FINAL REPORT

Caribou mortality and disease prevalence in west-central Alberta and east-central British Columbia

Prepared for

Petroleum Technology Alliance Canada | Alberta Upstream Research Petroleum Fund 16-ERPC-05

Final Report

fRI Research Caribou Program

June 30, 2017

Laura Finnegan[1], Tracy McKay[1], Karine Pigeon[1], Doug MacNearney[1], Barry Nobert[1], Helen Schwantje[2], Susan Kutz[3], and Bryan Macbeth[2,3]

[1]fRI Research Caribou Program, [2]Government of British Columbia, [3]University of Calgary

fRI Research
Informing Land & Resource Management

About the Authors

fRI Research is a unique community of Partners joined by a common concern for the welfare of the land, its resources, and the people who value and use them. fRI Research connects managers and researchers to effectively collaborate in achieving the fRI vision and mission.

Learn more at fRIresearch.ca and at friresearch.ca/program/caribou-program

Prepared by

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

Tracy McKay, Caribou Program, fRI Research, Hinton, AB, tmckay@friresearch.ca

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

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

Barry Nobert, Caribou Program, fRI Research, Hinton, AB, bnobert@friresearch.ca

Helen Schwantje, Government of British Columbia, helen.schwantje@gov.bc.ca

Susan Kutz, Faculty of Veterinary Medicine, University of Calgary & Canadian Wildlife Health Cooperative Alberta Node, skutz@ucalgary.ca

Bryan Macbeth, Faculty of Veterinary Medicine, University of Calgary, bjm197@mail.usask.ca

Disclaimer

Further analysis will be conducted for the submission of scientific journal publications, which may result in additional findings and conclusions. Any opinions expressed in this report are those of the authors and do not necessarily reflect those of project partners and funders.

Suggested citation:

Finnegan L., McKay T., Pigeon K., MacNearney D., Nobert B., Schwantje H., Kutz S., and Macbeth B. 2017. Caribou mortality and disease prevalence in west-central Alberta and east-central British Columbia. Year two report prepared for the Petroleum Technology Alliance Canada, Alberta Upstream Research Petroleum Fund 16-ERPC-05, June 2017. Pp x + 57

fRI Research
Informing Land & Resource Management

Executive Summary

Woodland caribou are declining across their range, mainly due to habitat disturbance and associated unsustainable rates of predation. However, caribou health and disease status are increasingly recognized as important factors in the survival and reproductive success of caribou. The goal of this two-year project was to increase understanding of mortality risk and caribou health in west-central Alberta and east-central British Columbia in the Redrock Prairie Creek, Narraway, A La Peche, and Little Smoky caribou herds. Our overall objectives were to 1) determine accurate causes of death for caribou mortality events, including the relative roles of predators, 2) investigate caribou health and disease and establish comprehensive health baselines for each caribou herd, 3) evaluate landscape-related mortality risk factors (terrain, natural disturbance, and anthropogenic disturbance), and 4) evaluate the link between predator occurrence and mortality risk. This research will provide insight into the relationships between landscape disturbance, predator occurrence, and caribou mortality events, and provides the first herd-specific baseline report of health and disease for boreal and southern mountain caribou herds in west-central Alberta and east-central British Columbia.

Between May 2013 and January 2017, we collected field data at 25 caribou mortality locations, using standardized site investigations, necropsies, and sampling protocols. We attributed 14 of these mortalities to probable predation, and we established that the predator guild for caribou in west-central Alberta and east-central British Columbia includes not only wolves, but also cougars and bears: 4 mortalities were from cougar, 4 from grizzly bear, 2 from wolf, and 3 had multiple predator signs. The remaining 11 mortalities were attributed to accidents, disease/health status, or unknown causes.

We used biological samples collected from caribou mortalities and winter fecal pellet sampling to evaluate health and disease in the Redrock Prairie Creek, Narraway, A La Peche, and Little Smoky caribou herds. From fecal pellet surveys, we detected a range of gastrointestinal parasites including Nematodes, Strongylates, tapeworm eggs, and Protostrongylid dorsal spine larvae. Prevalence of these gastrointestinal parasites was similar to prevalence previously reported for Alberta and British Columbia, and there were no apparent trends across sex or herd. Health testing from caribou mortalities revealed the presence of ectoparasites (winter tick) and bacteria (*Erysipelothrix rhusiopathiae*). Hair cortisol concentrations (HCC) were generally higher levels than reported for caribou elsewhere in Canada, although the method of data collection (hair collected from carcasses) makes direct comparisons difficult.

Using data collected at mortality sites along with GIS-based landscape variables, we assessed the roles of terrain and anthropogenic disturbance features in explaining caribou mortalities, including predation-related mortalities and mortalities of unknown cause, within and outside of protected areas. Mortality locations were associated with low elevation areas and proximity to streams. Outside of protected areas, mortality risk also increased with an increase in anthropogenic linear features (pipelines, roads, and seismic

lines). We used these results to produce spatially explicit surfaces of mortality risk based on models of landscape variables. Using results from previous research we produced annual probability of occurrence surfaces for wolves, grizzly bears, and cougars, and used these to assess mortality risk relative to predator occurrence. From this analysis we found that caribou mortality locations were associated with a higher probability of wolf and grizzly bear occurrence.

Overall, the results of this research project revealed that caribou predators in west-central Alberta and east-central British Columbia include cougars and bears in addition to wolves; this knowledge may have implications for management of alternate prey and predator populations in these caribou ranges. Our results also demonstrate the value of rapid mortality site investigations to accurately determine cause of death, and to collect valuable caribou health and disease data. The health and disease data gathered during this project is the first comprehensive herd-specific baseline health data collected for declining caribou herds in west-central Alberta and east-central British Columbia and provides insights into the overall health status of caribou herds in the area. These health and disease data also may be used to track changes in caribou health in the future, particularly with the expansion of moose, deer, and elk within caribou ranges, and within the context of climate change. Continued research focused on assessing and understanding caribou health may contribute to caribou recovery initiatives by identifying priority areas for restoration based on disease transmission risk, and by identifying herds that may be at highest risk of disease outbreaks. Finally, our spatially explicit surfaces of mortality risk can be used to target restoration activities to areas with the highest mortality risk within the Redrock Prairie Creek and Narraway caribou ranges, including areas of high linear feature densities and landscape disturbances located near riparian areas. In addition, the probability of occurrence surfaces we produced for wolves, grizzly bears, and cougars in the the Redrock Prairie Creek and Narraway caribou ranges can be used to target restoration activities in areas where species-specific predation risk is highest.

Acknowledgements

We thank fRI GIS analysts Julie Duval and Dan Wismer for all their hard work in generating GIS layers for this project. We would also like to thank the numerous researchers and volunteers that assisted with caribou mortality site investigations, fecal sample collection, and fecal swabbing: Leonie Brown, Karen Graham, Joe Kermish-Wells, Paul Kuchma, Terry Larsen, Cam McLelland, Brent Rutledge, Anja Sorensen, Kelsey Ridley, Amy Stenhouse, Gord Stenhouse, Leah Stenhouse, Becky Viejou, and members of the Aseniwuche Winewak Nation of Canada's Caribou Patrol (www.cariboupatrol.ca). Kelsey Ridley also provided essential assistance with sample and database management, and field logistics for this project. Thanks to Steve Wotton at Peregrine Helicopters for his always exemplary flying skills and assistance in the field. Dave Mair at Silvertip aviation also carried out VHF mortality flights during early stages of this project.

Wendy Crosina and Weyerhaeuser Canada Ltd. allowed us access to up-to-date caribou GPS data, facilitating our rapid mortality site investigations. Project collaborators Dave Hervieux, Julia Wachowski and Amy Flasko at Alberta Environment and Parks also notified us of mortalities of AEP collared caribou. We thank Wildlife Genetics International, particularly Renee Prive, for genetic profiling. At the University of Calgary, the members of the Kutz and Orsel laboratories carried out some of the laboratory health testing, and we extend a particular thanks to Taya Forde. The remainder of the laboratory work was completed by the Canadian Cooperative Wildlife Health Centre, Alberta Node.

We thank Alberta Environment and Parks, the British Columbia Ministry of Environment, and Alberta Parks for logistical support, and for research permits that facilitated biological sample collection. Funding for this work was provided by the Alberta Upstream Petroleum Research Fund (15-ERPC-08, 16-ERPC-05), Weyerhaeuser Canada Ltd., the Safari Club International Drayton Valley Chapter, and partners of the fRI Research Caribou Program. In-kind support was provided by the Faculty of Veterinary Medicine, University of Calgary. This project would not have been possible without the ongoing support provided by project champion Carol Barsky at the Canadian Association of Petroleum Producers (CAPP), and additional support from Lorie Mayes and Tannis Such at Petroleum Technology Alliance of Canada (PTAC) and Wendy Crosina at Weyerhaeuser.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

fRI Research
Informing Land & Resource Management

1. PROJECT BACKGROUND AND OBJECTIVES

1.1 INTRODUCTION

Boreal and mountain caribou populations are declining across Canada (McLoughlin et al. 2003, Festa-Bianchet et al. 2011, Environment Canada 2012, 2014, Hervieux et al. 2013). Habitat loss negatively affects caribou (Smith et al. 2000, Dyer et al. 2001, Sorensen et al. 2008), and has caused precipitous declines in caribou herds in western Canada because of associated unsustainable predation rates (Environment Canada 2012, 2014, Hervieux et al. 2014). Landscape disturbances have been directly linked to increased predation risk and mortality for caribou (Festa-Bianchet et al. 2011, Environment Canada 2012, 2014, Hervieux et al. 2014), and the federal recovery strategies for boreal and southern mountain caribou mandate the need for habitat restoration to reduce this predation risk, and to achieve self-sustaining caribou herds (Environment Canada 2012, 2014).

Considering that caribou declines are largely driven by unsustainable predation rates, directing restoration to areas that have high caribou mortality risk may serve to expedite recovery of caribou populations. Landscape disturbances affecting predator-prey dynamics result in increased predation risk for caribou (Festa-Bianchet et al. 2011, Whittington et al. 2011, DeCesare 2012*a*, Hervieux et al. 2014, Dickie et al. 2016), mainly through apparent competition caused by an increase in other ungulate prey and shared predators within caribou ranges (Robinson et al. 2002, DeCesare et al. 2010, Dawe 2011, Latham et al. 2011*b*, Serrouya et al. 2011, Peters et al. 2012). Within this altered predator-prey system, wolves are thought to be the primary cause of mortality for caribou in Alberta (McLoughlin et al. 2003, Hebblewhite et al. 2010, DeCesare 2012*b*, Hervieux et al. 2014), but potential caribou predators also include cougar, black bear, grizzly bear, and wolverine (Kinley and Apps 2001, Wittmer et al. 2005*a*, Stotyn et al. 2007), and it remains unknown whether these predators are a major source of caribou mortality in some parts of Alberta. Directly assessing the relationships between landscape characteristics, predator occurrence, and caribou mortality locations will contribute towards a better understanding of the relationship among anthropogenic disturbance, predator occurrence, and caribou mortalities.

In addition to issues surrounding predation risk, caribou herds in Alberta currently exist in small isolated populations, meaning that these already fragile populations may also be at increased risk from the effects of compromised health, disease transmission, or catastrophic disease outbreaks (Deem et al. 2001, McCallum and Dobson 2002). The relative importance of disease to wildlife is expected to increase with climate change and anthropogenic landscape change (Harvell et al. 2002, Hoberg et al. 2008), and for caribou, there may already be increased risk of disease transmission associated with the incursion of moose, deer, and elk into caribou ranges; a further layer of complexity to the apparent competition problem (Bergerud and Mercer 1989, Hoberg et al. 2008). Additional causes of caribou mortality include natural events (e.g., avalanches) and direct human causes (e.g., vehicle collisions), but the inter-relationships between caribou mortalities, predation events, and these potential confounding factors have not been well documented for caribou in west-central Alberta and east-central British Columbia.

Our project was focused within the Redrock Prairie Creek, Narraway, A La Peche, and Little Smoky caribou herds in Alberta and British Columbia. Our overall objectives were to: 1) determine accurate causes of death for caribou mortalities, 2) investigate caribou health and disease and establish comprehensive health baselines for each caribou herd, 3) evaluate landscape-related mortality risk factors (terrain, natural disturbance, and anthropogenic disturbance), and 4) evaluate the link between predator occurrence and mortality risk. This research will provide insight into the relationships between landscape disturbance, predator occurrence, and caribou mortality events, and also provides the first herd-specific baseline data of health and disease for west-central Alberta and east-central British Columbia boreal and southern mountain caribou herds. The results of this project may be used to inform caribou habitat restoration efforts, and to model and assess the effects of further landscape management on mortality risk for caribou. Our results also provide insight into the overall health status of caribou which could be used to help guide provincial recovery initiatives in Alberta and British Columbia.

1.2 Study area

Our study area included the ranges of the Redrock Prairie Creek (RPC), Narraway (NAR), A La Peche (ALP), and Little Smoky (LSM) caribou herds in west-central Alberta and east-central British Columbia (Figure 1.1). RPC, NAR, and ALP caribou are central mountain woodland caribou, and migrate between high elevation summer range (alpine and subalpine habitats) and low elevation winter range in the foothills (Edmonds and Bloomfield 1984, Brown and Hobson 1998, Committee and Natural Regions Committee 2006, COSEWIC 2014). LSM caribou are the boreal ecotype, remain in the foothills and boreal forest year round, and have relatively small seasonal shifts in range use (Bergerud 1992, Briand et al. 2009). Central Mountain caribou are listed as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and threatened under the Species at Risk Act (SARA), while boreal caribou are listed as threatened by COSEWIC and SARA (COSEWIC 2002, 2014, Environment Canada 2012, 2014).

All caribou are listed as threatened under Alberta's *Wildlife Act* (Alberta Woodland Caribou Recovery Team 2005).

Habitat types within the range of these caribou herds are diverse. Alpine areas consist of exposed ridges and meadows with graminoid, sedge (*Carex* spp.), and herbaceous ground cover, while subalpine areas are characterized by Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*), with dwarf shrubs (*Salix* and *Betula* spp.) along riparian zones. Foothills consist of lodgepole pine (*Pinus contorta*) and white spruce (*P. glauca*), uplands and lowlands with poorly drained muskeg, black spruce (*P. mariana*), and larch (*Larix laricina*; Natural Regions Committee 2006; Demarchi 2011).

The region includes both protected areas and areas managed by the provincial government (Figure 1.1). Development associated with the oil and gas, mining, and forestry industries is concentrated in the foothills in the eastern edges of the caribou ranges (Figure 1.1). Oil and gas activities date to the 1950s, a coal mine has been operating in the eastern portion of the RPC range since 1969, and forestry operations in the area began in the 1970s (Slater 2013). Anthropogenic disturbances include cutblocks, roads, seismic lines, pipelines, and wellsites, and natural disturbances consist of burnt areas resulting from wildfires.

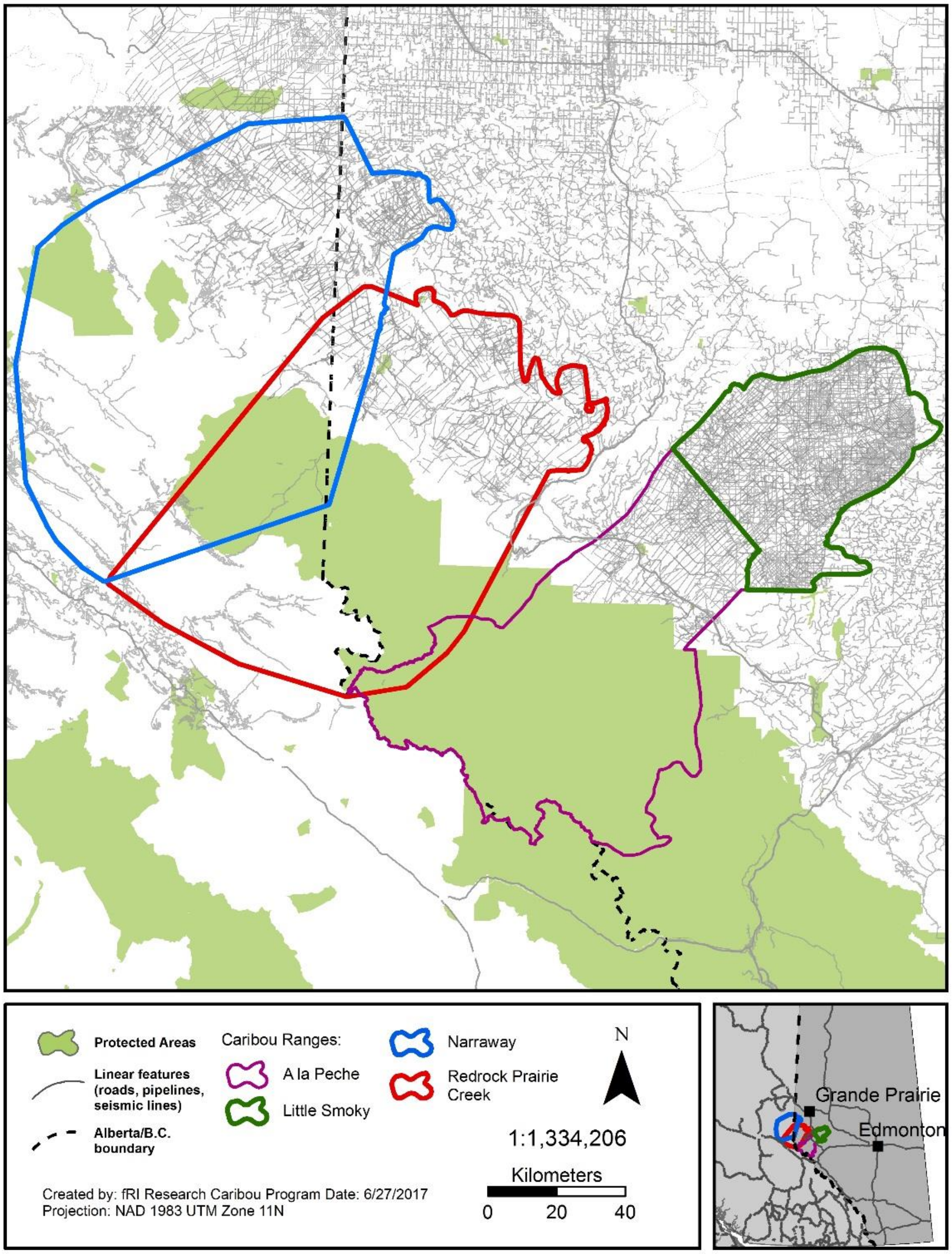

Figure 1.1. Range boundaries of the Redrock Prairie Creek, Narraway, A La Peche, and Little Smoky caribou herds in Alberta and British Columbia, including protected areas and linear disturbance features.

1.3 Project Objectives

Our specific research objectives included:

1. Determine accurate causes of caribou mortality, including the relative roles of predators, using data collected during rapid mortality site visits (within 24 hours of mortality signal of collared caribou mortality events) in the Redrock Prairie Creek, Narraway, A La Peche, and Little Smoky caribou ranges (Chapter 2).
2. Provide insight into the overall health status of caribou within west-central Alberta and east-central British Columbia, using biological samples from caribou mortalities and non-invasive fecal surveys to complete a preliminary evaluation of caribou health indicators, pathogens, and parasites within the Redrock Prairie Creek, Narraway, A La Peche, and Little Smoky herds, and to establish comprehensive, herd-specific health baselines (Chapter 3).
3. Investigate the relationships among terrain, anthropogenic disturbance features, predator occurrence, predation-specific caribou mortalities, and caribou predation within the Redrock Prairie Creek and Narraway herd ranges of west-central Alberta and east-central British Columbia (Chapter 4).

2. Caribou mortality investigations

Laura Finnegan, Doug MacNearney, Karine Pigeon, Barry Nobert, and Bryan Macbeth

2.1. Introduction

In west-central Alberta, previous predator research and management relative to caribou conservation has mainly focused on wolves (Kuzyk et al. 2006, DeCesare 2012*a*, Hervieux et al. 2014). However, west-central caribou ranges overlap with a number of other predators including cougar, grizzly bear, black bear, lynx, and wolverine. Although research in adjacent ranges in British Columbia has reported cougars, bears (black and grizzly) and wolverines as predators of caribou (Kinley and Apps 2001), it remains unknown whether these predators are a major source of caribou mortality in herds in west-central Alberta and east-central British Columbia .

Here we describe results from ongoing caribou mortality site investigations carried out within four caribou herds in west-central Alberta and east-central British Columbia between 2013 and 2017: the Redrock Prairie Creek (RPC), Narraway (NAR), A La Peche (ALP), and Little Smoky (LSM). Our goal was to determine the accurate cause of death of adult female caribou, and to use these data to evaluate the relative contributions of different predators to caribou mortality events.

2.2. Methods

We identified mortality events of adult female caribou collared with Geographic Positioning System (GPS) telemetry collars (Lotek Iridium GPS 4400, Newmarket, Ontario and Televilt Global Positioning System, Lindesberg, Sweden) between 2013 and 2017. Caribou were captured and collared as part of a collaboration between Alberta Environment and Parks and Weyerhaeuser Ltd., or as part of ongoing research by Alberta Environment and Parks (Alberta Animal Care Protocol 008). The collars were programmed to send a mortality signal after eight consecutive hours of immobility, indicating either that the animal had stopped moving, or that the collar had been removed from the animal. Our goal was to visit mortality sites within 24 hrs of receiving a mortality signal, however this was not always possible due to poor weather conditions or avalanche risk (see Table 2.1). We also visited mortality sites opportunistically when reported by Alberta Environment and Parks (GPS and VHF collars), the fRI Research Grizzly Bear Program (collaborative predation project), or the Caribou Patrol (www.cariboupatrol.ca).

At each mortality site, at least two trained personnel used standardized field protocols to determine plausible cause(s) of death of collared caribou (e.g. predation, accident, disease, senescence). These protocols included examination of the position, condition and distribution of the carcass, habitat type, identification of predator scat and prints, and collar condition. All sites were extensively documented via photography and detailed field notes. Although signs of predators may overlap, certain characteristic wounding or feeding patterns can help narrow to the most likely species (Alberta 2010).

We used necropsy and mortality sampling protocols and corresponding datasheets developed by the Boreal Caribou Health Program (BCHP) and CircumArctic Rangifer Monitoring and Assessment network (CARMA) to collect biological samples from carcasses. In some cases, we removed partial carcasses from the site for detailed necropsy by a wildlife veterinarian. In addition to biological samples, we also collected feces (caribou and predator) and ectoparasites at mortality locations. All samples and partial carcasses were bagged and stored in a freezer at -20°C for later examination and laboratory testing (see Chapter 3).

2.3. Results

We investigated 25 caribou mortalities over the four years of the study period, with the majority being GPS collared adult female caribou (Table 2.1; Figure 2.1). The probable cause of death for 14 of the caribou mortalities investigated was predation. Disease was the probable cause of death for three mortalities, two were caused by natural accidents (fall from a cliff and avalanche), three were the result of a collision with a vehicle, and three mortalities were of unknown causes.

Of the 14 mortalities that were classified as predation events, four were deemed to be cougar and five grizzly bear. Two of the cougar mortalities were confirmed through visual observation of the predator at the mortality site (F432 and F453), whereas the remaining two mortalities (F450 and 34075) were assigned by field investigation and interpretation of animal signs. Three of the mortalities attributed to grizzly bear (F446, F793, and 2326) were based on characteristic feeding signs such as peeling of the hide (Figure 2.2), burial piles, and grizzly bear scat containing caribou hair (Figure 2.2). At the fourth mortality attributed to grizzly bear, a grizzly bear was observed at the carcass of caribou 2166 within a day of the mortality event, and the entire carcass was buried, a characteristic pattern for bears (Figure 2.3). Finally, although wolf and grizzly bear tracks were identified at the mortality site of F440, antemortum haemorrhage surrounding wounds more compatible with the bite pattern of a grizzly bear were identified in the hide (Figure 2.4), suggesting grizzly bear predation of the caribou, rather than scavenging from a dead animal.

Two of the mortalities were associated with wolf predation, which was based on clear evidence from compatible tooth marks on the hide and the pattern of carcass consumption (Figure 2.5). We also visited a mortality at which signs of the presence of a wolverine were located, but the age of the caribou (indicated by tooth wear), and the unknown date of death (VHF collar), suggested it was most likely scavenging, rather than a predation event. Three mortalities had signs of multiple predators, and we were unable to determine with confidence which predator was responsible for the mortality. One caribou died after apparently falling off a cliff (F444), while another died in an avalanche (F458). Two males and one female from the ALP herd were killed in collisions with vehicles on Highway 40 North. One older caribou likely died from heavy winter tick infestations (964), while the probable cause of death for another was disease (F786). Mortality locations were distributed in a variety of habitats throughout the herd ranges (Figure 2.1). Chapter 3 details the results of our *ex situ* necropsies and detailed examination of caribou remains for health and disease assessment.

Table 2.1. Mortality dates (in chronological order) and probable cause of death for caribou in west-central Alberta and east-central British Columbia between 2013 and 2017. The number of days between the site visit and mortality event are in parenthesis.

ID	Mortality date	Remains	Herd	Collar type	Probable cause of death
F440	12 May 2013 (14)	Hide sections, long bones	RPC	GPS	Predation by grizzly bear, scavenging by wolf
F446	14 May 2013 (12)	Hide sections, rumen, skull fragment	RPC	GPS	Predation by grizzly bear
F793	7 May 2013 (23)	Hide sections, bones	NAR	GPS	Predation by grizzly bear
ALP_1	29 July 2013 (1)	Entire carcass (male)	ALP	NA	Road traffic accident
F432	19 Aug 2013 (4)	Hide sections, intact bones	RPC	GPS	Predation by cougar (visual)
F786	11 Oct 2013 (5)	Full carcass, scavenging by birds	NAR	GPS	Potentially disease (complete test results pending)
F444	23 Jan 2014 (1)	Full carcass – avalanche danger prevented ground visit before August	RPC	GPS	Accident (fall from cliff)
F439	27 Jan 2014 (6)	Large hide section	RPC	GPS	Predation by wolf
ALP_2	8 March 2014 (0)	Entire carcass (male)	ALP	NA	Road traffic accident
1354	30 Mar to 10 Apr 2014 (7-17)	Hide section, front legs	LSM	VHF	Predation/Scavenging by wolverine
F453	1 May 2014 (1)	Limbs, intact skull, spine, pelvis	RPC	GPS	Predation by cougar (visual)
969291	Unknown (unknown)	Bone fragment, tooth, hair	ALP	NA	Unknown (identified during grizzly bear cluster visits)
976627	Unknown (unknown)	Bones	ALP	NA	Predation by grizzly bear or cougar
1068	Unknown (unknown)	NA	NAR	VHF	Unknown (no remains found at site, only collar)

F448	26 Oct 2014 (2)	Intact upper torso and head, portion of liver	RPC	GPS	Predation by wolf
F450/2199	17 Dec 2014 (1)	Hide section, long bones	RPC	GPS	Predation by cougar
964	5 May 2015 (2)	Full carcass	LSM	GPS	Potentially disease (anemia/winter tick)
F454	15 May 2015 (10)	Bone fragments, mandible, hair	RPC	GPS	Predation by grizzly bear or cougar
34077	28 Sept 2015 (11)	Skeleton, muscle, skull, hair	LSM	GPS	Potentially disease
1982	Unknown (unknown)	Bone fragments	NAR	VHF	Unknown
34075	20 Oct 2015 (0)	Spinal column, long bones, mandibles, hair	LSM	GPS	Predation by cougar
2166	11 May 2015 (1, 20)	Hair, pelvis portion, bone fragments, metacarpus, radius and ulnas with hide portions	LSM	GPS	Predation by grizzly bear (visual)
2326	26 May 2015 (1, 25)	Mandible, hide, ear, skull portions	RPC	GPS	Predation by grizzly bear
ALP_3	21 Nov 2016 (1)	Full carcass	ALP	NA	Road traffic accident
F458	19 Jan 2017 (NA)	Avalanche hazard – no visit	RPC	GPS	Avalanche

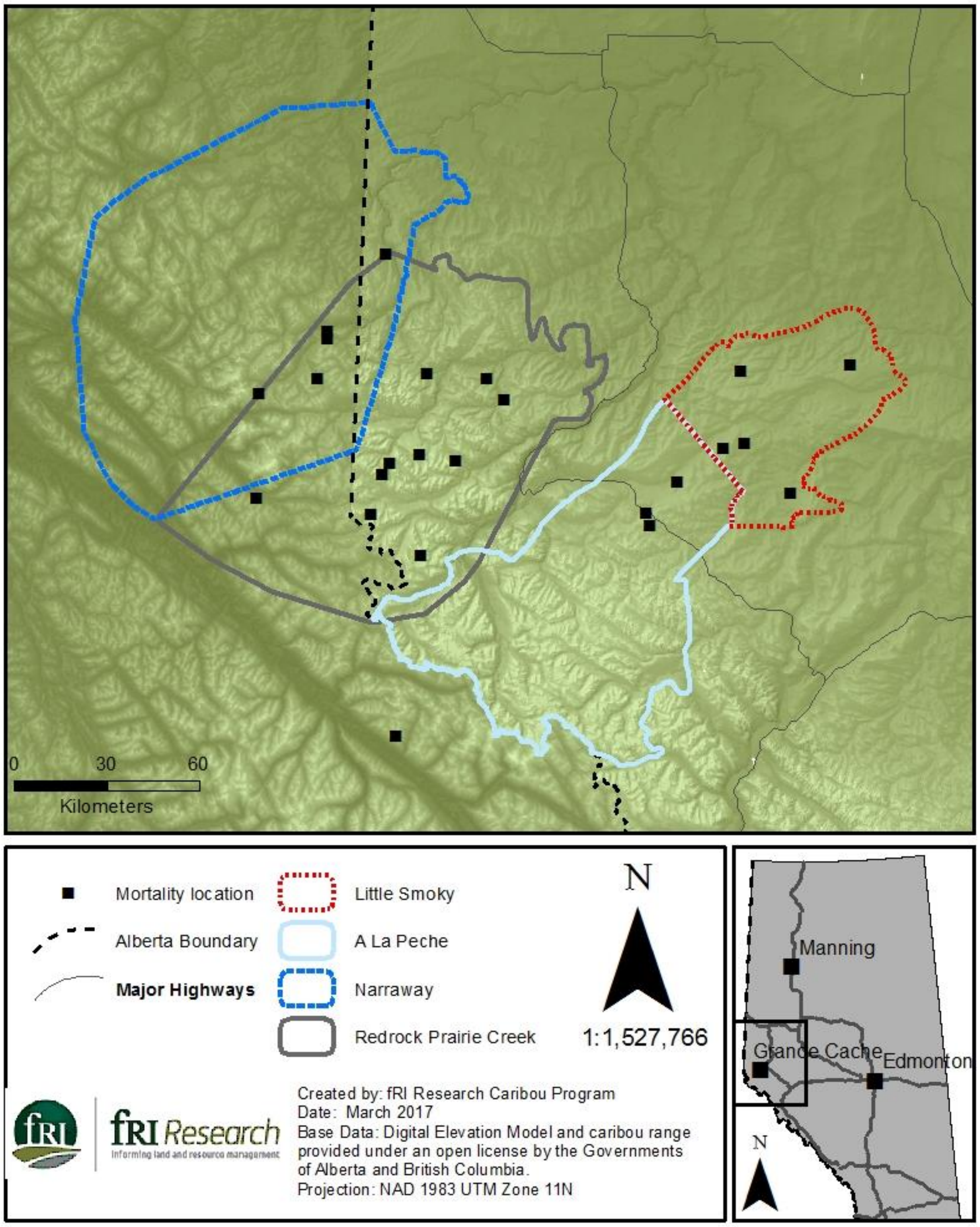

Figure 2.1. Mortality locations of collared caribou in west-central Alberta and east-central British Columbia between 2013 and 2017.

Figure 2.2. Top: Peeled caribou hide indicative of Ursid spp. feeding; bear scat is visible in the centre of the photo. Bottom: Grizzly bear scat containing caribou hair located at caribou mortality site.

Figure 2.3. Buried carcass of caribou 2166 characteristic of Ursid sp.

Figure 2.4. Hide of F440 showing puncture wounds most consistent with grizzly bear.

Figure 2.5. Hide of F439 showing puncture wounds attributed to wolf. Note also probable antemortum haemorrhage around the canine puncture wounds towards the bottom right of the photograph.

2.3. Discussion

Our results suggest that the predator guild associated with caribou mortalities in west-central Alberta and east-central British Columbia includes wolves, cougars, grizzly bears, and possibly black bears (DNA testing of bear scat is underway). Although we could only attribute 2 of the probable 14 predator-mediated mortalities to wolves, it is worth noting that for the first two years of this project, our research was focused within the ranges of central mountain caribou, where the distribution of caribou at high elevations during part of the year could be reducing overlap between caribou and wolves. Chapter 4 describes the risk of predation from wolves, cougars, and bears.

There were more probable predation events by cougar and grizzly bear than expected based on previous literature for west-central Alberta (McLoughlin et al. 2003, Kuzyk et al. 2006), and perhaps of most concern is the number of mortalities caused by cougars during the four years of data collection. Unlike bears, cougars are active throughout the year. Although predation rates upon female ungulates in Alberta tend to be higher during summer (Knopff et al. 2010), we found evidence of cougar predation year round. Increased cougar densities associated with range expansion (Knopff 2010), believed to mirror the expansion of white-tailed deer range (Dawe 2011), may be increasing the probability of encounters between caribou and cougars in west-central Alberta.

Our rapid field site investigations continued to demonstrate that to accurately associate mortality events to a specific predator or environmental event, prompt investigation is required (e.g., <1 week). Rapid mortality site investigations and necropsies on road-killed individuals also allowed us to carry out detailed health and disease testing, as described in Chapter 3.

The results of health and disease testing, combined with tests from the high quality samples collected at other mortality investigations will for the first time, allow for assessments of the role of disease and health as a potential cause of death, and will also provide baseline data to monitor caribou health into the future (see Chapter 3).

3. Evaluation of caribou health in west-central Alberta/east-central British Columbia

Laura Finnegan, Bryan Macbeth, Helen Schwantje and Susan Kutz

3.1 Introduction

Health is increasingly recognized as a factor that may contribute to diminished survival and reproduction in free ranging caribou. Some determinants of caribou health such as certain pathogens and severe nutritional defects may kill caribou or affect their reproductive output directly, while others may act through more subtle, chronic or cumulative effects (compromised immunity, reduced body condition; (Crete and Huot 1993, Hughes et al. 2009, Gustine et al. 2012). The relative importance of health on caribou population dynamics is expected to increase as climate change and the degradation of caribou ranges continues.

To date there has been little research on the disease and health status of woodland caribou in western Canada. Understanding the diversity, distribution, and prevalence of pathogens, the overall health status of caribou herds in Alberta and British Columbia, and the relationship between caribou herd health and landscape features (including sympatric ungulates and predators), will provide an important contribution to recovery planning. Here we present results from the first intensive health survey of boreal and central mountain caribou herds in west-central Alberta and east-central British Columbia. In year one of this project, we presented results from mortality monitoring, fecal surveys, and health assessments of caribou in west-central Alberta and east-central British Columbia; data included bacterial and pathogen testing, nutrition and toxicology analysis, and overall health indicators (bone marrow; see Finnegan et al. 2016 for detailed results). In this report, we present results from our second winter of fecal surveys and mortality assessments of collared and road-killed caribou from 2015 and 2016. Ultimately, we aim to establish comprehensive baseline health measurements for each herd. These data will provide insight into the overall health status of caribou in our study area, and may be used to help guide provincial recovery initiatives.

3.2 Methods

3.3.1. Sample collection

3.3.1.1. Collection of biological samples from caribou mortalities

We collected biological samples from radio-collared caribou mortalities either in the field (Figure 2.1), or *ex situ*, using standardized protocols developed by the British Columbia Boreal Caribou Health Research Program (BCHRP; Schwantje et al. 2014, 2016) and the CircumArctic

Rangifer Monitoring and Assessment (CARMA) Network (Kutz et al. 2013). We also opportunistically collected intact carcasses of two male and one female A La Peche caribou killed on highway 40 (2013, 2014, and 2016). Details of sample collection and storage are described in Finnegan et al. (2016).

3.3.1.2. Non-invasive fecal sampling

We collected caribou fecal samples in February 2014, between January 1st and March 31st (helicopter based) or May 31st (ground based) 2015, and between January 1st and March 31st 2016 (n = 466 fecal piles total; Figure 3.1). Details of sample collection and storage are described in Finnegan et al. (2016). We identified fecal samples from unique individuals for pathogen testing using genetic profiling of nuclear microsatellite markers (Wildlife Genetics International, Nelson; www.wildlifegenetics.ca).

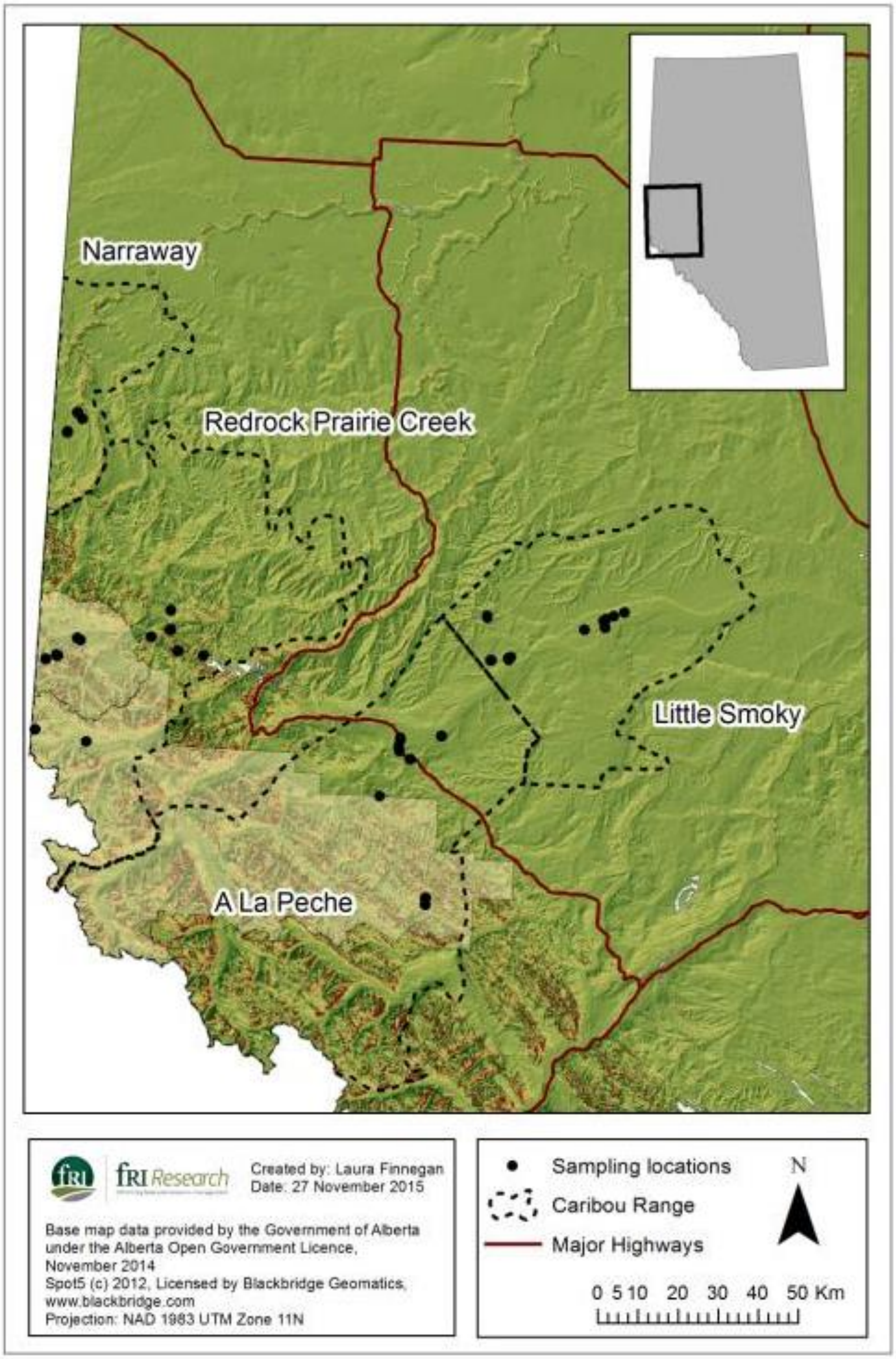

Figure 3.1. West-central Alberta caribou ranges showing provincial range boundaries and fecal pellet sampling locations in 2014 and 2015.

3.3.2. Health testing

3.3.2.1. Baseline health and disease parameters to test

Through research collaboration with the BCHRP and *Rangifer* health specialists at the Canadian Wildlife Health Cooperative (CWHC), and the University of Calgary Faculty of Veterinary Medicine (UCVM) and elsewhere we developed a diagnostic testing strategy to determine the baseline diversity, distribution, and prevalence of selected pathogens and parasites in caribou from west-central Alberta and east-central British Colombia (Table 3.1). Other health indicators including marrow fat, trace nutrient status (Prairie Diagnostic Services Inc., Saskatoon), and chronic stress levels (Western College of Veterinary Medicine, University of Saskatchewan) were also assessed using established protocols. Tests selected focused on pathogens, parasites, and health indicators that could be evaluated using samples gathered from mortality site investigations, non-invasively, or opportunistically (from road kills).

Table 3.1. Selected health indicators, type, potential significance, and sample(s) required to detect occurrence of pathogens or evaluate health status in caribou from west-central Alberta and east-central British Colombia. Adapted from Table 1 in British Columbia Boreal Caribou Health Program Year 1 Synthesis Report (Schwantje et al. 2014); further details regarding the potential significance of each selected health indicator can be found therein.

Health indicator	Type	Applicable samples
Erysipelothrix rhusiopathiae	Bacterium	Serum; blood; tissue; marrow; feces
Protostrongylid nematodes	Nematode parasites	Feces, various tissues
Abomasal nematodes	Nematode parasites	Feces; gastrointestinal tracts
Fascioloides magna	Trematode parasite	Feces; liver
Dermacentor albipictus (winter tick)	Ectoparasite	Hide section
Cortisol	Stress hormone	Hair; feces
Marrow fat content	Nutritional status	Intact long bone; mandibles
Trace nutrients	Nutritional status	Liver; blood

3.3.2.2. Laboratory work

Laboratory work was carried out by the UCVM and the CWHC in Calgary Alberta, Prairie Diagnostics Inc. (trace nutrients), and by the Western College of Veterinary Medicine, University of Saskatchewan (hair cortisol) by trained laboratory technicians or wildlife veterinarians. Diagnostic tests included enzyme-linked immunosorbent assays (ELISAs), molecular techniques (Polymerase Chain Reaction [PCR], full genome sequencing) and general and selective bacterial cultures. All diagnostic tests employed had been previously evaluated in *Rangifer* spp., either at the CWHC or as part of the BCHRP (Table 3.2).

Table 3.2. Health indicators and diagnostic tests used to evaluate disease prevalence and the overall health status of caribou in west-central Alberta and east-central British Colombia. Adapted from Table 5 in Schwantje et al. 2014.

Health indicator	Diagnostic test(s)
Erysipelothrix rhusiopathiae	Indirect Protein A/G-HRP ELISA to detect antibodies (in house assays: UCVM and CWHC, Calgary, AB) Direct PCR and selective tissue culture followed by full genome sequencing
Protostrongylid nematodes	Fecal Baermann with *a posteriori* PCR identification of dorsal-spine larvae (DSL) (in house assays: UCVM and CWHC, Calgary, AB)
Abomasal nematodes	Fecal floatation with morphological identification of parasite eggs (in house assays: UCVM and CWHC, Calgary, AB)
Fascioloides magna (Giant liver fluke)	Fecal sedimentations (Flukefinder®, Soda Springs, ID, USA) with morphological identification of fluke eggs (in house assays: UCVM and CWHC, Calgary, AB)
Dermacentor albipictus	Morphological identification, collection of voucher specimens
Hair cortisol	Oxford EA-65 Cortisol Competitive EIA kit (Oxford Biomedical, Lansing, MI, USA) (Western College of Veterinary Medicine (WCVM), University of Saskatchewan, Saskatoon, SK)
Marrow fat content	CWHC ungulate marrow fat assessment protocol (WCWM, University of Saskatchewan, Saskatoon, SK)
Trace nutrients and toxicology*	High-Performance-Liquid-Chromatography (HPLC) (in house assays: Prairie Diagnostic Services Inc., Saskatoon, SK)

*Trace nutrients and toxicology panels included Vitamin A and E, Beryllium (Be), Magnesium (Mg), Vanadium (V), Chromium (Cr), Manganese (Mn), Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Arsenic (As), Selenium (Se), Strontium (Sr), Molybdenum (Mo), Cadmium (Cd), Tin (Sn), Antimony (Sb), Barium (Ba), Thallium (Tl), Bismuth (Bi) and mercury (Hg).

3.3 Results

3.3.1. Summary of main necropsy findings and ectoparasites identified in caribou 2013-2017

3.3.1.1. Summary of findings 2013-2015

Necropsy of the male A La Peche animals killed as a result of a motor vehicle collisions in 2013 and 2014 (ALP_1 and ALP_2) detected no notable abnormalities, although severe decomposition of the internal organs of ALP_1 prevented a detailed examination. ALP_2 was in relatively poor condition with diminished internal fat deposits and had a mild to moderate winter tick infestation with no associated hair loss. Necropsy of Narraway female F786 detected two lungworms in one lung. Of the two Little Smoky females sampled, we detected two winter ticks on the hide of the female 1354, and female 964 was heavily infested with winter tick. Finally, we identified no winter ticks or other abnormalities on the hide of the Redrock Prairie

Creek female F448. A detailed description of necropsy findings from these individuals is in Finnegan et al. (2016).

3.3.1.1. Findings 2016-2017

The A La Peche female euthanized after a motor vehicle collision in 2016 (ALP_3) was approximately 4 to 5 years old. She had compound, comminuted fractures of the right and left metacarpals consistent with vehicle strike, and a linear laceration extending along her back, through the hide, to the epaxial muscles that occurred post mortem. She was in exceptional body condition with abundant fat stores. We found one *Echinococcus granulosus* cyst in her left caudal lung lobe, but this cyst was likely not clinically significant. We observed multifocal pitting of the cortex of her left kidney, as well as a few tan to white firm, millary, granular nodules in the cortex and medulla of her left kidney; fixed kidney samples will be submitted for further histopathology.

3.3.2. Bacteria

Using a combination of PCR and bacterial culture, we identified the bacterium *Erysipelothrix rhusiopathiae* in 9 of 17 caribou mortalities examined between 2013 and 2016 (Table 3.3).

Table 3.3. Erysipelothrix rhusiopathiae status of caribou sampled as part of mortality site investigations within west-central Alberta and east-central British Columbia between 2013 and 2016.

ID	Sex	Herd	Probable cause of death	*Erysipelothrix rhusiopathiae* tissue culture status
ALP_1	Male	ALP	Vehicle	Negative
Un-collared grizzly kill	Male	ALP	Predation	**Positive**
1354	Female	LSM	Predation/Disease?	Negative
964	Female	LSM	Ticks/starvation	Negative
2191	Female	LSM	Disease?	Negative
F440	Female	RPC	Predation	**Positive**
F444	Female	RPC	Accident	Negative*
F446	Female	RPC	Predation	**Positive**
F453	Female	RPC	Predation	**Positive**
F454	Female	RPC	Predation	Negative
F448	Female	RPC	Predation	**Positive**
F450/2199	Female	RPC	Predation	**Positive#**
F786	Female	NAR	Disease	**Positive**
F793	Female	NAR	Predation	**Positive**
1068	Female	NAR	Predation	Negative*
2326	Female	RPC	Predation	Negative
2166	Female	LSM	Predation	**Positive**

*marginal sample quality – significant autolysis or dried out
#lungs only; brain, muscle and marrow negative

3.3.3. Parasites

With the exception of two lungworms found during examination of F786 (too autolyzed for definitive identification), and the *Echinococcus granulosus* cyst in the left lung of ALP_3, we detected no parasites during necropsies; therefore parasite results reported here are from fecal samples only. A total of 201 fecal samples from 150 individual caribou were available for testing (Table 3.4).

3.3.3.1. Abomasal parasites 2015-2017

1.5% of caribou tested (n = 3/201) had Nematodirinae eggs in their feces, while 12.4% (n = 25/201) had Strongylate eggs. The intensity of infection was low (0.24 - 9.64 eggs/gram of feces). We detected tapeworm eggs (*Moniezia* spp.) in 12.4% (n = 25/201) of caribou tested, and for individuals the intensity of infections was low to high (0.51 – 125 eggs/gram of feces). Neither *Marshallagia* spp. eggs nor *Eimeria* spp. oocysts were detected within our samples. Table 3.4 summarizes results by herd and year.

Of those caribou sampled in multiple years, male 303 (RPC) sampled in January 2015, and February and March 2016 had higher prevalence of *Moniezia* spp. in 2015 (44 eggs/gr) than in 2016 (2.36, 2.85 egg/gr). Male 2104 (RPC) had 15.37 *Moniezia* spp. eggs/gr feces in March 2015 and none in March 2016. Female 603 (NAR) had 0.24 Strongylate egg/gr in March 2015 but no eggs were detected in feces collected in January or March 2016. Female 706 (RPC) had 4.6 Nematodirinae egg/gr and 74.6 *Moniezia* spp. egg/gr in January 2015, and no Nematodirinae and 48.5 *Moniezia* spp. egg/gr in March 2016.

Table 3.4. Number of caribou samples collected within the ranges four west-central Alberta and east-central British Colombia herds across two winters (2014/15 and 2015/16) with positive abomasal parasite results detected using fecal floatation (Nematodirinae, Strongylate, Moniezia spp). The total number of infected individuals (N), number of infected individuals by year (2015 or 2016), and intensity of infection (range of eggs per gram of feces (eggs/g)) in positive individuals, are shown.

Herd	Number of individuals (# samples)	Nematodirinae		Strongylate		*Moniezia spp.*	
		N(2015, 2016)	eggs/g	N(2015, 2016)	eggs/g	N(2015, 2016)	eggs/g
ALP	23 (25)	-	-	$2_{2,0}$	1.4, 1.7	-	-
LSM	41 (45)	-	-	$3_{3,0}$	2.8 – 9.68	$2_{1,1}$	13.1, 112.7
RPC	64 (93)	$3_{3,0}$	2.5 – 6.9	$4_{0,4}$	0.25	$16_{10,6}$*	2.3-125
NAR	24 (38)	-	-	$4_{2,3}$	0.24 – 1.71	$5_{0,5}$	0.51-16.6

*total of 10 samples from 10 individuals in 2015, and 9 samples from 6 individuals in 2016

3.3.3.2. Protostrongylid nematodes

Using Baerman larval counts we recorded dorsal spine Protostrongylid larvae (DSLs) in 16% (n = 32/201) of fecal samples tested across 27 individual caribou (Table 3.5, 3.6). The prevalence and intensity of infection of DSLs varied across herd ranges with the lowest prevalence in the ALP and LSM herds (4% and 7.3% of sampled individuals infected respectively), and highest prevalence in the RPC and NAR herds (12.5% and 25% of sampled individuals infected respectively; Table 3.5). Of those caribou sampled in multiple years, one had DSL in both years (LSM male 901), two had DSL in 2016 but none in 2015 (RPC female 508 and male 2102), and one had DSL in 2015 but none in 2016 (LSM male 1201). Considering caribou sampled multiple times during the same winter, the number of DSL recovered was inconsistent (Table 3.6).

Table 3.5. DSL larval counts detected using Baerman larval counts of caribou samples collected within the ranges four west-central Alberta herds across two winters (2014/15 and 2015/16). The total number of infected individuals (N), number of infected individuals by year (2014/15 or 2015/16), and intensity of infection (larvae per gram of feces (lpg)) in positive individuals, are shown.

Herd	Number of individuals (# samples)	DSL	
		$N_{(2014/15,\ 2015/16)}$	lpg
ALP	23 (25)	$1_{0,1}$	2
LSM	41 (45)	$3_{1,2}$	3.3-47.8
RPC	64 (93)	$8_{1,7}$	0.33-32.33
NAR	24 (38)	$6_{1,5}$	0.73-23.4

Table 3.6. Number of Protostrongylid dorsal spine larve (N) recovered from feces using Baerman larval counts of feces collected from caribou sampled within the Redrock Prairie Creek (RPC), Narraway (NAR), and Little Smoky (LSM) herds in west-central Alberta across multiple winters (2014/5 or 2015/6), and/or multiple times during the same winter (T1, T2). Data from caribou where no Protostrongylid dorsal spine larvae were recovered from feces (N = 123 individual caribou), or where the caribou was only detected during one sample event (N = 19 individual caribou) are not shown.

Individual	Sex	Herd	2014/15				2015/16			
			T1		T2		T1		T2	
			Date	N	Date	N	Date	N	Date	N
301	M	RPC	24/Jan/15	26	19/Apr/15	227	-	-	-	-
508	F	RPC	24/Jan/15	0	4/Mar/15	0	10/Feb/16	78	18/Mar/16	35
2102	M	RPC	13/Mar/15	0	-	-	4/Mar/16	73	-	-
5801	F	RPC	-	-	-	-	10/Feb/16	91	9/Mar/16	110
901	M	LSM	29/Jan/15	196	-	-	24/Feb/16	710	-	-
1201	M	LSM	14/Feb/15	3	-	-	24/Feb/16	0	-	-
5301	F	NAR	-	-	-	-	27/Jan/16	10	17/Mar/16	0
5507	F	NAR	-	-	-	-	27/Jan/16	1	17/Mar/16	14

3.3.3.3. Giant liver fluke (Fascioloides magna)

We detected no fluke eggs in fecal samples tested.

3.3.4. Hair cortisol

Hair cortisol concentration varied across individuals (4.92-62.6 pg/mg), there were no apparent trends across seasons, sexes or herds, or relative to probable cause of death (Table 3.7).

Table 3.7. Hair cortisol concentrations (pg/mg) of caribou sampled as part of mortality site investigations within west-central Alberta and east-central British Columbia between 2013 and 2016. Hair colour refers to the colours within the hair sample used for testing where 8 is near white, 5 is medium brown, 1 is black, and W indicates that there was white hair in the hair column.

ID	Sex	Herd	Mortality date	Probable cause of death	Sample Conc. (pg/mg)	Hair Colour
F440	F	RPC	12 May 2013	Predation	17.8	4
F446	F	RPC	14 May 2013	Predation	6.98	5-W
2166	F	LSM	11 May 2015	Predation	30.4	W-4
F448	F	RPC	26 Oct 2014	Predation	7.18	6-W
F454	F	RPC	15 May 2015	Predation	13.2	4-W
2326	F	RPC	26 May 2015	Predation	5.55	4-W
ALP_2	M	ALP	8 March 2014	Road traffic accident	7.04	W
1068	F	NAR	Sept 2014	Predation	62.6	W
F786	F	NAR	11 Oct 2013	Disease	8.10	4-W
ALP_1	M	ALP	29 July 2014	Road traffic accident	7.37	7-5
2197	F	RPC	1 May 2104	Predation	9.64	5-W
F444	F	RPC	23 Jan 2014	Accident (fall)	7.46	5-W
1354	F	LSM	April 2014	Predation	19.6	4-5
2191	F	LSM	20 Oct 2015	Predation	4.92	5-W

3.3.5. Nutrition and toxicology

Testing of samples from ALP_3 (roadkilled A La Peche female) is underway. Details of nutrition and toxicology results from caribou sampled between 2013 and 2015 are in Table 4.6 in (Finnegan et al. 2016).

3.4 Discussion

Using a combination of mortality site visits and non-invasive fecal sampling, this pilot project has provided new baseline health data for declining threatened and endangered woodland caribou populations in west-central Alberta and east-central British Columbia. Through collaborations with ongoing caribou health research programs in British Columbia, the North West Territories, and elsewhere, this project has also contributed towards a broader understanding of the role that health may play in woodland caribou population dynamics across their distributional range.

3.4.1. Bacteria

Across three years of sampling we cultured *E. rhusiopathiae* from the tissues of 9 of 17 caribou examined, 8 of which probably died from predation and one (F786) which was found intact and most likely died as the result of disease (Table 3.3). The ecology, pathogenesis, and epidemiology of *E. rhusiopathiae* in caribou and other free-ranging ungulates are poorly understood (see Schwantje et al. 2014, 2016 and Finnegan et al. 2016 for a brief review), but the bacterial pathogen was first identified in tissues of radio-collared boreal caribou from British Columbia which died during a period of unusually high mortality during 2013 (reviewed in Schwantje et al. 2014). Since that initial finding the BCHRP has been critically evaluating *E. rhusiopathiae* in woodland caribou, and to date evidence of exposure to this pathogen has been recorded in live-captured and dead individuals, and in five of six herds sampled (Schwantje et al. 2014, 2016). Although the pathogenesis of *E. rhusiopathiae* is unclear, multiple serotypes (strains) of the bacteria are also known to exist in a variety of species which affect the type and severity of disease in infected animals (e.g. chronic vs. per acute fatal; (Bender et al. 2011, Ho et al. 2012, Forde et al. 2016)). *E. rhusiopathiae* infections are also known to be transmitted between different species (Wang et al. 2010), and could add an additional layer of complexity to the role of apparent competition in the decline of boreal and mountain caribou. The BC Wildlife Health Program has identified this bacterium or exposure to it in live and dead moose (Forde et al. 2016, Schwantje et al. 2016), and we are pursuing similar investigations in moose, deer, and elk that inhabit AB caribou ranges, with preliminary data indicating moose and deer within west-central Alberta also are infected with *E. rhusiopathiae* (fRI Research Caribou Program unpublished data).

3.4.2. Parasites and Protostrongylid nematodes

Over two winters of data collection our assessment of parasites within caribou feces detected a low prevalence of Trichonstronglyes (Strongylate, Nematodirinae), and was consistent with results reported for boreal caribou in British Columbia (14% infected, Schwantje et al. 2014). Prevalence of *Moniezia* spp. (tapeworm) infection in west-central Alberta (12%) was also similar to that reported in British Columbia (8% infected, Schwantje et al. 2014), but the intensity of infection in some caribou in west-central Alberta was higher than that of British Columbia (Alberta: maximum of 112 and 125 eggs/g; British Columbia 18 to 21 eggs/g; Schwantje *et al.* 2014). We detected no trends in parasite infection across herds or throughout the winter, however of the four caribou that were sampled and infected in both winters, the intensity of infection was higher during the winter of 2014/15 than during the winter of 2015/16 for all four individuals.

Prevalence of DSLs in caribou from west-central Alberta in 2014-16 (16%) was lower than previous records from the same area 1976-1982 (28.4%, Gray and Samuel 1986), lower than reports from British Columbia (35%, Schwantje et al. 2014), but higher than previous records from north-east Alberta (8.3%, Gray and Samuel 1986). Like previous research we found that prevalence and the intensity of infection varied across herds (Gray and Samuel 1986, Schwantje et al. 2014), but prevalence was highest in the RPC (12.5%) and NAR (25%) herds, and intensity of infection was comparative in the LSM, RPC and NAR herds (maximum 47.8 lpg, 23.4lpg, and 32.3lpg respectively). Of note is that all fecal samples evaluated in this pilot study had been stored frozen for at least one month prior to analysis and thus our fecal samples may underestimate the true prevalence and intensity of *Ostertagia* infections and infections of other parasites (e.g. *Dictyocaulus*, a lung worm; see Finnegan et al. 2016).

3.4.3. Hair cortisol

We found no associations between HCC and probable cause of death (predation, accident, disease), and in contrast to previous research (Ewacha 2016*a*) there were no clear differences among herds or season, although further data are required to facilitate statistical comparisons. HCC were generally lower than fecal cortisol (10-63pgmg) and corticosterone (12-963pg/mg) measured in the same herds during winter (Pigeon et al. 2016), which is accordance with previous research comparing HCC and fecal cortisol (Bryan et al. 2013, Mastromonaco et al. 2014).

Hair cortisol concentrations (HCC) were generally higher (4.0-62.6pg/mg) than reported previously for captive (3-4 pg/mg, Ashley et al. 2011) and wild (0.6-6.9pg/mg, Macbeth 2013; 2.3-13.9pg/mg, Renaud 2012; ~1.49-2.72 pg/mg, Ewacha 2016) *Rangifer*, as well as for other cervids (4-6 pg/mg *Cervus elaphus,* Chiara et al. 2016; ~0.35-0.7pg/mg *Alces alces* (Ewacha 2016*b*). However, previous research has found differences in HCC relative to hair colour – with some studies reporting higher HCC in darker hair (Macbeth et al. 2010), and vice versa (Bennett and Hayssen 2010, González-de-la-Vara et al. 2011). Two of the highest HCC levels in this study were from samples dominated by white hair (caribou 1068 and 2166; Table 3.7); after discounting those two samples our HCC were still higher than reported previously, but only marginally so (4-19.6pg/mg), although as few other studies report hair colour along with HCC, direct comparisons are difficult.

Direct comparisons between our results are previous research are also difficult because in addition to hair colour there are a number of factors that may affect HCC. For example, in

Rangifer, HCC may be affected by seasonal changes in coat colour and hair growth, weathering, and collection site on the body (Ashley et al. 2011, Macbeth 2013). Although additional samples may allow us to account for colour and weathering in statistical modelling, because of the nature of sample collection for this study (hair from carcasses), consistent collection of hair samples from the shoulder area, as recommended by Macbeth (2013) may be difficult. Collecting hair from caribou during capture may provide a more effective means of using HCC to monitor long-term stress in caribou in Alberta, similar to collection protocols already implemented in British Columbia (H. Schwantje pers. comm.). Although further validation in caribou is needed, HCC is a promising indicator of wildlife health (Keay et al. 2006, Ashley et al. 2011). Implementing standardized protocols for sample collection (Cattet et al. 2014) and laboratory analysis (Kroshko et al. 2017) will facilitate direct comparisons across herds, sexes and seasons, providing valuable information that can be used to track changes in long-term stress in caribou in the future, relative to habitat restoration and other management actions within caribou ranges.

4. Assessing caribou mortality risk in west-central Alberta and east-central British Columbia

Tracy McKay, Doug MacNearney, Barry Nobert, Karine Pigeon, and Laura Finnegan.

4.1. Introduction

Human activities are a primary factor behind declines in boreal and mountain caribou (Hervieux et al. 2013, Johnson et al. 2015, Hebblewhite 2017), and landscape disturbances affecting predator-prey dynamics present the largest threat to caribou persistence (Festa-Bianchet et al. 2011, Environment Canada 2012, 2014). Specifically, anthropogenic disturbance in caribou ranges is linked to increased predation risk and unsustainable mortality rates for caribou (Environment Canada 2012, 2014, Hervieux et al. 2014).

Landscape disturbance can increase caribou predation risk through a number of mechanisms, including altered habitat use by predators and other prey species. Wolves use linear corridors as travel routes (James and Stuart-Smith 2000, Whittington et al. 2004, Latham et al. 2011*a*, McKenzie et al. 2012, Dickie et al. 2016), and wolves using linear features can increase their search rate while hunting (DeCesare 2012*a*, Dickie et al. 2016). Grizzly bears select disturbances such as cutblocks, roads, pipelines, and wellsites (Nielsen et al. 2004*a*, Roever et al. 2008, McKay et al. 2014*a*, *b*), and cougars and grizzly bears select edges created by cutblocks (Stewart et al. 2013, Knopff et al. 2014). Landscape disturbance can also result in apparent competition, whereby the conversion of mature forests into early succession stands results in an increase in habitat quality for other ungulate prey species such as moose, deer, and elk, increasing their abundance and spatial overlap with caribou, and thus increasing spatial overlap between caribou and shared predators like wolves, bears, and cougars (Robinson et al. 2002, DeCesare et al. 2010, Dawe 2011, Latham et al. 2011*b*, Serrouya et al. 2011, Peters et al. 2012). Wolf-mediated apparent competition between caribou and alternate prey has been linked to caribou declines across the boreal forest (James et al. 2004, Wittmer et al. 2005*b*, 2007, Environment Canada 2012, 2014, Johnson et al. 2015), and research also indicates that cougar-mediated apparent competition could play a role in declines of some caribou populations (Kinley and Apps 2001, DeCesare et al. 2010).

While a large body of evidence suggests that landscape disturbance results in increased predation risk for caribou (Festa-Bianchet et al. 2011, Whittington et al. 2011, DeCesare 2012*a*, Hervieux et al. 2014, Dickie et al. 2016), relatively few studies have directly assessed the relationships between landscape disturbance and caribou mortalities (but see James and Stuart-Smith 2000, Latham et al. 2011*a*, Apps et al. 2013). The majority of caribou mortalities are attributed to predation, although cause of death cannot always be confirmed (Wittmer et al. 2005*b*, Peters et al. 2012, Apps et al. 2013, Leblond et al. 2013). Investigating relationships between landscape characteristics and mortality locations from predation events and mortalities of unknown cause could provide a better understanding of how landscape features are associated with caribou mortality events.

Linking caribou mortalities to predator occurrence on the landscape could also provide insight into the relationships between landscape disturbance, predator habitat use, and caribou mortality events. Caribou predator research in west-central Alberta has mainly focused on wolves (Kuzyk et al. 2006, DeCesare 2012*a*, Hervieux et al. 2014); however, research from adjacent herds in British Columbia indicates that central mountain caribou predators include wolves, cougars, grizzly bears, black bears, and wolverines (Kinley and Apps 2001). As our field-based investigations in the RPCNAR ranges attributed predation-related caribou mortalities to either wolves, grizzly bears, or cougars (Chapter 2), the probability of occurrence of these predators on the landscape could influence overall caribou mortality risk in the RPCNAR.

Our objective was to investigate the relationships among caribou mortality locations, terrain features, landscape disturbances (natural and anthropogenic; landscape models), and predator occurrence (predator models), within and outside of protected areas in the Redrock Prairie Creek and Narraway (RPCNAR) caribou ranges. We compared caribou mortality locations and live GPS caribou collar locations to assess mortality risk for 1) all caribou mortality events, and 2) predation-specific mortalities only.

4.2. Methods

4.2.1 Caribou location data

Location data from GPS collars were collected between 2006 and 2015 from adult female caribou in the Redrock Prairie Creek (n = 50) and Narraway (n = 40) ranges. Caribou were collared as part of a long-term collaboration between Weyerhaeuser Company Limited and Alberta Environment and Parks and capture and handling protocols were approved under the Alberta Animal Care Protocol 008. Collars included Lotek models (Lotek 2200/3300/4400, Newmarket, Ontario, Canada) and Televilt collars (Televilt Global Positioning System, Lindesberg, Sweden). To match live caribou locations to mortality events using the appropriate landscape conditions and predation risk, we selected live caribou collar locations for analysis from individual caribou with telemetry data from the same year and season in which at least one mortality occurred (n = 69).

The mortality location dataset included known mortality events of 32 collared adult female caribou. Due to changes in collar technology across the study period, the temporal precision of the mortality data varied. For mortalities with a delayed time of detection, we estimated time of death whenever possible, based on collar location data, telemetry flight data, and field observations. Patterns of caribou habitat use differ according to season, which may affect mortality risk for caribou relative to landscape disturbance and predator overlap (Saher and Schmiegelow 2005, Jones et al. 2006, Briand et al. 2009). Therefore, we excluded mortality data if we could not assign the caribou mortality date to a specific caribou season (spring, summer, fall, early winter, or late winter; MacNearney et al. 2016).

For a number of mortality events, we were unable to determine probable cause of death due to delays in visiting the mortality site, or lack of evidence at the site. In other research focused on caribou mortalities (Peters et al. 2012, Apps et al. 2013, Leblond et al. 2013), based on previous evidence indicating that the majority of caribou mortality is predation-related (Wittmer et al. 2005*b*, Stotyn 2008), it was assumed that mortalities of unknown cause were caused by predation. Thus, to enable comparison with previous research, we followed this approach for our 'general' mortality analysis; including mortalities of unknown cause while excluding any mortalities with a known non-predatory cause of death (e.g., roadkill). However, we were also interested in assessing whether relationships with landscape disturbance and predator overlap would differ when only mortalities classified as probable predation were included in the analysis. Therefore, similar to Peters et al. (2012), we carried out a second 'predation-specific' mortality analysis; including only mortalities with strong field evidence of predation as the cause of death (see Chapter 2 for classification criteria).

For analysis we paired each mortality location with live caribou GPS collar locations from the caribou from the same herd, season, and year; excluding locations from caribou that did not live through the entire season-year. We randomly subsampled live caribou GPS locations to one location per day per individual caribou such that the number of locations paired with each mortality location ranged from 83 to 847.

4.2.3 Landscape variables

The RPCNAR study area includes protected areas as well as areas managed by the provincial government, with both anthropogenic disturbances (cutblocks, roads, seismic lines, pipelines, and wellsites) and natural disturbance (burnt areas) (Figure 1.1). We developed a suite of landscape variables (Appendix 1) based on preliminary results in our study area (Finnegan et al. 2016), caribou mortality studies in other areas (James and Stuart-Smith 2000, McLoughlin et al. 2005, Hebblewhite et al. 2010, Latham et al. 2011*a*, Apps et al. 2013), and predictors of predator occurrence (Nielsen et al. 2006, Knopff 2011, DeCesare 2012*b*). To determine the appropriate scale of influence for landscape variables, we calculated feature densities within three spatial scales (70m, 1km, and 5km; DeCesare et al. 2012). For all distance variables, we applied an exponential decay function ($1\text{-exp}^{(-0.002 \text{ x distance (m)})}$) to represent the diminishing effect of features at large distances; this decay causes the effect of distance to decrease rapidly beyond 500m, and to become approximately constant at distances greater than 2km.

4.2.3.1 Disturbance variables

For roads, pipelines, cutblocks, burnt areas, and wellsites, we generated annual datasets for distances to features, and feature densities at the 70m, 1km, and 5km scales. We were interested in the influence of early seral stage forest on mortality risk; therefore, we included only cutblocks and burnt areas ≤25 years old. All conventional seismic lines (>5m in width) in our study area were constructed prior to 2006; therefore, we generated a single dataset for seismic lines that was used across all years of analysis. We considered individual linear features in our analysis, but also combined roads, pipelines, and seismic lines to generate a comprehensive linear feature layer, and calculated the corresponding annual distances and densities for this layer. Due to low densities of anthropogenic features within protected areas (Figure 1.1), we were unable to include roads, pipelines, wellsites, or cutblocks in our analysis of mortalities in protected areas, but we are to include the variable of combined linear features.

4.2.3.2 Terrain and habitat variables

We used landcover derived from two sources: 1) a combination of airborne laser scanning and LandSat imagery, as described in Nijland et al. (2015), and 2) the Canadian Forest Service Earth Observation for Sustainable Development of Forest (EOSD) cover map, generated from LandSat imagery in 2000 (Natural Resources Canada 2009). We combined these layers to develop landcover data specific to each year of our study period, incorporating annual landscape change due to anthropogenic disturbance (cutblocks, wellsites, roads, and pipelines), and generating layers for alpine habitat, forest, and open habitat. We used these layers to calculate the proportion of alpine habitat available within 70m, 1km, and 5km, the distance to alpine habitat, and the distance to forest edges.

Using a 30m x 30m resolution digital elevation model (DEM), we extracted values of elevation, aspect, slope, terrain wetness (compound topographic index, CTI; Gessler et al. 2000), and terrain ruggedness (topographic position index, TPI; Jenness 2006). In addition, we calculated aspect as a binary variable incorporating south-facing slopes (135^{o} to 225^{o}) versus all other aspects. We obtained streams data from the British Columbia Freshwater Atlas (GeoBC 2009) and the Alberta Single Line Hydrography Network (Alberta Sustainable Resource Development 2000), and calculated distances to large streams and rivers (3^{rd} Strahler order and higher), and distance to all streams in the study area (Appendix 1).

4.2.4 Predator Resource Selection Functions

We used predator resource selection functions (RSFs) as indices of predation risk based on the assumption that predation risk for caribou is directly related to the probability of predator occurrence (Gustine et al. 2006, Ciuti et al. 2012, Leblond et al. 2016). We applied previously established RSF equations for grizzly bears, cougars, and wolves in west-central Alberta (Nielsen et al. 2006, Knopff 2011, DeCesare 2012*b*, Knopff et al. 2014) to calculate RSF values for each predator across the study area; updating landcover layers annually to account for landscape change, and calculating RSFs by year for each predator.

Grizzly bears do not present a year-round predation risk for caribou; therefore, we designated April 16 to November 15 as the grizzly bear predation season, based on average den exit and entry dates in west-central Alberta (Graham and Stenhouse 2014, Pigeon et al. 2016). Caribou locations and mortalities occurring outside of the designated grizzly bear predation season were assigned RSF values of 0. Grizzly bear RSFs for the Grande Cache population unit were previously available for the Alberta side of our study area (Nielsen et al. 2006, 2009), and we used these RSF coefficients to extrapolate RSF values for spring, summer, and fall into the British Columbia portion of the study area.

For wolves, we generated annual and seasonal (summer and winter) RSFs for the foothills and mountain regions within the RPCNAR using RSF equations from DeCesare (2012). We then generated annual and seasonal RSF surfaces across the study area by merging foothills and mountain RSFs based on Alberta natural subregions and British Columbia ecoregions (Natural Regions Committee 2006, GeoBC 2017).

Cougar habitat use data were not available for our study area; however, cougar RSF equations have been generated from research completed south-east of our study area, near the town of Nordegg, within the boreal foothills and mountains of west-central Alberta (Knopff 2011, Knopff et al. 2014). The Nordegg study area was largely similar to the RPCNAR in terms of landscape disturbance, terrain, protected areas, and landcover (Figure 1.1; Knopff et al. 2014); therefore, we used RSF equations derived in the Nordegg study area to approximate cougar habitat use within our study area.

We calculated predator RSF values at a 30m x 30m resolution and generalized the resolution to an appropriate spatial scale for each predator. For wolves, we calculated average RSF values using a 1km radius, based on previously reported prey detection and encounter distances (Mech and Boitani 2003, Muhly et al. 2010, Whittington et al. 2011). Predatory behaviour in grizzly bear populations is variable (Boertje et al. 1988, Zager and Beecham 2006), but grizzly bears are generally considered opportunistic carnivores, hunting at smaller spatial scales (Reynolds and Garner 1986, Zager and Beecham 2006, Kays and Wilson 2009). Therefore, we used a 70m radius for grizzly bear RSFs, assuming that bears would not be traveling long distances in search of adult ungulate prey. We also calculated average RSF values for cougars using a 70m radius, based on the assumption that cougars are ambush predators (Husseman et al. 2003, Chetkiewicz and Boyce 2009, Bartnick and Van Deelen 2013).

For data analysis, we used the relative probabilities of predator occurrence for each predator (RSF values scaled between 0 and 1) to allow for direct comparison between predator model coefficients. For each year of data, we extracted annual predator RSF values to caribou mortality location and live locations, and for wolves and grizzly bears, we matched mortality dates and live caribou locations with values from the appropriate predator season.

4.2.5 Data analysis

We completed all data exploration and statistical analyses within RStudio (RStudio Team 2015). We used the same analytical approach for the general mortality analysis (including mortalities of unknown cause) and the predation mortality analysis (mortalities with evidence of probable predation only), and before data analysis we partitioned datasets into locations from protected areas and unprotected areas due to differences in densities of anthropogenic features. We used conditional logistic regression ('clogit', package 'survival' in RStudio, Therneau 2015) to assess the influence of landscape variables and predator distribution on caribou mortalities; matching mortality locations to live caribou locations from the same herd, season, and year. For all analyses, variables were considered important predictors of mortality if the beta (β) coefficient ± standard error (SE) did not overlap zero. We used k-fold cross-validation for conditional logistic regression (package 'hab', Basille 2005) to assess the fit of our final models for protected and unprotected areas, and to evaluate the ability of models to predict mortality events.

4.2.5.1 Landscape models

Our initial dataset included a number of potential predictor variables and spatial scales (e.g., distance to road and road densities within 70m, 1km, and 5km; Appendix 1). First, to determine the best spatial scale for each predictor variable, we carried out univariate conditional logistic regression analyses, and selected one variable from each group based on values of quasi-likelihood under independence criterion (QIC, calculated in the R package 'MuMin'; Bartón 2015). Before building models, we screened all continuous variables for correlations, and to assess correlations between binary variables, we reviewed histograms and ran individual logistic regressions with single predictor variables. When two variables were correlated (correlation coefficient ≥0.5 or significant regression statistics [$p \leq 0.05$] between binary variables), we used the variable with the best univariate QIC for the final analysis.

Because our goal was to maximize the predictive ability of models rather than test competing hypotheses, we used a forward selection approach for model building (Hosmer and Lemeshow 2005, Nielsen et al. 2010). Specifically, using the variables selected from each set of predictors in our preliminary analysis, we ran a set of univariate conditional logistic regression analyses within the protected and unprotected area datasets. Using the variable with the lowest QIC as the predictor in our first model, we added the variable with the next best QIC, and determined whether the second (multivariate) model explained more variation than the first (univariate) model, based on QIC values. Selecting the variable with the next best univariate QIC, we continued to add variables one at a time to the combined models until we did not observe any improvement in the QIC.

4.2.5.2 Predator models

Before fitting predator models, we assessed correlations among predator RSF surfaces using Pearson's *r*. Due to strong negative correlations between wolf and cougar RSFs outside of protected areas (r = -0.7), we built separate wolf/grizzly bear models and cougar/grizzly bear models. For protected areas, we included wolf, grizzly bear, and cougar RSFs as covariates in the same model.

4.3 Results

Our dataset consisted of 32 caribou mortality events (general mortalities) between 2006 and 2015; 13 within protected areas and 19 outside of protected areas. Eighteen mortality events were classified as predation-related (predation mortalities), and 14 were of unknown cause. RSFs of wolf, grizzly bear, and cougar occurrence at the start (2006) and end (2015) of the study period are in Appendices 2 through 4.

4.3.1 Landscape models

Within protected areas, general caribou mortalities (n = 13) occurred closer to streams than live caribou locations (β = -3.77 ± 0.98), while predation mortalities (n = 6) occurred in areas of lower elevation compared to live locations (β = -4.64 ± 2.14). Outside of protected areas, general caribou mortalities (n = 19) occurred in areas with higher road densities, at lower elevations, and closer to forest edges and streams than live caribou locations (Table 4.1). Predation mortalities outside of protected areas (n = 12) occurred closer to streams and in areas with lower terrain ruggedness (TPI), and higher pipeline densities than live caribou locations (Table 4.1).

Table 4.1. Coefficients (β) and standard errors (SE) for landscape variables (terrain and disturbance) used to explain mortality risk for general mortalities and predation mortalities outside of protected areas in the RPCNAR between 2006 and 2015.

Landscape variable	General mortalities		Predation mortalities	
	β	SE	β	SE
Distance to stream	-2.64	0.84	-3.30	2.15
Elevation (km)	-3.34	1.16	–	–
TPI	–	–	-1.11	0.50
Road density	17.00	10.20	–	–
Pipeline density	–	–	109.65	31.60
Distance to forest edge	-3.51	1.50	–	–

Using landscape conditions in 2015, maps of predicted relative mortality risk for caribou based on general mortality and predation mortality models are shown in Figures 4.1 and 4.2.

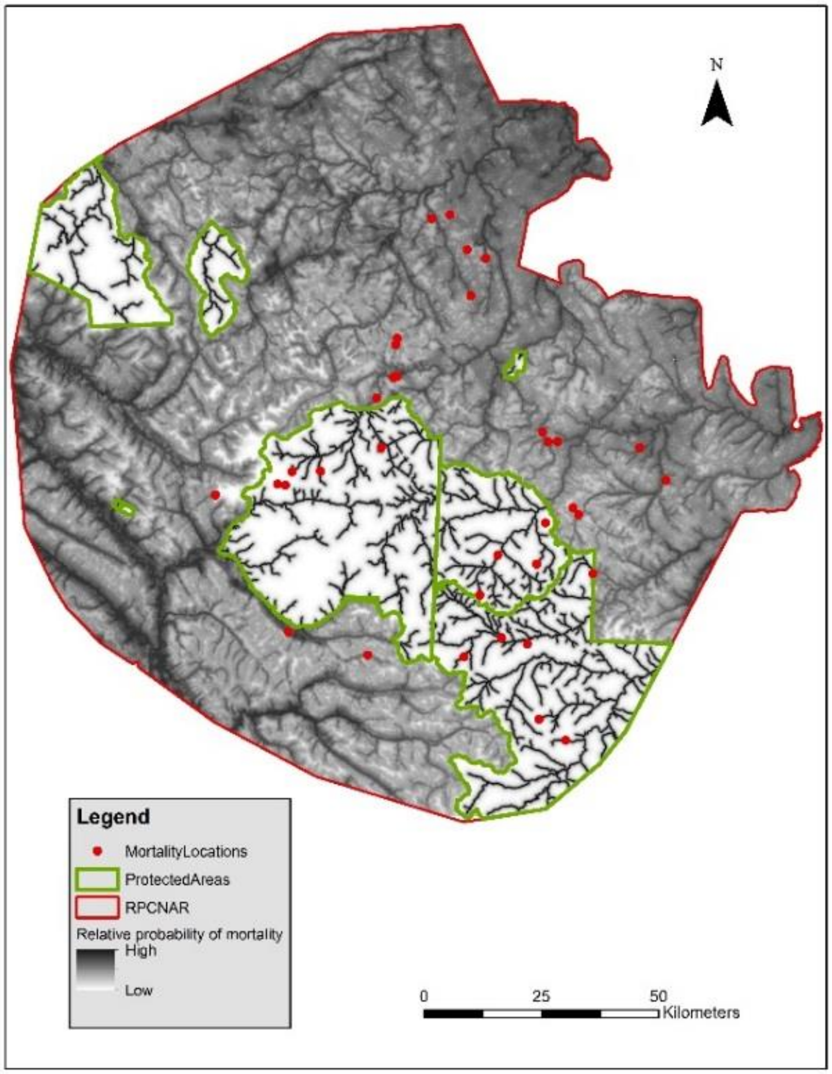

Figure 4.1. General mortality model, predicted relative probability of mortality for protected areas and outside of protected areas in the RPCNAR, based on landscape conditions in 2015.

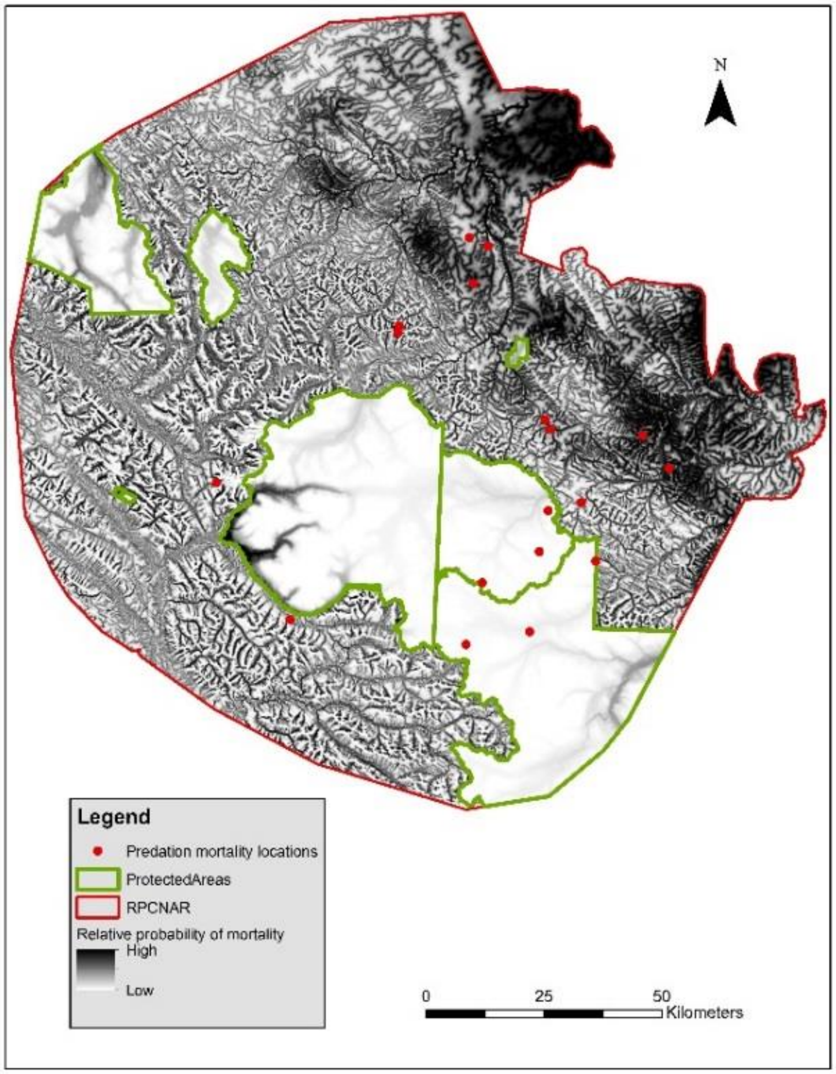

Figure 4.2. Predation mortality model, predicted relative probability of mortality for protected areas and outside of protected areas in the RPCNAR, based on landscape conditions in 2015.

Outside of protected areas, pipeline, road, and seismic line variables were correlated with each other. One of our goals was to specifically evaluate the relationships between individual linear features and caribou mortality locations, and our preliminary results suggested an influence from each linear feature type. Therefore, we present the results of separate univariate models including each of these linear features (pipelines, roads, and seismic lines), and a comparison of the univariate models using QIC values and model weights for each of the general mortality and predation mortality datasets. General mortalities occurred in areas of higher densities of pipelines, roads, and seismic lines than live caribou locations, while predation mortalities occurred in areas with higher densities of pipelines and roads, and closer to seismic lines than live caribou locations (Table 4.2). Figures 4.3 through 4.6 illustrate the predicted probabilities of caribou mortality in response to linear features outside of protected areas, based on univariate model coefficients.

Table 4.2. Coefficients (β), standard errors (SE), QIC values, and model weights for univariate linear feature models used to explain mortality risk for general mortalities and predation mortalities outside of protected areas in the RPCNAR between 2006 and 2015.

	Linear feature	β	SE	QIC	Weight
General mortality models	Pipeline density	85.8	29.9	193.8	0.069
	Road density	34.9	9.4	189.2	0.718
	Seismic line density	25.8	8.0	191.6	0.212
Predation mortality models	Pipeline density	121.3	31.6	109.4	0.875
	Road density	30.2	10.3	115.2	0.049
	Distance to seismic line	-2.6	0.9	114.3	0.076

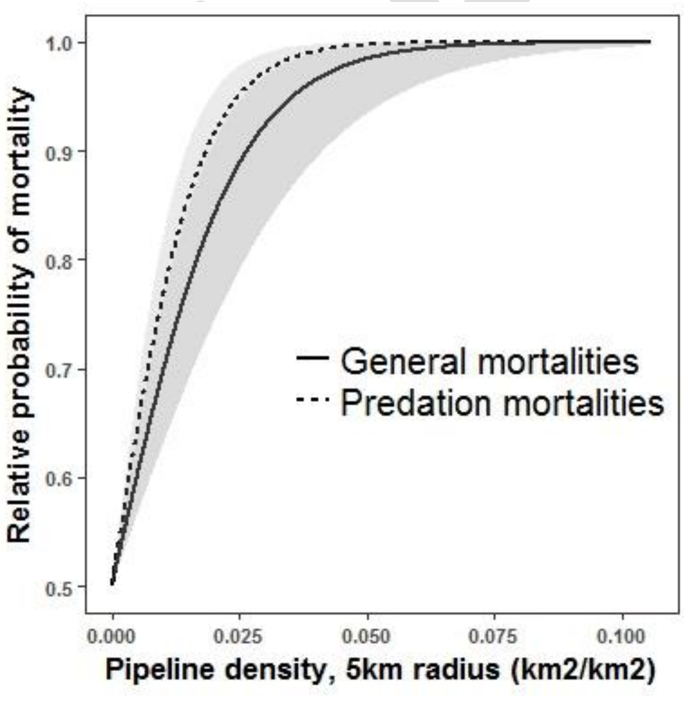

Figure 4.3. Predicted relative probability of mortality for general mortalities and predation mortalities in response to pipeline density outside of protected areas, in the RPCNAR between 2006 and 2015.

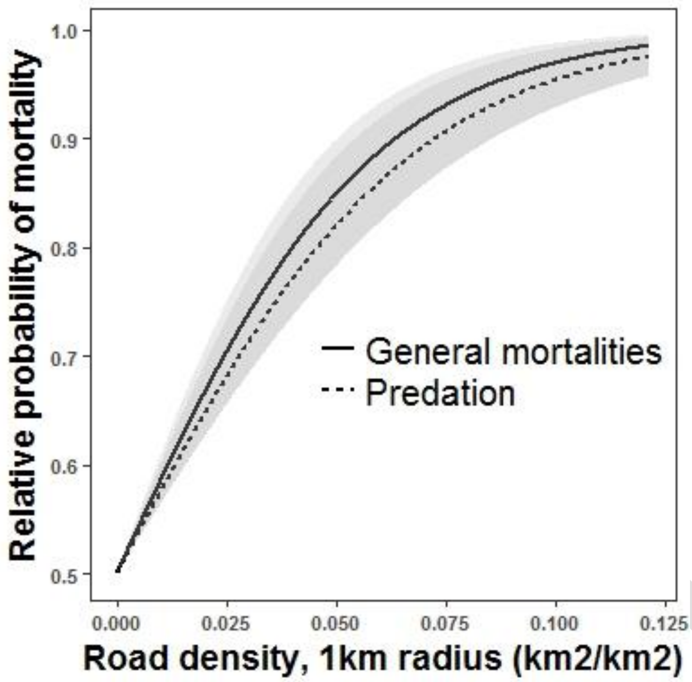

Figure 4.4. Predicted relative probability of mortality for general mortalities and predation mortalities in response to road density outside of protected areas, in the RPCNAR between 2006 and 2015.

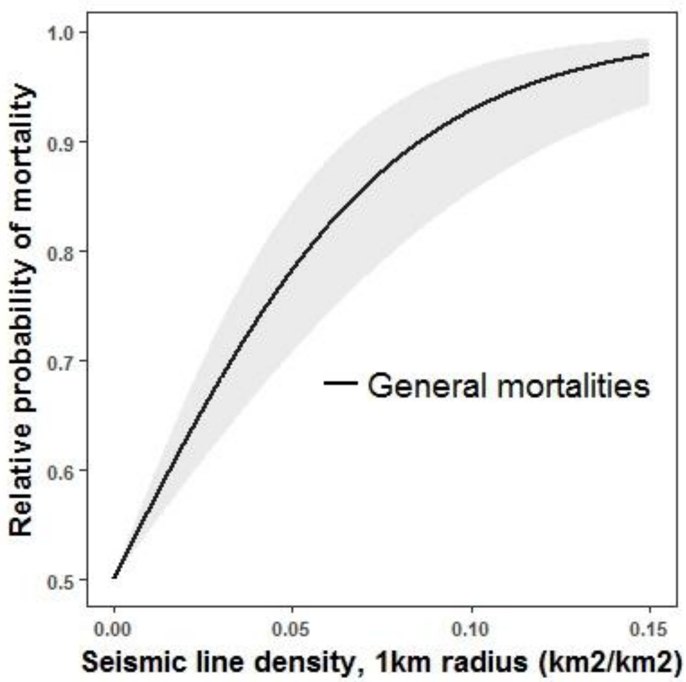

Figure 4.5. Predicted relative probability of mortality for general mortalities in response to seismic line density outside of protected areas, in the RPCNAR between 2006 and 2015.

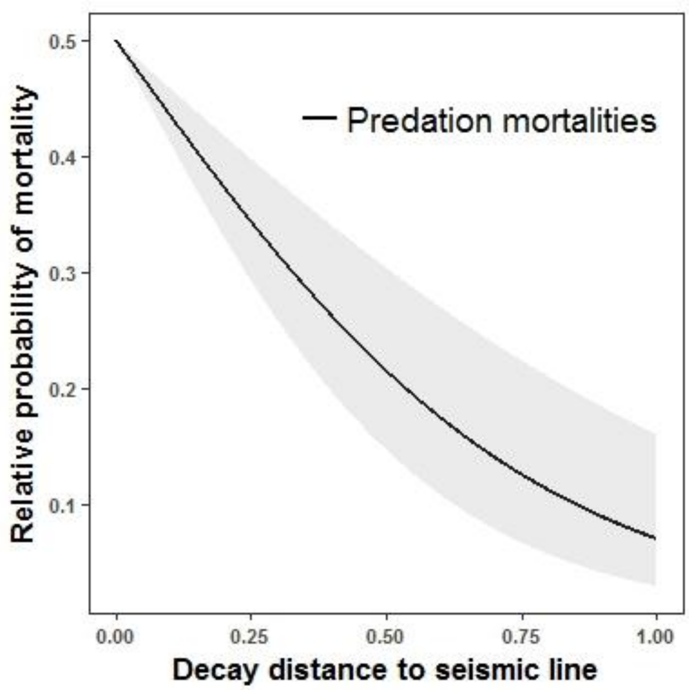

Figure 4.6. Predicted relative probability of mortality for predation mortalities in response to decay distance to seismic lines, outside of protected areas, in the RPCNAR between 2006 and 2015.

4.3.2 Predator models

Within protected areas, general caribou mortalities and predation mortalities occurred in areas with a higher probability of wolf occurrence than live caribou locations, and predation mortalities occurred in areas with higher probability of wolf and grizzly bear occurrence (Table 4.3).

Table 4.3. Coefficients (β) and standard errors (SE) for predator RSFs (wolf, grizzly bear, and cougar) used to explain mortality risk for general mortalities and predation mortalities within protected areas in the RPCNAR, between 2006 and 2015.

Predator RSF	General mortalities		Predation mortalities	
	β	SE	β	SE
Wolf	6.41	3.38	8.34	4.16
Grizzly bear	1.86	2.08	4.53	2.75
Cougar	-2.61	5.10	-2.61	8.07

Outside protected areas, general mortalities and predation mortalities occurred in areas with higher probabilities of wolf and grizzly bear occurrence when compared to live caribou locations (Tables 4.4a and 4.4b). Mortalities also occurred in areas with a low probability of cougar occurrence.

Tables 4.4. Coefficients (β) and standard errors (SE) for a. wolf/grizzly bear and b. cougar/grizzly bear RSF models used to explain mortality risk for general mortalities and predation mortalities outside of protected areas in the RPCNAR between 2006 and 2015.

	Predator RSF	General mortalities		Predation mortalities	
		β	SE	β	SE
a.	Wolf	9.08	2.13	10.3	2.52
	Grizzly bear	5.96	1.45	6.67	1.65
b.	Grizzly bear	5.05	1.35	5.44	1.53
	Cougar	-3.70	2.82	-6.22	3.44

4.3.3 Model validation

K-fold model validation indicated poor predictability of mortality locations for landscape and predator models ($r_s < 0.5$ in all cases); k-fold results for each model are found in Appendix 5. However, model comparison (QIC) of landscape models versus predator models indicated that landscape models were better predictors of general mortalities, while predator RSF models were better predictors of predation mortalities.

4.4 Discussion

We used 10 years of caribou mortalities and live caribou GPS locations from the Redrock Prairie Creek and Narraway caribou herds to assess how landscape disturbance, terrain, and overlap with predators influenced the spatial distribution of caribou mortalities. Both within and outside of protected areas, we found that elevation and distance to streams were consistently associated with high caribou mortality risk in the RPCNAR. Outside of protected areas, anthropogenic linear features also influenced mortality risk; high densities of linear features were associated with a higher probability of caribou mortality. Mortality risk increased with the probability of wolf and grizzly bear occurrence within and outside of protected areas. Results were similar between the general mortality (all mortalities) and the predation-only (probably predation) mortality analyses.

Streams are known predictors of grizzly bear habitat selection (Nielsen et al. 2002) and wolf habitat selection and movement (Latham et al. 2011*a*, DeCesare 2012*b*); therefore, the strong association between caribou mortalities and distance to streams was expected. Likewise, increased mortality risk at low elevations and in areas with low values of terrain ruggedness is consistent with previous research (Whittington et al. 2005, DeCesare 2012*b*, Apps et al. 2013). Using these same caribou GPS data, Hebblewhite et al. (2010) reported increased caribou survival with increased availability of alpine habitat, suggesting that areas of high elevation may provide a refuge for caribou. However, in our study area, grizzly bears select alpine habitat (Nielsen et al. 2006), and recent research suggests that caribou using high elevation habitat to avoid wolves may be at higher risk of predation from bears (Pinard et al. 2012, Leblond et al. 2016).

Outside of protected areas, linear features were important predictors in landscape models, and mortality risk consistently increased with increasing densities of roads, pipelines, and seismic lines. Previous research regarding the direct influence of linear features on caribou mortality risk has reported mixed results. In northeastern Alberta, James and Stuart-Smith (2000) found that caribou mortalities attributed to wolves took place closer to linear corridors than live caribou locations. In contrast, using collar data collected 10 years later within the same region, Latham et al. (2011*a*) reported that caribou mortalities were not closer to seismic lines or pipelines than live caribou locations, but mortalities did occur closer to roads. In British Columbia, Apps et al. (2013) found that caribou mortality risk increased with increasing road density. Our multivariate landscape models and univariate linear feature models for both general and predation mortalities detected strong associations between linear feature densities and caribou mortality risk. Linear features increase predator access to caribou, as they are selected by wolves and bears (James and Stuart-Smith 2000, Whittington et al. 2004, Latham et al. 2011*a*, DeCesare 2012*b*, McKenzie et al. 2012, McKay et al. 2014*a*). In addition, linear features facilitate wolf movement and search rates while hunting (DeCesare 2012*a*, Dickie et al. 2016), and encounters between caribou and wolves increase near linear features (Whittington et al. 2011). Our results therefore provide further evidence that linear features play a role in caribou population declines, and that outside of protected areas within RPCNAR caribou ranges, linear features (roads, conventional seismic lines, and pipelines) increase the probability of caribou mortality.

In accordance with previous research focused on apparent competition, we expected an association between early seral stage habitat and caribou mortalities (Wittmer et al. 2007, Hebblewhite et al. 2010). However, we found no evidence to suggest that the proportion of early seral stage habitat (recent burns in protected areas and cutblocks outside protected areas) predicted caribou mortality locations. Similarly, Apps et al. (2013) found that caribou were not more likely to die in landscapes with abundant early seral stage forests, possibly due to the limited availability of young forests in low elevation habitat within the study area; a similar pattern may be present in our study area. It is also important to consider that caribou generally avoid forestry cutblocks and early seral stage stands (Smith et al. 2000, Hins et al. 2009, DeCesare 2012*b*), and a caribou mortality cannot occur in these areas if a caribou is not present. In other words, the lack of association between early seral stage habitat and caribou mortalities may actually be a result of habitat avoidance. Regardless, grizzly bears are known to select for the foods available in early seral stands (Nielsen et al. 2004*a*, *b*), and larger scale impacts on caribou mortality rates may result from increasing alternate prey and associated increased predator densities associated with these habitats (Robinson et al. 2002, Dawe 2011, Latham et al. 2011*b*, Serrouya et al. 2011, Peters et al. 2012). The edges created by forest disturbances are known predictors of both grizzly bear and cougar occurrence (Stewart et al. 2013, Knopff et al. 2014), and proximity to forest edges increased the probability of mortality risk in our analysis.

When investigating the overlap between mortality locations and predators, general mortality locations were most strongly associated with the probability of wolf occurrence, and predation mortalities were also associated with higher grizzly bear RSF values within and outside of protected areas. These results are consistent with our landscape models; terrain and disturbance variables associated with caribou mortality risk (distance to streams, elevation, linear features, and distance to forest edges) are also important predictors of wolf and grizzly bear occurrence.

Outside protected areas, we detected a strong inverse relationship between wolf and cougar occurrence, suggesting spatial separation between the two predators. This relationship appeared to be driven by linear features; while wolves select seismic lines and roads, cougars avoid them (DeCesare 2012*b*, Knopff et al. 2014). Previous research also suggests that cougars may shift their habitat use and switch prey species with wolf expansion into their range (Kortello et al. 2007, Bartnick and Van Deelen 2013). Continued data collection and research on cougars is currently underway in the RPCNAR area, and will inform a region-specific habitat model for cougars with more information on cougar-specific predation risk for caribou.

Our analysis considered a large range of terrain and disturbance variables; however, k-fold validation suggested poor predictability of caribou mortality models, and therefore our results should be interpreted with caution. Poor validation results may be in part due to our small mortality sample size, and because of additional factors that we were unable to include in our analysis, such as caribou health and age, winter snow conditions, caribou herd size, and local population sizes of predators and alternate prey. Ongoing work, including analysis of caribou movement rates and habitat selection patterns prior to mortality events (e.g., Leblond et al. 2013), could provide further insights into caribou mortality risk.

In conclusion, our results suggest that caribou mortality risk in the RPCNAR is related to a combination of terrain and anthropogenic disturbance features including streams, elevation, and linear features, and is strongly associated with the probability of wolf occurrence. To reduce caribou mortality risk, habitat restoration efforts could be focused in areas of high linear feature densities, and towards landscape disturbances located near riparian areas. Restoration efforts could be further prioritized by using the probability of occurrence for wolves, grizzly bears, and cougars to identify areas within caribou ranges where the probability of caribou encounters with predators are highest.

5. Conclusions and Future Work

The overarching objectives of this project included: 1) determine accurate causes of caribou mortality, including the relative roles of predators, 2) provide insight into the overall health and disease status of caribou within west-central Alberta and east-central British Columbia, and establish comprehensive, herd-specific health baselines, and 3) assess potential mortality risk factors associated with predation in west-central Alberta and east-central British Columbia.

Using data collected from rapid site investigations of mortality events, we established that the predator guild associated with caribou mortalities in west-central Alberta and east-central British Columbia included not only wolves, but also cougars and bears. This knowledge could have implications for management of alternate prey and predator populations in these caribou ranges, and also demonstrates the value of rapid mortality site investigations to determine accurate cause of death for caribou.

Based on biological samples collected from non-invasive winter pellet collection and necropsies of collared female caribou and road-killed individuals, we detected the bacterium *Erysipelothrix rhusiopathiae* in 9 of the 17 caribou tested, detected lungworms in the Narraway herd, and identified individuals with heavy winter tick infestation in the Little Smoky herd. We also collected additional health indicator data (bone marrow, hair cortisol, and trace nutrients) for all the herds investigated. Although the broad scale and population-level impacts of *Erysipelothrix rhusiopathiae*, winter tick, pathogens, and additional heath indicator data are still poorly understood, research from British Columbia, and on other ungulates, suggest that these health indicators are of value for health monitoring of boreal and mountain caribou. Additionally, the ability to collect samples for health testing from mortalities, rapidly for collared individuals, and non-invasively from fecal pellets, make these potential health indicators attractive targets for health monitoring programs. Moreover, standardized sampling and laboratory practices across herds and provinces would facilitate direct comparisons and contribute towards baseline datasets of health in these declining caribou herds. Continued sample collection and research focused on assessing and understanding caribou health contribute towards a broader understanding of wildlife health and could be used to directly inform caribou recovery initiatives by identifying priority areas for restoration based on disease transmission risk. Baseline datasets could also help identify herds that may be at higher risk of disease outbreaks, particularly with the expansion of moose, deer, and elk within caribou ranges and within the context of climate change.

Our assessment of caribou mortality risk relative to landscape characteristics and predator occurrence were largely in accordance with previous research. Caribou mortalities were associated with low elevation areas, proximity to streams, and areas with higher densities of anthropogenic linear features. Specifically, mortalities were closer to seismic lines, in areas with higher densities of seismic lines, and in areas with higher densities of pipelines and roads. Caribou mortalities were also more likely to occur in areas with a higher probability of wolf occurrence (also associated with linear features and streams). Combined, these results support current management actions focused on restoration of seismic lines, and our spatially explicit landscape models of mortality risk could be used to target seismic line restoration activities to areas where caribou mortality risk is highest. In addition, our annual probability of occurrence surfaces for wolves, grizzly bears, and cougars could be used to target restoration activities to areas that would reduce species-specific predation risk for caribou.

Overall, this project used innovative field investigations, standardized laboratory techniques, and analysis of existing data to contribute knowledge that may be important for caribou recovery efforts. Ongoing and collaborative research (within and between provinces) to continue data collection on caribou health while using standardized mortality site investigations and standardized laboratory practices would contribute towards a baseline dataset on caribou health and disease in western Canada. This baseline health and disease dataset could then be used to track changes in predator-prey dynamics over time (e.g., cougar range expansion), and to monitor the potential spread of diseases and pathogens (e.g., winter ticks). More directly, the results of this report could be used by land managers to best direct caribou recovery initiatives and caribou habitat restoration priorities to areas where activities will have the greatest benefit for caribou and will be most cost-effective for stakeholders.

6. Literature Cited

Alberta Woodland Caribou Recovery Team. (2005) *Alberta Woodland Caribou Recovery Plan 2004/05 - 2013/14*. Alberta Sustainable Resource Development, Fish and Wildlife Division, Edmonton, AB. 48pp.

Apps, C.D., McLellan, B.N., Kinley, T.A., Serrouya, R., Seip, D.R. & Wittmer, H.U. (2013) Spatial factors related to mortality and population decline of endangered mountain caribou. *Journal of Wildlife Management*, **77**, 1409–1419.

Ashley, N.T., Barboza, P.S., Macbeth, B.J., Janz, D.M., Cattet, M.R.L., Booth, R.K. & Wasser, S.K. (2011) Glucocorticosteroid concentrations in feces and hair of captive caribou and reindeer following adrenocorticotropic hormone challenge. *General and comparative endocrinology*, **172**, 382–91.

Bartnick, T.D. & Van Deelen, T.R. (2013) Variation in cougar (*Puma concolor*) predation habits during wolf (*Canis lupus*) recovery in the southern Greater Yellowstone Ecosystem. *Journal of Zoology*, **91**, 82–93.

Bartón, K. (2015) MuMIn: Multi-Model Inference ver 1.13.4. Available from: cran.r-project.org/package=MuMIn.

Bender, J., Irwin, C., Shen, H., Schwartz, K. & Opriessnig, T. (2011) Erysipelothrix spp. genotypes, serotypes, and surface protective antigen types associated with abattatoir condemnations. *Journal of Veterinary Diagnostic Investigation*, **23**, 139–142.

Bennett, A. & Hayssen, V. (2010) Measuring cortisol in hair and saliva from dogs: Coat color and pigment differences. *Domestic Animal Endocrinology*, **39**, 171–180.

Bergerud, A. (1992) Rareness as an antipredator strategy to reduce predation risk for moose and caribou. *Wildlife 2001: Populations* (eds D. McCullough & R. Barrett), pp. 1008–1021. Elsevier Applied Science, New York.

Bergerud, A. & Mercer, W. (1989) Caribou introductions in eastern North America. *Wildlife Society Bulletin*, **17**, 111–120.

Boertje, R.D., Gasaway, W.C., Grangaard, D. V. & Kelleyhouse, D.G. (1988) Predation on moose and caribou by radio-collared grizzly bears in east central Alaska. *Canadian Journal of Zoology*, **66**, 2492–2499.

Briand, Y., Ouellet, J.-P.P., Dussault, C. & St-Laurent, M.-H.H. (2009) Fine-scale habitat selection by female forest-dwelling caribou in managed boreal forest: Empirical evidence of a seasonal shift between foraging opportunities and antipredator strategies. *Ecoscience*, **16**, 330–340.

Brown, W.K. & Hobson, D. (1998) Caribou in west-central Alberta: Information review and synthesis. Prepared for the Research Subcommittee of the West-central Alberta Caribou Standing Committee. 72 + xi.

Bryan, H.M., Adams, A.G., Invik, R.M., Wynne-Edwards, K.E. & Smits, J.E. (2013) Hair as a meaningful measure of baseline cortisol levels over time in dogs. *Journal of the American Association for Laboratory Animal Science,* **52**, 189-96.

Cattet, M., Macbeth, B.J., Janz, D.M., Zedrosser, A., Swenson, J.E., Dumond, M. & Stenhouse, G.B. (2014) Quantifying long-term stress in brown bears with the hair cortisol concentration: A biomarker that may be confounded by rapid changes in response to capture and handling. *Conservation Physiology*, **2**, 1–15.

Chetkiewicz, C.-L.B. & Boyce, M.S. (2009) Use of resource selection functions to identify conservation corridors. *Journal of Applied Ecology*, **46**, 1036–1047.

Chiara, C., Comin, A., Peric, T., Prandi, A., Pedrotti, L. & Mattiello, S. (2016) Use of hair cortisol for comparing population status in wild red deer (Cervus elaphus) living in areas with different characteristics. *European Journal of Wildlife Research*, **62**, 713–723.

Ciuti, S., Northrup, J.M., Muhly, T.B., Simi, S., Musiani, M., Pitt, J.A. & Boyce, M.S. (2012) Effects of humans on behaviour of wildlife exceed those of natural predators in a landscape of fear. *PLoS ONE*, **7(11)**.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). (2002) COSEWIC assessment and update status report on the woodland caribou Rangifer tarandus caribou in Canada. xii+98pp.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). (2014) COSEWIC assessment and status report on the caribou (Rangifer tarandus), northern mountain population, central mountain population and southern mountain population in Canada. xii+113pp.

Crete, M. & Huot, J. (1993) Regulation of a large herd of migratory caribou: summer nutrition affects calf growth and body reserves of dams. *Canadian Journal of Zoology*, **71**, 2291–2296.

Dawe, K.L. (2011) *Factors Driving Range Expansion of White-Tailed Deer, Odocoileus Virginianus, in the Boreal Forest of Northern Alberta, Canada*. PhD Thesis, University of Alberta. xiii+159pp.

DeCesare, N.J. (2012a) *Resource Selection, Predation Risk, and Population Dynamics of Woodland Caribou*. PhD Thesis, University of Montana. iii+267pp.

DeCesare, N.J. (2012b) Separating spatial search and efficiency rates as components of predation risk. *Proceedings Of The Royal Society B*, **279**, 4626–33.

DeCesare, N.J., Hebblewhite, M., Robinson, H.S. & Musiani, M. (2010) Endangered, apparently: The role of apparent competition in endangered species conservation. *Animal Conservation*, **13**, 353–362.

DeCesare, N.J., Hebblewhite, M., Schmiegelow, F., Hervieux, D., McDermid, G.J., Neufeld, L., Bradley, M., Whittington, J., Smith, K.G., Morgantini, L.E., Wheatley, M. & Musiani, M. (2012) Transcending scale dependence in identifying habitat with resource selection functions. *Ecological Applications*, **22**, 1068–83.

Deem, S.L., Karesh, W.B. & Weisman, W. (2001) Putting theory into practice: Wildlife health in conservation. *Conservation Biology*, **15**, 1224–1233.

Dickie, M., Serrouya, R., McNay, S. & Boutin, S. (2016) Faster and farther: Wolf movements on linear features and implications for hunting behaviour. *Journal of Applied Ecology*, **54**, 253–263.

Dyer, S., O'Neill, J., Wasel, S. & Boutin, S. (2001) Avoidance of industrial development by woodland caribou. *The Journal of Wildlife Management*, **65**, 531–542.

Edmonds, E. & Bloomfield, M. (1984) A study of woodland caribou (*Rangifer tarandus caribou*) in west-central Alberta, 1979-1983. *Alberta Energy and Natural Resources Fish and Wildlife Division*.

Environment Canada. (2012) Recovery strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal population, in Canada. *Species at Risk Act* Recovery Strategy Series. Environment Canada, Ottawa. xi+138pp.

Environment Canada. (2014) Recovery Strategy for the Woodland Caribou, Southern Mountain population (*Rangifer tarandus caribou*). *Species at Risk Act* Recovery Strategy Series. Environment Canada, Ottawa. viii+103pp.

Ewacha, M. (2016) Stress response of boreal woodland caribou, moose, and wolves to disturbance in eastern Manitoba. MSc thesis, University of Manitoba.

Festa-Bianchet, M., Ray, J.C., Boutin, S., Côté, S.D. & Gunn, A. (2011) Conservation of caribou (Rangifer tarandus) in Canada: an uncertain future. *Canadian Journal of Zoology*, **434**, 419–434.

Finnegan, L., Macbeth, B.J., Pigeon, K., Larsen, T., Schwantje, H. & Kutz, S. (2016) *Caribou Mortality and Disease Prevalence in West-Central Alberta*. Prepared for the Petroleum Technology Alliance of Canada and the Alberta Upstream Petroleum Research Fund.

Forde, T.L., Orsel, K., Zadoks, R.N., Biek, R., Adams, L.G., Checkley, S.L., Davison, T., Buck, J. De, Dumond, M., Elkin, B.T., Finnegan, L., Macbeth, B.J., Nelson, C., Niptanatiak, A., Sather, S., Schwantje, H.M., van der Meer, F. & Kutz, S.J. (2016) Bacterial genomics reveal the complex epidemiology of an emerging pathogen in arctic and boreal ungulates. *Frontiers in Microbiology*, **7**, 1–14.

GeoBC. (2009, 2016) Available from: http://www2.gov.bc.ca/gov/content/data/about-data-management/geobc

Gessler, P., Chadwick, O., Chamran, F., Althouse, L. & Holmes, K. (2000) Modeling soil-landscape and ecosystem properties using terrain attributes. *Soil Science Society of America Journal*, **64**, 2046–2056.

González-de-la-Vara, M. del R., Valdez, R.A., Lemus-Ramirez, V., Vázquez-Chagoyán, J.C., Villa-Godoy, A. & Romano, M.C. (2011) Effects of adrenocorticotropic hormone challenge and age on hair cortisol concentrations in dairy cattle. *Canadian Journal of Veterinary Research*, **75**, 216–221.

Government of Alberta. (2010) *Ranchers Guide to Predator Attacks on Livestock*. Available from: aep.alberta.ca

Graham, K. & Stenhouse, G.B. (2014) Home range, movements, and denning chronology of the grizzly bear (*Ursus arctos*) in west-central Alberta. *Canadian Field-Naturalist*, **128**, 223–234.

Gray, J.B. & Samuel, W.M. (1986) Parelaphostrongylus odocoilei (Nematoda: Protostrongylidae) and a protostrongylid nematode in woodland caribou (Rangifer tarandus caribou) of Alberta, Canada. *Journal of Wildlife Diseases*, **22**, 48–50.

Gustine, D.D., Barboza, P.S., Lawler, J.P., Adams, L.G., Parker, K.L., Arthur, S.M. & Shults, B.S. (2012) Diversity of nitrogen isotopes and protein status in caribou: implications for monitoring northern ungulates. *Journal of Mammalogy*, **93**, 778–790.

Gustine, D.D., Parker, K.L., Lay, R.J., Gillingham, M.P. & Heard, D.C. (2006) Calf survival of woodland caribou in a multi-predator ecosystem. *Wildlife Monographs*, **165**, 1–32.

Harvell, C.D., Mitchell, C.E., Ward, J.R., Altizer, S., Dobson, A.P., Ostfeld, R.S. & Samuel, M.D. (2002) Climate warming and disease risks for terrestrial and marine biota. *Science*, **296**, 2158–2162.

Hebblewhite, M. (2017) Billion dollar woodland caribou and the biodiversity impacts of the global oil and gas industry. *Biological Conservation*, **206**, 102–111.

Hebblewhite, M., Musiani, M., DeCesare, N., Hazenberg, S., Peters, W., Robinson, H. & Weckworth, B. (2010) *Linear Features, Forestry and Wolf Predation of Caribou and Other Prey in West Central Alberta.* Final Report to the Petroleum Technology Alliance of Canada (PTAC). 84 pp.

Hervieux, D., Hebblewhite, M., Decesare, N.J., Russell, M., Smith, K., Robertson, S. & Boutin, S. (2013) Widespread declines in woodland caribou (*Rangifer tarandus caribou*) continue in Alberta. *Canadian Journal of Zoology*, **91**, 872–882.

Hervieux, D., Hebblewhite, M., Stepnisky, D., Bacon, M. & Boutin, S. (2014) Managing wolves (*Canis lupus*) to recover threatened woodland caribou (*Rangifer tarandus caribou*) in Alberta. *Canadian Journal of Zoology*, **92**, 1029-1037.

Hins, C., Ouellet, J.P.P., Dussault, C. & St-Laurent, M.H.H. (2009) Habitat selection by forest-dwelling caribou in managed boreal forest of eastern Canada: Evidence of a landscape configuration effect. *Forest Ecology and Management*, **257**, 636–643.

Ho, T., Sato, H., Tazumi, A., Tsutsumi, N., Nagai, S., Iwata, A. & Nagano, T. (2012) Characterization of *Erysipelothrix rhusiopathiae* strains isolated from recent swine Erysipalas outbreaks in Japan. *Journal of Veterinary Medical Science*, **74**, 949–953.

Hoberg, E.P., Polley, L., Jenkins, E.J. & Kutz, S.J. (2008) Pathogens of domestic and free-ranging ungulates: global climate change in temperate to boreal latitudes across North America. *Revue scientifique et technique (International Office of Epizootics)*, **27**, 511–528.

Hosmer, D. & Lemeshow, S. (2005) *Applied Logistic Regression*. John Wiley & Sons, New York.

Hughes, J., Albon, S.D., Irvine, R.J. & Woodin, S. (2009) Is there a cost of parasites to caribou? *Parasitology*, **136**, 253–65.

Husseman, J.S., Murray, D.L., Power, G., Mack, C., Wenger, C.R., & Quigley, H. (2003) Assessing differential prey selection patterns between two sympatric large carnivores. *Oikos*, **101**, 591–601.

James, A.R.C., Boutin, S., Hebert, D.M. & Rippin, A.B. (2004) Spatial separation of caribou from moose and its relation to predation by wolves. *Journal of Wildlife Management*, **68**, 799–809.

James, A.R.C. & Stuart-Smith, A.K. (2000) Distribution of caribou and wolves in relation to linear corridors. *Journal of Wildlife Management*, **64**, 154–159.

Jenness, J. (2006) Topographic position index (tpi_jen.avx) extension for ArcView 3.x v. 1.3a. Available from: http://www.jennessent.com/arcview/tpi.htm.

Johnson, C.J., Ehlers, L.P.W. & Seip, D.R. (2015) Witnessing extinction - Cumulative impacts across landscapes and the future loss of an evolutionarily significant unit of woodland caribou in Canada. *Biological Conservation*, **186**, 176-186.

Jones, O.R., Pilkington, J.G. & Crawley, M.J. (2006) Distribution of a naturally fluctuating ungulate population among heterogeneous plant communities: ideal and free? *The Journal of Animal Ecology*, **75**, 1387–92.

Kays, R. & Wilson, D.E. (2009) *Mammals of North America*. Princeton University, Princeton, New Jersey.

Keay, J.M., Singh, J., Gaunt, M.C. & (2006) Fecal glucocoricoids and their metabolites as indicators of stress in various mammalian species: a literature review. *Journal of Zoo and Wildlife Medicine*, **37**, 234–244.

Kinley, T.A. & Apps, C.D. (2001) Mortality patterns in subpopulation caribou endangered mountain. *Wildlife Society Bulletin*, **29**, 158–164.

Knopff, K.H. (2010) *Cougar Predation in a Multi-Prey System in West-Central Alberta*. PhD thesis, University of Alberta.

Knopff, A.A. (2011) *Conserving Cougars in a Rural Landscape: Habitat Requirements and Local Tolerance in West-Central Alberta*. MSc thesis, University of Alberta.

Knopff, A.A., Knopff, K.H., Boyce, M.S. & St. Clair, C.C. (2014) Flexible habitat selection by cougars in response to anthropogenic development. *Biological Conservation*, **178**, 136–145.

Knopff, K.H., Knopff, A.A., Kortello, A. & Boyce, M.S. (2010) Cougar kill rate and prey composition in a multiprey system. *Journal of Wildlife Management*, **74**, 1435–1477.

Kortello, A., Hurd, T.E. & Murray, D.L. (2007) Interactions between cougars (*Puma concolor*) and gray wolves (*Canis lupus*) in Banff National Park, Alberta. *Ecoscience*, **14**, 214–222.

Kroshko, T., Kapronczai, L., Cattet, M.R.L., Macbeth, B.J., Stenhouse, G.B., Obbard, M.E. & Janz, D.M. (2017) Comparison of methanol and isopropanol as wash solvents for determination of hair cortisol concentration in grizzly bears and polar bears. *MethodsX*, **4**, 68–75.

Kutz, S., Ducrocq, J., Cuyler, C., Elkin, B., Gunn, A., Kolpashikov, L., Russell, D. & White, R. (2013) Standardized monitoring of Rangifer health during International Polar Year. *Rangifer Special Issue*, **33**, 91–114.

Kuzyk, G.W., Kneteman, J. & Schmiegelow, F.K.A. (2006) Pack size of wolves, Canis lupus, on caribou winter ranges in Westcentral Alberta. *The Canadian Field Naturalist*, **120**, 313–318.

Latham, A.D.M., Latham, M.C., Boyce, M.S. & Boutin, S. (2011a) Movement responses by wolves to industrial linear features and their effect on woodland caribou in northeastern alberta. *Ecological Applications*, **21**, 2854–2865.

Latham, A.D.M., Latham, M.C., McCutchen, N.A. & Boutin, S. (2011b) Invading white-tailed deer change wolf-caribou dynamics in northeastern Alberta. *The Journal of Wildlife Management*, **75**, 204–212.

Leblond, M., Dussault, C., Ouellet, J.P. & St-Laurent, M.H. (2016) Caribou avoiding wolves face increased predation by bears - Caught between Scylla and Charybdis. *Journal of Applied Ecology*, **53**, 1078–1087.

Leblond, M., Dussault, C. & Oullett, J.-P. (2013) Impacts of human disturbance on large prey species: do behavioral reactions translate to fitness consequences? *PloS ONE* **8(9)**.

Macbeth, B. (2013) *An Evaluation of Hair Cortisol Concentration as a Potential Biomarker of Long-Term Stress in Free-Ranging Grizzly Bears (Ursus Arctos), Polar Bears (Ursus Maritimius) and Caribou (Rangifer Tarandus Sp.).* PhD thesis, University of Saskatchewan.

Macbeth, B.J., Cattet, M.R.L., Stenhouse, G.B., Gibeau, M.L. & Janz, D.M. (2010) Hair cortisol concentration as a noninvasive measure of long-term stress in free-ranging grizzly bears (Ursus arctos): considerations with implications for other wildlife. *Canadian Journal of Zoology*, **88**, 935–949.

MacNearney, D., Pigeon, K., Stenhouse, G., Nijland, W., Coops, N. & Finnegan, L. (2016) Heading for the hills? Evaluating spatial distribution of woodland caribou in response to a growing anthropogenic disturbance footprint. *Ecology and Evolution*, **6**, 6484–6509.

Mastromonaco, G.F., Gunn, K., McCurdy-Adams, H., Edwards, D.B. & Schulte-Hostedde, A.I. (2014) Validation and use of hair cortisol as a measure of chronic stress in eastern chipmunks (*Tamias striatus*). *Conservation Physiology*, **2**, 1-12.

McCallum, H. & Dobson, A. (2002) Disease, habitat fragmentation and conservation. *Proceedings of the Royal Society B*, **269**, 2041-9.

McKay, T., Graham, K. & Stenhouse, G. (2014a) *Grizzly Bears and Pipelines: Response to Unique Linear Features.* Year 2 (2013) Final Report Alberta Upstream Petroleum Research Fund.

McKay, T., Sahlén, E., Støen, O.-G., Swenson, J.E. & Stenhouse, G.B. (2014b) Wellsite selection by grizzly bears Ursus arctos in west-central Alberta. *Wildlife Biology*, **20**, 310–319.

McKenzie, H.W., Merrill, E.H., Spiteri, R.J. & Lewis, M.A. (2012) How linear features alter predator movement and the functional response. *Interface focus*, **2**, 205–16.

McLoughlin, P.D., Dunford, J.S. & Boutin, S. (2005) Relating predation mortality to broad-scale habitat selection. *Journal of Animal Ecology*, **74**, 701–707.

McLoughlin, P.D., Dzus, E., Wynes, B. & Boutin, S. (2003) Declines in populations of woodland caribou. *Journal of Wildlife Management*, **67**, 755–761.

Mech, L.D. & Boitani, L. (2003) *Wolves. Behaviour, Ecology and Conservation*. University of Chicago Press, Chicago.

Muhly, T.B., Alexander, M., Boyce, M.S., Creasey, R., Hebblewhite, M., Paton, D., Pitt, J. a. & Musiani, M. (2010) Differential risk effects of wolves on wild versus domestic prey have consequences for conservation. *Oikos*, **119**, 1243–1254.

Natural Regions Committee. (2006) *Natural Regions and Subregions of Alberta.* Compiled by D.J. Downing and W.W. Pettapiece. Government of Alberta. Pub. No. T/852.

Natural Resources Canada. (2009) Earth Observation for Sustainable Development of Forests (EOSD) forest cover map. Available from: www.nrcan.gc.ca/forests/measuring-reporting/remote-sensing/13433

Nielsen, S.E., Boyce, M.S. & Stenhouse, G.B. (2004a) Grizzly bears and forestry I. Selection of clearcuts by grizzly bears in west-central Alberta, Canada. *Forest Ecology and Management*, **199**, 51–65.

Nielsen, S.E., Boyce, M.S., Stenhouse, G.B. & Munro, R.H.M. (2002) Modeling Grizzly Bear Habitats in the Yellowhead Ecosystem of Alberta: Taking Autocorrelation Seriously. *Ursus*, **13**, 45–56.

Nielsen, S., Cranston, J. & Stenhouse, G. (2009) Identification of Priority Areas for Grizzly Bear Conservation and Recovery in Alberta, Canada. *Journal of Conservation Planning*, **5**, 38–60.

Nielsen, S., McDermid, G., Stenhouse, G. & Boyce, M. (2010) Dynamic wildlife habitat models: Seasonal foods and mortality risk predict occupancy-abundance and habitat selection in grizzly bears. *Biological Conservation*, **143**, 1623–1634.

Nielsen, S.E., Munro, R.H.M., Bainbridge, E.L., Stenhouse, G.B., Boyce, M.S., & Roever, C.L. (2004b) Grizzly bears and forestry II. Distribution of grizzly bear foods in clearcuts of west-central Alberta, Canada. *Forest Ecology and Management*, **199**, 67–82.

Nielsen, S.E., Stenhouse, G.B. & Boyce, M.S. (2006) A habitat-based framework for grizzly bear conservation in Alberta. *Biological Conservation*, **130**, 217–229.

Nijland, W., N. C. Coops, D. Nielsen, and G. Stenhouse. 2015. Integrating optical satellite data and airborne laser scanning in habitat classification for wildlife management. *Journal of Applied Earth Observation and Geoinformation* 38:242–250.

Noss, R., Nielsen, S. & Vance-Borland, K. (2009) Prioritizing Ecosystems, Species, and Sites for Restoration. *Spatial Conservation Prioritization: Quantitative Methods and Computational Tools.* (eds A. Moilanen, K. Wilson & H. Possingham), pp. 158–171. Oxford University Press, London.

Peters, W., Hebblewhite, M., DeCesare, N., Cagnacci, F. & Musiani, M. (2012) Resource separation analysis with moose indicates threats to caribou in human altered landscapes. *Ecography*, **36**, 487–498.

Pigeon, K., Hornseth, M.L., MacNearney, D. & Finnegan, L. (2016a) *Analysis and Improvement of Linear Features to Increase Caribou Functional Habitat in West-Central and North-Western Alberta*. Final report prepared for FRIP OF-13-006, AUPRF 15-ERPC-01, BC OGRIS 15-04.

Pigeon, K.E., Stenhouse, G.B. & Côté, S.D. (2016b) Drivers of hibernation: linking food and weather to denning behaviour of grizzly bears. *Behavioral Ecology and Sociobiology*, doi: 10.1007/s00265-016-2180-5.

Pinard, V., Dussault, C., Ouellet, J.-P., Fortin, D. & Courtois, R. (2012) Calving rate, calf survival rate, and habitat selection of forest-dwelling caribou in a highly managed landscape. *The Journal of Wildlife Management*, **76**, 189–199.

Reynolds, H. V & Garner, G.W. (1986) Patterns of grizzly bear predation on caribou in northern Alaska. *International Conference of Bear Resource Management*, **7**, 59–67.

Robinson, H.S., Wielgus, R.B. & Gwilliam, J.C. (2002) Cougar predation and population growth of sympatric mule deer and white-tailed deer. *Canadian Journal of Zoology*, **80**, 556–568.

Roever, C.L., Boyce, M.S. & Stenhouse, G.B. (2008) Grizzly bears and forestry II: Grizzly bear habitat selection and conflicts with road placement. *Forest Ecology and Management*, **256**, 1262–1269.

Saher, D.J. & Schmiegelow, F.K. (2005) Movement pathways and habitat selection by woodland caribou during spring migration. *Rangifer*, **16**, 143–154.

Schwantje, H., J. Macbeth, B., Kutz, S. & Elkin, B. (2014) *British Columbia Boreal Caribou Health Program Progress Report: Year 1 (November 1, 2013 – December 31, 2014)*.

Schwantje, H., Macbeth, B., Kutz, S. & Elkin, B. (2016) *British Columbia Boreal Caribou Health Program*. Victoria, BC.

Serrouya, R., McLellan, B.N., Boutin, S., Seip, D.R. & Nielsen, S.E. (2011) Developing a population target for an overabundant ungulate for ecosystem restoration. *Journal of Applied Ecology*, **48**, 935–942.

Slater, S.C. (2013) *Woodland caribou conservation in Alberta: range delineation and resource selection*. MSc. Thesis, University of Alberta, Edmonton. 151 pp.

Smith, K.G., Ficht, E.J., Hobson, D., Sorensen, T.C. & Hervieux, D. (2000) Winter distribution of woodland caribou in relation to clear-cut logging in west-central Alberta. *Canadian Journal of Zoology*, **78**, 1433–1440.

Sorensen, T., McLoughlin, P.D., Hervieux, D., Dzus, E., Nolan, J., Wynes, B. & Boutin, S. (2008) Determining sustainable levels of cumulative effects for boreal caribou. *Journal of Wildlife Management*, **72**, 900–905.

Stewart, B., Nelson, T., Laberee, K., Nielson, S., Wulder, M. & Stenhouse, G. (2013) Quantifying grizzly bear selection of natural and anthropogenic edges. *The Journal of Wildlife Management*, **77**, 957–964.

Stotyn, S.A. (2008) Ecological interactions of mountain caribou, wolves and moose in the North Columbia Mountains, British Columbia. MSc. Thesis, University of Alberta, Edmonton.

Stotyn, S.A., Mclellan, B.N. & Serrouya, R. (2007) *Mortality Sources and Spatial Partitioning among Mountain Caribou, Moose, and Wolves in the North Columbia Mountains, British Columbia*. Prepared for: Columbia Basin Fish and Wildlife Compensation Program, Nelson, BC.

Therneau, T. (2015) A package for survival analysis in S. version 2.38. Available from: http://cran.r-project.org/package=survival.

van Rensen, C.K., Nielsen, S.E., White, B., Vinge, T. & Lieffers, V.J. (2015) Natural regeneration of forest vegetation on legacy seismic lines in boreal habitats in Alberta's oil sands region. *Biological Conservation*, **184**, 127–135.

Wang, Q., Chang, B. & Riley, R. (2010) *Erysipelothrix rhusiopathiae*. *Veterinary Microbiology*, **140**, 405–417.

Whittington, J., Hebblewhite, M., DeCesare, N.J., Neufeld, L., Bradley, M., Wilmshurst, J. & Musiani, M. (2011) Caribou encounters with wolves increase near roads and trails: a time-to-event approach. *Journal of Applied Ecology*, **48**, 1535–1542.

Whittington, J., St.Clair, C.C. & Mercer, G. (2004) Path Tortuosity and the Permeability of Roads and Trails to Wolf Movement. *Ecology and Society*, **9**.

Whittington, J., St.Clair, C. & Mercer, G. (2005) Spatial responses of wolves to roads and trails in mountain valleys. *Ecological Applications*, **15**, 543–553.

Wittmer, H.U., Mclellan, B.N., Seip, D.R., Young, J.A., Kinley, T.A., Watts, G.S. & Hamilton, D. (2005a) Population dynamics of the endangered mountain ecotype of woodland caribou (Rangifer tarandus caribou) in British Columbia , Canada. *Canadian Journal of Zoology*, **83**, 407–418.

Wittmer, H.U., McLellan, B.N., Serrouya, R. & Apps, C.D. (2007) Changes in landscape composition influence the decline of a threatened woodland caribou population. *The Journal of Animal Ecology*, **76**, 568–579.

Wittmer, H.U., Sinclair, A.R.E. & McLellan, B.N. (2005b) The role of predation in the decline and extirpation of woodland caribou. *Oecologia*, **144**, 257–267.

Zager, P. & Beecham, J. (2006) The role of American black bears and brown bears as predators on ungulates in North America. *Ursus*, **17**, 95–108.