SPATIAL FACTORS INFLUENCING NORTHERN MOUNTAIN CARIBOU (*Rangifer tarandus*) SURVIVAL AND DISTRIBUTION IN THE TELKWA RANGE

by

Laura Vivian Grant

B.Sc., University of Victoria, 2012

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN
NATURAL RESOURCES AND ENVIRONMENTAL STUDIES
(BIOLOGY)

UNIVERSITY OF NORTHERN BRITISH COLUMBIA

April 2017

Abstract

Human-induced habitat alteration has led to the decline of woodland caribou (*Rangifer tarandus caribou*) populations across Canada. The many challenges in conserving caribou are exemplified by a herd of northern mountain caribou in the Telkwa Range of central British Columbia. Despite population augmentation in the 1990s, this herd has declined to 18 individuals, yet mechanisms driving this decline are largely unknown. I used location data from caribou collared between 1991–2015 to investigate the influence of human disturbances – including forestry, roads, and recreation – on survival (N = 224) and habitat selection (N = 76). Results suggested that the decline of this herd was largely driven by a shift in predator-prey dynamics following forest harvest. Further exacerbating the decline were the cumulative effects of disturbance in the Telkwa Range. Roads, recreation, and forestry influenced the distribution of the Telkwa caribou herd, ultimately affecting habitat availability and the ability of caribou to successfully manage predation risk.

Table of Contents

List of Tables

List of Figures

List of Appendices

Acknowledgements

Funding for this project was provided by the following organizations: Habitat Conservation Trust Foundation, University of Northern British Columbia, Bulkley Valley Research Centre, Natural Sciences and Engineering Research Council of Canada, and the BC Ministry of Forests, Lands, and Natural Resource Operations. Their financial support enabled me to immerse myself in the research process and for that, I am extremely grateful.

First and foremost, I would like to thank my supervisor, Dr. Chris Johnson, for his guidance, patience, and constant support. With his mentorship, I have learned an incredible amount about ecology, writing, statistics, and research. Chris was very supportive of work-life balance. He gave me the space to grow as a scientist, but also as a person, and for that I am forever grateful. I would also like to thank my committee members. Quite literally, I would not be where I am today if I hadn't asked Conrad Thiessen for a job 3.5 years ago! Conrad has been instrumental in my growth as a scientist and has provided me with numerous opportunities to gain experience in the field. I have greatly appreciated his friendship and guidance throughout this process. It was an absolute pleasure working with Dr. Mike Gillingham. His ability to think critically has had a substantial influence on the quality of my research and my own abilities as a researcher. I feel very fortunate to have spent time with Mike as a member of the UNBC chapter of The Wildlife Society. We shared many casual chats and I genuinely feel fortunate to have been present for some of his statistics jokes.

I would like to thank the Local Ecological Knowledge experts that took the time to discuss recreation in the Telkwa Range with me. It was a pleasure to learn from them and they were critical to the success of my research. Also, special thanks to Dr. Scott McNay, Mike Klaczek, and Doug Heard for their help gathering data on the Chase and Wolverine herds.

I was fortunate to forge many friendships that made my experience at UNBC truly enjoyable. In particular, I would like to thank my friend and fellow *Rangifer* groupie, Kelsey Russell. Not only did we share many fruitful discussions about our mutual study species, but we also forged a friendship that I am certain will last for years to come. Thank you for being a shoulder to lean on, making me home-made pasta on a regular basis, and encouraging me to take a breaks. You whole-heartedly supported me through all of the ups and downs of this process and I could not have done this without you.

I would not be where I am today without my parents (Diane Costerton and Duncan Grant), my sister (Allyssa Grant), and my brothers (Leighton and Byron Grant). My mom's optimism is a breath of fresh air and my dad's advice always comes from the heart, but is tried and true. A special thank you to my sister. She has not only been instrumental in my time as a graduate student, but in my life as a role model and my most treasured confidant.

My most heartfelt thank you goes out to my partner, Peter Greene. He has supported me from day one in all of my endeavours both professionally and personally. His humour, intelligence, patience, and empathy made this process so much more enjoyable and ultimately, contributed to the completion of this project. Pete has not only played a huge role in forcing me to think more critically, but has constantly reminded me what is most important in life. I feel very privileged to call him my partner and look forward to many more adventures with him by my side.

Dedication

This thesis is dedicated to the memory of Dr. John William Costerton, a world-renowned microbiologist and the most terrific grandfather. Thank you for inspiring me to be a scientist.

Chapter 1: General Introduction

Background

Woodland caribou (*Rangifer tarandus caribou*) play an important role in the ecological, cultural, and economic systems of northern Canada, yet most caribou populations are currently in decline, with some herds reduced by more than 72% over the past 20 years (Festa-Bianchet et al. 2011). In British Columbia (BC), caribou occupy less than 40% of their historical range and the population is half of what it was in the late 19th century (Spalding 2000). Historically, caribou declines were most prevalent in the south of the Province, but are now evident in populations that were until recently, stable and relatively abundant, such as those classified as the northern ecotype (COSEWIC 2014).

The Province of BC recognizes three types of woodland caribou: mountain, northern, and boreal (Heard and Vagt 1998). The northern ecotype is federally recognized as a Designatable Unit (DU7) and spans two territories (Yukon and Northwest Territories), one Province (BC), and one state (Alaska) (COSEWIC 2011). Federally, northern mountain caribou (NMC) were assessed as Special Concern and provincially, as vulnerable (COSEWIC 2014, Environment Canada 2014). In BC, there are approximately 3,700 NMC in nine subpopulations, five of which are declining (COSEWIC 2014). Mechanisms driving the decline of NMC populations are complex; however, it is generally accepted that the primary cause of decline is a shift in predator-prey dynamics resulting from human-induced habitat loss and disturbance.

Caribou exhibit a low reproductive rate when compared to other ungulates (Bergerud 1974). Females typically do not breed until two–three years of age and are limited to one offspring annually. As a result, caribou populations are particularly sensitive to high rates of mortality, the main cause of mortality being predation (Bergerud and Elliot 1986, Seip 1991).

Grizzly bears (*Ursus arctos*), black bears (*Ursus americanus*), cougars (*Puma concolor*), and wolverines (*Gulo gulo*) prey on caribou, but wolves (*Canis lupus*) are the dominant predator of NMC in BC (Gustine et al. 2006). To avoid predation, caribou spatially separate themselves from predators and other ungulate species, such as moose (*Alces alces*) and deer (*Odocoileus* spp.) (Seip 1992, Stotyn 2008, Robinson et al. 2010, Steenweg 2011). The seasonal distribution of caribou reflects this strategy; caribou tend to forgo high-quality forage when selecting for high-elevation habitat, particularly during calving and summer. Given that the proximate cause of declining caribou populations is predation, it is clear that the effectiveness of this anti-predator strategy and ultimately, the predator-prey dynamics of woodland caribou, have changed (Festa-Bianchet et al. 2011). Human activities that affect the ability of caribou to spatially separate themselves from predators and/or increase the abundance of other prey species are hypothesized as the principal factors leading to the decline of NMC (Environment Canada 2014).

In BC, commercial logging generates large areas of early seral forest, which provides high-quality habitat for moose and deer (Schwartz and Franzmann 1991, Rempel et al. 1997, Serrouya 2013). These species are the primary prey of wolves and affect caribou populations through apparent competition, an indirect interaction between species that share a common predator (Holt 1977, Wittmer et al. 2007, DeCesare et al. 2009). An increase in the density of primary prey can result in an increase in the distribution and density of wolves and a subsequent increase in predation of caribou (Serrouya et al. 2011). Apparent competition has been demonstrated in populations of other species (Norbury 2001, Courchamp et al. 2003, DeCesare et al. 2009) and in the context of caribou, is supported by studies showing that survival of adult caribou is correlated with cutblock density and is lower in areas where early seral forest is more common (e.g. Smith 2004, Wittmer et al. 2007, Leblond et al. 2013, Losier et al. 2015).

Anthropogenic activities, such as the creation of linear features and recreation, can indirectly influence caribou by increasing the efficiency of predators and/or increasing predator access to habitat that would otherwise be isolated by topography or snow (Dickie et al. 2016). For example, linear features have been correlated with wolf-induced caribou mortalities and an increase in encounter rates between wolves and caribou (Whittington et al. 2011, Apps et al. 2013). Some have hypothesized that winter recreation, such as backcountry skiing and snowmobiling, can result in packed snow that allows increased access by wolves to caribou habitat (Bergerud 1996, Simpson 2000, Powell 2004); however, a correlation between recreational activity and caribou survival has yet to be established (but see Lesmerises et al. 2017).

In addition to exacerbating predation, human disturbance can result in the displacement of caribou from high-quality habitat. Many studies have shown that caribou avoid mines, settlements, forestry, recreational activity, and linear features, with the magnitude of avoidance varying with the intensity of the activity (e.g., Dyer et al. 2001, Nellemann et al. 2001, Johnson et al. 2005, Polfus et al. 2011, Johnson and Russell 2014). Avoidance may be a product of increased predation risk or perceived risk associated with disturbance and can result in the direct loss of high-quality habitat. For example, Dyer et al. (2001) found that 22–48% of their study area in Alberta received reduced use by caribou due to anthropogenic activity. Loss of high-quality habitat may have physiological consequences, ultimately influencing individual fitness and the productivity of caribou populations (Darby and

Duquette 1986). Additionally, avoidance responses to human activities may force caribou into areas of higher predation risk, directly influencing survival.

The Telkwa caribou herd (TCH) is an example of a NMC herd that has been confronted with cumulative landscape change associated with a number of human activities. Similar to other herds in central and southern BC, the TCH has demonstrated a steep decline in distribution and abundance. Historically, the distribution of this herd spanned a much larger area, which included the Bulkley Valley and Babine mountains, but is now constrained to the Telkwa Range (Spalding 2000). A decline in abundance was first noted during the late 1960s when the herd decreased from approximately 270 to 40 individuals (Cichowski 2014). In an effort to increase the long-term viability of the TCH, 30 caribou were translocated from the Chase herd to the Telkwa Range in 1997 and 1998. Initially, the translocation was successful, with numbers increasing to over 110 individuals by the mid-2000s; however, the TCH has steadily declined since 2007 and is currently comprised of approximately 18 individuals. This herd is at continual risk of extirpation, yet the mechanisms driving their decline are not well understood.

My research was designed to provide a fuller understanding of the relationship between human disturbance and the distribution and population dynamics of the TCH. First, I investigated the influence of anthropogenic and environmental factors on the survival of adult caribou. In this analysis, I included data from the Chase and Wolverine herds, which are relatively stable populations. This allowed for a comparison of the mechanisms driving the dynamics of stable and declining NMC herds. I hypothesized that caribou survival was negatively influenced by human disturbance that increased predator efficiency and/or abundance and that the magnitude of this influence varied among herds. Second, I investigated changes in habitat selection and distribution of the TCH. Habitat selection can influence the fitness of individual animals and ultimately, the productivity of wildlife populations (Reimers 1983). I examined how human disturbance in the Telkwa Range affected habitat selection by the TCH and how this relationship changed over time. I hypothesized that caribou avoided all forms of human disturbance in their home range and that the magnitude of avoidance changed over time. The alternative hypothesis was that the extent of degradation in the Telkwa Range provided few opportunities for caribou to avoid human disturbance and increased predation risk associated with human activities and landscape change.

As industrial development and human activities continue to intensify in northern Canada, it is important to understand the potential effects of such activities on wildlife and their habitat. By contributing to the overall understanding of the TCH's vulnerability to habitat disturbance, my research provides new insights on how these factors affect NMC. These results will better guide management in prioritizing conservation and recovery strategies for stable and declining herds, ultimately, resulting in the persistence of this charismatic yet vulnerable species.

Thesis Structure

I organized the thesis into three separate chapters. I addressed my two research objectives in separate chapters fit for journal publication, followed by a final chapter summarizing research findings. My first objective, which I address in Chapter 2, was to examine the relationship between caribou survival and disturbance, with a focus on disparities among herds with varying landscape conditions. My second objective, presented in Chapter 3, was to examine the influence of human disturbance on the distribution and habitat selection of caribou. In Chapter 4, I summarized my overall research findings, suggested potential mechanisms influencing the decline of the TCH, and proposed management implications.

Study Area

Telkwa Range

The Telkwa Range is found approximately 15 km SW of Smithers in central BC and is characterized by high-elevation, mountainous terrain scattered with low-elevation valley bottoms and rolling plateaus (Figure 1). The Telkwa Range is home to a number of large mammal species including caribou, mountain goat (*Oreamnos americanus*), moose, deer, elk (*Cervus elaphus*), wolves, grizzly bear, black bear, wolverine, coyote (*Canis latrans*), and lynx (*Lynx canadensis*). This area falls within four biogeoclimatic (BEC) zones: Boreal Altai Fescue Alpine (BAFA), Engelmann Spruce-Subalpine Fir (ESSF), Sub-Boreal Spruce (SBS), and Coastal Western Hemlock (CWH) (Banner et al. 1993).

The SBS zone (SBSmc2 and SBSdk) is found at low elevations in the study area, with mean annual temperatures from 1.7–5°C and annual precipitation from 440–900 mm. The SBSmc2, the most dominant subzone, is characterized by cool, moist summers, a deep snowpack, and hybrid white spruce (*Picea engelmanni x glauca*), subalpine fir (*Abies lasiocarpa*), and lodgepole pine (*Pinus contorta*).

As elevation increases, ESSFmc, and to a lesser extent ESSFwv, become more prevalent in the Telkwa Range. The ESSF has a relatively cold climate, with mean annual temperature ranging from -2–2°C and highly variable annual precipitation. Dominant tree species in the ESSFmc are subalpine fir, hybrid white spruce, and lodgepole pine. Mature ESSF forests are often associated with abundant arboreal lichens, serving as forage for caribou during winter.

Elevations above 1650 m are generally treeless and fall within the BAFA zone (MacKenzie 2006). This zone is characterized by cold mean annual temperatures (-4–0°C) and high annual precipitation (700–3000 mm), 70–80% of which is in the form of snow. Caribou tend to use the alpine tundra of the BAFA zone where terrestrial lichens are abundant.

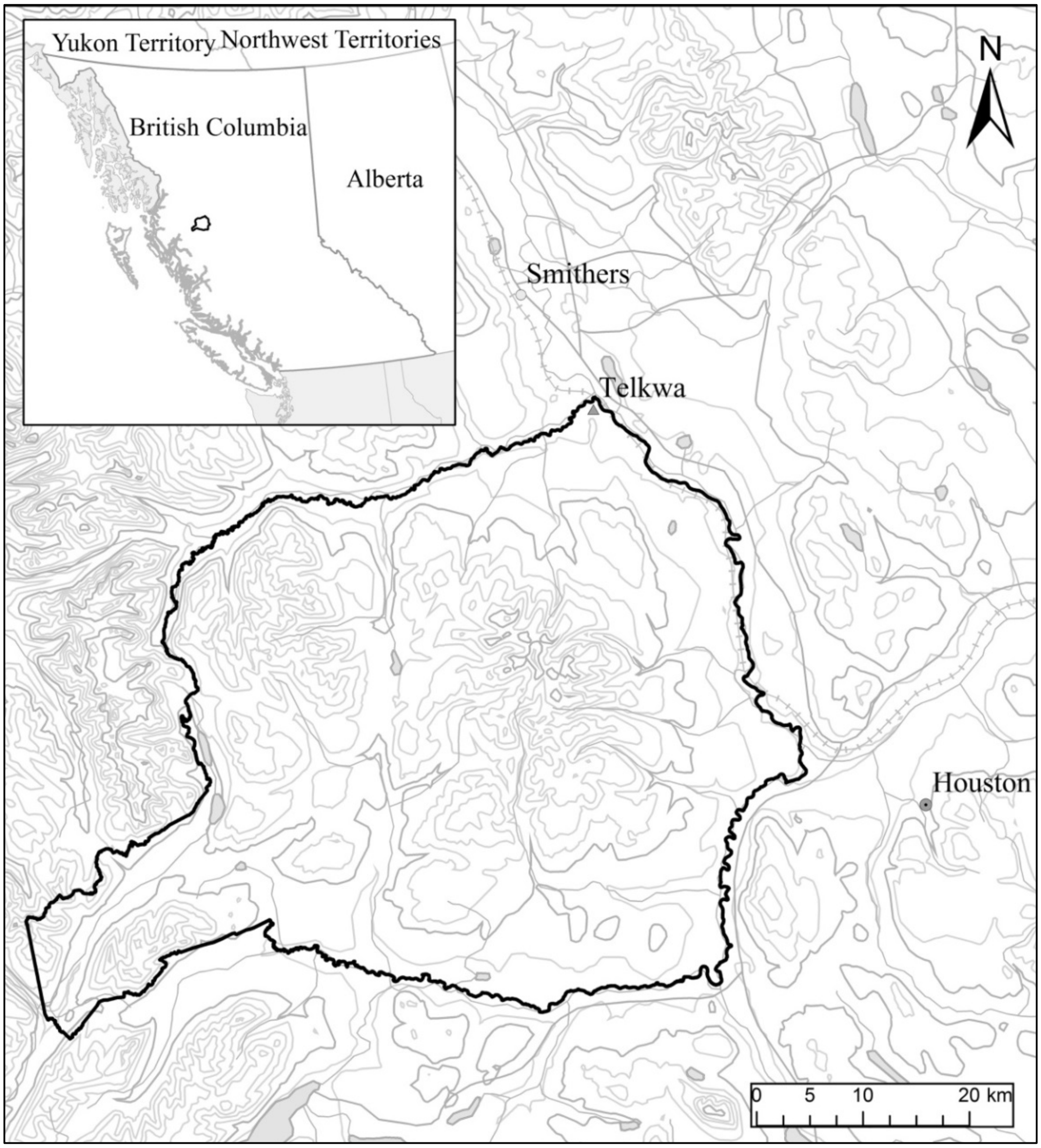

Figure 1. Distribution of the Telkwa caribou herd (outlined in black) in the Telkwa Range of central British Columbia, Canada.

The primary industrial activity in the Telkwa Range is forest harvesting (Cichowski 2014). An outbreak of mountain pine beetle (*Dendroctonus ponderosae*) over the last decade has resulted in an increase in salvage logging in or adjacent to caribou habitat in the Telkwa Range. Although the last active mine dates back to 1967, mineral exploration has occurred in the last decade and the area houses a number of coal and mineral tenures. Recreational activities include hiking, backcountry skiing, snowmobiling, hunting, horseback riding, and all-terrain vehicle use. With the exception of those related to hunting, there are currently no legal restrictions on recreational use in the Telkwa Range; however, there are a number of voluntary guidelines implemented by the Voluntary Recreation Access Management group. Hunting of the TCH was banned in the 1970s.

Chase and Wolverine Ranges

The Chase and Wolverine caribou herds inhabit the Omineca Mountains along the west side of the Williston Reservoir in north-central BC (Figure 2). The northern part of this area, home to the Chase caribou herd, is characterized by complex mountain ranges, which extend westward into high-elevation plateaus. The range of the Wolverine caribou herd lies in the southern part of this area. In contrast to its northern counterpart, this area is less mountainous and is characterized by large river valleys and a broad low-elevation plateau. The Omineca Mountains are home to moose, mountain goat, mule deer, white-tailed deer (*Odocoileus virginianus*), elk, and Stone's sheep (*Ovis dalli stonei*). Potential predators of caribou include wolves, wolverine, grizzly bear, black bear, and lynx.

The Omineca Mountains are an area of biogeoclimatic transition. Similar to the Telkwa Range, the southern portion is dominated by the SBS zone at low elevations (<1100 m), ESSF at mid elevations (900–1600 m), and the BAFA zone at high elevations (>1500 m).

Further north, in the area inhabited by the Chase caribou herd, the SBS zone gives way to the dry, cool Boreal and White Black Spruce (BWBSdk) and the ESSF zone is replaced by moist, cool Spruce Willow Birch (SWBmk). The mean annual temperature for the BWBSdk zone is -2.9–2°C and annual precipitation ranges between 330–570 mm. These forests are dominated by white spruce and lodgepole pine. The SWBmk zone has a mean annual temperature of -0.7– -3°C and 460–770 mm of precipitation. The dominant tree species in this zone are white spruce and subalpine fir.

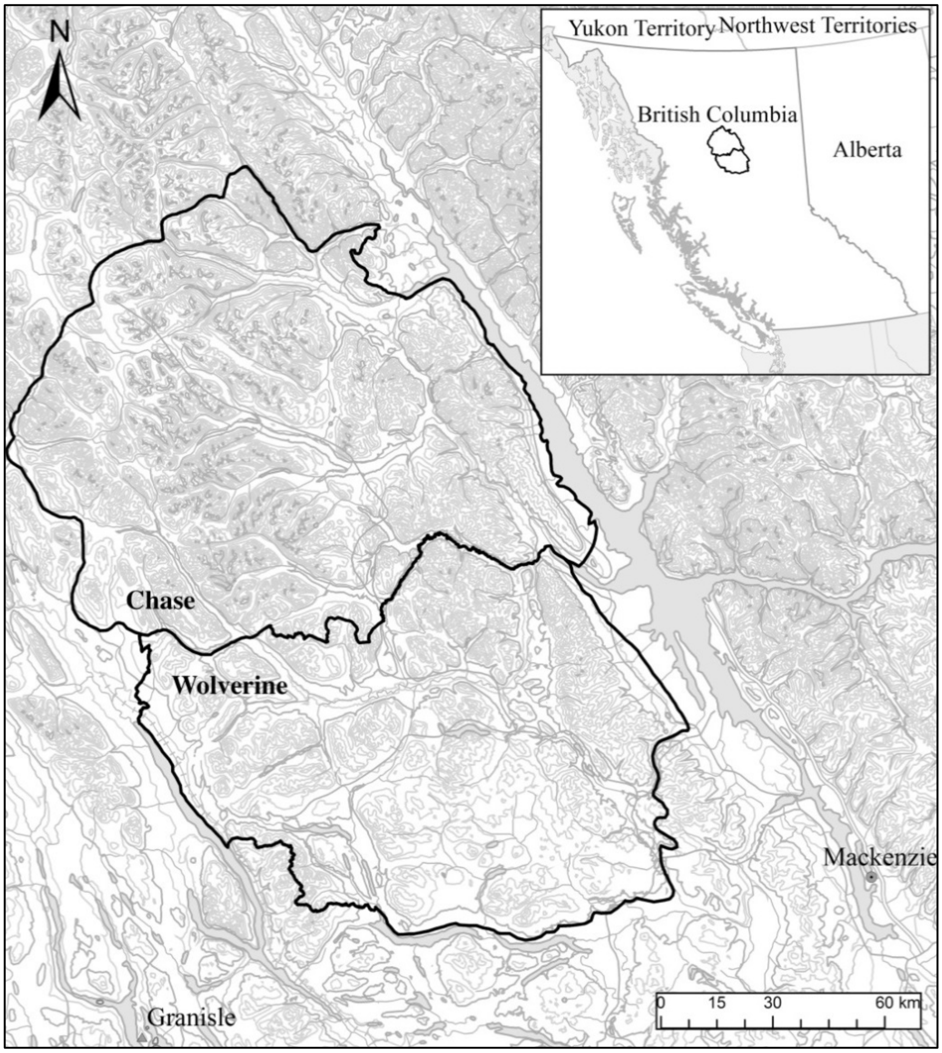

Figure 2. Distribution of the Chase and Wolverine herds (outlined in black) in the Omineca Mountains of central British Columbia, Canada.

As in the Telkwa Range, forest harvest is the predominant industrial activity in the Omineca Mountains (McNay and Sulyma 2008). For the Chase herd, extensive forest harvesting has occurred in the lower Mesilinka, Osilinka, and Swanell river valleys. Forest harvesting has occurred to a lesser extent across the range of the Wolverine herd, but has become more prevalent since the mountain pine beetle epidemic in the mid-2000s. Other human activities in the Omineca Mountains include recreation and hunting. The Chase caribou herd is currently hunted, whereas the Wolverine herd has not been hunted since the 1980s.

Chapter 2: The relationship between woodland caribou survival and disturbance: disparities among herds with varying landscape conditions.

Introduction

Survival plays an important role in the population dynamics of large herbivores (Gaillard et al. 1998, 2000, Wittmer et al. 2005*a*). The survival of woodland caribou is largely dictated by predation, which is generally accepted as being the proximate cause of population declines across Canada (Bergerud and Elliot 1986, Bergerud 1996, Stuart-Smith et al. 1997, Rettie and Messier 1998, Wittmer et al. 2005*b*, Festa-Bianchet et al. 2011). Over the last 100 years, landscape-scale habitat change has significantly altered the predator-prey dynamics of caribou by increasing the abundance and efficiency of predators. The differential effects of various forms of habitat change on predator-prey dynamics and associated mechanisms are not well studied. Understanding the influence of human disturbance on caribou survival can provide insight into the mechanisms driving the predator-prey dynamics of caribou, and ultimately, the trajectories of caribou populations.

Linear features, such as roads, trails, and seismic lines, provide predators with efficient travel routes that increase access and the potential for predator-prey encounters (James 1999, James and Stuart-Smith 2000, Dyer et al. 2001, Whittington et al. 2011). This can intensify predation on caribou; however, studies linking caribou survival and linear features have yielded inconsistent results. For example, Apps et al. (2013) found that caribou in close proximity to roads were more likely to be killed by wolves. In contrast, Latham et al. (2011) noted that wolves moved more quickly along linear features, but the probability of predation for caribou was not related to the adjacency of such features.

Roads and trails also enable a greater number of people to recreate in caribou habitat. Recreational use, both motorized and non-motorized, can negatively influence ungulate populations (Cassirer et al. 1992, Colescott and Gillingham 1998, Creel et al. 2002, Neumann et al. 2010, Harris et al. 2014). Motorized winter recreation in the form of snowmobiling can lead to range abandonment and/or increased accessibility to caribou habitat by wolves (Bergerud 1988, Seip et al. 2007). Similarly, backcountry skiing can directly disturb caribou, resulting in avoidance of high-quality habitat (Lesmerises et al. in review, Simpson 2000). To date, research on the potential effects of recreation on caribou has predominantly focused on changes in animal behaviour or population distribution (Mahoney et al. 2001, Reimers et al. 2003, Seip et al. 2007). The relationship between recreational activities and caribou survival has yet to be investigated (but see Lesmerises et al. 2017).

Although predator access and efficiency plays an important role in the predator-prey dynamics of caribou, the apparent competition hypothesis has gained considerable support in explaining the decline of caribou populations (Bergerud 1974, Bergerud and Elliot 1986, Seip 1992, Spalding 2000, Schaefer 2003, James et al. 2004, Courtois et al. 2007, Santomauro et al. 2012), as well as populations of other species (Norbury 2001, Courchamp et al. 2003, DeCesare et al. 2009). Apparent competition occurs between two species that are preyed upon by the same predator and is a mechanism through which habitat change can influence the survival of caribou (DeCesare et al. 2009).

Commercial logging across the distribution of woodland caribou results in early seral forests, which provide high-quality habitat for other ungulates, such as moose (Schwartz and Franzmann 1991, Rempel et al. 1997, Serrouya 2013). An increase in habitat for other ungulates can result in more primary prey for wolves and bears, ultimately increasing the distribution and abundance of predator populations (Serrouya et al. 2011). This suggests that caribou are more susceptible to mortality in areas where logging is prevalent. Although Apps et al. (2013) found that caribou survival was unrelated to the amount of early seral forest, most studies suggest a strong relationship between forestry and caribou survival (e.g. Smith 2004, Wittmer et al. 2007, Leblond et al. 2013, Losier et al. 2015). For example, Wittmer et al. (2007) found that survival of mountain caribou was lower in areas where early- and mid-seral forests were more common.

Some have hypothesized that a changing climate may be an increasingly important determinant of the population dynamics of caribou (Festa-Bianchet et al. 2011, Bastille-Rousseau et al. 2016). Variation in snow depth, density, and hardness can reduce the availability of winter forage and/or increase the energetic costs of foraging, linking snow conditions to individual fitness (Fancy and White 1985). Indeed, increasing snow accumulation was found to decrease the survival of reindeer in a predator-free environment in Finland (Kumpula and Colpaert 2003). Contrary to this, average yearly snow accumulation was not a significant predictor of mountain caribou survival in southern BC, where predation was a concern (Wittmer et al. 2007). Regardless, it is important to consider the potential relationship between changing climatic conditions, predator efficiency, and the nutritional quality of landscapes as these factors may interact to influence the survival of caribou.

Although predation is accepted as the proximate cause of caribou declines across Canada, the relationship between human disturbance and caribou mortality has received relatively little attention (but see Smith 2004, Wittmer et al. 2007, Apps et al. 2013, Leblond et al. 2013, Losier et al. 2015). There are even fewer studies that examine how this relationship varies among herds as a factor of landscape change and population trajectory. It is possible that small and declining populations are subject to inverse density dependence and as a result, are more susceptible to the effects of human disturbance and predation (Wittmer et al. 2005*b*). I used a long-term data set of radio/GPS collared caribou to model and test the influence of anthropogenic, environmental, and demographic variables on seasonal patterns of caribou mortality for three populations of woodland caribou. I investigated how these relationships may change among augmented and native herds with varying population trajectories. I hypothesized that caribou survival was negatively influenced by human disturbances that increased predator efficiency and/or abundance and that the magnitude of this influence varied among herds. My findings help to identify potential mechanisms influencing the decline of small populations of woodland caribou, while providing recommendations for herd-specific management and conservation efforts for caribou across Canada.

Methods

The Telkwa caribou herd is a population of NMC located in central BC (see Chapter 1 for study area details). Despite population augmentation in the late 1990s, this herd has declined to approximately 18 individuals. The augmentation involved the translocation of 30 animals from the Chase herd, a nearby northern mountain population of caribou. The Chase and Wolverine populations are located 100 km NE of the Telkwa Range, yet the abundance of these herds has changed relatively little compared to the steady decline of the TCH (Figure 3).

Statistical Analysis

I used the Andersen-Gill (A-G) method to model survival of caribou from the Telkwa, Wolverine, and Chase herds (Andersen and Gill 1982). This model is a formulation of the Cox Proportional Hazards (CPH) regression and accommodates left- and right-censored data. Based on a partial likelihood analysis, the CPH model calculates a hazard function $h_i(t)$ for an individual *i* at time *t* that is associated with covariate vectors $x_i = (x_{i1}, x_{i2}, x_{i3} \ldots x_{ip})$. This hazard function represents the proportional change in mortality risk per unit time due to a unit change in the covariate vectors. The CPH model is characterized by:

$$h_i(t) = h_0(t)\exp(\beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_p x_{ip})$$

where $h_0(t)$ represents the baseline hazard of an individual with covariate vector $x_1 = (0,0,\ldots 0)$.

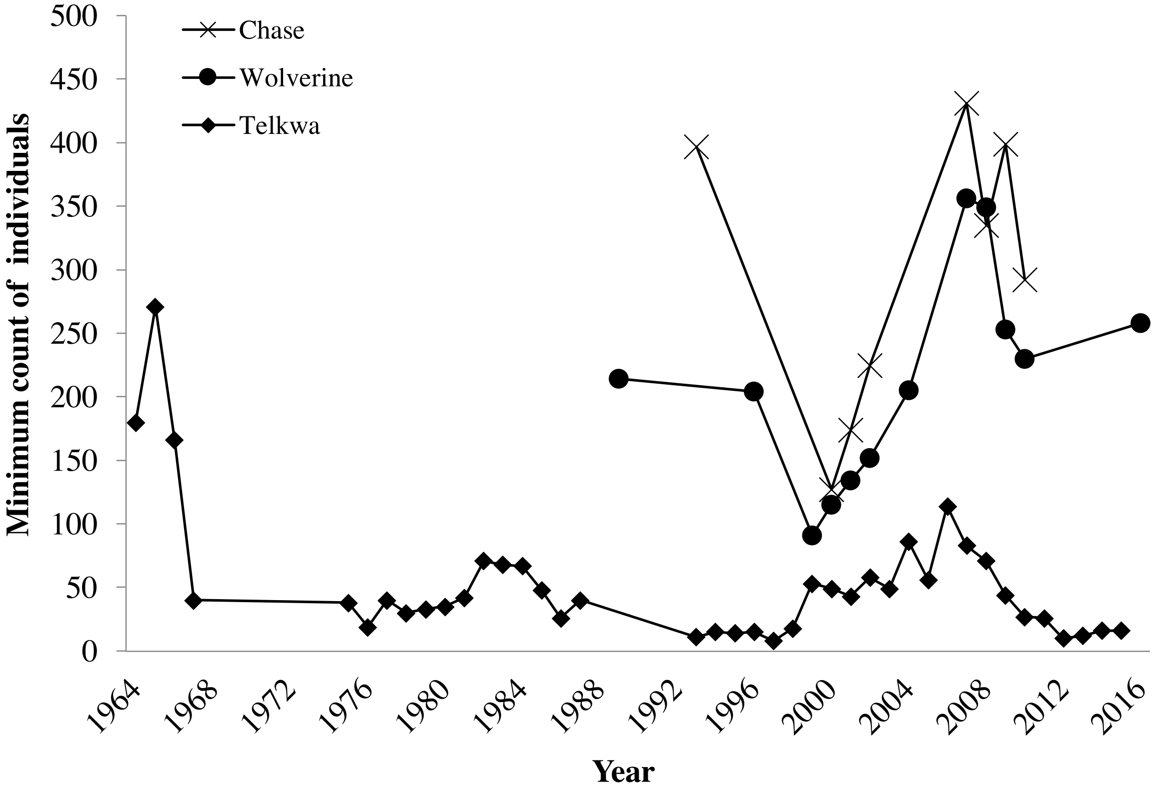

Figure 3. Minimum count of woodland caribou in the Telkwa (diamond), Chase (X), and Wolverine (•) populations of central British Columbia, Canada, between 1964–2016. Counts were included if survey methods were comparable among years.

In wildlife studies, the A-G method is typically parameterized using spatial occurrence data collected by VHF and GPS collars (e.g., Johnson et al. 2004). From 1991–2012, 224 caribou were captured and collared in the Telkwa, Chase, and Wolverine ranges using helicopter net-gunning. This included an augmentation program in the Telkwa Range in 1997 and 1998 when 30 individuals were relocated from the Chase herd. Caribou were equipped with VHF (Model LMRT-4, Lotek Engineering, Newmarket, Ontario, Canada) or GPS collars (GPS 1000, Lotek Engineering, Newmarket, Ontario, Canada). To ensure a balanced number of locations among individuals, one location per day per individual was randomly selected from GPS collar locations. Location data were structured so that each animal and their respective relocation intervals were treated as observations. Each observation was associated with an event, where '0' was a right-censored interval (i.e., the animal was alive) and '1' was a mortality event. Survival analyses were conducted using STATA (version 12.1, StataCorp. 2011).

Model Variables

Demographic factors used in model development included sex and native herd (Table 1). My ability to model survival on a seasonal basis was limited by sample size, therefore, season was included as a categorical variable: early winter (November 1–January 15), late winter (January 16–April 15), spring (April 16–June 30), and summer (July 1–October 31) (Roberts et al. 2003, Cichowski 2014). All categorical variables in this analysis were modelled using deviation coding (Menard 2002).

I used a digital elevation model (25 x 25-m; DataBC Distribution Service) to calculate the average elevation of caribou locations on a bi-weekly basis. Topography was classified into four classes: valley, gentle slope, steep slope, and ridgeline. Classes were generated using a digital elevation model and a topographic position index (TPI; Jenness (2016); 1500 radius, canyon threshold = -60, ridgeline threshold = 100, slope = 10°). I cross-referenced model outputs to satellite imagery to ensure the classification scheme adequately represented the study area. The mode TPI class of caribou locations was calculated on a bi-weekly basis. I used ClimateBC (version 5.2, University of British Columbia 2015) to calculate monthly mean temperatures (°C) and snowfall (cm) for each animal location. To ensure consistency among VHF and GPS collar data, monthly and bi-weekly measures were applied regardless of relocation interval length.

Table 1. Description and categorical codes in parentheses of demographic, environmental, and anthropogenic variables that were used to develop candidate Andersen-Gill models of survival for the Telkwa, Chase, and Wolverine caribou herds of central British Columbia, Canada, between 1991–2012.

Variable	**Description**
Demographic	
Sex	Female (0), Male (1)
Herd	Telkwa (0), Chase (1), Wolverine (2), Translocated (3)
Season	Early Winter (1): November 1–January 15; Late Winter (2): January 16–April 15; Spring (3): April 16–June 30; Summer (4): July 1–October 31
Environmental	
Snow	Total monthly snowfall accumulation (cm)
Temp	Mean monthly temperature (°C)
Elevation	Average elevation (m) on bi-weekly basis
TPI	Mode of Topographic Position Index on bi-weekly basis: Valley (1), Gentle Slope (2), Steep Slope (3), Ridgeline (4)
Anthropogenic	
Road Density	Road density (km/km^2) in average home range of caribou
CutblocksUnder25 Cutblocks26to40	Cutblock density (ha/km^2) in average home range of caribou separated into two age categories
Rec	Intensity of recreational use: Low (1): ≤20 users/month; Medium (2): 21–40 users/month; High (3): ≥41 users/month

Annual forest harvesting layers were developed using three spatial datasets: Vegetation Resource Inventory (VRI), Forest Tenure Cutblocks, and Reporting Silviculture Updates and Land Status Tracking Systems (RESULTS; DataBC Distribution Service). Primary prey have been found to be most abundant in cutblocks ≤25 years old (Nielsen et al. 2005, Latham et al. 2011), therefore annual layers were separated into two cutblock age categories: ≤25 years since harvest and 26–40 years since harvest. A road layer was developed using the Digital

Road Atlas, Forest Tenure Road Segments/Lines, and RESULTS layers. I used a moving window algorithm to calculate the density of both age categories of cutblocks (ha/km^2) and roads (km/km^2). The size of the moving window was equal to the area of the average annual home range of the Chase and Wolverine herds (957.98 km^2 minimum convex polygon (MCP)) (Eastman 2006, Anderson and Johnson 2014). I used Hawth's Tools in ArcGIS (version 10.4.1, ESRI Inc. 2015) to generate annual 100% MCPs for individuals with greater than 20 locations in a given year. The resulting areas were used to calculate a weighted average home range size. The Telkwa herd had a much smaller average annual home range (328.50 km^2 MCP), but it was necessary to have a measure of density that was comparable among the three populations.

Intensity of recreational use was separated into three categories: low, medium, and high. Categories were based on average frequency of users per month (Table 1). I conducted Local Ecological Knowledge surveys (Appendix A) with 13 experts and used that information to identify the intensity of recreational activity over the study period for the TCH. Initial experts were selected based on their ability to speak to historical activities in the Telkwa Range and additional participants were identified using the snowball or chain-referral sampling method (Goodman 1961). This method requires that initial participants identify potential candidates that meet the eligibility criteria. Interviewees were asked a number of questions designed to reveal the intensity and type of recreation activity in the Telkwa Range since 1985 (Appendix A). I compiled the responses and assigned an intensity of recreational use to three time periods: 1985–1995, 1996–2005, 2006–2015. Experts reported that recreation activity across the range of the Chase and Wolverine herds was relatively low compared to the Telkwa herd (D. Heard and J. Vinnedge, pers. comm.). This is consistent with those herds being much more distant from towns and other human activity.

In addition to instantaneous exposure to disturbance, I calculated variables representing additive exposure to disturbance. This involved the subsequent addition of densities or intensities encountered by an individual caribou over the period that it was monitored.

Model Development and Assessment

I developed two model sets to investigate variation in survival among monitored caribou (Figure 4, Table 2). For Model set 1, I developed 17 candidate models that represented three potential mechanisms driving caribou survival: demography, environment, and predation. Predation models were developed based on the hypotheses that caribou survival is influenced by human disturbance and environmental variables that increase a) predator efficiency, b) predator abundance, or c) predator efficiency and abundance.

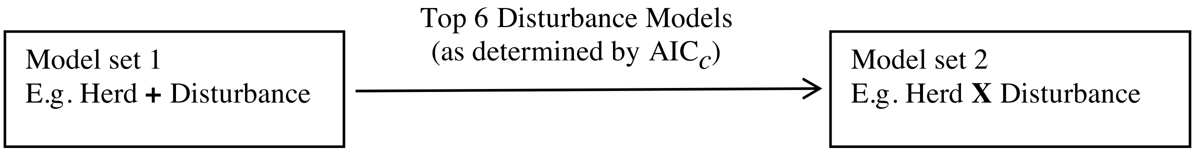

Figure 4. Explanation of the link between candidate Andersen-Gill model sets used to describe caribou survival generally (Model set 1) and differences in the disturbance-survival relationship among herds (Model set 2).

The top six human disturbance models from Model set 1, as determined using model selection methods described below, were then used to create six candidate models for Model set 2. These models differed from those in Model set 1 in that they included interaction terms between herd and disturbance variables, which allowed me to consider variation in the disturbance-survival relationship among the three herds. I used tolerance scores to assess the collinearity of model parameters; collinear terms (tolerance < 0.1) were not included in the same model (Menard 2002).

Table 2. Candidate Andersen-Gill models used to describe caribou survival in the Telkwa, Chase, and Wolverine herds of central British Columbia, Canada, between 1991–2012.

Model Name	**Covariates Included**
Model set 1	
Demographic	
Sex	Sex
Herd	Herd
Season	Season
All Demo	Sex + Herd + Season
Environmental	
Climate	Temp + Snow + Sex + Herd
Topo	Elevation + TPI + Sex + Herd
All Enviro	Temp + Snow + Season + Topo
Predator Abundance	
Forestry	CutblocksUnder25 + Cutblocks26to40 + Sex + Herd
Forestry Topo	CutblocksUnder25 + Cutblocks26to40 + Topo
Additive Forestry	Addt.CutblocksUnder25 + Addt.Cutblocks26to40 + Sex + Herd
Additive Forestry Topo	Addt.CutblocksUnder25 + Addt.Cutblocks26to40 + Topo
Predator Efficiency	
Roads	RoadDensity + Sex + Herd
Rec	Rec + Sex + Herd
Roads Rec	RoadDensity + Rec + Season + Snow + Sex + Herd
Additive Roads	Addt.RoadDensity + Sex + Herd
Additive Rec	Addt.Rec + Sex + Herd
Addt. Roads Rec	Addt.RoadDensity + Addt.Rec + Snow + Season + Sex + Herd
Predator Efficiency & Abundance	
All Dist	RoadDensity + CutblocksUnder25 + Cutblocks26to40 + Rec + Sex + Herd
Forestry Roads	RoadDensity + CutblocksUnder25 + Cutblocks26to40 + Sex + Herd
Additive All Dist	Addt.RoadDensity + Addt.Cutblocks26to40 + Addt.Rec + Sex + Herd
Additive Forestry Roads	Addt.RoadDensity + Addt. Cutblocks26to40 + Sex + Herd
Model set 2	
Herd*Forestry Topo 1	Herd*Cutblocks26to40 + Cutblocks26to40 + CutblocksUnder25 + Elevation + TPI + Sex + Herd
Herd*Forestry Topo 2	Herd*CutblocksUnder25 + CutblocksUnder25 + Cutblocks26to40 + Elevation TPI + Sex + Herd
Herd*Addt. Forestry Topo 1	Herd*Addt.Cutblocks26to40 + Addt.Cutblocks26to40 + Addt.CutblocksUnder25 + Elevation + TPI + Sex + Herd
Herd*Addt. Forestry Topo 2	Herd*Addt.CutblocksUnder25 + Addt.CutblocksUnder25 Addt.Cutblocks26to40 + Elevation + TPI + Sex + Herd
Herd*Roads	Herd*RoadDensity + RoadDensity + CutblocksUnder25 + Cutblocks26to40 + Sex + Herd
Herd*All Dist	Herd*Rec + Rec + RoadDensity + CutblocksUnder25 + Cutblocks26to40 + Sex + Herd

I used the Akaike Information Criterion (AIC_c), corrected for small sample size, to identify the most parsimonious survival model (Anderson et al. 2000). Specifically, I used the difference in AIC_c scores (ΔAIC_c) and AIC_c weights (w_i), which represented the approximate probability that the highest ranked model was the 'best' of the candidate model set, to rank models within and between sets. The AIC_c provides only a relative comparison among competing models. Thus, I used a jackknife sampling approach and the area under the curve (AUC) of the Receiver Operating Characteristic (ROC), to generate a cross-validated measure of the predictive accuracy of the most parsimonious models (Fielding and Bell 1997, Pearce and Ferrier 2000). The jackknife procedure iteratively excluded one record. For each iteration, the model was fit using the remaining records and the associated hazard function was used to calculate a probability for the withheld record. An AUC of 0.5–0.7, 0.7–0.9, or >0.9 indicates low, good, and excellent predictive accuracy, respectively (Manel et al. 2001). I used Schoenfeld residuals (Andersen and Gill 1982) to assess the proportional hazard assumption for each model.

Results

Model Selection

Over the course of the study, 224 animals were collared and monitored, including 175 females, 38 males, and 11 animals where sex was unknown. There were a total of 19,877 animal relocations, 104 mortalities, and 120 right-censored individuals (Table 3). The average duration of relocation intervals was 12.37 days. Caribou in the Telkwa herd experienced much higher cutblock and road densities in their home ranges when compared to neighbouring herds (Table 4). For all herds, cutblock density increased over time (minimum $r_s = 0.11$, $P < 0.001$, $n = 2001$); however, the magnitude of densities experienced by the TCH was consistently higher (Figure 5).

For Model set 1, which described additive factors influencing caribou survival, the most parsimonious model included both age categories of cutblock density, elevation, TPI, herd, and sex (Table 5; $w_i = 0.91$). This model had good predictive capacity (AUC = 0.70, SE = 0.04). The next highest ranked model included a larger suite of environmental variables: temperature, snow accumulation, elevation, TPI, season, herd, and sex. This model had considerably less support ($\Delta AIC_c = 4.61$, $w_i = 0.09$), but was relatively similar in terms of predictive accuracy (AUC = 0.69, SE = 0.04). Recreation and road density were not important factors in the top-ranked models (Appendix B).

Table 3. Summary of relocations, unknown fates, and mortality events for Telkwa, Chase, Wolverine, and translocated caribou monitored across central British Columbia, Canada, between 1991–2012.

Herd	**Relocations**	**Unknown Fates**	**Mortalities**
Telkwa	2001	5	22
Chase	4412	37	27
Wolverine	10980	64	42
Translocated	2484	14	13
Total	19877	120	104

Table 4. Mean cutblock (ha/km^2) and road (km/km^2) densities (± 1 SE) encountered by collared Telkwa, Chase, and Wolverine caribou in central British Columbia, Canada, between 1991–2012, as determined by a moving window analysis.

Herd	**Mean Cutblock Dens. (≤25 years; ha/km^2)**	**Mean Cutblock Dens. (26–40 years; ha/km^2)**	**Mean Road Dens. (km/km^2)**
Telkwa	20.81 (0.15)	4.00 (0.07)	1.61 (0.01)
Chase	3.21 (0.04)	3.35 (0.06)	0.21 (<0.00)
Wolverine	3.56 (0.03)	0.54 (0.01)	0.32 (<0.00)

Model set 2 addressed potential differences in the survival-disturbance relationship among herds. The most parsimonious model in this case was similar to the top model from Model set 1, but included an interaction term between 26–40 year old cutblock density and herd (Table 5; $w_i = 0.96$). This model had slightly less support ($\Delta AIC_c = 1.08$), but similar predictive capacity (AUC = 0.70, SE = 0.04) when compared to the top model from the first set. Also important, but with considerably less support, was the model including an interaction term between ≤25 year old cutblock density and herd, 26–40 year old cutblock density, elevation, TPI, and sex ($\Delta AIC_c = 6.24$, $w_i = 0.04$).

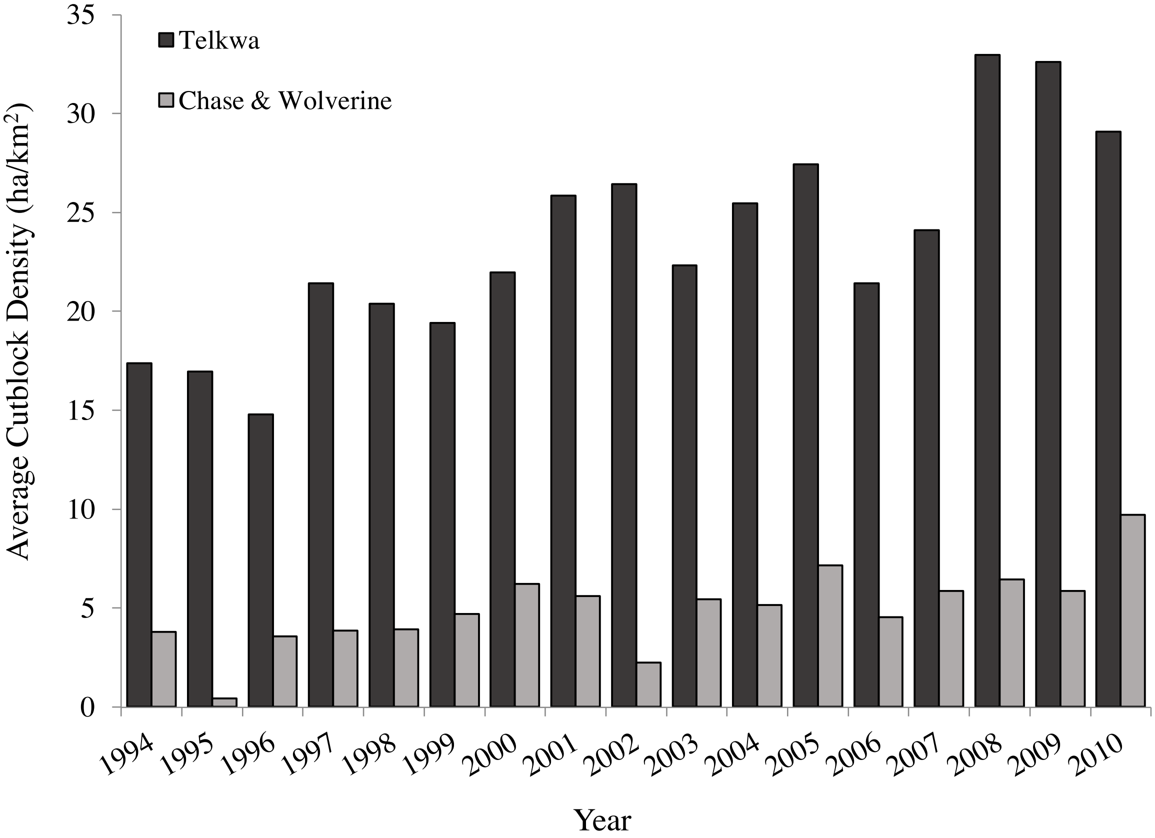

Figure 5. Average ≤40 year old cutblock densities (ha/km^2) encountered by collared caribou in the Telkwa, Chase, and Wolverine herds of central British Columbia, Canada, between 1994–2010, as determined by a moving window analysis.

Model Inference

The top ranked model from Model set 1 indicated a statistically significant relationship between caribou survival and elevation: as elevation increased, mortality risk per unit time decreased (Figure 6). Topography was also important, with animals being 44% and 22% more likely to survive on steep slopes and ridgelines respectively, when compared to valley bottoms.

Table 5. Most parsimonious Anderson-Gill survival models for woodland caribou from three populations across central British Columbia, Canada, between 1991–2012. Model parsimony was based on the difference in the Akaike Information Criterion (ΔAIC_c), and AIC_c weights (w_i). Results represent the models that contribute to a summed w_i of 0.99.

Model set 1 – Factors Influencing Caribou Survival					
	k	**Log Likel.**	**AIC_c**	**ΔAIC_c**	**w_i**
Forestry Topo	10	-304.80	632.65	0.00	0.909
All Enviro	13	-302.99	637.27	4.61	0.091
Model set 2 – Herd-Specific Interactions with Factors Influencing Caribou Survival					
	k	**Log Likel.**	**AIC_c**	**ΔAIC_c**	**w_i**
Herd*Forestry Topo 1	13	-300.15	631.57	0.00	0.958
Herd*Forestry Topo 2	13	-303.27	637.81	6.24	0.042

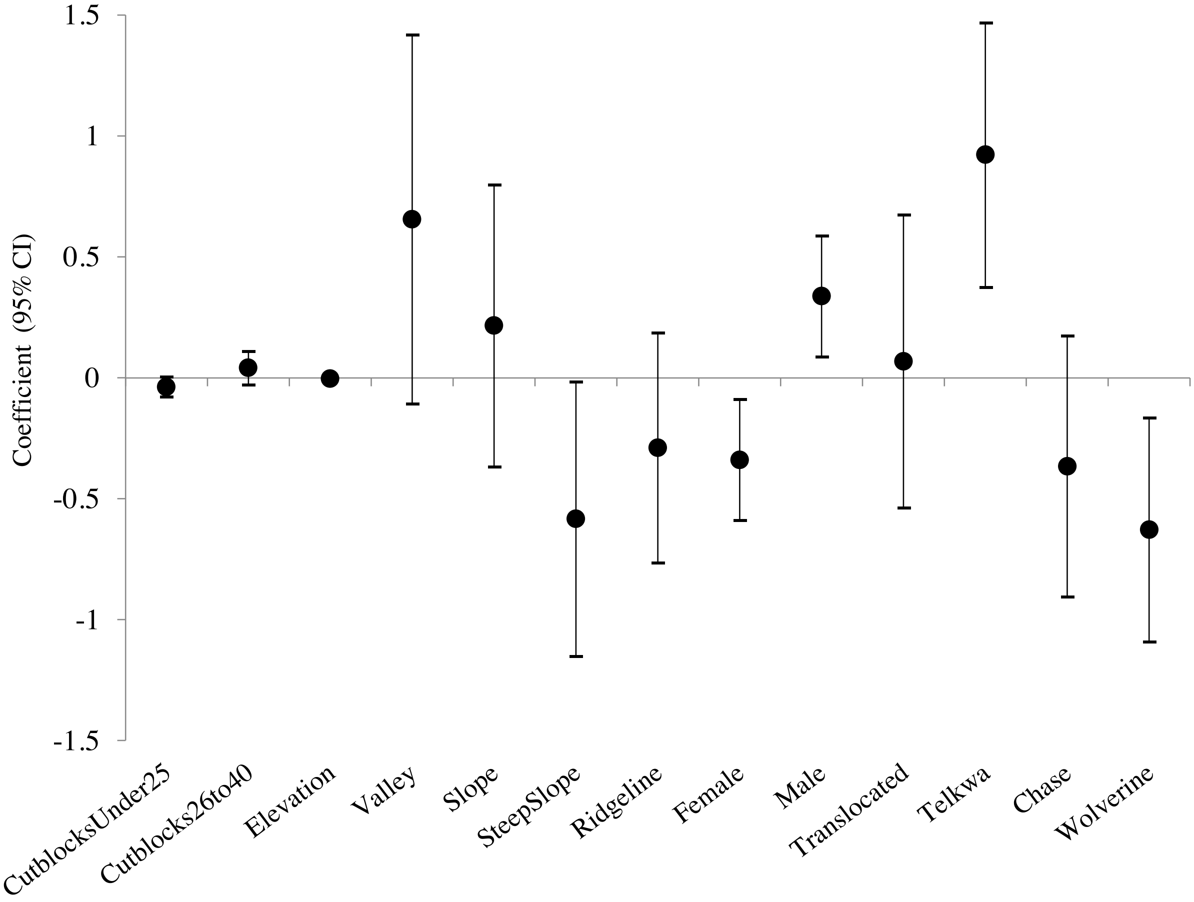

Figure 6. Coefficients and 95% confidence intervals of the most parsimonious Andersen-Gill survival model (Model set 1) for caribou from the Telkwa, Chase, and Wolverine herds of central British Columbia, Canada, 1991–2012.

Telkwa caribou were 1.5 times more likely to die than Chase, Wolverine, and translocated animals. Males had a 40% higher mortality risk than females, yet a male caribou from the Wolverine herd was more likely to survive than a female caribou from the Telkwa herd (Figure 7).

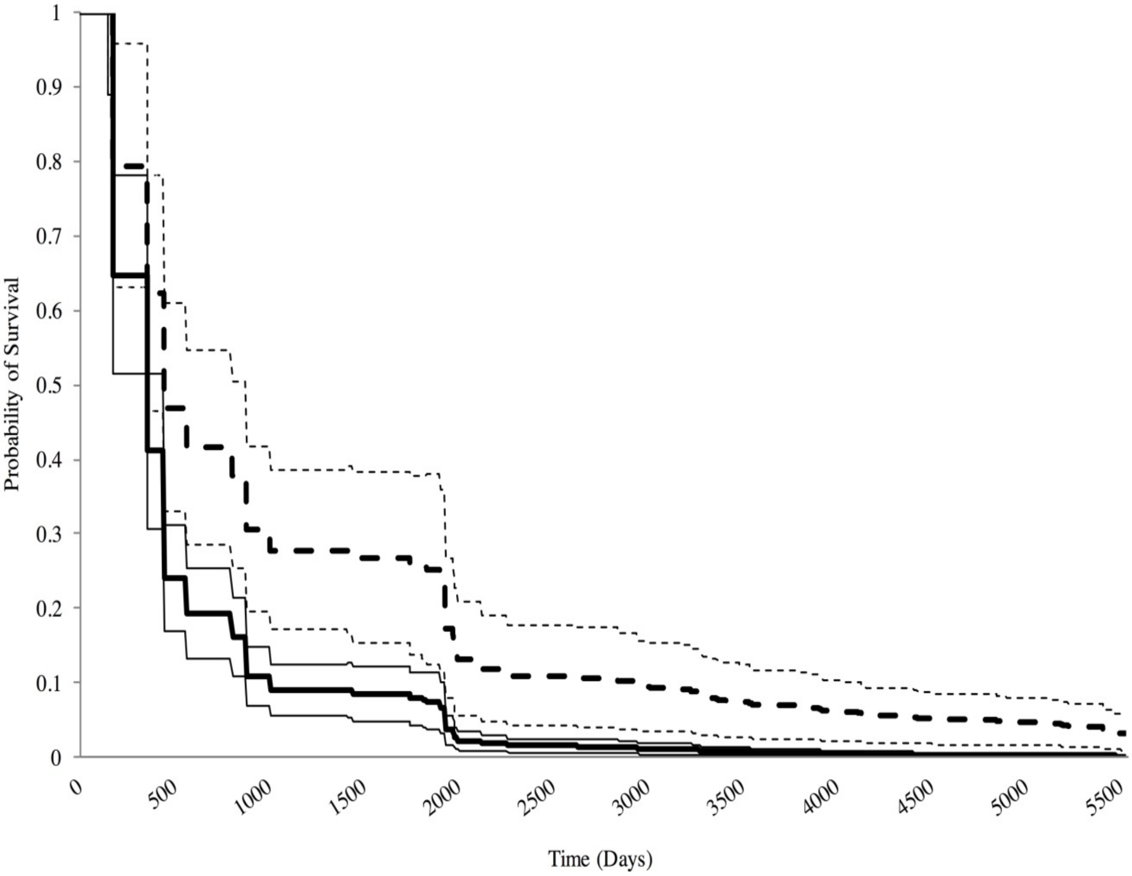

Figure 7. Predicted survival and 95% confidence intervals for a female caribou from the Telkwa herd (solid) and a male caribou from the Wolverine herd (dashed), based on the most parsimonious model (Model set 1, Table 5) describing caribou survival in central British Columbia, Canada, between 1991–2012. Unspecified covariates were held constant at their mean value (Cutblocks ≤25 years = 7.50 ha/km^2, Cutblocks 26–40 years =1.75 ha/km^2, Elevation =1507.58 m)

The top model included covariates for cutblock density and the mean parameter values suggested that mortality increased in areas where the density of 26–40 year old cutblocks increased. In contrast, mortality risk decreased across areas with a high density of young cutblocks (≤25 years old).

For Model set 2, the top ranked model suggested that the density of 26–40 year old cutblocks had a differential influence on mortality for the Chase, Wolverine, and Telkwa caribou; increasing cutblock density negatively affected Telkwa caribou survival and positively affected survival in the other herds (Figure 8). This is particularly evident when examining survival at four different cutblock densities (26–40 year old cutblocks; Figure 9).

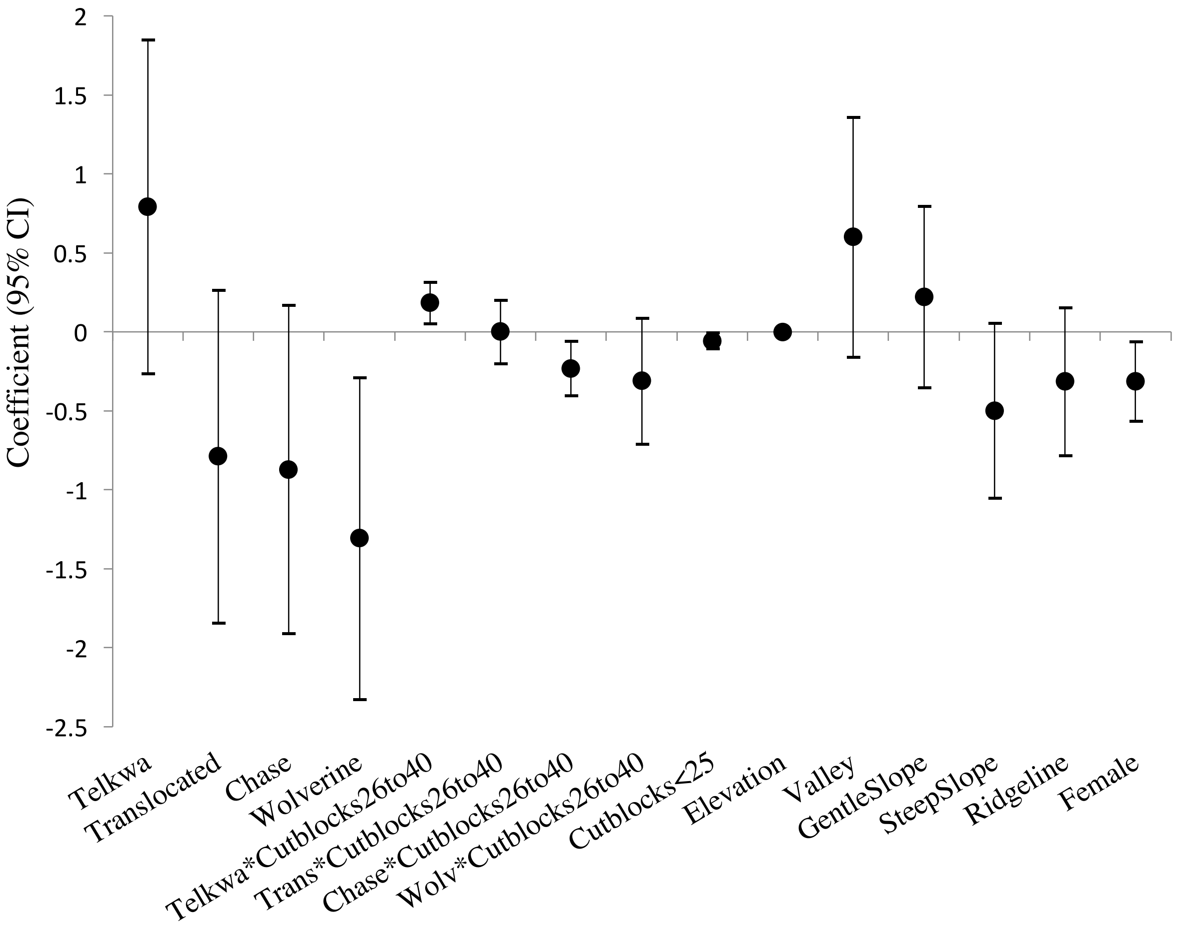

Figure 8. Coefficients and 95% confidence intervals of the most parsimonious Andersen-Gill model (Model set 2) explaining differences in survival among the Telkwa, Chase, and Wolverine herds of central British Columbia, Canada, between 1991–2012.

Global tests of the proportional hazards were not significant for the top models (maximum $\chi^2 = 16.49$, df = 13, $P = 0.224$), meaning the hazard functions for each covariate were consistent over time. Plots of scaled Schoenfeld residuals revealed symmetrical values around zero for each predictor variable, providing further evidence of proportional hazards.

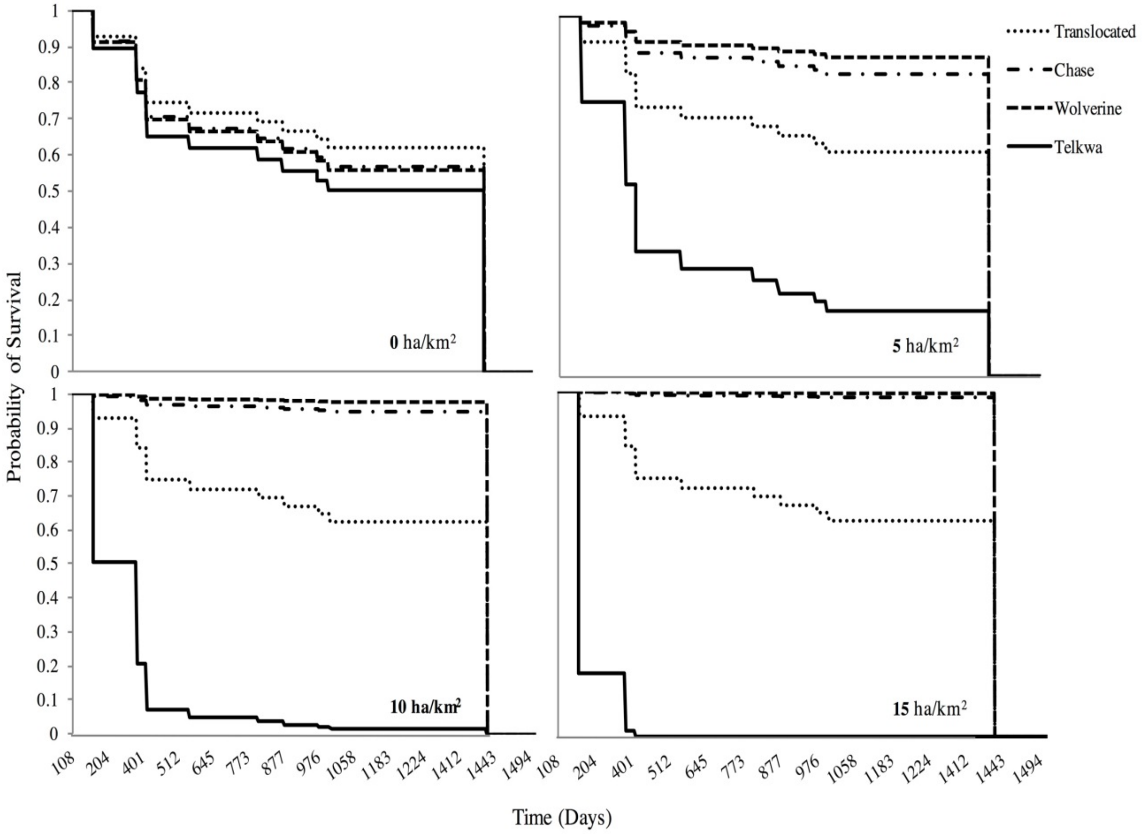

Figure 9. Predicted survival of Telkwa, Chase, Wolverine, and translocated caribou when exposed to a range of 26–40 year old cutblock densities (0 ha/km^2, 5 ha/km^2, 10 ha/km^2, and 15 ha/km^2) in central British Columbia, Canada, between 1991–2012, based on the most parsimonious interaction model (Model set 2, Table 5). Unspecified covariates were held constant at their mean values.

Discussion

Landscape-scale habitat change has altered the predator-prey dynamics of caribou across Canada with population level consequences (Festa-Bianchet et al. 2011). My results suggest that for a small, declining herd in central BC, this ecological phenomenon is largely driven by an increase in apparent competition following forest harvest. In particular, older cutblocks (26–40 years old) were important in explaining caribou survival in the Telkwa herd, suggesting a temporal lag in the mechanics of apparent competition. An interaction between herd and cutblock density, however, suggested a differential effect for Telkwa caribou compared to neighbouring herds. The relationship between survival and landscape-level forest harvesting appears to be influenced by herd-specific characteristics, such as magnitude of habitat change and population abundance.

Previous research revealed some uncertainty in the relationship between the survival of caribou and commercial logging. Two studies found that early seral forest was correlated with adult female survival, whereas another reported no relationship (Smith 2004, Wittmer et al. 2007, Apps et al. 2013). Although ≤25 year old cutblock density had a small effect, top models from both candidate sets indicated that this covariate positively influenced caribou survival, regardless of herd. One might predict the opposite effect given the findings of Nielsen et al. (2005), who showed that moose were most abundant in cutblocks that were approximately 23 years old. In theory, an increase in the density of ≤25 year old cutblocks should result in an increase in moose and predator abundance, and a subsequent decrease in caribou survival. It is likely, however, that moose abundance varies substantially within this age class of cutblocks (i.e., ≤25 years old), which could have influenced the relationship. Regardless, my results suggest that there may be a temporal lag in the mechanics of apparent competition. Though moose may be most abundant in younger cutblocks, the subsequent increase in predator populations and effect on caribou survival may take a number of years to unfold. This aligns with findings from Vors et al. (2007), who suggested a 2-decade lag between forest harvest and a corresponding decrease in caribou abundance.

The relationship between 26–40 year old cutblock density and survival differed significantly between the Telkwa, Wolverine, and Chase herds. An increasing density of 26–40 year old cutblocks negatively influenced the survival of Telkwa caribou. The effects of forest harvest, and assumed increases in apparent competition, appear to be more prominent in the Telkwa Range. Numerous studies have demonstrated that variation in behavioral response to disturbance can lead to differences in survival among individuals (e.g. McLoughlin et al. 2006, Dussault et al. 2012, Leclerc et al. 2014). It is possible that behavioral response to cutblocks differs among the Telkwa, Chase, and Wolverine herds, which ultimately influences the nature of the disturbance-survival relationship. Alternatively, this relationship may differ as a result of the TCH's exposure to much greater cutblock densities (Table 4). There may be a threshold in cutblock density after which the abundance of alternate prey and predators becomes a stronger driver of caribou survival. Also, the small size of the TCH may have a synergistic relationship with increasing predation. There is empirical evidence of inverse density dependence for woodland caribou as a consequence of altered predator-prey dynamics (Wittmer et al. 2005*b*). Regardless, cutblock density may explain some of the variation in survival among caribou herds ranging across areas with different levels of commercial forestry (Smith 2004, Wittmer et al. 2007, Apps et al. 2013, Leblond et al. 2013, Losier et al. 2015).

Road density did not play an important role in explaining caribou survival; however, limitations in the data could have influenced the statistical importance of this factor. First, there is no comprehensive inventory of roads in BC and as such, accurately quantifying changes in road density over time is impossible. Second, relocation intervals for caribou, the sampling interval for the survival analysis, were highly variable in length, meaning spatial covariates (cutblock and road densities) were based on average home range size. This yielded coarse measures of exposure, which could make it difficult to detect a statistical relationship. I am unaware of other studies that have reported specifically on the relationship between road density and the survival of woodland caribou at the scale of the landscape. At a finer scale, Apps et al. (2013) found that caribou in close proximity to roads were more likely to be killed by wolves. In contrast, Latham et al. (2011), found that the probability of predation for caribou was not related to the adjacency of linear features. Roads are a concern as they can increase wolf access and movement across the seasonal ranges of caribou, and they result in the displacement of caribou from habitat (Dyer et al. 2001, Leblond et al. 2011, Polfus et al. 2011, Johnson and Russell 2014, Dickie et al. 2016). The relationship between caribou survival and roads warrants further investigation.

There was no support for models that included recreation as a covariate, suggesting that recreation had no direct relationship to caribou survival or that the relationship was too weak to detect. Avoidance of recreationists by ungulates is well-documented (Cassirer et al. 1992, Colescott and Gillingham 1998, Creel et al. 2002, Neumann et al. 2010, Harris et al. 2014) and findings by Seip et al. (2007) showed that caribou were displaced from large areas of high-quality winter habitat by snowmobiles. Displacement may result in caribou being forced into low-quality habitat and/or areas with high predation risk. This would suggest that instantaneous exposure to recreation may have a delayed effect on caribou survival, however, given the temporal nature of the recreation variable used in this analysis, this effect should have been detected regardless. Perhaps there is no detectable relationship between recreation and survival because Telkwa caribou are at a relatively low density and they do not use areas with high-intensity recreation activity. Alternatively, the effects of recreation may play a lesser role in dictating caribou survival than previously proposed (Bergerud 1988). Although I invested considerable effort in quantifying trends in recreation activity, the measure was strictly temporal and relatively imprecise. This may have influenced my ability to detect a relationship.

The two top-ranked models in Model set 1 alluded to very different processes governing caribou survival: human-caused disturbance and climate. Although the climate-based model (All Enviro) had substantially less support, the results align with some literature and suggest that with increasing snow accumulation there is a decrease in caribou survival. Kumpula and Colpaert (2003) found a similar relationship with reindeer in a predator-free environment in Finland and Hegel et al. (2010) found a strong link between snow depth at calving and calf survival for woodland caribou in the Yukon. In contrast, average yearly snow accumulation was not a significant predictor of survival of mountain caribou in southern BC (Wittmer et al. 2007). There are two potential mechanisms that may drive a relationship between snow accumulation and caribou survival. First, deep snow can reduce the availability of winter forage and/or increase the energetic costs of foraging. Second, increasing snow depth has been related to an increase in the hunting efficiency of gray wolf and ultimately, higher predation rates on white-tailed deer and elk (Nelson and Mech 1986, Huggard 1993). In an environment where the density of caribou is low and predation is the lead cause of mortality, the role of snow accumulation in explaining caribou survival is complex (Fancy and White 1985). Nevertheless, my results suggest that it may be increasingly important to understand this relationship as snow conditions become less predictable with a changing climate (IPCC 2013).

In addition to snow accumulation, the climate-based model suggested that mean temperature had an effect on caribou survival. Mortality risk for caribou increased with increasing temperature, yet there is little evidence of this relationship in the literature. High mean monthly temperatures are associated with summer and fall months. Caribou tend to be at greater risk of predation during these seasons when subalpine and alpine areas are snow-free and more easily accessible to other ungulates such as moose and their predators (Seip 1992, Wittmer et al. 2005*b*). As global temperatures continue to increase, understanding the mechanisms driving this relationship may be important for caribou conservation.

Population augmentation and reintroduction is a controversial and often unsuccessful strategy for conserving small populations (Warren et al. 1996, Fischer and Lindenmayer 2000). A recent effort to augment a small population in southern BC was unsuccessful; a total of 19 caribou were translocated from northern to southern BC, 89% of whom died within one year (Leech 2015). It was hypothesized that translocated animals did not adopt the predator avoidance or habitat selection strategies of native caribou. In contrast, my results reveal a success story. In the late 1990s, 30 animals were translocated from the Chase to the Telkwa herd and results show that these translocated animals did not experience a higher mortality risk than native animals. The success of this translocation may be the result of the relatively short distance between the source and augmented populations (<200 km). Unlike those animals translocated from north-west BC to the south Purcells (>1000 km), caribou from the Chase herd had been exposed to very similar landscapes and ecological conditions in their home range. These findings suggest that with careful consideration of differences in the ecology of source and augmented populations, translocations can be conducted successfully.

Conclusions

The TCH has exhibited a steady decline over the last four decades, resulting in one of the smallest mountain caribou herds in the country (COSEWIC 2014). My findings show a relationship between survival and cutblock density, suggesting that the decline of this herd is at least partly driven by an increase in apparent competition as a result of commercial forestry. These results align with much of the scientific literature reporting the relationship between landscape change and the decline of woodland caribou populations (Courtois et al. 2007, Vistnes and Nellemann 2008, Festa-Bianchet et al. 2011). Furthermore, I provide novel evidence that the influence of commercial forestry may differ among herds with varying population trajectories and magnitudes of disturbance. It appears that the effects of apparent competition become most pronounced after cutblock density surpasses a certain threshold. Additionally, these results support the theory that small, declining herds, like the TCH, may be more susceptible to the effects of human disturbance.

My research suggests that individual caribou populations are faced with variation in risk, both spatially and temporally, across the landscape, which should be reflected in herd-specific management and conservation strategies. It is clear that further forest harvesting in the home range of the TCH must be limited in order to lessen apparent competition and ultimately, increase the likelihood of population recovery. Furthermore, forest management plans should be implemented in the home ranges of relatively stable and undisturbed caribou populations, such as the Chase and Wolverine herds, to ensure the composition of old forest represents that resulting from natural disturbance dynamics (Environment Canada 2014).

Chapter 3: Long-term distributional response of Northern Mountain caribou to human disturbance

Introduction

The availability of habitat resources is critical to the distribution and abundance of most species (Manly et al. 2002). Resource selection, the process whereby populations select resources that best meet their requirements for survival and reproduction, directly affects animal nutrition and plays an important role in caribou fitness (McLoughlin et al. 2005, Gaillard et al. 2010, DeCesare et al. 2014). Understanding resource selection can provide insight into the influence of anthropogenic activities on the distribution and abundance of caribou populations. The TCH provides an opportunity to investigate the long-term distributional response of caribou to human activities, while identifying potential mechanisms driving the decline of this herd.

There are number of biological factors that influence resource selection by wildlife including forage strategy, predation, competition, and disturbance (Manly et al. 2002). These factors vary spatially and temporally, resulting in substantial differences in resource selection among subpopulations of caribou (COSEWIC 2011). Generally, NMC feed on terrestrial lichens (*Cladina* spp., *Cladonia* spp., *Cetraria* spp., and *Stereocaulon* spp.) in high-elevation alpine habitat and on arboreal lichens (*Bryoria* spp.) in subalpine fir forests (Cichowski 1989). This predominantly alpine foraging strategy allows NMC to evade interspecific competition with other cervids and avoid predators. Landscape-scale habitat change over the last century, however, has significantly altered the effectiveness of these selection strategies, ultimately influencing the distribution and abundance of caribou populations across Canada (Spalding 2000, Festa-Bianchet et al. 2011).

Numerous resource selection studies have revealed that caribou avoid areas used by humans, with the strength of avoidance varying with the type and magnitude of human activity (Table 6; Dyer et al. 2001, Powell 2004, Seip et al. 2007, Vors et al. 2007, Vistnes and Nellemann 2008, Leblond et al. 2011, Polfus et al. 2011, Boulanger et al. 2012, Johnson and Russell 2014). The area of avoidance surrounding a human activity is referred to as the zone of influence (ZOI). The reported area of the ZOI for specific forms of disturbance varies considerably, likely as a function of the intensity of the disturbance and/or methodology (Polfus et al. 2011).

There are three potential mechanisms that explain why caribou avoid human activities and associated infrastructure. First, human activities may reduce the quality or quantity of habitat resources. Second, caribou may associate certain types of development, such as roads, trails, and seismic lines, with increased predation or mortality risk. Linear features, for example, are known to increase predator efficiency and the potential for predator-prey encounters (James and Stuart-Smith 2000, Whittington et al. 2011, Dickie et al. 2016, Lesmerises et al. 2017). Caribou, however, are known to avoid infrastructure such as mines, settlements, and cabins, which are not associated with increased predation. In these cases, caribou may perceive humans as predators. A response may follow the risk-disturbance hypothesis, which suggests that when encountering disturbance stimuli animals follow the same economic principles of predator-prey interactions, abandoning fitness-enhancing activities in order to reduce the probability of mortality (Frid and Dill 2002).

Avoidance of human activities may have a number of direct and indirect effects for caribou. Of greatest concern is the displacement of caribou from high-quality habitat. For example, Dyer et al. (2001) reported that 22–48% of their study area received reduced caribou use due to avoidance of wells, seismic lines, and roads. Likewise, Polfus et al. (2011) found that avoidance of human infrastructure by caribou in northern BC resulted in a loss of 8% of high-quality winter habitat and 2% of high-quality summer habitat. Displacement of caribou from high-quality habitat could have direct nutritional consequences, and ultimately, affect the fitness of individuals (Darby and Duquette 1986). Furthermore, it could force caribou into areas of higher predation risk, directly influencing caribou survival.

Table 6. Types of human disturbance and associated zones of influence as quantified by past research. Intensity/Age (Y/N) refers to whether or not the authors quantified the intensity or age of the disturbance.

Disturbance	**ZOI**	**Intensity/Age (Y/N)**	**Reference**
Mines	0.25–2 km	N	Polfus et al. 2011
	4 km	N	Weir et al. 2007
	11–14 km	N	Boulanger et al. 2012
Roads	250 m	N	Dyer et al. 2001
	1–2 km	Y (Low & High)	Polfus et al. 2011
	750 m–1.25 km	Y (Active & Derelict)	Leblond et al. 2011
	6–30 km	Y (All Season & Winter)	Johnson and Russell 2014
Seismic Lines	100 m–250 m	N	Dyer et al. 2001
	6–11 km	N	Johnson and Russell 2014
Powerlines	2.5 km	N	Nellemann et al. 2001
Cutblocks	13 km	N	Vors et al. 2007
Cabins	1.5 km	N	Polfus et al. 2011
Settlements	3–9 km	N	Polfus et al. 2011
	34–38 km	N	Johnson and Russell 2014
Wells	250 m–1km	Y (New & Old)	Dyer et al. 2001
	6–11 km	N	Johnson and Russell 2014
Recreation Area	Unknown	N/A	N/A

The influence of disturbance on the distribution or habitat selection of caribou may change over time. It is possible that habituation, where animals show a decreased response to human disturbance, may occur after long-term exposure (Reimers and Colman 2006). Apart from a study by Johnson and Russell (2014), who showed that avoidance of human development by Porcupine caribou weakened over time, there is little documentation of a habituation response by caribou (Colman et al. 2001). In contrast, caribou may demonstrate sensitization to disturbance, whereby the strength of avoidance may increase. Assessing how disturbance responses vary over time is difficult as it requires long-term and precise data describing the distribution of caribou and human activities.

The TCH has been steadily declining since the 1960s, a decline which has been accompanied by a substantial increase in human activity. The effects of anthropogenic change on the TCH's habitat and the implications of these effects for the distribution of the herd are complex and have yet to be quantified. I used a long-term dataset of radio/GPS collared caribou to statistically model the effects of environmental and anthropogenic factors on resource selection of the TCH for two time periods (1997–2007, 2013–2015). This allowed me to examine how human activities have influenced the distribution and resource selection of the herd and to test for a differential response over the last 30 years. I hypothesized that caribou avoided all forms of human disturbance in their home range and that the magnitude of avoidance changed over time. The alternative hypothesis was that the extent of degradation in the Telkwa Range provided few opportunities for caribou to avoid human disturbance and increased predation risk associated with human activities and landscape change. My findings help to identify mechanisms influencing the decline of the TCH that can be applied to other populations of NMC facing increasing levels of human activity and habitat change.

Methods

Locations

Between 1997–2007, 64 caribou were captured and collared in the Telkwa Range using helicopter net-gunning (see Chapter 1 for study area details). Sixty-one animals were outfitted with VHF collars (Model LMRT-4, Lotek Engineering, Newmarket, Ontario, Canada) and three with GPS collars (GPS 1000, Lotek Engineering, Newmarket, Ontario, Canada). This included 30 individuals relocated from the nearby Chase herd during an augmentation program in 1997 and 1998. To ensure a balanced number of locations among individuals, one location per week per individual was randomly selected from GPS collar locations between 1997–2007. Due to a hiatus in monitoring, collar data between 2008–2012 were not sufficient to model resource selection. Between 2013–2015, 12 caribou were equipped with GPS collars (GPS Remote-Release Collar, Advanced Telemetry System, Isanti, Minnesota, USA), all of which followed the same fix rate schedule; Dec 1–Mar 15 = six fixes/day, Mar 16–Apr 31 = four fixes/day, May 1–Aug 1 = six fixes/day, and Sept 1–Nov 31 = four fixes/day. I randomly selected four locations per day per individual to ensure consistency in the number of fixes.

Statistical Analysis

I used resource selection functions (RSFs) to quantify the selection strategies of the TCH relative to the availability of habitat and the distribution of human disturbances. An RSF is any model that yields values proportional to the probability of use of a resource unit by an organism (Manly et al. 2002). I used a paired/conditional logistic regression to generate coefficients for the RSFs (Compton et al. 2002, Manly et al. 2002, Johnson et al. 2004). I assumed that the RSF was of the following exponential form:

$$w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots\ldots + \beta_p x_p) = \exp(\beta' x)$$

whereby, β_p are covariates that represent the independent contribution of variables x_1 to x_p to the prediction of $w(x)$. The logistic regression uses presence (1) and pseudoabsence (0) data, whereby a presence is a known location of a caribou and a pseudoabsence is a randomly generated location representative of available habitat. Regression analyses were conducted using STATA (version 12.1, StataCorp. 2011).

I did not have adequate data to model resource selection on an individual basis for both time periods, therefore, models were based on pooled location data. For each caribou location, I generated five random locations within a radius equal to the 95th percentile longest movement of caribou in a 24-hour period (20.96 km). Relocation intervals for VHF collars did not allow for an accurate calculation of longest daily movement. To ensure a consistent domain of resource availability across time periods, the longest movement calculation was based on pooled GPS collar data (2013–2015) and was applied to both time periods. I assumed that daily movement distance remained consistent across seasons and that there was little change in this measure between 1997–2015.

Model Variables

I used existing literature to identify environmental and anthropogenic variables that may influence resource selection by caribou (Table 7). To quantify temporal variation in resource selection, I repeated the modelling process for two time periods. These represented a period of relatively stable population abundance following translocation (1997–2007) and a shorter time period that followed the rapid decline of the herd (2013–2015). Separate models were generated for two broadly defined seasons (winter: Nov 1–Apr 15, summer: Apr 16–Oct 31) and translocated versus native animals (Roberts et al. 2003, Cichowski 2014). All categorical variables in this analysis were modelled using deviation coding (Menard 2002).

Environmental variables included elevation, slope, and aspect, which I extracted from a TRIM Digital Elevation Model (25 x 25-m resolution; DataBC Distribution Service). Aspect was measured as deviation from north (0–180°) and did not include a measure of eastness. Northness directly affects temperature and vegetation growth and was therefore considered adequate for explaining variation in habitat selection by Telkwa caribou (Stronnen 2000).

Table 7. Description of environmental and human disturbance variables used to develop candidate resource selection models for native and translocated caribou in the Telkwa Range of central British Columbia, Canada, between 1997–2015.

Variable	Description
Environmental	
Elevation + Elevation^2	Quadratic function for elevation (m)
Slope + Slope^2	Quadratic function for slope (0–100%)
Aspect	Deviation from North (0–180°)
NDVI	Normalized Difference Vegetation Index. A measure of live green vegetation.
Vegetation Class	
Alpine Tundra (AT)	High-elevation, open to dense herbaceous or dwarf shrubland habitat; characterized by low dwarf shrubs, graminoids, hardy forbs, and lichens.
Alpine Unvegetated (AU)	High-elevation habitat dominated by rock outcrops, talus, steep cliffs, and other areas with sparse vegetation of grass, lichens, and low shrubs.
Engelmann Spruce-Subalpine Fir (EF)	Coniferous forest with shrub-dominated understories that include plant communities that may progress through seral lodgepole pine to a varied climax of Engelmann spruce and subalpine fir.
Subalpine Fir-Mountain Hemlock (EW)	Coniferous forest with shrub-dominated understories leading to a mixed climax of hemlock, subalpine fir, and/or amabilis fir.
Subalpine Meadow (FP)	High-elevation mosaic of stunted tree clumps and herb or dwarf shrub dominated openings, occurring above the closed forest and below the alpine.
White Spruce-Subalpine Fir (SF)	Coniferous subboreal forest with shrub-moss dominated understories that include communities that progress directly to a white spruce and subalpine fir climax, sometimes with lodgepole pine or trembling aspen.
Anthropogenic	
Dist ≤25Cut+ Dist ≤25Cut^2	Quadratic function describing distance (m) to cutblocks ≤25 years since harvest.
Dist 26–40Cut + Dist 26–40Cut^2	Quadratic function describing distance (m) to cutblocks 26–40 years since harvest.
RoadDens + RoadDens^2	Quadratic function describing the density of linear features (km/km^2) within the average home range area of caribou.
≤25CutDens + ≤25CutDens^2	Quadratic function describing the density of cutblocks ≤25 years old (ha/km^2) within the average home range area of caribou.
26–40CutDens + 26–40CutDens^2	Quadratic function describing the density of cutblocks 26–40 years old (ha/km^2) within the average home range area of caribou.
Dist_Low + Dist_Low^2	Quadratic function describing distance (m) to areas of low recreational use.
Dist_Med + Dist_Med^2	Quadratic function describing distance (m) to areas of medium recreational use.
Dist_High + Dist_High^2	Quadratic function describing distance (m) to areas of high recreational use.

I used the Broad Ecosystem Inventory (BEI) as a description of vegetation community (DataBC Distribution Service). As a measure of primary productivity, I included a normalized difference vegetation index (NDVI) based on data collected from the National Aeronautics and Space Administration (NASA) MODIS satellite (50 x 50-m resolution).

Anthropogenic disturbance in the Telkwa Range was represented by eight variables: distance to cutblocks (≤25 years and 26–40 years old), road density, cutblock density (≤25 years and 26–40 years old), and distance to high-, medium-, and low-use recreation areas. Annual cutblock layers were developed using Vegetation Resource Inventory, Forest Tenure Cutblock Polygon layers, and Reporting Silviculture Updates and Land Status Tracking Systems (RESULTS; DataBC Distribution Service). Primary prey have been found to be most abundant in cutblocks ≤25 years old (Nielsen et al. 2005, Latham et al. 2011), therefore annual layers were separated into two age categories of cutblocks: ≤25 years since harvest and 26–40 years since harvest. A road layer was developed using the Digital Road Atlas, Forest Tenure Road Segments/Lines, and RESULTS layers. I used a standard moving window algorithm to calculate the density of both age categories of cutblocks (ha/km^2) and roads (km/km^2; Eastman 2006, Anderson and Johnson 2014). The size of the moving window reflected the scale at which I investigated habitat selection and was equal to the area of the average annual home range of the TCH (328.50 km^2 MCP).

The Telkwa Range is home to three recreation areas commonly known as Hunter Basin, Starr Basin, and Grizzly Plateau. The spatial extent of these areas was quantified using recent monitoring data. Fixed-wing flights to monitor the spatial distribution of snowmobiles and skiers began in December 2013 and continued until March 2015. These flights, which occurred on a monthly basis between December and March, required flying a 2 x 2-km grid over the Telkwa Range (Figure 10) and recording intensity of snowmobile/ski tracks. These data were compiled in ArcGIS (version 10.4.1, ESRI Inc. 2015) and averaged across all months to delineate spatial boundaries for each recreation area (Figure 10). I assumed that the resulting spatial boundaries, which did not include low-elevation trails and roads, were consistent across winter and summer seasons.

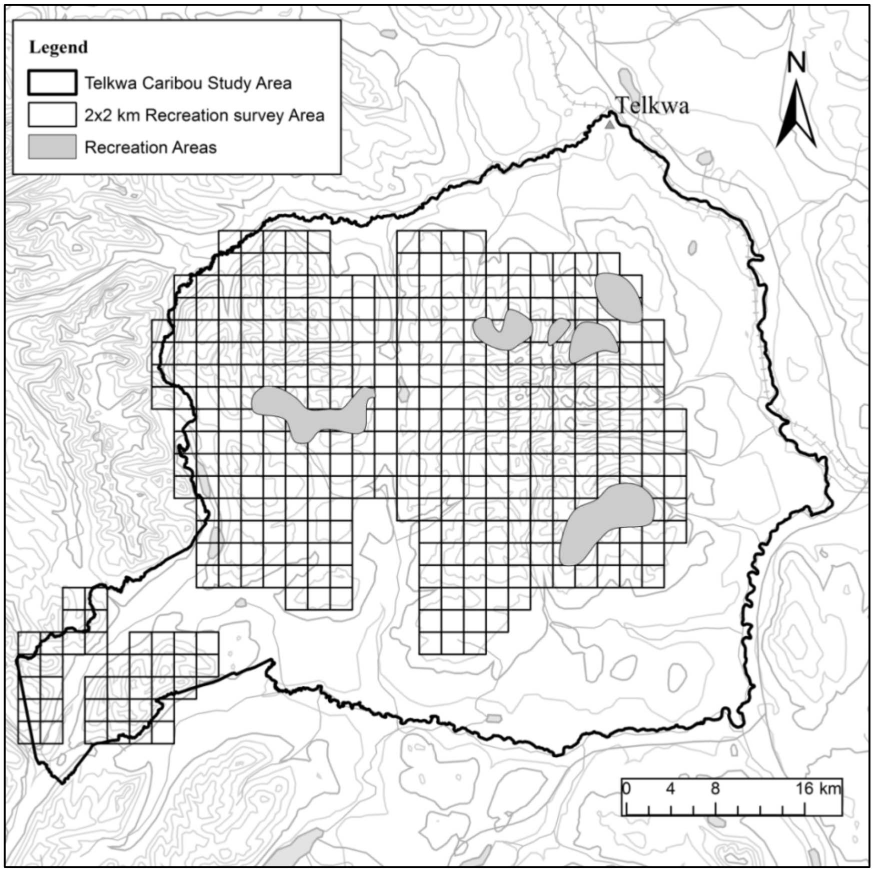

Figure 10. Grid (2 x 2-km) used to monitor recreational activity via aircraft in the Telkwa caribou study area (outlined in black) of central British Columbia, Canada between 2013–2015. The spatial extent of recreation areas (grey polygons) was based on compiled recreation monitoring flight data.

I interviewed 13 experts and then used their local ecological knowledge (LEK) to identify the intensity of use in each recreation area (Appendix A). Initial experts were selected based on their ability to speak to historical activities in the Telkwa Range and additional participants were identified using the snowball or chain-referral sampling method (Goodman 1961). Participants were asked to identify areas of low (≤20 users/month), medium (21–40 users/month), and high (≥41 users/month) recreational use in three different time periods (1985–1995, 1996–2005, 2006-2015). Responses were qualitatively compared and combined to designate areas of low, medium, and high recreational use for the 1997–2007 and 2013–2015 time periods. I then measured the distance of caribou and random locations from areas of low, medium, and high recreational use.

Model Development and Assessment

I constructed a series of 18 ecologically plausible models (Table 8) to investigate habitat selection by caribou. Models were developed to explore the influence of environmental variables alone, and in conjunction with human disturbance variables. Potential correlation between elevation and vegetation class was a concern, therefore, I developed two separate sets of human disturbance models with different baseline habitat covariates (topography and vegetation). Disturbance models addressed the influence of disturbances independently and collectively. All 18 models were compared among each other and subsequently, models were compared within the vegetation and topography sets (Appendix C). I used tolerance scores to test for multicollinearity among independent variables and I removed collinear terms (tolerance < 0.1) when necessary (Menard 2002).

I used the Akaike Information Criterion (AIC_c), corrected for small sample size, to identify the most parsimonious RSF models (Anderson et al. 2000). Specifically, I used the difference in AIC_c scores (ΔAIC_c) to measure absolute differences in parsimony among models and the AIC_c weights (w_i) to represent the relative support of the highest ranked model compared to others in the candidate model set. Information theoretic approaches provide only a relative ranking of model utility. Thus, I used a jackknife sampling approach and the area under the curve (AUC) of the Receiver Operating Characteristic (ROC) to test the predictive capability of the most parsimonious model from each set (Fielding and Bell 1997, Pearce and Ferrier 2000). The jackknife procedure iteratively excluded one cluster of use and availability locations. The model was then fit using the remaining clusters, and that RSF equation was used to calculate a probability for the withheld cluster. The ROC procedure was potentially biased by random locations that were actual caribou use locations (Boyce et al. 2002). However, that bias would result in a conservative measure of the AUC. An AUC of 0.5–0.7, 0.7–0.9, or > 0.9 indicates low, good, and excellent predictive accuracy, respectively (Manel et al. 2001).

Table 8. Candidate RSF models to describe habitat selection by native and translocated woodland caribou in the Telkwa Range of central British Columbia, Canada, between 1997–2007 and 2013–2015.

Model Name	**Covariates Included**
Habitat	
Topography (T)	Elevation^2+ Slope^2+ Aspect
Vegetation (V)	Veg Class + NDVI
Vegetation and Topo	Veg Class + Slope^2 + Aspect
Greenness and Topo	NDVI + Slope^2 + Aspect
Vegetation-Based	
Road Dens V	Vegetation + Road Dens^2
Cutblock Dens V	Vegetation + ≤25Cut Dens^2 + 26–40Cut Dens^2
Cutblock Dist V	Vegetation + Dist to $\le 25\text{Cut}^2$ + Dist to $26\text{–}40\text{Cut}^2$
Recreation Dist V	Vegetation + Dist to Low^2 + Dist to Med^2 + Dist to High^2
All Dens V	Vegetation + Road Dens^2 + ≤25Cut Dens^2 + 26–40Cut Dens^2
All Dist V	Vegetation + Dist to Low^2 + Dist to Med^2 + Dist to High^2 + Dist to $\le 25\text{Cut}^2$ + Dist to $26\text{–}40\text{Cut}^2$
All Disturbance V	Vegetation + Dist to Low^2 + Dist to Med^2 + Dist to High^2 + ≤25Cut Dens^2 + 26–40Cut Dens^2 + Road Dens^2
Topography-Based	
Road Dens T	Topography + Road Dens^2
Cutblock Dens T	Topography + ≤25Cut Dens^2 + 26–40Cut Dens^2
Cutblock Dist T	Topography + Dist to $\le 25\text{Cut}^2$ + Dist to $26\text{–}40\text{Cut}^2$
Recreation Dist T	Topography + Dist to Low^2 + Dist to Med^2 + Dist to High^2
All Dens T	Topography + Road Dens^2 + ≤25Cut Dens^2 + 26–40Cut Dens^2
All Dist T	Topography + Dist to Low^2 + Dist to Med^2 + Dist to High^2 + Dist to $\le 25\text{Cut}^2$ + Dist to $26\text{–}40\text{Cut}^2$
All Disturbance T	Topography + Dist to Low^2 + Dist to Med^2 + Dist to High^2 + ≤25Cut Dens^2 + 26–40Cut Dens^2 + Road Dens^2

Results

Model Selection

I used 20,481 collar locations (Table 9) to fit 18 seasonal habitat selection models (Table 8) for translocated and native caribou between 1997–2007 and 2013–2015. On an annual basis, the average length of relocation intervals for VHF collars ranged from 6–140 days (SD = 0.28–13.5; Figure 11). Fix success for GPS collars ranged from 76–98% between 2013–2015.

The most parsimonious model for translocated and native caribou in both time periods and seasons included the same disturbance variables (All Disturbance), but varied in the baseline habitat covariates (Table 10). The vegetation-based model was best at explaining habitat selection by translocated caribou in both seasons and native caribou during the winter of both time periods. In contrast, habitat selection by native caribou during the summer in both time periods was best explained by the topography-based model.

Table 9. Total number of locations, with range of the number of locations per individual in parenthesises, and associated collar type, for seasonal RSF models describing habitat selection by native and translocated caribou in the Telkwa Range of central British Columbia, Canada, between 1997–2007 and 2013–2015.

Time Period	**Winter**	**Summer**	**Collar Type**
1997–2007 Native	515 (11–63)	761 (11–63)	VHF/GPS
1997–2007 Translocated	1156 (11–73)	1570 (15–103)	VHF
2013–2015 Native	4806 (73–1468)	10461 (302–3005)	GPS

Within the topography-based model set, the most parsimonious model (All Disturbance T) was the same for translocated and native caribou, regardless of time period and season. There was little model selection uncertainty, with all top models yielding an w_i = 1.00. Predictive capacity was excellent for summer (average AUC = 0.91, SE = 0.0029) and winter models (average AUC = 0.98, SE = 0.005).

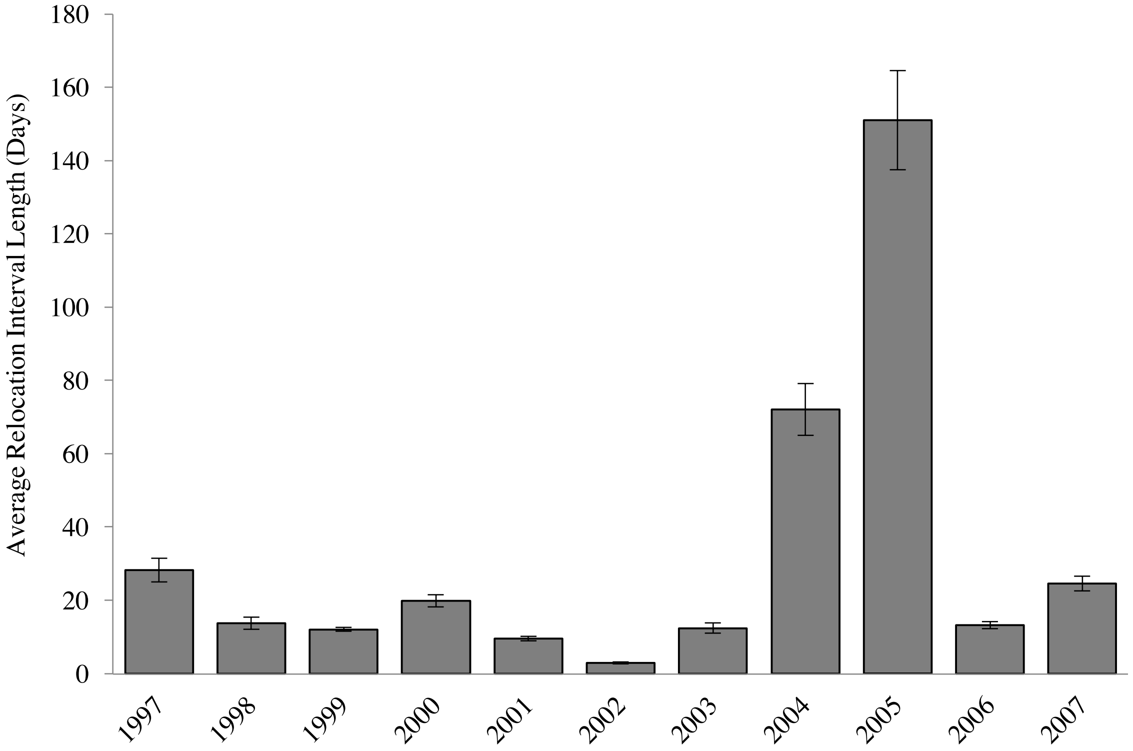

Figure 11. Average length of relocation intervals (days) for VHF collared caribou in the Telkwa Range of central British Columbia, Canada between 1997–2007.

With the exception of the summer 2013–2015 native caribou data, the top vegetation-based model (All Disturbance V) was unanimous across time periods and seasons and included the same disturbance variables as the top topography-based model. That model had excellent predictive capacity for summer (average AUC = 0.91, SE = 0.004) and winter (average AUC = 0.94, SE = 0.003). The most parsimonious summer model for native animals between 2013–2015 (All Dist V) also included quadratic terms for distance to medium recreation and distance to high recreation; however, rather than density measures, it included quadratic terms for distance to ≤25 year old cutblocks and distance to 26–40 year old cutblocks. This model had excellent predictive accuracy (AUC = 0.93, SE = 0.002).

Model Inference

Topography-based models indicated that elevation was a significant predictor of summer and winter habitat selection by caribou native to the Telkwa Range and that the nature of this relationship remained consistent over time (Figure 12, Table 11).

Table 10. Most parsimonious summer and winter RSFs for native and translocated woodland caribou in the Telkwa Range of central British Columbia, Canada, between 1997–2007 and 2013–2015. Model parsimony was based on the difference in the Akaike Information Criterion and AIC_c weights and was compared among all models (Overall ΔAIC_c and Overall w_i) and within vegetation-based and topography-based model sets (ΔAIC_c and w_i).

	k	**Log Likel.**	**AIC_c**	**ΔAIC_c**	**w_i**	**Overall ΔAIC_c**	**Overall w_i**
Summer Translocated 1997–2007							
Vegetation-Based							
All Disturbance V	16	-1607.13	3254.49	0.00	1.00	**0.00**	**1.00**
Topography-Based							
All Disturbance T	15	-1677.77	3392.70	0.00	1.00	**138.20**	**<0.001**
Winter Translocated 1997–2007							
Vegetation-Based							
All Disturbance V	16	-746.09	1532.43	0.00	1.00	**0.00**	**1.00**
Topography-Based							
All Disturbance T	15	-1003.07	2043.31	0.00	1.00	**510.87**	**<0.001**
Summer Native 1997–2007							
Vegetation-Based							
All Disturbance V	16	-735.62	1511.47	0.00	1.00	**13.03**	**<0.001**
Topography-Based							
All Disturbance T	15	-730.64	1498.44	0.00	1.00	**0.00**	**1.00**
Winter Native 1997–2007							
Vegetation-Based							
All Disturbance V	16	-200.25	440.74	0.00	0.99	**0.00**	**0.99**
Topography-Based							
All Disturbance T	15	-242.86	522.88	0.00	0.99	**82.13**	**<0.001**
Summer Native 2013–2015							
Vegetation-Based							
All Dist V	14	-7813.90	15661.97	0.00	1.00	**5108.07**	**<0.001**
Topography-Based							
All Disturbance T	15	-5452.05	10941.26	0.00	1.00	**0.00**	**1.00**
Winter Native 2013–2015							
Vegetation-Based							
All Disturbance V	16	-2118.65	4277.55	0.00	1.00	**0.00**	**1.00**
Topography-Based							
All Disturbance T	15	-2182.41	4401.99	0.00	1.00	**124.44**	**<0.001**

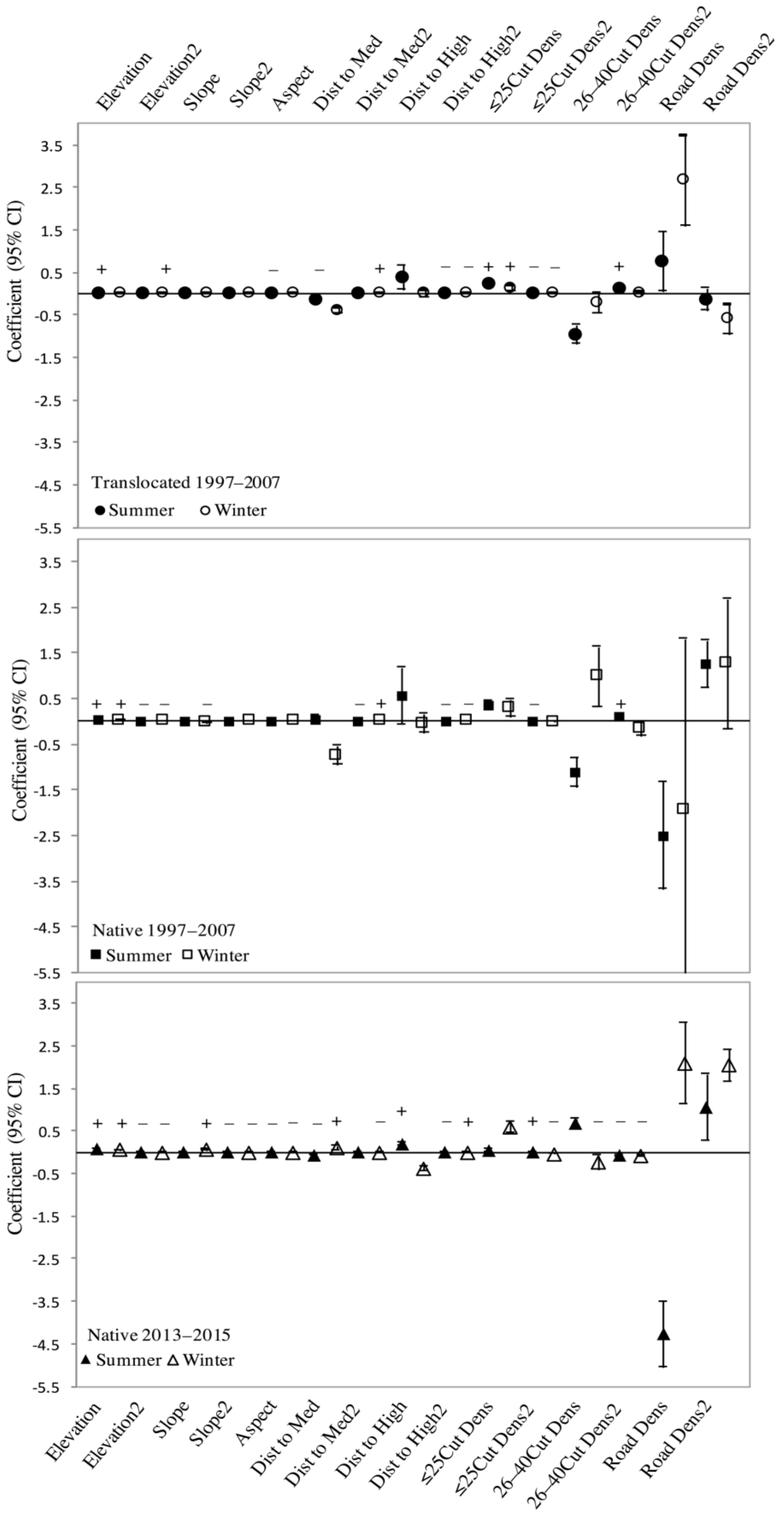

Figure 12. RSF coefficients and 95% confidence intervals for the most parsimonious topography-based models (All Disturbance T) describing habitat selection for native and translocated caribou in the Telkwa Range of central British Columbia, Canada, between 1997–2007 and 2013–2015. Filled shapes represent summer coefficients and unfilled shapes represent winter coefficients.

Table 11. Selection (S) and avoidance (A) of environmental and anthropogenic habitat variables for the most parsimonious vegetation (V) and topography (T) based models describing habitat selection by native and translocated caribou between 1997–2007 and 2013–2015 in the Telkwa Range of central British Columbia, Canada. Bullets (•) indicate variables that were not included in the top model and bold, italicized letters indicate covariate relationships that were inconsistent between topography-based and vegetation-based models.

	Translocated 1997–2007				Native 1997–2007				Native 2013–2015			
	Summer		Winter		Summer		Winter		Summer		Winter	
Variables	T	V	T	V	T	V	T	V	T	V	T	V
NDVI	•	A	•	S	•	A	•	A	•	A	•	S
AT	•	S	•	S	•	S	•	S	•	S	•	S
AU	•	S	•	A	•	S	•	A	•	S	•	S
EF	•	A	•	A	•	A	•	A	•	A	•	A
EW	•	S	•	S	•	A	•	S	•	S	•	S
FP	•	A	•	S	•	S	•	S	•	S	•	A
SF	•	A	•	A	•	A	•	A	•	A	•	A
Elevation*	S	•	A	•	S	•	S	•	S	•	S	•
Slope*	A	•	A	•	A	•	A	•	S	•	S	•
Aspect	A	•	A	•	A	•	A	•	A	•	A	•
Dist to Med*^	S	S	S	S	A	A	S	S	***S***	***A***	A	A
Dist to High*^	A	A	***S***	***A***	A	A	***S***	A	A	A	S	S
≤25CutDens*	S	S	S	S	S	S	S	S	***S***	•	S	S
26–40Cut Dens*	A	A	***A***	***S***	A	A	S	S	***S***	•	A	A
RoadDens*	S	S	S	S	A	A	A	A	***A***	•	S	S
Dist to ≤25Cut*^	•	•	•	•	•	•	•	•	•	***A***	•	N/A
Dist to 26–40Cut*^	•	•	•	•	•	•	•	•	•	***S***	•	N/A

* A quadratic term was used in the top model.

^Variable measures distance (m) from feature, therefore, selection represents a negative coefficient value and avoidance represents a positive coefficient value

Translocated animals also selected for high elevations in the summer, but differed from native animals in selecting low-elevation habitat in the winter. Furthermore, translocated animals selected for a wider range of elevations than native animals (Figure 13). This was particularly pronounced in the winter, when >70% of locations for native animals were between 1600–2000 m, while only 55% of locations for translocated caribou were within this range and 45% of the locations were below 1600 m.

Vegetation-based models revealed that native caribou predominantly selected for alpine tundra in both winter and summer (Figure 14, Figure 15, Table 11). This relationship remained consistent over time. Similarly, translocated caribou selected for alpine habitats in the summer, but showed more diverse selection strategies during the winter, when they strongly selected for Subalpine Fir-Mountain Hemlock (EW) forest. During both winter and summer translocated and native caribou demonstrated avoidance of White Spruce-Subalpine Fir (SF) and to a lesser extent, Engelmann Spruce-Subalpine Fir forest (EF).

In most cases, habitat selection by caribou was similar regardless of the application of topography or vegetation-based models (Figure 12, Figure 14, Table 11). Where the relationships differed between sets, I interpreted the model that had the lowest overall AIC_c score (i.e. $\Delta\mathrm{AIC}_c$).

The avoidance of recreation areas was highly variable and depended on season, time period, and origin of caribou. Translocated caribou selected for medium recreation areas, regardless of season. The same areas had a differential influence on native animals, seasonally and temporally. Native caribou between 1997–2007 selected for medium recreation areas in the winter and avoided those areas in the summer, however, the latter was a weak and insignificant relationship. In contrast, native caribou during the later time period avoided medium recreation areas in the winter and selected for those areas in the summer. During both summer and winter, the mean distance of caribou locations from the nearest medium use recreation area was much greater during the 2013–2015 period (Figure 16).

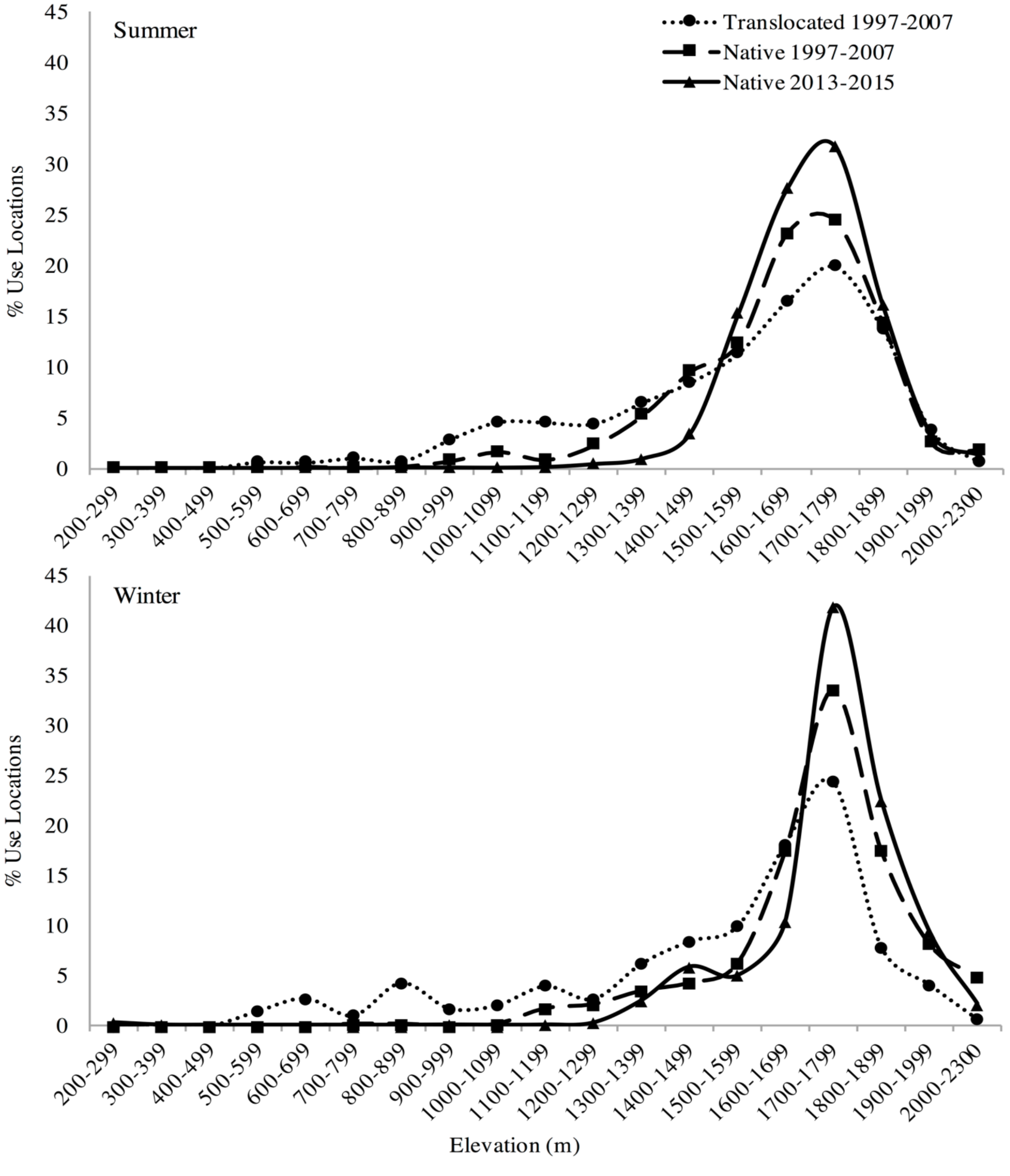

Figure 13. Percent of caribou locations relative to topographic elevation (200–2300 m) during the summer and winter seasons for translocated and native animals in the Telkwa Range of central British Columbia, Canada, between 1997–2007 and 2013–2015.

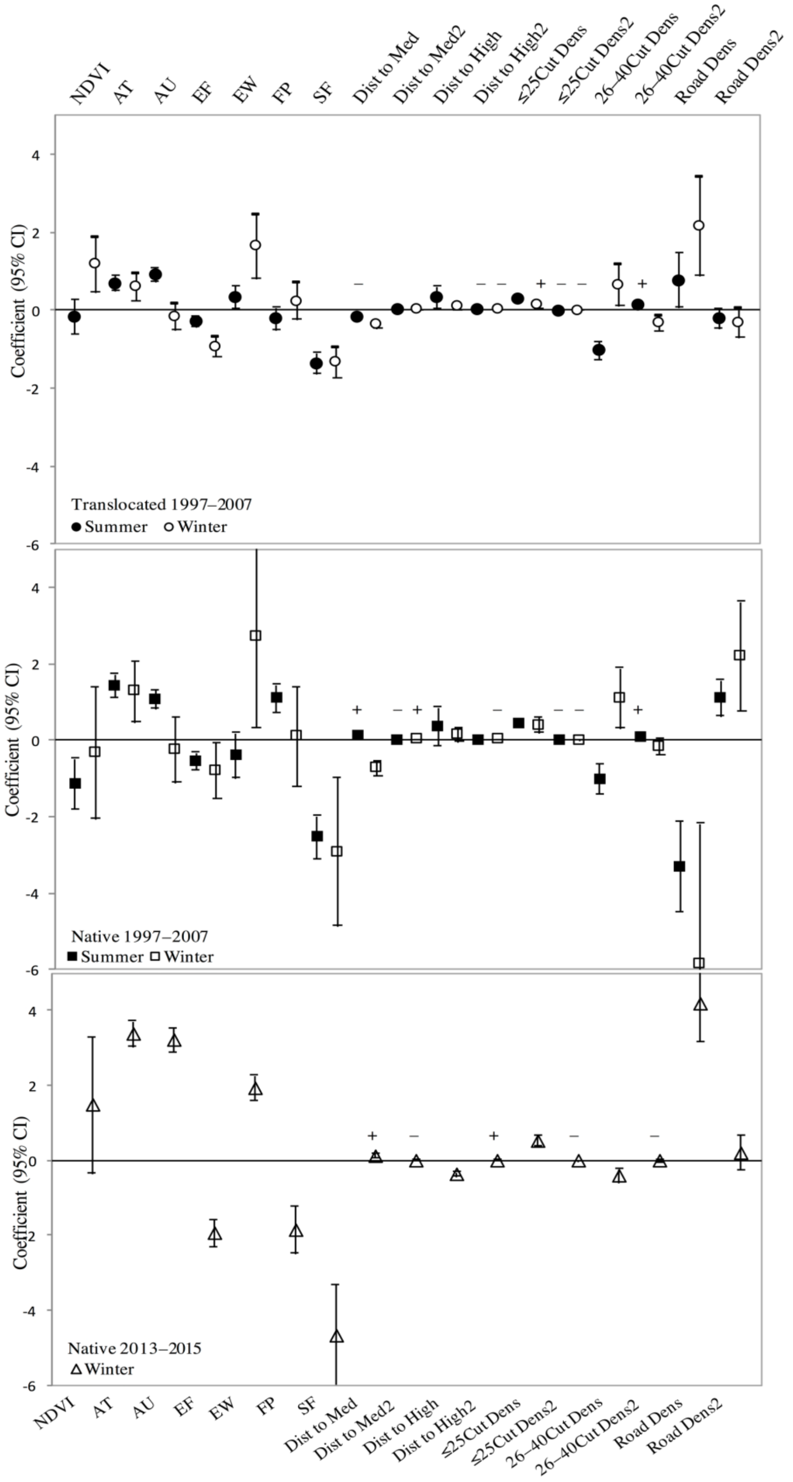

Figure 14. RSF coefficients and 95% confidence intervals for the most parsimonious vegetation-based models (All Disturbance V) describing habitat selection by native and translocated caribou in the Telkwa Range of central British Columbia, Canada, between 1997–2007 and 2013–2015. Filled shapes represent summer coefficients and unfilled shapes represent winter coefficients. Note, the top model for summer 2013–2015 differed and is therefore not included; see Figure 15.

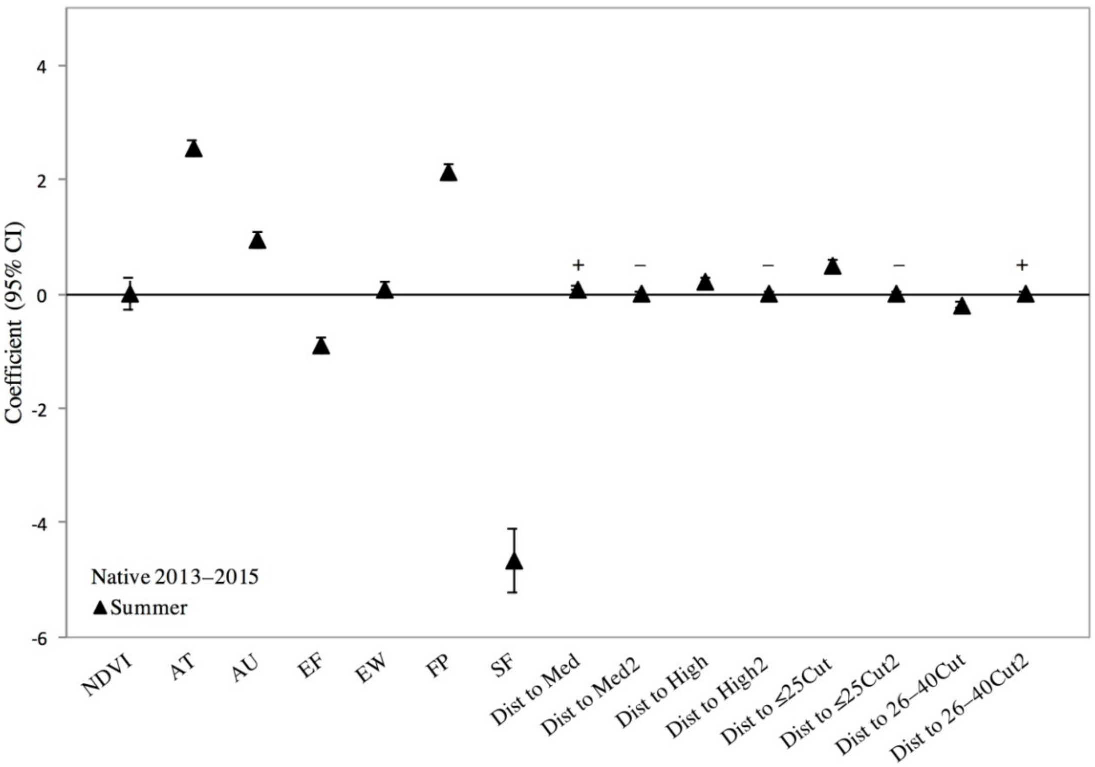

Figure 15. RSF coefficients and 95% confidence intervals for the most parsimonious vegetation-based model (All Dist V) describing summer habitat selection by native caribou in the Telkwa Range of central British Columbia, Canada, between 2013–2015.

Translocated and native caribou in both time periods demonstrated avoidance of high-use recreation areas in the summer. During the winter, translocated and native caribou in the earlier time period also avoided those areas. RSF coefficients suggested that native animals between 2013–2015 selected for high-use recreation areas in the winter, however, the average distance of caribou locations to those areas was much greater (~23 km) than in the earlier time period (~15 km, Figure 16).

Native and translocated caribou selected for areas of high ≤25 year old cutblock density, regardless of season and time period, whereas the relationship between 26–40 year old cutblock density and habitat selection was more complex.

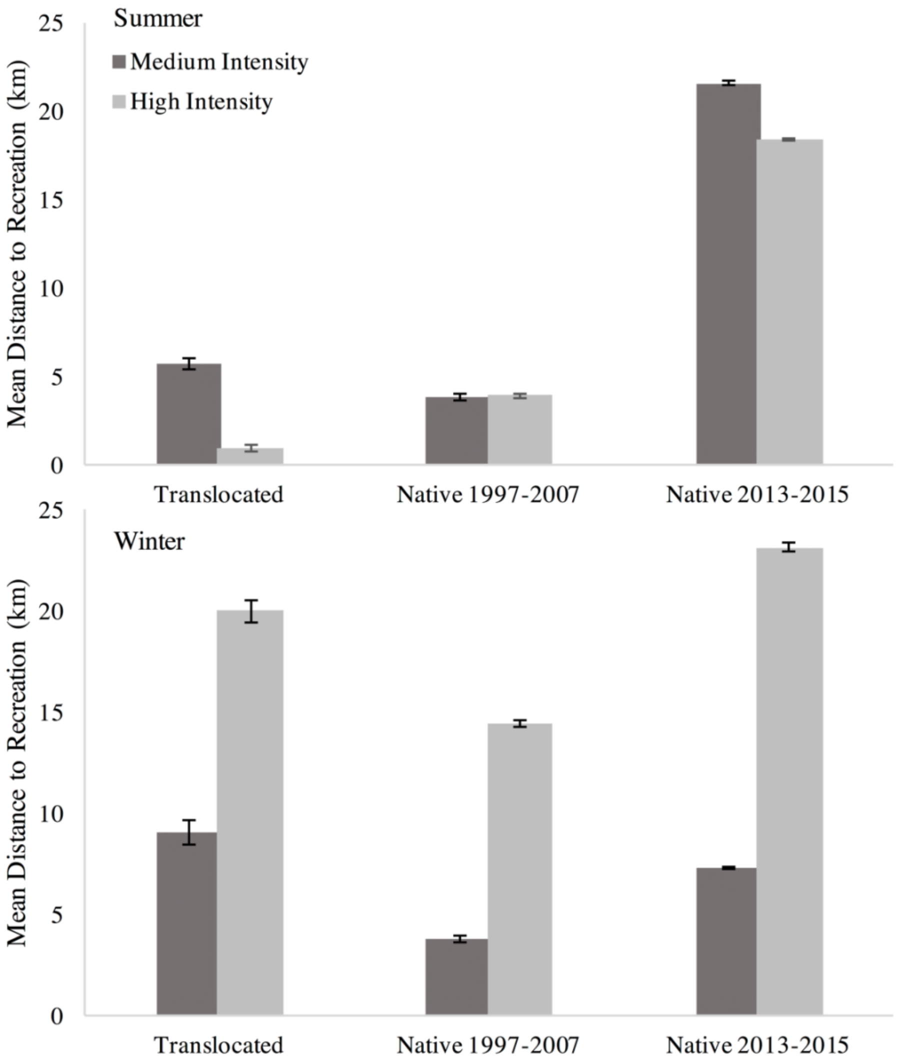

Figure 16. Mean distance (km) of native and translocated caribou locations from medium and high use recreation areas in the Telkwa Range of central British Columbia, Canada, between 1997–2007 and 2013–2015. Mean distances were calculated for summer (top panel) and winter (bottom panel).

Translocated and native caribou between 1997–2007 avoided areas of high 26–40 year old cutblock density in the summer and selected those areas during the winter. The opposite relationship was found with native animals between 2013–2015; caribou selected for high 26–40 year old cutblock densities in the summer and avoided those areas during the winter. Trends of occurrence in areas with a high density of ≤25 year old cutblocks and a low density of 26–40 year old cutblocks were consistent among translocated and native caribou seasonally and temporally (Figure 17, Figure 18). For example, 95–96% of native caribou locations between 1997–2007 were in areas with 0–1.0 ha/km^2 of 26–40 year old cutblocks. In contrast, only 15–17% of locations were associated with the same range of ≤25 year old cutblock densities.

The influence of road density on habitat selection differed between translocated and native animals during the 1997–2007 period. Native animals demonstrated strong avoidance of areas with high road density, particularly in the winter, whereas translocated animals selected for areas of high road density in both seasons. Native animals between 2013–2015 strongly avoided high road densities during the summer, but demonstrated selection for the same areas during the winter.

Discussion

Over the past 50 years, the TCH has steadily declined to fewer than 20 individuals and is at risk of extirpation. The magnitude of human activities and associated landscape-scale disturbance in the home range of the TCH has steadily increased over time, yet the role of this disturbance in their decline is largely unknown. My results suggest that disturbance plays an important role in explaining the distribution and habitat selection of the TCH. Caribou predominantly selected for high-elevation habitat regardless of season, suggesting that disturbance across valley bottoms has had a significant influence on their distribution. Generally, the influence of roads, forestry, and recreation on habitat selection aligned with current literature; however, the nature of these relationships varied over time and appeared to be particularly complex during the winter. There were no clear patterns of habitat selection indicating habituation or sensitization to human disturbance. My results suggest that human disturbance in the Telkwa Range has restricted the distribution and constrained the ability of Telkwa caribou to manage and adapt to predation risk.

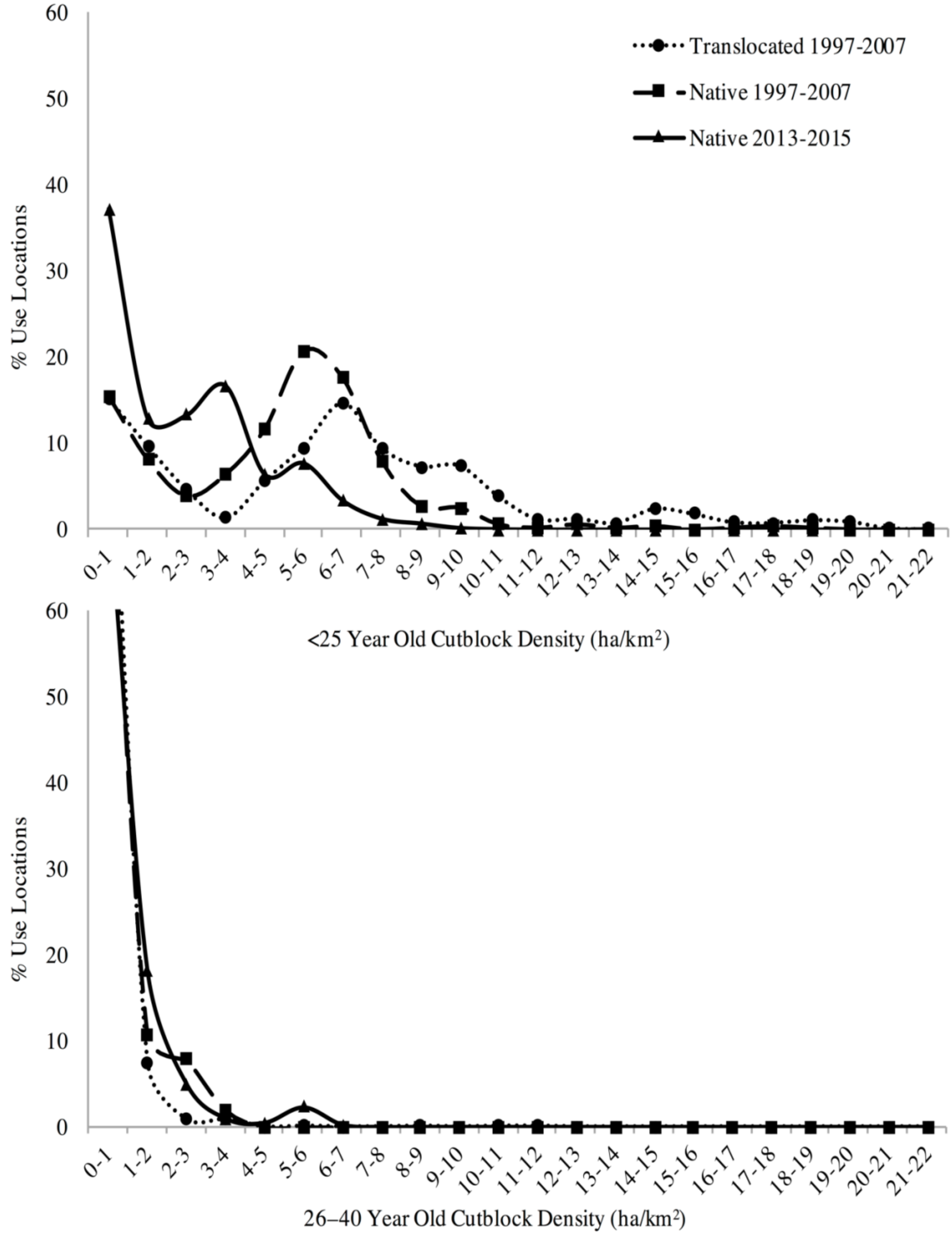

Figure 17. Percent of native and translocated caribou locations relative to ≤25 year old (top panel) and 26–40 year old (bottom panel) cutblock densities in the winter home range of the Telkwa caribou in central British Columbia, Canada, between 1997–2007 and 2013–2015.

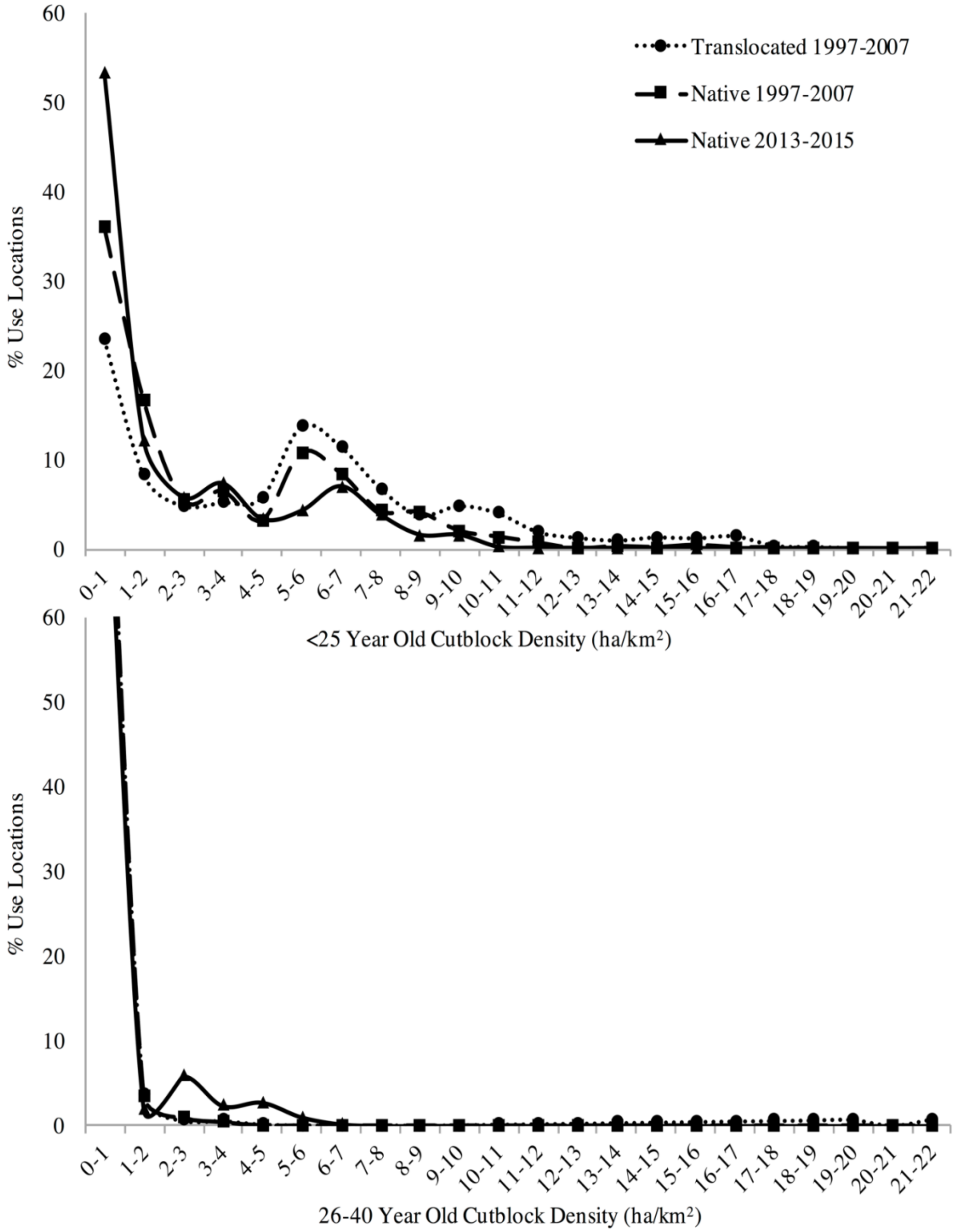

Figure 18. Percent of native and translocated caribou locations relative to ≤25 year old (top panel) and 26–40 year old (bottom panel) cutblock densities in the summer home range of the Telkwa caribou in central British Columbia, Canada, between 1997–2007 and 2013–2015.

Telkwa caribou responded most strongly to roads, demonstrating avoidance of high road densities in the summer, regardless of time period. This is consistent with current literature, which suggests that caribou strongly avoid linear features because of predator or human-caused risk (Nellemann et al. 2001, Dyer et al. 2002, Latham 2009, Ehlers 2012). The response during the winter was much less clear. In the earlier time period, native caribou avoided areas of high road density in the winter, but in the later time period selected for those areas. It is possible that avoidance of areas with high road density has become less pronounced over time, a pattern which has been documented in Porcupine Caribou (Johnson and Russel, 2014). Alternatively, road density in the home range of the TCH has likely increased over the last 20 years, limiting the ability of caribou to spatially separate themselves from areas of high road density. There is no comprehensive inventory of roads in BC and as such, I was unable to accurately quantify changes in road density over time, which may have affected my results. Furthermore, I was not able to differentiate between high and low use roads. It is possible that roads were well used in the earlier time period, but are no longer active and therefore, not perceived as a risk by caribou. Regardless, my results suggest that roads strongly influenced habitat selection by caribou and that they have likely resulted in direct and indirect habitat loss, particularly during the summer.

Native caribou demonstrated avoidance of high-use recreation areas in the summer, a response which remained consistent over time. These results align with current literature, which shows that recreation can displace caribou from high-quality habitat (Powell 2004, Seip et al. 2007). The response of native caribou to winter recreation was more variable. Although caribou in the earlier time period avoided areas of high use during the winter, caribou in the later time period selected for those areas. This suggests that habituation to high-use areas in the winter is occurring, yet this is not supported by the observed response to medium-use recreation areas. Caribou in the earlier time period selected for medium-use areas, while caribou in recent years avoided those areas. These inconsistent patterns of avoidance suggested that the influence of recreation in the winter was not static and may be driven by more than just intensity of recreational use. One possible explanation is that forage quality and quantity varied over time and among winter range areas. As a result, caribou may have responded differently to recreation areas depending on the quality of habitat within each area. It should also be noted that use locations suggested that caribou demonstrated a strong distance response to recreation during the winter; however, according to LEK holders there was only one high-use winter recreation area in the Telkwa Range. It is therefore likely that distances to those areas are inflated and should be interpreted with caution. Finally, I was unable to quantify change in the spatial extent of recreation areas during the study period, which could have influenced the results. While spatial extent was difficult for LEK holders to quantify, 77% of participants suggested that there has been an increase in recreational activity in the Telkwa Range.

Habitat selection by caribou was influenced by the magnitude of forest harvest across the landscape; however, the nature of this relationship differed depending on cutblock age. Native caribou selected for areas with high ≤25 year old cutblock densities, regardless of time period and season. Given the large moving window size used to determine densities, it is possible caribou were not actually selecting for cutblocks, but were using the remnant forests in these areas. Regardless, these results align with Dussault et al. (2012), who detected similar patterns of cutblock use. In contrast, the majority of literature suggests strong avoidance of cutblocks by caribou, but not all previous studies considered differential use by block age (Smith et al. 2000, Schaefer and Mahoney 2007, Vors et al. 2007, Ehlers 2012). Avoidance is hypothesized to be a response to increased predation risk resulting from apparent competition with moose, yet the timing of the mechanisms driving this process are not well understood. Although moose have been found to be most abundant in cutblocks that are approximately 23 years old (Nielsen et al. 2005), the subsequent effects on predation risk (see Chapter 2) and ultimately the distribution of caribou, appear to be delayed (Vors et al. 2007). Furthermore, there may be high-quality or abundant forage in early successional forests, including various species of forbs and shrubs, that attract caribou to these areas (Thomas and Gray 2002, Dussault et al. 2012, Thompson et al. 2015).

Native caribou occupied areas with relatively low densities of 26–40 year old cutblocks, yet model results suggested variable response to older cutblocks over time. Across the two time periods, the response shifted from selection to avoidance in the winter and vice versa in the summer. It is counterintuitive that Telkwa caribou would select for areas with high 26–40 year old cutblock densities in any season, as they are more likely to die in these areas (see Chapter 2). In a landscape as disturbed and dynamic as the Telkwa Range, the avoidance of one disturbance may result in the selection of another, making it difficult for Telkwa caribou to manage and adapt to predation risk. Alternatively, it is possible that selection is maladaptive and that areas with high 26–40 year old cutblock densities represent ecological sinks, where evolutionary cues and actual habitat quality diverge, resulting in poor habitat choices by caribou (Schlaepfer et al. 2002). Maladaptive choices by caribou have been documented in numerous studies and are proposed as being a result of habituation, range fidelity, maternally learned selection strategies, or an inability of caribou to adjust to a rapidly changing environment (Faille et al. 2010, Dussault et al. 2012, Beauchesne et al. 2013, Johnson et al. 2015, Losier et al. 2015).

In general, habitat selection by translocated caribou differed from that of native caribou. While native caribou strongly selected for high-elevation habitat (>1600 m) in both seasons, translocated animals selected for a wide range of elevations, demonstrating selection strategies more consistent with what is known about NMC found across ranges with less forestry-related disturbance (Cichowski 1989, Johnson et al. 2001, COSEWIC 2014). Furthermore, disturbances provoked different responses from translocated vs. native caribou. Translocated and native caribou responded similarly to recreation and young cutblocks, but differently to older cutblocks and roads. These results are similar to those of Leech (2015), who showed that translocated caribou displayed inconsistent patterns of selection compared to native caribou. These differences may be driven by individual variability, heritability in selection strategies, and/or space-use patterns that result from long-term spatial memory associated with the home range of the source population (Avgar et al. 2015).

Caribou were translocated from the Chase herd approximately 100 km NE of the Telkwa Range. Although the Chase and TCH share many characteristics, the magnitude of human disturbance in the Telkwa Range is much greater (see Chapter 2). It appears that translocated caribou were not accustomed to the magnitude of older cutblocks and roads in the Telkwa Range and demonstrated a response that increased apparent competition with moose. This did not appear to have an effect on the survival of translocated animals (see Chapter 2) and unlike similar translocation efforts with other populations of mountain caribou (Warren et al. 1996, Leech 2015), the translocation effort stabilised the decline of the TCH for a 10-year period. However, these results do suggest that the ecology and landscape conditions of both the source and augmented populations must be an important consideration during the planning of a translocation initiative (Ray et al. 2015).

Although I provide evidence that the influence of disturbance varies for native caribou over time and differs between translocated and native caribou, inference from those results are limited. First, I did not have adequate data to analyze individual variability in resource selection and I was limited to pooled resource selection models. Pooled models do not account for variation in habitat selection among individuals (Gillingham and Parker 2008, Barrier and Johnson 2012). In an attempt to address this, I ensured a relatively balanced sample size among individuals. Second, to ensure an adequate sample size, I separated location data into two broad seasons: summer and winter. Selection strategies are known to differ between early- and late-winter, and calving and rut seasons, thus, these results are generalised across several different periods (Cichowski 1989, Johnson et al. 2000, Gustine et al. 2006). Third, the majority of caribou between 1997–2007 were collared with VHF collars, whereas caribou between 2013–2015 were equipped with GPS collars. Although I ensured that the sampling scale was consistent across time periods (i.e., average home range size and constant 95% daily longest movement), the temporal scale of the data differed substantially, with GPS data being much more frequent. GPS collars yielded a much greater sample size for 2013–2015, which may lead one to conclude that models in the more recent time period would better predict habitat selection. This was not the case as model fit and predictive accuracy was comparable for the two time periods during the summer and greater for the earlier time period in the winter.

Conclusions

Disturbance played an important role in habitat selection by the TCH. Telkwa caribou predominantly selected for high-elevation habitat (>1600 m) in both seasons. This is uncharacteristic of NMC populations that occupy relatively undisturbed landscapes in central

BC, but consistent with those found in areas with a large amount of forest development across the low-elevation habitat matrix (Poole et al. 2000). The observed distribution of the TCH suggests that the magnitude of disturbance in valley bottoms has displaced most caribou from those habitats. Of the disturbances, road density provoked the greatest avoidance response, while the influences of forestry and recreation were variable. Response to forestry was dependent on cutblock age, but results indicated that caribou avoided 26–40 year old cutblocks, which may be a result of a temporal lag in the mechanics of apparent competition. Furthermore, my results provided evidence that the influence of recreation on caribou was not static and may be dependent on other factors, such as an interaction with habitat quality. These data suggested that the influence of human disturbance on habitat selection by the TCH has clearly changed over time; however, there were no patterns suggesting habituation or sensitization to disturbance.

The Telkwa caribou exist on a dynamic landscape, where the magnitude of human disturbance is constantly changing spatially and temporally. It is clear that this has had a significant influence on selection strategies and the distribution of the TCH. Potential consequences may include an increase in the likelihood of maladaptive distribution or patch use, habitat loss, and a constrained ability of the Telkwa caribou to successfully manage predation risk. It is therefore necessary for managers to minimize human disturbances that influence the distribution of the TCH. In particular, new road development in the Telkwa Range should be limited and restoration of inactive resource roads should be considered (Environment Canada 2014). Recreational activities should be regulated to prevent interactions with winter and summer range often used by caribou and forest harvest should be limited such that forest composition represents that resulting from natural disturbance dynamics (Seip 1998).

Chapter 4: General Research Summary

Woodland caribou were once one of Canada's most widely distributed large mammals. Now, many populations of caribou are declining or at serious risk of extirpation (Festa-Bianchet et al. 2011). These declines are largely attributed to human-induced habitat change, which has led to a shift in the predator-prey dynamics of caribou. In the home range of the TCH, a NMC herd nearing extirpation, the main forms of human disturbance are forestry, roads, and recreation. My study investigated the influence of these disturbances on the survival and habitat selection of the Telkwa caribou over time, providing insight into the mechanisms driving the decline of the TCH.

Survival plays an important role in the population dynamics of large herbivores (Gaillard et al. 1998, 2000, Wittmer et al. 2005*a*). Although predation is accepted as the proximate cause of caribou declines across Canada, there are relatively few studies that directly link human disturbance to caribou mortality (but see Smith 2004, Wittmer et al. 2007, Apps et al. 2013, DeCesare et al. 2014). There are even fewer studies that examine how this relationship varies among populations as a factor of landscape change. In Chapter 2, I used a long-term data set of radio/GPS collared caribou to statistically model and test the influence of anthropogenic, environmental, and demographic variables on seasonal patterns of caribou mortality for three populations of woodland caribou. I investigated how these relationships may change among augmented and native herds with varying population trajectories.

Resource selection directly affects animal nutrition and survival (McLoughlin et al. 2005, Gaillard et al. 2010, DeCesare et al. 2014). Understanding resource selection can therefore provide insight into the influence of anthropogenic activities on the distribution and abundance of caribou populations. In Chapter 3, I used a long-term dataset of radio/GPS collared caribou to statistically model the effects of environmental and anthropogenic factors on resource selection. I split the data into two periods and modelled resource selection for each time period. This allowed me to examine how human activities have influenced the distribution and resource selection of the TCH over the last 30 years.

Overall, my results suggested that forestry played the most significant role in the decline of the TCH. In BC, commercial logging generates large areas of early seral forest, which provides high-quality habitat for moose and deer (Schwartz and Franzmann 1991, Rempel et al. 1997, Serrouya 2013). These species are the primary prey of wolves and affect caribou populations through apparent competition (Holt 1977, Wittmer et al. 2007, DeCesare et al. 2009). My results suggested that the influence of forestry, and assumed increase in apparent competition, was dependent on two factors: cutblock age and the area of harvest. Young cutblocks (≤25 years old) did not negatively influence caribou survival or habitat selection by caribou. In fact, caribou were more likely to survive in areas with high densities of ≤25 year old cutblocks and actively selected for those areas. In contrast, in areas with increasing density of 26–40 year old cutblocks, caribou suffered higher mortality risk and for the most part, avoided those areas. This suggests a temporal lag in the mechanics of apparent competition: moose may not use recent cutblocks and/or wolves may take some period of time to respond to increasing moose density. The effect of apparent competition on caribou survival may take a number of years to unfold following forest harvesting.

The data describing both the survival (Chapter 2) and distribution (Chapter 3) of the TCH suggest that the influence of apparent competition may become more pronounced after cutblock densities surpass a threshold. The relationship between 26–40 year old cutblock density and survival differed significantly between the Telkwa, Wolverine, and Chase herds. With increasing density of 26–40 year old cutblocks, Telkwa caribou were more likely to die, while an increase did not negatively influence caribou survival in other herds. This suggests that the effects of forest harvest, and assumed increases in apparent competition, appear to be more prominent in the Telkwa Range. The magnitude of forestry experienced by the TCH is much greater than that of neighboring, relatively stable herds (Table 4, Figure 5). Thus, there may be a threshold in cutblock density after which the abundance of alternative prey and predators becomes a stronger driver of caribou mortality. Further research studying the survival response of a number of herds may identify that threshold in cutblock density for NMC.

Linear features, such as roads, provide predators with efficient travel routes that can increase access and the potential for predator-prey encounters (James 1999, James and Stuart-Smith 2000, Dyer et al. 2001, Whittington et al. 2011). This can result in caribou experiencing higher mortality risk in closer proximity to roads (Apps et al. 2013) and/or caribou avoiding roads (Dyer et al. 2001, Leblond et al. 2011, Polfus et al. 2011, Ehlers 2012, Johnson and Russell 2014). In the context of the Telkwa caribou, road density did not play an important role in explaining survival. Similarly, Latham et al. (2011) did not find a relationship between the probability of mortality and distance to linear features for woodland caribou in the boreal forest. My data suggested that there was not a strong risk of mortality associated with roads, yet of all the disturbances, caribou responded most strongly to roads. During the summer, caribou demonstrated avoidance of high road densities and during the winter the response varied from avoidance to selection over time. It appears that roads were not associated with an increase in mortality, yet observed caribou behaviour suggested a risk response. One possible explanation is that predation risk may have been greater historically, and caribou continued to demonstrate behaviour that reflected that risk. Alternatively, caribou may have responded to perceived risk in the form of human activity, not the direct encounter with predators. It is possible that the amount of activity on roads in the Telkwa Range has decreased over time, explaining the shift in caribou response from avoidance to selection.

Regardless of the mechanism, avoidance of roads by caribou could have important implications. First, avoidance of areas with high road density decreases habitat availability, which could have an influence on caribou fitness. Second, this response further limits the ability of the TCH to manage and adapt to other risks on the landscape. My results suggest that roads have a substantial influence on caribou distribution and resource selection, perhaps acting cumulatively with other disturbances, such as forest harvesting, to influence the decline of the TCH.

Recreational use, both motorized and non-motorized, can lead to range abandonment and/or increased accessibility to caribou habitat by wolves (Bergerud 1988, Simpson 2000, Seip et al. 2007, Lesmerises et al. 2017, Lesmerises et al. in review). I did not detect a relationship between recreation and Telkwa caribou survival. Whittington et al. (2011) reported that encounters between woodland caribou and wolves increased near linear features and at low elevations. I did not have data describing the movements and distribution of predators, but perhaps wolves used high-elevation snowmobile and hiking trails only infrequently. Regardless, recreation was a significant, but variable predictor of resource selection by caribou. The influence of recreation in the summer was clear: caribou avoided areas with high intensity of recreational use. The influence of recreation on the distribution of caribou during the winter was variable across time suggesting that the intensity of recreation varied or that other factors, such as forage quality and quantity, moderated the response to disturbance. Overall, my results suggest that it is unlikely that recreation is the primary mechanism influencing the decline of the TCH. Evidence from my research and other studies (Seip et al. 2007, Lesmerises et al. 2017, Lesmerises et al. in review), however, suggests that recreation will influence the distribution of woodland caribou and that such an impact can act cumulatively with other disturbances. For example, the TCH predominantly selects for high-elevation habitat, likely as a strategy to avoid disturbance or greater predator densities found across valley bottoms. Recreation areas overlap with remaining high-elevation habitat and may further limit habitat availability for Telkwa caribou.

Population augmentation and reintroduction is a controversial and often unsuccessful strategy for conserving small populations (Warren et al. 1996, Fischer and Lindenmayer 2000). A recent effort to augment a small population in southern BC was unsuccessful; a total of 19 caribou were translocated from northern to southern BC, 89% of whom died within one year (Leech 2015). In contrast, my results reveal a success story. In the late 1990s, 30 animals were translocated from the Chase to the Telkwa herd. Although translocated caribou displayed inconsistent patterns of selection compared to native caribou, they were not at a higher risk of mortality. In fact, native caribou were more likely to die than translocated caribou. My results support the hypothesis that translocated animals do not immediately adopt the habitat selection strategies of native caribou, but also suggest that this may not always affect mortality rates (Leech 2015). Unlike those animals translocated from north-west BC to the south Purcell Mountains (>1,000 km), caribou from the Chase herd had been exposed to very similar ecological conditions in their home range. Also, animal handling time and associated stress were less for caribou moved from the Chase to the Telkwa Range. These findings suggest that with careful consideration of differences in the ecology of source and augmented populations, translocations can be conducted successfully.

Despite population augmentation in the 1990s, the TCH has declined to fewer than 20 individuals and is at continual risk of extirpation. This decline has been accompanied by a substantial increase in human activity, the magnitude of which is unparalleled in neighbouring, relatively stable herds. It is generally accepted that the decline of caribou herds across Canada has resulted from a human-induced shift in predator-prey dynamics (Festa-Bianchet et al. 2011). My results suggest that this holds true for the TCH and that the decline of this herd has been largely driven by an increase in apparent competition following forest harvest. Although the primary driver of the decline appears to be forestry, my results indicate additional processes may be contributing to the current decline of the TCH. Forestry, roads, and recreation influenced caribou distribution and habitat selection. The magnitude and spatial extent of these disturbances may limit habitat availability and make it difficult for caribou to manage predation risk on the landscape using their adaptive strategy of dispersing away from predators (Bergerud et al. 1984).

My findings suggest that in order for the TCH to recover, further forest harvesting must be limited until the composition of old forest represents that resulting from natural disturbance dynamics (Environment Canada 2014). This may result in a lessening of apparent competition and a rebalancing of the predator-prey dynamics of the TCH. Although my data do not provide a definitive or causative relationship, the impacts of human activities on the distribution and survival of the TCH are likely cumulative. Thus, new road development in the Telkwa Range should not be permitted and recreational activities should be regulated to prevent interactions with winter and summer range often used by caribou (Environment Canada 2014). Until recently, there have been very few habitat protection measures in place across the range of the TCH and this has had population-level consequences. As industrial development and human activities continue to intensify in northern Canada (COSEWIC 2014) lessons learned from the TCH should be used to better guide conservation and management strategies for stable and declining herds of mountain caribou.

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Appendix A – Local Ecological Knowledge survey, and associated UNBC Research Ethics Board Approval, used to quantify historical recreation patterns in the home range of the Telkwa caribou of central, British Columbia, Canada, between 1985–2015.

Name:
Date:
Contact Information:
Place of Residence:
Association with Local Organization(s):

1. How many years have you resided in the Bulkley Valley?

2. On average, how many days per year do you spend in the Telkwa range?

3. What is your main recreational activity in the Telkwa range (e.g. hunting, snowmobiling, hiking, skiing, etc.)?

4. What areas in the Telkwa Range do you typically recreate in?

5. What human activities (e.g. forestry, mineral exploration, recreation, etc.) are you aware of occurring in the Telkwa range between 1985 and 2015?

6. In your opinion, what has been the most prevalent human activity in the Telkwa range between 1985-2015?

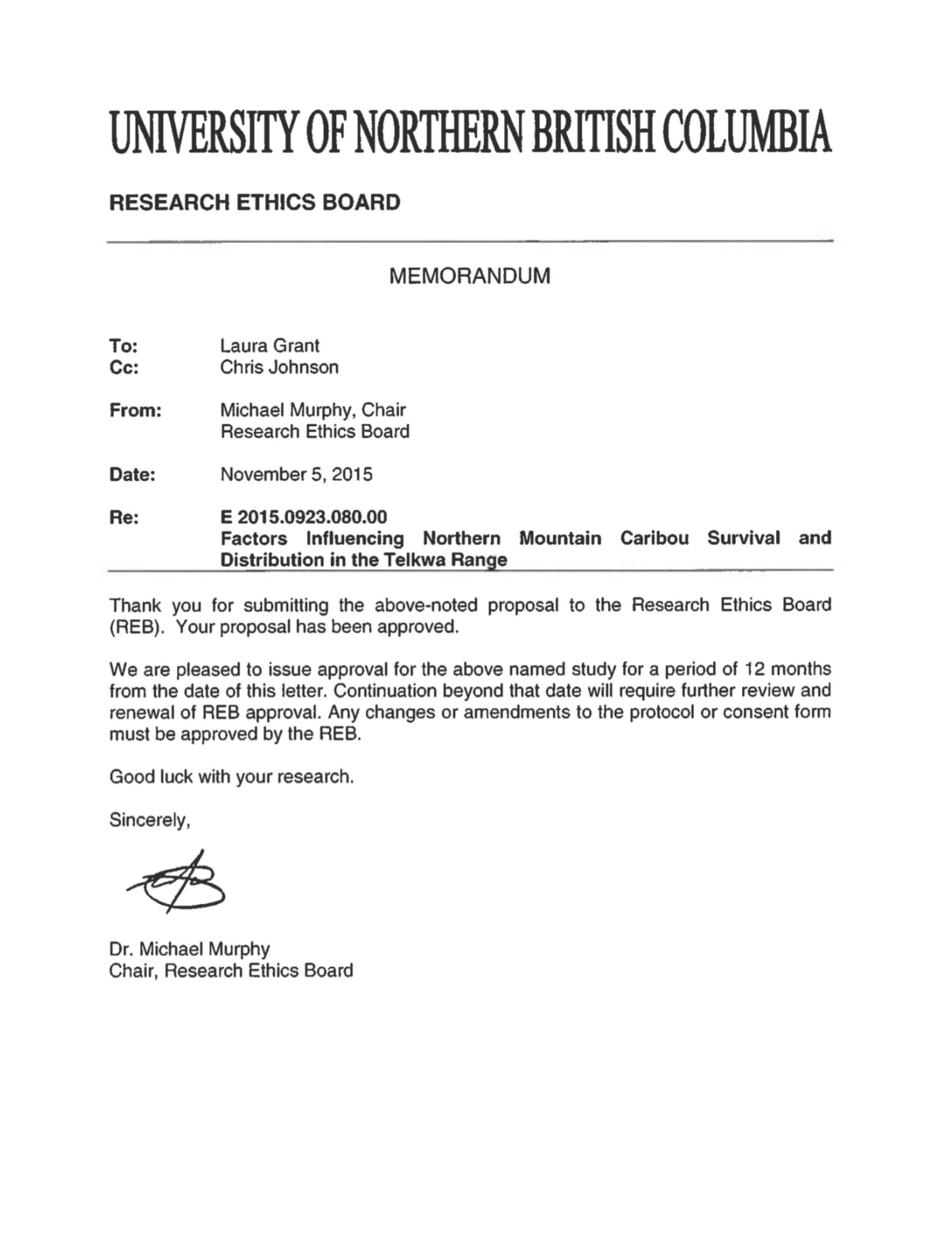
7. In which of the following time periods do you feel you can confidently speak to the intensity of recreational use in the Telkwa range?
    - o 1985-1995
    - o 1996-2005
    - o 2006-2015

8. In your opinion, has the intensity of recreational use in the Telkwa range changed over the last 30 years?

9. Rate the intensity (Low, Medium or High) of recreational use in the Telkwa range in the following time periods:
    - o 1985-1995:
    - o 1996-2005:
    - o 2006-2015:

10. On the three maps provided, mark recreational use areas during the three different periods (1985-1995, 1996-2005, 2006-2015). Indicate the intensity of use of these areas in the winter and summer using L (low), M, (medium), or H (high). If summer and winter vary, indicate varying intensities using different colored markers.

11. Is there anyone you would recommend that we speak to regarding human disturbance and/or recreation in the Telkwa range?



UNIVERSITY OF NORTHERN BRITISH COLUMBIA

RESEARCH ETHICS BOARD

MEMORANDUM

To: Laura Grant
Cc: Chris Johnson

From: Michael Murphy, Chair
Research Ethics Board

Date: November 5, 2015

Re: **E 2015.0923.080.00**
Factors Influencing Northern Mountain Caribou Survival and Distribution in the Telkwa Range

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Thank you for submitting the above-noted proposal to the Research Ethics Board (REB). Your proposal has been approved.

We are pleased to issue approval for the above named study for a period of 12 months from the date of this letter. Continuation beyond that date will require further review and renewal of REB approval. Any changes or amendments to the protocol or consent form must be approved by the REB.

Good luck with your research.

Sincerely,

Dr. Michael Murphy
Chair, Research Ethics Board

Appendix B – Model selection and statistical parameters for candidate A-G models describing survival of woodland caribou in the Telkwa, Chase, and Wolverine ranges of central British Columbia, Canada, between 1991–2012.

Table B1. Candidate Andersen-Gill models describing survival of woodland caribou in the Telkwa, Chase, and Wolverine ranges of central British Columbia, Canada, between 1991–2012 and associated AIC_c values including number of parameters (k), log-likelihood, Akaike's Information Criterion (AIC_c) scores, difference in AIC_c scores (Δ), and AIC_c weights (w_i).

Model set 1	k	**Log Likeli.**	AIC_c	ΔAIC_c	w_i
Cutblocks<25, Cutblocks26–40, Elevation, TPI, Sex, Herd	10	-304.79	632.65	0.00	0.9093
Temp, Snow, Elevation, TPI, Season, Sex, Herd	13	-302.99	637.27	4.61	0.0907
Elevation, TPI, Sex, Herd	8	-317.66	653.26	20.61	<0.001
Addt.Cutblocks<25, Addt.Cutblocks26–40, Elevation, TPI, Sex, Herd	10	-317.19	657.43	24.77	<0.001
CutblocksUnder25, Cutblocks26to40, Sex, Herd	6	-326.23	665.57	32.92	<0.001
RoadDensity, Cutblocks<25, Cutblocks26–40, Sex, Herd	7	-325.52	666.53	33.88	<0.001
RoadDensity, Cutblocks<25, Cutblocks26–40, Rec, Sex, Herd	9	-325.19	670.86	38.20	<0.001
Sex, Herd, Season	7	-332.82	681.13	48.47	<0.001
Sex	1	-342.05	686.16	53.51	<0.001
Addt.RoadDensity, Addt.Rec, Snow, Season, Sex, Herd	10	-331.97	686.99	54.33	<0.001
RoadDensity, Rec, Season, Snow, Sex, Herd	11	-331.54	688.80	56.14	<0.001
Temp, Snow, Sex, Herd	6	-337.86	688.82	56.16	<0.001
Addt.Rec, Sex, Herd	5	-339.52	689.81	57.16	<0.001
Addt.RoadDensity, Sex, Herd	5	-339.59	689.97	57.32	<0.001
RoadDensity, Sex, Herd	5	-339.84	690.46	57.81	<0.001
Addt.RoadDensity, Addt. Cutblocks26–40, Sex, Herd	6	-339.13	691.37	58.71	<0.001
Rec, Sex, Herd	6	-339.13	691.37	58.72	<0.001
Addt.Cutblocks<25, Addt.Cutblocks26–40, Sex, Herd	6	-339.13	691.37	58.72	<0.001
Addt.RoadDensity, Addt.Cutblocks26–40, Addt.Rec, Sex, Herd	7	-338.98	693.46	60.80	<0.001
Season	3	-350.01	706.32	73.66	<0.001
Herd	3	-354.37	715.04	82.39	<0.001

Table B1 Continued…

Model set 2	***k***	**Log_Likel.**	**AIC_c**	**ΔAIC_c**	**w_i**
Herd*Cutblocks26to40, Herd, Cutblocks26to40 CutblocksUnder25, Elevation, TPI, Sex	13	-300.15	631.57	0.00	0.9577
Herd*CutblocksUnder25, Herd, CutblocksUnder25, Cutblocks26to40, Elevation, TPI, Sex	13	-303.27	637.81	6.24	0.0423
Herd*Addt.CutblocksUnder25, Herd, Addt.CutblocksUnder25 Addt.Cutblocks26to40, Elevation, TPI, Sex	13	-313.10	657.48	25.91	<0.001
Herd*Addt.Cutblocks26to40, Herd, Addt.Cutblocks26to40 Addt.CutblocksUnder25, Elevation, TPI, Sex	13	-312.46	656.20	24.63	<0.001
Herd*Road Density, Herd, Road Density, CutblocksUnder25, Cutblocks26to40, Sex	10	-324.76	672.58	41.01	<0.001
Herd*Rec, Herd, Rec, Road Density, CutblocksUnder25, Cutblocks26to40, Sex	11	-324.73	675.17	43.60	<0.001

Table B2. Coefficients and statistical parameters of the most parsimonious Andersen-Gill model (Model set 1) describing caribou survival in the Telkwa, Chase, and Wolverine herds of central British Columbia, Canada, between 1991–2012.

Variable	**Coefficient**	**Robust SE**	**z**	**P>z**	**Lower 95% CI**	**Upper 95% CI**
CutblocksUnder25	-0.036	0.021	-1.70	0.088	-0.077	0.005
Cutblocks26to40	0.042	0.035	1.17	0.241	-0.028	0.111
Elevation	-0.003	0.001	-3.88	0.000	-0.005	-0.001
Valley	0.655	0.389	1.69	0.092	-0.106	1.417
Slope	0.216	0.298	0.73	0.467	-0.367	0.799
SteepSlope	-0.583	0.290	-2.01	0.044	-1.15	-0.015
Ridgeline	-0.288	0.243	-1.18	0.236	-0.765	0.189
Female	-0.338	0.127	-2.65	0.008	-0.588	-0.088
Male	0.338	0.127	2.65	0.008	0.088	0.588
Translocated	0.069	0.309	0.22	0.823	-0.537	0.676
Telkwa	0.922	0.278	3.31	0.001	0.377	1.468
Chase	-0.366	0.275	-1.33	0.184	-0.906	0.174
Wolverine	-0.626	0.236	-2.65	0.008	-1.089	-0.163

Table B3. Coefficients and statistical parameters of the most parsimonious Andersen-Gill model (Model set 2) explaining differences in caribou survival among the Telkwa, Chase, and Wolverine herds of central British Columbia, Canada, between 1991–2012.

Variable	**Coefficient**	**Robust SE**	**z**	**P>z**	**Lower 95% CI**	**Upper 95% CI**
Telkwa	0.790	0.539	1.47	0.142	-0.265	1.846
Translocated	-0.790	0.539	-1.47	0.142	-1.846	0.265
Chase	-0.873	0.530	-1.65	0.099	-1.911	0.165
Wolverine	-1.308	0.519	-2.52	0.012	-2.326	-0.290
Telkwa*Cutblocks26to40	0.182	0.067	2.71	0.007	0.051	0.314
Trans*Cutblocks26to40	-0.001	0.102	-0.01	0.991	-0.201	0.199
Chase*Cutblocks26to40	-0.233	0.872	-2.67	0.008	-0.404	-0.062
Wolv*Cutblocks26to40	-0.312	0.203	-1.54	0.125	-0.710	0.086
Cutblocks<25	-0.058	0.025	-2.33	0.020	-0.107	-0.009
Elevation	-0.003	0.001	-4.03	0.000	-0.005	-0.002
Valley	0.598	0.387	1.54	0.123	-0.161	1.357
GentleSlope	0.218	0.293	0.74	0.457	-0.356	0.792
SteepSlope	-0.499	0.283	-1.77	0.077	-1.054	0.054
Ridgeline	-0.316	0.238	-1.33	0.185	-0.783	0.151
Female	-0.315	0.128	-2.46	0.014	-0.566	-0.064
Male	0.315	0.128	2.46	0.014	0.065	0.566

Appendix C – Model selection and statistical parameters for candidate RSF Models describing habitat selection by native and translocated woodland caribou in the Telkwa Range of central British Columbia, Canada, between 1997–2015.

Table C1. Candidate models to describe winter resource selection by native woodland caribou from the Telkwa Range of central British Columbia, Canada, between 1997–2007 and associated AIC$_c$ values including number of parameters (*k*), log-likelihood, Akaike's Information Criterion (AIC$_c$) scores, difference in AIC$_c$ scores (Δ), and AIC$_c$ weights (w_i).

All Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	**w_i**
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2+ 26–40CutDens^2 + Road Dens^2	16	-200.25	440.74	0.00	0.9877
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2+ Dist_Under25^2 + Dist_26to40^2	14	-207.67	449.51	8.76	0.0123
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2	10	-229.57	482.20	41.45	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2+ 26–40CutDens^2 +Road Dens^2	15	-242.86	522.88	82.13	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	13	-250.92	533.10	92.36	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2	9	-283.99	588.44	147.69	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2 + Road Dens^2	12	-299.21	626.87	186.12	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2	10	-311.88	683.82	243.08	<0.001
Veg_Class + NDVI + Dist_Under25^2 + Dist_26to40^2	10	-330.38	683.82	243.08	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Under25^2 + Dist_26to40^2	9	-351.90	724.27	283.52	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2 + Road Dens^2	11	-349.94	725.59	284.85	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2	9	-357.00	734.47	293.73	<0.001
Veg_Class + NDVI+ Road Dens^2	8	-364.15	746.25	305.51	<0.001
Veg_Class + NDVI	6	-380.73	774.56	333.81	<0.001
Elevation^2 + Slope^2 + Aspect + Road Dens^2	7	-396.29	808.07	367.32	<0.001
Elevation^2+ Slope^2+ Aspect	5	-411.52	833.82	393.07	<0.001
Veg Class + Slope^2 + Aspect	8	-424.32	866.59	425.84	<0.001
NDVI + Slope^2 + Aspect	4	-790.48	1589.46	1148.72	<0.001

Table C1 Continued….

Vegetation-Based Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	**w_i**
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2+ 26–40CutDens^2 + Road Dens^2	16	-200.25	400.50	432.50	0.9877
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	14	-207.69	415.33	443.33	0.0123
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2	10	-229.57	459.14	479.14	<0.001
Veg_Class + NDVI + ≤25CutDens^2+ 26–40CutDens^2+ Road Dens^2	12	-299.21	598.41	622.41	<0.001
Veg_Class + NDVI + ≤25CutDens^2+ 26–40CutDens^2	10	-311.88	660.77	680.77	<0.001
Veg_Class + NDVI + Dist_Under25^2 + Dist_26to40^2	10	-330.38	660.77	680.77	<0.001
Veg_Class + NDVI+ Road Dens^2	8	-364.15	728.31	744.31	<0.001
Topography-Based Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	**w_i**
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2+ 26–40CutDens^2 + Road Dens^2	15	-242.86	485.72	515.72	0.9940
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2+ Dist_26to40^2	13	-250.91	501.83	527.83	0.0060
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2	9	-283.99	567.97	585.97	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Under25^2 + Dist_26to40^2	9	-351.90	703.80	721.80	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2+ 26–40CutDens^2	9	-357.00	714.01	732.01	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2+ 26–40CutDens^2+ Road Dens^2	11	-349.94	699.87	721.87	<0.001
Elevation^2 + Slope^2 + Aspect + Road Dens^2	7	-396.29	792.58	806.58	<0.001

Table C2. RSF coefficients and statistical parameters for the most parsimonious model describing winter habitat selection by native caribou in the Telkwa Range of central British Columbia, Canada, between 1997–2007.

Variable	**Coefficient**	**Robust SE**	**z**	**P>z**	**Lower 95% CI**	**Upper 95% CI**
NDVI	-0.346	0.881	-0.39	0.694	-2.071	1.379
AT	1.253	0.404	3.10	0.002	0.461	2.046
AU	-0.267	0.434	-0.62	0.538	-1.118	0.583
EF	-0.806	0.372	-2.17	0.03	-1.535	-0.077
EW	2.683	1.209	2.22	0.027	0.312	5.0538
FP	0.073	0.662	0.11	0.912	-1.225	1.371
SF	-2.936	0.989	-2.97	0.003	-4.873	-0.998
Dist to Med	-0.748	0.100	-7.44	<0.001	-0.945	-0.551
Dist to Med^2	1.80E-05	3.33E-06	5.40	<0.001	1.15E-05	2.45E-05
Dist to High	0.122	0.097	1.25	0.210	-0.069	0.313
Dist to High^2	-1.76E-05	3.90E-06	-4.52	<0.001	-2.53E-05	-9.99E-06
≤25Cut Dens	0.381	0.107	3.54	<0.001	0.170	0.592
≤25Cut Dens^2	-0.015	0.007	-2.11	0.035	-0.028	-0.001
26–40Cut Dens	1.087	0.406	2.68	0.007	0.290	1.883
26–40Cut Dens^2	-0.184	0.112	-1.64	0.101	-0.404	0.036
Road Dens	-5.859	1.874	-3.13	0.002	-9.532	-2.185
Road Dens^2	2.188	0.729	3.00	0.003	0.757	3.618

Table C3. Candidate models to describe summer resource selection by native woodland caribou from the Telkwa Range of central British Columbia, Canada, between 1997–2007 and associated AIC$_c$ values including number of parameters (k), log-likelihood, Akaike's Information Criterion (AIC$_c$) scores, difference in AIC$_c$ scores (Δ), and AIC$_c$ weights (w_i).

All Models	k	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	w_i
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2+ 26–40CutDens^2 +Road Dens^2	15	-730.64	1461.28	1491.28	0.9980
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2+ 26–40CutDens^2 +Road Dens^2	16	-735.61	1471.23	1503.23	0.0015
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2 + Road Dens^2	11	-743.97	1487.93	1509.93	<0.001
Elevation^2 + Slope^2+ Aspect + ≤25CutDens^2 + 26–40CutDens^2	9	-754.59	1509.17	1527.17	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2 + Road Dens^2	12	-752.11	1504.22	1528.22	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	13	-758.11	1516.21	1542.21	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2	10	-772.31	1544.61	1564.61	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Under25^2 + Dist_26to40^2	9	-781.34	1562.68	1580.68	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2	9	-781.90	1563.79	1581.79	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	14	-776.24	1552.48	1580.48	<0.001
Elevation^2 + Slope^2 + Aspect + Road Dens^2	7	-790.92	1581.83	1595.83	<0.001
Elevation^2+ Slope^2+ Aspect	5	-794.65	1589.28	1599.28	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med2 + Dist_High^2	10	-800.54	1601.07	1621.07	<0.001
Veg_Class + NDVI+ Road Dens^2	8	-805.17	1610.34	1626.34	<0.001
Veg_Class + NDVI + Dist_Under25^2 + Dist_26to40^2	10	-804.48	1608.97	1628.97	<0.001
Veg_Class + NDVI	6	-818.94	1637.88	1649.88	<0.001
Veg Class + Slope^2 + Aspect	8	-840.16	1680.31	1696.31	<0.001
NDVI + Slope^2 + Aspect	4	-1266.68	2533.37	2541.37	<0.001

Table C3 Continued...

Vegetation-Based Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	**w_i**
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2 + 26–40CutDens^2 +Road Dens^2	16	-735.61	1471.23	1503.23	1.0000
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2+ Road Dens^2	12	-752.11	1504.22	1528.22	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2	10	-772.31	1544.61	1564.61	<0.001
Veg_Class + NDVI + Dist_Low^2+ Dist_Med^2 + Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	14	-776.24	1552.48	1580.48	<0.001
Veg_Class + NDVI + Dist_Under25^2+ Dist_26to40^2	10	-804.48	1608.97	1628.97	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2	10	-800.54	1601.07	1621.07	<0.001
Veg_Class + NDVI+ Road Dens^2	8	-805.17	1610.34	1626.34	<0.001

Topography-Based Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	**w_i**
Elevation^2 + Slope^2 + Aspect + Dist_Low^2+ Dist_Med^2+ Dist_High^2+ ≤25CutDens^2+ 26–40CutDens^2 +Road Dens^2	15	-730.64	1461.28	1491.28	0.9995
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2 + Road Dens^2	11	-743.97	1487.93	1509.93	0.0005
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2	9	-754.59	1509.17	1527.17	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2+ Dist_26to40^2	13	-758.11	1516.21	1542.21	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Under25^2+ Dist_26to40^2	9	-781.34	1562.68	1580.68	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2+ Dist_High^2	9	-781.90	1563.79	1581.79	<0.001
Elevation^2 + Slope^2 + Aspect + Road Dens^2	7	-790.92	1581.83	1595.83	<0.001

Table C4. RSF coefficients and statistical parameters for the most parsimonious model describing summer habitat selection by native caribou in the Telkwa Range of central British Columbia, Canada, between 1997–2007.

Variable	**Coefficient**	**Robust SE**	**z**	**P>z**	**Lower 95% CI**	**Upper 95% CI**
Elevation	0.023	0.002	10.36	<0.001	0.019	0.027
Elevation^2	-6.17E-06	6.90E-07	-8.94	<0.001	-7.52E-06	-4.81E-06
Slope	-0.007	0.007	-0.95	<0.001	-0.021	0.007
Slope^2	-4.96E-05	7.51E-05	-0.66	0.509	-1.97E-04	9.76E-05
Aspect	-0.002	0.001	-1.52	0.128	-0.003	4.38E-04
Dist to Med	0.042	0.040	1.05	0.295	-0.036	0.119
Dist to Med^2	-7.26E-06	3.19E-06	-2.28	0.023	-1.35E-05	-1.01E-06
Dist to High	0.549	0.316	1.73	0.083	-0.071	1.169
Dist to High^2	-2.38E-05	1.36E-05	-1.75	0.007	-5.03E-05	2.79E-06
≤25Cut Dens	0.342	0.053	6.45	<0.001	0.238	0.446
≤25Cut Dens^2	-0.015	0.003	-4.67	<0.001	-0.022	-0.008
26–40Cut Dens	-1.121	0.167	-6.7	<0.001	-1.449	-0.793
26–40Cut Dens^2	0.089	0.031	2.93	0.003	0.029	0.150
Road Dens	-2.51	0.602	-4.16	<0.001	-3.686	-1.325
Road Dens^2	1.244	0.263	4.72	<0.001	0.728	1.760

Table C5. Candidate models to describe winter resource selection by translocated woodland caribou from the Telkwa Range of central British Columbia, Canada, between 1997–2007 and associated AIC$_c$ values including number of parameters (k), log-likelihood, Akaike's Information Criterion (AIC$_c$) scores, difference in AIC$_c$ scores (Δ), and AIC$_c$ weights (w_i).

All Models	k	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	w_i
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2+ ≤25CutDens2+ 26–40CutDens^2+Road Dens^2	16	-746.09	1532.43	0.00	1.000
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2+ Dist_26to40^2	14	-774.88	1583.94	51.50	<0.001
Veg_Class + NDVI + Dist_Low^2+ Dist_Med^2+ Dist_High^2	10	-836.86	1696.78	164.35	<0.001
Veg_Class + NDVI + ≤25CutDens^2+ 26–40CutDens^2+ Road Dens^2	12	-982.37	1993.19	460.76	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2	10	-990.11	2003.28	470.85	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2+ Dist_Med^2 + Dist_High^2+ ≤25CutDens^2+ 26–40CutDens^2+Road Dens^2	15	-1003.07	2043.31	510.87	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25s^2 + Dist_26to40^2	13	-1035.52	2102.32	569.89	<0.001
Veg_Class + NDVI + Dist_Under25^2 + Dist_26to40^2	10	-1113.24	2249.53	717.10	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High2^2	9	-1109.78	2240.02	707.58	<0.001
Veg_Class + NDVI+ Road Dens^2	8	-1124.92	2267.79	735.36	<0.001
Veg_Class + NDVI	6	-1167.41	2347.93	815.50	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2 + Road Dens^2	11	-1327.24	2680.20	1147.76	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2	9	-1329.93	2680.32	1147.89	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Under25^2 + Dist_26to40^2	9	-1463.26	2946.99	1414.56	<0.001
Elevation^2 + Slope^2 + Aspect + Road Dens^2	7	-1468.48	2952.46	1420.03	<0.001
Veg Class + Slope^2 + Aspect	8	-1470.70	2959.34	1426.91	<0.001
Elevation^2 + Slope^2 + Aspect	5	-1527.19	3065.16	1532.72	<0.001
NDVI + Slope^2 + Aspect	4	-1598.10	3204.71	1672.27	<0.001

Table C5 Continued…

Vegetation-Based Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	***w$_i$***
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2 + 26–40CutDens^2 +Road Dens^2	16	-746.09	1532.43	0.00	1.0000
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2+ Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	14	-774.87	1583.94	51.50	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2	10	-836.86	1696.78	164.35	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2 + Road Dens^2	12	-982.36	1993.19	460.76	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2	10	-990.11	2003.28	470.85	<0.001
Veg_Class + NDVI + Dist_Under25^2 + Dist_26to40^2	10	-1113.23	2249.53	717.10	<0.001
Veg_Class + NDVI+ Road Dens^2	8	-1124.92	2267.79	735.36	<0.001

Topography-Based Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	***w$_i$***
Elevation^2+ Slope^2+ Aspect + Dist_Low^2+ Dist_Med^2 + Dist_High^2 + ≤25CutDens^2 + 26–40CutDens^2 +Road Dens^2	15	-1003.07	2043.31	0.00	1.0000
Elevation^2+ Slope^2+ Aspect + Dist_Low^2 + Dist_Med^2+ Dist_High^2+ Dist_Under25^2+ Dist_26to40^2	13	-1035.52	2102.32	59.02	<0.001
Elevation^2+ Slope^2+ Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2	9	-1109.78	2240.02	196.71	<0.001
Elevation^2+ Slope^2+ Aspect + ≤25CutDens^2+ 26–40CutDens^2 + Road Dens^2	11	-1327.24	2680.20	636.89	<0.001
Elevation^2+ Slope^2+ Aspect + ≤25CutDens^2 + 26–40CutDens^2	9	-1329.93	2680.32	637.02	<0.001
Elevation^2+ Slope^2+ Aspect + Dist_Under25^2+ Dist_26to40^2	9	-1463.26	2946.99	903.69	<0.001
Elevation^2+ Slope^2+ Aspect + Road Dens^2	7	-1468.48	2952.46	909.16	<0.001

Table C6. RSF coefficients and statistical parameters for the most parsimonious model describing winter habitat selection by translocated caribou in the Telkwa Range of central British Columbia, Canada, between 1997–2007.

Variable	**Coefficient**	**Robust SE**	**z**	**P>z**	**Lower 95% CI**	**Upper 95% CI**
NDVI	1.158111	0.364	3.18	0.001	0.445	1.87
AT	0.596	0.180	3.31	0.001	0.243	0.949
AU	-0.178	0.176	-1.01	0.314	-0.523	0.1678
EF	-0.939	0.126	-7.47	<0.001	-1.186	-0.693
EW	1.634	0.422	3.87	<0.001	0.806	2.46
FP	0.225	0.244	0.92	0.356	-0.253	0.703
SF	-1.339	0.206	-6.51	<0.001	-1.742	-0.935
Dist to Med	-0.391	0.039	-9.78	<0.001	-0.469	-0.3123
Dist to Med^2	5.34E-06	1.27E-06	4.19	<0.001	2.85E-06	7.84E-06
Dist to High	0.089	0.047	1.88	0.06	-0.004	0.181
Dist to High^2	-1.23E-05	1.73E-06	-7.09	<0.001	-1.57E-05	-8.91E-06
≤25Cut Dens	0.115	0.047	2.45	0.014	0.023	0.208
≤25Cut Dens^2	-0.005	0.002	-2.15	0.032	-0.009	-4.27E-04
26–40Cut Dens	0.649	0.276	2.36	0.018	0.109	1.190
26–40Cut Dens^2	-0.337	0.104	-3.25	0.001	-0.540	-0.134
Road Dens	2.145	0.647	3.32	0.001	0.878	3.412
Road Dens^2	-0.322	0.199	-1.62	0.105	-0.711	0.068

Table C7. Candidate models to describe summer resource selection by translocated woodland caribou from the Telkwa Range of central British Columbia, Canada, between 1997–2007 and associated AIC$_c$ values including number of parameters (*k*), log-likelihood, Akaike's Information Criterion (AIC$_c$) scores, difference in AIC$_c$ scores (Δ), and AIC$_c$ weights (w_i).

All Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	**w_i**
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2+ 26–40CutDens^2+Road Dens^2	16	-1607.13	3254.49	0.00	1.000
Elevation^2 + Slope^2+ Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2+ 26–40CutDens^2+Road Dens^2	15	-1677.77	3392.70	138.20	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2+ Dist_Under25^2 + Dist_26to40^2	14	-1701.17	3436.51	182.02	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2	10	-1733.75	3490.56	236.07	<0.001
Elevation^2 + Slope^2+ Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	13	-1747.35	3525.97	271.48	<0.001
Veg_Class + NDVI + ≤25CutDens^2+ 26–40CutDens^2 + Road Dens^2	12	-1784.96	3598.37	343.88	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2	10	-1792.29	3607.63	353.13	<0.001
Elevation^2 + Slope^2+ Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2	9	-1783.22	3586.91	332.42	<0.001
Elevation^2 + Slope^2+ Aspect + ≤25CutDens^2 + 26–40CutDens^2	9	-1852.84	3726.14	471.64	<0.001
Elevation^2 + Slope^2+ Aspect + ≤25CutDens^2 + 26–40CutDens^2 + Road Dens^2	11	-1852.25	3730.21	475.71	<0.001
Veg_Class + NDVI + Dist_Under25^2 + Dist_26to40^2	10	-1945.58	3914.22	659.72	<0.001
Veg_Class + NDVI+ Road Dens^2	8	-1965.55	3949.04	694.55	<0.001
Elevation^2 + Slope^2+ Aspect + Dist_Under25^2 + Dist_26to40^2	9	-1964.21	3948.89	694.40	<0.001
Elevation^2 + Slope^2+ Aspect + Road Dens^2	7	-2007.86	4031.21	776.72	<0.001
Veg_Class + NDVI	6	-2022.92	4058.94	804.45	<0.001
Elevation^2 + Slope^2+ Aspect	5	-2057.64	4126.05	871.55	<0.001
Veg Class + Slope^2 + Aspect	8	-2067.74	4153.42	898.92	<0.001
NDVI + Slope^2+ Aspect	4	-2634.59	5277.69	2023.19	<0.001

Table C7 Continued…

Vegetation-Based Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	***w$_i$***
Veg_Class + NDVI + Dist_Low^2+ Dist_Med^2 + Dist_High^2 + ≤25CutDens^2 + 26–40CutDens^2 +Road Dens^2	16	-1607.12	3254.49	0.00	1.0000
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	14	-1701.16	3436.51	182.02	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2	10	-1733.75	3490.56	236.07	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2+ Road Dens^2	12	-1784.95	3598.37	343.88	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2	10	-1792.28	3607.63	353.13	<0.001
Veg_Class + NDVI + Dist_Under25^2 + Dist_26to40^2	10	-1945.57	3914.22	659.72	<0.001
Veg_Class + NDVI+ Road Dens^2	8	-1965.54	3949.04	694.55	<0.001
Topography-Based Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	***w$_i$***
Elevation^2 + Slope^2+ Aspect + Dist_Low^2 + Dist_Med^2+ Dist_High^2+ ≤25CutDens^2 + 26–40CutDens^2 +Road Dens^2	15	-1677.77	3392.70	0.00	1.0000
Elevation^2 + Slope^2+ Aspect + Dist_Low^2 + Dist_Med^2+ Dist_High^2+ Dist_Under25^2 + Dist_26to40^2	13	-1747.35	3525.97	133.28	<0.001
Elevation^2 + Slope^2+ Aspect + Dist_Low^2 + Dist_Med^2+ Dist_High^2	9	-1783.22	3586.91	194.21	<0.001
Elevation^2 + Slope^2+ Aspect + ≤25CutDens^2 + 26–40CutDens^2	9	-1852.84	3726.14	333.44	<0.001
Elevation^2 + Slope^2+ Aspect + ≤25CutDens^2 + 26–40CutDens^2+ Road Dens^2	11	-1852.24	3730.21	337.51	<0.001
Elevation^2 + Slope^2+ Aspect + Dist_Under25^2 + Dist_26to40^2	9	-1964.21	3948.89	556.19	<0.001
Elevation^2 + Slope^2+ Aspect + Road Dens^2	7	-2007.86	4031.21	638.52	<0.001

Table C8. RSF coefficients and statistical parameters for the most parsimonious model describing summer habitat selection by translocated caribou in the Telkwa Range of central British Columbia, Canada, between 1997–2007.

Variable	Coefficient	Robust SE	z	P>z	Lower 95% CI	Upper 95% CI
NDVI	-0.173	0.227	-0.760	0.446	-0.618	0.272
AT	0.691	0.104	6.66	<0.001	0.488	0.894
AU	0.890	0.087	10.190	<0.001	0.719	1.061
EF	-0.306	0.068	-4.480	<0.001	-0.440	-0.172
EW	0.318	0.153	2.080	0.038	0.018	0.617
FP	-0.227	0.146	-1.550	0.120	-0.514	0.060
SF	-1.365	0.139	-9.850	<0.001	-1.637	-1.094
Dist to Med	-0.168	0.024	-7.090	<0.001	-0.215	-0.122
Dist to Med^2	5.34E-06	1.27E-06	-1.050	0.292	2.85E-06	7.84E-06
Dist to High	0.308	0.147	2.100	0.036	0.020	0.595
Dist to High^2	-1.23E-05	1.73E-06	-2.400	0.016	-1.57E-05	-8.91E-06
≤25Cut Dens	0.302	0.031	9.910	<0.001	0.243	0.362
≤25Cut Dens^2	-0.017	0.002	-10.140	<0.001	-0.021	-0.014
26–40Cut Dens	-1.038	0.120	-8.630	<0.001	-1.274	-0.802
26–40Cut Dens^2	0.125	0.024	5.300	<0.001	0.079	0.171
Road Dens	0.768	0.363	2.110	0.034	0.056	1.480
Road Dens^2	-0.213	0.134	-1.590	0.112	-0.475	0.049

Table C9. Candidate models to describe winter resource selection by native woodland caribou from the Telkwa Range of central British Columbia, Canada, between 2013–2015 and associated AIC$_c$ values including number of parameters (*k*), log-likelihood, Akaike's Information Criterion (AIC$_c$) scores, difference in AIC$_c$ scores (Δ), and AIC$_c$ weights (w_i).

All Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	**w_i**
Veg_Class + NDVI + Dist_Low^2+ Dist_Med^2 + Dist_High^2 + ≤25CutDens^2+ 26–40CutDens^2+Road Dens^2	16	-2118.65	4277.55	0.00	1.000
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	14	-2155.40	4344.98	67.43	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2+ Dist_Med^2 + Dist_High^2 + ≤25CutDens^2+ 26–40CutDens^2 +Road Dens^2	15	-2182.41	4401.99	124.44	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2+ Dist_Under25^2+ Dist_26to40^2	13	-2225.65	4482.57	205.02	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2	10	-2612.80	5248.66	971.12	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2+ Dist_High^2	9	-2713.56	5447.58	1170.03	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2+ 26–40CutDens^2+ Road Dens^2	11	-2928.60	5882.92	1605.37	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Under25^2+ Dist_26to40^2	9	-3042.82	6106.10	1828.56	<0.001
Veg Class + Slope2 + Aspect	8	-2979.9	5976.72	1699.17	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2	9	-3142.72	6305.90	2028.35	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2 + Road Dens^2	12	-3187.84	6404.13	2126.59	<0.001
Elevation^2 + Slope^2 + Aspect + Road Dens^2	7	-3282.42	6580.32	2302.77	<0.001
Elevation^2 + Slope^2 + Aspect	5	-3302.10	6614.97	2337.42	<0.001
Veg_Class + NDVI + Dist_Under25^2 + Dist_26to40^2	10	-3326.28	6675.62	2398.07	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2	10	-3390.12	6803.30	2525.76	<0.001
Veg_Class + NDVI+ Road Dens^2	8	-3550.56	7119.08	2841.53	<0.001
Veg_Class + NDVI	6	-3573.54	7160.20	2882.65	<0.001
NDVI + Slope^2 + Aspect	4	-7704.15	15416.8	11139.2	<0.001

Table C9 Continued…

Vegetation-Based Models	***k***	**Log Likel.**	**AIC_c**	**ΔAIC_c**	**w_i**
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2+ ≤25CutDens^2+ 26–40CutDens^2+Road Dens^2	16	-2118.65	4277.55	0.00	1.0000
Veg_Class + NDVI + Dist_Low^2+ Dist_Med^2 + Dist_High^2 + Dist_Under25^2+ Dist_26to40^2	14	-2155.40	4344.98	67.43	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2	10	-2612.80	5248.66	971.12	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2+ Road Dens^2	12	-3187.83	6404.13	2126.59	<0.001
Veg_Class + NDVI + Dist_Under25^2 + Dist_26to40^2	10	-3326.28	6675.62	2398.07	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2	10	-3390.12	6803.30	2525.76	<0.001
Veg_Class + NDVI+ Road Dens^2	8	-3550.56	7119.08	2841.53	<0.001

Topography-Based Models	***k***	**Log Likel.**	**AIC_c**	**ΔAIC_c**	**w_i**
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2 + 26–40CutDens^2 +Road Dens^2	15	-2182.41	4401.99	0.00	1.0000
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	13	-2225.65	4482.57	80.58	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2	9	-2713.56	5447.58	1045.59	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2+ Road Dens^2	11	-2928.60	5882.92	1480.93	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Under25^2 + Dist_26to40^2	9	-3042.82	6106.10	1704.11	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2	9	-3142.72	6305.90	1903.91	<0.001
Elevation^2 + Slope^2 + Aspect + Road Dens^2	7	-3282.42	6580.32	2178.33	<0.001

Table C10. RSF coefficients and statistical parameters for the most parsimonious model describing winter habitat selection by native caribou in the Telkwa Range of central British Columbia, Canada, between 2013–2015.

Variable	**Coefficient**	**Robust SE**	**z**	**P>z**	**Lower 95% CI**	**Upper 95% CI**
NDVI	1.467	0.930	1.580	0.115	-0.356	3.290
AT	3.364	0.174	19.280	<0.001	3.02	3.710
AU	3.208	0.163	19.650	<0.001	2.888	3.528
EF	-1.949	0.184	-10.610	<0.001	-2.309	-1.589
EW	1.922	0.171	11.230	<0.001	1.587	2.258
FP	-1.862	0.328	-5.670	<0.001	-2.505	-1.219
SF	-4.683	0.692	-6.770	<0.001	-6.040	-3.327
Dist to Med	0.120	0.027	4.460	<0.001	0.067	0.173
Dist to Med^2	-2.70E-05	2.00E-06	-14.320	<0.001	-3.10E-05	-2.34E-05
Dist to High	-0.384	0.034	-11.190	<0.001	-0.452	-0.317
Dist to High^2	3.85E-06	1.21E-06	3.180	0.001	1.48E-06	6.22E-06
≤25Cut Dens	0.512	0.066	7.720	<0.001	0.382	0.641
≤25Cut Dens^2	-0.026	0.006	-4.040	<0.001	-0.039	-0.013
26–40Cut Dens	-0.421	0.095	-4.430	<0.001	-0.607	-0.234
26–40Cut Dens^2	-0.029	0.013	-2.150	0.032	-0.055	-0.003
Road Dens	4.185	0.519	8.070	<0.001	3.168	5.202
Road Dens^2	0.200	0.236	0.850	0.398	-0.263	0.663

Table C11. Candidate models to describe summer resource selection by native woodland caribou from the Telkwa Range of central British Columbia, Canada, between 2013–2015 and associated AIC$_c$ values including number of parameters (*k*), log-likelihood, Akaike's Information Criterion (AIC$_c$) scores, difference in AIC$_c$ scores (Δ), and AIC$_c$ weights (w_i).

All Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	**w_i**
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2+ 26–40CutDens^2 +Road Dens^2	15	-5452.05	10941.26	0.00	1.000
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	13	-5483.08	10997.44	56.18	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2	9	-5633.40	11287.24	345.98	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Under25^2 + Dist_26to40^2	9	-5866.18	11752.82	811.56	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2 + Road Dens^2	11	-5922.98	11871.69	930.43	<0.001
Elevation^2 + Slope^2 + Aspect + Road Dens^2	7	-5987.87	11991.23	1049.97	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2+ 26–40CutDens^2	9	-5998.32	12017.10	1075.84	<0.001
Elevation^2 + Slope^2 + Aspect	5	-6091.50	12193.77	1252.51	<0.001
NDVI + Slope2 + Aspect	4	-7704.15	15416.82	4475.56	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	14	-7813.90	15661.97	4720.71	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2+ ≤25CutDens^2+ 26–40CutDens^2 +Road Dens^2	16	-7952.54	15945.32	5004.06	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2	10	-8382.81	16788.67	5847.41	<0.001
Veg Class + Slope^2 + Aspect	8	-8357.77	16733.49	5792.23	<0.001
Veg_Class + NDVI + Dist_Under25^2 + Dist_26to40^2	10	-8510.10	17043.25	6101.99	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2 + Road Dens^2	12	-8793.75	17615.96	6674.70	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2	10	-8911.41	17845.87	6904.61	<0.001
Veg_Class + NDVI+ Road Dens^2	8	-8937.63	17893.21	6951.95	<0.001
Veg_Class + NDVI	6	-9259.29	18531.69	7590.43	<0.001

Table C11 Continued…

Vegetation-Based Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	**w_i**
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2+ Dist_26to40^2	14	-7813.89	15661.97	0.00	1.0000
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2+ Dist_High^2+ ≤25CutDens^2 + 26–40CutDens^2 +Road Dens^2	16	-7952.53	15945.32	283.35	<0.001
Veg_Class + NDVI + Dist_Low^2 + Dist_Med^2 + Dist_High^2	10	-8382.80	16788.67	1126.70	<0.001
Veg_Class + NDVI + Dist_Under25^2 + Dist_26to40^2	10	-8510.09	17043.25	1381.28	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2+ Road Dens^2	12	-8793.75	17615.96	1953.99	<0.001
Veg_Class + NDVI + ≤25CutDens^2 + 26–40CutDens^2	10	-8911.40	17845.87	2183.90	<0.001
Veg_Class + NDVI+ Road Dens^2	8	-8937.63	17893.21	2231.24	<0.001
Topography-Based Models	***k***	**Log Likel.**	**AIC$_c$**	**ΔAIC$_c$**	**w_i**
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + ≤25CutDens^2+ 26–40CutDens^2 +Road Dens^2	15	-5452.05	10941.26	0.00	1.0000
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2 + Dist_Under25^2 + Dist_26to40^2	13	-5483.08	10997.44	56.18	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Low^2 + Dist_Med^2 + Dist_High^2	9	-5633.39	11287.24	345.98	<0.001
Elevation^2 + Slope^2 + Aspect + Dist_Under25^2 + Dist_26to40^2	9	-5866.18	11752.82	811.56	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2 + Road Dens^2	11	-5922.98	11871.69	930.43	<0.001
Elevation^2 + Slope^2 + Aspect + Road Dens^2	7	-5987.87	11991.23	1049.97	<0.001
Elevation^2 + Slope^2 + Aspect + ≤25CutDens^2 + 26–40CutDens^2	9	-5998.32	12017.10	1075.84	<0.001

Table C12. RSF coefficients and statistical parameters for the most parsimonious model describing summer habitat selection by native caribou in the Telkwa Range of central British Columbia, Canada, between 2013–2015.

Variable	**Coefficient**	**Robust SE**	**z**	**P>z**	**Lower 95% CI**	**Upper 95% CI**
Elevation	0.080	0.002	43.390	<0.001	0.076	0.083
Elevation^2	-2.20E-05	5.41E-07	-41.070	<0.001	-2.33E-05	-2.21E-05
Slope	0.004	0.004	1.070	0.286	-0.003	0.012
Slope^2	-0.001	5.20E-05	-12.460	<0.001	-0.001	-0.001
Aspect	-0.002	3.81E-04	-5.750	<0.001	-0.003	-0.001
Dist to Med	-0.056	0.015	-3.820	<0.001	-0.085	-0.027
Dist to Med^2	4.61E-07	5.48E-07	0.840	0.400	-6.13E-07	1.53E-06
Dist to High	0.193	0.017	11.620	<0.001	0.160	0.225
Dist to High^2	-8.94E-06	5.66E-07	-15.800	<0.001	-1.00E-05	-7.83E-06
≤25Cut Dens	0.047	0.024	1.910	0.056	-0.001	0.095
≤25Cut Dens^2	0.007	0.001	4.820	<0.001	0.004	0.010
26–40Cut Dens	0.678	0.056	12.090	<0.001	0.568	0.788
26–40Cut Dens^2	-0.082	0.008	-10.330	<0.001	-0.098	-0.066
Road Dens	-4.275	0.395	-10.810	<0.001	-5.050	-3.500
Road Dens^2	1.057	0.397	2.660	0.008	0.279	1.835