Modelling Seasonal Habitats of Boreal Woodland Caribou at the Northern Limits of their Range: A Preliminary Assessment of the Lower Mackenzie River Valley, Northwest Territories, Canada

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1.0 Introduction

The northernmost range of boreal woodland caribou in Canada is in the Mackenzie River Delta area, Northwest Territories. Unlike barren-ground (*Rangifer tarandus groenlandicus*), Peary (*R. t. pearyi*), and mountain woodland caribou (*R. t. caribou*), boreal woodland caribou (*R. t. caribou*) in this area had not been the focus of scientific studies in the NWT until recently (Nagy et al. 2003; Nagy et al. 2005a).

Threats to boreal woodland caribou habitat include oil and gas exploration and development, roads and hydro developments, increased tourism and other non-consumptive human activities, forest fires, and climate change (Dyer et al. 2001; Dyer 1999; Dyer et al. 2002; Bradshaw et al. 1997; Bradshaw et al. 1998; Courtois et al. 2003; Schaefer and Pruitt 1991; Bayne et al. 2005). The degree of impact of past human disturbances and wildfires on boreal woodland caribou habitat in the NWT is not un-known. Elsewhere in Canada human activities and natural habitat disturbances have been shown to negatively affect caribou. In some areas, such as Nova Scotia and New Brunswick, boreal woodland caribou were extirpated.

The boreal woodland caribou range in the lower Mackenzie River Valley has already been altered by seismic activities, wildfires, and road development. The Mackenzie River Delta area is currently experiencing a significant increase in oil and gas exploration and extraction (Imperial Oil Resources Ventures Limited 2004). A pipeline along the Mackenzie River Valley has been proposed to deliver natural gas to the south (Imperial Oil Resources Ventures Limited 2004). These activities and subsequent gas exploration and development activities may have an impact on boreal woodland caribou and their habitats in the lower Mackenzie River area.

Linear disturbances such as seismic lines, roads, and cutlines, have significantly affected many wildlife populations throughout the world (James and Stuart-Smith 2000). Many wildlife species have been documented to avoid habitats with high densities of linear disturbances (McLellan and Shackleton 1988; Linke et al. 2005; Dyer et al. 2002). Renewed oil and gas development in the north will cause higher densities of linear disturbance, resulting mainly from seismic activity. Over 37,000 km of seismic lines were cut in the Mackenzie River Delta area from 1960 to 1990 (National Energy Board Records). The impacts of linear disturbance on wildlife in a northern environment have been poorly studied, however it is clear that permafrost terrain is easily degraded (Lambert 1972; Mackay 1970; Nicholas and Hinkel 1996; Zoltai and Pettapiece 1973) and disturbed vegetation is slow to recover (Billings 1987; Harper and Kershaw 1996). This suggests that 1) disturbance is more likely to alter wildlife habitat in the north; and 2) any alteration of wildlife habitat will last longer.

Climate change models for the Mackenzie River Valley predict an increase in wildfire frequency and severity (Kadonga 1997), increased snowfall across the region, the incursion of new species including forest pests (Sieben et al. 1997) and parasites (Kutz et al. 2004; Kutz et al. 2005), and significant changes in forest composition (Hartley and Marshall 1997; Chapin et al. 2004). How these changes will impact boreal woodland caribou is unknown.

In response to large-scale potential changes in habitats and animal populations, the Department of Environment and Natural Resources, GNWT in partnership with the Gwich'in Renewable Resource Board began collecting baseline information on boreal woodland caribou in the lower Mackenzie River area in 2001. Traditional knowledge of woodland caribou was documented during the winter of 2001/2002 (Auriat unpublished data). In the fall of 2001, a more detailed assessment was initiated to collect baseline information on the demography, distribution, movements, home range size, and habitat use for boreal woodland caribou in the Lower Mackenzie River area (Nagy et al. 2003; Nagy et al. 2005a). Here we expand on these reports to provide descriptions of seasonal caribou habitat use and spatial representations of caribou habitat using a GIS (Geographic Information System), resource selection functions (RSF), and satellite tracking data collected from May 2002 to January 2006. We describe the predictive capacity of models and assess the effect of sample size for their ability to predict population-level habitat conditions. We modified the linear stretch method used by Johnson et al. (2004) to map the models beyond the boundaries of the study area. Ultimately, RSF models were designed to establish seasonal habitat baselines that can be used to assess the impacts of future climate change and oil/gas development (Johnson et al. 2004; Nielsen et al. 2006).

2.0 Study Area

The 43,748 km^2 core study area is largely north of the Arctic Circle (66.55^o latitude) and is primarily in the Gwich'in Settlement Area in the Northwest Territories, although the western portion extends into the Yukon Territory and the northern portion extends into the Inuvialuit Settlement Region (Figures 1 and 2). The area is adjacent to the southern extent of the Mackenzie River Delta and is approximately 130 km north of the Mackenzie Mountains and 30 km east of the Richardson Mountains and therefore, between the ranges of the Porcupine barren-ground caribou herd to the west and the Cape Bathurst and Bluenose-West barren-ground caribou herds to the north and east (Nagy et al. 2005a; Nagy et al. 2005b). Moose (*Alces alces*) occur throughout the area but are at low densities. Predators include wolves (*Canis lupus*), black bears (*Ursus americanus*), and lynx (*Lynx Canadensis*), but numbers of wolves and black bears appear to be low based on frequency of sightings.

Terrain in the area is relatively flat to rolling with elevations ranging from near sea level to 400 m above sea level (asl). The median elevation is approximately 90 m asl. Open black spruce forests, fens, and shrub meadows dominate upland and lowland areas. White spruce (*Picea glauca*) and mixed stands of spruce and paper birch (*Betula papyrifera*) occur on steeper slopes along rivers and streams.

Wild fires have been common, with approximately 37 percent of area burned since 1960. The Dempster Highway follows nearly 160 km of the northwestern boundary of the study area between Inuvik (population approximately 3,500 people), Tsiigehtchic (population approximately 150 people) and Fort McPherson (population approximately 800 people).

Oil and gas exploration has led to 11,052 km of seismic lines within the core study area or an average of 0.25 km/km^2. The majority of the activity took place during 1970-1979 and 1965-1969 when 20.4 and 10.5 percent of the seismic lines were cut, respectively. More minor activity occurred during 1983-1989, although 68 percent of seismic lines have an unknown year of origin. The majority of the seismic lines occur on the eastern and southern portions of the core study area.

The regional study area (115,581 km^2) includes the Peel Plateau, Lower Mackenzie, and Middle Mackenzie areas mapped by Ducks Unlimited (Ducks Unlimited 2002; Ducks Unlimited 2003; Ducks Unlimited 2006)(Figure 3).

3.0 Methods

3.1 Capture and Collaring Work

Boreal woodland caribou in the study area were equipped with GPS, ARGOS, and VHF radio collars (Telonics, Mesa, Arizona) during capture in early May 2002, March 2003, March 2004, and March 2005 (Nagy et al. 2003; Nagy et al. 2005a). GPS collars were programmed to provide 3 locations per day (01:00 h, 09:00 h, and 17:00 h). ARGOS satellite collars were programmed to provide locations as follows: a) one location per day between 15 May and 21 June, and one location every 5 days for the remainder of the year, or, b) one location per day between 15 April and 15 June and one location every 2 days for the remainder of the year. Only GPS and class 3 ARGOS satellite locations were used for habitat analyses.

3.2 Modelling Approach

Spatial data were analyzed in ArcView 3.2 (Environmental Systems Research Institute) and ArcView 9.0 (Environmental Systems Research Institute). The core study area was defined using the Animal Movement Program extension for ArcView 3.2 (Hooge et al. 1999) to create a minimum convex polygon (MCP) around all caribou locations obtained during the period 1 May 2002 to 3 January 2006. This polygon was buffered by 3,137 m (95^{th} percentile distance between locations obtained at 8 hour intervals for GPS collared caribou) (J. Nagy unpublished data). The result was an area defined at 43,748 km^2 (Figure 1 and 2).

To assess habitat use, we used 13,433 caribou locations (n = 11,598 GPS and n = 1,835 class 3 ARGOS) obtained between 1 May 2002 and 3 January 2006 that fell within the core study area for which we had land cover information. Random locations were generated for the same study area at a sampling intensity of 1 point per km^2 resulting in 42,368 available locations.

A mosaic of land cover classified Landsat TM satellite imagery for the Lower Mackenzie River, Peel Plateau, and Middle Mackenzie River areas (Ducks Unlimited 2002; Ducks Unlimited 2003; Ducks Unlimited 2006) provided information on the use and availability of land cover types. We grouped similar land cover classes to provide good transition between scenes and to reduce the number of covariates to a manageable scale (Table 1). An National Topographic Series (NTS) based digital elevation model for the area provided information on slope, aspect, and elevation (Natural Resources Canada).

To assess the characteristics at or around each animal and random location, we determined land cover, median slope, aspect, and elevation within a 30 m buffer (resolution of the digital land cover maps) using ArcView 3.2. Frequency of use of land cover types (Table 1) by week were clustered into groups using a hierarchical cluster (Wards method) analysis (SPSS Inc. 2002); (McCune and Mefford 1999). This was done to identify time periods during which the frequency of use of land cover types among caribou was similar thus ensuring the seasonal models that were generated had good predictive capacity.

We used logistic regressions in STATA (StataCorp 2005b) to fit an resource selection (RSF) model (Boyce et al. 2002), taking the form:

$$w(x) = \exp(\exists_1 x_1 + \exists_2 x_2 + \ldots.. + \exists_n x_n) \quad \text{(equation 1),}$$

where covariates x_1 to x_n represent possible combinations of land cover and terrain variables for each season (Table 2 and 3) and $\exists_1$ to $\exists_n$ represent model coefficients. Non-significant ($p<0.05$) covariates were removed from each model, with final model selection based on an Akaike's Information Criterion (AIC) to select the most parsimonious model (Johnson et al. 2004).

For confirmatory purposes, we calculated log-likelihood X^2 statistics for assessment of overall model fit and used 95% confidence intervals to assess the strength of effect of each predictor covariate on the dependent variable (Johnson et al. 2004; StataCorp 2005b). We removed covariates that were not significantly different from zero. The program LOGIT removed variables with excessive colinearity (StataCorp 2005b).

To examine model performance, we partitioned RSF scores from the full model for random data into 10 equal interval bins (Boyce et al. 2002). Use locations were then assigned to the appropriate bin based on thresholds established for defining the original bins. We tested the resulting data to determine if the distribution of use locations was significantly different than that of random locations. Frequency of use and random locations for each bin were used to calculate use:availability ratios for each bin (Boyce et al. 2002). A use:availability ratio or area adjusted frequencies of 1 indicated that use was occurring at rates expected by chance (Boyce et al. 2002). For models with good predictive performance use:availability ratios for the highest level bins would be expected to be >1 (e.g., selection of habitats), while the lowest bins would be expected to be <1 (e.g. avoidance of habitats). Spearman rank correlations were used to test the relationship between bin rank and use:availability ratios to determine the predictive capacity of the seasonal model.

To determine whether we had a sufficient number of animals collared to account for individual variation in resource use, we generated 10 random subsets of 50, 60, 70, 80, and 90 percent of the collared animals for each season. We fitted logistic regression models for each subset of data (non-significant and collinear variables were excluded). We then used a Chow test to determine if the coefficients for logistic regression models generated using the random subsets of data were significantly different from the full model (StataCorp 2005b) (StataCorp 2005a).

3.3 Mapping the RSF

A 60 X 60 m grid was overlaid on the Lower Mackenzie River, Peel Plateau, and Middle Mackenzie River area (Ducks Unlimited 2002; Ducks Unlimited 2003; Ducks Unlimited 2006) land cover map. We used the mean value for the coefficient for each variable in the RSF models to calculate the RSF value for each grid cell in a GIS.

Johnson et al. (2004) and Nielsen et al. (2006) used linear stretch and binning GIS techniques to map models for their study areas, respectively. We generated seasonal RSF models for the core study area and then use the coefficients for these models to generate RSF scores for the regional study area. The relative availability of RSF scores must be the same in the core and regional study areas in order for the linear stretch and binning mapping techniques to work effectively at the two scales. If the maximum RSF score in the regional study area is greater than that in the core study area, relative probability of use will be skewed to lower values. To resolve this problem, we extracted the RSF value for the grid cells at caribou use locations and derived the median RSF value (median use RSF). To map the relative probability of use of caribou across the Lower Mackenzie River, Peel Plateau, and Middle Mackenzie River areas we reclassified all RSF values that were > median use RSF to the value of the median use RSF. We then used a linear stretch of the form:

$$w = ((w(x)-w_{min})/(w_{median}-w_{min})) \quad \text{(equation 2)}$$

where w(x) is the product of equation 1 and w_{min} and w_{median} represent the smallest RSF value available on the landscape and the median use RSF, respectively. As a result, the areas that we mapped as having a relatively high probability of use by boreal woodland caribou at the regional study area level had RSF values that were similar to that of a minimum of 50 percent of the caribou use locations in our study area. We reclassified relative probability of use into 5 equal interval categories (Table 4). These were then mapped. We overlaid the caribou use and random locations and extracted the category of relative probability of use for the grid cells that these locations fell within. We then calculated the ratio of use:availability for each category.

4.0 Results

We identified 6 caribou seasons using the hierarchical cluster analyses (Table 5). RSF models were generated for each of these seasons.

4.1 Season 1: Calving/post-calving

We used 1,695 locations from caribou in the lower Mackenzie River population to construct 8 logistic regression models and the most parsimonious model (Table 4 and 6). This most parsimonious model was statistically significant (X^2 (10)=765.67, $P < 0.001$). The distribution of use locations among RSF bins was significantly different from random (X^2 (9)=628.150, $P <$ 0.001). The Spearman rank correlation between bin rank and use:availability ratio of 0.976 ($P <$ 0.001) indicated that this model had good predictive capacity (Figure 4). The Chow test indicated that the coefficients estimated by logistic regression for each of the 10 random subsets of 50% of the collared animals (n = 12) for this season were not significantly different from that of the full model (P = 1.000). This suggests that the full model accounts for individual variation in resource use among caribou for this season. The categorized probability of use of boreal woodland caribou in the lower Mackenzie River Valley during the calving/post-calving season is shown in Figure 5.

Ratios of use:availability by relative probability of use category for the calving/post-calving season are depicted in Figure 6. Sixty-three percent of use locations fell within areas mapped as having a relatively high probability of use by boreal woodland caribou, 82% of use locations fell within areas mapped as having a moderate-high or high probability of use.

4.2 Season 2: Early/mid-summer

We used 1,918 locations from caribou in the lower Mackenzie River population to construct 8 logistic regression models and the most parsimonious model (Table 4 and 7). The most parsimonious model was statistically significant (X^2 (11)=738.17, $P < 0.001$). The distribution of use locations among RSF bins was significantly different from random (X^2 (9)=595.097, $P <$ 0.001). The Spearman rank correlation between bin rank and use:availability ratio of 0.903 (P < 0.001) indicated that this model had good predictive capacity (Figure 7). The Chow test indicated that the coefficients estimated by logistic regression for each of the 10 random subsets of 50% of the collared animals (n = 12) for this season were not significantly different from that of the full model (P = 1.000). This suggests that the full model accounts for individual variation in resource use among caribou for this season. The categorized relative probability of use for boreal woodland caribou in of the lower Mackenzie River Valley during the early/mid-summer season is shown in Figure 8.

Ratios of use:availability by relative probability of use category for the calving/post-calving season are depicted in Figure 9. Sixty-one percent of the use locations fell within areas mapped as having a relatively high probability of use by boreal woodland caribou, 88% of the use locations fell within areas mapped as having a moderate-high or high probability of use.

4.3 Season 3: Late summer/fall

We used 3,374 locations from caribou in the lower Mackenzie River population to construct 8 logistic regression models and the most parsimonious model (Table 4 and 8). The most parsimonious model was statistically significant (X^2 (11)=1,266.63, $P < 0.001$). The distribution of use locations among RSF bins was significantly different from random (X^2 (9)=954.158, $P <$ 0.001). The Spearman rank correlation between bin rank and use:availability ratio of 0.964 (P < 0.001) indicated that this model had good predictive capacity Figure 10). The Chow test indicated that the coefficients estimated by logistic regression for each of the 10 random subsets of 50% of the collared animals (n = 12) for this season were not significantly different from that of the full model (P = 1.000). This suggests that the full model accounts for individual variation in resource use among caribou for this season. The categorized probability of use for boreal woodland caribou in the lower Mackenzie River Valley during the late summer/fall season is shown in Figure 11.

Ratios of use:availability by relative probability of use category for the calving/post-calving season are depicted in Figure 12. Seventy percent of the use locations fell within areas mapped as having a relatively high probability of use by boreal woodland caribou, 88% of the use locations fell within areas mapped as having a moderate-high or high probability of use.

4.4 Season 4: Early winter

We used 2,136 locations from caribou in the lower Mackenzie River population to construct 8 logistic regression models and the most parsimonious model (Table 4 and 9). The most parsimonious model was statistically significant (X^2 (15)=1,467.6, $P < 0.001$). The distribution of use locations among RSF bins was significantly different from random (X^2 (9)=1521.878, $P <$ 0.001). The Spearman rank correlation between bin rank and use:availability ratio of 0.778 (P < 0.001) indicated that this model did not have good predictive capacity. However, the use:availability ratio for bins 1-9 were around 1 or < 1. The use:availability ratio for bin 10 was 3.5 suggesting that animals were highly selective during early winter and that this model has good predictive capacity (Figure 13). The Chow test indicated that the coefficients estimated by logistic regression for each of the 10 random subsets of 50% of the collared animals (n = 12) for this season were not significantly different from that of the full model (P = 1.000). This suggests that the full model accounts for individual variation in resource use among caribou for this season. The categorized probability of use for boreal woodland caribou in the lower Mackenzie River Valley during the early winter season is shown in Figure 14.

Ratios of use:availability by relative probability of use category for the calving/post-calving season are depicted in Figure 15. Sixty-nine percent of the use locations fell within areas mapped as having a relatively high probability of use of boreal woodland caribou, 94% of the use locations fell within areas mapped as having a moderate-high or high probability of use.

4.5 Season 5: Mid winter

We used 1,760 locations from caribou in the lower Mackenzie River population to construct 8 logistic regression models and the most parsimonious model (Table 4 and 10). The most parsimonious model was statistically significant (X^2 (16)=1,680.77, $P < 0.001$). The distribution of use locations among RSF bins was significantly different from random (X^2 (9)=2124.397, $P <$ 0.001). The Spearman rank correlation between bin rank and use:availability ratio of 0.952 (P < 0.001) indicated that this model had good predictive capacity (Figure 16). The Chow test indicated that the coefficients estimated by logistic regression for each of the 10 random subsets of 50% of the collared animals (n = 12) for this season were not significantly different from that of the full model (P = 1.000). This suggests that the full model accounts for individual variation in resource use among caribou for this season. The categorized probability of use for boreal woodland caribou in the lower Mackenzie River Valley during the mid winter season is shown in Figure 17.

Ratios of use:availability by relative probability of use category for the calving/post-calving season are depicted in Figure 18. Sixty-one percent of the use locations fell within areas mapped as having a relatively high probability of use of boreal woodland caribou, 76% of the use locations fell with areas mapped as having a moderate-high or high probability of use.

4.6 Season 6: Late winter/pre-calving

We used 2,917 locations from caribou in the lower Mackenzie River population to construct 8 logistic regression models and the most parsimonious model (Table 4 and 11). This most parsimonious model was statistically significant (X^2 (15)=1,801.17, $P < 0.001$). The distribution of use locations among RSF bins was significantly different from random (X^2 (9)=1639.207, $P < 0.001$). The Spearman rank correlation between bin rank and use:availability ratio of 0.918 ($P < 0.001$) indicated that this model had good predictive capacity (Figure 19). The Chow test indicated that the coefficients estimated by logistic regression for each of the 10 random subsets of 50% of the collared animals (n = 12) for this season were not significantly different from that of the full model (P = 1.000). This suggests that the full model accounts for individual variation in resource use among caribou for this season. The categorized probability of use for boreal woodland caribou in the lower Mackenzie River Valley during the late winter/pre-calving season is shown in Figure 20.

Ratios of use:availability by relative probability of use category for the calving/post-calving season are depicted in Figure 21. Sixty-eight percent of the use locations fell within areas mapped as having a relatively high probability of use of boreal woodland caribou, 90% of the use locations fell within areas mapped as having a moderate-high or high probability of occurrence.

4.7 Summary

Table 11 provides a summary of the proportions of the core and regional study area that fall within the 5 relative probability of occurrence categories and the proportions of caribou locations that fell within these areas.

5.0 Discussion

We defined 6 caribou seasons by clustering weekly periods with similar frequencies of use of land cover types. These seasons include: calving/post-calving, early/mid-summer, late summer/fall, early winter, mid-winter, late winter/pre-calving seasons for boreal woodland caribou in the core study. Other researchers defined seasons based on changes in movement rates (Ferguson and Elkie 2004). A comparison of monthly movement rates (Nagy et al. 2005a) and seasons defined in this paper indicate that movement rates varied significantly during some of the seasons that we defined. This suggests the use of cover types by boreal woodland caribou does not necessarily change with a change in movement rates change. Resource selection models are largely habitat based, and as a result, seasons should be defined by grouping periods with similar frequencies of use of land cover types.

We developed landscape-level RSF models for each seasonal period. Our analyses indicate that these models had good predictive capacity and that the sample sizes of collared animals used to generate these models were sufficient to account for individual variation in resource use.

Mapping procedures described in the literature are study area based, i.e., RSF models are generated using use and availability information derived for a study area and then the models are applied to the study area (Johnson et al. 2004; Nielsen et al. 2006). We generated our RSF models using use and availability information derived for our core study area and then applied the model to the Peel Plateau, Lower Mackenzie, and Middle Mackenzie areas mapped by Ducks Unlimited (Ducks Unlimited 2002) (regional study area). Linear stretch and binning techniques described in the literature (Johnson et al. 2004) (Nielsen et al. 2006)did not work consistently when we extrapolated our models beyond the study area. To resolve this problem, we standardized W_{max} to the median RSF score for locations used by caribou rather than to the maximum RSF value available in the regional study area. As a result, the areas that we mapped as having a relatively high probability of use by boreal woodland caribou at the regional study area level had RSF values similar to that of a minimum of 50 percent of the caribou use locations in our study area. Areas mapped as having a relatively high probability of use by boreal woodland caribou had use:availability ratios > 1, while those for the other categories of relative probability of use had use:availability ratios < 1.

The modified linear stretch procedure allowed us to make direct comparisons of the proportions of the core or regional study areas that fell within the 5 relative probability of use categories among seasons and to map the distribution of these areas. The resulting maps provide a baseline of the relative quality and distribution of boreal woodland caribou habitat currently available within the Lower Mackenzie River Valley that can be used to predict and measure the future impacts of wild fires, climate change, human disturbance, and industry on these caribou.

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Figure 1. Location of study area within the range of boreal woodland caribou in Canada.

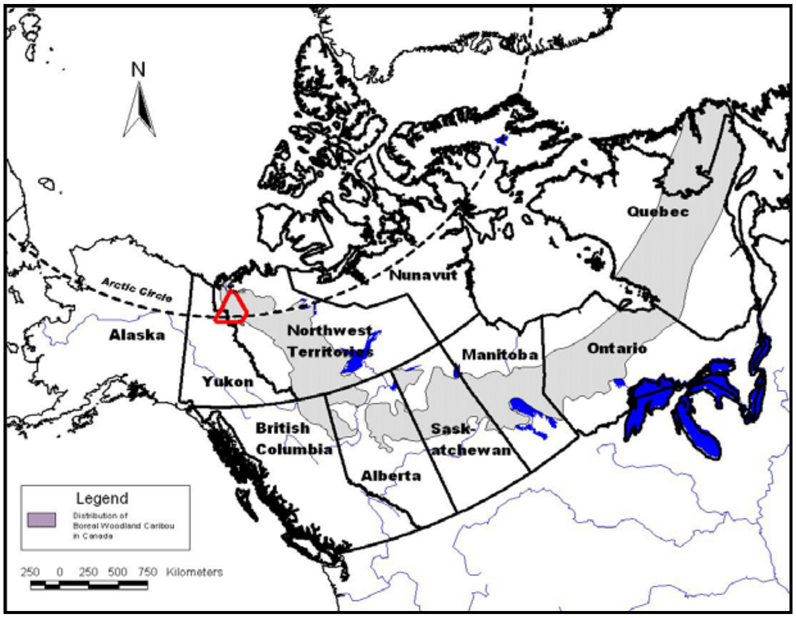

Figure 2. Location of the study area within the Lower Mackenzie River Area.

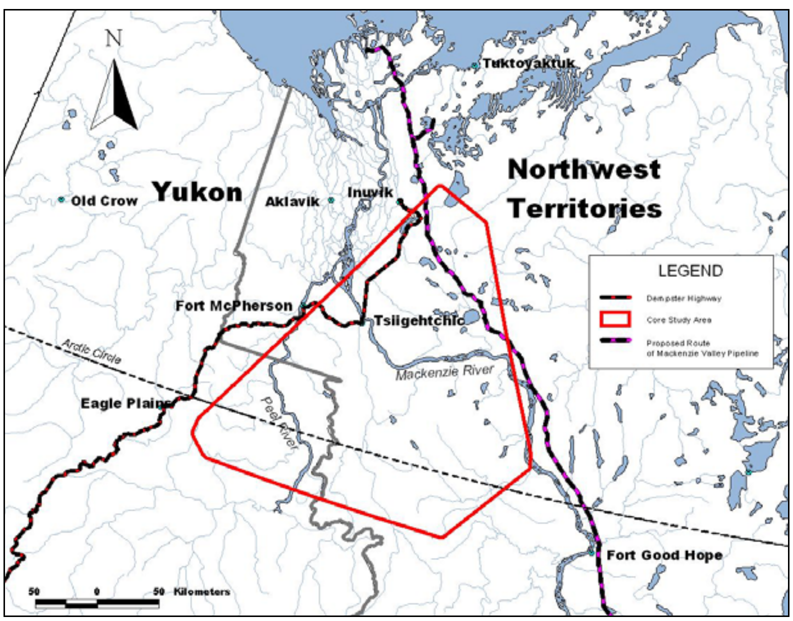

Figure 3. Location of the Lower Mackenzie River, Peel Plateau, and Middle Mackenzie River areas mapped by Ducks Unlimited.

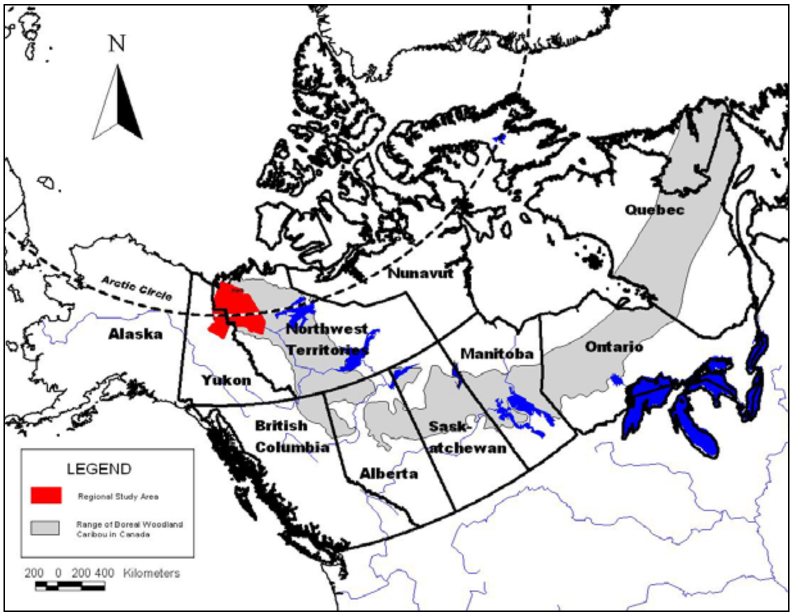

Figure 4. Ratio of use:availability by bin rank for the calving/post-calving season RSF model for boreal woodland caribou in the lower Mackenzie River Valley, Northwest Territories.

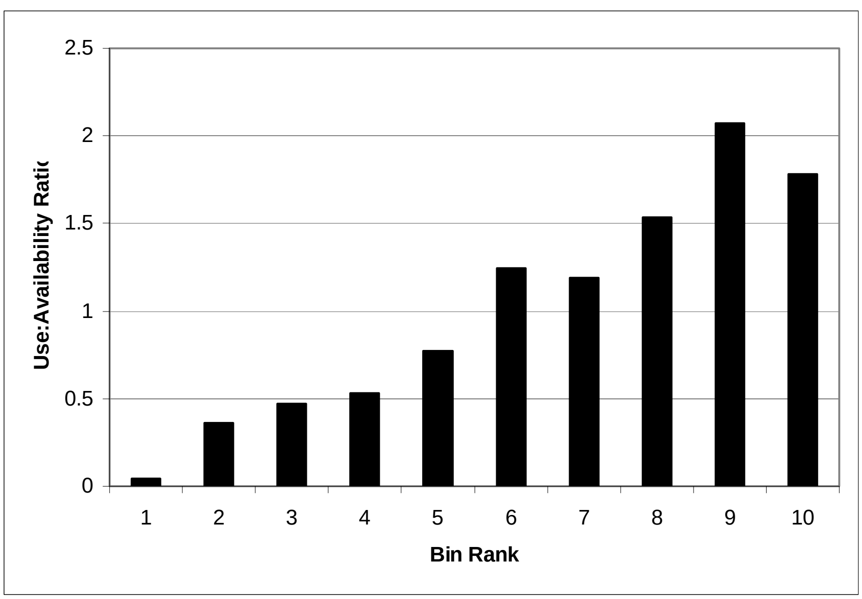

Figure 5. Categorized relative probability of use for boreal woodland caribou in the lower Mackenzie River Valley during the calving/post-calving season.

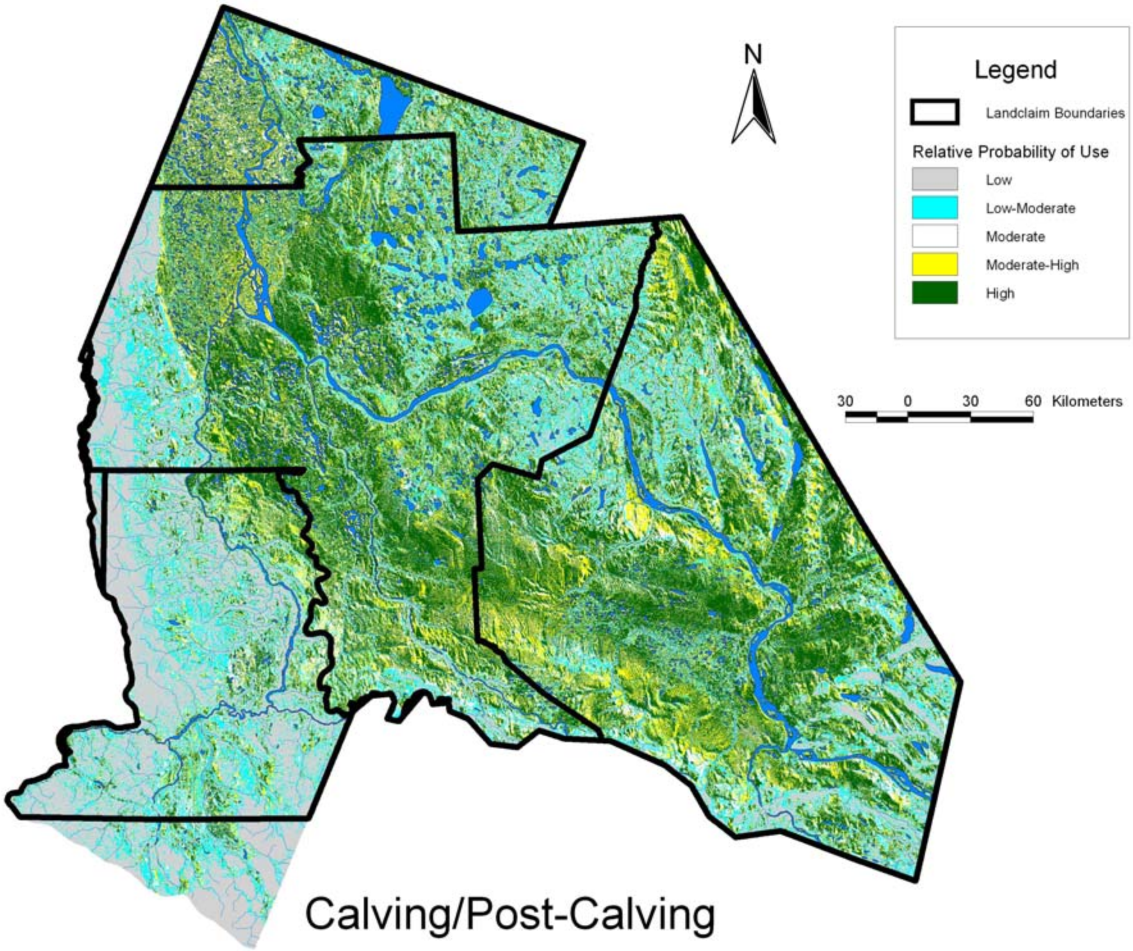

Figure 6. Ratio of use:availability by category of relative probability of use for the calving/post-calving season for boreal woodland caribou in the area of the lower Mackenzie River Valley, Northwest Territories

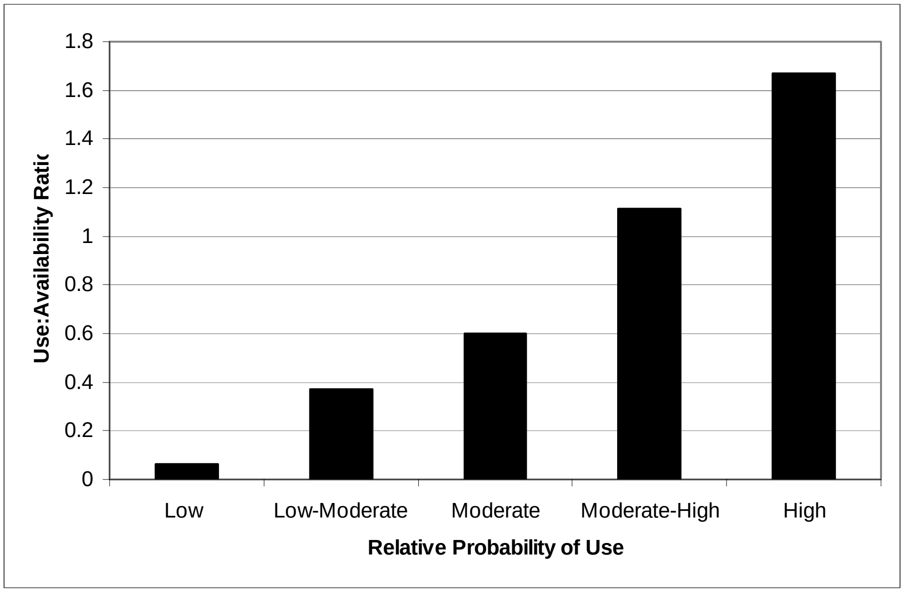

Figure 7. Ratio of use:availability by bin rank for the early/mid summer season RSF model for boreal woodland caribou in the lower Mackenzie River Valley, Northwest Territories.

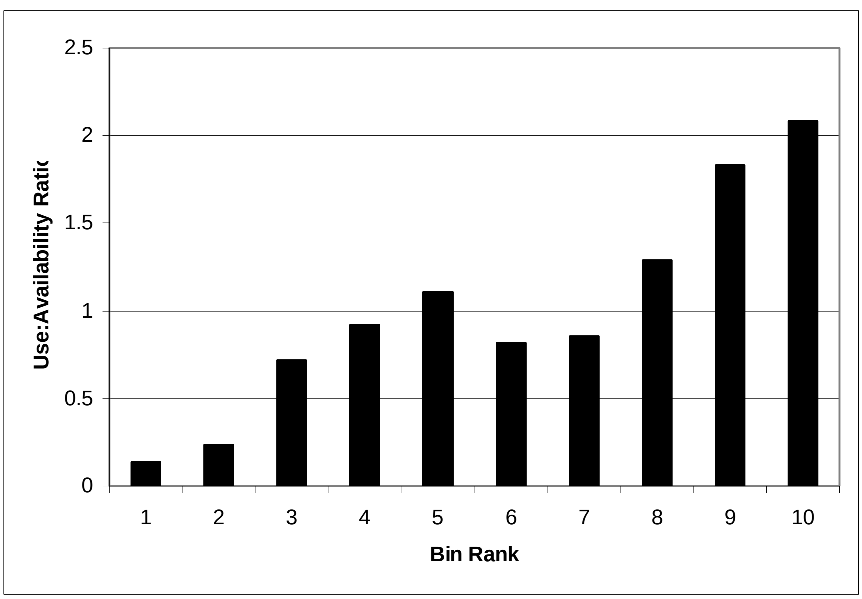

Figure 8. Categorized relative probability of use for boreal woodland caribou in the lower Mackenzie River Valley during the early/mid-summer season.

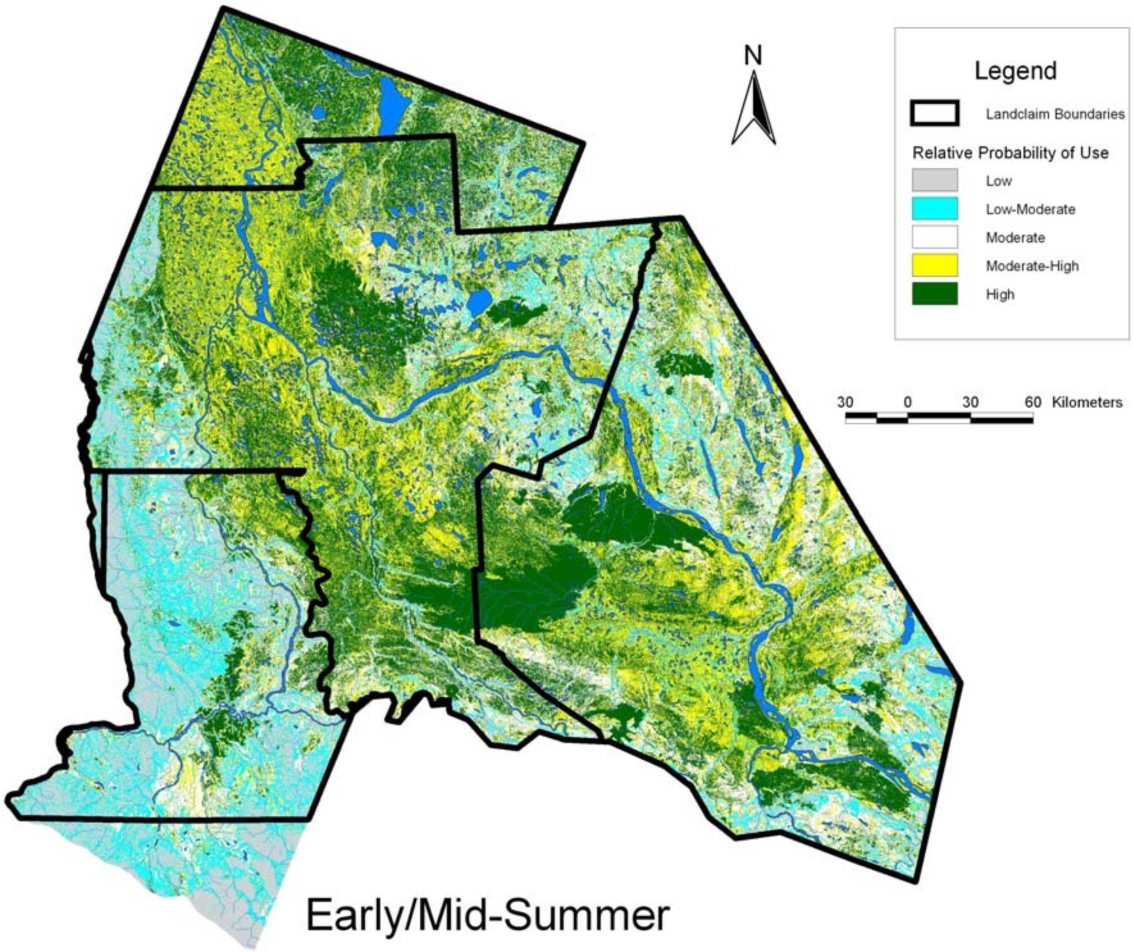

Figure 9. Ratio of use:availability by category of relative probability of use for the early/mid summer season for boreal woodland caribou in the lower Mackenzie River Valley, Northwest Territories.

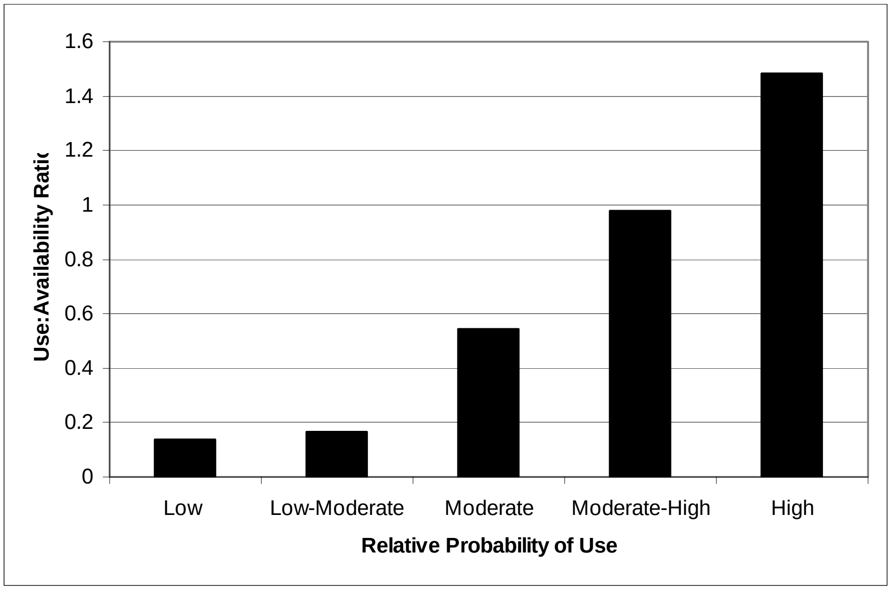

Figure 10. Ratio of use:availability by bin rank for the late summer/fall season RSF model for boreal woodland caribou in the lower Mackenzie River Valley, Northwest Territories.

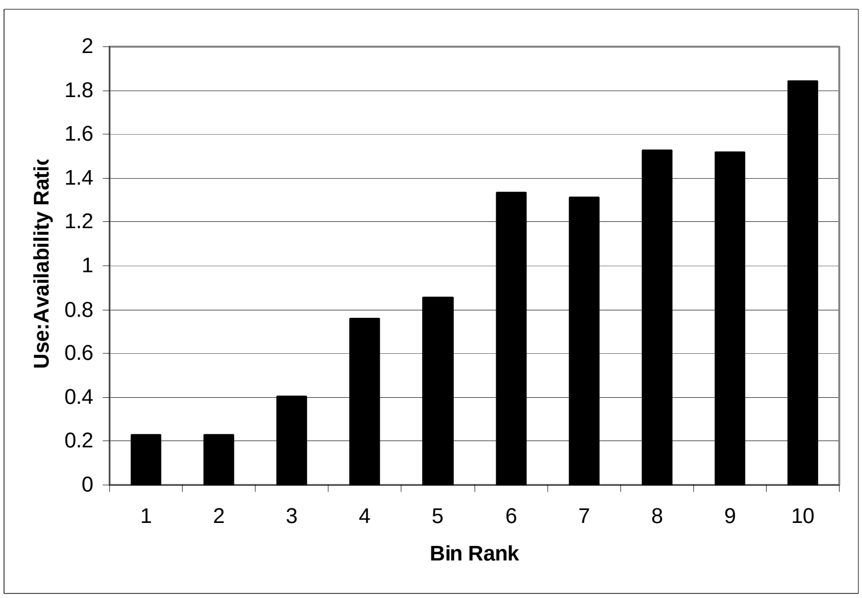

Figure 11. Categorized relative probability of use for boreal woodland caribou in the lower Mackenzie River Valley during the late summer/fall season.

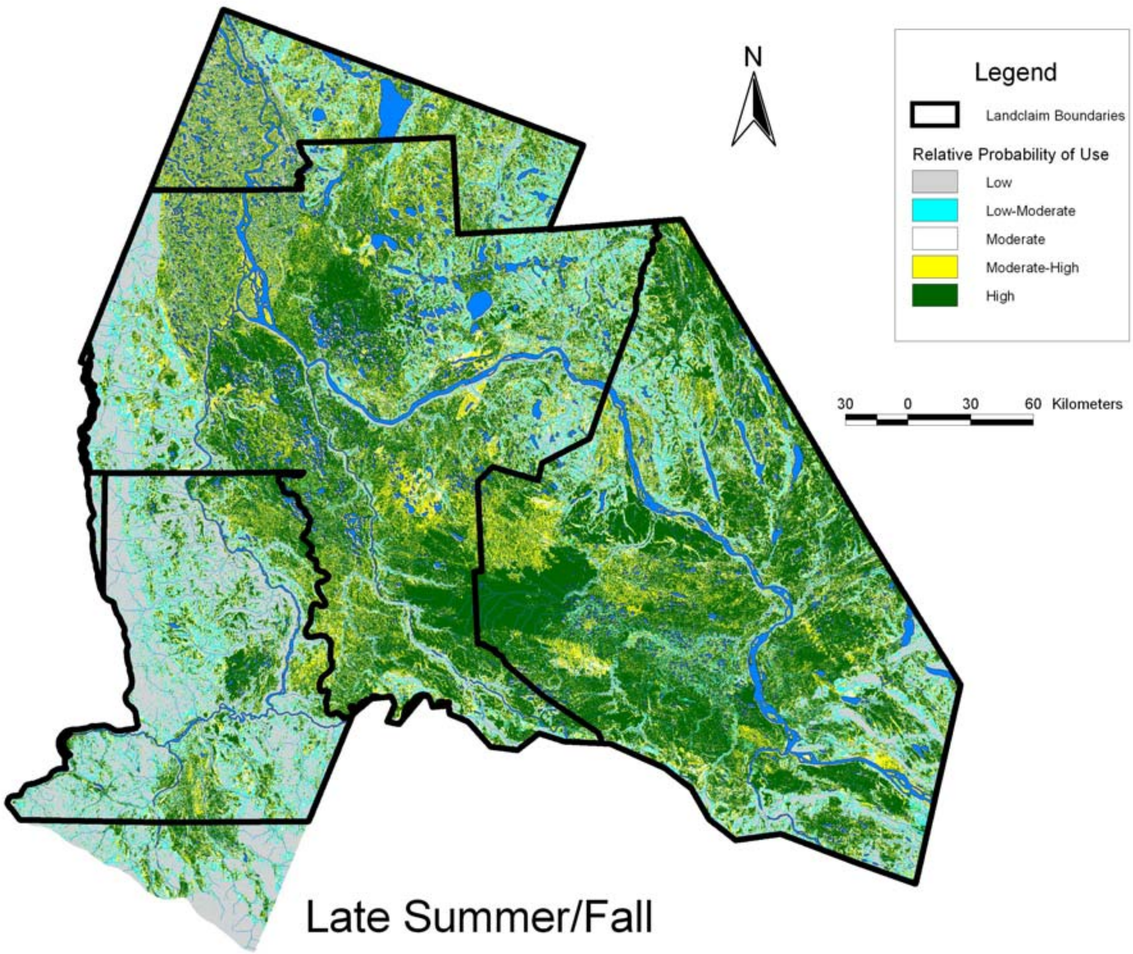

Figure 12. Ratio of use:availability by category of relative probability of use for the late summer/fall season for boreal woodland caribou in the lower Mackenzie River Valley, Northwest Territories.

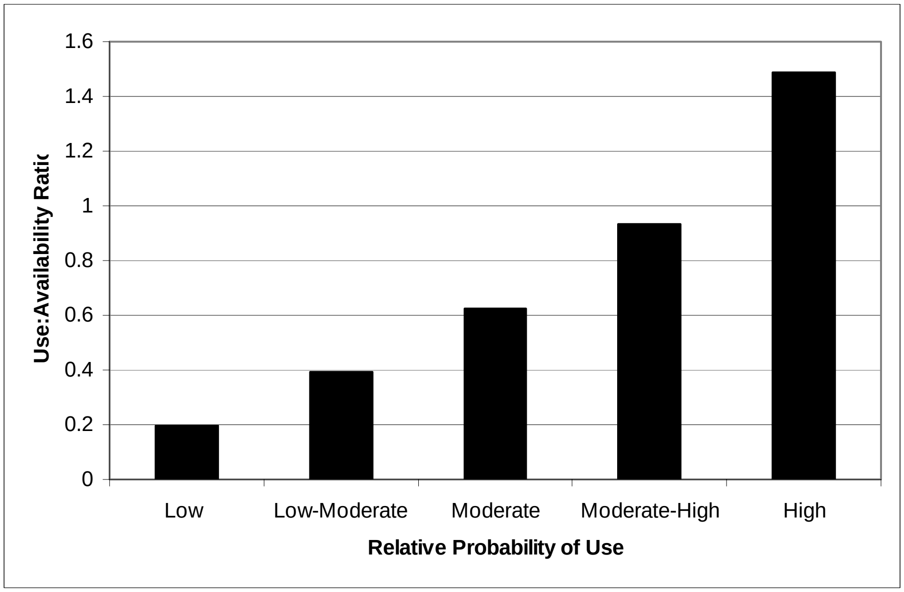

Figure 13. Ratio of use:availability by bin rank for the early winter season RSF model for boreal woodland caribou in the lower Mackenzie River Valley, Northwest Territories.

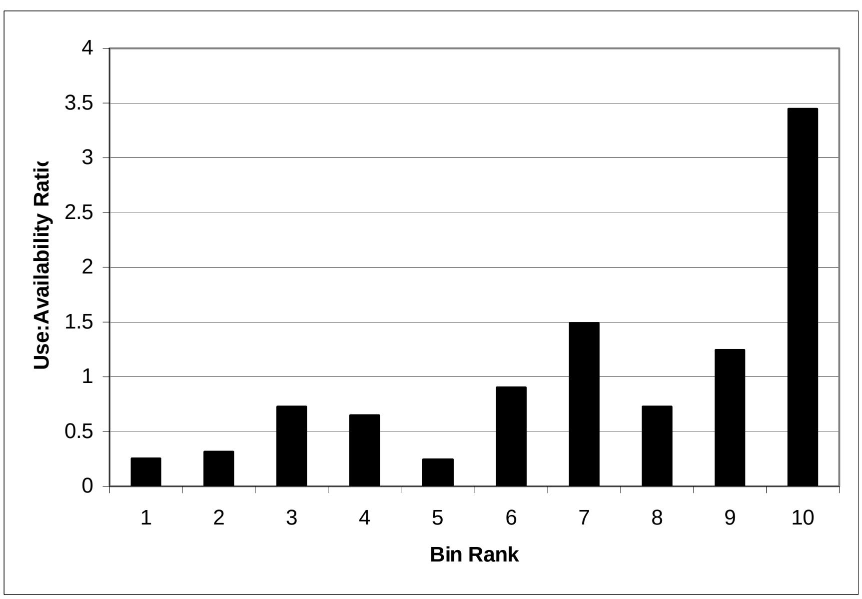

Figure 14. Categorized relative probability of use for boreal woodland caribou in the lower Mackenzie River Valley during the early winter season.

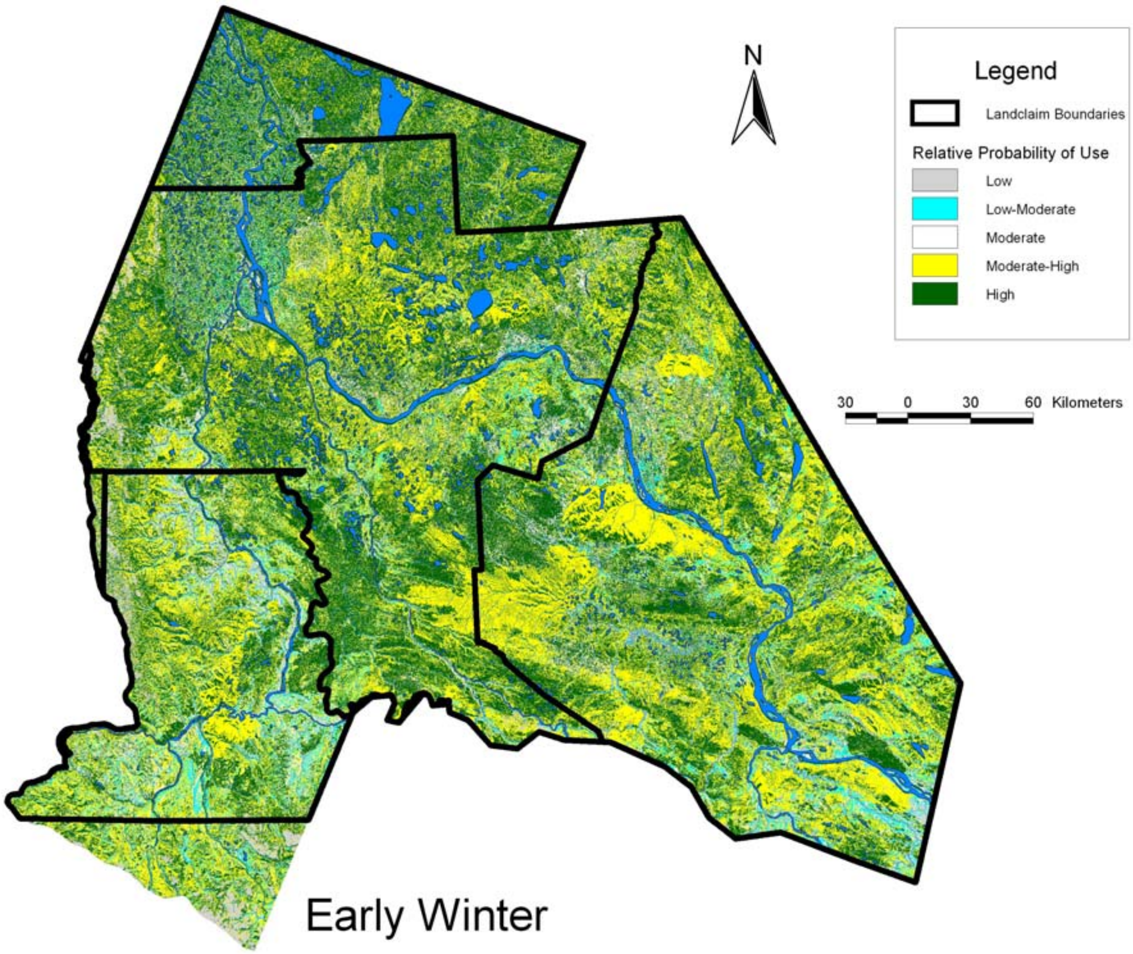

Figure 15. Ratio of use:availability by category of relative probability of use for the early winter season for boreal woodland caribou in the lower Mackenzie River Valley, Northwest Territories.

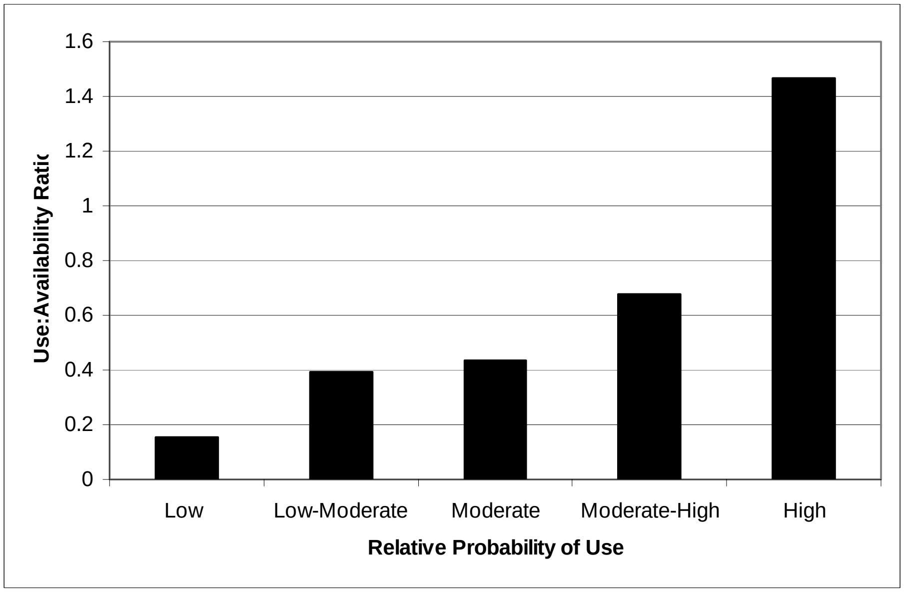

Figure 16. Ratio of use:availability by bin rank for the mid winter season RSF model for boreal woodland caribou in the lower Mackenzie River Valley, Northwest Territories.

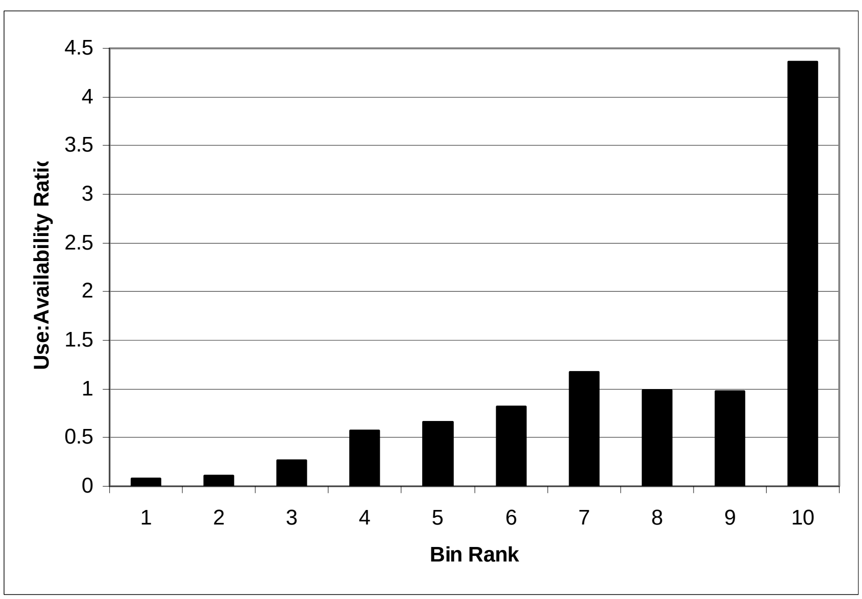

Figure 17. Categorized relative probability of use for boreal woodland caribou in the lower Mackenzie River Valley during the mid winter season.

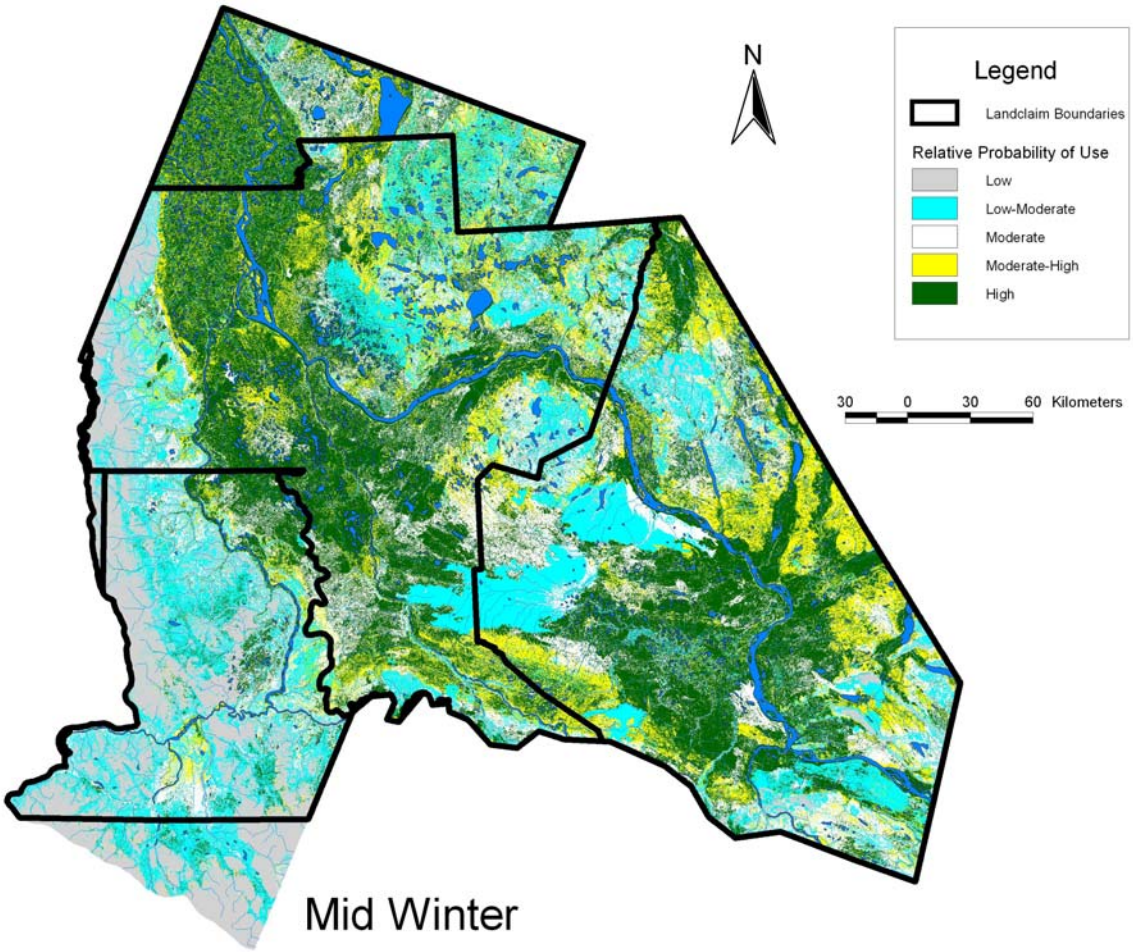

Figure 18. Ratio of use:availability by category of relative probability of use for the mid winter season for boreal woodland caribou in the lower Mackenzie River Valley, Northwest Territories.

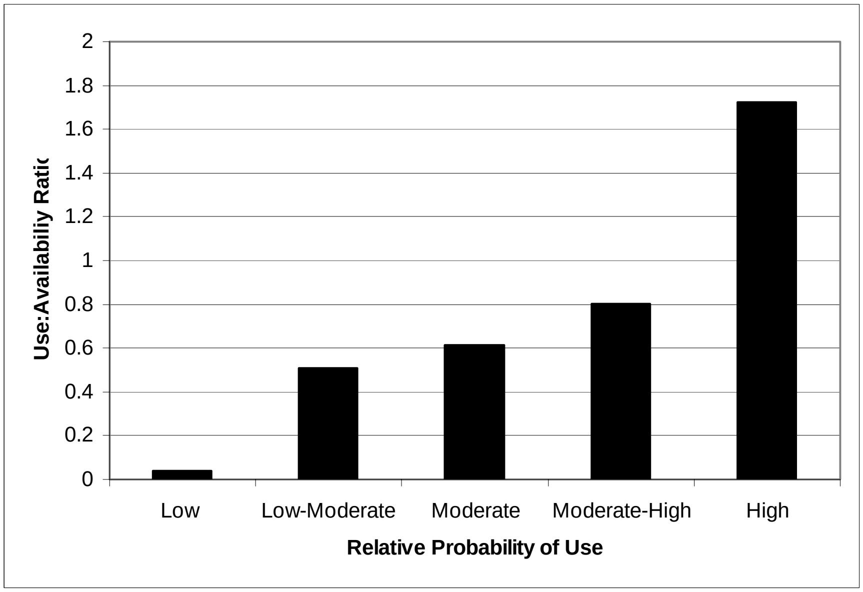

Figure 19. Ratio of use:availability by bin rank for the late winter/pre-calving season RSF model for boreal woodland caribou in the lower Mackenzie River Valley, Northwest Territories.

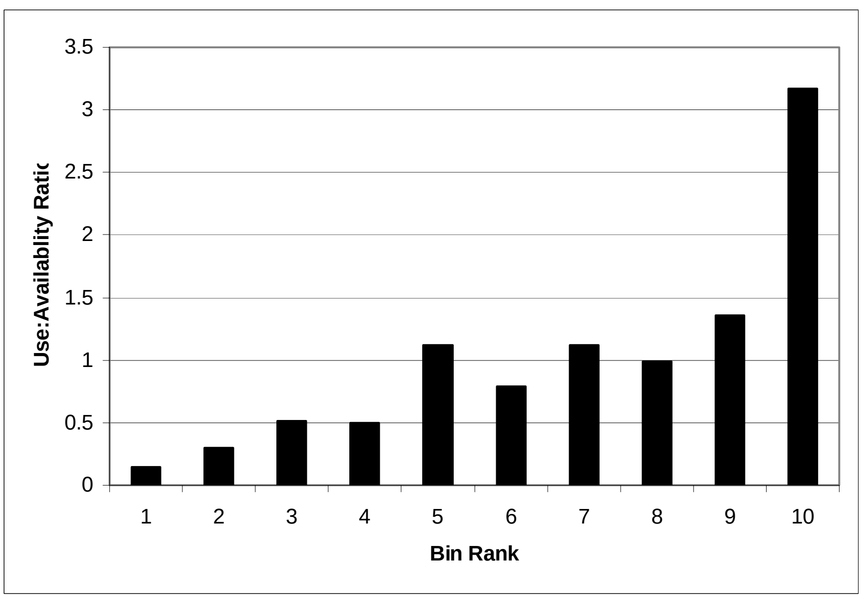

Figure 20. Categorized relative probability of use for boreal woodland caribou in the lower Mackenzie River Valley during the late winter/pre-calving season.

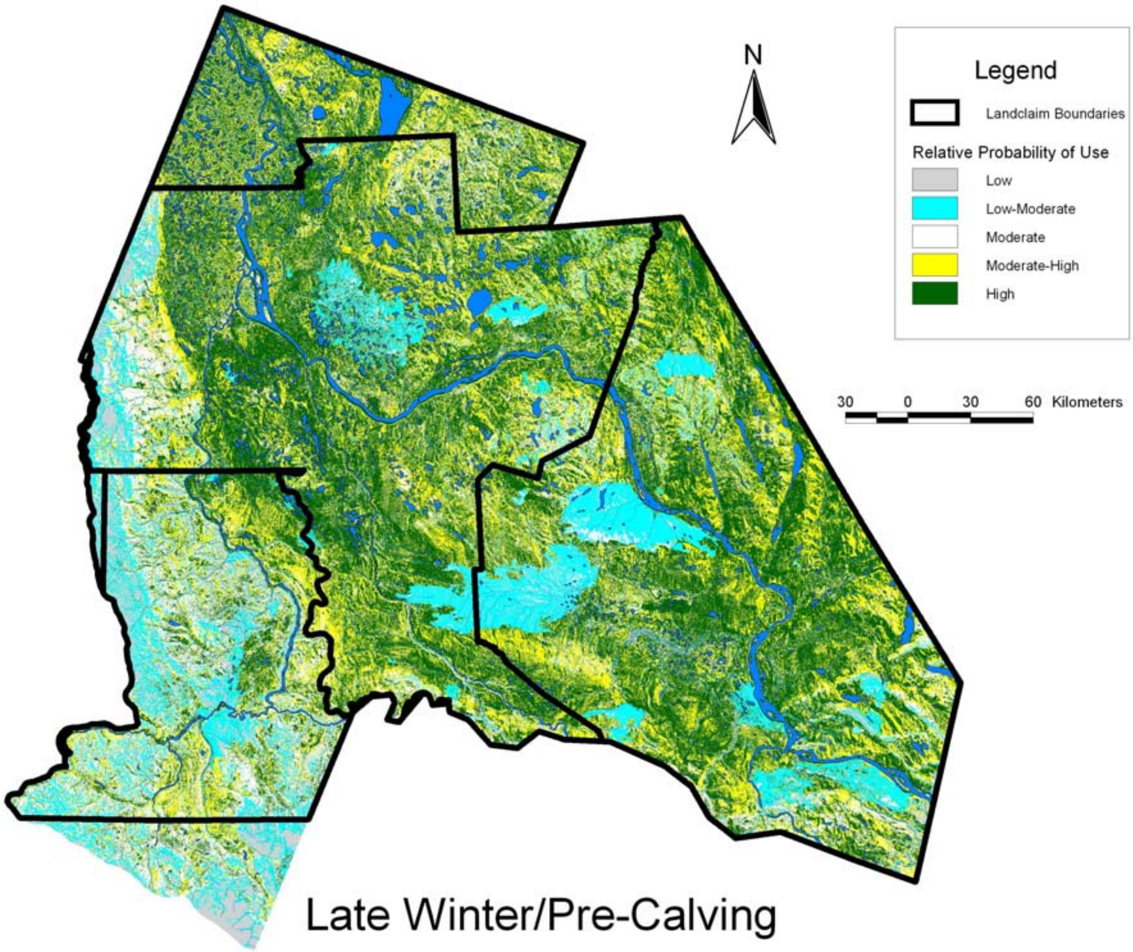

Figure 21. Ratio of use:availability by category of relative probability of use for the late winter/pre-calving season for boreal woodland caribou in the lower Mackenzie River Valley, Northwest Territories.

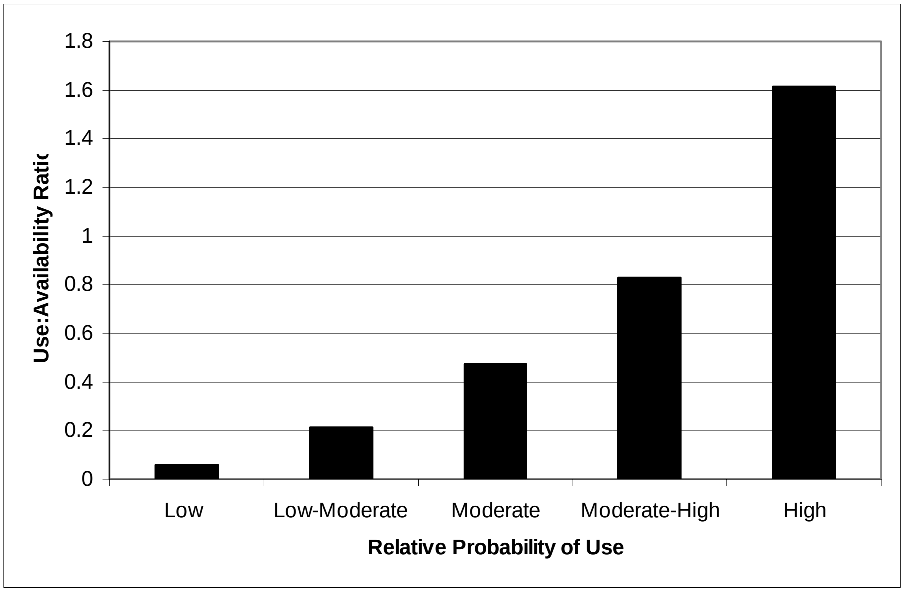

Table 1. Land cover variables used to generate RSF models.

Land Cover Variable	Ducks Unlimited Land Cover Types Combined
CSP	closed spruce
OCONLIC	open spruce-lichen, woodland needleleaf-lichen
OCONOT	open spruce-other, woodland needleleaf-other
CDEC	closed birch, closed poplar, closed decidous
ODEC	open deciduous
CMNDLD	closed mixed needleleaf/deciduous
OMNDLD	open mixed needleleaf /deciduous
TSH	tall shrub
LSH	low shrub-other, low shrub-tussock tundra, low shrub-lichen
DSH	dwarf shrub-lichen, dwarf shrub-other
RIPPAR	moss, wet herbaceous, mesic/dry herbaceous, aquatic bed, emergent aquatic, other
LICHEN	lichen
TUSTUN	tussock tundra-lichen, tussock tundra-other
WATER	clear water, turbid water
SPARNON	sparse vegetation, rock/gravel, non-vegetated soil
RECBURN	recent burn, unknown recent burn
URBAN	urban
UNKNOWN	snow, shadow, haze, cloud, cloud shadow
BACKGROUND	background

Table 2. Covariates used to derive seasonal RSF models for boreal woodland caribou model in the area of the lower Mackenzie River Valley, Northwest Territories.

Land Cover or Terrain Variables	Values
CSP	presence/absence (1/0)
OCONLIC	presence/absence (1/0)
OCONOT	presence/absence (1/0)
CDEC	presence/absence (1/0)
CMNDLD	presence/absence (1/0)
OMNDLD	presence/absence (1/0)
TSH	presence/absence (1/0)
LSH	presence/absence (1/0)
DSH	presence/absence (1/0)
RIPPAR	presence/absence (1/0)
LICHEN	presence/absence (1/0)
TUSTUN	presence/absence (1/0)
WATER	presence/absence (1/0)
SPARNON	presence/absence (1/0)
RECBURN	presence/absence (1/0)
Elevation	meters relative to mean sea level
Slope	degrees (rounded to 1 decimal)
Aspect: none[1]	presence/absence (1/0)
Aspect: north[2]	presence/absence (1/0)
Aspect: east[3]	presence/absence (1/0)
Aspect: south[4]	presence/absence (1/0)
Aspect: west[5]	presence/absence (1/0)

[1] Median aspect flat
[2] Median aspect $>315^{o}$ to 45^{o}
[3] Median aspect $>45^{o}$ to 135^{o}
[4] Median aspect $>135^{o}$ to 225^{o}
[5] Median aspect $> 225^{o}$ to 315^{o}

Table 3. Combinations of covariates used to identify the most parsimonious logistic regression model for each caribou season.

Model[1]
Veg[2]
Veg + Elev
Veg + Slope
Veg + Elev + Slope
Veg + Flat + N + E + S + W
Veg + Elev + Flat + N + E + S + W
Veg + Slope + Flat + N + E + S + W
Veg + Elev + Slope + Flat + N + E + S + W

[1]Veg, vegetation; Elev, elevation; Flat, no aspect; N, north facing; E, east facing; S, south facing; W, west facing

[2]Veg, csp, oconlic, oconot, cdec, cmndld, omndld, tsh, lsh, dsh, rippar, lichen, tustun, water, sparnon, recburn.

Table 4. Categories used to map relative probability of use across the Lower Mackenzie River, Peel Plateau, and Middle Mackenzie River areas for each season.

Relative probability of use category	Relative probability of use
Low	0.0 to 0.2
Low-moderate	0.2 to 0.4
Moderate	0.4 to 0.6
Moderate-high	0.6 to 0.8
High	0.8 to 1.0

Table 5. Seasons defined for boreal woodland caribou in the area of the Lower Mackenzie River Valley, Northwest Territories.

Season	Dates
1. calving/post-calving	15 May to 11 June
2. early/mid-summer	12 June to 30 July
3. late summer/fall	31 July to 29 October
4. early winter	30 October to 31 December
5. mid winter	1 January to 17 March
6. late winter/pre-calving	18 March to 14 May

Table 6. Coefficients and 95% confidence intervals of the most parsimonious RSF model for the calving/post calving season for boreal woodland caribou in the area of the lower Mackenzie River Valley, Northwest Territories.

Variable	∃ coefficient	95% Confidence Interval	
		Upper	Lower
Open conifer lichen	0.650	0.777	0.522
Open conifer other	0.646	0.769	0.524
Closed mixed needleleaf deciduous	-0.701	-0.200	-1.203
Low shrub	0.310	0.428	0.192
Ripparian	0.287	0.478	0.096
Tussock tundra	0.492	0.804	0.181
Water	-0.419	-0.167	-0.671
Recent burn	0.499	0.680	0.318
Elevation	-0.001	-0.001	-0.002
Slope	-0.252	-0.202	-0.302
Aspect: north	-0.388	-0.184	-0.592
Aspect: east	-0.216	-0.020	-0.411
Aspect: south	0.525	0.703	0.347
Aspect: west	0.450	0.624	0.277

Table 7. Coefficients and 95% confidence intervals of the most parsimonious RSF model for the early/mid-summer season for boreal woodland caribou in the area of the lower Mackenzie River Valley, Northwest Territories.

Variable	∃ coefficient	95% Confidence Interval	
		Lower	Upper
Open conifer lichen	0.505	0.374	0.636
Closed deciduous	-1.269	-2.257	-0.281
Closed mixed needleleaf deciduous	-1.039	-1.639	-0.438
Low shrub	0.513	0.402	0.624
Ripparian	0.878	0.737	1.019
Lichen	0.795	0.273	1.317
Tussock tundra	1.116	0.910	1.322
Sparse/non-vegetated	0.877	0.405	1.349
Recent burn	1.017	0.890	1.144
Elevation	-0.001	-0.002	-0.001
Slope	-0.125	-0.158	-0.092
Aspect: west	0.276	0.171	0.381

Table 8. Coefficients and 95% confidence intervals of the most parsimonious RSF model for the late summer/fall season for boreal woodland caribou in the area of the lower Mackenzie River Valley, Northwest Territories.

		95% confidence interval	
Variable	∃ coefficient	Lower	Upper
Open conifer lichen	0.333	0.233	0.433
Open conifer other	0.631	0.541	0.722
Closed mixed needleleaf deciduous	-0.689	-1.037	-0.342
Open mixed needleleaf deciduous	0.254	0.102	0.406
Low shrub	0.154	0.067	0.242
Ripparian	0.368	0.231	0.505
Tussock tundra	0.556	0.349	0.764
Water	-0.980	-1.197	-0.762
Recent burn	0.661	0.536	0.786
Slope	-0.330	-0.367	-0.293
Aspect: flat	-0.177	-0.301	-0.053
Aspect: north	-0.118	-0.218	-0.018
Aspect: west	0.175	0.087	0.262

Table 9. Coefficients and 95% confidence intervals of the most parsimonious RSF model or the early winter season for boreal woodland caribou in the area of the lower Mackenzie River Valley, Northwest Territories.

Variable	∃ coefficient	95% confidence interval	
		Lower	Upper
Closed spruce	-0.514	-0.727	-0.302
Open conifer lichen	1.567	1.469	1.664
Closed deciduous	-2.925	-4.889	-0.961
Closed mixed needleleaf deciduous	-1.321	-1.949	-0.693
Open mixed needleleaf deciduous	0.519	0.321	0.717
Tall shrub	-0.381	-0.557	-0.205
Low shrub	0.344	0.241	0.446
Ripparian	0.989	0.859	1.119
Lichen	-1.185	-2.184	-0.185
Water	0.469	0.319	0.620
Sparse/non-vegetated	-1.454	-2.446	-0.463
Aspect: flat	-0.283	-0.444	-0.123
Aspect: north	-0.296	-0.437	-0.156
Aspect: east	-0.199	-0.330	-0.067
Aspect: west	-0.326	-0.462	-0.191

Table 10. Coefficients and 95% confidence intervals of the most parsimonious RSF model or the mid winter season for boreal woodland caribou in the area of the lower Mackenzie River Valley, Northwest Territories.

Variable	∃ coefficient	Lower	Upper
Closed spruce	-0.597	-0.790	-0.405
Open conifer lichen	0.741	0.616	0.866
Open conifer other	-0.766	-0.889	-0.644
Closed deciduous	-2.114	-3.257	-0.971
Closed mixed needleleaf deciduous	-1.503	-2.061	-0.944
Open mixed needleleaf deciduous	-1.337	-1.726	-0.947
Tall shrub	-1.266	-1.519	-1.014
Low shrub	-1.317	-1.479	-1.155
Dwarf shrub	-2.081	-4.062	-0.100
Ripparian	0.338	0.186	0.490
Tussock Tundra	-0.523	-0.974	-0.072
Water	-0.825	-1.006	-0.644
Sparse/non-vegetated	-1.818	-2.966	-0.670
Recent burn	-1.650	-1.885	-1.416
Elevation	-0.003	-0.003	-0.002
Slope	-0.065	-0.095	-0.035
Aspect: east	-0.339	-0.469	-0.208

Table 11. Coefficients and 95% confidence intervals of the most parsimonious RSF model for the late winter/pre-calving season for boreal woodland caribou in the area of the lower Mackenzie River Valley, Northwest Territories.

Variable	∃ coefficient	95% confidence interval	
		Lower	Upper
Open conifer lichen	1.290	1.202	1.378
Open conifer other	0.192	0.105	0.280
Closed deciduous	-2.242	-3.380	-1.103
Closed mixed needleleaf deciduous	-1.326	-1.798	-0.855
Open mixed needleleaf deciduous	0.257	0.079	0.434
Tall shrub	-0.372	-0.519	-0.225
Dwarf shrub	-2.514	-4.482	-0.546
Ripparian	1.045	0.932	1.157
Water	0.330	0.195	0.465
Sparse/non-vegetated	-0.734	-1.407	-0.061
Recent burn	-0.887	-1.089	-0.684
Elevation	-0.001	-0.001	-0.001
Slope	-0.027	-0.046	-0.007
Aspect: flat	-0.685	-0.832	-0.538
Aspect: north	-0.480	-0.600	-0.361
Aspect: east	-0.547	-0.665	-0.429
Aspect: west	-0.295	-0.405	-0.185

Table 11. Proportions of the core and regional study area in the 5 relative probability of use categories and the percent of caribou locations found within these areas.

Season	Relative Probability of Use	Availability		Percent of caribou use locations
		Core study (% of area)	Regional study (% of area)	
Calving/post-calving	low	11	16	1
	low-moderate	15	17	6
	moderate	19	20	11
	moderate-high	17	16	19
	high	38	32	63
Early/mid-summer	low	5	9	1
	low-moderate	8	11	1
	moderate	17	21	10
	moderate-high	28	28	27
	high	41	31	61
Late summer/fall	low	18	22	3
	low-moderate	7	9	3
	moderate	9	10	5
	moderate-high	20	18	18
	high	47	40	70
Early winter	low	3	5	1
	low-moderate	4	5	2
	moderate	8	9	4
	moderate-high	37	36	25
	high	48	45	69
Mid-winter	low	6	11	0
	low-moderate	21	18	10
	moderate	22	20	13
	moderate-high	14	15	11
	high	38	36	65
Late winter/pre-calving	low	3	5	0
	low-moderate	12	11	3
	moderate	15	16	7
	moderate-high	27	27	22
	high	42	41	68