INTERIM REPORT

Mapping Resource Selection Functions for caribou and wolves in the Chinchaga caribou range

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Interim Report
fRI Research Caribou Program
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Disclaimer

This is a draft report and further analysis may be conducted for the submission of scientific journal publications that may result in additional findings and conclusions. Any opinions expressed in this report are those of the authors and do not necessarily reflect those of project partners and funders.

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Executive Summary

We used GPS telemetry location data from 63 adult caribou and 6 adult wolves to build spatially explicit resource selection function (RSF) rasters. These RSF rasters describe the within-home-range habitat selection (3rd order) of caribou and wolves in the interprovincial Chinchaga caribou range in British Columbia and Alberta. We based these RSFs on models that had been previously developed for the Alberta portion of the Chinchaga caribou range; refining the models further by dividing roads into separate categories (high-use roads, low-use roads, and winter roads), as well as including pipelines, and cutblocks. In addition to anthropogenic disturbances, we included covariates related to habitat and terrain that are known to influence the spatial distribution of caribou and wolves (e.g. elevation, topographic indices, canopy closure, tree species composition, and distance to water). We built seasonal RSF models (Caribou: spring, summer, fall, early winter, late winter; Wolves: denning, rendezvous, nomadic) to account for dynamics in habitat selection for both species throughout the year.

Caribou consistently selected for open canopy conifer forests and avoided areas with higher densities of high-use roads and cutblocks during all seasons. These results are similar to those previously reported in the Alberta portion of Chinchaga range, and within other boreal caribou herds. Wolves selected for areas close to streams and rivers during all seasons, and also selected areas with higher densities of anthropogenic features during the denning and rendezvous seasons (spring and summer). During the nomadic season (winter) wolves selected areas with higher densities of high-use roads, pipelines, and cutblocks, but avoided areas with higher densities of low-use roads and winter roads. Although these results are consistent with other studies that assessed habitat selection by wolves in the boreal forest, the dynamics in selection for high densities of anthropogenic features warrants further study because multiple hypotheses that were outside of the scope of this analysis could explain the observed results (i.e. seasonal changes in ease of travel on linear features due to snow packing, and dynamics in human traffic). According to k-fold cross validation, caribou and wolf RSF models had high predictive capability. The resulting RSF rasters can be used to identify important areas for caribou based on their relative probability of selection, and their potential overlap with wolves. This analysis provides insight into how caribou and wolves use the landscape, and the spatial RSF products will contribute to the ongoing objectives of this project that aims to understand wolf and caribou response to anthropogenic disturbance at different stages of development in the Chinchaga range. Furthermore, the RSFs are readily available to aid land managers in future decision making processes regarding caribou habitat restoration for the recovery of woodland caribou in Chinchaga.

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1. Introduction

1.1 Project Background

Woodland caribou (*Rangifer tarandus caribou*) populations are declining throughout their range and the boreal populations in British Columbia and Alberta are listed as threatened by federal Species at Risk Act (SARA). Caribou decline is believed to be linked to habitat degradation and loss resulting from industrial development within caribou range (Festa-Bianchet et al. 2011; Hervieux et al. 2013). Industrial development converts mature forest to early seral stages and fragments the landscape through clearcutting and construction of roads, pipelines, and seismic exploration corridors. Early seral habitat and abundant habitat edges create favourable conditions for apparent competitors of caribou (e.g. moose [*Alces alces*] and white-tailed deer [*Odocoileus virginianus*]). These ungulates sustain higher densities of predators such as wolves (*Canis lupus*), which increases incidental predation on caribou (Wittmer et al. 2005). Landscape fragmentation and higher densities of predators has increased predation risk for caribou, which has led to increased mortality rates of caribou, and population declines in many herds (DeCesare et al. 2010; Hervieux et al. 2013).

Because of the negative impact of anthropogenic disturbance on caribou populations, the federal Boreal Caribou Recovery Strategy requires less than 35% disturbed habitat within each caribou range, where 'disturbed habitat' is defined as the footprint of disturbance features plus a 500m buffer on all sides (Environment Canada 2012). Most of the boreal caribou herd ranges in British Columbia and Alberta exceed the 35% disturbance threshold, and thus habitat restoration is required to expedite the recovery of caribou populations. However, due to the variety of anthropogenic disturbance features (forestry cutblocks, access roads, oil and gas well sites, pipelines, and seismic lines), and their homogeneous placement on the landscape within caribou range, it is important to understand how caribou and their predators respond to different types of disturbance features. Understanding how caribou and their predators respond to anthropogenic disturbances will allow land planners to target restorative actions where they will provide the most benefit to caribou by reducing predation risk, increasing habitat connectivity, and ultimately increasing the amount of functional habitat within caribou range.

While previous research has addressed the differential response of caribou and their predators to disturbance features (e.g. Dyer et al. 2001; Sorenson et al. 2008; Latham et al. 2011; DeCesare et al. 2012), the response of animals depends on the availability and seasonal importance of surrounding habitats, and is thus expected to vary by herd and region (Boyce 2006; Vistnes and Nellemann 2007). Although habitat selection for Chinchaga caribou and wolves has been investigated previously (Rowe 2007; DeMars 2015), spatially explicit resource selection functions (RSFs) exist only for caribou during the calving period and do not cover the transboundary extent of the Chinchaga caribou range (DeMars 2015). In addition, it is increasingly recognized that an understanding of year-round habitat use is important for effective management of caribou due to the complex relationships between caribou survival and calving success, and the seasonal dynamics in exposure to anthropogenic disturbance, predation risk, and apparent competitors (Saher and Schmiegelow 2005; Boyce 2006; McLoughlin et al. 2010).

Therefore, this project aims to expand the depth of understanding of caribou and predator response to anthropogenic disturbance by carrying out detailed analysis within the Chinchaga caribou herd range, and by assessing animal response to anthropogenic features at different phases of development and at different temporal periods throughout the year. Specifically, the results of this analysis can be used to identify areas within the Chinchaga range that can be prioritized for restoration based on (i) their probability of use by caribou and (ii) the potential to reduce encounters with wolves. We also aim to provide detailed RSF geospatial rasters for the Chinchaga caribou range that describe the probability of habitat use by caribou and wolves, and which may be used in science-based decisions for wildlife management (Johnson et al. 2004).

1.2 Interim Report Objectives

This report addresses the following objectives in support of the overall project objective to understand the response of caribou and wolves to different disturbance features:

1. Develop resource selection functions (RSFs) that describe how caribou and wolves use the landscape in relation to disturbance and natural habitat attributes, and during distinct periods of the year. These RSFs can be used as a foundation to build future models that can include additional landscape metrics.
2. Provide caribou and wolf RSF rasters as geospatial products with the aim of helping land managers evaluate the potential for overlap between caribou and wolves, and identify areas that could be prioritized for restoration to reduce the probability of encounters between caribou and wolves and increase effective habitat for caribou.

2. Study Area

The study area encompasses the transboundary range of the Chinchaga caribou herd in northeastern British Columbia and northwestern Alberta (Figure 1). These caribou are the boreal ecotype, occur in the boreal forest year round, and have little or minimal seasonal shifts in home range (Bergerud 1992; Briand et al. 2009). Boreal caribou are listed as threatened under Alberta's *Wildlife Act* (Alberta Woodland Caribou Recovery Team 2005), the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002), and the Species at Risk Act (SARA; Environment Canada 2012). Boreal caribou are listed as a 'top priority' under the British Columbia Conservation Framework. A federal recovery strategy for this ecotype was released in 2012 (Environment Canada 2012).

The Chinchaga caribou range is characterized by boreal forest consisting of black spruce and larch in poorly drained muskeg and fen lowland areas, and white spruce, trembling aspen, and balsam poplar (*Populus balsamifera*) in upland areas (Natural Regions Committee 2006; Tigner et al. 2014). Elevation in the study area ranges from 600-800m above sea level with relatively flat topography (Figure 1). There is a high diversity of ungulates in the area including moose, white-tailed deer, and wood bison (*Bison bison athabascae*; Rowe 2007). Common predators in the area include wolves, black bears (*Ursus americanus*), grizzly bears (*Ursus arctos*), wolverines (*Gulo gulo*), and lynx (*Lynx canadensis*; Rowe 2007; DeMars 2015). The Chinchaga caribou range straddles both sides of the border between British Columbia and Alberta with approximately 50% of the total range area in each province (Figure 1).

The Chinchaga caribou range has been extensively altered by anthropogenic activities associated with oil and gas exploration, forestry, and recreational activities. The federal recovery strategy estimates that 74% of the habitat in Chinchaga is disturbed by anthropogenic activities, and that caribou populations are declining (Environment Canada 2012; Hervieux et al. 2013).

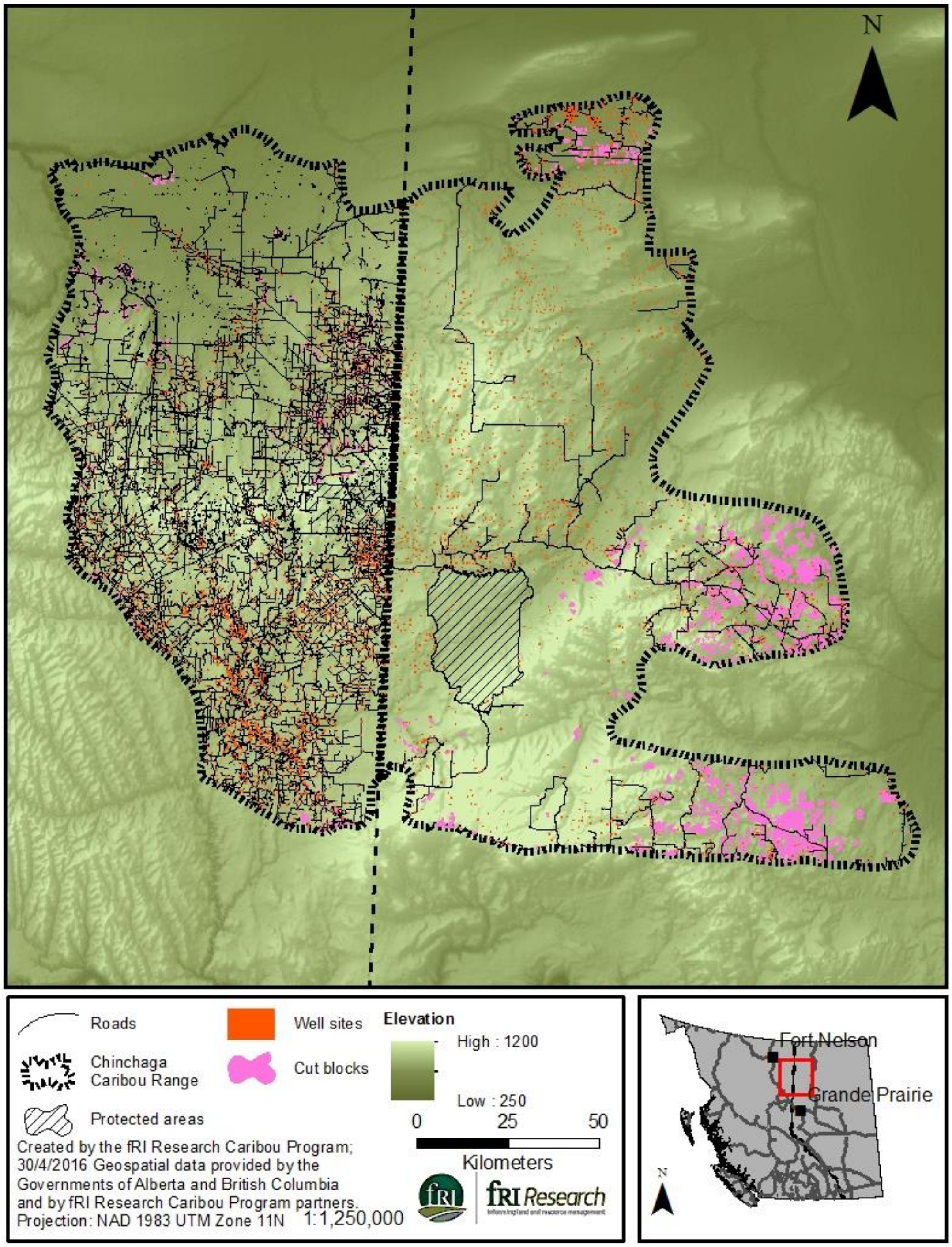

Figure 1. Study area map for the Chinchaga caribou range, northeastern British Columbia and northwestern Alberta.

3. Caribou Resource Selection Functions

3.1 Introduction

Previous RSF analyses have been conducted for boreal caribou herds in Alberta and British Columbia and elsewhere in Canada (e.g. Neufeld 2006; Antoniuk et al. 2007; Fortin et al. 2008; DeCesare et al. 2012), however, because RSF values depend on habitat availability on local landscapes and the scale of investigation (geographic and temporal) and therefore do not transfer well across regions (Boyce et al. 2002), there is a need for regional and scale specific analyses. Recently, fRI Research developed a base RSF for the Alberta portion of Chinchaga range covering 5 seasons within the annual period (Pigeon et al. 2016), however existing RSF rasters in the British Columbia portion of Chinchaga caribou range are limited to the calving season (DeMars 2015). Considering the importance of all seasonal periods in the life-history of caribou (Saher and Schmiegelow 2005), there is significant potential to improve the efficacy of management planning for caribou recovery by extending the coverage of RSF models developed in the Alberta portion of Chinchaga caribou range to include British Columbia, and by assessing resource selection for the full suite of biologically defined seasons.

3.2 Methods

3.2.1 Caribou location data

We used GPS telemetry data gathered from 63 adult female caribou in the Chinchaga range available from Alberta Environment and Parks (n=19), the British Columbia Ministry of Environment (n=9), and BCOGRIS (n=35). Caribou collared by Alberta Environment and Parks were fitted with Lotek 2200-3300 GPS telemetry collars between 2007 and 2010 (Lotek Engineering Systems, Newmarket, Ontario, Canada). Caribou were captured as part of ongoing monitoring by the government of Alberta; capture and handling protocols were approved under Alberta's Animal Care Protocol 008 (Hervieux et al. 2013). Caribou collared by the British Columbia Ministry of Environment were fitted with GPS-SimplexTM and POSREC-ScienceTM collars (Televilt Positioning, Sweden) in 2004 (Rowe 2007). Caribou collared under the BCOGRIS collaring program were fitted with ATS Iridium GPS G2110E (Advanced Telemetry Systems Inc., Isanti, Minnesota) or Vectronic GPS (Vectronic Aerospace, Berlin, Germany) collars between 2013 and 2016 (Culling and Culling 2013). Immobilization and collar installation conducted by the British Columbia Ministry of Environment and BCOGRIS followed Provincial Resource Information Committee standards (Rowe 2007; Culling and Culling 2013). Collars were programmed to record positional fixes at varying intervals according to collar type and season, such that a fix was attempted once every 1, 2, or 4 hours resulting in 6-24 potential fixes per day per animal. We included a random effect for each animal-year to account for the variance in number of fixes used in the analysis, and individual differences in behaviour and availability of habitat (Gillies et al. 2006). We retained telemetry locations for analysis if the Horizontal Dilution of Precision was < 10, indicating a positional accuracy of 35m and reducing the chances of misidentifying environmental covariates (Dussault et al. 2001; Lewis et al. 2007). The final dataset consisted of 127,151 locations from 63 individuals. Collared individuals spent time in Alberta and British Columbia regardless of collaring location.

To account for changes in the spatial distribution and behaviour of caribou throughout the year, we defined five distinct seasons for caribou (Spring = 8 April to 7 June, Summer = 8 June to 24 September, Fall = 25 September to 6 November, Early Winter = 7 November to 28 January, and Late Winter = 29 January to 8 April) following an approach developed by Rudolph and Drapeau (2012), and described in detail by MacNearney et al. (2016).

3.2.2 Landscape variables

We investigated resource selection of Chinchaga caribou within categories of attributes related to (1) topography, (2) landcover, and (3) anthropogenic features. We compiled data layers in British Columbia to provide the closest match possible to data layers used by Pigeon et al. (2016) when developing the Chinchaga caribou RSFs in Alberta. We derived topographic variables including slope, aspect, elevation, topographic position index (TPI; Jenness 2006), and compound topographic index (CTI; Gessler et al. 2000) from a 25m digital elevation model. We derived landcover variables from a combination of Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat imagery mapped at a 30m resolution, and developed for fRI Research by the Integrated Remote Sensing Studio at the University of British Columbia following the methods of Nijland et al. (2015). Prevailing winds are from the south-west in the study area and we therefore separated aspects into 3 categories (Flat = 0°; Lee = from NW to E aspect; and Wind = from SE to W aspect). We used spatial cutblock data provided by Daishowa-Marubeni International Ltd. (DMI), Canadian Forest Products (Canfor), Tolko Industries Ltd, and the government of British Columbia (Consolidated Cutblocks layer; www.data.gov.bc.ca). We calculated the density of anthropogenic linear features (pipelines and forestry and oil and gas access roads classified into high-use, low-use, and winter roads), cutblocks < 30 years old, and all other anthropogenic features (well sites and facilities) for each year of animal data (2004-2016) using a 1km radius circular moving window average in ArcGIS 10.2 (ESRI 2015). We chose a 1km radius as a middle ground density value because previous research has shown that anthropogenic features can influence caribou behaviour from very small scales (i.e. < 70m) up to 9km (Schaefer and Mahoney 2007; DeCesare *et al.* 2012; Johnson *et al.* 2015). Pigeon et al. (2016) also included conventional seismic lines in the linear feature footprint for Alberta; however we excluded seismic lines from this analysis because we were unable to acquire data for the seismic line footprint in British Columbia in time for this analysis. Pigeon et al. (2016) included variables for percent canopy cover and percent conifer cover; we did not have access to these covariates for the British Columbia portion of Chinchaga range. Instead, we built ordinal models of canopy cover and conifer cover by combining landcover classes and compared this layer to the layers used by Pigeon et al. (2016). Pearson correlation values were > 0.60, and thus we substituted the ordinal canopy cover and conifer cover covariates to replace the percent canopy and percent conifer covariates in RSF models. All covariates are further described in Table 2.

Table 1. GPS telemetry locations and the collared individuals by year (2004-2016) for Chinchaga caribou in British Columbia and Alberta.

	Caribou	
	Locations	**Individuals**
Year	-	-
2004	7,791	9
2005	2,836	7
2006	224	1
2007	9,903	5
2008	36,563	13
2009	36,554	12
2013	9,333	14
2014	11,916	22
2015	11,158	27
2016	873	18
Total	127,151	63

Table 2. Covariates used to assess 3rd order selection of boreal caribou (Rangifer tarandus caribou) within 5 seasons (Spring, Summer, Fall, Early Winter, and Late Winter) for collared caribou in the Chinchaga herd in British Columbia and Alberta between 2004 and 2016. Categories of attributes are shown in bold.

Covariate	**Description**
Topography	
Elev	Elevation based on 25m digital elevation model (DEM, m).
Flat	Aspect of 0°
Lee	Aspect indicates leeward slope (NW, N, E-facing slope).
CTI	Compound topographic index.
TPI	Topographic position index estimated within 1km radius.
Landcover	
Mixed	30m pixels with presence of deciduous trees (<70% conifer; 0-1).
ConiferCover_ordinal	Values of 0 (<25% of forested area is made up of conifer species), 1 (26-75% of forested area is made up of conifer species), or 2 (>75% of forested area is made up of conifer species). Classes derived from landcover classification with 30m pixel.
CanopyCover_ordinal	Values of 0 (<40% of canopy is covered by trees), 1 (41-60% of canopy is covered by trees), or 2 (>61% of canopy is covered by trees). Classes derived from landcover classification with 30m pixel.
Distance_water	Distance to large streams (km).
Anthropogenic features	
Road_high_1km	Proportional density of high-use roads within 1km radius (km^2/km^2).
Road_low_1km	Proportional density of low-use roads within 1km radius (km^2/km^2).
Road_winter_1km	Proportional density of winter roads within 1km radius (km^2/km^2).
Pipeline_1km	Proportional density of pipelines within 1km radius (km^2/km^2).
Cutblocks_1km	Proportional density of cutblocks (<30 yrs since harvest) within 1km radius (km^2/km^2).

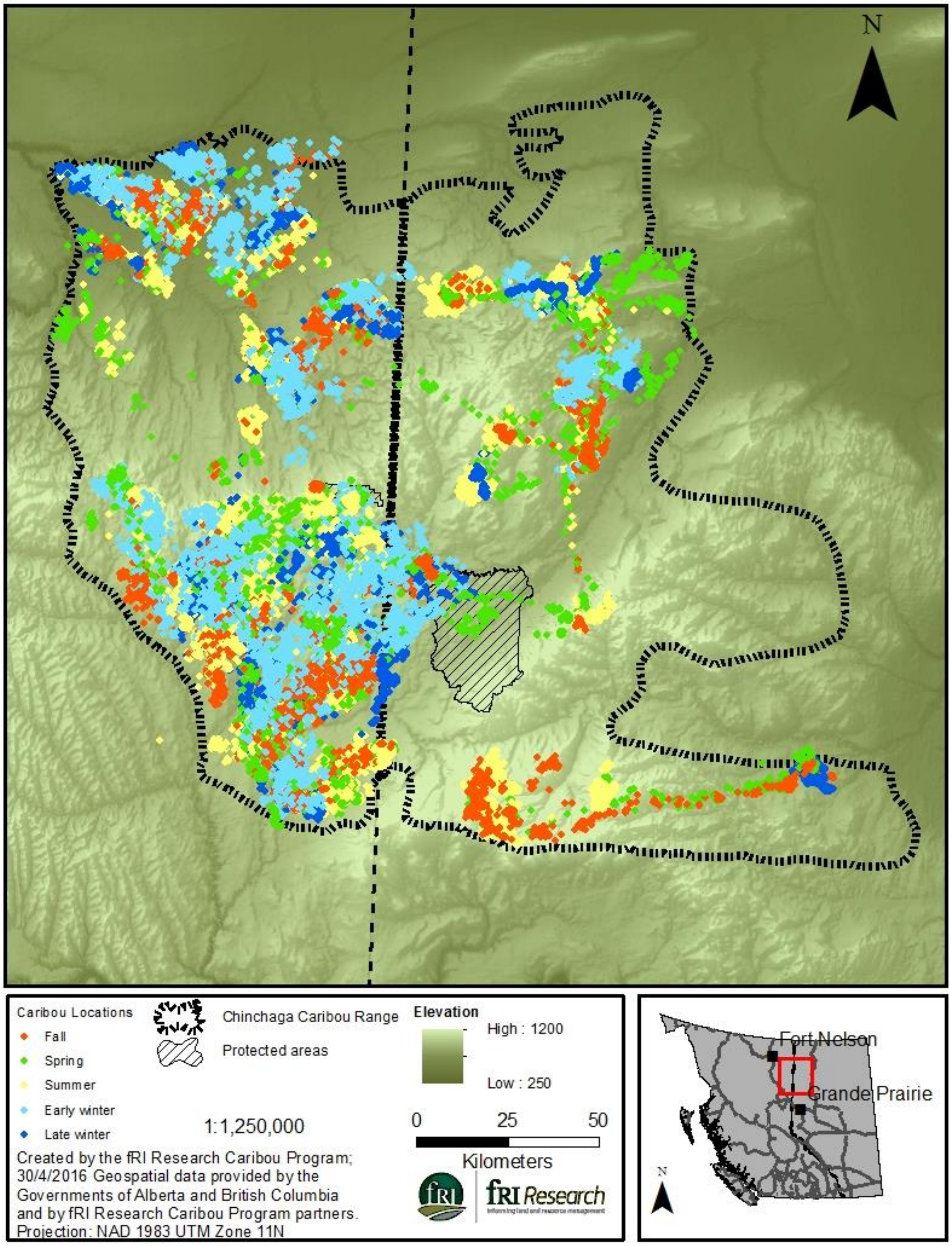

Figure 2. GPS telemetry locations for collared caribou in the Chinchaga range in Alberta and British Columbia between 2004 and 2016.

3.2.3 Data Analysis

We based our analysis of habitat selection on RSFs developed by Pigeon et al. (2016) under a generalized linear mixed model (GLMM) framework where the most parsimonious model for each season was determined from a suite of candidate models using Akaike's Information Criterion (AIC). We treated telemetry locations as 'used' locations and selected a random sample of 'available' locations from the minimum convex polygon (MCP) home range of each individual at a ratio of ten available locations for every used location. We then extracted landscape covariates to each used and available location and used these data to fit a GLMM for each season using the same parameters as the final models selected by Pigeon et al. (2016). In developing the base RSF for the Alberta portion of Chinchaga range, Pigeon et al. (2016) investigated groups of anthropogenic disturbance variables based on the likelihood of eliciting a similar response from caribou and thus anthropogenic variables were grouped into either (i) linear features, (ii) cutblocks < 25 yrs old, or (iii) all anthropogenic features (well sites and facilities) except cutblocks but including linear features. As we aimed to investigate the differential response of caribou to disturbance features of different types, we compared the model fit according to parameters from Pigeon et al. (2016) to a second model where disturbance covariates were broken into discrete categories by type and level of human use (high-use roads, low-use roads, winter roads, pipelines, and cutblocks). To avoid incorrect model interpretation due to collinearity between variables, we examined the covariates in each model for collinearity and removed one of a pair of variables if they had a Pearson correlation value >0.5. If the AIC score indicated greater parsimony for the model that examined anthropogenic features by type, we retained that model as the final model in that season. All covariates used in the RSF models were standardized to facilitate model convergence and interpretation.

We assessed the predictive ability of each final model using k-fold cross validation (Boyce et al. 2002), and generated maps of the relative probability of selection for each season (i.e. resource selection functions [RSFs]). These maps identify areas used by Chinchaga caribou more than expected from a random distribution. These maps can also be used to evaluate the influence of anthropogenic features on seasonal patterns of selection within the Chinchaga caribou ranges. For each season, we first tallied the relative probability of selection from the final models into 10 categories based on quantile values in relative probability, and then collapsed bins of similar probabilities into single bins so that selection increased significantly between each successive bin category (Nielsen et al. 2010). The final number of bins, based on the selection ratio within each season, varied between 8 and 10. We also calculated risk ratios on the final binning classification. Risk ratios are the ratio of the probability of an area being selected (bin) relative to the probability of selection of the lowest bin value (bin 1) for that season. We carried out all statistical analyses and data exploration in RStudio using R statistical software (RStudio 2015; R Development Core Team 2015).

3.3 Results

For all seasons, models with expanded anthropogenic disturbance classes were more parsimonious than models built using the covariates in the Pigeon et al. (2016) base RSFs. Across seasons, caribou consistently selected habitats with flat terrain, open canopies, and a higher proportion of coniferous trees than expected by random (Table 3). Anthropogenic features such as cutblocks, high-use roads, and winter roads were avoided in all seasons; however caribou showed slight selection for low-use roads during late winter and spring, and also for pipelines during summer and fall. Caribou selected areas farther than random from streams during spring and fall, but selected areas closer than random to streams during early and late winter. Finally, caribou selected habitat at higher elevations during spring and summer, and selected areas at lower elevations during early and late winter.

Using coefficients from the final models, we mapped RSFs and binned probabilities of selection per season (Table 4; Figures 3-7). Overall, Chinchaga caribou were at least 3 times more likely to select areas identified with the highest RSF value (bin 8 to 10, season-dependent) than areas that were attributed to the lowest RSF value (bin 1; Table 4). During fall, Chinchaga caribou were nearly 32 times more likely to select areas identified with the highest RSF value (RR bin 10 Table 4; Figure 5), while the lowest difference between selection occurred in late winter (RR bin 8 Table 4; Figure 7). K-fold validation yielded average Spearman rank correlations (R_s) ranging from 0.91 to 0.99 for used locations and from -0.03 to 0.07 for random locations: Spring R_s average: (Use: 0.99; Random: -0.03), Summer R_s average: Use: 0.91; Random: 0.07), Fall R_s average: Use: 0.99; Random: 0.008), Early Winter R_s average: Use: 0.99; Random: 0.03), and Late Winter R_s average: Use: 0.94; Random: -0.002).

Table 3. Standardized model coefficients (β) and standard errors (SE) describing 3rd order habitat selection for Chinchaga caribou during Spring, Summer, Fall, Early winter, and Late winter in Alberta and British Columbia between 2004 and 2016. Covariates are described in Table 2. Variables for which selection was statistically different from random are shown in bold.

	Spring		Summer		Fall		Ewin		Lwin	
	β	SE	β	SE	β	SE	β	SE	β	SE
Intercept	**-2.62**	**0.04**	**-2.48**	**0.07**	**-2.40**	**0.04**	**-2.60**	**0.04**	**-2.50**	**0.02**
Road_high_1km	**-0.07**	**0.01**	**-0.18**	**0.008**	-0.01	0.01	-0.01	0.01	**-0.02**	**0.01**
Road_low_1km	**0.05**	**0.009**	**-0.11**	**0.008**	**-0.07**	**0.01**	0.01	0.01	**0.07**	**0.009**
Road_winter_1km	**-0.16**	**0.01**	**-0.12**	**0.008**	**-0.04**	**0.01**	**-0.05**	**0.01**	-0.001	0.008
Pipeline_1km	**-0.09**	**0.008**	**0.02**	**0.006**	**0.11**	**0.008**	0.01	0.008	**-0.19**	**0.01**
Cutblocks_1km	**-0.06**	**0.01**	**-0.13**	**0.02**	**-0.13**	**0.02**	**-0.03**	**0.01**	-	-
Distance_water	**0.06**	**0.008**	-	-	**0.15**	**0.01**	**-0.19**	**0.009**	**-0.04**	**0.01**
CanopyCover_ordinal	**-0.26**	**0.01**	**-0.44**	**0.007**	-	-	**-0.59**	**0.02**	**-0.29**	**0.008**
ConiferCover_ordinal	**0.44**	**0.01**	-	-	**0.47**	**0.02**	**0.37**	**0.02**	**0.27**	**0.01**
Mixed	-	-	-	-	**-0.27**	**0.10**	-	-	-	-
Flat	-	-	**0.41**	**0.01**	-	-	**0.20**	**0.02**	**0.16**	**0.02**
Lee	**-0.04**	**0.02**	-	-	**-0.16**	**0.02**	-	-	-	-
DEM	**0.46**	**0.01**	**0.78**	**0.02**	-	-	**-0.34**	**0.02**	-	-
TPI	**0.10**	**0.009**	**0.04**	**0.006**	**0.20**	**0.01**	**0.15**	**0.009**	-	-
CTI	**0.41**	**0.008**	-	-	**0.40**	**0.009**	**-0.06**	**0.01**	-	-

Table 4. Proportion of available area (α_i), number of used locations (Use), proportion of used locations (μ_i), selection ratio ($w(x)$), and risk ratio (RR) per bin of relative probability of selection for each season (Spring, Summer, Fall, Early Winter, and Late Winter) from mixed logistic regression models assessing 3rd order selection of female boreal caribou in the Chinchaga herd in Alberta and British Columbia between 2004 and 2016. Selection ratios < 1 indicate avoidance while selection ratios > 1 indicate selection.

Spring

Bin	α_i	Use	μ_i	$w(x)$	RR*
1	0.06	101	0.01	0.10	1.00
2	0.08	217	0.01	0.16	1.68
3	0.08	452	0.03	0.32	3.27
4	0.09	742	0.04	0.50	5.14
5	0.09	1099	0.06	0.69	7.19
6	0.10	1549	0.09	0.90	9.37
7	0.11	1990	0.11	1.05	10.87
8	0.12	2438	0.14	1.15	11.97
9	0.14	3613	0.21	1.52	15.77
10	0.14	5237	0.30	2.17	22.50

Summer

Bin	α_i	Use	μ_i	$w(x)$	RR*
1	0.09	332	0.01	0.14	1.00
2	0.08	620	0.02	0.31	2.21
3	0.09	1120	0.04	0.48	3.45
4	0.10	1471	0.06	0.59	4.19
5	0.11	1967	0.08	0.70	5.02
6	0.26	7306	0.29	1.12	7.99
7	0.14	5461	0.22	1.54	11.00
8	0.12	6937	0.28	2.22	15.88

Fall

Bin	α_i	Use	μ_i	$w(x)$	RR*
1	0.05	51	0.00	0.08	1.00
2	0.07	123	0.01	0.15	1.85
3	0.08	263	0.02	0.27	3.37
4	0.10	388	0.03	0.33	4.15
5	0.10	543	0.04	0.43	5.32
6	0.11	862	0.07	0.65	8.04
7	0.11	1304	0.11	0.94	11.66
8	0.12	1736	0.14	1.19	14.83
9	0.13	2857	0.24	1.87	23.21
10	0.13	4005	0.33	2.55	31.66

Early Winter

Bin	α_i	Use	μ_i	$w(x)$	RR*
1	0.10	256	0.02	0.17	1.00
2	0.07	329	0.02	0.33	1.95
3	0.17	1053	0.07	0.43	2.53
4	0.11	1247	0.09	0.75	4.43
5	0.14	2127	0.15	1.01	5.99
6	0.17	2886	0.20	1.18	6.98
7	0.15	3725	0.26	1.70	10.00
8	0.09	2980	0.20	2.39	14.08

Late Winter

Bin	α_i	Use	μ_i	$w(x)$	RR*
1	0.04	255	0.02	0.42	1.00
2	0.05	339	0.02	0.47	1.13
3	0.13	1153	0.08	0.62	1.49
4	0.10	1274	0.09	0.87	2.08
5	0.08	1265	0.09	1.06	2.53
6	0.31	4862	0.33	1.08	2.57
7	0.14	2327	0.16	1.14	2.72
8	0.15	3150	0.22	1.39	3.32

*Risk ratio is expressed relative to bin 1. Within each season, risk ratios are the ratio of the probability of an area being selected (bin) relative to the probability of selection of the lowest bin value (bin 1) for that season.

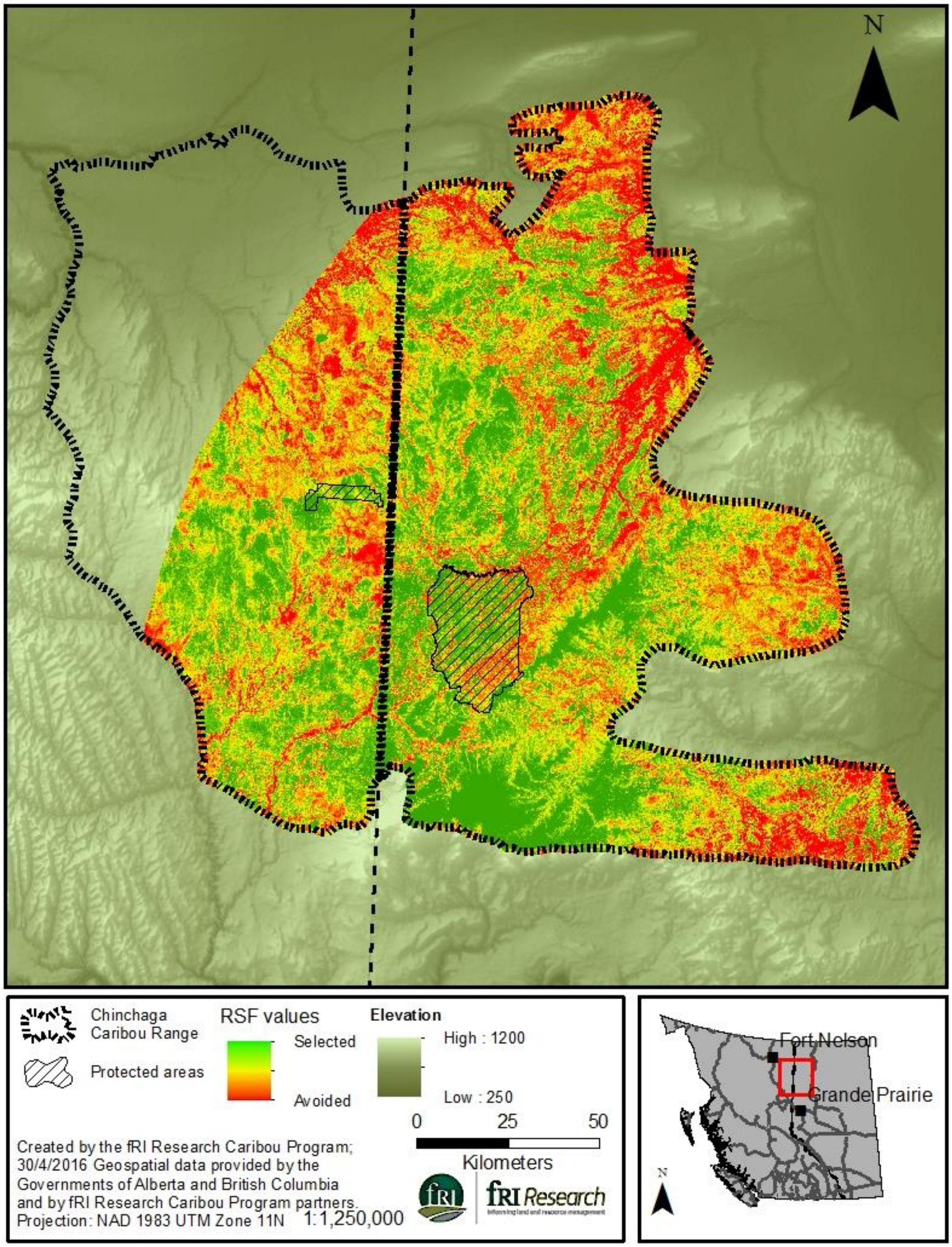

Figure 3. Relative probability of 3rd order habitat selection by caribou during spring in the Chinchaga caribou range, northeast British Columbia and northwest Alberta, Canada between 2004 and 2016. RSF values were not mapped in the northwest portion of the range where landcover data was not available.

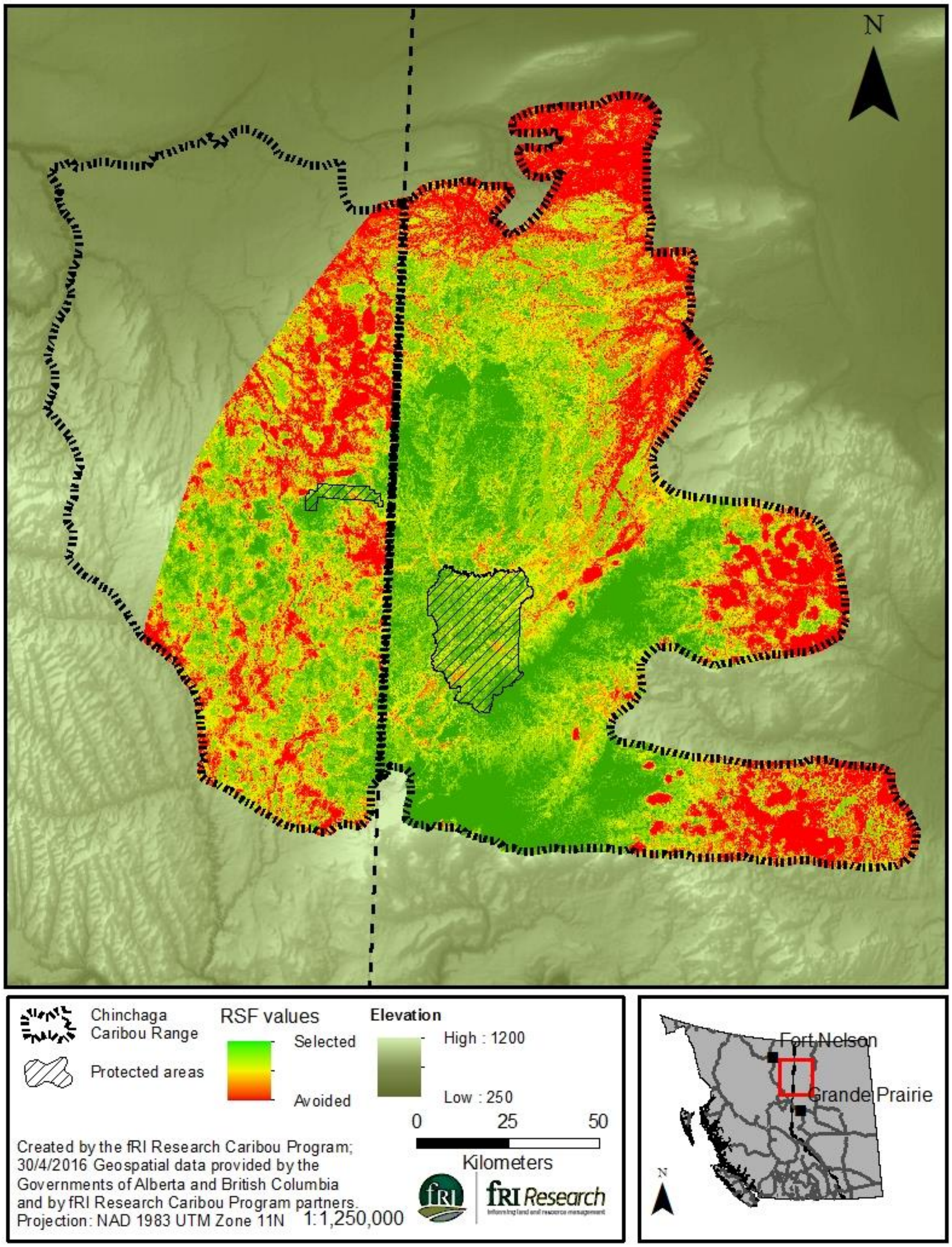

Figure 4. Relative probability of 3rd order habitat selection by caribou during summer in the Chinchaga caribou range, northeast British Columbia and northwest Alberta, Canada between 2004 and 2016. RSF values were not mapped in the northwest portion of the range where landcover data was not available.

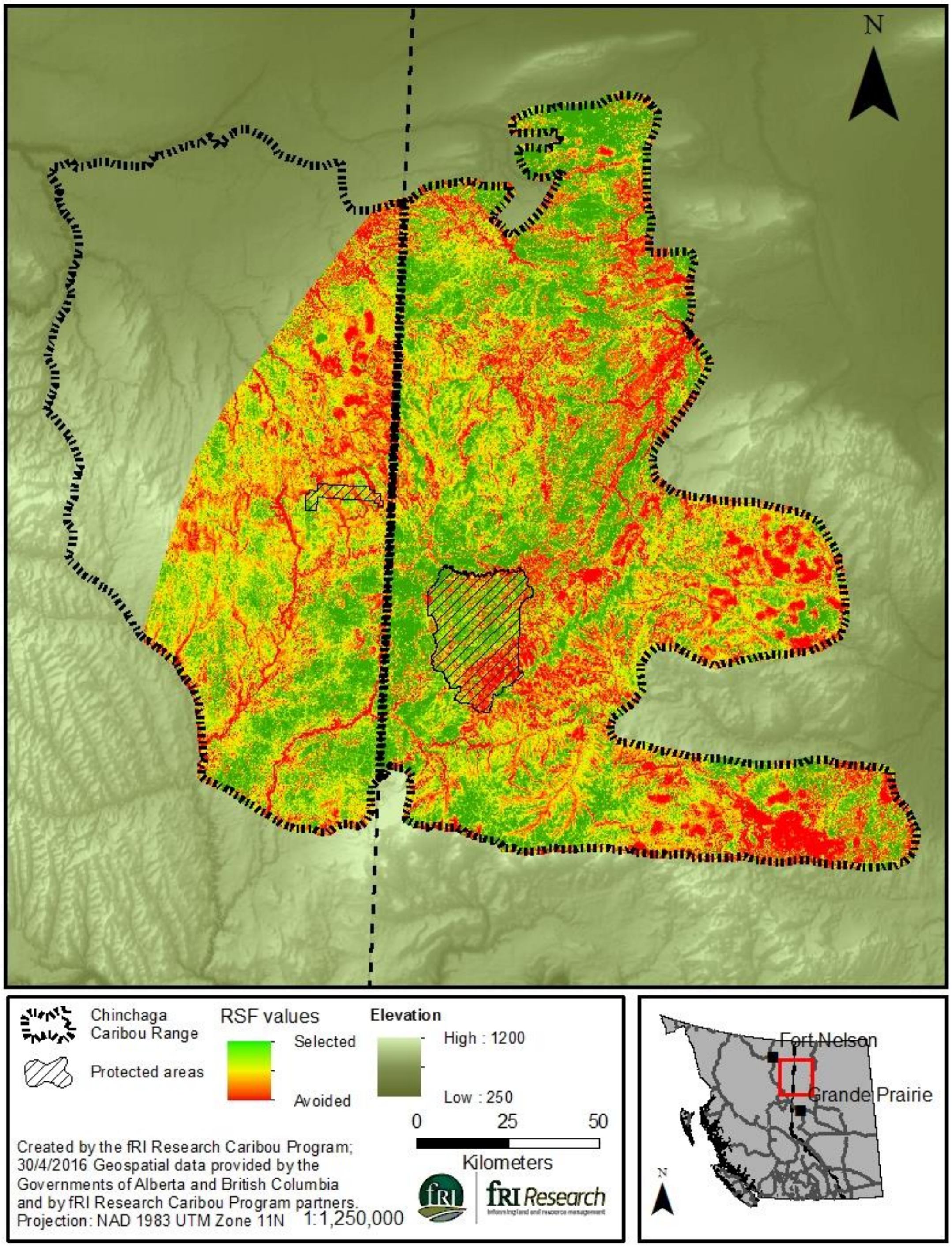

Figure 5. Relative probability of 3rd order habitat selection by caribou during fall in the Chinchaga caribou range, northeast British Columbia and northwest Alberta, Canada between 2004 and 2016. RSF values were not mapped in the northwest portion of the range where landcover data was not available.

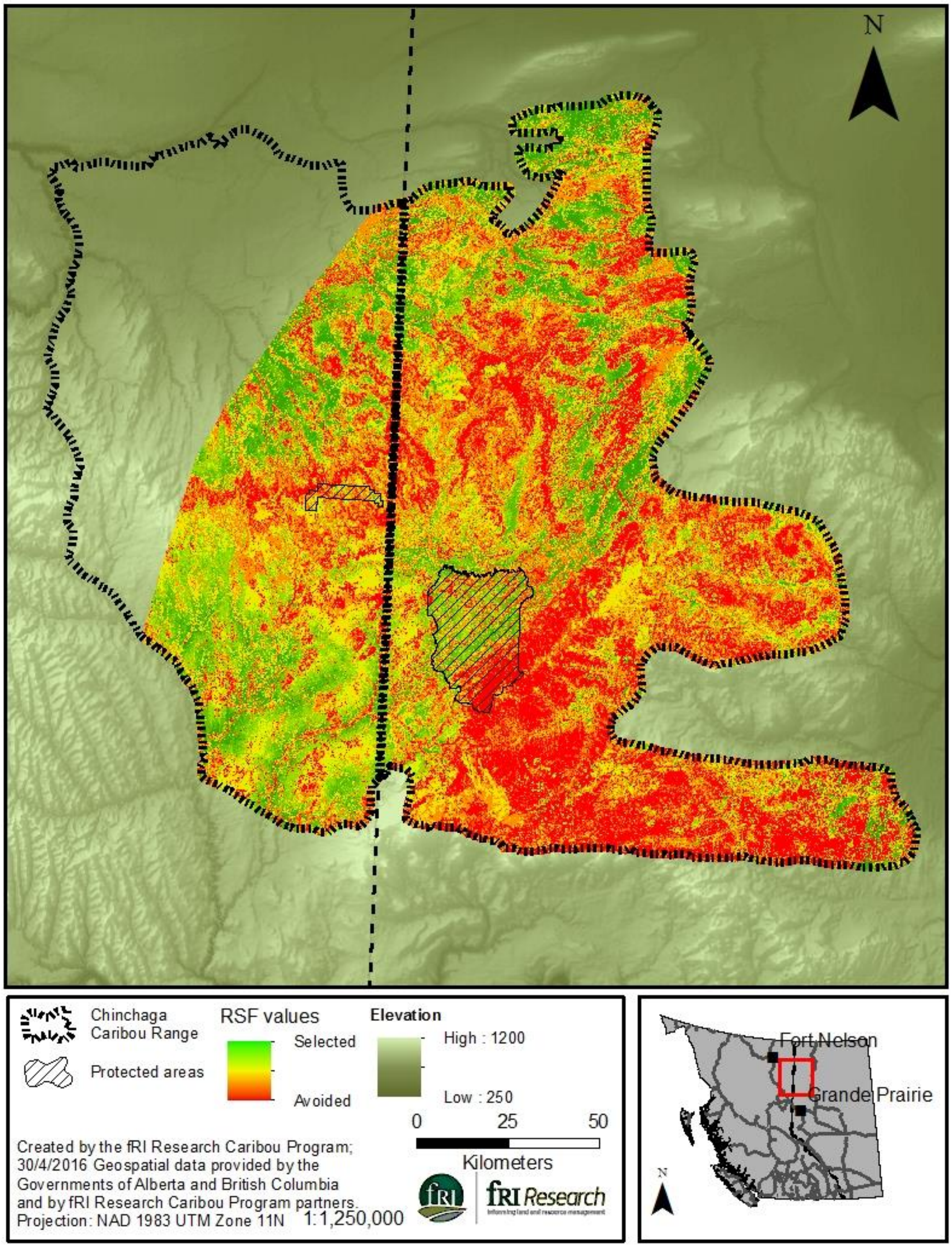

Figure 6. Relative probability of 3rd order habitat selection by caribou during early winter in the Chinchaga caribou range, northeast British Columbia and northwest Alberta, Canada between 2004 and 2016. RSF values were not mapped in the northwest portion of the range where landcover data was not available.

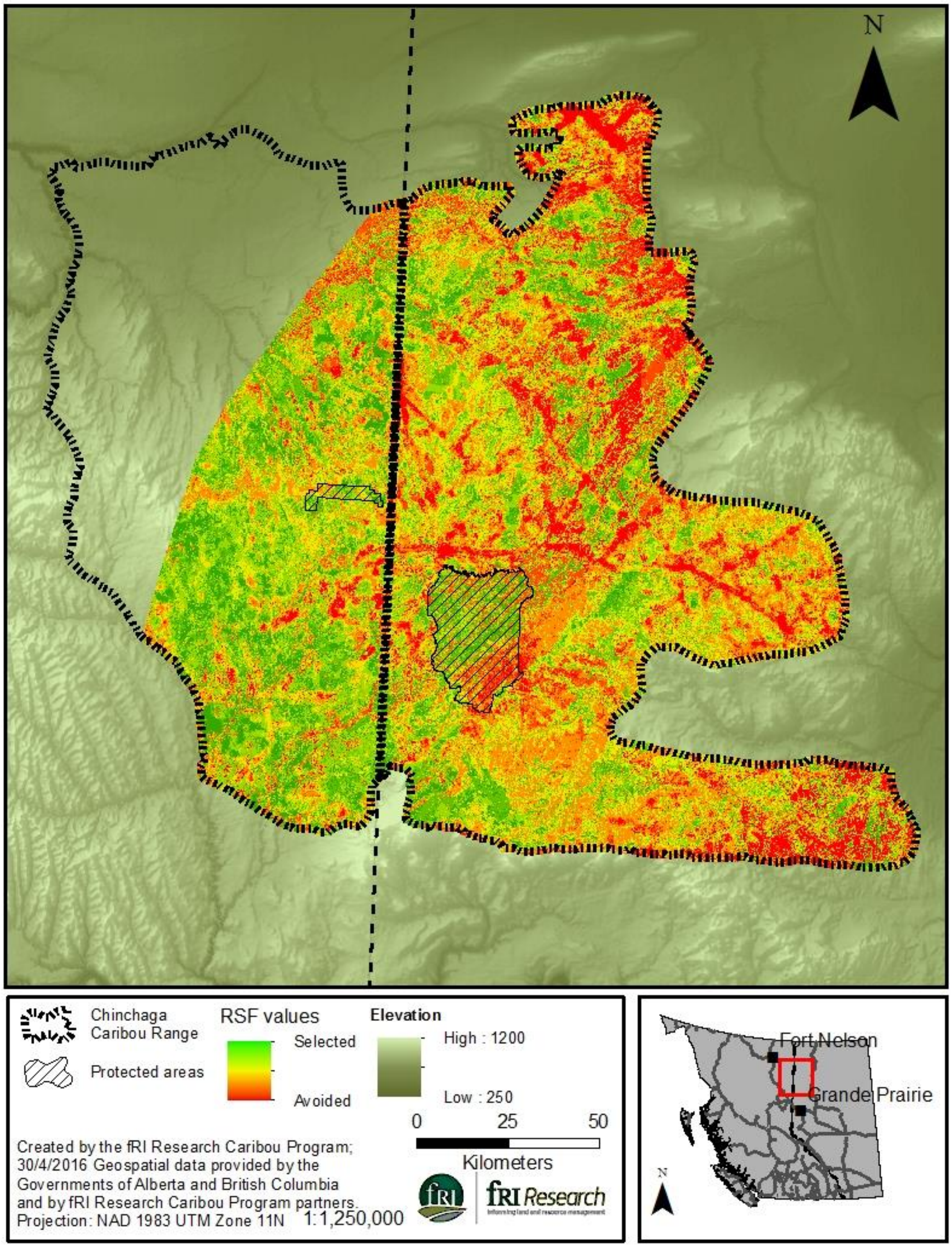

Figure 7. Relative probability of 3rd order habitat selection by caribou during late winter in the Chinchaga caribou range, northeast British Columbia and northwest Alberta, Canada between 2004 and 2016. RSF values were not mapped in the northwest portion of the range where landcover data was not available.

4. Wolf Resource Selection Functions

4.1 Introduction

Wolves are an important predator of caribou, and understanding how they respond to habitat features is needed to plan recovery actions for caribou. While many studies have documented a positive response of wolves to anthropogenic features that could increase this risk of predation for caribou in areas with greater levels of anthropogenic disturbance (i.e. Neufeld 2006; Latham et al. 2011; Whittington et al. 2011; DeCesare et al. 2012), a spatially explicit RSF model does not exist for the Chinchaga range. Pigeon et al. (2016) modeled wolf behaviour for the Alberta portion of Chinchaga range; we used this as a base model by which to build seasonal RSFs for the entire transboundary Chinchaga caribou range.

4.2 Methods

4.2.1 Wolf location data

We used data from six adult wolves in three packs collared with GPS collars (Simplex GPS collars, Televilt Positioning, Sweden and ATS GPS collars, Advanced Telemetry Systems Inc., Isanti, Minnesota) by the British Columbia Ministry of Environment in the Chinchaga caribou range during 2005 and 2006 (Rowe 2007). Immobilization and collar installation followed Provincial Resource Information Committee standards (Rowe 2007). Collars were programmed to record fixes every 6 hours and locations were downloaded after collar recovery. We followed the same data cleaning procedure for wolf GPS telemetry data as for caribou GPS telemetry data, as outlined in section 3.2.1. The final GPS telemetry dataset for wolves consisted of 7,451 locations from 6 individuals gathered between 2005 and 2007 (Table 5).

We accounted for seasonal variation in wolf behaviour by dividing GPS telemetry locations into three annual periods based on dates in previously published literature: Denning (April 20 – June 30), Rendezvous (July 1 – September 20), and Nomadic (September 21 – April 19) periods (Neufeld 2006). These periods reflect changes in pack behaviour associated with pup-rearing; movements during the denning season typically revolve around the den site, but as pups become more mobile pack movements during the rendezvous season consist of longer hunting trips and frequent returns to ‘rendezvous’ sites. When pups are fully grown the pack movements reflect larger territorial patrols without the return to specific sites (Neufeld 2006; Houle et al. 2010).

Table 5. Sample size of GPS telemetry locations for collared wolves with territories in the Chinchaga caribou range between 2005 and 2007.

	Wolves	
	Locations	**Individuals**
Year	-	-
2005	1,163	2
2006	4,402	6
2007	1,886	5
Total	7,451	6

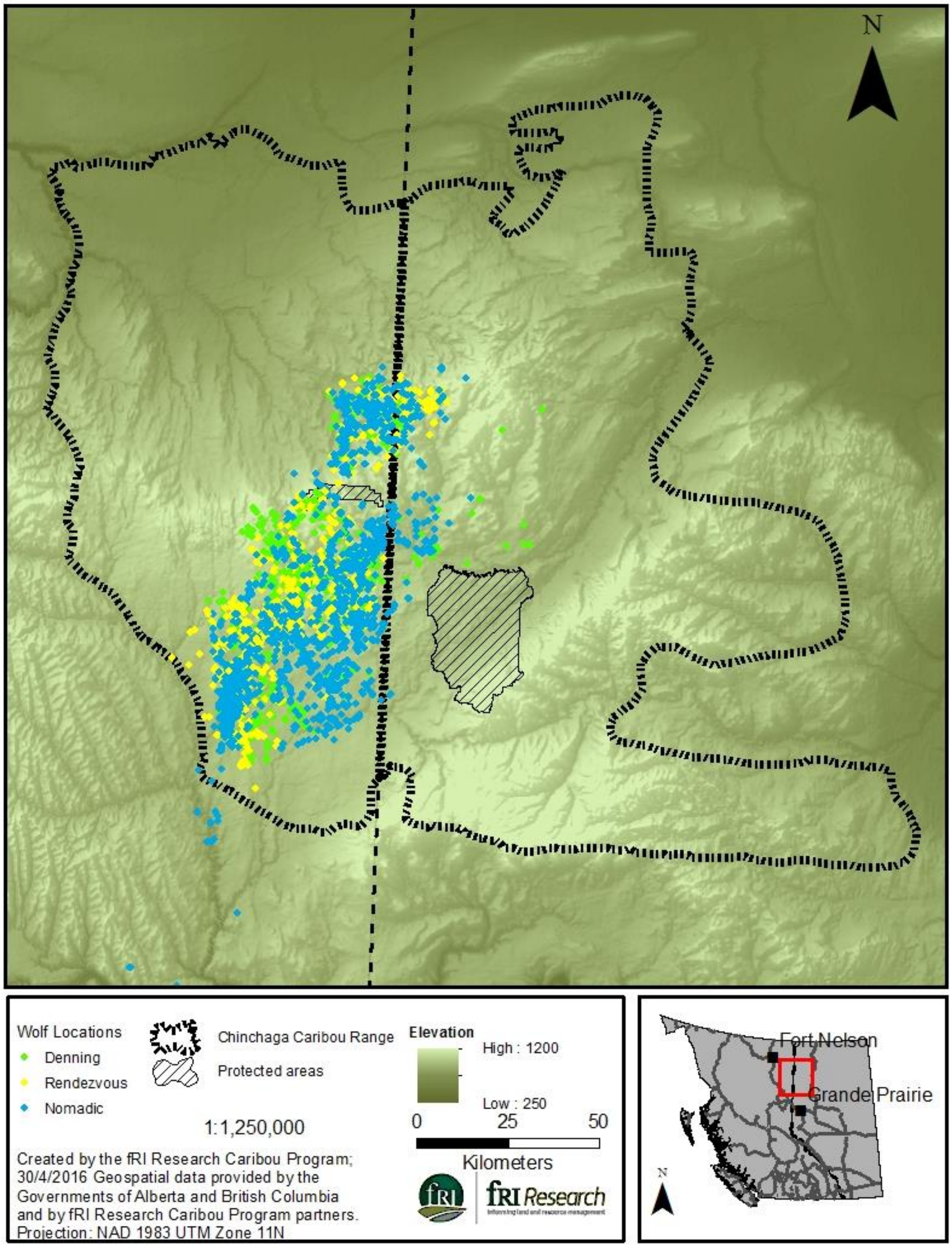

Figure 8. GPS telemetry locations for collared wolves in the Chinchaga range between 2005 and 2007.

4.2.2 Landscape variables

We used the same landscape variables to build wolf RSFs as for caribou RSFs; refer to section 3.2.2 for details.

4.2.3 Data Analysis

We used the same approach to develop wolf RSFs as we used for caribou RSFs (refer to section 3.2.3 for details) with one difference: Because of limited sample size of wolf locations occurring in Alberta base RSFs for wolves Pigeon et al. (2016) included season as a categorical variable. For our analysis we were able to include the full wolf telemetry dataset so we developed a separate model for each season.

4.3 Results

For all seasons, models with expanded anthropogenic disturbance classes were more parsimonious than models built using the covariates in the Pigeon et al. (2016) base RSFs. Across seasons, wolves consistently selected areas with sloped terrain, in valley bottoms with open canopies, and closer to streams and rivers than expected by random (Table 6). During denning and rendezvous seasons, areas with a higher density of anthropogenic features (cutblocks, pipelines, and all roads) were either selected or used in proportion to their availability; however during the nomadic season, areas with higher densities of low-use and winter roads were used less than expected. Wolves selected areas at lower elevation during the rendezvous season, and selected areas at higher elevation during the nomadic season.

Using coefficients from the final models, we mapped RSFs and binned probabilities of selection per season (Table 7; Figures 9-11). During the denning and rendezvous seasons, wolves in the Chinchaga caribou range were at least 7 times more likely to select areas identified with the highest RSF value (bin 7) than areas that were attributed to the lowest RSF value (bin 1; Table 7). However, during the nomadic season, the likelihood of selecting the highest RSF value (nomadic season bin 4; Table 7) was only 1.3 times higher than selecting the lowest RSF value (nomadic season bin 1; Table 7). K-fold validation yielded average Spearman rank correlations (R_s) ranging from 0.92 to 0.99 for used locations and from -0.08 to 0.02 for random locations: Denning R_s average: (Use: 0.93; Random: 0.02), Rendezvous R_s average: Use: 0.92; Random: -0.02), Nomadic R_s average: Use: 0.99; Random: -0.08).

Table 6. Standardized model coefficients (β) and standard errors (SE) describing 3rd order habitat selection for Chinchaga wolves during Denning, Rendezvous, and Nomadic periods between 2005 and 2007. Covariates are described in Table 2. Variables for which selection was statistically different from random are shown in bold.

	Denning		Rendezvous		Nomadic	
	β	**SE**	**β**	**SE**	**β**	**SE**
Intercept	**-2.48**	**0.05**	**-2.45**	**0.06**	**-2.44**	**0.07**
Road_high_1km	0.02	0.03	**0.06**	**0.03**	**0.50**	**0.02**
Road_low_1km	**0.13**	**0.03**	**0.09**	**0.03**	**-0.15**	**0.02**
Road_winter_1km	0.005	0.03	0.02	0.03	**-0.11**	**0.03**
Pipeline_1km	-0.01	0.03	**0.09**	**0.03**	**0.03**	**0.02**
Cutblocks_1km	-0.03	0.03	-0.07	0.04	**0.15**	**0.01**
Distance_water	**-0.29**	**0.04**	**-0.17**	**0.03**	**-0.40**	**0.02**
CanopyCover_ordinal	**-0.54**	**0.04**	**-0.32**	**0.03**	**-0.22**	**0.02**
ConiferCover_ordinal	-	-	-	-	**-0.15**	**0.02**
Flat	**-0.27**	**0.09**	**-0.24**	**0.11**	**-0.35**	**0.05**
DEM	-	-	**-0.13**	**0.04**	**0.40**	**0.02**
TPI	**-0.39**	**0.03**	**-0.36**	**-0.03**	**-0.27**	**0.02**
CTI	**-0.20**	**0.04**	**-0.36**	**-0.04**	-	-

Table 7. Proportion of available area (α_i), number of used locations (Use), proportion of used locations (μ_i), selection ratio ($w(x)$), and risk ratio (RR) per bin of relative probability of selection for each season (Denning, Rendezvous, Nomadic) from mixed logistic regression models assessing 3rd order selection of wolves with territories in the Chinchaga caribou range between 2005 and 2007. Selection ratios < 1 indicate avoidance while selection ratios > 1 indicate selection.

Denning						***Rendezvous***					
Bin	**α_i**	**Use**	**μ_i**	**$w_{(x)}$**	**RR***	**Bin**	**α_i**	**Use**	**μ_i**	**$w_{(x)}$**	**RR***
1	0.08	19	0.02	0.20	1.00	1	0.11	53	0.04	0.38	1.00
2	0.17	61	0.05	0.33	1.62	2	0.17	97	0.08	0.45	1.18
3	0.11	72	0.06	0.60	3.01	3	0.10	73	0.06	0.57	1.52
4	0.25	205	0.18	0.72	3.61	4	0.23	218	0.17	0.75	1.99
5	0.13	151	0.13	0.99	4.94	5	0.13	173	0.14	1.06	2.81
6	0.14	187	0.17	1.22	6.08	6	0.14	205	0.16	1.17	3.10
7	0.12	437	0.39	3.10	15.44	7	0.12	454	0.36	2.88	7.62
Nomadic											
Bin	**α_i**	**Use**	**μ_i**	**$w_{(x)}$**	**RR***						
1	0.44	1179	0.38	0.86	1.00						
2	0.11	308	0.10	0.91	1.06						
3	0.12	436	0.14	1.14	1.34						
4	0.33	1191	0.38	1.17	1.36						

*Risk ratio is expressed relative to bin 1. Within each season, risk ratios are the ratio of the probability of an area being selected (bin) relative to the probability of selection of the lowest bin value (bin 1) for that season.

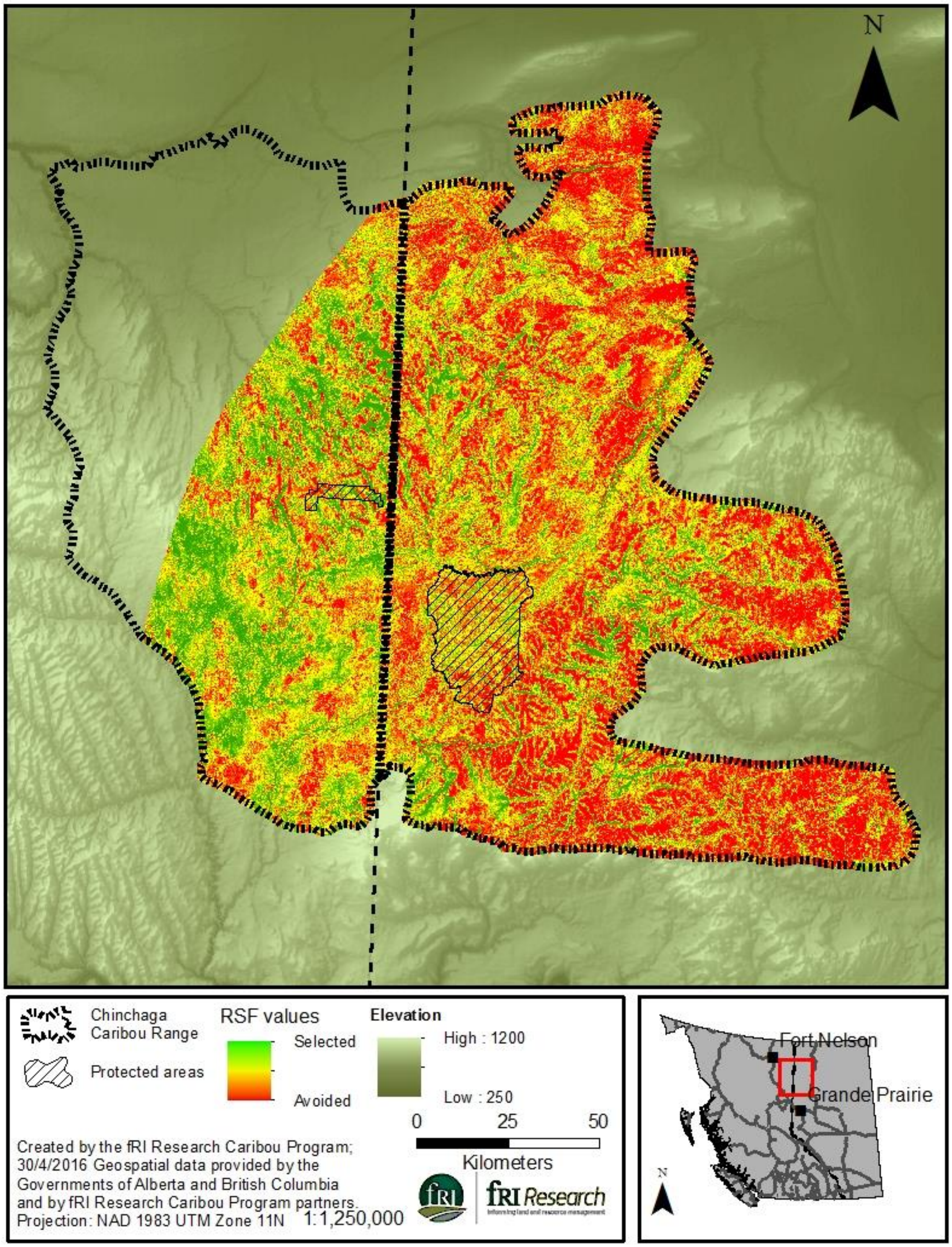

Figure 9. Relative probability of 3rd order habitat selection by wolves during denning in the Chinchaga caribou range, northeast British Columbia and northwest Alberta, Canada between 2005 and 2007. RSF values were not mapped in the northwest portion of the range where landcover data was not available.

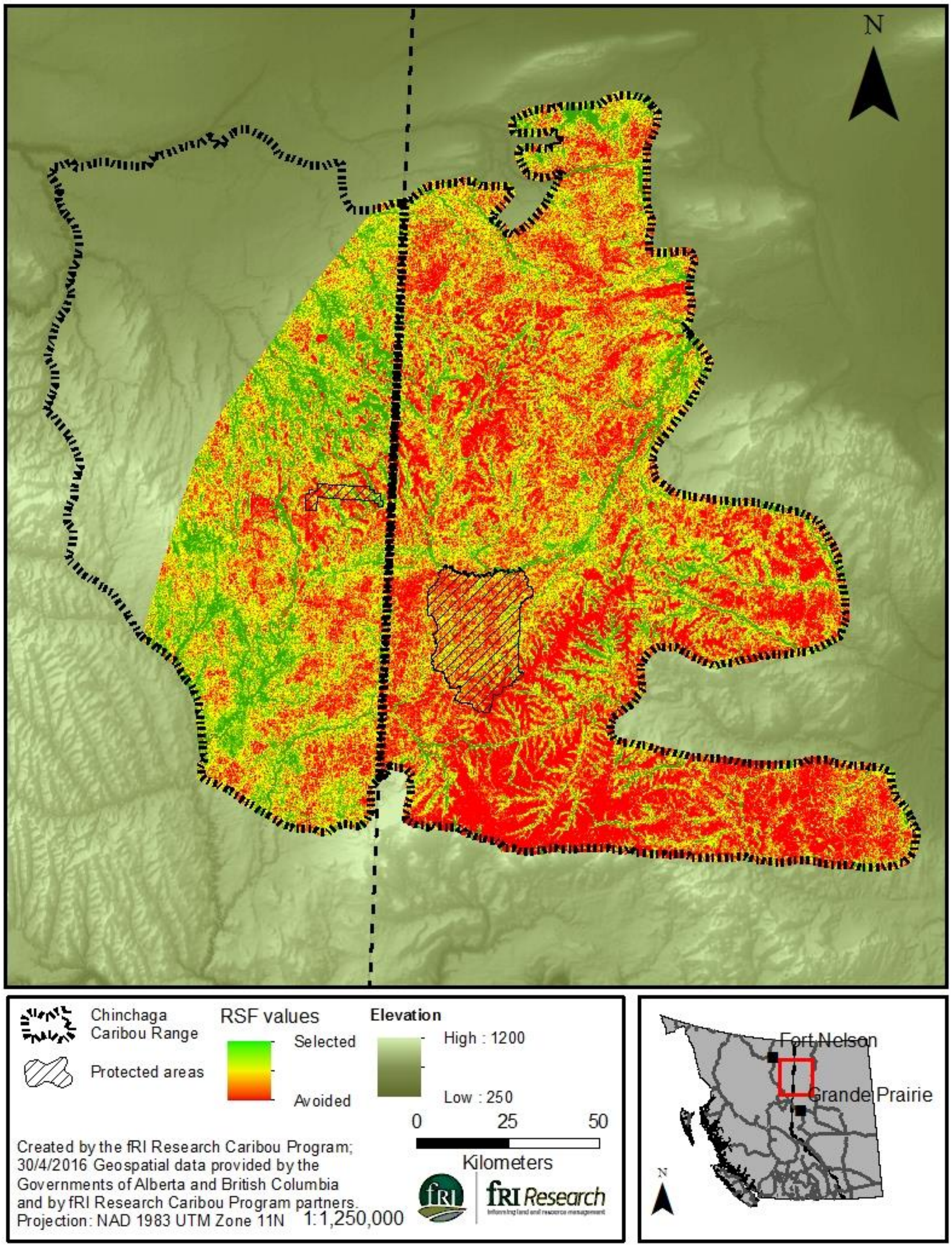

Figure 10. Relative probability of 3rd order habitat selection by wolves during the rendezvous season in the Chinchaga caribou range, northeast British Columbia and northwest Alberta, Canada between 2005 and 2007. RSF values were not mapped in the northwest portion of the range where landcover data was not available.

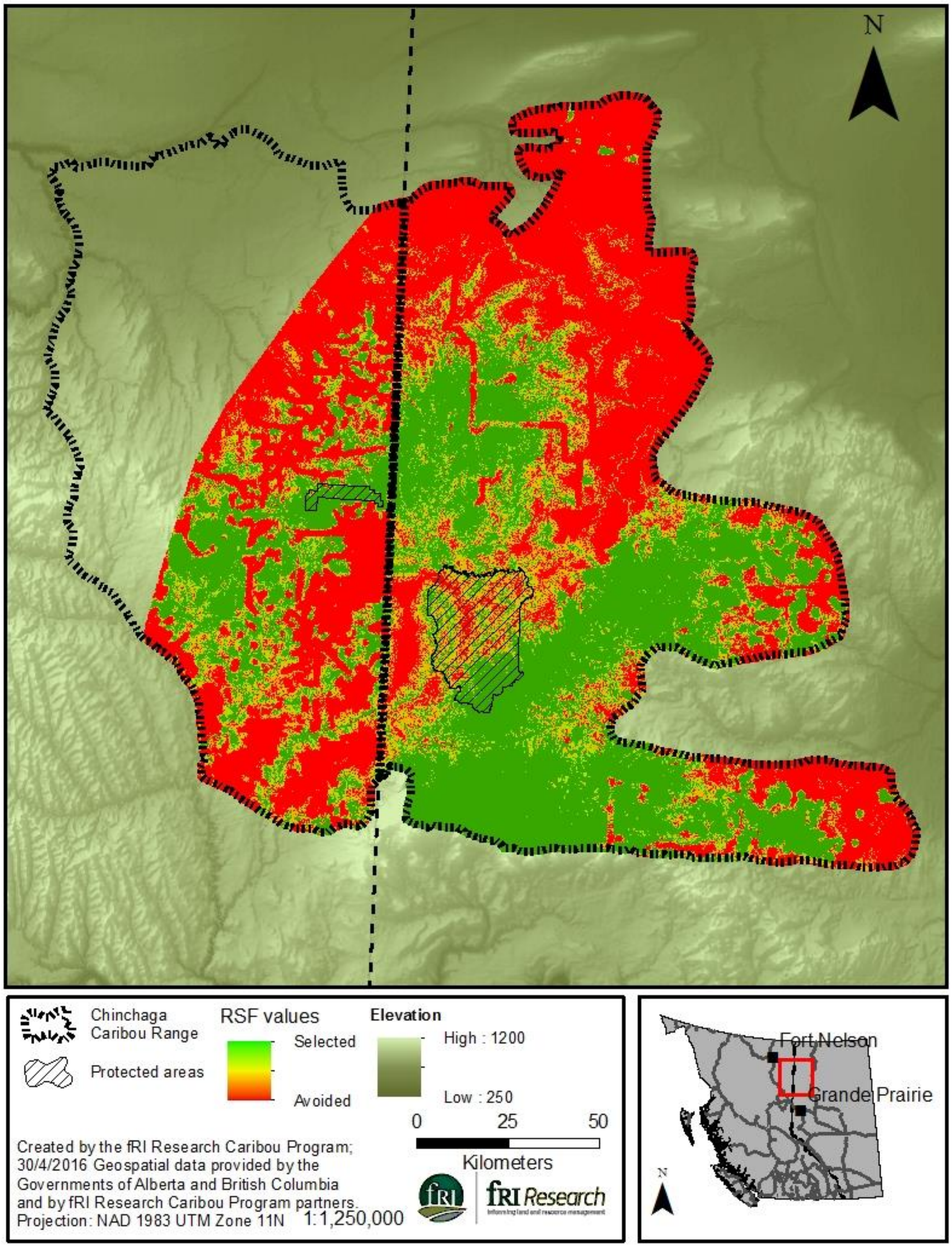

Figure 11. Relative probability of 3rd order habitat selection by wolves during the nomadic season in the Chinchaga caribou range, northeast British Columbia and northwest Alberta, Canada between 2005 and 2007. RSF values were not mapped in the northwest portion of the range where landcover data was not available.

5. Synthesis

5.1 Caribou

Using GPS telemetry locations spanning 10 years and gathered from 63 caribou within the Chinchaga boreal caribou range in British Columbia and Alberta, we found that within seasonal home ranges, Chinchaga boreal caribou:

- Selected areas with higher densities of high-use roads, winter roads, and cutblocks less than expected by chance during all seasons.
- Selected areas with higher densities of low-use roads less than expected by chance during summer and fall, but selected areas with higher densities of low-use roads more than expected by chance during late winter and spring.
- Selected areas with higher densities of pipelines less than expected by chance during late winter and spring, but selected habitats with higher densities of pipelines more than expected by chance during summer and fall.
- Consistently selected open canopy coniferous habitat on gentle terrain during all seasons.
- Selected areas at higher elevations during spring and summer, and selected areas at lower elevations during early and late winter.

5.2 Wolves

Using GPS telemetry locations spanning 3 years from 6 wolves in the Chinchaga caribou range, we found that within seasonal ranges, wolves:

- Selected open-canopy areas that were closer to streams and rivers than expected by random during all seasons.
- Selected areas with higher densities of anthropogenic features than expected by random during denning and rendezvous seasons.
- Selected areas with higher densities of high-use roads and cutblocks more than expected by random, but selected areas with higher densities of low-use and winter roads less than expected by random during the nomadic season.

6. Ongoing work and Next steps

The overarching objectives of this project are to:

1. Determine how different types of activity at well sites influences the behaviour of caribou and wolves and assess how this relationship changes seasonally and in relation to the surrounding habitat matrix. **Underway; RSF analysis presented in this report is the first step towards understanding this**

relationship, however the response to well sites is needed for full interpretation. Expected completion March 2017.

2. Assess caribou and wolf response to pipelines in relation to pipeline age and the surrounding habitat matrix. **Underway; as above. Expected completion March 2017.**
3. Use models of caribou and wolf use of pipelines developed in Alberta (FRIP OF-13-006) to model caribou and wolf use of pipelines in the BC portion of the Chinchaga caribou range, and validate models with field data collection. **Fieldwork planned for summer 2017. Expected completion of final models October 2017.**
4. Evaluate whether currently accepted 500m buffers on well sites and pipelines accurately reflect caribou functional habitat. **Expected completion October 2017.**
5. Synthesize the results from objectives a - d to provide guidelines for restoration and mitigation of disturbance features within caribou ranges to contribute towards caribou recovery in northwestern Alberta and northeastern BC. **Expected completion October 2017.**

Further analysis considering the specific response of caribou to the activity status of oil and gas well sites is underway and will facilitate a complete interpretation of these results in the context of habitat selection of caribou in general, but also habitat selection patterns specific to the Chinchaga caribou range. Future iterations of these models would benefit from additional data that was not available to fRI Research at the time of analysis, including landcover for the entire extent of Chinchaga caribou range in British Columbia (currently under development), and conventional seismic line footprint in British Columbia (requested).

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