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Multi-scale Habitat Selection by Boreal Woodland Caribou in the Sahtú, Gwich'in and Inuvialuit Regions of the Northwest Territories

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ABSTRACT

To expand upon previous Department of Environment and Natural Resource (ENR) studies of habitat selection by boreal woodland caribou in the northern part of their Northwest Territories (NWT) range (Nagy et al. 2005, 2006), resource selection function (RSF) analysis was carried out with data from 58 boreal caribou that were fitted with satellite and GPS collars between 2002 and 2011 in the Sahtú, Gwich'in and Inuvialuit Settlement Regions (ISR). Habitat selection by boreal caribou was evaluated at two spatial scales: the selection of home ranges within the study area (broad scale) and the selection for different areas within each caribou's home range (finer scale). Each scale of habitat selection was evaluated separately for the winter, calving, summer, and fall breeding seasons. To evaluate selection of home ranges within the study area, habitat features at random locations drawn within individual seasonal home ranges were contrasted to habitat features at random locations distributed throughout the study area. Habitat selection within home ranges was evaluated by comparing habitat features at each observed collar location to habitat features at random locations drawn from within individual seasonal home ranges. This approach allowed the two scales of habitat selection to be combined into RSF maps that captured both scales of habitat selection. Habitat features considered in the analysis included land cover type, vegetation productivity, slope, elevation, distance to lakes and rivers, density and distance to seismic lines, presence of roads, and presence of forest fires <40 years old. ENR's interpretation of the results differ somewhat from that presented in the contractor's report. To highlight these differences and to facilitate interpretation of the report, ENR's summary of the second and third order habitat selection results are presented in the Preface to the report. At both scales of selection, caribou avoided areas with roads, burns <40 years old, and areas with a high density of seismic lines or areas close to seismic lines. Caribou also tended to select areas with intermediate vegetation productivity at both scales. Selection for different land cover types varied seasonally. The habitat suitability maps for boreal caribou presented in this report are intended to be used to support range planning for boreal caribou, and to inform land use planning and environmental assessments.

PREFACE

In 2014, the Department of Environment and Natural Resources (ENR) hired Stantec Consulting Ltd. to undertake a habitat selection modeling project for boreal caribou within the northern portion of their range in the Northwest Territories (NWT), with financial support from the federal Habitat Stewardship Program for Species at Risk. The Executive Summary and report that follows were authored by Stantec in 2014. ENR has not made any substantive changes to the report other than reformatting it to Government of the Northwest Territories (GNWT) Visual Identity Program standards and correcting typographical errors. This Preface provides ENR's summary and interpretation of the results, which differ slightly from Stantec's.

Resource selection function analysis was used to assess habitat selection by boreal caribou at two different spatial scales: the selection of home ranges within the study area (broad scale) and the selection for different areas within each caribou's home range (finer scale). Each scale of habitat selection was evaluated separately for the winter, calving, summer, and fall breeding seasons. Home ranges for individual caribou were defined using their collar locations from each of the four seasons. To evaluate selection of home ranges within the study area, habitat features at random locations drawn from within each home range were contrasted to habitat features at random locations distributed throughout the study area. To evaluate habitat selection within each home range, habitat features at each observed collar location were compared to habitat features at random locations drawn from within the home range. This approach allowed the two scales of habitat selection to be combined to produce habitat suitability maps that capture both scales of selection. A total of 88,246 collar locations and an equal number of random locations were used in the analysis.

The habitat features considered at each observed and random location included land cover type, vegetation productivity (based on the normalized difference vegetation index [NDVI] which is a measure of vegetation greenness from which productivity is inferred), slope, elevation, distance to lakes and rivers, density and distance to seismic lines, presence of roads, and presence of forest fires <40 years old. Habitat features were measured using data layers derived from satellite imagery, remote sensing, and topographic data in a geographic information system (GIS). Values for continuous habitat variables were re-scaled between -1 to +1 so that the regression coefficients for different variables could be directly comparable to one another to assess the relative strength of selection for these different factors by caribou. The magnitude and direction of the regression coefficients (+ve or –ve) provide an indication of the strength of selection or avoidance for different habitat factors. The authors also tested for evidence of a functional response in habitat selection for certain resource covariates. A functional response in habitat selection means that the strength of selection or avoidance for a particular resource varies according to the availability of that resource in the landscape. For example, boreal caribou might show stronger selection for a land cover type when it is relatively scarce versus when it is relatively abundant.

In some cases the authors of the report concluded that there was avoidance or selection for different land cover types relative to the reference type when in fact the confidence limits around the regression coefficients (β) likely included 0, indicating that strength of selection or avoidance for the land cover type was probably not statistically different from the reference category. For cases where the standard error (SE) for a regression coefficient is equal to or greater than the regression coefficient (β) for a given variable, readers should be cautious about concluding whether there was in fact avoidance/selection for that land cover type. Tables P1 and P2 provide a summary of the findings about different factors affecting selection of seasonal home ranges within the study area (2nd order selection), and selection of areas within seasonal home ranges (3rd order), keeping the above caveats in mind. They are provided to facilitate the interpretation of the results presented in Tables 3 and 4 of the report.

At the broadest scale of habitat selection and across all seasons, boreal caribou were more likely to establish home ranges in areas without roads, in areas with south-facing slopes and intermediate elevation, areas with a low to intermediate density of seismic lines (<0.8 km/km^2), areas closer to lakes, and areas that hadn't burned in the last 40 years. The sparse conifer vegetation type was used as a reference category in all analyses. The "sparse conifer" cover type has lower canopy closure (<25%) than the "open" (26-60% canopy closure) and "closed" (61-100% canopy closure) canopy types. Relative to areas with sparse conifer cover, caribou consistently avoided mixed wood and deciduous vegetation types, and selected tall-shrub vegetation types year round. Selection for other vegetation types varied by season.

Table P1. Summary of 2nd order habitat selection – i.e., selection of home ranges within the study area. This table should be compared against Table 3 in the report. The following codes are used to summarize selection coefficients for different variables included in the analyses ('Quadratic' – means there was curvilinear response to the habitat variable, refer to Figure 2 in the report; 'R' = Reference category for a categorical variable; '+' = selected relative to the reference category; '-' = avoided relative to the reference category; '0' = neither selected nor avoided relative to the reference category (when SE ≥β); 'NA' = not included in the results table in the report).

Habitat Variables	Season			
	Breeding	Summer	Winter	Calving
Continuous Variables				
Seismic Line Density	Quadratic	Quadratic	Quadratic	Quadratic
NDVI	Quadratic	Quadratic	Quadratic	Quadratic
Distance to water	Quadratic	Quadratic	Quadratic	Quadratic
Elevation	Quadratic	Quadratic	Quadratic	Quadratic
Categorical Variables				
Land Cover				
Water	+	+	0	0
Bryoids (Moss and Lichen)	NA	NA	NA	NA
Herbaceous (Grasses)	0	0	-	-
Tall Shrub (>2 m)	+	+	+	+
Low Shrub (<2 m)	+	+	-	-
Wetland	+	0	0	0
Closed conifer forest (61-100% closure)	0	+	+	+
Open conifer forest (26-60% closure)	0	0	0	0
Sparse conifer forest (<25% closure)	R	R	R	R
Broadleaf forest	-	-	-	-
Mixed Wood forest	-	-	-	-
Other (no data, snow/ice, rock/rubble, exposed/barren)	0	0	-	-
Roads				
Roads (present)	-	-	-	-
Roads (absent)	R	R	R	R
Fire				
Fires > 40 yrs old	R	R	R	R
Fires ≤ 40 yrs old	-	-	-	-
Aspect				
North	R	R	R	R

Habitat Variables	Season			
	Breeding	Summer	Winter	Calving
South	+	0	+	+
East	0	0	0	0
West	+	+	0	+
Flat	0	-	-	-

Within their home ranges, caribou also avoided roads and areas that had burned within the last 40 years, and were more likely to use areas at intermediate distances to seismic lines (~3-5 km) and lakes (1-3 km) and at intermediate elevations (~100-500 m above sea level). The avoidance of areas close to seismic lines appeared to be stronger during the calving and summer season than during the winter and breeding season.

Table P2. Summary of 3rd order habitat selection – i.e. selection of habitat within home ranges. This table should be compared against Table 4 in the report. The following codes are used to summarize selection coefficients for different variables included in the analyses ['Quadratic' – means there was curvilinear response to the habitat, variable, refer to Figure 2 in the report; 'R' = Reference category for a categorical variable; '+' = selected relative to the reference category; '-' = avoided relative to the reference category; '0' = neither selected nor avoided relative to the reference category (when SE ≥β)].

Habitat Variables	Season			
	Breeding	Summer	Winter	Calving
Continuous Variables				
Seismic Line Density	Quadratic	Quadratic	Quadratic	Quadratic
NDVI	Quadratic	Quadratic	Quadratic	Quadratic
Distance to water	Quadratic	Quadratic	Quadratic	Quadratic
Elevation	Quadratic	Quadratic	Quadratic	Quadratic
Categorical Variables				
Land Cover				
Water	-	-	-	-
Bryoids (Moss and Lichen)	+	+	+	+
Herbaceous (Grasses)	0	+	0	0
Tall Shrub (>2 m)	+	+	-	-
Low Shrub (<2 m)	+	+	-	-
Wetland	0	+	-	-
Closed conifer forest (61-100% closure)	-	0	-	-
Open conifer forest (26-60% closure)	0	+	-	0
Sparse conifer forest (<25% closure)	R	R	R	R
Broadleaf forest	-	0	-	-
Mixed Wood forest	0	+	-	-
Other (no data, snow/ice, rock/rubble, exposed/barren)	+	+	-	-
Roads				
Roads (present)	-	-	-	-
Roads (absent)	R	R	R	R
Fires				
Fires > 40 yrs old	-	0	-	-
Fires ≤ 40 yrs old	R	R	R	R
Aspect				
North	R	R	R	R
South	0	0	+	0

Habitat Variables	Season			
	Breeding	Summer	Winter	Calving
East	0	0	+	0
West	0	0	+	+
Flat	0	-	-	0

At both scales of selection, caribou avoided areas with roads, burns <40 years old, and areas with a high density of seismic lines or areas close to seismic lines. Caribou also tended to select areas with intermediate vegetation productivity at both scales. Models that included additional terms to test for evidence of a functional response in habitat selection received much less support from the data than simpler models.

The seasonal RSF maps for second and third order selection and the combined second/third order maps included in the report display the relative probability of selection for different parts of the study area, and are based on a landscape that includes fires up to 2013 and seismic line data up to 2006. The RSF maps display the relative probability of selection of a landscape pixel if encountered by caribou, but should not be relied upon to predict caribou occurrence across the landscape.

EXECUTIVE SUMMARY

The boreal population of woodland caribou (*Rangifer tarandus caribou*) extends over much of boreal Canada, and is listed as Threatened under the Federal *Species at Risk Act* (SARA) and is on the NWT List of Species at Risk under the *Species at Risk (NWT) Act*. As part of conservation planning under the *SARA Boreal Caribou Recovery Strategy*, the Government of the Northwest Territories (GNWT) will delineate boreal woodland caribou habitat within the Northwest Territories (NWT).

Here a resource selection function (RSF) modeling approach is used to describe and map seasonal boreal woodland caribou habitat suitability.

RSFs model the probability of habitat selection by animals at a location based on the statistical relationship between animal locations and habitat features measured at those locations. The GNWT collected satellite telemetry collar data from 58 boreal caribou in the Sahtú, Gwich'in and Inuvialuit regions of the NWT from 2002-2011. These data provided accurate and precise locations of caribou that combined with spatial habitat data in a geographic information system (GIS) were used to calculate RSF models.

Boreal caribou habitat selection was modeled at the second and third orders of selection (i.e., caribou selection of home ranges within the caribou population range, and selection of habitat patches within the home range, respectively) by season, including: calving (April 29 to June 7), summer (June 8 to September 11), breeding (September 12 to October 21) and winter (October to April 28). RSF models with different combinations of habitat features were calculated for each order and season and ranked using Akaike's information criterion (AIC) to test which habitat features were influencing caribou distribution. In addition, RSFs were modeled with and without a generalized functional response (GFR) to test for a functional response in caribou habitat selection. The highest ranked RSF models were each evaluated using a k-fold cross-validation approach, and models from the same season, but different orders of selection, were combined to produce an integrated caribou RSF map per season.

Caribou habitat selection at second and third order scales was a function of several habitat covariates, including terrain, land cover, human development and fire. However, the top-ranked models did not include a functional response to habitat. At the second order of selection caribou were more likely to avoid establishing home ranges in areas with roads and burns <40 years old as well as mixed wood and broadleaf forest, and were more likely to select home ranges with intermediate values of normalized difference vegetation index (NDVI), elevation, and seismic line density. In addition, caribou were more likely to select south-westerly aspects and tall shrub land cover relative to northerly aspects and sparse

conifer (the reference land cover), respectively. Caribou were more likely to avoid closed conifer forest relative to sparse conifer forest in the breeding season and were more likely to select home ranges closer to lakes in the winter compared to other seasons.

At the third order of selection and across all seasons, caribou consistently were more likely to avoid habitat patches with roads, burns <40 years old and broadleaf forest and were more likely to select habitat patches at intermediate distances from seismic lines and lakes and with intermediate elevation values. Caribou were more likely to select habitat patches with open conifer forest relative to sparse conifer in the breeding and summer seasons, but were more likely to avoid them in the winter and calving seasons. Caribou were more likely to avoid habitat patches with closed conifer and mixed wood forest and wetlands relative to sparse conifer forest in the breeding, winter and calving seasons, but were more likely to select them in the summer. Caribou preferred habitat patches approximately 5 km from seismic lines.

Avoidance of patches near seismic lines was strongest during the calving season and avoidance was relatively weak during the breeding season. Caribou preferred habitat patches 1-3 km from lakes during most of the year. They selected elevations 200-400 m above sea level, preferring lower elevations in the summer and higher elevations in the breeding season.

Caribou were more likely to select habitat patches with NDVI values of approximately 5,000 in winter and approximately 6,000 in breeding and calving seasons, but preferred habitat patches with NDVI values up to approximately 7,000 in the summer. NDVI indicates the ratio of near infra-red to red spectral reflectance from vegetation (i.e., vegetation biomass) and has been found to be correlated with ungulate distribution and abundance. Second and third order RSF models had good predictive ability according to k-fold cross validation.

Boreal woodland caribou resource selection in the NWT varied across two spatial-temporal scales reflecting the dynamic nature of habitat selection. However, resource selection by caribou was typically more consistent across seasons at the second order of selection relative to third order, likely because establishment of home ranges within a population range is a longer temporal scale ecological process than selection of habitat patches within home ranges. Boreal caribou may be more likely to respond to seasonal variability in habitat at the patch scale than the home range scale.

The lack of functional response in caribou habitat selection at second and third orders of selection was surprising. In theory, habitat selection by animals depends on the availability of habitats from which they can select. However, it may be that habitat composition within the study area was not varied enough for a functional response to be effectively modeled.

Caribou avoided habitats with roads and recent burns, which is consistent with previous boreal caribou models in the NWT and elsewhere. However, caribou response to seismic lines varied across scales and seasons, indicating plasticity in caribou response to seismic lines. Caribou most strongly avoided establishing home ranges with a high-density of seismic lines and avoided habitat patches closer to seismic lines during calving. This may be because caribou are particularly vulnerable to predation during calving season and predators may use seismic lines to efficiently hunt caribou.

At the third order of selection, caribou shifted to higher food quality and quantity land cover and habitat types (i.e., higher NDVI or plant biomass) during the summer. During calving, caribou calves are vulnerable to predation and thus adult females may prefer habitat secure from predation over high-food quality and quantity habitat. As calves mature throughout the spring and into early summer, and as building energy reserves for winter becomes vital, foraging habitat may become higher priority than low predation risk habitat. Integrated (combined second and third order) RSF prediction maps provide a useful tool for identifying the location of potentially high-quality boreal woodland caribou habitat in the NWT.

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INTRODUCTION

The boreal population of woodland caribou (*Rangifer tarandus caribou*) has a range that extends over much of boreal Canada, and is listed as Threatened under the Canadian *Species at Risk Act* (SARA). In addition, the Government of the Northwest Territories (GNWT) recently (February 2014) listed boreal caribou as Threatened species under the *Species at Risk (NWT) Act*. Environment Canada has developed a national recovery strategy for boreal caribou (Environment Canada 2012) that requires jurisdictions in which this species resides [i.e., Northwest Territories (NWT), British Columbia (BC), Alberta (AB), Saskatchewan (SK), Manitoba (MB), Ontario (ON), Quebec (QC), and Newfoundland-Labrador (NFLD)] to develop range plans for each caribou range. Within the NWT, a single boreal woodland caribou range has been defined. This caribou range extends over a large geographic area (44,156,546 ha) that currently includes an estimated 6,500 caribou, and it has been assessed as likely self-sustaining based on the amount of undisturbed habitat (69%) currently within the range (Environment Canada 2012). The GNWT in collaboration with Environment Canada is tasked with maintaining this self-sustaining status. Essential to this objective is to conserve a minimum of 65% undisturbed high-quality habitats that provides the biophysical attributes necessary for boreal caribou survival and reproduction (Environment Canada 2012).

Habitat maps for range planning will help enable the GNWT and their co-management partners identify priority areas for minimizing potential negative effects of human land use activities on boreal caribou. To date, a Canada-wide boreal caribou habitat model has been developed, but it does not identify high-quality habitat at local scales (e.g., habitat patches within caribou home ranges) and the model specific to the taiga plains ecoregion in the NWT had poor validation results (Environment Canada 2011). Furthermore, it only considers the influence of road density on caribou habitat selection, whereas seismic lines are a more common and thus potentially more influential human disturbance within boreal caribou range in the NWT. A boreal caribou habitat suitability map was previously produced for portions of the NWT, but only within the Gwich'in and Inuvialuit settlement regions of the NWT (Nagy et al. 2006, Nagy 2011).

Here seasonal boreal woodland caribou habitat suitability maps are created for the northern portion of their range in the NWT using a resource selection function (RSF) modeling approach (Boyce and MacDonald 1999, Manly et al. 2002). RSFs are statistical functions that model the probability of habitat selection by animals. Here RSFs were calculated following a use/availability design (Manly et al. 2002) where the statistical function (a logistic regression) calculates probability of use of habitats by comparing habitat features measured at locations "used" by animals (i.e., known presences) to habitat features measured at locations that are "available" to the animal (i.e., presence or absence was not determined). Model covariates from the logistic regression were standardized between 0 and 1, and therefore coefficients indicate the relative strength (i.e., effect size) and type (i.e., positive or negative) of relationship between habitat and caribou selection. The statistical RSF model was used to produce a map of caribou habitat selection.

Generalized functional responses (GFRs) provide increased flexibility in modeling habitat selection by animals by allowing habitat selection at a location to change as a function of available habitat in the surrounding landscape (Matthiopoulos et al. 2011, Moreau et al. 2012). Therefore, functional responses may improve the ability for RSF maps to be extrapolated into regions where animal location data were not available to build the model (Matthiopoulos et al. 2011). We test whether GFRs parsimoniously improve the statistical fit of caribou RSF models.

The GNWT has collected satellite collar data from boreal caribou in the Sahtú and Inuvik Department of Environment and Natural Resources (ENR) administrative regions of the NWT boreal caribou range from 2002-2011. These data provide accurate and precise locations of caribou habitat use. Here these location data are combined with spatial geographic information system (GIS) habitat data to model habitat selection using RSFs. We compare the results of RSF models with and without a functional response using AIC, which compares models by balancing their fit to the data (i.e., the model log-likelihood) with complexity (i.e., the number of model parameters) (Burnham and Anderson 2002). The highest ranked RSF models were spatially extrapolated across the study area to delineate boreal woodland caribou habitat for conservation planning.

METHODS

Study Area

The study occurred within the north-western portion of the boreal caribou range of the NWT (Figure 1). Within the NWT, boreal caribou are considered to be one continuous population across five administrative regions (i.e., Inuvik, Sahtú, Dehcho, North Slave and South Slave). The majority of the boreal caribou population occurs within the taiga plains ecoregion of Canada, which is characterized by level to undulating terrain with some hill systems, extensive peat lands, long, cold winters and short, cool summers (Ecosystem Classification Group 2007). The northern extent of the boreal caribou's range (i.e., the Inuvik region) is characterized by stunted, open stands of white spruce (*Picea glauca*), black spruce (*Picea mariana*) and larch (*Larix laricina*), whereas the central part of the range (i.e., the Sahtú region) is characterized by open mixed black and white spruce stands with a shrubby understory of dwarf birch (*Betula grandulosa*), northern and common Labrador tea (Rhododendron spp.), mosses and lichens (Ecosystem Classification Group 2007). The southern extent of the range (i.e., the Dehcho, North Slave and South Slave regions) occurs primarily in mid-boreal zone, which is characterized by mixed wood forests of aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white spruce and occasionally paper birch (*Betula papyrifera*), containing diverse herb and shrub understories (Ecosystem Classification Group 2007).

Caribou Data Screening

Caribou location data were collected by the GNWT from adult female caribou within the Inuvik and Sahtú regions, from 2002-2011, using GPS or Argos satellite collar technologies. Location fix rates varied among animals from 8-120 hours between locations, and varied within individual animals in some cases. Erroneous locations were removed from analysis by deleting any locations acquired pre- or post-capture, clearly outside of the study area, and in excess of the re-location interval (e.g., less than eight hours apart). Furthermore, any satellite locations with location accuracy <250 m were removed, as positional errors >200 m may introduce error into RSF coefficient estimates (Johnson and Gillingham 2008). This amounted to removing <1% of the locations, which should not bias RSF coefficient estimates (D'Eon and Delparte 2005, Lewis et al. 2007).

Resource Selection Function Modeling

Spatial Scale of Caribou Habitat Selection

Scale is a fundamental characteristic of habitat selection by animals and must be explicitly defined in RSF models. Animals make decisions about habitat use within hierarchical spatiotemporal periods of their life histories, called "orders of selection" (Johnson 1980, Meyer and Thuiller 2006, DeCesare et al. 2012), and animal distribution and abundance is expected to reflect those decisions at different scales. Modeling habitat selection at multiple scales is appropriate to account for hierarchical habitat selection by caribou (DeCesare et al. 2012, Moreau et al. 2012). Scale has two important components, extent and grain, which are correlated with each other (Meyer and Thuiller 2006). Extent considers the landscape within which resource selection is made and grain considers the size of the habitat or resource patch that is selected.

Here boreal caribou habitat selection is modeled at the second and third orders of selection (i.e., selection of individual home ranges within the caribou population geographic range, and selection of habitat patches within the home range, respectively). For reference, the first order of selection is the selection of the geographic range of the species and fourth order of selection is the selection of food items within habitat patches by animals. At the second order of selection, a 100% minimum convex polygon (MCP) of the caribou location data, clipped to the boreal caribou population range for the NWT, defined the extent of available habitat within the caribou population range. Caribou home ranges were delineated for four seasons and for each year (see Seasonal Caribou Habitat Selection) by calculating 95% isopleths of kernel density estimates of caribou locations for each season and individual caribou using the geospatial modeling environment (GME) (Beyer 2012). Kernel density estimates were calculated using the smoothed cross validation bandwidth. An equal number of random locations were sampled within the caribou home range (i.e., used locations) and within the population MCP range. The number of used and available random locations was equivalent to the average number of locations collected per caribou, by season. For the third order selection models, a sample of random locations was drawn within each home range to define available habitat. The number of random locations was equivalent to the number of telemetry locations obtained for that caribou, by season.

Where possible, two different spatial grains of habitat measurements were used for second and third orders of selection, 1,000 m and 100 m, respectively. These spatial grains of habitat are within the order of magnitude that was most predictive of woodland caribou habitat selection at second and third orders of selection (DeCesare et al. 2012).

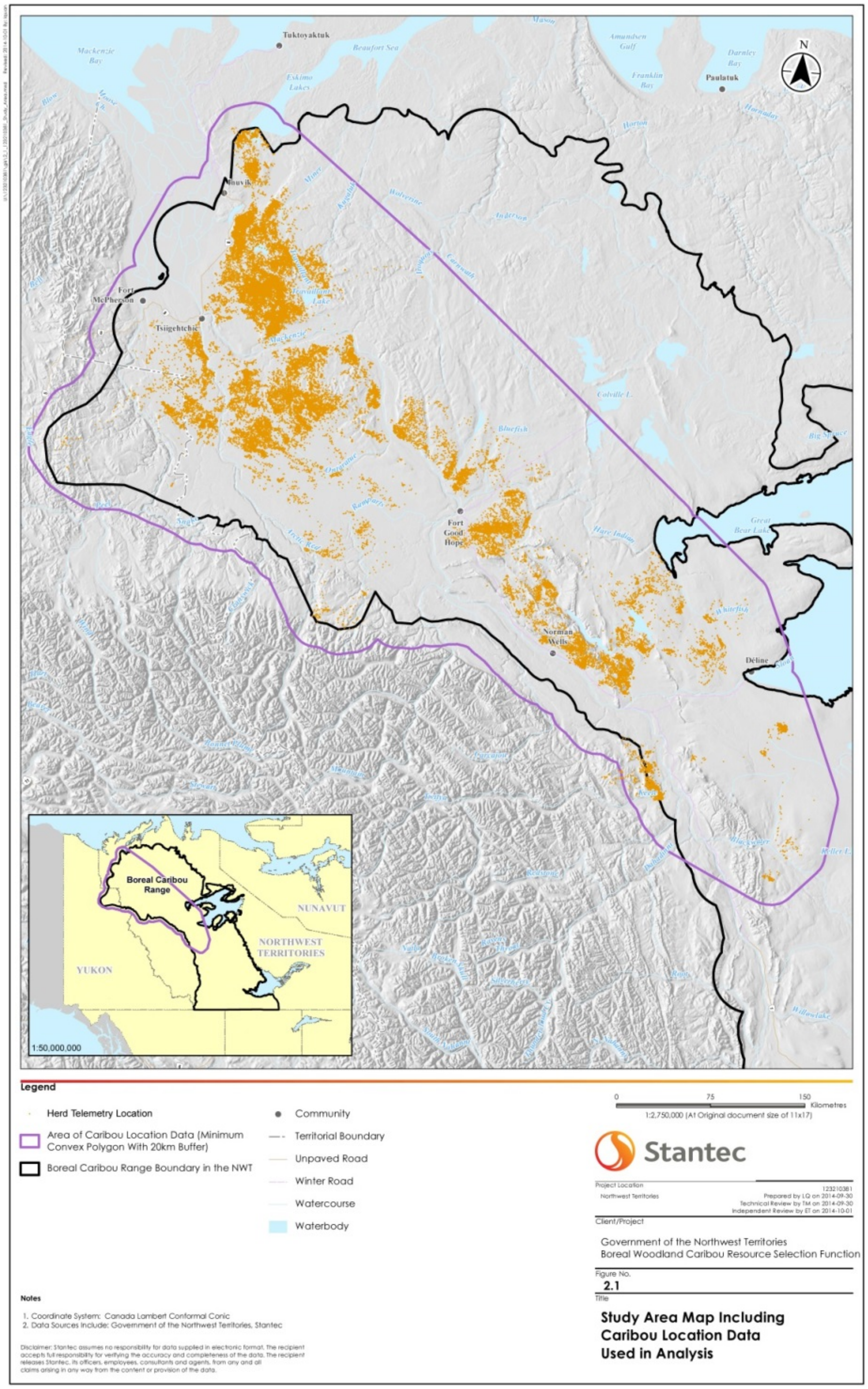

Figure 1. Study area map including caribou location data used in analysis.

Seasonal Caribou Habitat Selection

Here caribou habitat selection is modeled during four distinct seasons consistent with previous definitions of seasonal periods for caribou in the NWT (Nagy et al. 2006, Nagy 2011, Species at Risk Committee 2012), including: calving (April 29 - June 7), summer (June 8 - September 11), breeding (September 12 - October 21) and winter (October 22 - April 28).

Habitat Data

A suite of GIS habitat datasets were compiled that directly or indirectly represent habitat features important to caribou in the NWT, including, vegetation cover, age of burned areas, elevation, aspect, rivers and lakes, vegetation productivity and human disturbance features, such as roads, mines, seismic lines, oil and gas wells and settlements. All GIS measurements at telemetry locations were extracted using ArcGIS 10.1 and GME (Beyer 2012).

Fire

Fire history maps were downloaded from the GNWT Center for Geomatics (www.geomatics.gov.nt.ca). They include fires from 1965 to 2015, mapped at a scale of 1:250,000. They provide the outer extent of burned areas, thus there may be portions within the outer extent that did not burn, which may decrease precision in estimating caribou use of burned areas. The year that the area was burned was assigned to each caribou used (i.e., telemetry) and available location. The number of years since the last burn was calculated as the difference between the year of the actual telemetry location and year of the burn. To measure the number of years since fire at second order used locations (i.e., randomly sampled locations within caribou home ranges) and second and third order available locations (i.e., randomly sampled locations within caribou population and home ranges, respectively), data were divided proportionally into years when telemetry data were collected for the individual caribou. Then the difference between that year and the fire year was calculated. For locations that were not burned, the fire age was set at 100 years. Each location was then classified as one of two types, recent burn (≤40 years since burn) or old burn (>40 years since burn). This follows the definition of recent burn in Environment Canada's boreal caribou model (Environment Canada 2012).

Land Cover

Caribou habitat was defined using land cover mapping obtained from the Earth Observation and Sustainable Development of Forests database which was generated using circa 2,000 classified Landsat imagery at a 25 m resolution (Wulder et al. 2003). Dominant land cover was re-sampled at a 100 m and 1,000 m spatial grain for third and second order RSF models, respectively. Therefore, finer spatial grain data (e.g., 25 m pixels) were re-sampled at a coarser scale by taking the dominant land cover value of within 100 m and 1,000 m areas of the landscape. Originally, there were 36 land cover classes in the database.

To simplify the model specifically for caribou habitat selection, these were grouped into the following 12 classes: water, bryoids, herbaceous, tall shrub, low shrub, wetland, dense conifer forest, open conifer forest, sparse conifer forest, broadleaf forest, mixed wood forest and other (i.e., no data, cloud, shadow, snow/ice, rock/rubble and exposed/barren cover types). Sparse conifer forest was used as the reference category.

Human Disturbances

Data on the density of human disturbances, including mines, roads, settlements, and well sites, was obtained from Environment Canada's boreal ecosystem anthropogenic disturbance inventory maps. Human disturbances were interpreted from 2008-2010 Landsat imagery at a 1:50,000 viewing scale to produce a 1 km spatial resolution raster product[1]. Density of disturbances was calculated at a 1,000 m spatial resolution. However, many of the disturbances were rare in the NWT and therefore most of this data was not used, except road density, which was categorized into a binomial variable as either high (greater than 0 km/km^2) or low (0 km/km^2). Seismic line data was compiled by the Environmental Impact Screening Committee[2] from the GNWT and consisted of a compilation of the NWT data base, National Energy Board data, and National Topographic System data, and updates from seismic work that was done prior to 2006. Seismic line density was calculated at a 1,000 m spatial resolution and distance to nearest seismic line was calculated at a 100 m spatial resolution.

Vegetation Productivity

A measure of vegetation productivity was obtained by using the NDVI. NDVI was derived from MODIS satellite data with a 1,000 m spatial resolution, and annual summer NDVI datasets was downloaded from the US Geological Survey Earth Resources Observation and Science Center (https://lta.cr.usgs.gov/NDVI).

NDVI indicates the ratio of near infra-red to red spectral reflectance from vegetation (i.e., vegetation biomass) and has been found to be correlated with ungulate distribution and abundance (Pettorelli et al. 2005, Hebblewhite and Merrill 2009, Hamel et al. 2009). A NDVI value was attributed to each caribou location based on the year the location was collected. To assign an NDVI value to second order used locations (i.e., locations within caribou home ranges) and second and third order available locations (i.e., locations within caribou population and home ranges, respectively), data were divided proportionally into years when telemetry data were collected for the individual caribou.

[1] http://data.gc.ca/data/dataset/c5a9967d-1621-4dae-9f2a-79a55dbcebd0

[2] The Environmental Impact Screening Committee is a body established under the Inuvialuit Final Agreement that conducts environmental screening of development activities proposed for both the onshore and offshore areas of the Inuvialuit Settlement Region

Elevation and Aspect

A digital elevation model (DEM) was downloaded from Geobase[3] and used to measure elevation and aspect at each location. Aspect was converted to flat, north (316-45°), east (46-135°), south (136-225°) and west (226-315°) facing categories and north was used as the reference category.

Resource Selection Function Analysis

Statistical Data Screening

Prior to RSF analysis, typical data screening for regression analyses was completed, for example, testing for outliers, correlated covariates, interactions, and confounded factors (Zuur et al. 2009, Zuur et al. 2010). When habitat covariates were correlated (i.e., a correlation coefficient >0.7), the covariate that was least correlated to caribou habitat use was removed from analysis. Covariates were also screened to ensure that they did not have a variance inflation factor greater than ten, in which case they would have been removed from analysis (Neter et al. 1990).

A preliminary set of univariate models were built using generalized additive models (GAMs) to test for linear versus non-linear relationships between caribou use and each continuous covariate. GAMs were compared to generalized linear model (GLM) fits using AIC, generalized cross validation (GCV), and R^2 values. Lower AIC and GCV scores and higher R^2 values indicated better fitting models. If non-linear relationships were found, polynomial terms were included in RSF models. If a covariate could not reasonably be fit as a linear or quadratic relationship, we excluded it from the model. Furthermore, GAMs were used to identify the range of habitats over which the RSF could reasonably predict selection. Specifically, 95% confidence intervals around predicted relative probability of use were examined for each univariate model. Where confidence intervals were large (i.e., intervals diverged to two times as much as what was typical across the range of the data), data from those habitats were not used in the predictive model. This is similar to a process of removing outliers from the data, where unusual or rare habitat conditions were not included in the RSF models to avoid erroneously fitting the model to habitats that are underrepresented in the data. This was done for four covariates: NDVI, elevation, distance to seismic or seismic density and distance to lake. GAMs and GLMs were modeled using the mixed GAM computational vehicle package (Wood 2011) in R 3.0.

Statistical Models

Second and third order RSFs were modeled as generalized linear mixed models (GLMMs) with random effect intercepts and slopes for individual caribou to account for

[3] www.geobase.ca/geobase/en/metadata.do?id=3A537B2D-7058-FCED-8D0B-76452EC9D01F

individual behavioural variability in caribou selection of habitat and the hierarchical nature of the data (Gillies et al. 2006, Hebblewhite and Merrill 2008). In addition, GFR models were calculated to model the effects of habitat availability on habitat selection (Matthiopoulos et al. 2011). Functional responses were calculated for seismic line density or distance to seismic line and sparse conifer land cover covariates because they were of particular interest and relevance for boreal caribou in the study region. For GFRs, habitat availability was calculated as the mean value for the resource in the surrounding available habitat for each animal. GLMMs and GFRs were calculated using the linear mixed effects (lme4) package (Bates et al. 2014) in Program R.

R code to implement the GLMM is provided in Appendix A.

Model Selection

Within each season and order of selection, GLMM and GFR models were ranked using conditional AIC to select the most parsimonious model of caribou habitat selection (Burnham and Anderson 2002, Bolker et al. 2009, Greven and Kneib 2010). In some cases, caribou habitat selection may not be a function of available habitat and thus simpler GLMMs may prove to be parsimonious.

Calculating Caribou Resource Selection across Northwestern Northwest Territories

Probability of caribou resource selection was mapped for each season across northwestern NWT using the fixed-effect coefficients from the top-ranked RSF model. Equal area binning was used to display relative probability of selection categories, i.e., each category covers an equivalent area of the study area. The most recent and accurate GIS data available was used to calculate RSF maps (i.e., the 2013 fire data). Models from the same season, but different orders of selection, were combined to produce a single integrated caribou distribution map per season (DeCesare et al. 2012). Integrated seasonal maps were calculated by re-scaling each seasonal RSF model between 0 and 1 using a linear stretch, where the minimum RSF value is subtracted from each RSF value and divided by the difference between the maximum and minimum RSF. Then second and third order maps were multiplied to produce the integrated map.

Model Validation

Seasonal second and third order RSF models were each evaluated using the k-fold cross-validation approach described by Johnson et al. (2006). First, data were partitioned into five groups (i.e., folds), where one fifth of the data was withheld each time (i.e., testing data) and the remaining data (i.e., training data) was used to calculate the RSF. RSF scores were estimated on each testing dataset, and binned into ten ordinal classes (i.e., ranks). Expected utilization of each bin was calculated as the product of the spatial area of the bin on the landscape and the mid-point value of the raw RSF score for each bin divided by the sum of all area and mid-point product values for all bins. The expected number of observations within each bin was calculated as the product of its utilization value and the total number of used locations in the training dataset. Expected utilization was compared to actual utilization (i.e., the number of used locations in the testing data that fell within each bin) using a linear regression model, where regression models with slope of 1, an intercept of 0, an R^2 value close to 1, a non-significant $\chi 2$ goodness of fit value and a Spearman correlation of 1 indicates a predictive model.

RESULTS

Caribou telemetry data were collected from 58 adult female caribou within the Inuvik (n=39) and Sahtú regions (n=19) of the NWT, from 2002-2011, using GPS (n=42) and ARGOS satellite (n=16) collar technologies (Table 1). Data screening using GAMs revealed that elevation, NDVI, seismic line density/distance to seismic line and distance to lake should ideally be modeled with a quadratic term. Covariates that could not be fit as linear or quadratic relationships and thus were removed from further analysis included human settlement density and distance to river. GAMs also revealed high uncertainty in predicting caribou habitat selection at very high or low values of elevation, NDVI, seismic density/distance to seismic line and distance to lake. Specifically, locations with elevations >800 m, NDVI values <2,000 and >8,000, seismic densities >1.25 km/km^2 (for second order models), distance to seismic line values >15 km (for second order models), and distance to lake >8 km or >6 km (for second and third order models, respectively) were dropped from analysis because of high variability around GAM outputs.

Results of second and third order RSF models are described below. Mean, standard deviation, minimum and maximum habitat measurements at used and available caribou locations in the second and third order models are provided in Table 2.

All categorical covariates included in the RSF should be interpreted within the context of 'reference' categories (i.e., the category type that all other categories are compared to). The RSF model included four categorical covariates: burn, land cover, roads and aspect. Each had their own 'reference' category: old burn (>40 years), sparse conifer forest, no roads and north, respectively. The intercept of the RSF model provides the relationship between caribou resource selection and old burns, sparse conifer forest, no roads and north aspects. For example, if it is positive, than it suggests caribou select these categories as a whole. If a categorical covariate, for example, dense conifer, is positive, then it suggests dense conifer is selected relative to old burns, sparse conifer forest, no roads and north aspects. Furthermore, this is similar to comparing the effect of dense conifer relative to sparse conifer on its own, assuming all of the other factors remain the same, as the factors were not correlated or interacted with each other (i.e., they are independent effects).

Caribou Second Order Habitat Selection

The highest ranked seasonal second order RSF models had AIC weights of 1.000 indicating they markedly outperformed other models (Appendix B Table B1). The top-ranked models included fixed and random effect covariates for road density, distance to seismic line, elevation, distance to lake, land cover type, NDVI, aspect, and fire, and no functional response covariates.

The top-ranked second order RSF models indicated that across seasons, caribou were more likely to avoid establishing home ranges in areas with roads, burns <40 years old and mixed wood and broadleaf forest land cover, and were more likely to select home ranges with intermediate NDVI, elevation, and seismic line density (Table 3, Figure 2). In addition, across seasons caribou were more likely to select home ranges with south and westerly aspects and tall shrub land cover. Caribou were more likely to avoid home ranges with closed conifer forest (relative to sparse conifer) in the breeding season, but were more likely to select closed conifer forest across the remaining seasons and were more likely to select home ranges with low shrub, herbaceous and wetland habitats in the breeding and summer seasons, but were more likely to avoid them in the calving and winter seasons. Caribou were more likely to select home ranges at intermediate distances to lake in summer, calving and breeding season, but were more likely to select home ranges closer to lakes in the winter.

Relative probability of second order resource selection was mapped across the study area (i.e., the MCP of the caribou location data with a 20 km buffer) by season. Second order maps were relatively consistent across seasons, as high-value RSF habitats occurred in the central and north-central part of the study area during the breeding (Figure 3), summer (Figure 4) winter (Figure 5) and calving (Figure 6) seasons.

The low-probability of resource selection predicted in the relatively large area southwest of Fort Good Hope was the result of a very high-density of seismic lines in the region and the negative relationship between seismic line density and caribou locations.

Table 1. Summary of caribou telemetry data used in the resource selection function analysis, including region, collar type, state and end dates, relocation interval, and number of locations by season.

Caribou ID	GNWT ID	Region	Collar Type	Start Date	End Date	Relocation Interval (hours)	Number of Locations				
							Total	Breeding	Calving	Summer	Winter
1	BW26	Inuvik	GPS	10/03/2005	09/03/2007	4	4,070	451	499	720	2,400
2	BW27	Inuvik	GPS	10/03/2005	11/03/2007	8	2,122	235	234	559	1,094
3	BW28	Inuvik	GPS	10/03/2005	12/03/2007	8	2,138	236	235	558	1,109
4	BW29	Inuvik	GPS	10/03/2005	13/03/2007	8	1,842	232	225	317	1,068
5	BW30	Inuvik	GPS	10/03/2005	11/03/2007	8	2,111	234	237	553	1,087
6	BW31	Inuvik	GPS	10/03/2005	11/03/2007	8	2,127	236	234	543	1,114
7	BW33	Inuvik	Satellite	11/03/2005	14/04/2006	48	220	18	40	49	113
8	BW34	Inuvik	GPS	11/03/2005	09/03/2007	8	5,519	583	692	1,512	2,732
9	BW35	Inuvik	Satellite	11/03/2005	16/10/2005	48	127	17	37	47	26
10	BW36	Inuvik	Satellite	11/03/2005	17/10/2005	48	103	16	28	35	24
11	BW37	Inuvik	Satellite	11/03/2005	10/06/2006	48	158	14	32	22	90
12	BW39	Inuvik	Satellite	12/03/2005	30/06/2007	48	467	39	111	110	207
13	BW40	Inuvik	Satellite	12/03/2005	06/08/2008	48	589	57	130	95	307
14	BW41	Inuvik	Satellite	12/03/2005	18/04/2007	48	386	37	59	65	225
15	BW42	Inuvik	Satellite	12/03/2005	13/10/2007	48	451	49	85	88	229
16	BW45	Inuvik	GPS	02/04/2006	01/08/2009	8	3,608	357	478	1,012	1,761
17	BWC07/01	Inuvik	GPS	11/03/2007	01/08/2010	8	3,527	332	462	957	1,776
18	BWC07/04	Inuvik	GPS	11/03/2007	19/07/2009	8	2,470	233	345	658	1,234
19	BWC07/05	Inuvik	GPS	10/03/2007	01/08/2010	8	1,754	54	283	52	1,365
20	BWC07/09	Inuvik	GPS	11/03/2007	11/06/2008	8	1,145	88	180	290	587
21[1]	BWC08/01	Inuvik	GPS	13/03/2008	01/08/2011	8	1,930	159	250	12	1,509
22	BWC08/05	Inuvik	GPS	11/03/2008	02/08/2011	8	1,619	126	281	535	677

Caribou ID	GNWT ID	Region	Collar Type	Start Date	End Date	Relocation Interval (hours)	Number of Locations				
							Total	Breeding	Calving	Summer	Winter
23[2]	BWC08/07	Inuvik	GPS	11/03/2008	09/08/2008	8	442	0	110	188	144
24	BWC08/08	Inuvik	GPS	13/03/2008	01/08/2011	8	3,519	330	454	975	1,760
25	BWC08/09	Inuvik	GPS	13/03/2008	01/08/2011	8	2,907	269	344	854	1,440
26	BWC08/10	Inuvik	GPS	13/03/2008	02/08/2011	8	3,231	325	464	969	1,473
27	BWC08/11	Inuvik	GPS	13/03/2008	01/08/2011	8	3,028	293	448	852	1,435
28[3]	BWC18	Inuvik	GPS	11/03/2008	20/04/2008	8	116	0	0	0	116
29	BWC21	Inuvik	GPS	11/03/2008	05/07/2012	8	4,051	433	559	1,123	1,936
30[4]	BWC23	Inuvik	GPS	10/03/2008	30/06/2008	8	319	0	120	55	144
31	BWC35981	Inuvik	GPS	28/03/2003	07/07/2004	8	1,303	118	218	346	621
32	BWC35982	Inuvik	GPS	02/04/2003	06/06/2005	8	1,562	117	250	368	827
33	BWC35983	Inuvik	GPS	01/05/2002	07/05/2004	8	1,164	162	177	442	383
34	BWC35984	Inuvik	GPS	02/04/2003	06/06/2005	8	1,365	135	212	318	700
35	BWC36182	Inuvik	GPS	01/05/2002	06/06/2004	8	1,996	215	303	496	982
36	BWC36186	Inuvik	Satellite	02/04/2003	03/11/2005	120	248	21	76	75	76
37	BWC36187	Inuvik	Satellite	02/04/2003	27/10/2003	120	50	7	21	14	8
38	BWC36188	Inuvik	Satellite	02/04/2003	31/07/2005	120	217	15	80	49	73
39	BWC36189	Inuvik	Satellite	28/03/2003	03/11/2005	120	211	19	66	61	65
40	1010	Sahtú	GPS	30/03/2008	24/12/2009	8-24	1,120	124	149	390	457
41	1011	Sahtú	GPS	29/03/2008	10/12/2010	8-24	2,556	237	381	711	1,227
42	1012	Sahtú	GPS	29/03/2008	08/11/2010	8-24	2,677	240	378	739	1,320
43	1089	Sahtú	GPS	30/03/2008	24/06/2010	8-24	1,995	118	335	562	980
44	1500	Sahtú	GPS	15/04/2006	30/09/2009	8-24	1,288	133	194	523	438
45[5]	1501	Sahtú	GPS	15/04/2006	13/05/2006	24	29	0	15	0	14
46	1502	Sahtú	GPS	15/04/2006	30/09/2009	8-24	1,429	141	225	562	501

Caribou ID	GNWT ID	Region	Collar Type	Start Date	End Date	Relocation Interval (hours)	Total	Number of Locations Breeding	Calving	Summer	Winter
47	1503	Sahtú	GPS	15/04/2006	01/03/2010	8-24	1,792	190	203	579	820
48	1504	Sahtú	GPS	15/04/2006	30/09/2009	8-24	1,471	142	237	588	504
49	1600	Sahtú	GPS	15/03/2007	01/10/2010	8-24	2,210	221	314	711	964
50	1601	Sahtú	GPS	16/03/2007	02/08/2010	8-24	2,084	163	307	622	992
51	1603	Sahtú	GPS	15/03/2007	01/08/2010	8-24	1,984	145	305	586	948
52	1701	Sahtú	GPS	30/03/2008	30/10/2008	24	192	6	40	108	38
53	1702	Sahtú	GPS	31/03/2008	01/08/2010	24	1,678	117	273	518	770
54	1816	Sahtú	GPS	05/04/2005	11/11/2007	24	718	103	79	192	344
55	1302	Sahtú	Satellite	12/04/2005	13/03/2009	120	334	25	112	82	115
56	1800	Sahtú	Satellite	28/03/2005	06/04/2008	120	302	23	90	77	112
57	1801	Sahtú	Satellite	28/03/2006	29/05/2007	120	108	7	46	24	31
58[6]	1801	Sahtú	Satellite	23/01/2008	14/08/2008	48	67	0	16	27	24
Total							**88,246**	**8,397**	**12,758**	**23,575**	**43,516**

[1] Dropped from "summer" season analysis.

[2] Dropped from "breeding" season analysis.

[3] Dropped from "breeding", "calving" and "summer" season analysis.

[4] Dropped from "breeding" season analysis.

[5] Dropped from "breeding" and "summer" season analysis.

[6] Dropped from "breeding" season analysis.

Table 2. Mean, standard deviation, minimum and maximum habitat covariate values measured at used and available caribou locations at second and third orders of resource selection.

Order	Season	Covariate	Mean	SD	Maximum	Minimum
Second	Breeding	Elevation (m)	205	120	798	2
		Seismic Line Density (km/km^2)	0.25	0.21	1.25	0.00
		Distance to Lake (m)	1,220	1,306	11,443	0
		NDVI	5,994	569	7,977	2,034
	Summer	Elevation (m)	207	123	800	0
		Seismic Line Density (km/km^2)	0.25	0.21	1.25	0.00
		Distance to Lake (m)	1,206	1,290	12,371	0
		NDVI	5,990	573	7,991	2,040
	Winter	Elevation (m)	208	122	800	0
		Seismic Line Density (km/km^2)	0.25	0.21	1.25	0.00
		Distance to Lake (m)	1,124	1,232	12,827	0
		NDVI	5,983	576	8,000	2,000
	Calving	Elevation (m)	205	124	800	0
		Seismic Line Density (km/km^2)	0.25	0.20	1.24	0.00
		Distance to Lake (m)	1,157	1,231	11,678	0
		NDVI	5,982	600	7,999	2,005
Third	Breeding	Elevation (m)	207	111	961	12
		Distance to Seismic Line (m)	4,065	3,845	14,983	0
		Distance to Lake (m)	1,305	1,131	5,991	0
		NDVI	5,962	430	7,742	2,822
	Summer	Elevation (m)	204	128	995	15
		Distance to Seismic Line (m)	3,656	3,515	14,994	0
		Distance to Lake (m)	1,281	1,061	6,000	0
		NDVI	5,892	519	7,976	2,078
	Winter	Elevation (m)	202	82	998	16
		Distance to Seismic Line (m)	3,540	3,350	14,989	0
		Distance to Lake (m)	1,009	1,001	5,982	0
		NDVI	5,910	418	7,976	2,174
	Calving	Elevation (m)	198	98	971	3
		Distance to Seismic Line (m)	3,402	3,353	14,991	0
		Distance to Lake (m)	1,255	970	5,941	0
		NDVI	5,962	421	7,601	2,157

NOTES: Normalized difference vegetation index (NDVI).

Table 3. Resource selection function (RSF) coefficients (β), standard errors (SE) and t-values indicating the strength and type of selection by caribou for habitat covariates at the second order of resource selection, by season.

	Breeding			Summer			Winter			Calving		
Covariate	β	SE	t-value	β	SE	t-value	β	SE	t-value	β	SE	t-value
Intercept	0.26	0.02	15.09	0.26	0.02	12.85	0.34	0.01	27.11	0.32	0.02	21.09
Distance to Lake (DL)	0.02	0.02	1.09	0.03	0.02	1.31	-0.01	0.02	-0.55	0.04	0.02	2.04
Distance to Lake^2*	-0.03	0.02	-1.85	-0.03	0.02	-2.29	-0.01	0.01	-0.91	-0.05	0.01	-3.69
NDVI	0.21	0.02	9.02	0.24	0.03	9.11	0.21	0.02	8.62	0.16	0.02	8.06
NDVI^2	-0.22	0.02	-9.13	-0.24	0.03	-8.25	-0.23	0.03	-8.39	-0.18	0.02	-8.64
Open Conifer	0.02	0.01	2.04	0.00	0.01	0.83	0.00	0.00	0.42	0.01	0.01	1.33
Closed Conifer	-0.02	0.02	-0.94	0.04	0.01	3.93	0.04	0.01	4.62	0.10	0.01	6.76
Mixed Wood	-0.08	0.02	-4.88	-0.08	0.01	-7.91	-0.08	0.01	-10.06	-0.09	0.01	-6.18
Broadleaf	-0.16	0.02	-6.73	-0.18	0.01	-13.72	-0.18	0.01	-16.95	-0.16	0.02	-8.55
Tall Shrub	0.18	0.01	12.28	0.18	0.01	22.65	0.13	0.01	18.35	0.14	0.01	10.85
Low Shrub	0.03	0.01	3.32	0.02	0.01	2.84	-0.03	0.00	-6.61	-0.03	0.01	-3.44
Herbaceous	0.03	0.03	1.03	0.01	0.02	0.34	-0.07	0.01	-4.95	-0.05	0.03	-1.82
Wetland	0.02	0.01	1.89	0.01	0.01	1.42	-0.01	0.01	-2.12	-0.01	0.01	-0.95
Water	0.04	0.01	2.84	0.02	0.01	2.55	0.00	0.01	-0.21	0.01	0.01	0.81
Other	0.01	0.01	0.72	0.00	0.01	-0.33	-0.02	0.01	-3.93	-0.04	0.01	-3.65
Elevation	0.08	0.05	1.73	0.07	0.04	1.54	0.09	0.04	2.06	0.00	0.03	0.13
Elevation^2	-0.14	0.04	-3.43	-0.11	0.04	-3.14	-0.12	0.04	-3.42	-0.06	0.03	-2.27
East Aspect	0.02	0.02	1.06	-0.02	0.02	-1.22	0.00	0.02	0.10	0.02	0.02	1.10
South Aspect	0.04	0.02	2.07	0.01	0.02	0.52	0.04	0.02	2.00	0.06	0.02	3.07
West Aspect	0.04	0.02	2.39	0.03	0.02	1.72	0.02	0.02	1.41	0.04	0.02	2.39
Covariate	β	SE	t-value	β	SE	t-value	β	SE	t-value	β	SE	t-value
Flat Aspect	0.05	0.05	0.95	-0.08	0.04	-2.06	-0.09	0.03	-2.87	-0.09	0.04	-2.18
Burn (<40 years old)	-0.04	0.02	-1.80	-0.07	0.03	-2.40	-0.08	0.02	-4.00	-0.04	0.02	-1.84

	Breeding			Summer			Winter			Calving		
Covariate	β	SE	t-value	β	SE	t-value	β	SE	t-value	β	SE	t-value
Roads	-0.13	0.04	-2.97	-0.19	0.03	-6.03	-0.16	0.03	-5.52	-0.18	0.04	-4.41
Seismic Line Density	0.12	0.05	2.40	0.09	0.05	1.64	0.15	0.05	2.86	0.15	0.05	3.03
Seismic Line Density^2	-0.13	0.03	-4.02	-0.10	0.04	-2.62	-0.15	0.03	-4.71	-0.18	0.03	-5.81

NOTES: * Covariates with a ^{2} are the quadratic terms for that covariate.

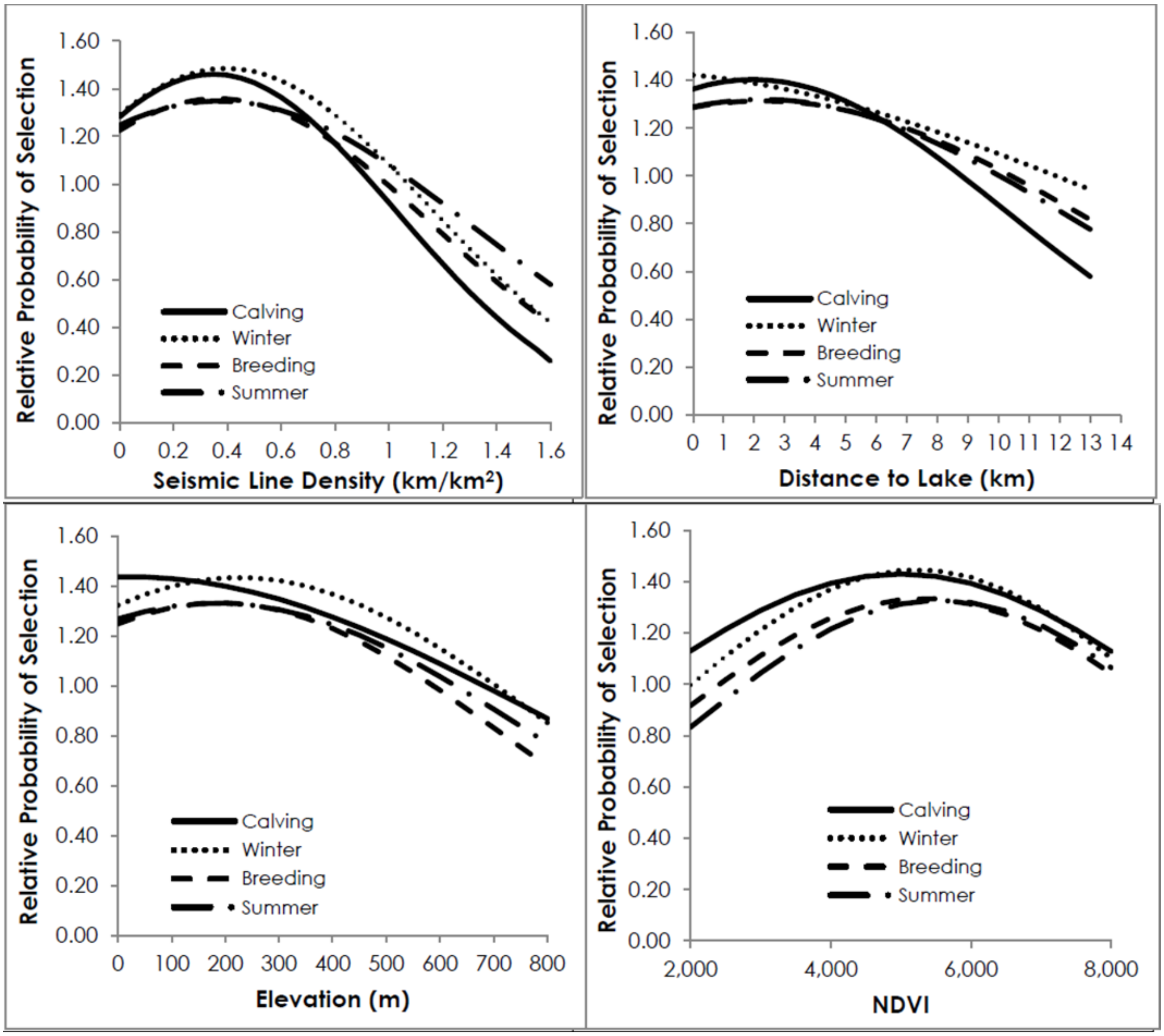

Figure 2. Relative probability of caribou selection of seismic line density (top left), distance to lake (top left), elevation (bottom left), and normalized difference vegetation index (bottom right) in the calving, winter, breeding and summer seasons at the second order of selection.

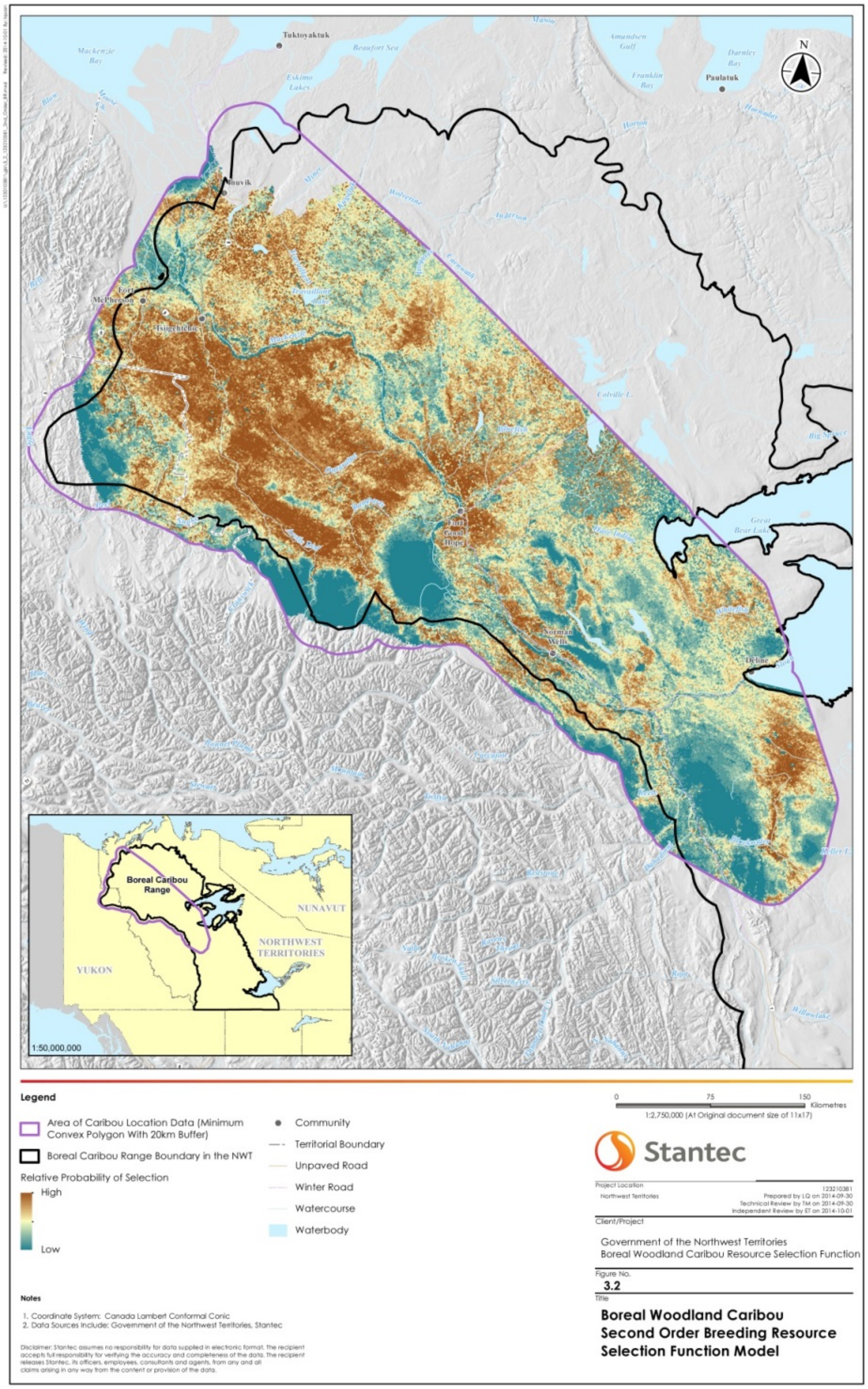

Figure 3. Boreal woodland caribou second order breeding resource selection function model.

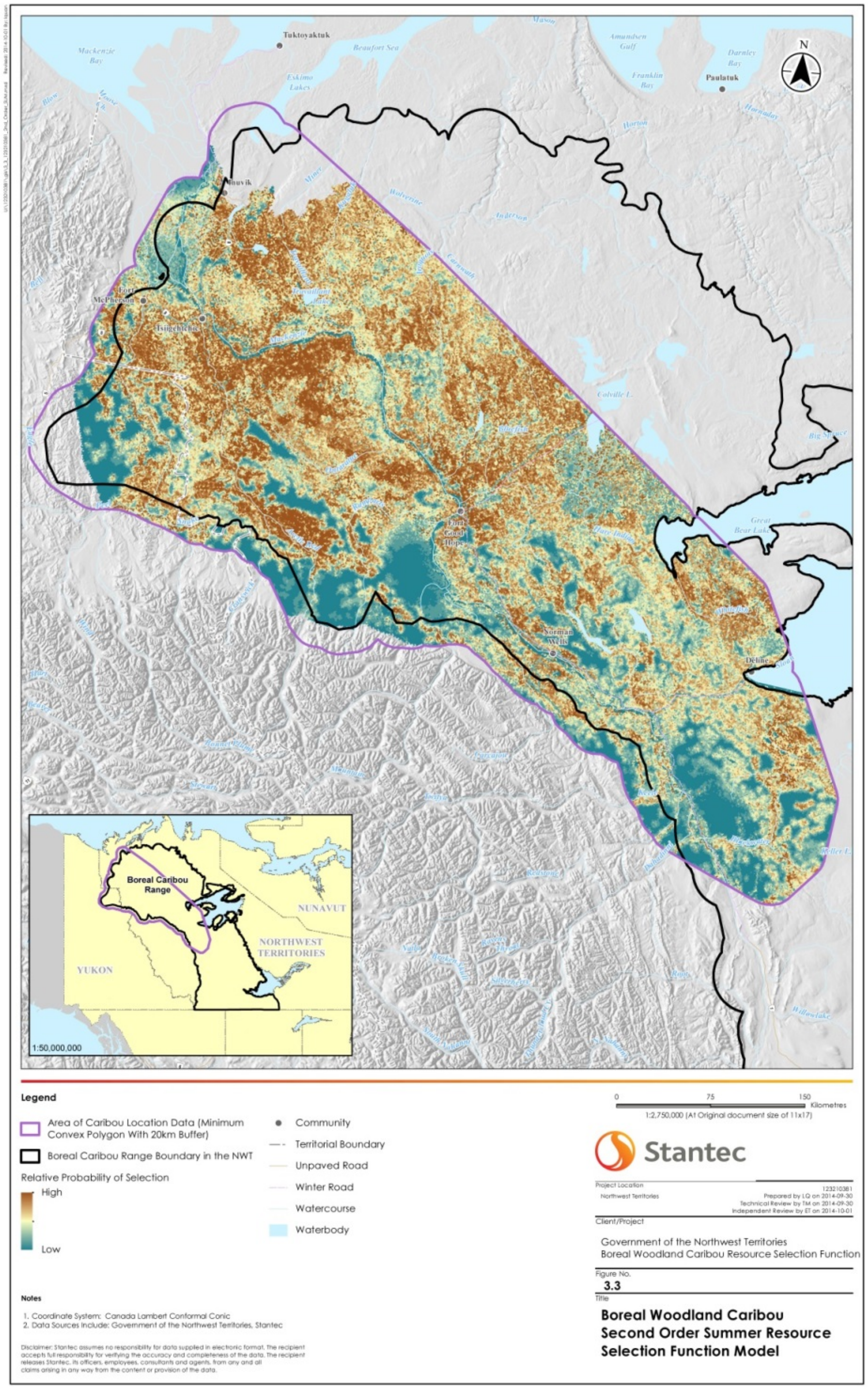

Figure 4. Boreal woodland caribou second order summer resource selection function model.

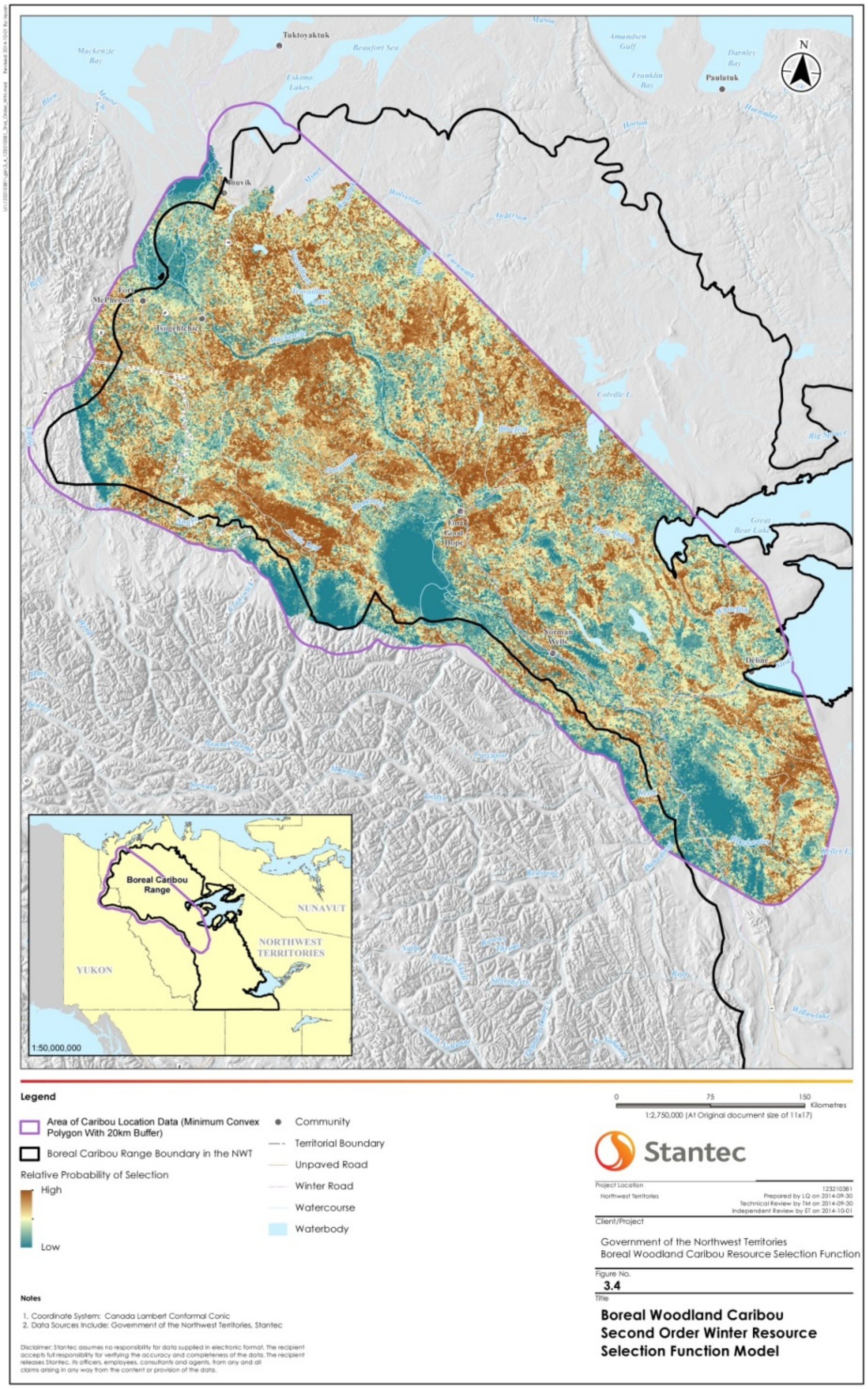

Figure 5. Boreal woodland caribou second order winter resource selection function model.

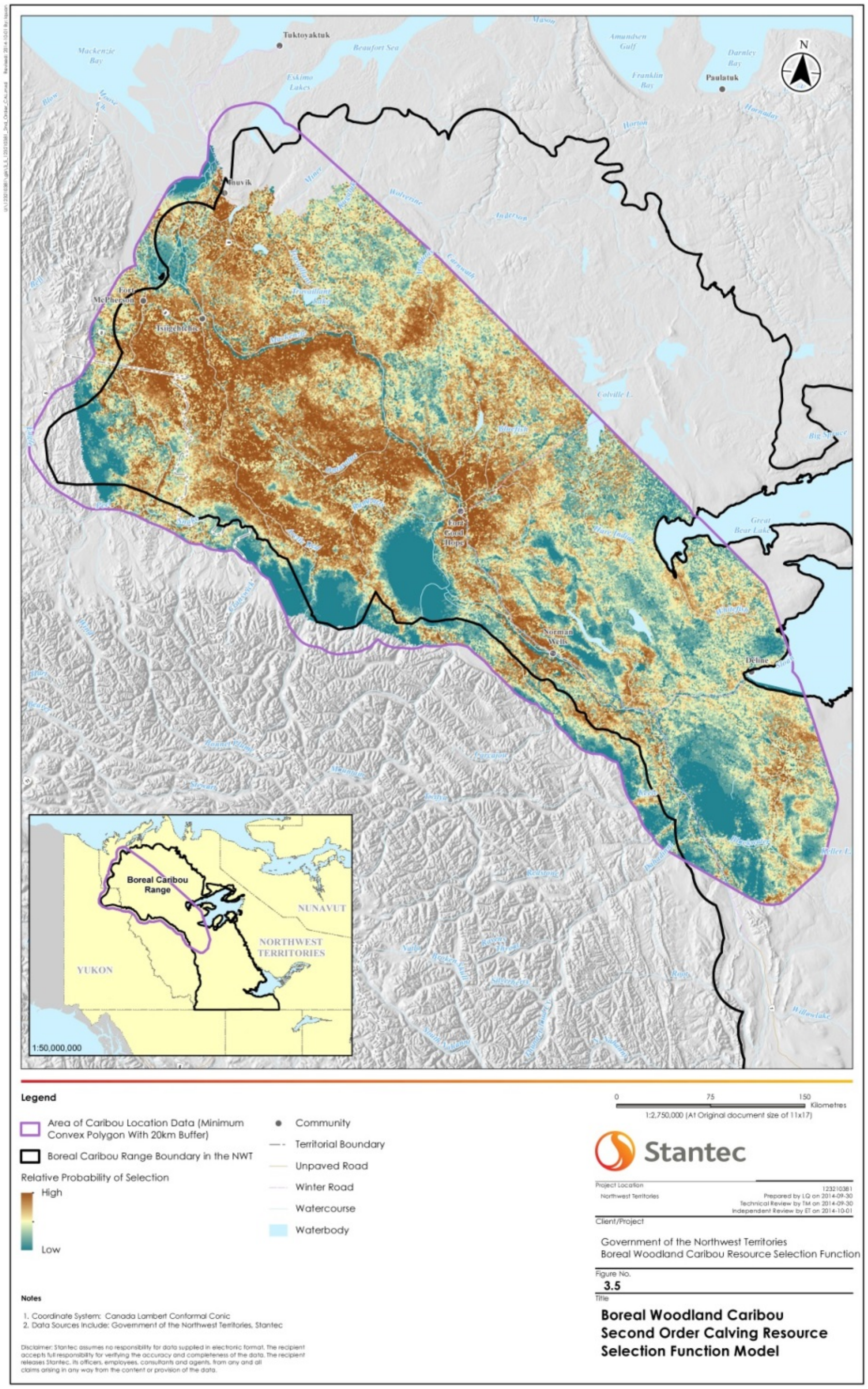

Figure 6. Boreal woodland caribou second order calving resource selection function model.

Caribou Third Order Habitat Selection

Across all seasons, the highest ranked third order RSF models had AIC weights of 1.000 (Appendix B Table B2). The top ranked seasonal third order RSF models included fixed and random effect covariates for road density, distance to seismic line, elevation, distance to lake, land cover type, NDVI, aspect, and fire, but no functional response covariates.

Across seasons, caribou consistently were more likely to avoid habitat patches with roads, broadleaf forest and burns <40 years old and were more likely to select habitat patches at intermediate distances from seismic lines and lakes and at intermediate elevation (Table 4). Caribou were more likely to select habitat patches with open conifer forest in the summer season (relative to sparse confer), but were more likely to avoid open conifer forest in the winter and calving seasons. Caribou were more likely to avoid habitat patches with closed conifer and mixed wood forest and wetlands in the breeding, winter and calving seasons, but not in the summer. Caribou were more likely to select habitat patches with tall and low shrubs in the breeding and summer seasons, but were more likely to avoid shrub habitats in the winter and calving seasons. Caribou were more likely to avoid habitat patches with herbaceous land cover in all seasons except for breeding.

Caribou were more likely to select intermediate distance to seismic lines, distance to lake, elevation and NDVI across most seasons, with a few exceptions (Figure 7). Caribou were more likely to prefer habitat patches approximately 5 km from seismic lines. Avoidance of patches near seismic lines was relatively weak during the breeding season compared to the rest of the year. Caribou preferred habitat patches 1-3 km from lakes during most seasons, but the effects of lakes were weak during the winter as caribou appeared to not avoid or select lakes. They were more likely to select elevations 100-300 m above sea level, preferring lower elevations in the summer and higher elevations in the breeding season. Caribou were more likely to select habitat patches with average NDVI values of approximately 5,000 in winter and approximately 6,000 in breeding and calving seasons, but were more likely to select habitat patches with average NDVI values up to approximately 7,000 in the summer.

Relative probability of third order caribou habitat selection was mapped across the northern portion of the study area (i.e., the MCP of the caribou location data with a 20 km buffer). RSF values for breeding habitat were relatively high around the Arctic Red and Snake Rivers and west of Fort McPherson (Figure 8). Predicted summer (Figure 9) and winter (Figure 10) RSF values showed distinct habitat patches in the north-central portion of the boreal caribou range, near the Mackenzie and Ontaratue Rivers. Calving RSF values were relatively high throughout the region, particularly around the Mackenzie, Ontaratue and Arctic Red Rivers (Figure 11).

Table 4. Resource selection function (RSF) coefficients (β), standard errors (SE) and t-values indicating the strength and type of selection by caribou for habitat covariates at the third order of resource selection, by season.

	Breeding			Summer			Winter			Calving		
Covariate	β	SE	t-value	β	SE	t-value	β	SE	t-value	β	SE	t-value
Intercept	0.40	0.03	14.77	0.25	0.04	6.28	0.44	0.02	24.69	0.39	0.02	19.61
Distance to Lake	0.13	0.02	7.50	0.13	0.02	5.59	0.05	0.02	2.68	0.20	0.02	11.27
Distance to Lake^2*	-0.12	0.02	-5.98	-0.16	0.02	-6.50	-0.04	0.02	-1.77	-0.19	0.02	-9.87
NDVI	0.23	0.04	5.72	0.23	0.04	5.25	0.33	0.03	11.47	0.24	0.03	8.73
NDVI^2	-0.22	0.04	-5.08	-0.19	0.04	-4.65	-0.38	0.03	-11.67	-0.24	0.03	-7.81
Open Conifer	0.00	0.01	-0.20	0.03	0.01	4.12	-0.05	0.01	-9.74	-0.01	0.01	-1.57
Closed Conifer	-0.11	0.03	-4.03	0.00	0.01	0.32	-0.10	0.01	-9.90	-0.04	0.02	-2.69
Mixed Wood	-0.03	0.03	-1.02	0.03	0.02	1.74	-0.09	0.01	-7.24	-0.04	0.02	-1.82
Broadleaf	-0.13	0.05	-2.38	-0.02	0.04	-0.58	-0.17	0.03	-6.54	-0.15	0.04	-4.02
Tall Shrub	0.03	0.02	1.87	0.02	0.01	2.01	-0.05	0.01	-7.87	-0.03	0.01	-2.52
Low Shrub	0.06	0.01	4.66	0.04	0.01	4.42	-0.03	0.01	-4.46	-0.02	0.01	-1.66
Bryoids	0.04	0.02	2.12	0.03	0.01	2.66	0.06	0.01	6.98	0.03	0.02	1.46
Herbaceous	0.05	0.05	1.08	0.04	0.03	1.08	0.00	0.03	0.10	-0.01	0.04	-0.21
Wetland	-0.01	0.02	-0.70	0.02	0.01	1.83	-0.04	0.01	-5.10	-0.05	0.01	-3.39
Water	-0.14	0.02	-6.05	-0.16	0.01	-11.41	-0.12	0.01	-14.14	-0.14	0.02	-7.83
Other	0.03	0.02	1.76	0.05	0.01	4.33	-0.09	0.01	-10.23	-0.06	0.02	-3.56
Elevation	0.18	0.04	4.78	0.19	0.08	2.22	0.19	0.06	3.35	0.29	0.04	7.14
Elevation^2	-0.25	0.07	-3.62	-0.58	0.17	-3.49	-0.32	0.08	-3.87	-0.54	0.07	-7.65
East Aspect	0.01	0.02	0.50	0.01	0.02	0.70	0.02	0.01	1.55	0.02	0.02	1.00
South Aspect	0.02	0.03	0.57	0.01	0.02	0.46	0.05	0.02	3.05	0.05	0.02	2.48
West Aspect	0.00	0.02	0.11	0.00	0.02	-0.07	0.02	0.01	1.72	0.05	0.02	3.06
Flat Aspect	-0.01	0.03	-0.50	-0.04	0.02	-1.74	-0.08	0.02	-3.72	-0.01	0.03	-0.27

	Breeding			Summer			Winter			Calving		
Covariate	**β**	**SE**	**t-value**	**β**	**SE**	**t-value**	**β**	**SE**	**t-value**	**β**	**SE**	**t-value**
Burn (<40 years old)	-0.06	0.03	-2.17	-0.02	0.02	-0.71	-0.12	0.02	-8.13	-0.07	0.02	-3.04
Roads	-0.37	0.05	-7.13	-0.25	0.04	-5.83	-0.25	0.03	-7.17	-0.21	0.05	-4.41
Distance to Seismic Line	0.05	0.02	2.49	0.17	0.04	4.64	0.08	0.02	3.61	0.11	0.03	4.40
Distance to Seismic Line^2	-0.07	0.02	-3.25	-0.23	0.04	-5.14	-0.11	0.02	-4.68	-0.14	0.03	-5.06

NOTE: * Covariates with a "2" are the quadratic terms for that covariate.

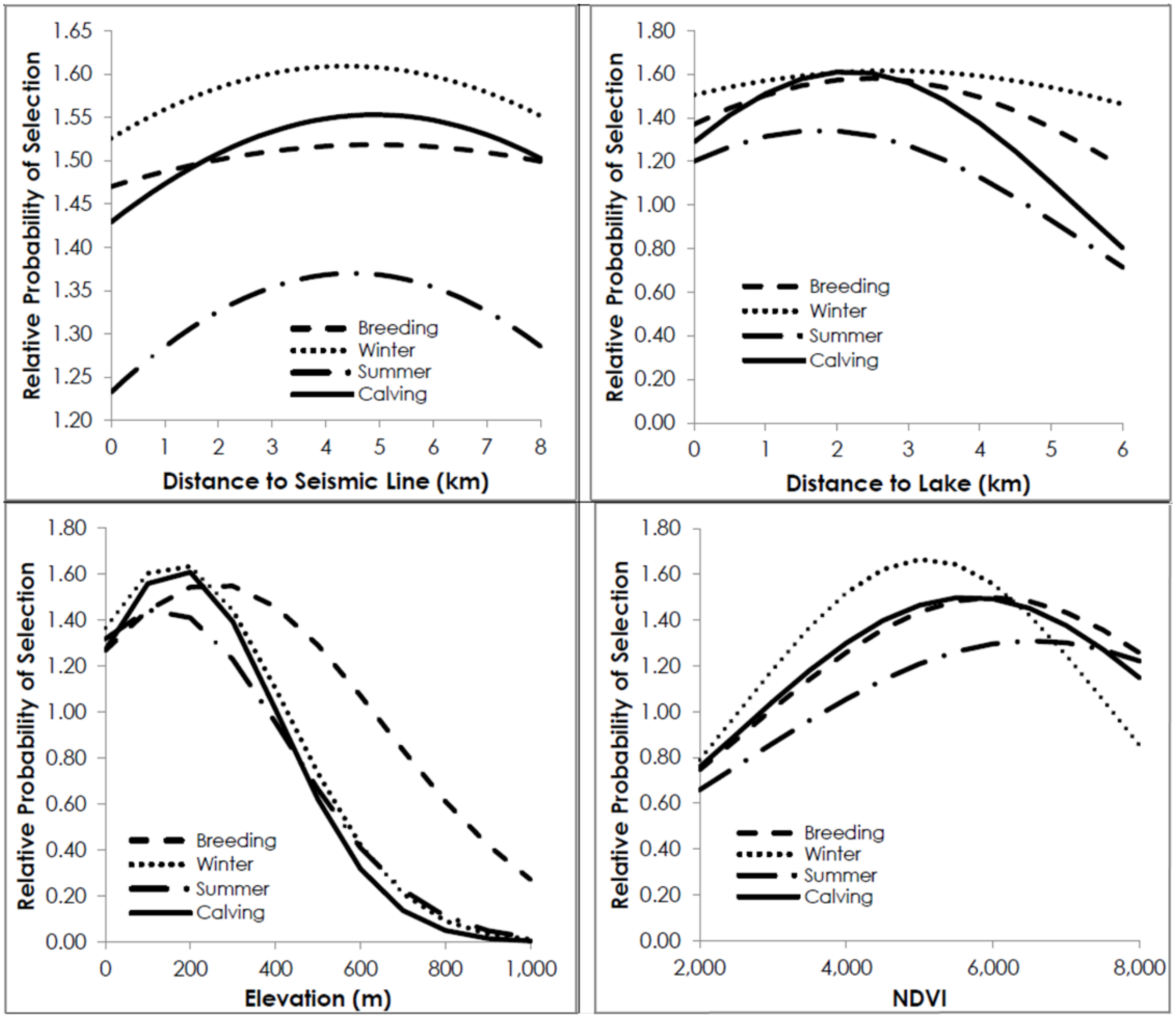

Figure 7. Relative probability of caribou selection of distance to seismic line (top left), distance to lake (top right), elevation (bottom left), and normalized difference vegetation index (bottom right) in the breeding, summer winter and calving seasons at the third order of selection.

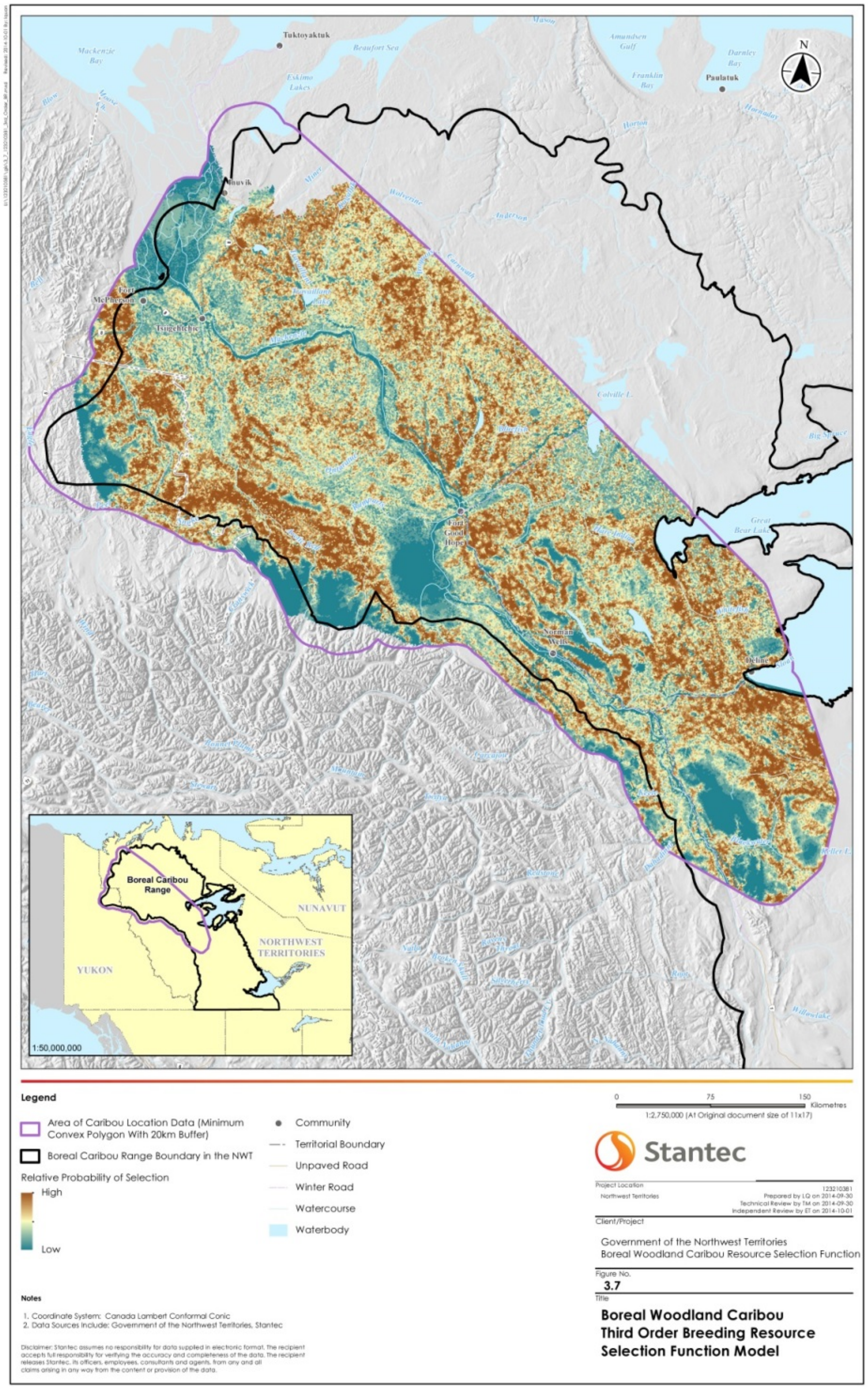

Figure 8. Boreal woodland caribou third order breeding resource selection function model.

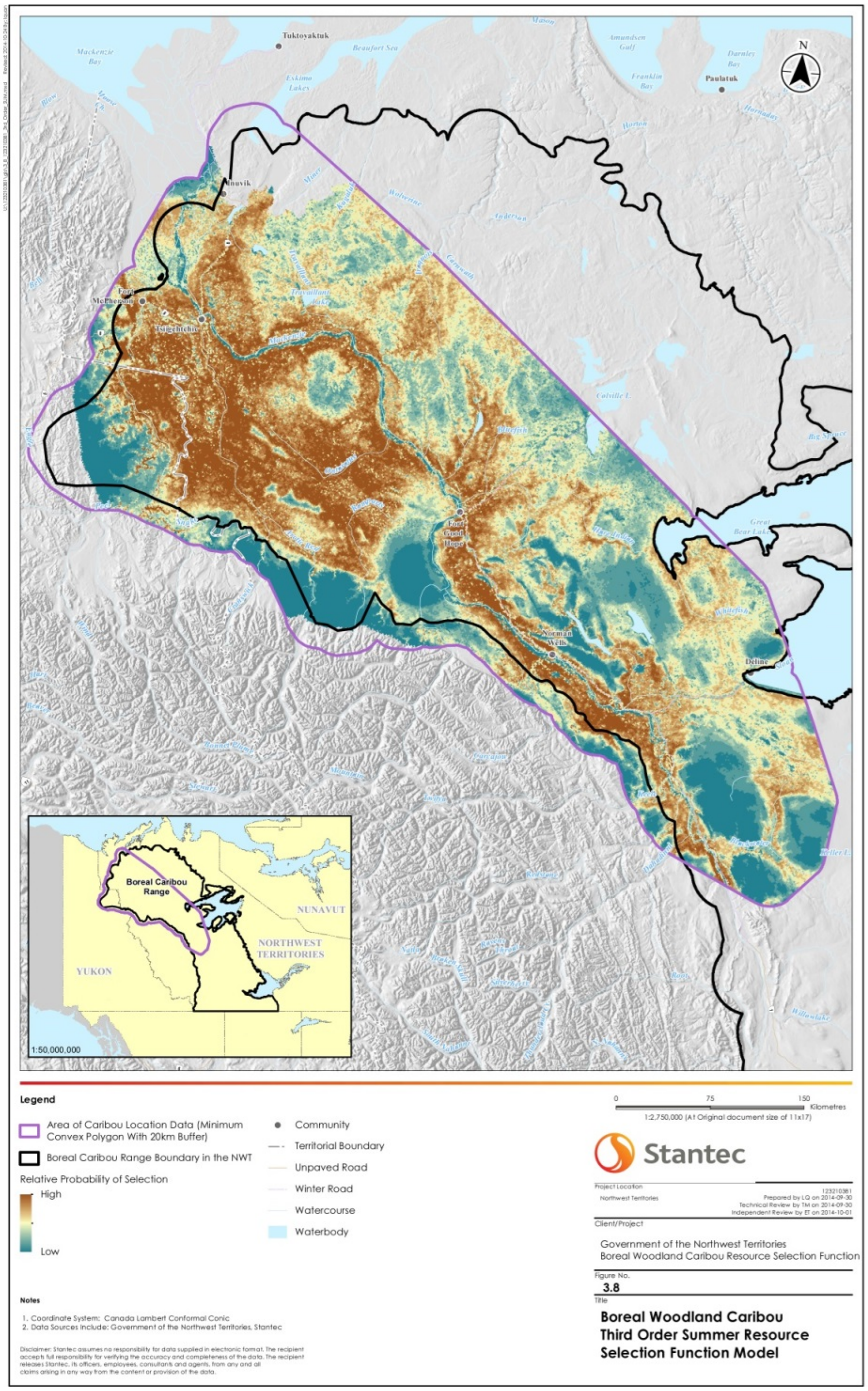

Figure 9. Boreal woodland caribou third order summer resource selection function model.

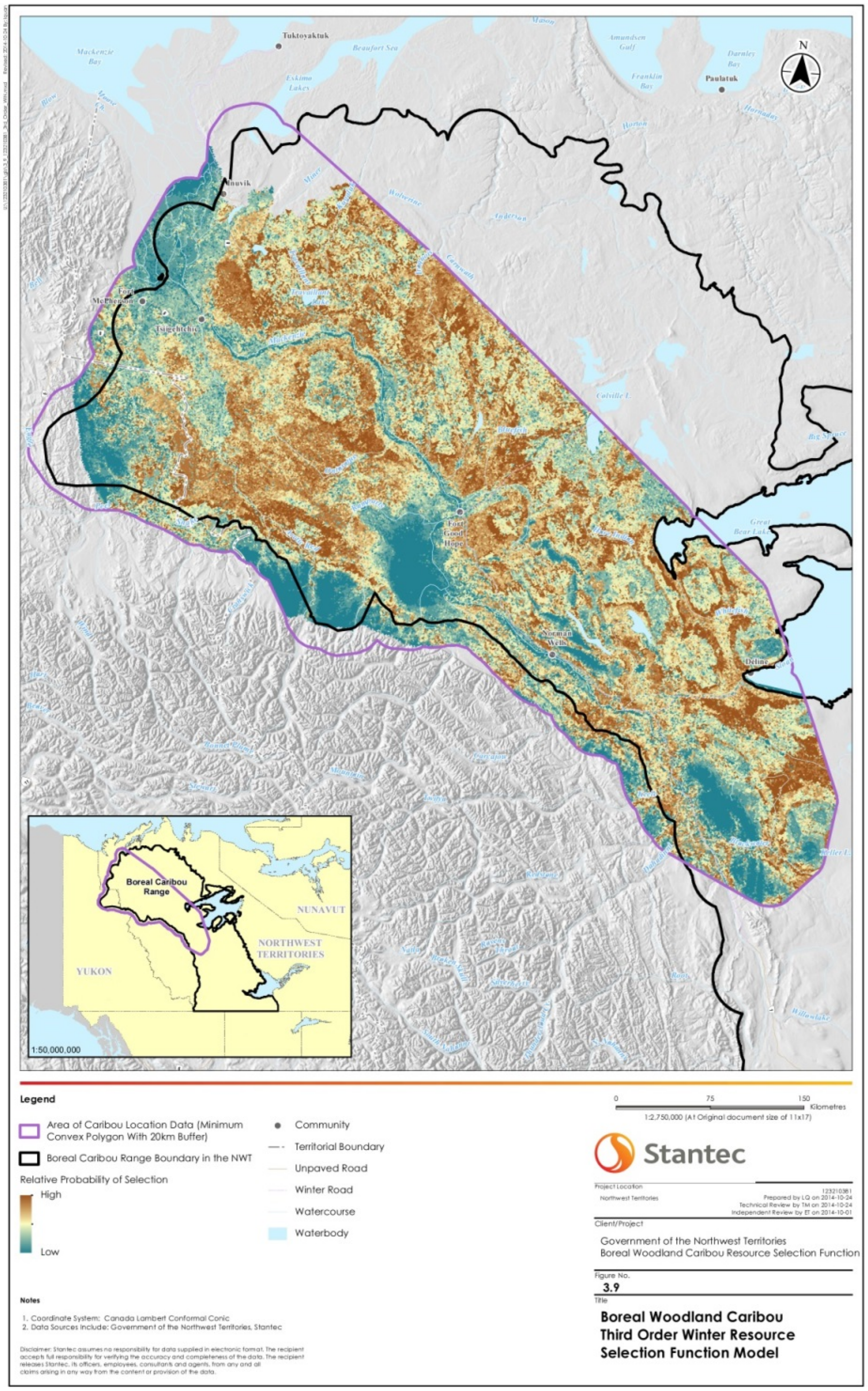

Figure 10. Boreal woodland caribou third order winter resource selection function model.

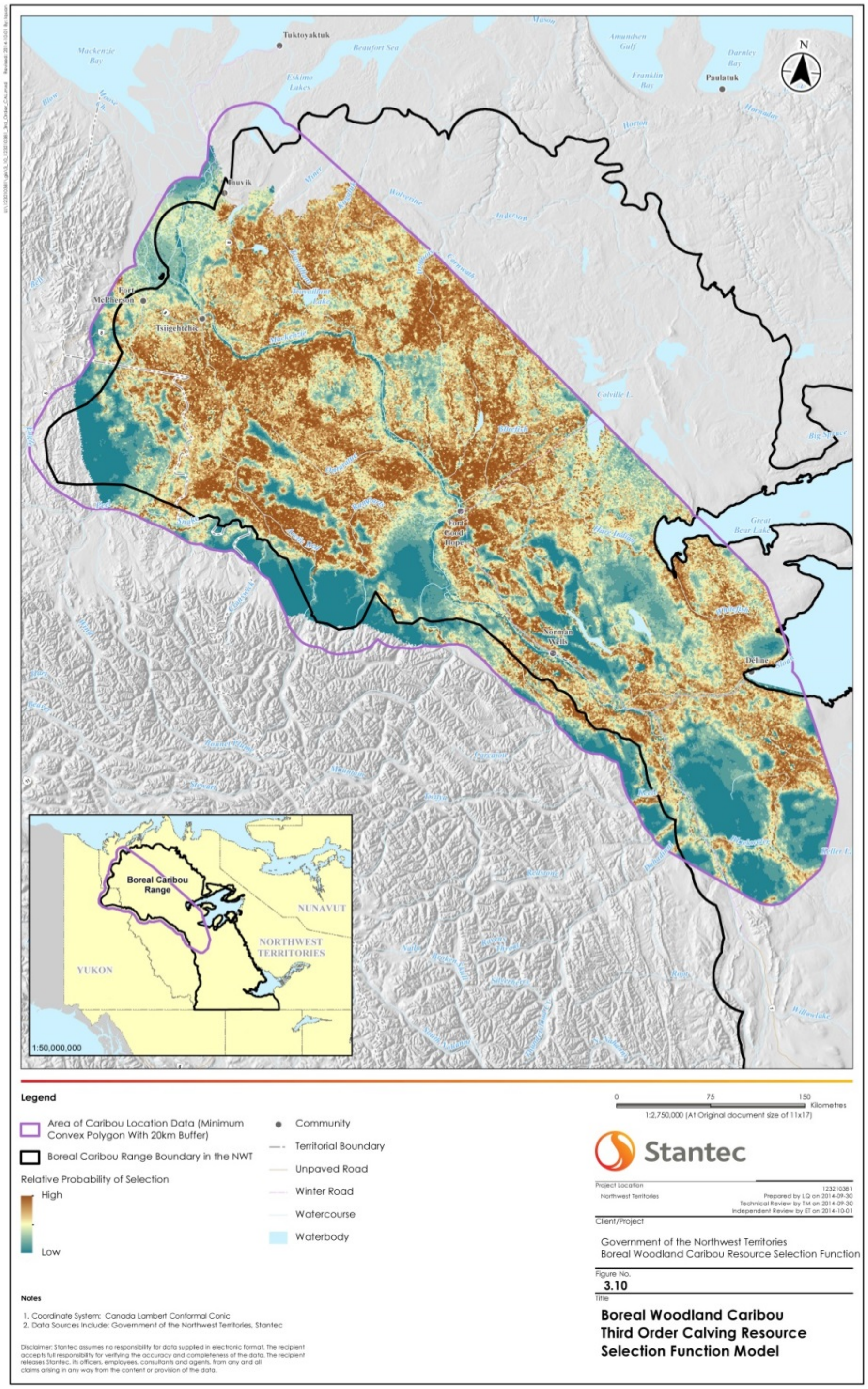

Figure 11. Boreal woodland caribou third order calving resource selection function model.

Seasonal Integrated Caribou Habitat Selection Maps

Integrated RSF maps were produced for each season to indicate the relative probability of caribou habitat selection as a product of both second and third order RSF models. High RSF values for breeding habitat occurred around the Artic Red River, as well as west of Fort McPherson and north and east of Fort Good Hope (Figure 12). In the summer (Figure 13) and winter (Figure 14), high RSF values occurred around the Mackenzie and Ontaratue Rivers, as well as southwest and northeast of Tsiigehtchic. In the breeding season, RSF values were high around the Artic Red, Mackenzie and Ontaratue Rivers, as well as around Fort Good Hope (Figure 15).

Model Validation

Second and third order RSF models had reasonably good predictive ability (Figure 16; Appendix C). At the second order of selection, the winter (slope = 1.02; intercept = -14; R^2=0.93; $\chi2$ p-value = 0.24; Spearman correlation (ρ)=0.97) and calving (slope = 1.02; intercept = -4; R^2=0.94; $\chi2$ p-value = 0.22; ρ=0.97) models had a very close fit to the data. The summer model (slope = 0.93; intercept = 35; R^2=0.95; $\chi2$ p-value = 0.24; ρ=0.90) slightly over-predicted low-RSF value habitat and slightly under-predicted high-RSF value habitat. The breeding model (slope = 0.85; intercept = -3; R^2=0.78; $\chi2$ p-value = 0.25; ρ=0.85) generally under-predicted RSF scores, particularly at high- RSF values. At the third order of selection, calving (slope = 1.04; intercept = -9; R^2=0.98; $\chi2$ p-value = 0.16; ρ=0.91), breeding (slope = 1.04; intercept = -7; R^2=0.99; $\chi2$ p-value = 0.17; ρ=0.95) summer (slope = 1.02; intercept = -12; R^2=0.91; $\chi2$ p-value = 0.22; ρ=0.96) and winter (slope = 1.02; intercept = -16; R^2=0.94; $\chi2$ p-value = 0.25; ρ=0.97) models fit the data well. However, the calving and breeding models slightly over-predicted high-RSF value habitat.

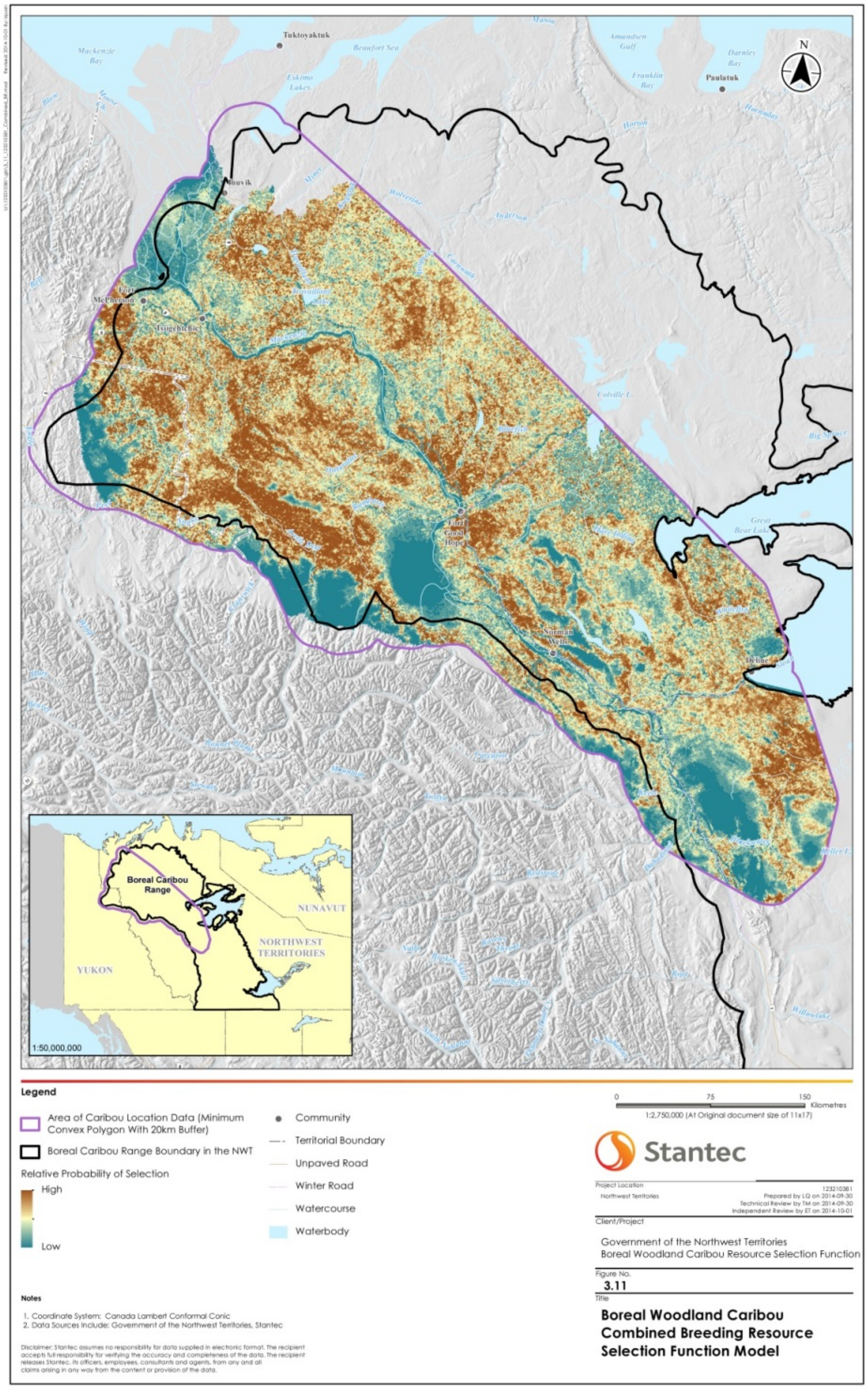

Figure 12. Boreal woodland caribou combined breeding resource selection function model.

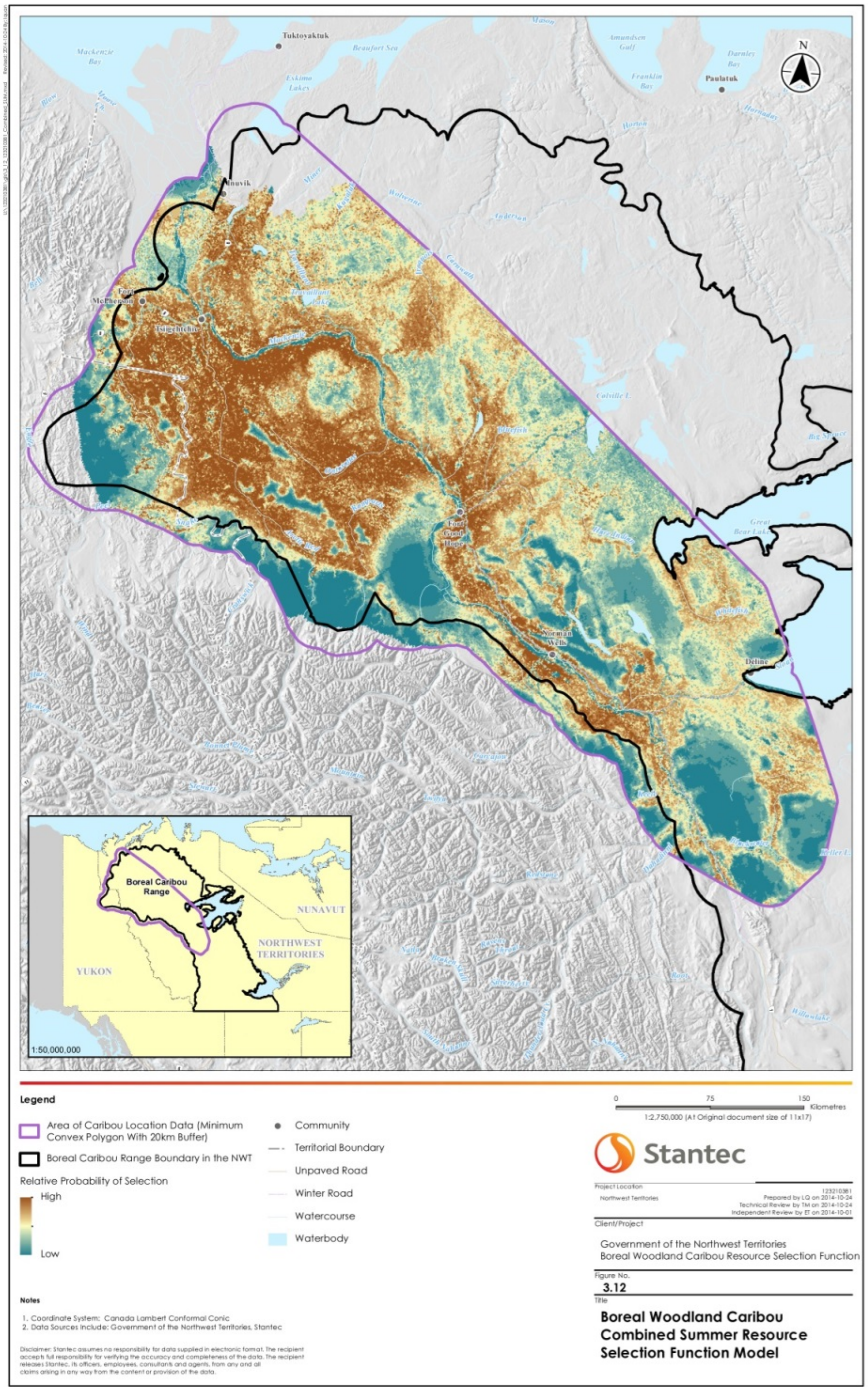

Figure 13. Boreal woodland caribou combined summer resource selection function model.

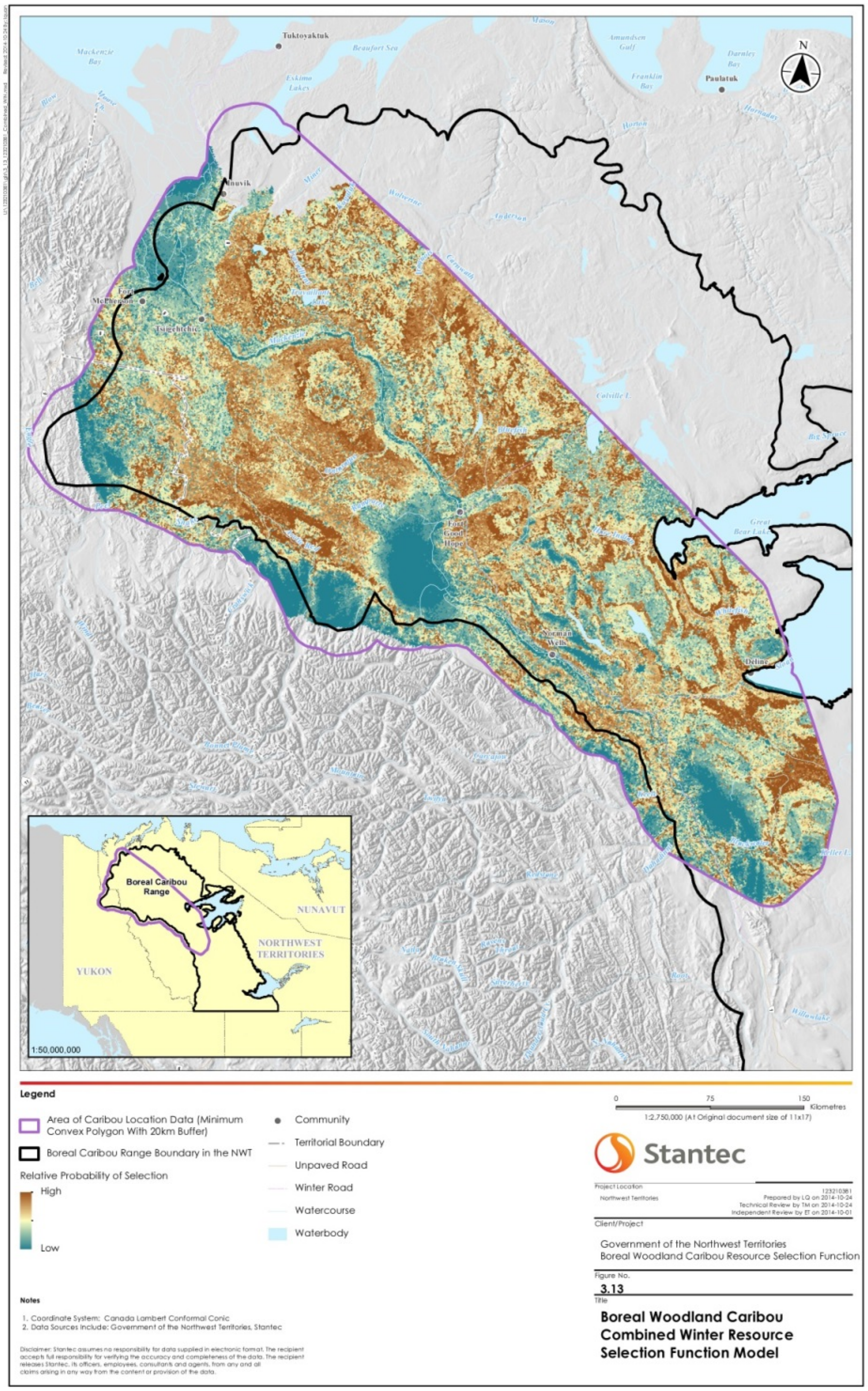

Figure 14. Boreal woodland caribou combined winter resource selection function model.

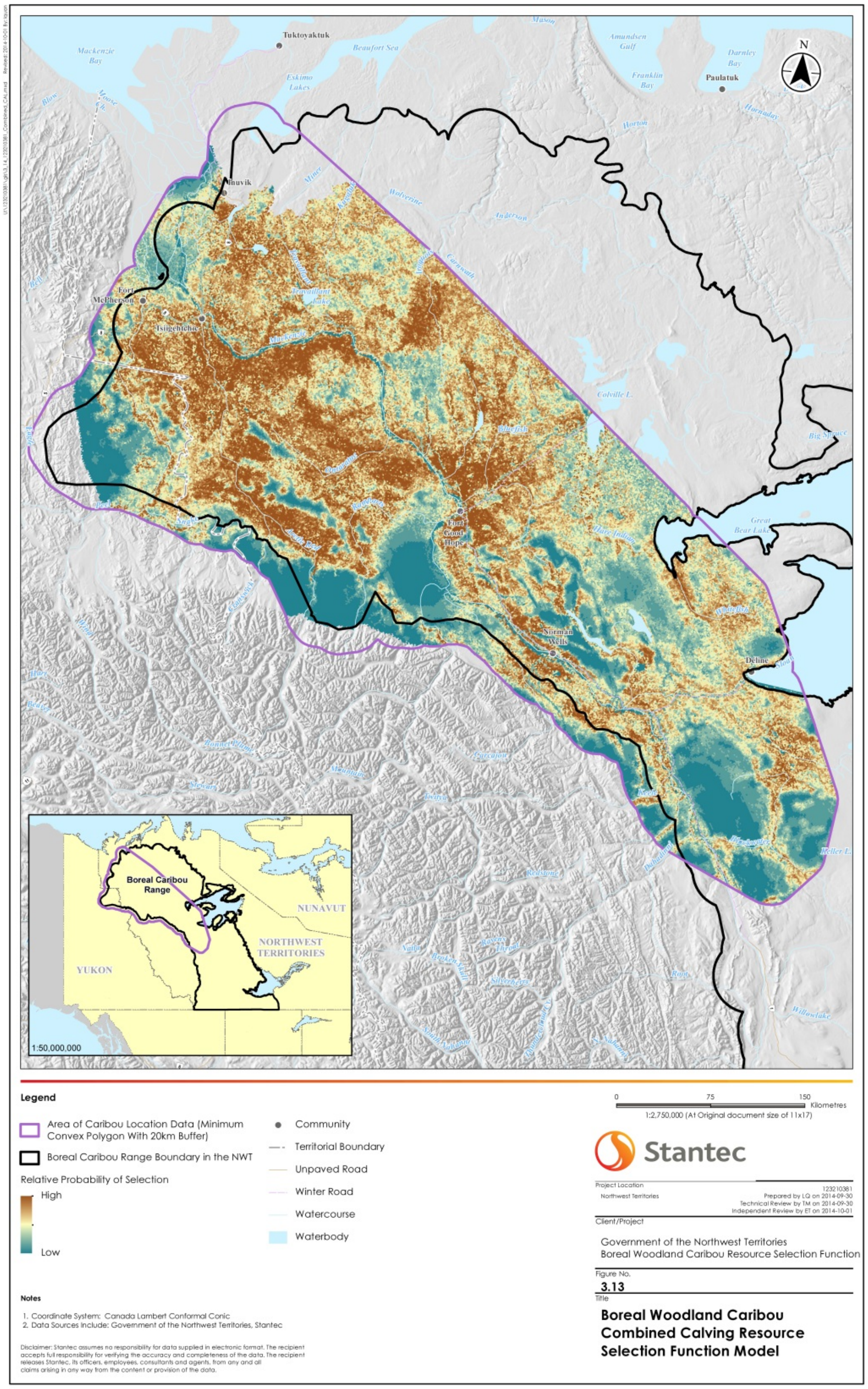

Figure 15. Boreal woodland caribou combined calving resource selection function model.

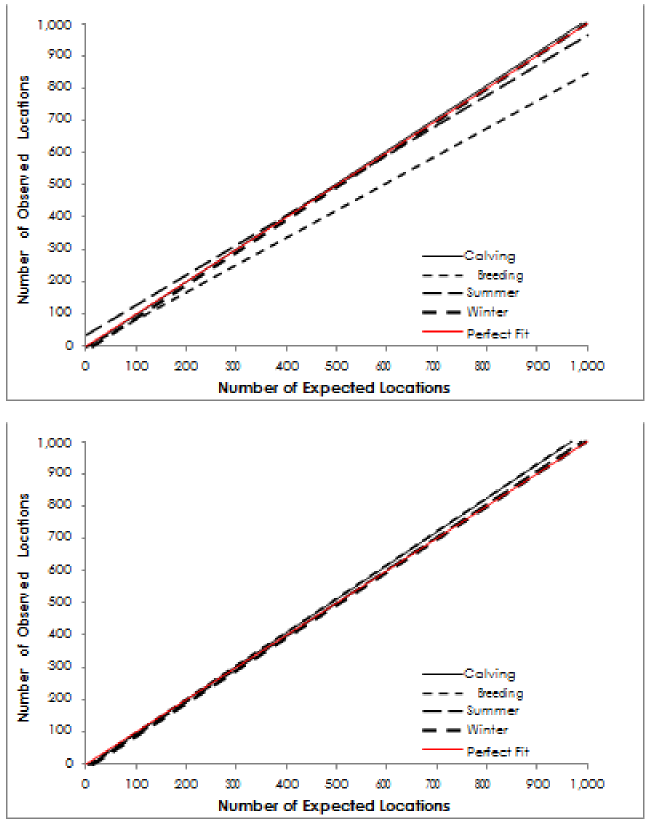

Figure 16. Average number of observed telemetry locations predicted by five-fold cross-validation at second (top) and third (bottom) orders of selection during the calving, breeding, summer and winter seasons. A perfect fitting model (observed=expected) is indicted by the red line.

DISCUSSION

Boreal woodland caribou resource selection in the NWT varied across two spatial-temporal scales and four seasons, reflecting the dynamic nature of caribou habitat selection. Resource selection by individual caribou was typically more consistent across seasons at higher orders (second order) of selection relative to lower orders (third order). This was not surprising, as establishment of home ranges within a population range represents a larger scale ecological process than selection of habitat patches within home ranges. For example, there is evidence to suggest animals may compensate for large-scale human disturbance by altering their habitat selection patterns at finer scales (Basille et al. 2013).

The lack of functional response in caribou habitat selection at second and third orders of selection was surprising. In theory, habitat selection by animals depends on the availability of habitats from which they can select. Indeed, multi-level functional responses have been reported for woodland caribou (Moreau et al. 2012). However, this was in a region where some areas were highly disturbed by different types of human activity (e.g., recent cut blocks and roads). In this study, it is possible the level of human disturbance, or habitat composition in general, was not varied enough in the study area for a functional response to be effectively modeled. As habitat continues to be modified by human activity in the future, perhaps a functional response will become evident for boreal caribou in the NWT, and it will be important to identify this functional response to understand the effects of human activity on caribou.

At the second and third orders of selection, caribou clearly avoided habitats with roads and <40 year old burns, which is consistent with previous boreal caribou models in the NWT (Environment Canada 2012) and that human disturbance negatively influences caribou (Festa-Bianchet et al. 2011, Species at Risk Committee 2012). However, caribou response to seismic lines varied across scales and seasons, indicating plasticity in caribou response to seismic lines.

Caribou consistently avoided areas with higher densities of seismic lines across orders and seasons of selection. This consistent avoidance of areas with a high density of seismic lines may be because caribou are vulnerable to predation near seismic lines, especially during calving season (McLoughlin et al. 2003, Wittmer et al. 2005, Pinard et al. 2012). Seismic lines may improve wolf access to caribou range (Latham et al. 2011, Whittington et al. 2011) and ultimately increase caribou predation risk. Caribou may avoid habitat with seismic lines at second and third orders of selection to attempt to mitigate this risk. However, caribou also selected home ranges with intermediate rather than low densities of seismic lines, suggesting they may not completely avoid seismic lines. This may be because intermediate densities of seismic lines do not support sufficiently high predator densities to cause caribou to abandon home ranges there, and instead caribou avoid patches close to seismic lines within those home ranges. Alternatively, this result may indicate a bias in the data if caribou were typically collared in more developed or developing areas than remote areas, as results would indicate caribou selection of intermediate densities of seismic lines when they may prefer low densities of seismic lines. Further analysis of high-resolution spatial-temporal caribou location data is needed to disentangle caribou response to seismic lines at second and third orders of selection. Nevertheless, in general, high-seismic line density areas are less preferred by caribou but home ranges with intermediate densities may be selected if caribou can avoid seismic lines at finer scales.

At the third order of selection, we found a shift to higher food quality and quantity land cover and habitat types (i.e., shrublands and higher NDVI) in the summer, which was consistent with other boreal caribou RSF models in the NWT (Species at Risk Committee 2012). During winter and calving in particular, caribou may be more vulnerable to predation and thus may select habitat secure from predation over high-food quality and quantity habitat. As calves mature throughout the spring and into early summer, and as building energy reserves for winter becomes vital, foraging habitat may become higher priority than low predation risk habitat. In addition, in winter caribou may shift to using forest land cover types with more terrestrial or arboreal lichens that may not be detected by NDVI.

An important limitation of RSF models in general is that they only predict the relative probability of selection of a particular resource or landscape pixel if encountered by a caribou, but do not predict where caribou may or may not occur. Other factors may influence animal use of habitat such as barriers (e.g., highways) and population density. Furthermore, the RSFs created here only indirectly account for the effects of predation and predation risk on caribou, as they do not directly measure the effect of predator density or distribution on caribou. In addition, the accuracy of the habitat data upon which the models were built, for example the land cover data, was not assessed as part of this project. Misclassification of land cover data may bias the coefficients of RSF models (Johnson and Gillingham 2008). Inaccurate seismic line location data and lack of data on the condition of seismic lines (e.g., whether they were open or re-vegetated) could also influence RSF results. Furthermore, seismic line data was only current to 2005, but caribou locations were obtained up to 2011, and further seismic work likely occurred in the study area between 2005 and 2011. RSF models should ideally be updated as new landscape data becomes available. For example they could be re-calculated with seismic line data collected by Environment Canada in 2009-2010. Finally, another important limitation of the RSF models is that predictions were limited to habitats where caribou selection could be precisely predicted. Thus, the models could continue to be improved by expanding the range of environments where boreal caribou location data are collected and using that data to re-calculate RSFs.

Integrated (combined second and third order) RSF prediction maps provide a useful tool for identifying the location of high-quality boreal woodland caribou habitat in the NWT. The seasonal second and third order RSF models each had good predictive ability, which suggests the integrated models are useful for predicting the current value of habitat to caribou in the NWT.

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APPENDIX A. Annotated R Code to Implement the Resource Selection Function Models

Below is annotated code that can be implemented in program R to calculate the top ranked second and third order seasonal resource selection function (RSF) models using the generalized linear mixed model (GLMM) described in the Methods (Section 2.0). Note that as per R convention, annotations are preceded with a # symbol.

Second Order RSF

```
# Boreal Caribou RSF for NWT, Second Order, GLMM

# load the data

data <- read.table(file="C:\\...\\all_2ndorder_20140506.txt", header=TRUE, sep="\t")

# identify landcover and aspect factors

data$lc<-factor(data$lc, levels = c("sparse conifer","open conifer","dense conifer","mixedwood","broadleaf","tall shrub","low shrub","byoids","herbaceous","wetland","water","other"))

data$aspct<-factor(data$aspct, levels = c("north", "east", "south", "west", "flat"))

#Create quadradtic covariates

data$"dtlake2" <-data$"dt_lake"*data$"dt_lake"

# divide the data into seasons

b_data<-subset (data, season=='breeding')

s_data<-subset (data, season=='summer')

w_data<-subset (data, season=='winter')

c_data<-subset (data, season=='calving')

# Standardizing continuous covariates (helps with model convergence)

# use same transformation in GIS

b_data$dem<-(b_data$dem-mean(b_data$dem))/sd(b_data$dem)

b_data$dem2<-(b_data$dem2-mean(b_data$dem2))/sd(b_data$dem2)
```

```
b_data$n_seis_d<-(b_data$n_seis_d-mean(b_data$n_seis_d))/sd(b_data$n_seis_d)

b_data$n_seis_d2<-(b_data$n_seis_d2-mean(b_data$n_seis_d2))/sd(b_data$n_seis_d2)

b_data$dt_lake<-(b_data$dt_lake-mean(b_data$dt_lake))/sd(b_data$dt_lake)

b_data$dtlake2<-(b_data$dtlake2-mean(b_data$dtlake2))/sd(b_data$dtlake2)

b_data$ndvi<-(b_data$ndvi-mean(b_data$ndvi))/sd(b_data$ndvi)

b_data$ndvi2<-(b_data$ndvi2-mean(b_data$ndvi2))/sd(b_data$ndvi2)

s_data$dem<-(s_data$dem-mean(s_data$dem))/sd(s_data$dem)

s_data$dem2<-(s_data$dem2-mean(s_data$dem2))/sd(s_data$dem2)

s_data$n_seis_d<-(s_data$n_seis_d-mean(s_data$n_seis_d))/sd(s_data$n_seis_d)

s_data$n_seis_d2<-(s_data$n_seis_d2-mean(s_data$n_seis_d2))/sd(s_data$n_seis_d2)

s_data$dt_lake<-(s_data$dt_lake-mean(s_data$dt_lake))/sd(s_data$dt_lake)

s_data$dtlake2<-(s_data$dtlake2-mean(s_data$dtlake2))/sd(s_data$dtlake2)

s_data$ndvi<-(s_data$ndvi-mean(s_data$ndvi))/sd(s_data$ndvi)

s_data$ndvi2<-(s_data$ndvi2-mean(s_data$ndvi2))/sd(s_data$ndvi2)

w_data$dem<-(w_data$dem-mean(w_data$dem))/sd(w_data$dem)

w_data$dem2<-(w_data$dem2-mean(w_data$dem2))/sd(w_data$dem2)

w_data$n_seis_d<-(w_data$n_seis_d-mean(w_data$n_seis_d))/sd(w_data$n_seis_d)

w_data$n_seis_d2<-(w_data$n_seis_d2-mean(w_data$n_seis_d2))/sd(w_data$n_seis_d2)

w_data$dt_lake<-(w_data$dt_lake-mean(w_data$dt_lake))/sd(w_data$dt_lake)

w_data$dtlake2<-(w_data$dtlake2-mean(w_data$dtlake2))/sd(w_data$dtlake2)

w_data$ndvi<-(w_data$ndvi-mean(w_data$ndvi))/sd(w_data$ndvi)

w_data$ndvi2<-(w_data$ndvi2-mean(w_data$ndvi2))/sd(w_data$ndvi2)

c_data$dem<-(c_data$dem-mean(c_data$dem))/sd(c_data$dem)

c_data$dem2<-(c_data$dem2-mean(c_data$dem2))/sd(c_data$dem2)

c_data$n_seis_d<-(c_data$n_seis_d-mean(c_data$n_seis_d))/sd(c_data$n_seis_d)
```

```
c_data$n_seis_d2<-(c_data$n_seis_d2-mean(c_data$n_seis_d2))/sd(c_data$n_seis_d2)

c_data$dt_lake<-(c_data$dt_lake-mean(c_data$dt_lake))/sd(c_data$dt_lake)

c_data$dtlake2<-(c_data$dtlake2-mean(c_data$dtlake2))/sd(c_data$dtlake2)

c_data$ndvi<-(c_data$ndvi-mean(c_data$ndvi))/sd(c_data$ndvi)

c_data$ndvi2<-(c_data$ndvi2-mean(c_data$ndvi2))/sd(c_data$ndvi2)


# Fit the RSF models

# load the lme4 and geepack packages

require(lme4)


# BREEDING DATA

# GLOBAL; Distance to Lake and NDVI and LC and Elevation and Aspect and Fire and
Distance to Seismic and Roads

summary(b_rsf_global<-
lmer(pttype~dt_lake+dtlake2+ndvi+ndvi2+lc+dem+dem2+aspct+fire_cat+rd_cat+n_seis_d
+n_sei s_d2+

        (0+dt_lake|caribouID)+

        (0+dtlake2|caribouID)+

        (0+ndvi|caribouID)+

        (0+ndvi2|caribouID)+

        (0+dem|caribouID)+

        (0+dem2|caribouID)+

        (0+aspct|caribouID)+

        (0+fire_cat|caribouID)+

        (0+rd_cat|caribouID)+

        (0+n_seis_d|caribouID)+
```

```
        (0+n_seis_d2|caribouID)+
        (1|caribouID),
        data=b_data,
        REML=F,
        verbose=T))
```

```
# SUMMER DATA
# GLOBAL; Distance to Lake and NDVI and LC and Elevation and Aspect and Fire and Distance to Seismic and Roads, GFR laNdCOVER and SEISMIC LINE model with random intercept and coefficient
summary(s_rsf_global<-
lmer(pttype~dt_lake+dtlake2+ndvi+ndvi2+lc+dem+dem2+aspct+fire_cat+rd_cat+n_seis_d
+n_sei s_d2+
        (0+dt_lake|caribouID)+
        (0+dtlake2|caribouID)+
        (0+ndvi|caribouID)+
        (0+ndvi2|caribouID)+
        (0+dem|caribouID)+
        (0+dem2|caribouID)+
        (0+aspct|caribouID)+
        (0+fire_cat|caribouID)+
        (0+rd_cat|caribouID)+
        (0+n_seis_d|caribouID)+
        (0+n_seis_d2|caribouID)+
        (1|caribouID), data=s_data,
        REML=F,
```

```
verbose=T))
```

WINTER DATA

GLOBAL; Distance to Lake and NDVI and LC and Elevation and Aspect and Fire and Distance to Seismic and Roads, with random intercept and coefficient

```
summary(w_rsf_global<-
lmer(pttype~dt_lake+dtlake2+ndvi+ndvi2+lc+dem+dem2+aspct+fire_cat+rd_cat+n_seis_d
+n_sei s_d2+
    (0+dt_lake|caribouID)+
    (0+dtlake2|caribouID)+
    (0+ndvi|caribouID)+
    (0+ndvi2|caribouID)+
    (0+dem|caribouID)+
    (0+dem2|caribouID)+
    (0+aspct|caribouID)+
    (0+fire_cat|caribouID)+
    (0+rd_cat|caribouID)+
    (0+n_seis_d|caribouID)+
    (0+n_seis_d2|caribouID)+
    (1|caribouID),
    data=w_data,
    REML=F,
    verbose=T))
```

CALVING DATA

GLOBAL; Distance to Lake and NDVI and LC and Elevation and Aspect and Fire and Distance to Seismic and Roads, GFR laNdCOVER and SEISMIC LINE model with random intercept and coefficient

```
summary(c_rsf_global<-
lmer(pttype~dt_lake+dtlake2+ndvi+ndvi2+lc+dem+dem2+aspct+fire_cat+rd_cat+n_seis_d
+n_sei s_d2+
        (0+dt_lake|caribouID)+
        (0+dtlake2|caribouID)+
        (0+ndvi|caribouID)+
        (0+ndvi2|caribouID)+
        (0+dem|caribouID)+
        (0+dem2|caribouID)+
        (0+aspct|caribouID)+
        (0+fire_cat|caribouID)+
        (0+rd_cat|caribouID)+
        (0+n_seis_d|caribouID)+
        (0+n_seis_d2|caribouID)+
        (1|caribouID),
        data=c_data,
        REML=F,
        verbose=T))
```

Third Order RSF

Boreal Caribou RSF for NWT, Third Order, GLMM

load the data

```
data <-
read.table(file="C:\\Work\\Stantec\\Projects\\NWT_boreal_caribou_rsf\\r_analysis\\all_
3rdor der_20140421.txt", header=TRUE, sep="\t")

# identify landcover and aspect factors

data$lc<-factor(data$lc, levels = c("sparse conifer","open conifer","dense
conifer","mixedwood","broadleaf","tall shrub","low
shrub","byoids","herbaceous","wetland","water","other"))

data$lc_num<-factor(data$lc_num)

data$aspct<-factor(data$aspct, levels = c("north", "east", "south", "west", "flat"))

#Create quadradtic covariates data$"dem2"<-data$"dem"*data$"dem" data$"ndvi2"<-
data$"ndvi"*data$"ndvi"

data$"dtlake2"<-data$"dt_lake"*data$"dt_lake" data$"dtseis2"<-
data$"dist_seis"*data$"dist_seis"

# divide the data into seasons

b_data<-subset(data, season=='breeding')

s_data<-subset(data, season=='summer')

w_data<-subset(data, season=='winter')

c_data<-subset(data, season=='calving')

# Standardising continuous covariates (helps with model convergence)

# use same transformation in GIS

b_data$dem<-(b_data$dem -mean(b_data$dem))/sd(b_data$dem)

b_data$dem2<-(b_data$dem2-mean(b_data$dem2))/sd(b_data$dem2)

b_data$dist_seis<-(b_data$dist_seis-mean(b_data$dist_seis))/sd(b_data$dist_seis)

b_data$dtseis2<-(b_data$dtseis2-mean(b_data$dtseis2))/sd(b_data$dtseis2)

b_data$dt_lake<-(b_data$dt_lake-mean(b_data$dt_lake))/sd(b_data$dt_lake)

b_data$dtlake2<-(b_data$dtlake2-mean(b_data$dtlake2))/sd(b_data$dtlake2)

b_data$ndvi<-(b_data$ndvi-mean(b_data$ndvi))/sd(b_data$ndvi)
```

```
b_data$ndvi2<-(b_data$ndvi2-mean(b_data$ndvi2))/sd(b_data$ndvi2)
s_data$dem<-(s_data$dem-mean(s_data$dem))/sd(s_data$dem)
s_data$dem2<-(s_data$dem2-mean(s_data$dem2))/sd(s_data$dem2)
s_data$dist_seis<-(s_data$dist_seis-mean(s_data$dist_seis))/sd(s_data$dist_seis)
s_data$dtseis2<-(s_data$dtseis2-mean(s_data$dtseis2))/sd(s_data$dtseis2)
s_data$dt_lake<-(s_data$dt_lake-mean(s_data$dt_lake))/sd(s_data$dt_lake)
s_data$dtlake2<-(s_data$dtlake2-mean(s_data$dtlake2))/sd(s_data$dtlake2)
s_data$ndvi<-(s_data$ndvi-mean(s_data$ndvi))/sd(s_data$ndvi)
s_data$ndvi2<-(s_data$ndvi2-mean(s_data$ndvi2))/sd(s_data$ndvi2)
w_data$dem<-(w_data$dem-mean(w_data$dem))/sd(w_data$dem)
w_data$dem2<-(w_data$dem2-mean(w_data$dem2))/sd(w_data$dem2)
w_data$dist_seis<-(w_data$dist_seis-mean(w_data$dist_seis))/sd(w_data$dist_seis)
w_data$dtseis2<-(w_data$dtseis2-mean(w_data$dtseis2))/sd(w_data$dtseis2)
w_data$dt_lake<-(w_data$dt_lake-mean(w_data$dt_lake))/sd(w_data$dt_lake)
w_data$dtlake2<-(w_data$dtlake2-mean(w_data$dtlake2))/sd(w_data$dtlake2)
w_data$ndvi<-(w_data$ndvi-mean(w_data$ndvi))/sd(w_data$ndvi)
w_data$ndvi2<-(w_data$ndvi2-mean(w_data$ndvi2))/sd(w_data$ndvi2)
c_data$dem<-(c_data$dem-mean(c_data$dem))/sd(c_data$dem)
c_data$dem2<-(c_data$dem2-mean(c_data$dem2))/sd(c_data$dem2)
c_data$dist_seis<-(c_data$dist_seis-mean(c_data$dist_seis))/sd(c_data$dist_seis)
c_data$dtseis2<-(c_data$dtseis2-mean(c_data$dtseis2))/sd(c_data$dtseis2)
c_data$dt_lake<-(c_data$dt_lake-mean(c_data$dt_lake))/sd(c_data$dt_lake)
c_data$dtlake2<-(c_data$dtlake2-mean(c_data$dtlake2))/sd(c_data$dtlake2)
c_data$ndvi<-(c_data$ndvi-mean(c_data$ndvi))/sd(c_data$ndvi)
c_data$ndvi2<-(c_data$ndvi2-mean(c_data$ndvi2))/sd(c_data$ndvi2)
```

Fit the RSF models

load the lme4 and geepack packages

require(lme4)

BREEDING DATA

GLOBAL; Distance to Lake and NDVI and LC and Elevation and Aspect and Fire and Distance to Seismic and Roads, GFR laNdCOVER and SEISMIC LINE model with random intercept and coefficient

```
summary(b_rsf_global<-
lmer(pttype~dt_lake+dtlake2+ndvi+ndvi2+lc+dem+dem2+aspct+fire_cat+rd_cat+dist_seis
+dtseis 2+
        (0+dt_lake|caribouID)+
        (0+dtlake2|caribouID)+
        (0+ndvi|caribouID)+
        (0+ndvi2|caribouID)+
        (0+dem|caribouID)+
        (0+dem2|caribouID)+
        (0+aspct|caribouID)+
        (0+fire_cat|caribouID)+
        (0+rd_cat|caribouID)+
        (0+dist_seis|caribouID)+
        (0+dtseis2|caribouID)+
        (1|caribouID),
        data=b_data,
        REML=F,
        verbose=T))
```

SUMMER DATA

GLOBAL; Distance to Lake and NDVI and LC and Elevation and Aspect and Fire and Distance to Seismic and Roads, GFR laNdCOVER and SEISMIC LINE model with random intercept and coefficient

```
summary(s_rsf_global<-
lmer(pttype~dt_lake+dtlake2+ndvi+ndvi2+lc+dem+dem2+aspct+fire_cat+rd_cat+dist_seis
+dtseis 2+
        (0+dt_lake|caribouID)+
        (0+dtlake2|caribouID)+
        (0+ndvi|caribouID)+
        (0+ndvi2|caribouID)+
        (0+dem|caribouID)+
        (0+dem2|caribouID)+
        (0+aspct|caribouID)+
        (0+fire_cat|caribouID)+
        (0+rd_cat|caribouID)+
        (0+dist_seis|caribouID)+
        (0+dtseis2|caribouID)+
        (1|caribouID),
        data=s_data,
        REML=F,
        verbose=T))
```

WINTER DATA

GLOBAL; Distance to Lake and NDVI and LC and Elevation and Aspect and Fire and Distance to Seismic and Roads, GFR laNdCOVER and SEISMIC LINE model with random intercept and coefficient

```
summary(w_rsf_global<-
lmer(pttype~dt_lake+dtlake2+ndvi+ndvi2+lc+dem+dem2+aspct+fire_cat+rd_cat+dist_seis
+dtseis 2+
	(0+dt_lake|caribouID)+
	(0+dtlake2|caribouID)+
	(0+ndvi|caribouID)+
	(0+ndvi2|caribouID)+
	(0+dem|caribouID)+
	(0+dem2|caribouID)+
	(0+aspct|caribouID)+
	(0+fire_cat|caribouID)+
	(0+rd_cat|caribouID)+
	(0+dist_seis|caribouID)+
	(0+dtseis2|caribouID)+
	(1|caribouID),
	data=w_data,
	REML=F,
	verbose=T))


# CALVING DATA

# GLOBAL; Distance to Lake and NDVI and LC and Elevation and Aspect and Fire and Distance to Seismic and Roads, GFR laNdCOVER and SEISMIC LINE model with random intercept and coefficient

summary(c_rsf_global<-
lmer(pttype~dt_lake+dtlake2+ndvi+ndvi2+lc+dem+dem2+aspct+fire_cat+rd_cat+dist_seis
+dtseis 2+
	(0+dt_lake|caribouID)+
```

```
(0+dtlake2|caribouID)+
(0+ndvi|caribouID)+
(0+ndvi2|caribouID)+
(0+dem|caribouID)+
(0+dem2|caribouID)+
(0+aspct|caribouID)+
(0+fire_cat|caribouID)+
(0+rd_cat|caribouID)+
(0+dist_seis|caribouID)+
(0+dtseis2|caribouID)+
(1|caribouID),
data=c_data,
REML=F,
verbose=T))
```

APPENDIX B. Model Selection Results for Second and Third Seasonal Caribou Resource Selection Functions

Caribou resource selection functions (RSF) for breeding, summer, winter and calving seasons ranked and weighted using Akaike's Information Criteria (AIC) are provided in Table 2 (second order) and Table 3 (third order). For all seasons and orders, the model that included all covariates, but no functional response covariates had the highest weight (AIC_w = ~1.000).

Table B1. Ranking and weight of second order caribou resource selection functions (RSFs) using Akaike's Information Criteria (AIC), where models with a difference in AIC (ΔAIC) less than two from the model with the lowest AIC are considered the top model(s), and AIC weight (AICw) indicates the relative strength of support for the model.

Model	Fixes Effect Covariate(s)	Random Effect Covariates (s)	Breeding			Summer			Winter			Calving		
			AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w
Roads	RD	γ0jt+γRDjt	24,555	10,126	0.000	69,206	35,037	0.000	120,901	47,573	0.000	35,970	12,358	0.000
Seismic Line Density Functional Response	$DS+DS^2+DSe+DS:DSe+DS^2:DSe$	γ0jt+γDSjt+γDS^2jt	19,975	5,546	0.000	54,084	19,915	0.000	97,960	24,632	0.000	30,174	6,562	0.000
Roads + Seismic Line Density Functional Response	$RD+DS+DS^2+DSe+DS:DSe+DS^2:DSe+RD:DSe$	γ0jt+γRDjt+γDSjt+γDS^2jt	19,950	5,521	0.000	53,850	19,681	0.000	97,723	24,395	0.000	30,090	6,478	0.000
Elevation Functional Response	$EL+EL^2+ELe+EL:ELe+EL^2:ELe$	γ0jt+γELjt+γEL^2jt	21,280	6,851	0.000	60,240	26,071	0.000	106,420	33,092	0.000	32,849	9,237	0.000
Distance to Lake Functional Response	$DL+DL^2+DLe+DL:DLe+DL^2:DLe$	γ0jt+γDLjt+γDL^2jt	23,338	8,909	0.000	65,376	29,756	0.000	114,127	39,988	0.000	34,801	11,189	0.000

Model	Fixes Effect Covariate(s)	Random Effect Covariates (s)	Breeding			Summer			Winter			Calving		
			AIC	ΔAIC	AIC$_w$	AIC	ΔAIC	AIC$_w$	AIC	ΔAIC	AIC$_w$	AIC	ΔAIC	AIC$_w$
Land Cover Functional Response	LC+LC*e*+LC:LC*e*	γ0jt	22,558	8,129	0.000	63,009	28,840	0.000	112,098	38,770	0.000	33,544	9,933	0.000
NDVI Functional Response	NV+NV^2+NV*e*+NV:NV*e*+NV^2:NV*e*	γ0jt+γNVjt+γNV^{2}jt	23,916	9,487	0.000	66,505	32,336	0.000	116,261	42,933	0.000	35,245	11,633	0.000
Aspect	AP	γ0jt	24,513	10,084	0.000	69,244	35,075	0.000	120,889	47,561	0.000	35,899	12,287	0.000
Fire	FR	γ0jt	24,577	10,148	0.000	69,488	35,319	0.000	120,812	47,484	0.000	36,058	12,446	0.000
Elevation + Land Cover Functional Response	EL+EL^2+LC+LC*e*+LC:LC*e*	γ0jt+γELjt+γEL^{2}jt	19,589	5,160	0.000	54,810	20,641	0.000	99,779	26,451	0.000	30,647	7,035	0.000
Distance to Lake + Elevation + Land Cover Functional Response	EL+EL^2+DL+DL^2+LC+LC*e*+LC:LC*e*	γ0jt+γELjt+γEL^{2}jt+γDLjt+γDL^{2}jt	18,814	4,385	0.000	52,229	18,060	0.000	96,791	23,464	0.000	30,024	6,412	0.000
Distance to Lake + NDVI + Land Cover Functional Response + Elevation	DL+DL^2+NV+NV^2+LC+EL+EL^2+DL*e*+LC*e*+DL:LC*e*+DL^2:LC*e*+NV:LC*e*+NV^2:LC*e*+EL:LC*e*+EL^2:LC*e*+LC:LC*e*	γ0jt+γDLjt+γDL^{2}jt+γNVjt+γNV^{2}jt+γELjt+γEL^{2}jt	18,377	3,948	0.000	50,073	15,904	0.000	94,563	21,236	0.000	29,467	5,855	0.000

Model	Fixes Effect Covariate(s)	Random Effect Covariates (s)	Breeding			Summer			Winter			Calving		
			AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w
Distance to Lake + NDVI + Land Cover Functional Response + Elevation + Aspect	DL+DL^2+NV+NV^2+LC+EL+EL^2+AP+DL*e*+LC*e*+DL:LC*e*+DL^2:LC*e*+NV:LC*e*+NV^2:LC*e*+EL:LC*e*+EL^2:LC*e*+LC:LC*e*+AP:LC*e*	γ0jt+γDLjt+γDL^{2}jt+γNVjt+γNV^{2}jt+γELjt+γEL^{2}jt	18,326	3,897	0.000	49,683	15,514	0.000	94,265	20,937	0.000	29,322	5,710	0.000
Distance to Lake + NDVI + Land Cover Functional Response + Elevation + Aspect + Fire	DL+DL^2+NV+NV^2+LC+EL+EL^2+AP+FR+DL*e*+LC*e*+DL:LC*e*+DL^2:LC*e*+NV:LC*e*+NV^2:LC*e*+EL:LC*e*+EL^2:LC*e*+LC:LC*e*+AP:LC*e*+FR:LC*e*	γ0jt+γDLjt+γDL^{2}jt+γNVjt+γNV^{2}jt+γELjt+γ EL^{2}jt+γFRjt	17,683	3,254	0.000	46,126	11,957	0.000	91,158	17,830	0.000	28,581	4,969	0.000
Distance to Lake + NDVI + Land Cover Functional Response + Elevation + Fire	DL+DL^2+NV+NV^2+LC+EL+EL^2+FR+DL*e*+LC*e*+DL:LC*e*+DL^2:LC*e*+NV:LC*e*+NV^2:LC*e*+EL:LC*e*+EL^2:LC*e*+LC:LC*e*	γ0jt+γDLjt+γDL^{2}jt+γNVjt+γNV^{2}jt+γELjt+γEL^{2}jt+γFRjt	17,950	3,521	0.000	46,434	12,265	0.000	91,510	18,183	0.000	28,634	5,022	0.000

Model	Fixes Effect Covariate(s)	Random Effect Covariates (s)	Breeding			Summer			Winter			Calving		
			AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w
Distance to Lake + NDVI + Land Cover Functional Response + Elevation + Aspect + Fire + Roads + Seismic Line Density Functional Response	DL+DL^2+NV+NV^2+LC+EL+EL^2+AP+FR+RD+DS+DS^2+DS*e*+LC*e*+DL:LC*e*+DL^2:LC*e*+NV:LC*e*+NV^2:LC*e*+EL:LC*e*+EL^2:LC*e*+LC:LC*e*+AP:LC*e*+FR:LC*e*+DS:LC*e*+DS^2:LC*e*+DS:DS*e*+DS^2:DS*e*+DL:DS*e*+DL^2:DS*e*+LC:DS*e*+NV:DS*e*+NV^2:DS*e*+EL:DS*e*+EL^2:DS*e*+AP:DS*e*+FR:DS*e*+RD:DS*e*	ɣ0jt+ɣDLjt+ɣDL^{2}jt+ɣNVjt+ɣNV^{2}jt+ɣELjt+ɣEL^{2}jt+ɣFRjt+ɣDSjt+ɣDS^{2}jt	14,817	388	0.000	36,081	1,912	0.000	74,263	935	0.000	24,118	506	0.000
Distance to Lake + NDVI + Land Cover Functional Response + Elevation + Aspect + Fire + Roads + Seismic Line Density	DL+DL^2+NV+NV^2+LC+EL+EL^2+AP+FR+RD+DS+DS^2+LC*e*+DL:LC*e*+DL^2:LC*e*+NV:LC*e*+NV^2:LC*e*+EL:LC*e*+EL^2:LC*e*+LC:LC*e*+AP:LC*e*+FR:LC*e*+DS:LC*e*+DS^2:LC*e*	ɣ0jt+ɣDLjt+ɣDL^{2}jt+ɣNVjt+ɣNV^{2}jt+ɣELjt+ɣEL^{2}jt+ɣFRjt+ɣDSjt+ɣDS^{2}jt	14,945	516	0.000	36,108	1,939	0.000	75,136	1,809	0.000	24,196	584	0.000

Model	Fixes Effect Covariate(s)	Random Effect Covariates (s)	Breeding			Summer			Winter			Calving		
			AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w
Distance to Lake + NDVI + Land Cover + Elevation + Aspect + Fire + Roads + Seismic Line Density Functional Response	DL+DL^2+NV+NV^2+LC+EL+EL^2+AP+FR+RD+DS+DS^2+DS*e*+DS:DS*e*+DS^2:DS*e*+DL:DS*e*+DL^2:DS*e*+LC:DS*e*+NV:DS*e*+NV^2:DS*e*+EL:DS*e*+EL^2:DS*e*+AP:DS*e*+FR:DS*e*+RD:DS*e*	ɣ0jt+ɣDLjt+ɣDL^{2}jt+ɣNVjt+ɣNV^{2}jt+ɣELjt+ɣEL^{2}jt+ɣFRjt+ɣDSjt+ɣDS^{2}jt	DNC			36,599	2,430	0	75,083	1,755	0	24,327	716	0.000
Distance to Lake + NDVI + Land Cover + Elevation + Aspect + Fire + Roads + Seismic Line Density	DL+DL^2+NV+NV^2+LC+EL+EL^2+AP+FR+RD+DS+DS^2	ɣ0jt+ɣDLjt+ɣDL^{2}jt+ɣNVjt+ɣNV^{2}jt+ɣELjt+ɣEL^{2}jt+ɣFRjt+ɣDSjt+ɣDS^{2}jt	14,429	0	1.000	34,169	0	1.000	73,328	0	1.000	23,612	0	1.000

NOTES:

RD = Road density class

DS = Density of Seismic Lines EL = Elevation

DL = Distance to Lake LC= Land Cover class

NV = Normalized difference vegetation index (NDVI) AP = Aspect

FR = Fire age

e = expectation covariate ɣ0jt = random intercept ɣXjt = random coefficient

Table B2. Ranking and weight of third order caribou resource selection functions (RSFs) using Akaike's Information Criteria (AIC), where models with a difference in AIC (ΔAIC) less than two from the model with the lowest AIC are considered the top model(s), and AIC weight (AIC_w) indicates the relative strength of support for the model.

Model	Fixed Effect Covariate(s)	Random Effect Covariate(s)	Breeding			Summer			Winter			Calving		
			AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w
Roads	RD	$\gamma 0jt+\gamma RDjt$	23,871	1,491	0.000	68,024	11,143	0.000	123,531	17,652	0.000	36,465	2,968	0.000
Distance to Seismic Line	DS+DS^2+Dse+DS:Dse+DS^2:DSe	$\gamma 0jt+\gamma DSjt+\gamma DS^2jt$	23,699	1,320	0.000	67,002	10,121	0.000	121,670	15,791	0.000	36,152	2,655	0.000
Roads + Distance to Seismic Line Functional Response	RD+DS+DS^2+DSe+DS:DSe+DS^2:DSe+RD:DSe	$\gamma 0jt+\gamma RDjt+\gamma DSjt+\gamma DS^2jt$	23,637	1,257	0.000	66,966	10,085	0.000	121,497	15,617	0.000	36,122	2,625	0.000
Elevation Functional Response	EL+EL^2+ELe+EL:ELe+EL^2:ELe	$\gamma 0jt+\gamma ELjt+\gamma EL^2jt$	23,771	1,391	0.000	66,921	10,040	0.000	120,981	15,102	0.000	36,198	2,701	0.000
Distance to Lake Functional Response	DL+DL^2+DLe+DL:DLe+DL^2:DLe	$\gamma 0jt+\gamma DLjt+\gamma DL^2jt$	23,564	1,184	0.000	66,832	9,951	0.000	122,117	16,238	0.000	35,382	1,885	0.000
Land Cover Functional Response	LC+LCe+LC:LCe	$\gamma 0jt$	23,586	1,207	0.000	67,441	10,560	0.000	122,718	16,839	0.000	35,965	2,467	0.000
NDVI Functional Response	NV+NV^2+NVe+NV:NVe+NV^2:NVe	$\gamma 0jt+\gamma NVjt+\gamma NV^2jt$	23,574	1,194	0.000	65,897	9,016	0.000	120,890	15,010	0.000	35,880	2,383	0.000
Aspect	AP	$\gamma 0jt$	23,902	1,522	0.000	67,984	11,103	0.000	123,235	17,356	0.000	36,327	2,830	0.000
Fire	FR	$\gamma 0jt$	23,917	1,538	0.000	68,060	11,179	0.000	116,676	10,797	0.000	36,461	2,964	0.000
Distance to Lake + NDVI	DL+DL^2+NV+NV^2	$\gamma 0jt+\gamma DLjt+\gamma DL^2jt+\gamma NVjt+\gamma NV^2jt$	23,210	830	0.000	64,635	7,754	0.000	119,868	13,989	0.000	34,850	1,353	0.000
Distance to Lake + NDVI + Land Cover Functional Response	DL+DL^2+NV+NV^2+LC+DLe+LCe+DL:LCe+DL^2:LCe+NV:LCe+NV^2:LCe+LC:LCe	$\gamma 0jt+\gamma DLjt+\gamma DL^2jt+\gamma NVjt+\gamma NV^2jt$	23,045	666	0.000	64,299	7,418	0.000	118,653	12,773	0.000	34,714	1,217	0.000
Distance to Lake + NDVI + Land Cover Functional Response + Elevation	DL+DL^2+NV+NV^2+LC+EL+EL^2+DLe+LCe+DL:LCe+DL^2:LCe+NV:LCe+NV^2:LCe+E	$\gamma 0jt+\gamma DLjt+\gamma DL^2jt+\gamma NVjt+\gamma NV^2jt+\gamma ELjt+\gamma EL^2jt$	22,838	459	0.000	63,458	6,577	0.000	116,692	10,813	0.000	34,439	942	0.000

Model	Fixed Effect Covariate(s)	Random Effect Covariate(s)	Breeding			Summer			Winter			Calving		
			AIC	ΔAIC	AIC$_w$	AIC	ΔAIC	AIC$_w$	AIC	ΔAIC	AIC$_w$	AIC	ΔAIC	AIC$_w$
Distance to Lake + NDVI + Land Cover Functional Response + Elevation + Aspect	DL+DL^2+NV+NV^2+LC+EL+EL^2+AP+DL*e*+LC*e*+DL:LC*e*+DL^2:LC*e*+NV:LC*e*+NV^2:LC*e*+EL:LC*e*+EL^2:LC*e*+LC:LC*e*+AP:LC*e*	*γ0jt+γDLjt+γDL^{2}jt+γNVjt+γNV^{2}jt+γELjt+γEL^{2}jt*	22,833	453	0.000	63,395	6,514	0.000	116,339	10,459	0.000	34,392	895	0.000
Distance to Lake + NDVI + Land Cover Functional Response + Elevation + Aspect + Fire	DL+DL^2+NV+NV^2+LC+EL+EL^2+AP+FR+DL*e*+LC*e*+DL:LC*e*+DL^2:LC*e*+NV:LC*e*+NV^2:LC*e*+EL:LC*e*+EL^2:LC*e*+LC:LC*e*+AP:LC*e*	*γ0jt+γDLjt+γDL^{2}jt+γNVjt+γNV^{2}jt+γELjt+γEL^{2}jt+γFRjt*	22,630	251	0.000	63,106	6,225	0.000	108,049	2,170	0.000	34,097	599	0.000
Distance to Lake + NDVI + Land Cover Functional Response + Elevation + Fire	DL+DL^2+NV+NV^2+LC+EL+EL^2+FR+DL*e*+LC*e*+DL:LC*e*+DL^2:LC*e*+NV:LC*e*+NV^2:LC*e*+EL:LC*e*+EL^2:LC*e*+LC:LC*e*	*γ0jt+γDLjt+γDL^{2}jt+γNVjt+γNV^{2}jt+γELjt+γEL^{2}jt+γFRjt*	22,642	263	0.000	63,167	6,286	0.000	108,464	2,585	0.000	34,152	655	0.000
Distance to Lake + NDVI + Land Cover Functional Response + Elevation + Aspect + Fire + Roads + Distance to Seismic Line Functional Response	DL+DL^2+NV+NV^2+LC+EL+EL^2+AP+FR+RD+DS+DS^2+DS*e*+LC*e*+DL:LC*e*+DL^2:LC*e*+NV:LC*e*+NV^2:LC*e*+EL:LC*e*+EL^2:LC*e*+LC:LC*e*+AP:LC*e*+FR:LC*e*+DS:LC*e*+DS^2:LC*e*+DS:DS*e*+DS^2:DS*e*+DL:DS*e*+DL^2:DS*e*+LC:	*γ0jt+γDLjt+γDL^{2}jt+γNVjt+γNV^{2}jt+γELjt+γEL^{2}jt+γFRjt+γDSjt+γDS^{2}jt*	22,658	278	0.000	61,993	5,112	0.000	105,911	32	0.000	33,829	332	0.000
Distance to Lake + NDVI + Land Cover Functional Response + Elevation + Aspect + Fire + Roads + Distance to Seismic Line	DL+DL^2+NV+NV^2+LC+EL+EL^2+AP+FR+RD+DS+DS^2+LC*e*+DL:LC*e*+DL^2:LC*e*+NV:LC*e*+NV^2:LC*e*+EL:LC*e*+EL^2:LC*e*+LC:LC*e*+AP:LC*e*+FR:LC*e*+DS:LC*e*+DS^2:LC*e*	*γ0jt+γDLjt+γDL^{2}jt+γNVjt+γNV^{2}jt+γELjt+γEL^{2}jt+γFRjt+γDSjt+γDS^{2}jt*	22,625	246	0.000	57,305	425	0.000	106,414	535	0.000	33,844	346	0.000
Distance to Lake + NDVI + Land Cover + Elevation + Aspect + Fire + Roads + Distance to Seismic Line Functional Response	DL+DL^2+NV+NV^2+LC+EL+EL^2+AP+FR+RD+DS+DS^2+DS*e*+DS:DS*e*+DS^2:DS*e*+DL:DS*e*+DL^2:DS*e*+LC:DS*e*+NV:DS*e*+NV^2:DS*e*+EL:DS*e*+EL2:DS*e*+AP:DS*e*+FR:DS*e*+RD:	*γ0jt+γDLjt+γDL^{2}jt+γNVjt+γNV^{2}jt+γELjt+γEL^{2}jt+γFRjt+γDSjt+γDS^{2}jt*	22,488	108	0.000	57,306	424	0.000	105,925	46	0.001	33,843	345	0.000
Distance to Lake + NDVI + Land cover + Elevation + Aspect + Fire + Roads + Distance to Seismic Line	DL+DL^2+NV+NV^2+LC+EL+EL^2+AP+FR+RD+DS+DS^2	*γ0jt+γDLjt+γDL^{2}jt+γNVjt+γNV^{2}jt+γELjt+γEL^{2}jt+γFRjt+γAPjt+γRDjt+γDSjt+γDS^{2}jt*	22,380	0	1.000	56,881	0	1.000	105,879	0	1.000	33,497	0	1.000

Model	Fixed Effect Covariate(s)	Random Effect Covariate(s)	Breeding			Summer			Winter			Calving		
			AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w	AIC	ΔAIC	AIC_w

NOTES:

RD = Road density class

DS = Distance to Seismic Line EL = Elevation
DL = Distance to Lake LC= Land cover class
NV = Normalized difference vegetation index (NDVI) AP = Aspect
FR = Fire age

e = expectation covariate ɣ0jt = random intercept ɣXjt = random coefficient

APPENDIX C. Model Validation Results for Second and Third Seasonal Caribou Resource Selection Functions

		Model			
Iteration	**Test Type**	**Breeding**	**Summer**	**Winter**	**Calving**
Test 1	Slope	1.02	1.04	1.10	1.05
	Intercept	-5	-20	-89	-14
	R^2	0.99	0.99	0.96	0.94
	χ^2 p-value	0.24	0.24	0.24	0.11
	rs	0.98	0.92	0.96	0.96
Test 2	Slope	0.95	0.92	0.95	0.98
	Intercept	8	35	43	6
	R^2	0.95	0.98	0.94	0.97
	χ^2 p-value	0.23	0.23	0.23	0.23
	rs	0.94	0.98	0.98	0.98
Test 3	Slope	0.04	0.76	1.00	0.99
	Intercept	16	121	-1	3
	R^2	0.00	0.87	0.93	0.89
	χ^2 p-value	0.23	0.23	0.23	0.25
	rs	0.42	0.71	0.99	0.96
Test 4	Slope	1.13	0.90	0.98	1.00
	Intercept	-19	47	17	0
	R^2	0.95	0.96	0.87	0.92

Iteration	Test Type	Model			
		Breeding	Summer	Winter	Calving
	χ^2 p-value	0.27	0.25	0.23	0.24
	rs	0.92	0.96	0.95	0.97
Test 5	Slope	1.09	1.02	1.05	1.07
	Intercept	-15	-10	-40	-17
	R^2	1.00	0.96	0.94	0.98
	χ^2 p-value	0.25	0.24	0.24	0.25
	rs	0.99	0.92	0.97	0.98
Average	Slope	0.85	0.93	1.02	1.02
	Intercept	-3	35	-14	-4
	R^2	0.78	0.95	0.93	0.94
	χ^2 p-value	0.25	0.24	0.24	0.22
	rs	0.85	0.90	0.97	0.97

		Model			
Iteration	**Test Type**	**Breeding**	**Summer**	**Winter**	**Calving**
Test 1	Slope	1.02	0.96	1.08	1.00
	Intercept	-4	19	-74	1
	$R2$	0.99	0.90	0.92	0.94
	χ^2 p-value	0.25	0.10	0.25	0.24
	rs	0.99	0.96	0.98	0.97
Test 2	Slope	1.02	0.99	1.01	1.01
	Intercept	-3	6	-4	-3
	$R2$	1.00	0.84	0.97	1.00
	χ^2 p-value	0.21	0.23	0.23	0.23
	rs	0.88	0.96	1.00	0.93
Test 3	Slope	0.99	0.97	1.02	1.04
	Intercept	2	13	-15	-10
	$R2$	0.99	0.96	0.96	1.00
	χ^2 p-value	0.03	0.24	0.25	0.10
	rs	0.93	0.94	0.95	0.98
Test 4	Slope	1.12	1.01	1.02	1.10
	Intercept	-19	-5	-13	-19
	$R2$	0.99	0.89	0.95	0.99
	χ^2 p-value	0.10	0.25	0.25	0.10

		Model			
Iteration	**Test Type**	**Breeding**	**Summer**	**Winter**	**Calving**
	rs	0.99	0.96	0.96	0.74
Test 5	Slope	1.05	1.18	0.96	1.06
	Intercept	-9	-93	29	-16
	R^2	1.00	0.98	0.89	0.99
	χ^2 p-value	0.23	0.25	0.27	0.13
	rs	0.93	0.96	0.96	0.94
Average	Slope	1.04	1.02	1.02	1.04
	Intercept	-7	-12	-16	-9
	R^2	0.99	0.91	0.94	0.98
	χ^2 p-value	0.17	0.22	0.25	0.16
	rs	0.95	0.96	0.97	0.91