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Boreal caribou calving areas and calf survival in relation to habitat, disturbance, and predation risk

Final report prepared for
Alberta Upstream Petroleum Research Fund 18-ERPC-03

fRI Research Caribou Program

June, 2019

Laura Finnegan and Tracy McKay

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Executive Summary

Boreal caribou are declining across their ranges, and low calf recruitment contributes to that decline. To ensure caribou persistence on the landscape, land managers require a comprehensive understanding of caribou calving habitat and where caribou calves may be exposed to high predation risk. Using GPS collar data from two boreal herds (Little Smoky and Chinchaga), we used a non-invasive approach to identify calving locations and to assess caribou calving habitat. We also used existing knowledge of predator habitat use (wolves, grizzly bears, black bears, cougars, and wolverines) to assess the link between calf survival and overlap with multiple predators.

Between 2000 and 2015, we found that 73% and 58% of Little Smoky and Chinchaga caribou had calves respectively, and approximately 50% of those calves survived past 4 weeks. At calving and throughout the calving season, caribou from both herds preferred areas with lower densities of anthropogenic disturbance. Little Smoky caribou also preferred areas at higher elevations and mixed and broadleaf forest during the calving season, while Chinchaga caribou preferred valley bottoms, water, and wetlands, and avoided mixed and broadleaf forest. It is possible that Little Smoky caribou with calves are reducing their exposure to predation from wolves during the calving season, while Chinchaga caribou may be prioritizing access to forage over predation risk.

We also found that calf fate was linked to the habitat selection patterns of their mothers. Calves were more likely to survive when their mothers avoided anthropogenic disturbance and wildfires from fine to large scales, and were also more likely to survive when their mothers selected areas with more cover and when they avoided valley bottoms. By linking calf survival to overlap with a number of predators, we found that calves were more likely to survive when their mothers avoided areas preferred by both wolves and bears (Little Smoky: grizzly bears, Chinchaga: black bears), rather than only avoiding areas preferred by wolves. We found no links between calf survival and spatial overlap with cougars and wolverines.

Using the results of our analysis, we created spatially explicit maps that predict areas where caribou are likely to calve, and areas with a higher probability of being used during the first few weeks after calves are born. Combined, these maps identify important caribou calving habitat that could be used in landscape planning. Also, by evaluating the links between calf survival and overlap with multiple predators, our analysis revealed that caribou use of wolf and bear habitat decreases calf survival. This information could be used to fine tune habitat restoration efforts to increase caribou calf survival. Overall, the result of this project could be used to prioritize areas for habitat restoration, or to inform management practices that mitigate human impacts on caribou during the vulnerable calving season.

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1. Introduction

1.1 Project background

Boreal caribou are declining across their ranges (Vors et al., 2007). The ultimate cause of caribou declines is habitat disturbance, which has increased the densities and distribution of alternate prey (moose, deer, elk) in caribou ranges, and increased the spatial overlap between shared predators (e.g. wolves) and caribou (Courtois et al., 2007; DeCesare et al., 2010; Festa-Bianchet et al., 2011; Hervieux et al., 2013; Peters et al., 2013). Low population recruitment contributes to caribou declines; due to increased predation rates, and many calves do not survive past their first winter (Hervieux et al., 2013).

Although calves are vulnerable to predation throughout the first year of their lives, they are most vulnerable during the neonatal period (i.e., 0 to 4 weeks after parturition; Adams et al., 1995; Gustine et al., 2006a; Schindler, 2018). As habitat heterogeneity and anthropogenic disturbance are linked to predation risk (DeCesare et al., 2014; DeMars and Boutin, 2018; Kauffman et al., 2007), understanding the habitat preferences of caribou with calves during the neonatal period could help mitigate the impacts of anthropogenic disturbance on caribou calves during this vulnerable time. In addition, because caribou calves are vulnerable to a number of predators, including wolves, grizzly bears, black bears, cougars, and lynx (Adams et al., 1995; Gustine et al., 2006a; Pinard et al., 2012), understanding where predators are mostly likely to occur on the landscape, and how caribou overlap with different predators is linked to calf survival, could help identify high risk areas for calf mortality. Results from this project could help prioritize areas for restoration within caribou ranges to focus on calving habitat and reduce the spatial overlap between caribou, their calves, and predators.

1.2 Project objectives

To inform landscape management within caribou ranges, land managers require knowledge of areas that are important to caribou across their annual range, including areas used during the calving season. In addition, understanding how anthropogenic disturbance and exposure to predation risk may impact calf survival could help inform habitat restoration priorities to increase calf survival. We used multi-year caribou GPS data collected from the Little Smoky and Chinchaga boreal caribou ranges in Alberta and British Columbia to identify areas used by caribou during the calving season. We also used landcover, topographic attributes, anthropogenic disturbance variables, and existing knowledge of predator distribution within these caribou ranges to link calf survival to landscape features and to overlap with predators. The specific objectives of this project were:

i) To use GPS location data from adult female caribou to identify calving locations and to determine the landcover, topographic, and anthropogenic disturbance attributes associated with calving sites and selected or avoided by females with calves during the calving season (Chapter 2).
ii) To use existing predator occurrence models developed within the Little Smoky and Chinchaga caribou ranges, or in similar and adjacent areas, to map predation risk during the calving season (Chapter 3).
iii) To compare habitat selection of caribou with calves that lived to habitat selection of caribou with calves that died; specifically, to determine whether landcover, topographic, and anthropogenic disturbance attributes and overlap with specific predators during the calving season are linked to calf fate (survival) (Chapter 4).

1.3. Study Area

The study area included the ranges of the Little Smoky and Chinchaga boreal caribou herds in Alberta and British Columbia (Figure 1.1). Boreal caribou are listed as threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the Species at Risk Act (Committee on the Status of Endangered Wildlife in Canada, 2002) and as threatened under Alberta's Wildlife Act (2005).

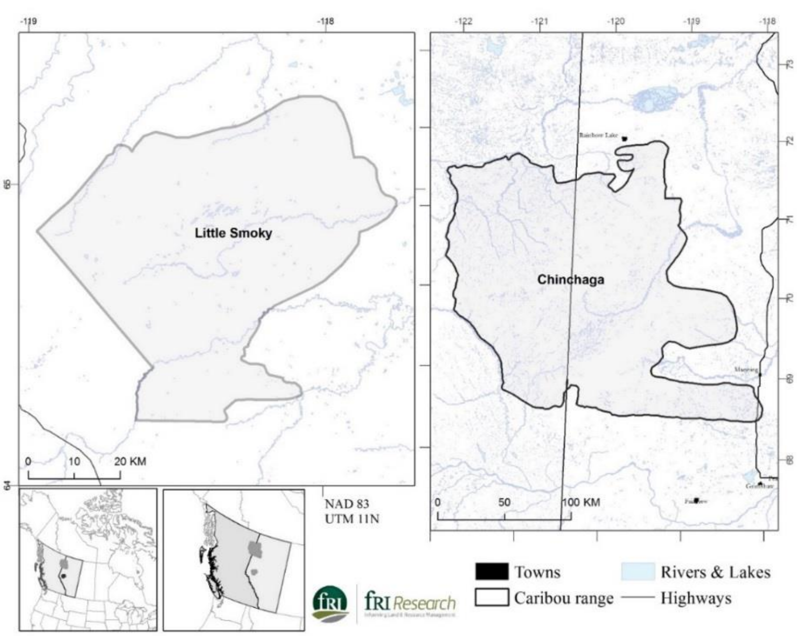

Figure 1.1. Map of the study area showing the provincial range boundaries of the Little Smoky caribou herd (Alberta), and Chinchaga caribou herd (Alberta and British Columbia), Canada.

2. Calving site and calving season habitat selection

2.1. Introduction

Predation is the main cause of caribou calf mortality, and the neonatal period (0 to 4 weeks post-parturition) is the most critical time for calf survival (Gustine et al., 2006a; Rettie and Messier, 1998; Wittmer et al., 2005a). Caribou calf survival decreases when their mothers are unable to spatially separate themselves from predators (Seip, 1992; Wittmer et al., 2005a). In particular, in boreal caribou ranges, the proximity of female caribou to anthropogenic landscape disturbance is associated with reduced survival of their calves, due to the altered predator-prey dynamics resulting from anthropogenic disturbance (DeMars and Boutin, 2018; Dussault et al., 2012; Leclerc et al., 2014). Caribou are also sensitive to direct disturbance by human activities during the calving season; therefore, industrial activities such as vehicle traffic, active logging, and oil and gas operations can also influence calving site selection (Keay et al., 2006; Pinard et al., 2012; Singh et al., 2010; Skarin et al., 2008; Vistnes and Nellemann, 2008). As an anti-predator strategy, while calving, female caribou tend to space themselves out on the landscape and avoid areas most commonly used by predators (Bergerud and Page, 1987; DeMars and Boutin, 2018; Leblond et al., 2016). However, due to the extensive footprint of anthropogenic disturbance within caribou ranges (Environment Canada, 2011), this strategy may result in some female caribou using suboptimal habitat during the calving season, reducing the likelihood of calf survival (Battin, 2004; Gustine et al., 2006a; Leclerc et al., 2014).

To better understand the associations between anthropogenic disturbance (i.e., cutblocks, roads, seismic lines, and pipelines) and calving habitat in boreal caribou ranges, in this Chapter we examined calving site selection and caribou habitat selection during the calving period (from parturition until 4 weeks after birth). Specifically, we investigated the relationships between landcover, topography, anthropogenic disturbance, and calving site and calving season habitat selection for two boreal caribou herds between 2000 and 2015. We used the resulting models to map the combined spatial probability of areas within provincial caribou range boundaries selected by caribou for calving sites and during the calving season.

2.2. Methods

2.2.1. Identifying calving events

To identify calving events, we used GPS collar location data (Lotek Engineering, Newmarket, Ontario) collected by the Governments of Alberta and British Columbia from the Little Smoky herd (n = 90 caribou) and the Chinchaga herd (n = 24 caribou) between 2000 and 2015. Capture and handling was carried out under the Government of Alberta's Animal Care Protocol no. 008 (Hervieux et al., 2013). We focused on GPS locations collected from adult female caribou during the calving season (April 15 — July 15). Our final dataset consisted of location data from 35 caribou from the Little Smoky herd (60 caribou-calving seasons) and 24 caribou from the Chinchaga herd (41 caribou-calving seasons). Further details regarding animal capture and GPS location data are included in Appendix A. We used the GPS location data and the individual based method (IBM) of DeMars et al. (2013) to estimate the timing and locations of calving events and subsequent calf survival. The IBM method is outlined in brief in Appendix A.

2.2.2. Calving site habitat selection

We used the calving events identified in section 2.2.1 to determine the locations of caribou calving sites. Using the GPS location data associated with the calving site, we used generalized linear mixed models (GLMMs) to assess caribou calving site selection in relation to a suite of variables describing landcover, topography, and anthropogenic disturbance. Details of variables are included in Appendix B. We assessed calving site selection at the herd-range (within provincial caribou range boundaries) and home-range (within the home-range of each individual caribou) scales. Model building and model selection are described in detail in Appendix C. To identify areas where caribou are likely to calve, we used our model coefficients to first map the probability of calving site selection at the herd- and home-range scales, and then multiplied and rescaled the results to show the combined herd- and home-range probabilities of calving site selection (DeCesare et al., 2012).

2.2.3. Calving season habitat selection

Using GPS location data from caribou that calved, we used GLMMs to assess calving season habitat selection of adult female caribou, including locations from one day after the calving event to 28 days post-parturition. When IBM analysis indicated probable loss of the calf less than 28 days post-parturition, we only included GPS location data collected during the time that the calf was alive. We used the same approach outlined for calving site selection analysis to build calving season habitat selection models at the herd- and home-range scales (see Appendix B for details). To map areas used by caribou during the calving season, we used model coefficients to first map the probability of calving season habitat selection at the herd- and home-range scales, and then multiplied and rescaled the results to show the combined herd- and home-range probabilities of calving season habitat selection.

2.3. Results

In Little Smoky, among 60 caribou-calving seasons, we predicted 44 calving events (73% calved; Appendix A: Table A.1). 20 calves (45%) survived to 4 weeks, with apparent calf death for the other 24 calves occurring between 1 and 28 days after birth (mean time of death = 12 days). In Chinchaga, among the 41 caribou-calving seasons, we predicted 24 calving events (58% calved; Appendix A: Table A.2). 12 calves (55%) survived to 4 weeks, with apparent calf death for the other 12 calves occurring between 4 and 28 days after birth (mean time of death = 12 days). Further details of calving events are in Appendix A, and are described in detail in Poole et al. (2018).

2.3.1. Calving site habitat selection

2.3.1.1. Little Smoky

At the herd and home-range scales, Little Smoky caribou selected calving sites in areas with lower densities of roads, seismic lines, and cutblocks (Table 2.1). K-fold cross validation indicated poor predictive power for the herd-range model, but fair predictive power for the home-range model. The combined herd- and home-range map of the probability of calving site selection is shown in Figure 2.1.

Table 2.1. Parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) for generalized linear mixed models used to identify factors determining calving site selection of caribou in the Little Smoky herd at the herd- and home-range scales in west-central Alberta, Canada, between 2000 and 2015. Mean (minimum, maximum) r_s values from K-fold cross validation are also shown. Variables are described in Table B.1.

	Herd			Home		
	β	LCL	UCL	β	LCL	UCL
Intercept	-2.13	-2.51	-1.75	-2.27	-2.64	-1.91
Road 1km	-1.34	-2.45	-0.22	-1.58	-2.68	-0.48
Seismic 90m	-0.23	-0.37	-0.08	-0.23	-0.37	-0.09
Cut 1km	-2.92	-6.10	0.25	-	-	-
Mean r_s (min, max)	0.14 (-0.28, 0.46)			0.34 (-0.15, 0.73)		

2.3.1.2. Chinchaga

At the herd- and home-range scales, Chinchaga caribou selected calving sites in wetter areas and at higher elevations (Table 2.2). K-fold cross validation indicated good predictive power for the herd-range scale model and excellent predictive power for the home-range scale model. The combined herd- and home-range map of the probability of calving site selection is shown in Figure 2.2.

Table 2.2. Parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) for generalized linear mixed models used to identify factors determining calving site selection of caribou in the Chinchaga herd at the herd- and home-range scale in north-western Alberta and north-eastern British Columbia, Canada, in 2004, 2005 and between 2007 and 2009. Mean, (minimum, maximum) r_s values from K-fold cross validation are also shown. Variables are described in Table B.1.

	Herd			Home		
	β	LCL	UCL	β	LCL	UCL
Intercept	-12.33	-16.83	-7.82	-10.47	-15.05	-5.89
Road 1km	-	-	-	-0.60	-1.50	0.30
Elevation	4.13	0.49	7.77	3.54	0.26	6.83
Wetness (CTI)	0.59	0.28	0.90	0.46	0.10	0.83
Water and wetlands	0.79	-0.15	1.73	0.80	-0.15	1.75
Mean r_s (min, max)	0.78 (0.53, 0.98)			0.85 (0.43, 0.96)		

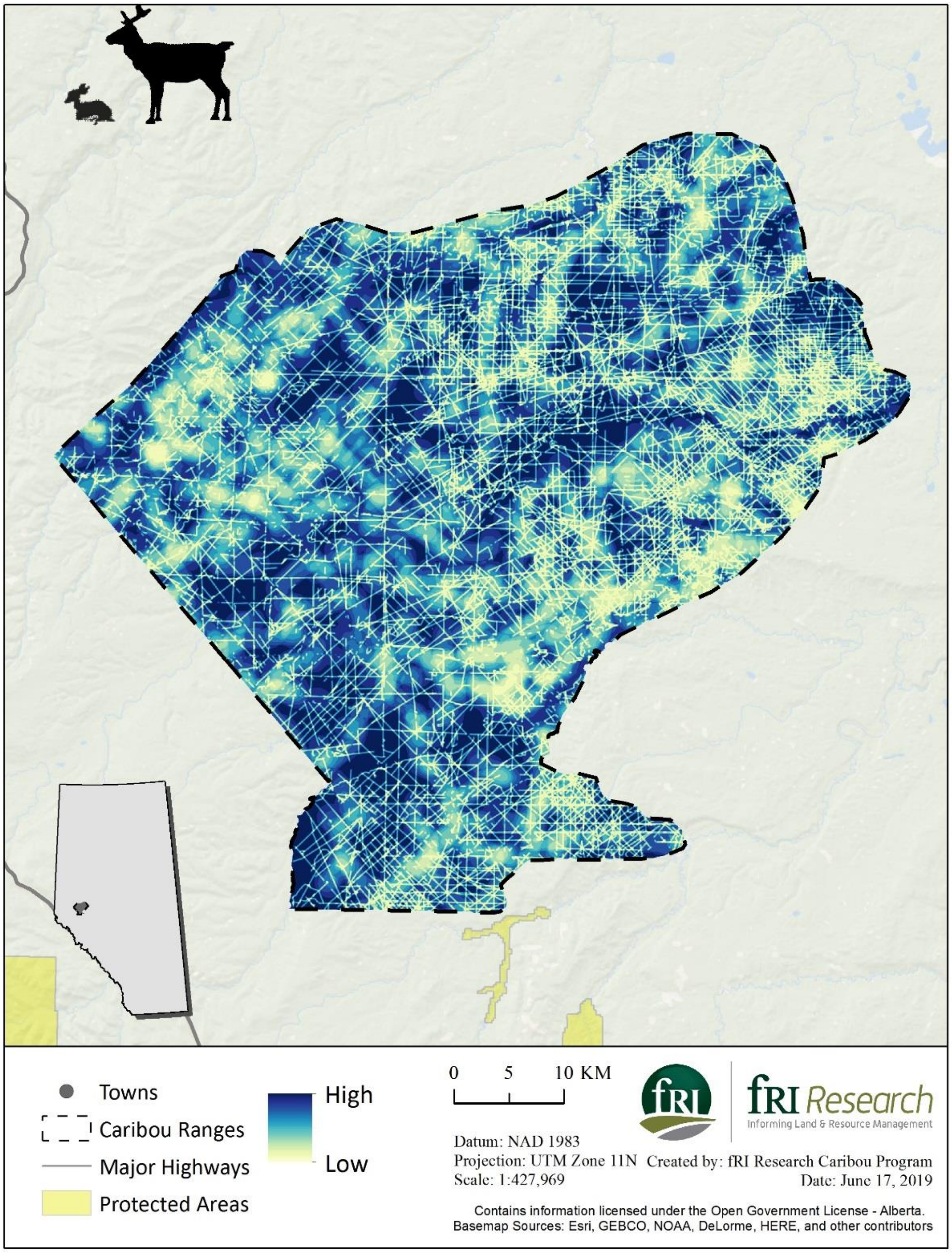

Figure 2.1. Combined predicted probability of calving site selection at the herd- and home-ranges scales for Little Smoky caribou range in west-central Alberta, Canada. Models of calving site selection were developed using GPS location data from adult female caribou collected between 2000 and 2015. Landscape condition data were updated to 2015.

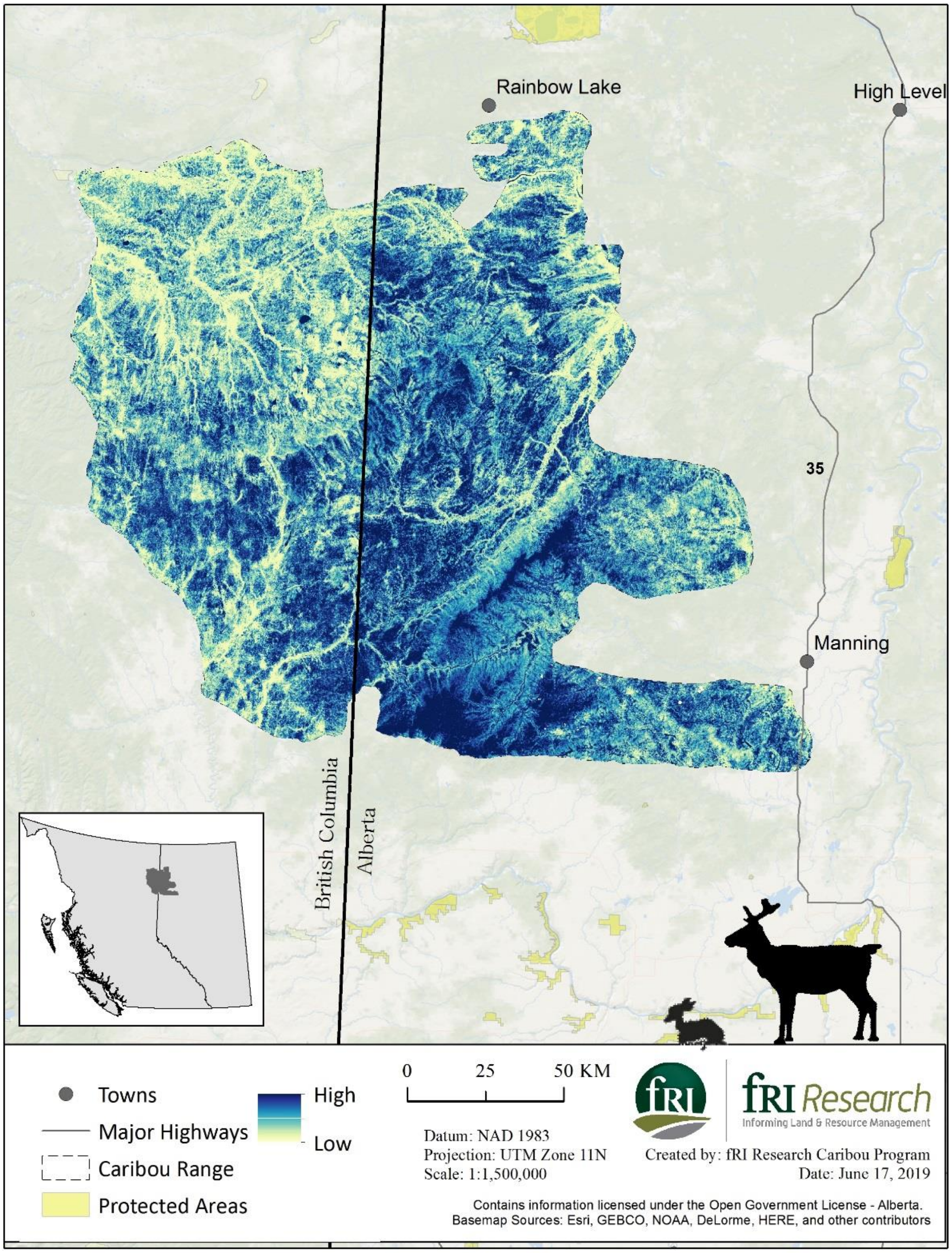

Figure 2.2. Combined predicted probability of calving site selection at the herd- and home-ranges scales for Chinchaga caribou range in north-western Alberta and north-eastern British Columbia, Canada. Models of calving site selection were developed using GPS location data from adult female caribou collected in 2004, 2005, and between 2007 and 2009. Landscape condition data were updated to 2015.

2.3.2. Calving season habitat selection

2.3.2.1. Little Smoky

During the calving season, at both the herd- and home-range scales, Little Smoky caribou selected areas with lower densities of roads, pipelines, seismic lines, cutblocks, and wellsites, and also selected mixed and broadleaf forest (Table 2.4). They selected wetter areas at the herd-range scale, shrub/herb landcover at the home-range scale, and avoided conifer forest at the home-range scale. K-fold cross validation indicated excellent predictive power of the herd-and home-range models. The combined herd- and home-range map showing the probability of calving season habitat selection is shown in Figure 2.3.

Table 2.4. Parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) for generalized linear mixed models used to identify factors determining calving season habitat selection of caribou in the Little Smoky herd at the herd- and home-range scale in west-central Alberta, Canada, between 2000 and 2015. Mean, minimum, and maximum r_s values from K-fold cross validation are also shown. Variables are described in Table B.1.

	Herd			Home		
	β	LCL	UCL	β	LCL	UCL
Intercept	-2.82	-2.92	-2.73	-1.54	-1.87	-1.22
Road 90m	-	-	-	-0.23	-0.28	-0.19
Road 1km	-0.42	-0.49	-0.34	-	-	-
Pipe 90m	-0.50	-0.63	-0.37	-0.58	-0.71	-0.45
Seismic 90m	-0.19	-0.20	-0.19	-0.17	-0.19	-0.17
Cut 1km	-5.50	-5.83	-5.18	-4.46	-5.00	-3.93
Well 1km	-0.15	-0.19	-0.10	-	-	-
Well 5km	-	-	-	-2.58	-2.83	-2.34
Wetness (CTI)	0.07	0.06	0.08	-	-	-
Shrub/herb	-	-	-	0.52	0.38	0.65
Conifer	-	-	-	-0.09	-0.16	-0.03
Mixed and broadleaf	0.56	0.47	0.65	0.12	0.01	0.22
Mean r_s (min, max)	0.93 (0.73, 0.99)			0.88 (0.71, 0.98)		

2.3.2.2. Chinchaga

During the calving season, at both the herd- and home-range scales, Chinchaga caribou selected areas with lower densities of wellsites, flatter areas (lower slope), and water and wetland habitat (Table 2.5). At the herd-range scale, Chinchaga caribou selected areas with lower densities of cutblocks and fires, selected west-facing areas, and avoided mixed and broadleaf forest. At the home-range scale, Chinchaga caribou selected north-west facing areas (Table 2.5). K-fold cross validation indicated good to excellent predictive power of the herd- and home-range scale modes (Table 2.5). The combined herd- and home-range map of the probability of calving site selection is shown in Figure 2.4.

Table 2.5. Parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) for generalized linear mixed models used to identify factors determining calving season habitat selection of caribou in the Chinchaga herd at the herd- and home-range scale in north-western Alberta and north-eastern British Columbia, Canada, in 2004, 2005, and between 2007 and 2009. Mean, minimum, and maximum r_s values from K-fold cross validation are also shown. Variables are described in Table B.1.

	Herd			Home		
	β	LCL	UCL	β	LCL	UCL
Intercept	-1.90	-2.28	-1.51	-3.21	-3.43	-2.99
Cut 5km	-11.66	-18.87	-4.44	1.62	-4.39	7.64
Fire 5km	-0.80	-1.08	-0.51	0.00	-0.24	0.23
Well 5km	-2.44	-3.06	-1.83	-0.71	-1.25	-0.17
Slope	-0.14	-0.22	-0.07	-	-	-
TPI	-0.04	-0.06	-0.02	-0.06	-0.08	-0.03
Northness	-	-	-	0.20	0.07	0.33
Eastness	-0.24	-0.38	-0.10	-0.14	-0.27	-0.05
Water and wetlands	0.43	0.21	0.64	0.19	0.29	0.68
Mixed and broadleaf	-0.87	-1.33	-0.41	-	-	-
Mean r_s (min, max)	0.89 (0.67, 0.99)			0.78 (-0.49, 0.98)		

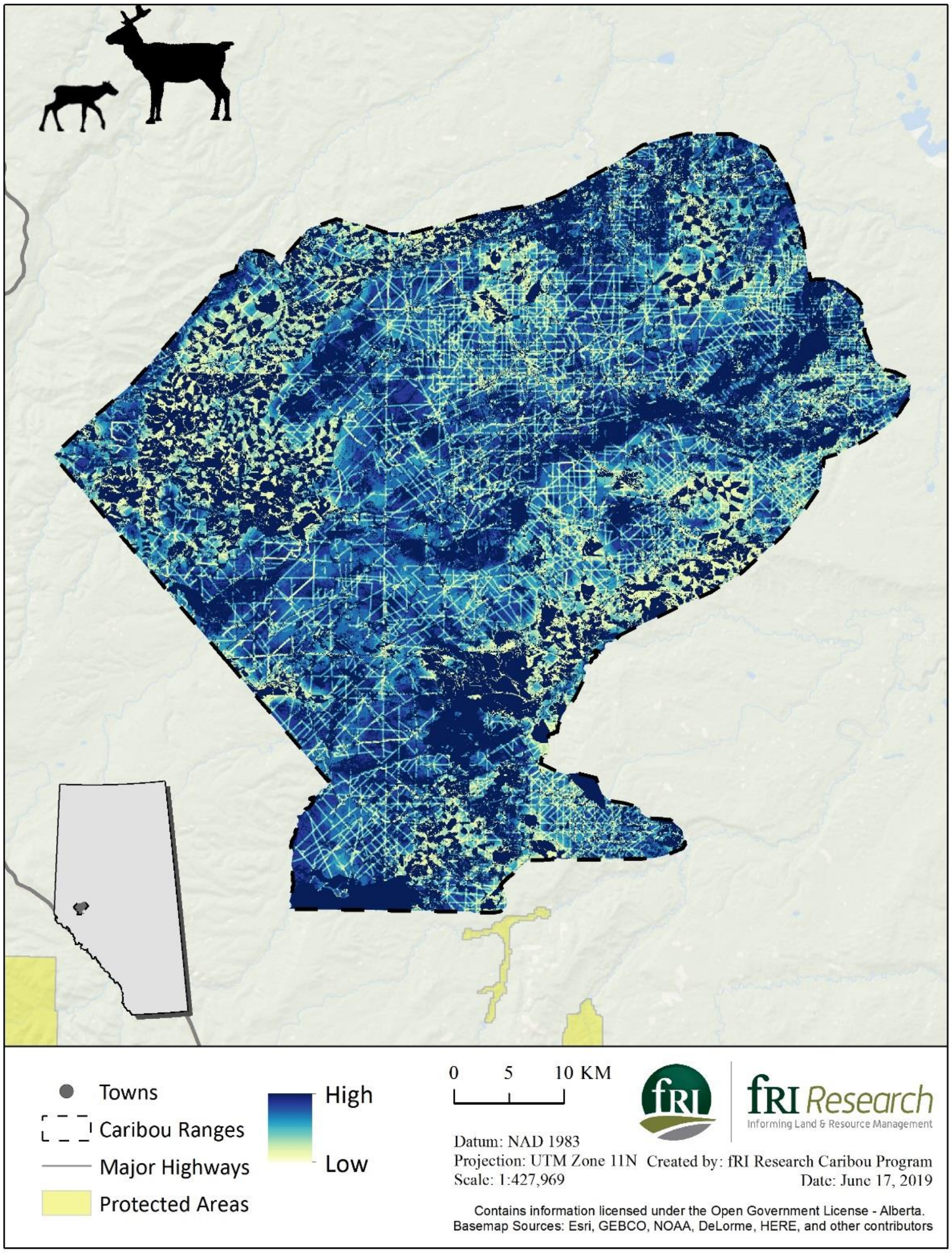

Figure 2.3. Combined predicted probability of calving season habitat selection at the herd- and home-ranges scales in Little Smoky caribou range in west-central Alberta, Canada. Models of calving season habitat selection were developed using GPS location data from adult female caribou collected between 2000 and 2015. Landscape condition data were updated to 2015.

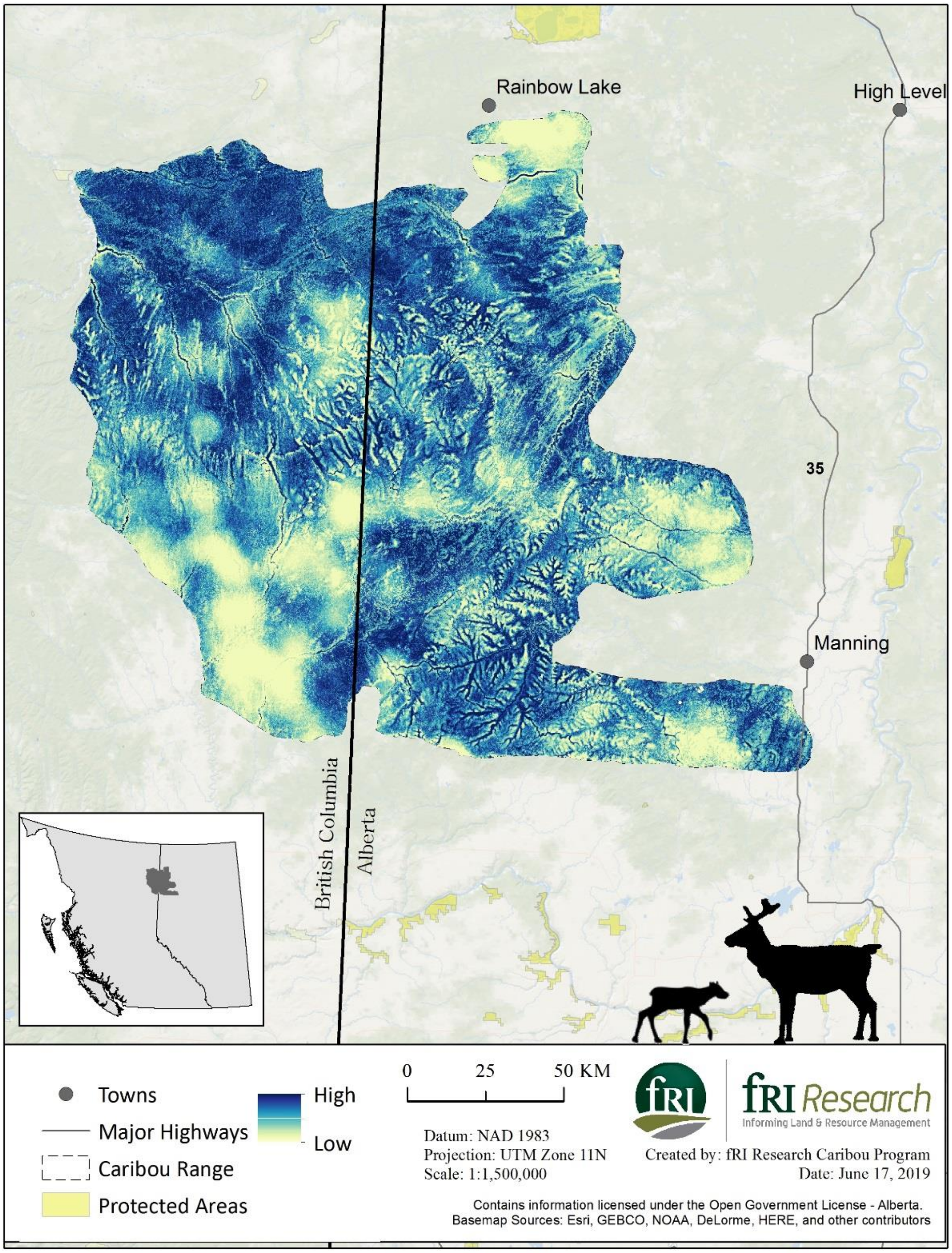

Figure 2.4. Combined predicted probability of calving season habitat selection at the herd- and home-ranges scales in Chinchaga caribou range in north-western Alberta and north-eastern British Columbia, Canada. Models of calving season habitat selection were developed using GPS location data from adult female caribou collected in 2004, 2005, and between 2007 and 2009. Landscape condition data were updated to 2015.

2.4. Discussion

We used GPS data and the non-invasive individual based method of DeMars et al. (2013) to identify calving sites and assess calving season habitat selection in the Little Smoky and Chinchaga boreal caribou herds. Although we were unable to confirm calving events with field observations of caribou with calves, field validation in other areas has indicated that the IBM approach is effective at determining calving events and calf survival (Bonar et al., 2018; DeMars et al., 2013). In addition, the estimated calving dates we identified in the Little Smoky and Chinchaga herds (25^{th} April – 7^{th} June), calf survival rates (~50%), and patterns of habitat selection are consistent with previous work (e.g., DeMars et al., 2013; Dussault et al., 2012; Nobert et al., 2016).

Generally, we found that caribou selected calving sites associated with lower densities of anthropogenic disturbance, a finding that is in line with previous research on boreal caribou (Leblond et al., 2016; Nobert et al., 2016; Pinard et al., 2012). Notably, we found that only variables describing densities of roads, seismic lines, and cutblocks were retained in the final models explaining calving site selection in Little Smoky, while multiple disturbance variables, landcover, and terrain explained calving site selection in Chinchaga. While there are well-established links between anthropogenic disturbance and altered predator-prey dynamics (e.g., DeCesare et al., 2014), a number of additional factors are associated with higher predation risk, such as landcover and elevation (DeMars and Boutin 2018; Whittington et al., 2011). During calving, female caribou normally avoid both direct human disturbance and areas most commonly used by predators (DeMars and Boutin, 2018; Dyer et al., 2001; Leblond et al., 2016); however, it is possible that the higher levels of anthropogenic disturbance in the Little Smoky range (95%; Chinchaga range: 76%, Environment Canada, 2011) limits the available locations for calving sites in Little Smoky. As a result, pregnant Little Smoky caribou may only be able to prioritize reducing their exposure to human disturbance at calving (DeCesare et al., 2014), rather than being able to reduce exposure to predation risk by both avoiding anthropogenic disturbance and selecting habitat and terrain less likely to be used by predators. In contrast, in Chinchaga, pregnant cows calved in areas with low densities of disturbance, at higher elevations, and in wetter areas. Like Little Smoky caribou, by selecting areas with lower densities of disturbance, Chinchaga caribou are likely reducing their exposure to predation risk (DeCesare et al., 2014; DeMars and Boutin, 2018; Mumma et al., 2017). However, in addition,, Chinchaga caribou may be selecting areas at higher elevations to reduce overlap with wolves and increase their ability to visually detect predators (Pinard et al. 2012; Whittington et al., 2011), while wetter areas may be acting as refugia from predators (DeMars, 2015; McLoughlin et al., 2005).

Throughout the calving season, Little Smoky and Chinchaga caribou continued to avoid areas with lower densities of anthropogenic disturbance, likely to minimize exposure to predation risk (DeMars and Boutin, 2018; Mumma et al., 2017; Viejou et al., 2018). Little Smoky caribou selected mixed and broadleaf forest and shrub and herb landcover during the calving season; a response that may be driven by access to vegetative forage in those habitats, as females with calves need to meet the high nutritional demands of lactation (Chan-McLeod et al., 1994; Parker et al., 2009). Similar use of mixed and deciduous stands, herb, and shrub habitat during the calving season has been described in other caribou herds (Leclerc et al., 2014; Nobert et al., 2016; Pinard et al., 2012). In areas like the foothills of the Little Smoky range, deciduous stands and herb and shrub habitat may be refugia from wolves that prefer lower elevations and valley bottoms (DeCesare, 2012; DeCesare et al., 2014; Lesmerises et al., 2012). In Chinchaga, during the calving season, caribou selected areas with lower slopes, valley bottoms (low TPI), and water and wetlands, but avoided mixed and deciduous stands. In areas like the Chinchaga herd range, with little topographic relief, avoiding mixed and deciduous stands is likely driven by decreasing exposure to predation risk (DeMars, 2015; McLoughlin et al., 2005); however, by selecting flat areas, lower slopes, and water and wetland habitat, Chinchaga caribou with calves may also be prioritizing access to vegetative food in fens and bogs over their exposure to predation risk from wolves that may also prefer those areas (DeCesare et al., 2014; DeMars, 2015; Mumma et al., 2017).

3. Mapping predation risk

To map predation risk during the caribou calving season, we used previously published models of predator occurrence as indices of predation risk (Ciuti et al., 2012; Gustine et al., 2006a; Leblond et al., 2016). For Little Smoky, we used published coefficients from resource selection functions (RSFs) for wolves, grizzly bears and cougars. Although black bears, wolverines, coyotes, and lynx are also predators of caribou calves (Andrén et al., 2011; Bastille-Rousseau et al., 2016; Kinley and Apps, 2001; Lewis et al., 2017), available models for these predators were developed within adjacent central mountain caribou ranges (Chow-Fraser, 2018) with lower levels of disturbance (Environment Canada, 2011) and different topography (e.g., alpine habitat). Therefore, we determined that these models may not reflect habitat use of these predators within boreal ranges, and so these species were not included in our analysis of predation risk for Little Smoky. For Chinchaga, we included RSFs for wolves, wolverines, and black bears in our analysis of predation risk. Like Little Smoky, other species (i.e., grizzly bears and lynx) may also be predators of caribou calves in that area; however, to our knowledge there are currently no occurrence models available for those species in the Chinchaga area, so we were unable to include these predators in our analysis. Because predation risk is linked to landscape change, we used annual landscape data (Little Smoky: 2000-2015; Chinchaga years: 2004-2009) to generate annual predator RSFs in each area.

3.1. Little Smoky.

For wolf RSFs, we used coefficients derived from 'summer' RSF models (16 May – 16 October) built within the study area (DeCesare et al., 2014). For grizzly bear RSFs, we used coefficients derived from models built for the Grande Cache population unit, which encompasses the Little Smoky caribou range (Nielsen, 2007), to generate RSFs as maximum RSF values for 'spring' (1 May – 15 June) and 'summer' (16 June – 31 July). As cougar RSFs were unavailable for our study area, we built cougar RSFs using coefficients derived from annual cougar models built in a study area south-east of our own; an area with similar habitat, terrain, and landscape disturbance (Knopff et al., 2014a; Knopff, 2011). We recognise that extrapolating RSFs can be problematic (Nielsen et al., 2010; Proffitt et al., 2011); therefore, the cougar RSFs we generated are likely an approximation of cougar predation risk in the Little Smoky range. Maps showing the predicted relative probability of wolf, grizzly bear, and cougar occurrence in the Little Smoky caribou range based on landscape conditions in 2015 are shown in Figures 3.1 – 3.3.

3.2. Chinchaga

For wolf RSFs, we used coefficients derived from 'denning' models (20 April – 30 June) built within the study area (MacNearney et al., 2016). As wolverine RSFs were unavailable for our study area, we built wolverine

RSFs using coefficients derived from 'summer' (2 April – 31 October) that were built in a study area just north of the Alberta portion of the Chinchaga range (Scrafford et al., 2017), combining male and female RSFs to generate an RSF representing the maximum probability of wolverine habitat use during summer. For black bears, we used GPS data (DeMars and Boutin, 2018, 2017) to build a calving season (15 April – 15 July) RSF in an area adjacent to the Chinchaga herd range; this area is similar to the Chinchaga herd range in terms of habitat and disturbance (see Appendix D for details). We then used coefficients from the resulting model (Table D.1) to predict a black bear RSF for the Chinchaga herd range. We recognise that the extrapolated wolverine and black bear RSFs we generated are likely an approximation of predation risk from those species in the Chinchaga range. Maps showing the predicted relative probability of wolf, wolverine, and black bear habitat use in the Chinchaga caribou range circa 2015 are shown in Figures 3.4 – 3.6.

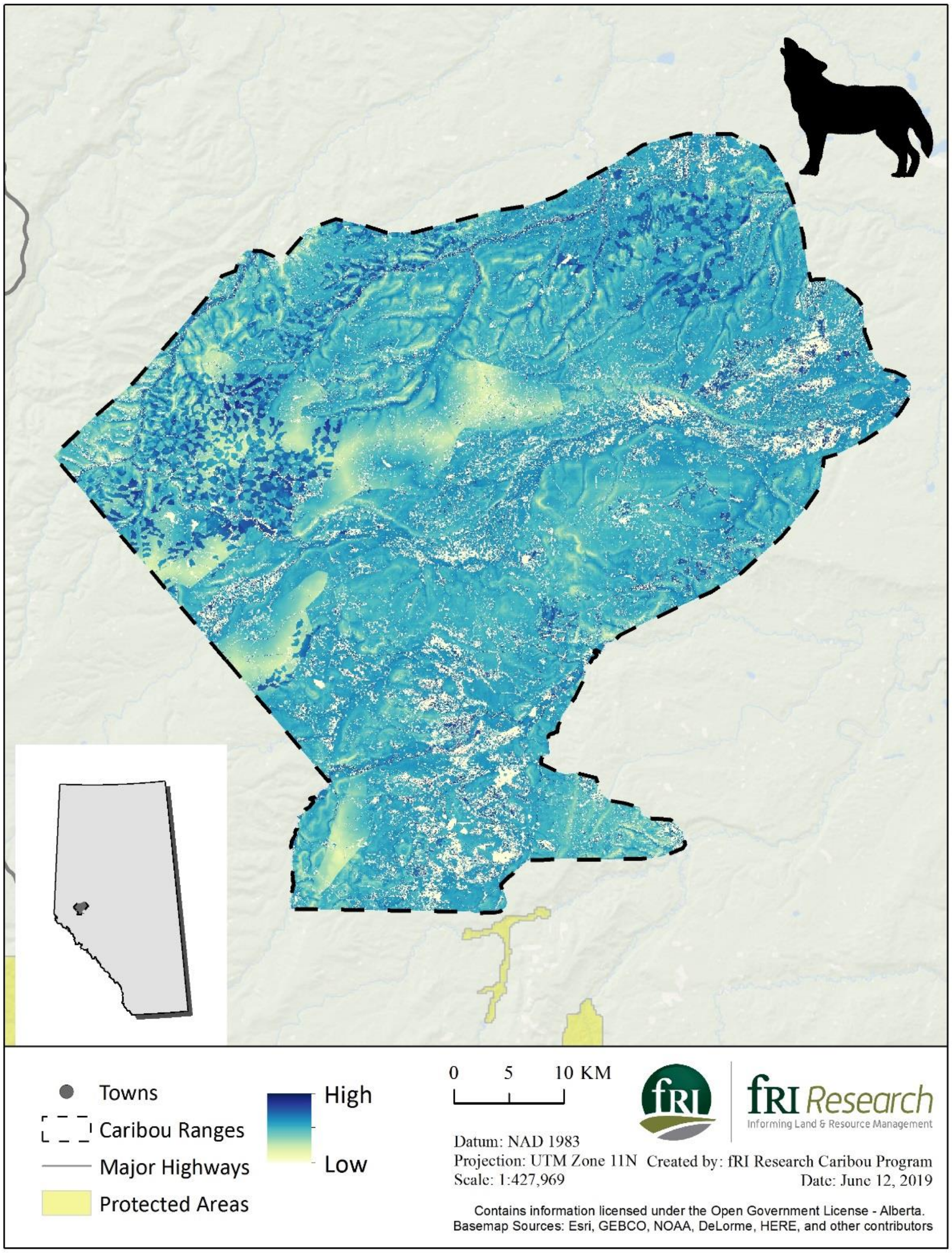

Figure 3.1. Predicted probability of wolf occurrence during summer in the Little Smoky caribou range in west-central Alberta, Canada. Coefficients were derived by DeCesare et al. (2014). Landscape condition data were updated to 2015.

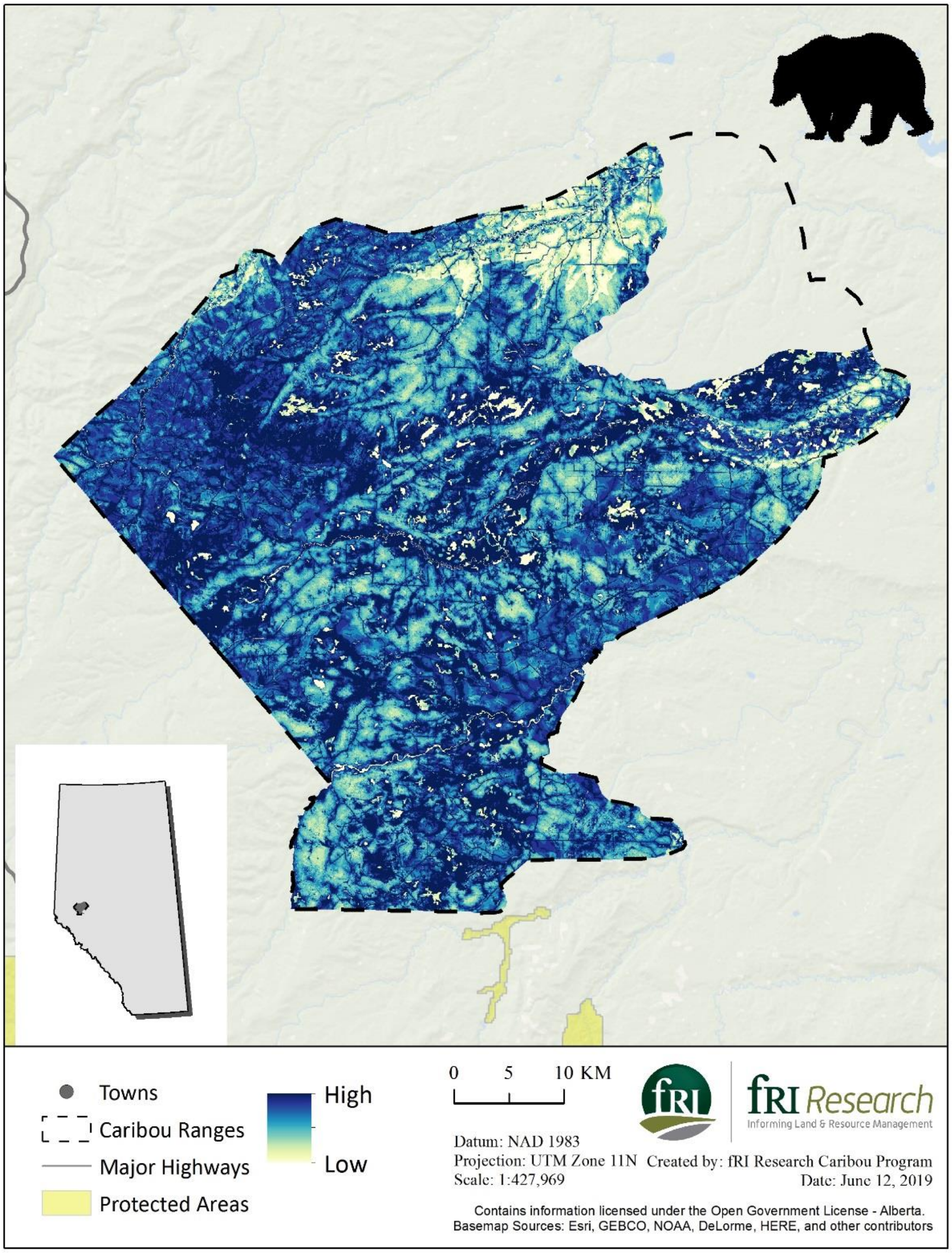

Figure 3.2. Predicted probability of grizzly bear occurrence (maximum of spring and summer habitat selection) in the Little Smoky caribou range in west-central Alberta, Canada. Coefficients were derived by Nielsen (2007). Landscape condition data were updated to 2015.

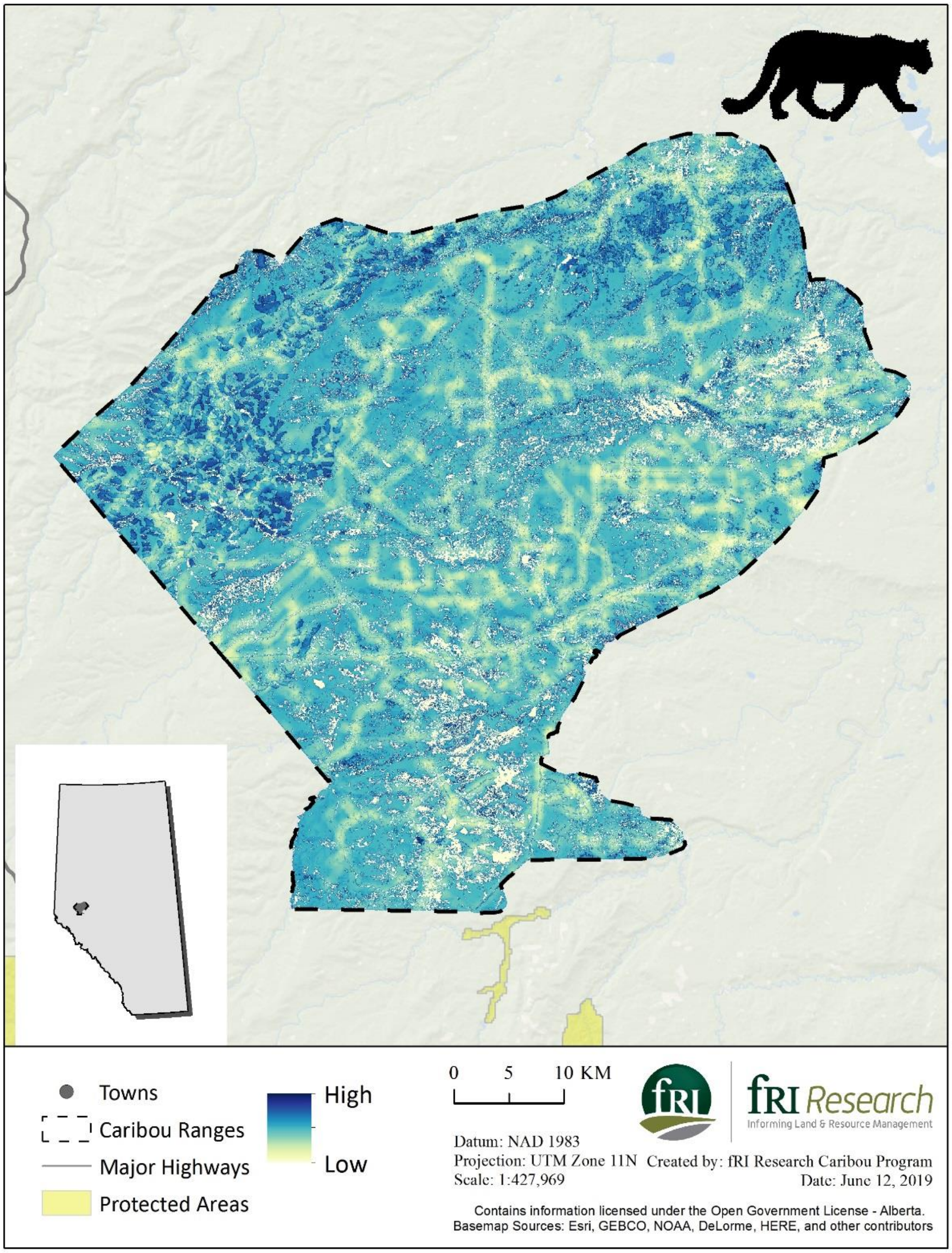

Figure 3.3. Predicted probability of cougar occurrence during summer in the Little Smoky caribou range in west-central Alberta, Canada. Coefficients were derived by Knopff et al. (2014a). Landscape condition data were updated to 2015.

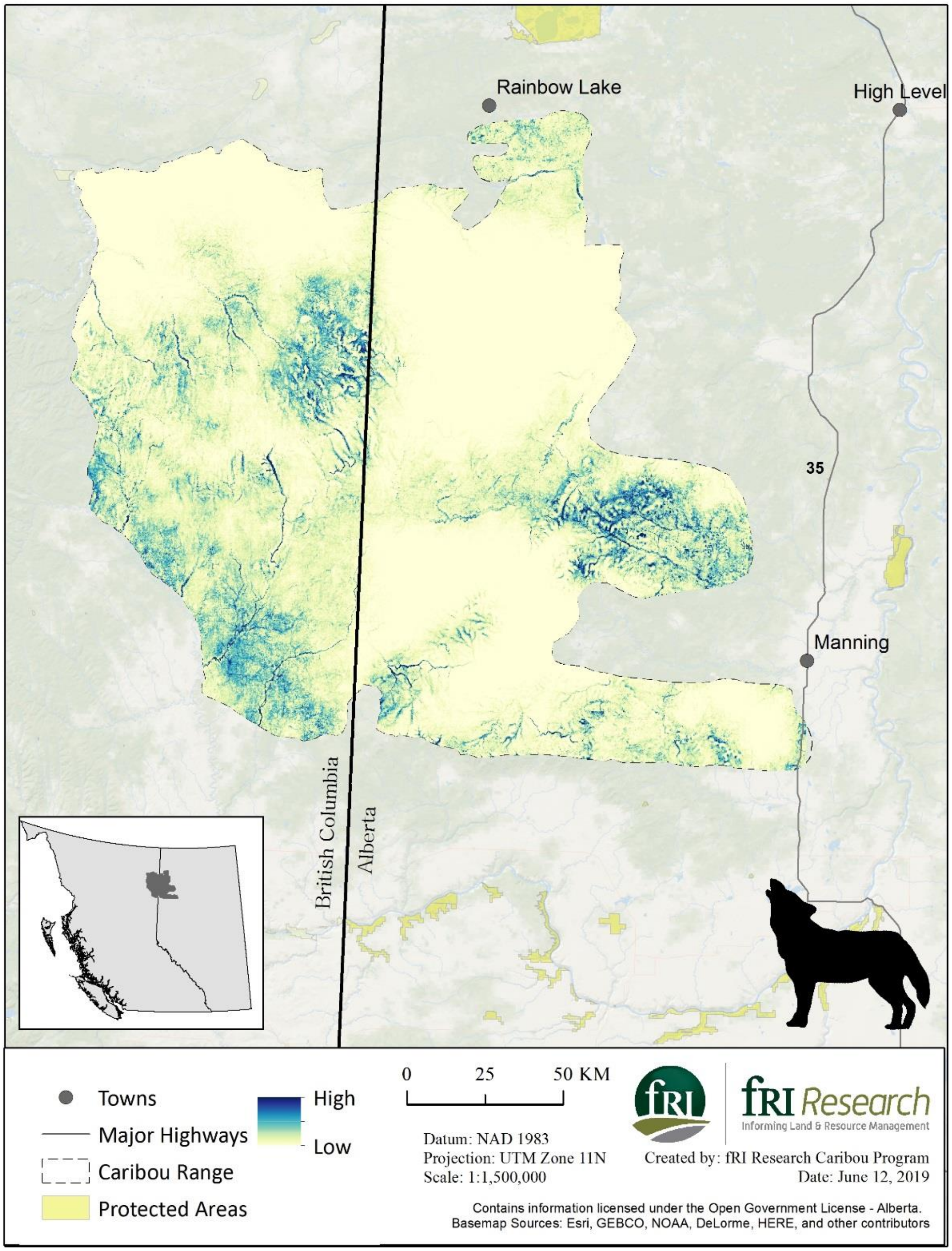

Figure 3.4. Predicted probability of wolf occurrence during summer in the Chinchaga caribou range in north-western Alberta and north-eastern British Columbia, Canada. Coefficients were derived by MacNearney et al. (2016). Landscape condition data were updated to 2015.

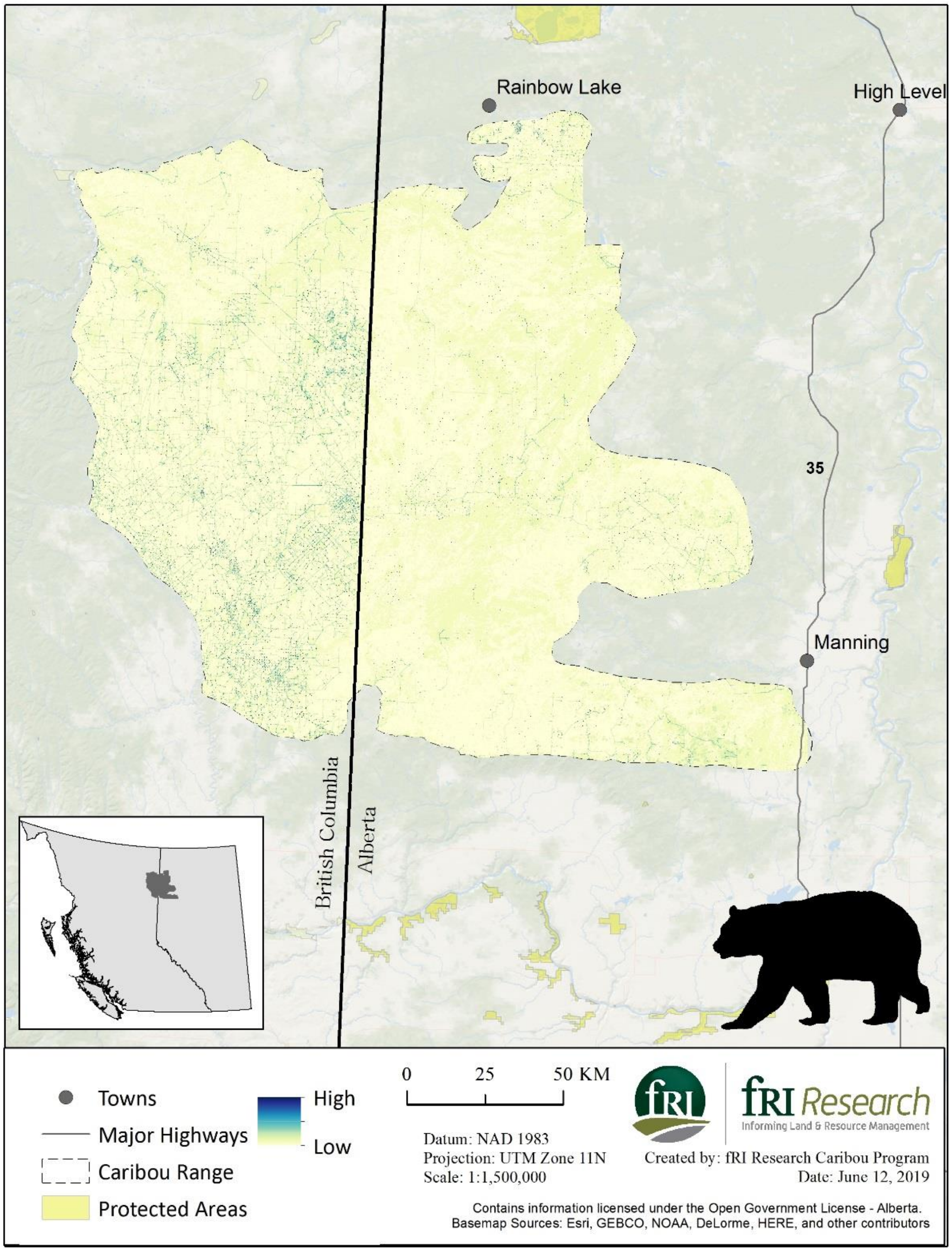

Figure 3.5. Predicted probability of black bear occurrence during the caribou calving season in the Chinchaga caribou range in north-western Alberta and north-eastern British Columbia, Canada. Coefficients were derived from a model of black bear habitat selection developed using GPS location data collected in an adjacent herd (Appendix D; DeMars & Boutin 2017; 2018). Landscape condition data were updated to 2015.

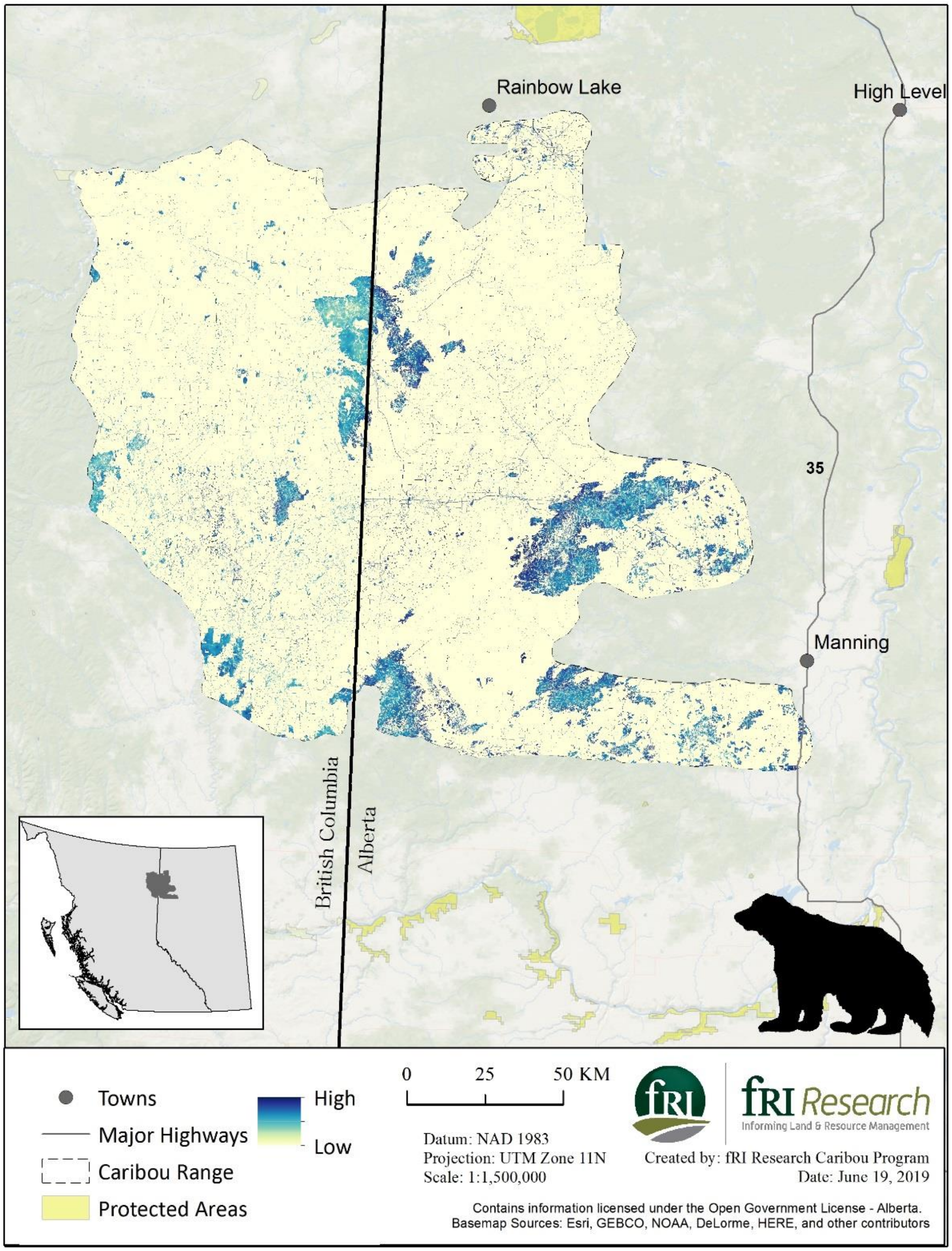

Figure 3.6. Predicted probability of wolverine occurrence during summer (maximum of male and female habitat selection) in Chinchaga caribou range in north-western Alberta and north-eastern British Columbia, Canada. Coefficients were derived by Scrafford et al. (2017). Landscape condition data were updated to 2015.

4. LINKING CALF SURVIVAL TO HABITAT SELECTION AND PREDATION RISK

4.1. INTRODUCTION

Throughout the calving season, female caribou need to fulfill their energetic needs while minimizing exposure to predators. In caribou ranges with extensive anthropogenic disturbance, the high energetic needs of lactation (Chan-McLeod et al., 1994; Parker et al., 2009), combined with the need to avoid predators may result in maladaptive habitat selection, where females with calves must compromise their access to forage in order to minimize exposure of themselves and their calves to anthropogenic disturbance and predators (Leblond et al., 2016; Viejou et al., 2018). However, in multi-predator systems, selecting habitat to minimize exposure to one predator may increase the probability of encountering other predators, with potential impacts on calf survival. For example, in eastern Canada, when caribou with calves avoided habitat used by wolves, the calves were at increased predation risk from black bears, and caribou that selected for areas preferred by black bears were more likely to lose their calves (Leblond et al., 2016). In the Rocky Mountains, research indicates that caribou with calves generally prioritize access to forage over predation risk, but avoid areas preferred by wolves and grizzly bears while selecting areas preferred by black bears, coyote, and wolverine (Chow-Fraser, 2018). Understanding how calf survival is linked to landcover, topography, anthropogenic disturbance, and overlap with multiple predators will help to inform habitat restoration priorities, with the potential to increase caribou calf survival.

In this Chapter, we assessed associations between landcover, topography, anthropogenic disturbance, predation risk, and caribou calf survival. Specifically, i) we investigated habitat selection at the herd- and home-range scales for caribou with calves that lived and for caribou that lost calves, and ii) we used latent selection differences to directly compare habitat selection of caribou with calves that lived and caribou that lost calves.

4.2. Methods

4.2.1. Habitat selection and calf survival

We assessed habitat selection of caribou with calves that lived and habitat selection of caribou that lost calves using two sets of GLMMs. We used the same approach outlined for calving season habitat selection to build models at the herd- and home-range scales, comparing adult female caribou GPS locations to available locations drawn from within the herd range or within individual caribou home ranges, and using univariate analyses to select the best scale for disturbance variables and predator RSFs (see Appendix B for details).

4.2.2. Latent selection difference and calf survival

We directly assessed differences in habitat selection (*latent selection difference* (Latham et al., 2013a) or *resource separation analysis* (Peters et al., 2013), between caribou with calves that lived and caribou that lost calves. Following Dussault et al. (2012) and Leclerc et al. (2014) we generated 100 datasets with different random pairings of GPS locations between a caribou with a calf that lived to GPS locations from a caribou that lost her calf (see Tables A.1 and A.2), restricting data to the same days for each caribou pair (see Appendix E for details). Positive values indicate that a landcover, topographic, anthropogenic disturbance, or predator occurrence variable is selected more by females that lost calves in comparison to females with calves that lived, and negative values indicate that a variable is selected less by females that lost calves in comparison to females with calves that lived.

4.3. Results

Due to negative correlations between predator RSFs at some scales and positive correlations between predator RSFs, landcover and disturbance, we were not able to include all predator RSFs in every model. However, we were interested in assessing the links between calf survival and all predators. Therefore, if a predator RSF was excluded from the model building process due to correlation, we built supplemental models including that predator RSF. These models are included in Appendix E.

4.3.1. Habitat selection and calf survival

4.3.1.1. Little Smoky

At the herd-and home-range scales, Little Smoky caribou with calves that lived selected areas with lower densities of disturbance than expected based on habitat availability within herd and home ranges. They also selected wet areas and mixed and broadleaf forest at the herd-range scale, and selected ridges (high TPI values) and north-facing areas at the home-range scale (Table 4.1). At both scales, Little Smoky caribou with calves that lived selected areas less likely to be used by wolves and grizzly bears and more likely to be used by cougars (Table 4.1).

At the herd- and home-range scales, Little Smoky caribou that lost calves selected areas with lower densities of disturbance than expected based on habitat availability within herd and home ranges. They also selected wet areas and mixed, broadleaf, and conifer forest at the herd-range scale (Table 4.1). At the herd-range scale they selected areas less likely to be used by wolves and more likely to be used by cougars, but at the home-range scale, they selected areas more likely to be used by wolves and less likely to be used by cougars. At both scales they selected areas more likely to be used by grizzly bears. K-fold cross validation indicated moderate to excellent predictive power of models (Table 4.1).

Table 4.1. Parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) for generalized linear mixed models used to identify factors determining calving season habitat selection of caribou with calves that lived and caribou that lost their calves in the Little Smoky herd at the herd- and home-range scales in west-central Alberta, Canada, between 2000 and 2015. Mean, minimum, and maximum r_s values from K-fold cross validation are also shown. Variables are described in Table B.1.

	Calf lived						Calf lost					
	Herd			Home			Herd			Home		
	β	LCL	UCL	β	LCL	UCL	β	LCL	UCL	β	LCL	UCL
Intercept	-1.45	-1.83	-1.08	10.02	8.25	11.80	-9.05	-10.15	-7.95	-20.02	-22.22	-17.81
Road 90m	-	-	-	-	-	-	-0.77	-1.00	-0.53	-	-	-
Road 1km	-1.25	-1.36	-1.15	-	-	-	-	-	-	-	-	-
Pipe 90m	-	-	-	-	-	-	-0.58	-0.84	-0.32	-0.52	-0.78	-0.25
Pipe 1km	-	-	-	-3.66	-3.96	-3.36	-	-	-	-	-	-
Seismic 90m	-0.19	-0.20	-0.18	-0.14	-0.16	-0.13	-0.15	-0.18	-0.13	-0.16	-0.18	-0.14
Cut 90m	-	-	-	-	-	-	-1.65	-2.07	-1.23	-1.49	-1.85	-1.13
Cut 1km	-	-	-	-28.95	-33.23	-24.67	-	-	-	-	-	-
Well 1km	-0.26	-0.32	-0.20	-	-	-	-	-	-	-0.99	-1.12	-0.86
Wetness (CTI)	0.08	0.06	0.09	-	-	-	0.06	0.03	0.08	-	-	-
TPI	-	-	-	0.72	0.42	1.02	-	-	-	-	-	-
Northness	-	-	-	-0.08	-0.14	-0.02	-	-	-	-	-	-
Water and wetlands	0.13	0.05	0.22	-	-	-	-	-	-	-	-	-
Conifer	-	-	-	-	-	-	0.52	0.35	0.70	-	-	-
Mixed and broadleaf	0.54	0.42	0.65	-	-	-	1.16	0.88	1.43	-	-	-
Wolf 90m	-	-	-	-0.04	-0.07	0.00	-	-	-	-	-	-
Wolf 1km	-0.64	-0.68	-0.59	-	-	-	-	-	-	1.41	1.29	1.52
Wolf 5km	-	-	-	-	-	-	-4.80	-5.08	-4.51	-	-	-
Grizzly bear 5km	-	-	-	-1.77	-1.77	-1.36	1.31	1.19	1.43	2.22	1.99	2.44
Cougar 1km	-	-	-	-	-	-	-	-	-	-1.36	-1.51	-1.22
Cougar 5km	0.41	0.33	0.49	-	-	-	4.05	3.79	4.31	-	-	-
Mean r_s (min, max)	0.98 (0.84, 1)			0.74 (0.06, 0.99)			0.55 (-0.83, 0.92)			0.78 (0.59, 0.96)		

4.3.1.2. Chinchaga

At the home-range scale, Chinchaga caribou with calves that lived selected areas with lower densities of disturbance than expected based on habitat availability, and avoided shrub and herb habitat, while at the herd-range scale, they selected areas at higher elevation. At the herd- and home-range scales, Chinchaga caribou with calves that lived selected valleys (low TPI values) and avoided mixed and broadleaf forest (Table 4.2). At both scales, Chinchaga caribou with calves that lived selected areas less likely to be used by wolves and wolverines, and at the herd-range scale they selected areas less likely to be used by black bears (Table 4.2; Appendix E: Table E.1).

At the herd-range scale, Chinchaga caribou that lost calves selected areas with higher densities of wildfires than expected based on habitat availability, lower elevations, west-facing areas, and water and wetland habitat. At the home-range scale, Chinchaga caribou that lost calves selected wetter areas (high CTI) and north or west-facing areas, and avoided conifer forest (Table 4.2). At both scales, Chinchaga caribou that lost calves selected areas less likely to be used by wolves, wolverines, and black bears (Table 4.2). K-fold cross validation indicated fair to moderate power of models (Table 4.2; Appendix E: Table E.1).

Table 4.2. Parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) for generalized linear mixed models used to identify factors determining calving season habitat selection of caribou with calves that lived and caribou that lost their calves in the Chinchaga herd at the herd- and home-range scales in north-western Alberta and north-eastern British Columbia, Canada, between 2000 and 2015. Mean, minimum, and maximum r_s values from K-fold cross validation are also shown. Variables are described in Table B.1.

	Calf lived						Calf lost					
	Herd			Home			Herd			Home		
	β	LCL	UCL	β	LCL	UCL	β	LCL	UCL	β	LCL	UCL
Intercept	-4.42	-6.14	-2.72	-14.71	6.19	23.22	18.97	14.95	22.98	3.09	-1.15	7.33
Fire 90m	-	-	-	-1.24	-1.62	-0.86	-	-	-	-	-	-
Fire 1km	-	-	-	-	-	-	2.05	1.56	2.54	-	-	-
Well 5km	-	-	-	-7.67	-10.87	-4.46	-	-	-	-	-	-
Elevation	3.28	1.46	5.11	-	-	-	-5.91	-9.73	-2.09	-	-	-
Wetness (CTI)	-	-	-	-	-	-	-	-		0.27	0.07	0.47
TPI	-0.04	-0.06	-0.02	-0.06	-0.09	-0.03	-	-	-	-	-	-
Eastness	-	-	-	-	-	-	-0.54	-0.80	-0.28	-0.25	-0.49	-0.01
Northness	-	-	-	-	-	-	-	-	-	0.25	0.02	0.48
Water and wetlands	-	-	-	-	-	-	0.88	0.50	1.27	-	-	-
Shrub/herb	-	-	-	-0.70	-1.30	-0.10	-	-	-	-	-	-
Conifer	-	-	-	-	-	-	-	-	-	-0.91	-1.41	-0.41
Mixed and broadleaf	-1.52	-2.13	-0.91	-0.84	-1.49	-0.20	-	-	-	-	-	-
Wolf 1km	-	-	-	-	-	-	-5.18	-7.02	-3.33	-1.56	-3.06	-0.05
Wolf 5km	-5.92	-6.97	-4.86	-2.71	-5.00	-0.43	-	-	-	-	-	-
Black bear 90m	-	-	-	-2.24	-4.71	0.22	-	-	-	-9.80	-15.33	-4.27
Black bear 1km	-	-	-	-	-	-	-3.05	-3.73	-2.37	-	-	-
Wolverine 1km	-	-	-	-	-	-	-	-	-	-0.85	-1.55	-0.16
Wolverine 5km	-	-	-	-2.39	-3.72	-1.06	-5.18	-7.02	-3.33	-	-	-
Mean r_s (min, max)	0.65 (-0.21, 0.94)			0.51 (-0.36, 0.96)			0.45 (-0.79, 0.97)			0.68 (-0.43, 0.97)		

4.3.2. Latent selection difference and calf survival

4.3.2.1. Little Smoky

In comparison to caribou with calves that lived, Little Smoky caribou that lost calves were more likely to select areas with higher densities of pipelines, seismic lines, and cutblocks, and more likely to select valleys (low TPI), and areas with lower slopes (Table 4.3). Little Smoky caribou that lost calves were also more likely to select areas used by wolves and grizzly bears, and areas less likely to be used by cougars (Table 4.3; Appendix E: Table E.2).

Table 4.3. Mean parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) for generalized linear mixed models used to identify factors determining calving fate in the Little Smoky herd in west-central Alberta, Canada, between 2000 and 2015. Models compared locations of caribou whose calf lived to those that lost calves across 100 iterations. The reference category for calf survival was 'calf lived'. Variables are described in Table B.1.

	β	LCL	UCL
Intercept	-4.55	-5.57	-3.54
Pipe 1km	1.68	1.35	2.01
Seismic 1km	0.22	0.18	0.26
Cut 1km	19.53	15.27	23.79
Slope	-0.09	-0.12	-0.07
TPI	-3.56	-3.75	-3.37
Wolf 5km	0.51	0.29	0.73

4.3.2.2. Chinchaga

In comparison to caribou with calves that lived, Chinchaga caribou that lost calves were more likely to select areas with lower densities of roads and higher densities of wildfires (Table 4.4). They were also more likely to select lower slopes and areas that were south or west facing, and were more likely to avoid mixed, broadleaf, and conifer forest (Table 5.4). Chinchaga caribou that lost calves were more likely to select areas used by wolves and black bears, and areas less likely to be used by wolverines (Table 5.4).

Table 4.4. Mean parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) for generalized linear mixed models used to identify factors determining calving fate in the Chinchaga herd at the herd- and home-range scale in north-western Alberta and north-eastern British Columbia, Canada, between 2000 and 2015. Models compared locations of caribou whose calf lived to those that lost calves across 100 iterations. The reference category for calf survival was 'calf lived'. Variables are described in Table B.1.

	β	LCL	UCL
Intercept	-39.05	-56.13	-21.97
Road 1km	-0.71	-1.31	-0.11
Fire 1km	9.53	7.80	11.26
Slope	-0.62	-0.73	-0.51
Eastness	-0.86	-1.05	-0.68
Northness	-0.43	-0.51	-0.34
Conifer	-0.73	-0.87	-0.58
Mixed and broadleaf	-1.19	-1.39	-0.99
Wolf 5km	9.02	3.31	14.74
Black bear 5km	11.9	8.53	15.31
Wolverine 5km	-1.74	-3.70	0.21

4.4 Discussion

We found that from large to fine spatial scales, habitat selection strategies of female caribou with calves influenced calf survival. Specifically, we found that calves were more likely to survive when their mothers avoided anthropogenic disturbance and areas preferred by multiple predators. In contrast, females were more likely to lose their calf if they selected for or showed no response to disturbance, or if females avoided only areas preferred by wolves, rather than avoiding areas preferred by both wolves and bears,. Overall, during the calving season, caribou with calves that lived appeared to balance their access to forage against predation risk from multiple predators.

At the herd- and home-range scales in Little Smoky, both caribou with calves that lived and caribou that lost calves avoided disturbance and selected mixed and broadleaf forest, a landcover type that is likely to have more vegetative food (Leclerc et al., 2014; Pinard et al., 2012). However, only caribou with calves that lived appeared to be able to avoid predation risk from both wolves and grizzly bears from large to fine scales. Also, although calving caribou in Little Smoky generally avoided disturbance, caribou that lost calves were less likely to avoid disturbance when compared to caribou with calves that lived, and were more likely to select habitat preferred by wolves and other predators (e.g., low slope and valley bottoms (Apps et al., 2013; DeCesare et al., 2014; Latham et al., 2011). The association between calf survival and overlap with wolves has been previously described (e.g., Chow-Fraser, 2018; Leblond et al., 2016; Viejou et al., 2018); however, the link between calf survival and bear occurence is less clear. For example, in eastern Canada, adult female caribou minimized their exposure to wolves, but did not minimize their exposure to predation risk from black bears (Leblond et al., 2016; Schindler, 2018), possibly because black bears rarely prey on adult caribou (Ballard, 1994; Edmonds, 1988; Peters et al., 2013; Wittmer et al., 2005b), and black bear predation on caribou calves is largely opportunistic (Bastille-Rousseau et al., 2011). Similarly, in Sweden, Sivertsen et al. (2016) found that semi-domesticated reindeer did not reduce their exposure to predation risk from brown bears during the calving season. In contrast, we found that adult female caribou with calves that lived appear to recognise predation risk from both wolves and grizzly bears, possibly because grizzly bears prey upon both adult caribou and their calves (Finnegan et al., 2016; Gustine et al., 2006a; Kinley and Apps, 2001), and unlike Swedish semi-domesticated reindeer (Sivertsen et al., 2016), wild caribou in our study area remain adapted to cope with predators. Similarly, in central mountain herds just west of the Little Smoky range, where grizzly bears occur in relatively high densities (Alberta Grizzly Bear Inventory Team, 2008), Chow-Fraser (2018) found that caribou with calves that lived minimized their exposure to predation risk from both wolves and grizzly bears, but selected areas preferred by black bears.

In Chinchaga, like Little Smoky, both caribou with calves that lived and caribou that lost calves avoided disturbance. However, in contrast to Little Smoky, Chinchaga caribou with calves that lived avoided mixed and broadleaf forest and selected higher elevations, while caribou that lost calves avoided conifer forest and selected lower elevations, wetter areas and wetlands. As discussed in Chapter 2, by avoiding mixedwood and deciduous stands and selecting higher elevations, caribou with calves that lived are likely decreasing their exposure to predation (DeMars, 2015; McLoughlin et al., 2005), and we did find that caribou with calves that lived avoided areas preferred by wolves, wolverines, and black bears. In comparison, by selecting flat areas, low slopes, water, and wetland habitat, Chinchaga caribou that lost calves may be prioritizing access to vegetative food in fens and bogs over exposure to predation risk (DeCesare et al., 2014; DeMars, 2015; Mumma et al., 2017). Although we found that Chinchaga caribou that lost calves avoided predation risk from wolves, wolverines, and black bears at the herd- and home-ranges scales, similar to Leblond et al. (2016), we found that in comparison to caribou with calves that lived, caribou that lost calves were more likely to select areas used by wolves and black bears. In addition, compared to caribou with calves that lived, caribou that lost calves avoided areas with more hiding cover (e.g., conifer and mixed and broadleaf forest) and selected previously burned areas, possibly selecting access to vegetative forage over reducing exposure to predation risk (Chow-Fraser, 2018; Dussault et al., 2012; Gustine et al., 2006a).

We found few links between calf fate and overlap with either cougars or wolverines during the calving season. In Little Smoky, areas preferred by cougars were avoided by wolves, and vice versa (Finnegan et al., 2016); therefore, it is possible that in Little Smoky caribou prioritize decreasing wolf predation risk over predation risk from cougars. Cougars are known predators of adult caribou, and in a study in west-central Alberta, 4 of 25 caribou mortalities investigated between 2013 and 2018 were attributed to cougars (Finnegan et al., 2016). However, cougar range expansion in Alberta is relatively recent (Knopff et al., 2014b), and adult female caribou may not yet perceive them as predators to avoid. For wolverines, like Chow-Fraser (2018), we found that caribou with calves either did not respond to wolverines, or selected areas preferred by wolverines, and exposure to wolverine predation risk was not linked to decreased calf survival. Although Gustine (2006a) reported that 5 of 17 calves killed by predators were attributed to wolverines (an equal number to those killed by wolves), is possible that in our boreal caribou herds, wolverines are less abundant than in the mountain herds included in their study; therefore, adult females do not prioritize minimizing their exposure to wolverine predation risk.

5. SYNTHESIS

Habitat restoration and management of predators and alternate prey are recognized as key components of caribou recovery (Environment Canada, 2014, 2012). However, restoring ecosystem function for caribou is complex because any conservation effort needs to balance a suite of biological, ecological, and economic factors (Hebblewhite, 2017; Schneider et al., 2012, 2010). Although habitat restoration is urgently needed within caribou ranges, the magnitude of the current disturbance footprint means that conservation efforts need to be prioritized (Noss et al., 2009), and prioritization schemes that consider the entire caribou life history, from parturition to predation, are likely to be the most effective for caribou recovery.

Here we used a non-invasive approach (DeMars et al., 2013) to identify areas that are used by caribou during the calving season and to link calf survival to habitat, disturbance and predation risk. Using GPS data collected between 2000 and 2015 in the Little Smoky and Chinchaga boreal caribou ranges we found that:

- Caribou calved between April 25th and June 8th. In Little Smoky, 73% of monitored females calved and 45% of those calves survived to 4 weeks. In Chinchaga, 58% of monitored females calved and 55% of those calves survived to 4 weeks.
- In both herds, caribou calved in areas with lower densities of anthropogenic disturbance, and Chinchaga caribou also calved in areas at higher elevations or in wet areas.
- During the weeks after the calving events (i.e., calving season), caribou in both herds continued to avoid areas with anthropogenic disturbance and selected habitat with more forage (Little Smoky: mixed and broadleaf forest and shrub/herb landcover; Chinchaga: water and wetlands). By selecting mixed and broadleaf forest, shrub/herb habitat, and high elevations, Little Smoky caribou seemed to balance access to forage and exposure to predation risk. In contrast, by selecting water, wetlands, and low elevations, Chinchaga caribou seemed to proiritize access to forage over minimizing exposure to predation risk.
- In both herds, caribou that lost calves were generally more likely to select anthropogenic disturbance, wildfires and areas used by grizzly bears or and black bears when compared to caribou with calves that lived.
- Chinchaga caribou that lost calves were also more likely to avoid forest habitat with more cover (conifer, mixed and broadleaf forest); possibly prioritizing access to forage over exposure to predation risk.

Overall, the results of our analyses were consistent with previous research on boreal and mountain caribou (DeMars and Boutin, 2018; Nobert et al., 2016; Pinard et al., 2012; Skatter et al., 2017) and further highlight the links between habitat disturbance, predation risk, and caribou survival (DeCesare, 2012; Leclerc et al., 2014; McLoughlin et al., 2003). Our models of calving site and calving season habitat selection (Chapter 2) could be used in spatio-temporal planning of human activities (i.e. harvesting, building of infrastructure, and habitat restoration) in caribou ranges to mitigate their impacts on caribou and their calves during the vulnerable neonatal period. Also, by building models of predation risk for multiple predators, our study revealed that caribou that were able to minimize their overlap with not only wolves, but also grizzly bears (Little Smoky) or black bears (Chinchaga) were likely to have their calf survive past 4 weeks of age. For other predators (cougars, wolverines), we found few links between overlap with areas likely to be used by those predators and calf survival, however we recognise that our models for those species were extrapolated, and may not accurately reflect realized predation risk from those species in our study area. In addition there were a number of predators that we could not include in models that are predators of caribou and their calves (i.e. black bears and wolverines in Little Smoky, coyote, lynx in both herd ranges). Including models of those predators when available may reveal further insights into links between calving season selection, access to forage, habitat disturbance, and overlap with a number of predators and survival of caribou calves.

Appendix A: Identifying calving sites – detailed methods and results

A.1 Identifying caribou calving sites

We used the individual based method (IBM) of DeMars et al. (2013) to estimate the timing and locations of calving events and calf survival. The IBM modeling approach uses movement patterns of individuals to identify sudden and marked reductions from normal movement patterns; these are termed 'break points'. Break points are based on three movement models: i) did not calve – M0; ii) calved and calf survived to 4 weeks – M1; and iii) calved with subsequent calf loss prior to 4 weeks – M2; Figure A1). The initial break point when the movement of the adult female caribou decreases (BP1) is linked to a particular GPS record, which is the assumed calving site. The second break point (BP2) is associated with the timing and location of the presumed calf mortality. Further details of the IBM approach can be found in DeMars et al. (2013) and additional details of our analysis were previously described in Poole et al. (2018).

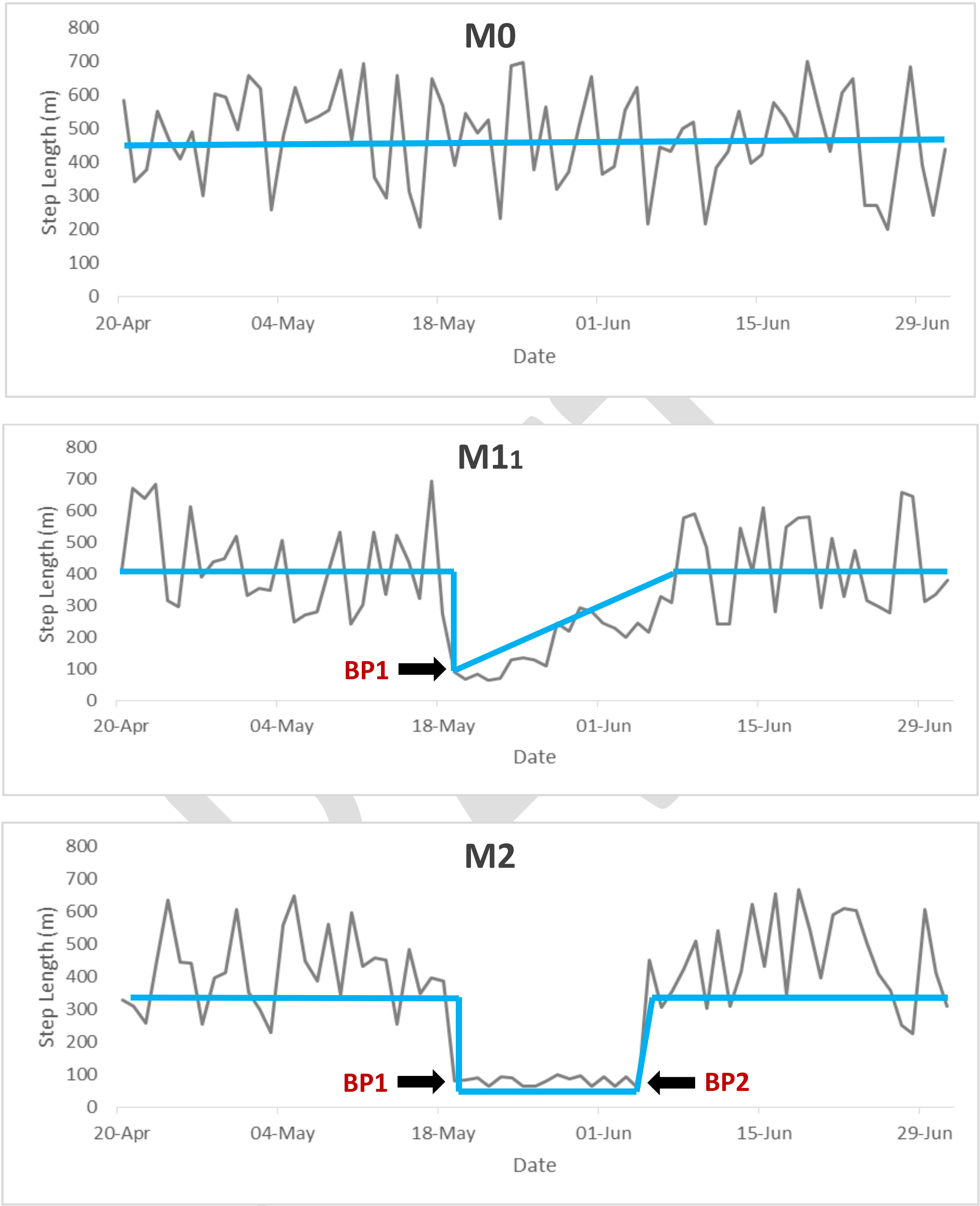

Figure A.1. Examples of movement models representing the three movement states of female caribou during the calving season identified using the individual-based method: caribou did not calve (M0), caribou calved and the calf survived (M1), and caribou calved and the calf died (M2). Break points associated with the estimated calving event (BP1) and calving mortality (BP2) are also shown.

A.2. Results

Table A.1. Summary of results from individual based (IBM) analysis of adult female caribou GPS location data during the calving season using to identify calving events and calf survival (Status, Calving Date, Calf Lost Date) for the Little Smoky caribou herd, Alberta, Canada, between 2000 and 2015.

Year	ID	Fix Rate Success	Status	Calving Date	Calf Lost Date
2015	C2240	0.98	Did not calve	-	-
2015	C2241	0.98	Calved; calf died	05/10/2015	05/29/2015
2015	C2242	0.99	Calved; calf died	05/15/2015	06/06/2015
2015	C2187	0.97	Calved; calf survived	05/12/2015	-
2014	C2187	0.97	Calved; calf survived	05/20/2014	-
2015	C2188	0.97	Did not calve	-	-
2014	C2188	0.97	Calved; calf died	05/27/2014	05/31/2014
2015	C2189	0.99	Calved; calf survived	05/18/2015	-
2014	C2189	0.98	Calved; calf died	05/24/2014	05/28/2014
2015	C2190	0.98	Did not calve	-	-
2014	C2190	0.98	Calved; calf died	05/30/2014	06/05/2014
2015	C2191	0.98	Calved; calf died	05/25/2015	05/31/2015
2014	C2191	0.98	Calved; calf survived	05/17/2014	-
2010	C1516	0.89	Calved; calf survived	05/19/2010	-
2009	C1516	0.94	Calved; calf died	05/24/2009	06/07/2009
2010	C1089	0.86	Calved; calf died	05/25/2010	06/27/2010
2009	C1089	0.9	Calved; calf survived	05/30/2009	-
2008	C1089	0.88	Calved; calf died	05/19/2008	05/28/2008
2007	C1089	0.89	Did not calve	-	-
2009	C1524	0.89	Calved; calf survived	06/03/2009	-
2008	C1353	0.89	Calved; calf survived	05/23/2008	-
2008	C1091	0.89	Did not calve	-	-
2007	C1091	0.88	Calved; calf survived	05/29/2007	-
2008	C1092	0.93	Did not calve	-	-
2007	C1092	0.88	Did not calve	-	-
2007	C1090	0.87	Calved; calf survived^	05/15/2007	-
2007	C1093	0.94	Calved; calf died	05/20/2007	06/02/2007
2005	C960	0.87	Calved; calf survived	05/09/2005	-
2005	C964	0.60	Calved; calf died	05/25/2005	06/04/2005
2005	C1015	0.88	Calved; calf survived	05/14/2005	-
2005	C1024	0.73	Calved; calf survived	05/17/2005	-
2005	C1034	0.71	Calved; calf survived	05/22/2005	-
2005	C1035	0.60	Did not calve	-	-
2004	C1009	0.72	Calved; calf died	05/22/2004	05/25/2004

2003	C1009	0.76	Calved; calf died	05/20/2003	05/30/2003
2004	C1017	0.78	Calved; calf survived	05/13/2004	-
2003	C1017	0.82	Calved; calf survived	05/26/2003	-
2004	C1010	0.66	Calved; calf survived	05/30/2004	-
2003	C1010	0.61	Calved; calf died	05/21/2003	06/04/2003
2004	C1012	0.87	Calved; calf died	05/12/2004	05/22/2004
2003	C1012	0.88	Calved; calf died	05/20/2003	05/24/2003
2004	C1019	0.87	Calved; calf survived	05/25/2004	-
2004	C1022	0.89	Calved; calf survived	05/27/2004	-
2004	C1023	0.85	Calved; calf died	05/27/2004	06/05/2004
2004	C1026	0.79	Calved; calf survived	05/22/2004	-
2004	C1027	0.66	Calved; calf survived	05/27/2004	-
2003	C992	0.78	Did not calve	-	-
2002	C992	0.76	Calved; calf died	05/22/2002	06/02/2002
2003	C1011	0.87	Calved; calf survived	05/23/2003	
2003	C1083	0.97	Calved; calf died	05/15/2003	05/16/2003
2002	C989	0.89	Did not calve	-	-
2002	C994	0.71	Did not calve	-	-
2002	C995	0.74	Calved; calf died	06/08/2002	07/01/2002
2002	C996	0.55	Calved; calf died	05/27/2002	06/03/2002
2002	C990	0.66	Calved; calf died	05/23/2002	06/13/2002
2002	C984	0.86	Calved; calf died	05/22/2002	06/03/2002
2001	C966	0.85	Calved; calf died	05/24/2001	06/05/2001
2000	C966	0.65	Calved; calf died	05/19/2000	05/25/2000
2000	C963	0.75	Calved; calf died	05/23/2000	06/10/2000

Table A.2. Summary of results from individual based (IBM) analysis of adult female caribou GPS location data during the calving season using to identify calving events and calf survival (Status, Calving Date, Calf Lost Date) for the Chinchaga caribou herd, Alberta and British Columbia, Canada, between 2004 and 2009.

Year	ID	Fix Rate Success	Status	Calving Date	Calf Lost Date
2009	C1520	0.90	Calved; calf survived	5/17/2009	-
2009	C1521	0.95	Calved; calf survived	5/13/2009	-
2009	C1522	0.93	Calved; calf survived	5/14/2009	-
2009	C1224	0.95	Calved; calf survived	5/12/2009	-
2008	C1224	0.96	Calved; calf died	5/24/2008	6/6/2008
2009	C1225	0.95	Calved; calf survived	5/7/2009	-
2008	C1225	0.97	Calved; calf died	5/10/2008	5/14/2008
2009	C1226	0.95	Calved; calf survived	5/12/2009	-
2008	C1226	0.91	Calved; calf died	4/25/2008	5/3/2008
2009	C1228	0.95	Calved; calf survived	5/14/2009	-
2008	C1228	0.95	Calved; calf died	6/1/2008	6/6/2008
2009	C1229	0.97	Did not calve	-	-
2008	C1229	0.96	Calved; calf died	5/26/2008	5/30/2008
2009	C1230	0.94	Calved; calf survived	5/11/2009	-
2008	C1230	0.95	Calved; calf survived	5/28/2008	-
2009	C1233	0.94	Calved; calf survived	5/4/2009	-
2008	C1233	0.95	Calved; calf died	5/8/2008	6/3/2008
2008	C1234	0.81	Calved; calf survived	5/6/2008	-
2007	C1234	0.93	Calved; calf died	5/15/2007	6/14/2007
2007	C1235	0.80	Calved; calf died	5/9/2007	5/17/2007
2007	C1236	0.97	Did not calve	-	-
2007	C1237	0.96	Did not calve	-	-
2007	C1238	0.96	Calved; calf died	5/18/2007	6/1/2007
2005	C152.341	76.09	Calved; calf survived	05/12/2005	-
2004	C152.341	89.37	Calved; calf died	05/23/2004	06/03/2004
2004	C152.019	0.85	Did not calve	-	-
2004	C152.027	0.85	Did not calve	-	-
2004	C152.039	0.76	Did not calve	-	-
2004	C152.049	0.78	Calved; calf survived	05/03/2004	-
2004	C152.070	85.60	Did not calve	-	-
2004	C152.120	93.21	Calved; calf died	05/21/2004	05/30/2004
2004	C152.209	89.95	Calved; calf died	05/07/2004	05/17/2004

Appendix B: Explanatory variables

The habitat and topographic variables that we used to build models of habitat selection are shown in Table B.1. For habitat, we used landcover derived from LandSat imagery captured in 2000 (Canadian Forest Service Earth Observation for Sustainable Development of Forest (EOSD) cover map; Natural Resources Canada 2009) which we re-classified and combined into 5 categories for data analysis: 1) conifer forest, 2) shrub and herb, 3) alpine, 4) mixed and broadleaf forest, and 5) water and wetlands. Using a 30m x 30m resolution digital elevation model (DEM), we extracted values of elevation, aspect, slope, terrain wetness (compound topographic index, CTI; Gessler et al. 2000), and topographic position index (TPI); positive TPI values indicate ridges or hilltops, while negative values represent valley bottoms (Jenness, 2006). We calculated aspect as indices of eastness and northness (Gustine et al., 2006b; Nobert et al., 2016).

For wildfires, pipelines, roads, wellsites, and seismic lines, we used open-source provincial datasets from Alberta and British Columbia. For wildfires, we only included wildfire ≤ 60 years old in our analysis. We were interested in the separate influences of pipelines, roads, and seismic lines on caribou, however, many pipelines within our study area are immediately adjacent to roads. Therefore, to isolate the influence of pipelines on caribou predation risk, we generated a pipeline dataset for the Little Smoky caribou range that excluded pipelines within 30m of roads. In the Chinchaga range, all pipelines were within 30m of roads, therefore we excluded pipelines from the Chinchaga analysis. For seismic lines, we only considered conventional seismic lines (> 5m in width) in our analysis in the Little Smoky caribou ranges. We were unable to acquire seismic line data for portion of the Chinchaga range that falls within British Columbia, therefore we excluded seismic lines from the Chinchaga analysis. For cutblocks, we used data provided by Alberta Forest Management Agreement (FMA) holders within our study area and open source data for British Columbia; we included cutblocks ≤ 30 years old in our analysis. Because landscape change within the study area was ongoing, we generated annual datasets for wildfire, pipelines, roads, wellsites, and cutblocks, (2000 to 2015). All conventional seismic lines (hereafter “seismic lines”) in our study area were constructed prior to 2006, therefore we generated a single dataset for seismic lines that was applied across all years of analysis.

For predators, we used coefficients available from within our study area (DeCesare et al., 2014; Nielsen, 2007) or coefficients available from areas adjacent to our study area (MacNearney et al., 2016; Scrafford et al., 2017) to map predator occurrence. We also developed a black bear habitat selection model using data collected in an area adjacent to the Chinchaga range (DeMars and Boutin, 2018, 2017) and used the resulting coefficients to map black bear occurrence in the Chinchaga range. Details of predator RSFs are in Chapter 4 and the black bear RSF is described in Appendix D. We calculated predator RSFs at three scales: 90m, 1km, and 5km (Table B.1).

Table B.1. Variables used to assess calving site and season habitat selection ('Calving'), calf survival habitat selection ('Calf fate') for Little Smoky and Chinchaga caribou herds, in Alberta and British Columbia, Canada, between 2000 and 2015. Variables used to build caribou calving season black bear habitat selection models in north-eastern British Columbia in 2013 and 2014 are also shown (see Appendix D for details). All raster data were 30 x 30 m resolution.

Variable	Description	Calving	Calf fate	Black bear
Disturbance				
Road_	Density of roads within 90m, 1km, and 5km radius (km/km^2)	x	x	x
Pipe_	Density of pipelines not adjacent to roads within 90m, 1km, and 5km radius (km/km^2)	x	x	x
Seismic_	Density of seismic lines within 90m, 1km, and 5km radius (km/km^2)	x	x	-
Cutblock_	Density of cutblocks within 90m, 1km and 5km radius (km^2/km^2)	x	x	x
Fire_	Density of areas affected by forest fires 60 years or younger within 90m, 1km and 5km radius (km^2/km^2)	x	x	-
Well_	Density of wellsites within 90m, 1km and 5km radius (wellsites/km^2)	x	x	x
Terrain				
Elevation	Digital elevation model, a measure of elevation (m)	x	x	-
Slope	Terrain slope (°)	x	x	-
Wetness (CTI)	Compound topographic index; measure of soil wetness, unitless	x	x	-
TPI	Topographic Position Index; difference in elevation (m) between a central cell and the mean elevation within a 30m radius, unitless	x	x	-
Eastness	Cosine of aspect (rad), -1 to +1	x	x	-
Northness	Sin of aspect (rad), -1 to +1	x	x	-
Landcover[a]				
Alpine	Glacier, snow, ice, talus	x	x	-
Water and Wetland	Water/Wetland: Land with water table near or above soil surface for enough time to promote wetland	x	x	x
Shrub herb	At least 20% ground cover, vascular plants with and without woody stem	x	x	x
Conifer	Coniferous trees are 75% or more of total basal area.	x	x	x
Mixed and broadleaf	Combined category of mixed forest and broadleaf forest; mixedwood: neither coniferous or broadleaf account for 75% or more of total basal area; broadleaf: broadleaf trees are 75% or more of total basal area.	x	x	x
Predator RSFs				
Wolf_	Resource selection function for wolves during summer (Little Smoky) or denning (Chinchaga) seasons within 90m, 1km, and 5km radius	-	x	-
Grizzly bear_[b]	Resource selection function for grizzly bears – maximum of spring and summer within 90m, 1km, and 5km radius	-	x	-
Cougar_[b]	Resource selection function for cougars – annual within 90m, 1km, and 5km radius	-	x	-
Black bear_[c]	Resource selection function for black bears during the caribou calving season within 90m, 1km, and 5km radius	-	x	-
Wolverine_[c]	Resource selection function for wolverines – maximum of male and female values during summer within 90m, 1km, and 5km radius	-	x	-

[a] Descriptions of landcover adapted from EOSD (Natural Resources Canada, 2009); [b]Little Smoky only; [c]Chinchaga only

Appendix C: Calving site and calving season habitat selection – detailed methods

We constructed resource selection functions (RSFs) for calving site and post-parturition habitat selection using a use-available design (Manly et al., 2002). As scale is important to consider when modeling caribou habitat selection (DeCesare et al., 2012; Schaefer et al., 2000), we examined selection at two scales: i) herd-range scale (second order selection) and ii) home-range scale (third order selection) (Johnson et al., 2006).

C.1. Calving site selection

For calving site RSFs, we assessed calving locations as determined in the IBM process described in A.1. We sampled 20 random locations from each provincial herd boundary (herd-range scale) and from each individual's home range (home-range scale), defining home range as the minimum convex polygon (MCP) enclosing all GPS telemetry locations for that individual during the calving season (15 April – 15 July). We extracted habitat covariates (see Table B.1) to calving locations (i.e., used locations) and random locations (i.e., available locations), and compared habitat covariates at used versus available locations using generalized linear mixed models (GLMM). We specified 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 (Bolker et al., 2009; Fieberg et al., 2010; Gillies et al., 2006). We fit models using the R package 'lme4' (Bates et al., 2015) in R (R Development Core Team, 2015). Before fitting models we assessed correlation among explanatory covariates and removed any one of 2 variables correlated at ≥ 0.6; using univariate analysis and Akaike's Information Criterion (AIC; (Burnham, 2004; Burnham and Anderson, 2002) to identify which of the pair of variables was most influential for downstream analysis. We also used univariate analysis and AIC to identify the most influential scale for each disturbance variable (90m, 1km, or 5km). Also, because moderate collinearity can be problematic when investigating ecological signals, we removed any covariates with a variance inflation factor > 3 (Zuur et al., 2010, 2009).

Our objective was to optimize model fit rather than test competing hypotheses; therefore, we first assessed resource selection within each category of variables (landcover, terrain, disturbance) and used AIC (Burnham, 2004; Burnham and Anderson, 2002) within the drop1 function in the R package 'stats' to retain only influential variables within each of the categories of variables (R Development Core Team, 2015). Once we identified influential variables within each category, we fit a global model that included all the influential variables combined. Finally, we followed the principle of parsimony and used the drop1 function a final time to remove any non-influential variables from the global model for each season. We present results as beta coefficients (β) and lower and upper 95% confidence intervals (LCL, UCL), where positive values indicate that a variable is selected more than expected when compared to a random distribution, and negative values indicate that a habitat or topographic variable is selected less than expected when compared to a random distribution. For mapping, we present results as the relative probability of selection (expβ/1+expβ). We evaluated the predictive ability of final models using k-fold cross validation (Boyce et al., 2002), randomly partitioning data into 20% testing and 80% training datasets and calculating the mean, minimum and maximum spearman rank correlations between fitted and predicted values (r_s) across 100 iterations. Values of r_s closer to 1 indicate better predictive power of a model.

C.2. Calving season habitat selection

We also used GLMMs to assess post-parturition habitat selection of caribou during the calving season. At the herd-range scale, we compared caribou GPS locations (used locations) to randomly sampled available locations within provincial herd range boundaries. At the home-range scale, we compared used locations to available locations within each individual caribou's home range. Home ranges were defined as minimum convex polygons (MCP) encompassing locations for that individual across the spring season, starting at one day past the calving date for an individual and ending with the death of a calf or 28 days after calving event (DeMars et al., 2013). At the herd- and home-range scales we generated 20 available locations per used location to ensure that model coefficients were consistently stable (Northrup et al., 2013). We fit and evaluated models using the approach outlined for calving site analysis. We present results as beta coefficients (β) and lower and upper 95% confidence intervals (LCL, UCL), where positive values indicate that a variable is selected more than expected when compared to a random distribution, and negative values indicate that a habitat or topographic variable is selected less than expected when compared to a random distribution. We also present results as the relative probability of selection. We evaluated the predictive ability of final models using k-fold cross validation.

Appendix D: Black bear habitat selection in north-eastern British Columbia

D.1. Methods

To build black bear habitat selection models we used GPS data collected during the caribou calving season in north-eastern British Columbia in 2012 and 2013 (DeMars and Boutin, 2018, 2017). The GPS data were collected adjacent to the Chinchaga boreal caribou range; therefore, habitat selection models built for that area likely approximate black bear habitat selection within the Chinchaga caribou range. Data were collected from 19 individuals. Further details about black bear GPS data and capture and handling can be found in DeMars and Boutin (2018).

At the home-range scale, we compared used locations (actual GPS locations) to available locations within each individual bear's caribou-calving season home-range, defined as minimum convex polygons (MCPs) encompassing locations for that individual across the calving season. We generated 20 available locations per used location (Northrup et al., 2013). We generated MCPs and available locations using Geospatial Modelling Environment (GME, Beyer, 2012), extracted habitat and disturbance variables (see Table B.1) to used and available locations using the R package 'raster' (Hijmans, 2014), and built habitat selection models (GLMMs) using the R package 'lme4' (Bates et al., 2015) in R (R Development Core Team, 2015); specifying black bear Animal ID as a random effect (Bolker et al., 2009; Fieberg et al., 2010; Gillies et al., 2006). The habitat and disturbance variables used to build models of habitat selection are shown in Table B.1. We fit and validated models using identical methods to those used to fit caribou habitat selection models (see Appendix C). We present results as beta coefficients (β) and lower and upper 95% confidence intervals (LCL, UCL).

D.2. Results

At the home-range scale, during the caribou calving season, black bears selected areas with higher densities of roads, cutblocks, and wellsites, and also selected mixed and broadleaf forest and shrub and herb landcover (Table D.1). K-fold cross validation indicated excellent predictive power for the model (Table D.1).

Table D.1. Parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) for generalized linear mixed models used to identify factors determining black bear caribou calving season habitat selection at the home-range scale in north-eastern British Columbia, Canada in 2012 and 2013. Mean, minimum, and maximum r_s values from K-fold cross validation are also shown. Variables are described in Table B.1.

	β	LCL	UCL
Intercept	-3.39	-3.43	-3.35
Road 90m	3.35	3.25	3.45
Cut 90m	0.35	0.27	0.43
Well 90m	3.25	3.03	3.47
Mixed and broadleaf	0.47	0.43	0.51
Shrub herb	0.20	0.14	0.26
Mean r_s (min, max)	0.96 (0.81, 1)		

APPENDIX E: LINKING HABITAT SELECTION AND PREDATION RISK TO CALF SURVIVAL

E.1. METHODS

We used GLMMs to assess latent selection differences (Latham et al., 2013b) between caribou that lost calves and caribou with calves that lived, using calf fate as the response variable (lost = 1, lived = 0). We included the caribou fate pair as a random effect within models and built models using the same approach outlined for calving site and calving season selection (see Appendix C). We generated 100 datasets, each with a different random pairing between caribou with calves that lived and caribou that lost calves, and used AIC to identify the most informative variables to include within final models. For AIC we used an identical approach to that used for other habitat selection models (see Appendix B), but including a random effect for each caribou pair and dataset (dataset1…100). Once we identified the most informative variables to carry forward to the final model, we then fit final models to each of the 100 datasets using the R packages 'lme4' (Bates et al., 2015) and 'plyr' (Wickham, 2010). We report results as the mean beta coefficients and lower and upper 95% confidence intervals averaged across all 100 models.

E.2. RESULTS

Table E.1. Mean parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) for generalized linear mixed models used to identify factors determining calving fate in the Little Smoky herd in west-central Alberta, Canada, between 2000 and 2015. Models compared locations of caribou whose calf lived to those that lost calves across 100 iterations. Shown are models including grizzly bears and cougars; the wolf model is in Table 5.1. The reference category for calf fate was 'calf lived'. Variables are described in Table B.1.

	Grizzly bear			Cougar		
	β	LCL	UCL	β	LCL	UCL
Intercept	-3.27	-23.89	17.35	5.65	4.72	6.58
Pipe 1km	-	-	-	0.04	-0.34	0.43
Seismic 90m	-	-	-	-	-	-
Seismic 1km	0.39	-0.09	0.87	0.21	0.16	0.25
Cut 1km	-	-	-	26.10	21.80	30.41
Slope	0.43	0.24	0.62	-0.03	-0.06	-0.01
TPI	0.43	-0.65	3.09	-2.82	-3.03	-2.60
Grizzly bear 1km	2.25	1.32	3.18	-	-	-
Cougar 1km	-	-	-	-2.11	-2.36	-1.87

Table E.2. Mean parameter estimates (β) and lower and upper 95% confidence intervals (LCL, UCL) alternate generalized linear mixed models used to identify factors determining calving season habitat selection of caribou with calves that lived in the Chinchaga herd in west-central Alberta, Canada, between 2004 and 2009. Models compared locations of caribou whose calf lived to those that lost calves across 100 iterations. Shown are models including wolverines and black bears; the wolf model is in Table 5.2. Variables are described in Table B.1.

	Wolverine			Black bear		
	β	LCL	UCL	β	LCL	UCL
Intercept	-2.52	-4.80	-0.23	11.15	7.88	14.43
Elevation	6.94	4.68	9.21	2.59	0.74	4.43
TPI	-0.04	-0.06	-0.01	-0.04	-0.06	-0.01
Mixed and broadleaf	-1.67	-2.27	-1.06	-1.46	-2.07	-0.85
Wolverine 5km	-1.06	-1.49	-0.62	-	-	-
Black bear 5km	-	-	-	-4.37	-5.14	-3.59

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