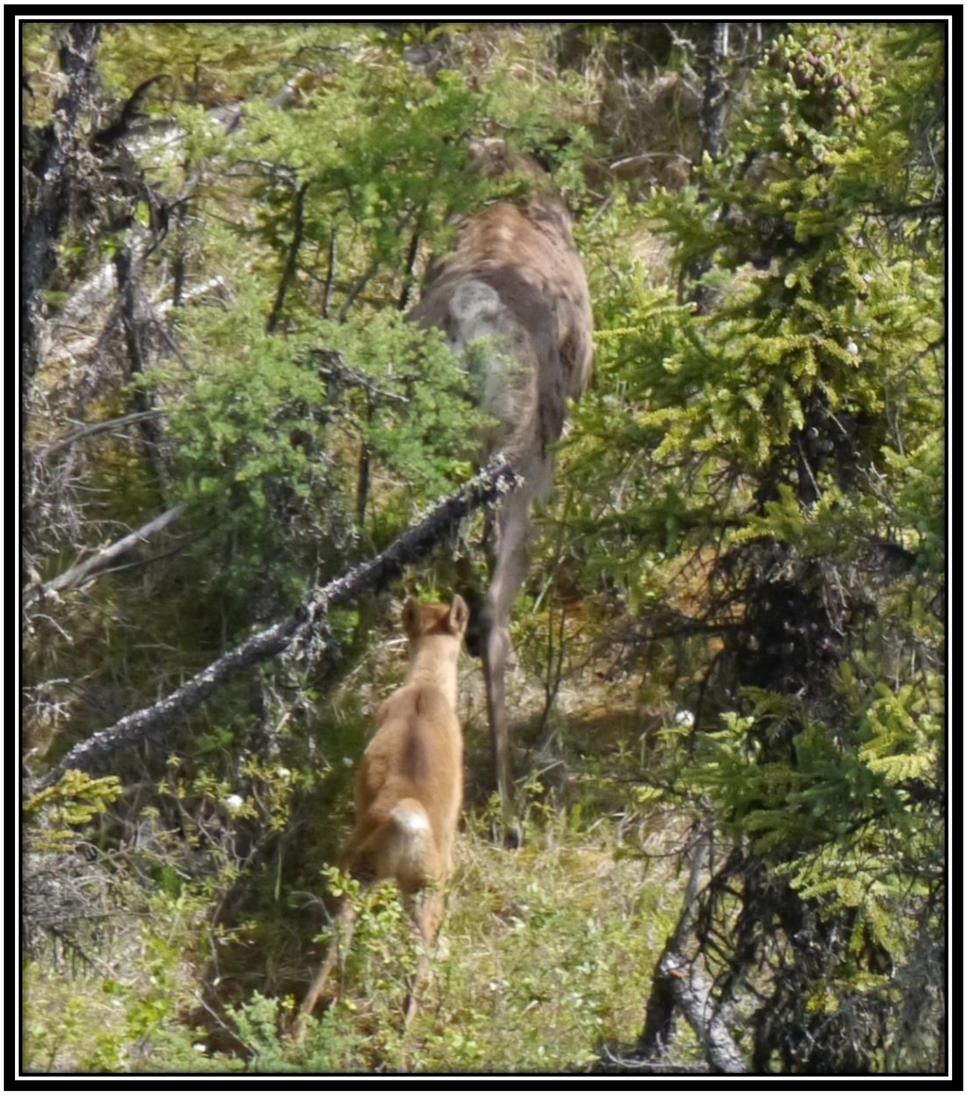
Assessing Spatial Factors Affecting Predation Risk to Boreal Caribou Calves: Implications for Management

2013 Annual Report



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EXECUTIVE SUMMARY

Boreal caribou (*Rangifer tarandus caribou*), an ecotype of woodland caribou, are federally listed as *Threatened* and provincially designated as *Red-listed* in British Columbia due to population declines throughout much of their distribution. High rates of calf mortality due to predation are a key demographic factor contributing to population declines. We initiated this four-year project in 2011 to evaluate spatial factors influencing predation risk to boreal caribou calves in northeast British Columbia. The project is a collaborative effort among government, industry, non-governmental organizations, First Nations and academia.

In 2013, we completed the last year of data collection for the project. Across the project's three years, we collected GPS data from 57 female caribou, 19 wolves (*Canis lupus*) and 19 black bears (*Ursus americanus*). We used these data to compare annual rates of parturition and calf survival as well to evaluate caribou and predator habitat selection during the calving season. For caribou, we further evaluated relative calving habitat quality by determining how variation in maternal habitat selection impacts neonate survival.

In the past year, we developed novel movement-based methods for inferring parturition and neonate survival rates. For 2013, we followed the movements of 30 females and estimated a parturition rate of 60-77%. This range was similar to our predicted rate in 2012 but below our 2011 estimate (80%) and lower than rates recorded in other studies. Adverse snow conditions in late winter and early spring may have contributed to the low rate of 2013 and likely caused the peak calving period to be delayed by approximately one week compared to the study's previous two years.

We estimated eight calves to have survived the neonate period in 2013, which equates to a ratio of 27 calves: 100 cows. This estimate was similar to our predicted rates of 28 calves: 100 cows in 2011 and 26 calves: 100 cows in 2012. All three rates are below annual recruitment thresholds associated with population stability (~29 calves: 100 cows), suggesting that BC caribou populations are continuing to sustain high rates of neonate mortality.

We used data from 35 parturient females across the study's three years to evaluate calving habitat selection. Females showed considerable variation in calving habitat selection; however, the majority of females calved in treed bog patches situated within landscapes comprised of a relatively high proportion of fens. Females also avoided areas of high linear feature density and calving areas were situated farther away from water sources than expected. This pattern of selection is consistent with the hypothesis that calving females move into landscapes with higher productivity than winter ranges yet within these areas use patches considered to be of lower predation risk.

We assessed calving habitat quality by linking variation in maternal selection of calving habitat to the probability of neonate survival. Results from these analyses were equivocal, perhaps due to a mismatch in the scale of caribou selection and the scale(s) most predictive of calf mortality. We are currently conducting further analyses to determine the best scale for assessing habitat quality and whether selection or habitat use is the best metric.

In this report, we present the project's first population-level analyses of predator habitat selection during the calving season. Both predators were closer to rivers and lakes than expected, perhaps due to wolves seasonally shifting to beaver (*Castor canadensis*) as a primary prey source and bears foraging on riparian sedges and grasses. In contrast to our results in 2012, bears showed a higher selection for nutrient-poor fens than wolves. We caution that the analyses of predator habitat selection in this report are preliminary with more detailed analyses forthcoming in the project's final report.

In 2014, the project's last year, we will be completing data analyses and preparing the final project report. Specific analyses to be completed include an evaluation of calving habitat selection at finer spatial scales, an expanded evaluation of habitat-performance relationships to determine the best metrics for determining calving habitat quality, a full analysis of predator habitat selection, and modelling of spatial factors influencing caribou-predator encounter rates.

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INTRODUCTION

Boreal caribou, an ecotype of woodland caribou, are *Red-listed* in British Columbia and federally designated as *Threatened* under the *Species At Risk Act* (Environment Canada 2012). Increasing predation rates are considered to be the proximate cause of population decline with predation rates indirectly facilitated by landscape disturbance within caribou range (McLoughlin *et al.* 2003; Sorensen *et al.* 2008; Festa-Bianchet *et al.* 2011). Increasing predation frequently results in low rates of calf recruitment, a key determinant of caribou population dynamics (DeCesare *et al.* 2012a). For many caribou populations, mortality is particularly high for neonate calves (0-4 weeks old; Adams *et al.* 1995; Stuart-Smith *et al.* 1997) with calf-to-cow ratios often dropping below levels associated with population stability (e.g. ~29 calves: 100 cows; Environment Canada 2008) by the end of the neonate period.

High rates of neonate calf mortality are considered to be an important factor in suspected population declines of boreal caribou herds in British Columbia (Culling & Cichowski 2010). In 2011, we initiated this project in northeast BC to assess caribou-predator spatial dynamics during the calving season and to identify spatial factors influencing predation risk to neonate calves. This project represents a collaborative effort among government, industry, non-governmental organizations, First Nations and academia.

One of the project's primary objectives is to identify key attributes of caribou calving habitat to better inform landscape-level planning within and adjacent to caribou range. In the project's first two years, we presented preliminary analyses of calving habitat selection and evaluated whether female caribou were selecting calving areas to reduce predation risk to vulnerable neonate calves or selecting areas with relatively higher forage quality to meet maternal nutritional demands. In this report, we update these analyses and specifically focus on female selection of calving areas within their herd's range (second-order selection; Johnson 1980). This scale of selection is likely the most relevant for informing management actions. To better evaluate unique attributes of caribou calving habitat, we further contrasted habitat selection of calving females with barren females and compared calving habitat selection to the selection of other seasonal areas within caribou range.

The federal *Recovery Strategy* for boreal caribou specifies habitat restoration as a key management lever for stabilizing or recovering populations considered to be not self-sustaining (Environment Canada 2012). Because caribou ranges have a wide geographic extent, an evaluation of habitat quality is necessary for prioritizing areas for restoration. Here, we evaluated calving habitat quality by determining how individual variation in calving habitat selection influences the probability of neonate calf survival. For these analyses, we developed novel methods for estimating individual calving status and calf survival (DeMars *et al.* 2013).

Because landscape disturbance within caribou range is negatively correlated with calf recruitment rates (Environment Canada 2008), we expected that females selecting areas with high levels of disturbance would have lower probabilities of neonate calf survival.

One mechanism proposed for increasing predation rates of caribou is that landscape disturbance facilitates predator use of caribou range (James & Stuart-Smith 2000; Latham *et al.* 2011). We investigated predator behaviour during the calving season by capturing and radio-collaring wolves and black bears within and adjacent to caribou range. Our 2012 analyses were limited to assessments at the individual level due to small sample sizes (DeMars *et al.* 2012). For 2013, we reached a sufficient sample size of each predator to assess population-level habitat selection. We evaluated predator habitat selection in a framework similar to caribou to facilitate an assessment of caribou-predator spatial overlap during the calving season.

For boreal caribou, critical habitat has been defined as the range of local populations (Environment Canada 2008). Typical caribou ranges, however, have a large spatial extent and often encompass multiple-use landscapes; consequently, management strategies need to be developed at multiple spatial scales including those below the range level. Inherent to a multi-scale management approach is the identification of seasonal habitats that have a high influence on population dynamics. In this report, we present a three-year analysis focused on identifying key attributes of caribou calving habitat in northeast BC, including a preliminary evaluation of calving habitat quality.

METHODS

Study Area

For 2013, our 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. For a full description of the physiography of this region, please see the 2011 Annual Report (DeMars *et al.* 2011). Our study area expansion was a direct result of the recent caribou monitoring program initiated by the BC Boreal Caribou Research and Effectiveness Monitoring Board (REMB) in support of the BC Boreal Caribou Implementation Plan (BC Ministry of Environment 2011). This program resulted in the deployment of an additional 30 GPS radio-collars on female boreal caribou distributed among the six ranges (Culling & Culling 2013). With these additional collars, we now have GPS data from caribou in the Chinchaga and Calendar ranges whereas 2011 and 2012 data was restricted to the Maxhamish, Parker, Prophet and Snake-Sahtaneh ranges.

Caribou Capture and Collaring

In 2011, we deployed Iridium GPS radio-collars on 25 female caribou distributed among four caribou ranges (DeMars *et al.* 2011). Because two collars failed within the first year, we deployed two replacement collars in March 2012. Although this original cohort of collars was expected to remain operational through the 2013 calving season, only one collar remained operational by end-November 2012. The mean data collection period for 2011-12 collars was 542 days (range: 254, 647) with nineteen collars remaining operational through two calving seasons. From December 2012 through February 2013, all animals with non-functioning collars were re-captured and re-fitted with VHF collars as part of the REMB monitoring program noted above. All animals were captured by net-gunning from a helicopter and physically restrained during collar replacement. For 2013, we did not deploy any further GPS radio-collars on caribou specifically for our project. Instead, we monitored those female caribou (n = 30) fitted with Iridium GPS collars (Advanced Telemetry Systems; model #2110E) as part of the REMB monitoring program (Culling & Culling 2013). These collars were deployed between December 2012 and March 2013 and were programmed for a GPS fix rate of every four hours during the calving season (April 15 – July 15) and every eight hours otherwise (B. Culling, *personal communication*). For this report, we used data from the REMB collars up to September 12, resulting in a mean per-collar data collection period of 226 days (range: 192, 268).

Wolf Capture and Collaring

We continued wolf collaring efforts in 2013 after collar failures in 2012 resulted in only three collars remaining operational through the 2012 calving season (DeMars *et al.* 2012). For this year, we deployed Iridium GPS radio-collars from Lotek (Lotek Wireless Inc., Newmarket, ON; model IridiumTrackM 2D). We programmed collars for a fix-rate of every 15 minutes from May 1 to June 30 and once per day otherwise. Based on the estimated battery life at this fix-rate, we set the timed-release mechanism to release 580 days after deployment, which suggests that the collars will be functional through two calving seasons.

Capture efforts began in January 2013 and continued until the first week of April 2013. We used similar capture methods as those used in 2012 (DeMars *et al.* 2012). Briefly, we used a Bell Jet Ranger 206 helicopter to locate wolf packs within our study area. Targeted animals were chemically immobilized using Telazol delivered by an appropriate sized aerial dart. For each wolf pack located, we attempted to deploy 1-4 GPS radio-collars per pack. We further deployed 1-2 VHF collars per pack to facilitate relocating packs in the event of GPS radio-collar failure. VHF collars were provided by BC MFLNRO.

Black Bear Capturing and Collaring

We also continued black bear collaring efforts in 2013 as we were unable to reach our target sample size of 20 bears in 2012 due to regulatory issues preventing further capture efforts after the deployment of four collars (DeMars *et al.* 2012). Based upon our experience in 2012, we scheduled black bear capture efforts for the end of May as this period appeared to be the peak of bear emergence from denning. We targeted large, mature bears occurring within or near caribou range and avoided young animals or females with cubs. We used a capture protocol similar to wolves, chemically immobilizing each targeted bear with Telazol delivered by aerial darts fired from a helicopter. For each captured bear, we estimated the animal's age, collected hair samples, and drew blood samples prior to attaching an Iridium GPS radio-collar (ATS; model #2110E). We programmed bear collars for a fix-rate of every 30 minutes from May 1 to June 30 and once per day otherwise. With this fix-rate schedule, the estimated battery life for the collars is 1.5 years which should allow for the collars to be operational through two calving seasons. After collar attachment, we monitored each bear until the animal displayed signs of recovering from the effects of anaesthesia (e.g. regaining head control).

All animals (caribou, wolves and black bears) were captured and handled in accordance with approved provincial and institutional animal care protocols (BC RIC 1998; Wildlife Act permits FJ12-80090 and FJ12-76949; University of Alberta Animal Use protocol # 748/02/13). The capture team consisted of B. Culling (aerial darting and net-gunning), D. Culling (for caribou and wolves), C. DeMars (bears), and pilots Z. Dancevic and C. Allen from Qwest Helicopters in Fort Nelson, BC.

Caribou Calf Surveys

We used a combination of aerial surveys and modelling of female movement patterns to estimate the parturition status of individual females and the survival status of neonate calves. For estimating parturition, we used movement-based methods (MBMs) outlined in DeMars *et al*. (2013). Specifically, we used the population-based method whereby parturition is predicted 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). We corroborated our parturition predictions by surveying all females at least once during the calving season to confirm calf presence / absence. 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 predictions generated from the two MBMs in DeMars *et al*. (2013). For the population-based movement method, 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). The other movement method, the individual-based method, 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. For females that could not be observed on aerial survey and had differing calf survival predictions by the two MBMs (n = 4), we used the predictions of the individual-based method to assign calf survival status as this method has a higher accuracy rate. By using this comparative approach, we limited the number of aerial surveys conducted with most females receiving only one survey in 2013.

Caribou Calving and Winter Site Sampling

We continued fine-scale sampling of calving and winter sites used by female caribou, following the same methodology established in the project's first year (see DeMars *et al*. 2011). Briefly, we recorded vegetation characteristics associated with reducing predation risk (e.g. concealment cover) and characteristics associated with forage abundance and quality (e.g. lichen and forb abundance; phenology class). We attempted to sample all calving sites that could reasonably be reached by foot or helicopter. For each calving site sampled, we randomly selected and sampled a winter location used by the same animal.

Calving Habitat Selection by Caribou

To assess calving habitat selection by female caribou, we developed resource selection functions (RSFs), a widely used modelling approach whereby environmental attributes associated with GPS (or "used") locations are compared to environmental attributes of random (or "available") locations generated within the spatial scale of interest (Manly *et al.* 2002; McLoughlin *et al.* 2011; DeCesare *et al.* 2012b). To specifically identify calving habitat, we compared 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 (in our study area, April 15 – July 15). For this report, RSFs were estimated at the second-order of selection (Johnson 1980) to specifically assess how calving areas and other seasonal areas differed from random areas within a herd's range. Compared to finer (e.g. third- and fourth-order) scales of selection, results derived from second-order selection analyses are likely more informative for potential management decisions within caribou range. Further, this RSF framework allows for more straightforward comparison of selection differences as the scale of availability is constant for large groups of individuals (i.e. all animals within a given range).

Prior to RSF development, we applied the following screening procedures to the raw GPS data. First, we removed the first two weeks of GPS locations post-capture to reduce the effects of captured-related behavioural alterations (Morellet *et al.* 2009). Second, we removed locations from 10:00 to 18:00 on dates of aerial surveys to reduce behavioural effects associated with helicopter disturbance. Third, we removed all locations with low positional accuracy (e.g. < three-dimensional fixes (Lewis *et al.* 2007). For the retained three-dimensional fixes, the mean horizontal measurement error of the ATS collars was estimated to be 7.7 m (C. DeMars, *unpublished data*). Finally, we used the methods of Bjørneraas et al. (2010) to exclude outlying locations that were beyond the range of possible caribou movement. Following these 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.

We partitioned the screened GPS data into calving, fall, and winter seasons to specifically assess for seasonal differences in habitat selection. We defined calving areas as those areas used by females with calves ≤ 4 weeks old. To identify calving GPS locations, we used the aerial survey data and the MBMs described above. Importantly, the MBMs yield predictions of calving date and calf loss date where appropriate. We used all calving locations from estimated parturition date to the estimated date of calf loss or four weeks post-calving, whichever came first. In the few instances ($n = 4$) where MBM predictions of survival conflicted with aerial survey data, we used the date that the calf was last visually observed as the last known date of survival. 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 (in our study area, April 15 – July 15), 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). All seasonal RSFs were estimated at the same second-order scale as for calving RSFs.

For each seasonal analysis, we characterized the extent of the seasonal area by constructing 80% utilization distributions (UDs) from the GPS location data. UDs derived from the 80% isopleth provide a better estimate of home 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 2). 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 this analysis to determine the number of points necessary to adequately represent a herd's range (here, 20,000 points). Subsequent 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.

We modelled RSFs using explanatory variables representing vegetation characteristics (cover type and normalized difference vegetation index [NDVI]), slope, natural features and anthropogenic disturbance (see Appendix 3 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 8 categories that were biologically meaningful to caribou (Table 1). 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. Because the DU data does not yet encompass the Chinchaga range, we excluded Chinchaga females from RSF analyses. 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 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.* 2008a; 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), 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 land cover, 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 - $\exp^{\alpha * distance}$; Nielsen *et al.* 2009) where the scaling value 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.

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: ~4%
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: ~14%
Upland conifer	Upland conifer	Mineral soils with tree cover >25%. Dominant tree species: black spruce, white spruce and pine. Areal coverage: ~5%
Upland deciduous	Upland deciduous	Mineral soils with tree cover >25% and >25% deciduous trees Dominant tree species: aspen and paper birch. Areal coverage: ~20%
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%)

We estimated 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 individual caribou as a random grouping effect, which creates a random intercept for each caribou. Because we were interested in variation among individual caribou to particular explanatory covariates, we also fit random slope GLMMs of the form

$$g(x) = \beta_0 + \beta x_{ij} + \ldots + \beta_n x_{nij} + \gamma_{nj} x_{nj} + \gamma_j \qquad \text{(Gillies } et\ al. \text{ 2006)}$$

where γ_j is the random intercept for caribou *j* and γ_{nj} is the random slope (or coefficient) for caribou *j* with respect to covariate x_n. The fixed-effects, or marginal, coefficients (βx_{ij}) yield population-level inferences that can be interpreted within the classic use-availability design of

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

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. We used the conditional coefficients of the GLMMs – the random slopes estimated for each individual – to explicitly maintain individual caribou as the sampling unit when evaluating caribou response to particular covariates. 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:

i. A null model of no fixed-effects and a random intercept for individual caribou;
ii. A random-intercept only model with only fixed-effects specified (see below);
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. Conifer swamp [Note: upland conifer models would not converge]
    b. Poor fen and rich fen
    c. Upland deciduous and deciduous swamp

For all models, the fixed-effects component of the model was the same, specifically:

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

For seasonal analyses outside of the calving season and for comparing females with calves to barren females, we estimated the Disturbance, Water, Forage, and Landscape Context models only. We used the individual random slope coefficients in a paired design to evaluate relative seasonal differences in selection. Specifically, we assessed the number of individuals whose selection coefficient either increased or decreased during calving compared to the selection coefficients estimated for the same set of individuals during other seasonal periods. 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 performance of the calving RSF model using Bayesian Information Criterion (BIC) scores and *k*-fold cross-validation (Boyce *et al.* 2002). For cross validation, we randomly partitioned the data by individual caribou into five folds, using four folds for model training then testing model prediction on the withheld individuals. For each test, we generated a predictive map from the training data set, reclassified this map into 10 ordinal bins of equal area then compared the frequency of test set GPS locations falling with a bin to bin rank using Spearman's correlation coefficient (r). 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 for each model with higher r values indicating better predictive performance. We did not evaluate the performance of other seasonal RSF models 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.

Calf Survival Analyses

To evaluate relative calving habitat quality, we used Cox proportional hazard models to relate variation in calving habitat selection to the probability of neonate calf survival. In this framework, variation in calving habitat selection is represented as the individual random slope coefficients derived from the calving RSF models. For females calving in multiple years, we specified RSF models that estimated random slope coefficients for each year. To account for females calving in multiple years, we used mixed-effects Cox models of the form

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

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 – in our analysis, the RSF random slope coefficients – 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 (see *Calf Survival Surveys*). Positive model coefficients are interpreted as an increasing risk of calf mortality with an increase in the associated covariate. We estimated a suite of Cox models that were analogous to the random slope RSF models listed above (e.g. a disturbance model using the random slope coefficients from the calving RSF Disturbance model).

Habitat Selection by Predators during the Calving Season

We conducted preliminary analyses of predator habitat selection during the calving season of caribou. We used a similar framework as for caribou, estimating RSFs for black bears and wolves using GLMMs. Because wolves, and to a lesser extent bears, are territorial, we estimated third-order RSFs where GPS locations are compared to random locations generated within an individual's or pack's seasonal home range. We defined predator home ranges using MCPs which may be more reflective of actual home range boundaries for territorial species than UDs (Boyle *et al.* 2009). We conducted a sensitivity analysis to determine the number of random points to be sampled to adequately characterize the calving season ranges of wolves and bears.

For both predator RSFs, we used GPS locations collected from May 1 – June 30. We screened the data by eliminating all 2-dimensional fixes and locations beyond the range of possible movement for each predator (Bjørneraas *et al*. 2010). We did not remove the first two weeks of data post-capture for bears although they were captured during this period. While we recognize that including this post-capture data may bias RSF inferences (Morellet *et al*. 2009), we wanted to preserve all bear movement data during the critical neonate period when caribou calves are most vulnerable to bear predation (Zager & Beecham 2006).

To model predator RSFs, we used the same suite of explanatory variables as for caribou. We conducted preliminary univariate analyses to determine the best predictive scale for land cover proportions and linear feature density for each predator. For the remaining water and disturbance variables, we considered only distance-to measures as the smaller extent of individual seasonal ranges (c.f. caribou herd ranges) resulted in densities of these variables being close to zero.

Our objective with these initial RSF analyses for predators was to compare predator habitat selection with caribou habitat selection at the population-level. We therefore estimated predator RSFs with random intercept-only GLMMs, specifying the individual animal as the random grouping factor for bears and individual wolf nested within pack as grouping factors for wolves. These analyses should be viewed as preliminary and not necessarily as final predictive models of predator habitat use during the calving season. A full analysis of predator habitat selection will be contained in the project's final report.

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).

RESULTS

Caribou Collaring

For 2013, we obtained data from 30 female caribou equipped with Iridium GPS radio-collars. One of these animals was a female captured in March 2012 as part of this project. This collar, however, ceased to transmit data in August 2013 and is scheduled to be replaced in December 2013 (B. Culling, *personal communication*). The other 29 animals were captured as part of the REMB monitoring program initiated in late 2012 / early 2013. Although the initial cohort of REMB collars totalled 30, one collar failed to transmit data during the calving season. One female in the Chinchaga was also predated by wolves in mid-June.

Wolf Capturing and Collaring

From January to April 2013, we captured a total of 23 wolves distributed among eight packs (Appendix 4). 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, the additional wolf was due to a mortality occurring shortly after collar deployment. This mortality was an individual in the Prophet pack and the cause of death appeared to be due to inter-pack aggression. Interestingly, this individual 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. We recovered both collars and subsequently re-deployed the still-functioning Lotek collar on an individual in the Snake pack. Combined with the data from 2012, we now have wolf GPS location data from all six caribou ranges.

Twelve of the 15 Lotek Iridium GPS collars transmitted data through the 2013 calving season. The other three collars have each collected < 120 locations since deployment and have not transmitted data since March 2013. One individual from the Snake pack – a young male – appears to have dispersed from the pack and is heading north into the NWT. This individual and an individual from the Chinchaga range (Big Arrow pack) were excluded from wolf RSF analyses. As of November 6, nine of the Iridium GPS collars are still transmitting data.

Black Bear Capturing and Collaring

From May 24 – 26, 2013, we captured 15 black bears distributed within or near three caribou ranges and the Fort Nelson core area (Appendix 5). 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 the individuals we captured last year.

Similar to last year, premature failures of the ATS black bear collars continued to be an issue. Only 8 bear collars remained operational through the calving season. We have recovered five of the non-functioning collars 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. We have yet to retrieve the collars as all three failed to transmit location data after their release.

Caribou Calving Rate and Calving Site Characteristics

Using our movement modelling approach, we predicted a minimum of 18 females having calved. Seven females were predicted not to have calved. For the remaining five females, modeled predictions were equivocal. Inspection of the raw movement data for four of these individuals suggest that all potentially calved and 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. We therefore estimate a calving rate range of 60 – 77% (18-23/30).

Three of the 18 predicted calving sites were located outside of current range boundaries although one of these sites was situated in the proposed Fort Nelson core area (Fig. 1). Of the 15 sites within caribou range, four were outside of core areas. The majority of calving sites were situated in treed bogs (n = 10) and poor fens (n = 3). Two sites were situated in conifer swamps and one each in open bog, rich fen and mixed-wood swamp. Mean calving date was May 22 (range: May 9, June 15; Fig. 2). Most calving sites in 2013 were inaccessible by road and helicopter; consequently, we sampled an additional two calving and winter sites for this year. A full analysis of fine-scale features of calving sites across the project's three years will be forthcoming in the project's final report.

Caribou Calf Surveys

We commenced calf survival surveys on June 15, 2013 with the last survey completed on July 9th, 2013. All females received at least one survey. During these surveys, we observed seven calves in total. Based on the survey data and our movement modelling, we estimated eight calves to have survived to four weeks of age, which equates to a standardized calf-to-cow ratio of 27 calves per 100 cows. Taking into account the uncertainty associated with our parturition rate estimate, the survival rate of neonate calves was estimated to be 35-44%. At the range level, two of four calves survived in Calendar, one of five survived in Chinchaga, two of four survived in Maxhamish, one of two survived in Snake-Sahteneh, and the sole calves in Parker and Fort Nelson core each survived while the sole calf in Prophet did not.

Calving Habitat Selection

The most predictive scale of response for calving habitat selection varied among explanatory covariates (Appendix 6). 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, we used distance to lake as it was a better predictor than distance to lake cluster.

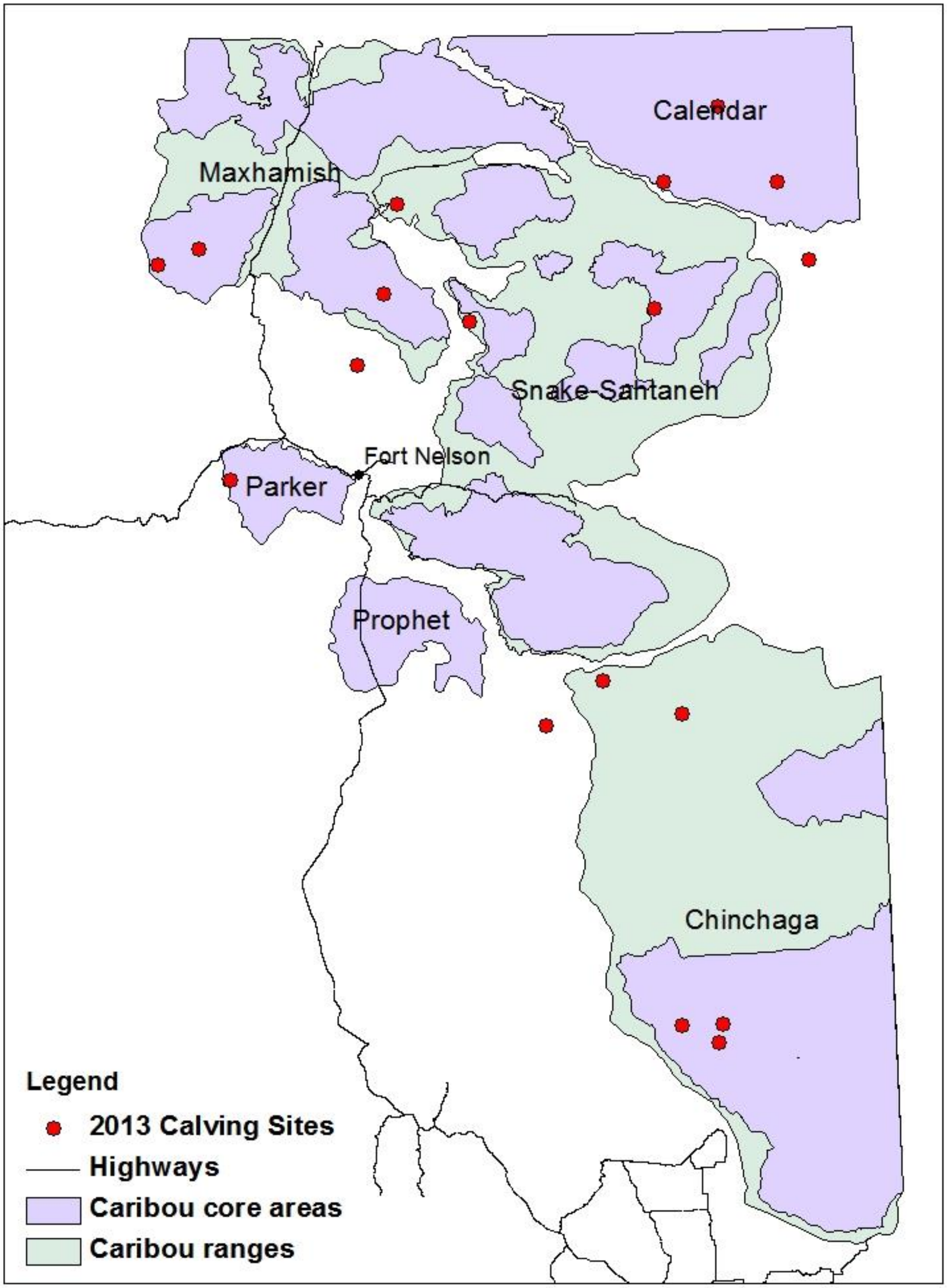

Figure 1: Distribution of calving sites for 18 female boreal caribou in northeast British Columbia during the 2013 calving season.

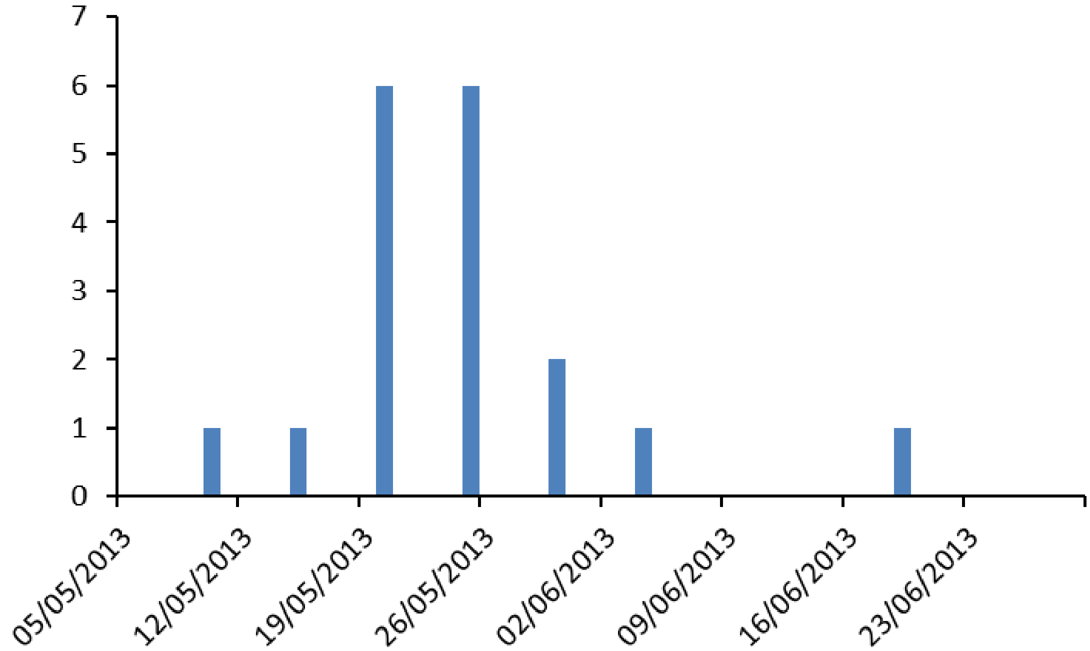

Figure 2: Distribution of calving dates for 18 female boreal caribou in northeast BC in 2013. Mean date of calving was May 22, 2013.

For calving RSF models, we used data from 35 females across the study's three calving seasons. Twelve females calved in two seasons. For the set of RSF models considered, we evaluated model performance using two measures: BIC and *k*-fold cross validation. Surprisingly, the top model identified by BIC was not the top model for prediction (Table 2). This result is likely due to the considerable variability in calving habitat selection among individual caribou, which may be better captured by more general models. This variability in selection is more explicitly revealed in the random slope models – which maintain the individual as the sampling unit – as a number of variables had 95% confidence intervals overlapping zero (Table 3; see also Appendix 7 for univariate comparisons – subset by range – of used caribou locations versus available locations).

The random intercept-only and Deciduous models were the best models for predicting calving habitat [Note: the Deciduous model was only evaluated against 10 tests during *k*-fold cross validation because of non-convergence of some training subsets]. All other model had *r* values <0.80. We were unable to estimate a Forage random slope model using calving season data as this model would not statistically converge.

Table 2: Performance of RSF models developed to assess calving habitat selection of female boreal caribou in northeast BC from 2011-13. Bayesian Information Criterion (BIC) measures model parsimony while Spearman's rank correlation (r) measures model predictive performance.

Model	**BIC**	***k*-folds (*r*)**
Null	2606262	n/a
Random Intercept	2046912	0.86
Disturbance	1555956	0.50
Forage	did not converge	n/a
Water	1531824	0.77
Conifer Swamp	1577131	0.76
Fen	1692517	0.58
Deciduous	1715543	0.89 *

Table 3: Fixed-effect coefficients and their 95% confidence intervals for the variables specified as random slopes in the suite of 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**	**Estimate**	**95% CI**
Disturbance	Dist. to early seral	1.59	-0.10, 3.28
	Dist. to well site	2.18	0.11, 4.26
	Line density (400-m)	-0.88	-1.89, 0.13
Water	Dist. to river	0.77	0.19, 1.36
	Dist. to lake	0.94	-0.09, 1.96
Conifer Swamp	Conifer swamp	-0.96	-2.03, 0.12
Fen	Poor fen	1.55	-0.40, 4.61
	Rich fen	0.19	-1.47, 0.62
Deciduous	Upland deciduous	-5.20	-11.25, 0.85
	Deciduous swamp	-0.62	-1.20, -0.04

Here, we focus on the fixed-effects of the Deciduous model for population-level inference as it was the top predictive model and had a significantly lower BIC value than the random-intercept only model. In general, caribou calved in areas with lower proportions of upland deciduous and deciduous swamp forests than random areas within their range (Table 4). Relative to treed bog, the dominant land covers within caribou calving areas were fens, conifer swamps, and upland conifer. Caribou calving areas were also generally lower in slope, higher in NDVI value and further away from rivers than other areas within their range. The effect of distance to lakes was small with calving areas essentially being randomly distributed with respect to lakes. Linear feature density also had a small effect on calving area selection with caribou selecting areas with slightly lower line density. For the other disturbance variables, calving areas were situated further away from active well sites and closer to early seral vegetation than random areas.

Table 4: Parameter estimates and their 95% confidence intervals from the top RSF model for predicting calving habitat of boreal caribou in northeast BC. In this model, upland deciduous and deciduous swamp were specified as the random slope variables.

Variable	Estimate	95% CI
Conifer swamp	0.19	0.19, 0.2
Deciduous swamp	-0.62	-1.20, -0.04
Other	-0.50	-0.51, -0.50
Poor fen	0.33	0.32, 0.34
Rich fen	0.84	0.83, 0.84
Upland conifer	0.33	0.32, 0.34
Upland deciduous	-5.20	-11.24, 0.84
Slope	-0.10	-0.10, -0.09
NDVI	0.15	0.14, 0.15
Dist. to river	0.32	0.32, 0.33
Dist. To lake	-0.01	-0.02, -0.01
Dist. To early seral	-0.25	-0.26, -0.25
Dist. To well	0.25	0.24, 0.25
Line density	-0.06	-0.07, -0.06

We compared calving habitat selection to the selection of other seasonal areas using 24 individuals for each comparison (Table 5). Because of differences in the timing of collar deployments and collar battery life spans, the same set of 24 individuals differed for each comparison (i.e. the set of 24 to compare calving to mid-winter was different than the set used to compare calving to late summer). Comparing calving to mid-winter, caribou showed relative selection for poor fens (21/24 individuals). The effect was less pronounced for other land covers; however, all land covers except conifer swamp had a majority of individuals show selection. A majority of calving females (16/24) also moved into areas with higher NDVI values and further away from rivers (15/24) and lakes (14/24). A small majority also moved into areas of lower linear feature density.

Table 5: Relative differences in seasonal habitat selection by boreal caribou in northeast BC. Model name refers to the variables specified as random slopes (for individual caribou) within the generalized linear mixed-effects RSF model (see text). Column numbers refer to the number of individual caribou (*n* = 24) that showed relative selection (i.e. a higher model coefficient) of that variable during calving compared to the seasonal area. For example, for distance-to variables column numbers refer to the number of individuals that were further way from the habitat element compared to the other seasonal area.

Model	Variable	Mid Winter	Late Summer	Late Fall
Disturbance	Dist. to early seral	11	12	13
	Dist. to well site	10	16	13
	Line density (400-m)	9	1	7
Water	Dist. to river	15	10	16
	Dist. to lake	14	3	14
Forage	NDVI	16	13	13
Conifer Swamp	Conifer swamp	12	8	11
Fen	Poor fen	21	16	17
	Rich fen	14	16	10
Deciduous	Upland deciduous	14	8	9
	Deciduous swamp	16	9	7

Comparing calving to late summer, the calving areas of 23 females had lower linear feature density than the areas used by these same individuals in late summer. Calving areas were also closer to lakes (21/ 24), and to a lesser extent rivers (14/24), than areas used in late summer. Two thirds of females had calving areas with higher proportions of fen and lower proportions of conifer swamp and upland deciduous forest. A majority of calving females (16/24) were also further away from active well sites.

Poor fens were also a key variable differentiating calving areas from late fall areas. Seventeen females showed relative selection for poor fens at calving. Calving areas also had lower proportions of deciduous swamps (17/24) and upland deciduous forest (15/24). Similar to the previous seasonal analyses, a majority of females (17/24) were in areas of lower linear feature density at calving compared to late fall. Distance to water effects were similar to the mid-winter comparison with females further from rivers (16/24) and lakes (14/24) at calving.

We assessed for effects of maternal status on habitat selection during the calving season by comparing the selection coefficients of barren females (*n* = 11) to calving females (*n* = 35). In general, the two distributions overlapped for all variables. Selection differences between the two groups were greatest for linear feature density (marginally stronger avoidance by calving females, p = 0.10) and poor fens (marginally stronger selection by calving females, p = 0.11).

Calf Survival Analyses

We related individual selection coefficients to the probability of calf survival to four weeks of age (Table 6). The strongest predictor of calf survival was conifer swamp. An increase in the proportion of conifer swamp in the landscape was associated with a decreased risk of calf mortality. Surprisingly, increases in line density and the proportion of rich fen were also weakly correlated with a decreased risk of calf mortality. Variables weakly correlated with an increasing risk of calf mortality were the proportion of poor fen and distance to early seral vegetation. Distance to water and distance to well site had no effect on the probability of calf survival.

Table 6: Effects of variation in calving habitat selection on the probability of neonate survival. Positive coefficients equate to an increase in calf mortality risk with an increasing values of the associated variable.

Model	Variable	Estimate	95% CI
Disturbance	Dist. to early seral	0.11	0.03, 0.18
	Dist. to well site	0.00	-0.06, 0.07
	Line density (400-m)	-0.11	-0.23, 0.01
Water	Dist. to river	-0.02	-0.15, 0.11
	Dist. to lake	0.05	-0.06, 0.16
Conifer Swamp	Conifer swamp	-0.18	-0.31. -0.05
Fen	Poor fen	0.10	0.00, 0.19
	Rich fen	-0.03	-0.06, 0.00
Deciduous	Upland deciduous	-0.01	-0.02. 0.00
	Deciduous swamp	-0.03	-0.06, 0.00

Habitat Selection by Predators during the Calving Season

We used data from 14 wolves and 19 black bears to develop preliminary RSF models for assessing predator habitat selection during the calving season. For wolves, the top ranked land cover type was "other", which is a combination of aquatic and anthropogenic habitats (Table 7). This top ranking may be driven by wolf selection of aquatic habitats as evidenced by wolf locations being closer to rivers and lakes than random locations. The second highest ranked land cover for wolves was rich fens. Treed bog, the reference category, and poor fens were the two lowest ranked land covers. Wolf response to disturbance variables was somewhat surprising. Wolf locations were further away from early seral vegetation and well sites than expected. Wolf locations were also in areas with lower linear feature density although the magnitude of this effect was small.

For bears, the top ranked land cover type was upland deciduous forest, followed by "other" and poor fen. The lowest ranked land covers were upland conifer, deciduous swamp and treed bog. Similar to wolves, bears were found closer to rivers and lakes than random locations. Bears also seemed to favor disturbance features as bear locations were closer to early seral vegetation, well sites and in areas of higher linear feature density than expected.

Table 7: Parameter estimates and their 95% confidence intervals from RSF models evaluating habitat selection by wolves and black bears during the calving season (May 1- June 30) of boreal caribou in northeast BC.

	Wolf		**Black Bear**	
Variable	**Estimate**	**95% CI**	**Estimate**	**95% CI**
Conifer swamp	0.22	0.21, 0.23	0.06	0.04, 0.09
Deciduous swamp	0.15	0.14, 0.16	-0.06	-0.08, -0.05
Other	0.67	0.66, 0.68	0.39	0.37, 0.41
Poor fen	0.00	-0.01, 0.01	0.30	0.27, 0.33
Rich fen	0.28	0.27, 0.29	0.24	0.22, 0.26
Upland conifer	0.10	0.09, 0.12	-0.13	-0.15, -0.10
Upland deciduous	0.15	0.14, 0.16	0.52	0.49, 0.55
Slope	-0.03	-0.04, -0.02	-0.02	-0.03, 0.00
NDVI	-0.19	-0.20, -0.17	0.04	0.02, 0.05
Dist. to river	-0.30	-0.31, -0.29	-0.22	-0.24, -0.21
Dist. To lake	-0.18	-0.18, -0.17	-0.20	-0.21, -0.18
Dist. To early seral	0.37	0.36, 0.38	-0.27	-0.29, -0.25
Dist. To well	0.10	0.09, 0.11	-0.14	-0.15, -0.12
Line density	-0.04	-0.05, -0.02	0.14	0.12, 0.16

DISCUSSION

In 2013, we effectively tripled our sample sizes of predators and, through collaboration with the REMB monitoring program, doubled our sample size of female caribou. As a result, our study area has expanded to include all six boreal caribou ranges in northeast BC. We currently have GPS data from female caribou and wolf packs in all six ranges as well as GPS data from black bears in three ranges. For this report, we limited our analyses to five ranges, excluding Chinchaga due to land cover GIS data being unavailable for this range. With GIS data for the Chinchaga expected to be available in the next six months, our analyses can be expanded to all six ranges which will allow for more robust inferences across the distribution of boreal caribou within BC.

Calving rates in 2013 for female caribou in northeast BC were similar to those recorded in 2012. We estimated a range of 60-77%, which contains our 2012 estimate of 73%. The rates for both 2012 and 2013 were lower than our estimate for 2011 (80%) and are low compared to rates recorded in other studies (85%, Stuart-Smith *et al.* 1997; 86%, Rettie & Messier 1998; 79%, Pinard *et al.* 2012). For 2013, low rates of calving may be attributable to the severe winter conditions that lasted until the end of April, conditions that likely contributed to a number of mortalities of radio-collared caribou during this time period (B. Culling, *personal communication*). 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 seemed to be evident in 2013 in our study area as peak calving date was approximately one week later than what we recorded in 2011 and 2012 and what Culling *et al*. (Culling *et al.* 2006) recorded in 2002-2004.

Rates of neonate calf survival in 2013 (35-44%) were also similar to rates recorded in 2012 (35%). Combined with parturition, these rates equated to similar cow-calf ratios at the end of the neonate period in 2013 (27 calves: 100 cows) and 2012 (26 calves: 100 cows). Both ratios are below annual cow-calf recruitment ratios associated with caribou population stability (~30 calves / 100 cows, (Environment Canada 2011). Cow-calf ratios are comprised of both parturition and neonate survival rates. While the more severe environmental conditions of 2013 may have affected parturition rates, it is less certain as to whether the adverse conditions affected neonate survival rates. Maternal condition can affect calf size with leaner mothers producing smaller calves (Adamczewski *et al.* 1987; Taillon *et al.* 2012). Although the effect of calf size on neonate survival is equivocal (Whitten *et al.* 1992; Roffe 1993; Adams *et al.* 1995; Pinard *et al.* 2012), the effects of small size may extend beyond the neonate period with smaller calves having lower overwinter survival rates (Whitten *et al.* 1992). Because calf recruitment rates are a key driver of caribou population dynamics (DeCesare *et al.* 2012a), low rates of recruitment suggest a declining population. Moreover, potential population declines this year could be steeper than in previous years as female survival is also expected to be lower this year compared to the project's first two years.

As in 2012, female caribou showed selection for calving areas with high proportions of fens. A majority of calving areas also had higher proportions of deciduous land covers, suggesting that many females move out of winter areas dominated by large treed bog complexes and into more patchy landscape mosaics at calving. Rettie & Messier (2000) reported a similar observation for boreal caribou populations in Saskatchewan, hypothesizing that females move into more productive areas at calving to meet nutritional demands yet within these areas they predominantly use patches associated with reducing predation risk (e.g. treed bogs; James *et al.* 2004). Although we focused on second-order selection in this analysis and did not specifically analyze resources used within calving areas, our results here support this hypothesis as calving areas were generally associated with higher NDVI values yet the majority of calving sites were located in treed bog patches. For the project's final report, we will be evaluating finer scales of selection to further test this hypothesis.

In general, female caribou in northeast BC do not appear to use lakeshore habitats at calving. The majority of calving areas were > 1 km away from the nearest lake and > 2 km away from lake clusters (Appendix 7). This result contrasts with studies conducted in Ontario which reported that female caribou used lakeshores and islands for calving (Bergerud 1985; Carr *et al.* 2011). Lakes in northeast BC, however, may not be as favourable for calving as lakes in eastern Canada. First, lakes in northeast BC are generally shallow and devoid of islands, which may impact their ability to provide refuge from predators. Second, both wolves and bears in northeast BC showed relative selection for aquatic habitats, being closer to lakes and rivers than expected. For wolves, the selection of aquatic habitats may reflect a seasonal shift toward beaver as a primary prey item (Culling *et al.* 2006; Latham 2009). Bears may select aquatic habitats to forage on emergent sedges and rushes in the spring (Mosnier *et al.* 2008). For female caribou in northeast BC, the avoidance of aquatic habitats may be a strategy for reducing predation risk.

Caribou response to landscape disturbance differed from our preliminary analyses from the project's first two years (DeMars *et al*. 2011, 2012). Females generally avoided areas of high linear feature density as measured within a 400-m radius. This scale of measurement, however, may reflect avoidance in terms of proximity rather than density *per se*. Future analyses will assess for directional changes in selection at varying spatial scales to more fully evaluate caribou perception of linear feature density. DeCesare *et al*. (2012b) suggested that caribou in west-central Alberta avoided densities of disturbance at a scale of 5-km for second-order selection; however, their disturbance index was a combination of linear features and cut blocks. The ability of caribou to perceive areas of low disturbance density has ramifications for potential habitat restoration actions such as linear feature reclamation. Such reclamation actions will require an integration of caribou scale of perception with the spatial scale necessary to provide predator refugia.

Overall, caribou showed considerable individual variation in calving habitat selection. This plasticity may have evolved as a part of the overall life history strategy of boreal caribou; that is, occurring at low densities and being unpredictable on the landscape. This variation may also be a reflection of the dispersion or “spacing away” (*sensu* (Bergerud & Page 1987) behaviour of females at calving. Dispersion by females to different areas within caribou range can create variability in selection depending on the scale considered (Wiens 1989). Variation in selection by caribou may have been further influenced by differences in resource availability among ranges. This change in selection with availability, known as a functional response in selection (Mysterud & Ims 1998), will be investigated in further calving habitat analyses. Accounting for functional responses can improve predictive performance of RSF models (Matthiopoulos *et al.* 2011); however, even after accounting for functional responses, the residual variation in selection among individuals may make the identification of an obligate calving habitat difficult for boreal caribou.

We provided a preliminary assessment of calving habitat quality by linking individual variation in calving habitat selection to the probability of calf survival. Results of this assessment were somewhat surprising as increasing proportion of poor fen in the landscape and increasing distance away from early seral vegetation were the strongest predictors of increasing calf mortality risk. Moreover, a decrease in linear feature density was associated with a decrease in calf mortality risk. These results initially seem counterintuitive but may be indicative of the following explanations. First, if predation is the primary cause of calf mortality (Adams *et al.* 1995; Valkenburg *et al.* 2004; Gustine *et al.* 2006), our results suggests that the numeric response of predators has more impact on neonate survival than the functional response. Caribou have not likely changed where they go to calve (i.e., poor fen landscapes) yet their calves are still being predated at high rates with little influence from linear feature density, which is thought to facilitate the functional response of predators (McKenzie *et al.* 2012). Because fens are higher in productivity than the treed bogs of winter ranges, fen landscapes likely have a higher risk of predation, which calving females may be trading off to access higher forage quality to meet maternal nutritional demands (Parker *et al.* 2009). This trade-off may be minimal when predator numbers are low but becomes magnified when predators numbers are high. A more thorough assessment of this explanation, however, would require an analysis of the interaction between predator numbers and linear feature density on calf survival rates.

The relationship between linear feature density and predator functional response provides a second explanation for the results of our survival analysis. Predator functional response may plateau at a relatively low density of linear features (e.g. 1 km/km^2; (McCutchen 2007) and many areas within boreal caribou ranges of northeast BC may have linear feature densities exceeding this plateau (Thiessen 2009). Consequently, detecting effects of line density on calf survival will be difficult in areas already highly impacted by linear features.

Scale and measurement issues also likely influenced our assessment of calving habitat quality. We assessed survival at scales of selection from the perspective of caribou and these scales may differ from the scales most predictive of mortality risk (Chalfoun & Martin 2007). Moreover, selection may not be the best metric for assessing habitat quality effects. Other studies have assessed habitat quality with simple use metrics (e.g. Sorensen *et al.* 2008; Nielsen *et al.* 2013). In other disciplines, such as medicine, survival is often modelled in terms of exposure or dose (Essebag *et al.* 2005), which in habitat-performance relationships may be equivalent to use. In the project's final year, we will be conducting multi-scale analyses with different habitat metrics to determine the most appropriate method for evaluating calving habitat quality.

For 2013, we successfully captured and radio-collared a sufficient sample size of wolves and black bears to begin habitat selection analyses for each predator. Our preliminary analyses suggest that both predators select for areas within or adjacent to aquatic habitats during the caribou calving season. For wolves, this pattern of selection may be due to a seasonal shift to beaver as a dominant prey item, as noted previously. Because wolves are denning at this time, den locations, which are frequently near water sources (Peterson & Ciucci 2003), may have further influenced wolf selection patterns. We did not exclude GPS locations found near den sites in these preliminary analyses because we wanted an initial assessment of time allocation within available land cover types by each predator. Among the other land cover types, poor fens and treed bogs were the lowest ranked for wolves, suggesting that wolves spend a relatively small amount of time in caribou habitat.

Black bears, conversely, showed relatively high selection for poor fens as it was the third-ranked land cover type. This finding is in contrast to our analyses of bear habitat use in 2012, which showed that < 5% of bear locations occurred in poor fens (DeMars *et al.* 2012). At this time, we are conducting further analyses of bear habitat selection to determine whether the selection for poor fens we report here is truly a population-level response or driven by a few individuals. Overall, the pattern of habitat selection by bears seems consistent with bears selecting habitats associated with early spring green-up (Mosnier *et al.* 2008). Bears were close in proximity to well sites and selected areas with high linear feature density. These findings may be due to bears foraging within well sites and along road sides as these areas are among the first to green-up in the spring (C. DeMars, *personal observation*). In addition to our ongoing habitat selection analyses, we are using mechanistic movement analyses to determine the relative importance of linear features in facilitating black bear movements within caribou range.

PROJECT OUTLOOK

We have now completed the final year of data collection and 2014 represents the project's final year. Our primary objectives for 2014 are to complete data analyses and prepare the project's final report (due December 2014). Specific analyses to be completed are:

1. Fine-scale analyses of calving habitat selection
   - We will integrate our current second-order selection analyses with finer scales of selection to provide a comprehensive, multi-scale assessment of calving habitat selection by caribou in northeast BC. Pending the development of land cover GIS data for the Chinchaga range, we anticipate that an end product of these analyses will be a predictive map of caribou calving habitat for the entire distribution of boreal caribou within BC.
2. Further assessments of calving habitat quality
   - For this report, we provided a preliminary assessment of calving habitat quality by linking individual variation in habitat selection to the probability of calf survival. We will be expanding on this analysis by evaluating different metrics (e.g. selection versus exposure) at multiple scales to determine the metrics and scales most appropriate for quantifying habitat quality. The end-goal of this analysis will be to further modify the predictive calving habitat map to depict current gradients in relative calving habitat quality for northeast BC.
3. Further analyses of predator habitat selection
   - As mentioned previously, analyses of predator habitat selection in this report should be viewed as preliminary. Future analyses will encompass an explicit evaluation of individual variation in selection and incorporate the predictive calving habitat map for caribou.
4. Modelling of predator-caribou encounter rates
   - We are currently using the empirical data from caribou, wolves and black bears to investigate spatial and numeric factors influencing encounter rates between predators and caribou during the calving season.

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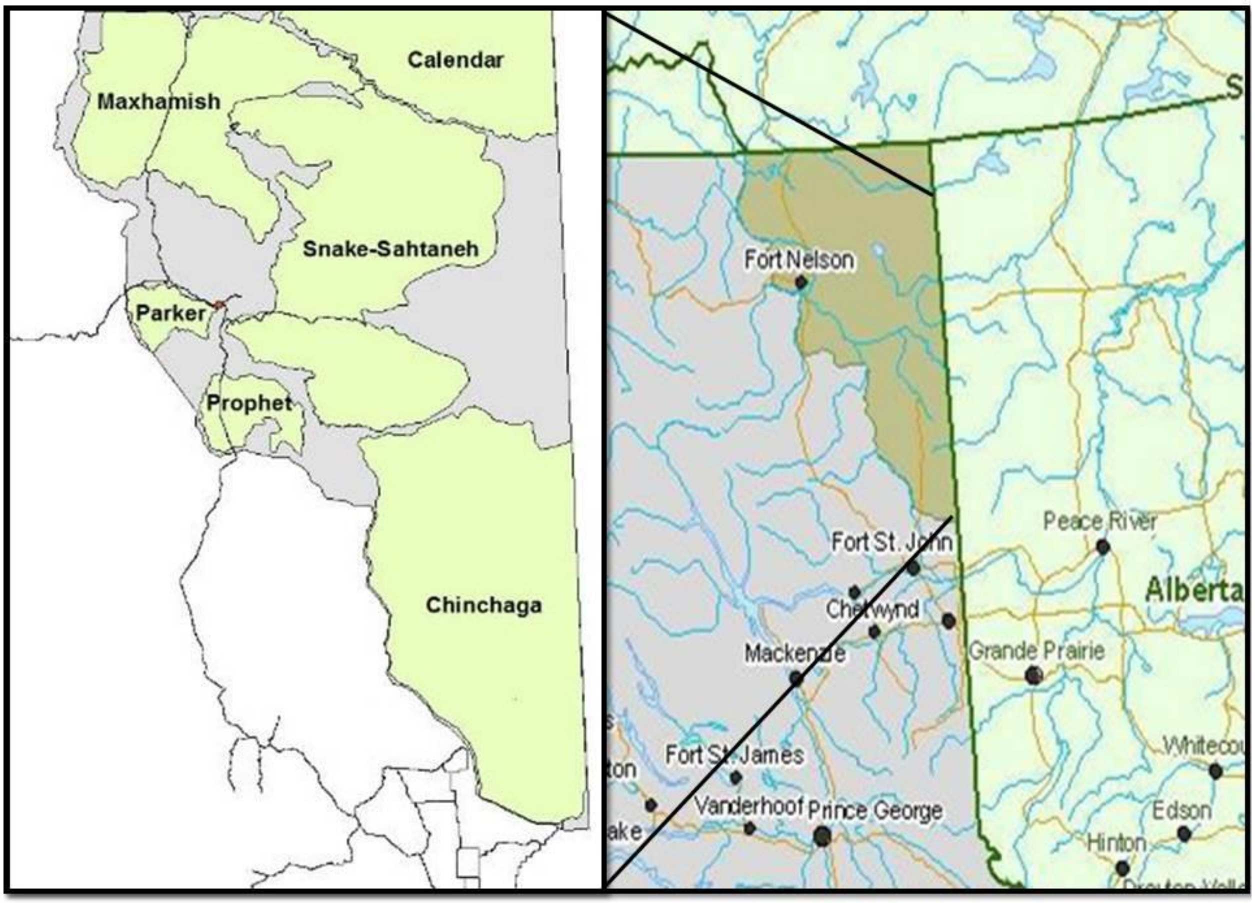
APPENDICES

APPENDIX 1

Study Area Map

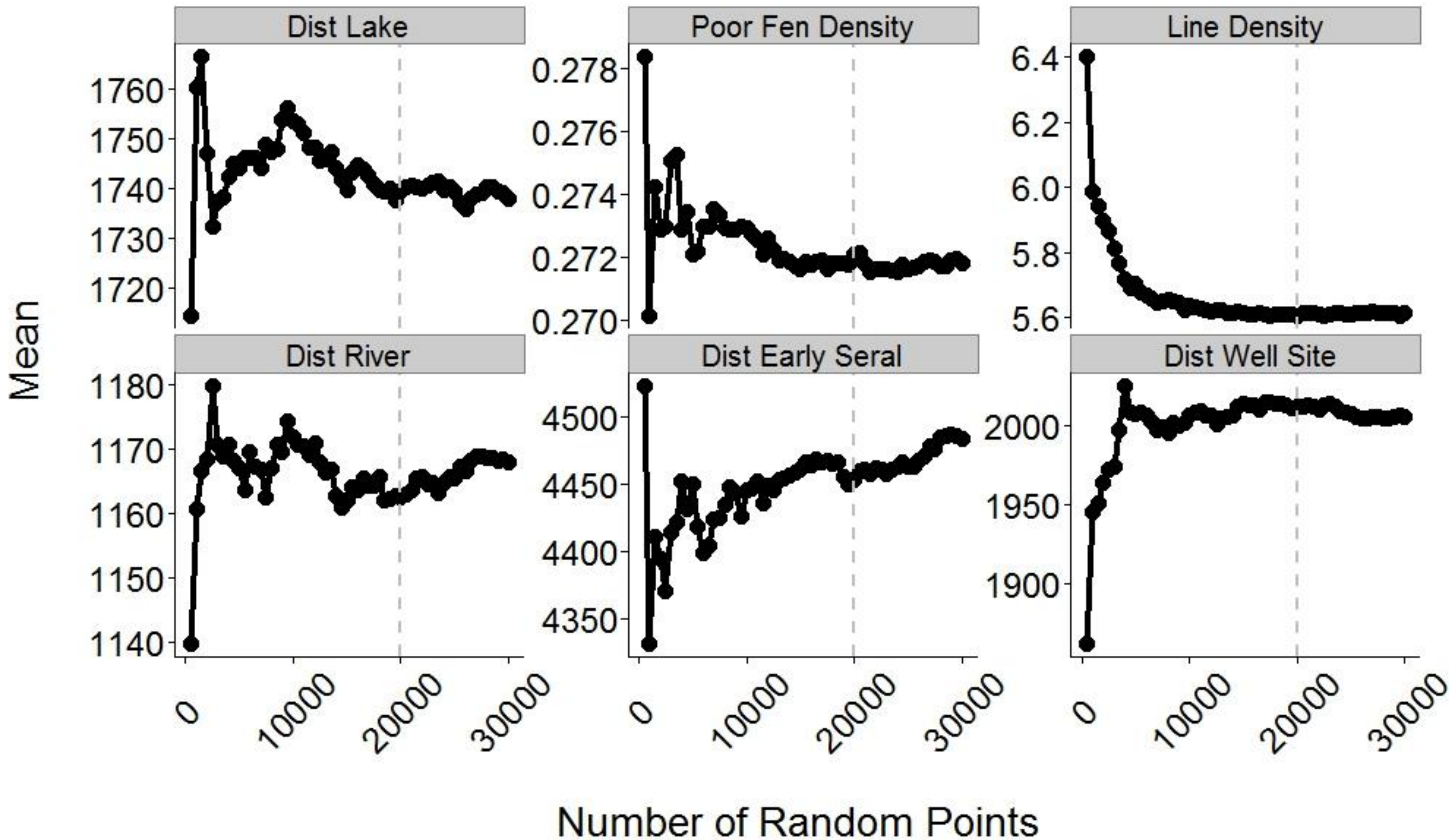
Boreal caribou distribution and ranges within British Columbia. In 2013, the project's study area expanded to included radio-collared caribou in all six caribou ranges.



APPENDIX 2

Random Point Sensitivity Analysis

Sensitivity analysis to determine the number of random points to adequately characterize availability at the range scale.



APPENDIX 3

GIS Data Sources

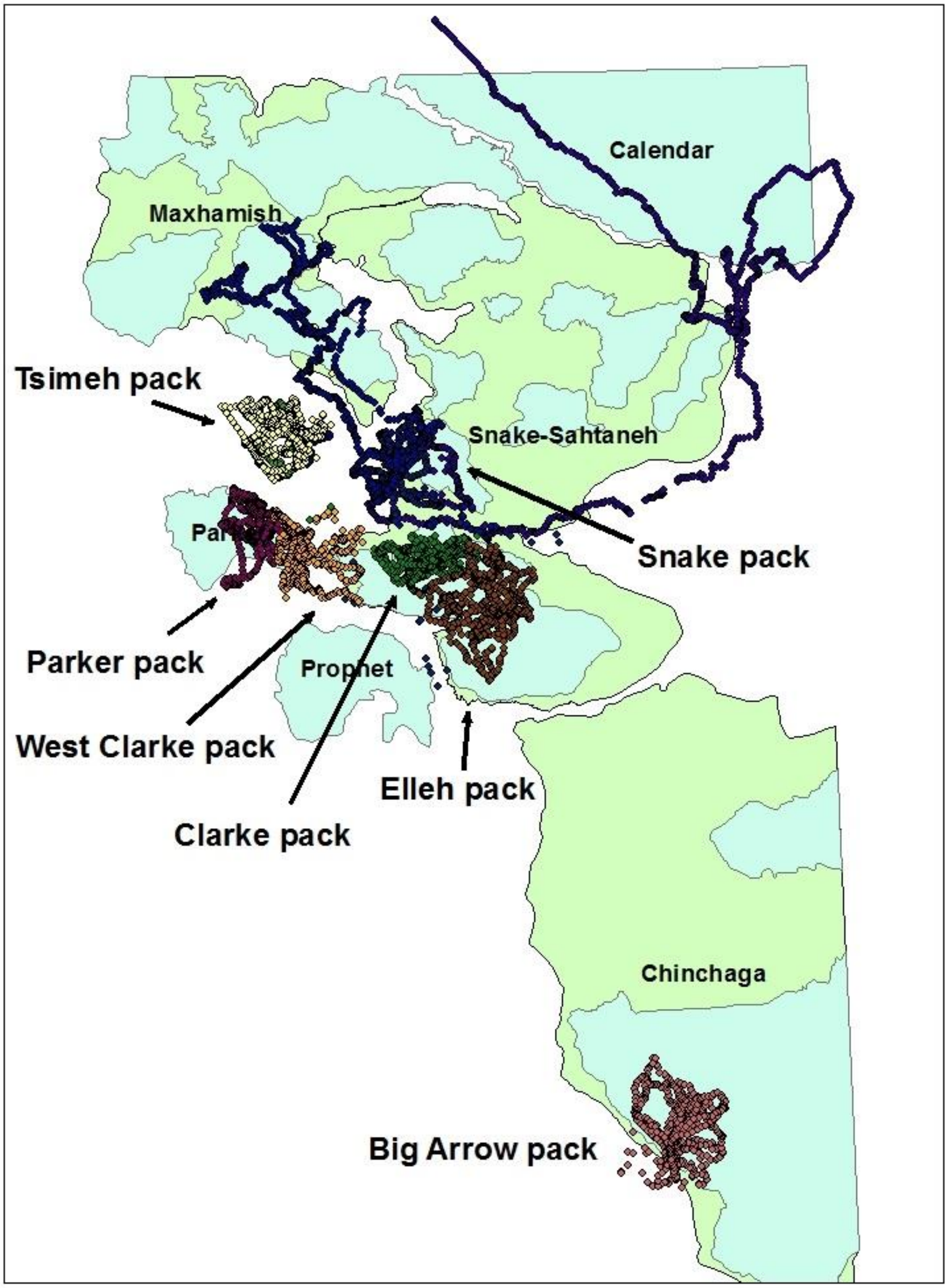
GIS data sources used to model resource selection functions.

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 4

Wolf GPS locations

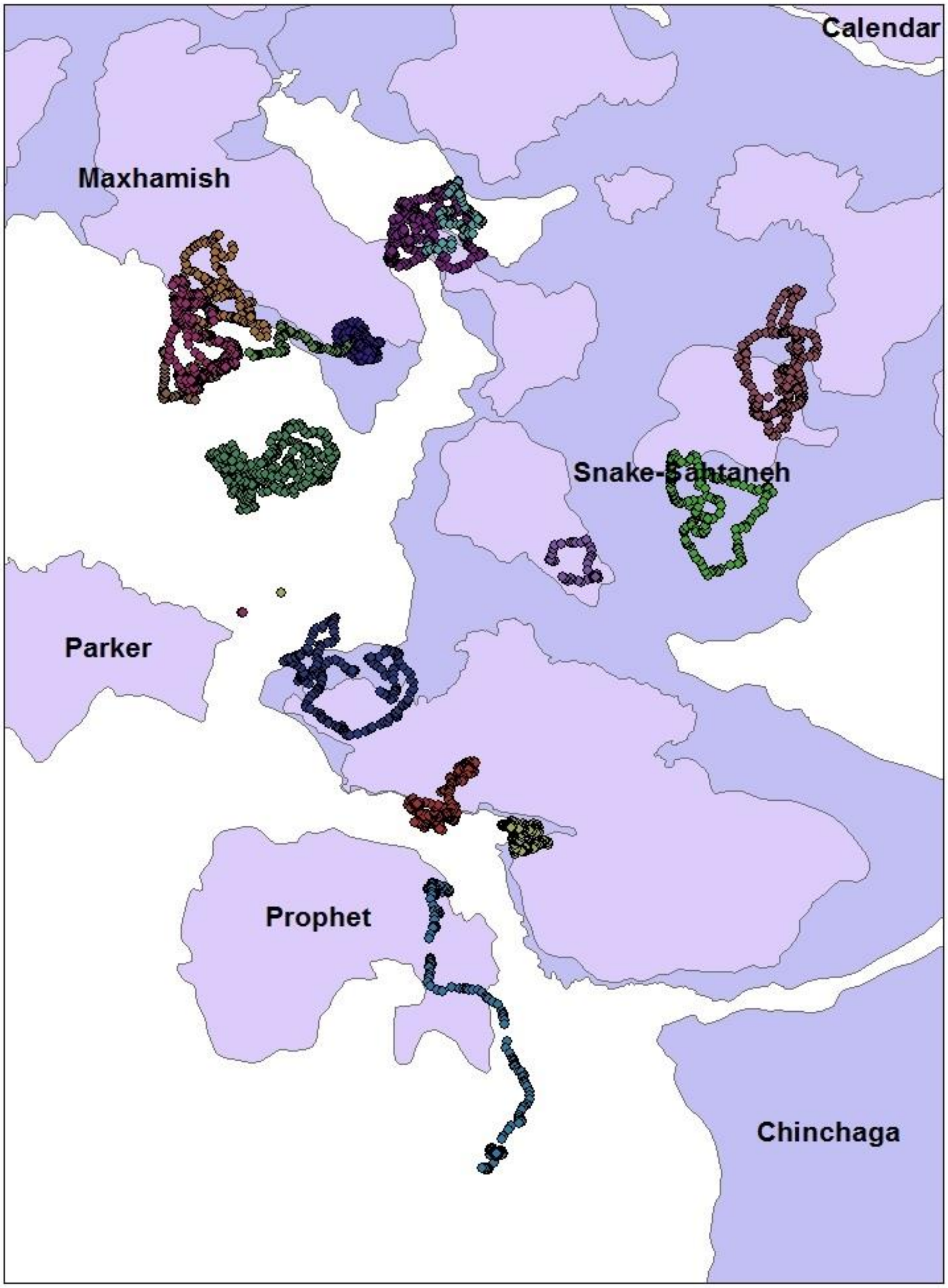
GPS locations from 15 wolves distributed among seven packs in northeast British Columbia. Location dates range from date of capture (Jan. – Apr. 2013, varies by individual) until June 7, 2013.



APPENDIX 5

Bear GPS Locations

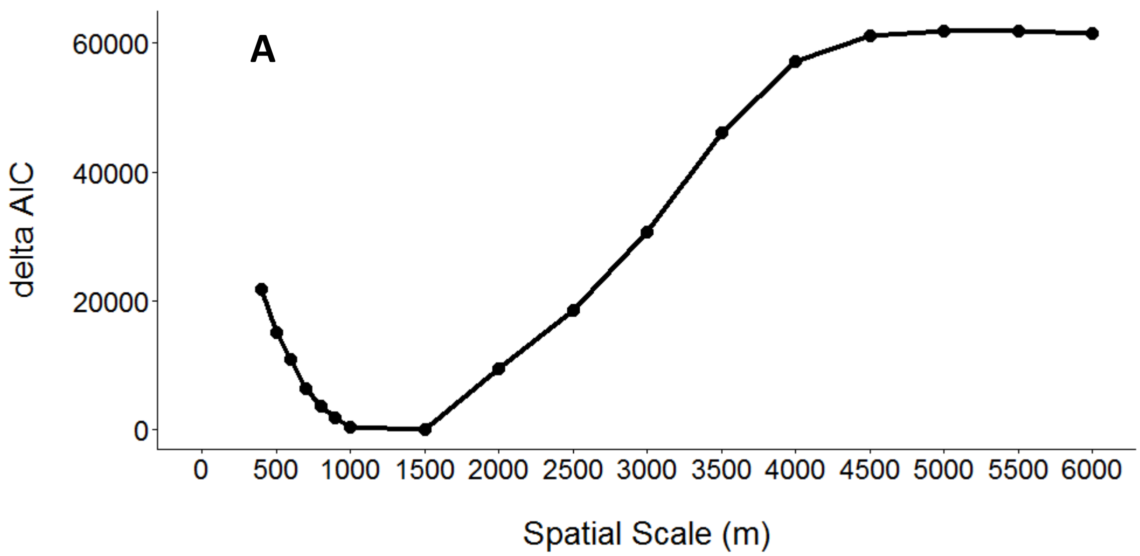
GPS locations from 15 black bears captured in northeast British Columbia. Location dates range from date of capture (May 24-26, 2013, varies by individual) until June 7, 2013

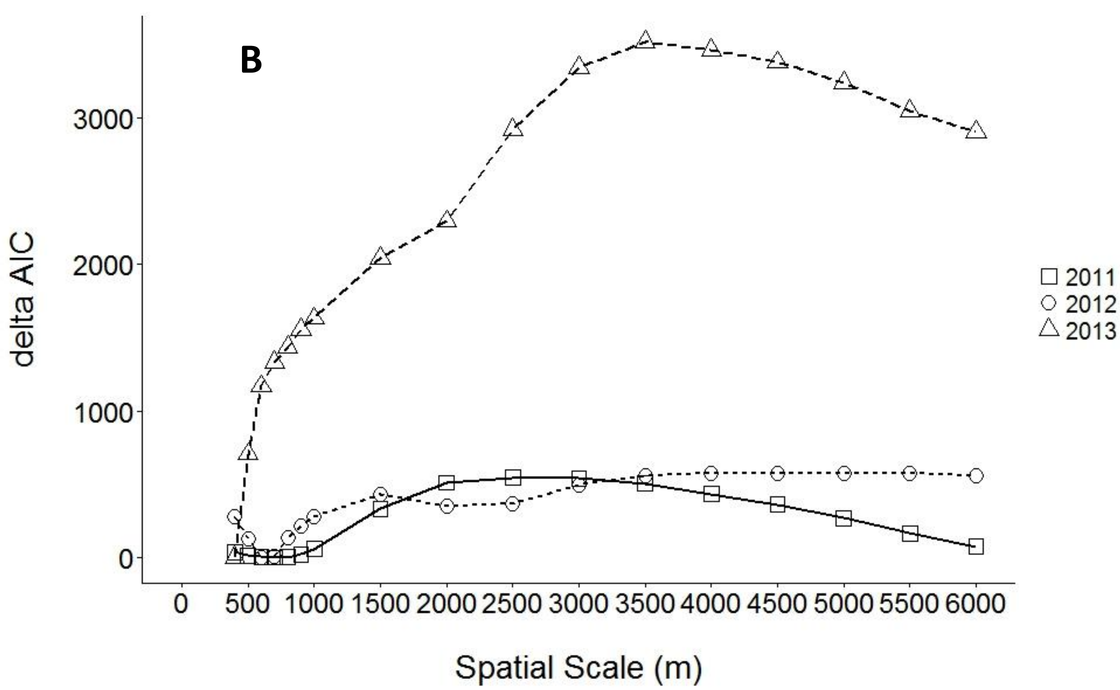


APPENDIX 6

Spatial Scale of Response Analyses

We used repeated univariate generalized linear models to identify the most predictive scale of response for explanatory covariates. 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). Delta AIC refers to the difference in AIC values between a given spatial and the best predictive scale.





APPENDIX 7

Univariate analyses of caribou used locations versus availability

Box plot summaries of caribou GPS locations versus available (or random) locations for variables used in resource selection function models to assess calving habitat selection by female boreal caribou in northeast BC. 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.

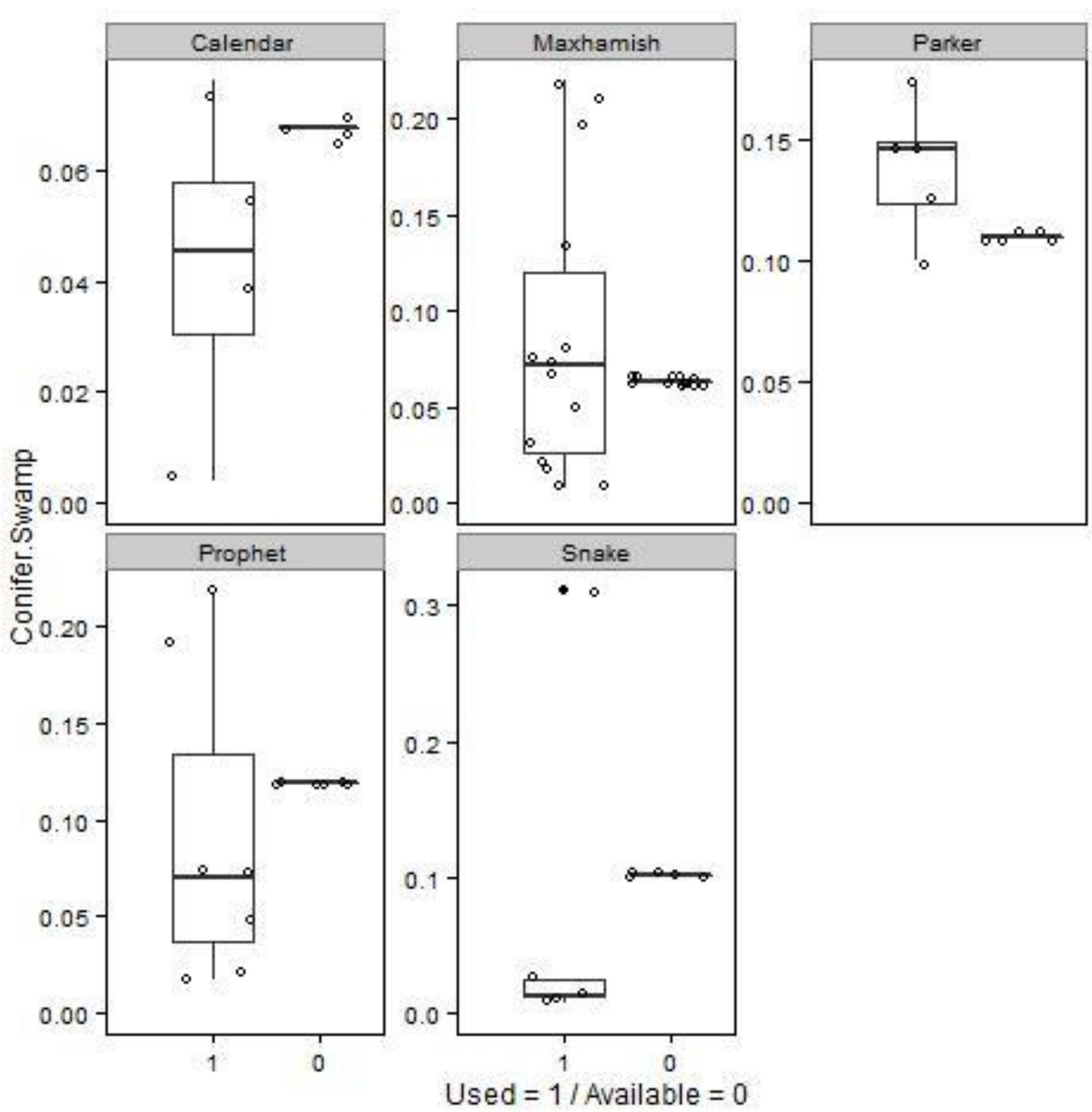


Figure A7.1 : Proportion of conifer swamp in a 1500-m radius

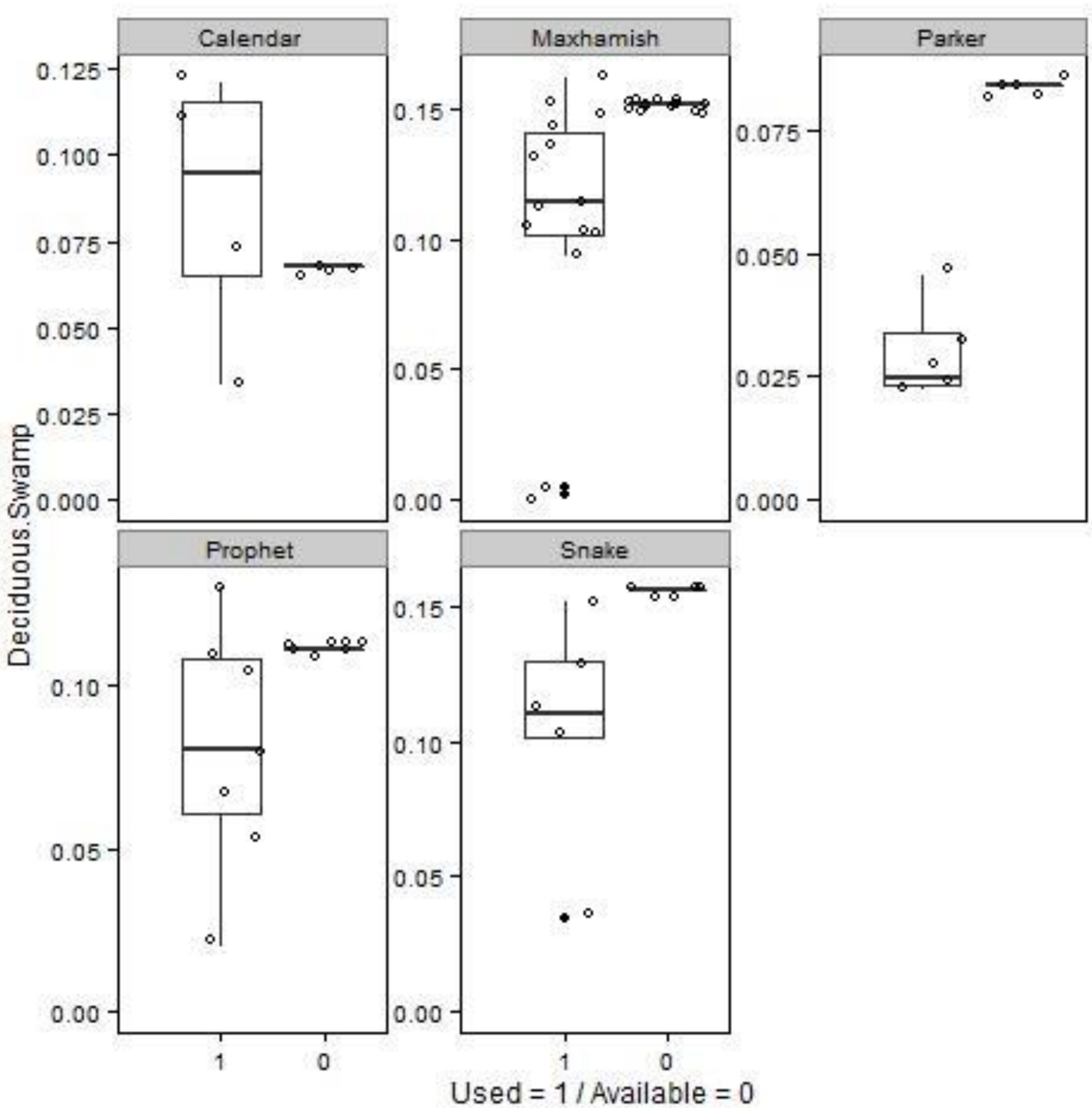


Figure A7.2 : Proportion of deciduous swamp in a 1500-m radius

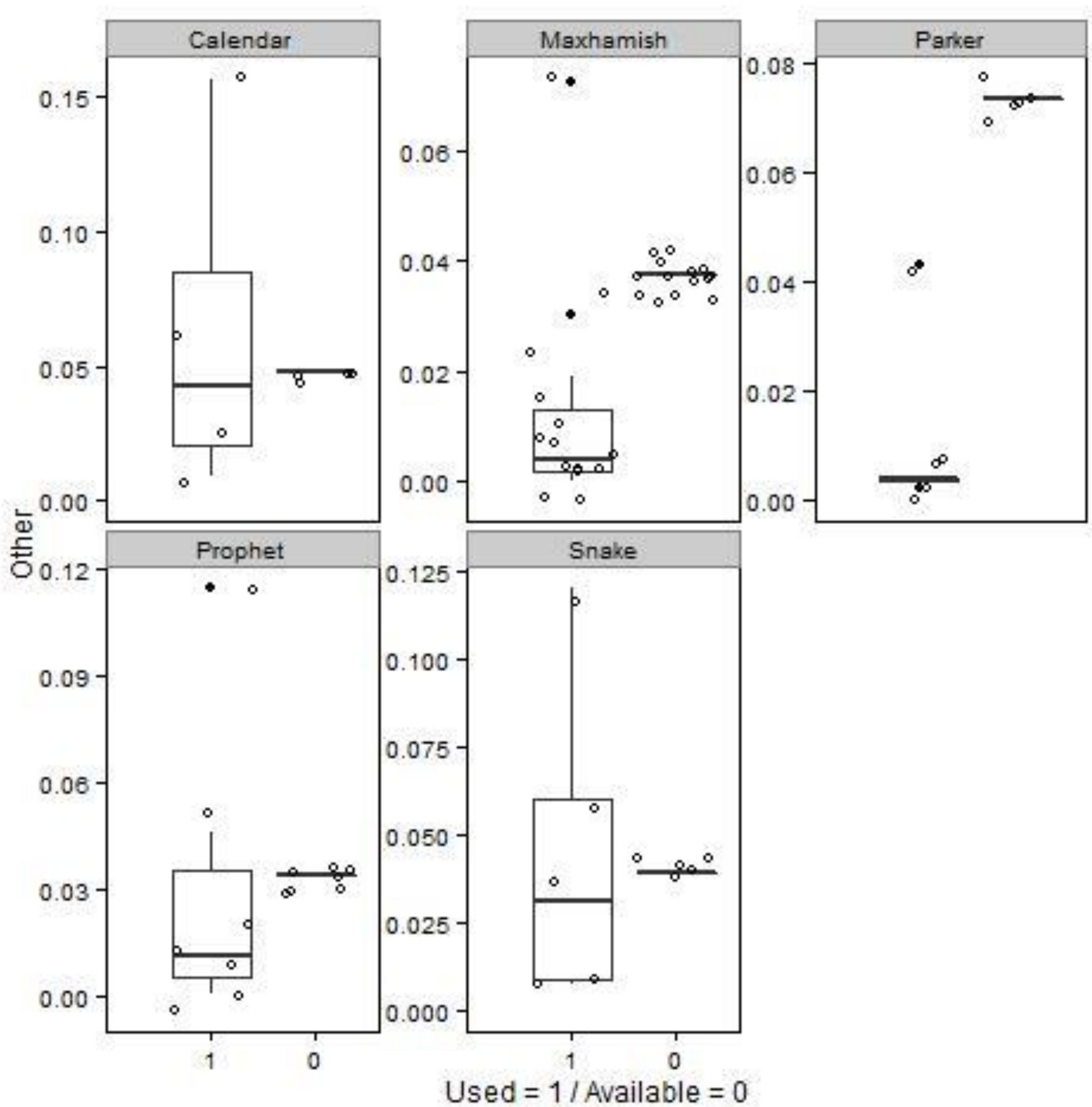


Figure A7.3 : Proportion of combined anthropogenic and aquatic habitats (“other”) in a 1500-m radius

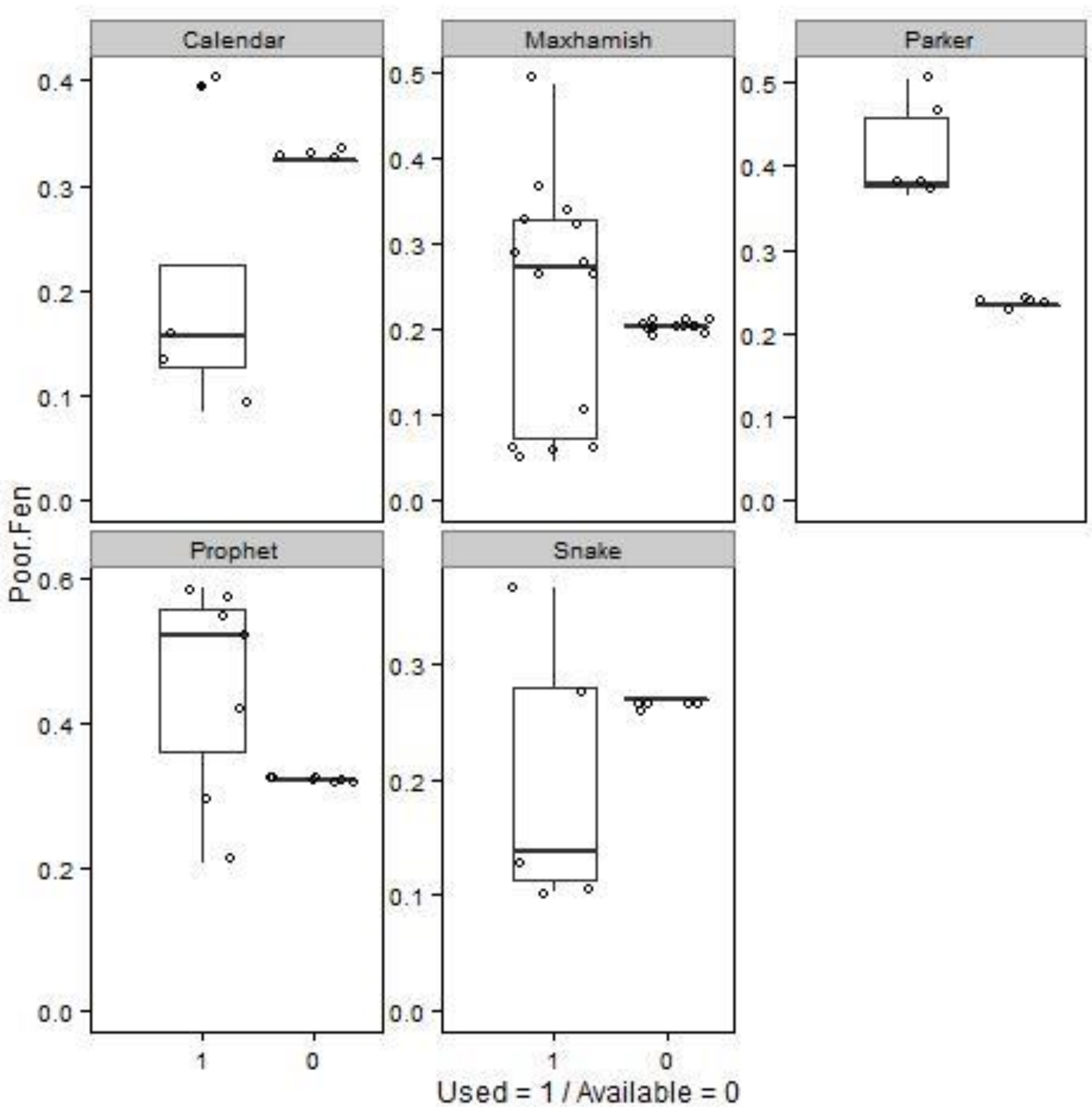


Figure A7.4 : Proportion of nutrient-poor fen in a 1500-m radius

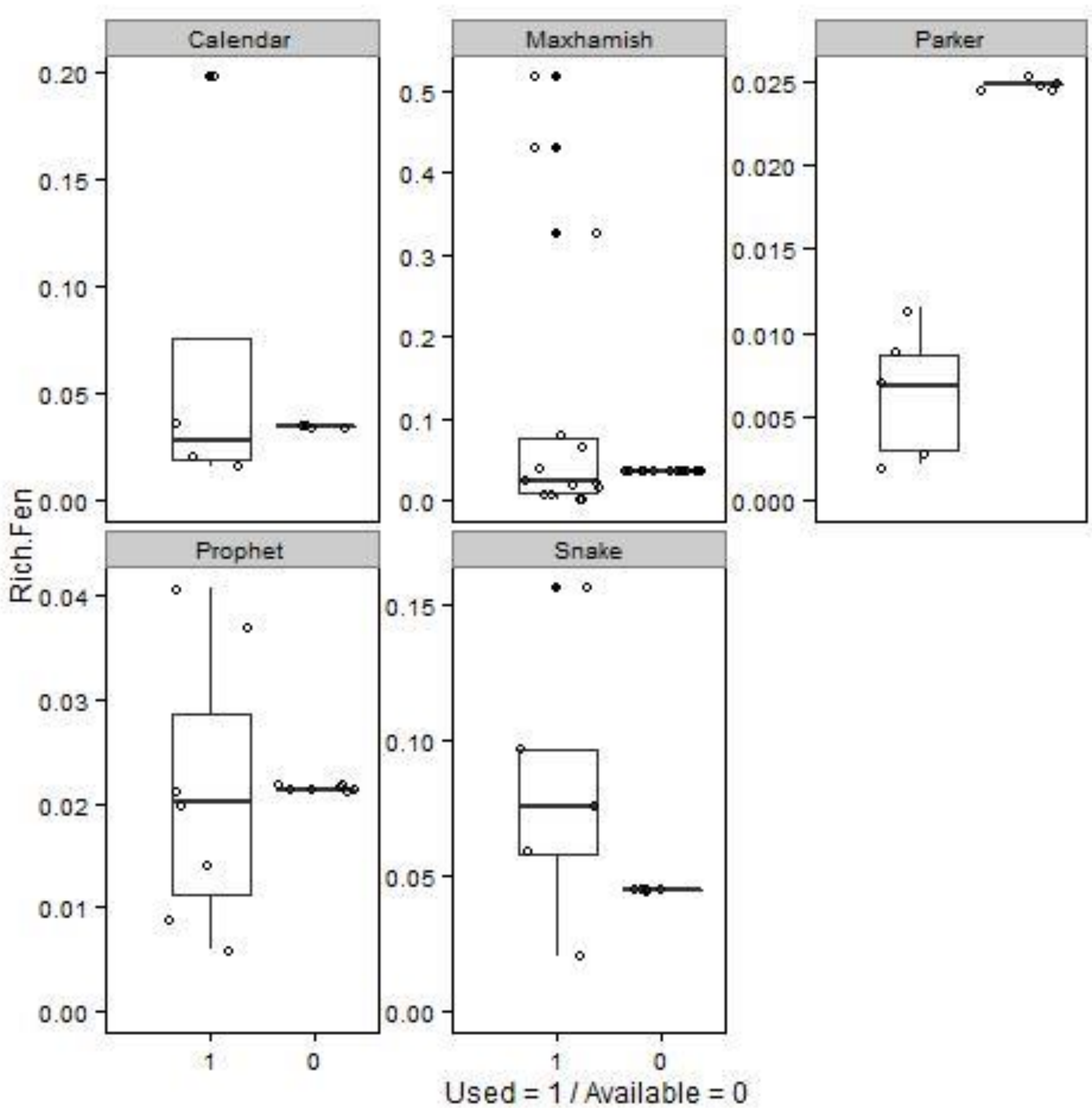


Figure A7.5 : Proportion of nutrient-rich fen in a 1500-m radius

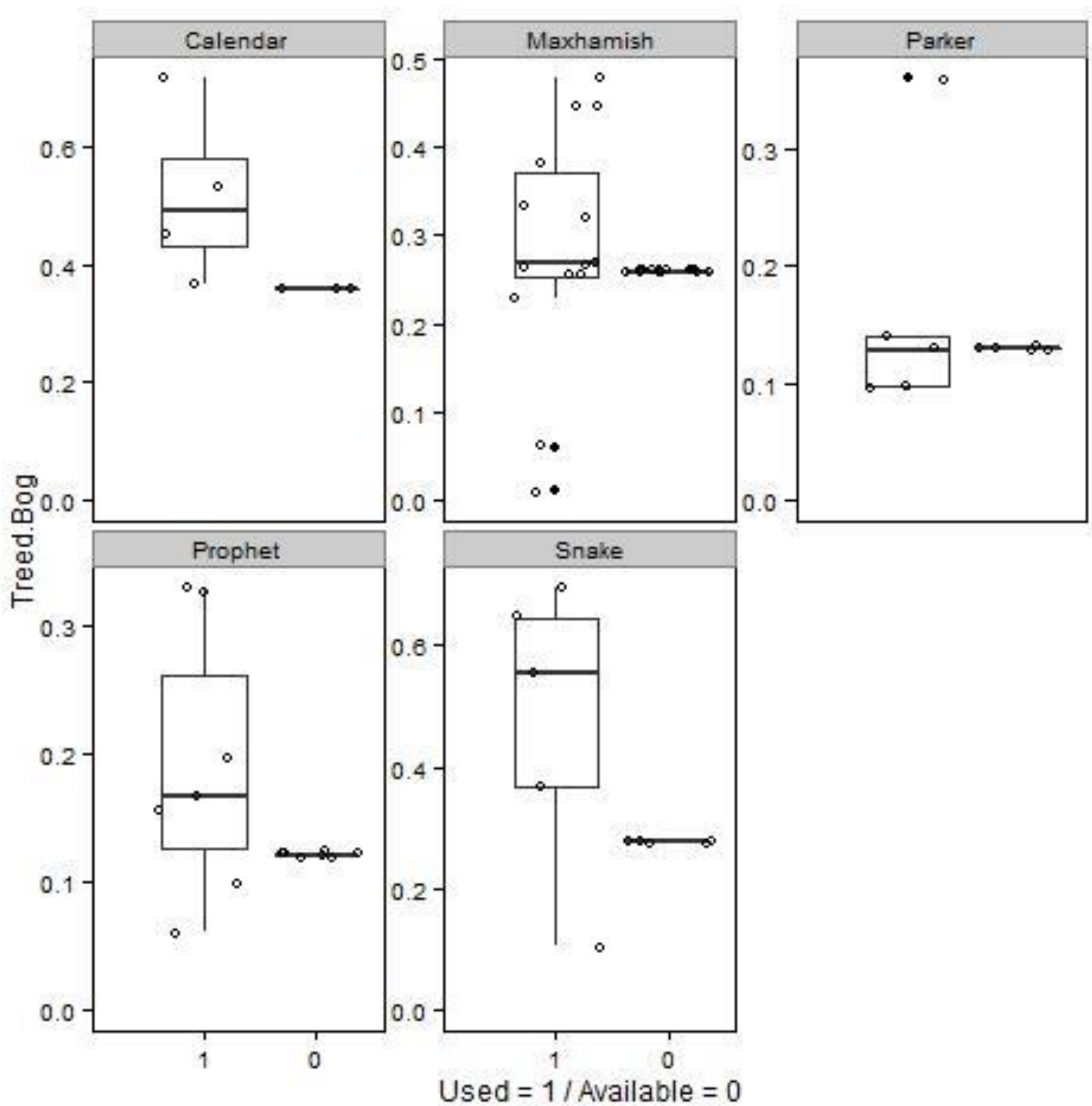


Figure A7.6 : Proportion of treed bog in a 1500-m radius

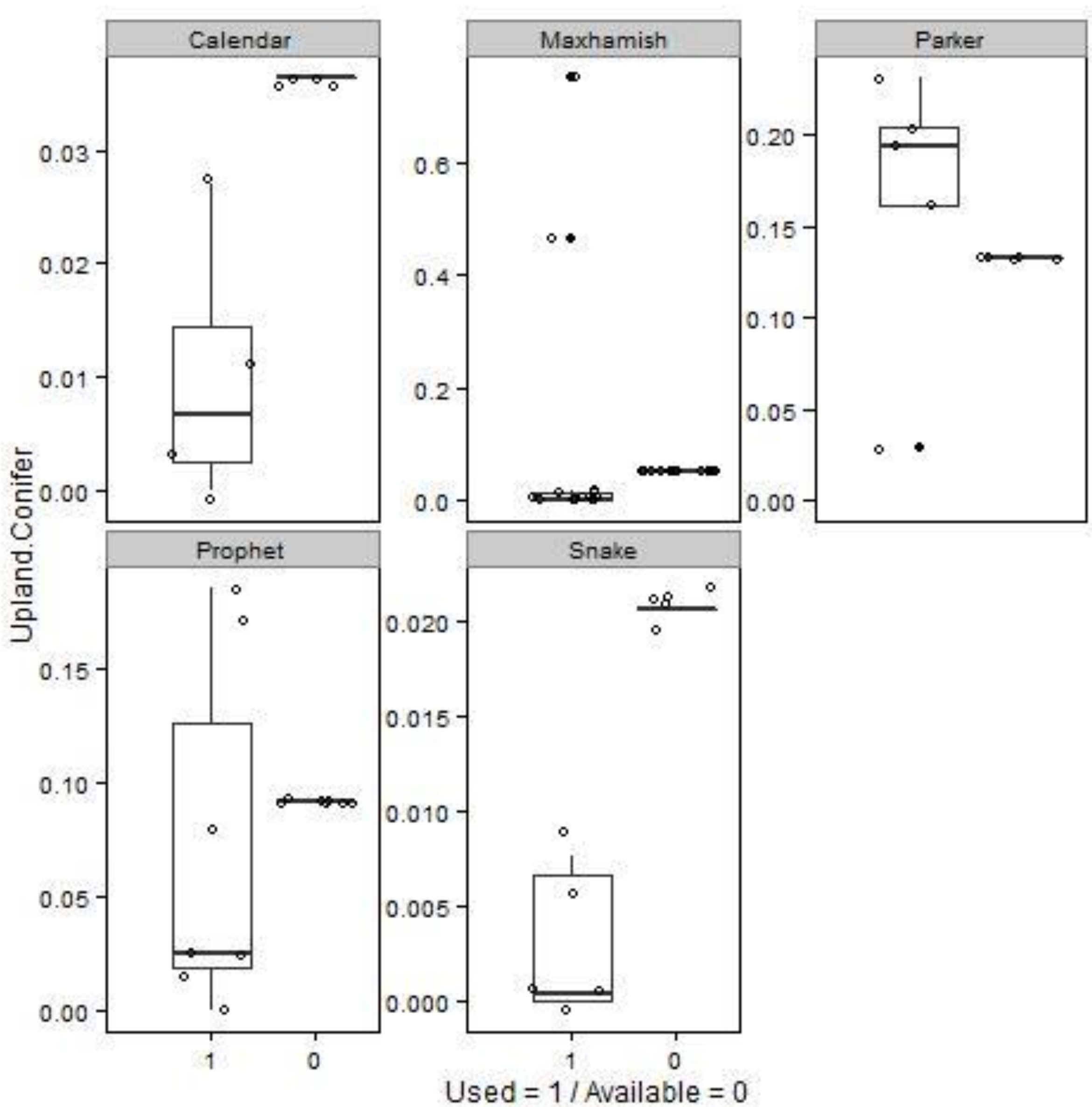


Figure A7.7 : Proportion of upland conifer forest in a 1500-m radius

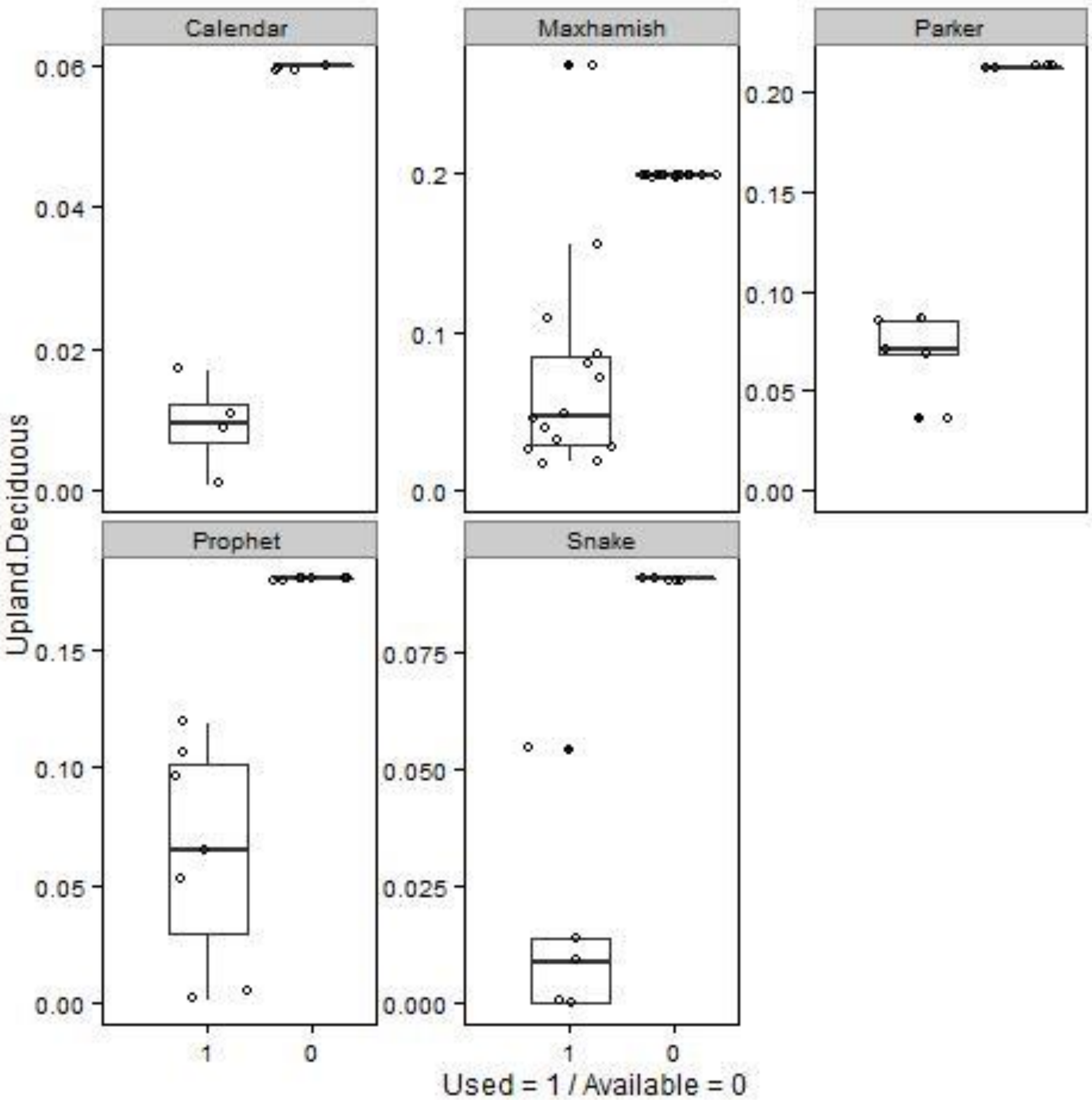


Figure A7.8 : Proportion of upland deciduous forest in a 1500-m radius

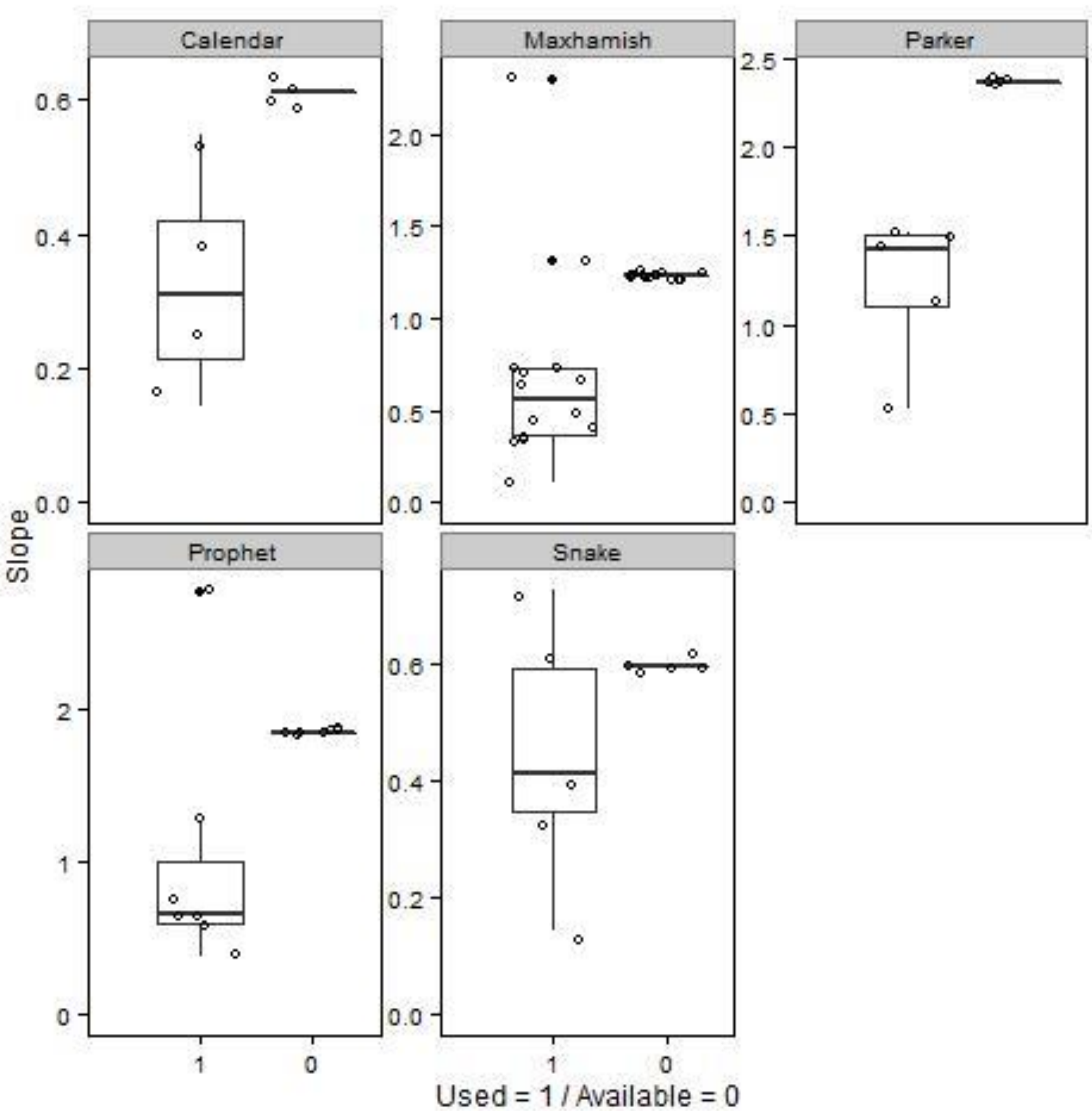


Figure A7.9 : Mean slope values of caribou locations versus available locations

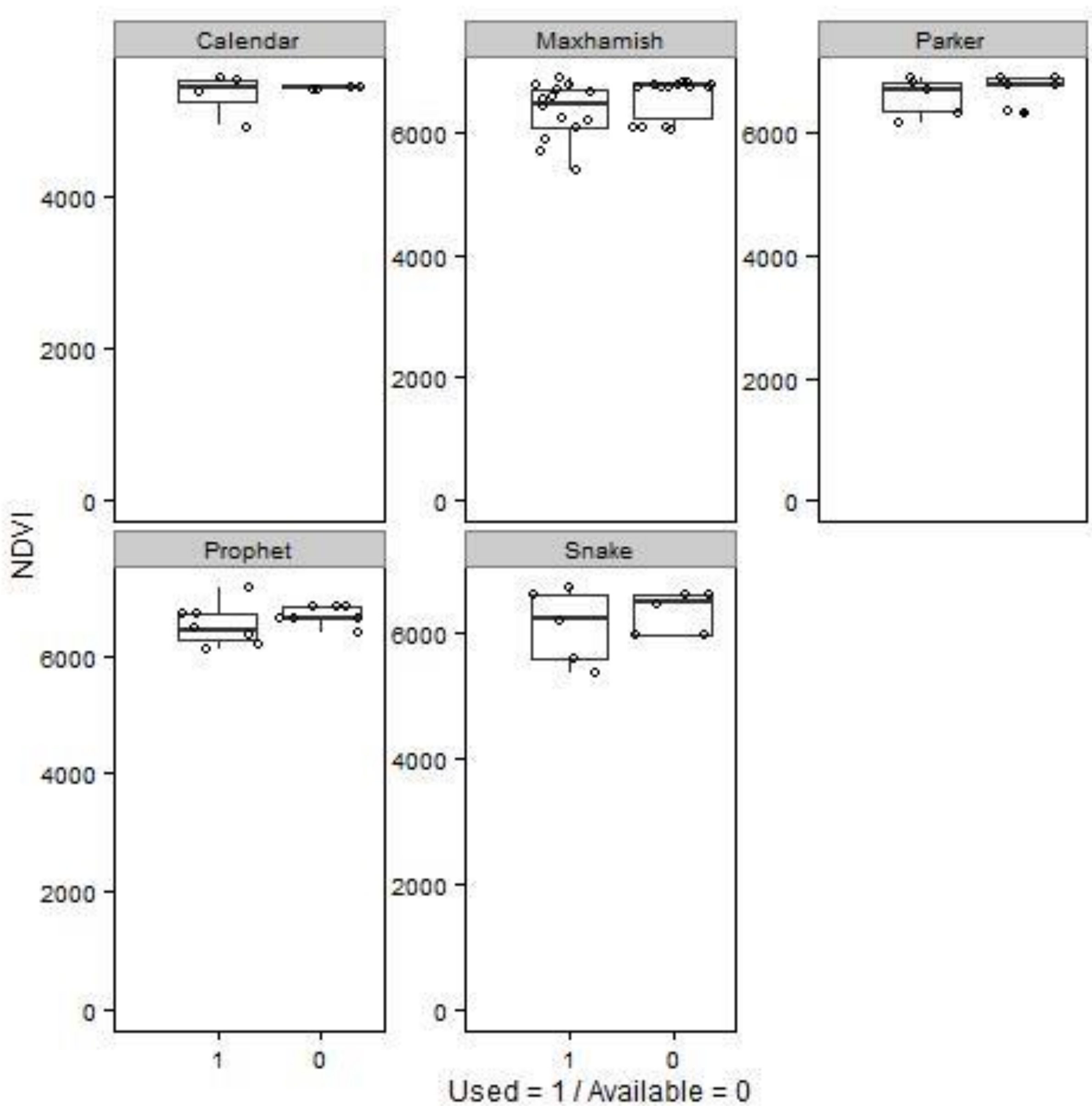


Figure A7.10 : Mean slope values of caribou locations versus available locations

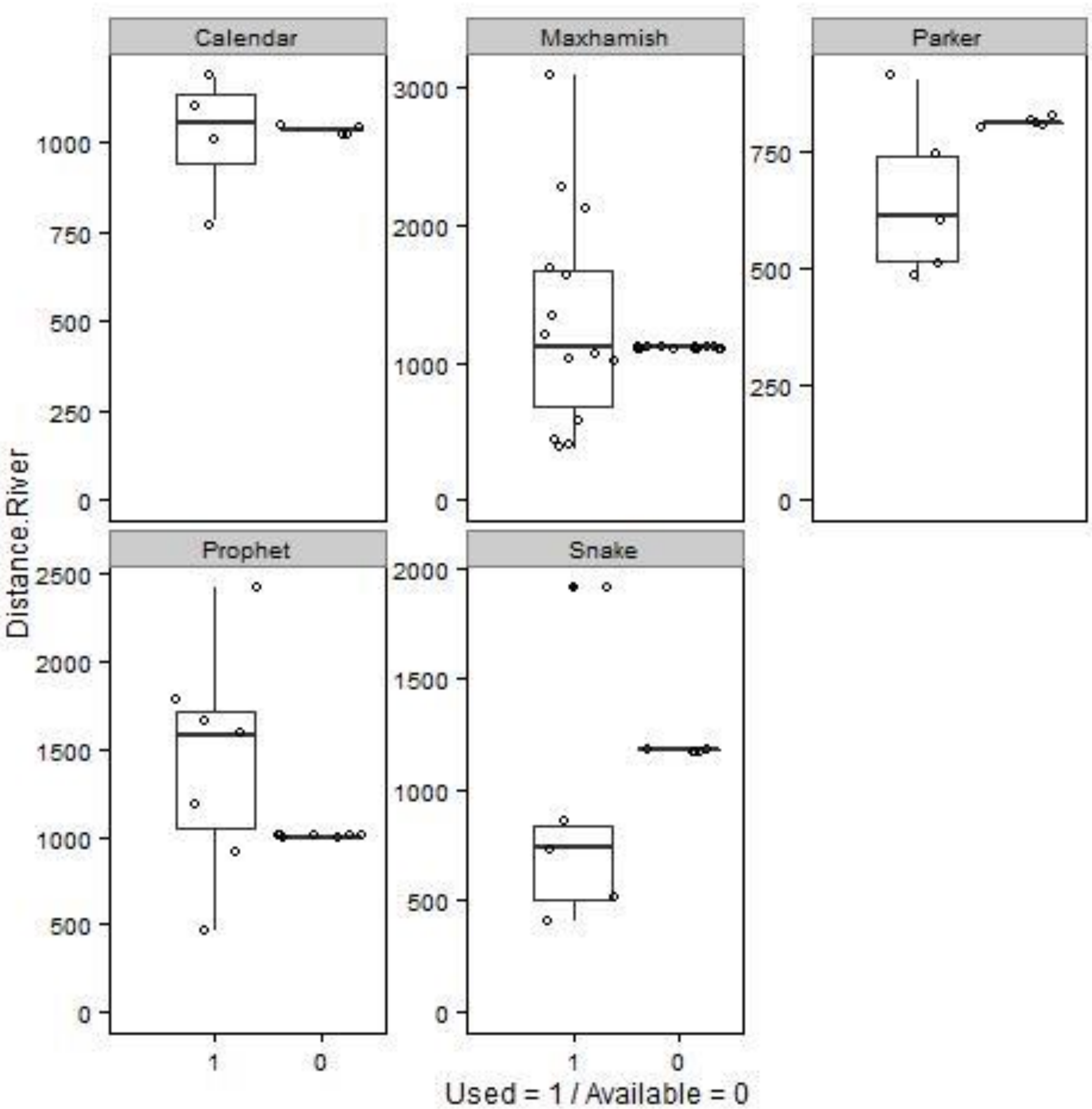


Figure A7.11 : Mean distance of caribou locations to the nearest river versus available locations

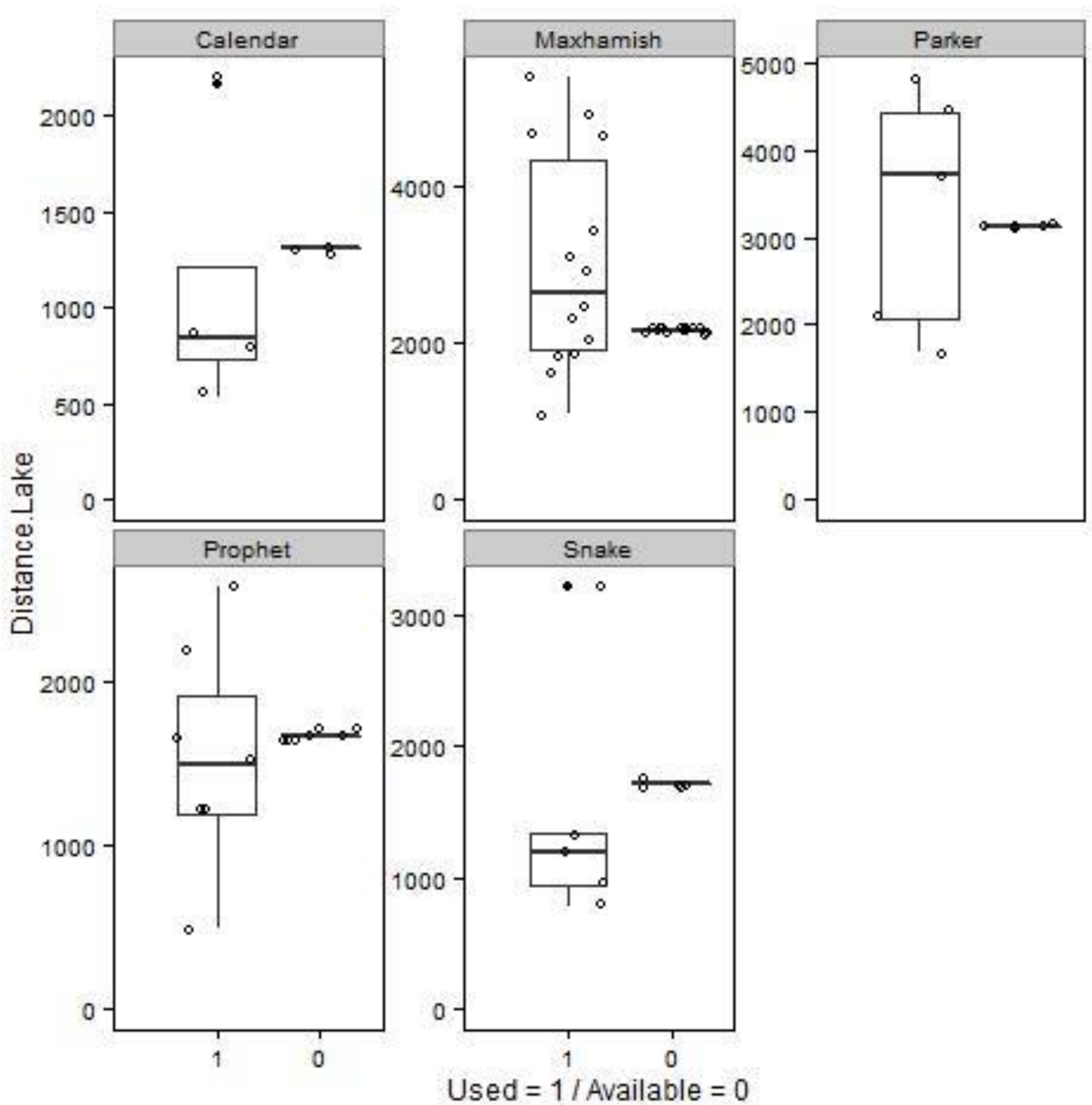


Figure A7.12 : Mean distance of caribou locations to the nearest lake versus available locations

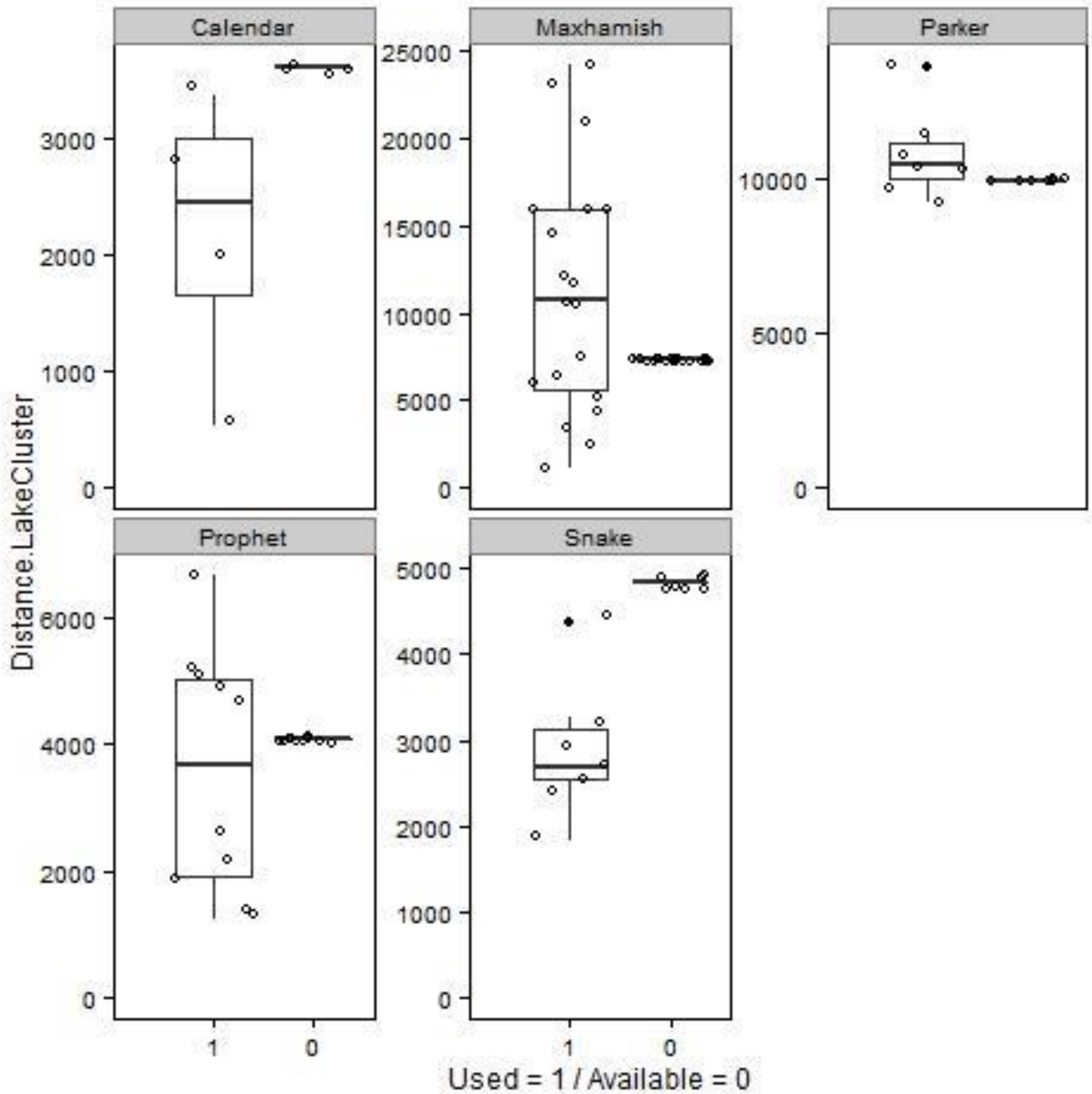


Figure A7.13 : Mean distance of caribou locations to the nearest lake cluster versus available locations

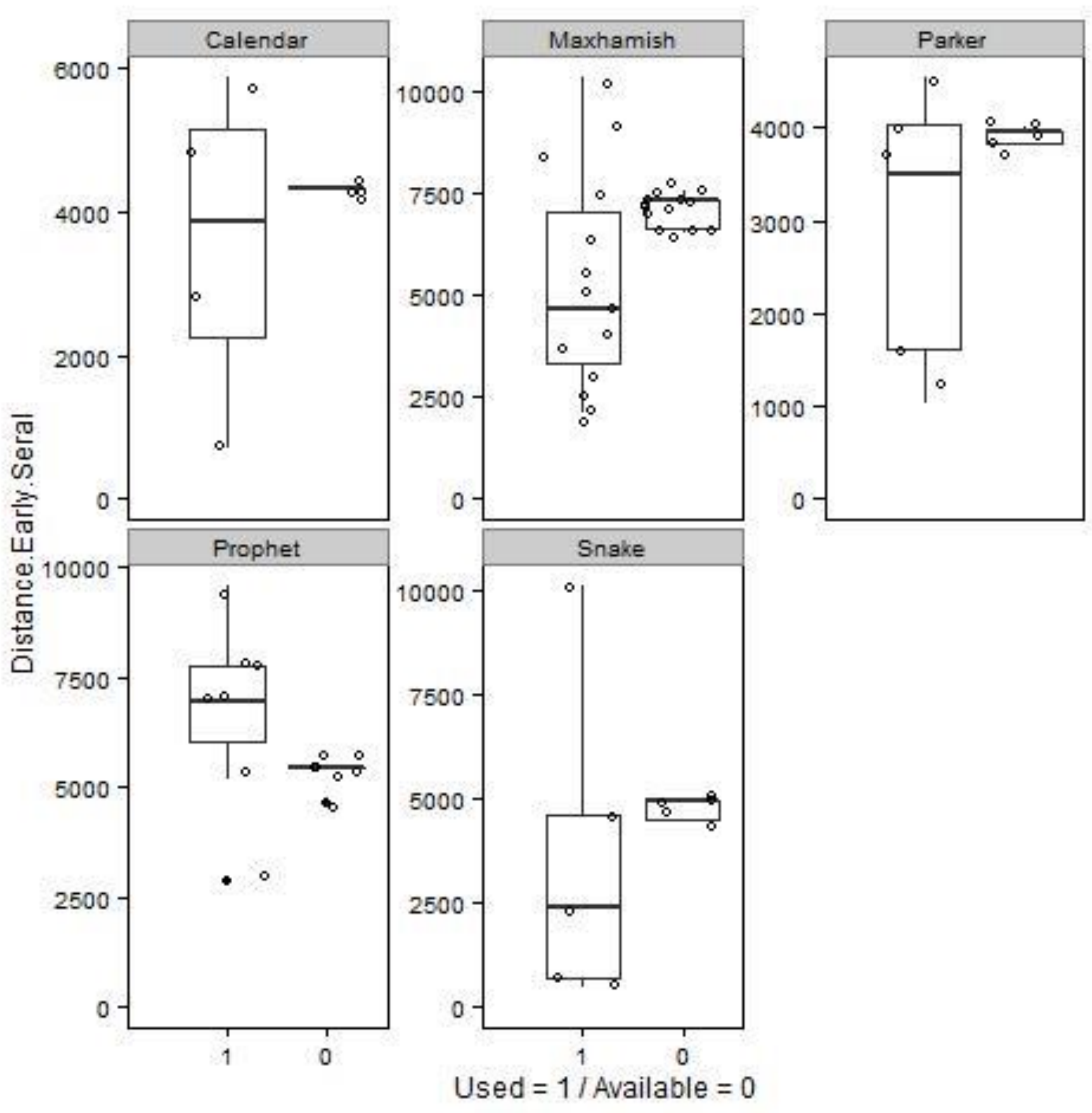


Figure A7.14 : Mean distance of caribou locations to the nearest early seral vegetation versus available locations

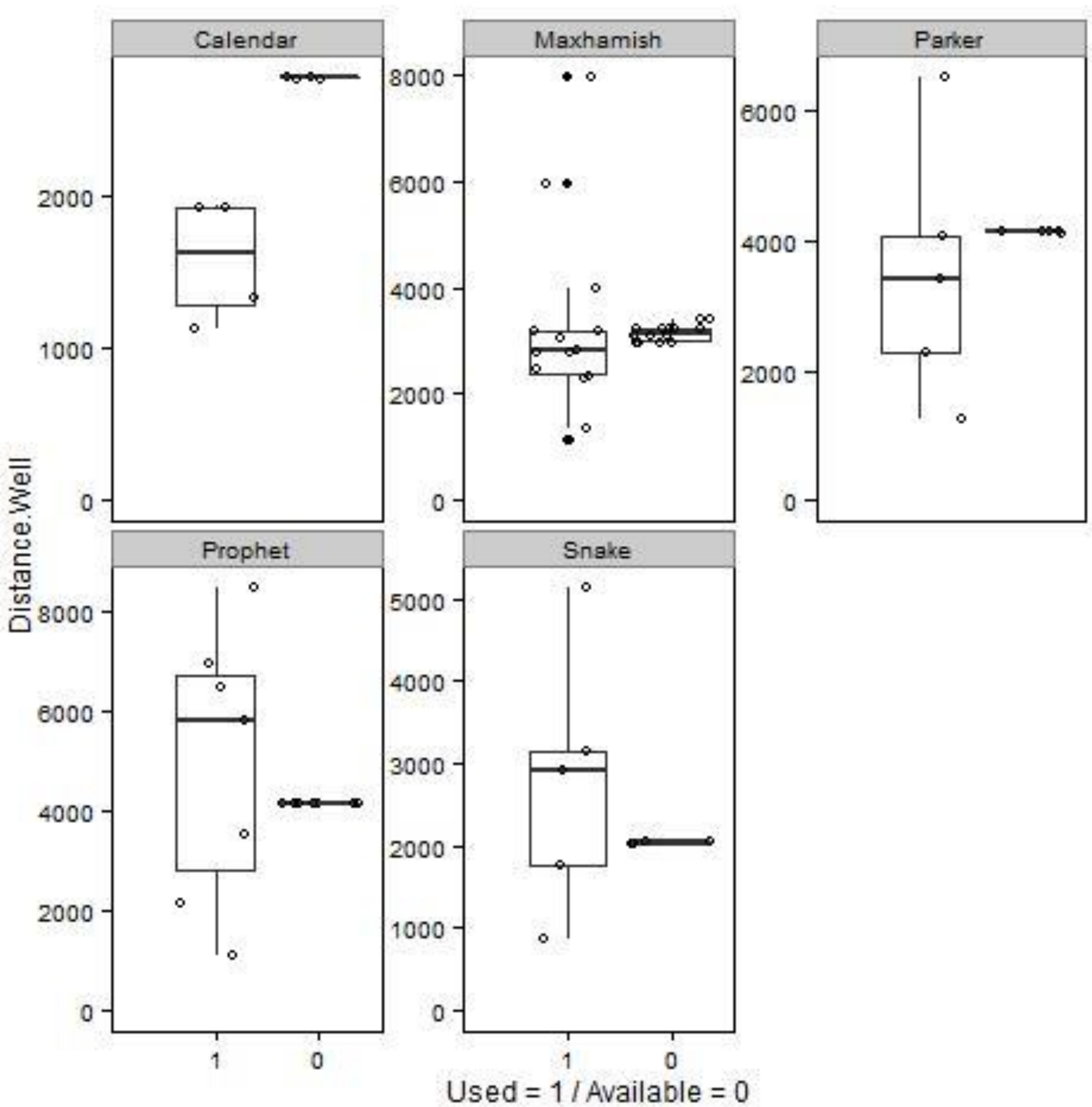


Figure A7.15 : Mean distance of caribou locations to the nearest active well site versus available locations

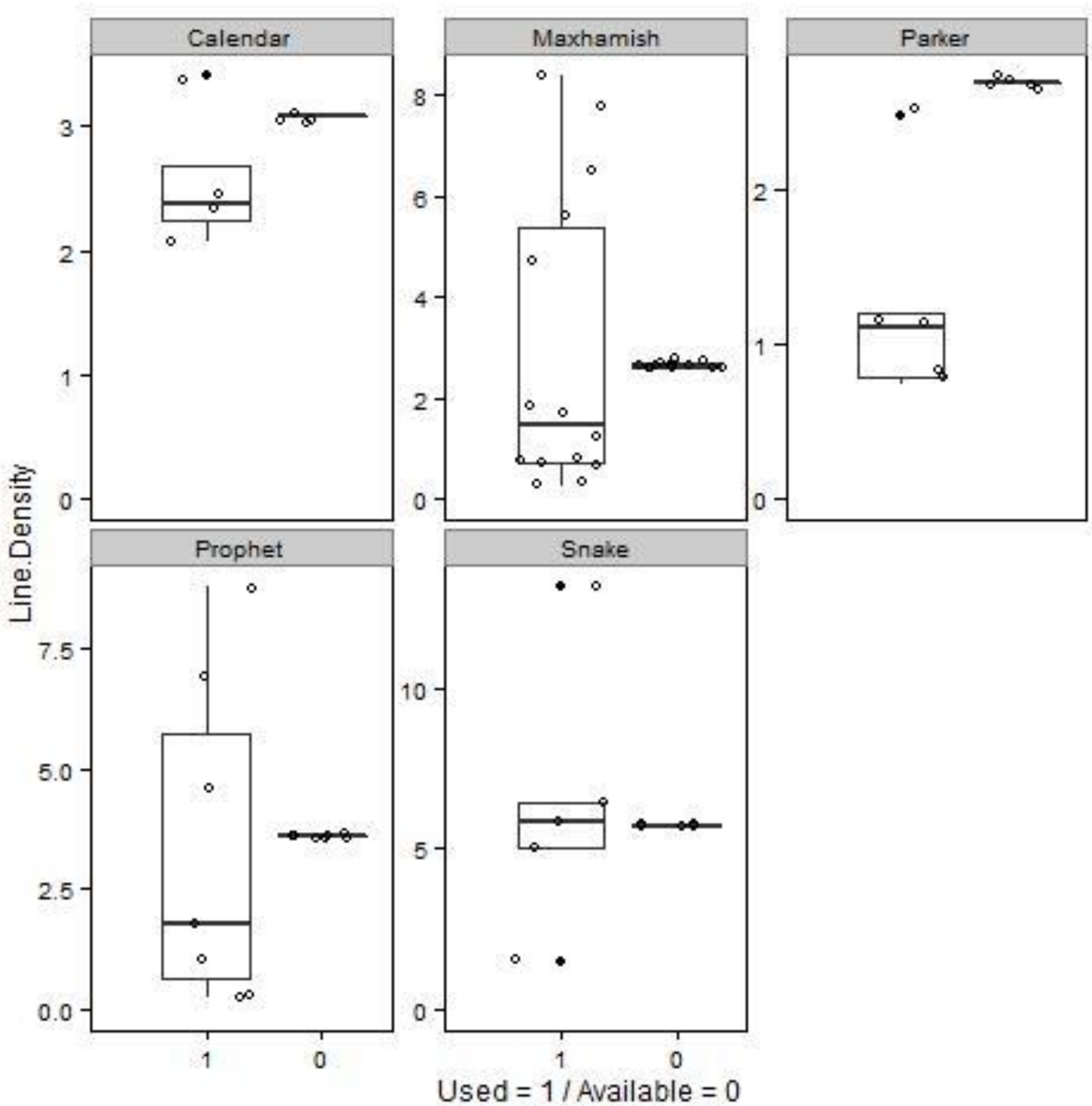


Figure A7.16 : Mean linear feature densities in a 400-m radius around caribou locations versus available locations