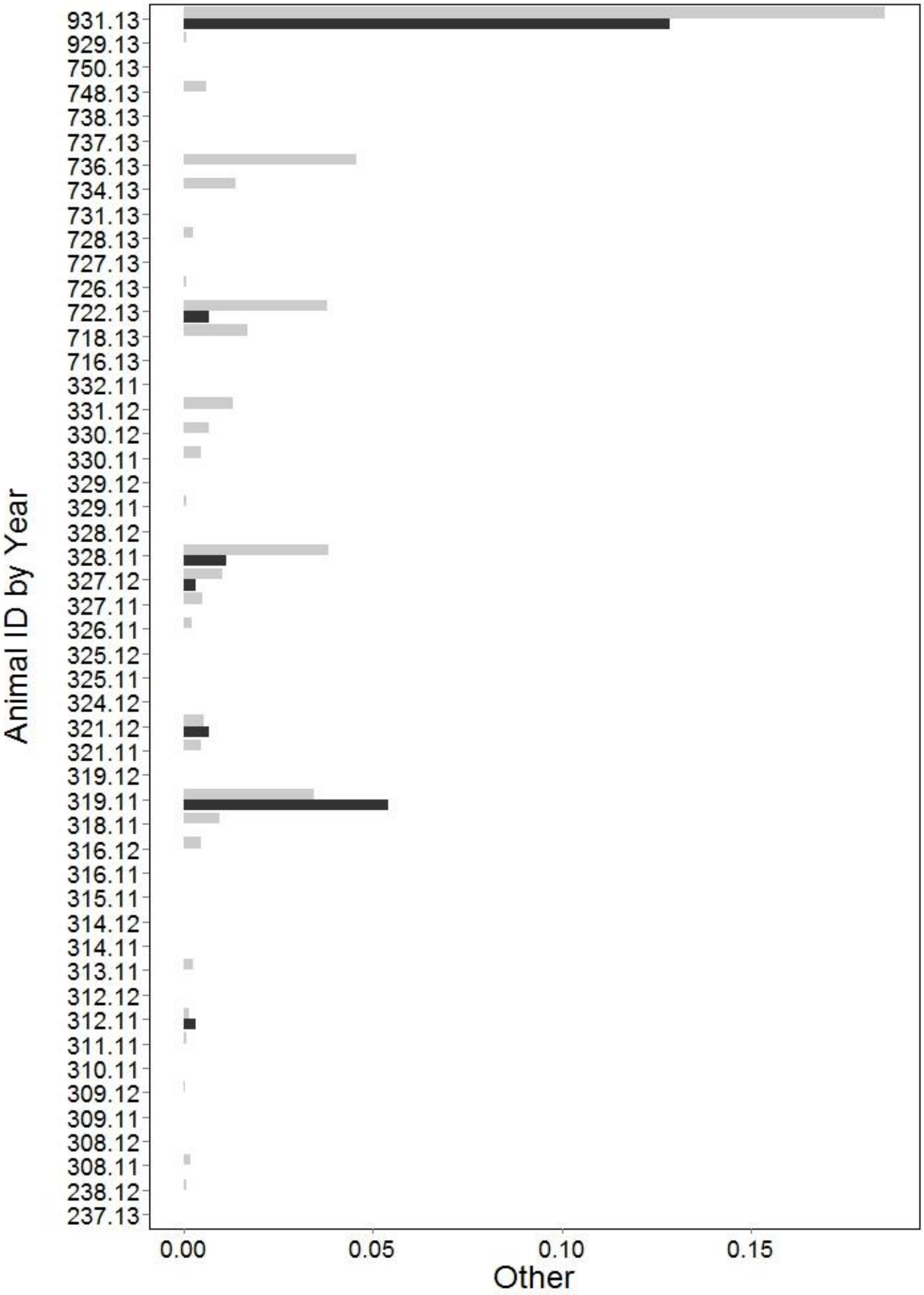


Figure A6.15: Mean proportion of the land cover class "other" for caribou GPS locations (black bars) compared to the mean proportion in calving areas (grey bars). Land cover was measured at the 30-m pixel scale. Comparisons are for each individual caribou in each calving season (2011-2013 calving seasons). Absence of both bars indicates that "other" was not contained in the female's calving area.

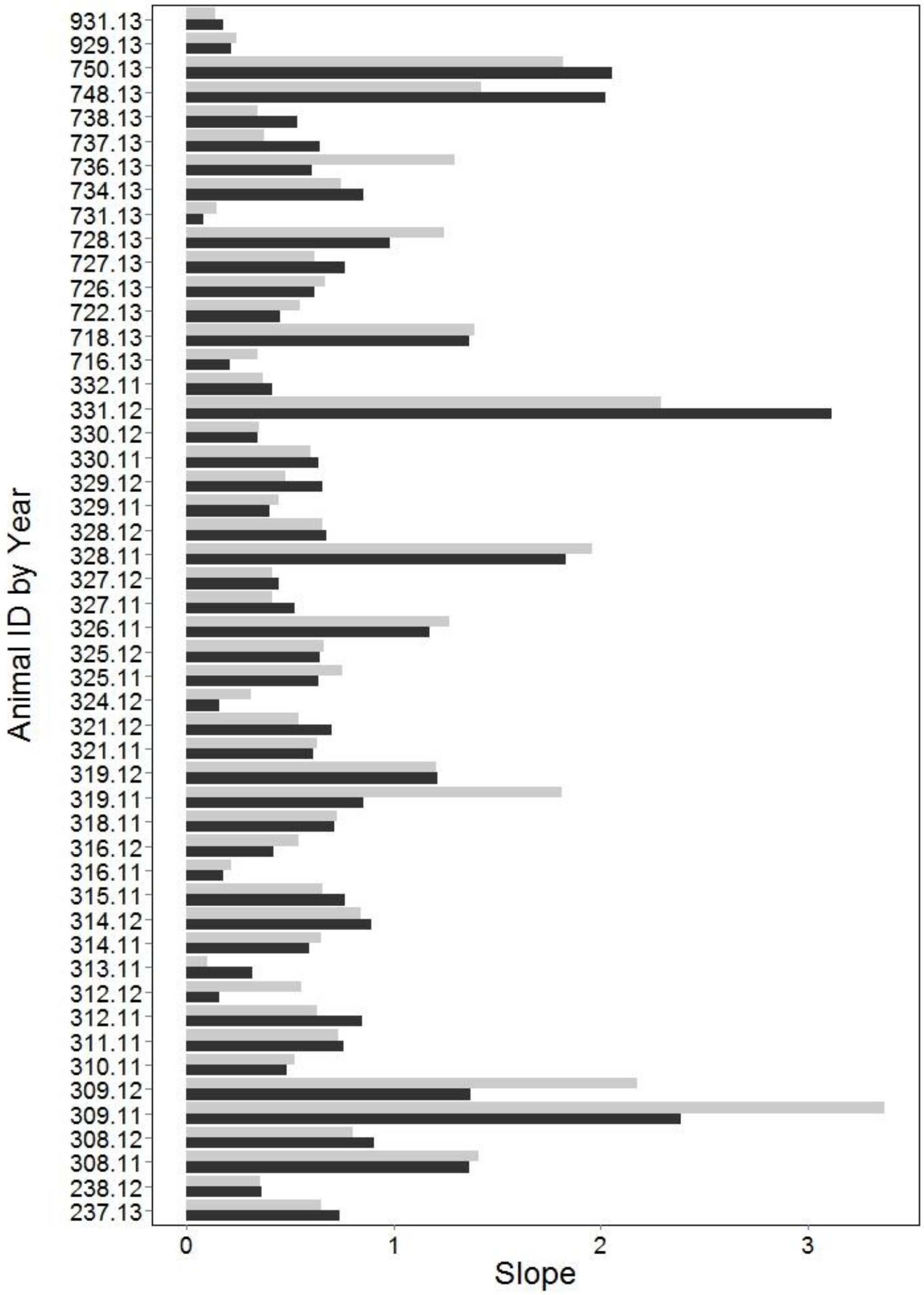


Figure A6.16: Mean slope value for caribou GPS locations (black bars) compared to the mean value in calving areas (grey bars). Slope was measured at the 30-m pixel scale. Comparisons are for each individual caribou in each calving season (2011-2013 calving seasons).

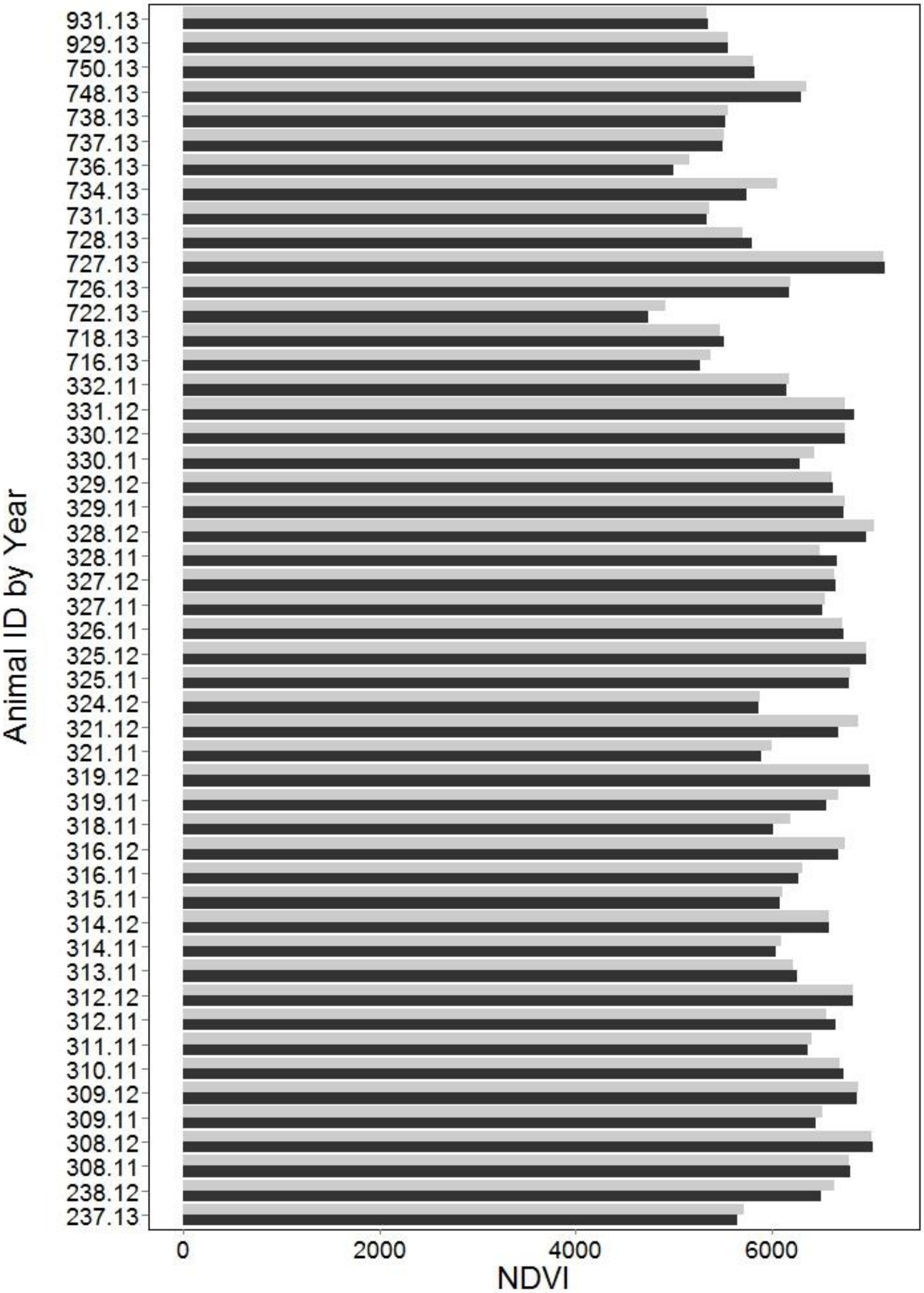


Figure A6.17: Mean value of the normalized vegetation difference index (NDVI) for caribou GPS locations (black bars) compared to the mean value in calving areas (grey bars). NDVI was measured at the 30-m pixel scale. Comparisons are for each individual caribou in each calving season (2011-2013 calving seasons).

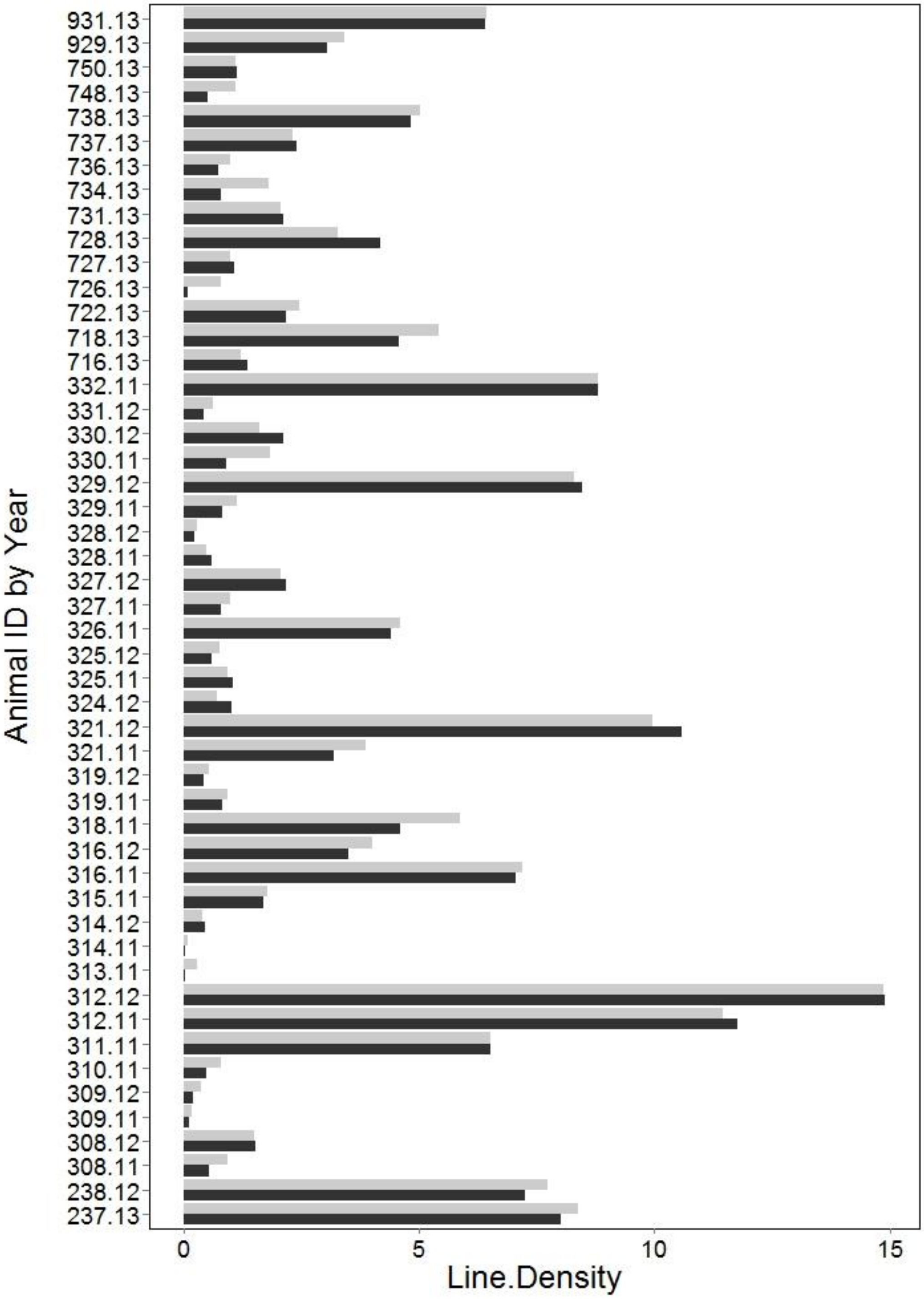


Figure A6.18: Mean value of linear feature density for caribou GPS locations (black bars) compared to the mean value in calving areas (grey bars). Linear feature density was measured in a 400-m radius. Comparisons are for each individual caribou in each calving season (2011-2013 calving seasons).

Wolf Second Order Selection

Second-order selection analyses for wolves entailed a comparison between random points generated within areas used by individual packs during the calving season (“used” locations) and random points generated within the distribution of caribou in NE BC (“available” locations). Figures A6.19 – A6.20 depict boxplots comparing average values of used versus available locations for each variable used in RSFs. Circles of “used” locations represent the average value calculated for each individual wolf pack. Circles of “available” locations are the average or expected values calculated for the distribution of caribou. Available values per pack are identical but the circles have been “jittered” for graphical purposes.

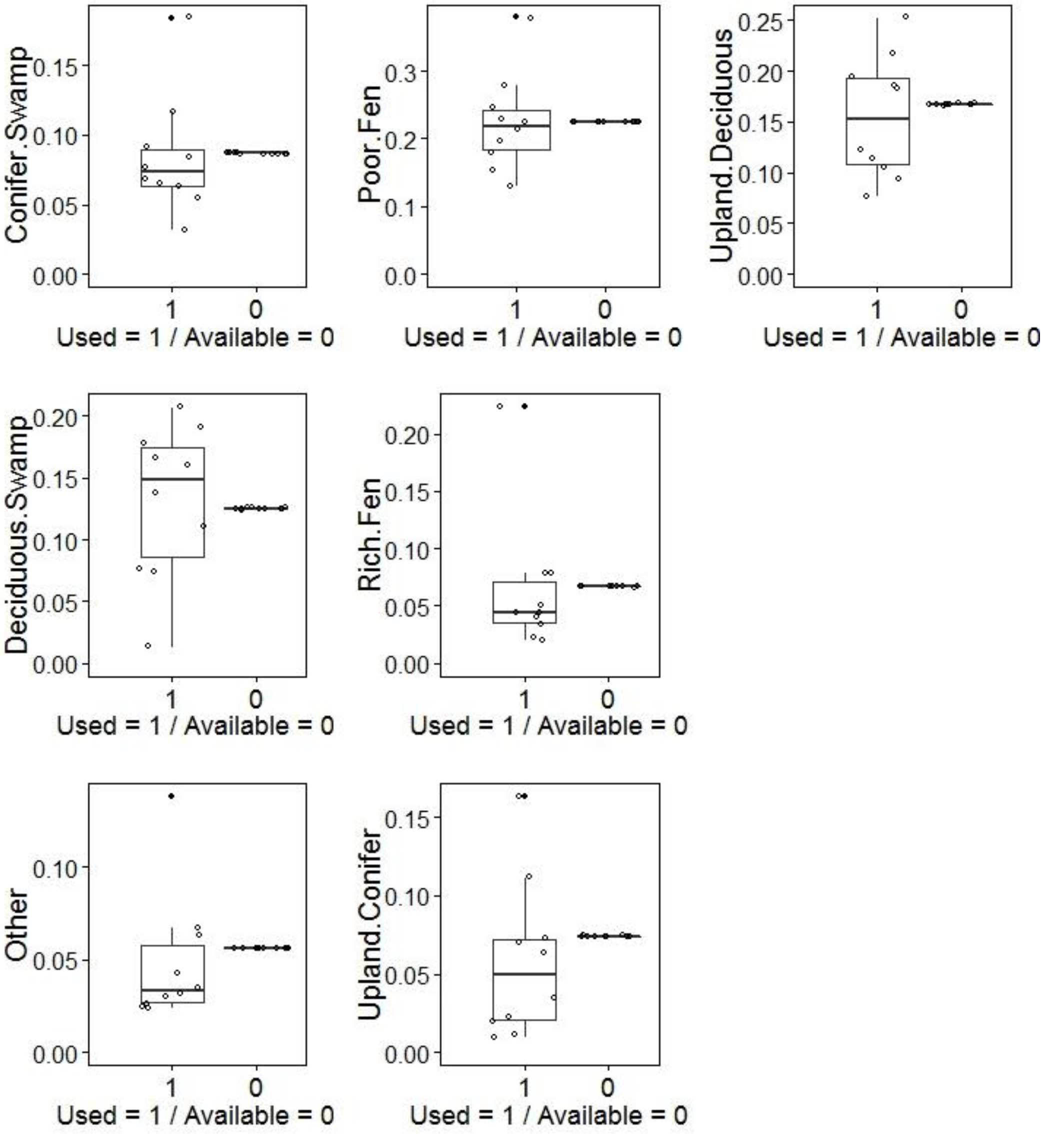


Figure A6.19: Mean proportion of all land cover classes within areas used by wolf packs during the calving season ("used" locations) compared to the mean proportion within the distribution of caribou in NE BC ("available" locations). Land cover proportions were calculated in a moving window analysis with a 6000-m radius.

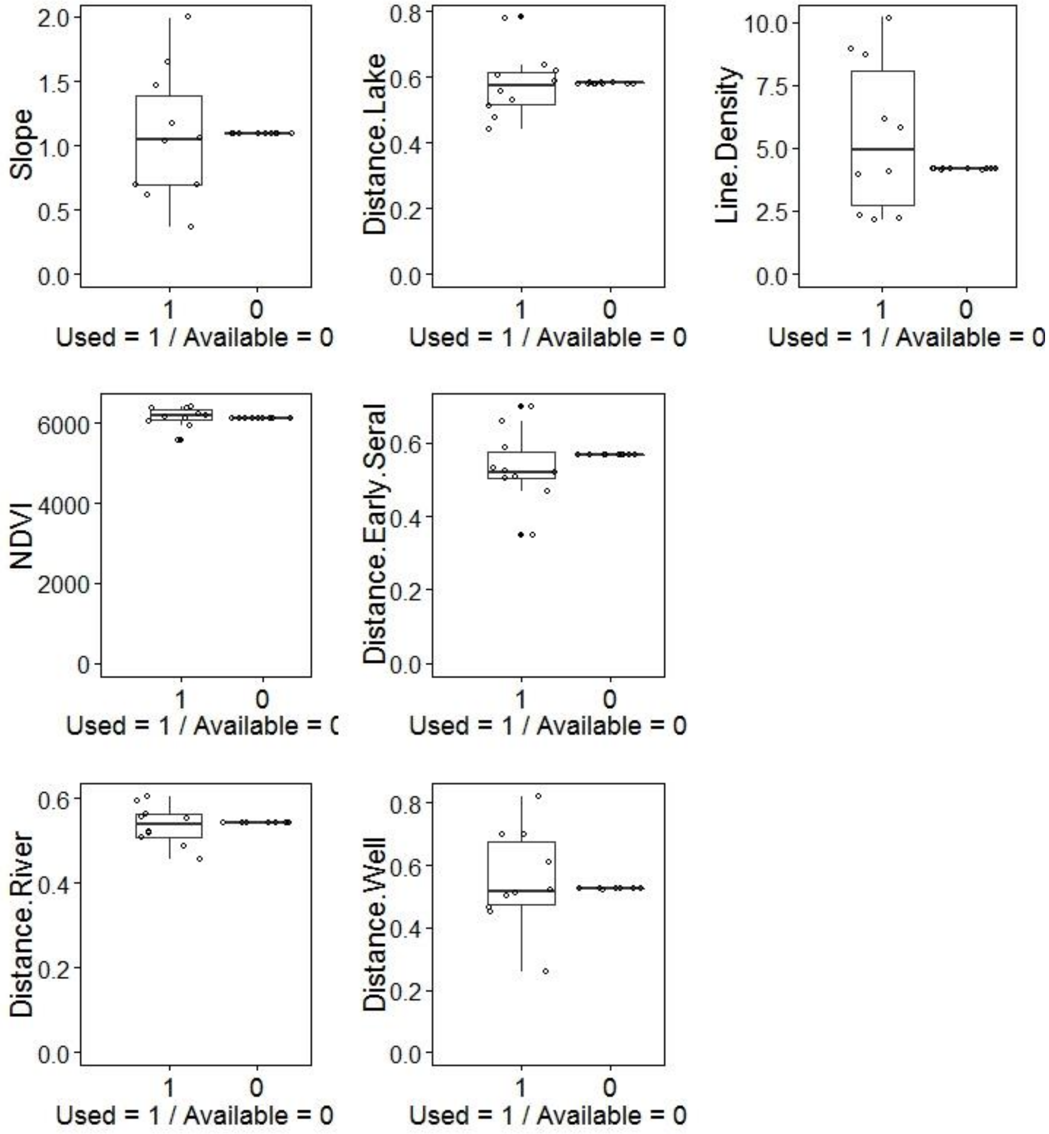


Figure A6.20: Mean values of slope, NDVI, distance-to variables, and linear feature density within areas used by wolf packs during the calving season ("used" locations) compared to the mean values within the distribution of caribou in NE BC ("available" locations). Slope and NDVI were calculated at the 3-m pixel scale. Distance-to variables were transformed using an exponential decay function. Linear feature density was calculated in a moving window analysis with a 6000-m radius.

Wolf Third Order Selection

Third-order selection analyses for wolves compared radio-collar GPS locations (“used” locations) of individuals to random points generated within areas used by individual packs during the calving season (“available” locations). Bar charts are shown to compare mean values of used and available resources for each individual wolf (Fig. A6.21).

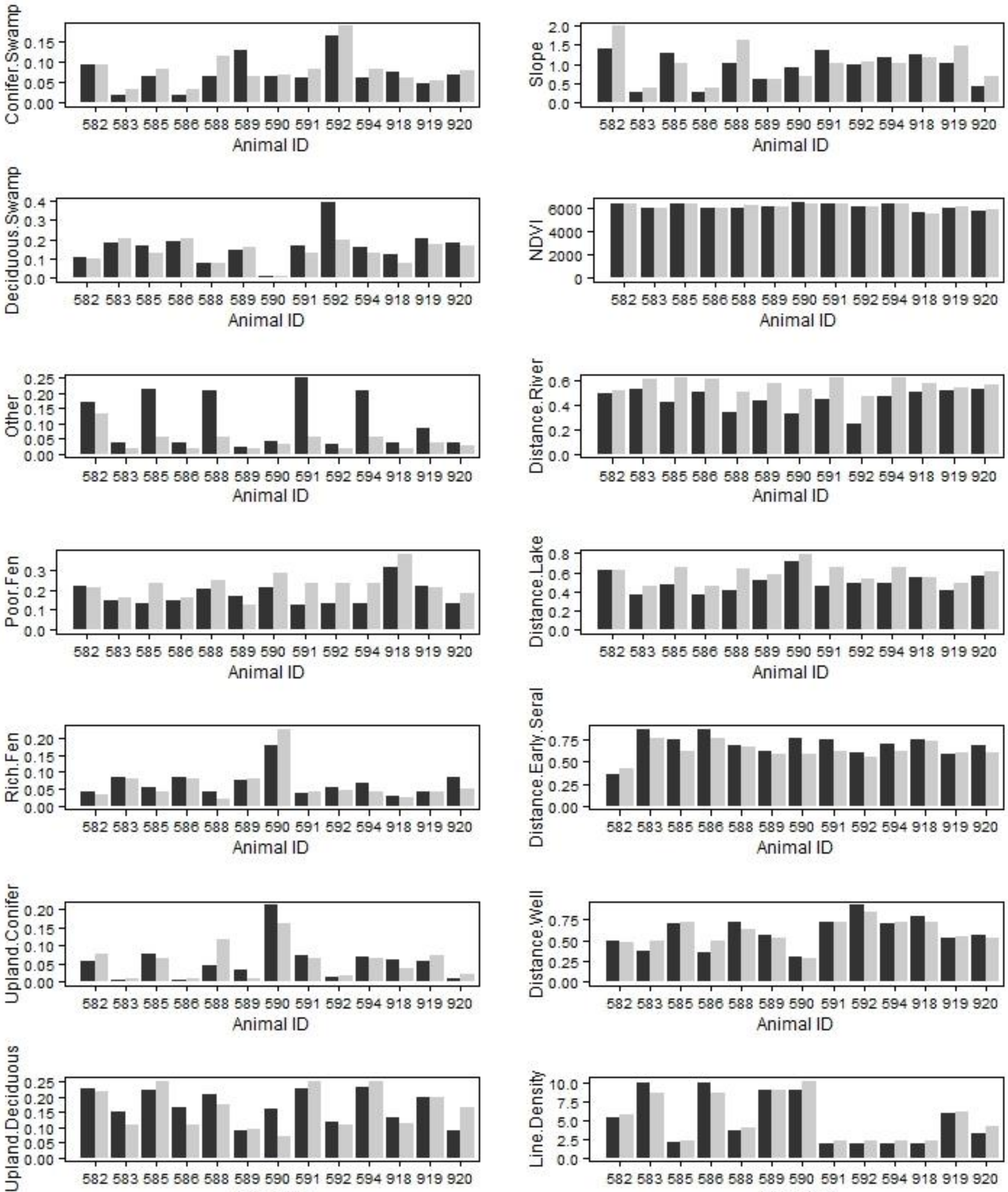


Figure A6.21: Univariate comparisons of mean values of used locations to available locations of variables contained in third-order RSF models for wolves. Used locations (black bars) were the radio-collar GPS locations of individual wolves while available locations (grey bars) were random locations generated within areas used by individual wolf packs during the calving season. Land cover proportions were calculated in a 400-m radius. Slope and NDVI were calculated at the 30-m pixel scale. Distance-to variables were transformed using an exponential decay function. Linear feature density was calculated in 6000-m radius.

Wolf Caribou Range Selection

We assessed resource selection when wolves specifically occurred within caribou range. For these analyses, we compared wolf GPS locations falling within caribou range to available points drawn within the same range (20,000 random points / range as per caribou). Bar charts are shown to compare mean values of used and available resources for each individual wolf (Fig. A6.22).

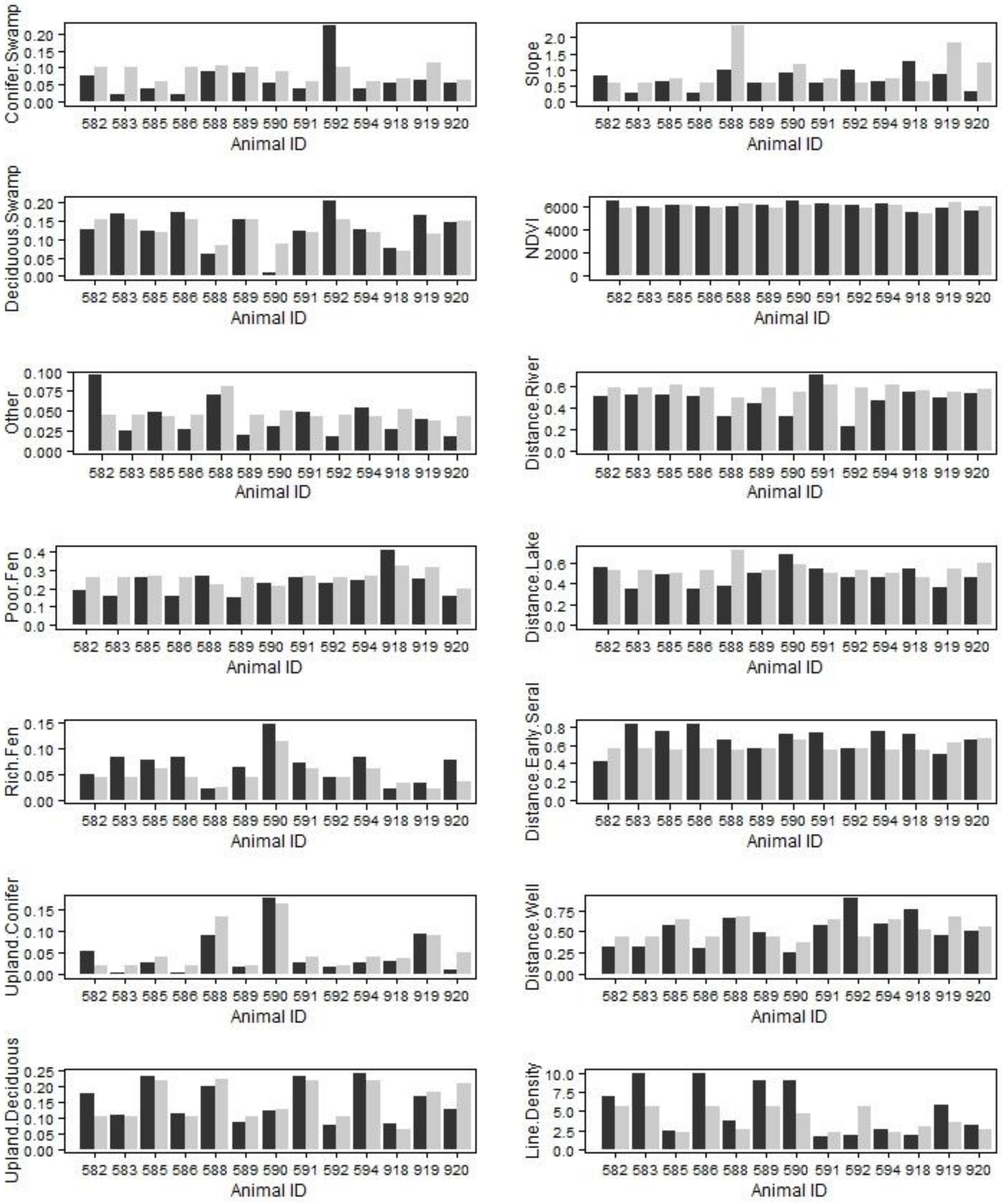


Figure A6.22: Univariate comparisons of mean values of used locations to available locations of variables contained in caribou range RSF models for wolves. Used locations (black bars) were the radio-collar GPS locations of individual wolves when in caribou range while available locations (grey bars) were random locations generated within caribou ranges. Land cover proportions were calculated in a 6000-m radius. Slope and NDVI were calculated at the 30-m pixel scale. Distance-to variables were transformed using an exponential decay function. Linear feature density was calculated in 6000-m radius.

Black Bear Second Order Selection

Second-order selection analyses for black bears compared random points generated within areas used by individuals during the calving season (“used” locations) and random points generated within the distribution of caribou in NE BC (“available” locations). Figures A6.23 – A6.24 depict boxplots comparing average values of used versus available locations for each variable used in RSFs. Circles of “used” locations represent the average value calculated for each individual bear. Circles of “available” locations are the average or expected values calculated for the distribution of caribou. Available values per pack are identical but the circles have been “jittered” for graphical purposes.

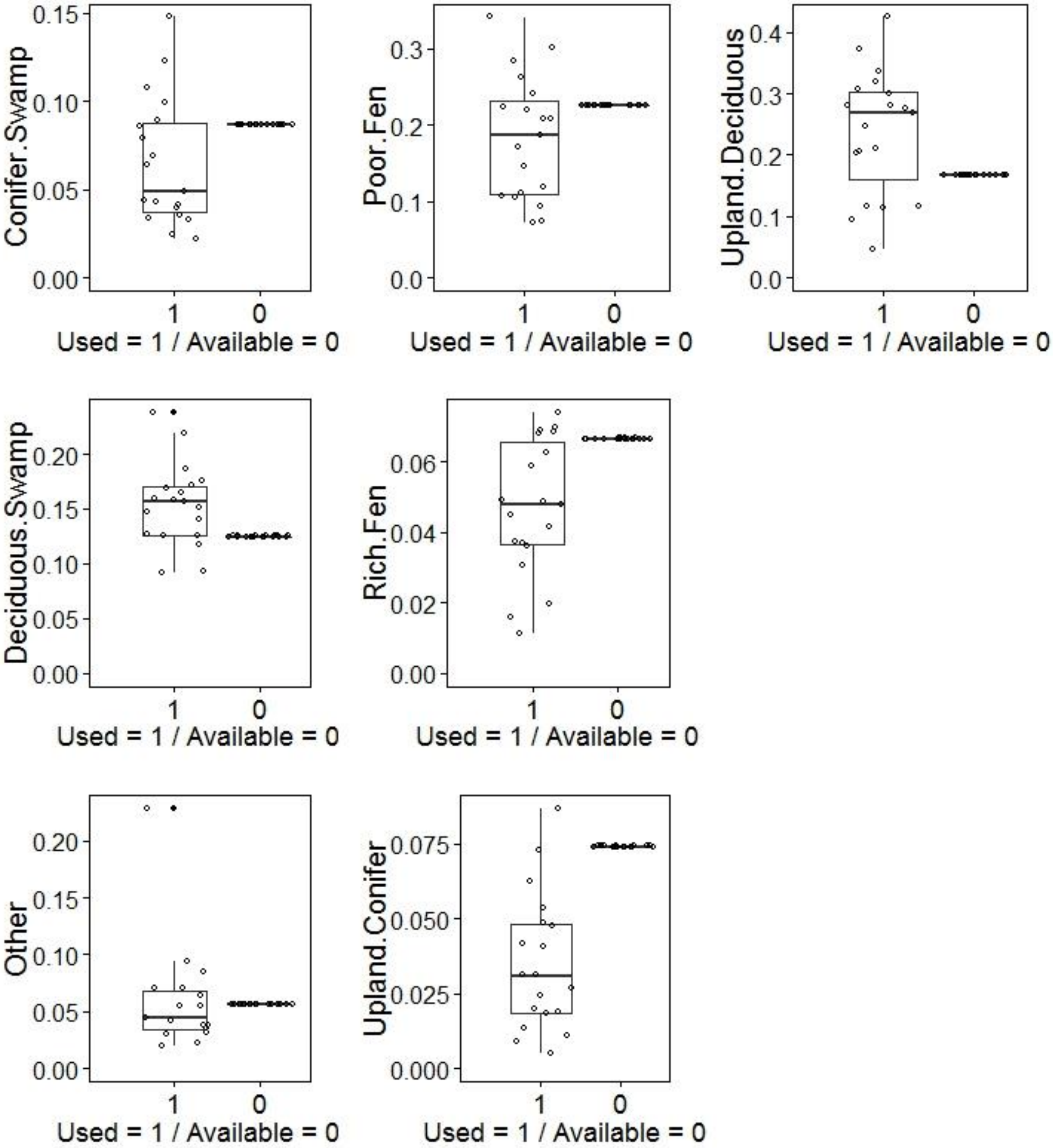


Figure A6.23: Mean proportion of all land cover classes within areas used by individual black bears during the calving season ("used" locations) compared to the mean proportion within the distribution of caribou in NE BC ("available" locations). Land cover proportions were calculated in a moving window analysis with a 6000-m radius.

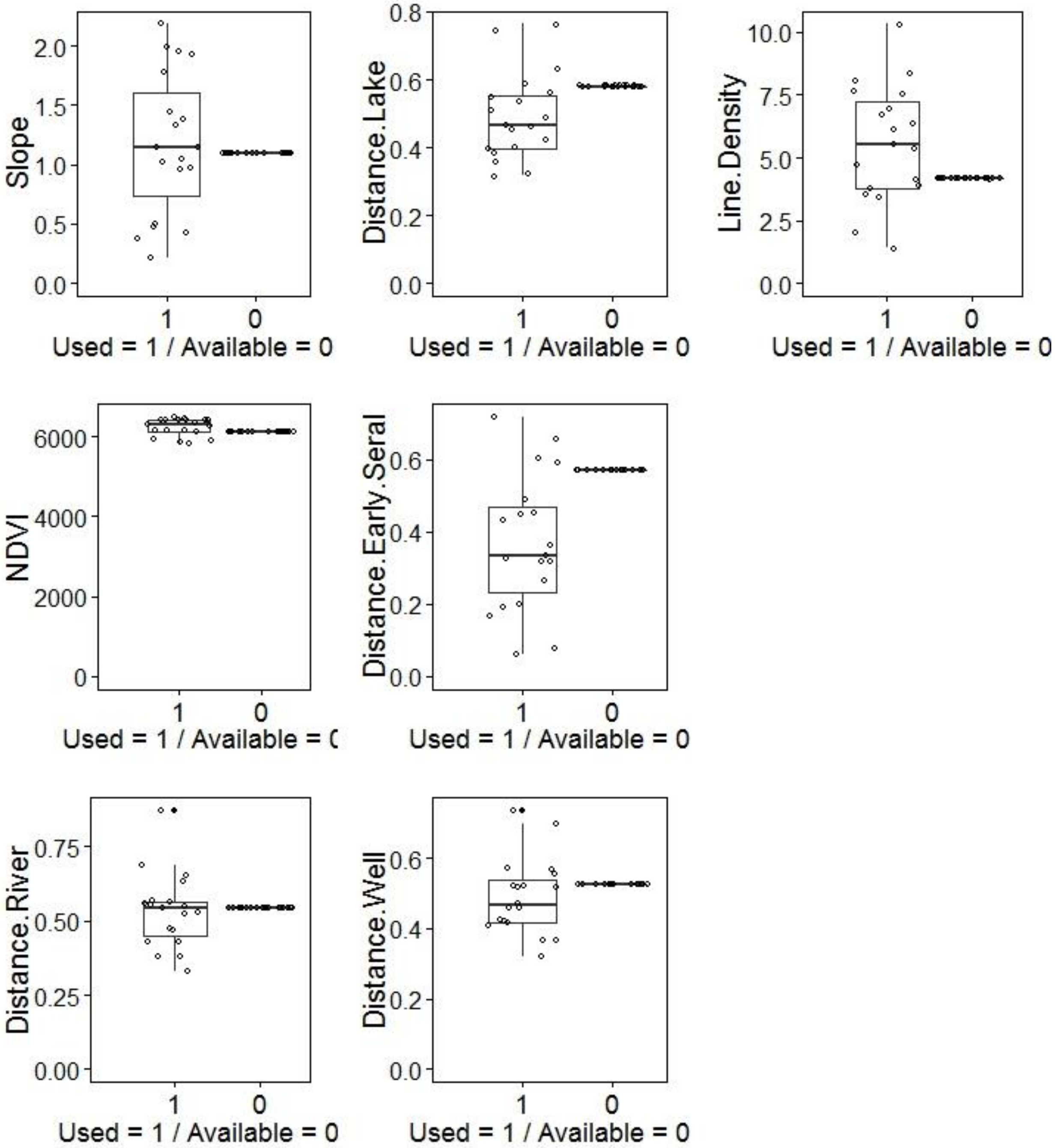


Figure A6.24: Mean values of slope, NDVI, distance-to variables, and linear feature density within areas used by individual black bears during the calving season ("used" locations) compared to the mean values within the distribution of caribou in NE BC ("available" locations). Slope and NDVI were calculated at the 3-m pixel scale. Distance-to variables were transformed using an exponential decay function. Linear feature density was calculated in a moving window analysis with a 6000-m radius.

Black Bear Third Order Selection

Third-order selection analyses for black bears compared radio-collar GPS locations ("used" locations) to random points generated within areas used by individuals during the calving season ("available" locations). Bar charts are shown to compare mean values of used and available resources for each individual bear (Fig. A6.25).

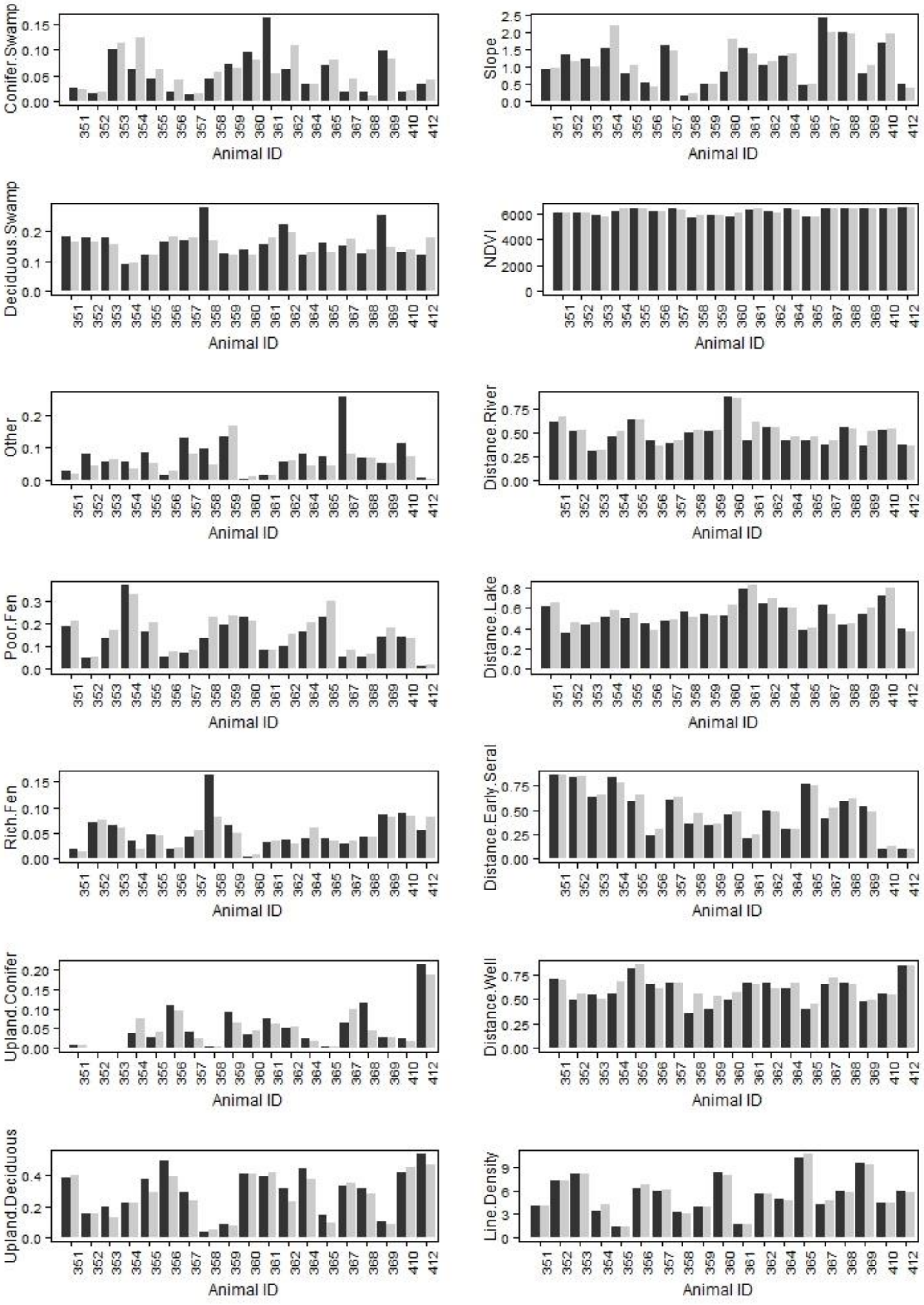


Figure A6.25: Univariate comparisons of mean values of used locations to available locations of variables contained in third-order RSF individual wolves while available locations (grey bars) were random locations generated within areas used by individuals during the calving season. Land cover proportions were calculated in a 400-m radius. Slope and NDVI were calculated at the 30-m pixel scale. Distance-to variables were transformed using an exponential decay function. Linear feature density was calculated in 2000-m radius.

Black Bear Caribou Range Selection

We assessed resource selection when black bears specifically occurred within caribou range. For these analyses, we compared bear GPS locations falling within caribou range to available points drawn within the same range (20,000 random points / range as per caribou). Bar charts are shown to compare mean values of used and available resources for each individual bear (Fig. A6.26).

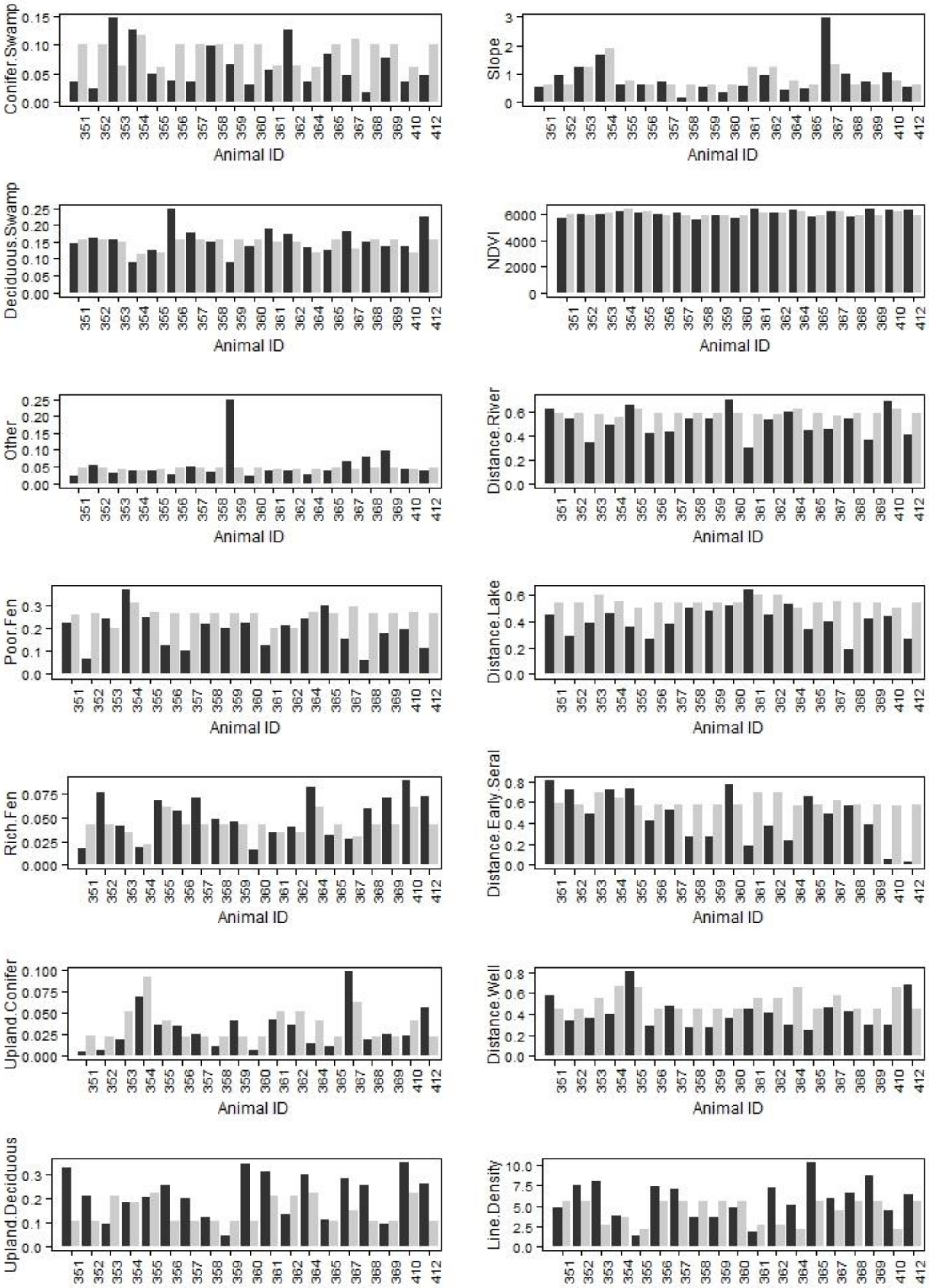
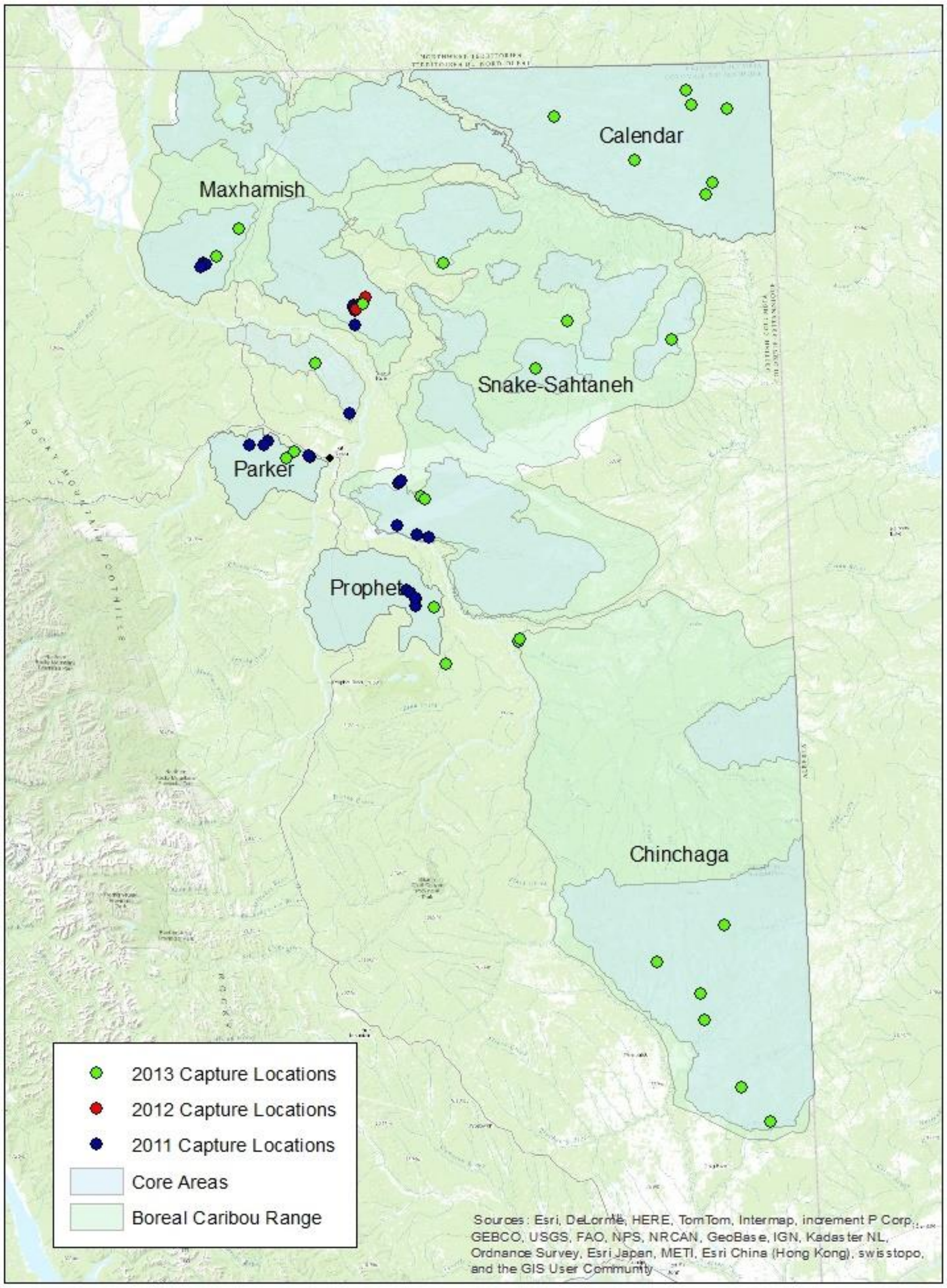


Figure A6.26: Univariate comparisons of mean values of used locations to available locations of variables contained in caribou range RSF models for black bears. Used locations (black bars) were the radio-collar GPS locations of individual wolves when in caribou range while available locations (grey bars) were random locations generated within caribou ranges. Land cover proportions were calculated in a 6000-m radius. Slope and NDVI were calculated at the 30-m pixel scale. Distance-to variables were transformed using an exponential decay function. Linear feature density was calculated in 6000-m radius.

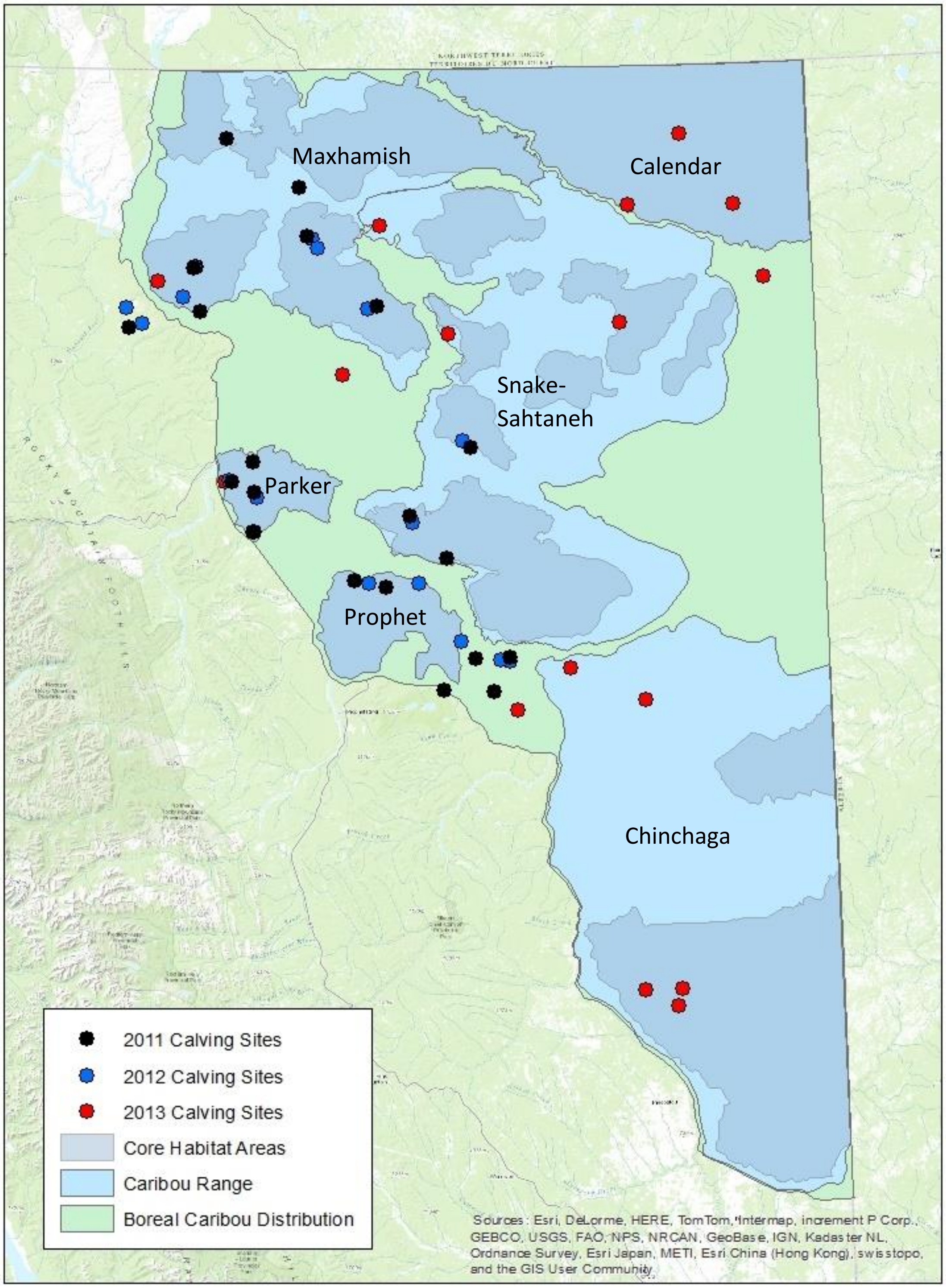
APPENDIX 7: *Caribou Spatial Data*

Capture and calving locations of 57 female boreal caribou in northeast British Columbia from 2011 to 2013. Calving locations include predicted calving sites (Fig. A5.2) and all locations of females accompanied by neonate calves (< 4 weeks old).



Sources: Esri, DeLorme, HERE, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Figure A7. 1: Capture locations of 57 female boreal caribou in northeast British Columbia. Twenty five females were captured in the winter of 2011, two in the winter of 2012 and 30 in the winter of 2013.



Sources: Esri, DeLorme, HERE, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Figure A7. 2: Calving sites of 57 female boreal caribou in northeast British Columbia from 2011 to 2013.

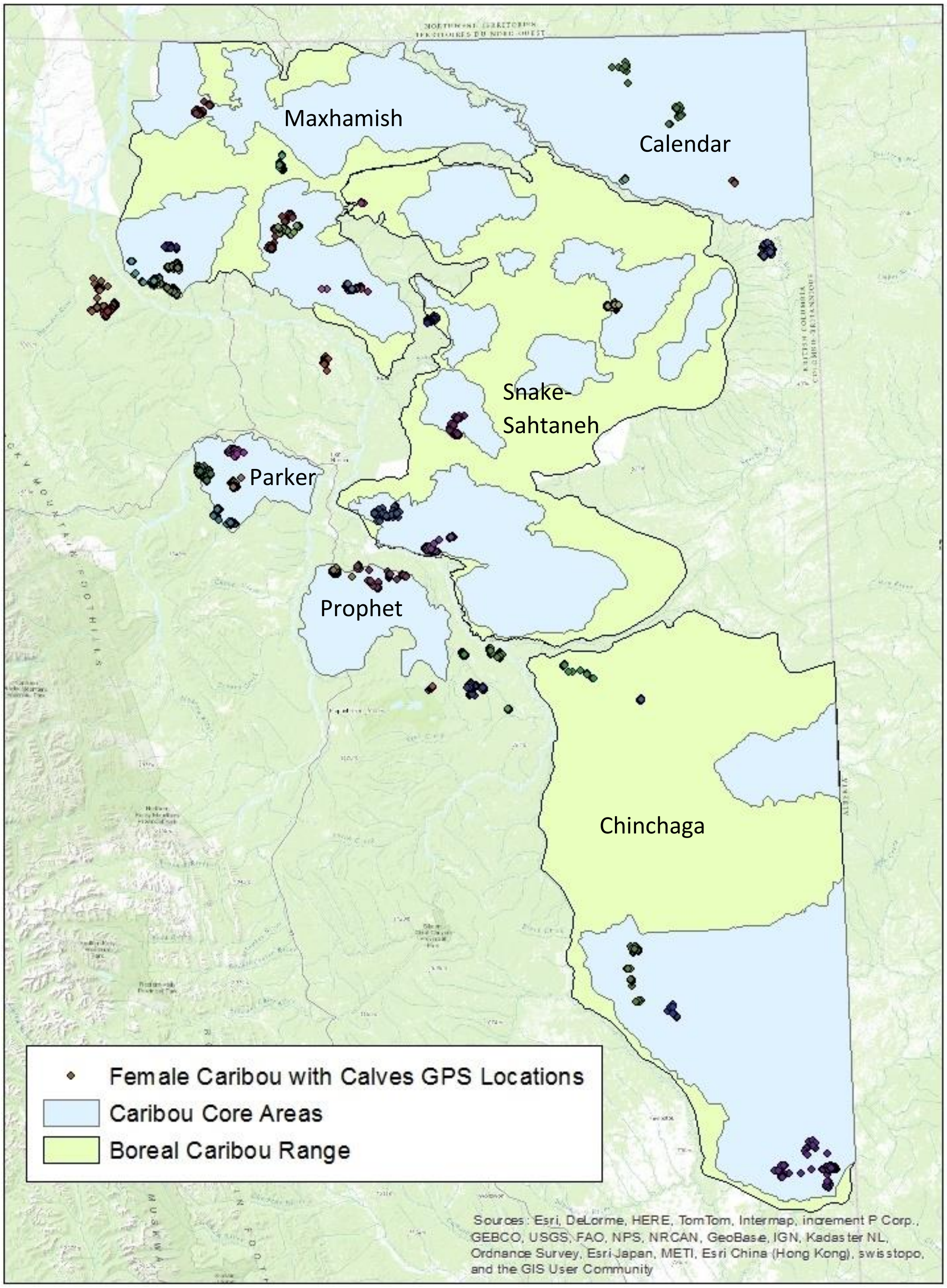
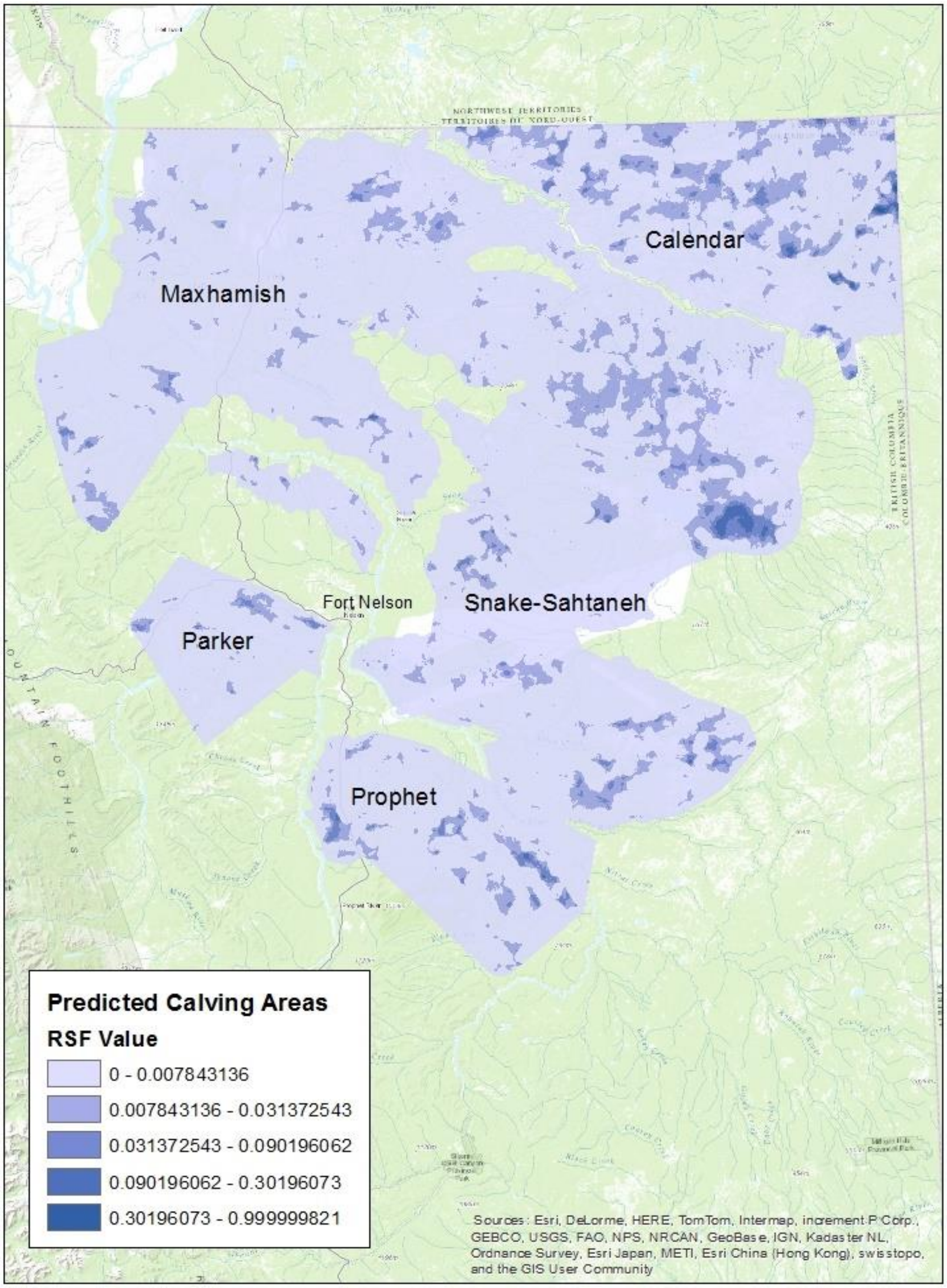


Figure A7. 3: GPS locations of 39 female boreal caribou with neonate calves (<4 weeks old) in northeast British Columbia from 2011 to 2013.



Sources: Esri, DeLorme, HERE, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Figure A7. 4: Predicted calving areas of boreal caribou in the Calendar, Maxhamish, Parker, Prophet and Snake-Sahtaneh caribou ranges as well as in the Fort Nelson core area in northeast British Columbia. Predictions were developed from a resource selection function (RSF) using GPS radio-collar data collected from 35 female caribou during the 2011 – 2013 calving seasons. Note that ranges were expanded to include females calving outside of previously delineated boundaries. The Chinchaga range was excluded due to poor predictive performance of the RSF model when extrapolated to this range.

APPENDIX 8: *Predator Spatial Data*

Capture locations and GPS locations from wolves and black bears during the calving season of caribou (May 1 – June 30) in northeast British Columbia from 2012 to 2013.

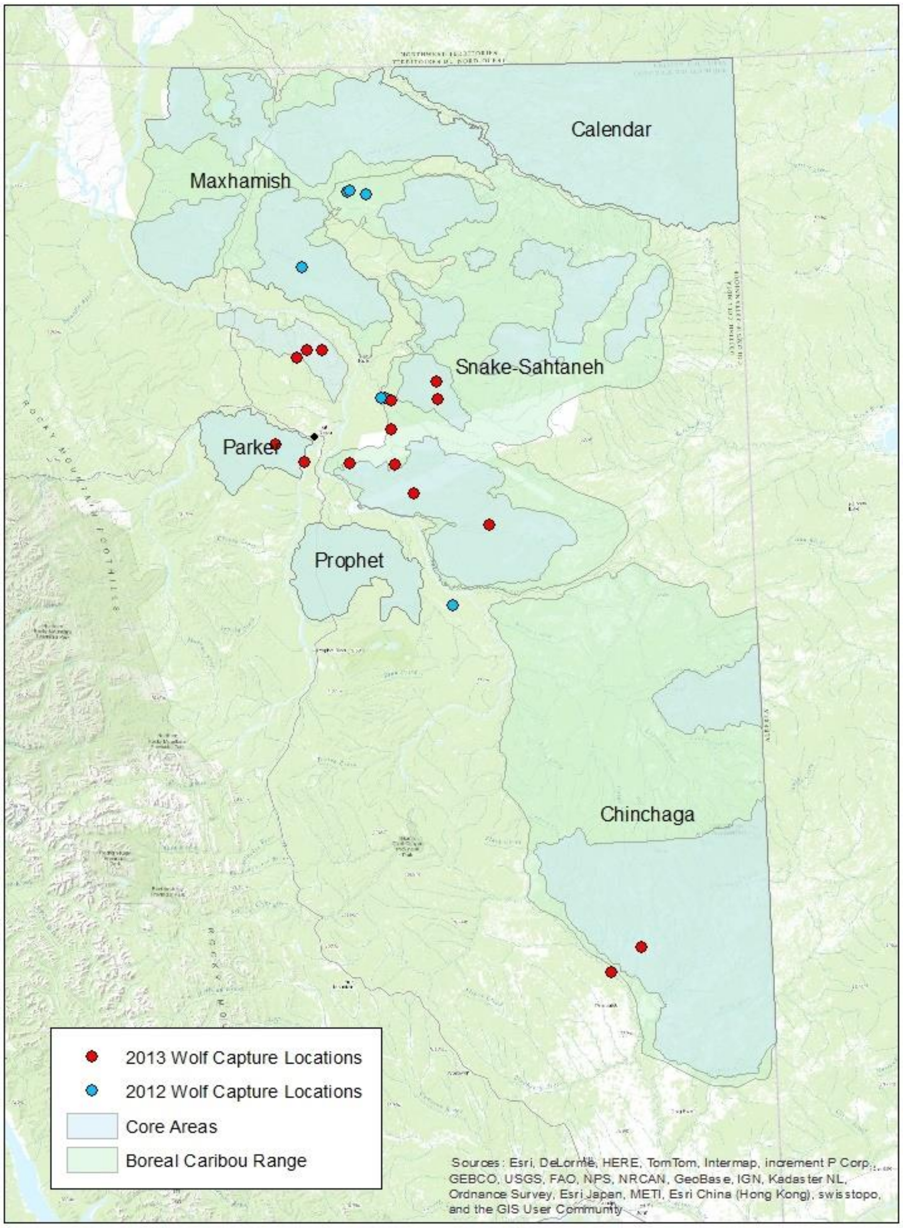


Figure A8. 1: Capture locations of 26 wolves captured in northeast British Columbia during the winter of 2012 (*n* = 10) and 2013 (*n* = 16).

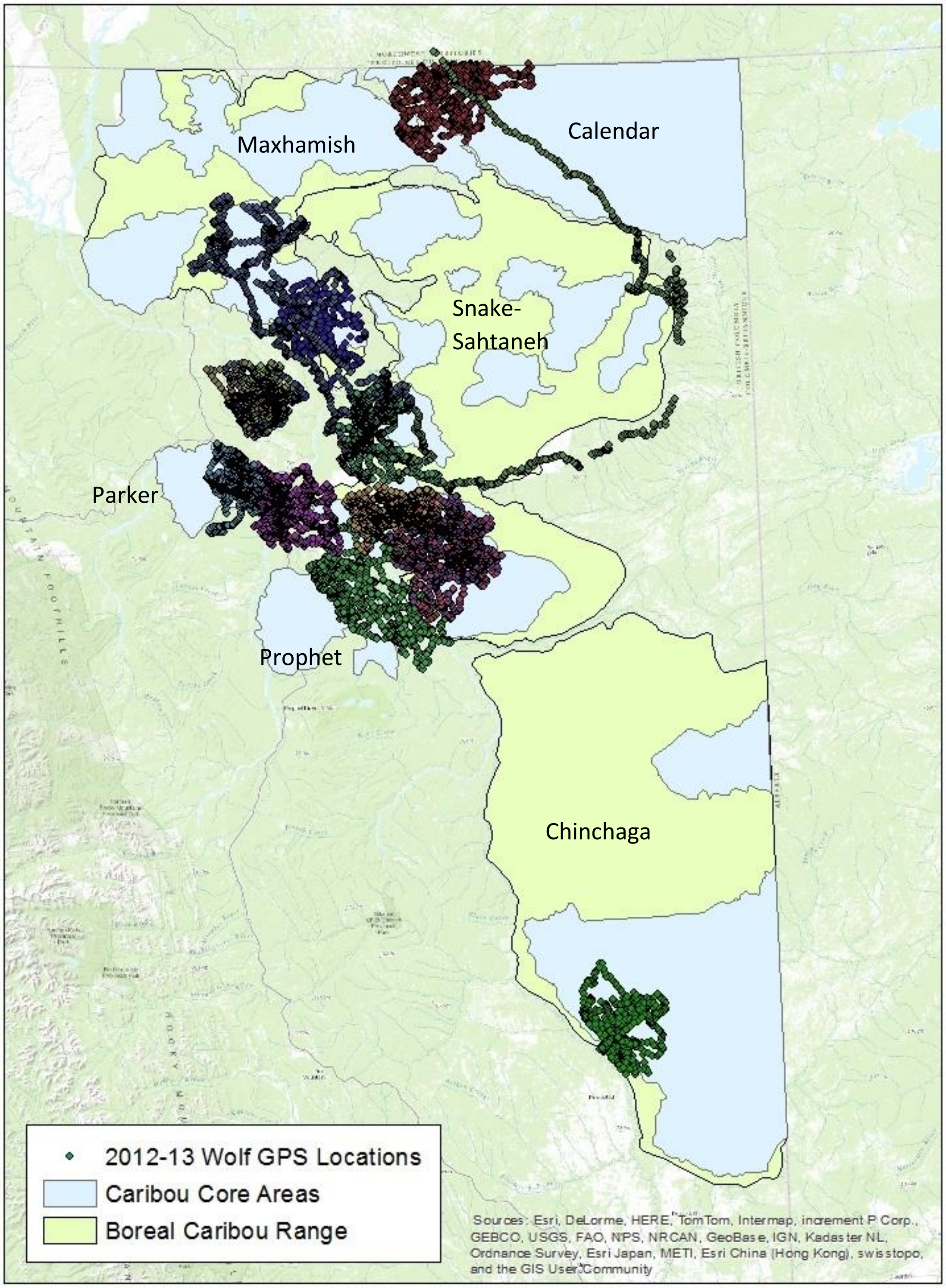
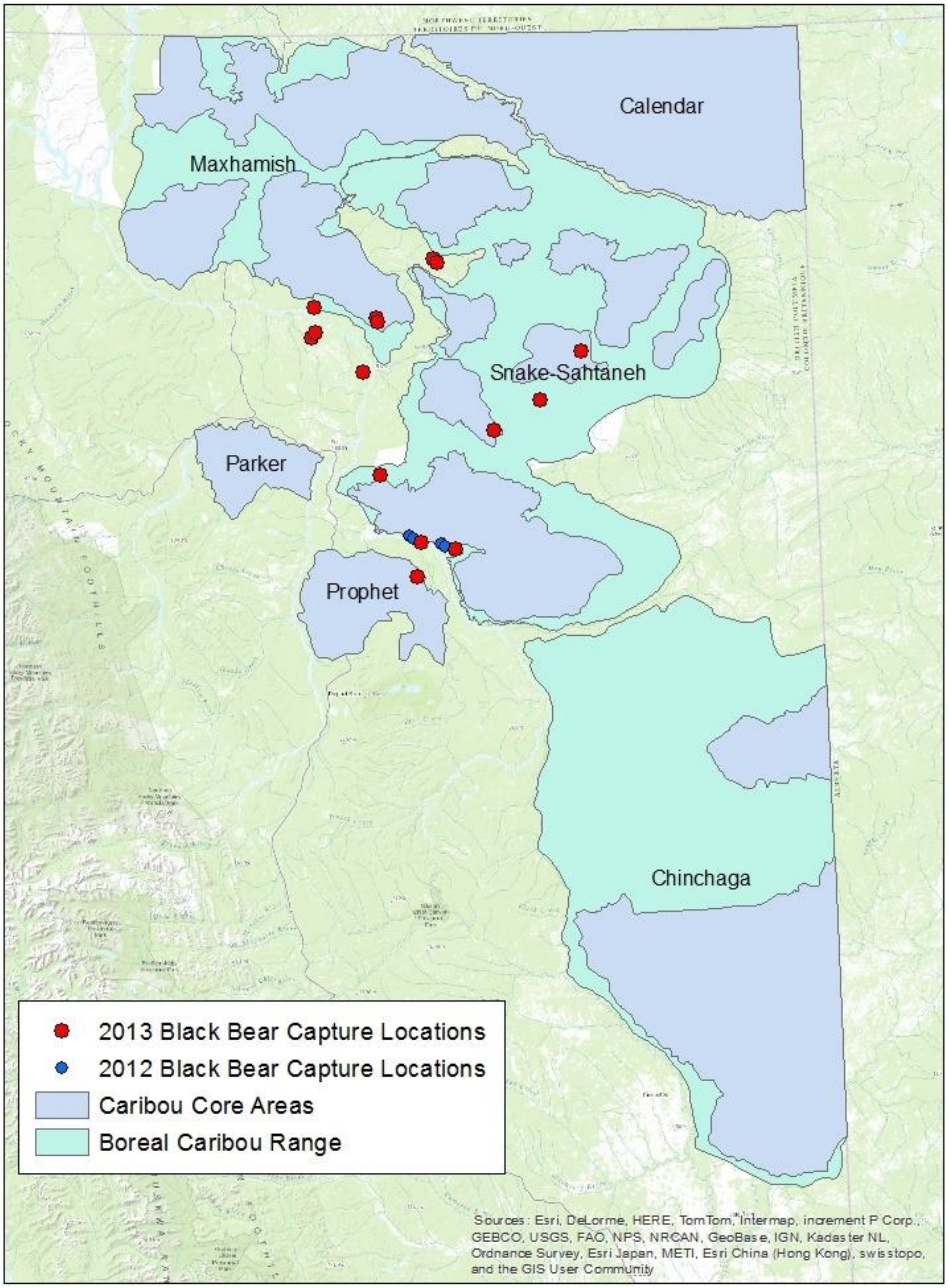


Figure A8. 2: GPS locations of 19 wolves during the 2012 and 2013 calving seasons (May 1 - June 30) of boreal caribou in northeast British Columbia.



Sources: Esri, DeLorme, HERE, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Figure A8. 3: Capture locations of 20 black bears captured in 2012 (*n* = 4) and 2013 (*n* = 16) in northeast British Columbia.

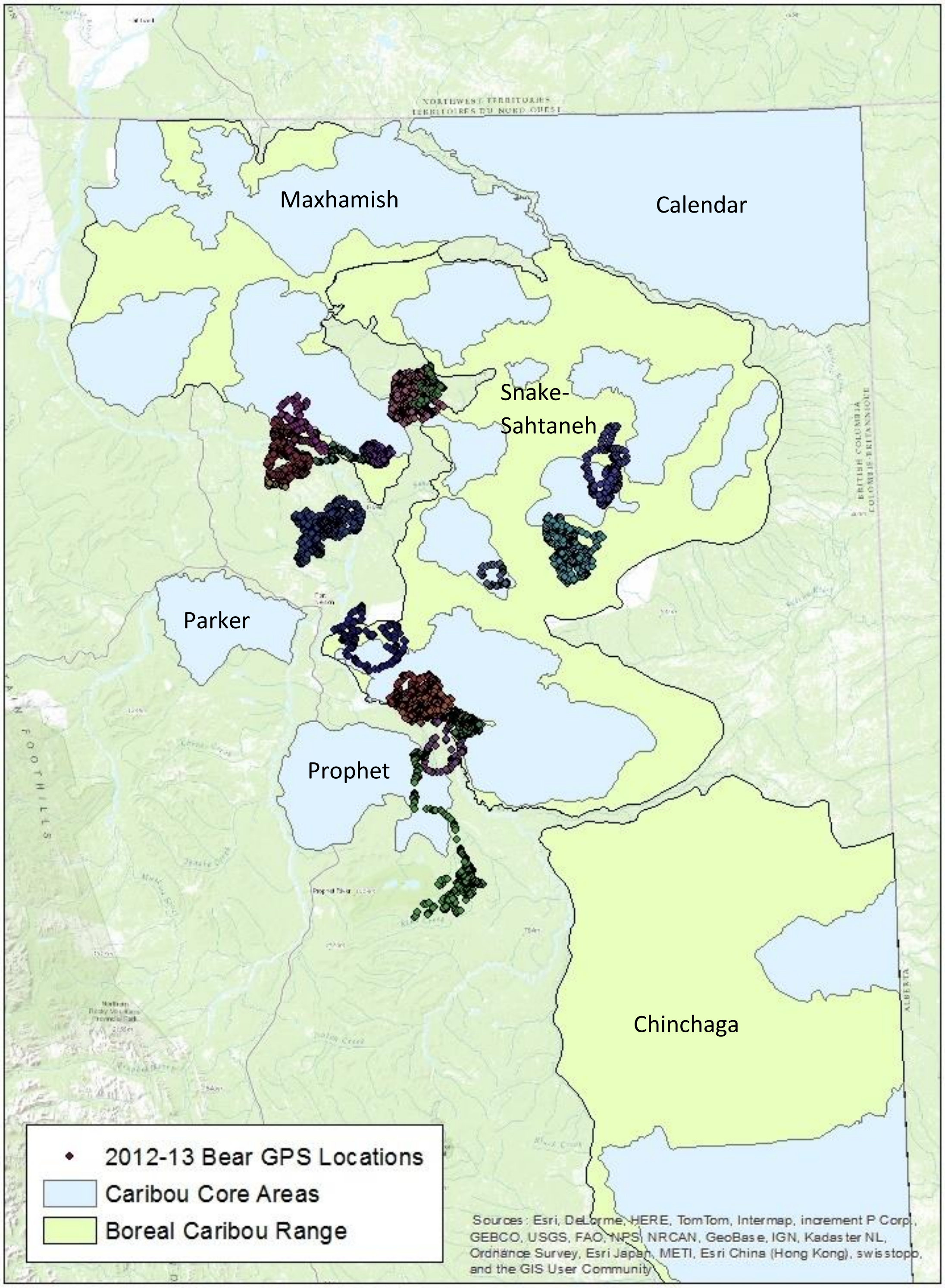
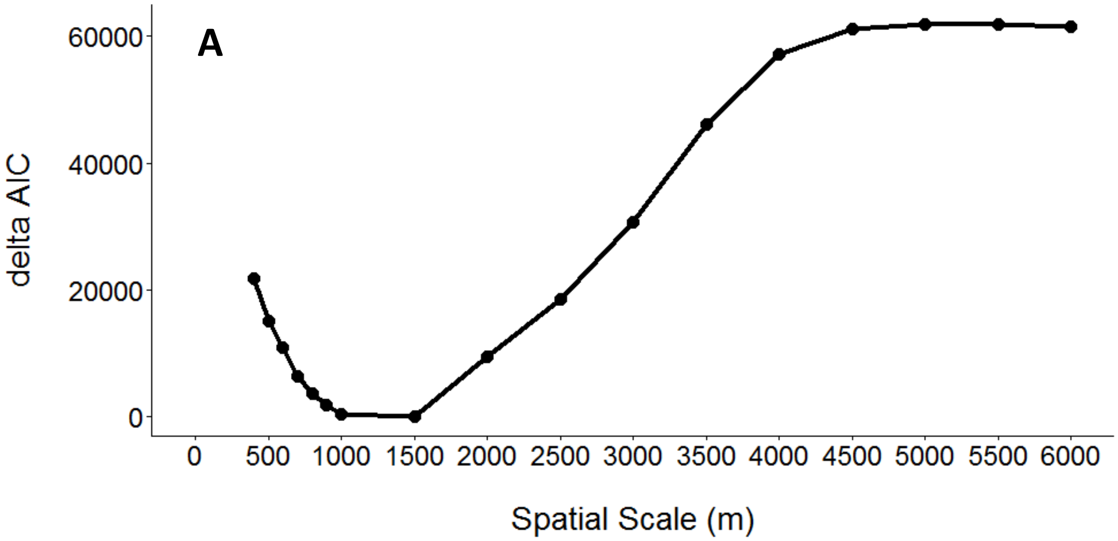
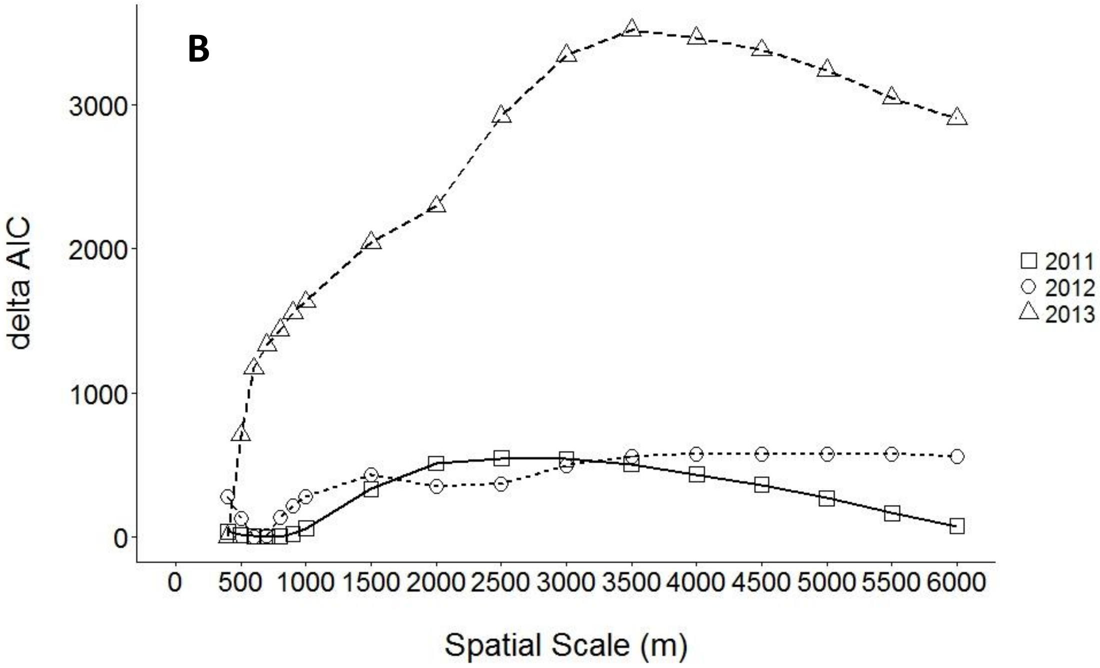


Figure A8. 4: GPS locations of 20 black bears during the 2012 and 2013 calving seasons (May 1 - June 30) of boreal caribou in northeast British Columbia.

APPENDIX 9: *Spatial Scale of Response Analyses*

We used repeated univariate generalized linear models to identify the most predictive scale of response for explanatory covariates used in resource selection modelling. The scale with the lowest AIC value was selected as the best predictor. Here, we show analyses for land cover (A) and linear feature density (B) to identify the most predictive scale for caribou. Delta AIC refers to the difference in AIC values between a given spatial and the best predictive scale.





APPENDIX 10: *Habitat Selection by Female Boreal Caribou Based on Season and Maternal Status*

The following tables list the conditional – or individual-level – parameter estimates for variables specified as random slope variables in generalized linear mixed-effect models (see main text) used to model second-order selection of habitat by female boreal caribou. All estimates are calculated as $\beta_n + \gamma_{nj}$, where β_n is the population-level slope for covariate x_n and γ_{nj} is the difference of the random slope for caribou *j* from β_n. Bold numbers indicate comparisons in which 95% confidence intervals overlapped (*n* = 1; see Table A10.19). Tables A10.1 – A10.6 are individual parameter estimates for mid-winter and calving, Tables A10.7 – A10.12 are estimates for late summer and calving, Tables A10.13 – A10.18 are estimates for late fall and calving, and Tables A810.19 – A10.24 are estimates for females with calves and females after calf loss.

Table A10.1: Conditional parameter estimates for variables specified as random slopes in the Disturbance model for individual female caribou in mid-winter and calving.

	Dist. to Early Seral		Dist. to Well		Line Density	
Animal ID	Mid-Winter	Calving	Mid-Winter	Calving	Mid-Winter	Calving
D030308	-2.42	-1.82	-0.65	-1.15	-1.70	-3.58
D030309	-1.07	0.51	-1.26	0.61	-0.83	-9.54
D030310	-2.75	-5.37	-0.65	0.88	-1.78	-3.04
D030312	-2.31	-8.62	-1.59	-0.84	0.02	0.18
D030314	1.23	-1.34	-1.26	0.21	-0.43	-8.13
D030316	-2.30	-2.42	-1.20	-0.61	-0.15	-0.96
D030318	-2.22	-3.37	-0.46	-1.45	0.21	-1.45
D030319	-2.15	-5.41	-1.14	-3.45	-0.97	-5.11
D030320	-1.66	-0.72	-0.76	-1.87	-0.65	-2.02
D030321	0.44	1.00	0.12	-0.11	-0.21	-0.31
D030324	-1.39	-1.11	-1.03	-1.31	-1.87	-3.75
D030325	-1.67	-4.83	-0.56	-0.53	-0.81	-3.94
D030326	-0.72	-4.16	-0.52	-2.09	-0.74	-1.46
D030327	0.41	-1.54	0.68	0.50	0.54	-3.25
D030328	-2.53	-2.04	1.06	-1.53	-2.08	-6.83
D030329	-2.03	-2.55	-1.24	1.64	-0.95	1.07
D030330	-2.04	-2.65	-0.61	-0.86	-1.14	-2.43
D030331	-1.65	-4.14	-0.52	-1.36	-0.76	-4.23
D030332	-0.87	0.71	-1.17	-4.32	-0.74	0.13
D031237	-1.25	-0.51	-0.66	-3.19	-2.61	1.88
D031716	-1.31	-2.69	-0.48	-0.36	-2.04	-2.62
D031726	-1.60	-3.89	-2.73	-0.90	-1.33	-3.51
D031734	-2.21	-3.15	-0.87	-1.12	-2.61	-2.57
D031748	-3.61	-1.30	-2.53	-0.46	-2.09	-3.05

Table A10.2: Conditional parameter estimates for variables specified as random slopes in the Water model for individual female caribou in mid-winter and calving.

	Dist. to River		Dist. to Lake	
Animal ID	Mid-Winter	Calving	Mid-Winter	Calving
D030308	1.27	0.62	2.77	3.27
D030309	0.17	1.18	4.36	0.75
D030310	2.48	1.42	3.63	0.81
D030312	0.37	0.10	4.61	0.17
D030314	0.70	2.90	5.42	3.12
D030316	1.51	0.08	3.48	2.13
D030318	0.52	0.68	4.23	0.23
D030319	1.58	0.87	3.47	0.30
D030320	1.12	0.59	3.20	1.60
D030321	0.46	2.44	3.66	0.39
D030324	0.46	-0.01	3.63	1.84
D030325	0.16	3.40	5.29	14.70
D030326	0.29	1.32	4.29	0.43
D030327	0.42	0.62	3.72	0.81
D030328	0.79	1.70	5.91	5.18
D030329	1.21	1.08	3.99	1.01
D030330	0.46	2.92	4.49	0.59
D030331	0.14	0.72	5.29	3.07
D030332	0.19	4.22	4.41	1.47
D031237	0.27	6.13	3.22	2.25
D031716	0.08	0.30	3.63	1.49
D031726	0.82	1.34	4.68	8.61
D031734	0.11	1.29	24.72	2.54
D031748	1.96	0.44	7.65	4.69

Table A10.3: Conditional parameter estimates for variables specified as random slopes in the Forage model for individual female caribou in mid-winter and calving.

	NDVI	
Animal ID	Mid-Winter	Calving
D030308	-3.02	0.44
D030309	-1.49	0.60
D030310	-2.68	-0.04
D030312	0.15	0.68
D030314	-0.80	-1.08
D030316	-1.29	0.28
D030318	-0.51	-1.10
D030319	-2.47	0.07
D030320	-3.17	-1.55
D030321	-1.66	-0.53
D030324	-2.09	-2.20
D030325	0.76	1.32
D030326	-1.64	0.69
D030327	-1.99	0.64
D030328	0.05	0.85
D030329	-0.50	0.56
D030330	0.08	0.26
D030331	0.80	0.90
D030332	-1.42	-1.66
D031237	-4.01	-1.51
D031716	-4.45	-1.41
D031726	-1.07	1.45
D031734	-0.83	0.90
D031748	-2.72	0.61

Table A10.4: Conditional parameter estimates for variables specified as random slopes in the Conifer model for individual female caribou in mid-winter and calving.

	Conifer Swamp	
Animal ID	Mid-Winter	Calving
D030308	-2.05	0.55
D030309	-0.07	-3.54
D030310	-1.58	-0.87
D030312	-0.82	-3.86
D030314	0.62	-2.37
D030316	-0.76	0.14
D030318	-1.58	-6.42
D030319	-1.43	-1.03
D030320	-5.47	0.52
D030321	-0.51	-3.54
D030324	-2.77	-4.13
D030325	0.05	2.60
D030326	-0.34	0.79
D030327	-1.72	0.33
D030328	-0.49	-2.96
D030329	-0.71	-2.74
D030330	1.01	-0.20
D030331	0.13	-2.06
D030332	-0.18	-5.46
D031237	-3.03	3.70
D031716	-2.63	-4.70
D031726	-0.48	2.46
D031734	0.70	1.16
D031748	-1.20	0.75

Table A10.5: Conditional parameter estimates for variables specified as random slopes in the Fen model for individual female caribou in mid-winter and calving.

	Poor Fen		Rich Fen	
Animal ID	Mid-Winter	Calving	Mid-Winter	Calving
D030308	0.64	3.45	-0.66	-3.51
D030309	-0.94	0.77	-0.54	-0.83
D030310	0.62	3.04	-0.79	-0.60
D030312	-2.66	-0.09	0.10	1.36
D030314	-0.91	7.61	-1.36	-1.44
D030316	-1.67	3.63	0.71	0.34
D030318	-3.48	-0.64	0.52	0.69
D030319	0.22	3.42	-0.65	-0.68
D030320	0.86	3.70	0.27	-4.31
D030321	-1.49	4.28	0.77	0.95
D030324	-3.31	-1.70	1.18	4.06
D030325	-1.70	3.92	0.02	-0.93
D030326	-0.85	2.87	-0.37	-3.19
D030327	-1.33	4.18	0.43	1.70
D030328	-2.32	1.09	-1.67	-16.20
D030329	-2.42	2.63	0.59	1.51
D030330	-0.83	2.32	0.51	-0.08
D030331	-1.64	0.58	-0.03	-9.76
D030332	-0.98	10.89	-0.62	2.86
D031237	-3.80	6.38	1.78	-2.74
D031716	-3.35	-4.59	1.36	3.19
D031726	-0.45	4.00	-0.66	-1.40
D031734	-1.21	2.46	-0.45	-0.90
D031748	0.39	4.03	0.05	-5.34

Table A10.6: Conditional parameter estimates for variables specified as random slopes in the Deciduous model for individual female caribou in mid-winter and calving.

	Deciduous Swamp		Upland Deciduous	
Animal ID	Mid-Winter	Calving	Mid-Winter	Calving
D030308	-1.30	-1.61	-5.66	-1.02
D030309	-1.01	-0.23	-2.75	-0.41
D030310	-1.91	-3.01	-5.43	-0.74
D030312	-2.28	-0.86	-1.15	-3.45
D030314	-2.55	-1.03	-1.99	-1.73
D030316	-1.19	-1.68	-2.89	-1.74
D030318	-2.04	-2.70	-1.33	-0.55
D030319	-2.29	-1.61	-3.55	-1.75
D030320	-2.69	-1.75	-14.35	-2.43
D030321	-0.48	-0.16	-2.59	-1.77
D030324	-2.37	-0.81	-3.84	-2.62
D030325	-1.11	-1.86	-1.38	-2.45
D030326	-0.80	-1.75	-2.63	-1.22
D030327	-2.47	-0.89	-1.66	-2.18
D030328	-1.59	-7.76	-0.74	-1.49
D030329	-0.88	-1.78	-1.78	-1.18
D030330	-0.78	-0.55	-2.32	-1.25
D030331	-1.15	-6.93	-1.42	-1.80
D030332	-1.10	-0.87	-2.57	-7.21
D031237	-2.55	-1.77	-5.25	-1.85
D031716	-2.66	-0.56	-4.97	-1.20
D031726	-0.53	-0.85	-1.68	-1.90
D031734	-0.75	-0.85	-2.56	-0.59
D031748	-4.49	-1.03	-4.64	-1.67

Table A10.7: Conditional parameter estimates for variables specified as random slopes in the Disturbance model for individual female caribou in late summer and calving.

	Dist. to Early Seral		Dist. to Well		Line Density	
Animal ID	Late Summer	Calving	Late Summer	Calving	Late Summer	Calving
D030308	-4.73	-1.69	-3.34	-0.79	-2.16	-3.84
D030309	-0.51	0.56	-0.18	1.21	-1.14	-9.06
D030310	-3.87	-5.18	-0.06	1.39	-1.25	-3.21
D030311	-0.64	-2.23	-0.73	-2.67	2.79	1.12
D030312	-1.99	-7.30	-1.68	0.00	0.73	0.06
D030313	-0.77	-0.54	0.05	1.20	-2.40	-7.91
D030314	-0.77	-1.37	-0.32	0.77	-0.27	-8.84
D030316	-1.09	-2.50	-0.19	0.07	3.44	-1.07
D030318	-1.41	-2.81	-0.19	-0.53	0.55	-1.41
D030319	-2.30	-5.23	-1.11	-3.39	-1.76	-5.27
D030321	1.74	1.11	-0.34	0.48	0.72	-0.36
D030324	-1.65	-1.17	-1.38	-0.50	0.60	-3.86
D030325	-1.88	-4.80	-0.08	0.14	-0.96	-4.18
D030327	-1.90	-1.34	1.16	1.14	-1.92	-3.38
D030329	-1.54	-2.66	-1.02	2.46	2.05	1.10
D030331	-2.36	-4.25	-0.41	-0.67	-1.42	-5.01
D030931	-2.53	-8.30	1.69	1.70	0.01	-0.77
D031237	0.02	-0.45	-1.88	-2.64	4.31	2.09
D031716	-1.27	-2.87	-1.25	0.43	-1.67	-2.73
D031726	-1.47	-3.92	0.26	-0.22	-0.20	-3.77
D031727	0.42	2.44	-2.18	3.23	1.69	-4.96
D031734	-1.56	-3.18	-1.00	-0.48	-0.67	-2.84
D031737	0.90	-0.74	-3.61	-1.76	-0.52	-3.17
D031738	1.02	1.29	1.25	5.29	-0.24	0.02

Table A10.8: Conditional parameter estimates for variables specified as random slopes in the Water model for individual female caribou in late summer and calving.

	Dist. to River		Dist. to Lake	
Animal ID	Late Summer	Calving	Late Summer	Calving
D030308	0.99	0.68	109.24	2.97
D030309	1.16	1.23	8.83	0.50
D030310	1.24	1.47	13.04	0.67
D030311	2.04	8.25	11.37	-0.38
D030312	0.70	0.15	9.11	-0.02
D030313	0.59	0.19	8.69	0.94
D030314	0.89	3.14	9.01	2.81
D030316	0.59	0.22	10.07	1.90
D030318	1.08	0.76	9.07	0.15
D030319	0.90	1.07	8.87	0.08
D030321	1.97	2.57	9.16	0.27
D030324	1.66	0.15	8.84	1.70
D030325	1.10	3.49	10.79	14.60
D030327	1.00	0.70	9.12	0.56
D030329	1.57	1.20	9.77	0.76
D030331	1.21	0.87	40.16	3.35
D030931	2.03	2.55	9.96	3.21
D031237	19.56	6.52	9.93	2.11
D031716	1.88	0.47	8.97	1.31
D031726	1.42	1.44	9.18	8.38
D031727	1.54	-0.39	8.85	-2.76
D031734	1.60	1.31	10.30	2.46
D031737	0.71	3.49	8.78	-3.09
D031738	1.57	-0.17	9.21	0.10

Table A10.9: Conditional parameter estimates for variables specified as random slopes in the Forage model for individual female caribou in late summer and calving.

	NDVI	
Animal ID	Late Summer	Calving
D030308	1.49	0.66
D030309	-0.85	0.89
D030310	-0.43	0.28
D030311	-0.14	-0.59
D030312	0.62	0.98
D030313	-1.07	-0.89
D030314	-0.77	-1.09
D030316	-1.31	0.81
D030318	0.46	-0.72
D030319	0.06	0.37
D030321	-1.02	-0.18
D030324	-0.96	-1.94
D030325	0.34	1.97
D030327	-0.14	0.97
D030329	-0.10	1.09
D030331	0.49	1.33
D030931	-2.94	-4.77
D031237	-1.63	-1.39
D031716	-2.26	-1.18
D031726	-0.82	2.17
D031727	-0.95	6.03
D031734	0.60	1.32
D031737	0.42	1.61
D031738	-1.13	-2.43

Table A10.10: Conditional parameter estimates for variables specified as random slopes in the Conifer model for individual female caribou in late summer and calving.

	Conifer Swamp	
Animal ID	Late Summer	Calving
D030308	2.20	1.08
D030309	-0.12	-2.74
D030310	1.59	-0.17
D030311	1.58	0.23
D030312	-2.16	-2.93
D030313	-3.35	-1.84
D030314	0.32	-1.83
D030316	0.52	0.45
D030318	-2.62	-5.10
D030319	0.32	-0.48
D030321	-0.85	-3.12
D030324	0.27	-3.42
D030325	0.68	2.59
D030327	0.94	0.54
D030329	0.67	-2.27
D030331	-0.41	-1.59
D030931	0.05	-3.17
D031237	2.44	3.86
D031716	0.36	-4.25
D031726	0.16	2.55
D031727	-0.57	2.12
D031734	0.77	1.37
D031737	2.25	-1.39
D031738	-1.50	-4.07

Table A10. 11: Conditional parameter estimates for variables specified as random slopes in the Fen model for individual female caribou in late summer and calving.

	Poor Fen		Rich Fen	
Animal ID	Late Summer	Calving	Late Summer	Calving
D030308	1.01	2.70	-5.39	-2.71
D030309	-0.37	0.17	0.20	0.47
D030310	2.28	2.29	-3.58	0.34
D030311	1.24	7.10	-4.92	-1.45
D030312	-3.69	-0.78	-0.04	2.65
D030313	-4.84	-4.10	1.28	4.76
D030314	-0.24	6.45	-0.73	-0.49
D030316	0.43	2.74	-0.65	1.52
D030318	-2.26	-1.15	-0.47	1.93
D030319	1.16	2.76	0.54	0.24
D030321	-0.05	3.40	0.28	2.24
D030324	-1.37	-2.50	0.00	5.57
D030325	0.04	3.04	-0.02	0.21
D030327	-0.46	3.39	0.00	3.03
D030329	-0.53	1.77	-0.99	2.77
D030331	-2.01	-0.10	-7.78	-9.65
D030931	-1.41	-1.75	-4.74	-3.48
D031237	0.21	5.68	-1.54	-1.93
D031716	-1.49	-5.63	-0.53	4.92
D031726	-0.67	3.03	-0.13	-0.30
D031727	0.43	-0.67	-0.10	4.55
D031734	-1.23	1.78	-0.92	0.30
D031737	-2.87	-3.13	-1.67	-0.56
D031738	1.39	8.80	0.87	10.23

Table A10.12: Conditional parameter estimates for variables specified as random slopes in the Deciduous model for individual female caribou in late summer and calving.

	Deciduous Swamp		Upland Deciduous	
Animal ID	Late Summer	Calving	Late Summer	Calving
D030308	2.25	-1.47	-4.95	-7.42
D030309	0.45	-0.20	-2.68	-6.80
D030310	-1.94	-2.73	-2.97	-6.96
D030311	-0.24	-0.64	-1.95	-8.55
D030312	-0.87	-0.77	-1.12	-9.23
D030313	-1.86	-1.33	-2.70	-7.91
D030314	-0.75	-0.82	-1.97	-7.95
D030316	-1.12	-1.48	-3.13	-7.88
D030318	0.00	-2.11	-1.22	-6.67
D030319	0.58	-1.65	-3.17	-8.45
D030321	0.71	0.00	-2.16	-7.92
D030324	-0.84	-0.70	-2.03	-8.38
D030325	-0.39	-1.69	-2.24	-8.43
D030327	-0.53	-0.77	-1.33	-8.15
D030329	-0.15	-1.55	-1.39	-7.37
D030331	-5.68	-6.77	-2.02	-8.30
D030931	-4.28	-3.73	-12.64	-130.79
D031237	-1.19	-1.53	-1.83	-7.92
D031716	-1.14	-0.41	-1.78	-7.16
D031726	-0.40	-0.68	-2.37	-7.93
D031727	-0.88	-0.44	-1.99	-6.95
D031734	-0.17	-0.75	-0.67	-6.73
D031737	-0.50	1.05	-0.80	-10.23
D031738	-0.37	0.65	-1.89	-24.33

Table A10.13: Conditional parameter estimates for variables specified as random slopes in the Disturbance model for individual female caribou in late fall and calving.

	Dist. to Early Seral		Dist. to Well		Line Density	
Animal ID	Late Fall	Calving	Late Fall	Calving	Late Fall	Calving
D030308	-0.68	-1.47	-0.88	-1.21	-1.63	-3.51
D030309	-0.37	0.91	0.40	0.71	-0.65	-9.49
D030310	-1.09	-5.43	0.99	0.93	-1.00	-3.13
D030311	-1.50	-1.80	-0.04	-3.00	2.93	1.04
D030312	-0.96	-7.39	-0.39	-0.64	0.28	0.31
D030313	-0.55	-0.12	0.44	0.86	-1.67	-8.06
D030314	-1.40	-1.04	-0.26	0.29	-0.36	-8.03
D030315	-0.44	0.84	-0.68	0.85	-0.40	-2.15
D030316	-1.07	-2.22	-0.17	-0.56	0.44	-0.76
D030318	-1.10	-3.01	-0.57	-1.20	-0.04	-1.28
D030319	-1.48	-5.37	-0.66	-3.48	-1.13	-4.84
D030320	-0.15	-0.32	-0.87	-1.88	-0.64	-1.74
D030321	-0.69	1.18	0.02	-0.03	-0.05	-0.18
D030324	-0.76	-0.79	-0.05	-1.31	0.33	-3.68
D030325	-1.57	-4.75	-0.24	-0.46	-1.30	-3.98
D030326	-1.44	-4.00	-0.26	-2.06	-0.35	-1.35
D030327	-0.58	-1.31	0.17	0.72	0.51	-3.23
D030328	-1.92	-1.77	0.52	-1.46	-1.33	-6.50
D030329	-1.13	-2.27	-0.17	1.73	0.61	1.27
D030330	-1.37	-2.41	-0.34	-0.84	-0.91	-2.25
D030331	-1.45	-3.88	-0.74	-1.31	-1.12	-4.00
D030332	-0.82	0.85	-0.18	-4.08	-0.24	0.24
D031237	-1.00	-0.22	-0.42	-3.43	0.44	2.14
D031238	-0.54	-1.18	-0.58	0.65	-0.06	3.22

Table A10.14: Conditional parameter estimates for variables specified as random slopes in the Water model for individual female caribou in late fall and calving.

	Dist. to River		Dist. to Lake	
Animal ID	Late Fall	Calving	Late Fall	Calving
D030308	0.07	0.87	-0.52	3.02
D030309	-0.17	1.44	-0.75	0.39
D030310	0.58	1.67	-1.39	0.57
D030311	0.07	7.83	1.12	-0.36
D030312	-0.34	0.36	-0.46	-0.12
D030313	0.22	0.35	-0.33	0.73
D030314	-0.22	3.23	-0.63	2.68
D030315	-0.13	2.41	-0.38	3.75
D030316	-0.08	0.38	-0.02	1.71
D030318	-0.12	0.92	-0.42	-0.08
D030319	0.04	1.15	-0.84	-0.05
D030320	-0.20	0.85	-0.09	1.27
D030321	-0.16	2.59	-0.69	0.08
D030324	0.11	0.22	-0.42	1.52
D030325	-0.15	3.78	-0.07	14.81
D030326	-0.21	1.54	-0.53	0.08
D030327	-0.11	0.88	-0.43	0.46
D030328	0.03	1.99	-0.11	4.77
D030329	-0.13	1.39	0.01	0.64
D030330	-0.01	3.28	-0.01	0.26
D030331	-0.12	1.01	0.55	2.71
D030332	-0.12	4.20	-0.73	1.08
D031237	0.01	6.26	-0.41	1.95
D031238	0.04	1.34	-0.48	2.70

Table A10.15: Conditional parameter estimates for variables specified as random slopes in the Forage model for individual female caribou in late fall and calving.

	NDVI	
Animal ID	Late Fall	Calving
D030308	0.32	0.33
D030309	0.59	0.48
D030310	-0.50	-0.06
D030311	-0.58	-0.76
D030312	0.93	0.42
D030313	0.00	-1.26
D030314	0.26	-1.16
D030315	0.25	-1.77
D030316	0.44	0.27
D030318	0.54	-1.10
D030319	0.19	-0.02
D030320	0.11	-1.54
D030321	0.45	-0.62
D030324	0.34	-2.26
D030325	-0.37	1.22
D030326	0.21	0.59
D030327	0.34	0.54
D030328	0.40	0.73
D030329	0.42	0.50
D030330	-0.28	0.13
D030331	0.15	0.80
D030332	0.24	-1.53
D031237	0.16	-1.37
D031238	0.27	0.00

Table A10.16: Conditional parameter estimates for variables specified as random slopes in the Conifer model for individual female caribou in late fall and calving.

	Conifer Swamp	
Animal ID	Late Fall	Calving
D030308	-0.12	0.21
D030309	-0.65	-3.76
D030310	-1.49	-1.04
D030311	0.13	-0.53
D030312	-1.14	-3.73
D030313	-1.23	-2.85
D030314	-0.38	-2.58
D030315	-0.26	-6.20
D030316	0.11	-0.15
D030318	-1.67	-6.38
D030319	-0.58	-1.39
D030320	0.47	0.20
D030321	-0.53	-3.62
D030324	-0.05	-4.55
D030325	0.36	2.30
D030326	-0.32	0.44
D030327	-1.09	-0.01
D030328	0.45	-3.26
D030329	0.19	-3.03
D030330	0.42	-0.50
D030331	0.49	-2.39
D030332	-0.31	-5.25
D031237	0.41	2.94
D031238	-0.13	-0.57

Table A10. 17: Conditional parameter estimates for variables specified as random slopes in the Fen model for individual female caribou in late fall and calving.

	Poor Fen		Rich Fen	
Animal ID	Late Fall	Calving	Late Fall	Calving
D030308	-0.02	4.23	0.11	-3.30
D030309	-0.65	1.41	1.38	-0.66
D030310	1.58	3.74	0.74	-0.56
D030311	2.28	8.08	2.29	-2.16
D030312	-2.14	0.99	0.73	1.44
D030313	-1.42	-3.28	1.62	3.64
D030314	-0.40	8.37	0.63	-1.19
D030315	-0.26	25.81	0.23	11.07
D030316	-0.06	4.25	0.50	0.44
D030318	-2.20	0.18	0.73	0.88
D030319	0.06	4.26	0.60	-0.48
D030320	-0.50	4.39	0.38	-4.11
D030321	-0.69	4.77	0.95	1.11
D030324	-0.37	-0.97	1.10	4.41
D030325	1.75	4.83	2.19	-0.80
D030326	-0.30	3.48	0.54	-3.01
D030327	-1.42	5.01	0.95	1.91
D030328	-0.20	1.77	0.12	-15.25
D030329	0.00	3.29	0.41	1.59
D030330	0.63	3.04	1.44	0.11
D030331	-0.42	1.21	0.41	-9.37
D030332	-0.42	10.63	0.78	2.69
D031237	-0.34	6.87	0.80	-2.34
D031238	-0.52	3.39	0.82	-1.02

Table A10.18: Conditional parameter estimates for variables specified as random slopes in the Deciduous model for individual female caribou in late fall and calving.

	Deciduous Swamp		Upland Deciduous	
Animal ID	Late Fall	Calving	Late Fall	Calving
D030308	0.32	-1.85	-1.73	-1.36
D030309	-0.37	-0.52	-0.86	-0.74
D030310	-1.88	-3.17	-1.82	-1.00
D030311	-0.85	-1.18	-3.55	-2.59
D030312	-0.48	-1.08	-0.20	-3.57
D030313	-0.73	-1.85	-1.59	-2.48
D030314	-0.25	-1.31	-1.05	-2.02
D030315	-0.74	-3.77	-0.89	-9.19
D030316	-0.22	-1.95	-1.02	-2.03
D030318	-0.35	-2.83	0.08	-0.94
D030319	-0.57	-1.86	-1.02	-2.15
D030320	0.25	-1.80	-1.26	-2.92
D030321	-0.17	-0.45	-1.09	-2.04
D030324	-0.38	-1.01	-1.38	-2.98
D030325	-0.88	-2.19	-2.55	-2.86
D030326	-0.23	-2.15	-1.10	-1.56
D030327	-0.47	-1.17	-0.38	-2.65
D030328	-0.54	-8.00	-1.25	-1.85
D030329	-0.27	-2.00	-1.01	-1.53
D030330	-0.43	-0.82	-2.22	-1.61
D030331	-0.45	-7.45	-0.67	-2.27
D030332	-0.25	-1.17	-1.22	-6.95
D031237	-0.17	-1.92	-1.08	-2.08
D031238	-0.11	-1.89	-0.88	-2.18

Table A10.19: Conditional parameter estimates for variables specified as random slopes in the Disturbance model for individual female caribou with neonate calves and after calf loss.

	Dist. to Early Seral		Dist. to Well		Line Density	
Animal ID	Post Loss	Calving	Post Loss	Calving	Post Loss	Calving
D030308.2011	0.47	3.03	-1.42	1.78	-2.26	-2.46
D030308.2012	0.80	2.93	0.40	1.87	-2.21	-2.24
D030309.2011	0.02	8.10	2.01	12.33	-1.37	-1.38
D030309.2012	0.58	6.39	0.28	6.81	-1.28	-1.27
D030312.2012	-2.81	-1.50	0.54	-1.51	1.89	2.34
D030313.2011	1.12	9.94	1.57	10.71	-2.23	-2.38
D030314.2012	1.03	6.61	3.52	6.96	-1.46	-1.56
D030315.2011	2.93	7.45	10.71	6.71	-2.99	-3.29
D030316.2011	0.77	2.83	0.51	3.78	0.62	0.66
D030319.2012	0.40	-1.32	3.05	-11.20	-1.16	-0.99
D030320.2011	0.71	3.88	0.80	1.13	0.05	0.08
D030321.2012	4.04	18.64	1.57	-0.32	1.06	1.09
D030325.2011	-1.25	0.37	2.54	3.23	-1.84	-1.91
D030327.2012	0.61	4.26	2.83	4.34	-1.70	-1.64
D030328.2011	0.50	3.30	0.61	2.37	-2.73	-2.83
D030329.2012	0.83	2.77	1.32	2.95	1.39	1.47
D030331.2012	-0.45	0.52	0.33	2.32	-3.66	-3.72
D031237.2013	5.99	11.97	-0.62	0.82	4.06	4.15
D031726.2013	0.64	0.95	3.90	2.51	0.17	0.26
D031731.2013	2.16	4.68	0.14	1.22	0.21	0.15
D031737.2013	2.54	4.30	-1.80	1.17	-2.16	-2.04
D031738.2013	5.07	22.55	0.79	26.86	**0.10**	**0.56**

Table A10.20: Conditional parameter estimates for variables specified as random slopes in the Water model for individual female caribou with neonate calves and after calf loss.

	Dist. to River		Dist. to Lake	
Animal ID	Post Loss	Calving	Post Loss	Calving
D030308.2011	0.29	0.39	2.52	4.87
D030308.2012	-0.16	1.83	3.16	3.41
D030309.2011	1.09	1.54	-0.23	1.94
D030309.2012	1.04	1.68	-0.15	1.19
D030312.2012	-0.05	-0.15	-0.18	-1.41
D030313.2011	0.44	0.52	-0.06	2.21
D030314.2012	0.41	2.77	1.46	5.64
D030315.2011	3.39	2.65	3.41	5.31
D030316.2011	-0.43	-1.65	1.49	4.69
D030319.2012	0.87	1.08	-0.64	2.02
D030320.2011	-1.12	0.99	7.58	2.61
D030321.2012	1.19	22.51	0.66	0.93
D030325.2011	0.93	5.49	9.95	20.05
D030327.2012	-0.28	0.77	1.15	1.43
D030328.2011	-0.31	0.63	3.57	6.93
D030329.2012	0.44	-0.23	1.08	4.68
D030331.2012	-0.08	1.28	4.18	5.25
D031237.2013	1.94	7.02	2.19	3.40
D031726.2013	0.26	1.98	0.80	10.56
D031731.2013	0.44	1.17	-0.12	1.40
D031737.2013	0.96	2.83	-1.75	-0.52
D031738.2013	0.31	0.24	0.69	0.95

Table A10.21: Conditional parameter estimates for variables specified as random slopes in the Forage model for individual female caribou with neonate calves and after calf loss.

	NDVI	
Animal ID	Post Loss	Calving
D030308.2011	0.28	0.76
D030308.2012	0.45	0.99
D030309.2011	-1.14	0.46
D030309.2012	-2.37	0.66
D030312.2012	1.04	3.70
D030313.2011	-0.51	-1.62
D030314.2012	-3.15	-6.23
D030315.2011	-0.38	-1.91
D030316.2011	-0.51	-1.42
D030319.2012	-2.37	0.78
D030320.2011	-3.58	-1.89
D030321.2012	-1.28	0.10
D030325.2011	0.00	2.14
D030327.2012	0.93	0.89
D030328.2011	-0.56	0.32
D030329.2012	0.31	0.47
D030331.2012	0.79	1.66
D031237.2013	0.15	-1.37
D031726.2013	-0.40	2.70
D031731.2013	0.61	0.27
D031737.2013	1.02	1.63
D031738.2013	-1.33	-2.81

Table A10.22: Conditional parameter estimates for variables specified as random slopes in the Conifer model for individual female caribou with neonate calves and after calf loss.

	Conifer Swamp	
Animal ID	Post Loss	Calving
D030308.2011	-1.11	-1.72
D030308.2012	-0.50	-1.56
D030309.2011	-2.20	-2.02
D030309.2012	-1.70	-3.28
D030312.2012	-15.24	-11.03
D030313.2011	-4.07	-3.68
D030314.2012	-1.93	-10.42
D030315.2011	-5.19	-6.33
D030316.2011	-0.70	-3.05
D030319.2012	-3.25	-2.84
D030320.2011	0.51	-1.76
D030321.2012	-2.76	-3.46
D030325.2011	1.25	-1.00
D030327.2012	-0.02	-1.89
D030328.2011	-1.15	-2.21
D030329.2012	-0.93	-9.71
D030331.2012	-1.17	-5.80
D031237.2013	2.85	-0.44
D031726.2013	-1.46	-0.75
D031731.2013	-3.99	-5.32
D031737.2013	-0.28	-3.49
D031738.2013	-2.11	-4.80

Table A10.23: Conditional parameter estimates for variables specified as random slopes in the Fen model for individual female caribou with neonate calves and after calf loss.

	Poor Fen		Rich Fen	
Animal ID	Post Loss	Calving	Post Loss	Calving
D030308.2011	-0.02	-0.50	-6.71	-4.44
D030308.2012	1.04	0.14	-4.85	-10.24
D030309.2011	-0.05	-0.64	-0.12	-3.28
D030309.2012	-0.38	-1.84	0.17	-4.59
D030312.2012	-3.18	-2.69	-0.36	-4.05
D030313.2011	-3.72	-2.11	-0.24	-0.81
D030314.2012	2.51	-0.29	-1.62	-10.64
D030315.2011	-0.45	-0.40	-1.80	-1.85
D030316.2011	2.03	-0.97	-1.49	-1.51
D030319.2012	1.02	1.90	-1.19	-9.80
D030320.2011	3.93	0.17	-11.39	-5.43
D030321.2012	0.18	0.19	-1.44	-3.11
D030325.2011	2.34	-0.04	-2.43	-11.20
D030327.2012	0.47	-0.61	-0.80	-1.94
D030328.2011	-0.73	-1.54	-6.27	-11.82
D030329.2012	0.15	0.92	-2.09	-10.55
D030331.2012	-1.09	-4.21	-9.10	-12.40
D031237.2013	0.67	-0.17	-4.40	-5.21
D031726.2013	-0.29	-0.42	-0.93	-5.20
D031731.2013	-2.13	-3.88	-0.81	-3.09
D031737.2013	-2.53	-10.13	-3.32	-13.05
D031738.2013	1.26	-0.95	-0.83	-1.61

Table A10.24: Conditional parameter estimates for variables specified as random slopes in the Deciduous model for individual female caribou with neonate calves and after calf loss.

	Deciduous Swamp		Upland Deciduous	
Animal ID	Post Loss	Calving	Post Loss	Calving
D030308.2011	0.11	-2.71	-2.16	-4.31
D030308.2012	-0.43	-9.82	-2.83	-7.45
D030309.2011	0.84	-3.12	-2.82	-4.11
D030309.2012	1.09	-2.38	-3.14	-3.01
D030312.2012	-1.52	-4.10	n/a	n/a
D030313.2011	-2.15	-3.14	-5.61	-4.68
D030314.2012	-0.52	-10.46	-3.27	-4.41
D030315.2011	-1.55	-2.99	-1.05	-9.86
D030316.2011	-1.11	-2.36	n/a	n/a
D030319.2012	-3.16	-10.65	-5.58	-7.28
D030320.2011	-1.77	-4.03	-5.29	-5.99
D030321.2012	0.60	-2.06	-1.86	-3.56
D030325.2011	-1.13	-3.31	-3.56	-5.41
D030327.2012	0.08	-2.08	-2.16	-3.68
D030328.2011	-4.66	-5.95	-1.69	-3.23
D030329.2012	-0.49	-2.80	n/a	n/a
D030331.2012	-5.83	-11.68	-1.76	-2.93
D031237.2013	0.22	-3.37	-1.96	-4.31
D031726.2013	-0.37	-2.48	-3.10	-4.26
D031731.2013	1.25	-1.18	-2.25	-9.47
D031737.2013	-1.16	-10.70	-2.41	-4.89
D031738.2013	-0.14	-1.82	-3.14	-16.60

APPENDIX 11: *Model Selection Results for Evaluating Spatial Factors Affecting Calf Survival*

We tested four hypotheses relating spatial factors to the survival probability of neonate calves (< 4 weeks old). Within each hypothesis, we evaluated a suite of models that described either (*a*) variation in maternal selection of resources at second- and third-order scales; or (*b*) exposure, defined as the mean value of explanatory covariates calculated at multiple spatial scales. We discriminated among models using Akaike's Information Criterion (AIC).

Table A11. 1: Model selection results for the disturbance hypothesis. Distance-to variables (early seral and well) were used only in second-order selection and local exposure analyses.

Metric	Scale	Model Variables	AIC
Selection	2nd order	early seral + well + line density	186
Exposure	Local	early seral + well + line density	189
Exposure	Buffer 2000m	line density	189
Exposure	Buffer 1500m	line density	189
Exposure	Calving Area	line density	189
Exposure	Buffer 1000m	line density	189
Selection	3rd order	line density	189
Exposure	Buffer 500m	line density	189
Exposure	Range	line density	189

Table A11. 2: Model selection results for the peatland refuge hypothesis. For exposure analyses, the proportion of treed bog and nutrient-poor fen was calculated within each scale. For second-order selection, the proportion of treed bog and nutrient-poor fen was calculated in a 1500-m radius, the most predictive scale for land cover type in resource selection function analyses (see Appendix 7). Third-order selection maintained treed bog and nutrient-poor fen at the pixel scale (30-m).

Metric	Scale	Model Variables	AIC
Exposure	Local	treed bog + poor fen	188
Selection	2nd order	treed bog + poor fen	189
Exposure	Buffer 500m	treed bog + poor fen	189
Exposure	Buffer 1000m	treed bog + poor fen	190
Exposure	Buffer 1500m	treed bog + poor fen	190
Exposure	Buffer 2000m	treed bog + poor fen	190
Selection	3rd order	treed bog + poor fen	190
Exposure	Calving Area	treed bog + poor fen	191
Exposure	Range	treed bog + poor fen	191

Table A11. 3: Model selection results for the lake refuge hypothesis. Third-order selection analyses were not considered as few calving areas contained lakes.

Metric	Scale	Model Variables	AIC
Selection	2nd order	distance to lake	188
Exposure	Local	distance to lake	189

Table A11. 4: Model selection results for the predation risk hypothesis. For each metric and scale, we used the most predictive explanatory variable for each predator (wolves and black bears; see Appendix 7). Predator habitat was defined as areas having resource selection function (RSF) values >75 percentile from predator-specific RSF models. For all model variables, we list the RSF analysis used to derive predator habitat predictions and for selection analyses we show the radius at which the variable was calculated where appropriate (in brackets).

Metric	Scale	Model Variables	AIC
Selection	3rd order	Density of Bear Habitat (500m; Caribou Range RSF)	175
Selection	2nd order	Density of Wolf Habitat (1000m)	183
Selection	3rd order	Density of Wolf Habitat (500m)	186
Selection	2nd order	Density of Bear Habitat (500m; Caribou Range RSF)	186
Exposure	Local	Distance to Bear Habitat (2nd Order RSF)	188
Exposure	Buffer 1000m	Density of Bear Habitat (Caribou Range RSF)	189
Exposure	Buffer 500m	Density of Bear Habitat (Caribou Range RSF)	189
Exposure	Buffer 1500m	Density of Bear Habitat (Caribou Range RSF)	189
Exposure	Buffer 2000m	Density of Wolf Habitat	189
Exposure	Calving Area	Density of Bear Habitat (2nd Order RSF)	189
Exposure	Range	Density of Bear Habitat (2nd Order RSF)	189
Exposure	Buffer 2000m	Density of Bear Habitat (Caribou Range RSF)	189
Exposure	Buffer 500m	Density of Bear Habitat (2nd Order RSF)	189
Exposure	Buffer 1000m	Density of Wolf Habitat	189
Exposure	Buffer 1500m	Density of Wolf Habitat	189
Exposure	Buffer 1000m	Density of Bear Habitat (2nd Order RSF)	189
Exposure	Buffer 1500m	Density of Bear Habitat (2nd Order RSF)	189
Exposure	Range	Density of Wolf Habitat	189
Exposure	Buffer 2000m	Density of Bear Habitat (2nd Order RSF)	189
Exposure	Local	Distance to Wolf Habitat	189
Exposure	Calving Area	Density of Wolf Habitat	189
Exposure	Local	Distance to Bear Habitat (Caribou Range RSF)	189
Exposure	Buffer 500m	Density of Wolf Habitat	189