FINAL REPORT

Behaviour and calving success of boreal caribou in relation to oil and gas development

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Final Report

fRI Research Caribou Program
Doug MacNearney, Karine Pigeon, Laura Finnegan

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Prepared by

Doug MacNearney, Caribou Program, fRI Research, Hinton, AB, dmacnearney@friresearch.ca

Karine Pigeon, Caribou Program, fRI Research, Hinton, AB, kpigeon@friresearch.ca

Laura Finnegan, Caribou Program, fRI Research, Hinton, AB, lfinnegan@friresearch.ca

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Executive Summary

Anthropogenic disturbance like oil and gas development is thought to negatively affect boreal caribou through displacement and degradation of habitat, and through creation of favourable conditions for other ungulates and their predators. Reproductive success may also be impacted by disturbance, and while some research has been conducted for barren ground caribou and for other ungulates, there is little knowledge regarding the effects that sensory and physical disturbance from oil and gas development may have on boreal caribou in Alberta.

We estimated the calving status (calf vs. no calf), and subsequent calf survival during the vulnerable neonatal period up to 4 weeks after calving using GPS telemetry data gathered from 62 adult female caribou from the Chinchaga and Little Smoky boreal caribou herds between 2000 and 2015. We employed an individual based method, developed using boreal caribou data from northeast British Columbia, which identifies changes in movement rates that are indicative of calving and calf mortality events. Field validation demonstrated that this approach predicts calving events and calf survival with high accuracy. We assessed site selection of adult female caribou at calving and during the calving season using a used versus available framework. We then used generalized linear mixed models to investigate habitat selection of caribou at the landscape and home range scale across six biologically defined seasons in relation to the proximity and density of anthropogenic disturbance features by type and age class. We paid particular attention to the response of caribou to oil and gas well sites due to the large fluctuations in human activity throughout the construction, drilling, producing, and post-abandonment phases of development, and the potential for differential responses of caribou to these phases. Finally, we investigated whether the calving status of individual caribou in a given year was related to the proximity and density of anthropogenic disturbance features throughout the gestational period.

We estimated 69 calving events from a total of 81 unique individual – year combinations in the Little Smoky and Chinchaga caribou ranges (85% parturition rate). Of the estimated calves born, we estimated that 52% succumbed to mortality before 4 weeks of age. Calf sites were located farther from well sites in all phases of development in both the Little Smoky and Chinchaga herd ranges, but the response to other disturbance features such as cut blocks differed between the two herds in accordance with the availability of habitat, suggesting that calf site selection is limited by the choices available to caribou in a particular range. When considering the relationship between calving status and the proximity and density of anthropogenic features, we found that in the Little Smoky range the probability of having a calf was negatively related to the overall exposure to anthropogenic disturbance density in the previous fall. This assessment would benefit from additional data to confirm this trend and allow a further investigation in Chinchaga where sample size was lower than Little Smoky. We did not find a relationship between calving status and the activity phase or proximity of well sites during the gestational period.

In our analysis of seasonal habitat selection we found that across all seasons and geographic scales and in both herds, caribou generally avoided anthropogenic disturbance at a rate greater than expected by chance. Little Smoky caribou had a higher overall exposure to disturbance within their range compared to Chinchaga caribou. The response of caribou to well sites varied slightly by phase of development and season, but overall well sites in high and moderate activity phases were avoided in Chinchaga more than well sites in the low activity phase. In Little Smoky we found a significant interaction between the phase of development and the distance to the nearest well site, with habitat selection increasing with distance from well sites in high and moderate activity phases, and remaining stable for distance to well sites in the low activity phase. Our analysis suggest that caribou avoid well sites in the high and moderate activity phases up to a distance of 3 km, however we were unable to identify a distance at which caribou stopped responding to well sites. This is potentially due to the limited availability of 'undisturbed' habitat, particularly in the Little Smoky range.

Overall, our detailed analyses of adult female caribou response and calving success in relation to well site status at different activity phases contributes new knowledge towards understanding the effect of anthropogenic disturbance, and associated sensory disturbance on caribou behavior. Although we did not find any clear linkages between disturbance and calving success *per se*, the strong patterns of avoidance by caribou of well sites in high activity phases suggests that planning the placement and timing of development of these features while also considering the spatio-temporal distribution of caribou within their ranges, may help to mitigate the negative effects of these developments on caribou in the future. In addition, calving site selection probability maps that we will provide as supplementary material (when the complete data set is analyzed) can be used by land planners and industrial partners to direct future development while considering areas preferred by caribou during the vulnerable calving season. In addition, these maps may also be used to direct habitat restoration efforts to areas where they will have the greatest benefit to caribou.

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1. Introduction

1.1 Project Background

Declines in boreal caribou populations throughout Alberta are believed to be a result of direct and indirect effects of anthropogenic disturbance within caribou ranges (McLoughlin *et al.* 2003; Hervieux *et al.* 2013). Under the federal recovery strategy, a minimum of 65% undisturbed habitat within each boreal caribou herd range is required to increase the probability of stabilizing populations (Environment Canada 2012). Currently, none of Alberta's boreal caribou herd ranges meet the 65% undisturbed habitat target, and land managers are under pressure to implement habitat restoration to achieve the 35% disturbance thresholds (Environment Canada 2011, 2012).

Given the extensive footprint of disturbance features within boreal caribou range in Alberta (e.g. forest cut blocks, oil and gas well sites, pipelines, roads, and seismic lines), restoration actions need to be prioritized to ensure maximum benefit to caribou recovery, and to ensure efficient use of caribou conservation resources. Research has demonstrated that the response of boreal caribou to anthropogenic disturbance features is related to disturbance type (Polfus *et al.* 2011; Johnson *et al.* 2015), disturbance age (Vors *et al.* 2007), and the intensity of human activity or other sensory disturbance associated with a particular disturbance feature (Neumann & Merriam 1972; Wolfe *et al.* 2000; Dyer *et al.* 2002; Leblond *et al.* 2013). Caribou response to anthropogenic disturbance has been measured at the population level and has been associated with reductions in recruitment and adult survival (Wittmer *et al.* 2007; McCarthy *et al.* 2011; Pinard *et al.* 2012); range shifts and changes in spatial distribution (Smith *et al.* 2000; Dyer *et al.* 2001b; Mahoney & Schaefer 2002; Schindler *et al.* 2007; Polfus *et al.* 2011), and local extirpation (Vors *et al.* 2007)). At the individual level, researchers have documented decreases in caribou use of habitat near disturbance (Polfus *et al.* 2011; DeCesare *et al.* 2012), and changes in individual behaviour to avoid crossing roads and pipelines (Wolfe *et al.* 2000; Dyer *et al.* 2002; Mahoney & Schaefer 2002; Leblond *et al.* 2013; Wilson *et al.* 2016). In addition, research has found that anthropogenic disturbance and associated displacements can have more subtle effects on caribou including decreased body condition (Cameron *et al.* 2005), and increased exposure to long term stress that may in turn negatively affect reproductive success (Adamczewski *et al.* 1987; Harrington & Veitch 1992; Cameron *et al.* 1993; Blas *et al.* 2007).

Poor recruitment of juveniles to reproductive age is recognized as a factor in the decline of boreal caribou (Schaefer *et al.* 1999; McLoughlin *et al.* 2003; Mahoney *et al.* 2016). Poor recruitment can be driven by high predation pressure during the first year of life, and studies have reported 40-50% calf mortality in the neonatal period two months after birth (Gustine *et al.* 2006; Pinard *et al.* 2012). The calving and post calving periods are thus critical times for caribou, and while calves surviving these periods are still more vulnerable than adults, their probability of survival increases significantly after the neonatal period (DeMars *et al.* 2011; Mahoney *et al.* 2016). Understanding how calf survival relates to habitat selection and anthropogenic disturbance is essential to manage and restore caribou habitat to promote population growth (Whitten *et al.* 1992). Caribou are particularly vulnerable to negative effects of poor recruitment because caribou produce a maximum of only one offspring per reproductive period, and population growth is thus fundamentally slower than apparent competitors such as moose (*Alces alces*) and whitetail deer

(*Odocoileus virginianus*) that are capable of producing twins or even triplets (Bergerud 1974; Johnstone-Yellin *et al.* 2009). While predation is often the proximate cause of calf mortality (Gustine *et al.* 2006; DeMars *et al.* 2011; Mahoney *et al.* 2016), there are a number of factors that may influence calf survival and vulnerability to predation before the calf is born. Calf survival is highly correlated with the condition of the mother (Adamczewski *et al.* 1987; Cameron *et al.* 1993), the birth weight of the calf (Adamczewski *et al.* 1987), the environmental conditions experienced by pregnant females during the gestational period (Bergerud 1971; Russell *et al.* 1998), and the habitat used post-parturition because it may influence the probability of encounters with predators (Gustine *et al.* 2006; DeMars *et al.* 2011; Leclerc *et al.* 2012; Pinard *et al.* 2012). Stress, displacement, and chronic sensory disturbance have implications for reproductive success in caribou and other animals (Adamczewski *et al.* 1987; Wingfield 1988; Blas *et al.* 2007), and could cause females to give birth to small calves with a low probability of survival (Adamczewski *et al.* 1987; Parker *et al.* 2009). In disturbed landscapes, boreal caribou have been shown to calve at locations with low anthropogenic disturbance densities (Leclerc *et al.* 2012), and calf survival is thought to be related to adult female habitat selection post parturition to reduce potential overlap with predators (Leclerc *et al.* 2012; Pinard *et al.* 2012; DeMars 2015). The proximate cause of most boreal calf mortalities is predation (Bergerud & Page 1987; Gustine & Parker 2008; DeMars *et al.* 2013). In barren ground caribou (*R.t. groenlandicus* and *R.t. grantii*), the combined effect of physical and sensory disturbance from petroleum development was found to negatively impact calving success (Cameron *et al.* 1992, 2005; Nellemann & Cameron 1996). However, the relative influence of exposure of pregnant females to sensory disturbance, and selection of degraded habitat associated with anthropogenic disturbance by females pre-and post parturition has not been investigated, particularly for boreal populations where disturbance features within caribou range are more diffuse compared to barren ground caribou, and where long-term exposure to disturbance may be higher. Sensory disturbance and stress related to anthropogenic disturbance have been shown to influence reproductive success and neonate survival in both domestic and wild animals (Phillips & Alldredge 2000; Shively, Alldredge & Phillips 2005; Nowak & Poindron 2006; Sheriff *et al.* 2009). Sensory disturbance is linked to habitat selection (Phillips & Alldredge 2000), and thus sensory disturbance and habitat selection by pregnant females have the potential to influence the susceptibility of calves to predation, and so affect overall calf survival and ultimately, herd growth rates.

The differential response of boreal caribou to disturbance features has been investigated for several different disturbance types, age classes, and activity intensities (Dyer *et al.* 2002; Leclerc *et al.* 2012; Leblond *et al.* 2013; Hébert & Weladji 2013; Johnson *et al.* 2015). However, the direct (behaviour) and indirect (reproductive success) effects of human activity at oil and gas well sites during different stages of development, from construction, drilling, and production through to reclamation and abandonment on boreal caribou, is currently unknown. Oil and gas well sites are common within boreal caribou range and undergo dramatic changes in human traffic and activity throughout their lifespan (McKay *et al.* 2014). Research has revealed differential responses of mule deer (Sawyer *et al.* 2009) and grizzly bears (McKay *et al.* 2014) to well sites at different stages of activity. In barren ground caribou, oil field development within traditional calving grounds displaced parturient females (Cameron *et al.* 1992; Nellemann & Cameron 1998). The effects of adult female proximity to oil and gas development on the reproductive success of boreal caribou has not been assessed, and a greater understanding of how well site activity and regeneration stage influences the behaviour and reproductive success of boreal caribou could be used to inform caribou recovery and development planning. For example, further knowledge of the direct and indirect impacts of oil and gas development on boreal caribou could be used to mitigate the negative impacts of well sites on caribou in the future, and could also be used to maximize the efficiency and cost-effectiveness of restoration actions within boreal caribou ranges.

In this study, we investigated the response of boreal caribou from two herds in Alberta (Chinchaga and Little Smoky) to oil and gas well sites at different phases of activity during development. We considered three levels of human activity at well sites: high (well site construction, drilling, completions activities, and facility construction), medium (production), and low (abandoned, reclaimed). We examined the direct effects (behaviour) of well site activity and other anthropogenic features on caribou using resource selection functions at the 2nd and 3rd orders of selection (Johnson 1980). We also investigated the indirect effects of well site activity on caribou by estimating caribou parturition dates and calf survival in relation to the proximity of adult female caribou to well sites at different activity phases of development during the gestation, calving, and post calving periods. The overarching goal of this project was to contribute to caribou conservation and landscape management efforts by (i) providing guidance on areas that may be prioritized for restoration of caribou habitat based on the probability of use during the post-calving period, and (ii) contributing knowledge that can be used to mitigate impacts of future industrial development within boreal caribou ranges on caribou habitat use and reproductive success. Recovery efforts will be most effective if directed towards actions that yield quantifiable improvements in caribou habitat quality, survival, and reproductive success.

1.2 Project Objectives

This project addressed the following objectives across one year of research:

1. Determine how different levels of human activity at well sites influence the behaviour of caribou, and assess how changes in caribou behaviour vary seasonally and across different regions (west-central Alberta vs. north-western Alberta).
2. Evaluate calving success and habitat selection of caribou during the calving season in relation to the proximity and density of oil and gas developments and other disturbances in boreal caribou herds in west-central and north-western Alberta.
3. Evaluate whether 500m buffers (Environment Canada 2012) on well sites and pipelines accurately reflect caribou functional habitat when considering information on well site activity and re-vegetation stage of pipelines.
4. Synthesize findings to support decision making with respect to restoration and mitigation of disturbance features within caribou range and contribute to caribou recovery in west-central and north-western Alberta.

2. Methods

2.1 Study Area

The study area encompasses the range of the Little Smoky and Chinchaga caribou herds in west-central and north-western Alberta (Figures 2.1 and 2.2). These caribou 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* (Alberta Woodland Caribou Recovery Team 2005), the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002), and the Species at Risk Act (SARA; Environment Canada 2012). A federal recovery strategy for this ecotype was released in 2012 (Environment Canada 2012).

The habitat in the Little Smoky caribou range is characterized by upper and lower Foothills Natural Subregions with elevation ranging from 850-1500m above sea level (Figure 2.1). Topography consists of low foothills and muskeg lowlands while forests consist of lodgepole pine (*Pinus contorta*), white spruce (*Picea glauca*), and trembling aspen (*Populus tremuloides*) in upland areas, and black spruce (*Picea mariana*) and larch (*Larix laricina*) in lowland areas (Edmonds & Bloomfield 1984; Natural Regions Committee 2006). Lowland areas contain regions of poorly drained muskeg and treed fens (Semeniuk *et al.* 2012). There is a high diversity of ungulates in the area including moose, whitetail deer, mule deer (*O. humionus*), and elk (*Cervus elaphus*). Common predators in the area include wolves (*Canis lupus*), black bears (*Ursus americanus*), grizzly bears (*Ursus arctos*), coyotes (*Canis latrans*), wolverines (*Gulo gulo*), lynx (*Lynx canadensis*), and cougars (*Puma concolor*) (Edmonds & Bloomfield 1984).

The Chinchaga caribou range is characterized by upper and lower Boreal Highland Natural Subregions, with elevation ranging from 600-800m above sea level and relatively flat topography (Figure 2.2). Forests are characteristic of the boreal forest and consist of black spruce and larch in poorly drained muskeg and fen lowland areas, with white spruce, trembling aspen, and balsam poplar (*Populus balsamifera*) in upland areas (Natural Regions Committee 2006; Tigner, Bayne & Boutin 2014). Ungulate and predator diversity is similar to that of the Little Smoky range with the addition of wood bison (*Bison bison athabascae*) (Rowe 2007). The Chinchaga caribou range extends eastward into British Columbia with the Alberta portion making up approximately 50% of the total range area. This project considered only the Alberta portion of this range.

The Little Smoky and Chinchaga ranges have been extensively altered by anthropogenic activities associated with oil and gas exploration, forestry, and recreational activities. The federal recovery strategy estimates that 74% of the habitat in Chinchaga range and 94% of the habitat in Little Smoky range is disturbed by anthropogenic activities.

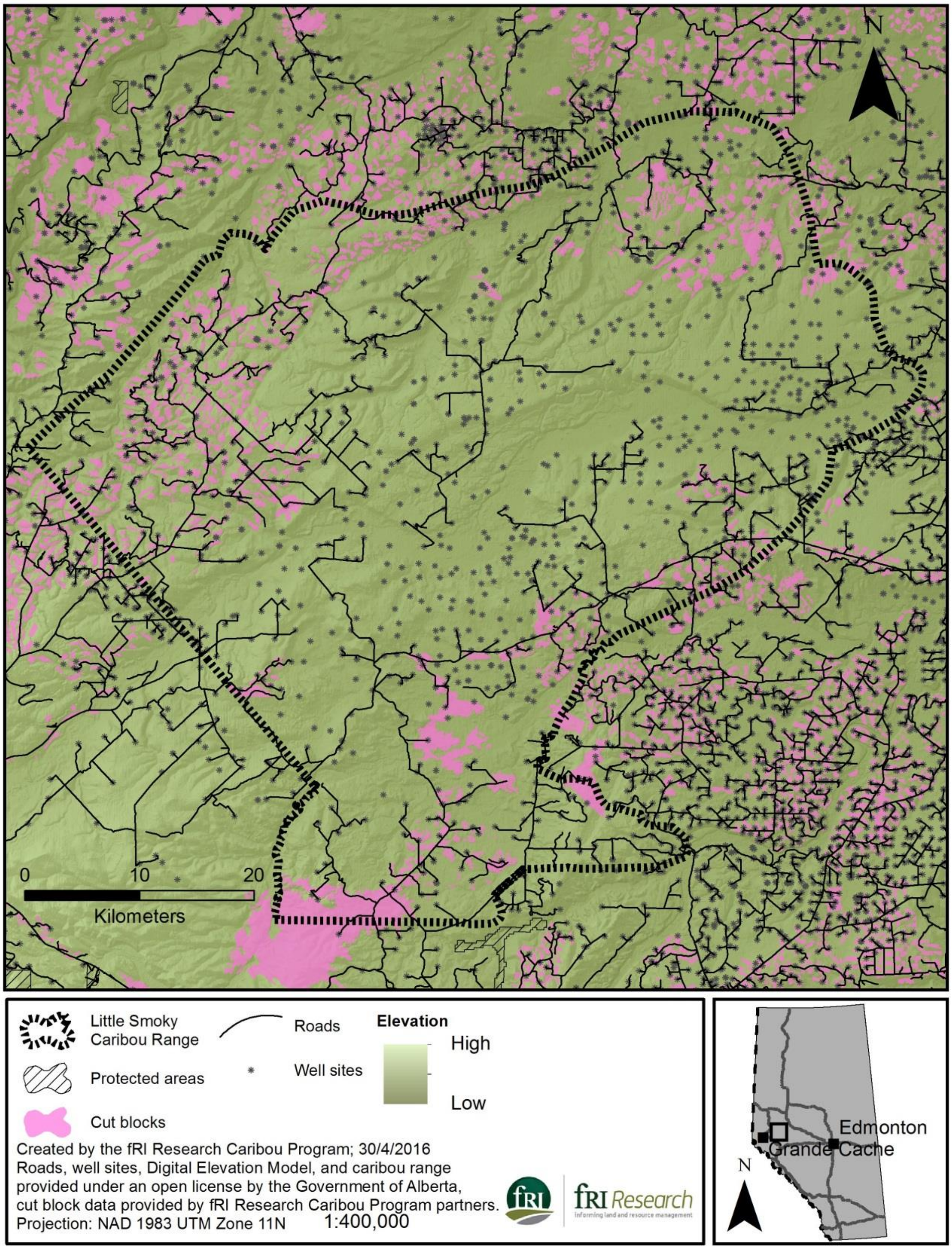

Figure 2.1. Study area map for the Little Smoky caribou range, west-central Alberta.

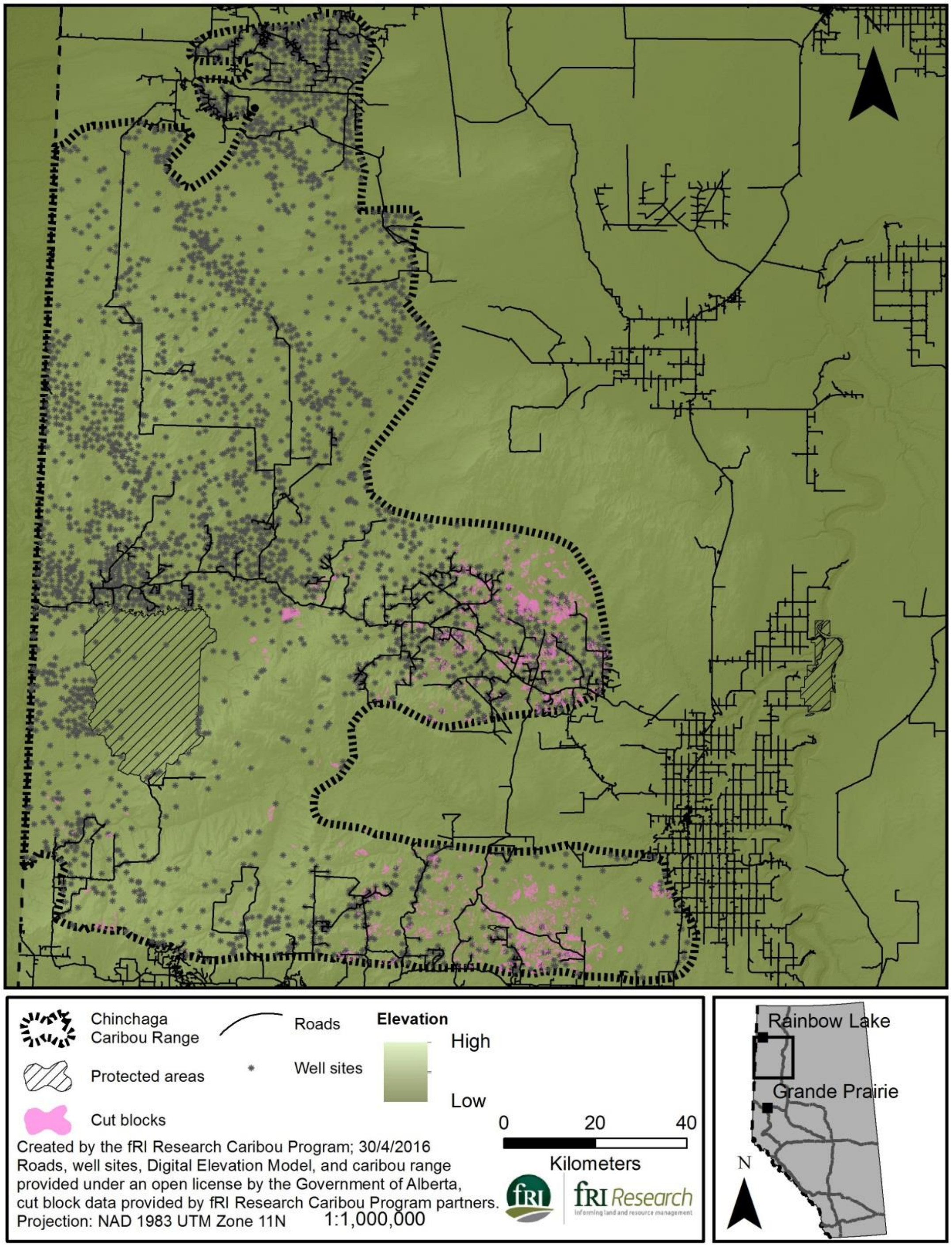

Figure 2.2. Study area map for the Chinchaga caribou range, north-western Alberta.

2.2 Animal Location Data

We used GPS telemetry data gathered from 62 adult female caribou (Chinchaga n = 18; Little Smoky n = 44) captured and fitted with Lotek 2200-3300 GPS telemetry collars between 1999 and 2015 (Lotek Engineering Systems, Newmarket, Ontario, Canada). Caribou were captured as part of ongoing monitoring by the government of Alberta; capture and handling protocols were approved under Alberta's Animal Care Protocol 008 (Hervieux *et al.* 2013). Between 1999 and 2015, collars were programmed to record positional fixes at varying intervals of once every 1, 2, or 4 hours resulting in 6-24 potential fixes per day per animal. We included a random effect for each animal-year to account for the variance in number of fixes used in the analysis, and individual differences in behaviour and availability of habitat (Gillies *et al.* 2006). We retained telemetry locations for analysis if the Horizontal Dilution of Precision was < 10, indicating a positional accuracy of 35m and reducing the chances of misidentifying environmental covariates (Dussault *et al.* 2001; Lewis *et al.* 2007). The final dataset consisted of 71,264 locations for Chinchaga caribou and 128,527 locations for Little Smoky caribou (Table 2.1).

Table 2.1. Sample size of GPS telemetry locations and the number of collared individuals by year for Chinchaga and Little Smoky caribou. A portion of the Little Smoky dataset was received after a significant delay from the time of data request; this data was not used for all analyses.

	Chinchaga		Little Smoky[1]		Little Smoky[2]	
	Locations	**Individuals**	**Locations**	**Individuals**	**Locations**	**Individuals**
Year	-	-	-	-		
1999	-	-	-	-	573	3
2000	-	-	-	-	4130	3
2001	-	-	-	-	3168	2
2002	-	-	-	-	11943	10
2003	-	-	-	-	16316	15
2004	-	-	-	-	18668	13
2005	-	-	-	-	8129	12
2006	-	-	-	-	740	2
2007	3718	5	16431	5	-	-
2008	25384	11	12179	5	-	-
2009	38489	11	5723	4	-	-
2010	3673	10	3092	2	-	-
2011	-	-	89	1	-	-
2014	-	-	18361	5	-	-
2015	-	-	8984	9	-	-
Total	71264	37	64859	31	63667	60

[1]Little Smoky data received Feb 2016; used for analysis of calving status and habitat selection.
[2]Little Smoky data received March 2016; used for analysis of calving status only.

2.3 Landscape variables

We investigated resource selection of Little Smoky and Chinchaga caribou within categories of attributes related to oil and gas well sites, other anthropogenic features, and landcover. Because our main objective was to investigate the effects of anthropogenic features, we did not consider topographic variables in this analysis. 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 start date (i.e. SPUD), a rig release date, and oil and gas production start and stop dates. From these dates we considered three levels of activity based on patterns in the intensity of activity during well site development: 1) high activity (30 days prior to SPUD date until 30 days after SPUD date), 2) medium activity (oil or gas production start date until production stop date), and 3) low activity (halt of production onwards). We assumed that the 30 day period before the SPUD date up until the rig release date encompassed the majority of high intensity activities such as well site construction and drilling (McKay *et al.* 2014; pers comm. J. Ezekiel 2016). For well sites that did not have a rig release date, we calculated the end of the high activity phase as 30 days after the SPUD date, consistent with McKay *et al.* (2014). We calculated the medium activity phase using the oil and gas production start and stop dates. After the halt of the producing phase, we considered well sites to be in a low activity phase meaning that they were abandoned, capped, or reclaimed.

We derived landcover variables from a combination of Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat imagery mapped at a 30m resolution (Franklin *et al.* 2002a; b; McDermid *et al.* 2009). We used spatial cut block data provided by Daishowa-Marubeni International Ltd. (DMI), Canadian Forest Products (Canfor), Tolko Industries Ltd, West Fraser Mills Ltd, and Alberta Newsprint Company. For seismic lines we used LiDAR to measure mean regeneration height along 100m segments within each herd range, and divided seismic lines into low, moderate, and high vegetation heights based on natural breaks in vegetation height (Little Smoky) or quantiles of vegetation height (Chinchaga) (Finnegan *et al.* 2014; Pigeon *et al.* 2016). We calculated the density of anthropogenic linear features (roads, truck trails, pipelines, and seismic lines), cut blocks (< 25 years old and > 25 years old), and all other anthropogenic features (well sites and facilities) for each year of animal data (2007-2010) using three sets of circular moving window averages with 70m, 500m, and 1km radii in ArcGIS 10.2 (Environmental Systems Research Institute (ESRI) 2015). We chose three radii based on previous research that showed that anthropogenic features can influence caribou behaviour from very small scales (i.e. < 70 m) up to 9 km (Schaefer & Mahoney 2007; DeCesare et al. 2012; Johnson et al. 2015). During model fitting for resource selection models, we chose the best fitting radii for each disturbance covariate according to Akaike's Information Criterion (AIC). We also created rasters representing the distance to the nearest anthropogenic disturbance feature by type and age (primary and secondary roads, seismic lines, pipelines <2 years old and > 2 years old, cut blocks < 25 years old and > 25 years old) to examine whether density or proximity of disturbance features best explained habitat selection by caribou. All covariates are further described in Table 2.2.

Table 2.2. Covariates used to describe habitat selection of caribou within Chinchaga and Little Smoky boreal herds in Alberta. AIC was used to determine the best fitting density of anthropogenic features at the 3rd order scale; 2nd order models considered only the 1km density of anthropogenic features.

Covariate	Description and units
Distance to well sites	
Dist_all	Distance to the nearest well site of any activity status (m)
Dist_lowact	Distance to the nearest well site with a status of low activity at the date of the telemetry location (m)
Dist_medact	Distance to the nearest well site with a status of medium activity at the date of the telemetry location (m)
Dist_highact	Distance to the nearest well site with a status of high activity at the date of the telemetry location (m)
Dist_medhighact	Distance to the nearest well site with a status of medium or high activity at the date of the telemetry location (m)
WellActivity	The activity status (low, medium, high, or medium/high) of the nearest well site (factor)
Density of anthropogenic disturbance	
S_A70 S_A500 S_A1k	Density of all seismic lines within a 70m, 500m, and 1km radius (km^2/km^2)
S_LV70 S_LV500 S_LV1k	Density of seismic lines with low vegetation height (Chinchaga <0.15m, Little Smoky < 1.5m) within a 70m, 500m, and 1km radius (km^2/km^2)
S_MV70 S_MV500 S_MV1k	Density of seismic lines with moderate vegetation height (Chinchaga 0.15 – 0.87m, Little Smoky 1.5 - 5m) within a 70m, 500m, and 1km radius (km/km^2)
S_HV70 S_HV500 S_HV1k	Density of seismic lines with high vegetation height (Chinchaga >0.87, Little Smoky >5m) seismic lines within a 70m, 500m, and 1km radius (km^2/km^2)
Lin70 Lin500 Lin1k	Density of linear features (roads, pipelines, seismic lines) within a 70m, 500m, and 1km radius (km^2/km^2)
A70 A500 A1k	Density of linear features (roads, pipelines, seismic lines) and well sites within a 70m, 500m, and 1km radius (km/km^2)
CB70 CB500 CB1k	Density of cut blocks < 25 years old within a 70m, 500m, and 1km radius (km^2/km^2)
CB_25_70 CB_25_500 CB_25_1k	Density of cut blocks > 25 years old within a 70m, 500m, and 1km radius (km/km^2)
ACB70 ACB500 ACB1k	Density of linear features (roads, pipelines, seismic lines), well sites and cut blocks within a 70m, 500m, and 1km radius (km^2/km^2)
Distance to anthropogenic disturbance	

CB_Y_dist	Distance to the nearest cut block < 25 years old (m)
CB_O_dist	Distance to the nearest cut block > 25 years old (m)
primRD_dist	Distance to the nearest primary road (m)
secRD_dist	Distance to the nearest secondary road (m)
newPL_dist	Distance to the nearest pipeline < 2 years old (m)
oldPL_dist	Distance to the nearest pipeline > 2 years old (m)
LS_dist	Distance to the nearest seismic line with low vegetation height (m)
MS_dist	Distance to the nearest seismic line with moderate vegetation height (m)
HS_dist	Distance to the nearest seismic line with high vegetation height (m)
Landcover	
Conif_Den	30m pixels with presence of moderate and dense canopy conifer forest (>80% conifer and > 70% canopy closure; 0 - 1)
Conif_Mod	30m pixels with presence of moderate and dense canopy conifer forest (>80% conifer and 30-70% canopy closure; 0 - 1)
Conif_Open	30m pixels with presence of open canopy conifer forest (>80% conifer and < 30 % canopy closure; 0 - 1)
Mixed	30m pixels with presence of mixed wood forest (21-79% conifer; 0 - 1)
Decid	30m pixels with presence of deciduous forest (<20% conifer ; 0 - 1)
Wetland_Treed	30m pixels with presence of treed wetland (>5% trees and wet moisture regime; 0 - 1)
Wetland_OpenBarrHerb	30m pixels with presence of open wetland (<5% trees and wet moisture regime), barren (<5% vegetated), or herbaceous landcover (0 - 1)
Shrub	30m pixels with presence of shrub (>5% shrub and any moisture regime; 0 - 1)
Random effect	
Animal_ID_YR	Individual animal ID GPS locations partitioned by year of collection

2.4 Estimating calving events, calf survival, and calf site selection

2.4.1 Calving events and calf survival

We used the individual based method (IBM) of DeMars *et al.* (2013) to estimate the timing and location of calving and calf loss events from the GPS telemetry data locations of female caribou. The IBM analyzes female movement rates, specifically mean step lengths, for sudden reductions (i.e. a break point) from normal movement patterns. The IBM method identifies these break points using three *a-priori* movement models representing the three states of females during the calving season: (M0) did not calve, (M1) calved and calf survived to 4 weeks, and (M2) calved with subsequent calf loss prior to 4 weeks. Step lengths are assumed to be exponentially distributed; therefore the scale parameter (interpreted as the step length) differs for each model. For female caribou that do not calve, the scale parameter (b0) of M0 remains constant over time (i.e. no difference in step length). In contrast, for females that do calve (M1 and M2) the scale parameter (b1 and b2) drops abruptly at calving from its pre-calving constant, at which point a break point in step length is identified (BP1). When a calf survives (M1), the scale parameter linearly increases until the pre-calving movement rate is reached. However, if the calf is lost (M2) there is an abrupt shift back to the pre-calving movement rate creating a second break point (BP2). IBM model parameters are calculated using maximum likelihood estimation (further details regarding IBM are available in the Supplementary Material of DeMars *et al.* 2013). We evaluated models M0, M1, and M2 using AIC where the best model is the one with the lowest AIC score (Burnham & Anderson 2002). Break points are linked to particular GPS records that are used to identify the timing and location of calving and calf loss events for female caribou predicted to have calved.

Prior to inclusion in the IBM analysis, we limited GPS telemetry locations to the period between April 15 and July 15 (pre/post calving season) and converted each individual dataset into a time-series using the 'adehabitatLT' package (Calenge 2006) in R version 2.13 (R Development Core Team 2015). Because GPS locations are rarely recorded at exact times, we allowed a deviation of one tenth of the time interval (i.e. 36 minutes for 6 hour fix interval). We assigned missing GPS fixes a N/A value, calculated step lengths from successive GPS locations, and removed the top 1% of step lengths from the time series to account for outliers in step length that occur at the beginning and end of the time series. To estimate calving events and subsequent estimates of survival, we only included GPS collars with a fix success rate >70% during the period of interest. A >70% success rate corresponds to 97% accuracy for detecting calving events and ~80% accuracy for detecting survival (DeMars *et al.* 2013).

2.4.2 Calving site selection

To provide insight into the site characteristics used by caribou during calving, we evaluated habitat characteristics at calf sites in relation to the available habitat. Because the IBM method does not provide a precise calving location due to the time intervals between fixes, we assumed that all GPS telemetry locations collected on the date of parturition within a 200m radius of the closest fix to parturition (from IBM) represented the calf site. We sampled 200 random locations from each individual's home range defined as the minimum convex polygon (MCP) enclosing all GPS telemetry locations during the calving season. We extracted habitat covariates (landcover, density, and proximity to disturbance; see Table 2.2), and compared habitat covariates at used telemetry locations to habitat covariates at the randomly sampled sites using generalized linear mixed models (GLMM) with Animal ID-year specified as a random effect to account for individual-based correlation and unbalanced sample sizes resulting from variable fix rates between individuals (Gillies *et al.* 2006; Bolker *et al.* 2009; Fieberg *et al.* 2010). We fit models using the R package 'lme4' (Bates *et al.* 2014) in R version 2.13 (R Development Core Team 2015).

2.5 Habitat selection by adult female caribou

2.5.1 Delineating caribou seasons

To account for changes in the spatial distribution and behaviour of caribou throughout the year related to the seasonal importance of different resources, we defined seasons using an individual-based recursive partitioning method that identifies seasonal onset dates (i.e. transition dates between seasons) based on inflection points in daily movement rates (Rudolph & Drapeau 2012). Recursive partitioning is an objective method to evaluate the modal pattern of movement rates while accounting for variation between individuals (Rudolph & Drapeau 2012). Movement patterns provide a biologically relevant link to seasonality, and transition periods are identifiable through temporarily elevated movement rates that indicate movement between seasonal ranges as opposed to smaller, within-range movements (Ferguson & Elkie 2004). We calculated daily movement rates for each individual using a rarefied dataset (location closest to noon per day) to account for differences in fix rate between individuals. Movement rates were calculated only when data from consecutive days were available, and only for individuals with > 50 locations in a given year. We smoothed movement rates using a 5 day moving window average to remove small fluctuations in movement rates that might interfere with the detection of larger movements between seasonal ranges (Basille *et al.* 2013). We determined onset dates for each individual and season based on inflection points in the daily movement rates, and defined the population onset date for each season as the average of the individual onset dates around which individual onset dates were normally distributed. When no inflection point was clearly detected by recursive partitioning for a given individual and season, we excluded that individual from the calculation of the population onset date.

2.5.2 Adult female habitat selection

We used GLMMs to assess habitat selection of boreal caribou in the Chinchaga and Little Smoky herds using the R package 'lme4' (Bates et al. 2014). We assessed selection at the 2nd and 3rd order scales (Johnson 1980) to account for the response of animals to environmental covariates at multiple spatial scales (Johnson *et al.* 2002). At the 2nd order scale (selection of the home range on the landscape), we compared "used" caribou GPS telemetry locations to randomly sampled "available" locations within the population range, and at the 3rd order scale (selection of habitat within the home range), we compared used locations to available locations within each individual home range defined as minimum convex polygons (MCP). We generated 10 available locations per used location to ensure that model coefficients were consistently stable (Northrup *et al.* 2013). To facilitate model interpretation and reduce computing time, we generated separate models per herd and season (spring, summer, fall, early winter, and late winter; see Results). For each used and available location, we extracted density and proximity of anthropogenic disturbance and landcover variable using each year to temporally match habitat covariates to animal locations. We also calculated the distance to the nearest well site and extracted the corresponding activity level. To extract the activity level of well sites to available locations, we assigned a random date to each available location from within the time period spanned by each individual-year-season. We assessed correlation among explanatory covariates and chose to remove any one of 2 variables correlated at ≥ 0.5, and because moderate collinearity can be problematic when investigating ecological signals, we removed any covariates with a variance inflation factor > 3 (Zuur, Ieno & Elphick 2010).

Our objective was to optimize model fit rather than test competing hypotheses, we therefore first assessed resource selection within each category of covariates (Landcover, Distance to Well Sites, Density of Anthropogenic Disturbance, and Distance to Anthropogenic Disturbance) for each of the 6 seasons and used the drop1 function in the R package 'stats' to retain only influential covariates within each of the categories of attributes (R Development Core Team 2015). We used the information-theoretic approach with Akaike's Information Criterion (AIC) within drop1 to assess variables (Burnham & Anderson 2002). Once all influential covariates were retained within each category of attributes, we fit a global model that included covariates identified within each category of attributes for each season. We followed the principle of parsimony and used drop1 a final time to remove any non-influential covariate from the global model for each season (Burnham & Anderson 2002). We standardized all continuous covariates to improve model convergence, and ranked selection as log odds, where positive values indicate that a landscape attribute is selected more than expected from random chance alone, while negative values indicate selection below what would be expected. We carried out all statistical analyses and data exploration in RStudio using R statistical software (RStudio 2012; R Development Core Team 2015).

To determine whether a 500m buffer on well sites accurately reflects their influence on caribou behaviour during different phases of development, we applied piecewise regression to the predicted response curves for well sites in different phases of development from the 3rd order habitat selection models. This approach provides a statistical analysis of distances to well sites where there is a change in the response of caribou selection.

2.5.3 Relationship between calving status and adult female habitat selection

To determine whether exposure of pregnant female caribou to oil and gas well sites and overall anthropogenic disturbance density during gestation were correlated with calf survival, we built four binomial mixed models for each season preceding calving with contrasts in reproductive success of individual caribou as the response variable (1: did not calve vs. calved; 2: did not calve vs. calf survived; 3: did not calve vs. calf died; 4: calf died vs. calf survived). We used the average distance to the nearest well site of each activity level and the density of anthropogenic disturbance at each GPS telemetry location as explanatory variables. We included a random effect for Animal ID-year to account for differences in sample size and available habitat between individuals (Gillies *et al.* 2006) and carried out analysis within the R package 'lme4' (Bates *et al.* 2014).

3. Results

3.1 Estimating calving events and calf survival

Our final data set included 23 individual-year combinations within the Chinchaga caribou range, and 59 individual-year combinations within Little Smoky caribou range. Using the IBM method, we estimated 14 no-calving events (Chinchaga n = 3; Little Smoky n = 11), 33 calving events where the calf lived to 4 weeks post parturition (Chinchaga n = 11; Little Smoky n = 22), and 36 calving events where the calf was lost before 4 weeks post parturition (Chinchaga n = 9; Little Smoky n = 25; Tables 3.1, 3.2, 3.3). Calving events occurred from April 25 to June 8, and calf loss events occurred between 2 and 30 days post parturition (Tables 3.1 and 3.2). An example of the movement patterns and AIC for models M0, M1, and M2 identified by the IBM method for each caribou can be found in Appendix 1.

Table 3.1. Calving status (did not calve, calved and calf survived, or calved and calf died), estimated date and time, and the percentage of fixes that were successful (Fix Success) for individual caribou (AID) within in the Chinchaga caribou range as determined by individual based modeling.

Year	AID	Fix Success	Status	Calving Date/Time	Calf Lost Date/Time
2007	C1234	0.93	Calved; calf died	5/15/2007 12:00	6/14/2007 8:00
2007	C1235	0.80	Calved; calf died	5/9/2007 10:00	5/17/2007 4:00
2007	C1236	0.97	Did not calve		
2007	C1237	0.96	Did not calve		
2007	C1238	0.96	Calved; calf died	5/18/2007 15:00	6/1/2007 7:00
2008	C1224	0.96	Calved; calf died	5/24/2008 22:00	6/6/2008 2:00
2008	C1225	0.97	Calved; calf died	5/10/2008 14:00	5/14/2008 4:00
2008	C1226	0.91	Calved; calf died	4/25/2008 6:00	5/3/2008 2:00
2008	C1228	0.95	Calved; calf died	6/1/2008 12:00	6/6/2008 16:00
2008	C1229	0.96	Calved; calf died	5/26/2008 10:00	5/30/2008 16:00
2008	C1230	0.95	Calved; calf survived	5/28/2008 22:00	
2008	C1233	0.95	Calved; calf died	5/8/2008 10:00	6/3/2008 4:00
2008	C1234	0.81	Calved; calf survived	5/6/2008 20:01	
2009	C1224	0.95	Calved; calf survived	5/12/2009 6:00	
2009	C1225	0.95	Calved; calf survived	5/7/2009 22:00	
2009	C1226	0.95	Calved; calf survived	5/12/2009 12:00	
2009	C1228	0.95	Calved; calf survived	5/14/2009 22:00	
2009	C1229	0.97	Did not calve		
2009	C1230	0.94	Calved; calf survived	5/11/2009 22:00	
2009	C1233	0.94	Calved; calf survived	5/4/2009 0:00	
2009	C1520	0.90	Calved; calf survived	5/17/2009 0:01	
2009	C1521	0.95	Calved; calf survived	5/13/2009 20:00	
2009	C1522	0.93	Calved; calf survived	5/14/2009 6:00	

Table 3.2. Calving status (did not calve, calved and calf survived, or calved and calf died), estimated date and time, and the percentage of fixes that were successful (Fix Success) for individual caribou (AID) in the Little Smoky caribou range as determined by individual based modeling.

Year	AID	Fix Success	Status	Calving Date/Time	Calf Lost Date/Time
2000	C963	0.75	Calved; calf died	5/23/2000 0:01	6/10/2000 0:01
2000	C966	0.65	Calved; calf died	5/19/2000 16:00	5/25/2000 8:00
2001	C966	0.85	Calved; calf died	5/24/2001 4:00	6/5/2001 12:00
2002	C984	0.86	Calved; calf died	5/22/2002 12:00	6/3/2002 20:00
2002	C989	0.89	Did not calve		
2002	C990	0.66	Calved; calf died	5/23/2002 12:01	6/13/2002 8:01
2002	C992	0.76	Calved; calf died	5/22/2002 12:00	6/2/2002 8:00
2002	C994	0.71	Did not calve		
2002	C995	0.74	Calved; calf died	6/8/2002 20:00	7/1/2002
2002	C996	0.55	Calved; calf died	5/27/2002 12:00	6/3/2002 8:00
2003	C1009	0.76	Calved; calf died	5/20/2003 12:02	5/30/2003 6:02
2003	C1010	0.61	Calved; calf died	5/21/2003 8:00	6/4/2003 4:00
2003	C1011	0.87	Calved; calf survived	5/23/2003 6:00	
2003	C1012	0.88	Calved; calf died	5/20/2003 4:00	5/24/2003 20:00
2003	C1017	0.82	Calved; calf survived	5/26/2003 6:01	
2003	C992	0.78	Did not calve		
2004	C1009	0.72	Calved; calf died	5/22/2004 12:00	5/25/2004 8:00
2004	C1010	0.66	Calved; calf survived	5/30/2004 12:00	
2004	C1012	0.87	Calved; calf died	5/12/2004 12:00	5/22/2004 16:00
2004	C1017	0.78	Calved; calf survived	5/13/2004 6:01	
2004	C1019	0.87	Calved; calf survived	5/25/2004 16:00	
2004	C1022	0.89	Calved; calf survived	5/27/2004 8:00	
2004	C1023	0.85	Calved; calf died	5/27/2004 12:00	6/5/2004
2004	C1026	0.79	Calved; calf survived	5/22/2004 12:00	
2004	C1027	0.66	Calved; calf survived	5/27/2004 12:01	
2005	C1015	0.88	Calved; calf survived	5/14/2005 20:00	
2005	C1024	0.73	Calved; calf survived	5/17/2005 20:00	
2005	C1034	0.71	Calved; calf survived	5/22/2005 4:01	
2005	C1035	0.60	Did not calve		
2005	C960	0.87	Calved; calf survived	5/9/2005 20:00	
2005	C964	0.60	Calved; calf died	5/25/2005 0:01	6/4/2005 0:01
2007	C1089	0.89	Did not calve		
2007	C1090	0.87	Calved; calf survived^	5/15/2007 22:01	
2007	C1091	0.88	Calved; calf survived	5/29/2007 8:01	
2007	C1092	0.88	Did not calve		
2007	C1093	0.94	Calved; calf died	5/20/2007 8:00	6/2/2007 16:00
2008	C1089	0.88	Calved; calf died*	5/19/2008 12:01	5/28/2008 6:01

2008	C1091	0.89	Did not calve		
2008	C1092	0.93	Did not calve		
2008	C1353	0.89	Calved; calf survived	5/23/2008 20:03	
2009	C1089	0.9	Calved; calf survived	5/30/2009 21:04	
2009	C1516	0.94	Calved; calf died	5/24/2009 21:03	6/7/2009 17:03
2009	C1524	0.89	Calved; calf survived	6/3/2009 1:03	
2010	C1089	0.86	Calved; calf died	5/25/2010 5:03	6/27/2010 17:03
2010	C1516	0.89	Calved; calf survived	5/19/2010 1:03	
2014	C2187	0.97	Calved; calf survived	5/20/2014 8:00	
2014	C2188	0.97	Calved; calf died	5/27/2014 2:00	5/31/2014 18:00
2014	C2189	0.98	Calved; calf died	5/24/2014 16:00	5/28/2014 6:00
2014	C2190	0.98	Calved; calf died	5/30/2014 4:00	6/5/2014 6:00
2014	C2191	0.98	Calved; calf survived	5/17/2014 18:00	
2015	C2187	0.97	Calved; calf survived	5/12/2015 16:00	
2015	C2188	0.97	Did not calve		
2015	C2189	0.99	Calved; calf survived	5/18/2015 12:00	
2015	C2190	0.98	Did not calve		
2015	C2191	0.98	Calved; calf died	5/25/2015 20:00	5/31/2015 20:00
2015	C2240	0.98	Did not calve		
2015	C2241	0.98	Calved; calf died	5/10/2015 6:00	5/29/2015 20:00
2015	C2242	0.99	Calved; calf died	5/15/2015 18:00	6/6/2015 2:00
2015	C964		Did not calve[+]		

^AIC chose M0, however a visual inspection of the movement pattern suggests that this animal calved and that the calf survived to 4 weeks post parturition. Poor model performance possibly due to low overall variation in movement rate.
*AIC chose M0, however a visual inspection of the movement pattern suggests that this animal calved and subsequently lost the calf. Poor model performance possibly due to low overall variation in movement rate.
[+]This animal died in early June 2015, during necropsy it was determined that she had not been pregnant and had not calved.

Table 3.3. Summary of calving status (number of individuals and proportion of sample population) for Chinchaga and Little Smoky caribou herds between 1999 and 2015.

	Chinchaga		Little Smoky	
Calving status	N	Proportion	N	Proportion
Did not calve	3	0.13	11	0.19
Calved; calf died	9	0.39	25	0.43
Calved; calf survived	11	0.48	22	0.38
Total	**23**		**58**	

3.2 Calving site selection

Caribou selected calving sites that were farther from well sites of all activity phases compared to a random distribution (Table 3.4). Landcover at calving sites in the Chinchaga range were predominantly treed wetland and shrub habitats, while calving sites in the Little Smoky range were predominantly moderate and dense canopy conifer forests (Table 3.5). For calving sites, deciduous forests were selected less than expected from a random distribution in the Chinchaga range, while landcover at calving sites in the Little Smoky range was highly variable and was not different from the habitat available when compared to a random distribution. Little Smoky caribou selected calving sites that were close to cut blocks but that were also in areas with lower densities of anthropogenic features. Chinchaga caribou selected calving sites that were far from cut blocks < 25 years old but also selected areas with higher densities of seismic lines with low vegetation heights and anthropogenic disturbances compared to a random distribution. A comparison of the relative density and proximity to anthropogenic features for used and available calving sites in the Chinchaga and Little Smoky ranges revealed that the average distance to cut blocks of Chinchaga calving sites was an order of magnitude greater than that of the Little Smoky calving sites (Table 3.5). In addition, although the density of seismic lines with low vegetation heights and the density of anthropogenic disturbance at calving sites were similar between the Chinchaga and Little Smoky caribou ranges, the density of seismic lines with low vegetation heights, and the density of anthropogenic disturbances at available locations in the Chinchaga range, were half those of the available locations in the Little Smoky range (Table 3.5).

Table 3.4. Standardized model coefficients (β) and standard errors (SE) describing 3rd order calf site selection for Chinchaga and Little Smoky caribou on the parturition date for each calving individual. Covariates are described in Table 2.2. Significant variables are in bold.

	Chinchaga		Little Smoky	
	β	**SE**	**β**	**SE**
Intercept	**-3.10**	**0.76**	**-3.68**	**0.34**
Dist_highact	-	-	**0.53**	**0.15**
Dist_medact	**0.36**	**0.10**	0.19	0.14
Dist_lowact	**0.31**	**0.08**	**0.25**	**0.11**
CB_Y_dist	**0.35**	**0.14**	**-0.77**	**0.18**
CB_O_dist	-	-	**-1.33**	**0.27**
AA_1k	**0.38**	**0.10**	**-1.10**	**0.17**
LS_1k	**0.68**	**0.08**	-	-
HS_1k	**-0.68**	**0.16**	-	-
Lcov_Conif_Den	-	-	0.07	0.24
Lcov_Conif_Open	-	-	1.31	0.85
Lcov_Conif_Mod	-1.12	0.82	-	-
Lcov_Mixed	-1.71	0.91	-0.04	0.29
Lcov_Decid	**-2.61**	**1.27**	-	-
Lcov_Wetland_OpenHerbBarr	-1.77	1.27	-0.10	0.33
Lcov_Wetland_Tree	-0.12	0.76	-0.25	0.36
Lcov_Shrub	0.20	0.76	-1.14	0.75

Table 3.5. Habitat attributes for calving sites and randomly sampled available locations within individual MCP home ranges (3rd order) selection for Chinchaga and Little Smoky caribou on the parturition date for each calving individual. Covariates are described in Table 2.2.

	Chinchaga		Little Smoky	
	Calf site	Available	Calf site	Available
Landcover (proportion)				
Shrub	0.35	0.17	0.01	0.04
Wetland_Tree	0.55	0.37	0.07	0.09
Wetland_Open	-	0.01	0.05	0.05
Conif_Mod	0.05	0.01	0.45	0.40
Conif_Open	0.01	0.02	0.01	0.003
Conif_Den	-	0.01	0.20	0.19
Mixed	0.02	0.16	0.11	0.11
Decid	0.01	0.10	0.03	0.04
Barren	-	0.001	0.04	0.05
Distance to anthropogenic disturbance (km; mean ± SD)				
Dist_highact	-	-	23.26 ± 10.16	23.28 ± 11.11
Dist_medact	5.93 ± 4.70	4.87 ± 3.80	2.90 ± 1.43	2.67 ± 1.67
Dist_lowact	1.92 ± 1.34	1.59 ± 1.01	1.65 ± 0.67	1.30 ± 0.70
primRD_dist	14.11 ± 9.74	17.08 ± 9.87	3.74 ± 2.01	3.36 ± 2.31
secRD_dist	4.63 ± 4.07	5.86 ± 4.96	1.03 ± 0.68	0.73 ± 0.56
CB_Y_dist	30.07 ± 19.28	27.64 ± 18.76	3.46 ± 2.76	3.90 ± 3.14
CB_O_dist	40.45 ± 22.43	41.39 ± 26.43	18.69 ± 12.53	21.22 ± 12.43
newPL_dist	7.81 ± 3.15	6.62 ± 4.35	8.66 ± 3.61	8.72 ± 4.92
oldPL_dist	4.12 ± 4.06	4.17 ± 4.09	3.39 ± 1.69	2.81 ± 2.17
Density of anthropogenic disturbance (km^2/km^2; mean ± SD)				
AA_1k	0.01 ± 0.01	0.01 ± 0.02	0.01 ± 0.01	0.02 ± 0.02
LS_1k	0.09 ± 0.04	0.05 ± 0.04	0.09 ± 0.03	0.09 ± 0.03
HS_1k	0.02 ± 0.02	0.03 ± 0.03	0.001 ± 0.002	0.001 ± 0.003

3.2 Adult female habitat selection

3.2.1 Caribou seasons

In each of the Chinchaga and Little Smoky herds, we identified five distinct seasons from inflection points in movement rates (spring, summer, fall, early winter, and late winter). Onset dates for seasons were normally distributed between individuals and we thus calculated a population level onset date for all seasons as the average of all individual onset dates (Table 3.6). We defined a sixth season (calving/post calving) using the earliest and latest estimated parturition dates of female caribou plus the 4 weeks following the last calving date (Table 3.6).

Table 3.6. Seasonal periods identified using inflection points in movement rates (spring, summer, fall, early winter, and late winter) and estimates of parturition dates (calving) for Chinchaga and Little Smoky caribou.

	Spring	Calving/post calving	Summer	Fall	Early winter	Late winter
Chinchaga	Apr 9 – Apr 24	Apr 25 –Jul 1	Jul 2 –Sept 24	Sept 25 – Nov 6	Nov 7 – Jan 28	Jan 29 – Apr 8
Little Smoky	Apr 11 – May 9	May 10 – Jul 1	Jul 2 – Sept 19	Sept 20 – Dec 3	Dec 4 – Jan 23	Jan 24 – Apr 10

3.2.2 Second order habitat selection

3.2.2.1 Chinchaga

At the 2nd order scale (placement of the home range on the landscape), caribou in the Chinchaga range selected habitat farther from medium and high activity well sites compared to a random distribution during all seasons except spring. Caribou selected areas closer to low activity well sites compared to random during calving and summer, but selected areas farther from low activity well sites compared to random during spring and early winter. Models including distance to well sites improved model parsimony for all seasons. During all seasons except early winter, models grouping well sites that were in the medium and high activity phases into one “medium/high” phase fit better than models separating the medium and high activity phases. During early winter there were more well sites in the high activity phase than during any other season, and the model separating well sites into medium and high activity phases fit best for this season.

Chinchaga caribou selected areas farther from cut blocks and selected areas with a lower density of anthropogenic disturbance and cut blocks in all seasons (Table 3.7). During spring, summer, and late winter, distance to seismic lines explained caribou habitat selection better than density of seismic lines, however during calving and fall, the opposite was true (Table 3.7). During spring, summer, and fall, caribou selected areas closer to seismic lines with low vegetation height but farther from seismic lines with high vegetation height. Covariates describing density and distance to seismic lines with moderate vegetation height were positively correlated with covariates describing seismic lines with high vegetation height, and negatively correlated with seismic lines with low vegetation height. Therefore, we excluded seismic lines with moderate vegetation height from 2nd order models. In addition, distance to cut blocks < 25 years old was positively correlated with distance to cut blocks > 25 years old, therefore only distance to cut blocks > 25 years old (the more parsimonious of the two variables) was considered within habitat selection models.

Inclusion of landcover improved model parsimony for all seasons except spring, and treed wetlands and shrub were selected in all seasons. Deciduous and mixed wood forests were selected less than random in all seasons, and open wetland, barren, and herb habitat was selected less than random during calving, summer, and late winter, but were selected more than random during the fall. Open canopy conifer forest was used as the reference category for 2nd order habitat selection models in the Chinchaga range.

Table 3.7. Standardized model coefficients (β) and standard errors (SE) describing 2nd order habitat selection for Chinchaga caribou during spring, calving, summer, fall, early winter, and late winter. Covariates are described in Table 2.2. Variables for which selection was statistically different from random are shown in bold. The reference category for Landcover was Open Canopy Conifer.

	Spring		Calving		Summer		Fall		Ewin		Lwin	
	β	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**
Intercept	**-2.73**	**0.09**	**-3.34**	**0.16**	**-2.85**	**0.09**	**-3.94**	**0.18**	**-3.61**	**0.07**	**-3.58**	**0.12**
Dist_highact	-	-	-	-	-	-	-	-	**0.37**	**0.01**	-	-
Dist_medact	-	-	-	-	-	-	-	-	**-0.94**	**0.02**	-	-
Dist_medhighact	**-0.31**	**0.03**	**0.16**	**0.01**	**0.39**	**0.01**	**0.24**	**0.01**	-	-	**0.03**	**0.013**
Dist_lowact	**0.32**	**0.02**	**-0.23**	**0.01**	**-0.29**	**0.01**	-0.02	0.01	**0.13**	**0.01**	0.01	0.01
primRD_dist	-	-	-	-	-	-	-	-	**0.81**	**0.01**	-	-
secRD_dist	-	-	-	-	-	-	**-0.70**	**0.01**	**0.10**	**0.01**	**0.38**	**0.01**
CB_O_dist	**0.68**	**0.02**	-	-	**0.25**	**0.01**	-	-	-	-	**0.73**	**0.01**
LS_dist	**-0.43**	**0.02**	-	-	**-0.35**	**0.01**	-	-	-	-	**-0.43**	**0.02**
HS_dist	**0.23**	**0.02**	-	-	**0.53**	**0.01**	-	-	-	-	**0.10**	**0.01**
AA_CB_1k	-	-	-	-	-	-	-	-	**-0.46**	**0.03**	-	-
AA_1k	-	-	**-0.68**	**0.02**	**-0.54**	**0.02**	**-0.14**	**0.01**	-	-	-	-
CB_Y_1k	-	-	**-0.96**	**0.05**	-	-	**-1.19**	**0.06**	-	-	-	-
CB_O_1k	-	-	**-0.89**	**0.15**	-	-	-	-	-	-	-	-
LS_1k	-	-	-	-	-	-	**0.20**	**0.01**	-	-	-	-
HS_1k	-	-	**-1.11**	**0.02**	-	-	**-0.57**	**0.02**	-	-	-	-
Lcov_Conif_ModDen	-	-	-	-	**0.17**	**0.08**	-	-	-	-	**0.69**	**0.04**
Lcov_Mixed	-	-	**-0.52**	**0.04**	**-0.71**	**0.08**	0.09	0.05	**-0.40**	**0.05**	-	-
Lcov_Decid	-	-	**-1.85**	**0.08**	**-2.33**	**0.12**	**-0.56**	**0.07**	**-1.68**	**0.10**	**-1.59**	**0.09**
Lcov_Wetland_OpenHerbBarr	-	-	**-1.48**	**0.12**	**-2.01**	**0.16**	**0.54**	**0.08**	-	-	**-0.87**	**0.10**
Lcov_Wetland_Tree	-	-	**0.61**	**0.03**	**0.79**	**0.08**	**1.10**	**0.04**	**1.06**	**0.04**	**1.28**	**0.03**
Lcov_Shrub	-	-	**0.48**	**0.03**	**0.49**	**0.08**	**1.82**	**0.04**	**1.61**	**0.04**	**1.02**	**0.04**

3.2.2.2 Little Smoky

At the 2nd order scale, caribou in the Little Smoky range selected areas farther from well sites of all activity phases compared to a random distribution during all seasons (Table 3.8). Inclusion of distance to well sites improved model parsimony during all seasons. Well sites in the high activity phase were present during all seasons except summer. The response to specific well site activity phases was variable between seasons, however caribou selected areas farther from well sites in the high activity phases during late winter, spring, calving, and summer, and selected areas farther from medium and high activity well sites during fall. During all seasons except spring, caribou selected areas farther from low activity well sites compared to a random distribution. Caribou selected areas closer than random to high activity well sites during early winter (Table 3.8).

Little Smoky caribou selected areas farther than random from cut blocks and roads during all seasons except late winter. During late winter, caribou selected areas closer than random to primary roads. Caribou selected areas with lower densities of seismic lines regardless of the vegetation height during all seasons except early winter when caribou selected areas with a higher density of seismic lines with low vegetation height.

Inclusion of landcover improved model parsimony for all seasons, and Little Smoky caribou selected treed and open wetlands and moderate/open conifer forest during all seasons. Caribou selected dense conifer in all seasons less than random. Caribou selected mixed wood forest and shrub habitat less than random during calving and summer, but more than random during early winter. Deciduous forest was used as the reference category for 2nd order habitat selection models for the Little Smoky range.

Table 3.8. Standardized model coefficients (β) and standard errors (SE) describing 2nd order habitat selection for Little Smoky caribou during spring, calving, summer, fall, early winter, and late winter. Covariates are described in Table 2.2. Variables for which selection was statistically different from random are shown in bold. The reference category for landcover was deciduous forest.

	Spring		Calving		Summer		Fall		Ewin		Lwin	
	β	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**
Intercept	**-3.06**	**0.18**	**-2.51**	**0.04**	**-2.39**	**0.05**	**-3.22**	**0.13**	**-3.62**	**0.31**	**-3.09**	**0.20**
Dist_highact	**0.13**	**0.02**	**0.31**	**0.01**	**0.11**	**0.01**	-	-	**-0.99**	**0.02**	**0.07**	**0.01**
Dist_medact	**0.16**	**0.02**	**-0.30**	**0.01**	**-0.11**	**0.01**	-	-	**0.46**	**0.02**	**-0.19**	**0.01**
Dist_medhighact	-	-	-	-	-	-	**0.07**	**0.01**	-	-	-	-
Dist_lowact	**-0.11**	**0.02**	**0.19**	**0.01**	**0.26**	**0.01**	**0.14**	**0.01**	**0.20**	**0.01**	**0.09**	**0.01**
primRD_dist	-	-	-	-	**0.05**	**0.01**	**0.61**	**0.01**	**0.19**	**0.02**	**-0.30**	**0.01**
secRD_dist	**0.04**	**0.02**	-	-	-	-	-	-	-	-	**0.52**	**0.01**
CB_Y_dist	**0.71**	**0.02**	-	-	-	-	-	-	-	-	**0.55**	**0.01**
CB_O_dist	**0.68**	**0.03**	-	-	-	-	**0.75**	**0.02**	**0.55**	**0.02**	**0.51**	**0.01**
newPL_dist	-	-	-	-	-	-	-	-	**-0.06**	**0.02**	-	-
oldPL_dist	-	-	-	-	-	-	-	-	**0.54**	**0.01**	-	-
CB_Y_1k	-	-	-	-	**-0.34**	**0.01**	-	-	-	-	-	-
LS_1k	**-0.22**	**0.02**	-	-	**-0.25**	**0.01**	**-0.29**	**0.01**	**0.39**	**0.02**	**-0.04**	**0.01**
MS_1k	-	-	-	-	**-0.73**	**0.02**	-	-	**-0.41**	**0.02**	-	-
HS_1k	**-0.50**	**0.04**	-	-	-	-	**-1.44**	**0.05**	-	-	**-0.72**	**0.03**
Lcov_Conif_Den	**-1.01**	**0.06**	**-0.99**	**0.04**	**-0.84**	**0.05**	**-1.34**	**0.05**	**-1.08**	**0.11**	**-0.40**	**0.03**
Lcov_Conif_ModOpen	**0.37**	**0.04**	-	-	**0.18**	**0.05**	**0.70**	**0.03**	**0.82**	**0.09**	**0.71**	**0.03**
Lcov_Mixed	-	-	**-0.74**	**0.04**	**-0.74**	**0.06**	-	-	**0.51**	**0.10**	**0.13**	**0.03**
Lcov_Wetland_OpenHerbBarr	**0.90**	**0.05**	**0.27**	**0.03**	**0.13**	**0.05**	**0.15**	**0.04**	**0.63**	**0.10**	**-0.27**	**0.04**
Lcov_Wetland_Tree	-	-	**0.09**	**0.04**	**0.14**	**0.05**	**0.48**	**0.04**	**0.58**	**0.10**	-	-
Lcov_Shrub	-	-	**-0.58**	**0.07**	**-0.61**	**0.07**	-	-	**0.35**	**0.12**	**-0.91**	**0.07**

3.2.3 Third order habitat selection

3.2.3.1 Chinchaga

At the 3rd order scale of selection, caribou in the Chinchaga range selected areas farther than random from medium and high activity well sites during all seasons except spring and summer (Table 3.9). During spring and summer, although inclusion of distance to medium and high activity well sites improved model parsimony, the covariate was not significant within models. Caribou habitat selection in relation to distance to low activity well sites varied by season, with caribou selecting areas farther than random from low activity well sites during spring, fall, and early winter, but closer to low activity well sites during calving, summer, and late winter (Table 3.9). During all seasons, the magnitude of selection for distance to medium and high activity well sites was greater than for distance to low activity well sites; indicating that caribou selected habitat farther from medium and high activity well sites when compared to low activity well sites (Figure 3.1). At the 3rd order scale, model parsimony was best for models that grouped medium and high activity phases of well site development into a single “medium/high” activity phase.

During calving, summer, and early winter, caribou in the Chinchaga range selected areas with a lower density of anthropogenic disturbance features including cut blocks when compared to a random distribution. However, during fall, Chinchaga caribou selected areas closer than random to secondary roads and cut blocks < 25 years old, and also selected areas with greater density of anthropogenic disturbance features. Relative to other seasons, model parsimony during spring and late winter was less dependent on the inclusion of anthropogenic features, with the exception of distance to well sites, density of seismic lines during spring, and distance to seismic lines and secondary roads during late winter. Density of cut blocks in late winter was zero for all used and available locations and thus could not be evaluated.

Inclusion of landcover improved model parsimony during all seasons, and caribou in the Chinchaga range selected for treed wetlands and shrub habitat during all seasons (Table 3.9). Caribou selected mixed wood and deciduous forests and open wetlands less than random during all seasons. Caribou selected moderate and dense canopy conifer forests more than random during the calving season, but less than expected from a random distribution during spring and late winter. Open canopy conifer forest was used as the reference category for 3rd order habitat selection models in Chinchaga.

Table 3.9. Standardized model coefficients (β) and standard errors (SE) describing 3rd order habitat selection for Chinchaga caribou during spring, calving, summer, fall, early winter, and late winter. Covariates are described in Table 2.2. Variables for which selection was statistically different from random are shown in bold. The reference category for landcover was Conif_Open

	Spring		Calving		Summer		Fall		Ewin		Lwin	
	β	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**
Intercept	**-2.11**	**0.09**	**-3.09**	**0.14**	**-2.50**	**0.33**	**-3.50**	**0.18**	**-3.17**	**0.09**	**-2.35**	**0.19**
Dist_medhighact	-0.02	0.03	**0.51**	**0.01**	-0.02	0.02	**0.53**	**0.02**	**0.23**	**0.01**	**0.46**	**0.03**
Dist_lowact	**0.20**	**0.03**	**-0.05**	**0.01**	**-0.08**	**0.01**	**0.07**	**0.01**	**0.09**	**0.01**	**-0.37**	**0.02**
primRD_dist	-	-	-	-	-	-	-	-	**-0.53**	**0.02**	-	-
secRD_dist	-	-	**0.14**	**0.01**	**0.55**	**0.12**	**-0.09**	**0.01**	**0.15**	**0.02**	**-0.76**	**0.02**
CB_Y_dist	-	-	-	-	**1.43**	**0.03**	**-0.75**	**0.03**	-	-	-	-
newPL_dist	-	-	**0.05**	**0.01**	**-0.14**	**0.01**	-0.02	0.02	-	-	-	-
LS_dist	-	-	-	-	-	-	-	-	**-0.26**	**0.02**	-0.01	0.01
MS_dist	-	-	-	-	-	-	-	-	**0.06**	**0.01**	-	-
HS_dist	-	-	-	-	-	-	-	-	**0.08**	**0.01**	**0.16**	**0.009**
AA_70	-	-	-	-	-	-	**0.26**	**0.01**	**0.21**	**0.01**	-	-
AA_500	-	-	-	-	**-0.05**	**0.01**	-	-	-	-	-	-
AA_1k	-	-	**-0.17**	**0.02**	-	-	-	-	-	-	-	-
CB_Y_1k	-	-	**-0.27**	**0.03**	-	-	-	-	**-0.18**	**0.02**	-	-
CB_O_1k	-	-	**-0.36**	**0.11**	-	-	-	-	**-1.68**	**0.68**	-	-
LS_1k	**0.12**	**0.02**	**0.37**	**0.01**	**0.07**	**0.01**	**0.41**	**0.01**	-	-	-	-
MS_500	-0.001	0.02	**-0.18**	**0.01**	**-0.16**	**0.01**	-	-	-	-	-	-
MS_1k	-	-	-	-	-	-	**-0.47**	**0.01**	-	-	-	-
HS_1k	**-0.34**	**0.03**	**-0.83**	**0.02**	**-0.85**	**0.02**	**-0.09**	**0.02**	-	-	-	-
Lcov_Conif_ModDen	**-0.56**	**0.08**	**0.23**	**0.09**	0.03	0.03	-	-	-	-	**-0.39**	**0.03**
Lcov_Mixed	**-0.83**	**0.07**	**-0.32**	**0.10**	**-0.32**	**0.04**	-	-	**-0.47**	**0.06**	**-1.10**	**0.04**
Lcov_Decid	**-1.79**	**0.12**	**-1.49**	**0.12**	**-1.32**	**0.09**	**-0.35**	**0.07**	**-1.23**	**0.11**	**-2.31**	**0.09**
Lcov_Wetland_OpenHerbBarr	**-1.37**	**0.18**	**-1.31**	**0.16**	**-1.35**	**0.14**	-0.09	0.08	-	-	**-1.37**	**0.11**
Lcov_Wetland_Tree	-	-	**0.41**	**0.09**	**0.13**	**0.02**	**0.99**	**0.03**	**0.69**	**0.04**	-	-
Lcov_Shrub	**0.15**	**0.04**	**0.37**	**0.09**	-	-	**1.37**	**0.04**	**1.24**	**0.04**	**0.18**	**0.02**

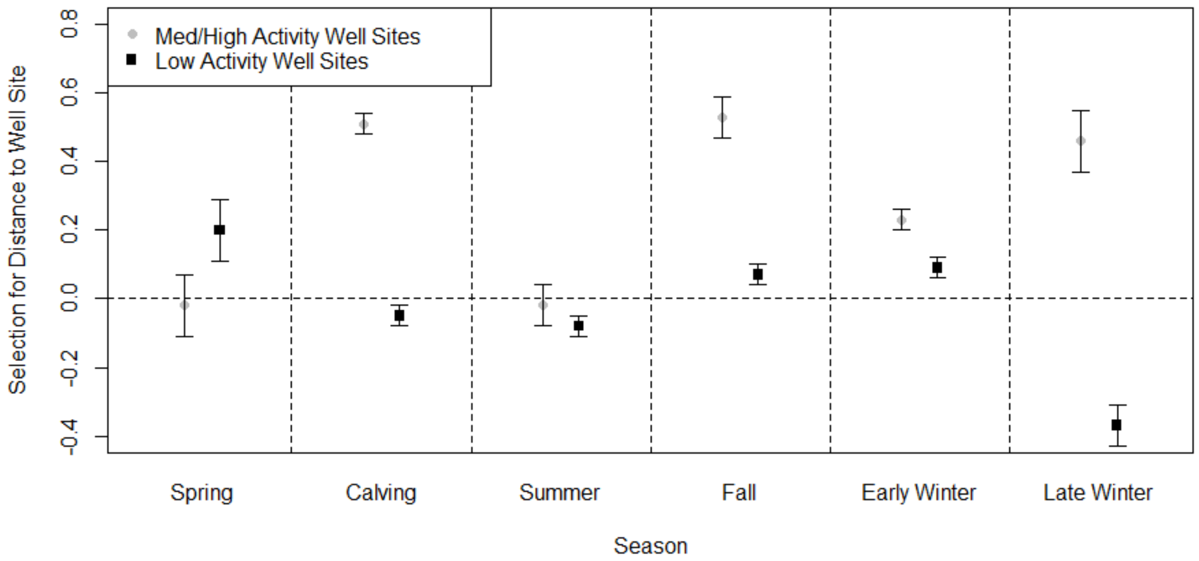

Figure 3.1. Selection coefficients for distance to medium/high and low activity well sites in the Chinchaga range at the 3rd order scale for spring, calving, summer, fall, early winter, and late winter. Positive coefficients indicate selection increased with increasing distance to well sites while negative coefficients indicate that selection decreased with increasing distance to well sites.

3.2.3.2 Little Smoky

At the 3rd order scale of selection, model parsimony for habitat selection of Little Smoky caribou was greatest for models including the distance to well sites. Habitat selection by Little Smoky caribou was explained in part by an interaction between the proximity and activity status of the nearest well site during early winter, late winter, and spring (Table 3.10). During early winter, habitat selection was relatively greater for low activity well sites compared to well sites in medium or high activity phases of development up to a distance of 3km from the nearest well site (Figure 3.2). During late winter, relative selection for high activity well sites was less than other activity phases up to a distance of 2.5km from the nearest well site (Figure 3.3). Caribou were closer to low activity well sites compared to random during the calving season, but were farther from medium and high activity well sites during the same season. During summer, caribou were farther from well sites in medium/high activity phases, and during fall caribou were farther from well sites in all activity phases compared to a random distribution.

During all seasons except spring, caribou in the Little Smoky range selected areas with a lower density of anthropogenic features compared to random (Table 3.10). During spring, caribou selected areas with a higher density of anthropogenic features but selected areas farther from seismic lines compared to a random distribution. During calving, caribou were closer to cut blocks > 25 years old and secondary roads, but selected areas with a lower density of seismic lines (all vegetation heights) more than random (Table 3.10). The scale of the response to disturbance density (density within 70m, 500m, or 1km radii) was highly variable between covariates and seasons. The most parsimonious density radius for seismic lines with low vegetation heights was always 70m, whereas density of seismic lines with moderate vegetation heights was most parsimonious when measured at a 500m radius, and model parsimony for the density of seismic lines with high vegetation heights varied between 70m, 500m, and 1k depending on the season.

Inclusion of landcover improved model parsimony during all seasons, but selection of landcover types by caribou in the Little Smoky range varied by season. During spring, caribou selected for deciduous and mixed wood forests and open wetlands, herb, and barren habitat but avoided treed wetlands more than random. During calving and summer, caribou selected open and treed wetlands. During fall and early winter, caribou selected open canopy conifer forests. Dense canopy conifer forests and shrub habitat were selected less than random during all seasons (Table 3.10). Moderate canopy conifer forest was used as the reference category for 3rd order habitat selection models in the Little Smoky range.

Table 3.10. Standardized model coefficients (β) and standard errors (SE) describing 3rd order habitat selection for Little Smoky caribou during spring, calving, summer, fall, early winter, and late winter. Covariates are described in Table 2.2. Variables for which selection was statistically different from random are shown in bold. The reference category for landcover was Conif_Mod

	Spring		Calving		Summer		Fall		Ewin		Lwin	
	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE
Intercept	**-2.32**	**0.05**	**-2.54**	**0.08**	**-2.49**	**0.11**	**-2.24**	**0.07**	**-2.07**	**0.04**	**-2.21**	**0.05**
Dist_highact	-	-	**0.07**	**0.02**	-	-	-	-	-	-	-	-
Dist_medact	-	-	**0.20**	**0.02**	-	-	**0.05**	**0.01**	-	-	-	-
Dist_medhighact	-	-	-	-	**0.31**	**0.01**	-	-	-	-	-	-
Dist_lowact	-	-	**-0.08**	**0.02**	-0.02	0.01	**0.07**	**0.01**	-	-	-	-
Dist_all	**-0.08**	**0.01**	-	-	-	-	-	-	-0.02	0.02	0.01	0.01
NearestWell_medact	-	-	-	-	-	-	-	-	**-1.16**	**0.10**	**-0.30**	**0.02**
NearestWell_highact	-	-	-	-	-	-	-	-	**-6.56**	**1.02**	**-4.71**	**1.49**
NearestWell_medhighact	**0.21**	**0.04**	-	-	-	-	-	-	-	-	-	-
Dist_all*NearestWell_medact	-	-	-	-	-	-	-	-	**0.36**	**0.04**	**0.15**	**0.02**
Dist_all*NearestWell_highact	-	-	-	-	-	-	-	-	**1.65**	**0.30**	**1.83**	**0.53**
Dist_all*NearestWell_medhighact	**0.25**	**0.04**	-	-	-	-	-	-	-	-	-	-
primRD_dist	-	-	**0.40**	**0.02**	**0.34**	**0.01**	**0.29**	**0.01**	**0.11**	**0.02**	**-0.19**	**0.01**
secRD_dist	-	-	**-0.08**	**0.01**	**-0.14**	**0.01**	-	-	-	-	**0.18**	**0.01**
CB_Y_dist	-	-	-	-	**0.12**	**0.02**	-	-	**0.17**	**0.02**	-	-
CB_O_dist	-	-	**-0.13**	**0.05**	-	-	-	-	-	-	-	-
newPL_dist	-	-	-	-	-	-	**0.25**	**0.02**	-	-	**0.04**	**0.02**
LS_dist	**0.10**	**0.01**	-	-	-	-	-	-	-	-	**0.03**	**0.01**
MS_dist	**0.10**	**0.02**	-	-	-	-	-	-	-	-	-	-
HS_dist	-	-	-	-	-	-	-	-	-	-	**-0.15**	**0.01**
AS_dist	-	-	-	-	-	-	**0.11**	**0.01**	-	-	-	-
AA_70	**0.09**	**0.01**	-	-	-	-	-	-	-	-	-	-
AA_500	-	-	-	-	**-0.37**	**0.01**	-	-	**-0.26**	**0.02**	**-0.37**	**0.01**
AA_1k	-	-	**-0.31**	**0.02**	-	-	**-0.25**	**0.01**	-	-	-	-
CB_Y_70	-	-	-	-	-	-	-	-	-	-	**-0.22**	**0.01**
CB_Y_1k	-	-	-	-	-	-	**-0.16**	**0.02**	-	-	-	-
LS_70	-	-	**-0.31**	**0.01**	**-0.22**	**0.01**	-	-	**0.18**	**0.01**	-	-
MS_500	-	-	**-0.22**	**0.02**	**-0.21**	**0.01**	-	-	**-0.09**	**0.01**	-	-
HS_70	-	-	-	-	**-0.06**	**0.02**	-	-	-	-	-	-
HS_500	-	-	**-0.14**	**0.02**	-	-	-	-	-	-	-	-
HS_1k	-	-	-	-	-	-	-	-	**0.14**	**0.01**	-	-
Lcov_Conif_Den	**-1.00**	**0.06**	**-0.50**	**0.04**	**-0.47**	**0.03**	**-1.67**	**0.05**	**-1.45**	**0.06**	**-0.61**	**0.02**
Lcov_Conif_Open	-	-	-	-	**-0.44**	**0.19**	**0.30**	**0.14**	**0.47**	**0.16**	**-0.26**	**0.12**
Lcov_Decid	**0.43**	**0.09**	**0.40**	**0.06**	-	-	0.05	0.06	**-0.42**	**0.09**	**-0.43**	**0.05**
Lcov_Mixed	**0.32**	**0.05**	-	-	-	-	**-0.09**	**0.04**	-	-	**-0.14**	**0.02**
Lcov_Wetland_OpenHerbBarr	**0.41**	**0.04**	**0.36**	**0.03**	**0.06**	**0.03**	-0.01	0.04	**0.29**	**0.04**	**-0.23**	**0.03**
Lcov_Wetland_Tree	**-0.33**	**0.06**	**0.52**	**0.03**	**0.36**	**0.03**	**0.16**	**0.03**	-	-	-0.26	0.03

Lcov_Shrub	-	-	**-0.15**	**0.07**	**-0.33**	**0.06**	**-0.26**	**0.07**	-	-	-0.78	0.06

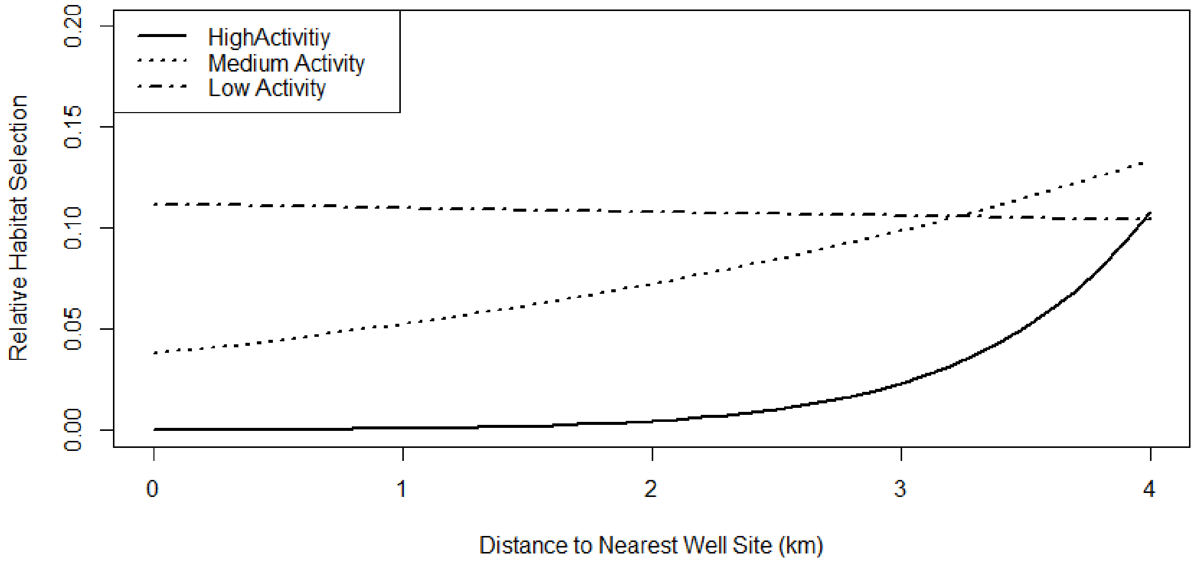

Figure 3.2. Relative habitat selection at the 3rd order scale in relation to the distance and activity status of the nearest well site for caribou in the Little Smoky range in early winter.

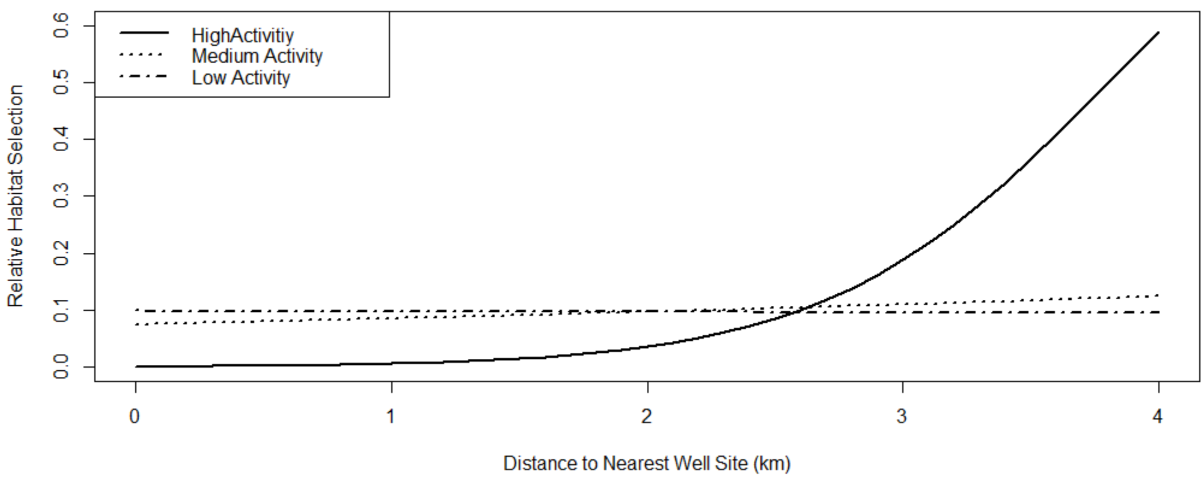

Figure 3.3. Relative habitat selection at the 3rd order scale in relation to the distance and activity status of the nearest well site for caribou in the Little Smoky range in late winter.

3.3 Relationship between caribou habitat selection and estimated calf survival

Of the models fit to explain calf survival in relation to distance to well sites and anthropogenic disturbance density in the Chinchaga and Little Smoky caribou range, only one contained a significant relationship between calving status and anthropogenic disturbance density. Little Smoky caribou that encountered lower densities of anthropogenic disturbance during fall were more likely to have a calf the following spring (pseudo R-squared = 0.065; beta = -478.22, p = 0.006, Figure 3.4). There was a similar trend in late winter, however the relationship was not significant (pseudo R-squared = 0.149, beta = -9.36, p = 0.08, Figure 3.5).

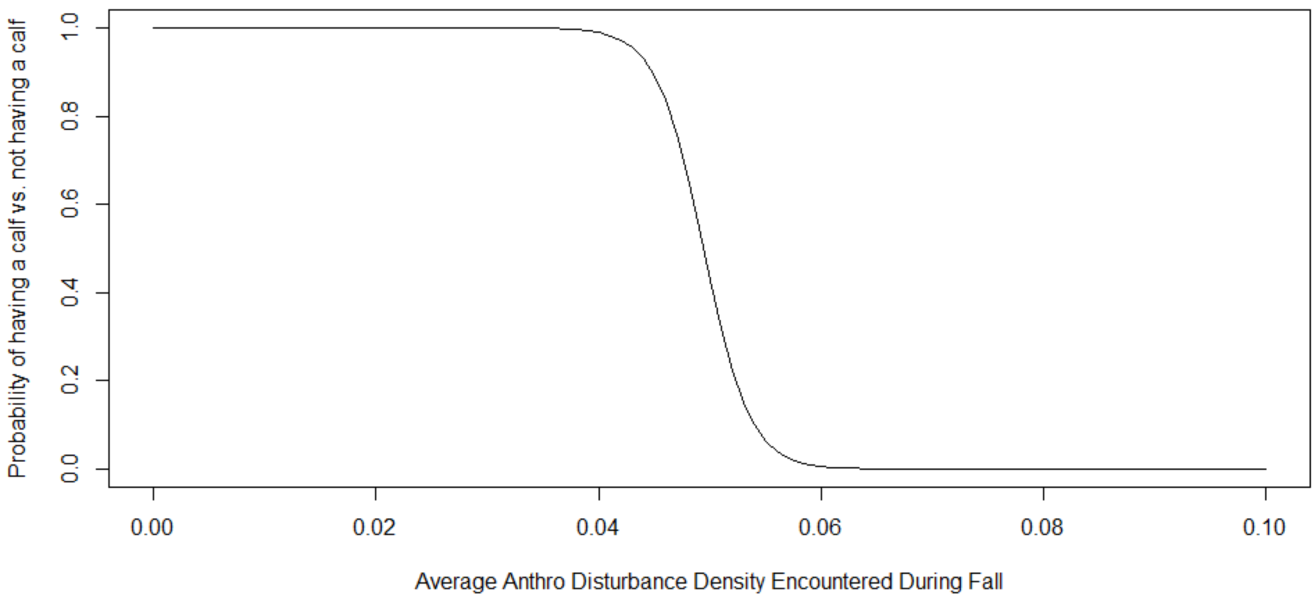

Figure 3.4. Probability of a female caribou in the Little Smoky range having a calf in relation to the average density of anthropogenic disturbance encountered in the fall preceding calving.

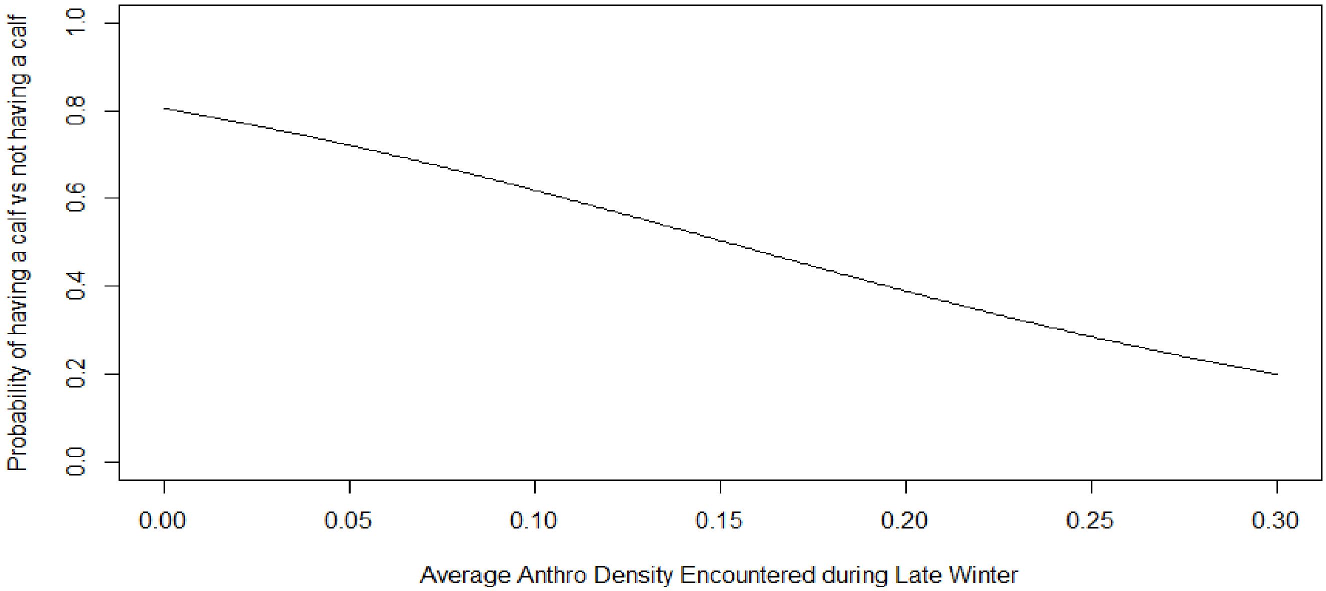

Figure 3.5. Probability of a female caribou in the Little Smoky range having a calf in relation to the average density of anthropogenic disturbance encountered in the late winter preceding calving.

4. Discussion

4.1 Habitat selection and well site activity

We used GPS data from caribou collected between 1999 and 2015 to assess adult caribou habitat selection relative to well sites in different phases of activity, and also to assess calving success and calving site locations relative to well sites and other anthropogenic and topographic covariates. Generally, we found that boreal caribou in two distinct ranges selected habitat that was farther from well sites than random, and that the activity status of well sites influenced the degree to which well sites were avoided by caribou. We could not identify a distance at which caribou no longer responded to well sites, but in most seasons the magnitude of selection against well sites was higher for well sites in medium or high activity phases than for well sites in the low activity phase. In the Little Smoky range during early and late winter, we identified a distance of 3km as the point when the relative selection for distance to high and low activity well sites were equal (Figures 3.4 and 3.5). Our results were similar at the 2nd and 3rd order of selection and indicated that the response of caribou to well sites was multi-scalar. Although there was some variation in the response to well sites, we found no evidence to refute the current 500m buffer applied to well sites under the Boreal Caribou Recovery Strategy (Environment Canada 2012). However, our results suggest that during early and late winter, Little Smoky caribou respond to well sites at distances greater than 500m (Figures 3.3 and 3.3).

Our results complement previous research conducted by fRI Research investigating the response of central mountain caribou (Redrock Prairie Creek and Narraway populations) to well sites at different phases of activity during early and late winter (MacNearney *et al.* 2015), as well as research on other ungulate species that showed a negative response to oil and gas development (Sawyer *et al.* 2006, 2009; Buchanan *et al.* 2014). In particular, our results are in accordance with those of Sawyer *at al.* (2009), who found that the differential response to well sites with different activity levels reduced mule deer habitat selection at distances of 2.7-3.7 kilometers from well sites (Sawyer *et al.* 2009). Similar to other studies investigating the effects of disturbance on caribou habitat selection and use of space (Dyer *et al.* 2001; Fortin *et al.* 2008; Hins *et al.* 2009; Hornseth & Rempel 2016), we found that the density and proximity of anthropogenic disturbance generally had a negative influence on habitat selection by caribou, but that there were seasonal and geographic differences in the response. In both ranges, caribou selected areas with lower densities of anthropogenic disturbance during calving, summer, and late winter. However, caribou selected for areas with higher densities of anthropogenic disturbance during spring in the Little Smoky range, and during fall and early winter in the Chinchaga range. Spring, fall, and early winter are associated with greater movement of caribou as caribou shift habitat preferences between winter range and calving range, and from summer range to winter range (Ferguson & Elkie 2004). During these periods of greater movement, there may be a higher potential to encounter disturbance features, and also reduced opportunities for caribou to avoidance disturbances that are frequently built in movement corridors constrained by landscape features like ridges or valleys (Saher & Schmiegelow 2005).

While the majority of our results confirmed our prediction that caribou would avoid areas near well sites, some of our findings differed from our predictions: At the 2nd order scale, and as expected, Little Smoky caribou avoided well sites regardless of activity phase. However, contrary to our predictions, we found no evidence that Little Smoky caribou were avoiding high activity well sites during early winter (Table 3.8). This unexpected result may in part be explained by a complex interplay between lag effects in wildlife response to changing habitat (Schlaepfer *et al.* 2002; Vors *et al.* 2007; Dussault *et al.* 2012) and thresholds of sensory disturbance in caribou (Bradshaw *et al.* 1998; Nellemann *et al.* 2001; Seip *et al.* 2007). For example, caribou may not immediately respond to well sites during periods of high activity, but rather may gradually alter their use of space so that by the time a well has transitioned into a lower activity phase, caribou are further from that area than expected from a random distribution. Furthermore, Sawyer *et al.* (2009) found that mule deer altered their use of habitat in relation to well site activity within a year of drilling (i.e. high activity). Our study only considered the response of caribou based on the proximity and activity phase of well sites on the precise date that a telemetry location was collected and did not assess the potential for a time lag effect to occur between phases of development and response of caribou. Therefore, further analysis is required to assess the time lag in caribou response to activity at well sites. Using mixed effects logistic regression at the individual and home range scales, we were able to identify a broad negative response to well sites at all activity phases. However, other studies measured habitat selection of ungulates before and during the development of oil and gas infrastructure, and thus could make inferences about the direct effects of development on wildlife in terms of habitat quality and associated habitat selection (Sawyer *et al.* 2006; Buchanan *et al.* 2014). We were unable to evaluate habitat selection on a landscape free of disturbance, and therefore could not measure the underlying quality of habitat before disturbances.

Due to delays in data acquisition, the habitat selection portion of this analysis was completed using approximately 50% of final GPS telemetry data available for caribou in the Little Smoky herd. Further analyses considering the full data set may strengthen the habitat selection models and reveal further patterns in the response of caribou to well sites at different phases of activity.

4.2 Calving success and well site activity

Information on calving periods, parturition rates, and calf survival for caribou is important given its implications for conservation. We estimated a parturition rate of 87% (20 of 23 potential calving events) for caribou in the Chinchaga range, and 81% (47 of 58 potential calving events) for caribou in the Little Smoky range. We also estimated the calf survival rate at 55% and 47% for the Chinchaga and Little Smoky caribou respectively. Our analysis of adult female movement rates revealed that between 1999 and 2015, all calves were born in the three week period between April 25 and June 8. This period overlaps with results of Rowe (2007) who identified the calving season as May 5 to May 27 for the British Columbia portion of Chinchaga range, and the results of other studies of boreal caribou that delineated the calving season using movement rates (May 7 to July 14, Ferguson & Elkie 2004).

Aside from a significant trend suggesting that the probability of a caribou having a calf in the Little Smoky range decreased in relation to the density of anthropogenic disturbance encountered during the previous fall, we found no strong relationship between the proximity or density of disturbance that females were exposed to prior to calving, and calving success. In addition, further investigation is needed to determine whether calving rates conform to pregnancy rates. Understanding whether calving rates conform to pregnancy rates could provide insight into whether exposure to stress and diseases can affect the ability of females to carry their pregnancy to term (Das Neves *et al.* 2009; Stieve *et al.* 2010; Schwantje *et al.* 2014). However, because there is evidence that stress responses to sensory disturbance tend to manifest as long term effects (Ashley *et al.* 2011), it may be difficult to identify the role of any one disturbance feature on the survival or reproductive success of caribou.

We identified quite different annual patterns in the calving success of Chinchaga caribou: In 2008, we estimated that 6 out of 8 calves that were born were lost before 4 weeks post parturition (75% calf mortality), followed by 9 calves being born and surviving to 4 weeks post parturition in 2009 (0% calf mortality). This strong annual effect was not explained by exposure to anthropogenic disturbance during calving or gestation, and indicates that there may be additional environmental factors that we did not consider in our models assessing reproductive success. Similarly, our analysis suggests that calf mortality between 2000 and 2004 (84%) in the Little Smoky range was higher than between 2005 and 2015 (44%), although smaller annual sample sizes of collared females make it difficult to determine whether these calf mortality rates are reliable estimates for the population. Additional analysis could help determine whether winter severity or unusually cold spring weather in 2008 would account for the disparity in calving success between 2008 and 2009 (Weladji & Holand 2003; Parker *et al.* 2009).

Because we examined existing GPS telemetry datasets to estimate calving status, we were unable to validate our estimates of parturition or calf survival with visual sightings as was performed by DeMars *et al.* (2013). However, DeMars *et al.* (2013) reported near certainty in parturition dates (97%), and reasonable confidence in neonate survival (87%) using the approaches used for this project. Despite the success reported by DeMars *et al.* (2013), we suggest that our estimates of parturition and neonate survival presented here should be interpreted cautiously. Although traditional studies of calf survival via radio collaring and monitoring neonates may have advantages over the IBM method when considering certainty of survival rates (e.g. exact identification of calf sites and calf mortality sites and calf birth weight (Gustine *et al.* 2006; Pinard *et al.* 2012), those methods are more invasive and likely therefore expose caribou to unnecessary additional stresses. The non-invasive aspect, and the ability to examine existing datasets collected over long time frames to estimate calving events and calf survival with the IBM method is appealing. Additionally, it is important to note that neonate survival up to 4 weeks post parturition does not equate to recruitment, and that ideally, these data should be complemented by data collected from winter surveys to estimate calf-cow ratios; calf-cow ratios obtained from winter surveys would give a more complete picture of calf survival from the neonatal period to 1 year of age.

5. Conclusions and ongoing work

The overarching objectives of this project were to (i) determine how activity at well sites influences the behaviour of caribou, (ii) determine whether 500m buffers on well sites accurately reflect the impact of these features on caribou habitat selection, and (iii) evaluate calving success for collared adult female caribou in relation to proximity and density of well sites and other anthropogenic features during the calving season and the gestational period. Using

GPS telemetry locations we found that overall, caribou avoid well sites at all phases of activity, but that there were some seasonal differences in their response. We found no evidence to refute the 500m buffers placed on oil and gas infrastructure, and found that caribou responded negatively to well sites to a distance of at least 3km during winter. We found a relationship between the density of anthropogenic disturbance encountered by adult female caribou during gestation and the probability of having a calf, however this relationship was only significant in the Little Smoky herd during the fall, and further investigation is needed to determine whether additional replicates in the Chinchaga range would reveal a similar pattern. This project contributes important knowledge to managers and the information provided here can be used to help mitigate impacts of oil and gas development on caribou now and into the future as recovery efforts proceed.

A portion of the telemetry data was received after considerable delay and was therefore excluded from parts of the analysis. The inclusion of these data in subsequent analyses for peer-review manuscript submission may reveal additional insights to those reported here.

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