FINAL REPORT

Analysis and improvement of linear features to increase caribou functional habitat in west-central and north-western Alberta

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fRI Research Caribou Program

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Executive Summary

Anthropogenic disturbance is extensive within caribou range in west-central and north-west Alberta, and habitat restoration is necessary for caribou persistence. Given the extent of the disturbance footprint, it is crucial to understand how disturbance is impacting caribou and how restoration efforts will be most effective in helping stabilize caribou populations. We used GPS data from caribou and wolves, field data on human and wildlife use of seismic lines and pipelines, vegetation heights extracted from LiDAR, non-invasive fecal DNA collections, and a suite of GIS variables associated with landscape, habitat, and anthropogenic features to 1) determine how caribou, their predators, and humans respond to seismic lines at different stages of regeneration, 2) evaluate whether the zone of influence of linear features changes in relation to the level of regeneration, 3) assess how human activity on linear features is affected by landscape attributes and regeneration, 4) assess the size and health of caribou populations, and 5) produce spatially explicit models to aid in the prioritization of areas for restoration.

In year one of this project, analysis of field data failed to reveal associations between wildlife use of linear features and regeneration (n = 95 plots). However, using GPS data, we found that central mountain caribou selected areas further from well sites in the drilling phase during winter, and that Chinchaga boreal caribou selected all types of anthropogenic features less than expected from chance. Chinchaga caribou also selected relatively high elevation, open mature conifer stands on shallow slopes and plains during spring and summer, and low elevation, open mature conifer stands and open habitats on shallow slopes and plains during fall and winter. Overall, regeneration height of seismic lines in the Chinchaga range was low (70% <1m). However, despite this extensive footprint, caribou selected areas further from seismic lines with low vegetation height during spring, summer, and late winter. In comparison, wolves selected flat areas at relatively high elevation in mixed forest and non-forested habitat near small streams, and away from high densities of linear features at the landscape scale but close to areas with high densities of anthropogenic features at the local scale. Wolves also selected for areas near seismic lines with low vegetation heights when in close proximity to seismic lines during the snow-free period but the influence of regeneration height on seismic lines diminished when wolves were located farther from seismic lines. Finally, both species also selected areas near seismic lines with high CTI values (high wetness).

Activity patterns of humans in relation to seismic lines (n = 1250) and pipelines (n = 435) were not consistent across caribou ranges, and models using GIS and field variables neither predicted human use of pipelines, nor human use of seismic lines in north-west Alberta. In west-central Alberta, high levels of human use occurred on seismic lines with low vegetation heights, in areas with low densities of well sites and high ungulate counts, and on seismic lines that were close to paved roads. The probability of human use was zero when vegetation heights reached 2.7m. The models for west-central Alberta correctly predicted 62-82% of human use on seismic lines. Using non-invasive fecal sampling, we measured stress (cortisol and corticosterone) and reproductive hormones (progesterone and testosterone) in west-central caribou herds. The final year of fecal collection is still underway but preliminary data revealed no differences in hormone levels among herds. Progesterone levels indicated that 51 out of 60 female caribou tested in west-central Alberta were pregnant at the time of sampling.

Analyses failed to reveal clear regeneration thresholds to identify when caribou and wolf habitat selection patterns were no longer affected by the presence of seismic lines. We were therefore unable to define a breakpoint at which seismic lines and their surrounding habitat should be considered functional caribou habitat again. Final results from fecal surveys (spring 2017) could help assess caribou functional habitat further. Nevertheless, our research findings reveal a suite of variables that can be used to prioritize seismic lines for restoration, and these variables can also be used to direct mitigation of human impact within caribou ranges. Based on our findings, we overlaid spatially explicit maps of the relative probability of habitat selection for caribou and wolf in the Chinchaga range. These resulting maps identify areas surrounding regenerating seismic lines that have the highest probability of overlap between caribou and wolves. From these probabilities, we then created a map of seismic lines ranked with respect to priority for restoration. This approach classified 1539km (2.9%) of seismic lines in the Chinchaga range as high or very high priority for restoration.

Overall, our detailed analyses of animal and human response to regenerating seismic lines and well site status contributes new knowledge towards understanding the effect of anthropogenic disturbances on animal behavior, and towards understanding areas of overlap between caribou and their predators. The covariates identified here, along with seismic lines identified as high priority for restoration, can be used by land planners and industrial partners to identify areas where restoration of previously disturbed areas will have the greatest benefit to caribou in the Chinchaga range. Ultimately, these results may be used to expedite restoration of caribou habitat to reach the disturbance targets outlined in the federal recovery strategies.

Acknowledgements

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1. Introduction

The boreal population of woodland caribou (*Rangifer tarandus caribou;* hereafter 'caribou') is listed as 'threatened' under the federal Species at Risk Act (Environment Canada 2012) and the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002). A growing body of evidence suggests that the ultimate cause of their decline is related to anthropogenic activities, in particular industrial development and resource extraction (McLoughlin *et al.* 2003; Johnson *et al.* 2015). Industrial activities have increased the extent of early seral habitats in caribou ranges, therefore facilitating population increases for their competitors (i.e. moose [*Alces alces*] and deer [*Odocoileus* sp.]) and their predators (wolves [*Canis lupus*]*;* DeCesare *et al.* 2010).

The federal recovery strategy for the boreal population of caribou established that at least 65% of the habitat within the range of each local population should be undisturbed to raise the probability of the population being self-sustaining to 60% (Environment Canada 2012). All of Alberta's caribou ranges exceed the disturbance levels mandated by the recovery strategy, and industrial users are under pressure to implement habitat restoration of disturbed areas to achieve this 65% target. Although the cumulative effects of industrial development within caribou ranges are of concern (i.e. Sorensen *et al.* 2008), linear features have been the focus of scientific inquiry because these features facilitate predator travel and predation within caribou ranges (Alberta Woodland Caribou Recovery Team 2005; Whittington *et al.* 2011; DeCesare 2012; Hervieux *et al.* 2013). In north-west Alberta alone, there is over 70,000km of seismic lines (Figure 1.1). It is therefore important to determine whether the extent of natural regeneration on linear features influences the response of caribou and their predators to these features. Anthropogenic disturbance alters the availability and extent of functional caribou habitat, however we currently lack an understanding of how caribou perceive regenerating anthropogenic disturbance features. When can regenerating disturbance features be considered functional caribou habitat again? Answering this question will benefit the recovery of caribou populations because accurately defining the extent of disturbed habitat within the range of each local population will allow land managers to prioritize areas for restoration in a way that will be most beneficial for caribou. In addition, monitoring of population demographics including health and population size is essential to assess the efficacy of actions and continually inform management practices to improve caribou habitat and attain self-sustaining populations of caribou.

Following these restoration goals, this two year FRIAA and industry funded project used existing GPS data and LiDAR-based terrain metrics to address the following research objectives:

- Determine whether caribou and predator response to roads and pipeline right of ways (RoWs) is influenced by the extent of re-vegetation and human use of these features, and evaluate whether the currently accepted 500m buffer on roads and pipeline RoWs apply when line characteristics incorporate information on regeneration.
- Assess how human activity of linear features is affected by topography, geographic barriers, and re-vegetation height.
- Determine whether activity at worksites (active industrial activity) affects the movements of caribou.
- Use non-invasive fecal DNA collections for caribou during the winter to determine the relationship between re-vegetation and current restoration activities on the distribution, and the size and health of caribou populations.
- Assess whether the response of boreal caribou in the Chinchaga range (mixedwood, upland, and peatland habitat) to re-vegetation stage of disturbed habitat differs from that of boreal and mountain caribou in conifer dominated landscapes.
- Produce a list of landscape variables (e.g. re-vegetation height and human use thresholds) that can be used to quantify the extent of caribou functional habitat in our study area and elsewhere.
- Create of a map evaluating priority areas for restoration that are the most beneficial for caribou, and the most cost effective for the forestry sector and other industrial landscape users.

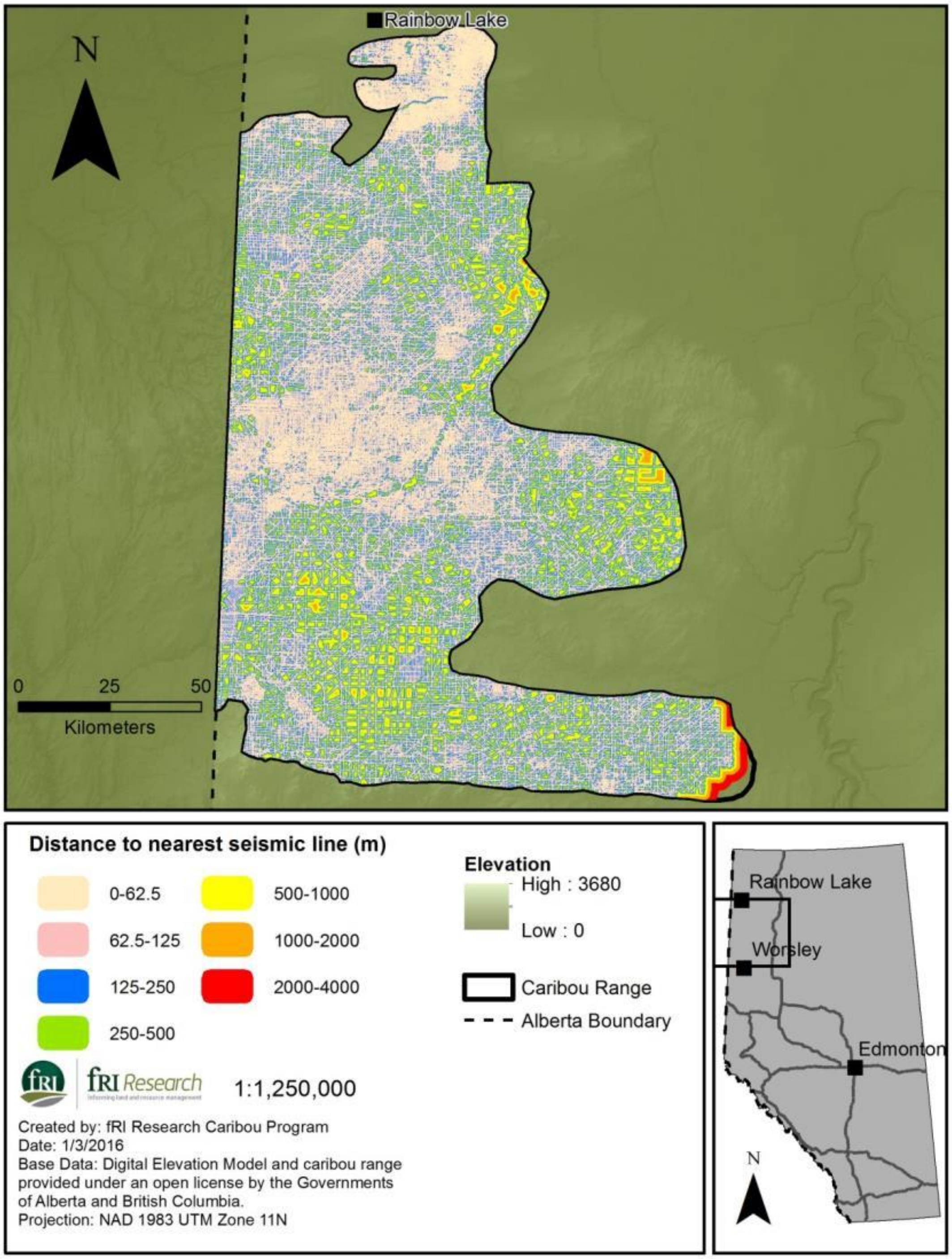


Figure 1.1. Seismic lines and seismic line footprint identified using distance buffers from 0m – 62.5m, 62.5m – 125m, 250m – 500m, 500m – 1000m, and 1000m – 2000m from seismic lines in the Chinchaga caribou range. The 2000m – 4000m buffer extent observed on the bottom-right section of the map is an artefact of the boundary from the digital data layer with available LiDAR-based regeneration values for seismic lines within the Chinchaga caribou range and does not reflect actual distances from seismic lines on the landscape at that boundary.

2. Baseline Resource Selection Function (RSF) for the Chinchaga caribou herd

Karine Pigeon

2.1 Introduction and objectives

Resource selection functions (RSFs) can be useful to identify and delineate areas preferred by animals, and can help conservation efforts by providing spatially explicit results to guide land-use planning (Johnson *et al.* 2004). RSFs allow researchers and land-use manager to identify habitat characteristics (i.e. stand type, elevation and slope, or anthropogenic features) that are either selected or avoided by animals, and therefore provide a measure of relative habitat quality. Of particular interest, RSFs allow land managers to quantify the potential impacts of various industrial activities on animals living within a landscape of interest, and to mitigate the effects of industrial activity and further development on animals in the future. Using data obtained from RSFs, particular industrial activities can be reduced in areas where potential impacts of land-use changes are high while these same activities can be shifted towards areas where the potential impacts of industrial activities are low.

A number of RSFs have been defined for mountain and boreal caribou including boreal herds in Alberta (e.g. Neufeld 2006; Fortin *et al.* 2008; DeCesare *et al.* 2012) but RSF values do not transfer well across regions (Boyce *et al.* 2002). Therefore, to better focus management efforts towards the successful conservation of boreal caribou, our objectives were to (1) define a baseline 3rd order RSF for a northern boreal caribou herd, the Chinchaga caribou herd in Alberta, and (2) compare selection patterns of the Chinchaga caribou herd with previously defined selection patterns for a west-central Alberta boreal caribou herd (the Little Smoky herd [LSM]; Johnson 1980; Neufeld 2006; DeCesare *et al.* 2012). By understanding the influence of landscape attributes related to the topography, landcover, and density of anthropogenic features within the seasonal home-ranges of the Chinchaga caribou herd, and by highlighting differences between Chinchaga caribou and west-central caribou, we can better prioritize herd-specific areas for caribou recovery (Noss, Nielsen & Vance-Borland 2009). Based on previous literature and expected behaviour of boreal caribou, we hypothesized that the presence and abundance of lichen, and anti-predator behaviour would drive year-round 3rd order selection of Chinchaga caribou (Rettie *et al.* 1997; Stuart-Smith *et al.* 1997; Nagy 2011). In west-central Alberta, high lichen biomass is associated with old, open, pine dominated forests, and in northern Alberta, high water tables and have been suggested to reduce lichen abundance (Dunford *et al.* 2006; Neufeld 2006). While boreal caribou in west-central Alberta have been shown to select dry, open conifer stands, north-eastern boreal caribou seem to prefer low canopy cover bogs and fens, potentially as a strategy to avoid predators (Stuart-Smith *et al.* 1997; McLoughlin *et al.* 2005; Neufeld 2006; Latham *et al.* 2011b). Based on previous research, we therefore expected Chinchaga caribou in north-western Alberta to either select open conifer stands with terrain features associated with relatively low water tables, or open bogs and fens throughout the year. However, consistent with predator-avoidance strategy, we also expected that Chinchaga caribou would be more likely to select high elevation open conifer stands during spring and summer, and lower elevation sites associated with open bogs and fens during fall and winter (e.g. Bergerud & Page 1987; Pinard *et al.* 2012). Finally, we hypothesized that Chinchaga caribou would be sensitive to anthropogenic features (McLoughlin *et al.* 2003; DeCesare *et al.* 2012), and therefore expected that throughout all seasons, Chinchaga caribou would select areas with high densities of anthropogenic features such as linear features (i.e. roads and seismic lines), cut blocks, and other anthropogenic features (i.e. well sites) less than expected based on a random distribution.

2.2 Methods

2.2.1 Study area

We investigated resource selection at the 3rd order of selection (Johnson 1980) for 18 individual boreal caribou captured and collared within the Chinchaga caribou range (Designatable Unit 6) between 2008 and 2010. The Chinchaga range extends east from the British Columbia – Alberta border towards highway 35 (117°32' – 57°18), north of Worsley (Figure 2.1). Elevation ranges between 273 m and 1113 m with lowland bogs, muskeg, and fens dominating the landscape. Dominant tree species include black and white spruce (*Picea mariana, P. glauca*), Western larch (*Larix laricina*), aspen (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*; (Natural Regions Committee 2006; Tigner, Bayne & Boutin 2014). The Chinchaga caribou range is extensively altered by anthropogenic activities associated with oil and gas exploration, forestry, and recreational activities with > 94 % of the Alberta range falling within 500 m of linear features. The Chinchaga caribou herd is listed as "threatened" under Alberta's Wildlife Act, by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and the federal Species at Risk Act (Environment Canada 2012). Unlike the migrating mountain caribou of west-central Alberta (i.e. Narraway, Redrock-Prairie Creek, and A la Peche herds), boreal caribou are mainly sedentary and inhabit low elevation boreal forests year-round (Bergerud 1992; Briand *et al.* 2009; Festa-Bianchet *et al.* 2011). Common predators in the area include wolves (*Canis lupus*), black bears (*Ursus americanus*), grizzly bears (*Ursus arctos*), coyotes (*Canis latrans*), wolverines (*Gulo gulo*), lynx (*Lynx canadensis*), and cougars (*Puma concolor*), while deer (*Odocoileus* spp.), moose (*Alces alces*), elk (*Cervus elaphus*), and bison (*Bison bison athabascae*) are also present (Rowe 2007).

2.2.2 Animal location data

Eighteen adult female caribou were captured and fitted with Lotek 2200 – 3300 GPS telemetry collars between 2008 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. We rarefied GPS locations to 6 hour intervals and restricted data analysis to GPS location with dilution of precision (DOP) < 10 to reduce mis-identification of environmental covariates (Lewis *et al.* 2007). We investigated resource selection within Minimum Convex Polygons (MCP) per individual-season yielding 72,126 observations from 39 individual-year and 111 individual-seasons. Seasonal variations in caribou behaviour are well known (Saher & Schmiegelow 2005; Nagy 2011; DeMars & Boutin 2013). We therefore investigated selection within 5 seasons (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) using methods outlined in (Rudolph & Drapeau 2012) to delineate seasons and therefore account for variations in seasonal selection and life history requirements. Low sample size and unknown pregnancy status of females prevented us from investigating the calving season separately; the calving period is therefore included within the spring season.

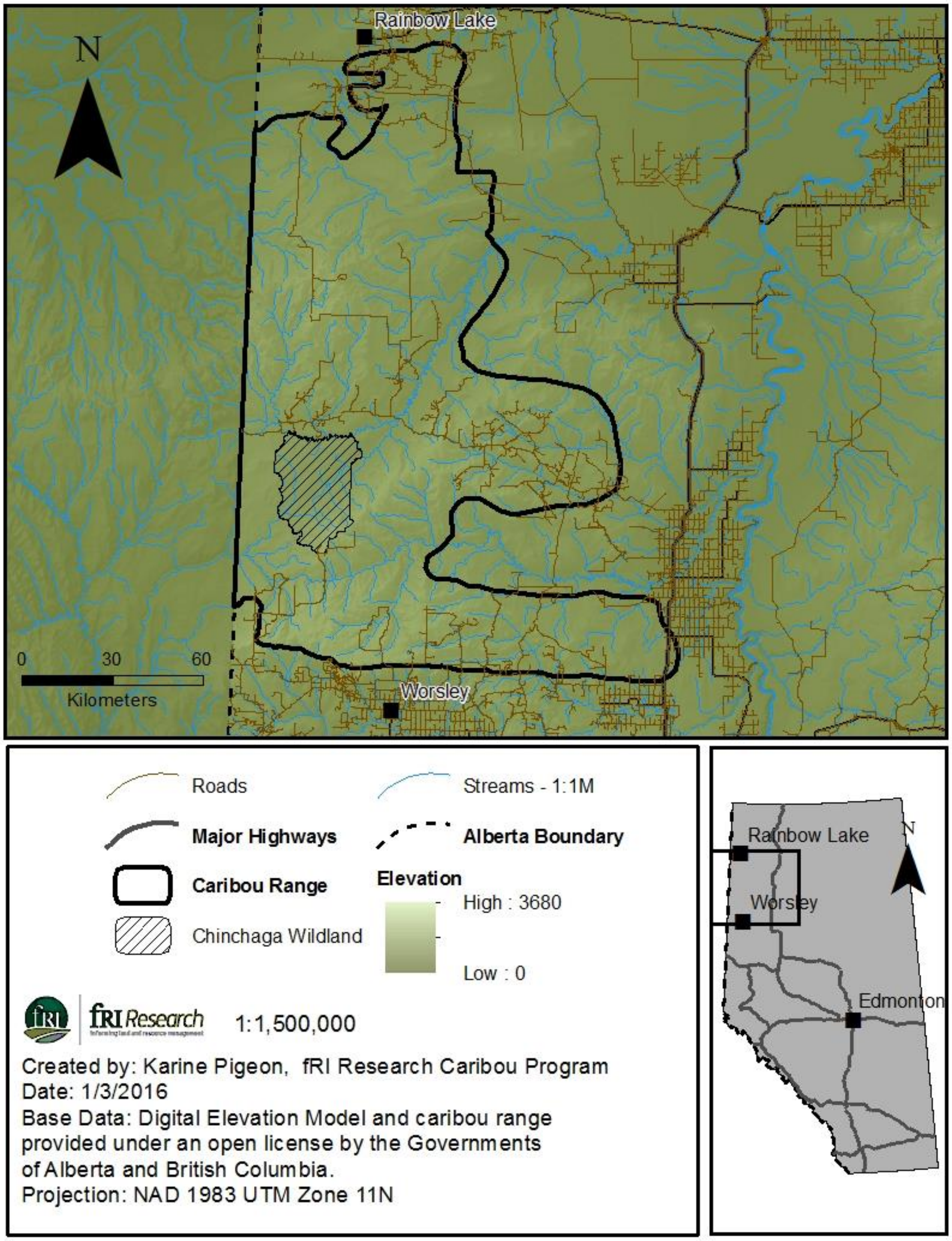


Figure 2.1. Study area used to assess 3rd order selection of caribou during spring, summer, fall, early winter, and later winter seasons in the Chinchaga range, Alberta, Canada between 2007 and 2010. The Chinchaga caribou range, major highways and roads, towns, major streams, the elevation gradient, and the Chinchaga Wildland are shown.

2.2.3 Landscape variables

We investigated resource selection of Chinchaga caribou within categories of attributes related to (1) topography, (2) landcover, and (3) anthropogenic features. We derived topographic variables including slope, aspect, elevation, topographic position index (TPI; (Jenness 2006)), and compound topographic indeed (CTI; terrain wetness; Gessler *et al.* 2000) from a 25-m digital elevation model, and derived landcover variables from a combination of Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat imagery mapped at a 30 m resolution and developed for fRI Research by Franklin *et al.* (2002a, b) and McDermid *et al.* (2009). Predominant 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 cut block data provided by Daishowa-Marubeni International Ltd. (DMI), Canadian Forest Products (Canfor), and Tolko Industries Ltd. We calculated the density of anthropogenic linear features (roads, truck trails, pipelines, and seismic lines), cut blocks < 25 years old, and all other anthropogenic features (well sites and facilities) for each year of animal data (2007 - 2010) using a 1-km radius circular moving window average in ArcGIS 10.2 (ESRI 2015). We chose a 1-km 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. < 70 m) up to 9 km (Schaefer & Mahoney 2007; DeCesare *et al.* 2012; Johnson *et al.* 2015). To represent the diminishing effect of the proximity of small and large streams on selection behaviour of caribou with large distances from streams, we used an exponential decay function ($1-\exp^{(-0.002 \times \text{distance})}$) as described by Nielsen, Cranston & Stenhouse (2009) to measure the distance to small and large streams. All covariates are further described in Table 2.1.

2.2.4 Data analysis

We used generalized linear mixed models (GLMM) to assess 3rd order selection of boreal caribou from the Chinchaga herd of Alberta, Canada using the R package ‘lme4’ (Bates *et al.* 2015). Within each individual seasonal MCP, we used Geospatial Modelling Environment (GME; Beyer 2012) within ArcGIS 10.2 (ESRI 2015) to generate 20 available locations per used location (actual GPS location from animals). We chose 20 available locations following preliminary analyses based on (Northrup *et al.* 2013) that indicated consistently stable coefficients with a ratio of at least 20 randomly generated available locations for every used location (fRI Caribou Program unpublished data). To facilitate model interpretation and reduce computing time, we generated separate models per season (Spring, Summer, Fall, Early Winter, and Late Winter), and specified an Animal ID - year random effect to account for individual-based correlation (Fieberg *et al.* 2010). We assessed correlation among explanatory covariates and chose to remove any one of 2 variables correlated at ≥ 0.5, and because moderate collinearity can be problematic when investigating ecological signals, we removed any covariates with a variance inflation factor > 3 (Zuur et al. 2010).

Our objective was to optimize model fit rather than test competing hypotheses, we therefore first assessed resource selection within each of the 3 categories of attributes mentioned above (Topography, Landcover, and Anthropogenic features) for each of the 5 seasons and used the drop1 function in the R package ‘stats’ to retain only influential covariates within each of the categories of attributes (R Core Team 2015). We used the information-theoretic approach with Akaike’s Information Criterion (AIC) within drop1 to assess variables (Burnham & Anderson 2002). Once all influential covariates were retained within each category of attributes we then fit a global model that included covariates identified within each category of attributes for each season. We followed the principle of parsimony and used drop1 a final time to remove any non-influential covariate from the global model for each season (Burnham and Anderson 2002). We standardized all continuous covariate to improve model convergence, and ranked selection as odds ratios, the ratio between the probability of an event to occur and the probability of the same event not to occur (Grimes & Schulz 2008). Here, an odds ratio > 1 refers to a landscape attribute being selected more than expected from random sampling, while an odds ratio < 1 indicates a selection below what would be expected from random sampling. We carried out all statistical analyses and data exploration in RStudio using R statistical software (Deepayan 2008; RStudio 2012; R Development Core Team 2015).

Table 2.1. Covariates used to assess 3rd order selection of boreal caribou (Rangifer tarandus) within 5 seasons (Spring, Summer, Fall, Early Winter, and Late Winter) for 18 female caribou in the Chinchaga herd Alberta, Canada between 2007 and 2010. Categories of attributes are shown in bold.

Covariate	**Description**
Topography	
Elev	Elevation based on 25-m DEM (m).
Slope	Slope (°).
Aspect	Flat (0°), leeward (Lee; NW, N, E-facing slope), or windward (Wind; SE, S, W-facing slope).
CTI	Compound topographic index.[a]
TPI	Topographic position index estimated within 1 km radii.[b]
Landcover	
Conif	30-m pixels with presence of conifer forest (> 70% conifer; 0 - 1).
Mixed	30-m pixels with presence of deciduous trees (< 70% conifer; 0 -1).
NonForest	30-m pixels with presence of shrub, herbaceous, or barren land (< 5% trees; 0 -1).
PctConif	Average percentage of conifer within 30-m pixel.
CC	Average percentage of canopy cover (%).
Dist_1m	Distance to large streams: Transformed distances (between 0 and 1) using a decay function.[c]
Anthropogenic features	
S_A1k	Density of all seismic lines within 1-km radius.
Lin1k	Density of all linear features within 1-km radius.
CB_25_1k	Density of cut blocks 0 – 25 years of age within 1-km radius.
A1k	Density of all anthropogenic features except cut blocks including well sites and facilities, and linear features within 1-km radius.
ACB1k	Density of all anthropogenic features within 1-km radius.

Using the global models for each season, we generated maps of the relative probability of selection (i.e. resource selection functions [RSFs]). These maps highlight areas used by Chinchaga caribou more than expected from a random distribution, and can therefore be used to mitigate land-use impacts on areas and landscape attributes selected by these caribou. 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 global models into > 8 categories based on natural break points in relative probability, and re-categorized the probabilities into 3 to 5 bins (season-dependent) so that selection increased significantly between each successive bin category (Nielsen *et al.* 2010). We assessed the overall variance explained by each model with conditional R^2 (R^2_c; Nakagawa & Schielzeth 2013), and also performed a k-fold cross-validation for each seasonal RSF (Boyce *et al.* 2002).

2.3 Results

Across seasons, Chinchaga caribou consistently avoided all anthropogenic features including roads, pipelines, seismic lines, young cut blocks, and oil and gas well sites and facilities (Table 2.2). Chinchaga caribou also consistently selected flat areas, depressions or plains, and shallow slopes (CTI values near zero), although CTI values were lower during winter when compared to spring, summer, and fall indicating that caribou selected slightly drier and steeper slopes during winter (Jenness 2006; Gessler et al. 2000). High elevation sites were selected more during summer, and low elevation sites more during winter (Table 2.2). Although selection for open canopy forest (low canopy cover) remained consistent across seasons, caribou selected conifer forests in all seasons except fall when they selected open habitats (Table 2.2). Finally, Chinchaga caribou selected areas near large streams less than expected from a random distribution, except during early winter (Table 2.2).

At the seasonal scale, Chinchaga caribou selected open conifer forests in high elevation, shallow slopes and plains far from anthropogenic features during spring and summer (Table 2.2, Figures 2.2 & 2.3). During fall, Chinchaga caribou selected high elevation shallow slopes and plains in open habitats near large streams and away from anthropogenic features (Table 2.2, Figure 2.4). Finally, during winter, Chinchaga caribou selected low elevation shallow slopes and plains in open conifer forests away from anthropogenic features (Table 2.2, Figures 2.5 & 2.6). In early winter, caribou also selected areas away from large streams while in late winter, they selected areas near drainages.

Using coefficients from the global models, we described the relative probability of selection for each season (i.e. an RSF; Figure 2.2 – 2.6) and binned probabilities to assess proportions of used locations and available areas, selection ratios, and risk ratios per season (Table 2.3). Overall, Chinchaga caribou were at least 18 times more likely to select areas identified with the highest RSF value (bin 3 to 5, season-dependent) than areas that were attributed to the lowest RSF value (bin 1; Table 3). During spring, Chinchaga caribou were nearly 34 times more likely to select areas identified with the highest RSF value (bin 5; Figure 2.2), while the lowest difference between selection occurred in late winter (RR bin 4; Table 2.3; Figure 2.6). The amount of variation explained by the seasonal RSFs ranged from 0.17 to 0.85 (Conditional R^2 (R^2_c): Spring R^2_c: 0.31, Summer R^2_c: 0.85, Fall R^2_c: 0.29, Early Winter R^2_c: 0.50, and Late Winter R^2_c: 0.17. k-fold validation yielded average Spearman rank correlations (R_s) ranging from 0.9 to 1.0 for used locations and from -0.02 to 0.3 for random locations: Spring R_s average: (Use: 1.0; Random: -0.02), Summer R_s average: Use: 0.9; Random: 0.3), Fall R_s average: Use: 1.0; Random: 0.002), Early Winter R_s average: Use: 1.0; Random: 0.1), and Later Winter R_s average: Use: 1.0; Random: 0.03).

Table 2.2. Standardized parameter estimates (β), standard errors (SE), z-value (Z), and P-values (P) for the global models per seasons (Spring, Summer, Fall, Early Winter, and Late Winter) used to investigate 3rd order selection of Topography, Landcover, and Anthropogenic attributes for Chinchaga boreal caribou in Alberta, Canada between 2007 and 2010. Parameters are ranked in order of effect size from selected to avoided based on odds ratio (OR): An odds ratio > 1 refers to an attribute being selected more than expected from a random distribution while an odds ratio < 1 indicates selection below what would be expected.

Parameter	**β**	***SE***	**Z**	***P***	**OR**	**Parameter**	**β**	***SE***	**Z**	***P***	**OR**
Spring						***Summer***					
CTI	0.52	0.01	44.56	<.0001	1.68	Flat1	0.62	0.02	41.16	<.0001	1.86
Elev	0.48	0.01	32.50	<.0001	1.61	Elev	0.48	0.02	20.75	<.0001	1.62
PctConif	0.35	0.01	27.35	<.0001	1.42	TPI	0.08	0.008	9.95	<.0001	1.08
Dist_1m	0.17	0.01	13.54	<.0001	1.19	A1k	-0.07	0.009	-7.79	<.0001	0.93
TPI	0.12	0.01	8.45	<.0001	1.13	Lin1k	-0.27	0.01	-25.07	<.0001	0.76
CB_25_1k	-0.04	0.02	-2.37	0.02	0.96	Canopy	-0.28	0.008	-34.55	<.0001	0.76
Lee1	-0.08	0.02	-3.70	0.0002	0.92	CB_25_1k	-4.31	0.30	-14.24	<.0001	0.01
A1k	-0.26	0.01	-19.43	<.0001	0.77						
Canopy	-0.73	0.02	-41.27	<.0001	0.48						
Fall						***Late Winter***					
CTI	0.48	0.01	35.50	<.0001	1.62	PctConif	0.31	0.01	29.50	<.0001	1.36
Dist_1m	0.34	0.02	20.00	<.0001	1.40	Flat1	0.20	0.02	10.61	<.0001	1.22
TPI	0.27	0.02	16.82	<.0001	1.31	Dist_1m	0.03	0.01	2.90	0.004	1.03
Lin1k	-0.06	0.01	-4.67	<.0001	0.94	S_A1k	-0.08	0.01	-5.98	<.0001	0.92
PctConif	-0.24	0.01	-19.40	<.0001	0.79	A1k	-0.24	0.01	-19.96	<.0001	0.79
Lee1	-0.26	0.03	-9.63	<.0001	0.77	Canopy	-0.73	0.01	-52.24	<.0001	0.48
CB_25_1k	-0.45	0.03	-13.57	<.0001	0.63						
Mixed	-1.30	0.05	-28.50	<.0001	0.27						
Early Winter											
TPI	0.40	0.01	29.66	<.0001	1.49						
Flat1	0.21	0.02	9.98	<.0001	1.23						
PctConif	0.20	0.01	17.49	<.0001	1.22						
CTI	0.08	0.01	6.50	<.0001	1.08						
Dist_1m	-0.05	0.009	-5.78	<.0001	0.95						
A1k	-0.07	0.01	-6.27	<.0001	0.93						
CB_25_1k	-0.08	0.01	-6.81	<.0001	0.92						
Lin1k	-0.18	0.01	-15.60	<.0001	0.84						
Elev	-0.87	0.02	-43.01	<.0001	0.42						
Canopy	-1.02	0.02	-59.92	<.0001	0.36						

Table 2.3. Proportion of available area (αi), proportion of used locations (μi), 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 between 2007 and 2010.

Spring

Bin	α_i	Use	μ_i	$w_{(x)}$	Selection	RR*
1	0.48	1215	0.10	0.20	Highly Avoided	1.00
2	0.25	2828	0.23	0.89	Moderately Avoided	4.41
3	0.14	3093	0.25	1.78	Slightly Selected	8.77
4	0.13	5349	0.43	3.27	Selected	16.15
5	0.00	63	0.01	6.89	Highly Selected	33.99

Summer

Bin	α_i	Use	μ_i	$w_{(x)}$	Selection	RR*
1	0.44	3220	0.15	0.33	Highly Avoided	1.00
2	0.30	6572	0.30	1.00	Neither Selected or Avoided	2.99
3	0.21	7819	0.36	1.72	Slightly Selected	5.13
4	0.03	1899	0.09	3.27	Selected	9.78
5	0.01	2158	0.10	6.66	Highly Selected	19.92

Fall

Bin	α_i	Use	μ_i	$w_{(x)}$	Selection	RR*
1	0.62	1136	0.14	0.23	Highly Avoided	1.00
2	0.17	1284	0.16	0.92	Slightly Avoided	4.00
3	0.09	1395	0.17	1.88	Slightly Selected	8.20
4	0.06	1338	0.17	3.03	Selected	13.20
5	0.06	2855	0.36	6.00	Highly Selected	26.16

Late Winter

Bin	α_i	Use	μ_i	$w_{(x)}$	Selection	RR*
1	0.50	2325	0.16	0.31	Highly Avoided	1.00
2	0.15	1458	0.10	0.63	Avoided	2.05
3	0.30	7330	0.49	1.65	Slightly Selected	5.37
4	0.05	3879	0.26	5.64	Highly Selected	18.33

Early Winter

Bin	α_i	Use	μ_i	$w_{(x)}$	Selection	RR*
1	0.82	3576	0.26	0.32	Highly Avoided	1.00
2	0.13	5207	0.38	2.96	Selected	9.26
3	0.05	4869	0.36	6.93	Highly Selected	21.70

*Risk ratio is expressed relative to bin 1.

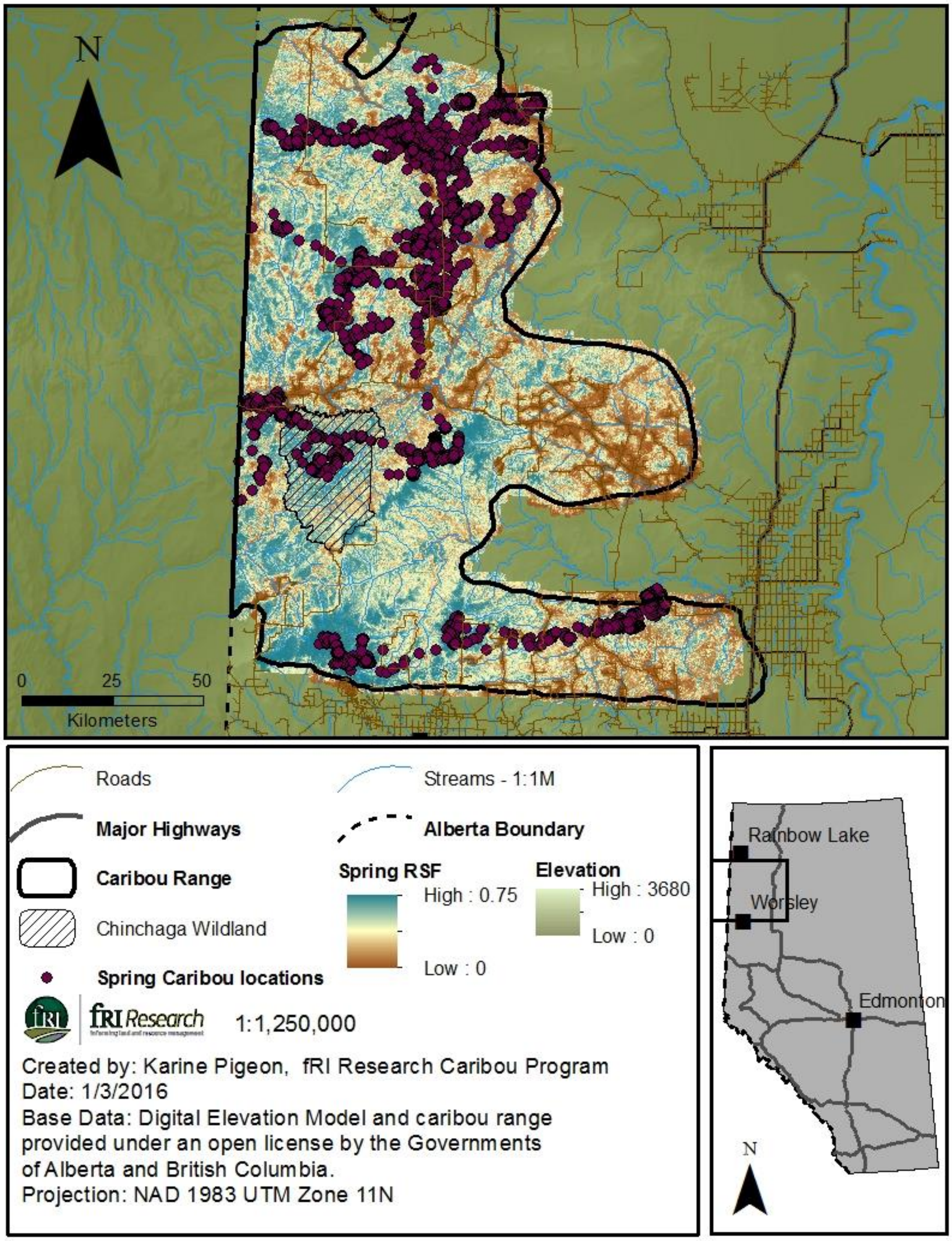
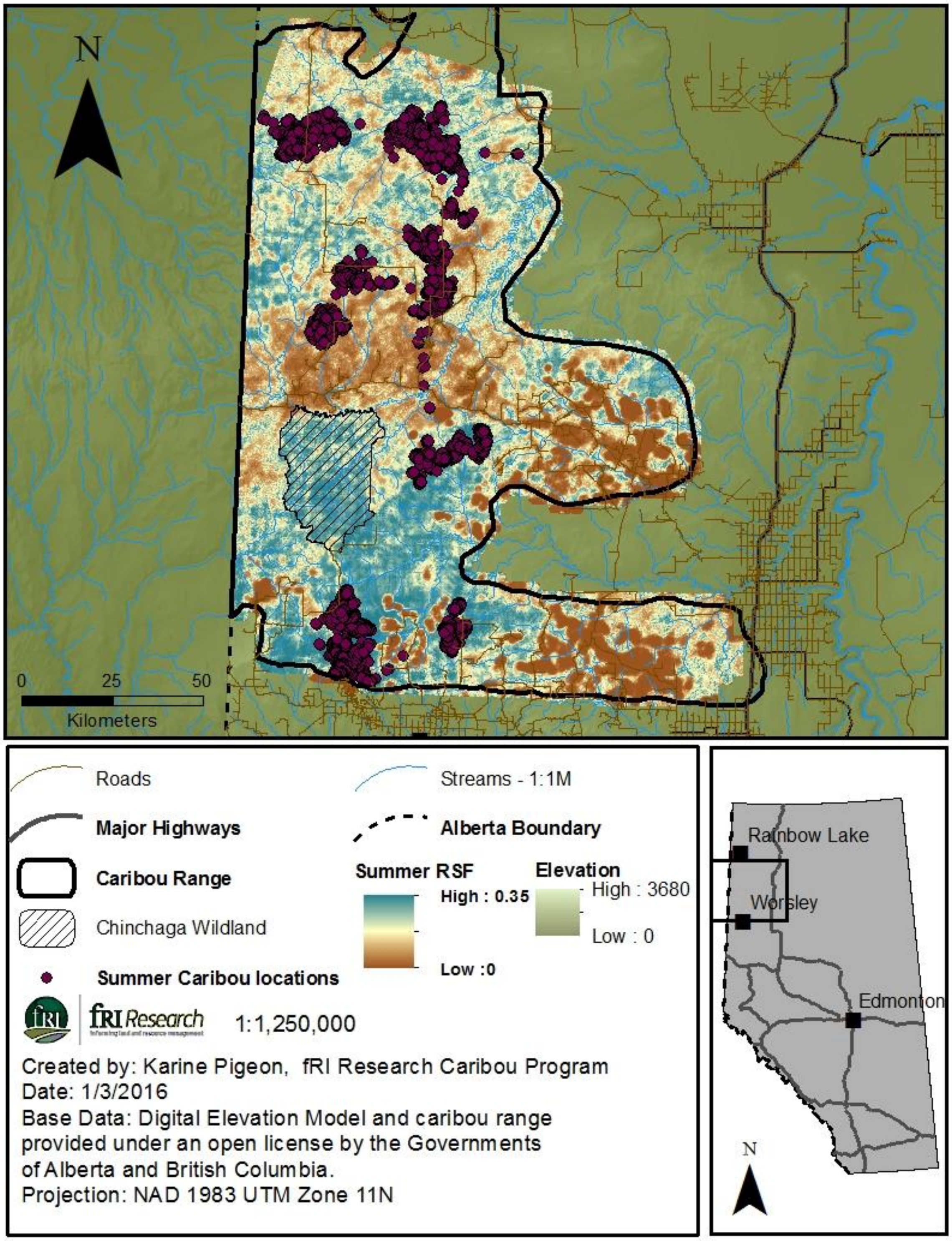
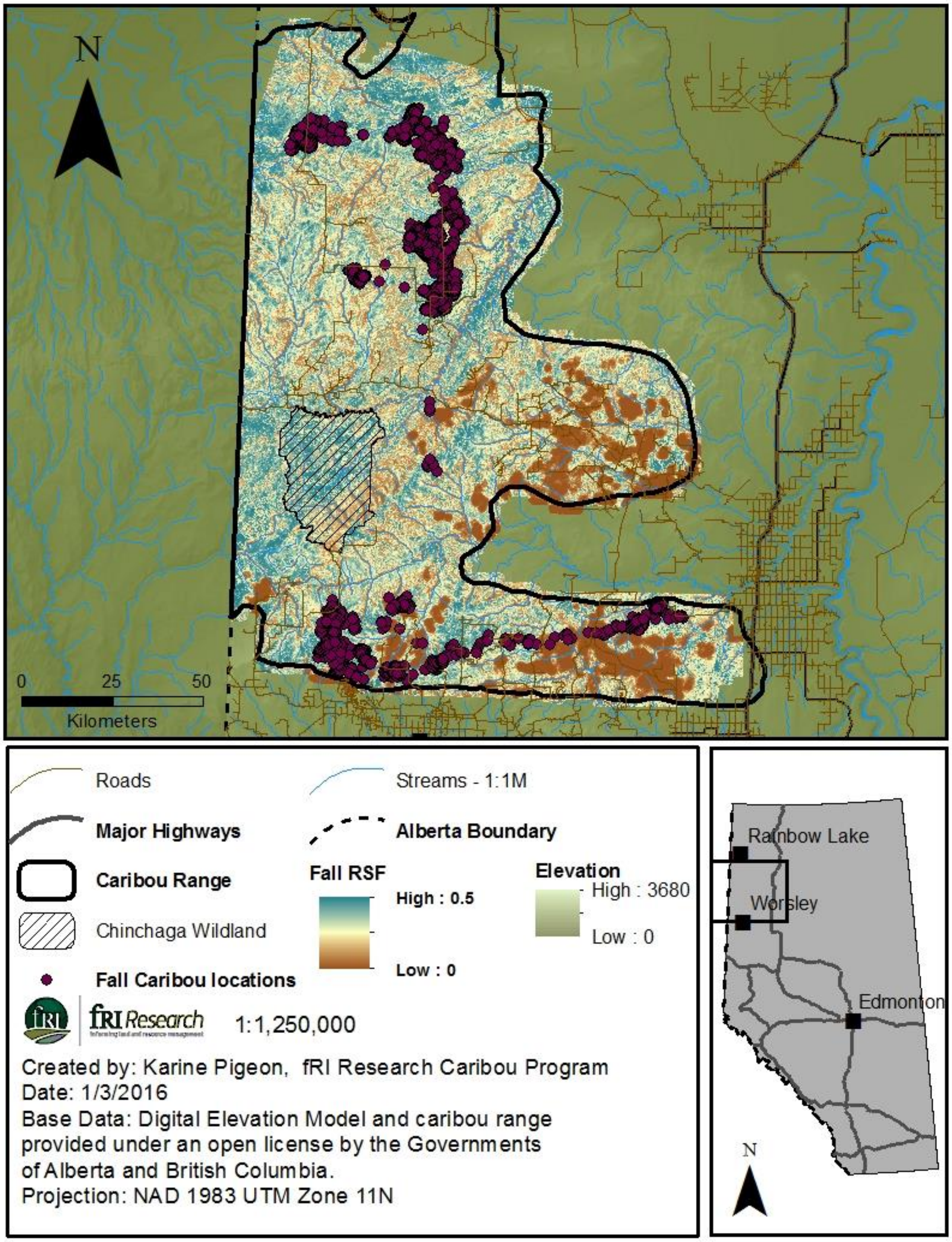


Figure 2.2. Relative probability of selection for boreal caribou during spring (8 April to 7 June) based on the global model defined from mixed logistic regression to assess 3rd order selection of 18 female caribou in the Chinchaga range, Alberta, Canada between 2007 and 2010.



Created by: Karine Pigeon, fRI Research Caribou Program
Date: 1/3/2016
Base Data: Digital Elevation Model and caribou range provided under an open license by the Governments of Alberta and British Columbia.
Projection: NAD 1983 UTM Zone 11N

Figure 2.3. Relative probability of selection for boreal caribou during summer (8 June to 24 September) based on the global model defined from mixed logistic regression to assess 3rd order selection of 18 female caribou in the Chinchaga range, Alberta, Canada between 2007 and 2010.



Created by: Karine Pigeon, fRI Research Caribou Program
Date: 1/3/2016
Base Data: Digital Elevation Model and caribou range provided under an open license by the Governments of Alberta and British Columbia.
Projection: NAD 1983 UTM Zone 11N

Figure 2.4. Relative probability of selection for boreal caribou during fall (25 September to 6 November) based on the global model defined from mixed logistic regression to assess 3rd order selection of 18 female caribou in the Chinchaga range, Alberta, Canada between 2007 and 2010.

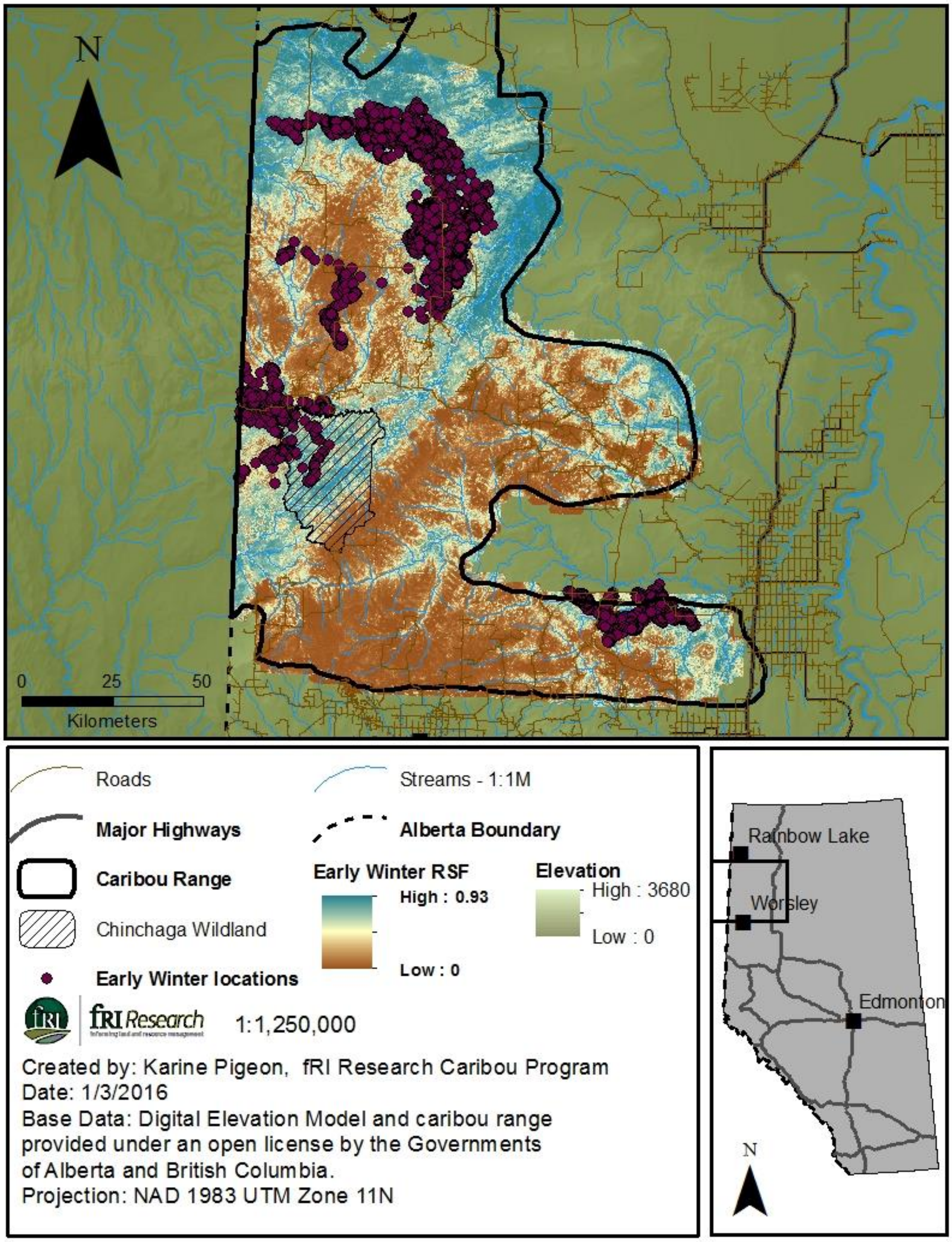


Figure 2.5. Relative probability of selection for boreal caribou during early winter (7 November to 28 January) based on the global model defined from mixed logistic regression to assess 3rd order selection of 18 female caribou in the Chinchaga range, Alberta, Canada between 2007 and 2010.

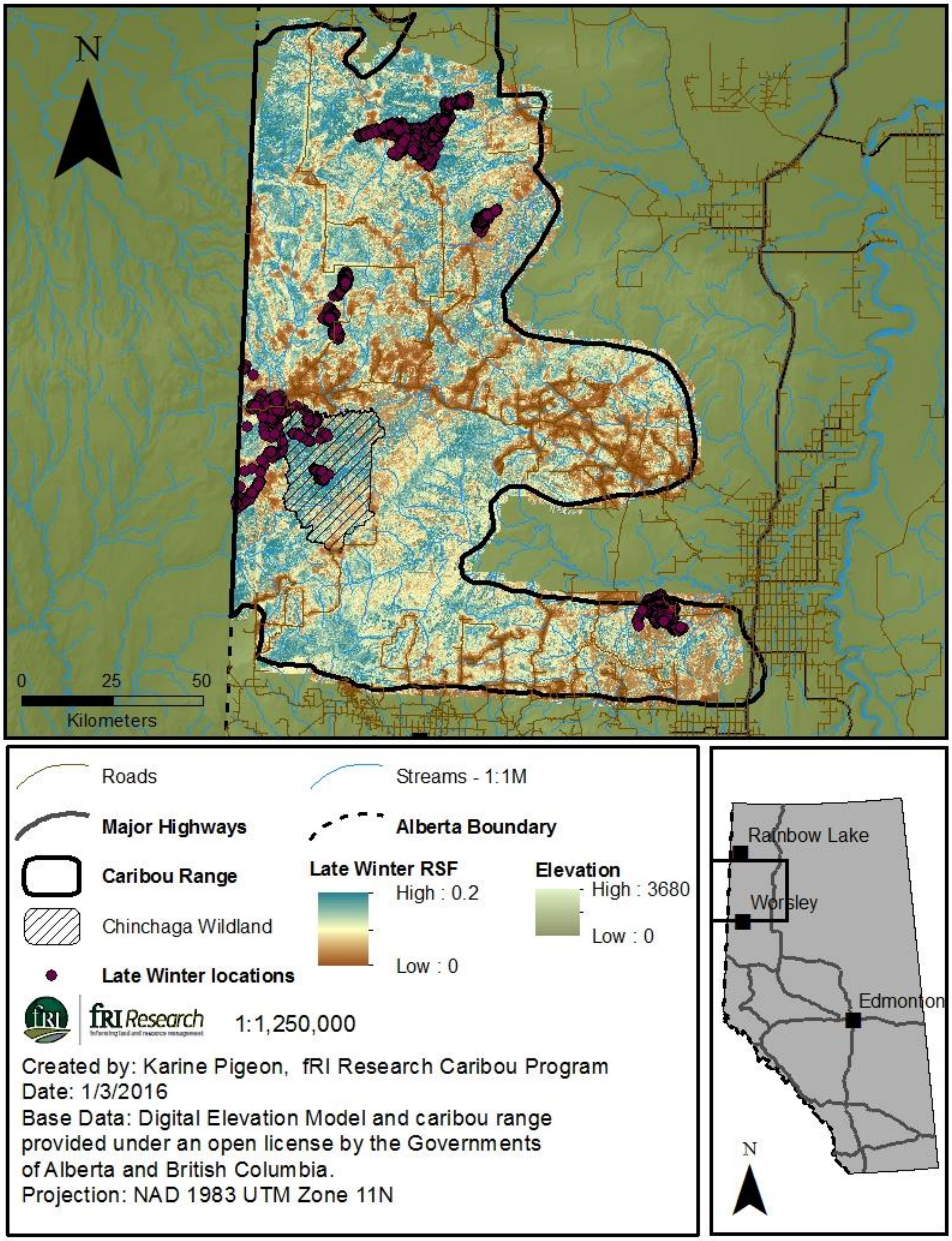


Figure 2.6. Relative probability of selection for boreal caribou during late winter (29 January to 8 April) based on the global model defined from mixed logistic regression to assess 3rd order selection of 18 female caribou in the Chinchaga range, Alberta, Canada between 2007 and 2010.

2.4 Discussion

Using 3 years of GPS location data obtained on 18 female caribou within the Chinchaga boreal caribou herd in Alberta, Canada, we demonstrated that Chinchaga boreal caribou (1) select all types of anthropogenic features less than expected from a random distribution, and (2) select high elevation open mature conifer stands on shallow slopes and plains during spring and summer, and low elevation open mature conifer stands and open habitats on shallow slopes and plains during fall and winter.

Our results are in accordance with the results of Neufeld (2006) who found that in the spring, the LSM boreal caribou herd selected areas far from young regenerating forests, linear features and well sites densities (1-km scale), and selected areas in mature forests further from large streams than expected from a random distribution. During summer, although many of Neufeld's (2006) estimates had large confidence interval, LSM and Chinchaga caribou also behaved similarly by avoiding young regenerating forests and areas with high densities of linear features and well sites. However, our results differ from Neufeld's (2006) in that the LSM caribou selected dense canopy cover rather than open conifer forests selected by Chinchaga caribou. During winter Chinchaga and LSM caribou similarly avoided anthropogenic features at the 1-km scale, and selected open conifer forests.

As was expected and observed with other boreal caribou herds (Dyer *et al.* 2001; Neufeld 2006; DeCesare *et al.* 2012; DeMars & Boutin 2013), Chinchaga caribou select areas with low densities of all types of anthropogenic disturbances. Selection for high elevation open conifer stands during spring and summer is consistent with predator-avoidance strategies (Bergerud & Page 1987). In addition, high lichen biomass has been associated with open pine dominated forests which is consistent with year-round selection for open conifer stands observed in the Chinchaga caribou herd (Szkorupa 2002; Dunford *et al.* 2006). The seasonal RSFs developed within this project can be used as tools to direct future restoration activities that would be most beneficial for caribou. These seasonal layers can also be used by land managers to develop future land-use plans that take into account spatial and temporal impacts of landscape changes on Chinchaga caribou.

3. Assessing the zone of influence of seismic lines for caribou: Does regeneration matter?

Laura Finnegan

3.1 Introduction

Functional caribou habitat is associated with a high probability of caribou occurrence and high levels of population level fecundity and survival (high calf recruitment and adult survival, and low predation risk). Fragmentation of habitat within caribou ranges reduces the extent of functional habitat available to caribou by increasing niche overlap with alternate prey (moose, deer, and elk), and correspondingly decreasing caribou survival through increased encounters with predators (James *et al.* 2004; DeCesare *et al.* 2010; Latham *et al.* 2013). For caribou, the negative effect of habitat disturbance extends beyond the physical footprint of the disturbance itself. Previous research has shown that caribou actively avoid areas between 250m and 4km from disturbed areas (Dyer *et al.* 2001; Polfus, Hebblewhite & Heinemeyer 2011; Boulanger *et al.* 2012; Johnson *et al.* 2015), and that caribou experience greater predation risk in areas with greater density of anthropogenic features/seismic lines despite an overall avoidance of these features (Latham *et al.* 2011 b, c; Whittington *et al.* 2011; DeCesare 2012). To reflect the loss of habitat surrounding disturbance features, the Boreal Caribou Recovery Strategy defines all disturbed habitat within caribou ranges as the disturbance feature itself buffered by 500m (Environment Canada 2012). However, it is unclear how regeneration of vegetation on disturbance features influences the response of caribou and their predators and at what stage of regeneration a disturbance feature might be considered restored and contribute to caribou functional habitat. Understanding how natural regeneration affects use of disturbed areas by caribou and their predators will help to identify areas where the probability of overlap between caribou and predators is highest, and may be used to prioritize areas for restoration within caribou ranges.

Seismic lines are one of the most pervasive disturbances within caribou ranges, with densities in some areas as high as 10km/km^2 (Lee & Boutin 2006; Sorensen *et al.* 2008). Seismic lines are slow to regenerate naturally due to soil removal and compaction during construction (Lee & Boutin 2006), and many seismic lines will need active restoration to return to pre-disturbance states. Understanding how caribou and their predators respond to these features at different stages of regeneration will help inform restoration priorities. However, until recently, the sheer extent of these disturbances within caribou ranges meant that broad scale analysis of animal response to regeneration stages were challenging. Now, the availability of high resolution light detection and ranging (LiDAR) data allows wide-scale mapping of habitat in three dimensional space (e.g. canopy cover and canopy height; Lefsky *et al.* 2002; Vierling et al. 2008; Martinuzzi et al. 2009). With vertical accuracies of approximately 40cm, and 1m horizontal resolution, LiDAR surfaces have sufficiently high resolution to accurately measure vegetation height along seismic lines, and LiDAR have been used to model vegetation regrowth of seismic lines in north-eastern Alberta (van Rensen *et al.* 2015). To our knowledge, no studies have assessed broad scale caribou response to regenerating seismic lines.

We used caribou global positioning satellite (GPS) data and LiDAR-based measurements of vegetation height along seismic lines to quantify natural regeneration of seismic lines, and to assess caribou habitat selection relative to distance to seismic lines, and to their natural regeneration. Our study took place within the range of the Chinchaga boreal caribou herd in north-west Alberta. The Chinchaga caribou range extends into north-east British Columbia and falls within the mixedwood natural sub-region (Natural Regions Committee 2006). Recent research has documented declines in this herd of 60% over the past decade (Hervieux *et al.* 2013).

3.2 Methods

3.2.1 Study area and animal location data

The study area and caribou location data are described in Chapter 2.

3.2.2 Landscape variables

To assess habitat selection relative to seismic lines distances in the Chinchaga caribou range, we investigated resource selection of caribou for three categories of attributes related to (1) topography, (2) landcover, and (3) anthropogenic features.

3.2.2.1 LiDAR-based disturbance data

We used LiDAR data collected between 2003 and 2008 by the Government of Alberta (GoA) to attribute vegetation height to 60,648km of seismic lines across our study area (Figure 3.1). Prior to extracting vegetation height, we subset the Chinchaga caribou range (17,517km^2) seismic line layers into 29 individual 28km x 28km tiles (780km^2, corresponding to 1:50,000 NTS map sheets) for data processing. The raw LiDAR signal returns (i.e. the Point Cloud) were resolved into two sets of points: Bare Earth, representing ground signals, and Full Feature, representing returns from the forest canopy. These point datasets were then converted to ASCII text files of x, y, and z coordinates, and were subsequently converted used to create ESRI grid surfaces for a Digital Elevation Model (DEM) and a Digital Surface Model (DSM) with 1m horizontal resolution. A canopy height surface was derived by subtracting the DEM from the DSM.

We obtained seismic line features (polyline) from GoA base features. We used an automated GIS process developed by Jerome Cranston, Arctos Ecological Consultants (cranston@ualberta.ca) to derive vegetation metrics for seismic lines from our LiDAR-based surfaces. To obtain accurate vegetation height data, this GIS process clips the canopy height surface to within 20m of the original seismic line feature. The automated process then creates a least-cost path raster (using vegetation height as the ‘cost’) between the start point (source) and endpoint (destination) of the line feature, and then converts this path to a line feature. We divided the resulting line features into segments of approximately 100m and we derived mean vegetation height along the least-cost path by overlaying the adjusted line feature with the canopy height surface.

We then calculated densities of seismic lines for three categories of vegetation heights using a moving window average at three separate. We chose a 70-m minimum radius based on DeCesare et al. (2012) who found that caribou responded to anthropogenic features at this scale. In addition, we used 500-m and 1-km radii because we wanted to validate the 500-m zone of influence previously defined (Dyer *et al.* 2001; Polfus *et al.* 2011), and to evaluate the usefulness of a 1-km radius as a middle ground density value because previous research has shown that anthropogenic features can influence caribou and wolf behaviour from very small scales (i.e. < 70 m) up to 9 km (Schaefer and Mahoney 2007; Johnson et al 2015). We partitioned vegetation heights into three categories based on quantiles across the study area (0-0.15m, 0.16-0.87m, 0.84-19.23m). Following provincial definitions of successful regeneration, we also partitioned seismic lines into those with vegetation heights > 3m and those with vegetation heights < 3m (Alberta Environment and Sustainable Development 2012). Details of covariates derived from these seismic lines are described in Table 3.1.

3.2.2.2 Additional anthropogenic disturbance data

We used data provided by the GoA, Forest Management Agreement holders and the Alberta Energy Regulator to map the density of additional disturbance features within our study area. We mapped well sites (buffered by 100m), pipelines, and roads using GoA base features and also calculated densities of these disturbances again using moving window averages with radii of 70m, 500m and 1000m. To provide a temporal match between caribou locations and disturbance features, we assigned a built-before-year to each disturbance feature by examining annual SPOT imagery. We extracted cut block location and cut block age from AVI data provided by Daishowa-Marubeni International Ltd (DMI), Canadian Forest Products (Canfor), and Tolko Industries Ltd. To reflect potential differences in selection patterns of animals for cut blocks in response to vegetation height, we further partitioned cut blocks into those < 25 and > 25 years old. Details of these covariates are in Table 3.1.

3.2.2.3 Terrain and habitat covariates

We used vegetation cover derived from Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat imagery mapped at a 30m x 30m resolution (McDermid *et al.* 2009) to determine the landcover that intersected each GPS location and each 100m seismic line segment. When seismic line segments fell within two or more landcover types, we used the habitat type that intersected the longest length of the seismic line section. For analysis, we grouped landcover into three categories (Mixed, Conifer, Non-forest) and recoded them into binary variables for logistic regression (Table 1). We also used Landsat imagery to extract values of canopy cover. We used a 30m x 30m resolution digital elevation model to extract values of elevation (elev), terrain wetness (compound topographic index, CTI; Gessler *et al.* 2000), and terrain ruggedness (topographic position index, TPI; Jenness 2006) for each GPS location (Table 3.1). We also used the mean CTI intersecting each 100m seismic line segment as an index of seismic line wetness. We extracted the landcover and topographic variables that intersected with seismic line segments and animal locations using Geospatial Modeling Environment (GME; Beyer 2012) and ArcGIS 10.2.2 (ESRI 2015).

3.2.3 Data analysis

We screened data for non-linear relationships, collinearity, and correlations following methods outlined by Zuur *et al.* (2010). We carried out data exploration and statistical analyses within R and RStudio (Deepayan 2008; RStudio 2012; R Development Core Team 2015).

Previous analysis found that animal response to linear features was best described at the individual scale (Neufeld 2006; DeCesare *et al.* 2012). We therefore carried out resource selection function (RSF) at the individual or 3rd order scale. We followed a ‘design III’ use-availability approach (Manly *et al.* 2002) and treated the individual animal as our sampling unit. We used two separate samples of available locations to investigate the effect of seismic lines on caribou habitat selection at the home range scale and within exponentially increasing distance buffers from seismic lines. First, to assess the effect of seismic lines on caribou habitat selection we drew available locations at a ratio of 20 available locations for every used GPS location within a minimum convex polygon (MCP) created for each animal/season/year combination. Second, to assess the effect of seismic line attributes (vegetation height and soil wetness) on caribou habitat selection, we created buffers of exponential distances around seismic lines (0-62.5m, 62.5-125m, 125-250m, 250- 500m, 500-1000m, 1000-2000m and 2000-4000m), and then drew availability at a ratio of 20:1, for each animal/season/year within each buffer. We used GME (Beyer 2012) and ArcGIS 10.2.2 (ESRI 2015) to generate available points.

We used generalized linear mixed models (GLMM) to determine relative caribou habitat selection in relation to distance to seismic lines and attributes of seismic lines, and to additional disturbance and natural covariates (see Table 3.1) (Gillies *et al.* 2006; Bolker *et al.* 2009). We used the R package ‘lme4’ (Bates *et al.* 2015) to construct models for each season and included animal-year as a random effect in all models. We standardized continuous variables to improve model convergence. We visualised results using the ‘ggplot2’ package (Wickham 2009).

Table 3.1. Covariates used to describe 3rd order selection of caribou within the range of the boreal Chinchaga herd in north-west Alberta. The covariates included in the analysis investigating the effect of seismic line distance within home-ranges (MCP) and the effect of seismic line attributes (Buffers) are marked by an x in their respective columns (MCP and Buffers).

Covariate	Description and units	MCP	Buffers
Null model			
Seis	Distance to nearest seismic line (m)	x	
Veght	Mean vegetation height of the nearest seismic line segment (m)		x
CTI_line	Mean CTI intersecting the nearest seismic line segment (unitless)[a]		x
Anthropogenic features			
S_A70 S_A500 S_A1k	Density of all seismic lines within a 70m, 500m and 1km radius (km^2/km^2)	x	x
S_LV70 S_LV500 S_LV1k	Density of seismic lines with low vegetation height (<0.15m) within a 70m, 500m, and 1km radius (km^2/km^2)	x	x
S_MV70 S_MV500 S_MV1k	Density of seismic lines with moderate vegetation height (0.15 – 0.87m) within a 70m, 500m, and 1km radius (km/km^2)	x	x
S_HV70 S_HV500 S_HV1k	Density of seismic lines with high vegetation height (>0.87) seismic lines within a 70m, 500m, and 1km radius (km^2/km^2)	x	x
S_L3m70 S_L3m500 S_L3m1k	Density of seismic lines with vegetation height <3m within a 70m, 500m, and 1km radius (km^2/km^2)	x	x
S_G3m70 S_G3m500 S_G3m1k	Density of seismic lines with vegetation height >3m within a 70m, 500m, and 1km radius (km^2/km^2)	x	x
Lin70 Lin500 Lin1k	Density of linear features (roads, pipelines, seismic lines) within a 70m, 500m, and 1km radius (km^2/km^2)	x	x
A70 A500 A1k	Density of linear features (roads, pipelines, seismic lines) and well sites within a 70m, 500m, and 1km radius (km/km^2)	x	x
CB70 CB500 CB1k	Density of cut blocks < 25 years old within a 70m, 500m, and 1km radius (km^2/km^2)	x	x
CB_25_70 CB_25_500 CB_25_1k	Density of cut blocks > 25 years old within a 70m, 500m, and 1km radius (km/km^2)	x	x
ACB70 ACB500 ACB1k	Density of linear features (roads, pipelines, seismic lines), well sites and cut blocks within a 70m, 500m, and 1km radius (km^2/km^2)	x	x

Table 3.1. continued

Covariate	Description and units	MCP	Buffers
Landcover			
CC	Mean canopy closure (%) of 30m x 30 pixel	x	x
Dist_W1M	Distance to large streams	x	x
Dist_W20k	Distance to small streams	x	x
fConif	30-m pixels with presence of conifer forest (> 70% conifer; 0 - 1)	x	x
fMixed	30-m pixels with presence of deciduous trees (< 70% conifer; 0 -1).	x	x
fNonforest	30-m pixels with presence of shrub, herbaceous, or barren land (< 5% trees; 0 -1)	x	x
Topographic			
Elev	Elevation of the 30m x 30m pixel	x	x
CTI	Compound topographic index, index of soil wetness[a]	x	x
TPI	Topographic position index, index of terrain ruggedness[b]	x	x
Random effect			
Animal_ID_YR	Individual animal ID GPS locations partitioned by year of collection	x	x
LandCovDiff	Difference in landcover type between GPS location and nearest seismic line segment (categorical variable accounting for direction of vegetation height difference)		x

[a] A wetness index that considers the slope and upstream contributing area (Gessler et al. 2000).

[b] Jenness 2006

3.2.3.1 Habitat selection relative to seismic line distance

Before constructing these models, we assessed whether interaction terms were required between distance to seismic lines and any of the other covariates using generalized additive models (GAM). For each scale of anthropogenic feature density (i.e. 70-m, 500-m, and 1-km scale), we first selected the most appropriate density scale by comparing the Akaike's Information Criterion (AIC) values of univariate models for each variable. We only retained one density scale per variable type to avoid collinearity issues and over-parameterization. If AIC could not distinguish between scales of anthropogenic feature density, we used values extracted at the 500m density as a conservative measurement of the effect of anthropogenic disturbances upon caribou (Dyer *et al.* 2001b). We used a two-stage approach to assess the effect of seismic lines on caribou habitat selection. First, we built three candidate sets of models containing all habitat, terrain, and anthropogenic covariates (see Table 3.1), and used an information-theoretic approach with AIC and the 'drop1' function to identify the most parsimonious combination of variables from each of the candidate model sets. If GAM suggested that interactions were required for more than one of the covariates within any of the three candidate model sets, we ran separate models including each of the interactions in turn, and chose the interaction to include in the candidate model using AIC values as described previously. This approach ensured that no more than three interaction terms were included in our global model. Second, we combined the remaining variables from each of the habitat, terrain, and anthropogenic models into a global model, and again ran the 'drop1' function to remove uninformative variables.

As we were interested in comparing whether the proximity to seismic lines affected caribou habitat selection across different seasons, we estimated unstandardized coefficients for each season by dividing standardized coefficients by the standard deviation of the original variables. We report values as unstandardized β coefficients and standard errors, unstandardized odds ratios and standard errors (expβ), and as the relative probability of selection [$p = \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 .... \beta_n x_n)/(1+\exp(\beta_0 + \beta_1 x_1 +$

$\beta_2 x_2 .... \beta_n x_n$)]. Odds ratios are the ratio between the probability of an event to occur and the probability of the same event not to occur (Grimes & Schulz 2008). Here, an odds ratio > 1 refers to a landscape attribute being selected more than expected from random sampling while an odds ratio < 1 indicates a selection below what would be expected from random sampling.

3.2.3.2 Effect of seismic line attributes – vegetation height and soil wetness

We used the global models identified during the previous stage of analysis as our base model to assess the effect of seismic line attributes on caribou habitat selection within each season. We built models within each buffer for each season, and again included animal-year as a random effect. Finally, because the difference in vegetation height between where an animal is located (GPS location) and the nearest seismic line segment likely influences the strength of selection for a seismic line (i.e. potential travel corridors), we generated a random effect variable derived from landcover type differences between the GPS location of the animal and the nearest seismic line segment. This variable (LandCovDiff; Table 3.1) accounts for the vegetation height difference and the direction of vegetation height difference between GPS locations and nearest seismic lines segments (i.e. is the vegetation height on the nearest seismic line segment likely equal, higher, or lower than where the animal is located). We did not include this variable as a fixed effect in the models because we were not interested in quantifying the effect of landcover and vegetation height differences but rather, we were interested in accounting for the effect of this potential difference on patterns of selection.

Because we applied these models within specified buffer distances from seismic lines, we removed the seismic line distance covariate from the global model. In addition to the covariates identified from the final model of the previous stage of analysis (MCP; *Effects of seismic line* section), we included covariates describing the attributes of seismic lines within our models. These covariates described the vegetation height of seismic lines (Veght) and wetness of seismic lines (CTI_line; Table 3.1). We also included covariates that were removed earlier in analysis because of correlation or collinearity with the seismic line distance covariate.

For each model within buffers and seasons, we calculated standardized coefficients and their associated standard errors for each covariate. We then converted standardized values to their original state using the method described previously and report values as unstandardized β coefficients and standard errors, unstandardized odds ratios, and standard errors (exp(β)), and the relative probability of selection ($p = \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 .... \beta_n x_n)/(1+\exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 .... \beta_n x_n))$).

3.3 Results

3.3.1 LiDAR-derived vegetation height along seismic lines

The average vegetation height along seismic lines was 0.97 m (range: 0 - 19.23m, standard deviation: 1.42m; Figure 3.1). Of 60,648km of seismic lines identified in the study area, 69.55% had vegetation heights of less than 1m. Quantile intervals (33%, 66%, 100%) for vegetation height on seismic lines were 0 - 0.15m; 0.16 - 0.87m; and 0.84 - 19.23m.

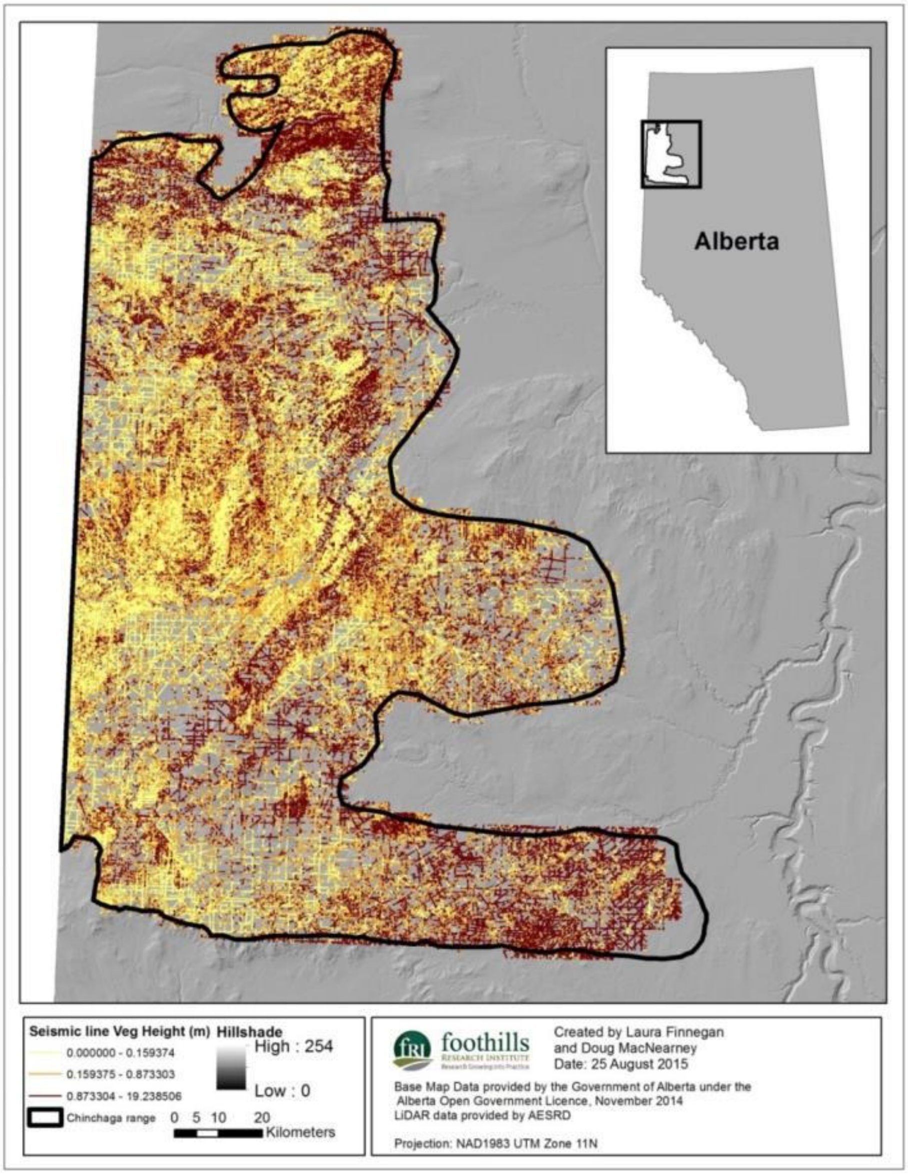


Figure 3.1. Seismic lines detected by LiDAR between 2003 and 2008 and displayed by vegetation height quantiles in the Chinchaga caribou range.

3.3.2. Habitat selection relative to seismic line distance

With the exception of early winter (seasons are defined in Chapter 2), caribou were consistently further from seismic lines when compared to a random distribution (mean odds ratio 1.004; Table 3.2). During spring, summer, and fall, caribou were further from seismic lines than expected from a random distribution when they were within areas with high densities of linear features (Figure 3.2 and 3.3), and when they were within areas with high densities of low vegetation-height seismic lines (Figure 3.4). During early winter, caribou were closer to seismic lines when compared to a random distribution, and were closer to seismic lines when they were within areas with low densities of linear features (Table 3.2; Figure 3.5). During late winter, caribou were further from seismic lines when compared to a random distribution but closer to seismic lines when they were within areas with low densities of linear features (Table 3.2).

Table 3.2. Unstandardized coefficients (β) and standard errors (SE) describing Chinchaga caribou habitat selection during spring, summer, fall, early, and late winter. Covariates are described in Table 3.1.

	Spring		Summer		Fall		Ewin		Lwin	
	β	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**
Intercept	-5.3388	0.1665	-9.1035	-0.2535	-3.1860	-0.5390	6.9053	-0.4203	7.4900	-0.9170
Seis	0.0016	0.0002	0.0016	0.0001	0.0010	0.0001	-0.0016	0.0001	0.0004	0.0001
S_LV500	-	-	-	-	7.0041	0.3579	-	-	-	-
S_MV70	-	-	-	-	-	-	-0.0121	0.0055	-	-
S_MV500	-	-	-	-	-15.5656	0.6415	-	-	-	
S_HV70	-	-	-	-	-1.2089	0.2966	-	-	-	-
S_HV500	-	-	-	-	-	-	-9.5081	0.5878	-4.9915	0.4857
S_HV1k	-14.6483	0.7336	-39.5554	0.8751	-	-	-	-	-	-
DST_W1M	-	-	0.0001	0.000008	0.0001	0.000001	-0.0001	0.000008	0.0002	0.000009
DST_W20k	0.0001	0.0000	0.0001	0.00002	0.0006	0.00002	-0.0001	0.00002	0.0001	0.00002
CC	-0.0194	0.0007	-0.0068	0.0006	-0.0314	0.0009	-0.0380	0.0007	-0.0282	0.0007
ELEV	-	-	0.0205	0.0008	-0.0034	0.0004	-0.0157	0.0004	0.0028	0.0007
TPI	0.0430	0.0034	0.0319	0.0033	0.0902	0.0052	0.1045	0.0036	0.0184	0.0038
CTI	0.3214	0.0114	0.3771	0.0091	0.1518	0.0156	0.0756	0.0105	-0.0467	0.0115
Lin500	0.3007	0.2500	-	-	-	-	-	-	2.2463	0.3540
Lin1k	-	-	-0.5857	0.2662	-	-	-3.4841	0.2801	-	-
ACB70	-	-	-	-	1.9092	0.1211	2.5354	0.0827	-	-
ACB500	-	-	-	-	-	-	-	-	-4.7619	0.2593
ACB1k	-17.0412	0.8775	-9.8113	0.7817	-	-	-	-	-	-
S_G3m500	-13.5604	1.1544	-12.8375	1.2441	-	-	-	-	-	-
S_G3m1k	-	-	-	-	-42.3648	2.6264	-4.9977	1.8667	-	-
Distance HWY35	-	-	-	-	-	-	0.0216	0.0013	-0.1204	0.0042
Seis*Lin500	0.0111	0.0014	-	-	-	-	-	-	-0.0077	0.0017
Seis*Lin1k	-	-	0.0113	0.0016	-	-	-0.0221	0.0019	-	-
Seis*S_LV500	-	-	-	-	0.0218	0.0025	-	-	-	-
Seis*ELEV	-	-	-	-	-	-	-	-	0.00001	0.000002

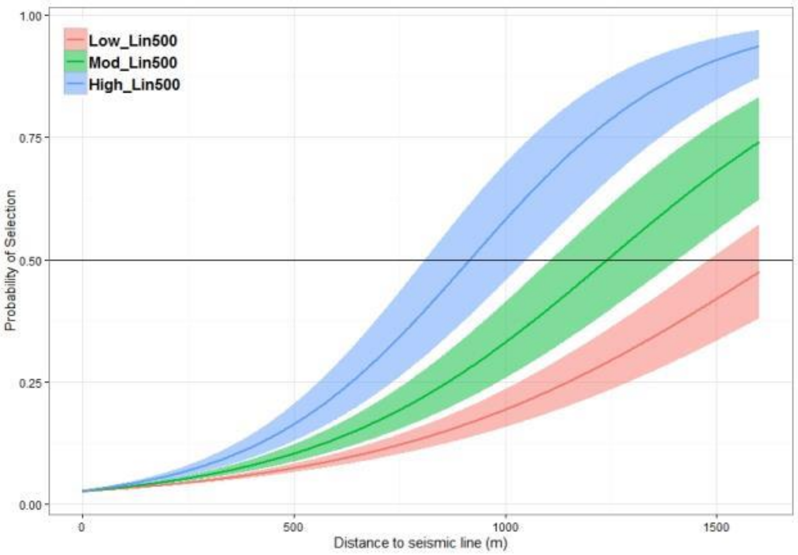


Figure 3.2. Relative probability of selection (± SE) of Chinchaga boreal caribou during spring in relation to the distance to the nearest seismic line in areas with low, moderate, and high densities of linear features (calculated using a 500m radius, see Table 3.1 for descriptions of covariates). Low, moderate, and high values were defined using the mean of the 0-33%, 33-66% and 66-100% quantiles of Lin500, all other covariates within the model were held at their mean for prediction.

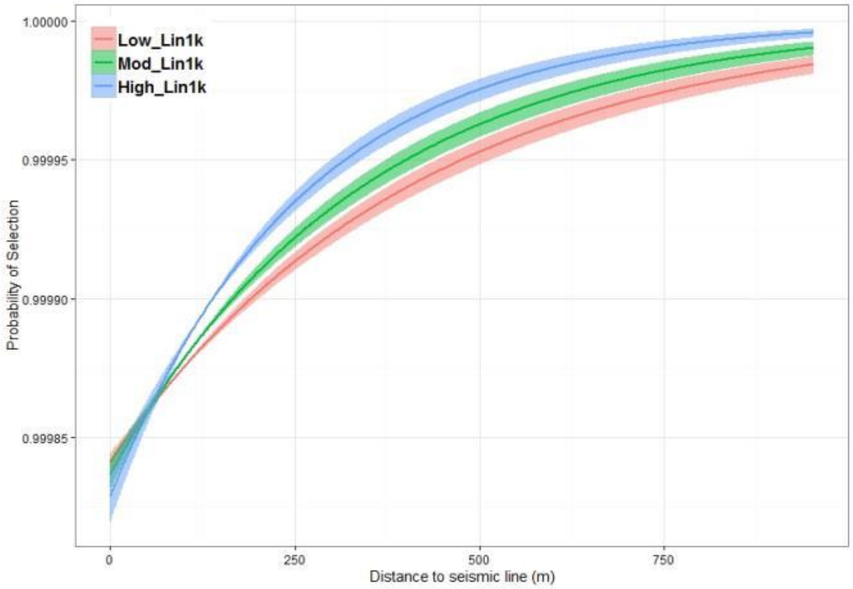


Figure 3.3. Relative probability of selection (± SE) of Chinchaga boreal caribou during summer in relation to the distance to the nearest seismic line in areas with low, moderate and high densities of linear features (calculated using a 1km radius, see Table 3.1 for descriptions of covariates). Low, moderate and high values were defined using the mean of the 0-33%, 33-66% and 66-100% quantiles of Lin1k, all other covariates within the model were held at their mean for prediction.

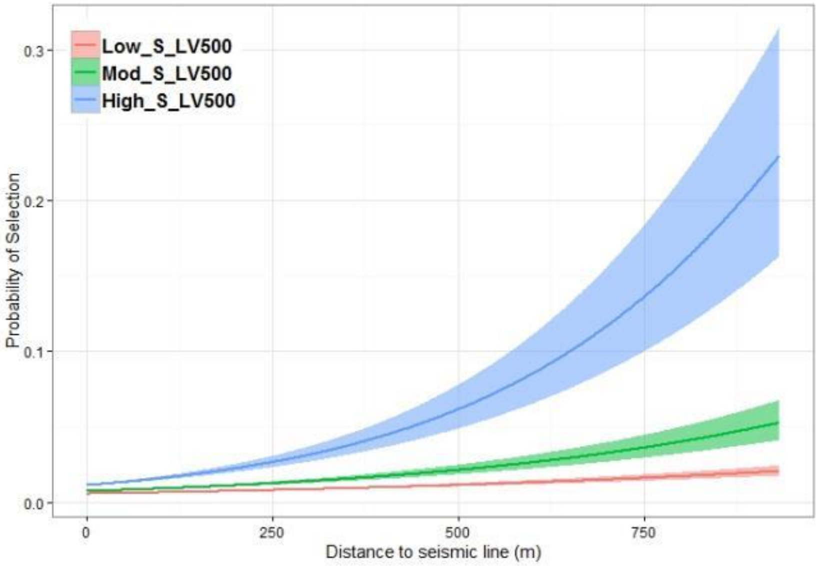


Figure 3.4. Relative probability of selection (± SE) of Chinchaga boreal caribou during fall in relation to the distance to the nearest seismic line in areas with low, moderate and high densities of low vegetation height seismic lines (calculated using a 500m radius, see Table 3.1 for descriptions of covariates). Low, moderate and high values were defined using the mean of the 0-33%, 33-66% and 66-100% quantiles of S_LV500, all other covariates within the model were held at their mean for prediction.

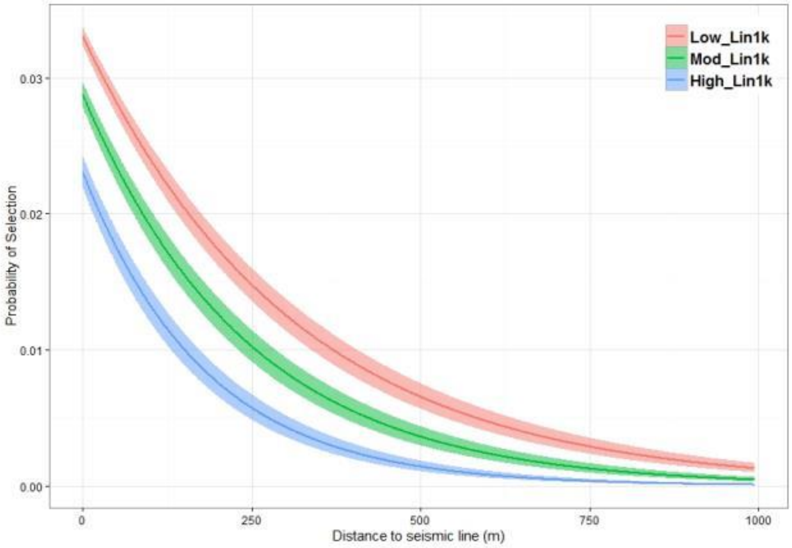


Figure 3.5. Relative probability of selection (± SE) of Chinchaga boreal caribou during early winter in relation to the distance to the nearest seismic line in areas with low, moderate and high densities of linear features (calculated using a 1km radius, see Table 3.1 for covariate description). Low, moderate and high values were defined using the mean of the 0-33%, 33-66% and 66-100% quantiles of Lin1k, all other covariates within the model were held at their mean for prediction.

3.3.3. Effect of seismic line attributes – regeneration height and soil wetness

Separating the 72091 caribou locations obtained from the Chinchaga caribou range according to their distance to seismic lines yielded 21977 locations within 62.5m of seismic lines, 16318 locations between 62.5m and 125m from seismic lines, 19340 locations between 125m and 250m from seismic lines, 12123 locations between 250m and 500m from seismic lines, 2287 locations between 500m and 1000m from seismic lines, and 46 locations greater than 1000m from seismic lines. We did not investigate selection patterns at distances greater than 1000m from seismic lines.

Caribou response to regeneration varied with respect to regeneration height of the nearest seismic line, wetness of the nearest seismic line, and proximity to the nearest seismic line. During spring, summer, and late winter, when caribou were within 62.5m of seismic lines, the probability of selection increased with increasing vegetation height. For every 1m increase in vegetation height, the odds of caribou occurrence within 62.5m of a seismic line increased 1.07 (1.03-1.12) times during spring, 1.31 (1.26-1.36) times during summer, and 1.07 (1.04-1.10) times during late winter (Table 3.3, Figure 3.6-3.11). During fall and early winter, the probability of selection decreased with increased vegetation height. For every 1m increase in vegetation height of the nearest seismic line the odds of caribou occurrence within 62.5m of that seismic line increasing by a factor of 0.8 (0.77-0.86) during fall, and 0.91 (0.87-0.95) during early winter (Table 3.3, Figure 3.6 - 3.11).

When caribou were between 62.5m and 125m from seismic lines, the probability of selection increased with increasing vegetation height during summer, fall, and late winter, but was not related to vegetation height during spring and early winter (Table 3.3, Figure 3.6-3.11). For every 1m increase in vegetation height, the odds of caribou occurrence increased 1.15 (1.1-1.2) times during summer, 1.14 (1.10-1.19) times during fall, and 1.06 (1.03-1.09) times during late winter.

When caribou were between 125m and 250m from seismic lines, the probability of selection increased with increasing vegetation height during spring and late winter, and decreased with increasing vegetation height during fall and early winter. There was no significant effect of vegetation height on the probability of selection during summer (Table 3.3, Figure 3.6-3.11). For every 1m increase in vegetation height, the odds of caribou occurrence increased 1.13 (1.102-1.17) times during spring, 1.06 (1.03-1.09) times during late winter, 0.91 (0.86-0.95) times during fall, and 0.89 (0.86-0.93) times during early winter.

When caribou were between 250m and 500m from seismic lines, the probability of selection increased with increasing vegetation height during early and late winter, and decreased with increasing vegetation height during spring and fall (Table 3.3, Figure 3.6-3.11). Again, there was no significant effect of vegetation height on the probability of selection during summer. For every 1m increase in vegetation height, the odds of caribou occurrence increased 1.04 (1.01-1.09) times during early winter and 1.15 (1.12-1.19) times during late winter. For every 1m increase in vegetation height, the odds of caribou occurrence increased 0.92 (0.88-0.95) times during spring and 0.89 (0.84-0.95) times during fall.

Finally, when caribou were between 500m and 1000m from seismic lines, the probability of selection decreased with increasing vegetation height during spring, early winter, and late winter, and increased with increasing vegetation height during summer (Table 3.3, Figure 3.6-3.11). There was no effect of vegetation height on the probability of selection during fall. For every 1m increase in vegetation height, the odds of caribou occurrence increased 0.93 (0.90-0.97) times during spring, 0.78 (0.68-0.90) times during early winter, and 0.72 (0.60-0.88) times during late winter. For every 1m increase in vegetation height the odds of caribou occurrence increased 1.23 (1.12-1.36) times during summer.

Table 3.3. Unstandardized coefficients (β) and standard errors (SE) describing Chinchaga caribou habitat selection during spring, summer, fall, early, and late winter within 0-62.5m, 62.5-125m, 125-250m, 250-500m and 500-1000m from seismic lines. Covariates are described in Table 3.1.

	0-62.5m		**62.5-125m**		**125-250m**		**250-500m**		**500-1000m**	
Spring	β	SE	β	SE	β	SE	β	SE	B	SE
Intercept	-5.8622	-1.1956	-5.2629	-0.6291	-8.4653	-2.7541	-9.4953	-0.2588	-10.0758	-0.2046
Veght	0.0712	0.0384	0.0259	0.0429	0.1286	0.0314	-0.0747	0.0491	-0.0629	0.0413
CTI_Line	0.2677	0.0826	0.1166	0.0496	0.3019	0.0301	0.3045	0.0315	0.3100	0.0321
DST W20k	0.0004	0.00005	0.0002	0.00005	0.00001	0.00005	-0.0002	0.0001	-0.0002	0.00005
CC	-0.0303	0.0022	-0.0266	0.0024	-0.0171	0.0022	-0.0182	0.0025	-0.0180	0.0025
TPI	0.0439	0.0068	0.0614	0.0070	0.0270	0.0068	0.0578	0.0094	0.0498	0.0081
CTI	-0.0220	0.0815	0.0822	0.0486	0.1102	0.0293	0.3162	0.0302	0.3299	0.0315
Lin500	-1.8469	0.3865	-0.3798	0.4622	2.5364	0.4724	-6.9468	1.0032	-10.5676	1.5261
SHV1k	-13.9751	1.3225	-12.2503	1.5362	-10.4218	1.3965	-3.9745	2.1965	-5.5487	-5.5487
ACB1k	-4.5256	1.3587	-13.8448	1.7465	-25.1104	1.8511	-20.1715	2.6535	-17.8899	2.3533
G3m500	-20.1788	3.9519	-29.2926	4.8083	-23.6015	4.3156	-57.8446	11.7374	-1364.4590	276.865
Summer										
Intercept	-13.2577	-0.6082	-13.8673	-0.2606	-11.3377	0.1739	-8.5400	-0.4332	-17.5170	-3.1670
Veght	0.2709	0.0384	0.1443	0.0425	-0.0236	0.0401	0.0280	0.0463	0.2112	0.0990
CTI_Line	0.1637	0.0617	0.1615	0.0365	0.2130	0.0238	0.0779	0.0710	0.4222	0.0710
DST 1W2	0.0001	0.00001	0.0001	0.00001	0.00003	0.00001	0.00004	0.00002	0.0001	0.0001
DST W20k	0.0001	0.00001	0.00004	0.00001	-0.0001	0.00004	0.0002	0.00005	0.0004	0.0002
CC	-0.0166	0.0018	-0.0155	-0.0019	-0.0177	0.0022	-0.0162	0.0020	0.0141	0.0058
ELEV	0.0051	0.0003	0.0037	0.0003	0.0035	0.0003	0.0006	0.0004	0.0006	0.0012
TPI	0.0004	0.0059	0.0382	0.0070	0.0598	0.0072	0.0490	0.0090	0.0472	0.0211
CTI	0.2745	0.0606	0.3212	0.0358	0.1695	0.0072	0.1720	0.0242	0.5894	0.0778
Lin1k	-0.5511	0.4706	6.7323	0.5100	-2.4491	0.5415	-1.8102	0.8991	4.5907	3.5089
SHV1k	-29.5918	1.4110	-35.5101	1.7122	-43.6293	1.9317	-35.1541	3.0468	35.1541	8.4255
ACB1k	-9.2541	1.3889	-8.0256	1.5167	-9.1664	1.6609	-10.8308	2.0494	-10.8308	6.2080
G3m1k	-53.6024	6.8346	-41.0944	7.1855	-17.6518	5.9897	-10977.87	12.6358	-10977.87	388440
Fall										
Intercept	-4.8212	-1.0991	-4.6938	-1.5996	0.2930	-1.5421	4.4951	-1.9590	3.5731	-8.0499
Veght	-0.2100	0.0550	0.1370	0.0413	-0.0984	0.0504	-0.1109	0.0578	-0.1153	0.2022
CTI_Line	-0.1596	0.0962	-0.0348	0.0648	0.1424	0.0404	0.1940	0.0415	0.3208	0.1227
S_LV500	4.5580	0.5232	6.2746	0.7322	9.1532	0.7234	9.2818	1.3294	19.8674	70.3852
S_MV500	-14.1993	0.9490	-18.7747	1.3679	-21.6079	1.4746	-18.8641	2.7543	39.5133	88.9981
ACB70	2.6630	0.1584	0.6853	0.3333	-0.1984	0.3351	-1.0198	0.4580	-2.4272	1.8226
G3m1k	-30.5591	3.9636	-45.3878	5.6680	-50.9050	6.0734	-30.6635	6.8964	-78.3893	54.5627
DST W1M	0.0002	0.00002	0.0001	0.00003	0.0002	0.00003	0.0002	0.00003	0.0003	0.0001
DST W20K	0.0004	0.0001	0.0004	0.0001	0.0008	0.0001	0.0007	0.0001	0.0015	0.0003
CC	-0.0335	0.0028	-0.0297	0.0033	-0.0317	0.0030	-0.0307	0.0039	-0.0140	0.0080
ELEV	-0.0003	0.0006	-0.0006	0.0008	-0.0072	0.0010	-0.0157	0.0013	-0.0328	0.0066
TPI	0.0774	0.0088	0.0861	0.0110	0.1112	0.0113	0.1843	0.0169	0.3638	0.0614
CTI	0.2378	0.0934	0.1514	0.0619	-0.0294	0.0382	0.1224	0.0394	1.1099	0.1542

Table 3.3. continued

	0-62.5m		62.5-125m		125-250m		250-500m		500-1000m	
Early Winter										
Intercept	0.0522	-1.4722	6.4879	-1.6696	5.7286	-1.3470	5.2465	-1.4777	5.0777	-4.3748
Veght	-0.0939	0.0401	0.0194	0.0350	-0.1103	0.0368	0.0465	0.0411	-0.2440	0.1398
CTI_Line	0.1063	0.0545	0.0412	0.0433	-0.0249	0.0299	-0.0217	0.0334	0.1605	0.0917
DST W1M	-0.00004	0.00001	-0.0001	0.00002	-0.0001	0.00003	0.0001	0.00002	0.00005	0.00008
DST W20K	-0.0001	0.00004	-0.0002	0.0001	-0.0001	0.0001	-0.0003	0.0001	-0.00003	0.00016
CC	-0.0361	0.0017	-0.0370	0.0012	-0.0353	0.0023	-0.0442	0.0032	-0.0784	0.0094
ELEV	-0.0090	0.0003	-0.0144	0.0008	-0.0150	0.0008	-0.0165	0.0010	-0.0019	0.0011
TPI	0.0747	0.0050	0.1004	0.0078	0.1243	0.0084	0.1819	0.0103	0.1086	0.0214
CTI	-0.0824	0.0537	-0.0345	0.0422	0.1530	0.0281	0.1158	0.0300	0.2057	0.0803
Lin1k	-2.4262	0.3925	-1.7882	0.5832	-3.0287	0.6506	-3.6728	0.9912	-59.3597	8.6759
S_HV500	-7.7663	0.9526	-8.2934	1.2902	-5.3291	1.4344	-13.2116	1.7935	-309.6392	440.7338
ACB70	1.9740	0.0830	1.9770	0.1972	2.5054	0.2079	0.8966	0.3195	1.0036	0.9997
G3m1k	-6.1335	3.6989	-8.1758	4.0575	-16.3563	4.5373	4.9554	5.6043	348.7294	50.1659
DST_HWY35	0.0456	0.0038	0.0173	0.0030	0.0149	0.0028	0.0312	0.0030	-0.0990	0.0204
Late Winter										
Intercept	9.5224	-1.9925	6.0341	-1.7615	6.8326	-1.4001	-6.4942	-2.2100	36.3880	-29.1225
Veght	0.0700	0.0248	0.0598	0.0283	0.0615	0.0258	0.1462	0.0264	-0.3194	0.1905
CTI_Line	0.2523	0.2523	0.0704	0.0428	0.1415	0.0298	0.2818	0.0364	-0.1350	0.1469
DST W1M	0.0002	0.00002	0.0001	0.00002	0.0002	0.00002	0.0006	0.00003	0.0002	0.0002
DST W20K	0.0003	0.00005	-0.00002	0.0001	0.0002	0.00005	-0.0004	0.0001	-0.0019	0.0006
CC	-0.0345	0.0018	-0.0418	0.0021	-0.0291	0.0021	-0.0248	0.0026	-0.0293	0.0117
ELEV	-0.0043	0.0012	0.0040	0.0015	0.0011	0.0016	0.0107	0.0023	-0.0395	0.0315
TPI	0.0124	0.0064	0.0211	0.0077	0.0020	0.0084	0.1520	0.0129	0.3755	0.0955
CTI	-0.3503	0.0661	-0.1311	0.0422	-0.1123	0.0285	-0.0817	0.0355	0.6599	0.1538
Lin500	-0.4994	0.4544	3.0509	0.5554	4.9052	0.5755	-8.9363	1.3269	-70.0931	64.5245
S_HV500	-3.4919	0.8059	-7.0972	1.0567	7.2784	1.2874	20.5222	2.2743	20.2768	169.2892
ACB500	-8.8385	1.1675	-12.9798	1.4101	-23.2040	1.7075	-22.7494	2.5946	3.6259	63.7509
DST_HWY35	0.1002	0.0073	-0.1241	0.0086	-0.1294	0.0079	-0.0906	-0.0102	-0.1943	0.0709

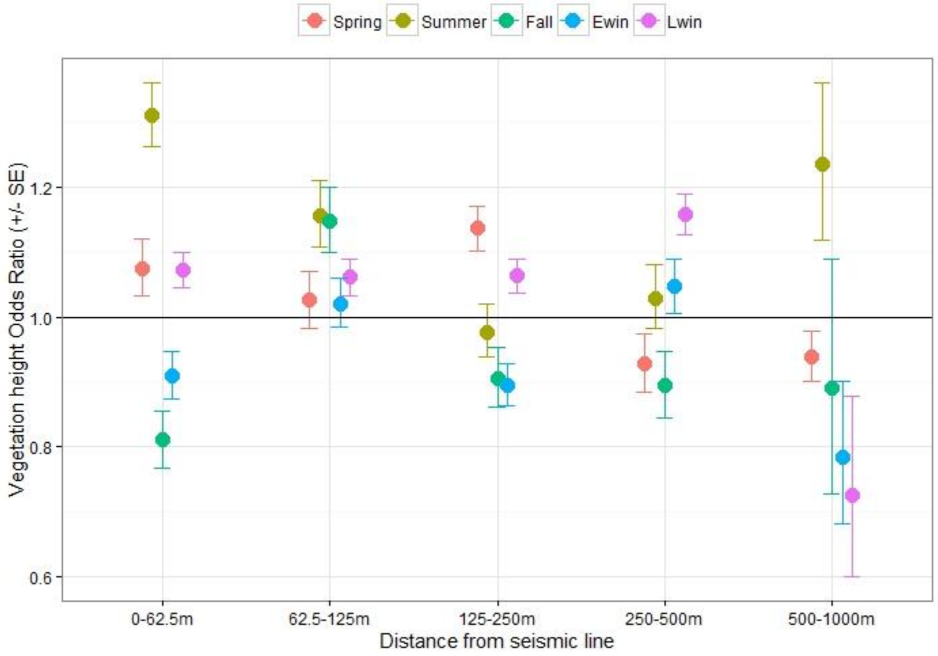


Figure 3.6. Unstandardized vegetation height odds ratios (± SE) of Chinchaga boreal caribou during spring, summer, fall, early, and late winter within 0-62.5m, 62.5-125m, 125-250m, 250-500m and 500-1000m from seismic lines .

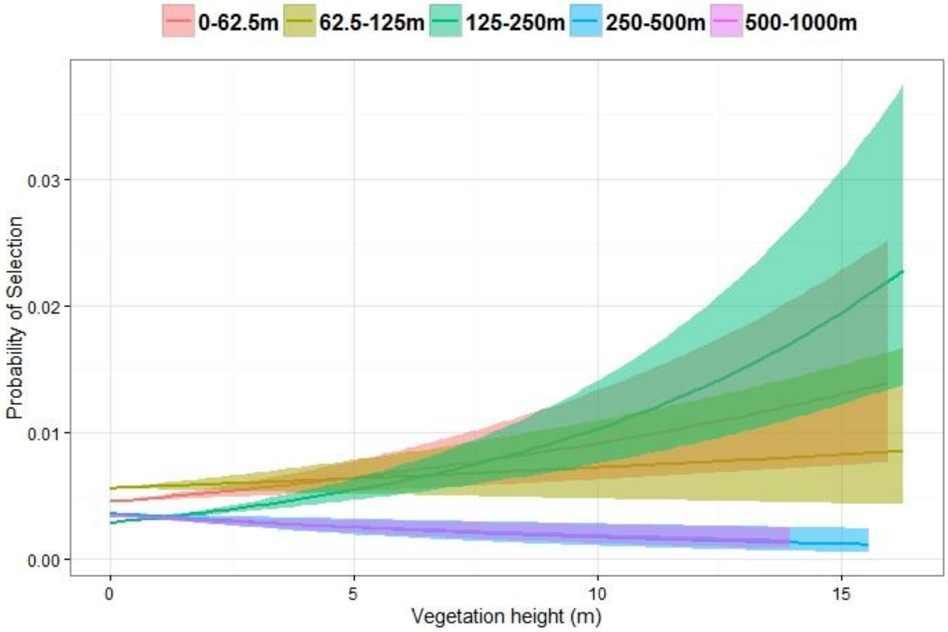


Figure 3.7. Relative probability of selection (± SE) of Chinchaga boreal caribou during spring, within 0-62.5m, 62.5-125m, 125-250m, 250-500, and 500-1000m of seismic lines. All other covariates within the model were held at their mean for prediction.

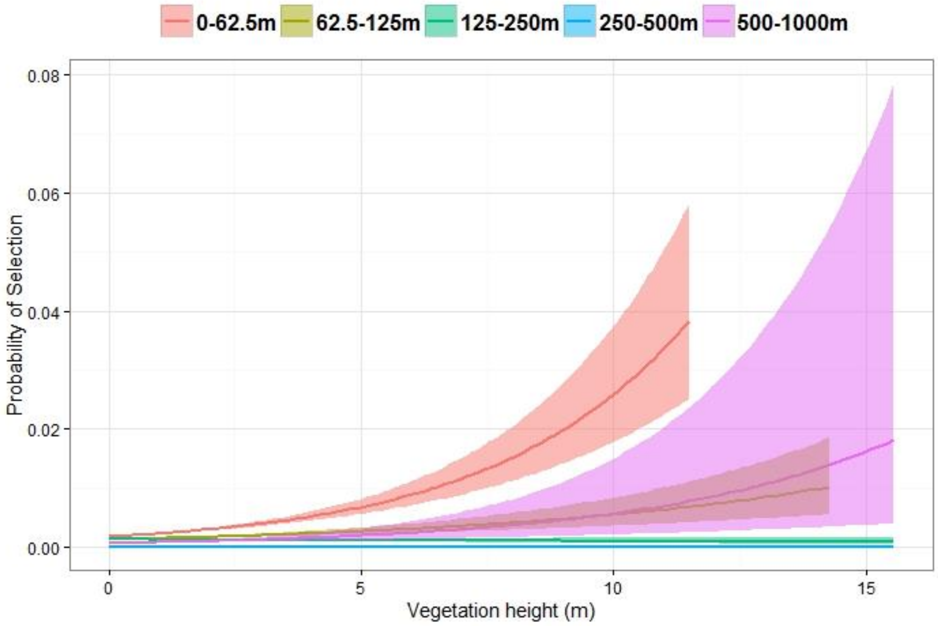


Figure 3.8. Relative probability of selection (± SE) of Chinchaga boreal caribou during summer, within 0-62.5m, 62.5-125m, 125-250m, 250-500, and 500-1000m of seismic lines. All other covariates within the model were held at their mean for prediction.

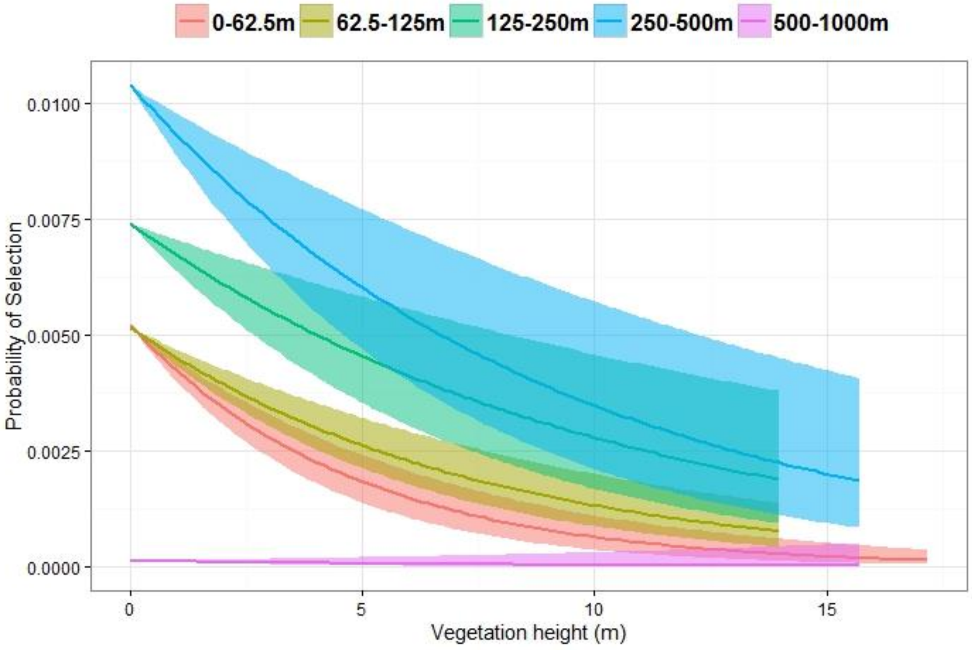


Figure 3.9. Relative probability of selection (± SE) of Chinchaga boreal caribou during fall, within 0-62.5m, 62.5-125m, 125-250m, 250-500, and 500-1000m of seismic lines. All other covariates within the model were held at their mean for prediction.

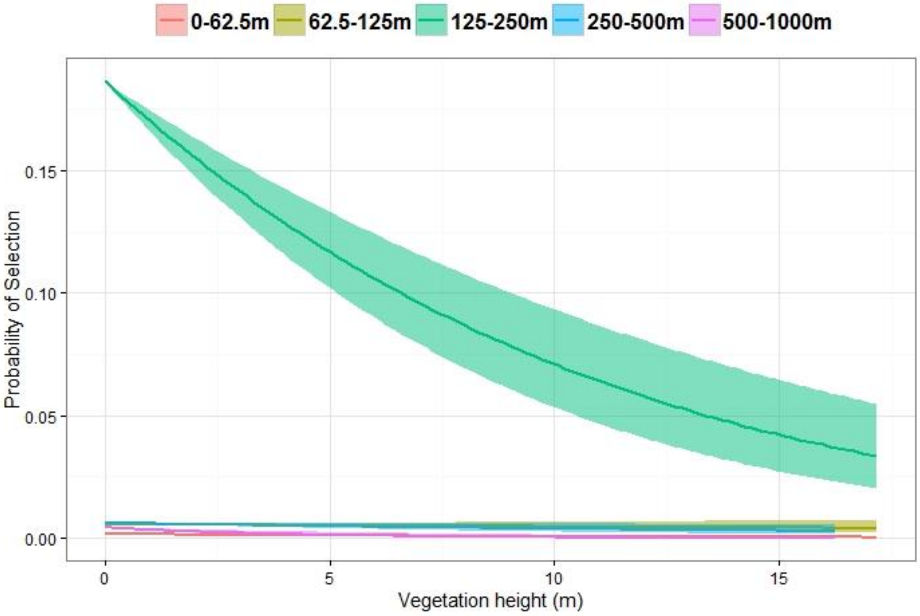


Figure 3.10. Relative probability of selection (± SE) of Chinchaga boreal caribou during early winter, within 0-62.5m, 62.5-125m, 125-250m, 250-500, and 500-1000m of seismic lines. All other covariates within the model were held at their mean for prediction.

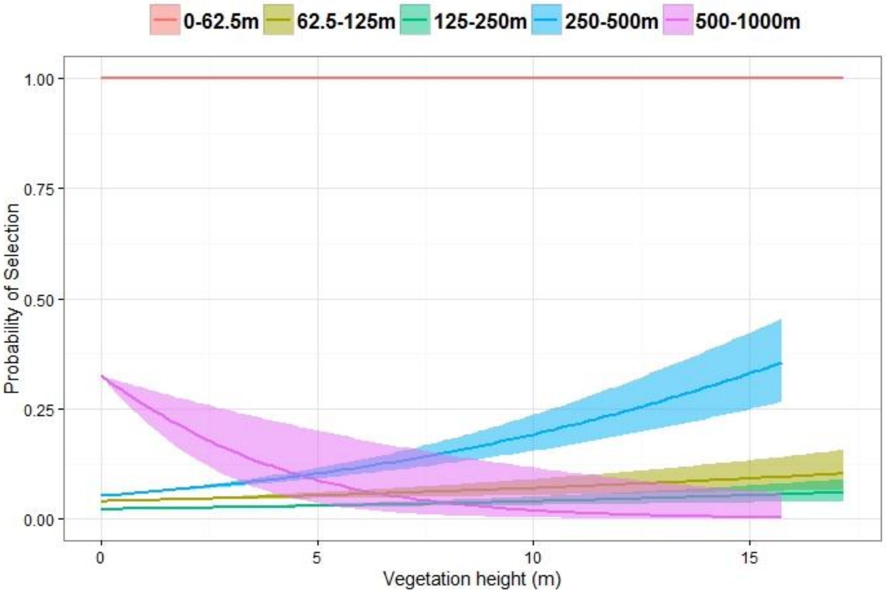


Figure 3.11. Relative probability of selection (± SE) of Chinchaga boreal caribou during late winter, within 0-62.5m, 62.5-125m, 125-250m, 250-500, and 500-1000m of seismic lines. All other covariates within the model were held at their mean for prediction.

During spring and summer, caribou consistently selected seismic lines with higher CTI values (Table 3.3, Figure 3.12). During fall, the probability of selection increased with decreasing CTI values when caribou were within 62.5m of seismic lines. Between 62.5 and 125m from seismic lines, CTI values of the nearest seismic line had no effect on the probability of selection while at distances greater than 125m from seismic lines, the probability of selection increased with increasing CTI values (Table 3.3, Figure 3.12). During early winter, when caribou were within 125m of seismic lines, the probability of selection increased with increasing CTI values while when caribou were between 125m and 500m from seismic lines, CTI value had no effect on the probability of selection. When caribou were more than 500m from seismic lines during early winter, the probability of selection increased with increasing CTI values. During late winter, the probability of selection increased with increasing CTI values until caribou were 500m from seismic lines after which the CTI values had no effect on the probability of selection (Table 3.3, Figure 3.12).

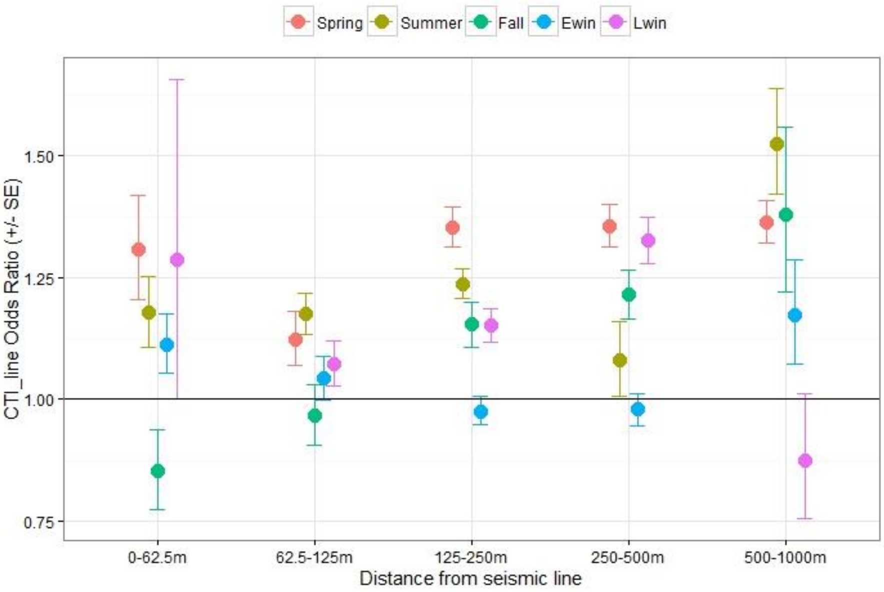


Figure 3.12. Unstandardized CTI (CTI_line) odds ratios (± SE) of Chinchaga boreal caribou during spring, summer, fall, early, and late winter within 0-62.5m, 62.5-125m, 125-250m, 250-500m and 500-1000m from seismic lines .

3.4 Discussion

Using LiDAR-based measurements of regeneration height on seismic lines collected within the Chinchaga caribou range between 2003 and 2008, and caribou GPS data collected between 2007 and 2009, we assessed whether different stages of re-vegetation of seismic lines affected the relative probability of selection of caribou near seismic lines. We found that circa 2007, the regeneration height upon seismic lines in the Chinchaga caribou range was low. The majority (69.55%) of seismic lines had regeneration heights less than 1m in height, and only 21.69% had regenerated to heights above 1.5m. Using logistic regression, we found that vegetation height, seismic line wetness, and distance to seismic lines affected the relative probability of selection of areas close to seismic lines by caribou. In all seasons except early winter, caribou selected areas further from seismic lines when compared to a random distribution. The strength of this response was most evident during spring when caribou selected for areas further than 800m from seismic lines regardless of the surrounding linear feature density (Figure 3.2). Considering vegetation height upon seismic lines and seismic line wetness, caribou consistently selected wetter seismic lines across all seasons, however, their response to vegetation height varied. When caribou were close to seismic lines, they selected for seismic lines with high vegetation height during spring, summer, and late winter, and selected for seismic lines with low vegetation height during fall and early winter. These results suggest that selection of areas close to seismic lines by caribou may be driven by caribou use of seismic lines as a source of food, or as movement corridors (wet seismic lines). If these same seismic lines are used by predators (see Chapter 4), and as revealed by previous research (Whittington *et al.* 2005; Stewart *et al.* 2013; Tigner *et al.* 2014), it is possible that wet, low vegetation height seismic lines could be acting as ecological traps for caribou, particularly during early winter (Figure 3.5 and 3.6).

Consistent with previous research, we found that caribou selected areas further from seismic lines more than areas closer to seismic lines during most seasons (Dyer *et al.* 2001; Polfus *et al.* 2011; Boulanger *et al.* 2012). This result is in accordance with the hypothesis that disturbances negatively affect caribou by removing caribou habitat, and by reducing the potential use of the surrounding habitat matrix (Polfus *et al.* 2011; Johnson *et al.* 2015). Although we could not identify a zone of influence for caribou habitat selection relative to distance to seismic lines across all seasons, during spring caribou selected areas further than 800m from seismic lines, and this result is consistent with previous assessments of the zone of influence of seismic lines (Dyer *et al.* 2001; Polfus *et al.* 2011). We also found that during spring, summer, and fall, relative habitat selection was consistently higher when caribou were closer to seismic lines that occurred in areas with higher densities of linear features. This result suggests that caribou selection of areas closer to seismic lines, at least during the snow free months, is an artifact of the low availability of habitat that is far from linear features or disturbances available to caribou, rather than selection of seismic lines themselves (see Figure 1.1). This selection for lower quality habitat in areas with high densities of anthropogenic disturbance has also been described in other ungulates (Sawyer *et al.* 2006).

Considering vegetation height, we found that response of caribou to regeneration varied across seasons. During spring, summer, and early winter, caribou selected areas closer to seismic lines with high vegetation height, and this result was strongest during summer when the odds of caribou occurrence increased 1.31 times for every 1m increase in vegetation height. Spring and summer include the calving period and the vulnerable post-parturition period. During those seasons, research has found that caribou have a stronger avoidance response relative to habitat disturbance, potentially to reduce predation risk and maximize calf survival (Nagy 2011; Pinard *et al.* 2012; DeCesare *et al.* 2012). Given this behavioral response, areas with seismic lines with higher vegetation height may be perceived as less risky by caribou during summer when compared to areas with lower vegetation height seismic lines. During fall and early winter, we found that the opposite was true, and caribou selected areas closer to seismic lines with low vegetation height. It is possible that during those seasons, caribou behavior is driven more by forage availability and energy-efficient travel between habitat patches rather than by predation risk (Avgar *et al.* 2015). This behavior may in turn result in areas close to low vegetation height seismic lines being attractive as food sources or travel corridors during fall and early winter. The consistent selection of areas closer to seismic lines with higher CTI values may also reflect selection for seismic lines with more vegetative food (low vegetation), or with higher densities of regeneration (higher vegetation).

If low vegetation height sesimic lines contain important food resources for caribou (James & Stuart-Smith 2000), then the selection of areas near these low vegetation height seismic lines, especially during winter, may create ecological traps for caribou. Caribou predators such as wolves and black bears select these seismic lines as travel corridors because they facilitate movement, and because they attract ungulates like moose, deer, and elk (Latham, Latham & Boyce 2011a; Whittington *et al.* 2011; Stewart *et al.* 2013; Tigner *et al.* 2014). It is therefore likey that the probability of encounters with predators are increased when caribou are close to low vegetation height seismic lines (Whittington *et al.* 2011).

3.5 Conclusions

Our findings do not refute the currently accepted 500m buffer applied to seismic lines across caribou ranges. We found that regeneration height affected selection of seismic lines by caribou, but as there was no clear regeneration threshold identified across all seasons, we were unable to identify the zone of influence of seismic lines at different stages of regeneration. We found that during spring, summer, and late winter, caribou selected areas closer to seismic lines with high vegetation heights. This suggests that caribou may perceive seismic lines with higher regeneration (>5m) as lower impact disturbances. However, the contribution of these areas to 'restored' caribou habitat in a conservation context also depends on the response of predators to seismic lines. Wolf response to regenerating seismic lines is described in Chapter 4, and these results will aid in interpreting the role of regeneration of vegetation on seismic lines in the restoration of caribou habitat. However, caribou also selected for areas closer to seismic lines with low vegetation heights during some seasons. Research has found that wolves also prefer low vegetation seismic lines (Dickie 2015), and that these areas may be ecological traps for caribou. Again the wolf habitat selection analysis described in the Chapter 4 will help to interpret these results further.

The goal of this analysis was to use regeneration height and attributes of seismic lines to help prioritize seismic lines for restoration. By integrating results of caribou and predator habitat selection relative to seismic line regeneration and other attributes on the landscape (i.e. disturbance densities, terrain, and habitat covariates) we can identify areas within disturbed habitats where potential overlap between caribou and their predators is highest. The results of caribou habitat selection presented here and of wolf habitat selection presented in Chapter 4 are integrated in Chapter 6 to help inform habitat restoration priorities within the Chinchaga boreal caribou range.

4. Assessing the zone of influence of seismic lines for wolves: Does regeneration matter?

Karine Pigeon

4.1 Introduction

Previous research has shown that wolves use seismic lines as travel corridors and select areas closer to seismic lines when compared to a random distribution (Neufeld 2006). Wolf selection for seismic lines in turn increases predation risk for caribou when they are close to seismic lines (Latham *et al.* 2011b; Whittington *et al.* 2011; DeCesare 2012). To better focus management efforts towards the successful recovery of Chinchaga boreal caribou in Alberta, our objectives were to (1) assess wolf habitat selection relative to their distance to seismic lines within the Chinchaga caribou range while taking terrain, habitat, and anthropogenic features of the landscape into account, and (2) assess how vegetation height and seismic line wetness influenced the selection patterns of wolves for these seismic lines. By understanding how wolves respond to seismic lines, and by understanding how regeneration (vegetation height) of these seismic lines influences the selection patterns of wolves for these linear features, we can better prioritize herd-specific management actions towards caribou recovery (Finnegan *et al.* 2014; Dickie 2015). Based on previous literature and expected wolf behaviour, we hypothesized that wolves would select for seismic lines, and that the zone of influence of seismic lines would be similar to that previously reported for caribou (Neufeld 2006; Latham *et al.* 2011b; Whittington *et al.* 2011; McKenzie *et al.* 2012). Also, as Dickie (2015) observed in northeastern Alberta, we expected that natural regeneration of seismic lines would reduce the benefit of linear features for wolf movement. We therefore predicted that selection for seismic lines would decrease with increasing vegetation height on seismic lines, and that increased vegetation height would reduce the zone of influence of seismic lines (James & Stuart-Smith 2000; Mckenzie *et al.* 2012; Dickie 2015). Finally, we expected that wolf selection of seismic lines would vary seasonally, and that wolves would show increased selection for seismic lines during snow-free seasons (Latham *et al.* 2011b).

4.2 Methods

4.2.1 Study area

We investigated resource selection at the 3rd order of selection (Johnson 1980) for 4 individual wolves captured and collared within the Chinchaga caribou range (Designatable Unit 6) between 2006 and 2007. The study area is described in section 2.2.1 (Chapter 2; Figure 2.1).

4.2.2 Animal location data

We used wolf GPS data for 4 individuals captured by the British-Columbia Ministry of Environment Fish & Wildlife Section using aerial darting between 2006 and 2007 and fitted with ATS GPS collars (data.gov.bc.ca; Rowe 2007). Captured individuals provided 6 animal-years of data and a total of 485 observations rarefied at 2 hour intervals. To assess wolf habitat selection relative to their distance to seismic lines within the Chinchaga caribou range, we first investigated resource selection within Minimum Convex Polygons (MCP) per individual-season by comparing every wolf GPS location to 20 random locations drawn within individual MCPs. Then, to evaluate how vegetation height and seismic line wetness affected the selection of these seismic lines, we subsequently assessed the selection of seismic lines by wolves using the same GPS locations, but this time compared to 20 random locations drawn within specific distances (buffers) of seismic lines (0m – 62.5m, 62.5m – 125m, 125m – 250m, 250m –

500m, 500m – 1000m, and 1000m – 2000m), and included vegetation height of seismic lines as a covariate in models. See Chapters 2 and 3 for additional details. To account for variations in seasonal selection and life history requirements, we classified wolf locations into 3 seasons as per Neufeld (2006): denning = 20 April to 30 June, Rendezvous = 1 July to 20 September, and Nomadic = 21 September to 19 April, and included wolf season as a categorical variable in models.

4.2.3 Landscape variables

Landscape covariates are described in Chapter 3 (section 3.2).

5.2.4 Data analysis

We used generalized linear mixed models (GLMM) to assess 3rd order selection of wolves from the Chinchaga caribou range of Alberta, Canada using the R package ‘lme4’ (Bates et al. 2015). Within each individual seasonal MCP, we used Geospatial Modelling Environment (GME; Beyer 2012) within ArcGIS 10.2 (ESRI 2015) to generate 20 available locations per used location (actual GPS location from animals) following preliminary analyses based on Northrup *et al.* (2013) that indicated consistently stable coefficients with a ratio of at least 20 randomly generated available locations for every used location (fRI Caribou Program unpublished data). We specified an Animal ID - year random effect to account for individual-based correlation. We assessed correlation among explanatory variables and chose to remove any one of 2 variables correlated at ≥ 0.5, and because moderate collinearity can be problematic when investigating ecological signals, we also removed any variable with a variance inflation factor > 3 (Zuur *et al.* 2010).

Our objective was to optimize model fit rather than test competing hypotheses, we therefore first assessed resource selection within each of the 3 categories of attributes mentioned above (Topography, Landcover, and Anthropogenic features; Table 3.1) and used the drop1 function in the R package ‘stats’ to retain only influential variables within each of the categories of attributes (R Core Team 2015). For each scale of density variable (i.e. 70m, 500m, and 1km scale), we first selected the most appropriate density scale by comparing Akaike’e Information Criterion (AIC) values of univariate models for each variable. We only retained one density scale per variable type to avoid collinearity issues and over-parameterization. Because of low sample size, we included season as a fixed effect (no interaction) in the models. We used the information-theoretic approach with AIC within drop1 to assess variables (Burnham and Anderson 2002). Once all influential variables were retained within each category of attributes, we fit a global model that included all variables identified within each category of attributes. We followed the principle of parsimony and used drop1 a final time to remove any non-influential variable from the global model for each season (Burnham and Anderson 2002). We standardized all continuous variables to improve model convergence and carried out all statistical analyses and data exploration in RStudio using R statistical software (R Core Team 2015; RStudio 2015; Wickham 2010). We used odds ratio derived from standardized variables as a measure of effect size. Odds ratios are the ratio between the probability of an event to occur and the probability of the same event not to occur (Grimes and Schulz 2008). Here, an odd ratio > 1 refers to a landscape attribute being selected more than expected from random sampling while an odds ratio < 1 indicates a selection below what would be expected from random sampling.

5.3 Results

5.3.1 Habitat selection relative to seismic line distance

Our wolf locations in the Chinchaga caribou range occurred in areas without cut blocks (zero densities), we therefore removed all anthropogenic variables with cut block data from the models, and because we did not retain season in the final model (non-influential variable), we describe results for all seasons inclusively. Wolves in the Chinchaga caribou range selected flat areas (TPI values near zero) at high elevation within mixed forest and non-forested areas (Table 4.2). These wolves also avoided high densities of linear features within a broad (1km) scale but selected high densities of anthropogenic features including all types of linear features, and oil and gas facilities at a fine (70m) scale (Table 4.2). Finally, although the effect of seismic line distance on wolves in the Chinchaga caribou range was relatively small, wolves also selected areas close to seismic lines more than expected from a random distribution (Table 4.2; Figures 4.1 and 4.2).

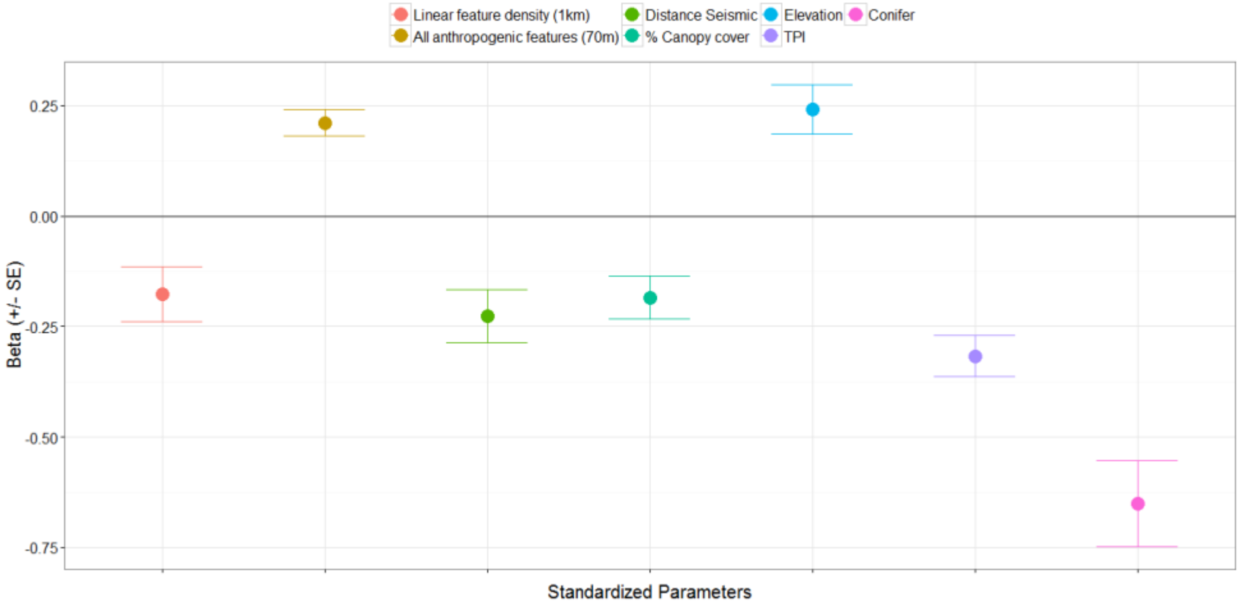


Figure 4.1. Standardized coefficients and standard errors (Beta +/- SE) from the final mixed logistic regression model assessing home-range scale (MCP) selection of wolves in the Chinchaga caribou range in Alberta, Canada between 2006 and 2007. All coefficients (Betas) are standardized and centered around zero to allow for a comparison of effect size.

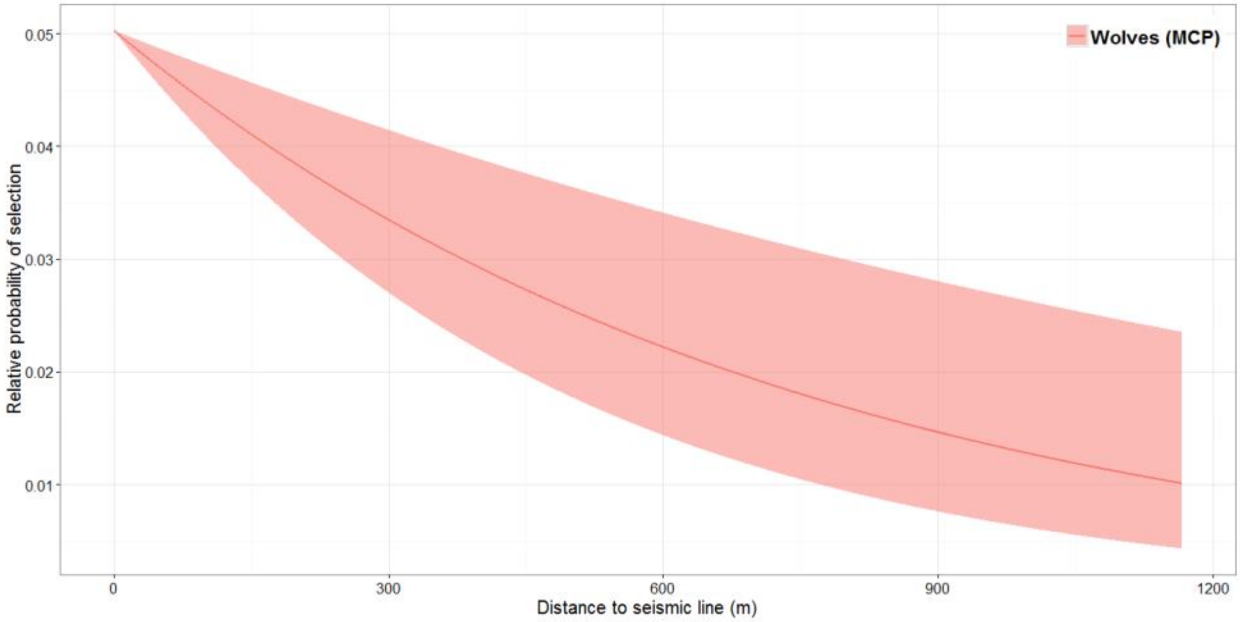


Figure 4.2. Relative probability of selection (+/- 95% confidence intervals) of wolves in the Chinchaga caribou range in Alberta, Canada between 2006 and 2007 as a function of seismic line distance (m).

Table 4.2. Parameter estimates (β), standard errors (SE), z-value (Z), P-values (P), and odds ratio from standardized parameter estimates (OR) for the final model investigating habitat selection relative to seismic lines for wolves in the Chinchaga caribou range in Alberta, Canada between 2006 and 2007.

Parameter	β	*SE*	Z	*P*	*OR*
fConif	-0.65	0.1	-6.4	<.0001	0.52
CC	-0.009	0.003	-3.5	<.0001	0.83
TPI	-0.4	0.007	-6.1	<.0001	0.72
ELEV	0.004	0.002	2.6	0.008	1.27
Lin1k	-3.4	1.4	-2.4	0.01	0.84
A70	2.5	0.4	6.7	<.0001	1.24
SEIS_NEARM	-0.001	0.0003	-3.8	<.0001	0.80

4.3.2 Effect of seismic line attributes–vegetation height and soil wetness

Separating the 485 wolf locations obtained from the Chinchaga caribou range according to their distance to seismic lines yielded 212 locations within 62.5m of seismic lines, 83 locations between 62.5m and 125m from seismic lines, 112 locations between 125m and 250m from seismic lines, 59 locations between 250m and 500m from seismic lines, 18 locations between 500m and 1000m from seismic lines, and 2 locations greater than 1000m from seismic lines. We did not investigate selection patterns at distances greater than 1000m from seismic lines, and because of low sample sizes, all of these results should be interpreted with caution.

Wolf response to seismic lines varied according to seismic line distance (distance buffers), density of anthropogenic features within the local (70m) scale, elevation, TPI, distance to small (Dist_W20k) streams, distance to the main highway (HWY 35), density of low vegetation height seismic lines at the landscape (1km) scale, and seismic line wetness (CTILWM). Wolf response to seismic lines with different vegetation heights also varied per season (Table 4.3).

When wolves were within 62.5m of seismic lines during the rendezvous season, they selected areas near seismic lines with low vegetation heights more than expected (Table 4.3, Figure 4.3). For every 1m increase in vegetation height, the odds of wolf occurrence while within 62.5m of seismic lines increased by a factor of 0.02 (0.006-0.008) during the rendezvous season, a snow-free period (Table 4.3, Figure 4.3). In comparison to the rendezvous season, wolves selected areas near seismic lines with higher vegetation during the nomadic and denning period. Overall, while within 62.5m of seismic lines, wolves selected for level sites (TPI values near zero) at high elevation, near small streams, and away from high densities of low vegetation seismic lines at the landscape (1km) scale but within areas with high densities of anthropogenic features at the local (70m) scale.

When wolves were between 62.5m and 125m from seismic lines, their selection patterns were not influenced by the regeneration height on the nearest seismic lines. At this distance, wolves selected flat areas away from high densities of low vegetation seismic lines at the 1km-scale but selected areas with high densities of anthropogenic features at the 70m- scale (Table 4.3).

While between 125m and 250m from seismic lines, wolves selected areas near seismic lines with low vegetation heights during the denning season, but in contrast, wolves selected areas near seismic lines with high vegetation during the nomadic and rendezvous seasons (Table 4.3; Figure 4.3). For every 1m increase in vegetation height, the odds of wolf occurrence while between 125m and 250m from seismic lines increased by a factor of 0.008 (0.002-0.04) during the denning season (Table 4.3, Figure 4.3). Regardless of season, while between 125m and 250m from seismic lines, wolves selected areas where the nearest seismic line had high CTI values (wet seismic lines), and again selected level areas at high elevation near small streams and within high densities of anthropogenic features at the 70m- scale (Table 4.3).

When wolves were located farther than 250m of seismic lines, vegetation heights of the nearest seismic lines did not influence wolf habitat selection patterns Table 4.3, Figure 4.3). However, at scales greater than 250m of seismic lines, wolves selected for areas where the nearest seismic line CTI values were low, suggesting that at this distance, wolves display an overall selection for dry sites. When between 250m and 500m from seismic lines, wolves again selected high-elevation level areas within high densities of anthropogenic features at the 70-m scale. No other covariate explained selection patterns of wolves located within > 500m and < 1km from seismic lines (Table 4.3).

Table 4.3. Unstandardized coefficients (β) and standard errors (SE) describing habitat selection of wolves in the Chinchaga caribou range during the denning, nomadic, and rendezvous period while within 0-62.5m, 62.5-125m, 125-250m, 250-500m and 500-1000m of seismic lines. The denning season was set as the reference category, and significant parameters are shown in bold. Covariates are described in Chapter 3, Table 3.1.

	0-62.5m		**62.5-125m**		**125-250m**		**250-500m**		**500-1000m**	
	β	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**
(Intercept)	-4.54	2.80	2.74	3.57	-5.88	3.59	6.17	10.30	2.16	16.66
Veght	-0.47	0.46	-0.03	0.35	**-4.82**	**1.59**	-0.92	0.82	-0.02	0.62
SLV1k	**-11.23**	**2.57**	**-10.36**	**4.14**	-4.99	4.17	-4.82	9.54	19.43	22.67
DST HWY35	-0.02	0.01	-0.03	0.02	-0.02	0.02	-0.08	0.05	0.06	0.11
DST W20k	**0.002**	**0.0002**	0.16	0.11	**0.001**	**0.0004**	0.001	0.001	-0.00004	0.001
ELEV	**0.005**	**0.002**	-0.0002	0.002	**0.004**	**0.002**	**0.01**	**0.003**	-0.01	0.01
TPI	**-0.08**	**0.01**	**-0.07**	**0.02**	**-0.04**	**0.01**	-0.03	0.01	0.02	0.02
CTILWM	-0.005	0.09	-0.10	0.14	**0.27**	**0.13**	**-0.50**	**0.18**	**-0.81**	**0.33**
A70	**2.48**	**0.57**	**4.25**	**0.68**	**2.09**	**1.05**	**3.19**	**1.33**	3.63	2.24
Nomadic	0.13	0.36	0.39	0.44	**-0.66**	**0.30**	-0.83	0.55	0.45	1.18
Rendezvous	0.47	0.40	-0.29	0.51	-0.30	0.37	-0.57	0.60	0.16	1.16
Veght:Nomadic	0.46	0.47	-0.14	0.41	**5.37**	**1.59**	1.47	0.84	-0.69	0.83
Veght:Rendezvous	**-3.37**	**1.37**	0.35	0.41	**4.54**	**1.64**	0.95	0.93	-0.42	1.02

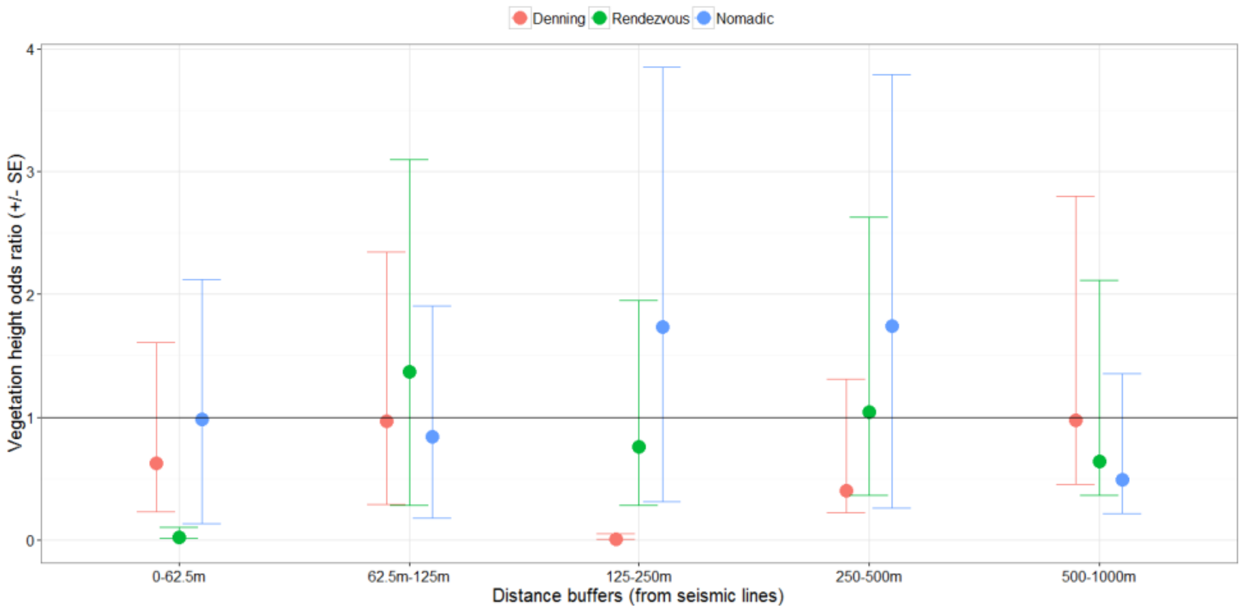


Figure 4.3. Unstandardized odds ratio and standard errors (± SE) for wolves near seismic lines in the Chinchaga caribou range during the nomadic, rendezvous, and denning seasons. Distance buffers refer to the distance of wolves and associated random locations to the nearest seismic lines within 0-62.5m, 62.5-125m, 125-250m, 250-500m and 500-1000m buffers.

4.4 Discussion

Using 2 years of GPS location data obtained from 6 wolf-years within the Chinchaga boreal caribou herd in Alberta, Canada, we demonstrated that within their home-range, wolves select flat areas at high elevation in mixed or non-forested habitat types away from high densities of linear features at the 1km-scale, but near areas with high densities of anthropogenic features at the 70-m scale. Overall, when investigating selection patterns within specific distances of seismic lines, wolves also selected flat areas at high elevation away from high densities of linear features at the landscape scale but selected areas with high densities of anthropogenic features at the local scale. Overall, wolves also selected sites close to small streams.

When investigating selection patterns of wolves in the Chinchaga caribou range at the home-range scale, the relative probability of selection decreased minimally with increasing distances from seismic lines. Therefore, although wolves generally chose to be closer to seismic lines, similar to previous research findings (Neufeld 2006; Latham *et al.* 2011b), defining a specific zone of influence for seismic lines in the Chinchaga was not straightforward. It is likely that seismic line attributes play an important role in selection for seismic lines because specific attributes such as vegetation heights and wetness would facilitate or impede travelling efficiency on these lines (Dickie 2015). Acquiring additional wolf location data and seismic line attributes could help better define the zone of influence of seismic lines for wolves in the Chinchaga caribou range.

However, as expected, the influence of vegetation heights on seismic lines diminished when wolves were located farther from seismic lines (> 250m), and wolves selected for sites near seismic lines with low vegetation heights when in close proximity to seismic lines (< 62.5m) during the snow-free period, similar to previous research findings (Dickie 2015). We did not observe selection for particular vegetation heights of seismic lines when wolves were located between 62.5m and 125m from seismic lines, but wolves again selected for sites near seismic lines with low vegetation heights, specifically during the denning season, when located between 125 and 250m from seismic lines. The observed discrepancy in selection patterns at the intermediate scale (> 62.5m and < 125m) could be due to small sample sizes. Linear features benefit movement for wolves (Latham *et al.* 2011b; McKenzie *et al.* 2012), and Dickie (2015) observed that wolves selected for seismic lines during summer and winter, selected low vegetation height seismic lines more than high-vegetation height seismic lines, and travelled twice as fast while travelling on conventional seismic lines when compared to the surrounding forest. Our results are in accordance with the 'movement facilitation hypothesis' and the findings of Dickie (2015), and suggest that wolves are selecting low vegetation height seismic lines to facilitate their movements year-round. Dickie (2005) also found that wolves in northeast Alberta travelled slower on seismic lines with vegetation heights > 5m, and we also found no selection for seismic lines with moderate to high vegetation heights suggesting that these seismic lines are less desirable for travel within the Chinchaga caribou range.

4.4.1 Conclusions

Although limited by the restricted GPS dataset available that matched the time period when LiDAR was flown within our study area (circa 2005), to our knowledge, this analysis is the first to specifically assess habitat selection patterns of wolves in the Alberta portion of the Chinchaga range. This study is also one of the first to integrate regeneration height of anthropogenic disturbances within wolf habitat selection models. Similar to research conducted elsewhere, we found that wolves in the Chinchaga caribou range selected for anthropogenic disturbances including seismic lines, and selected areas with TPI values around zero, and areas closer to small streams (Neufeld 2006; Latham *et al.* 2011b; DeCesare 2012). Our assessment of wolf response to regeneration in the Chinchaga range was also largely in accordance with results reported from north-east Alberta (Dickie 2015).

Because we found that wolves select for areas close to low vegetation height seismic lines during the rendezvous season, and in Chapter 3 we found that caribou also selected for these areas during the same time period (fall), it is probable that low vegetation height seismic lines are ecological traps for caribou during the snow-free months. In the next Chapter, we integrate the results of habitat selection of caribou (Chapter 3) and wolves (this Chapter) to create spatial models integrating landscape and anthropogenic covariates and regeneration height of seismic lines to map the probability of overlap between these two species and help inform habitat restoration priorities within the Chinchaga boreal caribou range.

5. Priority seismic lines for restoration: Assessing the probability of overlap between wolves and caribou in the Chinchaga caribou range.

Karine Pigeon, Laura Finnegan, and Doug MacNearney

We assigned priority codes for restoration to seismic line segments based on the probability of caribou overlap with wolves as determined from RSF maps. We first merged RSF maps for each distance to seismic category (buffers) to create seasonal RSF maps. We then created a maximum RSF for caribou and wolves respectively by adding the values from species-specific seasonal RSFs such that habitats with high probability of selection in multiple seasons received a higher score than habitats with high probability of selection for only one season. With this method, habitats with low probability of selection across seasons also received a low score. We used a 1km-radius moving window average (equal distance to the maximum distance buffer from seismic lines) over the two species-specific maximum RSFs to create one final RSF per species that accounted for habitat selection across all distance to seismic categories and seasons. To link RSF values to each seismic line segment, we then extracted values from the final RSF per species to each seismic line segment. We then classified these RSF values into categories of low, medium, high, and very high probability of selection by quantiles for each species RSF values, and then added the caribou RSF values to the wolf RSF values to create a categorical variable representing the probability of overlap between caribou and wolves (Table 5.1). We used this variable to assign priorities to each seismic line segment for restoration, and because we are most interested in restoring areas with high probability of selection by caribou, we gave caribou RSF categories twice the weight of wolf RSF categories to assign priority levels for restoration of seismic lines. Because the highest probability of overlap between wolves and caribou was rare, we collapsed the upper categories into a single “Very High” priority category for restoration of seismic lines.

We assigned priority rankings to 52,874km of seismic lines in the Chinchaga caribou range (Table 5.2). Of these line segments, we identified 751km (1.4%) as very high priority for overlap, and 788km (1.5%) as high priority based on the potential probability of overlap between caribou and wolves (Table 5.2). Overall, seismic lines with a high probability of overlap between wolves and caribou were rare due in part to 83.3% of seismic lines by length falling in the lowest RSF category for caribou (Table 5.3). The low RSF category attributed to seismic lines in respect to caribou is likely due to the general avoidance of seismic lines by caribou (chapter 2 and 3). Our ability to identify a small portion of the seismic line footprint where the probability of overlap between caribou and wolves is greatest provides an achievable target to begin habitat restoration, and provides land managers with science-based criteria expected to increase caribou functional habitat and further reduce potential encounters between caribou and wolves.

Table 5.1. Restoration priority classification of seismic lines based on quantiles of RSF scores for wolves and caribou in the Chinchaga caribou range, Alberta, Canada, between 2006 and 2010. Quantile values are in brackets following the ranking description.

		Wolf RSF			
Caribou		Low (0-0.12)	Medium (0.13 – 0.24)	High (0.25-0.58)	Very High (0.59-2.38)
RSF	Low (0-0.32)	3	4	5	6
	Medium (0.33-0.51)	5	6	7	8
	High (0.52-0.67)	7	8	9	10
	Very High (0.68-1.94)	9	10	11	12

Table 5.2. Length (km) and percent of the total seismic footprint by priority level in the Chinchaga caribou range in Alberta, Canada based on seismic line footprint with available LiDAR-based vegetation data (circa 2005).

Priority for Restoration					
Low	Medium-Low	Medium	Medium-High	High	Very High
5,102 km (9.6%)	12,200 km (23.1%)	18,852 km (35.7%)	15,180 km (28.7%)	788 km (1.5%)	751 km (1.4%)

Table 5.3. Length (km) and percent of total footprint for seismic lines in each category of overlap for wolves and caribou in the Chinchaga caribou range in Alberta, Canada between 2006 and 2010.

		Wolf RSF			
Caribou RSF		Low (0-0.12)	Medium (0.13 – 0.24)	High (0.25-0.58)	Very High (0.59-2.38)
	Low (0-0.32)	5,102 km (9.6%)	12,200 km (23.1%)	13,380 km (25.3%)	13,378 km (25.3%)
	Medium (0.33-0.51)	5,471 km (10.3%)	1,802 km (3.4%)	724 km (1.3%)	732 km (1.4%)
	High (0.52-0.67)	64 km (0.1%)	2 km (0.004%)	1 km (0.002%)	15 km (0.02%)
	Very High (0.68-1.94)	< 1 km (0.001%)	0 km -	0 km -	< 1 km (0.001%)

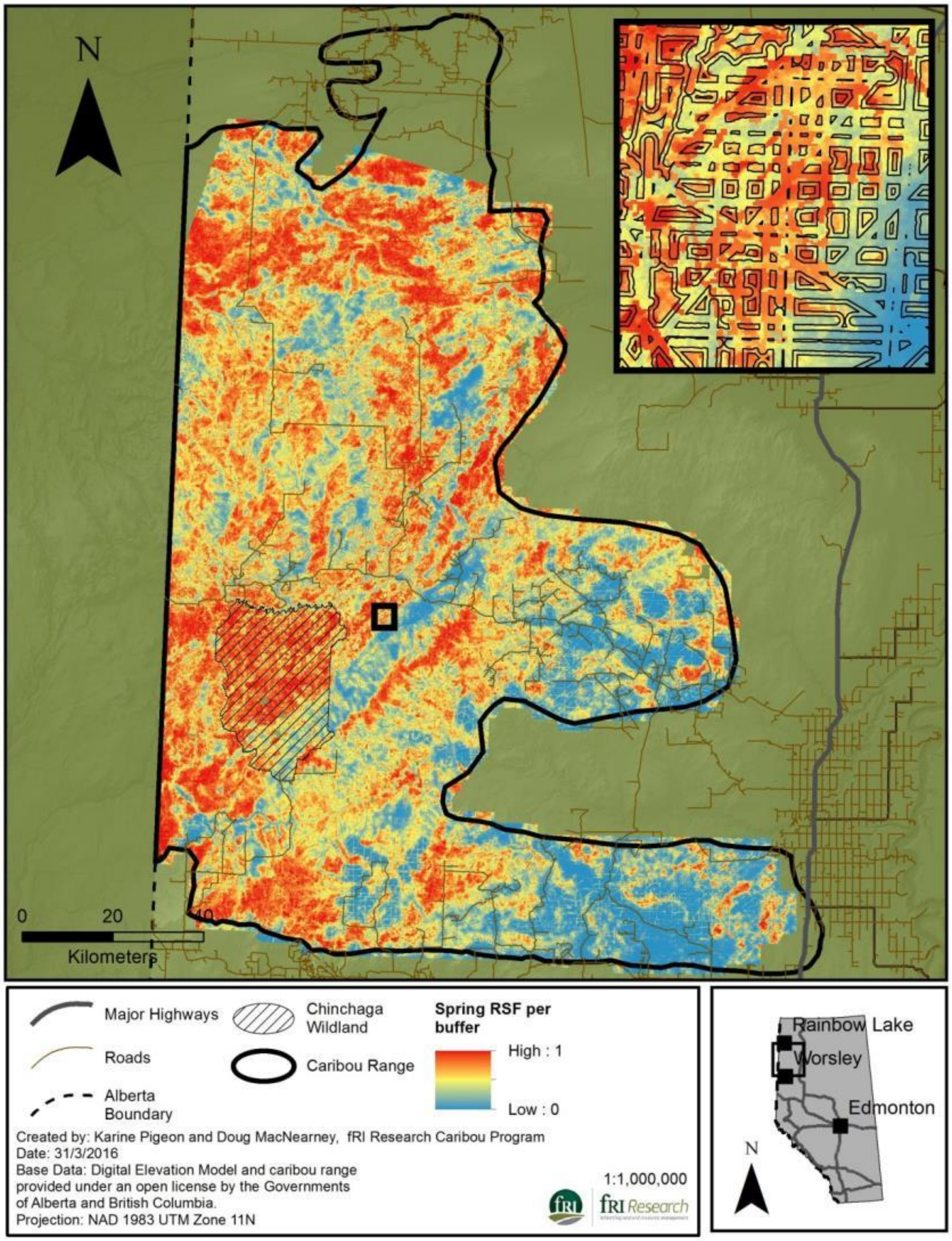


Figure 5.1. Relative probability of selection for boreal caribou during spring (8 April to 7 June) based on the effect of seismic line attributes for caribou locations within 0-62.5m, 62.5-125m, 125-250m, 250-500m, and 500-1000m buffers from seismic lines within in the Chinchaga range, Alberta, Canada between 2007 and 2010 (see Chapter 3).

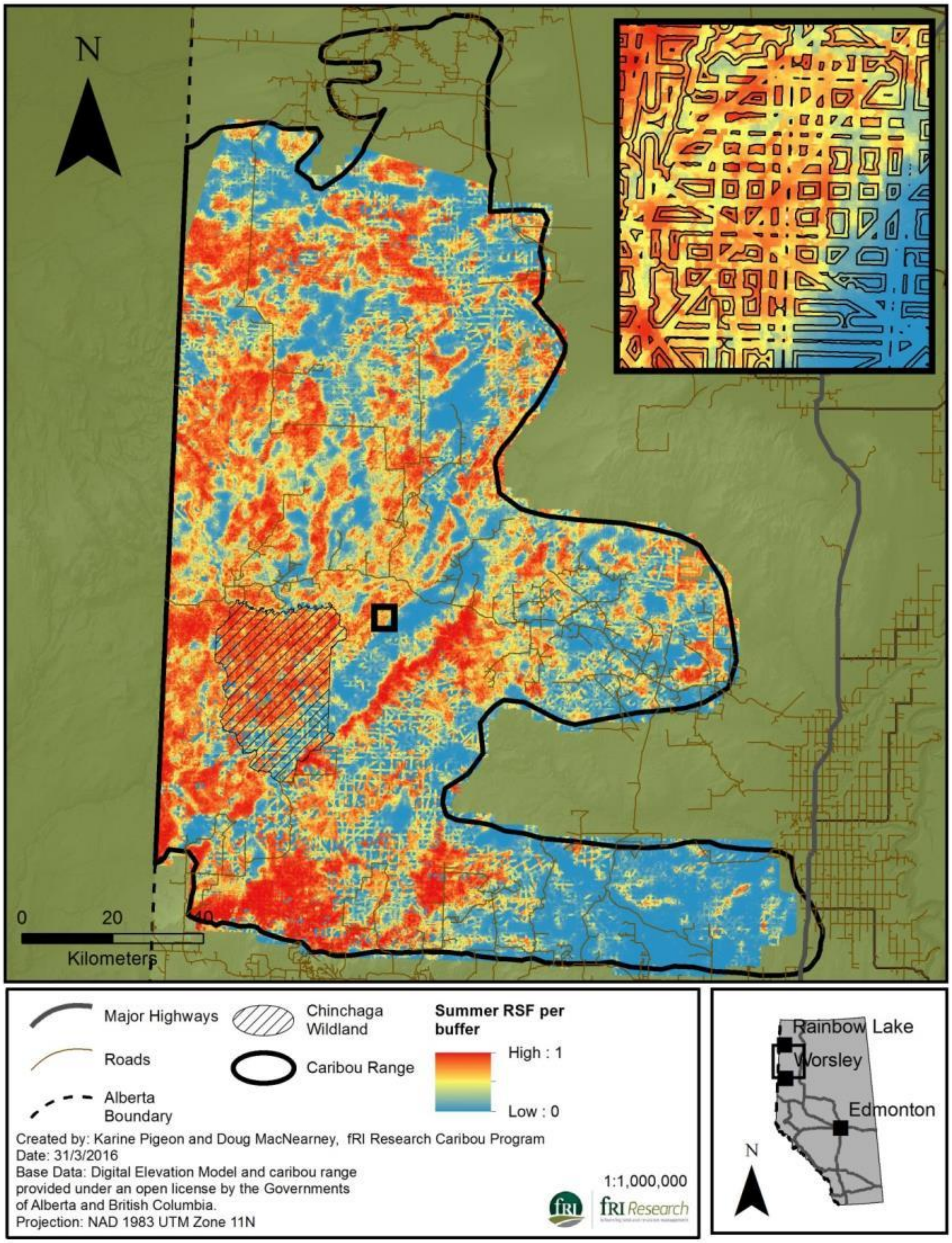


Figure 5.2. Relative probability of selection for boreal caribou during summer (8 June to 24 September) based on the effect of seismic line attributes for caribou locations within 0-62.5m, 62.5-125m, 125-250m, 250-500m, and 500-1000m buffers from seismic lines within in the Chinchaga range, Alberta, Canada between 2007 and 2010 (see Chapter 3).

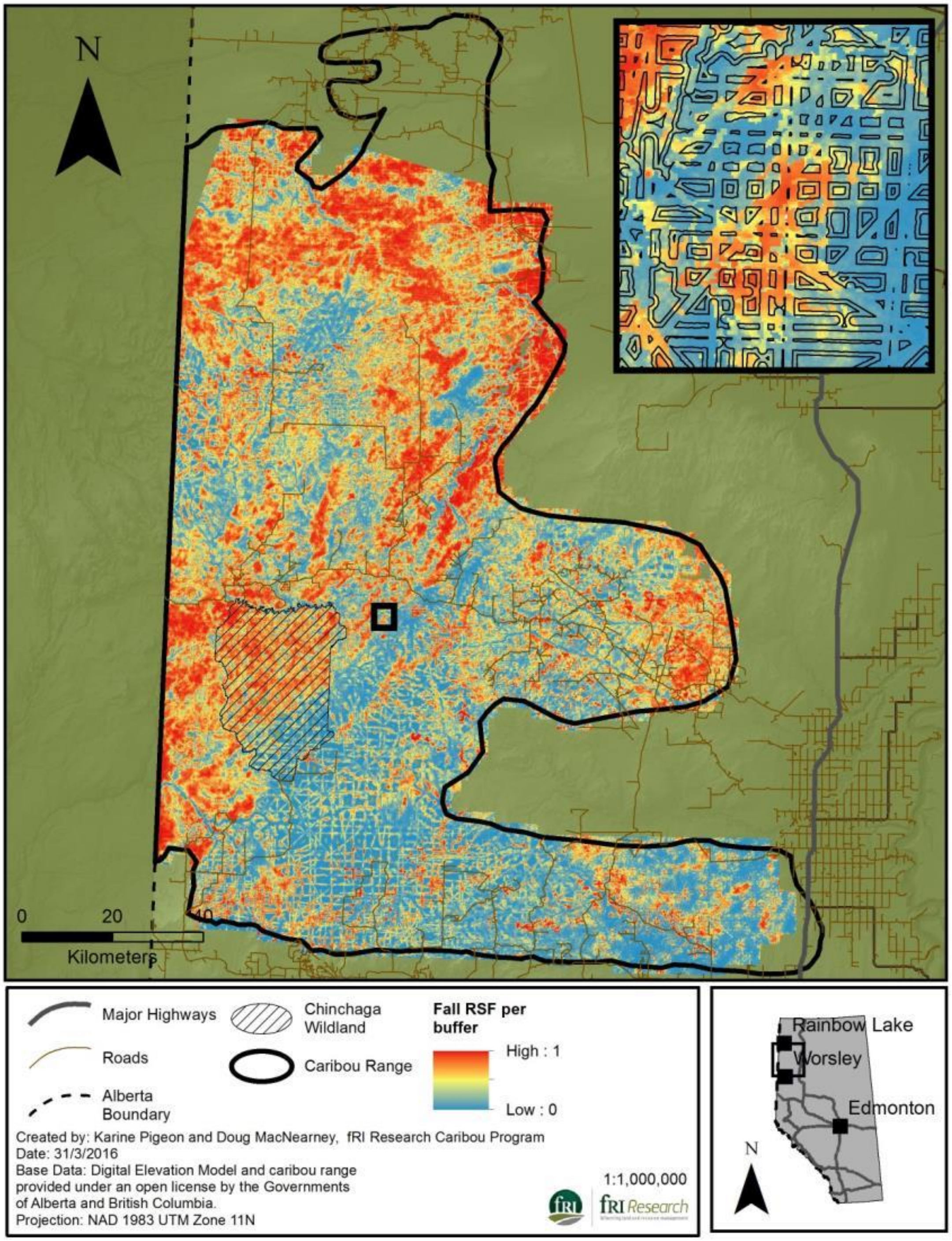


Figure 5.3. Relative probability of selection for boreal caribou during fall (25 September to 6 November) based on the effect of seismic line attributes for caribou locations within 0-62.5m, 62.5-125m, 125-250m, 250-500m, and 500-1000m buffers from seismic lines within in the Chinchaga range, Alberta, Canada between 2007 and 2010 (see Chapter 3).

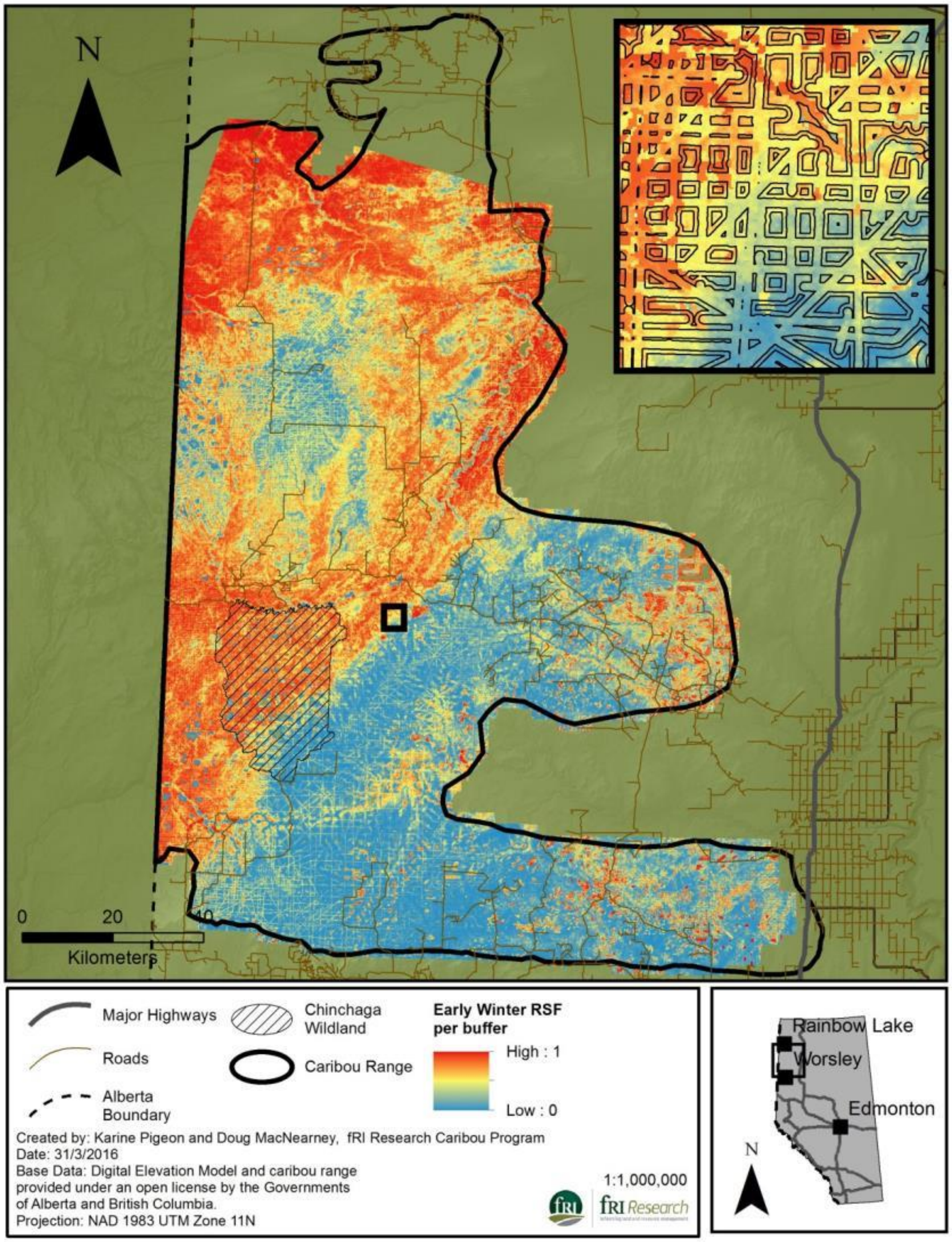


Figure 5.4. Relative probability of selection for boreal caribou during early winter (7 November to 28 January) based on the effect of seismic line attributes for caribou locations within 0-62.5m, 62.5-125m, 125-250m, 250-500m, and 500-1000m buffers from seismic lines within in the Chinchaga range, Alberta, Canada between 2007 and 2010 (see Chapter 3).

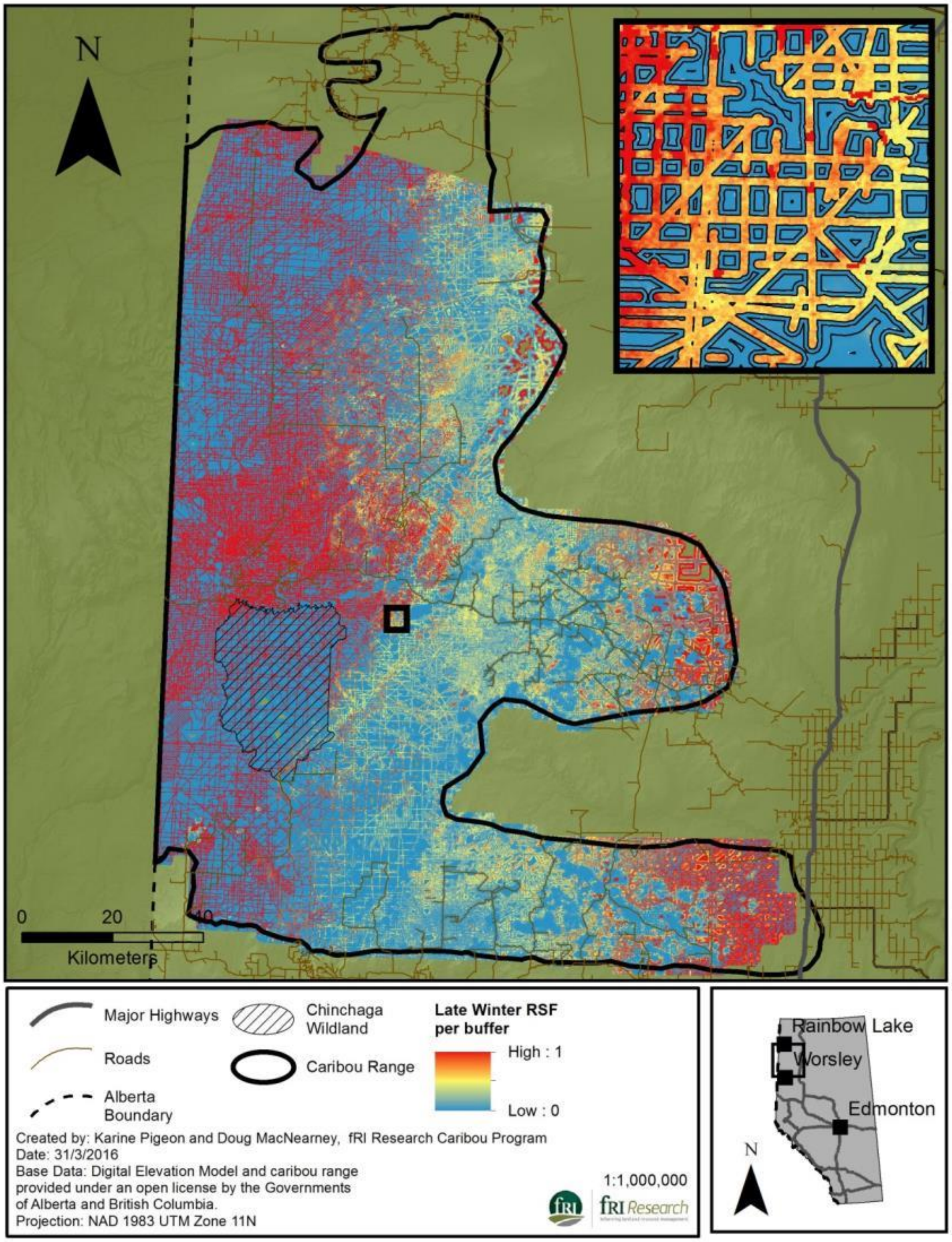


Figure 5.5. Relative probability of selection for boreal caribou late winter (29 January to 8 April) based on the effect of seismic line attributes for caribou locations within 0-62.5m, 62.5-125m, 125-250m, 250-500m, and 500-1000m buffers from seismic lines within in the Chinchaga range, Alberta, Canada between 2007 and 2010 (see Chapter 3).

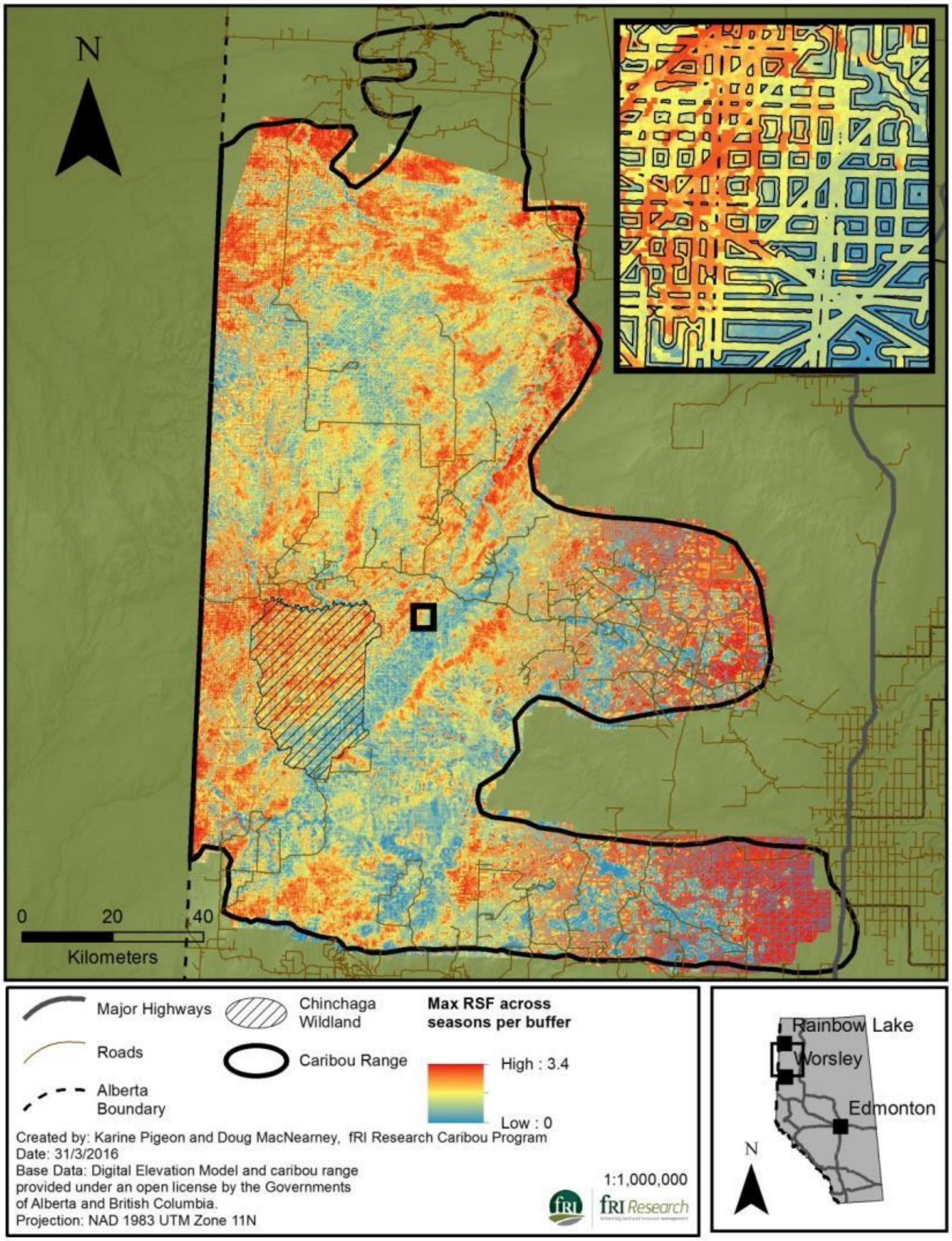


Figure 5.6. Maximum relative probability of selection for boreal caribou across all seasons based on the cumulative effect of seismic line attributes for caribou locations within 0-62.5m, 62.5-125m, 125-250m, 250-500m, and 500-1000m buffers from seismic lines within in the Chinchaga range, Alberta, Canada between 2007 and 2010 (see Chapter 3).

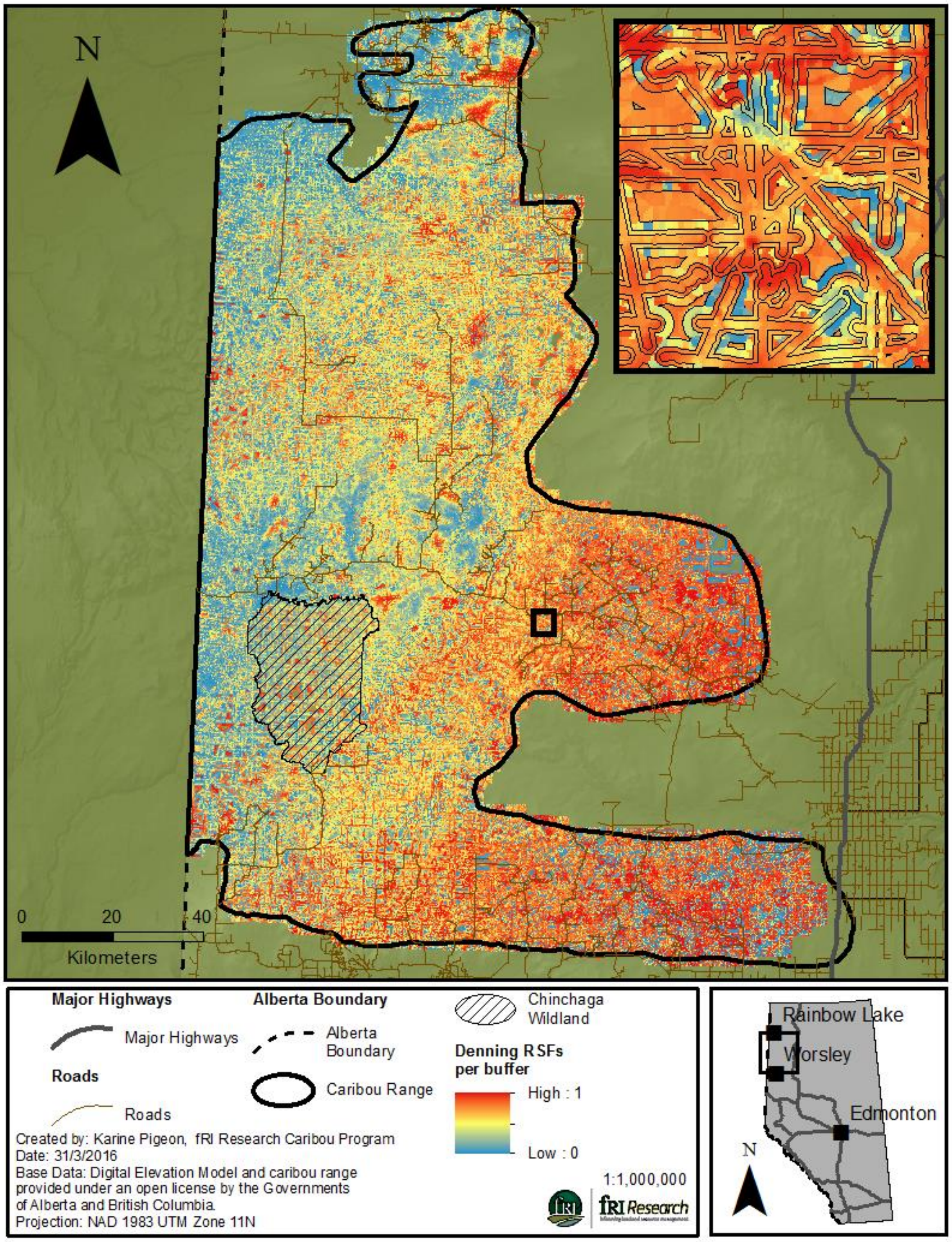
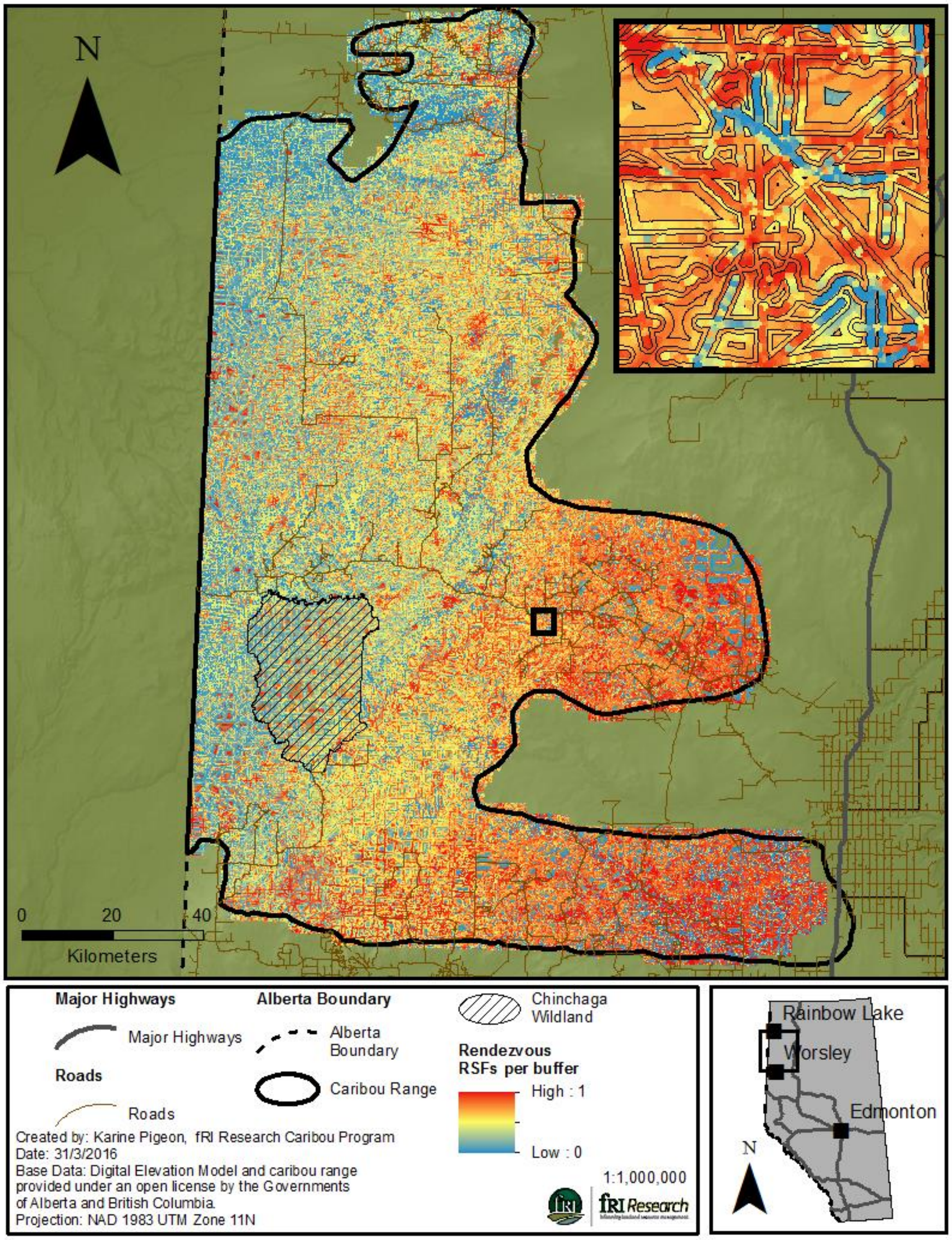
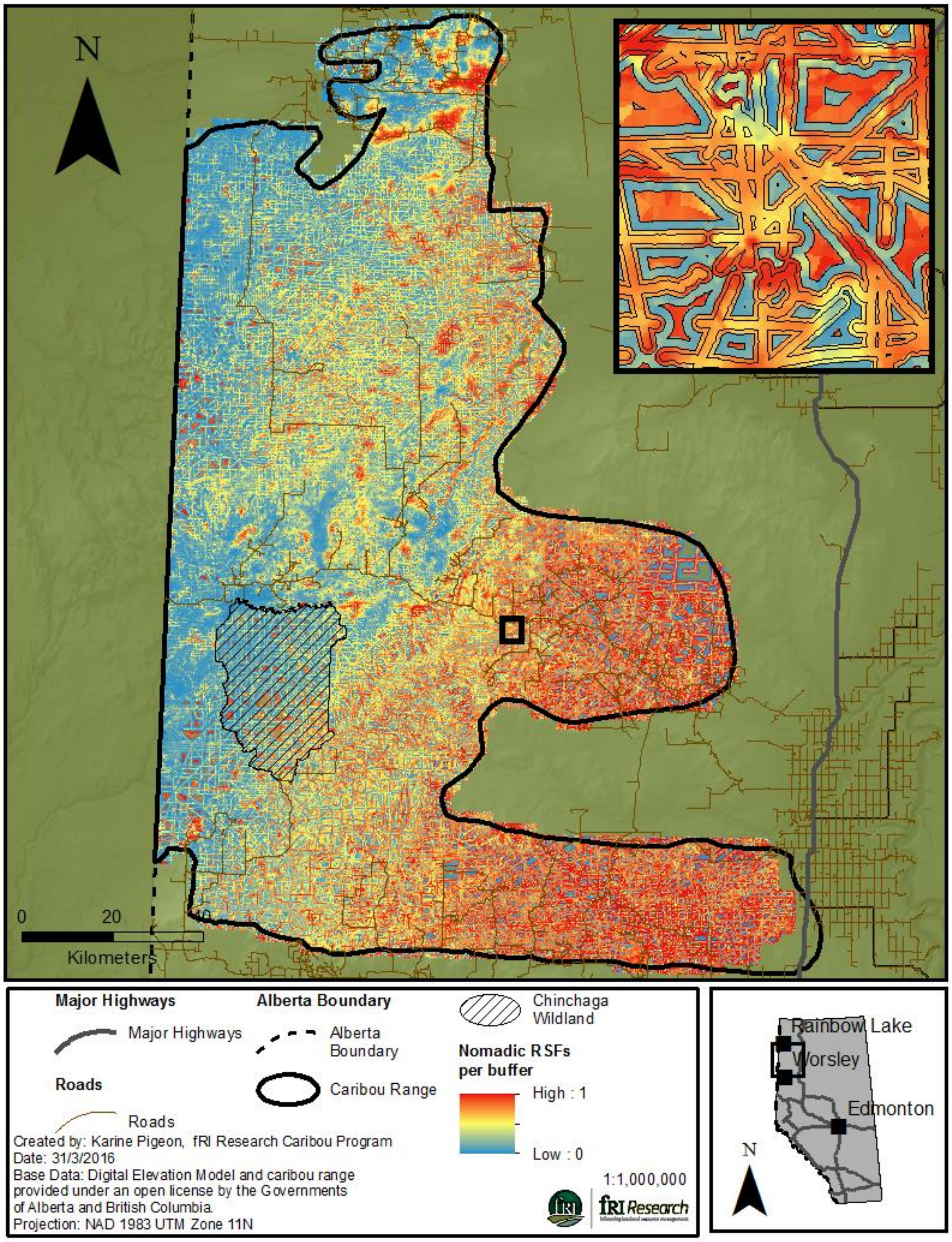


Figure 5.7. Relative probability of selection for wolves during the denning season (20 April to 30 June) based on the effect of seismic line attributes for wolf locations within 0-62.5m, 62.5-125m, 125-250m, 250-500m, and 500-1000m buffers from seismic lines within in the Chinchaga caribou range, Alberta, Canada between 2006 and 2007 (see Chapter 4).



Created by: Karine Pigeon, fRI Research Caribou Program
Date: 31/3/2016
Base Data: Digital Elevation Model and caribou range provided under an open license by the Governments of Alberta and British Columbia.
Projection: NAD 1983 UTM Zone 11N

Figure 5.8. Relative probability of selection for wolves during the rendezvous season (1 July to 20 September) based on the effect of seismic line attributes for wolf locations within 0-62.5m, 62.5-125m, 125-250m, 250-500m, and 500-1000m buffers from seismic lines within in the Chinchaga caribou range, Alberta, Canada between 2006 and 2007 (see Chapter 4).



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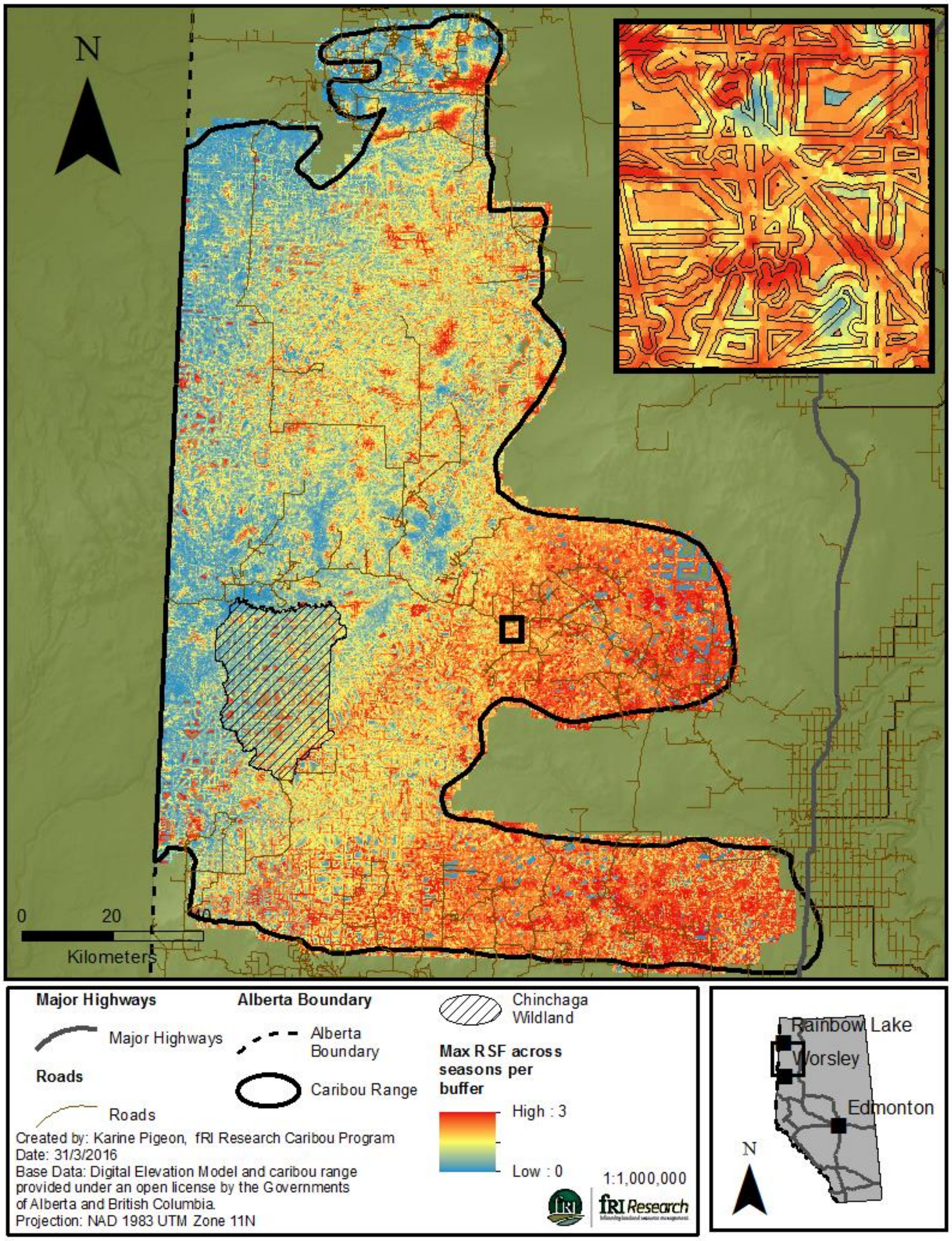
Projection: NAD 1983 UTM Zone 11N

Figure 5.9. Relative probability of selection for wolves during the nomadic season (21 September to 19 April) based on the effect of seismic line attributes for wolf locations within 0-62.5m, 62.5-125m, 125-250m, 250-500m, and 500-1000m buffers from seismic lines within in the Chinchaga caribou range, Alberta, Canada between 2006 and 2007 (see Chapter 4).



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Base Data: Digital Elevation Model and caribou range provided under an open license by the Governments of Alberta and British Columbia.
Projection: NAD 1983 UTM Zone 11N

Figure 5.10. Maximum relative probability of selection for wolves across all seasons based on the cumulative effect of seismic line attributes for wolf locations within 0-62.5m, 62.5-125m, 125-250m, 250-500m, and 500-1000m buffers from seismic lines within in the Chinchaga caribou range, Alberta, Canada between 2006 and 2007 (see Chapter 4).

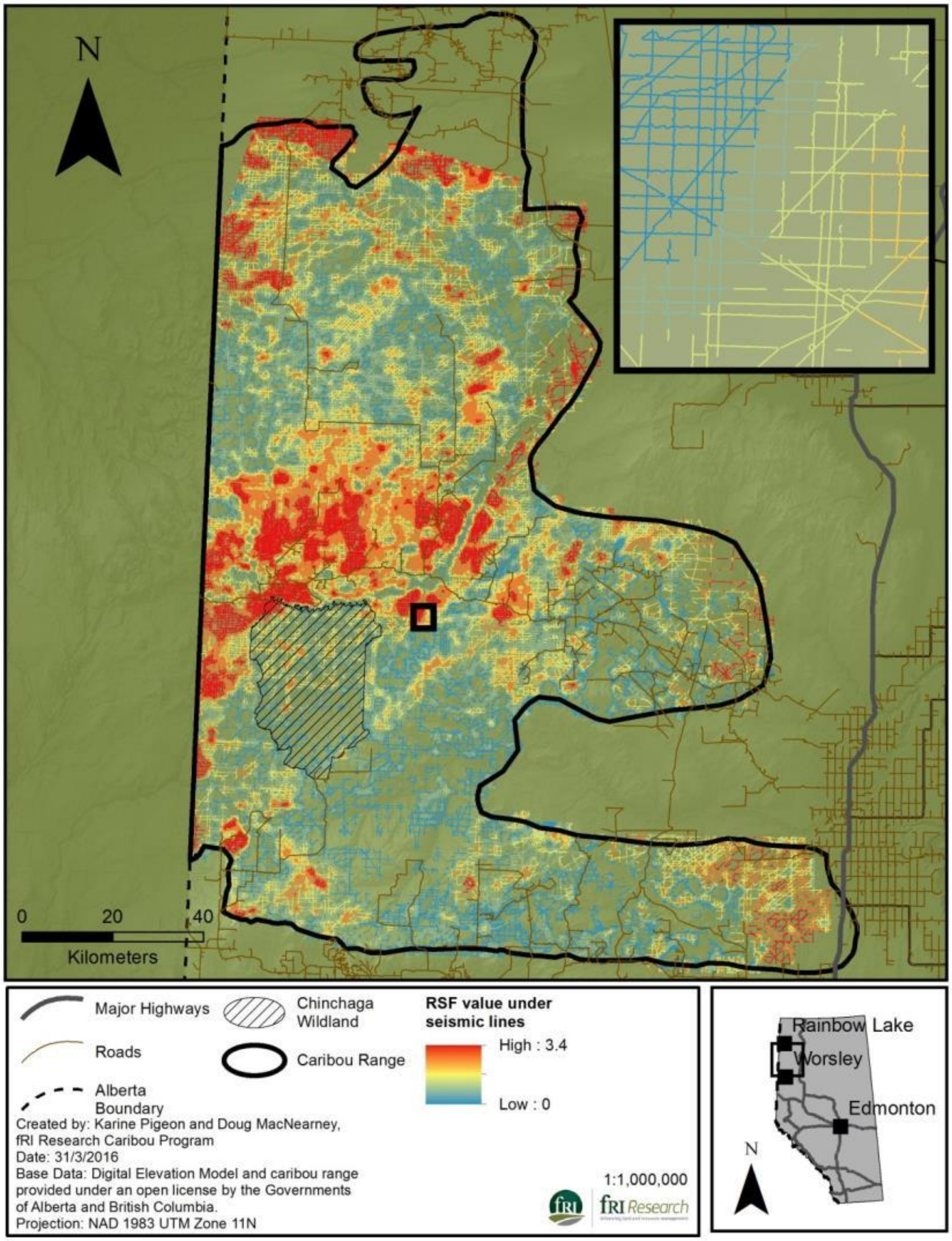

Figure 5.11. Seismic line priority ranking for restoration based on the overlap between the relative probability of selection for wolves and caribou taking into account vegetation heights on seismic lines, seismic line wetness (CTI), landscape and habitat attributes, and anthropogenic factors in the Chinchaga caribou range, Alberta, Canada between 2006 and 2010.

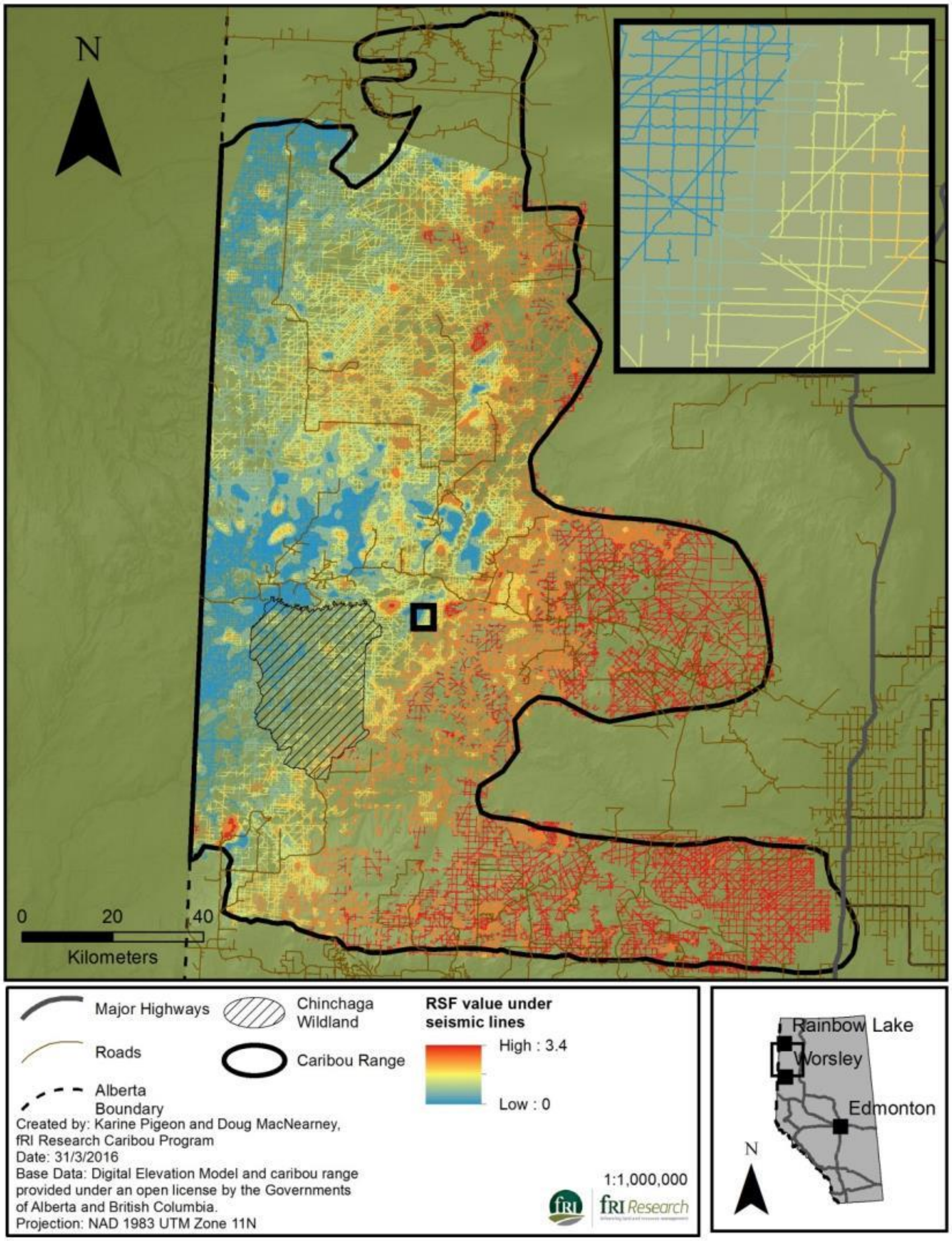

Figure 5.12. Seismic line priority ranking for restoration based on the relative probability of selection for wolves and taking into account vegetation heights on seismic lines, seismic line wetness (CTI), landscape and habitat attributes, and anthropogenic factors in the Chinchaga caribou range, Alberta, Canada between 2006 and 2010.

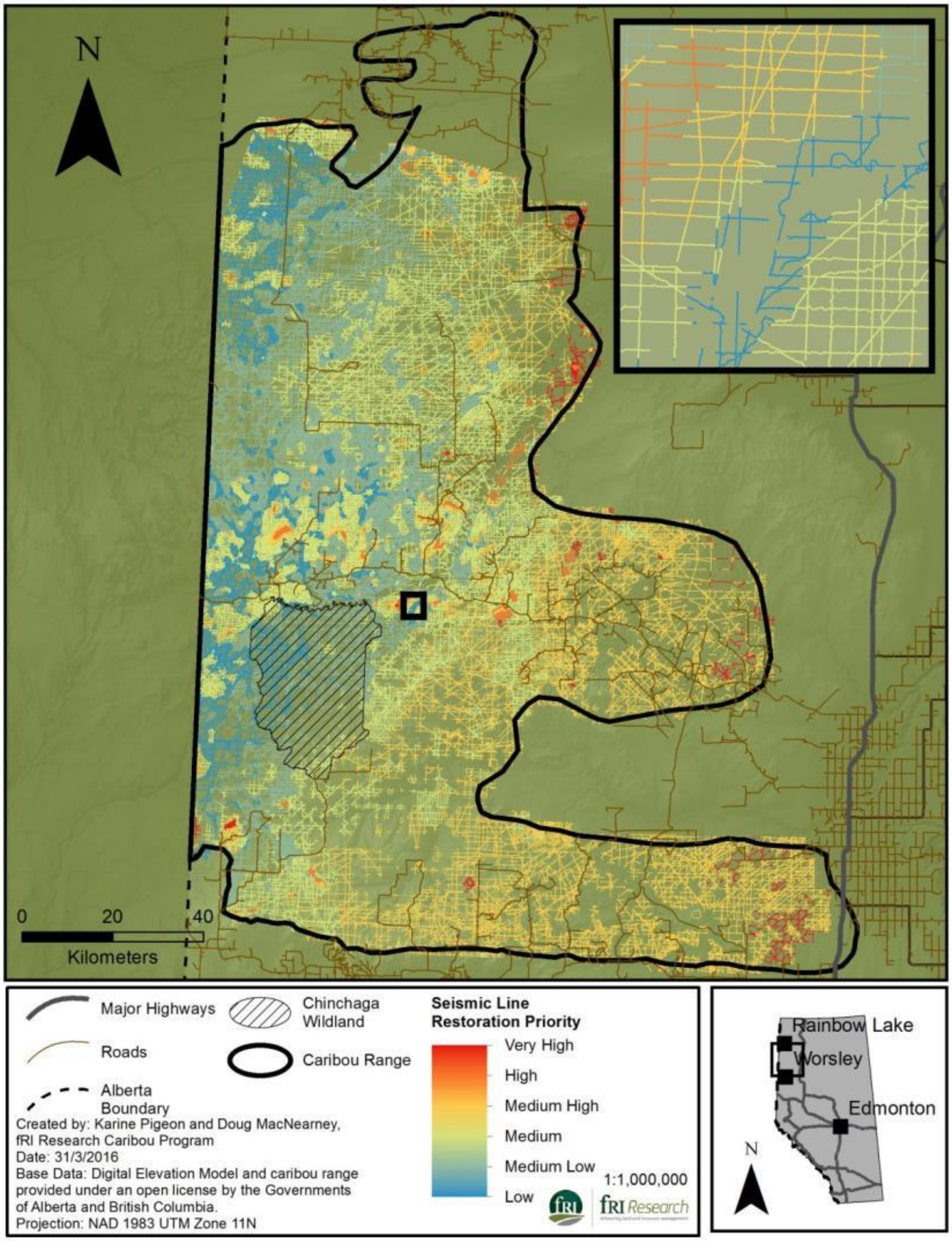

Figure 5.13. Seismic line priority ranking for restoration based on the overlap between the relative probability of selection for wolves and caribou taking into account vegetation heights on seismic lines, seismic line wetness (CTI), landscape and habitat attributes, and anthropogenic factors in the Chinchaga caribou range, Alberta, Canada between 2006 and 2010.

6. Predicting human activity levels on seismic lines and pipelines

Megan Hornseth, Doug MacNearney, and Karine Pigeon

6.1 Introduction

Linear features including seismic lines and pipelines leave a large anthropogenic footprint, increase predation risk, and regenerate slowly: active management of restoration efforts is therefore a necessary component to caribou recovery (James & Stuart-Smith 2000; Lee & Boutin 2006; Sorensen *et al.* 2008). Boreal and central mountain caribou are protected under SARA with a target under the federal boreal recovery strategy to achieve a minimum of 65% undisturbed habitat within the range of each local population (boreal), or within low elevation winter range (central mountain; Environment Canada 2012, 2014). Currently this threshold has been surpassed within many ranges (Komers & Stanojevic 2013). Restoration of linear features is costly and time consuming so a targeted approach to prioritize regeneration is necessary to maximize conservation efforts (Noss *et al.* 2009). A major factor limiting regeneration on seismic lines is human activity; however, intensity of use can differ across the boreal forest.

We developed four hypotheses to explain human activity levels on seismic lines and pipelines based on a literature review and observations of activities on the landscapes. These hypotheses are: Ease of Travel, Recreation, Hunting, and Industry. The ease of travel hypothesis, similar to Pigeon et al. (accepted) [see Finnegan *et al.* 2014 for details] predicts that human activity will be greater on linear features where site and landscape characteristics do not impede access, due to soil wetness, distance to road, or slope. The recreation hypothesis predicts that human activity will be greater on linear features where site and landscape characteristics do not impede access and provide opportunities for recreational activities, such as camping. The hunting hypothesis predicts that human activity will be greater on linear features where there is a greater abundance of ungulates as well as increased proximity to access roads and campsites (Pigeon et al. accepted, van Rensen *et al.* 2015). The industry hypothesis predicts that human activity level is related to industrial activities such as harvest cut block maintenance and oil and gas development (Pigeon et al. accepted). Finally, the global hypothesis includes all variables from the above hypotheses. The variables used in each hypothesis are outlined in Tables 6.1 and 6.2.

6.2 Methods

6.2.1 Field data collection

Using a GIS, we selected linear features (pipelines and seismic lines) that intersected with active roads in the study area (Figure 6.1). We conducted human use surveys from June to October 2014 and 2015. Field crews recorded data on vegetation and topographic variables, and human use level at 3 subplots within each site. Subplots were located at 0m, 100m, and 500m from the access road along each linear feature. We did not sample candidate sites where linear features had been altered or removed due to forestry activities.

6.2.2 GIS data

We combined caribou ranges into three different landscapes based on similar characteristics: The eastern landscape consisted of the Little Smoky and A la Peche ranges, the western landscape consisted of the Red Rock Prairie Creek and Narraway ranges, and the Northern landscape included the Chinchaga range (Figure 6.1). We used LiDAR data collected between 2003 and 2008 and wet areas mapping to calculate the average depth to the water table and mean vegetation height (see White *et al.* 2012; Finnegan *et al.* 2014; MacNearney *et al.* 2015 and Chapter 3 (this report) for details). For each seismic line, vegetation height and depth to the water table was averaged across 100m segments and extracted at each subplot point. We did not estimated vegetation height on pipelines since access is actively maintained and vegetation is removed. We extracted the topographic metrics, slope and elevation, from 30m x 30m resolution digital elevation grids (see Chapter 2 and 3). In the northern landscape where depth to water table was not available, we used the Compound Topographic index (CTI) as a measure of soil wetness, whereby large values are in flat areas, more susceptible to wet soils, and small values indicate areas with steeper slopes that are more likely associated with dry soil types (Moore *et al.* 1991; Gessler *et al.* 2000). At each subplot, we measured distance along roads to the nearest access road intersection, recreational campsite (layer provided by the GoA), and cut blocks (≤ 15 years old) using a least-cost path tool developed in ArcGIS 10.2.2.

We estimated ungulate abundance based on grid count models developed by the fRI Research Grizzly Bear Program (Larsen et al. in prep). These ungulate models were developed using aerial survey data obtained from the Government of Alberta, and zero-inflated negative binomial regression models with species distribution as the response variables, and local environmental conditions representing terrain, vegetation, and anthropogenic features as explanatory variables. (Larsen et al. in prep).

We buffered points by 1261m to create 5km^2 circles centered on each subplot to summarize land cover and anthropogenic disturbances at each site. We used a composite land cover map (Franklin *et al.* 2002a, b; McDermid *et al.* 2009) described in Table 1 and selected upland (Upland Treed, Upland Herb) land cover categories to represent areas with dry and mesic moisture regimes, and lowland (Lowland Treed and Lowland Herb) land cover categories to indicate areas with wet and aquatic moisture regimes. We summarized three anthropogenic features at this scale: well sites (count), seismic line density, and pipeline density.

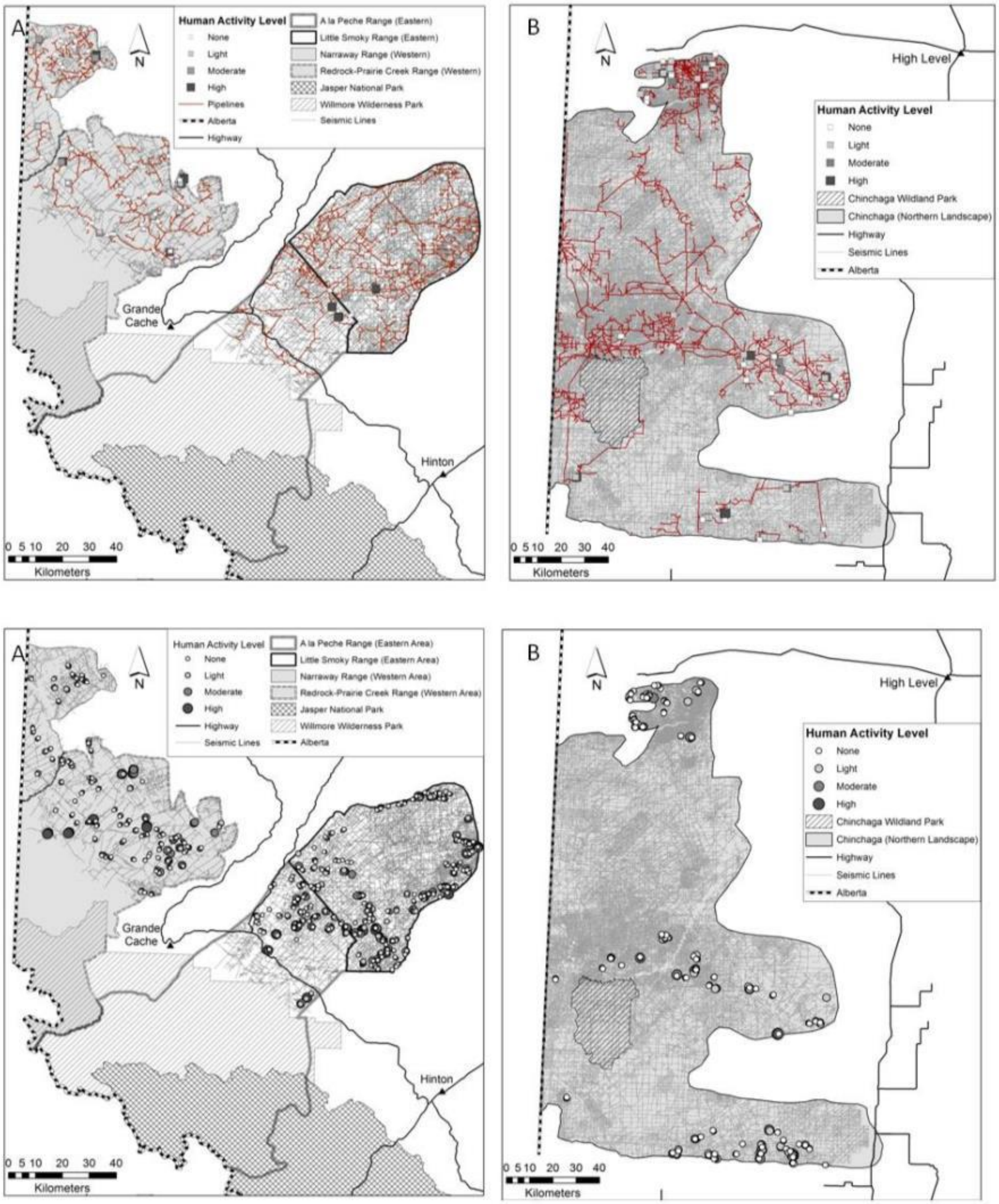

Figure 6.1. Distribution of pipeline (top) and seismic line (bottom) subplots assessed for human activity across A) Eastern and Western Landscapes in west-central Alberta and B) Northern landscape in northern Alberta. Lighter, smaller squares/circles indicate lower activity levels and larger, darker circles indicate higher levels of human activity. Grey lines indicate seismic lines and red lines indicate pipelines.

Table 6.1. Variable description and range of values in each landscape.

Variable Name	Description	Eastern	Western	Northern
Human use	Zero, light, moderate, high[a]	Zero-High	Zero-High	Zero-High
Seismic line attributes				
Depth to Water	The average depth to the water table along seismic line (m)	0.02-71.8	0.01-84.0	-
Vegetation Height	Average vegetation height measured along 100m segments of seismic lines using LiDAR (Seismic line analysis only)	0-8.6	0-5.2	0-12.0
Topography				
Slope	Average slope measured along 100m segments of seismic lines; LiDAR	1.1-26.8	1.3-54.7	0-10.0
Elevation	Elevation (m) at point	865-1663	804-1751	446-1020
CTI	Steady state wetness index used to estimate soil water content (Northern Landscape only)	-	-	-
Landcover[b]				
Upland Trees	>5% tree cover by crown closure, mesic or dry moisture regime	0.2-1.0	0.3-0.9	-
Wetland Trees	>5% tree cover by crown closure, wet or aquatic moisture regime	0-0.5	0-0.2	-
Upland Herb	>5% herbaceous cover, mesic or dry moisture regime	0-0.3	0-0.1	-
Wetland Herb	>5% herbaceous cover, wet or aquatic moisture regime	0-0.3	-	-
Anthropogenic features				
Distance to paved road	Distance to nearest paved road as traveled by vehicle (km)	0-21.3	0-19.3	0-66.5
Distance to campsite	Distance in kilometers to nearest recreational campsite as traveled by vehicle	0.1-114.6	0.4-63.1	0.1-176.9
Seismic Line Density	Density of seismic lines within a $5km^2$ area around the point	1.3-7.9	0.3-5.0	0-15.8
Distance to cut block	Distance in kilometers to nearest forestry cut block as traveled by vehicle	0-53.5	0.5-29.4	0-70.2
Well sites	Count of all well sites within a $5km^2$ area	0-10	0-5	0-10
Pipeline Density	Density of pipelines within a $5km^2$ area around the point	0-2.7	0-2.4	0-5.6
Ungulate counts [b]				
Moose	Moose grid count model	1.5-22.4	1.1-16.4	-
Goat	Goat grid count model	0-0.5	0-3.5	-
Mule deer	Mule deer grid count model	0.3-0.8	0.3-1.0	-
White-tailed deer	White-tailed deer grid count model	0.2-8.5	0.1-14.4	-

[a] Zero: no evidence of human use; Light: some evidence of human use in the past (e.g. overgrown ATV tracks), Moderate: signs of infrequent human use (e.g. ATV tracks that are lightly overgrown), High: signs of frequent heavy human use (e.g. heavily used ATV tracks, no vegetation on tracks, potentially deep ruts).

[b] Land cover attributes measured as the proportion within a $5km^2$ area around the point.

[c] Larsen et al. *in prep*.

Table 6.2. Variable name and inclusion by hypothesis. A indicates the variable was included in all landscapes, W indicates the variable was only available for the west-central region of Alberta, N indicates it was used only in the Northern landscape. The global model included all variables.

Variable Name	Ease of Travel	Recreation	Hunting	Industry
Human use	*W*	*W*	*W*	*W*
Depth to Water	*W*	*W*	*W*	
Vegetation Height	*A*	*A*	*A*	
Slope	*A*	*A*	*A*	
Elevation		*A*	*A*	
CTI	*N*	*N*	*N*	
Upland Trees[a]	*W*	*W*		
Wetland Trees[a]	*W*	*W*		
Upland Herb[a]	*W*	*W*		
Wetland Herb[a]	*W*	*W*		
Distance to paved road	*A*	*A*	*A*	
Distance to campsite		*A*	*A*	
Seismic Line Density		*A*	*A*	*A*
Distance to cut block				*A*
Well sites				*A*
Pipeline Density				*A*
Moose			*W*	
Goat			*W*	
Mule deer			*W*	
White-tailed deer			*W*	

[a] Land cover attributes measured as the proportion within a 5km^2 area around the point.

6.2.3 Data analysis

To assess the relationship among four levels of human activity (zero, light, moderate, and high) to variables associated with each of the hypotheses (Table 6.2), we used ordinal linear mixed models (OLMMs) from the R package ‘vcrpart’ (Bürgin 2015). OLMMs are based on multivariate generalized linear mixed models and are a useful approach for ranked, clustered data. This approach utilizes varying coefficients to relate the linear effects of covariates to human activity levels (Bürgen & Ritschard 2015). OLMMs are appropriate for this dataset because the relationship between variables differs within different activity levels and does not meet the assumption of parallel slopes within ordinal logistic regression. We used the cumulative link function to compare the probability of the highest activity category to the probability of lower categories. This reverses the coefficients in comparison to other regression methods.

We used plot ID (PlotID) as a random effect to account for spatial autocorrelation among subplots (Bolker *et al.* 2009). We did not include observer or season in models because they were found to be non-significant in previous analyses (Pigeon et al. accepted). We used Akaike Information Criterion (AIC) to compare competing hypotheses and assess the goodness-of-fit. When a significant top-model was identified, non-significant variables were removed from the model using step-wise removal procedures because our goal was to predict levels of human activity, not create explanatory models. Additionally, where possible we split the data into training (85%) and validation data (15%). The training data was used to create the model and the validation data was used to evaluate the model's ability to predict activity level based on landscape characteristics using new data.

We used post-hoc piecewise regression on the final models to determine breakpoints in mean vegetation height where the relationship between the probability of zero human activity and the probability of high activity levels changed. These breakpoints can be used to determine thresholds in mean vegetation height where human activity changes. We used linear regression on the probability of zero human activity and high human activity in relation to mean vegetation height to determine the breakpoints for the eastern and western seismic line top models. We used the piecewise.regression function from the 'SiZer' package in R with 1000 bootstrap replicates and α = 0.05 (Sonderegger 2012; R Development Core Team 2015). We conducted all statistical analyses in program R (R v 3.2.3, R Development Core Team 2015).

6.3 Results

Sampling intensity differed across the three landscapes and by linear feature type (i.e. pipelines vs. seismic lines; Figure 6.1). Human activity was generally higher on pipelines than on seismic lines (Table 6.3). In the eastern landscape, 14.5% of the pipeline subplots were classified as high level of human activity vs. 4% of seismic lines classified into this same category. On the northern landscape, 8% of pipeline subplots had high levels of human activity while only 2% of seismic lines were classified as high human activity. On the western landscape, high levels of human activity were more equal across linear feature type with 5% of pipelines and seismic lines classified as high level of human activity. Additionally, seismic lines were more likely to have zero human activity on any landscape when compared to pipelines. 60-72% of seismic lines had zero activity in comparison to 45% to 59% of pipelines (Figure 6.2).

Table 6.3. Distribution of subplots sampled on pipeline and seismic lines across 5 ranges in 3 landscapes. The percent of the total number of subplots in each category is in parentheses. Little Smoky and A la Peche ranges were combined to form the eastern landscape, Red Rock Prairie Creek and Narraway were combined to form the western landscape, the northern landscape consists of the Chinchaga range.

Activity Level	**Eastern**	**Western**	**Northern**
Pipelines			
None	36 (58.1%)	110 (58.5%)	52 (45.2%)
Light	9 (14.5%)	49 (26.1%)	40 (34.8%)
Moderate	8 (12.9%)	19 (10.1%)	14 (12.1%)
High	9 (14.5%)	10 (5.3%)	9 (7.8%)
Total Subplots	*62*	*188*	*115*
Total Plots	*31*	*71*	*41*
Seismic lines			
None	385 (60.3%)	208 (71.2 %)	190 (71.7%)
Light	172 (26.9%)	47 (16.1%)	51 (19.2%)
Moderate	57 (8.9%)	22 (7.5%)	18 (6.8%)
High	25 (3.9%)	15 (5.1%)	6 (2.2%)
Total Subplots	*639*	*292*	*265*
Total Plots	*281*	*104*	*110*

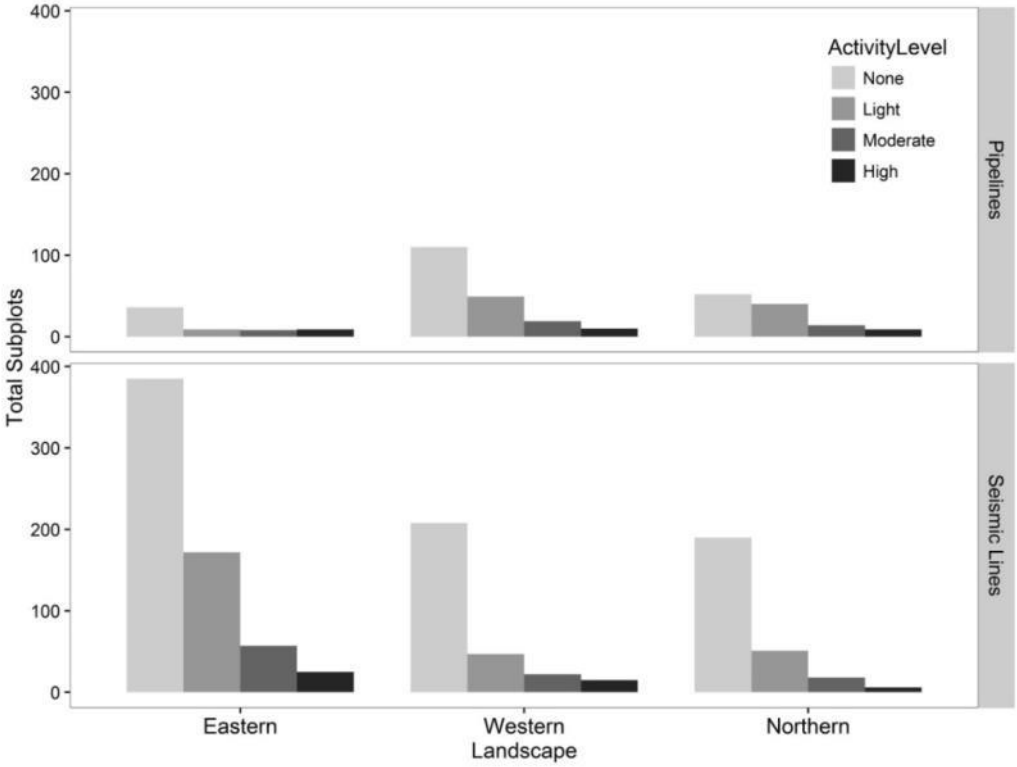

Figure 6.2. Number of subplots by activity level summarized by landscape for pipelines and seismic lines.

6.3.1 Human activity levels on pipelines

On the western landscape, the recreation model best described human activity levels on pipelines (Table 6.4). However, this model explained only a small part of the variation in the data when compared to the null model (ΔAIC 6.5). Using step-wise removal procedures, human activity levels were more closely related to elevation and distance to campsite, whereas the probability of increased human activity was higher on pipelines at higher elevations and further from recreational campsites (Table 6.5). On the northern and eastern landscapes, the variables assessed did not explain variations in human activity on pipelines and the null model was the top model (Table 6.4).

Table 6.4. Model selection results of human activity levels on pipelines in the eastern, western, and northern landscapes. A global model was not possible for the eastern landscape due to high multicollinearity.

Landscape	*Hypothesis*	*AIC*	*ΔAIC*	*# of Variables*
Eastern	*Null*	*123.5*	*0*	*1*
	Hunting	128.8	5.5	3
	Recreation	130.0	6.5	5
	Travel	132.7	9.2	4
	Industry	132.8	9.3	5
Western	Recreation	295.9	0	7
	Hunting	297.1	1.2	7
	Industry	302.1	6.2	6
	Null	*302.4*	*6.5*	*1*
	Global	303.6	7.7	12
	Industry	132.8	9.3	5
Northern	*Null*	*243.6*	*0*	*1*
	Travel	248.8	5.3	3
	Industry	249.3	5.7	6
	Recreation	250.9	7.3	5
	Global	252.8	9.2	10

Table 6.5. Parameter estimates (β), standard errors (SE), Z statistic, and p value for the variables in the final model for the western landscape.

	β	**SE**	**Z statistic**	**p value**
Variables				
Distance to Campsite	1.30	0.43	3.20	<0.001
Elevation	1.46	0.63	1.72	0.085
Thresholds				
1|2	0.61	0.42	1.45	-
2|3	4.82	0.75	6.45	-
3|4	8.84	1.19	7.42	-

6.3.2 Human activity levels on seismic lines

6.3.2.1 Eastern landscape

In the eastern landscape, the global model was the top model and had 15 variables after checking for collinearity (Table 6.6). This model was revised using step-wise removal procedures to include only 3 variables: mean vegetation height, proportion of upland herb, and white-tailed deer grid count. Human activity levels were highest on seismic lines with low vegetation heights, low proportions of upland herb and high white-tailed deer grid counts (Table 6.7).

The overall correct classification rate of the top model was 0.62 (range: 0.33-0.81) for the model evaluation data (Table 6.8A). This model correctly classified 81% of the zero human activity evaluation plots and 67% of evaluation plots with high levels of human activity. All misclassifications except 2 were predicted to be within one class of the actual activity level. The overall correct classification rate for all of the data was 0.72 (range: 0.49-0.93; Table 6.8B). In this case, the top model correctly classified 93% of the plots with zero human activity, 78% of the plots with light human activity, and 68% of the plots with high human activity. This model poorly predicted the moderate activity levels, correctly predicting only 49% of all the moderate plots; of these misclassifications, over half of the moderate plots were predicted as light activity.

Table 6.6. Model selection results of human activity levels on seismic lines in the eastern, western, and northern landscapes.

Landscape	Hypothesis	AIC	ΔAIC	# of Variables
Eastern	Global	1055.1	0	15
	Recreation	1056.9	1.8	10
	Travel	1057.9	2.8	8
	Hunting	1061.9	6.8	9
	Industry	1063.8	8.7	6
	Null	*1065.5*	*10.4*	*1*
Western	Global	372.8	0	14
	Hunting	375.9	2.5	9
	Recreation	381.3	14.9	9
	Null	*385.9*	*15.4*	*1*
	Travel	389.4	15.8	7
	Industry	389.0	18.5	6
Northern	Travel	362.9	0	4
	Null	*364.6*	*1.7*	*1*
	Recreation	365.8	2.9	5
	Global	371.5	8.6	8
	Industry	371.5	8.6	6

Table 6.7. Parameter estimates (β), standard errors (SE), Z statistic, and p values for the variables in the final model to predict human activity levels on seismic lines in the eastern landscape.

Variables	β	SE	Z statistic	p value
Mean Vegetation Height	1.07	0.22	5.00	<0.001
Upland Herb	0.62	0.28	2.21	0.027
White-tailed Deer	-0.74	0.29	-2.57	0.010
Thresholds	**β**	**SE**	**Z statistic**	
1|2	1.18	0.30	3.92	
2|3	4.71	0.42	11.20	
3|4	7.49	0.65	11.53	

Table 6.8. Cross tabulation of predicted activity class and observed activity class for the eastern landscape for (A) model evaluation data only and (B) all data.

		None	Light	Moderate	High	Number of plots
		Predicted Activity Class				
Observed Activity Class	**A. Evaluation data**					
	None	52	11	0	1	64
	Light	8	20	2	0	30
	Moderate	0	5	3	1	9
	High	1	0	0	2	3
	Correct Classification Rate	*0.81*	*0.67*	*0.33*	*0.67*	*98*
	B. All Data					
	None	359	25	0	1	384
	Light	33	135	4	0	172
	Moderate	3	23	28	3	57
	High	1	1	6	17	25
	Correct Classification Rate	*0.93*	*0.78*	*0.24*	*0.68*	*639*

6.3.2.2 Western landscape

In the western landscape, the top model was the global model and had 14 variables after checking for collinearity (Table 6.6). This model was revised using step-wise procedures to include only 6 variables. These variables were mean vegetation height, density of seismic lines, mule deer grid count, distance to nearest paved road, number of well sites within an area of 5 km^2, and distance to nearest campsite. The probability of higher human activity decreased with vegetation height, seismic line density, well site counts, and distance to campsites whereas the probability of higher human activity increased with distance to paved road and mule deer grid counts (Table 6.9).

The overall correct classification rate of this model was 0.82 (range: 0.50-1.00) for the model evaluation data and 0.86 (range: 0.51-1.00) for all of the data (Table 6.10). This model correctly classified 86% of the zero and light human activity evaluation plots, 50% of the moderate plots, and all of the high use evaluation plots. However, there were only 4 moderate plots and 1 high activity plot in the evaluation dataset. When applied to the full dataset, this model correctly classified 95% of the plots with zero human activity, 68% of the plots with light human activity, 64% of the moderate use plots, and 87% of the plots with high human activity (Table 6.10B).

Table 6.9. Parameter estimates (β), standard errors (SE), Z statistic, and p value for the variables in the final model for the western landscape.

	β	SE	Z statistic	p value
Variables				
Mean Vegetation Height	0.94	0.43	2.18	0.029
Seismic Line Density	1.46	0.63	2.32	0.020
Mule deer	-1.87	0.36	-5.22	<0.001
Distance to Paved Road	-0.49	0.14	-2.41	0.016
Well site density	0.66	0.25	2.11	0.035
Distance to campsite	0.12	0.04	3.08	0.002
Thresholds				
1|2	3.19	0.75	4.28	-
2|3	6.87	1.22	5.65	-
3|4	10.31	1.83	5.64	-

Table 6.10. Cross tabulation of predicted activity class and observed activity class for the western study landscape for (A) model evaluation data only and (B) all data.

		None	**Light**	**Moderate**	**High**	**Number of plots**
		Predicted Activity Level				
Observed Activity Level	**A. Evaluation data**					
	None	19	2	1	0	22
	Low	1	6	0	0	7
	Moderate	1	0	2	1	4
	High	0	0	0	1	1
	Correct Classification Rate	*0.86*	*0.86*	*0.50*	*1.00*	*34*
	B. All Data					
	None	198	8	2	0	208
	Low	13	32	2	0	47
	Moderate	1	6	14	1	22
	High	0	0	2	13	15
	Correct Classification Rate	*0.95*	*0.68*	*0.64*	*0.87*	*292*

6.3.2.3 Northern landscape

On the northern landscape, the east of travel model best described human activity on seismic lines (Table 6.6). However, this model is only slightly better than the null model (ΔAIC 1.7). Using step-wise removal procedures in this model resulted in only one significant variable, CTI. Human activity levels were higher on areas with lower CTI values (Table 6.11).

Table 6.11. Parameter estimates (β), standard errors (SE), Z statistic, and p value for the variables in the top model for human activity use on seismic lines in the northern landscape. CTI is the compound topographic index, an estimate of soil wetness.

	β	**SE**	**Z statistic**	**p value**
Variable				
CTI	0.42	0.25	1.68	0.09
Thresholds				
1|2	1.64	0.39	4.25	
2|3	3.97	0.48	8.23	
3|4	6.25	0.88	7.06	

6.3.3 Post-hoc piecewise regression

We completed post-hoc piecewise regressions on both the eastern and western landscapes to examine the relationship between human activity levels on seismic lines and mean vegetation height. On the eastern landscape, the relationship between vegetation height and the probability of human activity being zero changed at a vegetation height of 2.7m whereas the breakpoint between vegetation height and the probability of high level of human activity was at 1.7m (Figure 6.3). On the western landscape, the relationship between vegetation height and the probability of human activity being zero changed at a vegetation height of 4.1 m whereas the breakpoint between vegetation height and a probability of high level of human activity was at 1.0m (Figure 6.4).

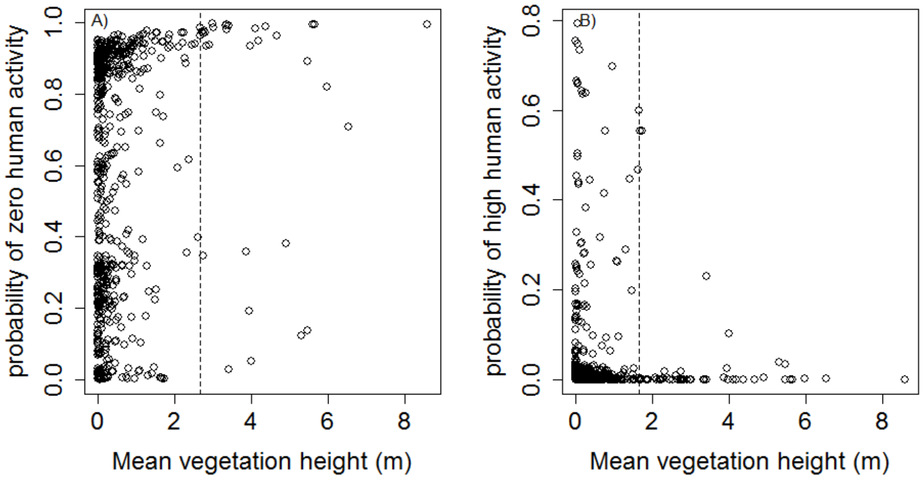

Figure 6.3. Probability of human activity levels being (A) 'Zero' and (B) 'High' as a function of vegetation height from LiDAR on the eastern landscape using ordinal linear mixed model with a cumulative link function (Table 6.7). The vertical dashed lines represent the mean vegetation height where the probability of human activity being zero (2.7m; panel A) and the probability of high levels of human activity (1.7m, panel B) changed in relation to vegetation height according to post-hoc piecewise regression.

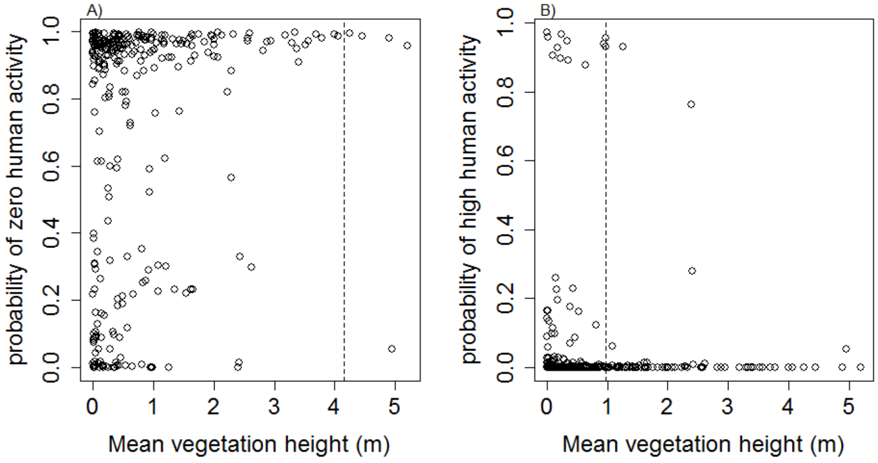

Figure 6.4. Probability of human activity levels being (A) 'Zero' and (B) 'High' as a function of vegetation height from LiDAR on the western landscape using ordinal linear mixed model with a cumulative link function (Table 9). The vertical dashed lines represent the mean vegetation height where the probability of human activity being zero (4.1m; panel A) and the probability of high levels of human activity (1.0m, panel B) changed in relation to vegetation height according to post-hoc piecewise regression.

6.4 Discussion

Our results show that human activity patterns are not consistent across landscapes in the boreal forest, or across linear feature type (seismic lines vs. pipelines). Generally, we found less evidence of high levels of human activity on seismic lines than on pipelines. However, activity levels on pipelines were poorly explained by GIS variables. The western landscape was the only landscape that had a significant model explaining human activity levels on pipelines. On this landscape, human activity was weakly related to elevation and distance to campsites, where pipelines at lower elevations and closer to campsites had an increased probability of human activity. This model was not strong enough to predict patterns of human activity on evaluation plots. On the other two landscapes, the null model was the top model, indicating that patterns of human activity were not well explained by *a* priori hypotheses with the available GIS variables. Poor model performance could be due to a number of factors including sampling distribution and limited GIS data.

In contrast, we were able to develop models to predict human activity on seismic lines for 2 of the 3 landscapes. These models predicted human activity levels on 62% and 82% of evaluation plots (data not used in model development) on the eastern and western landscapes, respectively. Both models had higher predictive ability on the extremes of human activity levels. The eastern model correctly predicted 81% of evaluation plots with zero human activity and 67% of plots with high levels of human activity. The western model correctly predicted 86% of evaluation plots with zero human activity and the only evaluation plot with a high level of human activity. On both landscapes, human activity levels were higher in areas with increased ungulate grid counts (mule deer on the western landscape, white-tailed deer on the eastern landscape), and lower vegetation heights. van Rensen *et al.* (2015) found that seismic line regeneration was slower on features with vegetation heights less than 3m, and Pigeon et al. (accepted) found that off-highway vehicle use was minimal when field measurements of vegetation reached a height of 2.4 to 4.3m. This is consistent with our results suggesting that human activity levels decline when mean vegetation height reaches between 1.0 and 4.1m, as determined from LiDAR. There were additional factors affecting the probability of human activity on each landscape (Tables 6.7 and 6.9). The global model was the top model on both landscapes, indicating that human activity is a product of a multitude of factors related to ease-of-travel, recreation, hunting, and industry.

On the northern landscape, human activity on seismic lines was only related to CTI, where the probability of increased human activity levels was related to lower CTI values. This relationship indicates that the probability of human activity was greater in dry locations on the landscape. However, this model was not strong enough to accurately predict human use on evaluation data. Still, this result is consistent with previous studies (MacNearney *et al.* 2015; van Rensen *et al.* 2015). Unfortunately, there were a more limited number of GIS variables available to assess level of human activity on the northern landscape. Unavailable data layers included depth to the water table (CTI was used as a substitute), and ungulate grid count model information. Additionally, land cover was only available for 70% of the subplots. However, because preliminary analyses on this subset of data showed that there were no significant relationships between the land cover variables and human activity levels on either the pipelines or seismic lines, it is unlikely that the lack of landcover data for some of our plots was limited our models. The northern landscape is located in the upper and lower boreal highland subregions, whereas the western and eastern landscapes are located in the upper foothills and subalpine subregions (Natural Regions Committee 2006). Patterns of human activity across these landscapes are driven by different factors. In the northern landscape, human activity is primarily industrial in nature, and road access is limited, whereas in the eastern and western landscapes human activity is driven by a combination of factors including tourism, hunting, recreation, and industrial uses.

7. Non-invasive monitoring of caribou in west-central Alberta

Laura Finnegan

7.1. Introduction

Fecal pellets are a non-invasive method to collect information on caribou herd size and growth rates, health, herd demographics and socio-genetics, and to assess health through the measurement of stress and pregnancy hormones (Ball 2010; Ball *et al.* 2010; Polfus & Heinemeyer 2011; Hettinga *et al.* 2012; Flasko 2014). For declining populations of woodland caribou in Alberta (Hervieux *et al.* 2013), fecal pellets provide opportunities to establish baselines for health monitoring as recovery actions are implemented, and to address direct and indirect factors that may negatively impact caribou population health and contribute to population decline. Fecal pellet surveys can also complement health data collected during collaring efforts and necropsies (fRI Research Caribou Program ongoing research) by extending sampling to a larger proportion of individuals in the population and removing bias due to sex and age. Additionally, fecal samples offer a relatively low-cost opportunity to validate calf-cow and gender ratios collected via sight-based population surveys conducted by Alberta Environment and Parks.

Here we describe the results of preliminary analysis of fecal morphology and hormones measured from fecal pellets that were collected non-invasively across west-central Alberta in the winters of 2014 and 2015. Fecal morphology has previously been used to distinguish between young and adult caribou (Morden 2010; Ball 2010; Flasko 2014), and may therefore contribute towards our knowledge of west-central herd demographics. For hormone analysis, we focused on four key hormones that have previously been used to measure stress levels in caribou (cortisol and corticosterone), and to assess reproductive status (progesterone and testosterone). Cortisol and corticosterone measurements are increasingly used in wildlife research as indices of overall health, and can provide an understanding of how stressors can affect the overall survival and reproductive success of wildlife. For mammals, one of the main physiological responses to stressors is the activation of the hypothalamic-pituitary-adrenal (HPA) axis which produces glucocorticoids (GC; [cortisol and corticosterone], Reeder & Kramer 2005). Short term elevated concentrations of GC allow the animal to escape from stressors (Wingfield *et al.* 1998), however chronic activation of the HPA, and corresponding long-term elevated GC concentrations may have negative effects including suppression of digestion, reproduction, and the immune response (Boonstra *et al.* 1998; Blas *et al.* 2007; Sheriff *et al.* 2010a). Recent research has found that fecal GC values reflect true baseline hormone levels, and are also indicative of an animal's stress response (Sheriff *et al.* 2011). Fecal GCs like cortisol and corticosterone are therefore ideal to assess exposure of caribou to long term environmental stressors (Sheriff *et al.* 2010b), and can be used to assess the indirect effects of anthropogenic activities upon caribou (Freeman 2008).

For caribou, one of the main drivers behind population declines is low levels of recruitment (Hervieux *et al.* 2013). The immediate threat to caribou recruitment is elevated levels of predation because of habitat-disturbance-driven increases in predator densities and distribution within caribou ranges (Latham *et al.* 2011c; Hervieux *et al.* 2013, 2014). However, habitat disturbance may also have more subtle effects upon caribou. For example, chronic elevated GC levels may suppress reproductive hormones and may ultimately negatively affect reproductive rates (Sheriff *et al.* 2011). Monitoring levels of reproductive hormones during winter (mid and late gestational period) will provide valuable information on the reproductive potential of west-central caribou. In addition, comparison of pregnancy rates during winter to calf:cow counts during the following fall will provide indices of the potential and realised recruitment rate in west-central caribou herds. Monitoring pregnancy rates and calf survival over time will allow land managers to evaluate the success of recovery actions implemented under the federal recovery strategies. To assess female reproduction, we used the hormone progesterone. Progesterone concentrations are associated with either the luteal phase in cycling females (September - February), or with pregnancy (October - June), and have previously been used to evaluate the pregnancy rates within caribou herds (Polfus & Heinemeyer 2011). In males, we measured the hormone testosterone. Elevated testosterone concentrations are associated with breeding season and sexual maturity in males (Whitehead & West 1977), and in young males, lower values may be indicative of nutritional stress (Ryg 1984). Testosterone levels may also be used to distinguish between young and adult males, thus contributing towards our knowledge of herd demographics (Flasko 2014).

Our objective for this part of the project was to use non-invasive fecal DNA collections to determine the relationship between regeneration and activity status of anthropogenic disturbances and the distribution, size, and health of caribou herds in west-central Alberta. However, because the field data collection for this work is carried out over the winter, here we present preliminary analysis and results using data collected during the first two winters of our fecal surveys. Once the genetic and hormone laboratory work is completed (summer 2016 to winter spring 2017) we will provide a final report in the spring of 2017 that will detail the final results of analysis addressing our research objective.

7.2 Methods

7.2.1. Study area

The study area included the range of four caribou herds in west-central Alberta (Little Smoky, A La Peche, Redrock-Prairie Creek and Narraway; Figure 7.1). Little Smoky caribou are boreal caribou, occur in the forest year round, and show little or minimal seasonal shifts in home range (Festa-Bianchet *et al.* 2011a). Boreal caribou are listed as threatened under Alberta's Wildlife Act, COSEWIC (2002), and the Species at Risk Act (SARA). A federal recovery strategy for this ecotype was released in 2012 (Environment Canada 2012). The A La Peche, Redrock-Prairie Creek, and Narraway herds are central mountain caribou. These caribou undertake short migrations from summer and calving ranges at high elevations to winter ranges at lower elevations (Festa-Bianchet *et al.* 2011). Central mountain caribou are listed as threatened under the Alberta Wildlife Act and SARA and are listed as endangered by COSEWIC (2014).

The range of these caribou herds spans two forest ecozones (boreal and montane cordillera), three natural regions (boreal, foothills and rocky montains), and seven natural sub-regions (lower boreal highlands, upper boreal highlands, lower foothills, upper foothills, subalpine, alpine, and montane). Elevation ranges from 700 to 2300m above sea level. Forests are primarily coniferous and characterized by lodgepole pine (*Pinus contorta*), white spruce (*Picea glauca*), and trembling aspen (*Populus tremuloides*) in upland areas, and lowlands consist of black spruce (*Picea mariana*), larch (*Larix laricina*), and muskeg. At high elevations, forests include Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*).

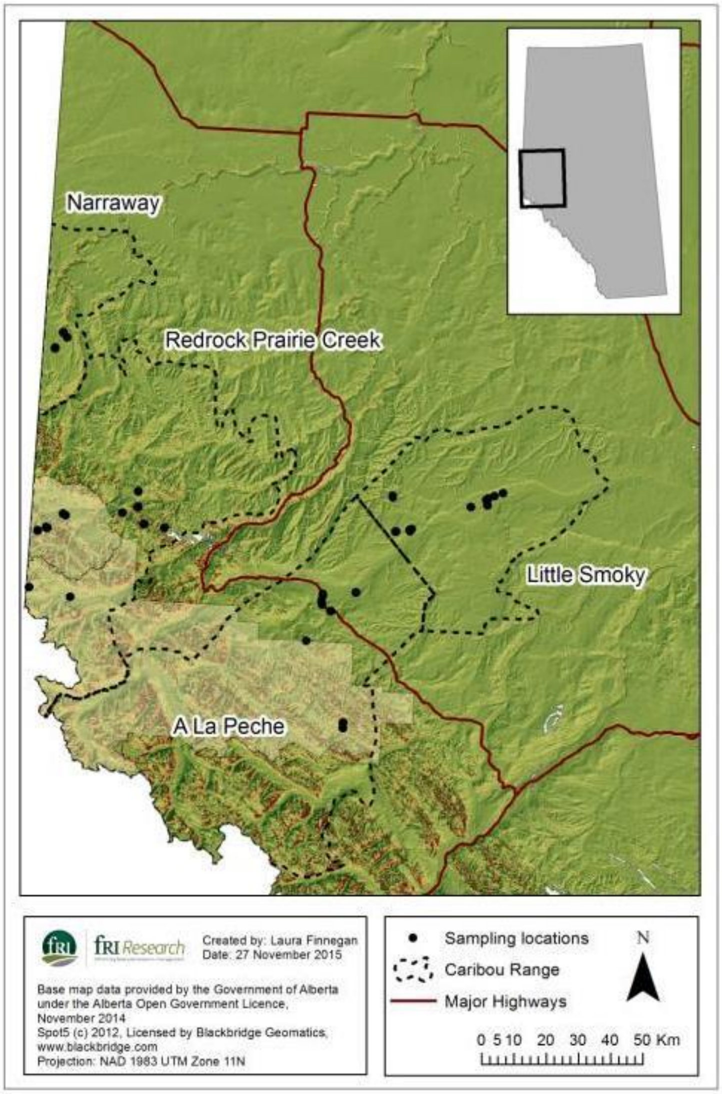

Figure 7.1. Study area in west-central Alberta showing the four herd ranges and the fecal pellet sampling locations visited during the winter of 2013/14 and 2015/16.

7.2.2. Field collection

We collected caribou fecal samples in February 2014 and between January 1st and March 31st (helicopter based) or May 31st (ground based) 2015 (n = 217 fecal piles; Figure 7.1). We located the majority of our sampling sites by flying in a helicopter to GPS locations of collared female caribou approximately one week after the collared animal had left the area, and by searching for evidence of track networks and cratering. We also opportunistically sampled sites by searching for tracks and cratering *en route* to the collared animal's location. If caribou were still present at the site upon arrival, the helicopter did not land and if possible, the site was revisited at a later date. At each site, we estimated the number of animals present by counting unique sets of tracks approaching or leaving the area. Following the existing Alberta Environment and Parks protocols, we sampled 1.5 times the number of fecal piles as caribou estimated to have visited the site. The Caribou Patrol (www.cariboupatrol.ca) also collected opportunistic samples from A La Peche and Little Smoky caribou herds during their winter and spring patrols (2015 only).

Patrollers noted the location and number of caribou and revisited the site (within 24 hours) to collect samples after caribou had left the area. At helicopter and ground-based survey locations, two sets of fecal pellets were collected from each fecal pile and samples were stored in sterile Whirl-Paks® for genetic and hormone testing (~10 pellets per Whirl-Pak ®). Samples were kept in a cooler with snow during field collection and kept at -20°C in a freezer to maintain DNA and hormone quality until laboratory work.

7.2.3. Laboratory work

7.2.3.1. Identifying unique individuals - genetics

We identified unique individuals and sex using genetic profiling carried out by Wildlife Genetics International, Nelson (www.wildlifegenetics.ca). We thawed fecal pellets collected for genetic profiling and swabbed the epithelial coat of ~ 5 pellets with a clean toothpick. Toothpicks were stored in envelopes at room temperature until DNA extraction.

DNA was extracted by clipping a 3mm length from the soiled end of each toothpick. Samples were then processed using the Qiagen DNeasy Blood and Tissue kits using associated protocols. DNA (3µl) was then amplified at 7 microsatellite markers (Rt5, BL42, OheD, BMS1788, Rt1, FCB193, Rt24) that were previously used for caribou genetic research, and that have sufficient allelic diversity to identify unique individuals. DNA was also amplified using a ZFX/ZFY marker to identify sex. Genotyping and error checking occurred in three stages. First, all samples were amplified at all markers and the confidence of accurately determining the allele at each marker was determined by peak height and visual inspection (so called 'confidence scores'). Samples with low confidence scores at >2 markers were removed from downstream amplification. Second, of the remaining samples, those with low confidence scores at any marker were re-amplified, sometimes numerous times, using additional DNA extract (5 µl) and confidence in allelic scoring was again assessed. Any samples that failed at this step were also removed from downstream amplification. These two steps ensured that unique individuals were identified using only samples with high confidence scores at all microsatellite markers. Finally, during the error checking phase, individuals with similar genotypes (1 or 2 marker difference) were reanalysed at mismatching markers. This process identified genotyping errors that could erroneously identify unique individuals. In addition, any individuals with outlying genotypes were also amplified at the mitochondrial DNA 16S rRNA gene to confirm species ID.

7.2.3.2. Hormone assays

Hormone assays were carried out by the Endocrinology laboratory at Toronto Zoo (http://www.torontozoo.com). Caribou fecal pellets were processed for hormone extraction and analysis using standard techniques developed for reindeer and caribou (Morden 2010). Fecal samples were subjected to methanol extractions overnight and the resulting supernatants were analyzed for reproductive and stress hormones using enzyme immunoassays specific for progesterone (female samples only), testosterone (male samples only), cortisol and corticosterone (male and female samples).

7.2.3. Fecal morphology

We used fecal pellet morphology measurement protocols previously developed for caribou (Morden 2010; Flasko 2014). We used digital calipers to measure the length, width, and depth to the nearest 0.1mm of three fecal pellets from each unique caribou identified from genetic profiling. The same laboratory technician measured every fecal pellet to reduce human errors and bias. We then calculated the mean fecal pellet volume for each caribou by calculating the product of the length, width, and depth of each pellet and averaging values across the three pellets measured for each caribou.

7.2.4. Data analysis

We carried out data exploration using methods outlined in Zuur *et al.* (2010), removing variables with correlation values greater than 0.6, and collinear variables with variation inflation factors greater than 3. We then used generalized linear models (GLM), implemented within the R package ‘lme4’ (Bates *et al.* 2015), to assess the relationship between hormones levels, herd and sex, and relative to levels of other hormones. We also assessed the relationships between mean fecal pellet volume (mm^3) and levels of reproductive and stress hormones, herd and sex. We log transformed mean fecal pellet volume to achieve a normal distribution of residuals. We present values as mean values or β coefficients ± 95% confidence intervals. We visualised our results using the R package ‘ggplot2’ (Wickham 2009).

7.3. Results

Of 217 samples sent to the laboratory, 44 (20%) failed during genotyping, and mitochondrial DNA analysis revealed that 4 samples with outlying genotypes (2%) were deer. The remaining 169 samples (78%) were assigned to 98 unique individuals; 34 male and 64 female (Table 7.1). 13 individuals, all female, were sampled during more than one sampling event.

Table 7.1. Summary of number of sites visited, number of fecal piles sampled, and the number of unique individuals and their sex identified using genotyping at 7 microsatellite markers and the ZFX/ZFY sex marker during fecal based surveys of west-central caribou herds (Little Smoky, LSM; A La Peche, ALP; Redrock Prairie Creek, RPC and Narraway, NAR) in 2014 and 2015.

	Number of fecal piles sampled	Number of sampling locations	Number of unique individuals (M, F)
ALP	29	10	19 (10, 9)
LSM	56	10	31 (8, 23)
NAR	16	3	7 (2, 5)
RPC	68	11	41 (14, 27)

There were no differences between cortisol or corticosterone values among herds or between sexes (Table 7.2- 7.4; Figure 7.2). One Little Smoky female had 349.93ng of corticosterone per gram of feces, and one Little Smoky male had 963.87 ng of corticosterone per gram of feces (Table 7.2 and 7.3). These two values were the highest across all the samples collected. The proportion of pregnant females identified from progesterone levels was also similar among herds with 51 of the 60 females sampled having progesterone levels indicative of pregnancy (Table 7.2). There was a significant positive relationship between cortisol and corticosterone values (Table 7.4).

We found no relationship between corticosterone values and testosterone or progesterone values among herds, nor between cortisol values and progesterone values (Table 7.5). However, males with higher cortisol levels also had higher testosterone levels (Table 7.5; Figure 7.3). We also found no difference between the volume of fecal pellets (mm^3) between sexes, however mean pellet volume in the Narraway herd was larger than that of the A La Peche herd (Table 7.6). There was no relationship between pellet volume and hormone levels (Table 7.6; Figure 7.4). There were no clear associations between pellet volume of females that were pregnant and those that were not (Figure 7.4).

Table 7.2. Mean cortisol and corticosterone values (ng/g) measured from fecal pellets collected from female caribou in west-central Alberta in 2014 and 2015 (Little Smoky, LSM; A La Peche, ALP; Redrock Prairie Creek, RPC and Narraway, NAR). Ranges of hormone values are given in parenthesis. The number of females sampled in each herd (N), and the proportion of females with elevated progesterone levels indicative of pregnancy is also shown.

Herd	Cortisol (ng/g)	Corticosterone (ng/g)	N	Proportion pregnant
ALP	16.83 (9.96 - 26.05)	75.84 (28.22 - 187.66)	8	0.88
LSM	20.09 (9.24 - 38.23)	103.59 (29.41 - 349.93)	22	0.82
NAR	18.806 (11.96 - 26.15)	123.2384 (39.32 - 223.57)	5	1.00
RPC	22.83 (9.16 - 44.86)	66.5492 (19.93 - 167.62)	25	0.80

Table 7.3. Mean cortisol, corticosterone and testosterone values (ng/g) measured from fecal pellets collected from male caribou in west-central Alberta in 2014 and 2015 (Little Smoky, LSM; A La Peche, ALP; Redrock Prairie Creek, RPC and Narraway, NAR). Ranges of hormone values are given in parenthesis. The number of males (N) sampled in each herd is also shown.

Herd		Cortisol (ng/g)	Corticosterone (ng/g)	Testosterone (ng/g)	N
ALP		18.31 (11.24 - 31.72)	75.17 (21.69 - 145.91)	68.02 (35.73 - 172.58)	9
LSM		20.62 (10.01 - 42.87)	212.38 (22.33 - 963.87)	42.82 (24.93 - 80.82)	8
NAR		20.22 (14.08 - 26.35)	107.06 (87.86 - 126.26)	84.55 (68.67 - 100.43)	2
RPC	26.30 (11.64 - 63.8)	76.33 (22.09 - 139.53)	94.02 (43.15 - 148.21)	14	

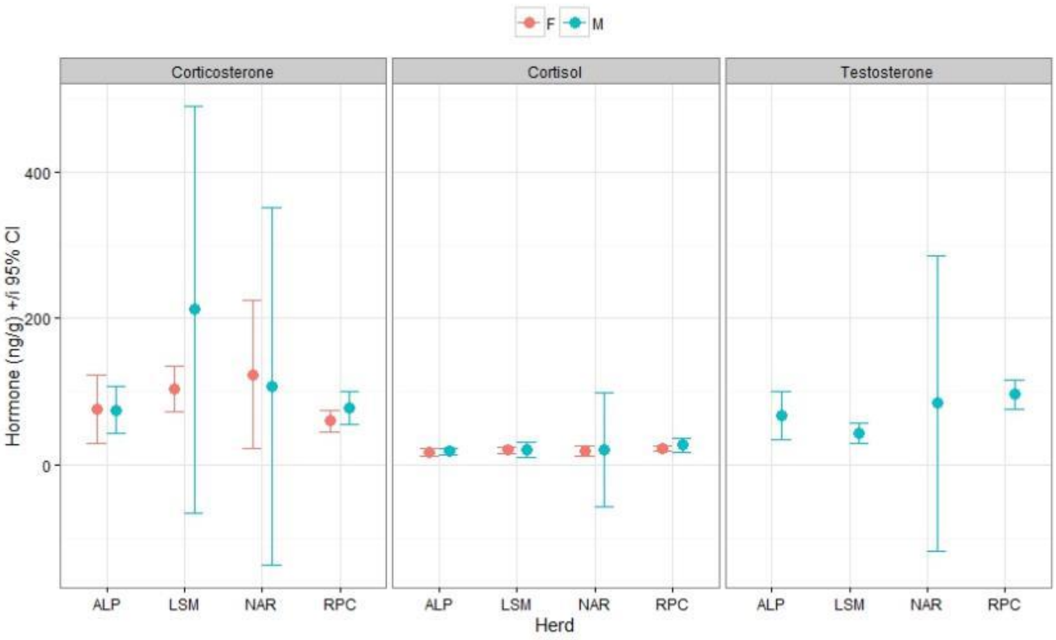

Figure 7.2. Mean hormone values (ng/g ± 95% CI) measured from fecal pellets collected from male and female caribou in west-central Alberta in 2014 and 2015 (Little Smoky, LSM; A La Peche, ALP; Redrock Prairie Creek, RPC and Narraway, NAR).

Table 7.4. β coefficients (± 95% confidence intervals) describing the relationship between cortisol (ng/g) and corticosterone (ng/g) between sexes and among herds in west-central Alberta (Little Smoky, LSM; A La Peche, ALP; Redrock Prairie Creek, RPC and Narraway, NAR). The reference category for sex was Female and the reference category for herd was ALP. Significant associations are shown in bold.

	β	95% CI		β	95%CI
Intercept	12.738	6.468	Corticosterone	**0.054**	**0.018**
Male	1.508	8.692	Male:LSM	-6.862	11.573
LSM	1.764	7.402	Male:NAR	0.776	17.310
NAR	-0.589	10.233	Male:RPC	1.443	10.547
RPC	6.494	7.268			

Table 7.5. β coefficients (± 95% confidence intervals) describing the relationship between cortisol or corticosterone values (ng/g), and reproductive hormones (progesterone and testosterone) among caribou herds in west-central Alberta (Little Smoky, LSM; A La Peche, ALP; Redrock Prairie Creek, RPC and Narraway, NAR). The reference category for herd was ALP. Significant associations are shown in bold.

	Cortisol				**Corticosterone**			
	Female: Progesterone		**Male: Testosterone**		**Female: Progesterone**		**Male: Testosterone**	
	β	**95% CI**	**β**	**95% CI**	**β**	**95% CI**	**β**	**95% CI**
Intercept	17.030	8.141	-0.536	9.309	60.68	51.194	-26.664	153.660
Hormone	0.000	0.003	**0.277**	**0.101**	0.008	0.017	1.497	1.666
LSM	3.229	7.438	9.294	9.511	30.374	46.776	174.934	157.002
NAR	1.927	10.265	-2.670	14.838	50.884	64.555	7.138	244.941
RPC	5.812	7.284	1.033	8.454	-7.414	45.806	-39.805	139.546

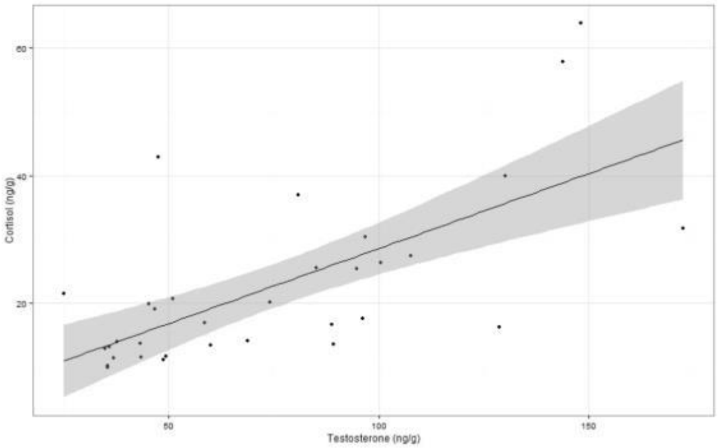

Figure 7.3. The relationship between cortisol and testosterone values in male caribou in west-central Alberta sampled in the winter of 2014 and 2014/15. The regression line was fitted using a generalized linear model (see Table 7.5 for model coefficients) and the shaded area is the 95% confidence interval around fitted values.

Table 7.6. β coefficients (± 95% confidence intervals) describing the relationship between pellet volume (log transformed, mm3) and hormone levels in caribou in west-central Alberta (Little Smoky, LSM; A La Peche, ALP; Redrock Prairie Creek, RPC and Narraway, NAR). The reference category for herd was ALP. For the models including cortisol and corticosterone the reference category for sex was Female. Significant associations are shown in bold.

	Cortisol		Corticosterone		Female: Progesterone		Male: Testosterone	
	β	**95% CI**	**β**	**95% CI**	**β**	**95% CI**	**β**	**95% CI**
Intercept	7.1418	0.2000	7.0672	0.1768	7.2020	0.2325	7.1837	0.4028
Hormone	-0.0033	0.0058	0.0005	0.0005	0.0000	0.0001	-0.0003	0.0042
LSM	-0.0227	0.1976	-0.0819	0.1980	-0.1139	0.2225	0.0789	0.4085
NAR	**0.4545**	**0.2736**	**0.4074**	**0.2708**	**0.3567**	**0.2842**	0.5775	0.6249
RPC	0.1807	0.1909	0.1486	0.1829	0.1335	0.2193	0.1239	0.3669
Male	0.0996	0.1306	0.0639	0.1293	-	-	-	-

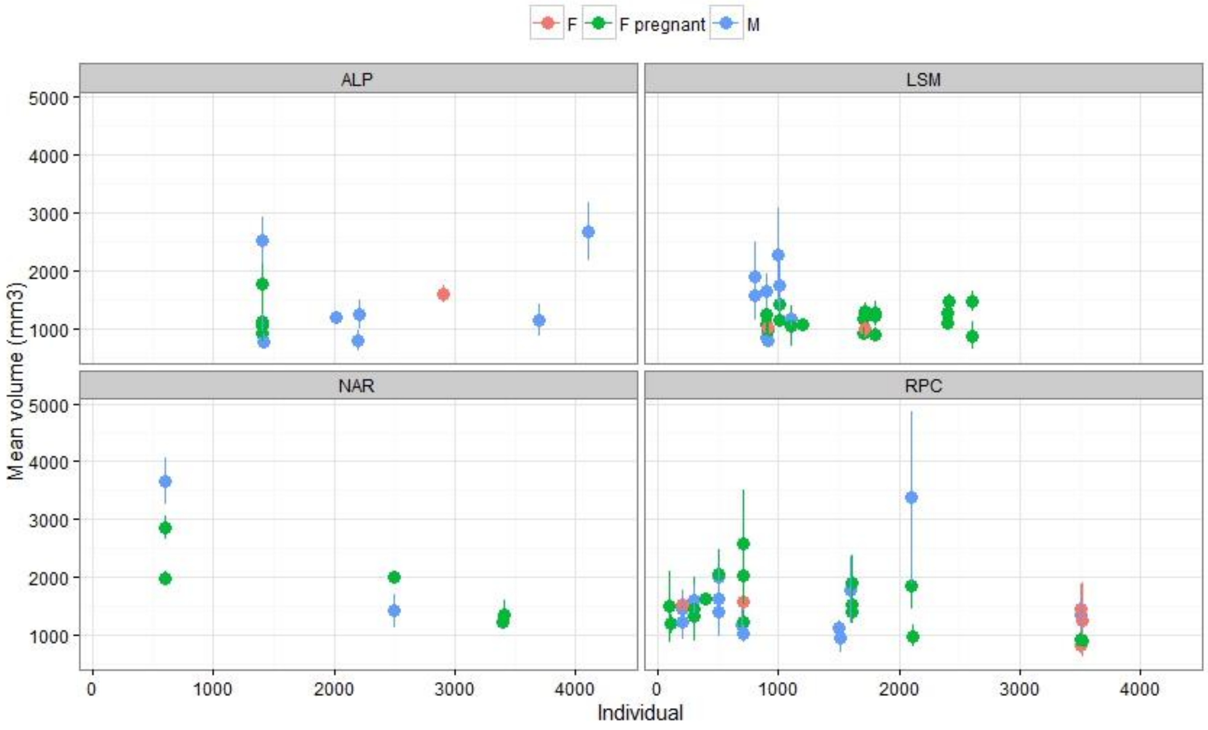

Figure 7.4. Mean fecal pellet volume (± 95% confidence intervals) among herds and reproductive status (male, female and pregnant female) of caribou in west-central Alberta (Little Smoky, LSM; A La Peche, ALP; Redrock Prairie Creek, RPC and Narraway, NAR).

7.4. Discussion

Using data collected via non-invasive fecal pellet sampling, we used established protocols and laboratory techniques to assess the health (stress hormones), reproductive status, and demography of west-central caribou herds. Using genetics, we identified 98 animals across four herds. It should be noted that because of our targeted sampling strategy, this number is not an estimate of herd size but rather represents a minimum size for each herd. Proposed transect-based sampling in the coming winters will provide accurate herd estimates. 85% of female caribou sampled had progesterone levels indicative of pregnancy. We found no significant differences in hormone levels among herds or between sex, and fecal pellet morphology failed to distinguish between adults and calves. These results provide information on the reproductive status and overall health of caribou herds in west-central Alberta, and when combined with additional results from our current winter's fecal collection, these results will help inform effective management for caribou in west-central Alberta.

There is a wealth of research supporting the hypothesis that boreal caribou declines across most of Canada are driven primarily from the top down (predator-mediated), rather than from the bottom up (nutrition and health) (DeCesare *et al.* 2010; Festa-Bianchet *et al.* 2011; McLellan *et al.* 2012). Our results support this hypothesis as we found an 85% pregnancy rate in our research herds. The pregnancy rate in our study area is similar to research findings from elsewhere (Polfus & Heinemeyer 2011; Joly *et al.* 2015) and indicates no evidence of significantly reduced reproductive rates for west-central female caribou. Testosterone levels were also similar to those reported for other herds in Alberta (Flasko 2014). Our results therefore do not refute the hypothesis that caribou declines are driven by unsustainable rates of predation and corresponding low population recruitment rather than low pregnancy rates predicted to accompany population declines due to poor nutrition and over grazing (Cameron *et al.* 1993, 2005). However, it should be noted that additional factors may affect females carrying their calves to full-term, and that one of these main factors is disease. Isolated and fragmented wildlife populations are at increased risk of disease outbreaks, many of which can affect reproduction in caribou (Deem *et al.* 2001; Schwantje *et al.* 2014). In addition, the incursion of moose, deer, and elk into caribou ranges also increases the risk of disease transmission (Hoberg *et al.* 2008). Ongoing assessments of pathogens in west-central caribou herds (fRI Research Caribou Program ongoing work) may help to determine whether extrinsic and intrinsic factors drive low herd recruitment in caribou.

Levels of cortisol and corticosterone in west-central Alberta were similar to those reported previously (~150ng/g (Freeman 2008). However, our analysis of hormone levels revealed no evidence of different stress levels among west-central caribou herds, despite substantially different disturbance densities within each of these herds, and the use of protected areas during some of the winter by central mountain caribou (Festa-Bianchet *et al.* 2011; DeCesare *et al.* 2012; Hervieux *et al.* 2013). Additional samples collected this winter will allow us to build models that evaluate cortisol and corticosterone levels from samples collected inside of and outside of protected areas, relative to month of collection, and the habitat matrix surrounding sampling locations. This approach may help to identify more significant associations between long term stress of caribou and landscape condition within caribou ranges, and may in turn help to direct restoration priorities within caribou ranges into the future.

Our measurements of fecal pellet morphology failed to distinguish between adults and younger animals. Previous research on herds in Alberta and Manitoba found that fecal pellet morphology was effective at discriminating between adults and younger animals (Morden 2010; Ball 2010; Flasko 2014). However, all previous studies included some level of classification between calves and adults *a priori* based on capture histories, cementum-based age assessment, or detailed knowledge of captive herds. To our knowledge, our research is the first to use fecal pellet morphology to distinguish between animals with no *a priori* knowledge of age. It is possible that additional samples from this winter's fecal pellet collection could help to discriminate between adults and calves. It is also possible that assessing morphology across month of collection could help with this discrimination. For example, (Flasko 2014) sampled pellets during fall and winter and was able to distinguish between adults and calves when using samples collected during fall, but not when using samples collected during winter. Our samples were collected from December through to May; considering that calves are born in June, this time period included calves that were between 6 and nearly 12 months of age. Our second winter of fecal collection and increased sample size will allow us to increase the number of covariates included in our models, including month of collection, and may help us distinguish between adults and calves.

7.5. Conclusions

Our research represents some of the first to use non-invasive fecal sampling to assess the potential health-related effects of habitat disturbance on west-central caribou herds. We found no clear differences in chronic stress levels among west-central Alberta herds during this year’s preliminary analysis, but we also could not include covariates for month of collection, or anthropogenic disturbance densities in these models. Additional fecal pellet collection currently underway will allow us to expand our models and address this question in more detail.

The goal of this analysis was to use non-invasive fecal DNA collections to assess the relationship between anthropogenic disturbances and the distribution, size, and health of caribou herds in west-central Alberta. Ongoing fecal pellet collection and genetic and hormone laboratory work in 2016 will allow us to assess this question in more detail. We will provide a final report to in March 2017 that will include the final results of this analysis. Ultimately, this analysis will allow us to assess the direct and indirect effects of habitat disturbance on caribou population viability within west-central Alberta. Results from this analysis will enable land planners to direct habitat restoration efforts for caribou to areas where they are most needed, and will facilitate adaptive management and restoration tactics that continually improve the health and population level recruitment of caribou herds in west-central Alberta.

8. Synthesis (year 1 and 2 results)

Our results and findings in relation to the project objectives over two years of research are as follows:

- **Determine whether caribou and predator response to roads and pipeline RoWs is influenced by the extent of re-vegetation and human use of these features, and evaluate whether currently accepted 500m buffers on roads and pipeline RoWs apply when line characteristics incorporate information on regeneration.**
  - We recorded ungulate, ursid, and canid sign on 95 pipelines and inactive roads in west-central Alberta in 2014.
  - There were no associations between wildlife signs and human use.
  - Elk and deer were detected on pipelines with low lateral cover.
  - The hyper-abundance of moose signs prevented us from building models.
  - Canids were detected on pipelines and roads that occurred in areas within high densities of oil and gas facilities.
  - Ursids were detected on pipelines and roads with wildlife trails.
  - Because regeneration was not a significant covariate in the year one models, in year two we focused on assessing animal use using GPS data and LiDAR measurements of regeneration on seismic lines.
  - Combining these field data with other data from fRI Research Caribou Program projects in the future could help identify attributes of pipeline RoWs that make them attractive to predators and alternate prey (moose, deer, and elk), and could help identify putative zones of influence of pipeline RoWs and roads relative to underlying attributes (e.g. WAM, landcover, etc.).

- **Assess how human activity of linear features is affected by topography, geographic barriers, and re-vegetation height.**
  - We quantified human use (zero, low, moderate, and high) using data collected from pipelines (LSM/ALP n = 31 [62 subplots]; RPC/NAR n = 71 [188 subplots]; Chinchaga n = 41 [115 subplots]), and seismic lines (LSM/ALP n = 281 [639 subplots]; RPC/NAR n = 104 [292 subplots]; Chinchaga n = 110 [265 subplots]) during the summers of 2014, and 2015.
  - We used four hypotheses to build models predicting human use: Ease of travel, hunting, recreation, and industry-models, and included a range of covariates linked to these hypotheses within models (e.g. distance to roads, vegetation height, ungulate counts, etc.)
  - Models failed to find relationships between human use and pipeline attributes.
  - In the Chinchaga caribou range, higher human use levels occurred on drier seismic lines (lower CTI). However, models poorly predicted human use.
  - In the RPC and NAR ranges, human use on seismic lines was associated with low vegetation height on seismic lines, areas with low well site densities and high mule deer counts, and seismic lines closer to paved roads. The model correctly classified 95% of the plots with zero human activity and 87% of the plots with high human activity.
  - In the LSM and ALP ranges, human use on seismic lines was associated with low vegetation height on seismic lines, and areas with high white-tailed deer counts. Human use was also higher on seismic lines that occurred in areas with low proportion of upland herb landcover. The model correctly classified 93% of the plots with zero human activity and 68% of the plots with high human activity.
  - Overall, the negative effects of humans on natural regeneration of seismic lines may be highest on seismic lines closer to paved roads that have vegetation height of <3m, and in areas with lower densities of well sites and

lower proportions of upland herb. Seismic lines that occur in areas with high counts of mule and white tailed deer may be used more heavily during the fall hunting season.

- **Determine whether activity at worksites (active industrial activity) affects the movements of caribou.**
    - We examined habitat selection by caribou (early and late winter) in relation to the proximity and development phase of oil and gas wells (drilling, producing, or inactive/abandoned) within RPC and NAR caribou range (GPS data from 2007 to 2013).
    - We found that caribou used habitat farther away from oil and gas well sites than expected by chance regardless of the development phase of the well site.
    - In early and late winter, there was a negative relationship between the probability of caribou occurrence and distance to well sites in different phases of development. For well sites in the drilling phase, the relative selection increased faster at distances > 0.66km from well sites than at distances < 0.66km.
    - We did not observe an inflection point where the relationship became neutral or positive, suggesting that there is no threshold distance where the effect of well sites is no longer apparent.
    - Well site drilling may displace caribou. However, it is unlikely that this displacement will have severe negative effect upon caribou during winter. Ongoing analysis (fRI Research Caribou Program) assessing the affect of well site activity on caribou during more vulnerable stages of their life history (e.g. calving) may help to inform best management practices that have the least negative effect on caribou.

- **Use non-invasive fecal DNA collections for caribou during the winter to determine the relationship between re-vegetation and current restoration activities on the distribution, size, and health of caribou populations.**
    - During the winters of 2013/14 and 2014/15, we collected 217 fecal samples from four caribou herds in west-central Alberta.
    - Genetic profiling revealed that these 217 samples were collected from 98 individuals (34 males and 64 females).
    - Hormone assays of progesterone revealed that 51 out of 60 females tested were pregnant.
    - We found no difference in cortisol or corticosterone levels (indicative of long term stress) between herds or sexes.
    - Males with higher levels of cortisol also had higher levels of testosterone.
    - We found no associations between fecal pellet morphology and reproductive hormones, nor were there clear differences in fecal morphology among individuals. Therefore, our current dataset could not contribute knowledge towards herd demographics in west-central Alberta.
    - We are currently finishing our third and final winter of fecal surveys. These additional samples will allow us to carry out more detailed analyses including comparisons across the winter months, and relative to landscape condition within each herd range. Additional samples may also allow us to assess herd demographics in more detail.
    - We will provide a supplemental report including the results of analysis from three winters of fecal collection in the spring of 2017.

- **Assess whether the response of boreal caribou in the Chinchaga range (mixedwood, upland, peatland habitat) to disturbed habitat differs from that of boreal and mountain caribou in conifer dominated landscapes.**
    - We used three years of GPS location data obtained on 18 female caribou within the Chinchaga boreal herd to assess differences in habitat selection between the Chinchaga caribou range and west-central caribou.
    - Chinchaga caribou behaved similarly to boreal caribou in west-central Alberta and selected areas far from young regenerating forests, linear features, and well sites, and selected areas in mature forests further from large streams than expected from a random distribution.
    - During summer however, Chinchaga caribou behaved differently than boreal caribou in west-central Alberta by selecting open conifer forests rather than dense canopy cover, as observed by Neufeld (2006).
    - As expected and observed with other boreal caribou herds, Chinchaga caribou select areas far from all types of anthropogenic disturbances.
    - The seasonal RSFs developed within this project can be used as tools to direct future restoration activities that would be most beneficial for caribou. These seasonal layers can also be used by land managers to develop future land-use plans that take into account spatial and temporal impacts of landscape changes on Chinchaga caribou.

- **Produce a list of landscape variables (e.g. re-vegetation height, human use thresholds, etc.) that can be used to quantify the extent of caribou functional habitat in our study area and elsewhere.**
    - We used LiDAR measurement of regeneration (circa) 2005 within the Chinchaga boreal caribou range and GPS data from wolves (2006 - 2007) and caribou (2007 - 2009) to assess caribou and wolf response to regenerating seismic lines.
    - 70% of seismic lines in the Chinchaga caribou range had regeneration heights less than 1m and 93% of the Chinchaga range is within 500m of seismic lines.
    - Despite the large seismic line footprint in the Chinchaga caribou range, caribou consistently selected for areas further from seismic lines than expected from a random distribution, and caribou were closer to seismic lines when they were in areas with high densities of seismic lines.
    - When caribou were close to seismic lines, they selected for seismic lines with high vegetation during spring, summer, and early winter, and selected for seismic lines with low vegetation height during fall and late winter.
    - These results suggest that caribou are close to seismic lines because of the low availability of habitat far from linear features. Considering regeneration, caribou may perceive seismic lines with higher vegetation height as less disturbed than seismic lines with lower vegetation height. However, we could not find a threshold when caribou ceased to respond to seismic lines, and caribou also selected for low vegetation height seismic lines during fall and early winter.
    - Overall, wolves selected flat areas at high elevation in mixed or non-forested habitat types near small streams, away from high densities of linear features at the landscape scale, but near areas with high densities of anthropogenic features at the local scale.
    - During the snow-free rendezvous season, when < 62.5m from seismic lines, wolves selected areas near seismic lines with low vegetation height.
    - For wolves, the influence of regeneration height on seismic lines decreased with increasing distances from seismic lines.

  - These results suggest that during the snow free months, wolves may use seismic lines as access corridors, thereby potentially increasing encounters with caribou that are also near low vegetation height seismic lines during fall.

- **Create a map evaluating priority areas for restoration that would be most beneficial for caribou in the Chinchaga caribou range, and most cost effective for the forestry sector and industrial landscape users.**
  - We generated spatially explicit maps of the relative probability of selection (RSFs) that take into account the regeneration stages of seismic lines, landscape and habitat attributes, and anthropogenic factors for wolves and caribou in the Chinchaga range.
  - We combined these species-specific RSFs to produce a spatially explicit map identifying areas surrounding seismic lines with high probability of overlap between caribou and wolves.
  - Finally, we ranked seismic lines with respect to priority for restoration based on the probability of overlap between caribou and wolves.
  - Using this approach, we classified 1,539 km (2.9%) of the seismic lines in the Chinchaga caribou range as high or very high priority for restoration.
  - Our seismic line priority ranking can be used by land managers and industry partners as a least-cost and effective approach for restoration.

To our knowledge, this study is the first of its kind conducted in the Chinchaga caribou range and in west-central Alberta. Using GPS data from caribou and wolves, field data on human and wildlife use, innovative remote sensing approaches including vegetation heights from LiDAR, non-invasive fecal DNA collection, and GIS variables, we provide the first assessment of habitat selection patterns for caribou and wolves in the Chinchaga range, the first assessment of how regeneration stages of seismic lines influence selection patterns for these animals, and the first assessment of human use of linear features relative to regeneration and landscape attributes. Using these same data, we also assessed the size and health of caribou populations in west-central Alberta, evaluate human and wildlife use of pipelines, assessed how activity at well sites influence caribou behavior, and provide a list of variables that can be used to increase understanding of caribou functional habitat.

Finally, we provide the first spatially explicit map of the Chinchaga caribou range with priority ranking of seismic lines for restoration based on the relative probability of selection for wolves and caribou. This map product is aimed towards effective and cost-efficient restoration of seismic lines that will be most beneficial to caribou. Overall this research contributes new knowledge to inform science-based habitat restoration efforts for caribou, and the results of this project can be used as a tool by land managers and industrial partners to expedite restoration of caribou habitat towards achieving the disturbance targets set within the recovery strategies.

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