FINAL REPORT

Caribou and wolf behaviour in relation to oil and gas development

Prepared for
British Columbia Oil and Gas Research and Innovation Society (BCIP-2016-15)

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Results and opinions presented herein are subject to revision for peer-reviewed pulications. Any opinions expressed in this report are those of the authors, and do not necessarily reflect those of the organizations for which they work, or fRI Research.

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EXECUTIVE SUMMARY

Woodland caribou in Alberta and British Columbia are federally listed as threatened under the Canadian Species at Risk Act (SARA). Throughout their range, the decline of woodland caribou populations is thought to result from habitat degradation and fragmentation caused by industrial activities. Infrastructure associated with oil and gas development accounts for a significant portion of the disturbance footprint in many boreal caribou ranges. While researchers have studied the behavioural response of caribou to various types of oil and gas infrastructure, the response of caribou and wolves to different levels of human activity associated with operational phases of development related to at oil and gas has yet to be properly understood.

The goal of this project was to understand the response of caribou and wolves to oil and gas developments relative to different activity phases, and relative to the age of the disturbance. Our previous analyses revealed that well site activity influenced selection by wolves and caribou, and that both species selected areas further from high-activity well sites compared to low-activity well sites. Specifically, during all seasons, caribou avoided areas near high- and moderate-activity well sites, while wolves avoided areas near high-activity well sites during the nomadic winter season, but selected areas near moderate-activity well sites during all seasons. In addition, wolves selected areas near low-activity well sites during the nomadic season, and caribou also selected these areas during that season. Regarding other anthropogenic disturbances, our results show that Chinchaga caribou avoided areas with high densities of cut blocks across the year. Chinchaga caribou also avoided areas near roads and pipelines and avoided areas with higher densities of roads and pipelines during all seasons. During fall, when caribou are moving to winter ranges, caribou selected areas near high- and low-use roads, avoided areas near winter-roads, and selected areas near pipelines. Caribou also consistently selected open habitat and wetlands on gentle terrain, and avoided dense and moderate canopy conifer forest during all seasons. Finally, caribou also selected areas at higher elevations during late winter, spring, and summer, and selected areas at lower elevations during fall and early winter. During all seasons wolves in the Chinchaga caribou range selected areas near cut blocks, pipelines, and high and low-use roads, and selected areas with higher densities of pipelines, and high- and low-use roads. Wolves also selected open habitat and gentle slopes during all seasons.

Using field data of animal tracks and signs to address specific use of pipelines by predator and prey species, we observed that deer were more likely to use pipelines with slight slopes, presence of moose signs, and low vegetation heights, while moose were more likely to use pipelines with high lateral cover below 1 m, and pipelines that fell within forest stands with dominant broadleaf species. Bears were more likely to use pipelines with slight slopes and presence of ungulate signs, and were more likely to use pipelines with broadleaf species growing as a secondary species. Pipeline age had no clear effect on the use of pipelines

for canines, bears, and ungulates although bears and ungulates seemed to use young pipelines more than old pipelines, and canines seemed to use old pipelines more than young pipelines, especially in non-forested habitats. Overall, models also revealed that ungulates were more likely to use pipelines in areas of low road densities, and in proximity to water, while predators were more likely to use pipelines with slight slopes.

With a goal of identifying areas that could be prioritized for restoration within the Chinchaga boreal caribou range, we overlaid seasonally and spatially explicit resource selection functions for wolves and caribou. Using this approach we identified 17% of the Chinchaga boreal range that could be prioritized for restoration based on the highest cumulative relative probability of overlap between caribou and wolves throughout the year. At a fine scale, our analysis suggests that wolf-caribou co-occurrence was highest near low-activity well sites and near pipelines, while pipelines with slight slopes were used by ungulates, canines and wolves, and moose also used pipelines in broadleaf stands. Combined, this information could be used to direct restoration treatments at a fine scale to reduce the spatial overlap between caribou and their predators.

This study is, to our knowledge, the first to (i) develop interprovincial, seasonal RSF surfaces to map the relative probability of use for caribou and wolves in the Chinchaga caribou range using a robust GPS telemetry dataset and landscape data covering the entirety of the Chinchaga caribou range, (ii) quantify the response of caribou and wolves to oil and gas well sites at different levels of human activity, iii) and assess how fine scale habitat and terrain characteristics, and pipeline attributes influence use of pipelines by ungulate and predator species using non-invasive methods. This study is therefore addressing a knowledge gap in an effort to inform restoration efforts for caribou. The results of this project will be valuable to land managers planning for caribou recovery by allowing recovery actions to be prioritized in a manner that maximizes their benefit to caribou and increases the probability of caribou persistence in the Chinchaga caribou range.

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1. Introduction

1.1 Project background

Woodland caribou (*Rangifer tarandus caribou*) populations are declining throughout their range and boreal woodland caribou are listed as threatened by the Canadian Species at Risk Act (Environment Canada 2012). Caribou decline is linked to habitat degradation and loss resulting from industrial development within caribou ranges (Environment Canada 2012). Because of the negative impact of anthropogenic disturbance on caribou populations, the federal Boreal Caribou Recovery Strategy requires that less than 35% of habitat within each caribou range be classified as 'disturbed', where 'disturbed habitat' is defined as the footprint of disturbance features plus a 500m buffer on all sides (Environment Canada 2012). Most of the boreal caribou herd ranges in British Columbia and Alberta exceed the 35% disturbance threshold, and habitat restoration is therefore required to expedite the recovery of caribou populations. However, given the extensive footprint of disturbance features within boreal caribou ranges (e.g., forest cut blocks, oil and gas well sites, pipelines, roads, and seismic lines), restoration actions need to be prioritized to ensure maximum benefit to caribou recovery, and to ensure efficient use of conservation resources (Schneider *et al.* 2012; Hebblewhite 2017). By introducing multiple filters by which to prioritize restoration activities, the daunting task of habitat restoration for caribou can be approached in a methodic and objective manner, with measurable criteria by which to quantify restoration progress (Pigeon *et al.* 2016).

Due to the variety of anthropogenic disturbance features such as forestry cut blocks, access roads, oil and gas well sites, pipelines, and seismic lines, and their widespread placement on the landscape within caribou ranges, the over-arching goal of this project was to understand how caribou and their predators respond to different types of disturbance features. Understanding how caribou and their predators respond to anthropogenic disturbances will allow land managers to target restorative actions where they will provide the most benefit to caribou by reducing predation risk, increasing habitat connectivity, and ultimately restoring ecosystem function for caribou. One way to prioritize restoration activities is to account for the variable response of caribou, alternate prey, and predators to anthropogenic disturbance features by disturbance type and age, and the intensity of human activity or other sensory disturbances associated with a particular anthropogenic feature (Wolfe *et al.* 2000; Dyer *et al.* 2002; Sawyer *et al.* 2009; Lesmerises *et al.* 2012; Leblond *et al.* 2013; McKay *et al.* 2014). Because predation events are inherently linked to the probability of encounter between predator and prey (McKenzie *et al.* 2012), restoration of caribou habitat that aims to minimize encounters between caribou and predators could increase the effectiveness of restoration efforts. Determining how predators such as wolves and their primary prey (moose, deer, and elk) respond to anthropogenic disturbance within caribou range may therefore increase the pay-off of habitat restoration efforts by allowing land managers to prioritize areas that once restored, would reduce the likelihood of encounters between predators and caribou.

Despite the growing body of research suggesting that caribou response to anthropogenic disturbances is linked to the amount, type, and stage of development of disturbance features, at the onset of this project, there were some key knowledge gaps in understanding caribou response to types of oil and gas infrastructure during specific phases of development (but see Dyer *et al.* 2002). In western Canadian boreal caribou ranges, there is significant economic interest in oil and gas reserves, and the infrastructure related to oil and gas development accounts for a large portion of the disturbance footprint. While oil and gas well sites have a relatively small physical footprint on the landscape compared to larger disturbance features such as forestry cut blocks, oil and gas well sites are numerous and diffuse throughout caribou range, and undergo dramatic changes in human traffic and activity throughout their existence (McKay *et al.* 2014). Research has revealed differential responses of mule deer (Sawyer *et al.* 2009) and grizzly bears (McKay *et al.* 2014) to well sites at different stages of activity, and our research for this project has revealed similar differential responses of caribou and wolves to well sites at different stages of activity (MacNearney *et al.* 2016; 2017). Similarly, pipeline right of ways (hereafter pipelines), like seismic lines and roads, contribute towards the linear feature disturbance footprint within caribou ranges. However, pipelines have received little specific attention relative to wildlife use in comparison to seismic lines (McKenzie *et al.* 2012; Tigner *et al.* 2014; Dickie *et al.* 2017) and roads (Bowman *et al.* 2010; Dussault *et al.* 2012; Northrup *et al.* 2012). Because of specific levels of human use and re-disturbance, wildlife response to pipelines are likely different to responses observed on seismic lines or roads. For example, because most seismic lines are not re-disturbed some are actively regenerating (van Rensen *et al.* 2015), but in accordance with CSA Z662-15, active pipelines must be kept cleared of vegetation that would hinder easy visibility of the pipeline from the air, or that would prevent easy maintenance by crews on the ground (Alberta Energy Regulator 2016). In addition, the low level of vehicular traffic on pipelines (at least one inspection per year, CSA Z662-07) is considerably lower than that of roads.

In this report, we address the knowledge gap relative to wildlife response to pipelines by investigating wildlife use of pipelines within the Chinchaga boreal caribou range in Alberta and British Columbia. We considered a number of field-based and GIS-based attributes of pipelines (i.e., lateral cover, height of woody vegetation, primary and secondary tree species, slope, habitat type of the adjacent forest stand, and densities of anthropogenic features such as roads, pipelines, and regenerating cut blocks in the vicinity of the pipeline), and we also investigated wildlife use of recently constructed pipelines versus older pipelines (Chapter 2). We identify areas that could be prioritized for restoration within the Chinchaga boreal caribou range based on the seasonal probability of overlap between caribou and wolves (Chapter 3), and provide a synthesis of all the project results combined (Chapter 4). Specific project objectives are described in the next section.

1.2. Project objectives

- Determine how different types of activity at well sites influence the behaviour of caribou and wolves, and assess how this relationship changes seasonally and in relation to the surrounding habitat matrix.
- Assess caribou and wolf response to pipelines in relation to pipeline age and the surrounding habitat matrix.
- Use models of caribou and wolf use of pipelines developed in Alberta (FRIP OF-13-006) to model caribou and wolf use of pipelines in the British Columbia portion of the Chinchaga caribou range, and validate models with field data collection.
- Evaluate whether currently accepted 500m buffers on well sites and pipelines accurately reflect caribou functional habitat.
- Synthesize the results from objectives 1-4 to provide guidelines for restoration and mitigation of disturbance features within caribou ranges to contribute towards caribou recovery in northwestern Alberta and northeastern British Columbia.

Ultimately, results of this research will help guide restoration efforts to increase effective habitat for caribou within their ranges by identifying areas where habitat restoration has the greatest chance of decreasing overlap between caribou and wolves, and increasing caribou habitat quality and functionality. By providing insight into the linkage between human activity at well sites, and response of caribou and wolves, this project generates science-based criteria to support decision making for land managers within caribou ranges.

1.3 Study area

The study area encompassed the interprovincial range of the Chinchaga caribou herd in northeastern British Columbia and northwestern Alberta (Figure 1.1). Caribou in the Chinchaga range are the boreal designated unit, occur in the boreal forest year round, and have little or minimal seasonal shifts in home range (COSEWIC 2012). The Chinchaga caribou range is characterized by boreal forest consisting of black spruce and larch in poorly drained muskeg and fen in lowland areas, and white spruce, trembling aspen, and balsam poplar (*Populus balsamifera*) in upland areas (Natural Regions Committee 2006). Elevation in the study area ranges from 500-900m above sea level with relatively flat topography (Figure 1.1). There is a high diversity of ungulates in the area including moose, white-tailed deer, and wood bison (*Bison bison athabascae*; Rowe 2007). Common predators include wolves, black bears (*Ursus americanus*), grizzly bears (*Ursus arctos*), wolverines (*Gulo gulo*), and lynx (*Lynx canadensis*; Rowe 2007). The Chinchaga caribou range straddles both sides of the border between British Columbia and Alberta with approximately 50% of the total range area in each province (Figure 1.1). The federal recovery strategy estimates that 74% of the habitat in the Chinchaga caribou herd range is disturbed by anthropogenic activities.

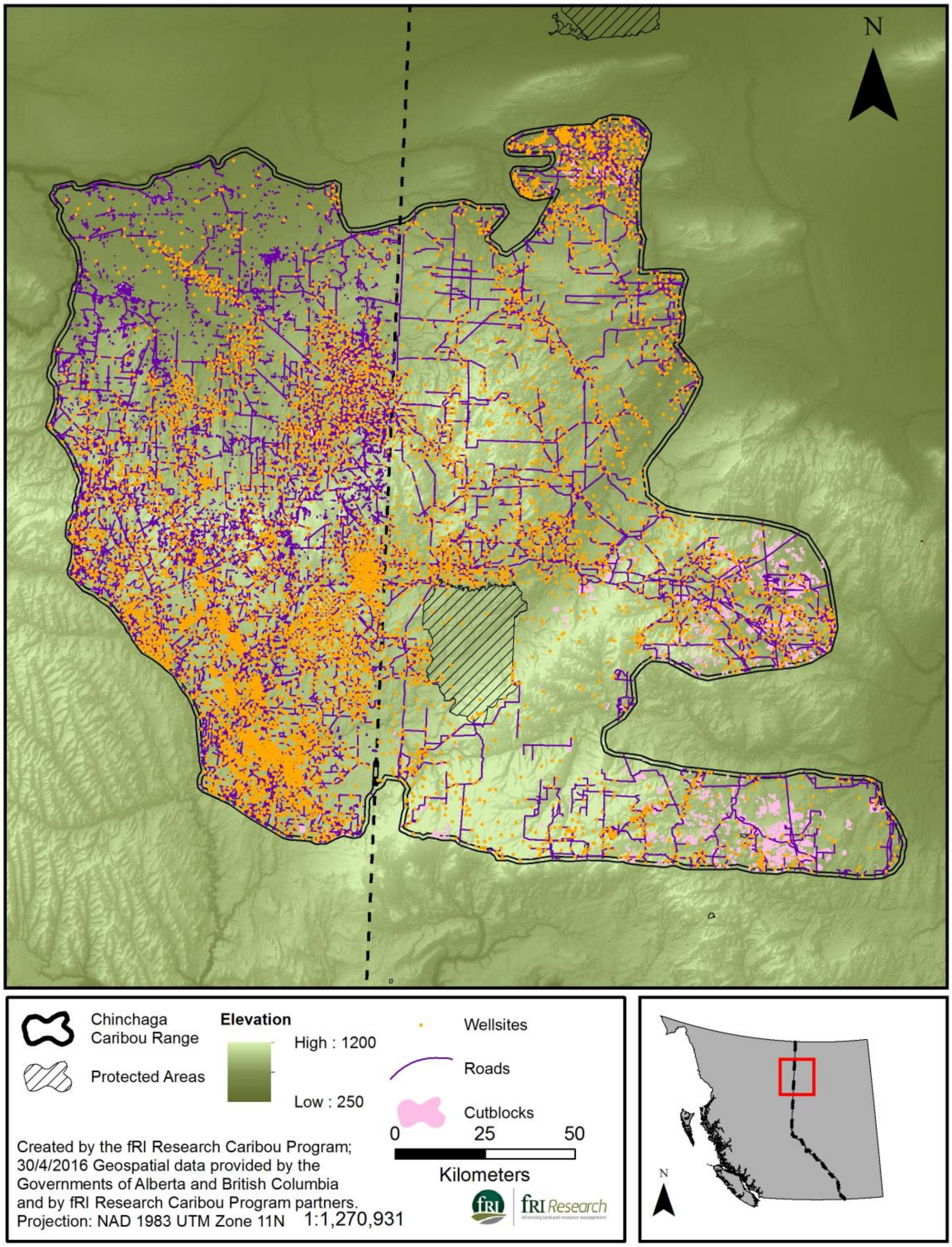

Figure 1.1. Chinchaga caribou range showing roads, protected areas, well sites, and the elevation gradient in northeastern British Columbia and northwestern Alberta.

2. Animal use of pipelines in the Chinchaga caribou range

2.1 Background

In this chapter, we assessed how terrain and habitat characteristics, and pipeline attributes influenced the use of pipelines by ungulates and predators. The goal of this analysis was to investigate ungulate and predator use of pipelines in Alberta using non-invasive methods, and assess the relevance of models developed with data collected in Alberta to predict pipeline use in British Columbia. More specifically, our objectives were to (1) assess use of pipelines by caribou, primary prey (moose, deer, and elk), canines, and bears in the Alberta Chinchaga caribou range using non-invasive methods (i.e., tracks and signs), and (2) extrapolate animal probability of use of pipelines to the British Columbia portion of the Chinchaga caribou range and validate these models with newly collected field data (summer 2017).

Using tracks and signs data collected in the Alberta portion of the Chinchaga caribou range, we also specifically assessed the use of pipelines by canines, bears, and ungulates as a function of pipeline age and the surrounding forest type (i.e., landcover class: Broadleaf, Conifer, Wetland, NonForest). In a previous report (MacNearney *et al.* 2016), we observed that caribou selected areas closer to pipelines < 2 years old more than expected from a random distribution, but also selected areas further from pipelines > 2 years old. However, during summer, caribou selected areas further from all pipelines, while during fall, caribou selected areas closer to all pipelines. Although we did not observe animal tracks on pipelines < 2 years old, our objective here was to further assess how pipeline age might be associated with their use. More specifically, our objectives were to (3) investigate whether canines, bears, and ungulates used young (< 10 year old) or old (> 15 year old) pipelines more, and (4) determine whether the surrounding habitat matrix influenced pipeline use.

2.2 Methods

2.2.1 Field data collection

Field crews recorded tracks and signs (i.e., tracks, scats, or pellets) of canines, bears, cougar, caribou, elk, deer, and moose at 180 subplots (69 pipelines) in the Alberta portion of the Chinchaga caribou herd range in 2015, and at 90 subplots (36 pipelines) in the British Columbia portion of the Chinchaga caribou herd range in 2017. Details of field data collection are in Appendix 1. As tracks and signs were often difficult to identify due to substrate and degradation over time, field crews also recorded a measure of their confidence level when identifying tracks and signs (low, moderate, or high). For data analysis, we used only records identified with moderate (n = 2) and high (n = 214) confidence levels. We treated tracks and signs data as a measure of 'presence' but not as an adequate measure of 'absence' because the surface conditions where tracks are observed (i.e., hardpack trail vs. muddy trail, bare ground vs. heavily vegetated ground) influence the probability of tracks and signs being detected at particular sites. Weather can also influence the probability of detecting tracks and signs, and the timeframe during which the animal was present at a site cannot be adequately known because site conditions and weather influence the persistence of tracks and signs at sites (Reid *et al.* 2013).

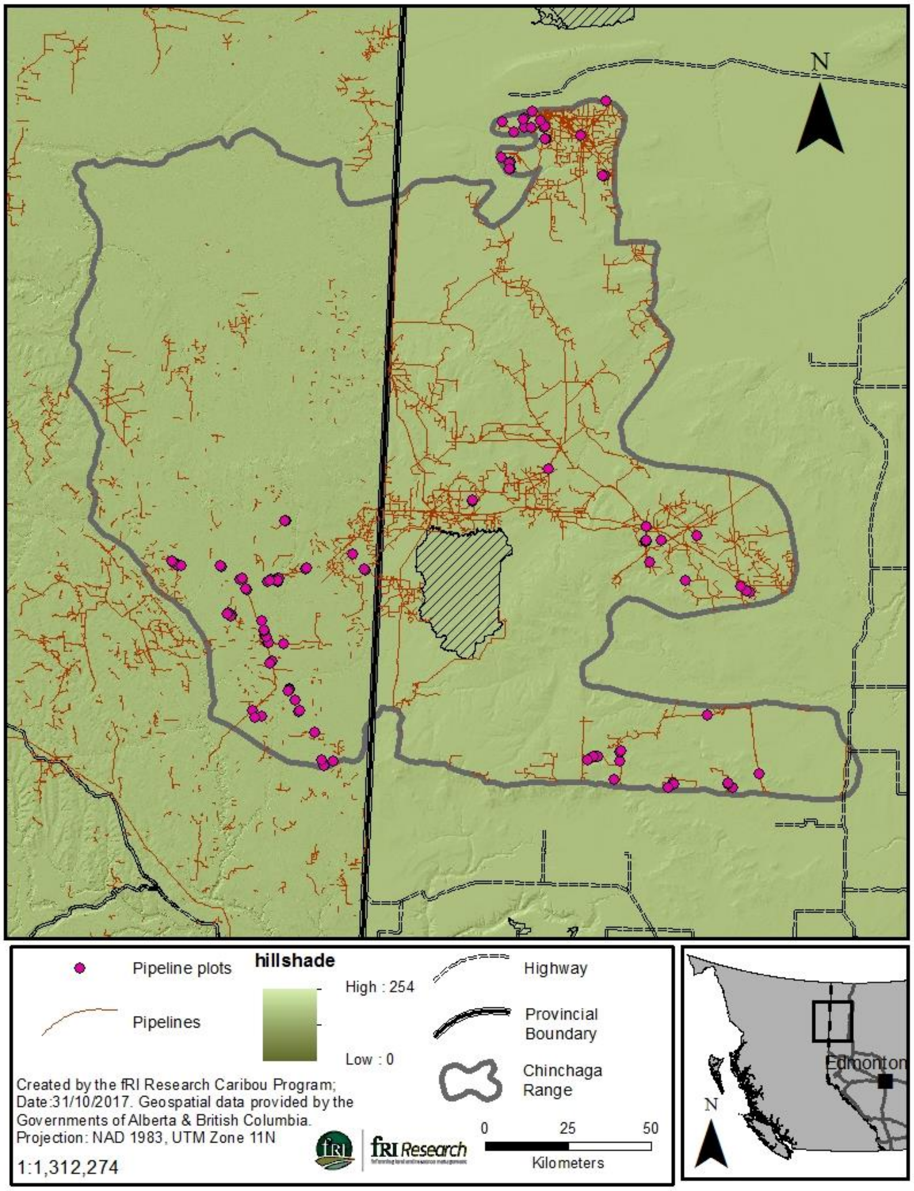

Figure 2.1. Vegetation and animal use plots established on pipelines in Alberta in 2015 and British Columbia in 2017 within the Chinchaga caribou range.

Figure 2.2. Aerial (left) and ground (right) view of a pipeline in Chinchaga caribou range.

2.2.2 Landscape covariates

We considered a suite of habitat, terrain, and anthropogenic variables to explain the use of pipelines by wildlife in the Chinchaga caribou range (Appendix 1 and 2). To reduce the possibility of erroneous interpretations due to variation in data quality, we only included variables with available and analogous data in Alberta and British Columbia. We derived topographic variables including slope, aspect, elevation, topographic position index (TPI; Jenness 2006), and compound topographic index (CTI; Gessler *et al.* 2000) from a 25m digital elevation model. We derived habitat variables from a combination of Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat imagery mapped at a 30m resolution, and developed for fRI Research by the Integrated Remote Sensing Studio at the University of British Columbia following the methods of (Nijland *et al.* 2015). The study area is fairly flat and we therefore included a binary variable 'Flat' based on the presence or absence of a legitimate value for aspect. For anthropogenic variables, we used spatial cut block data provided by Daishowa-Marubeni International Ltd. (DMI), Canadian Forest Products (Canfor), Tolko Industries Ltd, and the government of British Columbia (Consolidated Cut blocks layer; www.data.gov.bc.ca), and pipeline and road data provided by the British Columbia Oil and Gas Commission, the government of British Columbia, and the government of Alberta. We were unable to acquire data for conventional seismic lines in British Columbia, and we therefore excluded seismic lines from the analysis. We considered cut blocks for analysis if they had been cleared < 30 years prior to collection of animal data to account for the early stages of regeneration on cut blocks before forest communities become established. We treated anthropogenic features as binary, and calculated the density of pipelines, roads, and cut blocks using a circular moving window average in ArcGIS 10.2 (Environmental Systems Research Institute (ESRI) 2015). We selected moving window radii of 1km and 90m based on research suggesting that caribou can respond to disturbance feature density at very fine (i.e., 70m) and coarse (i.e., > 9km) scales (Schaefer & Mahoney 2007; DeCesare *et al.* 2012; Johnson *et al.* 2015).

2.2.3 Data analysis

Using Generalized Linear Mixed Models (GLMMs), we were able to account for the hierarchical design of our data by including a random effect for subplots visited on the same seismic lines (i.e., (1|PlotID) as a random effect) because up to three subplots were sampled on the same seismic line (i.e., identical PlotID at different distances – 0m, 100m, and 500m from road intersection). We used a multi-step approach to optimize models, and first built separate 'Vegetation', 'Terrain', 'Trees', and 'Species' models using field data associated with each of these model categories (see Appendix 1 and 2). We then used the 'drop1' function (R Development Core Team 2015) to retain informative variables within each model category. Using only informative variables within each of these categories, we then built a 'field data' model and again used the 'drop1' function to optimize the model. As a third step, we built 'Anthropogenic', 'Habitat', and 'Terrain' models using Geographic Informative System (GIS)-derived variables only and used the same procedures as described for the field data to identify informative variables. We standardized all continuous variables to improve model convergence, and prior to model building, we also excluded one of any two variables correlated at > 0.5 (Zuur *et al.* 2010). We conducted all analyses using the R package lme4 and RStudio (Bates *et al.* 2014; R Development Core Team 2015). We used the Area under the curve (AUC) Receiver Operating Characteristic (ROC) to assess model performance (Hosmer & Lemeshow 2005). As a general rule, ROC values of 0.5 suggest poor model performance, ROC between 0.7 and 0.8 are considered acceptable, ROC between 0.8 and 0.9 excellent, and ROC > 0.9 outstanding. We also report marginal R^2 values (R^2 attributed to fixed effects of mixed models; Nakagawa & Schielzeth 2013).

Using data collected on subplots in the British Columbia portion of the Chinchaga caribou range, we assessed the validity of using Alberta-based models to explain pipeline use by ungulates and predators in the British Columbia portion of the range. We first generated Resource Selection Functions (RSFs) spanning the entire extent of the Chinchaga caribou range (including both provinces) from the informative variables retained in GIS-based models for ungulate and predator use of pipelines based on the Alberta data, and evaluated the ability of the respective RSFs to predict pipeline use by ungulates and predators in the British Columbia portion of the range using Fisher's exact test.

2.3 Results

2.3.1. Use of pipelines by alternate prey and predators

In Alberta, we recorded 56 subplots with moose tracks, 11 subplots with deer tracks, 37 subplots with bear tracks, and 14 subplots with canine tracks. We only observed evidence of caribou tracks on 3 subplots, and observed no elk tracks. From the 180 subplots sampled in Alberta on 69 unique pipelines, we subsequently removed 22 subplots from analyses because of missing field data. In British Columbia, we recorded 35 subplots with moose tracks, 19 subplots with deer tracks, 5 subplots with elk tracks, 26 subplots with caribou tracks, 11 subplots with bear tracks, and 15 subplots with canine tracks. From the 107 subplots sampled on 36 unique pipelines in British Columbia, we subsequently removed 2 subplots from analyses because of missing field data. Summary of field attributes collected at the 158 subplots in Alberta and the 105 subplots in British Columbia used for data analysis are in Tables 2.1 to 2.4.

Table 2.1. Mean (min-max) values of subplots sampled on pipelines and in the forest stand adjacent to pipelines with presence of animal tracks collected in the Chinchaga caribou range in Alberta in 2015 and in British Columbia in 2017. Ungulates and Predators fields include subplots with observations of more than one species. Variables are described in detail in Appendix 2.

Species	Slope[1]	VegHT[2]	VegCover[3]	LatCov0to1m[4]	OFF.LatCov0to1m[5]	Off.domAvgTreeHT[6]
Alberta						
Deer	1.6 (0-6)	0.8 (0.5-1.5)	77.8 (60-98)	53.5 (25-90)	47.8 (5-100)	9.2 (4-18)
Moose	1.1 (0-5)	1.4 (0.3-5)	78.8 (20-100)	62.52 (10-100)	62.28 (10-100)	10.82 (3-25)
Ungulates	*1.2 (0-6)*	*1.2 (0-6)*	*79.6 (20-100)*	*29.2 (0-98)*	*64.29 (10-100)*	*10.6 (3-25)*
Bears	1.2 (0-5)	01.7 (0.4-7)	84.4 (35-100)	64.9 (12-100)	60.3 (5-100)	12.2 (3-27)
Canines	1.5 (0-5)	0.9 (0.2-2.5)	71.0 (25-100)	45.7 (5-98)	65.3 (10-98)	10.4 (4-18)
Predators	*1.2 (0-5)*	*1.5 (0.2-7)*	*82.2 (25-100)*	*59.4 (5-100)*	*61.6 (5-100)*	*11.8 (3-27)*
British Columbia						
Deer	2.6 (0-30)	1.5 (0.2-3.0)	78.4 (40-100)	61.4 (10-100)	63.6 (2-100)	8.6 (2.7-21)
Moose	2.4 (0-30)	1.5 (0.5-3)	78.5 (25-100)	64.3 (5-100)	63.7 (2-100)	8.2 (1.5-21)
Elk	0.4 (0-1)	1.9 (1.3-2.5)	92.8 (80-100)	81.6 (56-100)	64.2 (25-90)	13.7 (4.0-19)
Caribou	1.3 (0-18)	0.9 (0.2-2.0)	81.6 (30-100)	38.7 (1-100)	68.2 (25-100)	5.0 (1.3-14)
Ungulates	*1.9 (0-30)*	*1.3 (0.2-3)*	*80.6 (25-100)*	*54.8 (1-100)*	*66.4 (2-100)*	*7.2 (1.3-21)*
Bears	3.8 (0-30)	1.5 (0.4-3)	78.0 (30-100)	58.2 (2-100)	49.3 (2-100)	10.2 (2.0-21)
Canines	3.6 (0-30)	1.4 (0.4-3)	61.5 (30-100)	50 (1-100)	72.5 (2-100)	6.8 (2.0-21)
Predators	*2.5 (0-30)*	*1.4 (0.4-3.0)*	*67.6 (30-100)*	*52.5 (1-100)*	*65.3 (2-100)*	*8 (2.0-21)*

[1]Slope degree along pipeline, [2]Mean online vegetation height, [3]Mean % vegetation ground cover, [4]Online % lateral cover between 0 and 1m from ground, [5]% lateral cover between 0 and 1m from ground in adjacent stand, [6]Mean tree height of the dominant tree species in adjacent stand.

Table 2.2. Tree and human use attributes of pipeline subplots with presence of animal tracks collected in the Chinchaga caribou range in Alberta in 2015 and in British Columbia in 2017. The total number of subplots with signs of each species is given (# subplots). Tree and Conifer refer to the number of subplots with signs of each species with trees, and conifer, present as dominant and subdominant vegetation structure. Ungulates and Predators fields include subplots with observations of more than one species.

				Dominant Trees		Subdominant Trees	
Alberta	**Species**	**# subplots**	**Human presence**	**Tree**	**Conifer**	**Tree**	**Conifer**
	Deer	10	8	1	0	0	-
	Moose	50	19	15	2	7	2
	Ungulates	*55*	*20*	*15*	*2*	*7*	*6*
	Bears	32	14	10	1	7	0
	Canines	10	8	3	1	1	0
	Predators	*39*	*20*	*11*	*1*	*7*	*0*
British Columbia	Deer	19	6	17	5	9	1
	Moose	35	8	31	9	15	2
	Elk	5	1	5	1	5	2
	Caribou	26	7	25	11	16	12
	Ungulates	*62*	*14*	*56*	*20*	*32*	*14*
	Bears	11	5	11	5	8	3
	Canines	15	5	14	2	3	0
	Predators	*23*	*10*	*22*	*6*	*9*	*3*

Table 2.3. Tree attributes of subplots located in the forest stand adjacent to pipelines with presence of animal tracks collected in the Chinchaga caribou range in Alberta in 2015 and in British Columbia in 2017. The total number of subplots with signs of each species is given (# subplots). Tree and Conifer refer to the number of subplots with trees, and conifer, present as dominant and subdominant vegetation structure. Ungulates and Predators fields include subplots with observations of more than one species.

			Dominant Trees		Subdominant trees	
	Species	**# subplots**	**Tree**	**Conifer**	**Tree**	**Conifer**
Alberta	Deer	10	10	9	9	6
	Moose	50	49	29	40	28
	Ungulates	*55*	*55*	*24*	*43*	*29*
	Bears	32	32	18	29	19
	Canines	10	10	6	10	6
	Predators	*39*	*39*	*23*	*36*	*26*
British Columbia	Deer	19	19	14	10	17
	Moose	35	35	31	15	9
	Elk	5	5	3	3	1
	Caribou	26	26	24	19	16
	Ungulates	*62*	*62*	*46*	*35*	*26*
	Bears	11	11	6	7	5
	Canines	15	15	9	7	6
	Predators	*23*	*23*	*14*	*13*	*11*

Table 2.4. Soil attributes (Clay, Loam, Organic, and Sand; proportion of subplots) of pipeline subplots with presence of animal tracks collected in the Chinchaga caribou range in Alberta in 2015 and in British Columbia in 2017. The total number of subplots with signs of each species is given (# subplots). Ungulates and Predators fields include subplots with observations from more than one species.

	Species	# subplots	Clay	Loam	Organic	Sand
Alberta	Deer	10	0.1	0.5	0.4	0
	Moose	50	0.14	0.52	0.30	0.04
	Ungulates	*55*	*0.15*	*0.53*	*0.31*	*0.04*
	Bears	32	0.22	0.38	0.34	0.03
	Canines	10	0.20	0.60	0	0.20
	Predators	*39*	*0.21*	*0.46*	*0.28*	*0.05*
British Columbia	Deer	19	0.21	0.26	0.26	0.26
	Moose	35	0.29	0.31	0.26	0.14
	Elk	5	0.40	0.40	0.20	0.00
	Caribou	26	0.27	0.04	0.54	0.15
	Ungulates	*62*	0.26	0.21	0.39	0.15
	Bears	11	0.27	0.27	0.27	0.18
	Canines	15	0.13	0.20	0.07	0.60
	Predators	*23*	0.22	0.22	0.13	0.43

We had sufficient field data to assess use of pipelines in Alberta for moose, deer, canine, and bear species. We could not assess pipeline use for caribou or elk because of insufficient presence data in Alberta (n = 3 and n = 0 respectively). Based on field data, deer in Alberta were more likely to use pipelines with slight slopes (Slope; range of data: 0 to 6°), low vegetation height on pipelines (VegHT), and presence of moose signs (Moose; Table 2.5). Moose in Alberta were more likely to use pipelines with high lateral cover between 0 and 1 m height (LatCov0to1m), presence of deer sign (Deer), and secondary tree species in the adjacent forest stands being either conifer (not broadleaf) or absent (Off.secT.BL; Table 2.5). Bears in Alberta were more likely to use pipelines with broadleaf secondary tree species on pipelines (On.secT.BL), and with presence of ungulate signs (Ungulates; Table 2.5). For canines in Alberta, there were no influential variables explaining the presence of canine tracks although canine tracks were somewhat positively associated with presence of human activity (β: 6.0 ± 1.7, p-value: 0.09). For deer and bear species in Alberta, we could not identify any influential GIS-based variables. Still, based on GIS data, moose and all ungulate species combined were more likely to use pipelines near water, and within areas of low densities of roads and pipelines within a 1km radius (Table 2.6). For canines and all predators combined, we observed more signs on pipelines with some degree of slope present (range of data: 0 to 6°, Table 2.6).

Table 2.5. Parameter estimates (β), standard errors (SE), and p-values for best selected generalized linear mixed models used to assess moose, deer, bear, and canine use of pipelines within the Alberta portion of the Chinchaga caribou range in Alberta, Canada using field-based variables collected in 2015.

	Moose			Deer			Bear		
	β	SE	p-value	β	SE	p-value	β	SE	p-value
Intercept	-1.0	0.2	<0.0001	-4.7	0.9	<0.0001	-2.4	0.5	<0.0001
LatCov0to1m[1]	0.5	0.2	0.02	-	-	-	-	-	-
Off.secT.BL[2]	-0.6	0.2	0.006	-	-	-	-	-	-
Deer	1.9	0.8	0.02	-	-	-	-	-	-
Moose	-	-	-	2.1	0.8	0.007	-	-	-
Ungulates	-	-	-	-	-	-	1.2	0.5	0.03
Slope[3]	-	-	-	0.6	0.3	0.05	-	-	-
VegHT[4]	-	-	-	-2.2	0.9	0.02	-	-	-
On.secT.BL[5]	-	-	-	-	-	-	0.6	0.3	0.02

[1]Online % lateral cover between 0 and 1m from ground , [2]Secondary tree species in the adjacent forest stands being broadleaf (1) or not broadleaf (0), [3]Slope degree along pipeline, [4]Mean pipeline vegetation height, [5]Secondary tree species on the pipeline being broadleaf (1) or not broadleaf (0).

Table 2.6. Parameter estimates (β), standard errors (SE), and p-values for best selected generalized linear mixed models used to assess moose, canine, ungulate, and predator use of pipelines within the Alberta portion of the Chinchaga caribou range in Alberta, Canada during 2015 using GIS-based variables. GIS-based models for deer and bear species did not identify any influential GIS-based variable, we therefore ran models including all ungulate species, and all predator species combined: The ungulate variable includes 56 moose signs, 11 deer signs, and 3 caribou sign while the predator variable includes 39 bear signs and 15 canine signs.

	Moose			Ungulate			Canine			Predator		
	β	SE	p-value	β	SE	p-value	β	SE	p-value	β	SE	p-value
Intercept	-1.0	0.2	<0.0001	-0.9	0.2	0.0002	-3.0	0.7	<0.0001	-1.3	0.3	<0.0001
Dist2Water[1]	-0.7	0.2	0.004	-0.7	0.2	0.004	-	-	-	-	-	-
RdsPipe_1km[2]	-0.6	0.3	0.02	-0.8	0.3	0.005	-	-	-	-	-	-
Slope[3]	-	-	-	-	-	-	0.8	0.3	0.007	0.5	0.2	0.02

[1]Distance to the nearest stream, [2]Density of roads and pipelines within 1km, [3]Slope of ground under pipeline and adjacent forest stand, GIS-derived, degrees.

For field-based models, performance based on AUC ranged from acceptable to excellent: ROC values for models of moose, deer, and bear were 0.79, 0.86, and 0.93 respectively. Marginal R^2 (R^2 attributed to the fixed effects of the models) were 0.18, 0.64, and 0.11 respectively. For GIS-based models, performance based on AUC was excellent: ROC values for models of moose, canine, ungulate, and predator were 0.81, 0.91, 0.83, and 0.90 respectively. Marginal R^2 for GIS-based models were 0.17, 0.14, 0.22, and 0.3 for moose, canine, ungulate, and predator models respectively.

Overall performance of RSFs to predict pipeline use in British Columbia was poor for ungulate data, and fair for predator data (Tables 2.7 and 2.8). Fisher's exact test revealed that the ungulate RSF failed to accurately represent use of pipelines in British Columbia (p = 0.0005, Figure 2.3). However, based on Fisher's exact test, the predator RSF adequately represented predator use in British Columbia (p = 0.4, Figure 2.4).

Table 2.7. Proportion of available area (αi), proportion of used pipelines (μi), selection ratio (w(x)), and risk ratio (RR) per bin of relative probability of use from mixed logistic regression models assessing ungulate use of pipelines in the Alberta portion of the Chinchaga caribou range in 2015. Use_AB represents the number of observed ungulate use on pipelines per Resource Selection Function (RSF) bin in Alberta, and Use_BC represents the number of observed ungulate use per bin in the British Columbia portion of the Chinchaga range in 2017.

Bin	α_i	μ_i	$w_{(x)}$	RR	Use_AB	Use_BC
1	0.20	0.13	0.64	1	7	21
2	0.20	0.30	1.45	2.26	16	4
3	0.40	0.50	2.5	3.97	28	26
4	0.20	0.07	0.37	0.57	4	11

Table 2.8. Proportion of available area (α_i), proportion of used pipelines (μ_i), selection ratio ($w_{(x)}$), and risk ratio (RR) per bin of relative probability of use from mixed logistic regression models assessing predator use of pipelines in the Alberta portion of the Chinchaga caribou range in 2015. Use_AB represents the number of observed predator use on pipelines per Resource Selection Function (RSF) bin in Alberta, and Use_BC represents the number of observed predator use per bin in the British Columbia portion of the Chinchaga range in 2017.

Bin	α_i	μ_i	$w_{(x)}$	RR	Use_AB	Use_BC
1	0.24	0.2	0.84	1	8	5
2	0.21	0.15	0.74	0.88	6	8
3	0.20	0.18	0.88	1.04	7	4
4	0.17	0.3	1.79	2.12	12	4
5	0.17	0.15	0.90	1.06	6	2

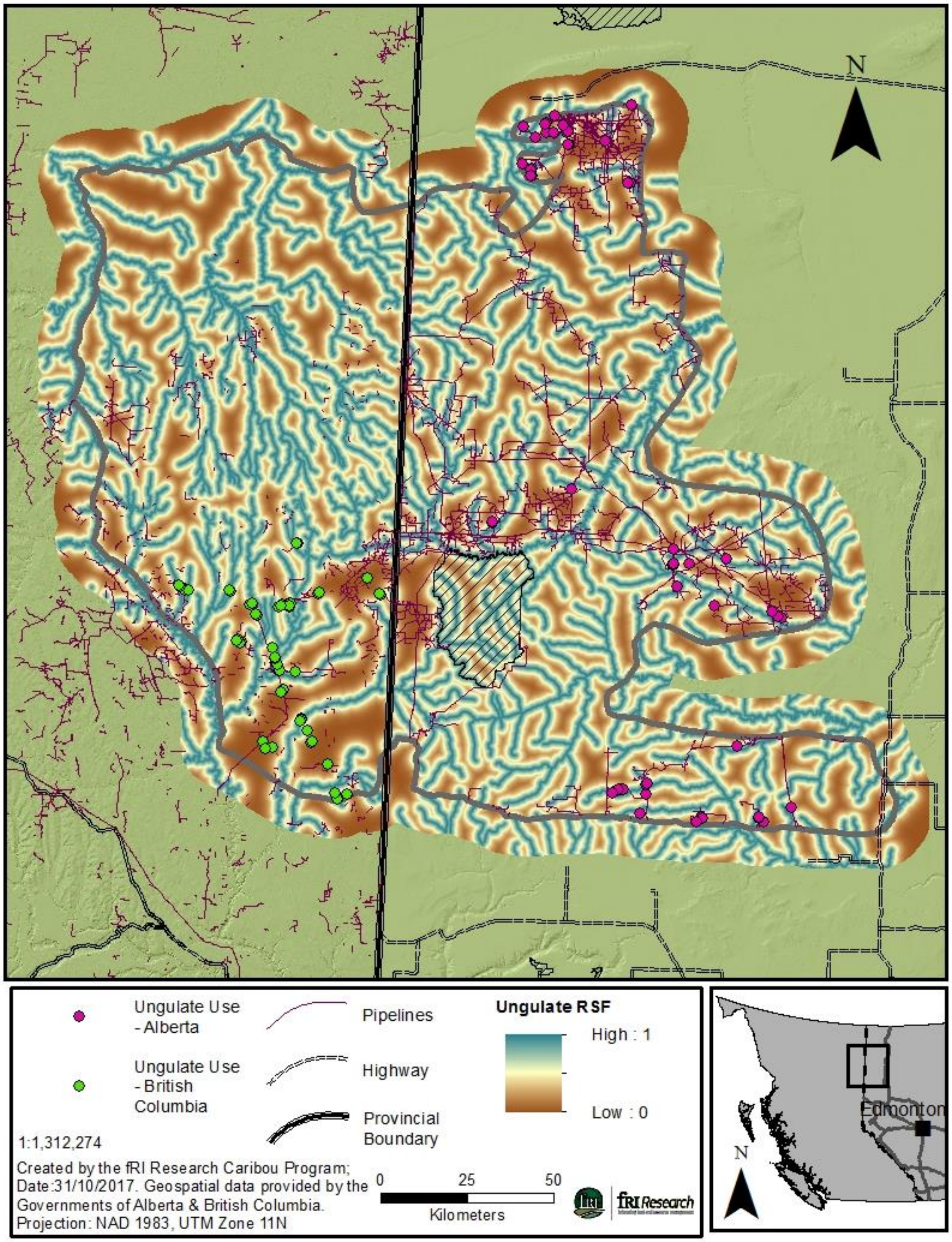

Figure 2.3. Relative probability of pipeline use by ungulate species (moose, deer, and caribou) in the Chinchaga caribou range based on best selected mixed logistic regression model developed from tracks and signs collected on pipelines in the Alberta portion of the range in 2015.

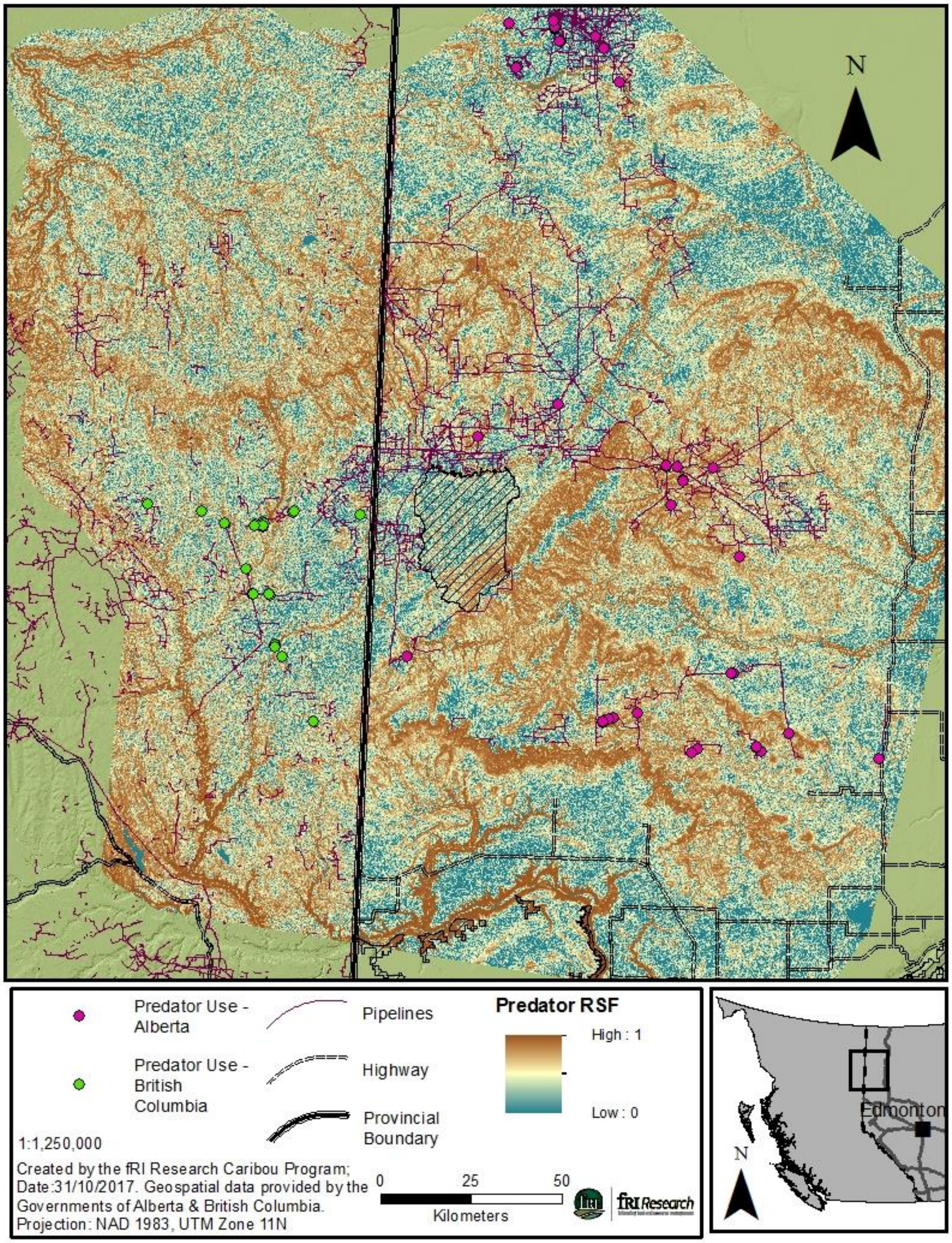

Figure 2.4. Relative probability of pipeline use by predator species (bears and canines) in the Chinchaga caribou range based on best selected mixed logistic regression model developed from tracks and signs collected on pipelines in the Alberta portion of the range in 2015.

2.3.2. Use of pipelines as a function of age and surrounding forest type

Although canine tracks were observed on both young, and old pipelines, we observed a greater proportion of canine tracks on old pipelines, especially within non-forested habitat types (Table 2.9). We also observed very few canine tracks on pipelines aged 10 to 15 year old, regardless of landcover type and we observed no canine tracks on pipelines within wetlands, regardless of pipeline age (Table 2.9). Generally bears seem to use young pipelines more than older pipelines, although bear signs were common on pipelines of any age. Specifically bears used young pipelines that fell in conifer stands and in non-forest, and used old pipelines that fell in broadleaf stands (Table 2.9). For ungulates, we observed no obvious interactions between pipeline age and landcover class and ungulate use, although we generally observed more ungulate signs on young pipelines (Table 2.9).

Table 2.9. Percent of canine, bear, and ungulate tracks recorded on pipelines less than 10 years old (fPipe<10), 10 to 15 years old (fPipe10_15), and more than 15 years old fPipe>15) within landcover classes in the Alberta portion of the Chinchaga caribou range in during 2015.

	Landcover	fPipe<10	fPipe10_15	fPipe>15
Canine	Broadleaf	6.6%	6.6%	13.3%
	Conifer	13.3%	0%	6.6%
	NonForest	13.3%	0%	26.7%
	Wetland	0%	0%	0%
Bear	Broadleaf	10.3%	0%	15.4%
	Conifer	17.9%	5.1%	0%
	NonForest	12.8%	2.6%	7.7%
	Wetland	10.3%	12.8%	2.6%
Ungulate[1]	Broadleaf	9.7%	3.2%	6.5%
	Conifer	14.5%	1.6%	3.2%
	NonForest	11.3%	3.2%	11.3%
	Wetland	12.9%	9.7%	1.6%

[1]3 caribou, 11 deer, and 56 moose track observations.

2.4. Conclusions

Results from our field-based models for ungulates are consistent with previous findings that linked greater use and presence of deer and moose with productive early seral stands (Bjørneraas *et al.* 2011; Fisher *et al.* 2016). We found that deer used pipelines with low regenerating trees heights (~1m) compared to pipelines with taller vegetation, and that moose used pipelines with high lateral cover below a 1m height. Although our field-based models did not reveal any influential variables for canines, bears were more likely to use pipelines with ungulate signs, and with presence of broadleaf tree species as secondary tree species. Overall, low sample sizes prevented us from observing clear, species-specific patterns of pipeline use. However, we still found evidence that moose and deer target productive early seral stands, and that bears potentially target areas used more by these ungulate species. Pipeline age had no clear effect on the use of pipelines for canines, bears, and ungulates although bears and ungulates seemed to use young pipelines more, and canines seemed to use old pipelines more, especially in non-forested habitats.

Overall, field-based data explained animal use of pipelines better than GIS-based variables, and these results could be due to selection of pipelines occurring at fine scales that are not easily represented with GIS-based variables (i.e., the use of pipelines is likely best explained at scales < 90m). Our attempt to use data obtained from the Alberta portion of the Chinchaga range to explain pipeline use on the British Columbia portion of the range also yielded low performance. Although moose signs were common on pipelines in both provinces, and deer observations were similar between both provinces, we recorded only 3 observations of caribou signs in Alberta, and over 20 different caribou signs in British Columbia. The differences in species-specific observations between the two provinces likely explains, at least in part, the low performance of Alberta models in British Columbia, especially in respect to ungulate models. It is also likely that topography, habitat characteristics, and the density of anthropogenic features between the two provinces differ enough to justify the use of province-specific modelling approaches to understand pipeline use in the Chinchaga caribou range.

3. Prioritizing areas for restoration: Caribou–wolf overlap

3.1 Background

Low sample sizes for pipeline-specific models (see Chapter 2) precluded us from accurately predicting the co-occurrence of caribou and wolves on pipelines, and we therefore could not use these models to prioritize areas for habitat restoration for caribou (Objective 5). As an alternative, we used our seasonal 3rd order RSF models (MacNearney *et al.* 2017) to 1) estimate spatio-temporal overlap between caribou and wolves based on seasonal patterns of selection for the two species, and 2) identify areas with high priority for restoration towards caribou conservation based on the greatest spatio-temporal overlap between caribou and wolves across the year (i.e., overlapping high RSF values for both species).

3.2 Methods

3.2.1. Rescaling RSFs

Because RSF models predict the relative probability of selection of one habitat relative to another, RSF values can only be compared within the same model. Therefore, to enable direct comparisons between our caribou and wolf RSFs, we re-scaled the wolf and caribou seasonal RSFs to approximate selection ratios. Selection ratios represent the relative probably of selection with a value of 1 representing selection equal to availability, a value < 1 representing avoidance, and a value > 1 representing selection. To re-scale RSFs into selection ratios, we first binned the raster values from wolf and caribou seasons RSFs into 10 ranked equal-area bins, then we calculated selection ratios within the 10 ranked equal-area bins, combined bins with similar selection ratios together, and finally, calculated selection ratios within the resulting bins and re-classified the rasters with the appropriate selection ratios. This approach allowed us to combine (multiply) wolf and caribou RSFs together and use the combined RSFs to identify areas with a value greater than or equal to 1 as those areas that were likely to be selected by both caribou and wolves during the same season.

3.2.1. Combining/overlaying caribou and wolf RSFs

We defined the degree of caribou and wolf RSF overlap using 1) wolf-seasons (denning, rendezvous, and nomadic) and 2) data pooled across the entire year. Because caribou RSFs were defined using caribou-seasons (spring, summer, fall, early winter, and late winter) we first needed to match seasonal caribou RSFs to wolf-seasons. To match wolf and caribou seasons, we calculated the weighted average of the five seasonal caribou RSFs based on the number of days that each caribou-season occurred within a particular wolf-season (Table 3.1).

Table 3.1. Temporal overlap (no. of days) between wolf and caribou seasons used to weight caribou RSF rasters within the Chinchaga caribou range.

Wolf-season	Caribou-season	No. of days
Denning	Spring	48
Denning	Summer	22
Rendezvous	Summer	81
Nomadic	Summer	3
Nomadic	Fall	42
Nomadic	Early winter	82
Nomadic	Late winter	69
Nomadic	Spring	10

3.2.1. Identifying areas with a high probability of overlap

To identify areas with a high probability of overlap between wolves and caribou, we multiplied the seasonal wolf RSF raster with its matching weighted caribou RSF raster.We then used Jenk's natural breaks in ArcGIS 10 (Environmental Systems Research Institute (ESRI) 2015) to categorize the resulting wolf-caribou overlap rasters into five groups representing the probability of overlap between the two species (low, low-medium, medium, high, and very high). We set the lowest value of the 'high' category to 1 to ensure the 'high' and 'very high' categories were greater than 1, and therefore represented areas that both caribou and wolves were selecting (i.e., overlapping areas).

3.3 Results

We classified between 17% and 23% of the Chinchaga caribou range as high or very high probability of overlap between caribou and wolves (Table 3.2). We observed the greatest spatial overlap between areas with a high probability of caribou and wolf selection during the denning season (23% of range), although this result was only marginally higher than the spatial overlap between the two species during the rendezvous and nomadic seasons (17% for both seasons). We identified 19% of the Chinchaga range as high or very high probability of overlap between caribou and wolves across the year. Within the Chinchaga caribou range, areas with a high probability of overlap between the two species occurred in the south-west of the range, and there appeared to be few areas with a high probability of overlap between the two species in the protected Chinchaga Wildland Provincial Park in Alberta (Figures 3.1 to 3.4).

Table 3.2. Area (km²) and percent (%) of the Chinchaga caribou range identified as having a low, low-medium, medium, high, and very high probability of overlap between caribou and wolves based on seasonal 3rd order RSF values. Results are given for the entire year, and for each of the three wolf seasons (Denning, Rendezvous, and Nomadic).

Season	Low		Low-medium		Medium		High		Very high	
	km²	%	km²	%	km²	%	km²	%	km²	%
Entire year	18,778	41	11,753	26	6,193	14	5,962	13	2,717	6
Denning	22,397	49	8,946	20	3,496	8	8,332	18	2,232	5
Rendezvous	16,627	37	10,518	23	10,286	23	6,404	14	1,568	3
Nomadic	19,244	42	11,603	26	6,776	15	4,427	10	3,354	7

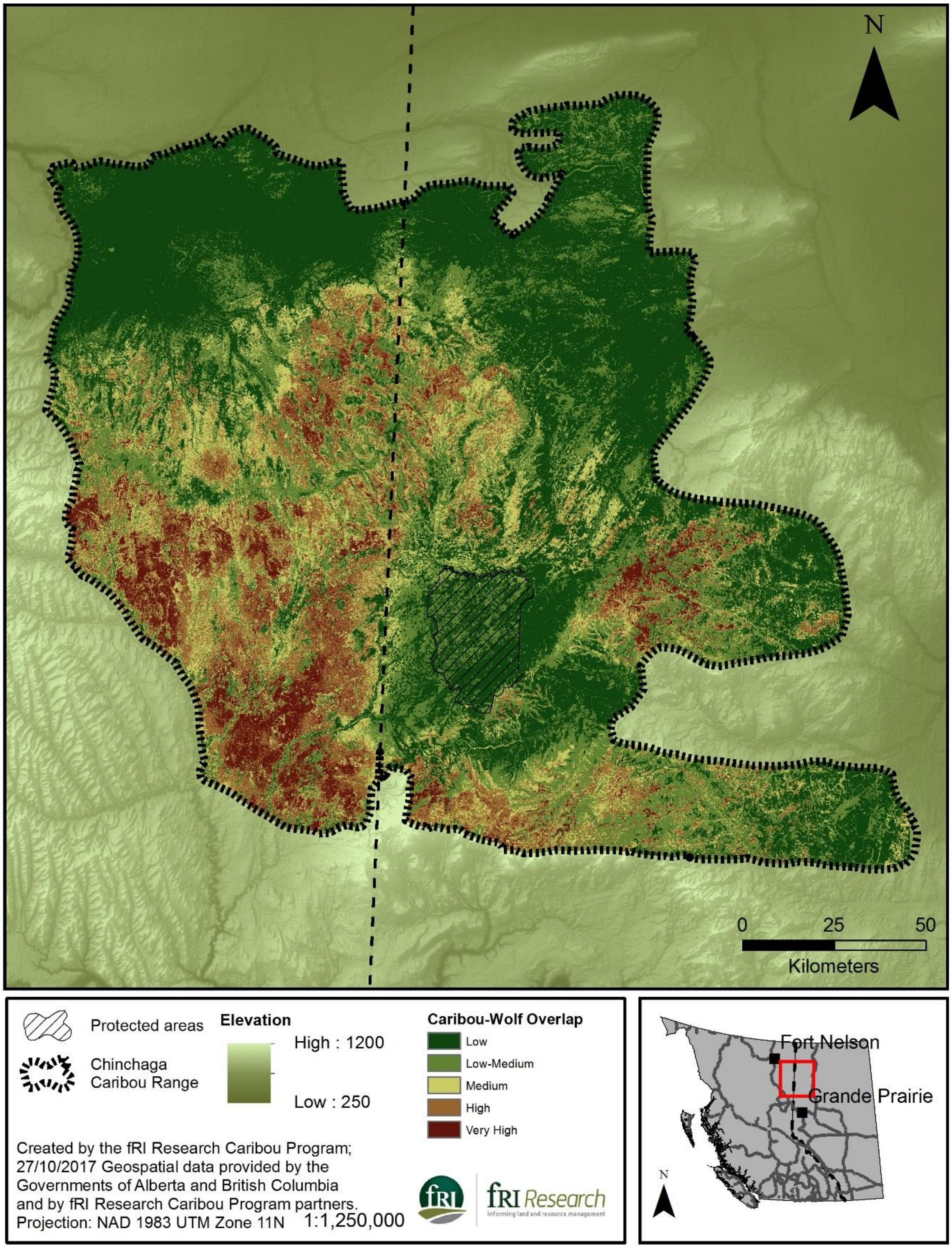

Figure 3.1. Caribou-wolf overlap across the entire year in the Chinchaga caribou range.

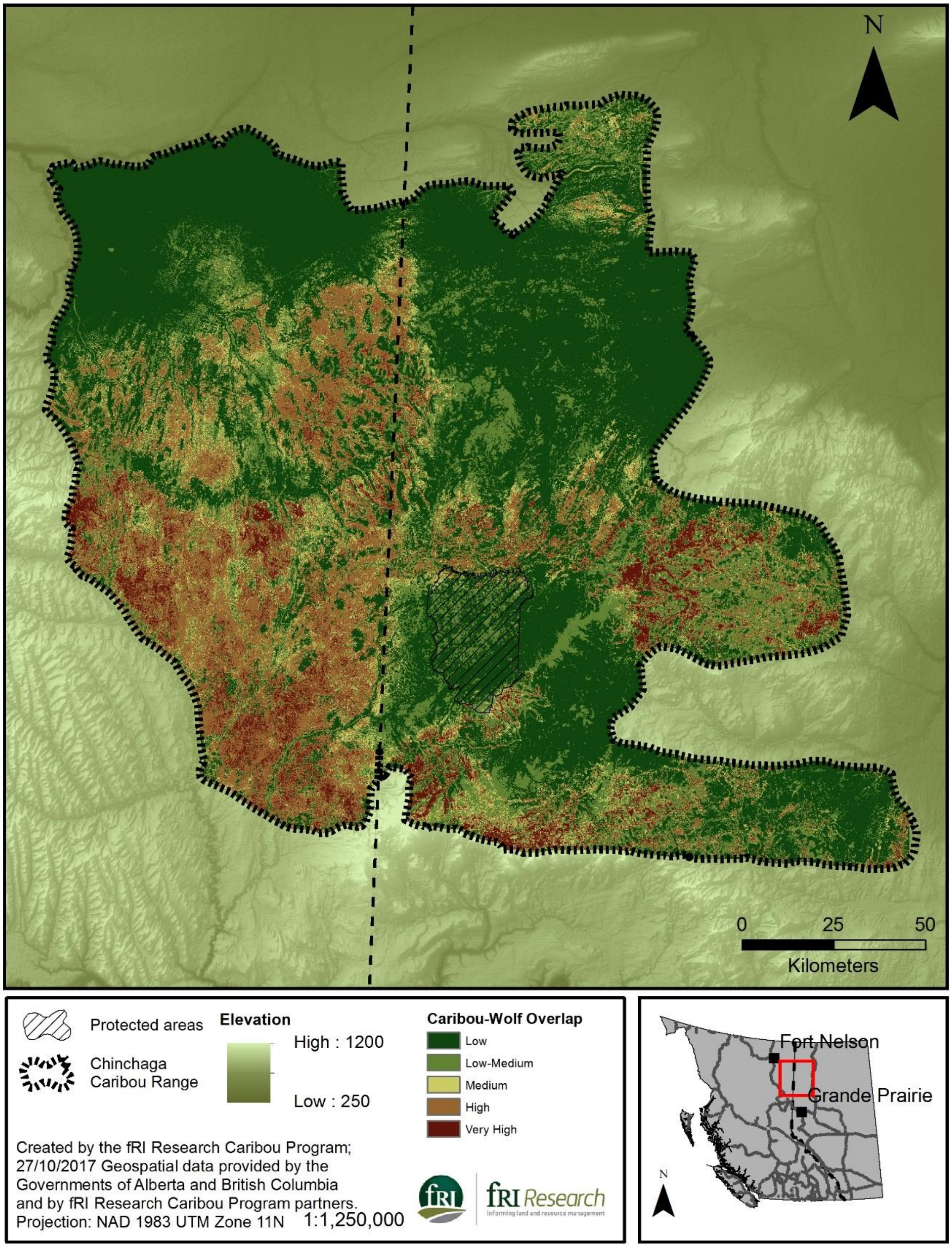

Figure 3.2. Caribou-wolf overlap during the wolf denning season in the Chinchaga caribou range.

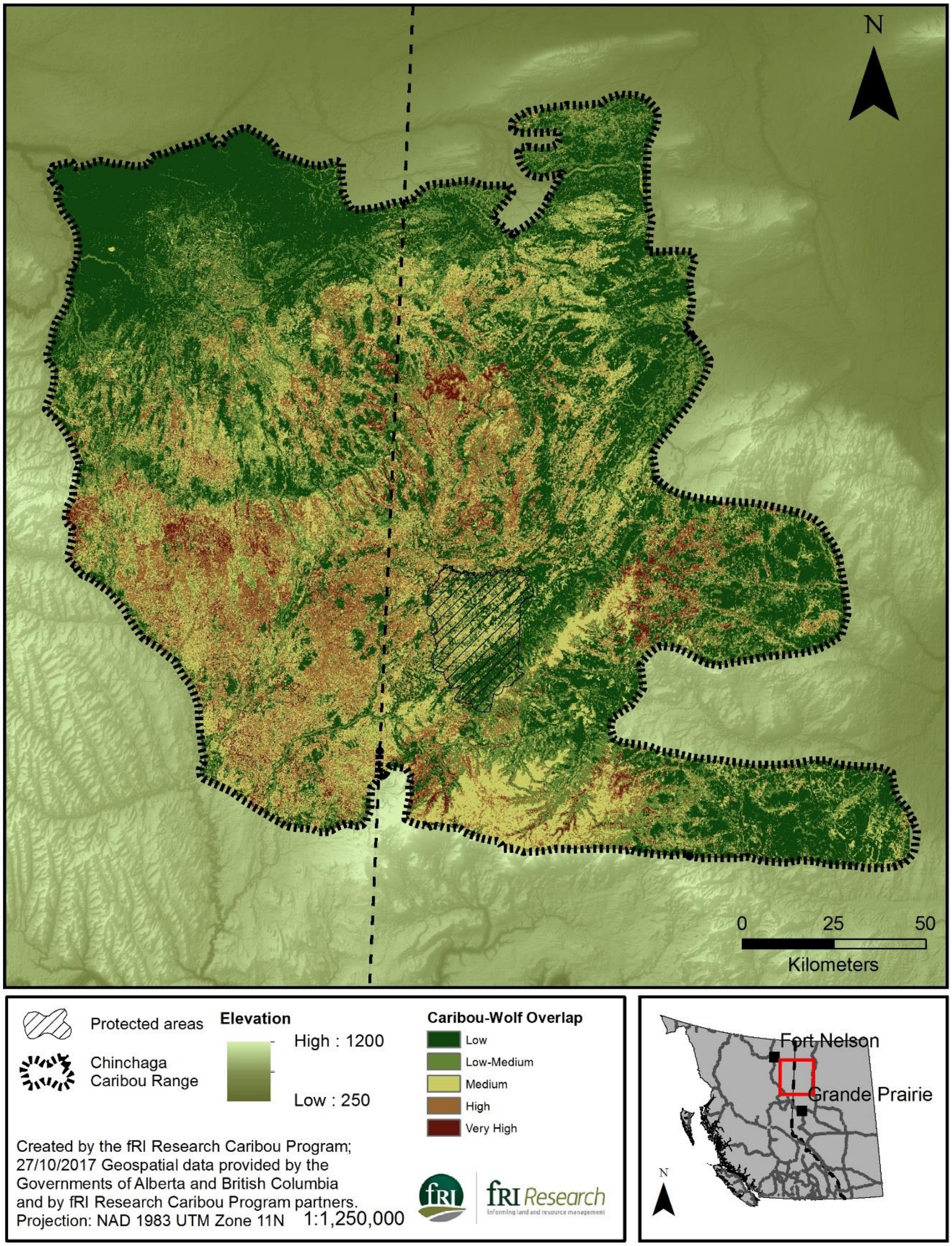

Figure 3.3. Caribou-wolf overlap during the wolf rendezvous season in the Chinchaga caribou range.

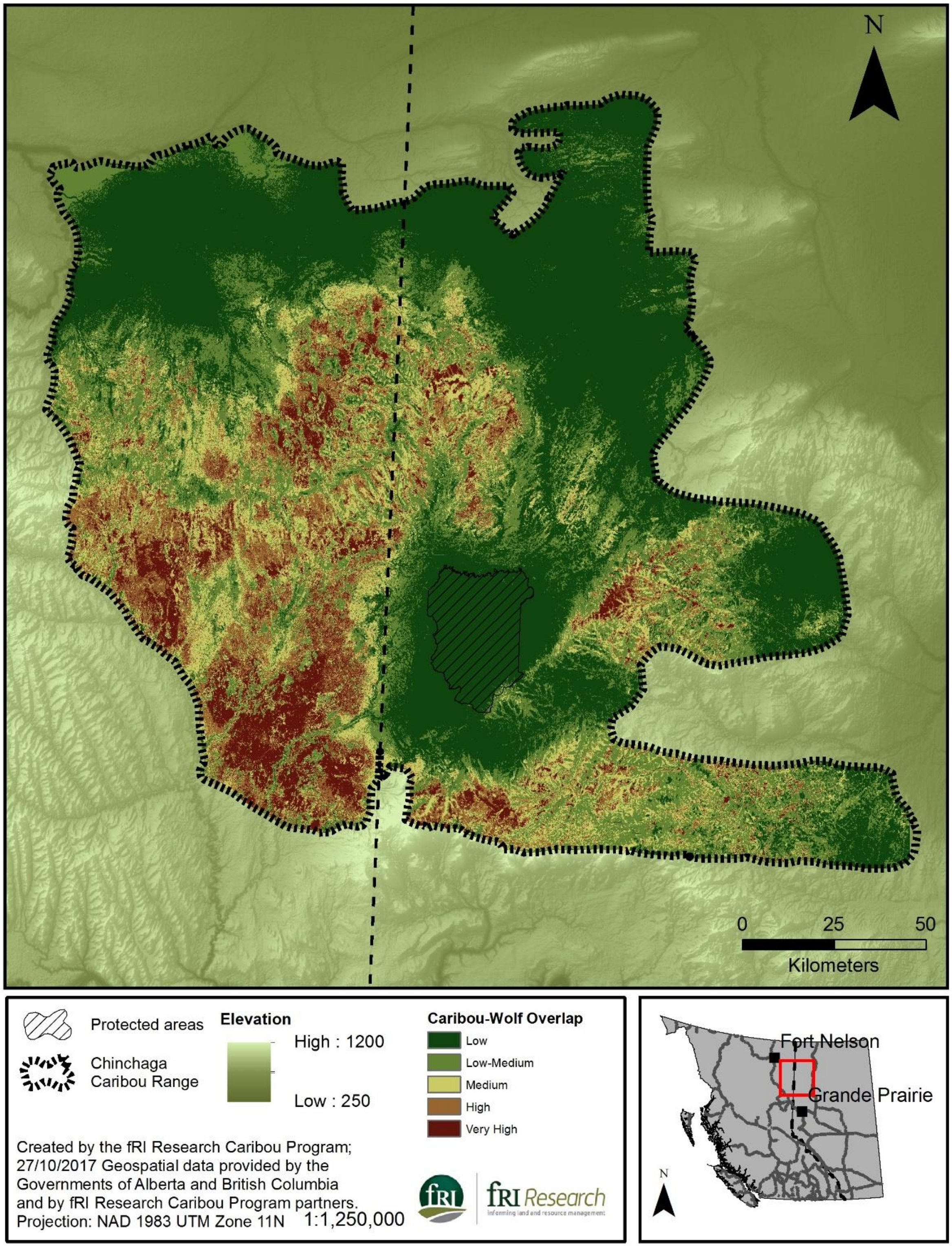

Figure 3.4. Caribou-wolf overlap during the wolf nomadic season in the Chinchaga caribou range.

4. Summary of Project Results

4.1. Caribou and Wolf Response to Well Site Activity

Objective 1: *Determine how different types of activity at well sites influences the behaviour of caribou and wolves, and assess how this relationship changes seasonally and in relation to the surrounding habitat matrix.*

4.1.1. Caribou response to human activities at well sites

Using baseline RSFs, and including explicit variables for distance to well sites, we investigated the response of caribou to high, low, and moderate activity well sites. We found that caribou:

- Selected habitat that was, on average, 30km from the nearest high-activity well site, 5km from the nearest moderate-activity well site, and 1.5m from the nearest low-activity well site. Regarding the 30km avoidance distance, although caribou avoid wellsites, they are unlikely to response to wellsites at such large geographic scales. This result is likely an artifact of data combined with our interpretation of avoidance distances directly from the logistic regression curve (rather than for example a gam curve).
- Avoided areas near high- and moderate-activity well sites during all seasons.
- Avoided areas near low-activity well sites during all seasons except late winter, when caribou selected areas near low-activity well sites.

4.1.2. Wolf response to human activities at well-sites

Using baseline RSFs and including explicit variables for distance to well sites, we investigated the response of wolves to high, low, and moderate activity well sites. We found that wolves:

- Selected habitat that was, on average, 15km from the nearest high-activity well site, 1.5km from the nearest moderate-activity well site, and 1km from the nearest low-activity well site.
- Avoided areas near high-activity well sites during the nomadic season, but did not select or avoid areas near high-activity well sites during the denning or rendezvous seasons.
- Selected areas near moderate-activity well sites during all seasons.
- Avoided areas near low-activity well sites during the denning season, but selected areas near low-activity well sites during the nomadic season, when caribou also selected areas near low-activity well sites.

A detailed description of data analysis and results can be found in (MacNearney *et al.* 2016) and (MacNearney *et al.* 2017).

4.2. Caribou and wolf response to pipelines and anthropogenic disturbance

Objective 2: *Assess caribou and wolf response to pipelines in relation to pipeline age and the surrounding habitat matrix.*

4.2.1. Caribou response to pipelines and anthropogenic disturbance

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

- Avoided areas with high densities of cut blocks during all seasons.
- Avoided areas near roads and areas with high densities of roads during all seasons except fall. During fall, when caribou are migrating towards winter ranges, caribou selected areas near high- and low-use roads, but avoided areas near winter-roads.
- Avoided areas near pipelines and areas with higher densities of pipelines during all seasons except fall. During fall, caribou selected areas near pipelines.
- Consistently selected open habitat and wetlands on gentle terrain, and avoided dense and moderate canopy conifer forest during all seasons.
- Selected areas at higher elevations during late winter, spring, and summer, and selected areas at lower elevations during fall and early winter.

4.2.2. Wolf response to pipelines and anthropogenic disturbance

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

- Selected open habitat, and gentle slopes during all seasons, but avoided flat areas during all seasons.
- Avoided wetlands, and dense and moderate canopy forest during all seasons.
- Selected areas near cut blocks during all seasons.
- Selected areas near pipelines and areas with high density of pipelines during all seasons.
- Selected areas near high-use and low-use roads and areas with high densities of high- and low-use roads during all seasons. Wolves also selected areas near winter roads during the nomadic (winter) season, but avoided areas near winter roads during the denning (spring) season.

A detailed description of data analysis and results can be found in (MacNearney *et al.* 2016) and (MacNearney *et al.* 2017).

4.4. Wildlife use of pipelines in the Chinchaga caribou range

Objective 3: *Use models of caribou and wolf use of pipelines developed in Alberta to model caribou and wolf use of pipelines in the British Columbia portion of the Chinchaga caribou range, and validate models with field data collection.*

Based on data collected at 180 subplots in Alberta, we only recorded evidence of caribou use at 3 subplots, and evidence of canine use at 14 subplots. From data collected on 90 subplots in British Columbia, we recorded evidence of caribou use at 26 subplots, and canine use at 15 subplots. Although use of pipelines by caribou in British Columbia was relatively high, low sample size in Alberta prevented us from developing caribou-specific models of pipeline use. In addition, evidence of canine use on pipelines was relatively low for both provinces, and we therefore had a limited ability to assess canine-specific use of pipelines using non-invasive methods. Still, in an effort to understand how terrain and habitat characteristics, and pipeline attributes influence the use of pipelines by predator and prey species, we modelled use of pipelines for moose, deer, canine, and bear species using field data, and modeled the use of pipelines for ungulates and predators using GIS-derived variables. From these models we found that:

- Deer were more likely to use pipelines with slight slopes, presence of moose signs, and low vegetation heights.
- Moose were more likely to use pipelines with high lateral cover below 1m, and also more likely to use pipelines within forest stands with dominant broadleaf species.
- Bears were more likely to use pipelines with slight slopes, with broadleaf species growing as a secondary species on pipelines, and with the presence of ungulates signs.
- Overall, ungulates were more likely to use pipelines in areas of low road densities, and in proximity to water, while predators were more likely to use pipelines with slight slopes.
- Pipeline age had no clear effect on the use of pipelines for canines, bears, and ungulates although bears and ungulates seemed to use young pipelines more, and canines seemed to use old pipelines more, especially in non-forested habitats.

4.5. Synthesis

Objective 4: *Evaluate whether currently accepted 500m buffers on well sites and pipelines accurately reflect caribou functional habitat.*

Our analysis of caribou and wolf response to pipelines and well sites, which considered not only the disturbance, but also the intensity of activity, and age of the disturbance, revealed no evidence to refute the 500m buffer that reflects the loss of functional habitat to caribou around disturbances. In fact, our analysis of caribou response to well sites suggest that the effects of producing well sites on caribou habitat selection extend further than 500m. In addition, our results suggest that during part of the year, well sites and pipelines may become ecological traps for caribou; during fall, caribou selected areas near pipelines while wolves selected pipelines through the year, and during late winter, both caribou and wolves selected low-activity well sites.

Objective 5: *Synthesize the results from objectives 1-4 to provide guidelines for restoration and mitigation of disturbance features within caribou ranges to contribute towards caribou recovery in northwestern Alberta and northeastern British Columbia.*

4.5.1. Prioritizing areas for habitat restoration for caribou

4.5.1.1. Broad scale

Understanding patterns of habitat selection by caribou and their predators is an important step in understanding the effects of different disturbances and the landscape matrix on the probability of use, and co-occurrence of caribou and their predators. Using wolf and caribou GPS data, we carried out the first detailed resource selection function analysis of caribou and wolves in the Chinchaga caribou ranges (Alberta and British Columbia). The resulting spatial maps identified 17% of the Chinchaga caribou range as areas that could be prioritized for habitat restoration to reduce the spatial overlap between caribou and wolves (see Figure 3.1), and could be used towards effective and cost-efficient restoration of habitat for caribou. However, it must be remembered that both the caribou and wolf RSFs were built at the 3rd order scale, and the wolf RSF was produced using data from less than 10 individuals that were collared in British Columbia. Our analysis of animal use of pipelines demonstrated that differences in topography, habitat characteristics, and the density of anthropogenic features across the Chinchaga range likely correspond to differences in wildlife response, while previous research has also demonstrated the value of assessing the spatial distribution of wildlife at multiple scales. Additional wolf data gathered from from GPS collars or camera traps in the Alberta portion of the Chinchaga range, and RSFs built at the 2nd order scale, could be used to further validate and fine tune our RSFs and the map the probability of overlap between caribou and wolves.

4.5.1.2. Fine scale

Using GPS telemetry data and field surveys, we identified oil and gas disturbances and attributes of oil and gas disturbances associated with use by caribou, alternate prey (moose, deer, and elk), and caribou predators (wolves and bears). This information could be used to direct more fine scale restoration planning within areas identified as having a high probability of overlap between wolves and caribou at a broad scale (see previous sections). Specifically, restoration could be targeted towards:

- Inactive well sites – to reduce the probability of overlap between caribou and wolves during winter.
- Pipelines – to reduce the probability of overlap between caribou and wolves during fall:

- Disused pipelines could be immediately restored while reducing line of sight could be evaluated as a mechanism to reduce pipeline use by wolves, and potentially reduce the probability of encounter between wolves and prey on active pipelines.
- Pipelines with slopes and in broadleaf stands – field data suggests that these pipelines were most used by moose, bears, and canines.

4.5.2. Conclusions

Effective habitat restoration for caribou will require a coordinated effort that considers 1) fine scale responses of caribou, alternate prey, and predators to disturbances, and 2) the cumulative and interactive effects of disturbances across caribou ranges. The ultimate goal of habitat restoration is to reduce the probability of encounters between caribou and their predators, and thus reduce unsustainable predation rates of caribou. To our knowledge, this study is the first to assess seasonal patterns of habitat selection by caribou and wolves in the Chinchaga caribou range while considering not only disturbance features, but also the activity stage of the disturbance feature. This study is also one of the first to assess wildlife response to pipelines at broad and fine scales.

In the context of habitat restoration for caribou, the results of this project may be used to target restoration treatments across the Chinchaga caribou range, and also to plan fine scale restoration targets of specific pipelines and well sites. In addition, our analysis of caribou response to well site activity revealed seasonal patterns, and differences in the response of caribou to well sites of different level of activity. These patterns could be considered when informing best management practices for 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, and to mitigate the effects of future disturbances on caribou.

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APPENDIX 1: FIELD DATA AND FIELD-DERIVED ENVIRONMENTAL VARIABLES

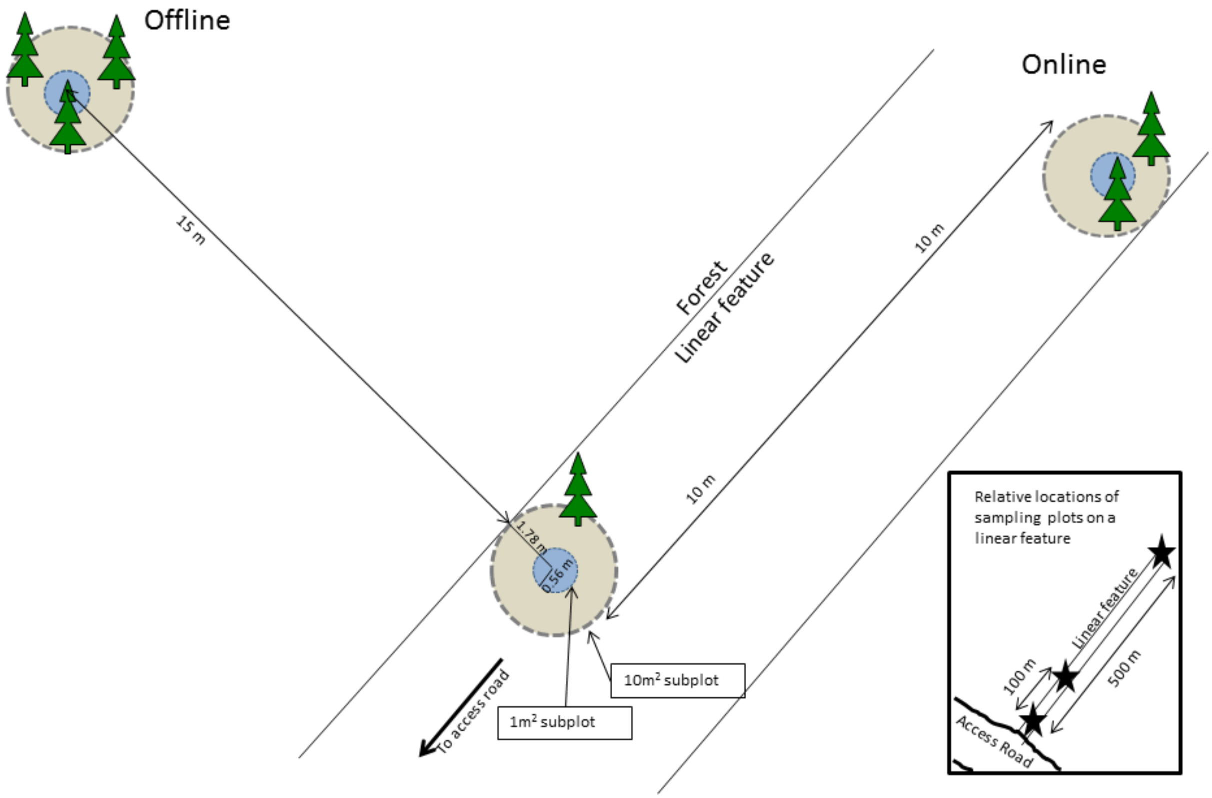

Figure A1.1: Sampling plots showing the location of online and offline subplots relative to access roads (0m, 100m, and 500m).

Table A1.1. Vegetation structure, regeneration data, and presence of tracks and signs from caribou, moose, deer, elk, bears, canines, and humans recorded at subplots located on pipelines in the Chinchaga caribou between June and September of 2015 (Alberta) and 2017 (British Columbia).

Variable	Description
Terrain	
Slope	Slope degree along pipeline
Soil	Soil type (loam, organic, sand, clay)
fSoil.Wet	Soil wetness category (wet, mesic, dry)
Vegetation	
VegHT	Average woody vegetation height, online plot, m
VegCover	Mean percentage of ground cover for all vegetation at plot (%)
LatCov1to1m	% lateral cover between 0 and 1m from ground
OFF.LatCov0to1m	% lateral cover between 0 and 1m from ground in adjacent stand
Trees	
dHT.Stand	Height of dominant tree species in adjacent stand
Off.domAvgTreeHT	Average tree height of the dominant tree species in adjacent stand
Off.domMinTreeHT	Minimum tree height of the dominant tree species in adjacent stand
Off.domMaxTreeHT	Maximum tree height of the dominant tree species in adjacent stand
DomTree.spp	Dominant tree species on pipeline (Broadleaf, Pine, Spruce, Larch, None)
OFF.DomTree.spp	Dominant tree species in adjacent stand (Broadleaf, Pine, Spruce, Larch, None)
SecTree.spp	Co-dominant tree species on pipeline (Broadleaf, Pine, Spruce, Larch, None)
OFF.SecTree.spp	Co-dominant tree species in adjacent stand (Broadleaf, Pine, Spruce, Larch, None)
Wildlife	
Caribou	Presence of caribou tracks or pellets, 0-1
Moose	Presence of moose tracks or pellets, 0-1
Deer	Presence of deer tracks or pellets, 0-1
Elk	Presence of elk tracks or pellets, 0-1
Bear	Presence of bear tracks, digging, or scats, 0-1
Canine	Presence of tracks or scats from a canine (coyote, fox, or wolf), 0-1

APPENDIX 2: GIS-DERIVED ENVIRONMENTAL VARIABLES

Table A1.2 Environmental variables used to model use of pipelines from prey and predator tracks and signs data in the Chinchaga caribou range in 2015 and 2017.

Variable	Description
Habitat	
Age	Age of the adjacent forest stand, years
fNonForest	Binary landcover class, 0-1
fMixed	Binary landcover class, 0-1
fBroadleaf	Binary landcover class, 0-1
fWetland	Binary landcover class, 0-1
fConifer	Binary landcover class, 0-1
Dist2Water	Distance to nearest stream, m
Terrain	
DEM	Elevation, m
TPI	Terrain ruggedness, unitless
CTI	Soil wetness, unitless
Slope	Slope of the ground under the seismic line and adjacent forest stand, degrees
fFlat	Binary aspect of slope, northeast (1), southwest (0), 0-1
Anthropogenic	
RdsPipes_1KM	Density of roads and pipelines within 1km (landscape-scale), km/km^2
RdsPipes_90M	Density of roads and pipelines within 90m (local-scale), km/km^2
Cuts_1KM	Density of 0-30 year old cutblocks within 1km, km/km^2
Cuts_90M	Density of 0-30 year old cutblocks within 90m (3 pixels), km/km^2
Wells_1KM	Density of active well sites within 1km, km/km^2
Wells_90M	Density of active well sites within 90m (3 pixels), km/km^2
CutsWells_1KM	Density of 0-30 year old cutblocks & active well sites within 1km, km/km^2
CutsWells_90M	Density of 0-30 year old cutblocks & active well sites within 90m (3 pixels), km/km^2
RdsPipesCutWells_1KM	Density of 0-30 year old cutblocks, active roads and pipelines, & active well sites within 1km, km/km^2
RdsPipesCutWells_90M	Density of 0-30 year old cutblocks, active roads and pipelines, & active well sites within 90m (3 pixels), km/km^2