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Analysis and Improvement of Linear Features to increase Caribou Functional Habitat in West-Central and North-Western Alberta

Interim Report March 2015

Prepared and edited by

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RESEARCH GROWING INTO PRACTICE

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Executive Summary

Habitat degradation and fragmentation due to human activities is thought to be the ultimate cause of woodland caribou decline in Alberta. Disturbance is currently extensive in caribou range, and restoration actions may be necessary for caribou to persist in these landscapes. It is crucial to understand how disturbance is impacting caribou and how restoration effort will be most effective in reversing negative impacts and stabilizing caribou populations.

In year one of this two year project we studied the relationship between disturbance and caribou in a number of ways. In order to prioritize features for restoration we investigated the use of pipelines and inactive roads by humans, ungulates, and wildlife to determine if landscape and vegetation variables could predict the characteristics of linear features that make them attractive for use. We found that inactive roads were associated with higher rates of use by human motorized traffic when compared to pipelines. Predators were more likely to use linear features where game trails occurred, and where the density of human industrial features was low. As an increase in vegetation height and in soil wetness was associated with lower use by humans, replanting of roads may help deter human users, which in turn may allow vegetation to recover naturally. Predictive models that will help prioritize linear features for restoration at the landscape level are currently under development.

We also investigated the response of caribou to human activity levels at oil and gas well sites. We found that in the early and late winter, caribou selected habitat that was farther away from well sites than expected by chance, and heightened human activity at well sites (drilling, producing) was associated with greater avoidance than inactive (capped, abandoned, or decommissioned) well sites.

In year two of this project we will extend our study of human and wildlife use of roads and pipelines to include the ranges of Redrock-Prairie Creek and Narraway mountain caribou herds in west-central Alberta and the Chinchaga caribou herd in the boreal sub-region of north-western Alberta. Doing so will provide important context for the applicability of our findings across a wider region, as well as strengthen our inference and recommendations for management. We will provide maps outlining priority restoration areas as determined by this research, as well as the list of variables used to develop these maps so that this approach can be applied elsewhere in caribou conservation planning. We are also currently studying caribou population health through non-invasive fecal sampling, with the aim of using pregnancy hormones to validate current sight-based estimates of caribou reproductive rates, and establishing a baseline for stress levels and parasite exposure for further monitoring of population health and the recovery effort.

Acknowledgements

We would like to thank West Fraser Mills and Rick Bonar for making this project possible and for their continued support of the Caribou Program. We are grateful to FRIAA for supporting this research and to Richard Scott for his assistance throughout the year. Thank you to Wendy Crosina and Weyerhaeuser for access to their caribou GPS dataset, the result of a long term collaboration with Alberta Environment and Parks, and to John Davies, Stephane LaRochelle and Simon Lee at Alberta Energy for providing the well site dataset for analysis. We are grateful to Alberta Environment and Parks for their continued support of this research; in particular Dave Hervieux, Sandi Robertson and Julia Wachowski.

Thanks to Kelsey Greenlay for her assistance in the office and field, Flurina Deagle for help with fieldwork this summer and Leonie Brown, Karine Pigeon and Paul Kuchma for fecal survey help this winter. This project would have been impossible without the support of Gord Stenhouse and the fRI Grizzly Bear Program team; notably Terry Larsen who provided assistance with study design, statistical analysis and interpretation. John Cook also provided insight into important caribou foods from his ongoing UNBC/NCASI study and Bryan Macbeth DVM provided input for health monitoring. We are grateful to Steve Wotton at Peregrine Helicopters for his excellent flying skills. Invaluable GIS support was provided by Julie Duval, Kevin Myles and Josh Crough at the fRI GIS Program.

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Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1. General introduction

Habitat degradation and fragmentation resulting from anthropogenic activities are believed to have contributed to declines in woodland caribou populations across their range (Vors and Boyce 2009). The persistence of caribou is likely to depend on the ability of land users and managers to restore disturbed caribou habitat to a functional level (Environment Canada 2008; Festa-Bianchet et al. 2011). Boreal and mountain caribou are protected under SARA with a target under the federal boreal recovery strategies to achieve a minimum of 65% undisturbed habitat within the range of each local population (Environment Canada 2008, 2012, 2014). Under the recovery strategy disturbed habitat consists of all anthropogenic footprint (e.g. cut blocks, seismic lines, well sites) and a surrounding 500m buffer, as well as burned areas (no associated buffer). Currently most caribou ranges in Alberta have less than 30% undisturbed habitat (Environment Canada 2012), and industry is under pressure to implement habitat restoration of disturbed areas to achieve this 65% target. To prioritize areas for restoration and contribute to current range planning efforts, it is imperative to understand how caribou respond to disturbed areas as vegetation regenerates, and to determine at what point disturbed areas become functional habitat for caribou. This understanding is also crucial in monitoring and evaluating the success of restoration efforts (Hobbs and Norton 1996).

The response of caribou to anthropogenic disturbance has been documented in short and long term studies, and through direct and indirect effects on population vital rates, physiology, behaviour and distribution. Proximity to anthropogenic disturbance has been found to negatively impact caribou in terms of recruitment and adult survival rates (Wittmer et al. 2007; McCarthy et al. 2011; Pinard et al. 2012), increased stress (Ashley et al. 2011), range shifting and changes in spatial distribution (Smith et al. 2000; Dyer et al. 2001; Mahoney and Schaefer 2002; Schindler et al. 2007; Polfus et al. 2011), decreases in body condition (Cameron et al. 2005), and local population declines and extirpation (Vors et al. 2007). As restoration efforts proceed, baseline data and progressive monitoring of various population health metrics is crucial in tracking recovery success.

Currently, caribou monitoring takes place via sight-based surveys of caribou numbers and calf/cow ratios by Alberta Environment and Parks. This project is aimed at complementing these efforts by conducting research that contributes to a holistic understanding of caribou ecology in an industrial landscape. Specifically, we aim to (i) evaluate coarse and fine scale behavioural responses (i.e. resource selection and movement) of caribou, their predators, and competitors to disturbed and partially restored features, and (ii) evaluate and monitor population health via non-invasive fecal surveying methods by collecting data on stress and pregnancy hormones as well as parasite and pathogen exposure. The ultimate goal for this project is to integrate the research results and predictive maps of priority areas for restoration and conservation into ongoing range and habitat restoration planning for caribou in west-central and north-western Alberta, and provide continued feedback to evaluate restoration efforts and develop management practices that improve the chances of caribou persistence on the landscape

1.2. Study area

The study area encompasses the range of four caribou herds in west-central Alberta (Narraway, Redrock-Prairie Creek, A La Peche and Little Smoky) and one caribou herd in North-western Alberta (Chinchaga; Figure 1.1). The Little Smoky and Chinchaga caribou herds belong to the boreal ecotype, occur in the boreal forest year round, and have little or minimal seasonal shifts in home range (Bergerud 1992; Briand et al. 2009). Boreal caribou are listed as threatened under Alberta's *Wildlife Act*, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and the *Species at Risk Act* (SARA), and a federal recovery strategy for this ecotype was released in 2012 (Environment Canada 2012). The Narraway, Redrock-Prairie Creek and A La Peche herds belong to the southern mountain ecotype. These caribou undertake short migrations from a summer range at high elevations to a winter range at lower elevations where they feed primarily on terrestrial and arboreal lichens (Wittmer et al. 2007). Southern mountain caribou are also listed as threatened under the Alberta *Wildlife Act*, COSEWIC and SARA, and a proposed federal recovery strategy was released in 2014 (Environment Canada 2014). Boreal and mountain caribou are covered under the provincial recovery plan that outlines ultimate goals of: 1) achieving self-sustaining woodland caribou herds; 2) maintaining the distribution of caribou in Alberta; and 3) ensuring habitat requirements are met for woodland caribou over the long-term throughout caribou ranges in the province (Alberta Woodland Caribou Recovery Team 2005).

The range of these caribou populations encompasses an area roughly 33,000 km^2 in size that spans two forest ecozones (boreal and montane cordillera), three natural regions (boreal, foothills and rocky mountains) and nine natural sub-regions (dry mixedwood, central mixedwood, lower boreal highlands, upper boreal highlands, lower foothills, upper foothills, subalpine, alpine and montane). Approximately 78% (26,000 km^2) of caribou range is managed by the provincial government for a number of uses including oil and natural gas extraction and forestry, while protected areas under federal and provincial jurisdiction make up roughly 6% (2000 km^2; Jasper National Park) and 16% (5,400 km^2; Wildland Parks and Wilderness Areas) of caribou ranges respectively. The range of these four caribou population overlaps with two grizzly bear management areas, 7 FMA holders, and several timber quota holders. For the purpose of this project the caribou that occur in west-central Alberta and those that occur in north-western Alberta are divided into separate study areas.

In west-central Alberta, elevation ranges from 700 to 2300 m above sea level and contains a high diversity in plant and wildlife species. Forests in caribou range are mainly coniferous and are characterized by lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*) with patches of trembling aspen (*Populus tremuloides*) in upland areas, while lowland areas consist primarily of black spruce (*Picea mariana,*) larch (*Larix laricina*), and poorly drained muskeg (Smith et al. 2000; Saher and Schmiegelow 2005; Natural Subregions Committee 2006). At higher elevations, forests are characterized by Engelmann spruce (*Picea engelmannii*), and subalpine fir (*Abies lasiocarpa*), and alpine habitats consist of exposed ridges and meadows with graminoid, sedge (*Carex* spp.), and herbaceous ground cover with patches of stunted subalpine fir krummholz in less exposed areas. A variety of ungulate species occur in this area including whitetail and mule deer (*Odocoileus virginianus* and *O. hemionus*), moose (*Alces alces*), and elk (*Cervus elaphus*) at lower elevations and bighorn sheep (*Ovis canadensis*) and mountain goats (*Oreamnos americanus*) at higher elevations. Primary predators of caribou in this area are grizzly bears (*Ursus arctos*), cougars (*Felis concolor*), and wolves (*Canis lupus*), and additional predators include black bears (*Ursus americanus*), lynx (*Lynx canadensis*), wolverines (*Gulo gulo*), and coyotes (*Canis latrans*) (Stevenson et al. 2001; Stotyn et al. 2007; Wittmer et al. 2007).

The landscape in north-western Alberta differs from west-central as elevation is lower (600-800m above sea level), topography is relatively flat, and forests are characteristic of the boreal forest including black spruce, larch, and poorly drained muskeg and fen in lowland areas, and white spruce, trembling aspen, and balsam poplar (*Populus balsamifera*) in upland areas (Natural Subregions Committee 2006; Tigner et al. 2014). Moose are the most abundant ungulate in this area, although whitetail and mule deer, elk, and wood bison (*Bison bison athabascae*) are also present (Rowe 2007). The predator guild for this region includes wolves, black bears, grizzly bears, coyotes, wolverine, and lynx.

1.3. Project Objectives

This FRIAA project was undertaken to build upon existing knowledge and datasets that have been collected by the fRI Caribou Program over the past 2 years; specifically our assessment of seismic lines in West-Central Alberta, and is aligned with the FRIAA themes of *Integrated Land Management* and *Operational Improvement*. Re-vegetation stages were derived from LiDAR based terrain metrics across the study area (circa 2007), and will be used in conjunction with field data on current re-vegetation state and human/wildlife use of disturbed areas, and long term telemetry datasets from caribou to analyse animal movements in response to re-vegetation stage and human activity of disturbed areas. Genetic and population health metrics will be assessed from caribou feces as a complement to ongoing government monitoring programs, and predictive maps of priority restoration areas will be produced using the data collected on current re-vegetation stage and human/wildlife use of disturbed areas. The ultimate goal of the project is to integrate our research findings and predictive maps into ongoing range and restoration planning for west-central and north-western caribou herds. Our specific objectives for Year One of this two year project are as follows:

1. Assess how human activity of linear features (pipeline RoWs, inactive roads) is affected by topography, geographic barriers and re-vegetation height.
2. Determine whether caribou and predator response to inactive roads and pipeline RoWs is influenced by the extent of re-vegetation and human use of these features.
3. Determine whether activity at worksites (active industrial activity) affects the movements of caribou.

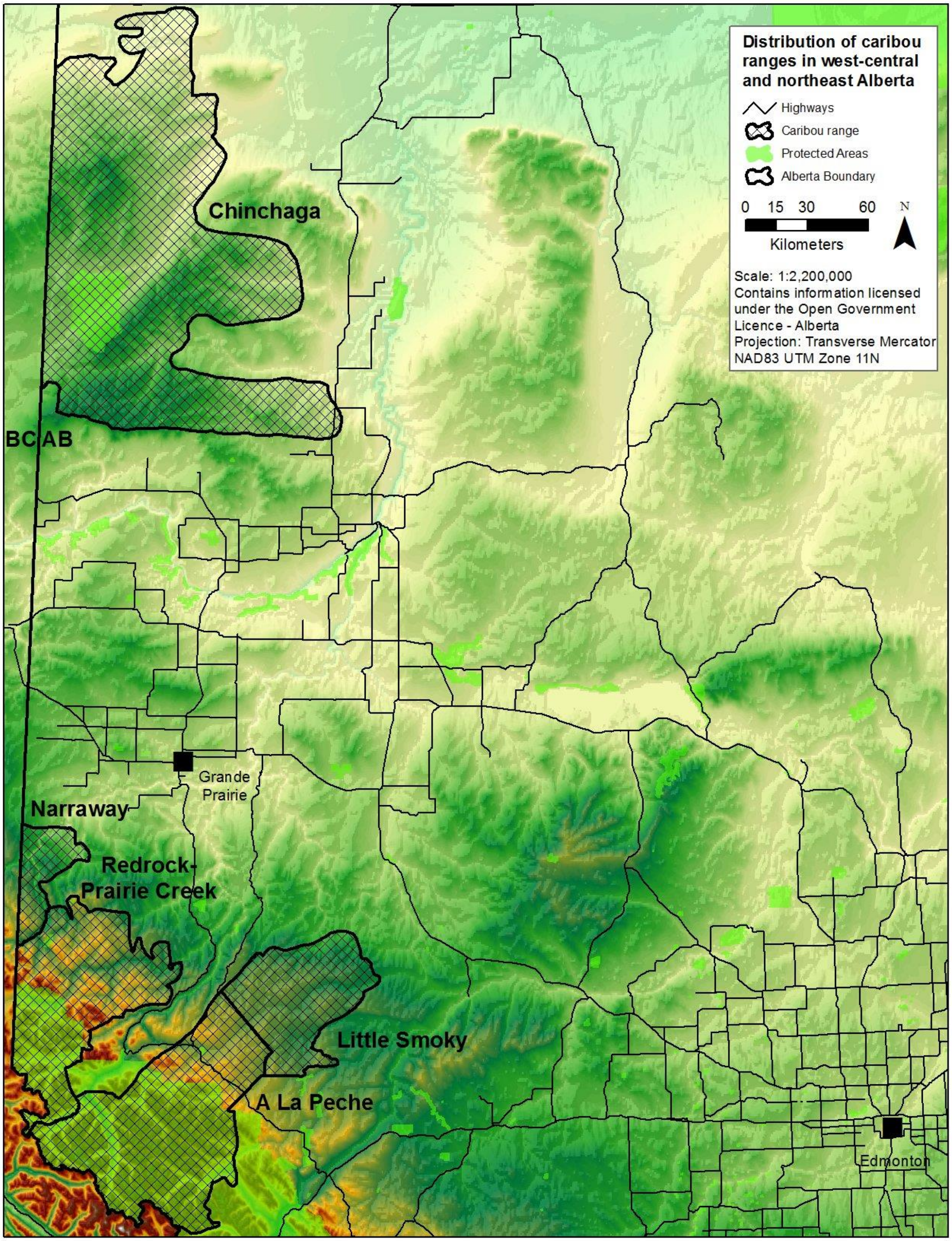

Figure 1.1. Map of caribou ranges in west-central and northeast Alberta that define the study area.

Chapter 2. Motorized human use of inactive roads and pipeline right-of-ways in relation to vegetation regrowth (Objective 1)

Meghan Anderson, fRI Caribou Program

2.1. Introduction

Linear features (seismic lines, pipelines, roads) comprise a large portion of the industrial footprint in caribou range, and restoration of these features is likely to aid in caribou population recovery (Sorensen et al. 2008). Linear features impact a number of wildlife species by reducing the amount and quality of available habitat, fragmenting habitats (Fahrig 1997; Chalfoun et al. 2002; With and Crist 2011), and increasing negative effects related to edge habitat (Donovan et al. 1997 Dijak and Thompson III 2000; Ries and Sisk 2004).

Caribou are believed to be negatively impacted by linear features in multiple direct and indirect ways. Direct habitat loss occurs via clearing of caribou habitat (Dyer et al. 2001). Indirect effects include mortality from motor vehicle collisions and poaching (Johnson 1985), changes to predator-prey relationships/apparent competition (James and Stuart-Smith 2000; McLoughlin et al. 2005; Latham et al. 2011*a*), energy costs associated with habitat disturbance (Murphy and Curatlo 1987; Bradshaw et al. 1998), displacement, and avoidance (Cameron et al. 1992; Nellemann and Cameron 1996; James and Stuart-Smith 2000).

Most important of these effects is the change to predator-prey relationships linked to disturbance. In the context of caribou decline, anthropogenic disturbance is thought to have increased the amount of forage for other ungulate species (e.g. moose, deer, and elk), thus increasing the density of other ungulates and creating a numeric response in wolves. Linear features are thought to increase predation rates by facilitating travel and access to caribou habitat for wolves, and high wolf densities sustained by high ungulate density has translated into increased rates of predation on caribou, which is believed to have made a significant contribution to their decline (James et al. 2004; Latham et al. 2011*b*; Whittington et al. 2011; Hervieux et al. 2013).

Mitigating the negative effects of linear features on caribou is a priority. Currently, the recovery of pipelines and roads to a natural state is being impeded by unmanaged use of people using these features by motorized off-road vehicles. Humans drive All Terrain Vehicles (ATVs) on linear features for work or recreation purposes and in turn damage ground vegetation and compact the soil (Revel et al. 1984; Lee and Boutin 2006). Restoration of linear features is costly and time consuming, and a targeted triage approach is likely the best use of conservation time and money (Noss et al. 2009). By determining what vegetation and topographic variables are associated with human use of linear features, effective strategies can be developed to reduce human use and increase the rate and effectiveness of recovery efforts for linear features. To our knowledge, there are no previous studies on human use of pipelines and inactive roads.

In this chapter we test characteristics of linear features that make them more or less desirable for use by motorized human use, as well as assess topographical features such as vegetation height, vegetation density (e.g. dense woody vegetation and/or high percent cover) that might act as barriers to human use. We collected data on levels of human use across the Little Smoky (LSM) and A La Peche (ALP) caribou ranges from June to October 2014. Our objective was to determine whether levels of human motorized use of linear features could be explained by vegetation or measured topographic variables. We developed *a-priori* hypotheses using biotic and abiotic attributes of linear features that we believed would attract or deter humans from using seismic lines (Table 2.1). The end goal is to give land managers methods to organize effective restoration strategies that concurrently increase the rates of re-vegetation along linear features, and reduce human movement in caribou habitat.

2.2. Methods

2.2.1. Site selection

Using a geographic information system (GIS), we selected linear features (pipelines and inactive roads) that intersected with active roads in the ALP and LSM caribou ranges (Figure 2.1). Inactive roads were defined as those roads no longer being used for industrial access, and were identified using GIS as the overlap between a current industrial access roads layer and a cumulative footprint road layer (Base Map Data provided by the Government of Alberta under the Alberta Open Government Licence; Inactive road data provided by the Foothills Landscape Management Forum, November, 2014). The status of the road (active/inactive) was confirmed during site visits. We conducted human use surveys from June to October in 2014. Field crews recorded data on vegetation, topographic variables, and human use at each site at subplots located 0, 100 and 500m from the access road along each linear feature (Table 2.2). Candidate sites where linear features had been altered or removed due to forestry activities were not sampled. In addition to field data we used a GIS to calculate landscape variables which might be related to human activity (Table 2.3).

Table 2.1. Working hypotheses and predictions for candidate models proposed to identify factors determining levels of human motorized use of pipelines and roads in the ALP and LSM caribou ranges during summer and fall months.

Hypotheses	Predictions
Vegetation	
1) Vegetation re-growth best explains human use.	a) Height of vegetation and presence of coniferous vegetation on linear features deters ATV users. b) Lateral cover of vegetation and presence of coniferous vegetation on linear features deters ATV users.
Human activity	
2) Density of oil and gas activity best explains human use.	a) Oil and gas workers may be using the linear features for work purposes or in their off time.
3) Distance to highway or nearest city and slope best explains human use.	a) Humans are more likely to use a linear feature closer to a paved highway and that has a lower slope. b) Humans are more likely to use a linear feature closer to a city and that has a lower slope.
4) Hunting opportunity best explains human use	a) Humans are more likely to use a linear feature if there is a wildlife trail present, if it is close to a city, and if it has a lower slope. b) Humans are more likely to use a linear feature if a wildlife trail is present, if it has dry soil, and if coniferous vegetation is present.
Topography	
5) Terrain wetness best explains human use.	a) High soil wetness deters ATV users.
6) Wet soil types and slope best explains human use	a) Wet soil types (organic) and steep slopes deters ATV users.
Vegetation and topography/ human activity and topography	
7) Vegetation and soil wetness best explains human use	a) High lateral vegetation cover and soil wetness deters ATV users.

We measured the distance along roads from the start of linear feature sample plots to paved highways to approximate the effort required by humans to drive to and use the feature. We also measured the distance along roads from sites to major cities, under the hypothesis that features closer to urban centers would receive more human use (Table 2.1). The distances along backcountry roads were calculated using a least cost path calculation with the gdistance package using the statistical software R (R Core Team 2014; van Etten 2014). We also measured the density of oil and gas facilities (plants, well sites, camps) within a 5km radius of each sample plot using ArcGIS, under the hypothesis that areas with a higher density of oil and gas facilities would receive more human use (Table 2.1).

2.2.2. Data analysis

We used ordinal logistic regression (cumulative mixed link models; CLMMs) to investigate human motorized use of linear features in relation to vegetation, human activity, and topographic variables such as slope, soil type, and soil wetness. Human use was treated as a categorical variable (none, light, moderate, or heavy), and datasets for pipelines and inactive roads were combined and a categorical variable was added to account for differences by feature type. CLMMs were computed using the ordinal package in R (Christensen 2015; R Core Team 2014). We used an information-theoretic model selection approach with multiple working hypotheses (Table 2.1) to model the probability of human motorized use in relation our covariates (Tables 2.2 and 2.3). All continuous variables were standardized and checked for collinearity using a Spearman correlation cut-off value of 0.5 (Zuur et al. 2009). The reference categories for the categorical variables “soil wetness”, “wildlife trail”, “feature type”, and “coniferous” were dry soil (0), absence of a wildlife trail (0), pipelines, and absence of coniferous vegetation (0), respectively.

We tested for the appropriate threshold structure (flexible, equidistant, and symmetric) amongst levels of human motorized use for each models using Akaike information criterion (AIC). To obtain an estimate of which model variables had the largest effect on human use of linear features we compared McFadden pseudo R^2 values for models which included single terms (McFadden 1974).

Table 2.2. Field-based vegetation, topographic, and human use data recorded at each linear feature from June to October 2014.

Category	Covariate	Description	Range
Human Use	Human use	Human use level (4 categories)	None to heavy
Vegetation	Coniferous	Presence of coniferous vegetation (binary; 0 = absent, 1 = present).	0, 1
	Vegetation height	Presence of woody vegetation with a height > 1 meter (binary; 0 = false, 1 = true).	0, 1
	LateralCov	% cover of vegetation in vertical direction measured on a 1m high board	0-100
Animal use	Wildlife trail	Presence or absence of a wildlife trail (binary; 0 = no wildlife trail, 1 = wildlife trail present).	0, 1
Topography	Slope	Slope (degrees)	0 – 16.4
	Soil	Soil type (5 categories)	Loam; organic; clay; rock/gravel; sand
	Wetness	Soil Wetness (4 categories)	Dry to surface water present

Table 2.3. GIS-based human activity variables sampled at sample sites on pipelines and inactive roads.

Category	Covariate	Description	Range
Human activity	DistanceHWY	Distance (km) from 0m point on linear features along roads to main, paved highway in meters	0 – 250
	DistanceCity	Distance (km) from 0m point on linear features along roads to the nearest major city.	93-331
	DensityOilGas	Point density per km^2 of oil and gas facilities and wellsites within a 5km radius.	0 – 2.23

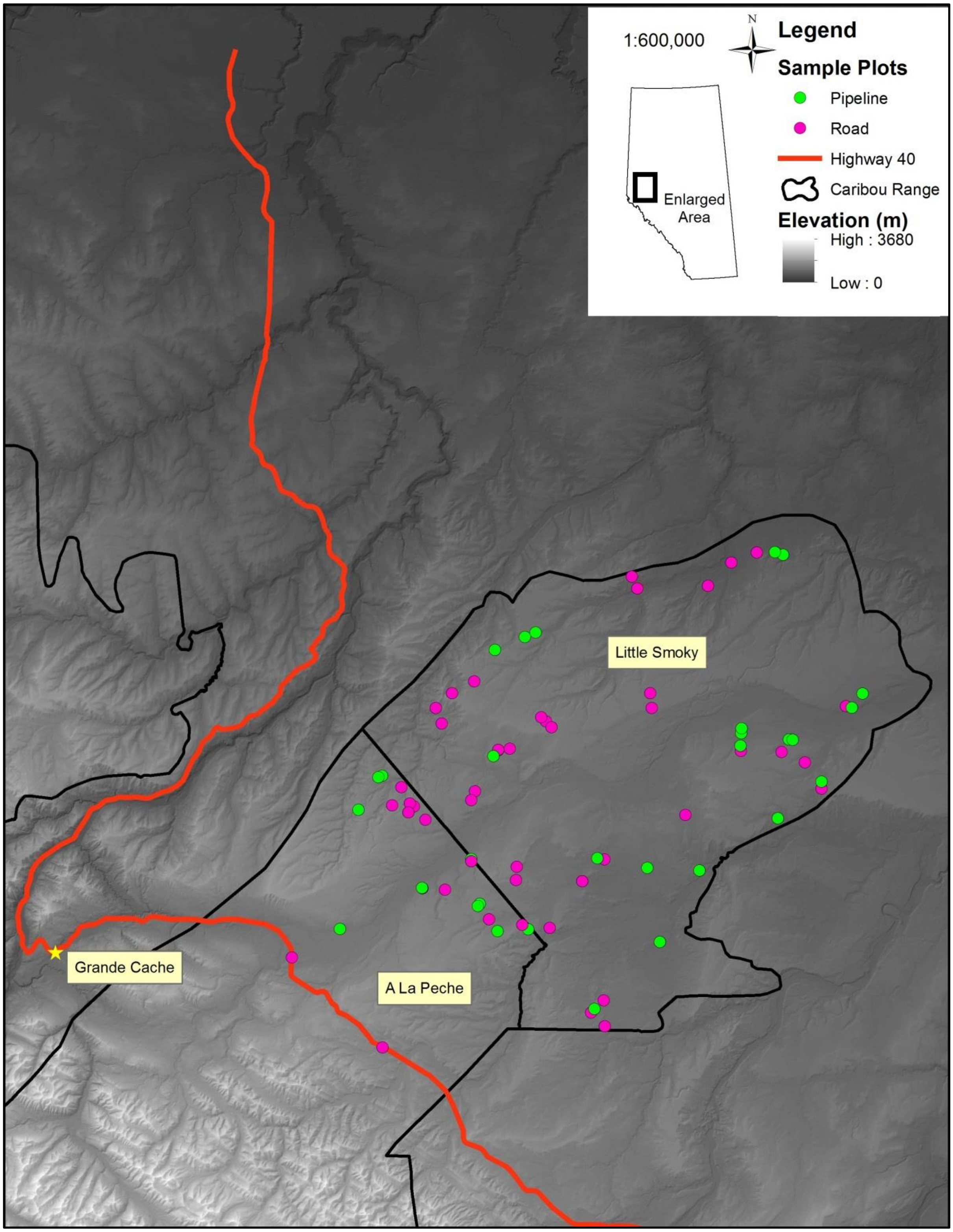

Figure 2.1. Locations of sample plots on pipelines (purple dots) and inactive roads (green dots) visited from June to October 2014 in LSM and ALP caribou range.

2.3. Results

During the 2014 field season we surveyed 35 pipelines and 54 inactive roads in ALP and LSM caribou range (Figure 2.1). For CLMM models the flexible threshold structure had the lowest AIC across all the models and therefore was selected as the threshold structure for all *a-priori* models.

Of the 10 *a-priori* models tested the best AIC selected model was the 4b human activity model which included the presence of a wildlife trail, soil wetness, presence of coniferous vegetation, and feature type as variables (Appendix 1). This model was based on the hypothesis that humans primarily use linear features for hunting.

The best AIC model indicated there was a decreased probability of human use as soil wetness increased compared to dry soils, and when coniferous vegetation was present (Table 2.4; Figures 2.2 and 2.5). There was also a higher probability of human use on inactive roads when compared to pipelines (Table 2.4; Figure 2.4). Contrary to our predictions, human use of linear features decreased with the presence of a wildlife trail (Table 2.4; Figure 2.3).

When comparing pseudo R^2 values for each variable in the top model, coniferous vegetation had the greatest pseudo R^2 (pseudo R^2 = 0.0495), followed by the presence of a wildlife trail (pseudo R^2 = 0.0316; Table 2.5).

Table 2.4. Maximum likelihood parameter estimates (β), standard errors (SE), lower and upper confidence interval (LCL; UCL), Z statistic, and P value for the best AIC cumulative mixed link model to estimate the probability of human motorized use of pipelines (n=35) and roads (n=54) in the ALP and LSM caribou ranges between June and October 2014

Coefficient	β	SE	LCL	UCL	z value	P value
Wetness 1	**-2.2903**	0.6108	-3.4874	-1.0931	-3.7496	0.0002
Wetness 2	**-1.6426**	0.8056	-3.2216	-0.0637	-2.0390	0.0414
Wetness 3	-2.4407	1.3632	-5.1124	0.2310	-1.7905	0.0734
Wildlife trail	**-2.7157**	0.8918	-4.4637	-0.9677	-3.0450	0.0023
Feature type	**2.9931**	1.1278	0.7827	5.2035	2.6540	0.0080
Coniferous	**-3.1156**	0.8498	-4.7812	-1.4501	-3.6664	0.0002
1|2	-2.7681	1.1236	-4.9704	-0.5658	-2.4635	NA
2|3	0.0829	1.1672	-2.2048	2.3706	0.0710	NA
3|4	4.5326	1.3030	1.9788	7.0864	3.4786	NA

Table 2.5. McFadden pseudo-R^2 values for models containing a single variable predicting human use of linear features from cumulative link mixed models with field data collected from June-October 2014 in the ALP and LSM caribou ranges. Linear features included pipelines (n=35), and inactive roads (54).

Variable	Pseudo R^2
Soil wetness	0.0266
Wildlife trail	0.0316
Feature type	0.0116
Coniferous	0.0495

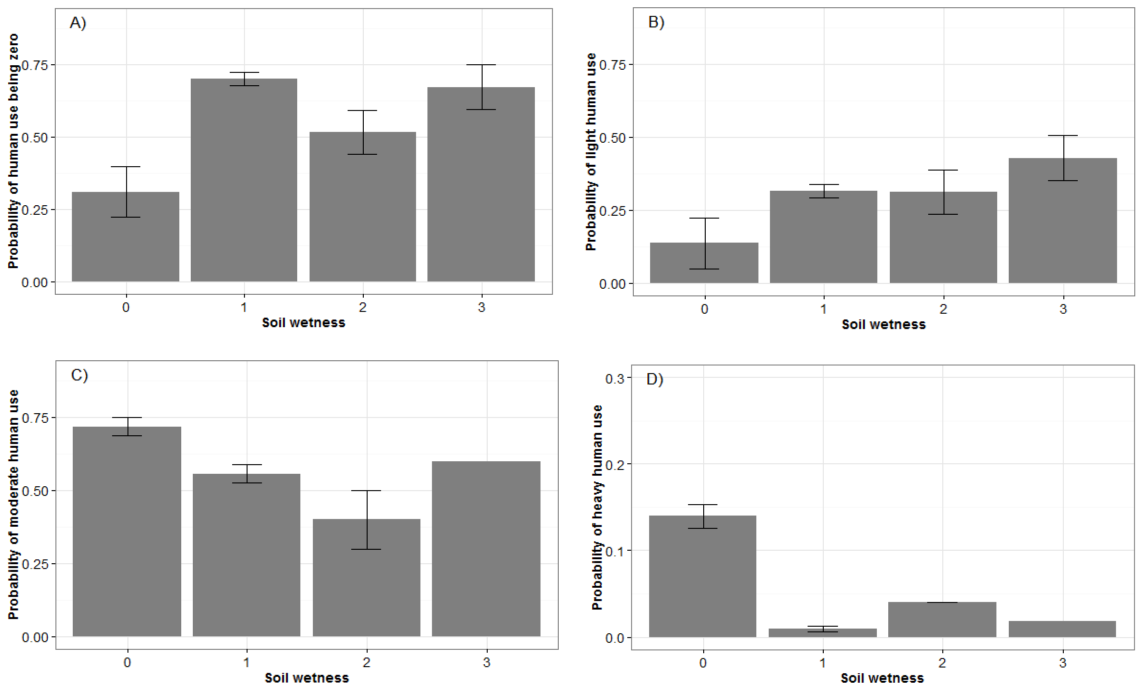

Figure 2.2. Mean predicted probability and SE of motorized human use of pipelines (n=35) and inactive roads (n=54) being zero (A), light (B), moderate (C), and heavy (D) as a function of increasing soil wetness in ALP and LSM caribou range. Note the y-axis scaling in panel (D) has been adjusted to aid in visualization.

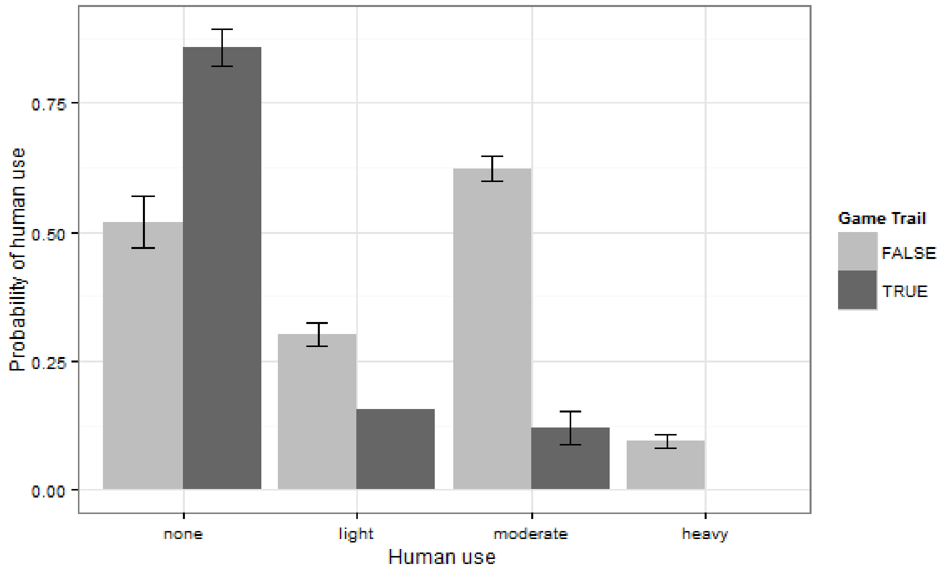

Figure 2.3. Mean predicted probability and SE of motorized human use of pipelines (n=35) and inactive roads (n=54) as a function of the presence or absence of a wildlife trail in ALP and LSM caribou range.

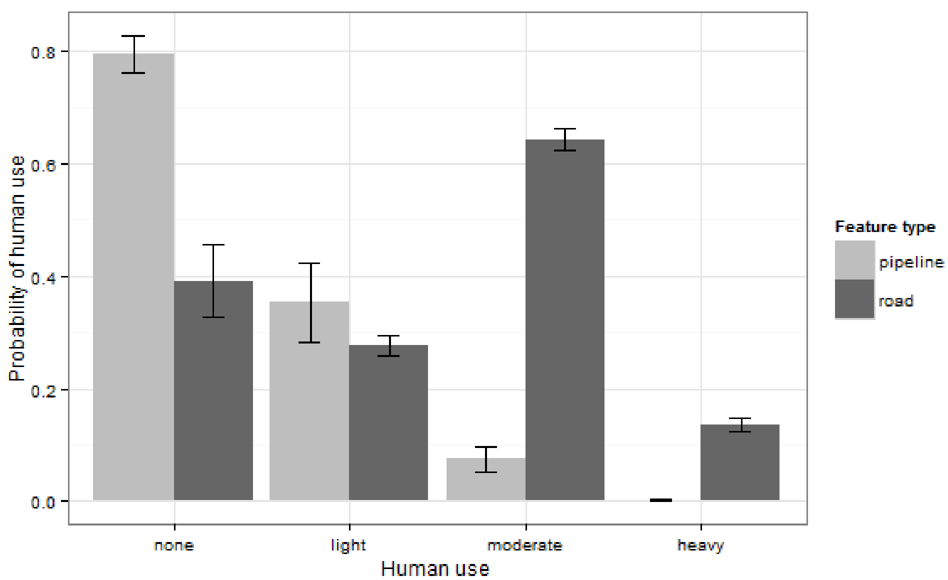

Figure 2.4. Mean predicted probability and SE of motorized human use of pipelines (n=37) and inactive roads (n=56) as a function of type of linear feature in ALP and LSM range.

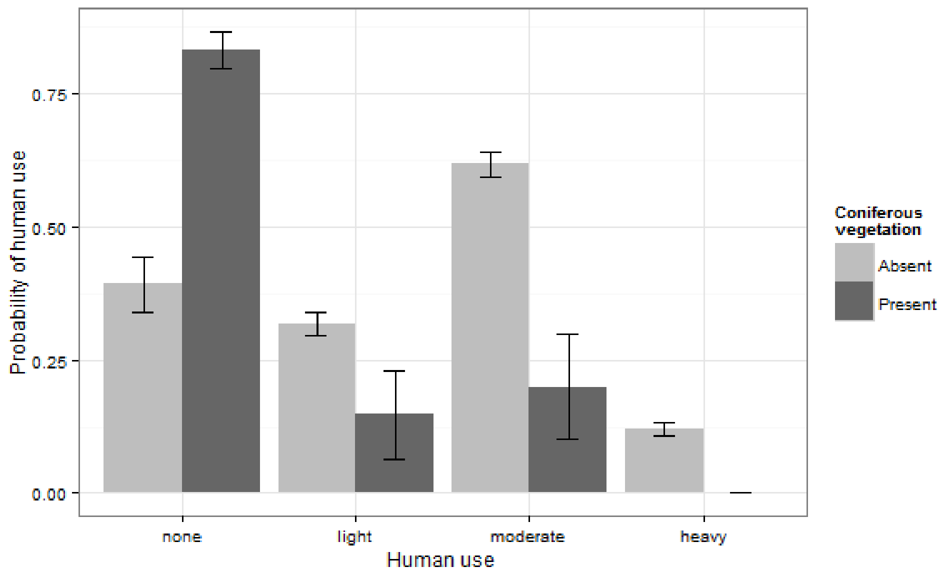

Figure 2.5. Mean predicted probability and SE of motorized human use of pipelines (n=37) and inactive roads (n=56) as a function of the presence or absence of coniferous vegetation in ALP and LSM caribou range.

2.4. Discussion

During the 2014 field season 30% of pipelines and 79% of inactive roads had ATV trails. On linear features used by humans vegetation growth is likely to be impeded and thus restoration success will be lower. Linear features with trails are likely to contribute to a permanent disturbance footprint with continued negative impacts on caribou, and furthermore these features are unlikely to regenerate to a natural state in their entirety without considerable investment by humans.

Our top model predicted that human motorized use of linear features decreased with increasing soil wetness, presence of a wildlife trail, and absence of coniferous vegetation. Additionally, humans used inactive roads more than pipelines. Of the variables included in our top model, the presence or absence of coniferous vegetation had the greatest impact on predicting human use of linear features. Our model predicted moderate and heavy use occured on dry soils and the probability of zero human use was greatest on wet soils. In a study of human use of seismic lines in the same area previous research found that wet soil types deterred human use (Finnegan et al. 2014).

Contrary to our prediction that humans would use linear features with wildlife trails for hunting purposes, human use of linear features (use category >1) was associated with linear features that lacked wildlife trails. This may be explained by a tendency for wildlife to avoid linear features used by humans. For example Dyer et al. (2002) found caribou used areas within 250m of roads with moderate traffic less than expected when compared to random use. Bears have also been found to use disturbed sites where human activity present less than expected by chance (Swenson et al. 1996; Mueller et al. 2008; Martin et al. 2010; Ordiz et al. 2013). While bears with cubs will use areas within 200m of roads in the spring more than expected by chance (Graham et al. 2010), bears adapt their behaviour to avoid periods of high human activity (Olson et al. 1998; Martin et al. 2010) and select for high cover in areas with high human use (McLellan and Shackleton 1988; McLellan and Shackleton 1989; Ordiz et al. 2011).

Human use was more frequent and intense on inactive roads when compared to pipelines. This is not surprising as travel was probably easier on inactive roads because we found them often free of vegetation (average lateral cover 5%) and with heavily compacted soils. In contrast, pipelines had herbaceous and shrub vegetation as well as large woody debris (cut trees, stumps) which would deter motorized use (average lateral cover of 16%). The probability of human use was also lower when coniferous vegetation was present on linear features, which is unsurprising as travel on an ATV becomes slower and more difficult when navigating through trees.

Human motorized use of linear features impedes natural restoration of linear features and consequentially a large portion of caribou habitat remains in a disturbed state long after the initial disturbance. Environmental impacts of off road vehicles include trampling and removal of vegetation, decreased seed germination, decreased soil moisture and nutrients, soil compaction, and increased soil erosion (Baldwin 1973, Webb et al. 1978, Kay 1981, Bleich 1988).

2.5. Management Application

We found that human motorized use occurs primarily on inactive roads and infrequently on pipelines. Based on results presented here our data suggest that:

- Human use was highest on active roads with dry soils. These would be an appropriate starting consideration for access management and restoration programs.

Field data collected in year two will allow us to assess use of pipelines and roads separately and ultimately inform separate restoration activities for these different linear features. Models such as ours that link human use to spatial attributes of vegetation and topography will allow land managers to make informed decisions that increase caribou functional habitat.

Chapter 3. Wildlife use of inactive roads and pipeline right-of-ways in relation to vegetation regrowth (Objective 2)

Meghan Anderson, fRI Caribou Program

3.1. Introduction

Caribou populations in Alberta are believed to be declining due to indirect effects precipitated by habitat disturbance, in particular linear features (Latham et al. 2011*b*; Boutin et al. 2012; Hervieux et al. 2013). Linear features act as travel corridors by predators such as wolves (James and Stuart-Smith 2000; Latham et al. 2011*a*) that can travel three times faster on linear features when compared to surrounding forests, resulting in greater search efficiency for prey and more wolf-caribou encounters (James 1999; Whittington et al. 2011; DeCesare 2012). Linear features also contain early-seral habitat, which is attractive to other ungulates such as deer, moose, and elk (Wittmer et al. 2007; Latham et al. 2011*b*; Serrouya et al. 2011; Dawe et al. 2014).

Most research on the effects of increased predation due to linear features has focused on wolves; however bears are also important predators of caribou, particularly caribou neonates (Rettie and Messier 1998; Zager and Beecham 2006). Both black bears and grizzly bears select for disturbed habitat (Nielsen et al. 2004; Graham et al. 2010; Latham et al. 2011*a*; Stewart et al. 2013) and grizzly bear movement rates are faster along linear features when compared to non-linear features (Roever et al. 2010; McKay et al. 2013). Considering the increase in bear forage and movement rates along linear features, there is a potential that linear features may facilitate increases in caribou-bear encounters and thus predation.

Typically, caribou are thought to avoid linear features as an anti-predator strategy or to avoid motorized vehicle activity (Bradshaw et al. 1997; James and Stuart-Smith 2000; Nellemann et al. 2000, 2001; Dyer et al. 2001; Boulanger et al. 2012). However, caribou may also be attracted to linear features to take advantage of high quality forage in the summer, although this hypothesis has not been thoroughly explored (James and Stuart-Smith 2000; Dyer et al. 2001; Latham et al. 2011*a*). Assuming that predation risk is elevated for caribou close to linear features, it is important to understand why caribou use linear features.

Here we present data on the use of pipelines and inactive roads by caribou, other ungulates, and predators at different stages of re-vegetation. We collected field data on wildlife tracks and signs as well as vegetative forage for ungulates and bears on linear features in the foothills of Alberta in the Little

Smoky (LSM) and A La Peche (ALP) caribou ranges. Our objective was to evaluate how caribou, their predators, and other ungulates respond to linear features (1) at different re-vegetation stages and (2) subject to different levels of human use. We were also interested in (3) the relationship amongst presence of caribou, their predators, and other ungulates on linear features at different stages of re-vegetation. We established a series of hypotheses for why elk/deer, moose, bears, and canids use linear features (Tables 3.1-3.4). There were insufficient caribou tracks/signs (see Results) for hypothesis testing.

Table 3.1. Working hypotheses and predictions for candidate models aimed at identifying factors determining elk and deer use of pipelines and inactive roads in the ALP and LSM caribou ranges between June and October 2014.

Hypothesis	Prediction
1. Food availability	Elk and deer select pipelines and roads with high percent cover of elk/deer forage and dry soil types.
2. Oil and gas development	Elk and deer select pipelines and roads in areas of high oil and gas development for a potential high food density and predator avoidance.
3. Predator avoidance	a) Elk and deer avoid pipelines and roads used by predators and select for lines with high lateral cover.
	b) Elk and deer avoid pipelines and roads used by predators and select for lines with high lateral cover and high local density of oil and gas facilities.
4. Predator avoidance and food	a) Elk and deer avoid pipelines and roads used by predators and select linear features with high lateral cover, high elk/deer forage, and dry soil types.

Table 3.2. Working hypotheses and predictions for candidate models aimed at identifying factors determining moose use of pipelines and inactive roads in the ALP and LSM caribou ranges between June and October 2014.

Hypothesis	Prediction
1. Food availability	Moose select pipelines and roads with high percent cover of moose forage and wet soil types.
3. Predator avoidance	a) Moose select pipelines and roads with low predator use.
	b) Moose avoid pipelines and roads used by predators, and select linear features with high lateral cover, higher elevations, and wet soils.
4. Predator avoidance and food	Moose avoid pipelines and roads used by predators, and select linear features with high lateral cover, high cover of moose forage, and wet soil types.

Table 3.3. Working hypotheses and predictions for candidate models aimed at identifying factors determining bear use of pipelines and inactive roads in the ALP and LSM caribou ranges between June and October 2014.

Hypothesis	Prediction
1. Food availability	Bears select pipelines and roads with high percent cover of bear forage and ungulate use.
2. Human avoidance	Bears select pipelines and roads with low human use, low local oil and gas facility density, and high lateral cover.
3. Human avoidance and food	Bears select pipelines and roads with low human use, low local oil and gas facility density, high lateral cover, high percent cover of bear forage, and ungulate use.
4. Movement corridor	Bears select pipelines and roads with wildlife trails and low lateral cover.

Table 3.4. Working hypotheses and predictions for candidate models aimed at identifying factors determining canine use of pipelines and inactive roads in the A La Peche and Little Smoky caribou ranges between June and October 2014.

Hypothesis	Prediction
1. Food availability	a) Canines select pipelines and roads used by ungulates.
	b) Canines select pipelines and roads used by ungulates, at lower elevations, and with dry soil types.
2. Human avoidance	Canines select pipelines and roads with low human use and low local oil and gas facility density.
3. Human avoidance and food	Canines select pipelines and roads with low human use, low local oil and gas facility density, and high ungulate use.
4. Movement corridor	Canines select pipelines and roads with wildlife trails and low lateral cover.

3.2. Methods

3.2.1. Field data collection

We recorded presence of tracks and scat for canids (*Canis* spp.), bears (*Ursus* spp.), caribou, elk, deer, and moose at random field plots on pipelines and inactive roads during the 2014 field season from June to October in LSM and ALP caribou range (Figure 2.1). Tracks and scat of wildlife can either be unclear (e.g. only a partial print) or can be difficult to differentiate between species. Therefore we also recorded an index of confidence in our ability to properly identify signs of wildlife (0 = no confidence, 1 = somewhat confident, 2 = confident). Only confident signs were included in the analysis. On each linear feature we recorded data at 0, 100, and 500m subplots from an active road. At each subplot we recorded the presence of wildlife species via the presence of tracks or scat. We also recorded vegetative, soil, and topographic attributes at each plot (Tables 3.5 and 3.6). Vegetation percent cover of known caribou, elk/deer, moose, and bear forage species was also recorded in 1m^2 and 10m^2 plots (Appendices 2 and 3). At each subplot, vegetation percent cover was recorded at two locations (0m and 20m from the start of the plot).

Table 3.5. Field based vegetative and biotic covariates in wildlife models predicting use of pipelines and inactive roads in the ALP and LSM caribou ranges.

Category	Covariates	Description	Range
Wildlife	Caribou use	Caribou tracks or pellets (binary; 0 = not detected, 1 = detected)	0 - 1
	Wolf use	Wolf tracks or scat (binary; 0 = not detected, 1 = detected)	0 - 1
	Bear use	Bear tracks or scat (binary; 0 = not detected, 1 = detected)	0 - 1
	Predator use	Tracks or scat of canid, bear, or felid species (binary; 0 = not detected, 1 = detected)	0 - 1
	Moose use	Moose tracks or pellets (binary; 0 = not detected, 1 = detected)	0 - 1
	Elk and deer	Tracks or pellets of elk or deer (binary; 0 = not detected, 1 = detected)	0 - 1
	Ungulate use	Tracks or pellets or of caribou, elk, moose, or deer species (binary; 0 = not detected, 1 = detected)	0 - 1
Vegetation	Ground cover	Percent cover of ground vegetation	0-100%
	Forage cover	Percent cover of caribou, elk/deer, moose, or bear forage	0-100%
	Lateral Cover	Percent cover of vegetation covering a 1m high board.	0–100%
Topographic	Soil	Soil type (4 categories)	Loam/sand, clay, rock/gravel
	Wetness	Terrain wetness (4 categories)	Dry to surface water present
Human	Human use	Human use level (4 categories)	None to heavy

Table 3.6. Geographic information system (GIS) based topographic and human covariates in wildlife models predicting use of pipelines and inactive roads in ALP and LSM caribou range.

Category	Covariates	Description	Range
Topography	Elevation	Elevation in meters calculated using a 5 m digital elevation model (DEM)	0-1750
	Slope	Slope (degrees)	0-36
Human	Facility density	Density of oil and gas facilities (wellsites, plants) within a 5 km radius	0-3.7

3.2.2. Data Analysis

We analysed the use of pipelines and roads by caribou, elk/deer, moose, bears, and canids using generalized linear mixed effects models. We chose mixed effects models to account for the hierarchical nature of the data by using the linear feature identification number as a random effect (Breslow and Clayton 1993). Use of linear features was defined as the presence of wildlife signs (tracks or scat) which were modeled as a function of vegetation, biotic, and topographic variables (Tables 3.5 and 3.6) to test our *a-priori* hypotheses (Tables 3.1-3.5). All continuous variables were checked for collinearity (cutoff value of 0.50) and standardized before being used in models (Zuur et al. 2009). From the *a-priori* models (Tables 3.1-3.4), the top model according to Akaike Information Criterion (AIC) was selected by comparing the AIC and model weights of candidate models (Burnham et al. 2011). Modeling was performed using the statistical software R and the lme4 package (Bates et al. 2014; R Development Core Team 2014).

3.3. Results

During the 2014 field season we visited a total of 95 pipelines and inactive roads (Figure 2.1). At subplots on these features we recorded tracks/scat of caribou on 7, canids on 19, bears on 19, felids on 1, elk on 20, deer on 48, and moose on 67. The totals per year are summarized by wildlife group in Table 3.7. Signs of caribou tended to be found on linear features with light human use but there was no observable trend for the use of linear features by predators and other ungulate with respect to human use (Table 3.8).

Table 3.7. Count and percentage of tracks and scat of caribou, predators (bears, wolves, cougars), and other ungulates (deer, elk, moose) from June to October 2014 on pipelines and inactive roads in ALP and LSM caribou range. Data was collected between June and October 2014.

Feature	Caribou	Predators	Other ungulates
Pipeline (38)	1 (3%)	8 (21%)	28 (45%)
Road (57)	6 (11%)	25 (44%)	45 (79%)

Table 3.8. Observations of caribou, predators (bears, canines, and felids), and other ungulates (elk, deer, moose) signs (tracks, scat) per category of human motorized use on pipelines and inactive roads in ALP and LSM caribou range. Data was collected between June and October 2014.

Level of Human Use	Caribou	Predator	Other ungulates
None	0%	30%	32%
Light	71%	19%	18%
Moderate	14%	40%	31%
Heavy	14%	12%	18%

3.3.1. Caribou

The number of pipelines and roads on which we found signs of caribou use (Table 3.8) was too low to allow us to use models to analyse the data; a more robust sample size from data collected in year two may allow us to build predictive models.

3.3.2. Other ungulates

Of the five *a-priori* models used to describe elk and deer use of pipelines and roads the predator avoidance model had the greatest AIC weight of 0.4756 (Appendix 4). However, contrary to our predictions the probability of elk using a linear feature decreased with increased lateral cover (Table 3.9). Predator use was not a significant coefficient in the elk/deer model (Table 3.9).

Elk and deer tracks were most likely to be found on linear features where the percent lateral cover of vegetation was 5% (SE = 0.90%), which was lower than the average of 10% (SE = 1.42%) lateral cover on linear features where signs of elk and deer were not detected (Figure 3.1).

Of the four *a-priori* models used to describe moose use of pipelines and inactive roads the predator avoidance model had the greatest AIC weight of 0.53 (Appendix 5). Unfortunately, this model is uninformative because the only coefficient, predator use, was not significantly different from zero (Table 3.10).

Table 3.9: Maximum likelihood parameter estimates (β), standard errors (SE), 95% lower and upper confidence intervals (LCL; UCL), Z statistic, and P value for the best AIC mixed effects model to estimate the probability of elk and deer use of pipelines and inactive roads (n=95) in ALP and LSM caribou range between June and October 2014. Coefficients significantly different from zero are in bold font.

Coefficient	β	SE	z value	P value	LCL	UCL
Intercept	-1.0114	0.2492	-4.0593	0.0000	-1.4998	-0.5231
Predator use	0.5505	0.4610	1.1939	0.2325	-0.3532	1.4541
Lateral cover	-0.7856	0.3651	-2.1515	0.0314	-1.5013	-0.0699

Table 3.10. Maximum likelihood parameter estimates (β), standard errors (SE), 95% lower and upper confidence interval (LCL; UCL), Z statistic, and P value for the best AIC mixed effects model to estimate the probability of moose use of pipelines and inactive roads (n=95) in ALP and LSM caribou range between June and October 2014.

Coefficient	β	SE	z value	P value	LCL	UCL
Intercept	-0.8478	0.1669	-5.0804	0.0000	-1.1748	-0.5207
Predator use	0.0392	0.3715	0.1055	0.9160	-0.6889	0.7673

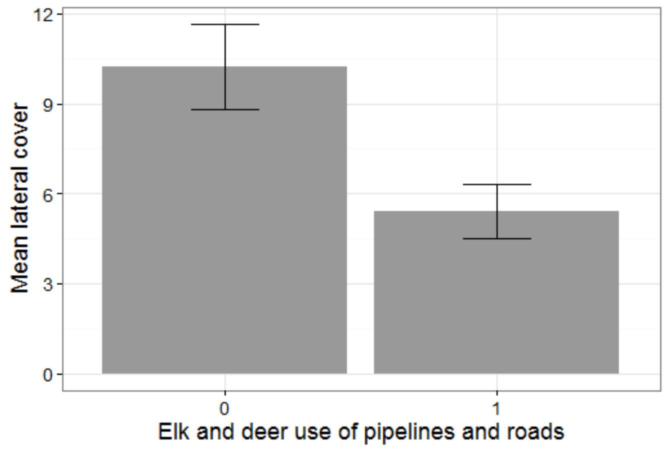

Figure 3.1. Mean and SE of lateral cover of pipelines and inactive roads in the LSM and ALP caribou ranges were elk and deer tracks and sign were detected (1) and not detected (0).

3.3.3. Predators

Of the four *a-priori* models used to describe bear use of pipelines and inactive roads the movement model had the greatest AIC weight of 0.98 (Appendix 6). The model coefficient conformed to our predictions: the probability of bear use of pipelines and roads increased with the presence of a wildlife trail (Table 3.11). Of linear features on which we found bear scat or tracks 55% had a wildlife trail.

Of the five *a-priori* models used to describe canid use of pipelines and roads the human avoidance model had the greatest AIC weight of 0.5874 (Appendix 7). As predicted, the probability of canine species using linear features decreased with increasing oil and gas facility density (Table 3.12). On average, tracks or scat of canid species were found on linear features with an oil and gas facility density of 0.05/km^2 (SE=0.08), whereas linear features where signs of canine use were not detected had an average facility density of 0.61/km^2 (SE=0.70)(Figure 3.2).

Table 3.11. Maximum likelihood parameter estimates (β), standard errors (SE), 95% lower confidence interval (LCL; UCL), Z statistic, and P value for the best AIC mixed effects model to estimate the probability of bear use of pipelines and inactive roads (n=95) in ALP and LSM caribou range between June and October 2014. Coefficients significantly different from zero are in bold.

Coefficient	β	SE	z value	P value	LCL	UCL
Intercept	-5.1162	2.5238	-2.0272	0.0426	-10.0627	-0.1697
Wildlife trail	3.0235	1.3193	2.2917	0.0219	0.4377	5.6093
Lateral cover	0.0917	0.4810	0.1906	0.8488	-0.8511	1.0345

Table 3.12. Maximum likelihood parameter estimates (β), standard errors (SE), 95% lower confidence interval (LCL; UCL), Z statistic, and P value for the best AIC mixed effects model to estimate the probability of canine use of pipelines and inactive roads (n=95) in ALP and LSM caribou range between June and October 2014. Coefficients significantly different from zero are in bold.

Coefficient	β	SE	z value	P value	LCL	UCL
Intercept	-3.1623	0.6649	-4.7558	0.0000	-4.4656	-1.8590
Human use	0.4837	0.2669	1.8120	0.0700	-0.0395	1.0068
Facility density	-1.2490	0.5496	-2.2724	0.0231	-2.3262	-0.1717

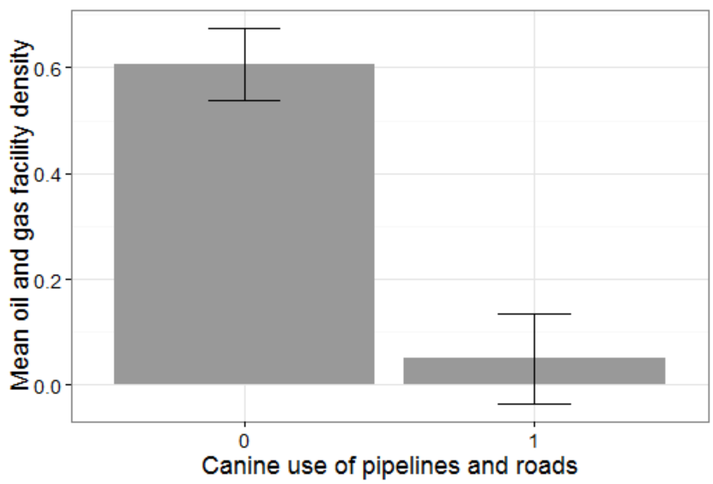

Figure 3.2. Mean and SE of oil and gas facility density (facilities/ 5 km^2) around pipelines and inactive roads in the LSM and ALP caribou ranges where canine tracks or scat were detected (1) and not detected (0).

3.4. Discussion

We found that elk and deer were detected on linear features used by predators. This relationship is likely due to predators selecting for areas used by ungulates (Cumming and Beange 1993; Kuzyk 2002; Oakleaf et al. 2006; Bowman et al. 2010). We did not get informative results from our moose model, however moose signs were among the most common found on linear features. This may indicate a hyper-abundance of moose in which sub-optimal habitats may be used at a greater rate, and the ability to predict moose occurrence based on habitat variables may be reduced. We anticipate that additional data collection in year two will allow us to better model moose use of linear features.

The best predictor of bear use of linear features was the presence of a wildlife trail. This suggests that bears may be using linear features as movement corridors (McKay et al. 2013), especially considering that models aiming to predict bear use as a function of foraging opportunities (forage plants and ungulate use) were not among the best fitting models. Additional data collection in year two will be used to corroborate this hypothesis. For canids, the use of pipelines and inactive roads diminished with increasing density of oil and gas facilities. This is consistent with previous research showing that wolves strongly avoid human activity (Stephens and Peterson 1984; Thurber et al. 1994; Berger 2007). In fact, in some studies ungulates have been shown to take advantage of this behaviour by selecting areas close to roads as refuge habitat in areas of high human activity (Stephens and Peterson 1984; Kunkel and Pletscher 2000; Berger 2007; Hebblewhite and Merrill 2007).

3.5. Management Application

Because of low sample sizes additional data collection in year two will be necessary before any data collected may be used for management applications.

Chapter 4. Caribou response to activity at oil and gas well sites (Objective 3)

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4.1. Introduction

Within the range of boreal and mountain caribou anthropogenic disturbance is thought to be the ultimate cause of population decline (Festa-Bianchet et al. 2011; Hervieux et al. 2013). Across the boreal forest the conversion of forest to early seral stage via anthropogenic disturbance is believed to have resulted in an increase in ungulates (e.g., moose, deer, and elk) within caribou ranges (Gasway et al. 1989; Serrouya et al. 2011), where historically there was spatial separation (Bergerud 1988). This increase in ungulate density and distribution is hypothesised to have resulted in a numerical response in wolves, and a decrease in caribou populations (primarily via a decrease in calf survival) caused by increased predation; so called 'apparent competition' (Wittmer et al. 2005; DeCesare et al. 2010; Hervieux et al. 2013). Therefore, a priority for caribou conservation is minimizing the impacts of current and future industrial development on caribou, while restoring previously disturbed areas.

Caribou respond poorly to human presence on the landscape (Wolfe et al. 2000). Caribou have shifted annual ranges to avoid areas with human activity such as tourist resorts, active roads and pipelines (Nellemann et al. 2000, 2001). They also physically space away from areas when there are high levels of disturbance such as helicopter or plane presence (Harrington and Veitch 1991), and areas with high snowmobile, ATV and pedestrian traffic (Webster 1997; Freeman 2008). Avoidance of disturbance associated with timber harvest, roads, seismic lines, pipelines and well sites (Smith et al. 2000; Dyer et al. 2001; Oberg 2001; Williamson-Ehlers 2012) means that the influence of these features extends far beyond the direct footprint of the development. This loss of habitat adjacent to development is accounted for in the caribou recovery strategy by buffering all human disturbance by 500 meters (Environment Canada 2014). While the constant 500 m buffer provides a simple approach to quantifying and visualizing the level of disturbance within a caribou range, it ignores the fact that human activity is not constant across all disturbance types (e.g., abandoned well sites versus active well sites). Studies show wildlife tends to exhibit greater response to the level of human activity associated with human infrastructure compared to the infrastructure alone (Hebblewhite and Merrill 2008; McKay et al. 2014b).

A good example of how industrial development goes through degrees of human activity at various phases of operation can be seen in oil and gas well sites. The initial drilling phase has the greatest activity with the presence of many workers and heavy equipment clearing vegetation and drilling the well (McKay et al. 2014b). Post-drilling activity decreases to one-worker visiting per day for wells producing oil and gas, while those wells that are capped, abandoned or reclaimed may only receive one worker visit per year (McKay et al. 2014b). McKay et al. (2014b) found that grizzly bears were more likely to use oil and gas well sites with less activity. To our knowledge the influence of human activity at disturbance features has not been assessed for caribou. The goal of this study was to gain a better understanding of the impact of varying phases of well site activity on habitat use by caribou. We addressed three specific questions: 1) How do oil and gas well sites influence habitat use by caribou? 2) Are effects on caribou greater when well sites are in an active phase (drilling or oil and gas being produced) versus inactive (capped, abandoned or reclaimed)? 3) To what degree does the peak activity during drilling further impact habitat use by caribou compared to the oil producing or inactive phase? The results from this research can be used to develop best practices for well site construction within caribou ranges and to determine whether the currently applied 500m buffer is applicable at all stages of development.

4.2. Methods

To determine the influence of well site activity on caribou habitat selection we developed 10 *a priori* resource selection functions (RSF, Manly et al. 2002; Table 4.1). An RSF quantifies habitat selection by comparing habitat an animal used with the available habitat in the surrounding area. As a result, if caribou are farther from well sites than expected by random chance, the RSF will show stronger selection for habitat farther away from well sites. To explore the relationship between well site activity and habitat selection by caribou, we included an interaction between distance to the nearest well site and the activity at that well site within the RSF model. Then we applied a model selection approach (Burnham & Anderson 2002) to the 10 competing RSFs, some with and without the well site effects, to empirically test the response of caribou to well sites and determine whether activity phase had an additional influence (Table 4.1).

4.2.1. Study Area

We explored habitat selection relative to well site activity among caribou within the Narraway (NAR) and Redrock-Prairie Creek (RPC) populations in west-central Alberta, Canada (Figure 4.1). NAR and RPC are southern mountain caribou populations that make seasonal migrations between summer ranges (in alpine and subalpine habitat) and winter ranges (lower elevation foothills) located within Alberta and British Columbia (Edmonds and Bloomfield 1984; Brown and Hobson 1998). In the spring between April and May southern mountain caribou migrate to summer ranges at high elevations where the females give birth to their calves. Migration back to winter ranges typically occurs between October and November (Edmonds and Bloomfield 1984). As a result of their migratory nature, NAR and RPC ranges span mountainous and foothill habitats classified as lower and upper foothills, subalpine, and alpine natural subregions (Natural Regions Committee 2006).

Table 4.1. Ten competing resource selection function (RSF) models for quantifying caribou response to oil and gas well sites in west-central Alberta.

Model	Covariates
1	Null model (intercept only)
2	Distance to Well
3	Distance to Well x Active Well *
4	Distance to Well x Drilling ^
5	Distance to Well x Well Activity†
6	Land cover
7	Land cover + Distance to Well
8	Land cover + Distance to Well x Active Well*
9	Land cover + Distance to Well x Drilling^
10	Land cover + Distance to Well x Well Activity†

* Binary variable of the activity at the nearest oil and gas well site (1= drilling or producing oil; 0 = inactive)
^ Binary variable of the activity at the nearest oil and gas well site (1= drilling; 0 = producing oil or inactive)
† Activity at the nearest oil and gas well site where inactive is the reference category with drilling and producing oil as separate categories.

Land use activities within the study area include mining, forestry, oil and gas exploration and both motorized (ATVs, snowmobile) and non-motorized (hiking, hunting, fishing, camping) recreation. The intensity of these activities varies across the study area but is primarily focused within the winter range of the two herds. NAR range contains a small portion of the Kakwa Wildland Provincial Park in Alberta and portions of five different protected areas in British Columbia, amounting to roughly 19% of its total range. In comparison, RPC range contains a large portion of the Kakwa Provincial Park in British Columbia and portions of three different protected areas in Alberta, amounting to roughly 40% of its total range. In 2012, the NAR population was estimated at 96 individuals whereas the RPC population was estimated at 127 individuals (Environment Canada 2014); both populations are in decline (Hervieux et al. 2013).

Well site data were available for Alberta on public lands with industrial activity, which included the north-eastern portions of the NAR and RPC ranges (Figure 4.1). We defined the study area as a minimum convex polygon that bounds a 3600 m buffer (representing the mean daily movement distance by caribou across our study area in both winter and summer) of well sites within the RPC and NAR herd ranges. Only caribou with > 80% of seasonal GPS collar locations within the study area were considered for this analysis.

4.2.2. GPS collar data

We used GPS location data collected from 49 collared adult female caribou within the NAR (n = 25) and RPC (n = 24) populations between 2007 and 2013 (Lotek GPS 1000, 2000, 2200, 3300 and 4400 models; Lotek, Newmarket, Ontario, Canada). Caribou were captured using helicopter net-gunning and fitted with GPS collars as outlined by Slater (2013). Capture protocols were approved by the University of Alberta Animal Care Committee (Protocol 731910). Because this effort spanned multiple years, the GPS tracking schedule varied (1, 2, 3, 4 and 6 hour fix intervals). The GPS data was rarefied so that subsequent fixes were separated by at least 4 hours, with the exception of the calving season where all fixes were retained. We removed all locations with a dilution of precision (DOP) greater than 12 and obvious outlier locations that fell outside the annual range of these populations.

4.2.3. Habitat selection models

The response of caribou to well sites was quantified using an RSF at the within home range scale (3rd order, Meyer and Thuiller 2006) based on a used-available design (Manly et al. 2002). We considered 10 competing RSF models, using varying combinations of distance to nearest well site, vegetation cover and an interaction term between distance to well site and well site activity (Table 4.1). The competing models were built using a generalized linear mixed model (Bates et al. 2014), pooling data across individual caribou within a season, and accounting for variations among individuals by including a unique ID for each individual caribou as a random effect. Competing models were ranked based on Bayesian Information Criterion (BIC, Burnham and Anderson 2002).

Because the RPC and NAR herds display a seasonal migration, habitat selection was analyzed separately for six distinct seasons: spring (NAR May 5 – June 1; RPC May 10 – June 1), calving (June 1 – June 20), summer (June 20 – October 8), fall (October 8 – November 29), early winter (November 29 – February 5), and late winter (NAR February 5 – May 5; RPC February 5 – May 10). During transition times between seasons, caribou exhibit elevated movement rates as they move between seasonally occupied ranges, after which movement rates decrease to reflect local movements within a seasonal range (Ferguson and Elkie 2004). MacNearney et al. (2014) identified these six seasons for the NAR and RPC herds using individual-based recursive partitioning to identify inflection points in movement rates that demark seasonal transitions (Rudolph & Drapeau 2012).

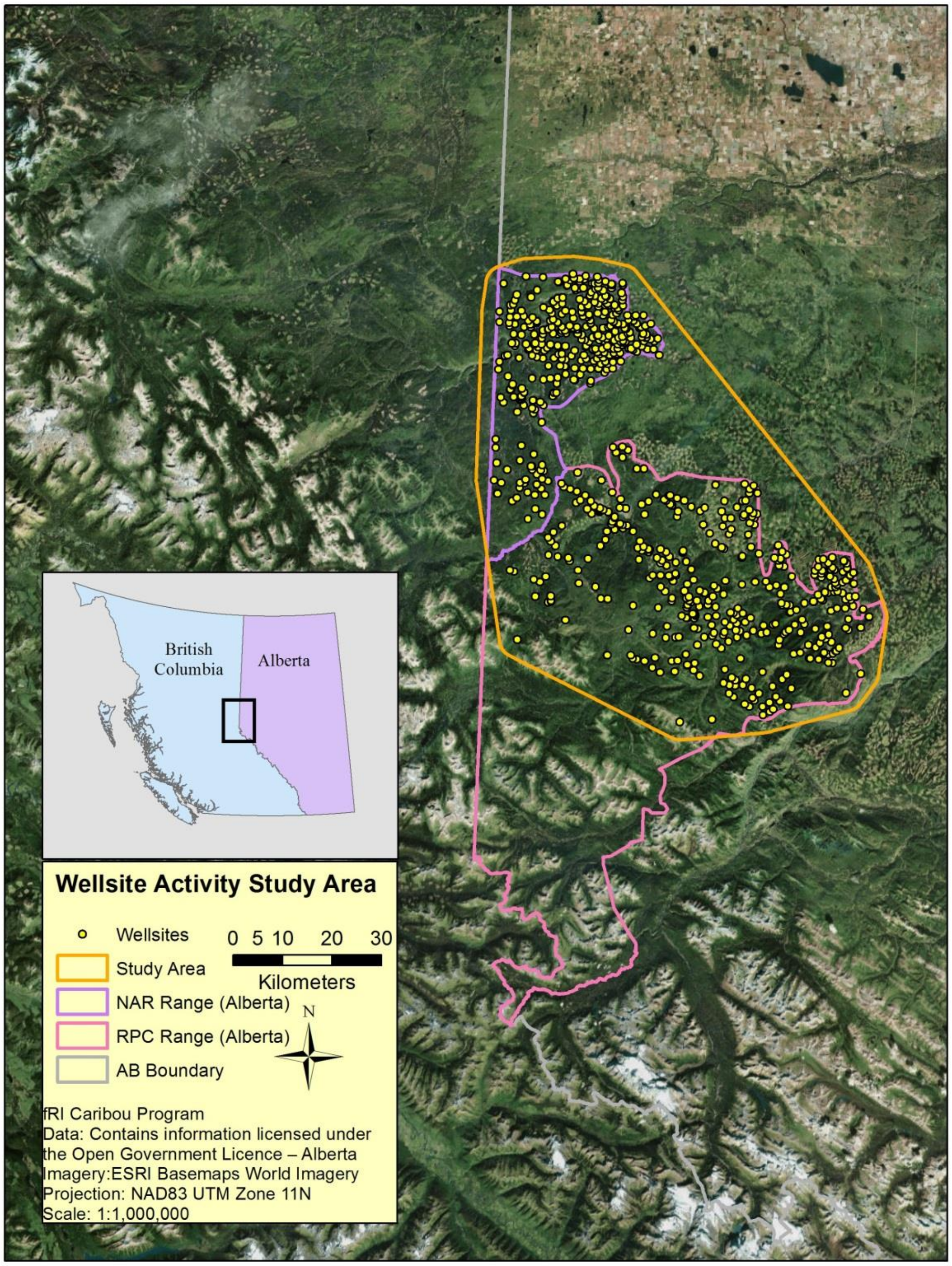


Figure 4.6. The study area in west-central Alberta where we examined habitat selection of caribou in the Narraway (NAR) and Redrock-Prairie Creek (RPC) caribou herds with respect to oil and gas wells. The distribution of well sites was not uniform throughout caribou range; we limited our analysis to individual caribou with > 80% of early or late winter GPS locations within the minimum convex polygon bounding the well sites.

For every “used” GPS location, 10 available locations were randomly drawn from within a 95% kernel home range created for each caribou/season (Wand and Jones; Sheather and Jones 1991). Each available point was assigned a random date between the minimum and maximum dates observed among the corresponding used locations for that caribou/season. For each used and available location we calculated the distance (km) to the nearest well site and extracted the activity status. Locations of oil and gas well sites and activity information were provided by the Alberta Energy Regulator (AER). The AER activity data includes a drilling date and oil and gas production start and stop dates. From these dates we considered three activity phases: 1) drilling, 2) producing oil and 3) inactive. The drilling phase we presumed to be 30 days before and after the drilling date, consistent with McKay et al. (2014b). The producing oil phase was between the oil and gas production start and stop dates. All other dates the well was in an inactive phase meaning it was abandoned, capped, or reclaimed.

To represent the non-linear diminishing effect of well site disturbance at large distances (e.g., 2 km) compared to small ones (e.g., 0.1 km) we used a decay term for the distance covariate [1-exp (-2 x distance)] previously used for grizzly bears (Nielsen et al. 2009). To help account for additional landscape factors we included vegetation cover mapped at a 30 x 30 m resolution for 2013 using Landsat-8 Operational Land Imager (OLI) spectral data and slope and elevation as ancillary datasets (IRSS 2014). The original 15 vegetation cover classes were merged to 7 cover classes: barren, herbaceous, alpine herbaceous, wetland, mixed deciduous forest, open conifer forest and closed conifer forest (Table 4.2). We considered closed conifer as the reference category which also included all rare land cover types (<1% of used and available locations). We conducted a post-hoc analysis of RSF model coefficients to identify breakpoints where there was a significant increase in the predicted rate of change (e.g. slope) of habitat selection as a function of proximity and activity phase of the nearest well site (R package “SiZer”; Sonderegger 2012).

We carried out RSF modelling using the “glmer” function within the lme4 package in the statistical software R (Bates et al. 2014; R Development Core Team 2014). Distance to well sites and extraction of underlying vegetation cover were carried out in ArcGIS 10.1 (ESRI 2013).

Table 4.2. The original 15 vegetation cover classes with a description of the criteria used to derived them from 8 Operational Land Imager (OLI) spectral data (IRSS Report 2014) and the pooled classes they were grouped into for the RSF analysis.

Original Class	Description	Pooled Class
Conifer Dense	>75% crown closure; >80% conifer	Reference
Conifer Moderate	40-75% crown closure; >80% conifer	Con Mod Opn
Conifer Open	6-40% crown closure; >80% conifer	Con Mod Opn
Deciduous Closed	>50% crown closure; >80% broadleaf	Mixed Deciduous
Deciduous Open	6–49% crown closure; >80% broadleaf	Mixed Deciduous
Mixed Closed	>50% crown closure; 26–79% broadleaf	Mixed Deciduous
Mixed Open	6–49% crown closure; 26–79% broadleaf	Mixed Deciduous
Herb	<25% shrub cover; <6% tree cover	Herb
Alpine Herb	<6% vegetation cover, Alpine Elevations	Alpine Herb
Alpine Bare	<25% shrub cover; <6% tree cover; Alpine Elevations	Barren
Barren	<6% vegetation cover	Barren
Water	>6% standing or flowing water	Reference
Agriculture	Landuse Agriculture, crops, pasture etc.	Reference
Wetland	>10% Vegetation Cover; ‘wet’ or ‘aquatic’ moisture regime	Wetland
Regeneration	>25% shrub or tree cover; Canopy < 5m height	Reference

4.3. Results

Habitat selection was examined only in early and late winter due to the distribution of caribou locations during the study period (Table 4.3). Drilling activity was rare during late winter, and < 1% of caribou locations were near a well site in the drilling phase during late winter. Drilling was more common in early winter, and 11% of caribou locations were near a well site in the drilling phase during that season (Table 4.4). As a result of this low sample size we did not consider RSF models with drilling activity as a covariate in our late winter models.

The top two RSF models for both early and late winter included vegetation cover and distance to nearest well site interacting with an activity type (Table 4.5). The sole difference between early and late winter was the type of activity phase interacting with distance to well. In early winter the top model included all three activity phases (drilling, producing oil and inactive), while in late winter the drilling and oil producing phases were merged into a single “active” phase for comparison against inactive wells. Based on the top RSF models caribou consistently selected for habitat farther away from well sites than expected by chance (Figure 4.2). In early winter caribou selected habitat farther away from wells in the drilling phase than oil producing or inactive wells. However, in early winter caribou selected habitat closer to oil producing wells than to inactive wells (Table 4.6). In the late winter caribou selected habitat farther away from active well sites (drilling or oil production) than inactive well sites (Table 4.6). We found a significant increase in early winter habitat selection at distances greater than 0.66 km (95% CI = 0.61-0.70km) from wells in the drilling phase, while the relationships remained linear for oil producing and inactive phases (Figure 4.2).

Table 4.3. Summary of the number of caribou within the study area (>80% of GPS collar locations within study area) during the six seasons.

Season	Herd	No caribou >80% locations in Study Area	Total Caribou/year
Calving	NAR	0	15
	RPC	0	8
	Total	0	23
Fall	NAR	1	29
	RPC	0	27
	Total	1	56
Spring	NAR	0	34
	RPC	2	30
	Total	2	64
Summer	NAR	0	30
	RPC	0	27
	Total	0	57
Winter_early	NAR	12	36
	RPC	7	32
	Total	19	68
Winter_late	NAR	16	38
	RPC	12	34
	Total	28	72

Table 4.4. Frequency of activity phase (drilling, not active or producing oil) for the nearest well site among the seasonal RSF datasets (early winter, late winter) for each individual caribou/year. Caribou are defined as a unique individual within a particular year, for example caribou F404_2008 is individual F404 observed during the year 2008.

	Early Winter				Late Winter			
Caribou	Drilling	Not active	Producing oil	Total	Drilling	Not active	Producing oil	Total
F404_2008	2826	1519	0	4345	0	4686	1111	5797
F404_2009	0	3926	485	4411	0	4662	1069	5731
F408_2009	0	4521	22	4543	0	3785	2012	5797
F410_2010	0	154	1045	1199				
F414_2009	243	569	3698	4510	0	4286	1621	5907
F414_2010	55	3337	1019	4411	0	5556	307	5863
F416_2010	0	1190	295	1485	0	5033	709	5742
F423_2011					0	5572	258	5830
F424_2011					0	1520	4266	5786
F432_2013					0	5885	0	5885
F441_2013					0	4466	0	4466
F444_2013					0	3250	1216	4466
F446_2013					0	2554	1791	4345
F733_2012	0	2607	1518	4125	0	3491	2240	5731
F733_2013	0	2840	1637	4477	0	4454	1299	5753
F742_2008					0	2114	1417	3531
F744_2008	0	3779	621	4400	0	5195	426	5621
F758_2008	0	3531	0	3531				
F759_2009	1153	2834	523	4510	163	4486	1082	5731
F759_2010	1223	2083	1116	4422				
F760_2008	25	3148	292	3465				
F761_2008	0	3531	0	3531	82	5671	0	5753
F761_2009	593	3233	684	4510	133	3884	1725	5742
F763_2009					181	5396	154	5731
F763_2010	1332	2080	977	4389				
F770_2009	938	1962	1632	4532	260	4644	882	5786
F774_2012	0	2879	1543	4422	0	4944	820	5764
F777_2012					0	3911	841	4752
F782_2012					0	4893	750	5643
F784_2012					0	3328	2480	5808
F786_2013					0	3124	1232	4356
F787_2013					0	3722	612	4334
F792_2013					0	3214	1109	4323
Grand Total	8388	49723	17107	75218	819	117726	31429	149974

Table 4.5. Ranking of ten competing seasonal RSF models based on Bayesian information criterion (BIC). Drilling activity was rare during the late winter therefore models which featured drilling as a factor were omitted during that season.

Season	**Model**	**Covariates**	**df**	**Δ BIC**	**BIC weight**
Early Winter	1	Null model (intercept only)	2	362.18	< 0.01
	2	Distance to Well	3	353.55	< 0.01
	3	Distance to Well x Active Well *	5	360.51	< 0.01
	4	Distance to Well x Drilling ^	5	339.25	< 0.01
	5	Distance to Well x Well Activity†	7	309.17	< 0.01
	6	Land cover	8	68.08	< 0.01
	7	Land cover + Distance to Well	9	66.91	< 0.01
	8	Land cover + Distance to Well x Active Well*	11	67.57	< 0.01
	9	Land cover + Distance to Well x Drilling^	11	47.69	< 0.01
	10	Land cover + Distance to Well x Well Activity†	13	0.00	> 0.99
Season	Model	Covariates	df	Δ BIC	BIC weight
Late Winter	1	Null model (intercept only)	2	160.10	0.00
	2	Distance to Well	3	133.56	0.00
	3	Distance to Well x Active Well	5	133.10	0.00
	4	Distance to Well x Drilling	5	133.47	0.00
	5	Distance to Well x Well Activity	7	130.08	0.00
	6	Land cover	8	26.01	0.00
	7	Land cover + Distance to Well	9	2.46	0.23
	8	Land cover + Distance to Well x Active Well	11	0.00	0.77
	9	Land cover + Distance to Well x Drilling	NA	NA	NA
	10	Land cover + Distance to Well x Well Activity	NA	NA	NA

* Binary variable of the activity at the nearest oil and gas well site (1= drilling or producing oil; 0 = inactive)

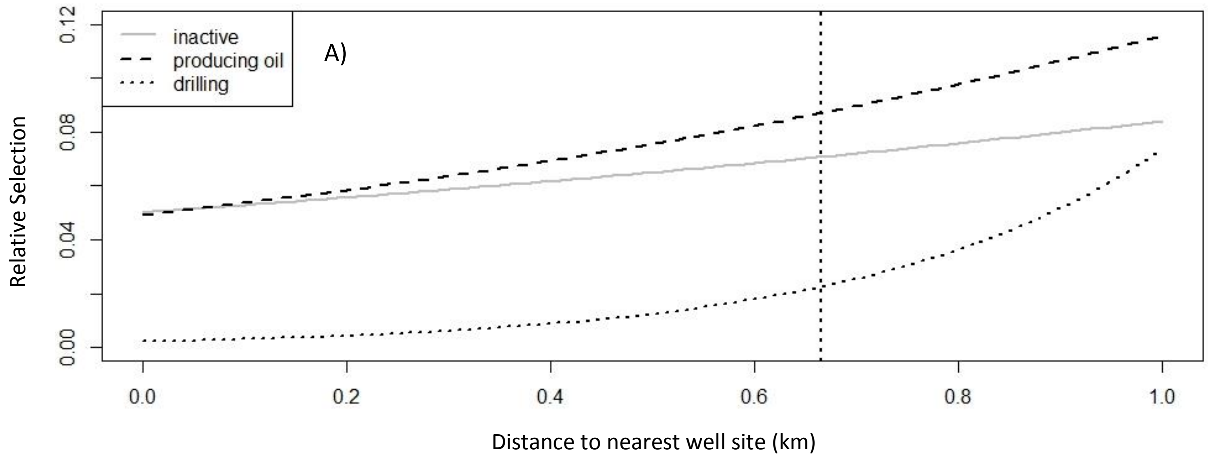
^ Binary variable of the activity at the nearest oil and gas well site (1= drilling; 0 = producing oil or inactive)

† Activity at the nearest oil and gas well site where inactive is the reference category with drilling and producing oil as separate categories.

Table 4.6. Estimated beta parameters for top RSF models during the early and late winter seasons along with associated standard errors (SE), odds ratios (OR), and p-values. The RSF models were constructed from 49 GPS collars deployed on caribou within the Narraway and Redrock Prairie Creek herds in west-central Alberta from 2007 to 2013.

Season	Covariate	Beta	SE	OR	p-value
Early Winter	Intercept	-2.99	0.17	0.05	<0.01
	Distance to Well*	0.52	0.17	1.68	<0.01
	Well Site Activity				
	Drilling	-3.16	1.01	0.04	<0.01
	Producing Oil	-0.02	0.23	0.98	0.93
	Distance to Well * Drilling	3.03	1.02	20.70	<0.01
	Distance to Well * Producing Oil	0.34	0.25	1.41	0.16
	Vegetation Cover				
	Barren	-0.22	0.1	0.80	0.02
	Alpine Herb	0.92	0.06	2.51	<0.01
	Conifer Moderate Open	0.24	0.04	1.27	<0.01
	Mixed-Deciduous Forest	-0.41	0.13	0.66	<0.01
	Herb	0.16	0.11	1.17	0.14
	Wetland	0.47	0.04	1.60	<0.01
Late Winter	Intercept	-2.70	0.10	0.07	<0.01
	Distance to Well	0.42	0.10	1.52	<0.01
	Well Site Activity				
	Active^	-0.35	0.17	0.70	0.04
	Distance to Well * Active	0.25	0.19	1.28	0.18
	Vegetation Cover				
	Barren	-0.49	0.07	0.61	<0.01
	Alpine Herb	0.49	0.09	1.63	<0.01
	Conifer Moderate Open	0.21	0.03	1.23	<0.01
	Mixed-Deciduous Forest	0.00	0.04	1.00	0.99
	Herb	-0.26	0.09	0.77	<0.01
	Wetland	-0.12	0.04	0.89	0.01

* Distance to well measured in kilometers as decaying function [1-exp (-2 x distance)]
^ Active well sites are either in the drilling or oil producing phase



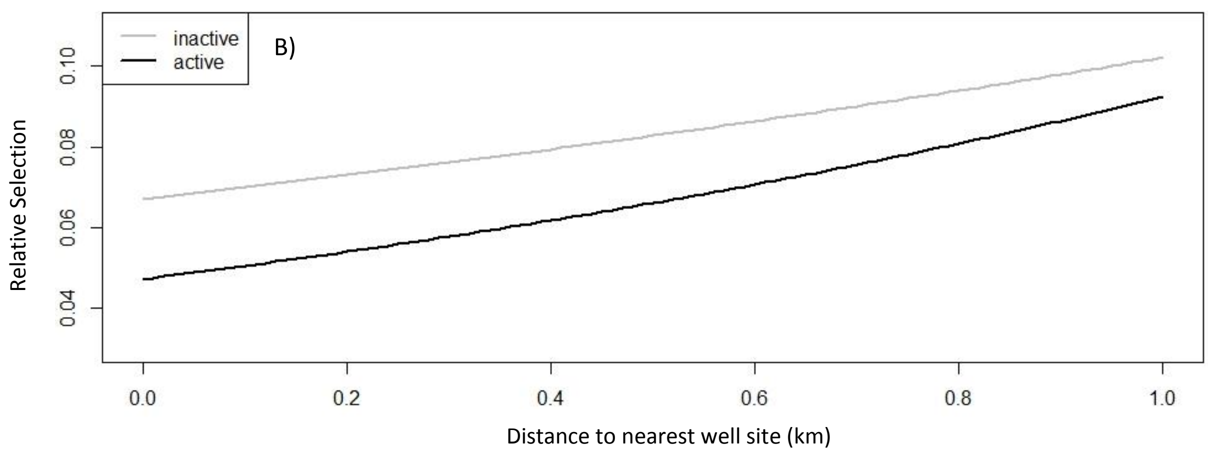


Figure 4.7. RSF model predictions of caribou habitat selection for early (A) and late winter (B) in relation to distance to the nearest well site and associated activity phase of that well site. Distance to nearest well site was transformed into a decaying exponential function based on the formula [1 - exp(-2*distance)] where distance is measured in kilometers. The vertical line in panel A represents the breakpoint (0.66 km) at which predicted habitat selection increased significantly in relation to distance to well sites in the drilling phase.

4.4. Discussion

We found that caribou used habitat farther away from oil and gas well sites than expected by chance Figure 4.2). In both early and late winter periods, there was a negative relationship between the probability of caribou occurrence and distance to well sites in different phases of development (Figure

4.2). The relative selection of habitat increased faster at distances greater than 0.66 km than at closer distances for well sites in the drilling phase; however 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. An expansion of this analysis in year two may reveal further patterns.

These results suggest that caribou do not perceive all well sites equally. Greater human activity at oil and gas well sites, particularly in the drilling phase when a well site is first established, appears to have a stronger negative impact on caribou habitat use because caribou tend to avoid these sites more than low activity sites like abandoned or reclaimed wells (Figure 4.2). McKay et al. (2014b) found a similar effect in grizzly bears, where bears preferred to use older well sites rather than newly cleared well sites, and inactive wells (abandoned, capped or reclaimed) were preferred over active wells in the drilling or oil producing phase. This finding underlines the impact human presence can have on habitat selection, because other studies have shown that grizzly bears sometimes prefer human disturbed areas like cut blocks (Nielsen et al. 2004; Stewart et al. 2012), roads (Roever et al. 2008; Graham et al. 2010) and well sites (Laberee et al. 2014). Understanding the influence of human activity on habitat selection is important for accurately predicting species occurrence on the landscape (Hebblewhite and Merrill 2008; McLoughlin et al. 2011). Predicting occurrence is especially important for threatened species like woodland caribou for identifying and prioritizing areas to restrict disturbance, and in determining effective set back distances for development.

Under the federal boreal recovery strategy disturbed habitat, including well sites, is buffered by 500m to reflect both the direct (avoidance) and indirect (increased predation) effects of these features on reducing functional habitat (areas with high probability of caribou occurrence (food) and high recruitment rates (reduced predation)). Our results suggest that these inactive well sites have less of an impact on caribou habitat use when compared to well sites in the drilling phase, but that all well sites regardless of activity phase negatively affect the probability of caribou occurrence. A greater emphasis on limiting the duration of high activity periods such as drilling at well sites could benefit caribou.

4.5. Management Application

Our data revealed no evidence to refute the federal buffer of 500m applied around well sites. We found that relative habitat selection by caribou remains consistently negative around well sites in the active drilling phase to a distance > 600 m and probability of caribou occurrence increased with distance from well sites across all activity phases.

Chapter 5. Summary of fecal collection effort 2015

Doug MacNearney, fRI Caribou Program

5.1. Introduction

Population health monitoring is an important aspect of conservation planning for species at risk. For declining populations of woodland caribou in Alberta, knowledge of the underlying health status is essential to establish a baseline for monitoring and to address direct and indirect factors that may negatively impact population health and contribute to population decline (Leendertz et al. 2006). Fecal pellet surveys are a non-invasive means to collect genetic information from caribou herds and assess health through stress and pregnancy hormones as well as parasite and pathogen exposure (Verocai et al. 2013; Polfus and Heinemeyer 2011; Keay et al. 2006). Baseline data collected through a monitoring program can be used by forest managers to establish objective criteria when evaluating the effectiveness of recovery actions such as habitat restoration. Fecal pellet surveys complement health data collected during collaring efforts and necropsies by extending sampling to a larger proportion of individuals in the population, removing bias due to sex and age, and offering a relatively low-cost opportunity to validate calf-cow ratios and gender ratios collected via sight-based flight surveys.

The contribution of population health to declines in caribou populations is currently poorly understood due to a lack of comprehensive data; however emerging research conducted by the British Columbia Boreal Caribou Health Program (BCHP) suggests that boreal caribou in northeast British Columbia have a much higher exposure rate to parasites and pathogens than previously expected (Macbeth et al. 2014). Parasites and pathogens such as *Neospora caninum* and *Erisipelothrix rhusiopathiae* are suspected to be factors in several recent caribou fatalities examined by BCHP, and baseline knowledge of their regional presence could help direct management decisions for caribou recovery (Macbeth et al. 2014). Gastrointestinal parasites such as trematodes (i.e. *Fascioloides magna*), protostrongylid nematodes, and abomasal nematodes can also have a range of impacts on population health, including neurological disease, reduced pregnancy rates, poor body condition, and death (Pollock et al. 2009; Stein et al. 2002; Trainer 1973). While some pathogens and parasites can only be detected from blood or tissue samples, presence of gastrointestinal parasites can be confirmed from fecal samples via identification of larvae (Verocai et al. 2013).

In addition to providing direct information on pathogen and parasite exposure, fecal pellets can be used to assess population health indicators such as stress and pregnancy hormones (glucocorticoids and progesterone; Ashley et al. 2011; Polfus and Heinemeyer 2011; Freeman 2008), as well as genetic immune markers which provide information on disease and parasite resistance (e.g. MHC alleles; Paterson et al. 1998).

Collecting baseline data on health indicators such as stress and pregnancy hormones, and monitoring the exposure level of caribou to a wide range of pathogens and parasites will be informative in monitoring the response to recovery actions. In addition, monitoring allows managers to track caribou response to the effects of changes in global climate which is predicted to increase the frequency of thermal stress, as well as exposure to vectors of disease due to range expansion of white tailed deer (Hoberg et al. 2008). As populations continue to decline, the consequences of disease outbreak and stress are greater (Heard et al. 2013), and the ability to track hormonal health and exposure to pathogens through time may allow for timely decisions to ensure persistence of caribou on the landscape through to recovery.

5.2. Methods

We collected caribou fecal samples between January 1st and March 31st, 2015. Sampling sites were located by flying by helicopter to GPS telemetry locations roughly one week after the collared animal had left the vicinity, and searching for evidence of track networks and cratering (Figure 5.1). Sites were also sampled opportunistically by searching for track networks from the helicopter. If caribou were still present at a site upon arrival, the helicopter did not land and the site was not disturbed until a later date after caribou had vacated the area. At each site the number of animals present was estimated by counting unique sets of tracks approaching or leaving the area. Following existing Alberta Environment and Parks protocols we sampled 1.5 times the number of fecal piles as caribou estimated at the site. Three samples of fecal pellets were collected from each pile and stored in sterile Whirl-Paks® for genetic, hormone, and pathogen analysis. Samples were labelled and kept in a cooler with ice during collection and later transferred to a freezer (-20°C) to maintain DNA quality.

5.3. Fecal sampling results 2015

From January to March 2015 we visited 20 individual sampling locations (6 RPC; 7 LSM; 2 NAR; 2 ALP); and sampled a total of 268 fecal piles (Figure 5.2 and Table 5.1). The unbalance in sampling between herds was related to the number of active GPS collars in each herd, inclement weather which restricted sampling effort, and the availability of landing sites. Three of four collared caribou in the NAR herd remained in British Columbia for the entirety of the sampling period; permitting restrictions prevented us from visiting these locations.

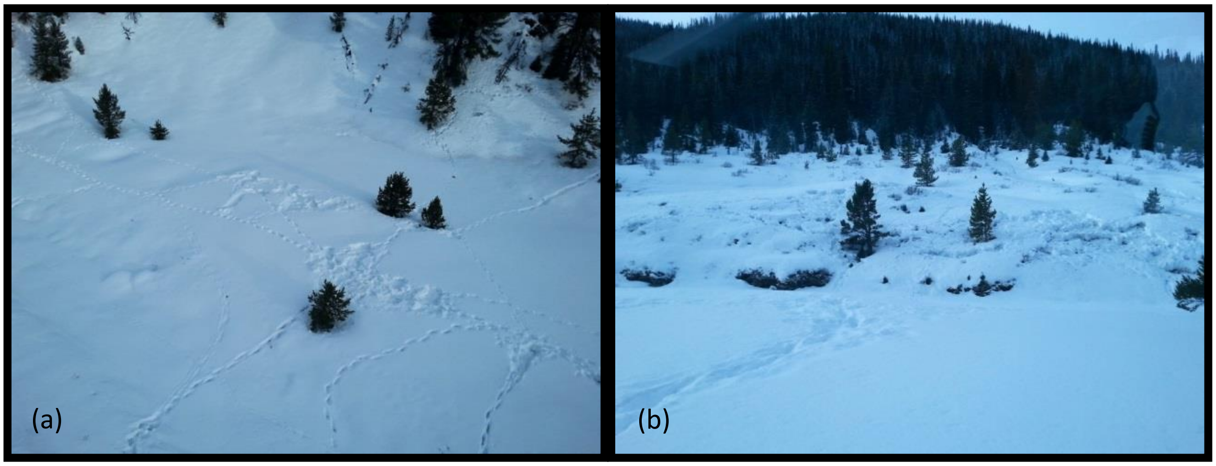


Figure 5.1. Caribou track networks (a) and cratering sites (b) observed from the air during fecal sampling.

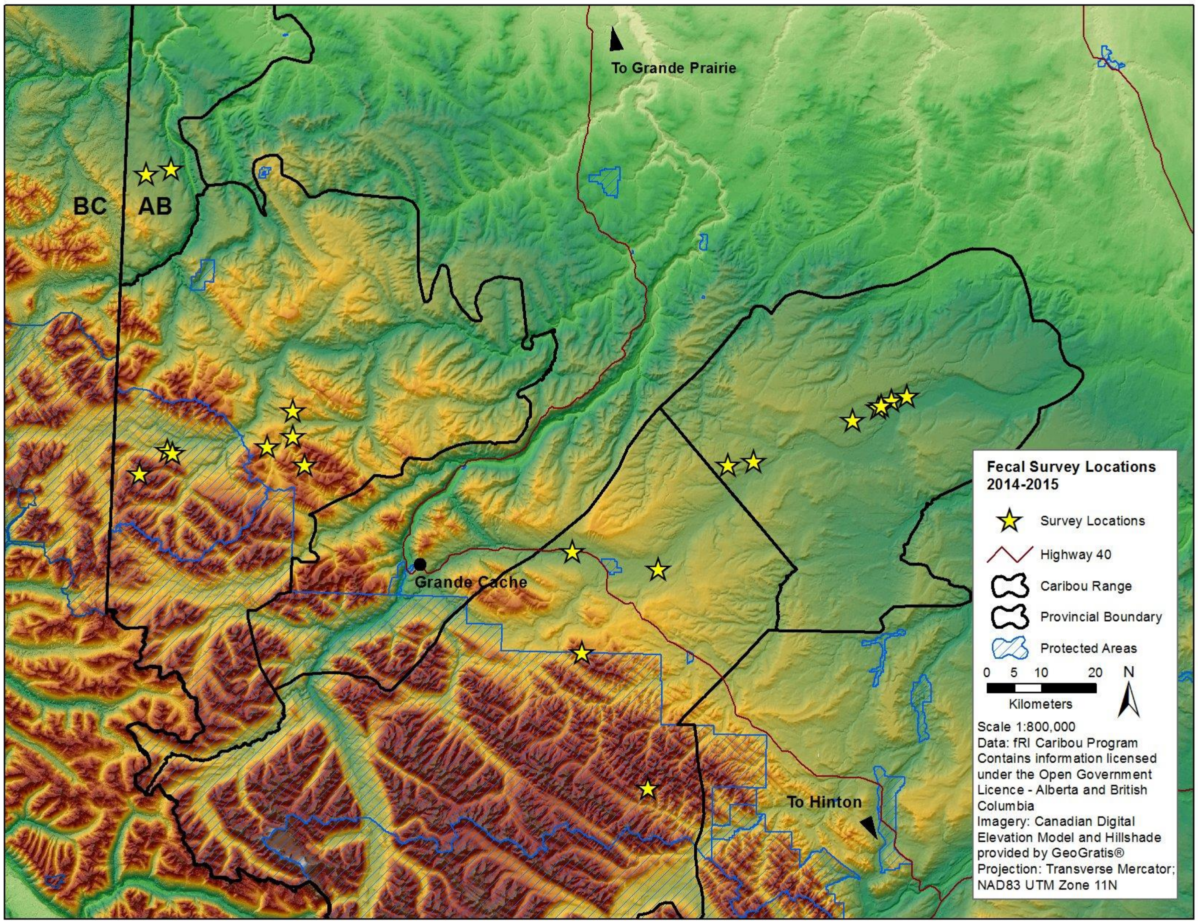


Figure 5.2. Map of sites in West-Central Alberta visited for caribou fecal collection 2015 (n=20).

Table 5.1. Fecal sampling effort for Redrock-Prairie Creek (RPC), Narraway (NAR), Little Smoky (LSM), and A La Peche (ALP) caribou herds spanning Jan 1st – Mar 31st 2014-2015.

Date	Herd	Site Number	Number of Samples
1/24/2015	RPC	1	24
1/24/2015	RPC	2	12
1/24/2015	RPC	3	3
1/29/2015	LSM	4	21
1/29/2015	LSM	5	27
1/29/2015	RPC	6	27
1/29/2015	NAR	7	27
2/14/2015	LSM	8	8
2/14/2015	LSM	9	5
2/14/2015	LSM	10	3
3/3/2015	NAR	11	2
3/3/2015	ALP	12	11
3/4/2015	RPC	13	9
3/4/2015	RPC	14	9
3/4/2015	LSM	15	21
3/7/2015	LSM	16	6
3/12/2015	ALP	17	19
3/13/2015	RPC	18	13
3/13/2015	RPC	19	18
3/21/2015	ALP	20	3
	Total:	**20**	**268**

5.4. Year Two Research

- **Laboratory work**
  - During the summer of 2015 samples will be sent to a genetic laboratory to determine the gender and number of unique individuals sampled. Samples from unique individuals will then be used for hormonal assays and parasite/pathogen exposure.
  - We will use PCR-based methods to identify the presence of pathogens such as *Mycobacterium avium* and *Paratuberculosis* spp. Larger parasites such as trematodes (*Facioloides magna*), protostrongylid nematodes (*Parelaphostrongylus odocoilei*; *P. andersoni*; *P.tunuis*; *Elaphostrongylus rangiferi*; *Varestrongylus eleguneniensis*), and abomasal nematodes (*Ostertagia gruehneri*; *Marshallagia marshalli*) will be identified based on the presence of dorsal-spined larvae and eggs in feces.

- **Fecal surveys**
    - In the winter of 2015/2016 we will augment our samples collected to date with additional samples collected across west-Central Alberta.
- **Outcomes**
    - The results from this activity will be used as a baseline for health and pathogen monitoring of caribou in this region and to assess the immediate risk of caribou populations to negative impacts of stress inducing anthropogenic industrial and recreational activities.
    - Additionally, we will be able to cross-validate the current estimates of reproductive success (calving dates from telemetry data, calf/cow ratios) based on progesterone levels, and assess the overall exposure to pathogens and parasites detectable from fecal analysis.

Chapter 6. Does response of boreal caribou to re-vegetation stage vary across different sub-regions?

Laura Finnegan fRI Caribou Program, Jerome Cranston Arctos Ecological Consultants

6.1. Introduction

Caribou functional habitat is associated with a high probability of caribou occurrence and high levels of population level fecundity (high calf recruitment, low predation risk). Fragmentation of habitat within caribou range reduces the extent of functional habitat available to caribou, increases niche overlap with alternate prey driving a numerical response in wolf populations, and ultimately decreases caribou survival due to apparent competition (James et al. 2004; DeCesare et al. 2010). The effect of habitat disturbance extends beyond the physical footprint of the disturbance itself (Dyer et al. 2001; Polfus et al. 2011; Boulanger et al. 2012). For caribou predators the opposite is true as they frequently select for anthropogenic disturbance, in particular linear access corridors which may facilitate movement (Whittington et al. 2005; Stewart et al. 2013; Tigner et al. 2014). To reflect this reduction of functional habitat all disturbed habitat within caribou ranges includes both the disturbance feature, and a 500m buffer (Environment Canada 2012). It is unknown whether this buffer reflects how caribou and their predators respond to linear features at all stages of re-vegetation. Understanding of how re-vegetation stage affects use of disturbed areas by caribou and their predators will help prioritize areas for restoration within caribou ranges.

Remote sensing is increasingly used to inform landscape planning for species at risk (Weclaw and Hudson 2004; Nielson et al. 2010). High resolution light detection and ranging (LiDAR) data increases the accuracy of remote sensing based habitat assessments as these data provide information in three dimensional space (e.g. canopy cover and canopy height; Lefsky et al. 2002), and have been used both to remotely map habitats for wildlife at a fine scale (Vierling et al. 2008; Martinuzzi et al. 2009; McKay et al. 2014a), and to predict vegetation regrowth patterns within caribou ranges (van Rensen et al. 2015). LiDAR surfaces have sufficiently high resolution (1m horizontal resolution) to accurately measure vegetation height within linear access corridors; with vertical and horizontal accuracies of about 40 cm.

Recent research in west-central Alberta has assessed how caribou, wolves and grizzly bears respond to vegetation height of linear features (Finnegan et al. 2014). Although analyses from Phase One of this project revealed no effect of vegetation stage on selection of areas near seismic lines by caribou or their predators, assessments of movement rates of grizzly bears and wolves found that both species moved faster near seismic lines that had low vegetation height (<1.4m). This research was focused within the lower and upper foothills and subalpine ecoregions. It remains unknown whether this pattern applies in other natural subregions, including the mixedwood and boreal highlands sub-regions in north-western Alberta. Following this, the goals of this activity are to use LiDAR based measurements of vegetation height to determine how caribou respond to seismic cutlines at different stages of re-vegetation within a mixedwood sub-region. Our objectives were to create a GIS layer of LiDAR attributed seismic lines for the Chinchaga caribou range in north-western Alberta (year one and two), and to determine caribou response to these seismic lines at different stages of re-vegetation (year two). Here we outline the process of attributing vegetation height to seismic lines and the progress achieved to date.

6.2. Methods: LiDAR vegetation height along seismic lines

We used LiDAR data collected between 2003 and 2008, provided to fRI by Alberta Environment and Parks, to attribute vegetation height to 60,648 km of seismic lines across our study area (Figure 6.1; and see study area description in Chapter 1). Prior to extracting vegetation height we subset the Chinchaga caribou range (17,517 km^2) seismic layers into 29 individual 28km x 28km tiles (780km^2, corresponding to 1:50,000 NTS map sheets) for data processing (Figure 6.1). The raw LiDAR signal returns (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 to Bare Earth (Digital Elevation model, or DEM) and Full Feature (Digital Surface Model, or DSM) ESRI grid surfaces at 1m horizontal resolution. A Canopy Height surface was derived by subtracting the DEM from the DSM.

Seismic line features (polyline) were obtained from AESRD base features. We developed an automated GIS process to derive topographic and vegetation metrics for seismic lines from our LiDAR-based surfaces. Because the process is automated it is far less expensive than Softcopy interpretation, thereby freeing up more resources to be directed to actual on-the-ground reclamation treatments.

Although GIS tools can extract underlying raster attributes from digitized lines (e.g. mean, minimum, and maximum values for slope and elevation), seismic line features digitized by photo-interpreters usually are not accurate enough to yield reliable information on vegetation along the entirety of the line. In addition, seismic cutline right-of-ways are typically so narrow (3 to 6m) that small errors in digitizing or geo-referencing will cause the digitized line to lie outside the corridor and fall within adjacent forest stand. To obtain accurate canopy height values for vegetation on the seismic line the line must precisely follow the actual seismic corridor. To obtain accurate vegetation height data our GIS process clips the canopy height surface to within 20m of the original seismic line feature. A least-cost path raster was then generated between the start point (source) and endpoint (destination) of the line feature and this path was then converted to a line features. The resulting line features were divided into segments of approximately 100m and we derived mean and maximum vegetation height along the least-cost path by overlaying the adjusted line feature with the canopy height surface.

6.3. LiDAR vegetation height along seismic lines – progress to date

LiDAR processing and vegetation height attribution has been completed for 13 of the 39 tiles that include the range of Chinchaga caribou (Figure 6.1). The remaining tiles will be completed by June 2015 with animal analysis proceeding soon after.

6.4. Upcoming Research (Year Two)

- LiDAR vegetation height
    - We will complete the LiDAR based inventory of vegetation height along seismic cutlines in West-central Alberta
- Animal response
    - We will use animal GPS data provided by AESRD and freely available via the BC Species inventory database to determine how vegetation height of seismic lines affects use and movement of both caribou and their predators, and how this is related to the proximity of the seismic line (e.g. <500m, <100m).
    - We will compare results from this analysis to that from other boreal caribou ranges (Little Smoky) to determine whether response of caribou to re-vegetation is consistent within caribou ecotypes.
- Outcomes
    - We will produce a map of seismic lines within the Chinchaga caribou range ranked with respect to their priority for restoration based on animal movement data.

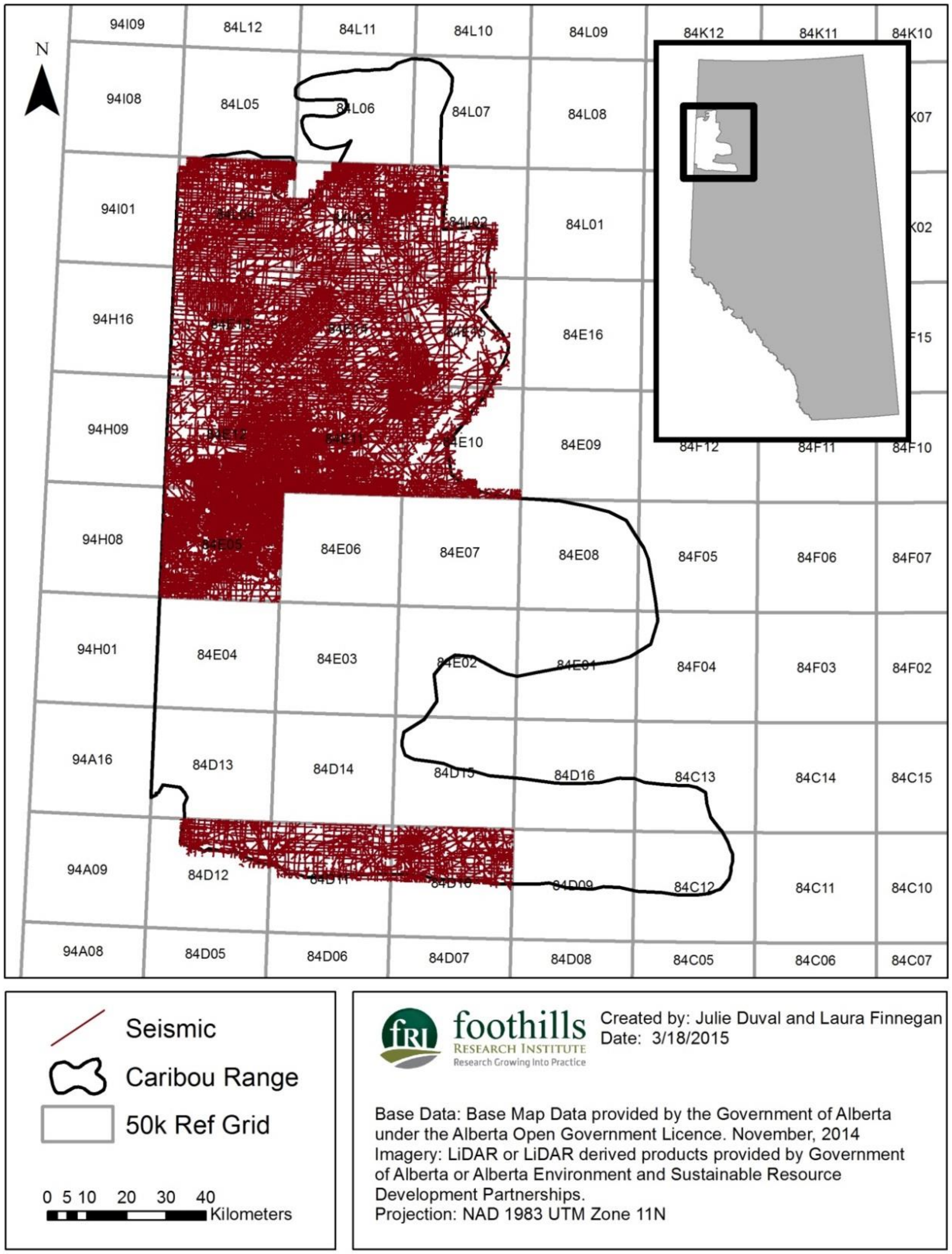


Figure 6.1. The range of the Chinchaga caribou herd showing the vegetation attributed seismic lines completed to date (March 2015).

Chapter 7. Key Research Findings

We investigated the relationship between human and wildlife use of inactive roads and pipelines using terrain and vegetation variables, as well as the response of caribou to industrial activity levels on oil and gas well sites. This research indicates that:

- Use of these pipelines and roads by humans, predators, and other ungulates is predicted by the ease of travel (low vegetation, dry soil, presence of a trail).
- Caribou are avoiding well sites regardless of activity level, but high levels of activity (drilling or producing) invoke a stronger negative response up to 600m from well sites.
- Soil wetness and vegetation ground cover are two landscape variables that can be used in predictive models to identify linear features to prioritise for restoration.

Chapter 8. Ongoing research

Data collection is underway to support the remaining objectives of this project, including fecal surveys to establish a baseline health assessment for stress and pregnancy hormones and endoparasites, and further study of caribou response to linear features in different ranges and sub-regions to validate and corroborate current findings. Moving forward, the current status of the project objectives are as follows:

Year 1 (2014-2015):

5. 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. **Completed for LSM and ALP.**

6. Assess how human activity of linear features is affected by topography, geographic barriers and re-vegetation height. **Completed for LSM and ALP.**

7. Determine whether activity at worksites (active industrial activity) affects the movements of caribou. **Completed for RPC and NAR.**

Year 1 and 2 (2014-2016):

1. Evaluate whether currently accepted 500m buffers on roads and pipeline RoWs apply when line characteristics incorporate information on regeneration. **Underway; additional data collection (RPC, NAR, Chinchaga) and final data analysis will take place in Year 2 (2015-2016)**
2. 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. **Underway; fecal samples collected and awaiting laboratory processing.**
3. Assess whether the response of boreal caribou in the Chinchaga range (mixedwood upland peatland habitat) to re-vegetation stage of disturbed habitat differs from that of boreal and mountain caribou in conifer dominated landscapes. **Data compilation and processing underway.**

Year 2 (2015-2016):

4. Produce a list of landscape variables (e.g. re-vegetation height, human use thresholds) that can be used to quantify the extent of caribou functional habitat both in our study area, and elsewhere. **Underway; additional field data to be collected (RPC, NAR, Chinchaga) and predictive maps to be developed for the study area in Year 2.**

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Chapter 10. Appendices

A.1. Model selection results for models of human motorized use of pipelines and inactive roads using Akaike Information Criterion (AIC).

Table A.1. Akaike Information Criterion (AIC), Delta AIC (Δ AIC), and AIC weight (AIC_w) for cumulative link mixed candidate models predicting human motorized use of pipelines and roads. Field data collected in ALP and LSM caribou range between June and October 2014 on 35 pipelines and 54 inactive roads. The best AIC model is in bold.

Model/Hypothesis	AIC	Δ AIC	AIC_w
Vegetation			
1. a) Vegetation height + coniferous +feature type	479.9401	19.6404	0.0001
b) Lateral cover + coniferous + feature type	478.2206	17.9208	0.0001
Human activity			
2. a) Facility density + feature type	493.2405	32.9408	0.0000
3. a) Distance to city + slope + feature type	494.7924	34.4926	0.0000
b) Distance to hwy + slope + feature type	495.0656	34.7658	0.0000
4. a) Wildlife trail + slope + distance to city + feature type	483.7524	23.4526	0.0000
b) Wildlife trail + wetness + feature type + coniferous	**460.2997**	**0.0000**	**0.9998**
Topography			
5. a) Terrain wetness + feature type	486.8443	26.5446	0.0000
6. a) Soil type + slope + feature type	489.0930	28.7933	0.0000
Vegetation and Topography			
7. a) Lateral cover + wetness + feature type	482.7078	22.4081	0.0000

A.2. Target plant species in 10m2 subplots on pipelines and inactive roads

Table A.2. Plant species sampled in the 10m2 subplot categorized as forage for bears, caribou, moose, elk, and deer.

Species/Group	Bear Forage?	Caribou Forage?	Moose Forage?	Elk/deer Forage?	Common name & notes
***Alnus* spp.**	No	Yes[1,5]	Yes[8,9]	No	Alder. Caribou may avoid *Alnus tenuifolia*
Amelanchier alnifolia	Yes[10]	Possible	Yes[8]	No	Saskatoon.
Betula glandulosa*; *B. pumila	No	Yes[1,3,5]	Yes[8]	No	Dwarf and bog birch.
***Lonicera* spp.**	Yes[10]	Possible	Yes[8]	Yes[7]	Honeysuckles.
***Ribes* spp.**	Yes[10]	Possible	Yes[8]	Yes[7]	Currants and gooseberries
***Rosa* spp.**	Yes[10]	Yes[1]	Yes[8]	No	Roses
***Salix* spp.**	No	Yes[1,3,4]	Yes[8,9]	Yes[7]	Willow species.
Shepherdia canadensis	Yes[2]	Possible	Yes[8]	No	Buffaloberry.
Viburnum edule	Yes[10]	Yes[1]	Yes[8]	No	Highbush cranberry
***Alectoria* & *Usnea* spp.**	No	Yes[1,3,4,5]	Possible[9]	No	Sampled only on fallen trees that intersect the subplot, as a percentage of cover of the entire plot.

[1]Cook, John. 2014. Personal communication.

[2] Nielsen, S.E., R.H.M. Munro, E.L. Bainbridge, G.B. Stenhouse, M.S. Boyce. 2004. Grizzly bears and forestry II. Distribution of grizzly bear foods in clearcuts of west-central Albert, Canada. Forest Ecology and Management: 199:67-82.

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A.3. Target plant species in 1m2 subplots on pipelines and inactive roads

Table A.3. Plant species sampled in the 1m^2 subplot categorized as forage for bears, caribou, moose, elk, and deer.

Species/Group	Bear Forage?	Caribou Forage?	Moose Forage	Elk/deer forage	Common name & notes
***Cladonia* spp.**	No	Yes[1,3,4,5]	No	No	Lichens.
***Cladina* spp.**	No	Yes[1,3,4,5]	No	No	Reindeer lichens.
***Cetraria* spp.**	No	Yes[1,4]	No	No	Iceland moss; reindeer lichens.
***Flavocetraria* spp.**	No	Yes	No	No	Lichen.
***Stereocaulon* spp.**	No	Possible[1]	No	No	White lichen avoided by caribou (Cook 2014)
***Peltigera* spp.**	No	Possible[1]	No	No	Terrestrial lichen avoided by caribou (Cook 2014)
Pleurozium schreberi	No	No	No	No	Red-stemmed feathermoss, a competitor to reindeer lichens and common boreal bryophyte.
Other bryophytes	No	No	No	No	All other bryophytes grouped together.
Arctostaphylos uva-ursi	Yes[2]	Possible	No	No	Bearberry.
Empetrum nigrum	Yes[9]	Yes[4]	No	No	Crowberry.
***Rhododendron* spp. & *Kalmia* spp.**	No	No[1]	Yes[8,9]	No	Ericaceous shrubs widely found in the boreal forest but not heavily utilized by caribou.
Vaccinium vitis-idaea	Yes[2]	Yes[3,4]	Yes[8]	No	Lingonberry.
***Vaccinium* spp.**	Yes[2]	Yes[3,4,5]	Yes[8,9]	Yes[6]	The blueberries/huckleberries.
***Carex* spp.**	Yes[8]	Yes[3,4,5]	Yes[8,9]	Yes[6,7]	Sedges.
Other graminoids	Yes[8]	Yes[1,3,4,5]	No	Yes[6,7]	Grasses excluding sedges and horsetails.
***Equisetum* spp.**	Yes[2]	Yes[1,3,5]	Yes[8]	No	Horsetails.
Artemesia arctica	No	Yes[1]	No	No	Boreal sagebrush
Cornus canadensis	Possible	Yes[1,5]	Yes[8,9]	No	Bunchberry
***Chamerion* spp.**	Possible	Yes[1,3]	Yes[8,9]	No	Fireweed. (Formerly *Epilobium* spp.)
***Trifolium* spp.**	Yes[2]	Yes[1]	No	No	Clover.
Lathyrus	Yes[2]	Yes[1]	No	No	Peavine.
Hedysarum alpinum* & *H. boreale	Yes[2]	Possible	No	No	Sweet vetches. *H. sulfurescens* is also present but appears to be of lesser value to bears.
***Pedicularis* spp.**	Possible	Yes	No	No	Lousewort.
Mushrooms	No	Yes	No	No	

[1]Cook, John. 2014. Personal communication.

[2]Nielsen, S.E., R.H.M. Munro, E.L. Bainbridge, G.B. Stenhouse, M.S. Boyce. 2004. Grizzly bears and forestry II. Distribution of grizzly bear foods in clearcuts of west-central Albert, Canada. Forest Ecology and Management: 199:67-82.

[3]Boertje, R.D. 1984. Seasonal diets of the Denali caribou herd, Alaska. Artic 37(2):161-165

[4]Thomas, D.C., E J. Edmonds, and W.K. Brown. 1996. The diet of woodland caribou populations in west-central Alberta. Rangifer Special Issue 9:337-342

[5]Bergerud, A.T. 1972. Food habits of Newfoundland caribou. Journal of Wildlife Management 36(3):913-923.

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[7] Edge, W.D., C. Les Marcum, and S.L. Olson-Edge. Summer Forage and Feeding site Selection by Elk. Journal of Wildlife Management 52(4):573-577.

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A.4. Model selection results for models of elk and deer use of pipelines and inactive roads using Akaike Information Criterion (AIC).

Table A.4. Akaike information criteria (AIC) and AIC weight for candidate models to describe the probability of elk and deer use of pipelines and inactive roads in LSM and ALP caribou range between June and October 2014.

Hypothesis	Model	AIC	Δ AIC	AIC_w
1. Food availability	Elk/deer forage + soil type	305.0151	4.4147	0.0523
2. Oil and gas development	Facility density	304.4002	3.7998	0.0711
3. a) Predator avoidance	Predator use + lateral cover	300.6003	0.0000	0.4756
b) Predator avoidance	Predator use + lateral cover + facility density	301.5007	0.9003	0.3032
4. Predator avoidance and food	Predator use + lateral cover + facility density + elk/deer forage + soil type	306.8003	6.2000	0.0214
5. Null	None of the *a priori* models explain the data	304.2611	3.6608	0.0763

A.5. Model selection results for models of moose use of pipelines and inactive roads using Akaike Information Criterion (AIC).

Table A.5. Akaike information criteria (AIC) and AIC weight for candidate models to describe the probability of moose use of pipelines and inactive roads in LSM and ALP caribou range between June and October 2014.

Hypothesis	Model	AIC	Δ AIC	AIC_w
1. Food availability	Vegetation cover + soil type	304.8679	3.2841	0.1016
3. a) Predator avoidance	Predator use	301.5838	0.0000	0.5251
b) Predator avoidance	Predator use + vegetation over 1m + elevation + soil wetness	303.3120	1.7282	0.2213
4. Predator avoidance and food	Predator use + vegetation over 1m + vegetation cover + soil type	308.7897	7.2058	0.0143
5. Null	None of the *a priori* models explain the data	304.2611	2.6773	0.1377

A.6. Model selection results for models of bear use of pipelines and inactive roads using Akaike Information Criterion (AIC).

Table A.6. Akaike information criteria (AIC) and AIC weight for candidate models to describe the probability of bear use of pipelines and inactive roads in ALP and LSM caribou range between June and October 2014.

Hypothesis	Model	AIC	Δ AIC	AIC_w
1. Food availability	Bear forage + ungulate use	144.0556	11.8460	0.0026
2. Human avoidance	Human use + facility density + lateral cover	145.5527	13.3431	0.0012
3. Human avoidance and food	Human use + facility density + lateral cover + bear forage + ungulate use	144.9052	12.6957	0.0017
4. Movement corridor	Wildlife trail + lateral cover	132.2096	0.0000	0.9790
5. Null	None of the *a priori* models explain the data	140.5090	8.2994	0.0154

A.7. Model selection results for models of canid use of pipelines and inactive roads using Akaike Information Criterion (AIC).

Table A.7. Akaike information criteria (AIC) and AIC weight for candidate models to describe the probability of canid use of pipelines and inactive roads in LSM and ALP caribou range between June and October 2014.

Hypothesis	Model	AIC	Δ AIC	AIC_w
1. a) Food availability	Ungulate use	155.1538	8.7131	0.0075
b) food availability and topography	Ungulate use + elevation + soil type	158.8875	12.4468	0.0012
2. Human avoidance	Human use + facility density	146.4407	0.0000	0.5874
3. Human avoidance and food	Human use + facility density + ungulate use	148.4297	1.9890	0.2173
4. Movement corridor	Wildlife trail + vegetation over 1m	148.9657	2.5250	0.1662
5. Null	None of the *a priori* models explain the data	153.1539	6.7132	0.0205