

Recovery of southern mountain caribou (*Rangifer tarandus caribou*) habitat following wildfire in Ulkatcho territory, British Columbia, Canada

By

Olivier Bélanger-Jumeau

Bachelor of Arts, Thompson Rivers University, 2023

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of

MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCES

in the Department of Sciences

Thesis examining committee:

Jill Harvey (PhD), Research Chair and Thesis Supervisor, Faculty of Science

Emily Studd (PhD), Committee Member, Faculty of Science

Karl Larsen (PhD), Committee Member, Faculty of Science

Adam Ford (PhD), Committee Member, Faculty of Science, the University of British Columbia

© Olivier Bélanger-Jumeau, 2025

Thompson Rivers University

All rights reserved. This thesis may not be reproduced in whole or in part, by
photocopy or other means, without the permission of the author.

ABSTRACT

Southern mountain caribou (SMC) are a threatened ecotype of woodland caribou (*Rangifer tarandus caribou*) that depend on mature conifer forests for winter lichen forage. SMC inhabit mountainous regions of central and south-eastern British Columbia (BC) and are some of the most southerly distributed caribou in the world, resulting in high exposure to human-caused habitat disturbance since colonial settlement of Canada. Caribou in this group have also coexisted with natural disturbances such as wildfire for millennia, however recent shifts in fire regimes towards larger and more frequent wildfires pose a significant threat to these herds. Given the recent success of caribou recovery strategies that integrate Traditional Ecological Knowledge with Western scientific tools, there is a growing need to combine these knowledge systems to improve our understanding of caribou–fire–habitat dynamics. In west-central BC, the Ulkatcho people have coexisted with whudzih (caribou) for millennia, developing deep relational ties with local herds. In recent decades however, all four herds in Ulkatcho territory have declined, with increasing wildfire activity a growing concern among the Ulkatcho community. Nearly one-third of caribou range in Ulkatcho has burned since 2000, raising questions about the ability of important habitat to recover and the long-term future of caribou in the region. This thesis investigates two interrelated research questions led by Ulkatcho First Nation: (1) How long does it take for winter caribou habitat to recover following wildfire in lodgepole pine (*Pinus contorta*) forests? and (2) How does wildfire influence the ecological interactions between caribou and sympatric herbivores such as moose (*Alces alces*) and bears (*Ursus arctos horribilis* and *Ursus americanus*)? To address these questions, I conducted a field-based study across five stand-replacing fires in Ulkatcho territory, representing a 90-year history of post-fire habitat recovery. Using a combination of Traditional Ecological Knowledge, lichen and vegetation surveys, tree-

ring and stand structure analysis, and geospatial methods, I quantified post-fire trajectories of winter habitat recovery and dietary niche between caribou and other herbivores and predators. Chapter 2 presents the results of Bayesian hurdle models that estimates the earliest point of stand-level terrestrial lichen recovery to occur at 59 years after fire, and the recovery of high-quality forage sites, identified through a "Think Like A Caribou" approach, to occur at 74 years after fire. Arboreal lichens of the *Bryoria* genus had established in lodgepole pine stands as early as 40 years after stand-replacing fire, although not at suitable loadings to support caribou. Despite lichen recovery occurring within 60 years of fire, regenerating lodgepole pine stands remained up to eight times denser than forest structure of known caribou habitat selection, with stem densities only approaching suitable levels for caribou after 100 years of prolonged self-thinning. Overly dense stands limit the ability of caribou to access forage and detect and avoid predators. These findings suggest that stem density, alongside lichen abundance, may be a key limiting factor for the recovery of winter habitat in these forests. Chapter 3 explores the effect of wildfire on differences in the dietary niches between caribou and sympatric herbivores, including moose (*Alces alces*), black bears (*Ursus americanus*), and grizzly bears (*Ursus arctos*). Using Principal Coordinates Analysis and species-specific forage models, I found that early post-fire seral stages (<20 years) displayed increased overlap in dietary niche between caribou, moose and bears, potentially influencing apparent competition interactions in the study area. Moose responded positively to early-seral conditions and showed greater habitat use in recently burned areas, including at the calving ground of the Itcha-Ilgachuz caribou herd. Overlap in dietary niche between caribou and black bears, a species that caribou calving grounds may not have adapted to, was also greater in recent burns (<20 years). At the same time however, an 18-year-old burn near the Itcha-Ilgachuz calving grounds was found to have high observed presence of

key summer caribou forage, namely willow (*Salix* spp.), blueberries (*Vaccinium* spp.), and graminoids, although these same forage species may also attract moose and predators, potentially offsetting any benefit through increased predation risk. This thesis helps guide the Ulkatcho First Nation's management of caribou in an increasingly uncertain future. These findings demonstrate that caribou habitat recovery in lodgepole pine forests takes many decades and is shaped not just by the availability of lichens but also by stand structure, in particular stem density. By centering Indigenous knowledge and using caribou-centric models to assess habitat, this work supports more holistic approaches to understanding caribou, their habitat, and their ability to adapt to rapidly changing fire regimes.

PREFACE

The Indigenous knowledge shared in this thesis, and now passed onto readers, comes with a responsibility to appreciate and understand the appropriate use of this information. Ulkatcho Elders and knowledge holders have offered key elements of their knowledge to help readers understand the importance of the relationship between caribou and people in Ulkatcho territory, and why looking after caribou and the land is essential to preserving Ulkatcho culture.

The following members of Ulkatcho First Nation have contributed their knowledge to this thesis: Corinne Cahoose, George Leon, Bella Leon, Jallie Jack, Maureen Sill, Gary Holte, Leona Toney, Alyisha Knapp, Nora Brubaker, Danny Cahoose, Gertie Capoose, Carolyn Cahoose, Douglas Sill, Glen Cahoose, Tina Alexis, Mike Holte, “Sh’boom” Allan Louie, Matthew Cahoose, Mabelene Leon, Evan Cahoose and Graham West.

We affirm that the Ulkatcho First Nation have intellectual property rights to their oral traditions, oral histories, and their knowledge. Meetings with Ulkatcho First Nation Elders and community members were approved by Thompson Rivers University’s Research Ethics Board, study #103885.

TABLE OF CONTENTS

Abstract.....	iii
Preface.....	vi
Table of Contents.....	vii
Acknowledgements.....	ix
List of Figures	x
List of Tables	xii
Chapter 1: Introduction	1
References	10
Chapter 2: Caribou winter habitat recovery following wildfire in lodgepole pine forests in Ulkatcho territory, west-central British Columbia, Canada.....	14
Abstract	14
Introduction	16
Methods	25
Results	35
Discussion	45
Conclusion	53
References	55
Chapter 3: Recovery of caribou and sympatric herbivore forage following wildfire in Ulkatcho territory, west-central British Columbia, Canada	66
Abstract	66
Introduction	68
Methods	74
Results	83
Discussion	97
Conclusion	105
References	111

Chapter 4: Conclusion	120
References	126

ACKNOWLEDGEMENTS

This thesis is the product of many people's hard work and dedication, and I extend sincere gratitude to everyone who has supported this project. Thank you to the Elders and members of Ulkatcho First Nation for welcoming me to your community and teaching me about the history of your land, people and caribou. I hope these chapters reflect my deep respect for the knowledge that was shared with me, and for the relationships between people and caribou in Ulkatcho that continue to this day. Special thanks to Alyisha Knapp and Craig Waythomas for their continued support throughout this project, from our first meeting in September, 2023, and earlier. It has been a privilege to work with Ulkatcho First Nation on this research.

Thank you to all research assistants who joined me during fieldwork in the summer and fall of 2024. In no particular order, I thank Mike Reeder, Courtenay Campbell, Keira Holte, Sarah McIntyre, Andrea Robinson, Alyna Huss, Ethan Furlong, Lewis McKnight, Steffen Masaites, Tristan Jumeau, Philippe Jumeau, Matt Surgeonor, Graham West, and Craig Waythomas. Friendships and memories made in this period will stay with me for a lifetime.

Thank you to Dr. Emily Studd and Dr. Adam Ford for their guidance over the last two years, and to the countless other conversations I have had with professors and caribou biologists across Canada and the United States throughout this thesis. Your time and willingness to share your knowledge have been invaluable in shaping the direction of this work. I extend a special thank you to my supervisor, Dr. Jill Harvey, for her continued faith in me and for creating the space for me to grow as a scientist and as a person. I will look back on this time with fondness and inspiration for many years to come.

Lastly, thank you to my parents for their unwavering support of my dreams and ambitions, and to my brother for being the friend and role model that he is.

LIST OF FIGURES

Figure 1: The locations and ranges of the four Southern Mountain Caribou (whudzih, <i>Rangifer tarandus caribou</i>) herds in Ulkatcho territory, west-central British Columbia.....	20
Figure 2: The relational network between lodgepole pine (chundoo, <i>Pinus contorta</i>), arboreal and terrestrial lichen, caribou (whudzih, <i>Rangifer tarandus caribou</i>) and the Ulkatcho people in Ulkatcho territory, west-central British Columbia.....	23
Figure 3: Diagram of field plot layout used to characterize lichen abundance, stand structure and understorey plant composition at burned and unburned sites in Ulkatcho territory, west-central British Columbia.....	28
Figure 4: Generalized Additive Models and Generalized Linear Models showing the response of vascular plant competition, moss competition, canopy cover and live large tree basal area over time-since-fire following stand-replacing wildfire in lodgepole pine (chundoo, <i>Pinus contorta</i>) forests in Ulkatcho territory, west-central British Columbia.....	38
Figure 5: The estimated recovery trajectory of stand-level terrestrial caribou (whudzih, <i>Rangifer tarandus caribou</i>) forage lichens following stand-replacing wildfire in lodgepole pine (chundoo, <i>Pinus contorta</i>) forests in Ulkatcho territory, west-central British Columbia.....	40
Figure 6: The estimated recovery trajectory of high-quality caribou forage sites of terrestrial lichens following stand-replacing wildfire in lodgepole pine (chundoo, <i>Pinus contorta</i>) forests in Ulkatcho territory, west-central British Columbia.....	41
Figure 7: The proportion of arboreal lichen abundance classes recorded at five historical stand-replacing wildfires Ulkatcho territory, west-central British Columbia.....	42
Figure 8: Stems per hectare of lodgepole pine (chundoo, <i>Pinus contorta</i>) stands following stand-replacing wildfire in Ulkatcho territory, west-central British Columbia.....	43
Figure 9: Photographic comparison of an unburned lodgepole pine (chundoo, <i>Pinus contorta</i>) stand aged 149.3 years with a stem density of 1141 stems per hectare and a lodgepole pine stand 63 years after stand-replacing fire with a stem density of 9125 stems/ha in Ulkatcho territory, west-central British Columbia.....	44
Figure 10: The locations and ranges of the four Southern Mountain Caribou (whudzih, <i>Rangifer tarandus caribou</i>) herds in Ulkatcho territory, west-central British Columbia.....	76
Figure 11: Principal Coordinates Analysis using Jaccard distance of dietary similarity across ‘all seasons’, ‘winter’, and ‘summer’ between caribou (whudzih, <i>Rangifer tarandus caribou</i>) and moose (duni, <i>Alces alces</i>), black bears (sus, <i>Ursus americanus</i>) and grizzly bears (shas, <i>Ursus arctos horribilis</i>) in Ulkatcho territory, west-central British Columbia.....	86

Figure 12: Dietary niche overlap over time-since-fire between caribou (whudzih, <i>Rangifer tarandus caribou</i>) and moose (duni, <i>Alces alces</i>), black bear (sus, <i>Ursus americanus</i>) and grizzly bear (shas, <i>Ursus arctos horribilis</i>) following stand-replacing wildfire in Ulkatcho territory, west-central British Columbia.....	89
Figure 13: Key plants driving high forage similarity between caribou and sympatric herbivores at recent burns (<20 years) in Ulkatcho territory, west-central British Columbia.....	90
Figure 14: Probability of presence of key plant forage for caribou, moose, black bear and grizzly bear over time since fire following stand-replacing wildfire in Ulkatcho territory, west-central British Columbia.....	92
Figure 15: Predicted probability of presence of caribou (whudzih, <i>Rangifer tarandus caribou</i>) winter lichen forage following stand-replacing wildfire in Ulkatcho territory, west-central British Columbia.....	95
Figure 16: Probability of moose pellet presence over time-since-fire following stand-replacing fire in Ulkatcho territory, west-central British Columbia.....	96

LIST OF TABLES

Table 1: Summary of site characteristics at each sampled historical fire in Ulkatcho territory, west-central British Columbia.....	27
Table 2: Hurdle model summary of the covariates affecting terrestrial lichen presence and abundance after stand-replacing wildfire in Ulkatcho territory.....	37
Table 3: Summary of site characteristics at each sampled historical fire in Ulkatcho territory, west-central British Columbia.....	77
Table 4: Summary of Jaccard dissimilarity scores between the dietary niche of caribou and moose, black bear and grizzly bear in Ulkatcho territory, west-central British Columbia.....	85
Table 5: Summary of Jaccard dissimilarity results between caribou and sympatric herbivores at each historical fire site.....	89
Table 6: Summary of Wald results of the effect of time since fire on the probability of presence of key plant forage for caribou, moose, black bear and grizzly bear in Ulkatcho territory, west-central British Columbia.....	94
Table 7: Summary of Wald results for the effect of time since fire on the likelihood of presence of winter caribou forage found in Ulkatcho territory, west-central British Columbia.....	95

CHAPTER 1: Introduction

Southern mountain caribou (*Rangifer tarandus caribou*)

Southern mountain caribou (SMC) are a threatened population of woodland caribou (*Rangifer tarandus caribou*) that occupy montane forests and alpine areas of central and south-eastern British Columbia (BC) and south-west Alberta, Canada. Caribou in this group rely on mature conifer forests in winter where arboreal and terrestrial lichens grow in abundance and where deep snowpacks facilitate the avoidance of predators, especially wolves (*Canis lupus*) (Environment Canada, 2014). In summer, SMC often select alpine tundra as their preferred habitat, where elevational separation from wolves and bears (*Ursus arctos horribilis*, grizzly bear and *Ursus americanus*, black bear) support lactating females and the survival of neonate calves (Bergerud *et al.*, 1984).

Such is the dependence of caribou on extensive and intact landscapes; SMC act as an umbrella species that support the ecological integrity of montane ecosystems (Environment Canada, 2014). At a species level, caribou provide food for grizzly bears and wolverines (*Gulo gulo*), two species of Special Concern in BC. At a systems level, the conservation of caribou habitat protects numerous other species that are sensitive to habitat change, such as fisher (*Pekania pennanti*, Blue-listed) and mountain goats (*Oreamnos americanus*). Alongside their ecological significance, SMC have provided local First Nation Peoples with food, clothing, tools and oral tradition since time immemorial. Many First Nations have stewarded SMC herds and their habitat for millennia, developing deep relational ties with caribou that cannot be fully understood by Western knowledge systems (Parlee and Caine, 2018). Since colonial settlement of North America, caribou across their range have endured sustained population decline and regional extirpation (Bergerud, 1974).

Due to their southern distribution, SMC are exposed to high levels of human-caused landscape disturbance, such as logging, oil and gas development, alpine recreation and the construction of roads and hydroelectric dams (Lamb *et al.*, 2025). Population declines among SMC are thought to be related to these disturbances and the subsequent loss and fragmentation of important habitat (Johnson *et al.*, 2015). Tied to this habitat change are increased levels of apparent competition from moose (*Alces alces*) and other ungulates such as elk (*Cervus canadensis*). Although caribou and moose co-exist naturally, the disturbance of mature forests to early seral stages can support greater densities of moose and elk, which in turn can support greater densities of wolves, bears, and mountain lions (*Puma concolor*) (Hebblewhite *et al.*, 2007; Ehlers *et al.*, 2016). In this multiple predator – multiple prey interaction, caribou are more vulnerable to decline due to their typically lower reproductive rate (Bergerud, 1974), a function of female caribou reaching reproductive maturity later than moose (Schwartz, 1992; Bergerud, 2000) and almost exclusively giving birth to single offspring (Bergerud, 1996), whereas moose may calve twins under suitable conditions (Schwartz, 1997).

Although increases in predator abundance affect caribou adults, greater predation pressure can be particularly detrimental to the survival of calves (Gustine *et al.*, 2006). In many SMC herds, the proportion of calves surviving their first 10 months (recruitment rate) often falls below the level required for natural replacement (15%; Caribou Recovery Program, 2023), largely due to predation. Because of this, many management strategies attempt to reduce predation pressure to increase the recruitment of calves. In north-eastern BC, the West Moberly and Salteau First Nations prevented the collapse of the nearly extirpated Klinse-Za population through a combination of maternity pens - where females are brought to a secure area to calve away from wolves and bears - and wolf reductions. This combined approach recovered herd numbers from 38

in 2013 to 101 in 2021, securing the possibility of traditional harvesting practices for future generations (Lamb *et al.*, 2022). In early 2025, Parks Canada opened a caribou breeding facility in Jasper National Park that permanently houses females from the Brazeau and Tonquin herds with the goal of annually releasing captive-born calves. Such intense management approaches highlight the desperate current state of SMC populations, although recent shifts towards Indigenous-led caribou management have proven successful (Lamb *et al.*, 2022).

Combining Indigenous and Western approaches in caribou management

Prior to recent shifts towards more Indigenous-led recovery strategies, many efforts to recover caribou were led by government working groups and biologists. These attempts often revolved around the translocation of caribou from more-stable northern herds to rapidly declining herds in the south, such as the now-extirpated South Selkirk, Purcells-South and Columbia South populations (Kinley, 2010). These translocations experienced mixed success and involved only small amounts of engagement with local Indigenous Peoples.

Although Western science brings useful tools for monitoring caribou populations - such as habitat modelling, population estimates and genetic sampling - the integration of Indigenous knowledge systems is critical to effective caribou management (Parlee and Caine, 2018). Strategies like the Klinse-Za project included Traditional Ecological Knowledge from the West Moberly and Salteau First Nations alongside the expertise of leading caribou biologists to successfully prevent population collapse (Lamb *et al.*, 2021). Importantly, the inclusion of Indigenous Guardians, Elders and youth in recovering the Klinse-Za caribou allowed for the intergenerational transmission of knowledge, helping to preserve traditional practices for future generations of West Moberly and Salteau First Nations.

Due to the sheer dominance of Western scientific approaches however, and the prevalence of the English language in Canada, Indigenous knowledge systems can become overpowered in colonial research, even when attempts are made to treat both knowledge systems as equal. Efforts to incorporate multiple knowledge systems must therefore be both genuine and respectful (Bartlett *et al.*, 2012), and recognize inherent biases towards Western knowledge systems and language.

Wildfire in high-elevation forests in British Columbia

High-elevation forests in west-central and south-east BC consist of the following biogeoclimatic ecosystem classification (BEC) zones (Meidinger and Pojar 1991); Engelmann Spruce–Subalpine Fir (ESSF): dominates subalpine forests from 1500 to 2200 meters and is characterized by cold, snowy winters and short, cool summers. The dominant tree species in this zone are Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) with some whitebark pine (*Pinus albicaulis*), and, in very dry areas, lodgepole pine (*Pinus contorta*); Montane Spruce (MS): occupies mid- to high-elevation sites from 900 to 1500 meters, often below the ESSF. It is frequently dominated by hybrid spruce (*Picea glauca* × *engelmannii*) and lodgepole pine (*Pinus contorta*); Alpine Tundra (AT): lies above treeline and lacks continuous forest cover. This zone consists primarily of low-growing shrubs, grasses, sedges, and lichens, with sparse or no tree cover. Subalpine fir and whitebark pine may occur as stunted krummholz near the treeline.

Wildfire regimes often vary across each of these BEC zones. In the ESSF, wildfires are infrequent but typically severe, with return intervals of 200 to 500 years (Veblen, 1991; Wong *et al.*, 2003). These high-intensity, stand-replacing fires are driven by fuel accumulation and play an important role in resetting forest succession. The MS zone exhibits a mixed-severity fire regime

with return intervals of up to 80 years (Baron *et al.*, 2022), reflecting a relatively warmer and drier climate. Fires in this zone range from low-intensity surface burns to occasional crown fires. In contrast, the AT zone experiences very rare or absent fire activity due to sparse vegetation, thin soils, and harsh climatic conditions.

In recent decades, notable shifts in the fire regimes of high-elevation forests have occurred across western Canada (Parisien *et al.*, 2023; Maslowski, 2024), largely driven by climate change, historical fire suppression, and increased human activity. Warmer temperatures, reduced snowpack, and prolonged droughts have led to longer fire seasons and more frequent, severe wildfires, disrupting historical fire return intervals. As a result, montane forests are expected to experience more unpredictable and extreme fire events, presenting new challenges for the wildlife species that depend upon them.

Wildfire and southern mountain caribou

Given the natural occurrence of wildfires in high-elevation forests in western Canada, it is probable that SMC have co-existed with fire for millennia (Bergerud, 1974; Klein, 1982), adapting to the relatively long return intervals in these forests. In the ESSF zone, where fire return intervals historically exceeded 100-200 years, fires create a mosaic of forest ages, of which SMC use late-successional patches with high terrestrial and arboreal lichen abundance in winter (Environment Canada, 2014). In spring and summer, caribou may capitalize on the emergence of protein-rich vascular plants that grow shortly following fire, at a time when their diets shift from predominantly lichens to a diverse range of shrubs, grasses and sedges (Apps and Dodd, 2017). The availability of these vascular plants enables caribou to meet the substantial increase in energy and protein demands that occur in the summer months, especially for

parturient and lactating females (K. Denryter, personal communication, 2025). The patchy, infrequent nature of historical fires in the high-elevation forests likely maintained the spatial and temporal continuity of both winter and summer habitat, allowing caribou to move between suitable areas as stand structure changed over time.

However, the future relationship between wildfire and SMC is less certain. Increasing frequency, size, and severity of wildfires, in combination with widespread logging, may accelerate the loss of mature forests, fragment remaining habitat, and shorten the time available for lichen-rich forests to establish. Considerable research also indicates that moose respond positively to the early seral conditions that result after fire and logging (Loranger *et al.*, 1991; Maier *et al.*, 2005; Joly *et al.*, 2016; Mumma *et al.*, 2024), thus adding further challenges to caribou in the form of increased apparent competition and predator densities. As a result, more frequent fire events, combined with human-mediated disturbance and increased predation pressures, may outpace the ability of caribou habitat, and subsequently caribou, to recover. If trends in wildfire activity in western Canada continue (Parisien *et al.*, 2023), the fire regimes that once maintained caribou habitat may become a threat, jeopardizing the survival of endangered SMC. Should caribou in the southern mountain population disappear, the loss to First Nation Peoples and culture would be irrevocable, marking the end of a relationship between humans and caribou that has endured for countless generations. Given that caribou display high fidelity to traditional habitat and migration routes, guided by herd memory and the social transmission of knowledge from older individuals, once these herds are lost, recovery to historic ranges is unlikely.

Ulkatcho people, land and caribou

The Ulkatcho First Nation (UFN) is a community of the Dakelh (Southern Carrier) Nation located in the Chilcotin Plateau of west-central BC. The term "Ulkatcho" derives from a Dakelh translation meaning "fat of the land", reflecting the historical abundance of fish and game in Ulkatcho territory, particularly around Gatcho Lake. Prior to colonization, Ulkatcho Village at Gatcho Lake was an important trading and potlatch center, located at the junction of major trails connecting the Fraser River, the Central Coast, and the Chilcotin Plateau. Seasonal potlatch houses at Gatcho Lake and Nagwuntl'oo in Anahim Lake served as gathering sites for trade, ceremony, and social exchange. These gatherings were also key for the organization of caribou hunts, which required the involvement of many families to construct drift fences, herd caribou and process meat. Since time immemorial, caribou have held immeasurable importance to Ulkatcho people and culture. Corinne Cahoose, a member of UFN, describes how "the caribou story ties us to the land. Years ago...our nations relied on caribou for the meat and hide for the clothing. Caribou were plentiful, herds after herd. It is a sad history of our people and our caribou."

Over the past three generations, all four caribou herds in Ulkatcho¹ have declined (Caribou Recovery Program, 2023). The Ulkatcho people attribute this decline to a culmination of predation, primarily from yus (wolves), shas (grizzly bears), sus (black bears) and booscho (mountain lion), and habitat change, caused by logging, pine beetle, ranching and wildfire.

¹The term *Ulkatcho* can be used to describe both the people of Ulkatcho, and the land in Ulkatcho territory.

Many UFN members also note how the abundance of moose increased in Ulkatcho during the early 20th century, with Corinne Cahoose explaining how “years ago, according to my ancestors, moose came after caribou. Caribou were here before the moose”.

The majority of forests in Ulkatcho lie above 1000m. These forests typically form part of the MS zone up to 1600m and the ESSF zone from 1600m to the treeline, where AT becomes prevalent. Despite this, due to the dry climate in the region, the vast majority of stands in Ulkatcho are dominated by chundoo (lodgepole pine, often called jackpine by the Ulkatcho people). These dry lodgepole pine forests provide caribou with terrestrial and arboreal lichens in winter, and likely experience high-severity, stand-replacing wildfire every 75-125 years, with stands at lower elevation more prone to disturbance. Like many regions in western Canada however, the frequency of fires in Ulkatcho appears to be changing. Between 2000 and 2023, 32% of caribou range in Ulkatcho burned, compared to 6.5% in the 80 years between 1919 and 1999 (Canadian National Fire Database, n.d; Appendix 1). Given the decline in caribou in Ulkatcho over the past century, recent changes in fire activity have become a concern for many Ulkatcho people. Specifically, two key questions have become increasingly pertinent for the community:

1. How long does it take for winter caribou habitat in lodgepole pine forests to recover after fire? (Chapter 2)
2. How does fire affect the dynamic between caribou and moose in Ulkatcho territory? (Chapter 3)

To answer these questions, I performed a field-based study across Ulkatcho territory that combined Ulkatcho ecological knowledge with quantitative measurements of caribou habitat and forage recovery. Coupled with GIS mapping and tree-ring analysis at a laboratory at Thompson

Rivers University in Kamloops, BC, two studies were conducted to address my research questions. Chapter 2 answers the first question above and is formatted as a manuscript for a planned submission as an original research article to an academic journal yet to be decided. Chapter 3 answers the second research question and is also formatted as a manuscript for a planned submission as an original research article to an academic journal yet to be decided. To summarize the outcomes of both studies, Chapter 4 discusses the main contributions of my thesis.

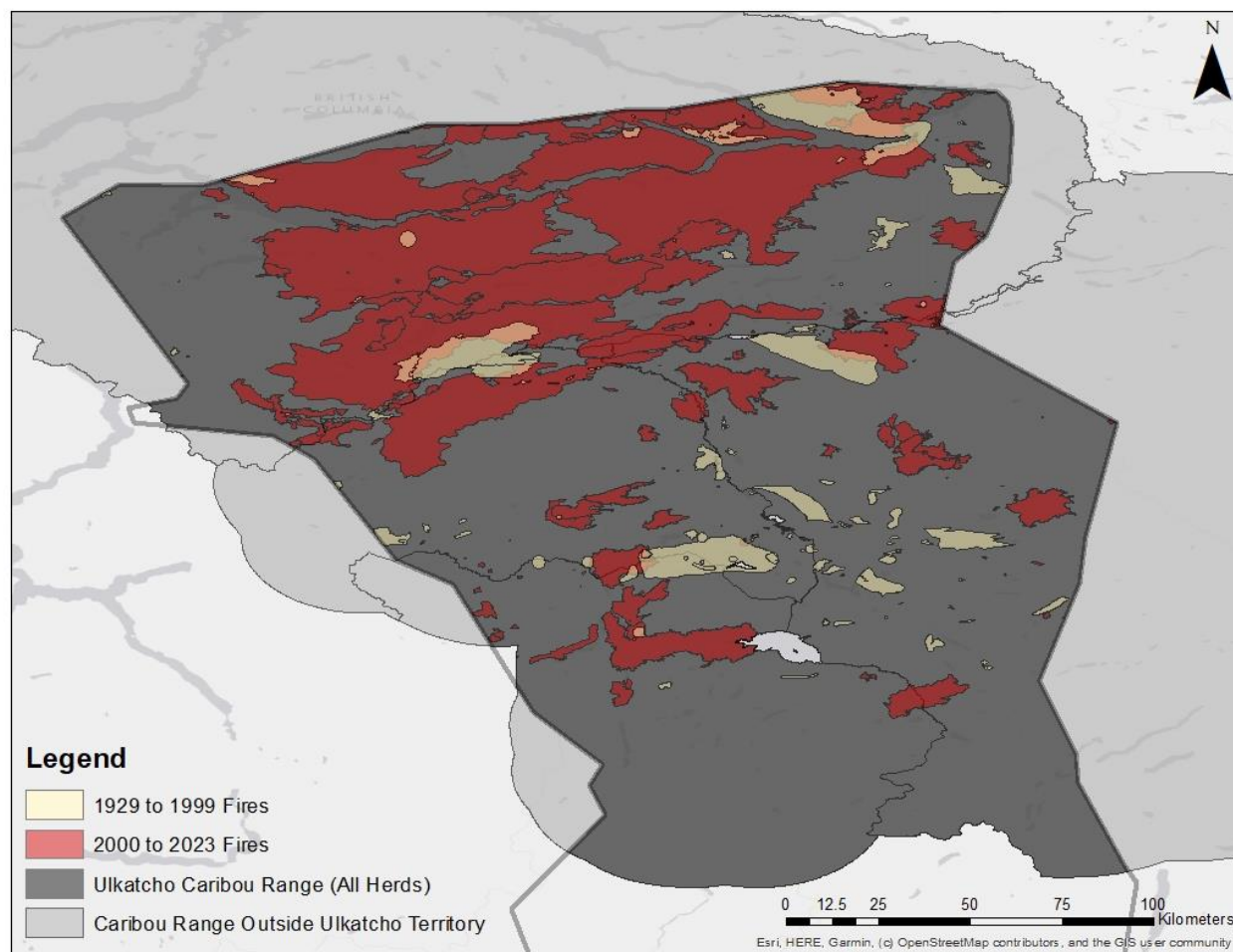
References

- Apps, C., & Dodd, N. (2017). Caribou habitat modelling and evaluation of forest disturbance influences across landscape scales in west-central BC. Ministry of Forests, Lands and Natural Resource Operations.
- Baron, J. N., Gergel, S. E., Daniels, L. D., & Hessburg, P. F. (2022). A century of transformation: Fire regime transitions from 1919 to 2019 in southeastern British Columbia, Canada. *Landscape Ecology*. <https://doi.org/10.1007/s10980-022-01506-9>
- Bartlett, C., Marshall, M., & Marshall, A. (2012). Two-Eyed Seeing and other lessons learned within a co-learning journey of bringing together Indigenous and Western knowledges. *Journal of Environmental Studies and Sciences*, 2(4), 331–340. <https://doi.org/10.1007/s13412-012-0086-8>
- Bergerud, A. T. (1974). Decline of caribou in North America following settlement. *Journal of Wildlife Management*, 38(4), 757–770. <https://doi.org/10.2307/3800042>
- Bergerud, A. T., Butler, H. E., & Miller, D. R. (1984). Antipredator tactics of calving caribou: Dispersion in mountains. *Canadian Journal of Zoology*, 62(8), 1566–1575. <https://doi.org/10.1139/z84-230>
- Caribou Recovery Program. (2023). 2023 status of BC caribou herds. https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/bc_caribou_herds_population_estimates.pdf
- Ehlers, L. P., Johnson, C. J., & Seip, D. R. (2016). Evaluating the influence of anthropogenic landscape change on wolf distribution: Implications for woodland caribou. *Ecosphere*, 7(12), e01600. <https://doi.org/10.1002/ecs2.1600>
- Environment Canada. (2014). Recovery strategy for the woodland caribou, Southern Mountain population (*Rangifer tarandus caribou*) in Canada. https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/rs_woodland%20caribou_bois_s_mtn_0614_e.pdf
- 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), 1–32. [https://doi.org/10.2193/0084-0173\(2006\)165\[1:CSOWCI\]2.0.CO;2](https://doi.org/10.2193/0084-0173(2006)165[1:CSOWCI]2.0.CO;2)
- Hebblewhite, M., Whittington, J., Bradley, M., Skinner, G., Dibb, A., & White, C. A. (2007). Conditions for caribou persistence in the wolf-elk-caribou systems of the Canadian Rockies. *Rangifer*, 27(4), 35–50. <https://doi.org/10.7557/2.27.4.322>
- 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. <https://doi.org/10.1016/j.biocon.2015.03.012>
- Joly, K., Chapin, F. S., & Klein, D. R. (2016). Winter habitat selection by moose in a northern boreal forest in Alaska: Effects of landscape composition and structure. *Forest Ecology and Management*, 366, 51–59. <https://doi.org/10.1016/j.foreco.2016.02.004>

- Kinley, T. A. (2010). Augmentation plan for the Purcells-South mountain caribou population. British Columbia Ministry of Environment. Retrieved from https://www.env.gov.bc.ca/wld/speciesconservation/mc/files/Augmentation_Plan_for_the_Purcell_South_Population.pdf
- Klein, D. R. (1982). Fire, lichens, and caribou. *Journal of Range Management*, 35(3), 390–395. <https://doi.org/10.2307/3898658>
- Lamb, C. T., Williams, S., Boutin, S., Bridger, M., Cichowski, D., Cornhill, K., DeMars, C., Dickie, M., Ernst, B., Ford, A., Gillingham, M. P., Greene, L., Heard, D. C., Hebblewhite, M., Hervieux, D., Klaczek, M., McLellan, B. N., McNay, R. S., Neufeld, L., & Serrouya, R. (2024). Effectiveness of population-based recovery actions for threatened southern mountain caribou. *Ecological Applications*, 34(4), e2965. <https://doi.org/10.1002/eap.2965>
- Lamb, C. T., Steenweg, R., Serrouya, R., Hervieux, D., McNay, R. S., Heard, D. C., McLellan, B. N., Shores, C., Palm, E., Giguere, L., Hubner, J., Polfus, J., Klaczek, M., Crosland, N., White, S., Russell, M., & Ford, A. T. (2025). The erosion of threatened southern mountain caribou migration. *Global Change Biology*. <https://doi.org/10.1111/gcb.17095>
- Loranger, A. J., Bailey, T. N., & Larned, W. W. (1991). Effects of forest succession on populations of moose *Alces alces* in south-central Alaska. *Wildlife Biology*, 17(3), 261–267.
- Maier, J. A. K., Ver Hoef, J. M., McGuire, A. D., Bowyer, R. T., Saperstein, L., & Maier, H. A. (2005). Distribution and density of moose in relation to landscape characteristics: Effects of scale. *Canadian Journal of Forest Research*, 35(9), 2233–2243. <https://doi.org/10.1139/x05-110>
- Maslowski, N. I. (2024). Historic perspectives and future challenges: The impacts of short-interval wildfires on forest regeneration in Glacier National Park, British Columbia (Master's thesis, Thompson Rivers University). https://www.tru.ca/_shared/assets/Maslowski_thesis60265.pdf
- Meidinger, D., & Pojar, J. (Eds.). (1991). *Ecosystems of British Columbia*. British Columbia Ministry of Forests, Special Report Series No. 6.
- Mumma, M. A., Gillingham, M. P., McNay, R. S., & Boutin, S. (2024). Fire-mediated habitat change drives moose population dynamics in boreal forests. *Ecological Applications*, 34(1), e2873. <https://doi.org/10.1002/eap.2873>
- Parlee, B., & Caine, K. (2018). *When the caribou do not come: Indigenous knowledge and adaptive management in the Western Arctic*. UBC Press.
- Parisien, M.-A., Barber, Q. E., Bourbonnais, M. L., Daniels, L. D., Flannigan, M. D., Gray, R. W., Hoffman, K. M., Jain, P., Stephens, S. L., Taylor, S. W., & Whitman, E. (2023). Abrupt, climate-induced increase in wildfires in British Columbia since the mid-2000s. *Communications Earth & Environment*, 4, Article 309. <https://doi.org/10.1038/s43247-023-00977-1>

- Veblen, T. T., Hadley, K. S., Reid, M. S., & Rebertus, A. J. (1991). Disturbance and stand development of a Colorado subalpine forest. *Journal of Biogeography*, 18(6), 707–716. <https://doi.org/10.2307/2845552>
- Wong, C., Dorner, B., & Sandmann, H. (2003). Estimating historical variability of natural disturbances in British Columbia (Land Management Handbook No. 53). B.C. Ministry of Forests, Research Branch; B.C. Ministry of Sustainable Resource Management, Resource Planning Branch.

Appendix 1



Between 2000 and 2023, 32% of caribou range in Ulkatcho territory, west-central British Columbia, burned. In the 80 years between 1919 and 1999, this figure was 6.5%. Fire polygons obtained from the Canadian National Fire Database. Caribou herd boundaries obtained from the British Columbia Provincial Caribou Recovery Project.

CHAPTER 2: Recovery of winter habitat for southern mountain caribou following wildfire in Ulkatcho, west-central British Columbia, Canada

ABSTRACT

The Ulkatcho people have co-existed with caribou since time immemorial, harvesting the herds for meat, clothing and tools and developing deep relational ties with caribou. Today all four herds in Ulkatcho are Threatened and the availability of winter habitat is considered a limiting factor in their recovery. Caribou in this area use mature lodgepole pine stands in winter, however nearly a third of all caribou range in Ulkatcho burned between 2000 and 2023. We combined Ulkatcho ecological knowledge with lichen and stand structure measurements at five stand-replacing wildfires to assess the 90-year recovery of winter caribou habitat. Canopy cover and competition from mosses and vascular plants were tested for their effects on lichen recovery. “Think Like A Caribou” methods were designed to capture the recovery of high-quality forage sites. Bayesian hurdle models were fitted by 308 lichen plots and found stand-level caribou lichen recovery at 59 years after fire. Recovery of high-quality forage sites occurred later at 74 years after fire. Arboreal lichens had established by 40 years post-fire, although not at sufficient loadings to sustain caribou. Stems per hectare of regenerated lodgepole pine failed to reach suitable openness for caribou within 90 years post-fire. Stands were up to eight times denser than forest structure of known caribou habitat when lichen recovery occurred. Our findings suggest it may take over 100 years after stand-replacing fire for lodgepole pine to reach suitable openness to attract caribou. The prolonged self-thinning of lodgepole pine may therefore present a greater limiting factor than lichen abundance for caribou in these forests. Our results demonstrate the

importance of adopting a holistic approach towards habitat, one that includes both stand structure and lichen abundance alongside Traditional Ecological Knowledge.

Key words: caribou; wildfire; habitat; lichen; lodgepole pine; stand density

Introduction

Southern mountain caribou (SMC) are an endangered ecotype of woodland caribou (*Rangifer tarandus caribou*) that rely on mature, high-elevation conifer forests of central and south-east British Columbia (BC) (Environment Canada, 2014). In winter, these subalpine forests provide SMC with terrestrial and arboreal lichen forage and deep snowpacks that facilitate the avoidance of predators, such as wolves (*Canis lupus*). In recent decades however, SMC populations have declined considerably, with seven of the 24 herds in this group becoming extirpated since 2000 (Caribou Recovery Program, 2023). The causes of these declines derive primarily from habitat degradation and fragmentation (Johnson *et al.*, 2015) and includes the loss of food, predator refugia, and shelter (Lamb *et al.*, 2024). For many SMC herds, the suitability of winter habitat is considered a major limiting factor in their recovery (Apps and Dodd, 2017).

Due to their southern distribution, SMC herds are exposed to substantial levels of human-mediated disturbances, such as logging, road construction, and oil and gas development, all of which are thought to be linked to changes in habitat quality (Lamb *et al.*, 2025). Alongside this, natural disturbances such as wildfire can also affect the availability and distribution of important winter habitat (Gustine *et al.*, 2014). High-elevation forests in SMC range often consist of Engelmann Spruce–Subalpine Fir (ESSF) and Montane Spruce (MS) biogeoclimatic ecosystem classification (BEC) zones (Meidinger and Pojar 1991). Fire return intervals in these forests historically exceeded 100-200 years (200 years: Veblen *et al.*, 1991; 100 years: Wong *et al.*, 2003), with high intensity crown fires creating a mosaic of forest ages, of which caribou use late-successional patches with high lichen abundance in winter (Environment Canada, 2014). It is probable therefore that SMC have coexisted with fire for millennia (Bergerud, 1974), adapting to the relatively long fire return intervals that occur in these forests. In some areas, fire likely

benefits caribou habitat over long time periods (Klein, 1982) by opening forest canopy and creating conditions for the growth of terrestrial lichens (Coxson and Marsh, 2001). Today however, wildfire severity and extreme burning conditions across Canada are increasing (Hanes *et al.*, 2019; Parisien *et al.*, 2023) with wildfire occurrence expected to double in BC by the end of the century (Wotton *et al.*, 2017). Increasing frequency, size, and severity of wildfires may accelerate the loss and fragmentation of mature forests and shorten the time available for lichen-rich stands to establish (Russell *et al.*, 2025).

For terrestrial lichens, recovery from severe disturbance such as wildfire can take many decades (Kershaw, 1977; Thomas *et al.*, 1996; Coxson and Marsh, 2001; Greuel *et al.*, 2021). Specifically, lichen growth after fire is affected by several biotic and abiotic factors, including time since fire, canopy cover, basal area and stem density, soil moisture and nutrients, snow-depth, and competition from vascular plants and mosses (Kershaw, 1977; Goward, 1999; Coxson and Marsh, 2001; Sulyma and Coxson, 2001; Haughian and Burton, 2015). Similarly, the growth of arboreal lichens, another important winter food for SMC, can take many decades to recover from fire. The growth of arboreal lichens is tied to several environmental conditions, notably tree species and age, and variables that influence forest ventilation, such as stand openness, wind regime and canopy cover (Goward, 1998). These factors determine the unique drying cycles that many arboreal lichens are sensitive to (Goward *et al.*, 2022).

Alongside the importance of lichens to wintering caribou, other factors such as stem density and predation risk can also influence habitat selection, especially after fire (Thomas *et al.*, 1996). For example, overly dense stands limit the ability of caribou to run freely and escape predators, while also reducing access to forage (Wilson *et al.*, 2023). High tree densities can also reduce the ability of caribou to see predators and other herd members (Thomas *et al.*, 1996),

meaning caribou may avoid dense stands resulting from fire (Cichowski, 1989; Goward *et al.*, 1999), even if lichen abundance is high (Thomas *et al.*, 1996).

Given the importance of winter habitat to caribou, much work has been done on the relationships between fire and caribou across their North American distribution (Kershaw, 1977; Coxson and Marsh, 2001; Joly *et al.*, 2003, 2007; Gustine *et al.* 2014; Greuel *et al.*, 2021). Few of these studies have implemented Indigenous knowledge systems however, a critical component of caribou management and recovery (Parlee and Caine, 2018). Across Canada, caribou have provided food, clothes, tools and oral tradition to Indigenous peoples since time immemorial (Hummel and Ray, 2008; Sharp and Sharp, 2015) and are emblematic of Indigenous knowledge systems, reflecting long-standing relationships of land stewardship and ecological understanding (Parlee and Caine, 2018). In recent years, caribou recovery strategies have integrated both Indigenous knowledge systems and Western scientific tools to successfully recover declining populations (Lamb *et al.*, 2022). These collaborative approaches allow for Indigenous communities, who have long-standing relationships with caribou and their habitats but who have been marginalized from previous recovery efforts, to lead the management of caribou habitat in their respective territories.

In west-central BC, the people of Ulkatcho have coexisted with whudzih (caribou) for millennia, developing deep spiritual and ecological ties with caribou that cannot be fully understood outside of Ulkatcho cosmology. Corinne Cahoose, a member of Ulkatcho First Nation (UFN), describes how “the caribou story ties us to the land. Years ago...our nations relied on caribou for the meat and hide for the clothing. Caribou were plentiful, herds after herd. It is a sad history of our people and our caribou.”

Over the past three generations, all four herds in Ulkatcho have declined (Caribou Recovery Program, 2023). In the north of Ulkatcho, Corinne Cahoose recalls many caribou. "...Sigutlat Lake, Qualcho Lake, Johnny Lake...thousands and thousands of caribou in that area. Back in the day there has been thousands." These caribou, known as the Tweedsmuir-Entiako herd by the Caribou Recovery Program (CRP), have declined 63.5% from 487 animals in 1987 to 178 in 2023 (Cichowski, 2015; CRP, 2023; Figure 1). In the west of Ulkatcho, Bella Leon, a UFN member, recalls more caribou. "Lots of caribou, so many. Used to go up into the Rainbows, go up and look down at hundreds of caribou." Today the Rainbow Mountains herd numbers 40 animals and has an unsustainable calf recruitment rate (Dodd, 2017; CRP, 2023). In the south and east of Ulkatcho, Corinne Cahoose recalls her father's stories of caribou. "My dad said they followed caribou on their migration routes...along the Charlotte Alplands...Itchas...". Maureen Sill, a UFN member, also remembers seeing her first caribou in this area. "Mom take us into the mountains. Way back. First time I seen caribou." Since 2003, the Itcha-Ilgachuz herd declined 80% from 2800 animals to 559 in 2023 (f, 2018; CRP, 2023). The Charlotte Alplands herd, despite extensive government-led relocations, numbers 27 animals (Appendix 1; CRP, 2023). All four herds in Ulkatcho belong to the Northern group of the SMC population and are listed as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2014).

The Ulkatcho people attribute the decline of caribou to a culmination of predation and habitat change, caused by logging, pine beetle, ranching and wildfire. Between 2000 and 2023, 32% of caribou range in Ulkatcho burned, compared to 6.5% in the 80 years between 1919 and 1999 (Canadian National Fire Database, n.d.; Appendix 2). The average size of fires in Ulkatcho

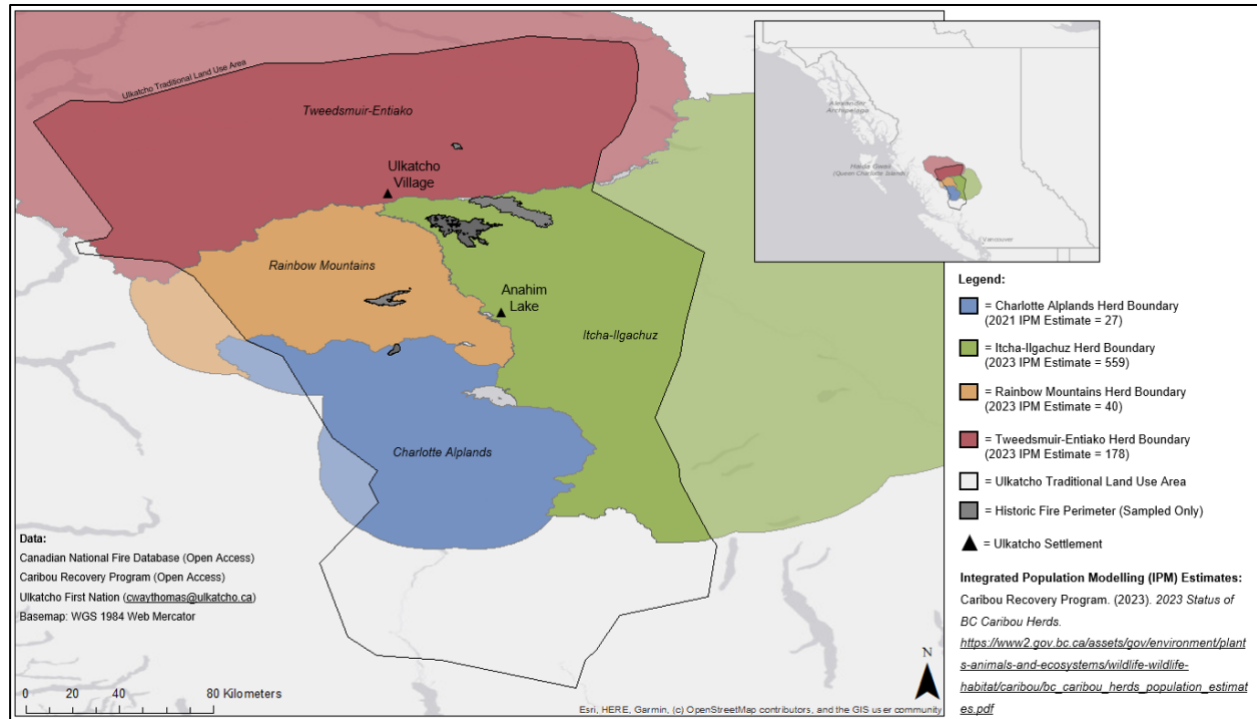


Figure 1

The locations and ranges of the four southern mountain caribou (whudzih, *Rangifer tarandus caribou*) herds in Ulkatcho territory, west-central British Columbia. The Tweedsmuir-Entiako herd in the north (estimated population = 178), the Itcha-Ilgachuz herd in the east (population estimate = 559), the Charlotte Alplands herd in the south-west (population estimate = 27) and the Rainbow Mountains herd in the west (population estimate = 40). Highlighted area represents the Ulkatcho Traditional Land Use Area. Black triangles represent the locations of Ulkatcho settlements.

was also four times larger in the last 23 years compared to the previous 80 years (Canadian National Fire Database, n.d.). In Ulkatcho, mature and old growth chundoo forests (*Pinus contorta*, lodgepole pine, often referred to as jack pine by the Ulkatcho) are prevalent across the territory and provide critical winter habitat for caribou (Apps and Dodd, 2017). Douglas Sill, a UFN member, describes the importance of these mature forests to caribou. “Mature timber. Around 140 years. They eat lichen from the branch... both if its steep. Wildfire and pine beetle not helping.” George Leon, an Elder from UFN, describes how these stands provide lichen forage for caribou. *Caribou like to eat lichen on the ground in the timber* (translated from Dakelh). Gary Holte, a UFN member, also states the importance of these mature forests. “High alpine jack pine trees. 80 years, old-growth jack pine.” Due to the dry climate in the region, high severity, stand-replacing fires likely occur in lodgepole stands every 75 to 125 years (British Columbia Ministry of Forests, 2022), with stands at higher elevation less prone to disturbance (Apps and Dodd, 2017).

Caribou in Ulkatcho are also linked to lodgepole pine at three key stages in their life-history. First, in fetal development, mature and open lodgepole stands provide the lichen biomass to sustain pregnant cows in winter, whilst also providing adequate line of sight to detect predators (Cichowski; 1993; Apps and Dodd, 2017). Second, during birth, the “space out” strategy used by parturient females to avoid predators (Bergerud and Page, 1987; Gustine *et al.*, 2006) leads to several Ulkatcho calves being born inside high elevation lodgepole pine forests each year (Gharajehdaghpoor, unpublished map). Finally, in death, the Ulkatcho people use caribou antler to cut the bark of lodgepole pine in spring for the high carbohydrate k’unih (cambium) (Hebda *et al.* 1996). Bella Leon, a UFN member, also recalls the use of caribou as a scraping tool. “Bones scraped and made into a scraper”.

The network between caribou, lodgepole pine, lichen, and the Ulkatcho people has occurred since time immemorial (Figure 2). The impact of wildfire on this network remains uncertain, however, and has become a concern for the Ulkatcho people in the face of increasing fire frequency and size in their territory. As Ulkatcho caribou populations decline, this co-led study with UFN investigates the post-fire recovery of winter caribou habitat in Ulkatcho. The goal of this study is to use a holistic approach to assess habitat, one that incorporates lichen abundance, stand density, traditional ecological knowledge and caribou-centric forage models to better understand post-fire habitat. The specific objectives of the study are: (1) to estimate recovery trajectories of caribou forage lichens following fire, (2) assess the impacts of stand-level covariates on post-fire lichen recovery, and (3) to better understand the dynamics of lodgepole pine stem density on the suitability of post-fire caribou habitat. We hypothesize that: (1) terrestrial lichens take multiple decades to recover from stand-replacing fire (Thomas *et al.*, 1996; Coxson and Marsh, 2001; Joly *et al.*, 2003, 2007; Greuel *et al.*, 2021) and that (2) terrestrial lichen abundance is strongly negatively influenced by high levels canopy cover and competitive exclusion from vascular plants and mosses (Coxson and Marsh, 2001; Sulyma and Coxson, 2001). We also expect that (3) stems per hectare plays an important role in caribou habitat suitability (Thomas *et al.*, 1996; Wilson *et al.*, 2023) and that (4) *Bryoria spp.* arboreal lichens will establish in in post-fire lodgepole pine stands as early as 40-years after stand-replacing fire (Trevor Goward, personal communication).

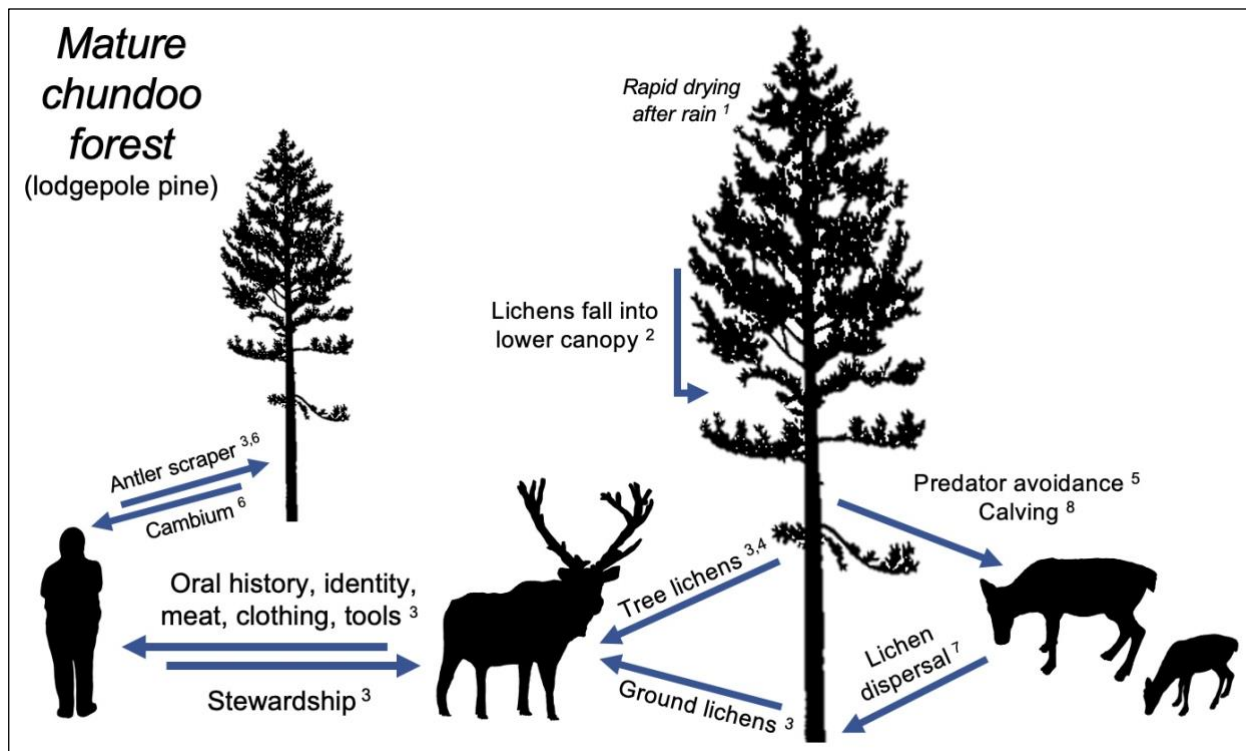


Figure 2

The relational network between lodgepole pine (chundoo, *Pinus contorta*), arboreal and terrestrial lichen, caribou (whudzih, *Rangifer tarandus caribou*) and the Ulkatcho people in Ulkatcho territory, west-central British Columbia. Each blue arrow represents an ecological or cultural interaction. Caribou and human vectors developed from authors original photos. Lodgepole pine vector credit: Government of Canada, n.d. References: 1) Goward (1998). 2) Goward et al. (2024). 3) Ulkatcho First Nation (2024). 4) Cichowski (1993). 5) Apps & Dodd (2017). 6) Hebda et al. (1996). 7) Goward (1999). 8) Gharajehdaghpoor, unpublished map.

Study Area

Caribou in Ulkatcho are bounded by the Rainbow Mountains to the west (2,450m), and the Itcha and Ilgachuz Mountains to the east (2,350m and 2,400m respectively) (Figure 1). The Dean River valley separates these two ranges at 1,100m above sea level, while to the North, Ulkatcho territory overlaps with the Tweedsmuir-Entiako herd range until the southern foothills of Wells Gray Peak, near Eutsuk Lake and Tetachuk Lake (850m). To the south, Ulkatcho territory encompasses the Charlotte Alplands, where caribou use the slopes surrounding Trumpeter Mountain (2400m) and the lowlands around Charlotte Lake (1175m). Winters in the study area are cold and summers cool, with frequent growing-season frosts a result of high elevations and the rain shadow of the westerly Coast Mountains (Apps *et al.*, 2001). The climate is considered unproductive for tree growth, with forests at lower elevations more prone to disturbance and replacement (Apps and Dodd, 2017). In descending order from highest elevation to lowest, the four biogeoclimatic zones (Meidinger and Pojar, 1991) prevalent in the study area are the following:

- Alpine Tundra (AT) - extensive at the highest elevations of all three mountain ranges and devoid of forest;
- Engelmann Spruce - Subalpine Fir, specifically the very dry, very cold sub-zone (ESSFxv) - occurs between 1650m and 1825m, with mature forests dominated by lodgepole pine. Some areas of Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) exist alongside whitebark pine (*Pinus albicaulis*) in this zone;
- Montane Spruce, specifically the very dry, very cold subzone (MSxv) - mature forests in this zone are even-aged lodgepole pine stands;

- Sub-boreal Pine Spruce, specifically the moist, cold subzone (SBPSmc) in the north and the very dry, cold subzone (SBPSxc) in the south - even-aged stands of lodgepole pine again dominate this zone, with Engelmann spruce in wetter areas.

All three of the Rainbow, Ilgachuz and Itcha mountain ranges are dormant shield volcanoes belonging to the Anahim Volcanic Belt (Kuehn, 2014). The significant volcanic history of the study area has resulted in basalt-derived soils of generally coarse texture and weak development (Goward, 1999). The major topographic relief created by these shield volcanoes likely provides Ulkatcho caribou with elevational separation from predators (T. Gharajehdaghipoor, personal communication, 2024).

Methods

Community Meetings

Project approval was received from Ulkatcho Chief Lynda Price and Council in October 2023. In April 2024, a research ethics application was approved by Thompson Rivers University to conduct three transcribed meetings with Ulkatcho elders and band members (study #103885). These meetings took place on July 10th in Anahim Lake, and November 22nd, 2024, in Anahim Lake and Nimpo Lake, respectively. Ten questions relating to caribou and wildfire in Ulkatcho were asked at all three meetings (Appendix 3). Discussion contributions from each attendee were hand-transcribed by designated research assistants. Knowledge shared by the Ulkatcho people during these meetings was used to (1) spatially and ecologically define important caribou habitat, (2) understand the significance of caribou to Ulkatcho, and (3) understand the foraging and behavioral ecology of caribou in the study area.

Site Selection

Five historical fires were selected for lichen abundance and stand structure sampling in August and September 2024 (fire years: 1937, 1961, 1981, 2006, 2010; Table 1). A greater number of fires could not be sampled due to the limited number of fires that occurred before 2000 that had not returned or been logged since the initial disturbance (Appendix 2). The search area for historical fires was defined by a combination of known caribou habitat provided by Ulkatcho Elders, and pre-existing telemetry data for the Itcha-Ilgachuz and Rainbow Mountains herds provided by the CRP (Appendix 4). Historical fire boundaries from the Canadian National Fire Database (CNFD) were downloaded into ArcMap Pro (version 3.11.8). Fires in this database begin in 1919, although boundaries from 1919 to 1986 are frequently inaccurate and must be verified using BC Air Photo collections. Historical fires that overlapped with areas of caribou winter activity were selected for further investigation. Winter activity for the Itcha-Ilgachuz and Rainbow Mountains herds was defined as habitat used between November and April between the years of 1984 to 2023 (Appendix 4) in the telemetry data. Locations and descriptions of winter habitat provided by Ulkatcho Elders were used to select relevant fires in the Charlotte Alplands and Tweedmsuir-Entiako herd ranges. Most prospective fires were dropped due to overlapping logging cuts and roads, repeat burns, inaccurate or unclear burn perimeters, unfeasible access, or no water nearby. One fire was selected from each of the following burn age classes: 0-15, 16-30, 31-50, 51-70, 71-90 years. For each fire that occurred after 1986, burn severity was mapped using Differenced Normalized Burn Ratio (dNBR) (Parks *et al.*, 2021; Key and Benson, 2006) in Google Earth Engine and ArcMap Pro. For fires that occurred before 1986, BC Air Photos were used to verify burn perimeter. Tree cores were used to verify the occurrence of the last stand-replacing fire at all burn sites.

Table 1

Summary of site characteristics at each sampled historical fire in Ulkatcho territory, west-central British Columbia.

Fire Year	Burn Age Class (Years)	Latitude	Longitude	Elevation	Unburned Stand Type	Unburned Stand Age (Years)	BEC Zone
2010	0-15	52°33'01"N	125°43'38"W	1466m	<i>Pinus contorta</i> dominant, <i>Picea engelmannii</i> subdominant	130.6	ESSF
2006	16-30	*	*	*	<i>P. contorta</i> dominant, <i>P. engelmannii</i> subdominant	149.3	ESSF
1981	31-50	53°09'22"N	125°28'52"W	1049m	Co-dominant <i>P. contorta</i> and <i>P. engelmannii</i>	87.3 (<i>P. contorta</i> only)	SBPS
1961	51-70	52°56'47"N	125°24'48"W	1105m	<i>P. contorta</i> dominant, <i>P. engelmannii</i> subdominant	105.9	SBPS
1937	71-90	52°21'08"N	125°43'22"W	1244m	Co-dominant <i>Abies lasiocarpa</i> and <i>P. engelmannii</i>	122.7	MS

* Undisclosed at the request of the community due to sensitivity of Itcha-Ilgachuz calving grounds.

Sampling

30 to 45 plots (Figure 4) were randomly placed at each fire using ArcMap Pro with 50 meters spacing using the *Create Random Points* function in the *Analysis* tab. Plots consisted of a 10m x 10m grid. In the 2006 and 2010 fires, 15 plots were placed in each of unburned, low severity and high severity. In the 1937, 1961 and 1981 fires, 15 plots were placed in each of unburned and burned (identified from BC Air Photos). 15 plots were chosen to capture differences in lichen abundance at the stand-level. Unburned stands adjacent to burned areas were sampled to better understand pre-fire lichen abundance and forest characteristics.

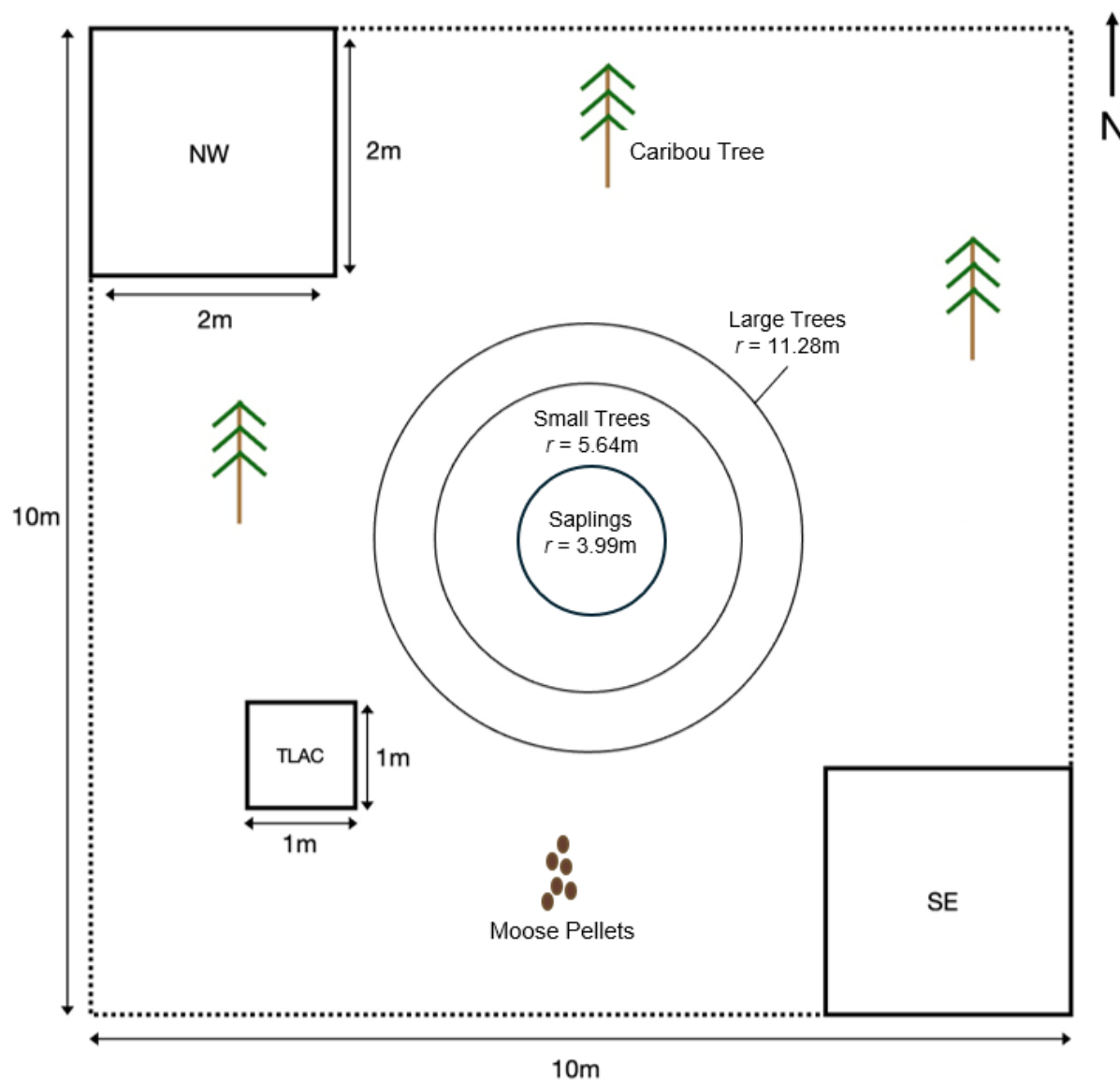


Figure 3

Diagram of field plot layout used to characterize lichen abundance, stand structure and understorey plant composition at burned and unburned sites in Ulkatcho territory, west-central British Columbia. Lichen species, lichen percent cover, canopy cover and competition from vascular plants and mosses was measured inside each corner quadrat (NW and SE). Species and count of conifer saplings (height $< 10\text{cm} \geq 130\text{cm}$) was measured inside a 3.99m radius fixed plot at plot center. Small trees (height $\geq 130\text{cm}$ and diameter-at-breast-height [DBH] $< 12.5\text{cm}$) were counted within a 5.64m fixed-radius plot. Large trees (DBH $\geq 12.5\text{cm}$) were counted within an 11.28m fixed-radius plot. Three 'Caribou Trees' with the highest abundance of arboreal lichens within 3 meters of the ground were selected for sampling. 'Think Like A Caribou' plots were selected by walking the 10 meter plot and placing a 1m^2 quadrat over the area of greatest terrestrial lichen abundance known to be consumed by caribou in winter. The frequency of moose pellets was recorded at each plot.

Terrestrial Lichen Abundance

In the northwest (NW) and southeast (SE) corner of each plot (Figure 4), a 2m x 2m quadrat was placed to measure terrestrial lichen abundance (Figure 4). Percent cover of each lichen species was ocularly recorded using a photo-based key developed from www.waysofenlichenment.net and the grouping of caribou lichens used by Greuel *et al.* (2021): *Cladonia rangiferina* Group (*C. rangiferina* and *C. stygia*), *Cladonia mitis* Group (*C. mitis* and *C. arbuscula*), *Cladonia stellaris* and *Cladonia uncialis*. All other lichens were identified to genus; *Stereocaulon* spp., *Cladonia* spp. (that were not present in pre-determined groupings) and *Peltigera* spp. Canopy cover was measured at the center of each corner quadrat using a spherical densiometer.

Competition from Mosses and Vascular Plants

Percent cover of each understory vegetation species present in NW and SE corner quadrats (Figure 4) was ocularly recorded. Cover values of all vascular plants (plants containing a xylem and phloem) were summed to form a measure of total vascular plant competition at each corner quadrat. Cover values of all mosses were grouped to form a single measurement of total moss competition at each corner quadrat. Species names for plants were recorded in Dakelh if it existed in Hebda *et al.* (1996) or was listed in the Dakelh language database at www.firstvoices.com/dakelh-southern-carrier. For plants that did not exist in either resource, the English common name was used. Plants were identified to genus and species level where possible, or otherwise to genus.

Stand Structure and Age

The following fixed-radius circular plots were placed at the center of each 10m x 10m plot: 3.99m, 5.64m, 11.28m (Figure 4). All saplings (height > 10cm < 130cm) within the 3.99m radius plot were counted, with species recorded in Dakelh. All small trees (height $\geq$ 130cm and diameter-at-breast-height [DBH] < 12.5cm) within the 5.64m radius plot were counted and recorded in Dakelh, along with living status. All large trees (DBH $\geq$ 12.5cm) within the 11.28m radius plot were counted and recorded in Dakelh, along with living status and individual DBH.

Small tree and large tree counts were converted to hectares and summed to provide total stems per hectare. This was used as a metric of stem density. Total DBH of live large trees was converted to basal area (square meters per hectare) by calculating the cm² of cross-sectional area of each individual tree stem, summing this value over each plot, and multiplying this by the plot expansion factor (25) to a per hectare basis. These measurements were collected to provide an index of stand structure that could be compared with studies of winter caribou habitat selection in BC (Terry *et al.*, 2001). Sapling counts were used to understand stand regeneration.

Increment borers were used to collect cores of three canopy-dominant trees within each 10m x 10m plot. These cores were aged in the lab using a microscope. Tree cores that did not hit the pith were age-corrected using the pith locator method developed by Applequist (1958). For burn plots in the 2006 and 2010 fire, branch whorls were counted to estimate the age of young lodgepole pine. Stand age was measured to verify the occurrence of the last stand-replacing fire.

Arboreal Lichen

Three trees inside each 10m x 10m plot with the highest arboreal lichen loading within three meters of the ground were selected for sampling (Figure 4) (three meters approximates the reach of wintering caribou; Goward and Campbell, 2005). Each tree was photographed and

assigned an abundance value based on the mean spacing of arboreal lichen strands (adapted from Esseen, 1981): None (no lichens present), Sparse (mean distance between specimens > 150cm), Moderate (mean distance between specimens 100-150cm), abundant (mean distance between specimens 50-100cm) and Very Abundant (mean distance between specimens 0-50cm). Qualitative notes on tree health, tree species, air flow, caribou sightlines, branch structure and dominant lichen genus were recorded.

Think Like A Caribou (TLAC)

To capture a more caribou-centric understanding of habitat recovery, we implemented ‘Think Like a Caribou’ quadrats to simulate likely foraging behavior in post-burn stands — asking ourselves: *if we were wintering caribou, where would we crater for lichens?* Here, 1m x 1m quadrats were selectively placed over the greatest density of preferred terrestrial lichens within each 10m x 10m plot (Figure 4). Field assistants were encouraged to ‘think like a caribou’ when walking the plot and placing the quadrat. In descending order, *Cladonia* spp., *Cladina* spp. and *Stereocaulon* spp. were considered preferred species (Holleman and Luick, 1977; Denryter *et al.*, 2017). This design provided a more relevant assessment of lichen abundance for caribou, aligning with the kincentric ways of knowing that form part of many Indigenous cultures (Salmon, 2000; Bhattacharyya and Slocombe, 2017), in which animals have agency and self-thought.

Statistical Analysis

Analyses were completed in R-4.4.2 (R Core Team, 2023) and *ggplot2* (Wickham, 2016) was used for all graphs.

Covariates Impacting Lichen Recovery

Following the methods of Greuel *et al.* (2021), we used the *glmmTMB* package (Brooks *et al.*, 2017) to construct a two-step hurdle model to assess how stand-level factors affect lichen recovery after fire. This approach simplified lichen recovery into two components: (1) the probability of lichen occurrence (presence/absence) modelled with a binomial generalized mixed model (GLMM), and (2) the cover of lichen conditional on presence modelled using a Gamma GLMM for continuous, non-zero lichen cover. Caribou lichen cover was the response variable and was calculated as the sum of all lichen cover at each corner quadrat known to be consumed by caribou (Holleman and Luick, 1977). It included *C. rangiferina* Group, *C. mitis* Group, *Stereocaulon* spp. and *Cladonia* spp. (Cladina Group). A hurdle model was chosen to account for the high proportion of zero values in our dataset.

In this model we focused on the effects of ecological covariates we hypothesized to influence lichen recovery after wildfire: canopy cover (CC), moss competition (MC), vascular plant competition (VPC), tree stems per hectare (SPH) and stand basal area (BA) (Kershaw, 1977; Goward, 1999; Coxson and Marsh, 2001, Haughian and Burton, 2015). To avoid confounding the effects of covariates with time since fire (TSF), we tested for collinearity between TSF and covariates using Pearson correlation coefficients. Predictably, CC, SPH and BA were strongly collinear with TSF ($r > 0.6$); therefore, we residualized each by regressing it against TSF. This removed the effect of time since fire and reduced multicollinearity, and in doing so altered the interpretation of these variables (Dormann *et al.*, 2012). Specifically, the residuals now tested the effects of unusually high or low levels of each covariate relative to what is typical for TSF, rather than the absolute raw values. ANCOVA and multiple regression were

not used as our goal was to completely isolate the effects of TSF in order to assess the effect of covariates on lichen presence and abundance without the influence of time. We also tested for collinearity between each covariate. This revealed high collinearity between canopy cover and stems per hectare. We subsequently dropped stems per hectare from the model as canopy cover was considered a more direct influencer of lichen abundance (Coxson and Marsh, 2001). MC and VPC were both scaled to a mean of zero and a standard deviation of one. This was done to reduce computational issues with the Gamma model. We also hypothesized that selected covariates may not act independently and may interact in meaningful ways. For example, mosses may reduce lichen cover when CC is greater (Coxson and Marsh, 2001). Conversely, greater CC may limit understory vegetation growth and provide less competition to lichens. We used pairwise interactions to include these ecological relationships in our model. VIF (Variance Inflation Factor) analysis revealed moderate multicollinearity, with most VIF values < 5 . However, the interaction between MC and VPC showed a $VIF > 5$, indicating inflated collinearity. This interaction term was subsequently dropped. We then compared the fit of the interactive model with an additive-only model using Akaike Information Criterion (AIC). The additive-only model performed negligibly better for both binomial ($\Delta AIC = -2.14$) and Gamma ($\Delta AIC = -2.60$) parts of the model. Due to the importance of including interactions, we selected the interactive model that included the main effects of CC (residuals), MC (scaled), VPC (scaled), BA (residuals) and interactions between $CC \times MC$ and $CC \times VPC$. Random intercepts were included to account for spatial autocorrelation between paired corner quadrats.

Response of Covariates to Time Since Fire

The next phase of modelling used the package *mgcv* (Wood, 2017) to produce a separate Generalized Additive Model (GAM) or Generalized Linear Model (GLM) for each covariate with an interaction term with TSF. GAMs with gamma distribution were used for each of VPC, MC and CC. GAMs were selected to account for expected non-linearity between covariates and TSF. A GLM with Tweedie distribution was used for BA. Random effects were not included as the goal of this step was to visualize how each covariate responded over TSF.

Lichen Recovery

To estimate the recovery trajectory of caribou lichen cover over TSF, we constructed a Bayesian hurdle gamma model using the *brms* package (Bürkner, 2017). This modelled both lichen presence (binary hurdle component) and lichen abundance conditional on presence (gamma distribution with log link). Covariates selected for this model were informed by the results of our two-step hurdle model. Specifically, we incorporated MC, VPC, CC and TSF in the gamma model. A random intercept for paired quadrats was included, with priors specified based on our two-step hurdle model. 4000 iterations were run across the default four chains used by the *brms* package.

Predicted lichen cover was calculated as the product of the posterior estimates of probability of presence and the conditional mean abundance. To estimate convergence with unburned controls, we calculated a static benchmark of lichen cover from unburned control plots using a hurdle gamma model. We then identified recovery convergence as the first time point where the 95% credible interval for predicted cover in burned plots overlapped with the static control estimate. This allowed us to say, with 95% confidence, that post-burn lichen cover is statistically similar to unburnt controls at x years after fire. Unburned lodgepole pine stands older

than 80 years were used as controls after being identified as important caribou habitat by Ulkatcho Elders. The same Bayesian gamma hurdle approach was used to estimate the convergence year between TLAC burn plots and TLAC controls. TLAC plots were not spatially nested and only contained measurements of the covariate CC and BA. The same hurdle model was used to calculate a static lichen cover for TLAC controls, where cover was the product of the probability of presence and the conditional mean abundance. *ggplot2* was used to create a stacked bar plot of arboreal lichen abundance by site. This was done to visualize arboreal lichen abundance over TSF.

Stand Density

A GAM was constructed of total stems per hectare over TSF to visualize stand density over time. Stems per hectare of unburned controls and the findings of caribou stand density selection by Terry *et al.* (2001) were also plotted to allow comparison between burn and unburned sites.

Results

Covariates Affecting Lichen Recovery

In the gamma part of the hurdle model, the main effects of VPC, MC and CC were all significant in limiting caribou lichen cover (Table 2). Vascular plant competition had the strongest negative effect (Estimate = -0.762 , $SE = 0.121$, $z = -6.326$, $p < 0.001$), indicating that greater vascular plant presence substantially reduces lichen cover post-fire. Moss competition also showed a significant negative association with lichen abundance (Estimate = -0.454 , $SE = 0.157$, $z = -2.894$, $p = 0.0038$), also suggesting competitive exclusion. Residuals of

canopy cover were negatively associated with lichen abundance (Estimate = -0.013 , $SE = 0.006$, $z = -2.131$, $p = 0.033$), with unusually higher canopy cover limiting lichen abundance.

The main effect of BA was non-significant. Interactions between CC and moss and CC and vascular plants were non-significant. In the binomial part of the hurdle model, the main effects of all covariates and interactions were non-significant in predicting the likelihood of zero caribou lichen cover (Table 2). This indicates that lichens were able to colonize alongside competition from mosses and vascular plants and across varying levels of canopy cover, however the gamma part of the model showed that lichen cover was affected by these covariates. The effect of VPC in the binomial model was also only marginally non-significant, with greater plant cover associated with higher likelihood of lichen absence.

GAMs showing the relationship between VPC, MC, and CC against TSF showed non-linear relationships for each covariate (Figure 4). VPC displayed a sharp increase in cover between 0- and 25-years post-fire and a secondary but smaller peak at 65 years post-fire (Figure 4a). Moss cover increased from 0-50 years after fire before declining for the next 40 years (Figure 4b). Canopy cover increased between 0 and 50 years before plateauing and declining

Table 2

Hurdle model summary of the covariates affecting terrestrial lichen presence and abundance after stand-replacing wildfire in Ulkatcho territory. Bolded p-values indicate statistical significance.

Term	Estimate	Standard Error	Statistic	p-value
Binomial				
(Intercept)	2.703569	1.141699	2.368022	0.017883
Canopy Cover (residuals)	0.051526	0.034444	1.495937	0.13467
Moss Competition	0.599871	0.770477	0.778571	0.436233
Vascular Plant Competition	-1.06762	0.608506	-1.75449	0.079346
Live Basal Area	0.217407	0.225928	0.962288	0.335905
Canopy x Moss	0.059316	0.049409	1.20053	0.229934
Canopy x Vascular Plant	0.011399	0.030027	0.379635	0.704216
Gamma				
(Intercept)	1.481866	0.130039	11.39559	<0.001
Canopy Cover (residuals)	-0.01376	0.006454	-2.1316	0.03304
Moss Competition	-0.45477	0.157139	-2.89405	0.003803
Vascular Plant Competition	-0.76205	0.121563	-6.26874	<0.001
Live Basal Area	-0.02088	0.028621	-0.72966	0.465597
Canopy x Moss	0.003913	0.005795	0.67522	0.499536
Canopy x Vascular Plant	-0.00541	0.006556	-0.82511	0.409307

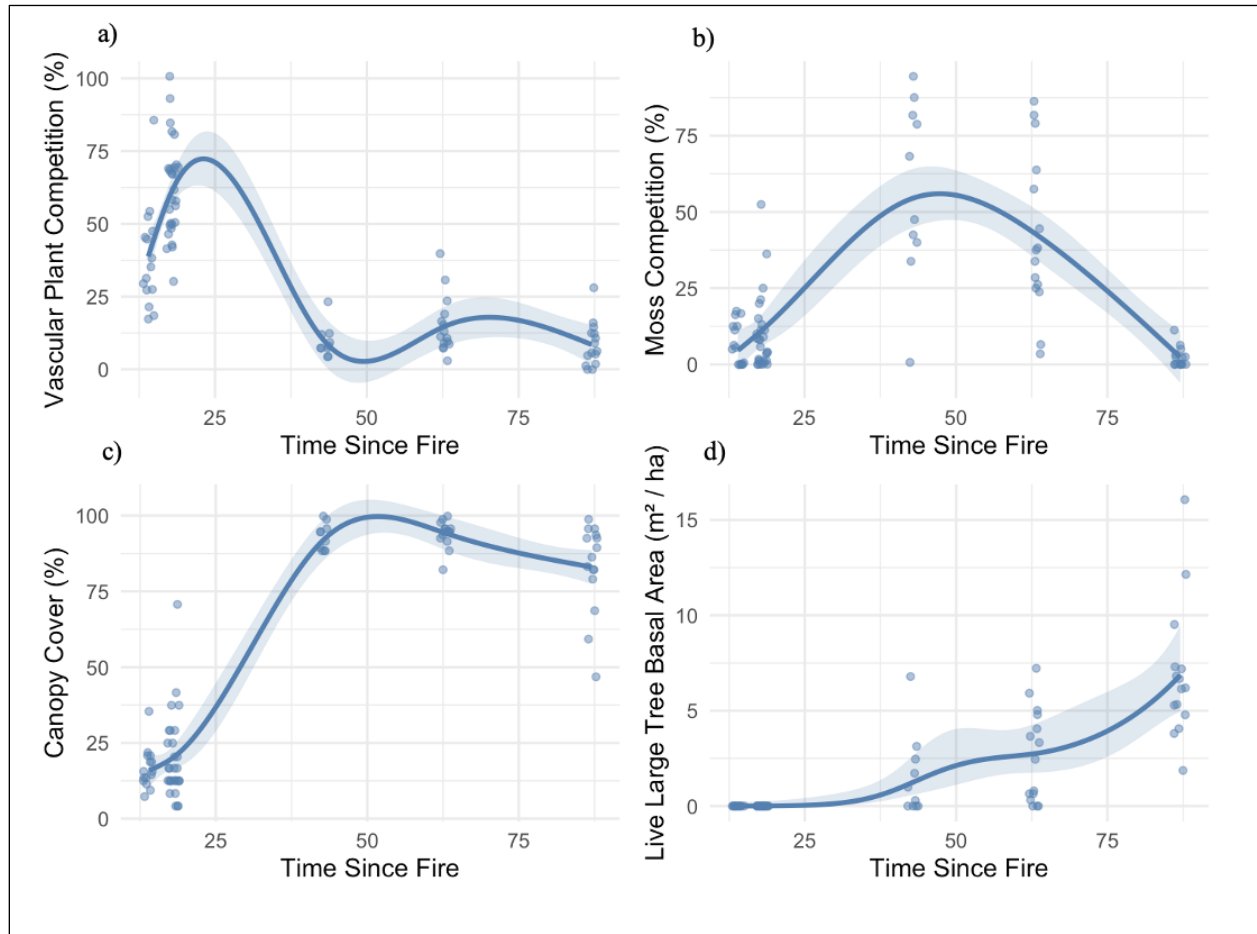


Figure 4

a) Generalized Additive Model showing the response of vascular plant competition over time since fire following stand-replacing wildfire in lodgepole pine (chundoo, *Pinus contorta*) forests in Ulkatcho territory, west-central British Columbia. Solid blue line represents the model curve. Shaded blue band represents the 95% confidence interval. Each blue circle represents an individual burn plot. b) Generalized Additive Model showing moss competition over time since fire. c) Generalized Additive Model showing canopy cover over time since fire. d) Generalized Linear Model showing basal area of live large trees per hectare over time since fire.

steadily from 60- to 90-years post-fire (Figure 4c). Basal area showed a steady increase over time, with a plateau between 40- and 60-years post-fire (Figure 4d).

Lichen recovery intervals

The Bayesian model for stand-level lichen recovery found statistical convergence with unburned controls at 59 years after fire (Figure 6). The model for TLAC plots found recovery of high-quality forage sites at 74 years after fire (Figure 6). Arboreal lichens meanwhile had established in lodgepole stands at 40 years post-fire (Figure 7). Only as stands reached 90 years post-fire did trees start carrying predominantly ‘very abundant’ lichen loadings (Figure 7). Over 95% of sampled lodgepole pine ($n = 267$) exclusively hosted *Bryoria* spp. with no other arboreal lichen genus present.

Stand Density and Basal Area

At all post-burn sites, total stems per hectare was higher than stands of known caribou selection, despite the recovery of terrestrial lichens (Figure 8; Terry *et al.*, 2001). This suggests that, even though lichen abundance was sufficient for caribou, these stands may be too dense to attract foraging caribou (Figure 9b). Figure 8 indicates that prolonged self-thinning of lodgepole pine over 100 years after fire may be required to reach suitable stand openness to attract caribou.

Burn Severity

After ground-truthing dNBR severity mapping, we found the difference between high and low severity plots difficult to distinguish. All burn plots sites were homogenous in the complete scorching of dead standing legacy trees, regardless of severity. Plots that were identified as low

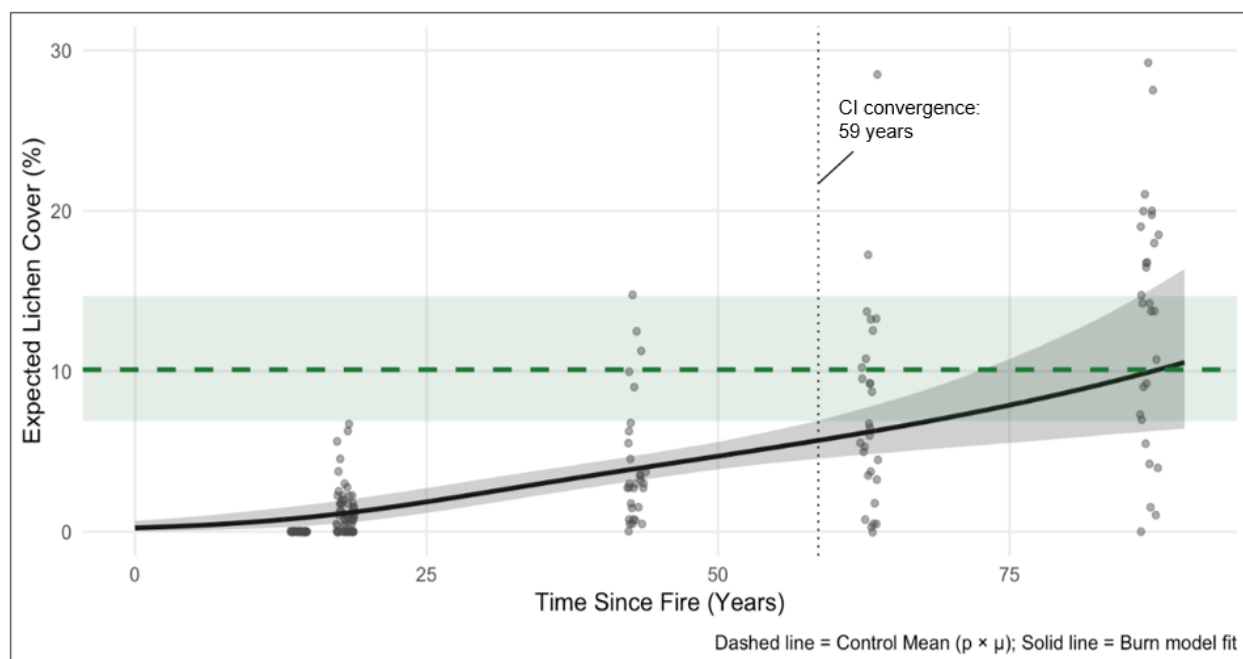


Figure 5

The estimated recovery trajectory of stand-level terrestrial caribou (whudzih, *Rangifer tarandus caribou*) forage lichens following stand-replacing wildfire in lodgepole pine (chundoo, *Pinus contorta*) forests in Ulkatcho territory, west-central British Columbia. Solid black line represents the curve of a Bayesian hurdle gamma model using 4000 iterations to create posterior estimates of lichen abundance at each year since fire. Shaded grey band represents the 95% credible interval of the posterior estimate. Dashed green line represents a hurdle-based mean of lichen abundance in unburned control stands aged 80 years and older. Shaded green band represents the 95% confidence interval of the hurdle-based control mean. 80 years was used as a minimum age threshold for controls of good caribou habitat as identified by Ulkatcho Elders and community members. Statistical similarity between burn plots and unburned control plots was identified at the convergence of 95% credible and confidence intervals. Each grey circle represents lichen percent cover from each burned plot.

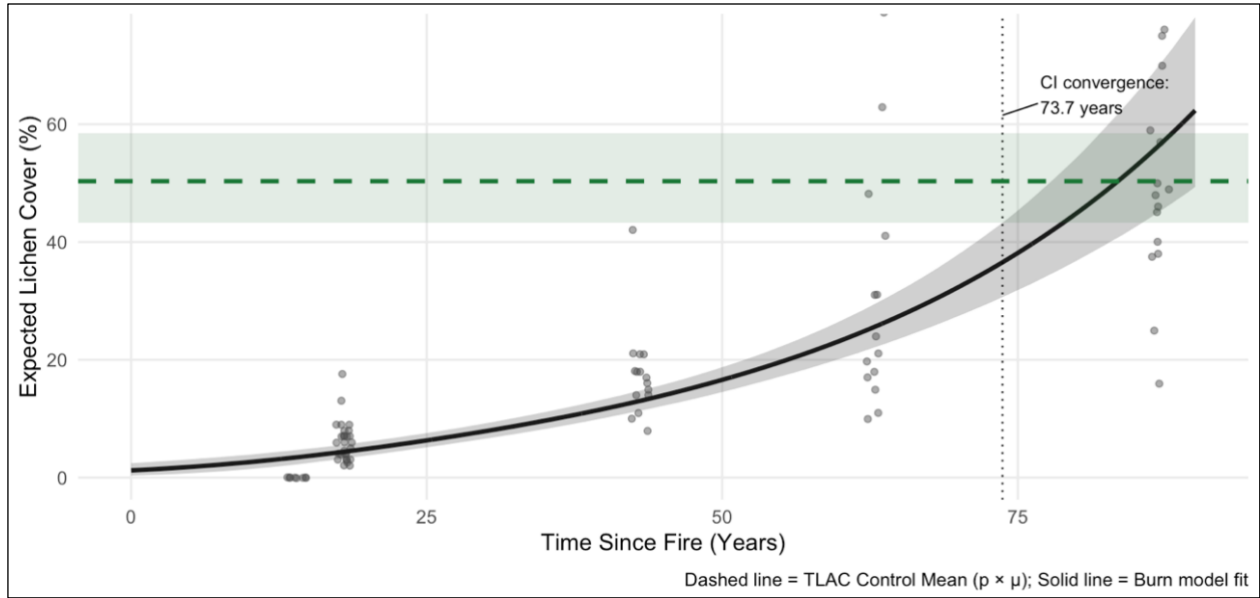


Figure 6

The estimated recovery trajectory of high-quality caribou forage sites of terrestrial lichens following stand-replacing wildfire in lodgepole pine (chundoo, *Pinus contorta*) forests in Ulkatcho territory, west-central British Columbia. Solid black line represents the trajectory of a Bayesian hurdle gamma model using 4000 iterations to create posterior estimates of lichen abundance at each year since fire using abundance measurements from ‘Think Like A Caribou’ plots. Shaded grey band represents the 95% credible interval of the posterior estimate. Dashed green line represents a hurdle-based mean of lichen abundance in ‘Think Like A Caribou’ plots at unburned control stands aged 80 years and older. Shaded green band represents the 95% confidence interval of the hurdle-based control mean. 80 years was used as a minimum age threshold for controls of good caribou habitat as identified by Ulkatcho community members. Statistical similarity between burn plots and unburned control plots was identified at the convergence of 95% credible and confidence intervals. Each grey circle represents lichen percent cover from each burned plot.

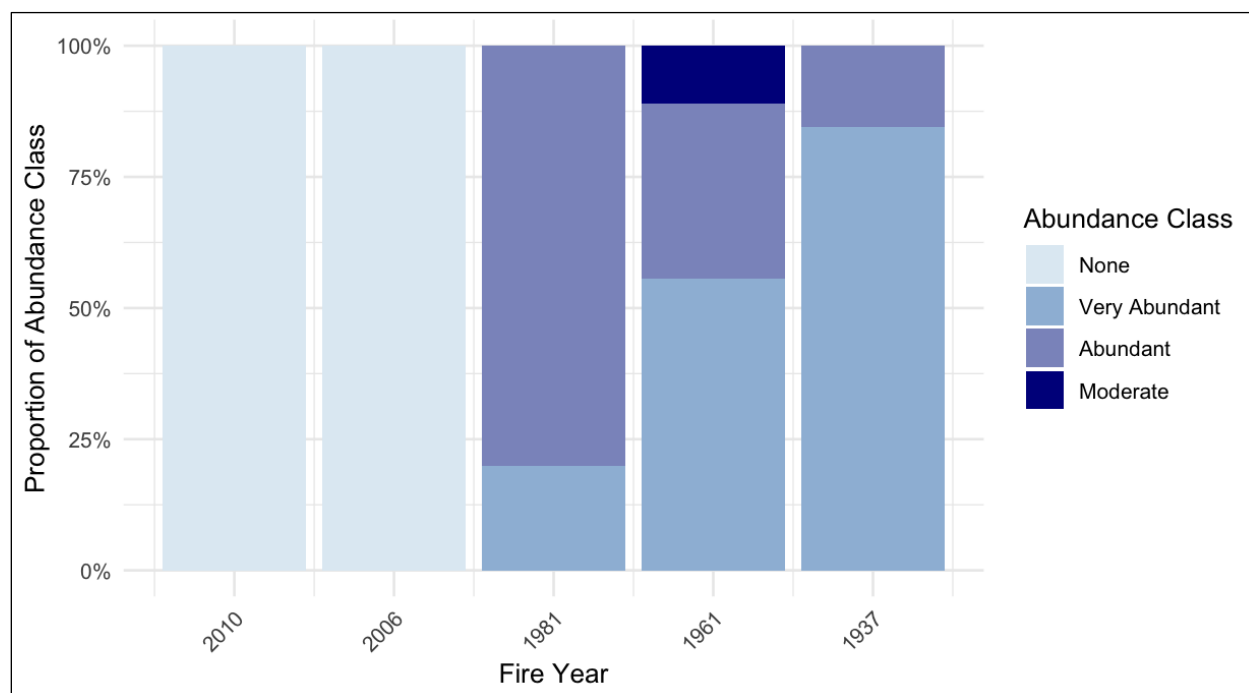


Figure 7

The proportion of arboreal lichen abundance classes recorded at five historical stand-replacing wildfires in Ulkatcho territory, west-central British Columbia. Each column represents a sampled burn site. Each shading of blue represents a different abundance class of arboreal lichen.

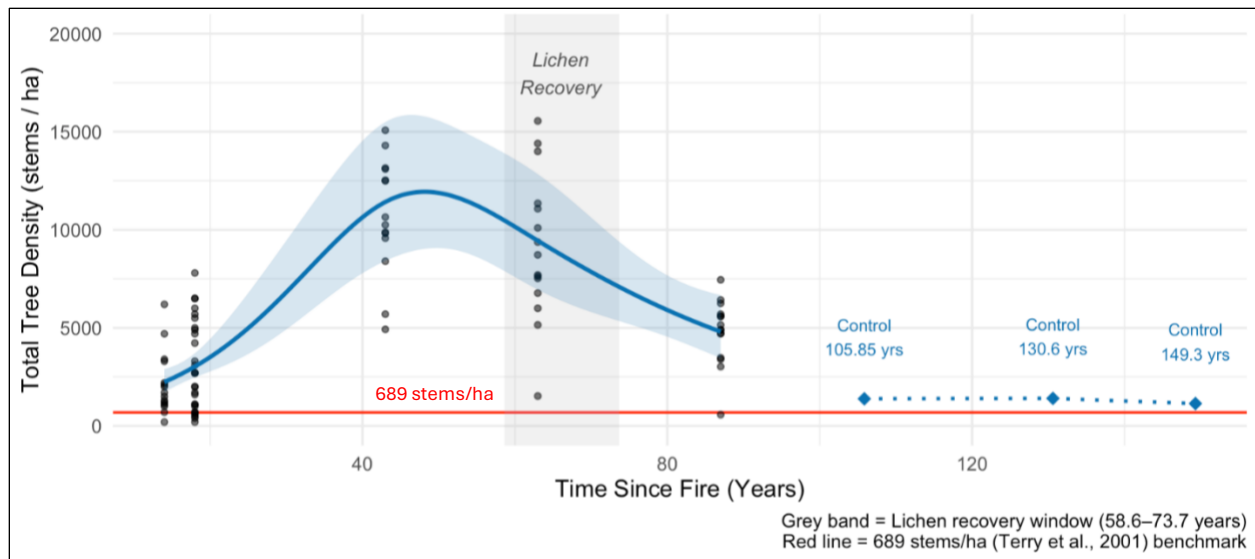


Figure 8

Stems per hectare of lodgepole pine (chundoo, *Pinus contorta*) stands following stand-replacing wildfire in Ulkatcho territory, west-central British Columbia. Solid blue line represents the curve of a Generalized Additive Model of total stems per hectare at sampled historical fires (dead and live trees combined). Shaded blue band represents the 95% confidence interval of the model. Vertical grey bar represents the window of earliest terrestrial caribou lichen recovery (59–74 years) found within Ulkatcho territory following stand-replacing wildfire. This interval is based on our Bayesian hurdle models of the earliest point of statistical lichen convergence between burn and control plots of stand-level (59) and ‘Think Like A Caribou’ (74) lichen plots. Blue diamonds represent total stems per hectare of unburned control sites identified as important caribou habitat by Ulkatcho Elders. Red line represents stems per hectare of stands selected by foraging caribou in northern British Columbia (Terry *et al.*, 2001). Each grey circle represents total stems per hectare at each burned plot.

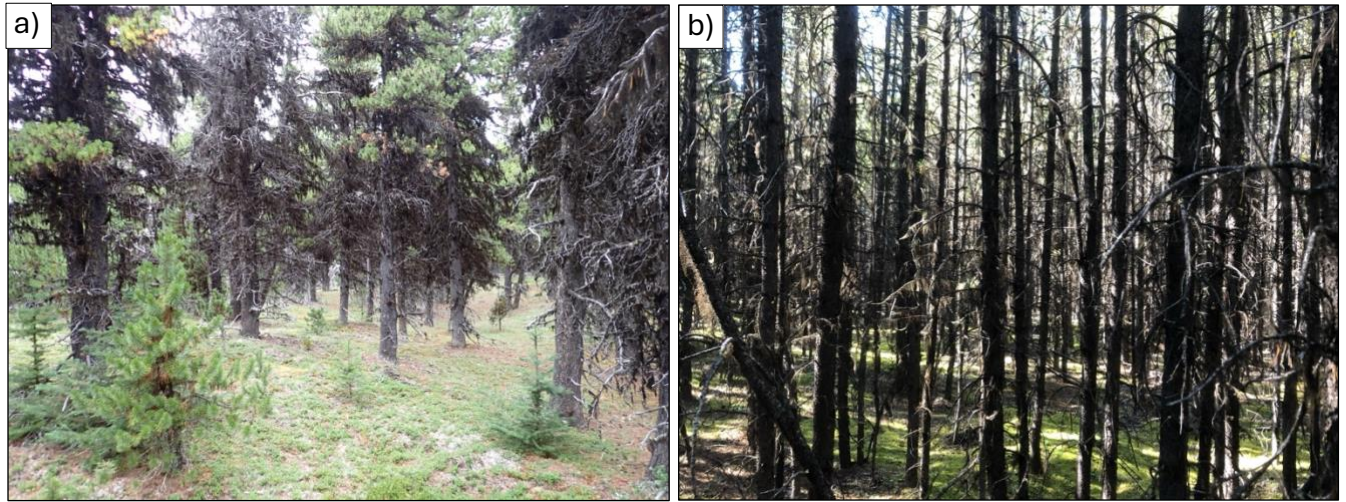


Figure 9

a) Lodgepole pine (chundoo, *Pinus contorta*) stand aged 149.3 years with a stem density of 1141 stems/ha in Ulkatcho territory, west-central British Columbia. b) Lodgepole pine stand 63 years after stand-replacing fire with a stem density of 9125 stems/ha in Ulkatcho territory, west-central British Columbia. Terrestrial caribou lichen abundance in this stand was statistically similar to controls of good caribou habitat identified by Ulkatcho Elders and community members.

severity based on remotely sensed imagery, were often along the burn perimeter and captured a mix of high-severity burn and unburned forest. Additionally, one limitation of dNBR is its dependence on pre-fire vegetation density. In homogeneous stands with sparse vegetation, such as lodgepole pine forests in Ulkatcho, dNBR may record areas of low severity even if the fire caused complete vegetation loss (Miller and Thode, 2007). We subsequently grouped ‘high severity’ and ‘low severity’ plots as ‘burned’ for the 2006 and 2010 study sites. Across all sampled fires, lodgepole pine cores were consistently aged within five years of the mean stand age at each burn, indicating some homogeneity in the occurrence of stand-replacing fire. Although lodgepole pine are often associated with stand-replacing fire, they may also display resistance to mixed- and low-severity burns (Zimmerman and Omi, 1998). We found multiple fire-scarred lodgepole pine trees across the study area, suggesting a history of mixed-severity fires in Ulkatcho.

Discussion

Lodgepole pine tree density may present a greater limiting factor for post-fire winter caribou habitat than lichen abundance

We found post-fire caribou lichen recovery takes at least 59 years after fire (Figure 6), consistent with the 40- 60-year recovery thresholds reported in similar studies (Thomas *et al.*, 1996; Joly *et al.*, 2003, 2007; Greuel *et al.*, 2021; Russell *et al.*, 2025). At this time however, lodgepole pine trees were up to eight times denser than forest structure of known winter selection by caribou (Terry *et al.*, 2001; Ulkatcho First Nation, 2024; Figure 8). By 87 years post-fire, stands remained four times denser than areas known to attract foraging caribou in the study area. Overly dense stands limit the ability of caribou to run freely and escape predators, while also reducing access to forage (Wilson *et al.*, 2023). High tree densities can also reduce the ability of

caribou to see predators and other herd members (Thomas *et al.*, 1996), meaning caribou may avoid dense stands resulting from fire (Cichowski, 1989; Goward *et al.*, 1999), even if lichen abundance is high (Thomas *et al.*, 1996). Few studies that assess post-fire caribou habitat consider stem density however, a significant influencer of habitat selection, and especially important in lodgepole pine stands due to their propensity to regenerate at high densities (Lotan *et al.*, 1985).

Our models indicate that lodgepole pine stands may take over 100 years after stand-replacing fire to reach preferred openness for caribou (Figure 8), many decades after terrestrial lichen recovery. This aligns with Goward *et al.* (1999), who speculated that only after a period of prolonged self-thinning, usually lasting 100-120 years, do lodgepole stands become open enough to attract foraging caribou in the Itcha-Ilgachuz range. We posit that the self-thinning of lodgepole pine, and the ability of caribou to evade predators and move freely, may be greater limiting factors for post-fire winter habitat recovery than lichen abundance in these stands. Although Apps and Dodd (2017) examine the use of recent burns (5-20 years) by caribou in the study area, we recommend further spatial analysis investigate longer post-fire habitat selection thresholds by these caribou. Our results here demonstrate that caribou habitat in the study area should be assessed holistically, largely as caribou themselves have a holistic view of habitat that balances predation risk alongside lichen availability (Thomas *et al.*, 1996; Gustine *et al.*, 2006; Avgar *et al.*, 2015; Derguy *et al.*, 2025).

Post-fire chrono-sequences of mosses and lichens

We found terrestrial caribou lichen cover to be negatively associated with competition from mosses ($p = 0.0038$). This was likely a result of greater competition for light and space at

these quadrats, with lichens struggling to compete when stand- and microsite-level conditions were more suitable for mosses. In lodgepole pine stands, lichens are positively associated with high-heat and high-light microsites with low-moisture (Haughian and Burton, 2015). Here they are able to better compete with desiccation-intolerant mosses (Sulyma and Coxson, 2001). Stand-level variables like canopy cover can therefore be a significant influencer of lichen and moss development by dictating light and moisture levels on the forest floor (Coxson and Marsh, 2001).

Predictably, we found caribou lichen cover to be negatively associated with residuals (unusually high values) of canopy cover ($p = 0.03304$). This was likely due to greater shading and reduced desiccation at these sites which favoured mosses (Sulyma and Coxson, 2001). Interestingly however, our interaction term for canopy cover and moss competition was not significant in reducing lichen cover, possibly due to model complexity and the use of residuals of canopy cover. It is important here to note that, while residualizing canopy cover allowed us isolate its effects from time since fire, this meant we were testing the effects of canopy cover relative to expected levels given time since fire, rather than absolute effects of raw canopy cover. Nonetheless, our results here were consistent with similar studies on the post-fire chronosequences of mosses and lichens in lodgepole pine stands (Sulyma and Coxson, 2001; Coxson and Marsh, 2001). In these studies, initial regeneration after stand-replacing fire was characterized by dense pine and the development of moss mats. When pine began to self-thin after 50 years, the opening of canopy led to decreases in forest floor humidity, enhancing *Cladonia* spp. growth and facilitating the start of a quasi ‘lichen age’ (Coxson and Marsh, 2001). Our models in the Ulkatcho study area found moss cover to grow steadily after fire and to peak at 50 years (Figure 4b) before declining as lodgepole pine self-thinned and canopy cover declined (Figure 4c). At this point, humidity levels on the forest floor likely decreased and we

captured the emergence of the subsequent ‘lichen age’ 60-90 years after fire (Figure 6), with quadrats at this burn age-class containing higher abundance (~7% to ~20%) of *Cladonia* spp. lichens.

The role of stand-replacing fire in re-establishing optimal winter caribou habitat

The period of lichen dominance in post-fire lodgepole pine stands may last from 80 to 150 years post-fire (Coxson and Marsh, 2001). After this time, basal area and canopy cover of mature pine increases and mosses once again dominate the forest floor, persisting until the next stand replacing event (Coxson and Marsh, 2001). This indicates that there is a limited period in mid-late seral stands where caribou lichen forage is optimal. Given the importance of stand openness for caribou, this window may only last for 30-50 years, beginning when pine have self-thinned and ending when canopy cover of mature trees closes. Stand-replacing fire may therefore be key in re-establishing these windows of optimal winter forage in mid-late seral stands (Klein 1982; Schaefer, 1988; Schaefer and Pruitt, 1991). Although our 90-year sampling history was too short to capture the importance of fire across such timescales, we did capture the negative effect of canopy cover and moss competition on the abundance of caribou lichens (Table 2). If the stands we sampled reach late-seral maturity, increases in canopy cover post-thinning may lead to stand-level conditions more suitable for mosses, driven by greater shading on the forest floor. Without stand-replacing fire therefore, these mature lodgepole stands may persist in a closed-canopy, moss-dominant phase (Coxson and Marsh, 2001) that likely provides little benefit to foraging caribou. This supports the notion that caribou and their habitat in Ulkatcho are fire-influenced (Bergerud, 1974; Klein 1982; Goward *et al.*, 1999). Given that many other herds in the Southern Mountain population rely on stands of subalpine fir and spruce (Environment

Canada, 2014), where fire return intervals are typically greater (260-500 years; Veblen, 1991; Robertus *et al.*, 1992) than for lodgepole pine (75-125 years; British Columbia Ministry of Forests, 2022), it is also likely that caribou in Ulkatcho have been influenced by fire more so than other herds in the Southern Mountain population, such is their dependence on mature lodgepole pine stands (Cichowski, 1993; Apps and Dodd, 2017; Ulkatcho First Nation, 2024; Figure 2). However, the frequency of fires impacting these caribou is changing (Canadian National Fire Database, n.d.) and may have caused pronounced increases in herd-level migration distance (~14 kilometers per decade since 1984) (Lamb *et al.*, 2025). Further, recent increases in fire size and frequency may have caused changes in caribou-wolf interactions by benefitting apparent competition species such as moose (Bergerud, 1974).

The effects of vascular plants on caribou lichens

Our hurdle model also revealed caribou lichens to be strongly negatively associated with competition from vascular plants ($p < 0.001$; Table 2). Similar to mosses, this was likely caused by high levels of competition for space and light on the forest floor when conditions were more favourable for vascular plants. In lodgepole pine stands, lichens develop on nutrient-poor sites where nutrient-dependent plants are typically less successful (Haughian and Burton, 2015). Even after stand-replacing fire, soil nutrients can recover quickly (Smithwick *et al.*, 2009) and the growth of vascular plants may become self-perpetuating, with the decomposition of plant matter replenishing nutrients in the organic layer that lead to continued plant growth (Forero *et al.*, 2021). Combined with the removal of canopy cover, vascular plant growth can suppress the initial recovery of caribou lichens (Kershaw, 1977), an effect that likely occurred in the study area. We found high levels of vascular plant competition at early post-fire seral stages (Figure

4a), possibly due to the removal of canopy cover and a potential flush of nutrients. Only when canopy cover opened at 50 years after fire (Figure 4c), and after mosses had prevailed over vascular plants (Figure 4b), were lichens able to establish in greater abundance. Here lichens probably benefitted from drier forest floor conditions and the nutrient-poor soils left behind by the preceding period of moss dominance (Koranda and Michelson, 2020) that prevented vascular plants from re-establishing.

Importantly, our methods – including our Bayesian hurdle models - did not capture the effects of soil nutrients on the development of mosses, vascular plants or lichens, despite being known to dictate the competitive effects of vascular plants on caribou lichens (Haughian and Burton, 2015). Our results may also be limited by the small number of sites sampled per burn age-class (Russell and Johnson, 2019). Here we recognize that our sample size of five historical fires substantially restricts the modelling power of our data. Our modelling approach was therefore designed to be robust and modest in its predictions and used available stand-level covariates to make use of within-fire variation. However, without including a larger sample of fires, we cannot confidently generalize recovery trajectories outside of the study area. Even within Ulkatcho, our analysis should be interpreted as a preliminary estimate of lichen recovery, useful for informing local management but not definitive. Given the high number of potential fires that were dropped during site selection due to logging and repeat burns, it is worth noting that there were very few fires within Ulkatcho that met our required burn-age classes that we did not sample. The 1937 site for example, was the only burn within the 71-90 age-class that we could verify had not been disturbed since the initial fire. Nonetheless, our analysis provides UFN with an interpretive estimate of the time since fire recovery trajectory of caribou lichens, while assessing some of the stand-level covariates affecting this recovery. Such is the importance of

microhabitat conditions on the development of plants, mosses, and lichens (Haughian and Burton, 2015), future studies should also aim to integrate finer-scale covariates, such as soil nutrients and moisture, slope, and aspect to better understand the factors affecting lichen recovery in these stands.

Thinking like a caribou and the recovery of high-quality forage sites

During the dominant stage of lichen development, lichen ‘supercolonies’ become increasingly abundant (Goward *et al.*, 1999; Coxson and Marsh, 2001) and provide wintering caribou in the study area with high-biomass forage (Cichowski, 1989). Our “Think Like A Caribou” methods captured the recovery of these high-quality forage sites by simulating caribou forage selection within each plot (Figure 6). Here we found the earliest statistical convergence of high-quality forage sites with unburned controls at 74 years after fire, 15 years later than stand-level lichen recovery (Figure 6). This is significant for caribou as it is these sites of dense, high-biomass lichens that are the target of winter cratering (Cichowski, 1989). These sites are likely more valuable to caribou than broadly distributed stand-level lichen abundance because they provide a more efficient ratio of energy expenditure to carbohydrates acquired (Fancy and White, 1985) and are likely easier to smell underneath snowpack (Bergerud and Nolan, 1970). The longer recovery of these high-quality sites was expected given that they require more time and more open stand structure to develop (Coxson and Marsh, 2001). Foraging caribou may also accelerate the growth of these supercolonies by trampling and fragmenting lichens, leading to the development of supercolonies of preferred species for caribou (Goward, 1999). This of course requires the return of caribou to post-burn stands however, and our models found recovery of

high-quality forage sites to occur before stands reached what is likely preferable openness for caribou.

Importantly, our ‘Think Like A Caribou’ method did not fully account for differences in the frequency of high-quality forage sites between burned and unburned plots. Instead, sampling was limited to a single high-quality forage site per plot, regardless of whether more were present. Given that high-quality forage sites were more frequent in unburned control plots, we expect the true recovery of these sites takes longer than 74 years. Nonetheless, our attempts to think more qualitatively about caribou behavior received positive feedback from Ulkatcho research assistants, especially Ulkatcho youth. We encourage future research to supplement the modelling assumption that caribou forage within randomly placed, equidistant quadrats by integrating a more caribou-centric sampling design. Not only did this enhance our habitat modelling framework but also allowed for greater collaboration with Ulkatcho knowledge systems.

Lodgepole pine host arboreal lichens as early as 40-years after stand-replacing fire

Although commonly perceived to be more reliant on terrestrial lichens, caribou in Ulkatcho often forage for arboreal lichens, especially *Bryoria* spp., in winter (Cichowski, 1993; Ulkatcho First Nation, 2024). These lichens can establish in lodgepole pine stands much sooner than other conifer species, with lodgepole stands at 60 years studied to host *Bryoria* spp. loadings that other conifers require 120 to 150 years to develop (Edwards *et al.*, 1960; Stevenson *et al.*, 2001). Our results found *Bryoria* spp. lichens had homogenously colonized lodgepole pine trees as early as 40 years after stand-replacing fire (Figure 7), although the abundance at this stage was likely insufficient to attract caribou. The rapid establishment of *Bryoria* spp. in lodgepole stands is likely a product of lodgepole pine’s unique branch architecture, defoliation

patterns, and canopy closure that combine to create optimal drying cycles for these lichens (Stevenson, 1985; Goward, 1998; Bäcklund *et al.*, 2016; Goward *et al.* 2022).

Our mixed methods approach to measuring arboreal lichens allowed us to quantitatively assess lichen abundance while observing patterns of lichen establishment (why and where are these lichens present?). In our field notes, two observations became apparent: (1) *Bryoria* spp. was most abundant on the defoliated inner branch of lodgepole pine and (2) lodgepole pine growing at high densities had fewer branches within 3 meters of the ground (caribou winter reach). Observation 1 is typical of the development of arboreal lichens in conifer forests, in which the loss of needles in the inner concentric zone of the tree creates suitable wetting-drying cycles for *Bryoria* spp. to establish (Goward, 1998; Goward *et al.*, 2024). Observation 2 may have more implications for caribou. In dense stands resulting from fire, lodgepole pine may lose almost all their lower branches (Eversman *et al.*, 2002), leaving few sites for arboreal lichens to establish. These lower branches rarely grow back as the tree matures, meaning trees from the initial cohort after fire may carry less lichen-carrying branches available to caribou than trees from the secondary cohort that grew under more open conditions after self-thinning. This suggests that stages of succession, and the opening of dense stands can influence the quality and availability of arboreal lichen forage for caribou in post-fire lodgepole pine stands.

Conclusions

Our study highlights the dynamic interactions between forest structure, successional stage, and forage quality that shape post-fire winter caribou habitat in Ulkatcho. While stand-level terrestrial lichen recovery occurs within 60 years, structural constraints of high stem densities may persist for decades after, possibly delaying habitat suitability for caribou despite

lichen abundance. At smaller scales, mosses, canopy cover, and vascular plant competition influence lichen development. Our results strongly suggest that post-fire caribou habitat recovery is not just a function of lichen abundance, but also depend on stand openness, microhabitat conditions, and the distribution and accessibility of high-quality forage sites. Integrating Ulkatcho ecological knowledge was essential to understanding how caribou in the study area perceive and use habitat over time, offering invaluable guidance to our research approach. We recommend that future caribou habitat assessments in these forests employ holistic approaches to habitat recovery that integrate Ulkatcho ecological knowledge (Parlee and Caine, 2018) alongside metrics of stand density and forage quality. This integrated, holistic framework is critical in the context of a changing fire regime and declining caribou populations.

Acknowledgements

The student author of this study, who is of European descent, recognizes the inability of the English language to communicate the ecological knowledge described in this paper. Only Dakelh can effectively transmit the ecological relationships present within Ulkatcho territory. Out of respect for this, I use the Dakelh names for each plant and animal species when its presence in Ulkatcho is first referenced. I use the English name thereafter to allow comparison with studies that occurred outside of Ulkatcho territory. I wish to thank all members of the Ulkatcho Community. Funding for this project was provided by BC Parks Living Labs, Ulkatcho Community, Mitacs, and a NSERC Discovery Grant to Harvey.

References

- Adams, L. G., Singer, F. J., & Dale, B. W. (1995). Caribou calf mortality in Denali National Park, Alaska. *The Journal of Wildlife Management*, 59(3), 584–594. <https://doi.org/10.2307/3802467>
- Appelquist, M. B. (1958). A simple pith locator for use with off-center increment cores. *Journal of Forestry*, 56(2), 141.
- Apps, C. D., Kinley, T. A., & Young, J. A. (2001). Multi-scale habitat modeling for woodland caribou in the Itcha, Ilgachuz, and Rainbow mountains of west-central British Columbia. British Columbia Ministry of Environment, Lands and Parks.
- Apps, C., & Dodd, N. (2017). Caribou habitat modelling and evaluation of forest disturbance influences across landscape scales in west-central BC. Ministry of Forests, Lands and Natural Resource Operations.
- Avgar, T., Baker, J. A., Brown, G. S., Hagens, J. S., Kittle, A. M., Mallon, E. E., McGreer, M. T., Mosser, A., Newmaster, S. G., Patterson, B. R., Reid, D. E. B., Rodgers, A. R., Shuter, J., Street, G. M., Thompson, I., Turetsky, M. J., Wiebe, P. A., & Fryxell, J. M. (2015). Space-use behaviour of woodland caribou based on a cognitive movement model. *Journal of Animal Ecology*, 84(4), 1059–1070. <https://doi.org/10.1111/1365-2656.12357>
- Bäcklund, S., Jönsson, M., Strengbom, J., Frisch, A., & Thor, G. (2016). A pine is a pine and a spruce is a spruce—The effect of tree species and stand age on epiphytic lichen communities. *PLOS ONE*, 11(1), e0147004. <https://doi.org/10.1371/journal.pone.0147004>
- Bhattacharyya, J., & Slocombe, S. (2017). Animal agency: Wildlife management from a kincentric perspective. *Ecosphere*, 8(10), Article e01978. <https://doi.org/10.1002/ecs2.1978>
- Bergerud, A. T. (1974). Decline of caribou in North America following settlement. *Journal of Wildlife Management*, 38(4), 757–770. <https://doi.org/10.2307/3800042>
- Bergerud, A. T. (1996). Evolving perspectives on caribou population dynamics: Have we got it right yet? *Rangifer*, 16, 95–115. <https://doi.org/10.7557/2.16.4.1225>
- Bergerud, A. T., & Nolan, M. J. (1970). Food habits of hand-reared caribou (*Rangifer tarandus* L.) in Newfoundland. *Oikos*, 21(2), 348–350. <https://doi.org/10.2307/3543960>
- Bergerud, A. T., & Page, R. E. (1987). Displacement and dispersion of parturient caribou at calving as antipredator tactics. *Canadian Journal of Zoology*, 65(7), 1597–1606. <https://doi.org/10.1139/z87-249>
- British Columbia Ministry of Forests. (2022). Best Management Practice Guide for Fuel Treatment: Central Plateau Fire Weather Zone. Government of British Columbia. https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/wildfire-status/prevention/fire-fuel-management/fuels-management/central_plateau_fire_weather_zone_for_review.pdf

- Brooks, M. E., Kristensen, K., van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Maechler, M., & Bolker, B. M. (2017). glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *The R Journal*, 9(2), 378–400. <https://doi.org/10.32614/RJ-2017-066>
- Bürkner, P.-C. (2017). brms: An R package for Bayesian multilevel models using Stan. *Journal of Statistical Software*, 80(1), 1–28. <https://doi.org/10.18637/jss.v080.i01>
- Caribou Recovery Program. (2023). 2023 status of BC caribou herds. https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/bc_caribou_herds_population_estimates.pdf
- Cichowski, D. (1989). Seasonal movements, habitat use, and winter feeding ecology of woodland caribou in west-central British Columbia [Master's thesis, University of British Columbia]. <https://open.library.ubc.ca>
- Cichowski, D. (1993). Seasonal movements, habitat use, and winter feeding ecology of woodland caribou in west-central BC. <https://www.for.gov.bc.ca/hfd/pubs/Docs/Mr/Lmr/Lmr079.pdf>
- Cichowski, D. (2015). Tweedsmuir-Entiako caribou population status and background information summary. https://a100.gov.bc.ca/pub/acat/documents/r55188/TweedsmuirCaribouPopulationStatusandBackgroundInf_1542742511092_2741941772.pdf
- COSEWIC. (2014). COSEWIC assessment and status report on the Caribou (*Rangifer tarandus*), Southern Mountain population, in Canada. Committee on the Status of Endangered Wildlife in Canada. https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/cosewic/sr_Caribou_Southern_Mountain_2014_e.pdf
- Coxson, D. S., & Marsh, J. (2001). Lichen chronosequences (postfire and postharvest) in lodgepole pine (*Pinus contorta*) forests of northern interior BC. *Canadian Journal of Botany*, 79(12), 1449–1464. <https://doi.org/10.1139/b01-127>
- Denryter, K. A., Cook, R. C., Cook, J. G., & Parker, K. L. (2017). Straight from the caribou's mouth: Dietary monoterpenes and their implications for a declining boreal ungulate. *Canadian Journal of Zoology*, 95(12), 885–895. <https://doi.org/10.1139/cjz-2016-0114>
- Derguy, L., Leblond, M., & St-Laurent, M.-H. (2025). Living in fear: How experience shapes caribou responses to predation risk. *Ecosphere*, 16(1), e07155. <https://doi.org/10.1002/ecs2.70155>
- Dickie, M., Serrouya, R., DeMars, C., Cranston, J., & Boutin, S. (2017). Evaluating functional recovery of habitat for threatened woodland caribou. *Ecosphere*, 8(9), e01936. <https://doi.org/10.1002/ecs2.1936>
- Dodd, N. (2017). Unpublished summary. BC Ministry of Forests, Lands and Natural Resource Operations, Williams Lake, BC.
- Dormann, C. F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., García Márquez, J. R., Gruber, B., Lafourcade, B., Leitão, P. J., Münkemüller, T., McClean, C. J., Osborne, P. E., Reineking, B., Schröder, B., Skidmore, A. K., Zurell, D., & Lautenbach, S. (2013).

- Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. *Ecography*, 36(1), 27–46. <https://doi.org/10.1111/j.1600-0587.2012.07348.x>
- Edwards, R. Y., Ritcey, R. W., & Flood, B. C. (1960). Reproduction in the caribou (*Rangifer tarandus*). *Journal of Mammalogy*, 41(4), 523–535.
- Ehlers, L. P., Johnson, C. J., & Seip, D. R. (2016). Evaluating the influence of anthropogenic landscape change on wolf distribution: Implications for woodland caribou. *Ecosphere*, 7(12), e01600. <https://doi.org/10.1002/ecs2.1600>
- Environment Canada. (2014). Recovery strategy for the woodland caribou, Southern Mountain population (*Rangifer tarandus caribou*) in Canada. https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/rs_woodland%20caribou_bois_s_mtn_0614_e.pdf
- Esseen, P. A. (1981). Host specificity and ecology of epiphyte macrolichens in some central Swedish spruce forests. *Wahlenbergia*, 7, 73–80.
- Eversman, S., Knight, R. L., McEwen, L. C., & Redente, E. F. (2002). Patterns of lichen diversity in Yellowstone National Park. *The Bryologist*, 105(1), 27–42. [https://doi.org/10.1639/0007-2745\(2002\)105\[0027:POLDIY\]2.0.CO;2](https://doi.org/10.1639/0007-2745(2002)105[0027:POLDIY]2.0.CO;2)
- Fancy, S. G., & White, R. G. (1985). Energy expenditures by caribou while cratering in snow. *The Journal of Wildlife Management*, 49(4), 987–993. <https://doi.org/10.2307/3801384>
- Forero, L. E., Kulmatiski, A., Grenzer, J., & Norton, J. M. (2021). Plant–soil feedbacks help explain biodiversity–productivity relationships. *Communications Biology*, 4, 789. <https://doi.org/10.1038/s42003-021-02329-1>
- Gharajehdaghipour, T. (n.d.). [*Unpublished map of Itcha-Ilgachuz calving locations*]. Unpublished data.
- Government of Canada. (2002). COSEWIC assessment and update status report on the woodland caribou (*Rangifer tarandus caribou*) in Canada. Committee on the Status of Endangered Wildlife in Canada. https://www.sararegistry.gc.ca/virtual_sara/files/cosewic/sr_woodland_caribou_e.pdf
- Goward, T. (1998). Observations on the ecology of the lichen genus *Bryoria* in high elevation conifer forests. *Canadian Field-Naturalist*, 112(3): 496–501 https://www.waysofenlichenment.net/public/pdfs/Goward_1998_Bryoria_ecology.pdf
- Goward, T. (1999). Fire, terrestrial lichens, and the Itcha-Ilgachuz caribou. University of British Columbia. <https://www.env.gov.bc.ca/wld/documents/mc09goward2.pdf>
- Goward, T., & Campbell, J. (2005). Arboreal hair lichens in a young, mid-elevation conifer stand, with implications for the management of mountain caribou. *The Bryologist*, 108(3), 427–434. <https://www.jstor.org/stable/20061123>

- Goward, T., Burgess, D., Miège, D., & Armleder, H. (1999). Assessment of terrestrial woodland lichens in the sub-boreal pine spruce zone (SBPSxc) [Unpublished report]. B.C. Ministry of Forests, Cariboo Forest Region.
- Goward, T., Coxson, D. S., Gauslaa, Y., Esseen, P. A., & Resler, L. M. (2022). Stand openness predicts hair lichen (*Bryoria*) abundance in the lower canopy, with implications for the conservation of Canada's critically imperiled Deep-Snow Mountain Caribou (*Rangifer tarandus caribou*). *Forest Ecology and Management*, 512, 120148. <https://doi.org/10.1016/j.foreco.2022.120148>
- Goward, T., Coxson, D. S., & Gauslaa, Y. (2024). The manna effect: A review of factors influencing hair lichen abundance for Canada's endangered Deep-Snow Mountain Caribou (*Rangifer arcticus montanus*). *The Lichenologist*, 56(2), 139–155. <https://doi.org/10.1017/S0024282924000161>
- Greuel, R. J., Degré-Timmons, G. É., Baltzer, J. L., Johnstone, J. F., McIntire, E. J. B., Day, N. J., Hart, S. J., McLoughlin, P. D., Schmiegelow, F. K. A., Turetsky, M. R., Truchon-Savard, A., van Telgen, M. D., & Cumming, S. G. (2021). Predicting patterns of terrestrial lichen biomass recovery following boreal wildfires. *Ecosphere*, 12(4), e03481. <https://doi.org/10.1002/ecs2.3481>
- 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), 1–32. [https://doi.org/10.2193/0084-0173\(2006\)165\[1:CSOWCI\]2.0.CO;2](https://doi.org/10.2193/0084-0173(2006)165[1:CSOWCI]2.0.CO;2)
- Gustine, D. D., Brinkman, T. J., Lindgren, M. A., Schmidt, J. I., Rupp, T. S., & Adams, L. G. (2014). Climate-driven effects of fire on winter habitat for caribou in the Alaskan–Yukon Arctic. *PLoS ONE*, 9(7), Article e100588. <https://doi.org/10.1371/journal.pone.0100588>
- Griffiths, F. (2011). Modelling the population dynamics of the Itcha-Ilgachuz caribou herd to determine the effects of removals for translocation (Master's thesis). Simon Fraser University.
- Haughian, S. R., & Burton, P. J. (2015). Microhabitat associations of lichens, feathermosses, and vascular plants in a caribou winter range, and their implications for understory development. *Botany*, 93(4), 221–231. <https://doi.org/10.1139/cjb-2014-0238>
- Hanes, C. C., Wang, X., Jain, P., Parisien, M. A., Little, J. M., & Flannigan, M. D. (2019). Fire-regime changes in Canada over the last half-century. *Canadian Journal of Forest Research*, 49(3), 256–269. <https://doi.org/10.1139/cjfr-2018-0293>
- Hebblewhite, M. (2017). Billion dollar boreal woodland caribou and the biodiversity impacts of the global oil and gas industry. *Biological Conservation*, 206, 102–111. <https://doi.org/10.1016/j.biocon.2016.12.014>
- Hebblewhite, M., Whittington, J., Bradley, M., Skinner, G., Dibb, A., & White, C. A. (2007). Conditions for caribou persistence in the wolf-elk-caribou systems of the Canadian Rockies. *Rangifer*, 27(4), 35–50. <https://doi.org/10.7557/2.27.4.322>
- Hebda, R. J., Turner, N. J., Birchwater, S., Kay, M., & The Elders of Ulkatcho. *Ulkatcho Food and Medicine Plants*. Williams Lake, BC: Progressive Printers Inc.

- Holleman, D. F., & Luick, J. R. (1977). Lichen species preference by reindeer. *Canadian Journal of Zoology*, 55(9), 1368–1371. <https://doi.org/10.1139/z77-177>
- Hummel, M., & Ray, J. C. (2008). *Caribou and the North: A shared future*. Dundurn Press.
- 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. <https://doi.org/10.1016/j.biocon.2015.03.012>
- Joly, K., Dale, B. W., Collins, W. B., & Adams, L. G. (2003). Winter habitat use by female caribou in relation to wildland fires in interior Alaska. *Canadian Journal of Zoology*, 81(7), 1192–1201. <https://doi.org/10.1139/z03-109>
- Joly, K., Bente, P., & Dau, J. (2007). Response of overwintering caribou to burned habitat in northwest Alaska. *Arctic*, 60(4), 401–410. <https://doi.org/10.14430/arctic197>
- Kershaw, K. A. (1977). Studies on lichen-dominated systems. XX. An examination of some aspects of the northern boreal lichen woodlands in Canada. *Canadian Journal of Botany*, 55(4), 393–410. <https://doi.org/10.1139/b77-050>
- Key, C. H., & Benson, N. C. (2006). Landscape Assessment (LA) ground measure of severity, the composite burn index; and remote sensing of severity, the normalized burn ratio. In D. C. Lutes et al. (Eds.), *FIREMON: Fire effects monitoring and inventory system* (pp. LA1–LA51). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. <https://doi.org/10.2737/RMRS-GTR-164>
- Kinley, T. A. (2010). Augmentation plan for the Purcells-South mountain caribou population. British Columbia Ministry of Environment. Retrieved from https://www.env.gov.bc.ca/wld/speciesconservation/mc/files/Augmentation_Plan_for_the_Purcell_South_Population.pdf
- Klein, D. R. (1982). Fire, lichens, and caribou. *Journal of Range Management*, 35(3), 390–395. <https://doi.org/10.2307/3898658>
- Koranda, M., & Michelsen, A. (2020). Mosses reduce soil nitrogen availability in a subarctic birch forest via effects on soil thermal regime and sequestration of deposited nitrogen. *Journal of Ecology*, 109(3), 1424–1438. <https://doi.org/10.1111/1365-2745.13567>
- Kuehn, C. (2014). A Second North American hot-spot: Pleistocene volcanism in the Anahim Volcanic Belt, west-central British Columbia (Doctoral thesis, University of Calgary, Calgary, Canada). PRISM Repository. <https://hdl.handle.net/11023/1936https://doi.org/10.11575/PRISM/25002>
- Lamb, C. T., Williams, S., Boutin, S., Bridger, M., Cichowski, D., Cornhill, K., DeMars, C., Dickie, M., Ernst, B., Ford, A., Gillingham, M. P., Greene, L., Heard, D. C., Hebblewhite, M., Hervieux, D., Klaczek, M., McLellan, B. N., McNay, R. S., Neufeld, L., & Serrouya, R. (2024). Effectiveness of population-based recovery actions for threatened southern mountain caribou. *Ecological Applications*, 34(4), e2965. <https://doi.org/10.1002/eap.2965>

- Lamb, C. T., Steenweg, R., Serrouya, R., Hervieux, D., McNay, R. S., Heard, D. C., McLellan, B. N., Shores, C., Palm, E., Giguere, L., Hubner, J., Polfus, J., Klaczek, M., Crosland, N., White, S., Russell, M., & Ford, A. T. (2025). The erosion of threatened southern mountain caribou migration. *Global Change Biology*. <https://doi.org/10.1111/gcb.17095>
- Lotan, J. E., Brown, J. K., & Neuenschwander, L. F. (1985). Role of fire in lodgepole pine forests. In D. M. Baumgartner, R. G. Krebill, J. T. Arnott, & G. F. Weetman (Eds.), *Lodgepole pine: The species and its management* (pp. 133–152). Washington State University, Office of Conferences and Institutes.
- McLoughlin, P. D., Dzus, E., Wynes, B., & Boutin, S. (2003). Declines in populations of woodland caribou. *The Journal of Wildlife Management*, 67(4), 755–761. <https://doi.org/10.2307/3802682>
- Meidinger, D., & Pojar, J. (Eds.). (1991). *Ecosystems of British Columbia*. British Columbia Ministry of Forests, Special Report Series No. 6.
- Miller, J. D., & Thode, A. E. (2007). Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). *Remote Sensing of Environment*, 109(1), 66–80. <https://doi.org/10.1016/j.rse.2006.12.013>
- Parisien, M.-A., Barber, Q. E., Bourbonnais, M. L., Daniels, L. D., Flannigan, M. D., Gray, R. W., Hoffman, K. M., Jain, P., Stephens, S. L., Taylor, S. W., & Whitman, E. (2023). Abrupt, climate-induced increase in wildfires in British Columbia since the mid-2000s. *Communications Earth & Environment*, 4, Article 309. <https://doi.org/10.1038/s43247-023-00977-1>
- Parlee, B., & Caine, K. (2018). *When the caribou do not come: Indigenous knowledge and adaptive management in the Western Arctic*. UBC Press.
- Parks, S. A., Holsinger, L. M., Voss, M. A., Loehman, R. A., & Robinson, N. P. (2018). Mean composite fire severity metrics computed with Google Earth Engine offer improved accuracy and expanded mapping potential. *Remote Sensing*, 10(6), 879. <https://doi.org/10.3390/rs10060879>
- Rebertus, A. J., Veblen, T. T., & Roovers, L. M. (1992). Fire-induced changes in forest structure in the Colorado Front Range. *Journal of Vegetation Science*, 3(4), 507–516. <https://doi.org/10.2307/3235806>
- Russell, K. L. M., & Johnson, C. J. (2019). Post-fire dynamics of terrestrial lichens: Implications for the recovery of woodland caribou winter range. *Forest Ecology and Management*, 434, 1–16. <https://doi.org/10.1016/j.foreco.2018.12.033>
- Russell, K. L. M., Johnson, C. J., & Hegel, T. M. (2025). Importance of scale, season, and forage availability for understanding the use of recent burns by woodland caribou during winter. *Canadian Journal of Forest Research*, 55(1), 45–56. <https://doi.org/10.1139/cjfr-2024-0284>
- Salmon, E. (2000). Kincentric ecology: Indigenous perceptions of the human-nature relationship. *Ecological Applications*, 10(5), 1327–1332. [https://doi.org/10.1890/1051-0761\(2000\)010\[1327:KEIPOT\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2000)010[1327:KEIPOT]2.0.CO;2)

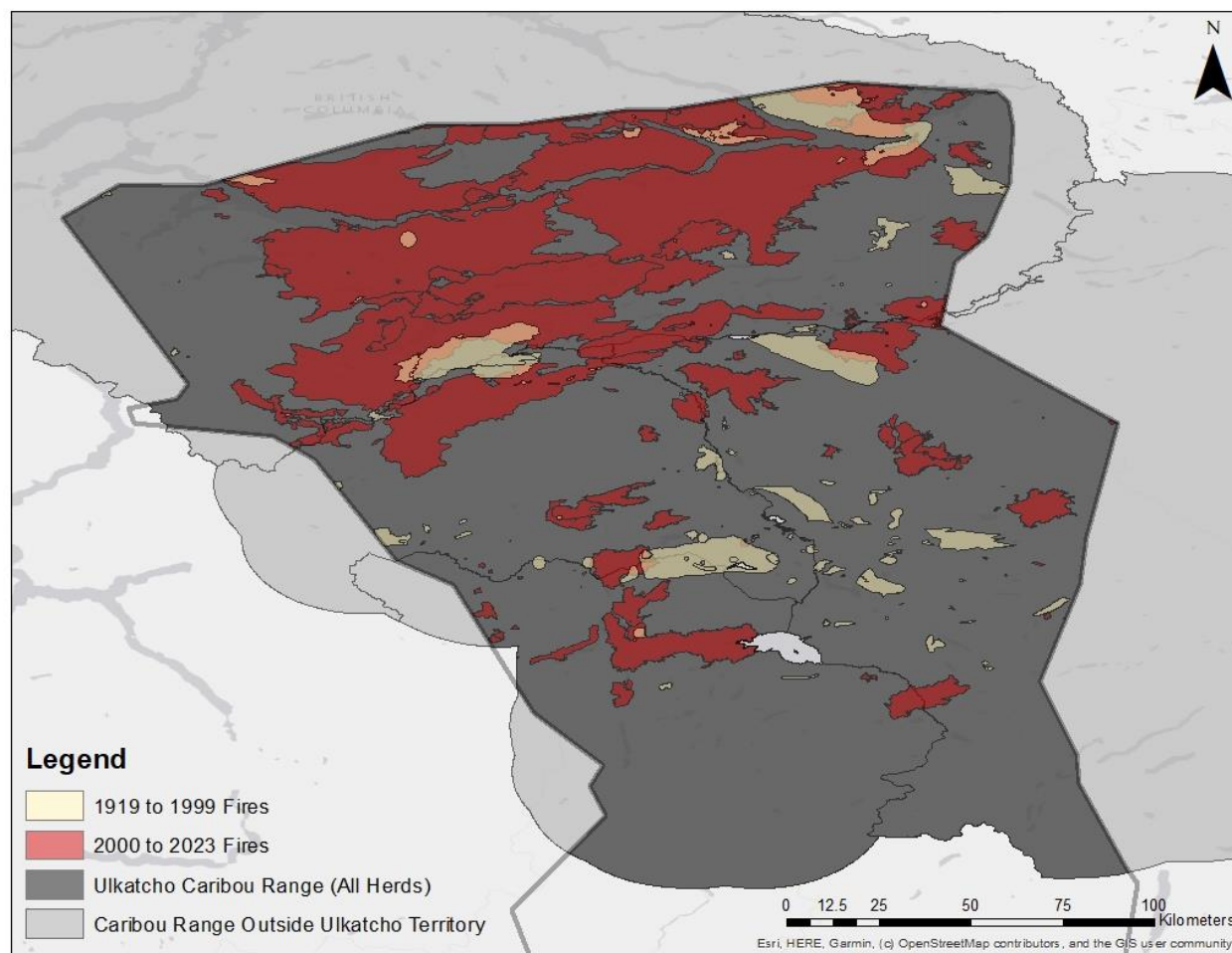
- Schaefer, J. A., & Pruitt, W. O. Jr. (1991). Fire and woodland caribou in southeastern Manitoba. *Wildlife Monographs*, 116, 3–39
- Schaefer, J. A. (1988). Fire and woodland caribou (*Rangifer tarandus caribou*): An evaluation of range in southeastern Manitoba (Master's thesis, University of Manitoba).
- Seip, D. R., & Cichowski, D. B. (1994). Population ecology of caribou in BC. *Rangifer*, 9, 73–80. <https://doi.org/10.7557/2.16.4.1223>
- Sharp, H. S., & Sharp, K. (2015). *Hunting caribou: Subsistence hunting along the northern edge of the boreal forest*. University of Nebraska Press. <https://doi.org/10.2307/j.ctt1d9nhpn>
- Smithwick, E. A. H., Kashian, D. M., Ryan, M. G., & Turner, M. G. (2009). Long-term nitrogen storage and soil nitrogen availability in post-fire lodgepole pine ecosystems. *Ecosystems*, 12(5), 792–806. <https://doi.org/10.1007/s10021-009-9265-2>
- Stevenson, S. K. (1985). Enhancing the establishment and growth of arboreal forage lichens in intensively managed forests: Problem analysis. British Columbia Ministry of Forests.
- Stevenson, S. K., Armleder, H. M., & Jull, M. J. (2001). Mountain caribou in managed forests: Recommendations for managers (2nd ed.). British Columbia Ministry of Environment, Lands and Parks.
- Sulyma, R., & Coxson, D. S. (2001). Microsite displacement of terrestrial lichens by feather moss mats in late seral pine-lichen woodlands of north-central British Columbia. *The Bryologist*, 104(4), 505–516. [https://doi.org/10.1639/0007-2745\(2001\)104\[0505:MDOTLB\]2.0.CO;2](https://doi.org/10.1639/0007-2745(2001)104[0505:MDOTLB]2.0.CO;2)
- Terry, E. L., McLellan, B. N., Watts, G. S., & Flaa, J. P. (2001). Early winter habitat use by mountain caribou in the North Cariboo and Columbia Mountains, British Columbia. *Rangifer*, 21(Special Issue No. 14), 133–140. <https://doi.org/10.7557/2.21.5.1726>
- Thomas, D. C., Barry, S. J., & Alaie, G. (1996). Fire-caribou-winter range relationships in northern Canada. *Rangifer*, 16(2), 57–67. <https://doi.org/10.7557/2.16.2.1198>
- Veblen, T. T., Hadley, K. S., Reid, M. S., & Rebertus, A. J. (1991). Disturbance and stand development of a Colorado subalpine forest. *Journal of Biogeography*, 18(6), 707–716. <https://doi.org/10.2307/2845552>
- Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. Springer-Verlag. <https://ggplot2.tidyverse.org>
- Wilson, S. F., Nudds, T. D., Green, P. E. J., & de Vries, A. (2023). Effect of forest understorey stand density on woodland caribou (*Rangifer tarandus caribou*) habitat selection. *Canadian Journal of Forest Research*, 53(8), 1012–1023. <https://doi.org/10.1139/cjfr-2023-0105>
- Wittmer, H. U., Sinclair, A. R. E., & McLellan, B. N. (2005). The role of predation in the decline and extirpation of woodland caribou. *Oecologia*, 144(2), 257–267. <https://doi.org/10.1007/s00442-005-0055-y>

- Wood, S. N. (2017). Generalized additive models: An introduction with R (2nd ed.). Chapman and Hall/CRC.
- Wotton, B. M., Flannigan, M. D., & Marshall, G. A. (2017). Potential climate change impacts on fire intensity and key wildfire suppression thresholds in Canada. *Environmental Research Letters*, 12(9), 095003. <https://doi.org/10.1088/1748-9326/aa7e6e>
- Young, J. A., Youds, J. A., & Freeman, N. L. (2001). Status of Charlotte Alplands caribou herd: A successful short distance caribou transplant. https://www.env.gov.bc.ca/cariboo/env_stewardship/wildlife/inventory/caribou/northcar/charalp/charalp01.pdf
- Zimmerman, G. T., & Omi, P. N. (1998). Fire restoration options in lodgepole pine ecosystems. In T. L. Pruden & L. A. Brennan (Eds.), *Fire in ecosystem management: Shifting the paradigm from suppression to prescription* (pp. 285–297). Tall Timbers Research Station.

Appendix 1

The final report on these relocations concluded that “discussions should be initiated with local First Nations Bands to encourage them not to harvest caribou from this herd for sustenance use.” (Young *et al.*, 2001). Proposals to relocate Itcha-Ilgachuz caribou 700km east to the Purcell Mountains occurred throughout the 2000’s (Kinley, 2010; Griffiths, 2011) infringing on Ulkatcho hunting rights and rights to subsistence. These proposals were rejected by UFN and the Ulkatcho voluntarily withdrew their rights to hunt caribou in 2019 after Indigenous harvest became non-viable.

Appendix 2



Map showing all fires within Ulkatcho caribou range between 1919 and 2023. Between 2000 and 2023, 32% of caribou range in Ulkatcho territory, west-central British Columbia, burned. In the 80 years between 1919 and 1999, this figure was 6.5%. Fire polygons obtained from the Canadian National Fire Database. Caribou herd boundaries obtained from the British Columbia Provincial Caribou Recovery Project.

Appendix 3

Community Meeting Discussion Questions

1. How important are caribou to the Ulkatcho?
2. What do the Ulkatcho use caribou for?
3. What are the threats to caribou survival in Ulkatcho?
4. What do caribou eat?
5. Do caribou in Ulkatcho prefer ground or tree lichens?
6. What makes good caribou habitat?
7. Where do caribou in Ulkatcho go in winter?
8. How large did the herds used to be?
9. What is the relationship between moose and caribou?
10. What do the caribou need to return to historical population sizes?

Appendix 4

The collaring of caribou from the Itcha-Ilgachuz and Rainbow Mountains herds began in 1984 and has since occurred over 4 periods: 1984-1988, 1995-2000, 2012-2014, 2019-2023. The metadata of these telemetry data was not provided and the number of females, males and calves collared is uncertain. Telemetry data from the Charlotte Alplands herd only contains a small number of full caribou years from 1984 - 2000. Some collared caribou in the Charlotte Alplands herd were also translocated from the Itcha-Ilgachuz herd, and their habitat selection may not be representative of the herd's historical habitat use (Young *et al.*, 2001). A request was made for telemetry data from the Tweedsmuir-Entiako herd.

CHAPTER 3: Recovery of caribou and sympatric herbivore forage following wildfire in Ulkatcho territory, west-central British Columbia, Canada

ABSTRACT

The Ulkatcho people of west-central British Columbia (BC) have co-existed with caribou since time immemorial, harvesting local herds for meat, clothing and tools and developing deep relational ties with caribou. Moose in contrast have become increasingly abundant in Ulkatcho within the last century. Across Canada, recent declines in caribou have been linked to increases in moose abundance and increased density of wolves and other predators, such as bears. Shifts in wildfire regimes may be causing habitat alteration in these multiple prey – multiple predator ecosystems. As a result, the availability of forage after wildfire can provide important insights into mechanisms of apparent competition. We integrated Ulkatcho ecological knowledge, vegetation sampling, and Western scientific dietary studies to characterize forage use between caribou and sympatric herbivores in Ulkatcho territory. Using these data, we conducted Principal Coordinate Analyses (PCoA) based on Jaccard distances to investigate dietary niche overlap between caribou and moose, black bears, and grizzly bears within Ulkatcho. We then assessed how forage similarity between species changed over time since fire and used a Generalized Linear Model (GLM) to test the hypothesis that moose activity is greatest at earlier post-fire seral stages. Caribou displayed high dietary partitioning with moose and bears in Ulkatcho, a concept that is embedded within Ulkatcho knowledge systems. At burned sites, forage similarity between caribou and each of moose and bears was greatest at early post-fire successional stages (<20 years), driven by the presence of shared forage such as willow, blueberry and graminoids, and the delayed recovery of caribou-specific forage such as lichens. This increase in forage similarity

at recent burns was marginal relative to forage selection in unburned areas however, and did not show a strong signal of dietary convergence between species. Our results indicate that stand-replacing fire may temporarily increase the availability of important summer forage for caribou (namely blueberry, willow, and graminoids), helping to explain caribou selection of recent burns in summer. We also found moose pellet presence, an index of moose activity, to be greatest in recent burns (<20 years) and to be significantly negatively associated with time since fire. Our study furthers the understanding of both caribou-moose-fire dynamics, and lesser understood caribou-bear-fire dynamics, and provides a preliminary insight into potential fire-mediated mechanisms of apparent competition in Ulkatcho territory. We also apply our findings to the impacts of a recent burn at the calving grounds of the Itcha-Ilgachuz caribou herd, a population of great significance to the Ulkatcho people.

Introduction

Few wildlife species in Canada allow for greater reconciliation between Indigenous and colonial approaches to conservation than caribou (*Rangifer tarandus*) (Lamb *et al.*, 2022). Throughout their distribution, caribou provide food, clothing, tools and oral tradition to Indigenous peoples across Canada (Hummel and Ray, 2008; Sharp and Sharp, 2015) and are emblematic of Indigenous knowledge systems, reflecting long-standing relationships of land stewardship and ecological understanding (Parlee and Caine, 2018). Over the last century however, caribou populations have declined across much of their range (Bergerud, 1974; Seip and Cichowski, 1994; McLoughlin *et al.*, 2003; Festa-Bianchet *et al.*, 2011; Hebblewhite, 2017), with many herds now listed as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). This decline is widely attributed to habitat degradation and fragmentation (Johnson *et al.*, 2015) and the subsequent increase in apparent competition caused by increases in moose abundance (Lamb *et al.*, 2024). Although moose and caribou coexist across their respective ranges, disturbance of mature forest can benefit moose, who often select for early seral conditions created by logging and wildfire (Loranger *et al.*, 1991; Maier *et al.*, 2005; Joly *et al.*, 2016; Mumma *et al.*, 2024) more so than caribou, who are often dependent on older, mature stands with high lichen biomass (Apps and Dodd, 2017). Greater densities of moose can support greater densities of wolves (*Canis lupus*) (Courtois and Oullet, 2007) and black and grizzly bears (*Ursus americanus* and *Ursus arctos*) (Ballard, 1992), all of which are predators of both caribou and moose (Reynolds and Garner; 1987; Ballard, 1994; Young and McCabe, 1997; Wittmer *et al.*, 2005, Hebblewhite *et al.*, 2007; Leblond *et al.* 2016). In this multiple predator – multiple prey interaction, caribou are more vulnerable to decline due to their typically lower reproductive rate (Bergerud, 1974), a function of female caribou reaching reproductive maturity later than

moose (Schwartz, 1992; Bergerud, 2000) and almost exclusively giving birth to single offspring (Bergerud, 1996), whereas moose may calve twins under suitable conditions (Schwartz, 1997).

Precipitous declines in caribou populations threaten the ability of Indigenous peoples to maintain traditional harvesting practices (Parlee and Caine, 2018) and have left many communities with little choice but to impose harvest restrictions on herds that were once plentiful. In response to this, some Indigenous groups have implemented conservation approaches that use traditional ecological knowledge to recover caribou herds (Lamb *et al.*, 2022). In north-eastern British Columbia (BC), the West Moberly First Nation and Salteau First Nation prevented the collapse of the nearly extirpated Klinse-Za caribou herd through Indigenous-led conservation, recovering herd numbers from 38 in 2013 to 101 in 2021. This project combined Indigenous and Western knowledge systems to create an effective management framework that was able to maintain traditional harvesting practices for future generations. The success of this strategy emphasizes the importance of including traditional knowledge across all aspects of caribou management (Parlee and Caine, 2018).

In west-central BC, the Ulkatcho people of the West Chilcotin have co-existed with whudzih (woodland caribou, *Rangifer tarandus caribou*) since time immemorial, harvesting the herds for meat, fat, clothing and tools and developing deep relational ties with caribou. Elders recall hunting caribou in large groups and sharing the meat across the community (Ulkatcho First Nation, n.d.), however all four herds in Ulkatcho territory (Figure 1) are now Threatened and Indigenous harvest of caribou in the territory was banned in 2019. The Ulkatcho people attribute the decline of caribou to a culmination of predation, primarily from yus (wolves), shas (grizzly bears), sus (black bears) and booscho (mountain lion, *Puma concolor*), and habitat change, caused by logging, pine beetle, ranching and wildfire. Between 2000 and 2023, 32% of caribou

range in Ulkatcho burned, compared to 6.5% in the 80 years between 1919 and 1999 (Canadian National Fire Database, n.d.; Appendix 1). Considerable research suggests that moose respond positively to the early seral conditions that result after fire (Loranger *et al.*, 1991; Maier *et al.*, 2005; Joly *et al.*, 2016; Mumma *et al.*, 2024), although this can vary across burn severity and time since fire (Lord and Kielland, 2015; Brown *et al.*, 2017). Generally, moose selection for post-burn habitat is greatest between 11 and 30 years after fire (Loranger *et al.*, 1991; Maier *et al.*, 2005; Joly *et al.*, 2016; Mumma *et al.*, 2024) and is likely driven by an increase in the quality and quantity of key forage (Lord and Kielland, 2015).

Since the start of the 20th century, moose have become increasingly abundant in Ulkatcho. Corinne Cahoose, a member of Ulkatcho First Nation (UFN), describes how “years ago, according to my ancestors, moose came after caribou. Caribou were here before the moose”. Bella Leon, a member of UFN, explains that “those days nothing but caribou until moose move in. Caribou used for long time before moose.” Ulkatcho oral accounts place the increase in moose abundance at some point during the early 1900’s. Gary Holte, a member of UFN, explains how “moose come to country in nineteen-thirties, twenties, nineteen-ten.” Nora Brubaker, a member of UFN, recalls seeing moose all her life. “They were there when I was born in fifty-two. They came from back east...I don’t remember when they showed up. Not originally from here.” The increased abundance of moose in Ulkatcho during the early 20th century is consistent with oral and historic accounts of moose expansion throughout BC during this period (Darimont *et al.*, 2005; Johnson *et al.*, 2012), with habitat disturbance attributed as a key driving factor.

Within Ulkatcho, moose and caribou are known to display strong resource partitioning. Bella Leon explains how “caribou don’t like moose, move separately” while Maureen Sill, a member of UFN, states how the movement of each species is different, especially in winter.

“Moose...going up the mountains but lots of snow they move back down” whereas there are “quite a bit of caribou in the mountains”. Douglas Sill, a member of UFN, also describes how they “use different habitat” and are “not usually seen together”. Many Ulkatcho people highlight the dietary differences between moose, who were described as eating primarily k'idlih (*Salix* spp., willow), and caribou, who were noted for their primary consumption of terrestrial and arboreal lichens. George Leon, an Elder from UFN, explained how *caribou like to eat lichen on the ground in the timber* (translated from Dakelh) while Douglas Sill explained the importance of mature chundoo stands (*Pinus contorta*, lodgepole pine) in providing arboreal lichen forage for caribou. “Mature timber. Around 140 years. They eat lichen from the branch.” These observations of resource partitioning between moose and caribou are indicative of sympatric ungulates that have co-evolved under high competition pressure (Connell, 1980). Despite this general forage separation however, moose and caribou diets often overlap in summer when both species consume forbs and deciduous plants (Boer, 2007). Increased overlap in summer habitat use between moose and caribou has been linked with greater caribou mortality (Peters *et al.*, 2013; Christopherson *et al.*, 2019), with wolves known to select for habitat with greater ungulate forage to increase the likelihood of encountering prey (Seip, 1992; Gurarie *et al.* 2011). In summer, caribou in Ulkatcho have been found to select for recent burns (<20 years), likely as vascular plant forage is more readily available (Apps and Dodd, 2017). In winter however, caribou may be negatively affected by fire due to their selection for mature forests with high lichen abundance (Cichowski, 1993; Apps and Dodd, 2017). Given the increase in moose abundance in Ulkatcho over the last century, and changes in the fire regime over a similar period (Appendix 1), understanding the effects of wildfire on moose and caribou forage may provide insights into apparent competition interactions in Ulkatcho territory. Specifically, understanding

how moose and caribou habitat respond to fire, and how fire influences forage availability and dietary overlap between the two species, have become important questions for UFN. Further, although similar research often focuses solely on moose and caribou forage, both black bears and grizzly bears present a substantial predation threat to caribou, especially calves (Ballard, 1992; Young and McCabe, 1997; Gustine *et al.*, 2006). Bears also forage extensively on vegetation throughout their life-histories (Grizzly bear: McLellan and Hovey, 2011; Black bear: Raine and Kansas, 1990) and the availability and distribution of key foods for both bear species, in particular *Vaccinium* spp., may be influenced by historical wildfires (Hamer and Herrero, 1987). Many Ulkatcho Elders and community members cite predation on caribou by bears in Ulkatcho as a leading cause of caribou mortality, alongside wolf predation.

This study, co-led with UFN, integrates Ulkatcho ecological knowledge with vegetation sampling and Western dietary studies to investigate the effects of wildfire on dietary niche overlap between caribou and moose, black bear and grizzly bear in Ulkatcho territory. Our main goal is to assess how forage similarity between selected wildlife is impacted by fire, and to test the hypothesis that moose activity is greatest at earlier post-fire seral stages. We also aim to investigate the effects of stand-replacing fire on the availability of key plant species for selected wildlife, and to apply our findings to a recent burn at the calving grounds of the Itcha-Ilgachuz caribou herd, an area of critical summer habitat. The overarching objective of this study is to provide UFN with insights into both caribou-moose-fire and caribou-bear-fire dynamics within Ulkatcho territory, with the view to better understanding the effects of fire on the future of caribou in Ulkatcho.

Study Area

Caribou herds in Ulkatcho are bounded by the Rainbow Mountains to the west (2,450m), and the Itcha and Ilgachuz Mountains to the east (2,350m and 2,400m respectively). The Dean River valley separates these two ranges at 1,100m, while to the North, Ulkatcho territory overlaps with the Tweedsmuir-Entiako herd range until the southern foothills of Wells Gray Peak, near Eutsuk Lake and Tetachuk Lake (850m). To the south, Ulkatcho territory encompasses the Charlotte Alplands, where caribou use the slopes surrounding Trumpeter Mountain (2400m) and the lowlands around Charlotte Lake (1175m). Caribou in the Rainbow Mountains and Itcha-Ilgachuz herds spend winters in the alpine, although individuals in the Itcha-Ilgachuz herd often display elevational migration to lower altitude lodgepole pine forests in winter (Cichowski, 1989). Almost all caribou in the study area spend summers exclusively in the alpine. Moose in northern BC typically spend winters at lower elevations in response to increased snowpack at higher elevation (Demarchi, 2003) with some cow moose migrating to higher elevations in spring and summer to calve (Poole *et al.*, 2007). Grizzly bears select winter dens in alpine and high-elevation conifer forests where spring forage quality is also greater (Ciarnello *et al.*, 2005; Pigeon *et al.*, 2014) and spend summer and fall following changes in the availability of key foods (McClelland *et al.* 2020). Black bear denning selection is more variable but often occurs at high elevations (Johnson and Pelton, 1980). Both bear species in the study area are likely drawn to low-elevation salmon-bearing streams in the fall (Mueller and Boulanger, 2013).

Winters in the study area are cold and summers cool, with frequent growing-season frosts a result of high elevations and the rain shadow of the westerly Coast Mountains (Apps *et al.*, 2001). In descending order from highest elevation to lowest, the four biogeoclimatic zones (Meidinger and Pojar, 1991) prevalent in the study area are the following:

- Alpine Tundra (AT) - extensive at the highest elevations of all three mountain ranges and devoid of forest;
- Engelmann Spruce - Subalpine Fir, specifically the very dry, very cold sub-zone (ESSFxv) - occurs between 1650m and 1825m, with mature forests dominated by lodgepole pine. Some areas of Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) exist alongside whitebark pine (*Pinus albicaulis*) in this zone;
- Montane Spruce, specifically the very dry, very cold subzone (MSxv) - mature forests in this zone are even-aged lodgepole pine stands;
- Sub-boreal Pine Spruce, specifically the moist, cold subzone (SBPSmc) in the north and the very dry, cold subzone (SBPSxc) in the south - even-aged stands of lodgepole pine again dominate this zone, with Engelmann spruce in wetter areas.

All three of the Rainbow, Ilgachuz and Itcha mountain ranges are dormant shield volcanoes belonging to the Anahim Volcanic Belt (Kuehn, 2014). The significant volcanic history of the study area has resulted in basalt-derived soils of generally coarse texture and weak development (Goward, 1999). The major topographic relief created by these shield volcanoes likely provides Ulkatcho caribou with elevational separation from predators (T. Gharajehdaghipour, personal communication, 2024).

Methods

Community Discussions

Project approval was received from Ulkatcho Chief Lynda Price and Council in October 2023. In April 2024, a research ethics application was approved by Thompson Rivers University to conduct three transcribed meetings with Ulkatcho Elders and band members (study #103885).

These meetings took place on July 10th in Anahim Lake, and November 22nd, 2024, in Anahim Lake and Nimpo Lake, respectively. Ten questions relating to caribou, moose and wildfire in Ulkatcho were asked at all three meetings (Appendix 2). Discussion contributions from each attendee were hand-transcribed by designated research assistants. Knowledge shared by the Ulkatcho people was used to learn about the ecological relationships between moose and caribou, the key vegetation forage for each species, and the predators that hunt caribou and moose in the study area. A history of fire in Ulkatcho territory was also discussed with focus on how it affects key wildlife forage.

Site Selection

Five historical fires were selected for lichen and vascular plant sampling in August and September 2024 (fire years: 1937, 1961, 1981, 2006, 2010; Figure 10). The search area for historical fires was defined by a combination of known caribou habitat provided by Ulkatcho Elders and pre-existing telemetry data provided by the Caribou Recovery Program (CRP). Caribou habitat was used to define our search area as caribou display high fidelity to their home range. The distribution of bears and moose is more stochastic in comparison, and the two latter species often exist where caribou do not. The opposite (caribou inhabiting areas not inhabited by bears or moose) is less common. Historical fire boundaries from the Canadian National Fire Database (CNFD) were downloaded into ArcMap Pro (version 3.11.8). Historical fire boundaries that overlapped with areas of high caribou activity were selected for further investigation. Most prospective fires were dropped due to overlapping logging cuts and roads, repeat burns, inaccurate or unclear burn perimeters, unfeasible access, low caribou use, or no water nearby. One fire was selected from each of the following time-since-fire categories: 0-15, 16-30, 31-50,

51-70, 71-90 (Table 3). An initial attempt to map burn severity for each fire that occurred after 1986 was made using Differenced Normalized Burn Ratio (dNBR) (Parks *et al.*, 2021; Key and Benson, 2006) in Google Earth Engine and ArcMap Pro. However, ground-truthing in the field revealed little difference between high and low severity pixels. Burn severity was subsequently dropped and tree cores were sampled to verify the occurrence of the last stand-replacing fire. All fires sampled were stand-replacing events in lodgepole pine stands.

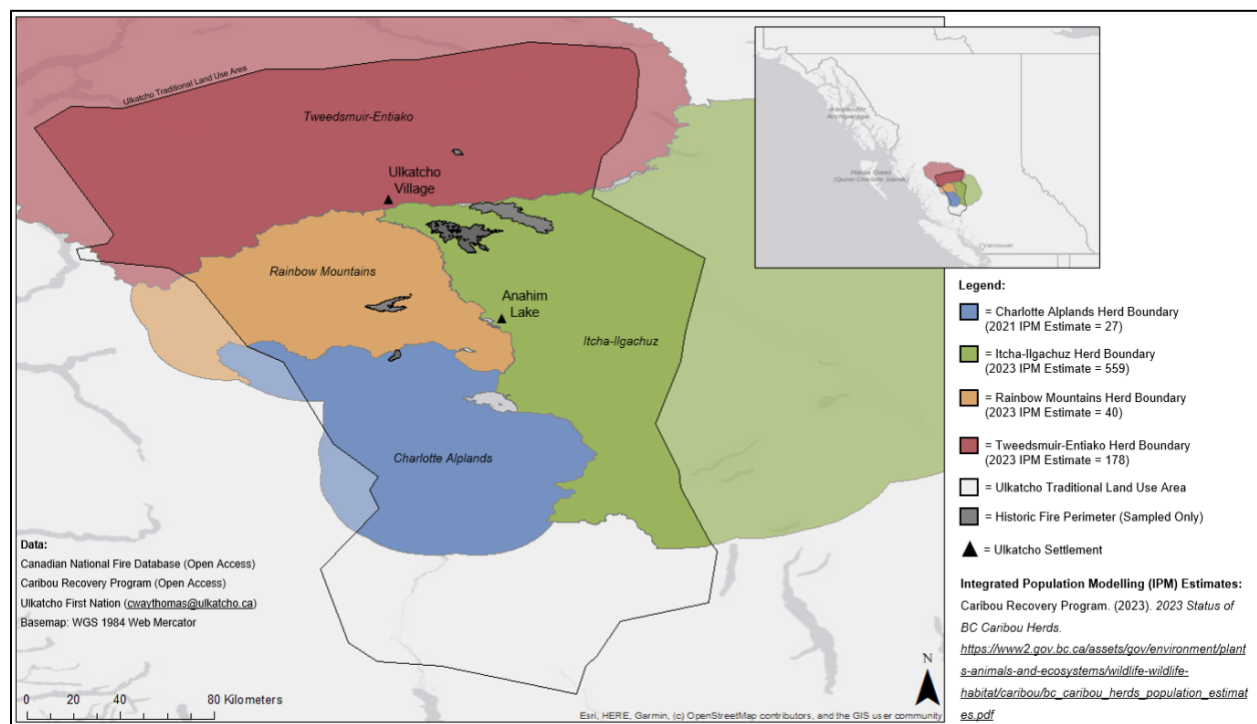


Figure 10

The locations and ranges of the four southern mountain caribou (whudzih, *Rangifer tarandus caribou*) herds in Ulkatcho territory, west-central British Columbia. The Tweedsmuir-Entiako herd in the north (estimated population = 178), the Itcha-Ilgachuz herd in the east (population estimate = 559), the Charlotte Alplands herd in the south-west (population estimate = 27) and the Rainbow Mountains herd in the west (population estimate = 40). Highlighted area represents the Ulkatcho Traditional Land Use Area. Black triangles represent the locations of Ulkatcho settlements.

Table 3

Summary of site characteristics at each sampled historical fire in Ulkatcho territory, west-central British Columbia.

Fire Year	Burn Age Class (Years)	Latitude	Longitude	Elevation	Unburned Stand Type	Unburned Stand Age (Years)	BEC Zone
2010	0-15	52°33'01"N	125°43'38"W	1466m	<i>Pinus contorta</i> dominant, <i>Picea engelmannii</i> subdominant	130.6	ESSF
2006	16-30	*	*	*	<i>P. contorta</i> dominant, <i>P. engelmannii</i> subdominant	149.3	ESSF
1981	31-50	53°09'22"N	125°28'52"W	1049m	Co-dominant <i>P. contorta</i> and <i>P. engelmannii</i>	87.3 (<i>P. contorta</i> only)	SBPS
1961	51-70	52°56'47"N	125°24'48"W	1105m	<i>P. contorta</i> dominant, <i>P. engelmannii</i> subdominant	105.9	SBPS
1937	71-90	52°21'08"N	125°43'22"W	1244m	Co-dominant <i>Abies lasiocarpa</i> and <i>P. engelmannii</i>	122.7	MS

* Undisclosed at the request of the community due to sensitivity of Itcha-Ilgachuz calving grounds.

Sampling Methods

Plots consisted of a 10m x 10m grid and were randomly placed at each fire using ArcMap Pro with 50 meters spacing using the *Create Random Points* function in the *Analysis* tab. 15 to 30 plots were placed in each of the following treatments: stand-replacing burn or unburned control.

Vegetation Forage

In the northwest (NW) and southeast (SE) corner of each 10m x 10m plot, a 2m x 2m quadrat was placed to measure understory vegetation. Vegetation percent cover by plant species was ocularly measured and species names were recorded in Dakelh if it existed in Hebda *et al.* (1996) or was listed in the Dakelh language database at www.firstvoices.com/dakelh-southern-carrier. Vegetation included all vascular plants (forbs, grasses, and shrubs) and mosses. For vegetation that did not exist in either resource, English common name was used. Plants were identified to genus and species level where possible, or otherwise genus.

Lichen Cover

Terrestrial lichen cover was ocularly recorded in each NW and SE corner quadrat using a photo-based key developed from www.waysofenlichenment.net and the grouping of caribou lichens used by Greuel *et al.* (2021): *Cladonia rangiferina* Group (*C. rangiferina* and *C. stygia*), *Cladonia mitis* Group (*C. mitis* and *C. arbuscula*), *Cladonia stellaris* and *Cladonia uncialis*. The following lichens were identified to genus level; *Stereocaulon* spp. and *Cladonia* spp. (not included in pre-determined groupings). *Peltigera* spp. lichens were also recorded but were dropped from analysis due to avoidance by caribou (Denryter *et al.*, 2017).

Arboreal lichens were recorded at three trees inside the 10m x 10m plot having the highest arboreal lichen loading within three meters of the ground. Each tree was photographed and assigned an abundance value based on the mean spacing of lichen strands (adapted from Esseen, 1981): None (no lichens present), Sparse (mean distance between specimens > 150cm), Moderate (mean distance between specimens 100-150cm), abundant (mean distance between specimens 50-100cm) and Very Abundant (mean distance between specimens 0-50cm).

Moose Pellets and Bear Scat

Counts of moose pellet groups (Härkönen and Heikkilä, 1999) were tallied inside each 10m² plot. This was done to infer moose activity in the sampling area. ‘Moose pellet groups’ were defined as a distinct grouping of individual pellets. Bear scat was also recorded in field notes when encountered in burn sites.

Selecting Wildlife Species for Forage Analysis

Wildlife species that met both of the following criteria were chosen for review: (1) identified as a predator of caribou by the Ulkatcho people or facilitate increased caribou predation by proxy of apparent competition (Lamb *et al.*, 2024) and (2) forage on vegetation during its life-history. Wolves and mountain lions were identified as key predators of caribou by the Ulkatcho but do not primarily forage on vegetation and were dropped from analysis. Both species remain relevant through their predation on moose. The four species selected for forage analysis were caribou, moose, black bear and grizzly bear.

Wildlife Forage Analysis

Thompson Rivers University library, University of Alaska library, Web of Science and Google Scholar were used to search for peer-reviewed dietary studies for each wildlife species using keywords such as “forage”, “diet”, or “food habits”. The search area for studies was initially restricted to pine-dominant regions of BC, western Alberta, Montana and Colorado. Studies from the Boreal were initially excluded due to limited similarity in vegetation composition with pine forests in Ulkatcho. The review was later opened to studies from the Boreal to increase the number of literatures sources reviewed. Oral and written accounts from Ulkatcho Elders and band members were integrated into analysis and provided the most spatially accurate forage information within the study area. Despite this, many oral accounts were less complete than Western dietary studies, often containing between one and three preferred forage species or plant groups per wildlife taxa, whereas Western studies typically provided a much broader depiction of diet. A total of 48 dietary studies and 15 Ulkatcho oral and written accounts were included in the review (caribou $n = 23$, moose $n = 24$, black bear $n = 7$, grizzly bear $n = 8$). These data consisted of 10 Ulkatcho accounts of caribou diet, two accounts for each of moose and grizzly bear diet, and one account of black bear diet.

Dataset Construction

Following the methods of Jorgensen (2021) we used tables in Microsoft Excel to input wildlife forage selection based on our dietary review and the sampled plant communities in Ulkatcho. Within tables, each plant species found in sampling plots was assigned a column, and each dietary study was assigned an individual row. For each dietary account, if a plant species was recorded as consumed, a ‘1’ was assigned in the corresponding column. If it was not consumed, or recorded as ‘trace’ consumption, it was assigned a ‘0’. Due to the unique

consumption of terrestrial and arboreal lichens by caribou, *Cladonia* spp., *Cladina* spp., and *Stereocaulon* spp. were grouped as ‘Terrestrial Lichens’ and *Bryoria* spp. and *Alectoria* spp. were grouped as ‘Arboreal Lichens’. Studies were separated into ‘winter diet’ (November – April), ‘growing season’ (May – October) and ‘general’ (no information on season provided). Studies that covered multiple seasons were given individual rows for each season. Coniferous tree species (*Pinus* spp., *Abies* spp., and *Picea* spp.) were not recorded in vegetation plots and were excluded from analysis. Plant species recorded during sampling that were not recorded as consumed by any animal during the review were removed from the table to isolate relevant species. Plant species that possessed only a single occurrence of consumption across all dietary studies were maintained in analysis as they were considered important in understanding the diversity of diets across selected wildlife. To reduce the effect of incomplete dietary records producing false absences and subsequent high dissimilarity during ordination, we developed three Datasets: (1) All individual Western studies and all individual Ulkatcho accounts (2) All individual Western studies and a single data point of combined Ulkatcho accounts per wildlife species, (3) Ulkatcho accounts only. We hypothesized Dataset 2 to be the least biased and most representative as it contained a greater number of complete and combined dietary studies.

Statistical Analysis

Statistical analyses were completed in R-4.4.2 (R Core Team, 2023) and *ggplot2* (Wickham, 2016) was used for all graphs.

Dietary Partitioning

To visualize patterns of forage similarity between wildlife species in Ulkatcho, we performed a series of Principal Coordinates Analyses (PCoA) using Jaccard dissimilarity to identify dietary niches based on sampled Ulkatcho plant communities. This approach is appropriate for presence-absence or zero-inflated data (such as our vegetation dataset) in which species may consume only a subset of available plants (Legendre and Gallagher, 2001). First, we performed PCoA's using the *vegan* R package (Oksanen *et al.*, 2022) for each of 'winter', 'growing season' and 'general' forage selection to assess dietary overlap between species when all sampled plants were available. All three Datasets were used for this phase of modelling, however Jaccard dissimilarity results found Dataset 2 displayed the least dissimilarity between wildlife species across all seasons. Based on our prior concerns about the bias of incomplete dietary accounts in Datasets 1 and 3, we selected Dataset 2 to be used exclusively for the rest of analysis. Six-letter plant codes (Appendix 3) were designed to increase the interpretability of figures and results during community dissemination.

Next, we assessed how forage use by caribou differed from sympatric herbivores across a time since fire (TSF) gradient. For this step, separate PCoA ordinations were performed on the available plant forage at each historical fire: 1937, 1961, 1981, 2006, and 2010. We then compared pairwise overlap between caribou and other species by computing the mean Jaccard dissimilarity at each TSF site. This allowed us to assess how post-fire successional stage influenced dietary niche overlap between selected wildlife and to identify the key vegetation species driving these changes.

Predicted Likelihood of Key Forage

To test whether the occurrence of key forage for selected wildlife changed was significantly influenced by TSF, we fit binomial generalized linear models (GLMs) with a logit link, using presence/absence as the response variable and TSF as the predictor. NW and SE corner quadrats were aggregated to contain either presence (1) or absence (0) of plant species within 10m² plots, therefore models did not require a random effect. Models were run separately for a subset of key forage species relevant to caribou, moose, black bear, and grizzly bear. Subset selection was guided by our dietary review. Two models were constructed for each of winter and summer caribou diet. We then used the Wald results of each GLM to assess the significance of TSF on the presence of key forage by assessing the strength and direction (negative or positive) of the test estimate and the likelihood of the Z-value being true if the true effect of TSF was zero (P-values).

Moose Pellets

We used moose pellets as an index of moose time spent in burns. Pellet presence was treated as a binomial response variable, recorded at each 10m² plot as either present (1) or absent (0). We used a generalized linear model (GLM) with logit link and binomial distribution to test our hypothesis that the likelihood of moose pellet presence was strongly negatively associated with increasing TSF.

Results

Dietary Separation

A total of 78 understory vascular plants species were recorded in vegetation plots. 38 species were known to be consumed by selected wildlife. Jaccard dissimilarity tests found high

dietary separation between caribou and sympatric herbivores in Ulkatcho when all sampled vegetation was available (Table 4). Dietary separation between moose and caribou was greatest during winter and weakest during summer (Table 4; Figure 11). At burned sites, we found forage similarity between caribou and each of moose, black bear and grizzly bear to be greatest at recent burns (<20 years) (Figure 12; Table 5), although this effect was marginal in size. This was driven by the high likelihood of presence of important shared forage among wildlife, specifically 'ilhtsul (blueberry, *Vaccinium* spp.), willow and graminoids (Figure 13). This was likely also amplified by the delayed recovery of caribou-specific forage such as lichens, and to a lesser extent chasli mai (bunchberry, *Cornus canadensis*). Delayed recovery in key forage for other wildlife also caused greater similarity in recent burns. For both bear species, dunih (bearberry, *Arctostaphylos uva-ursi*) and nawus (soapberry, *Shepherdia canadensis*) were identified as niche dietary foods and showed a delayed recovery after fire.

Table 4

Summary of Jaccard dissimilarity scores between caribou dietary niche and moose, black bear and grizzly bear in Ulkatcho territory, west-central British Columbia.

Season	Comparison	Jaccard Dissimilarity*
Dataset 1: Individual Western Accounts and Individual Ulkatcho Accounts		
All Seasons	caribou vs moose	0.930
All Seasons	caribou vs black bear	0.917
All Seasons	caribou vs grizzly bear	0.924
Winter	caribou vs moose	0.961
Summer	caribou vs moose	0.851
Summer	caribou vs black bear	0.873
Summer	caribou vs grizzly bear	0.887
Dataset 2: Individual Western Accounts and Combined Ulkatcho Accounts		
All Seasons	caribou vs moose	0.907
All Seasons	caribou vs black bear	0.887
All Seasons	caribou vs grizzly bear	0.899
Winter	caribou vs moose	0.961
Summer	caribou vs moose	0.839
Summer	caribou vs black bear	0.860
Summer	caribou vs grizzly bear	0.878
Dataset 3: Ulkatcho Accounts Only†		
All Seasons	caribou vs moose	0.967
All Seasons	caribou vs black bear	1
All Seasons	caribou vs grizzly bear	1
Summer	caribou vs black bear	1
Summer	caribou vs grizzly bear	1

* Jaccard dissimilarity values range from 0 (complete overlap) to 1 (no overlap).

† Ulkatcho accounts contained insufficient records of winter-specific diet to conduct Jaccard dissimilarity for winter. Dissimilarity tests using only Ulkatcho accounts were restricted by incomplete dietary reviews.

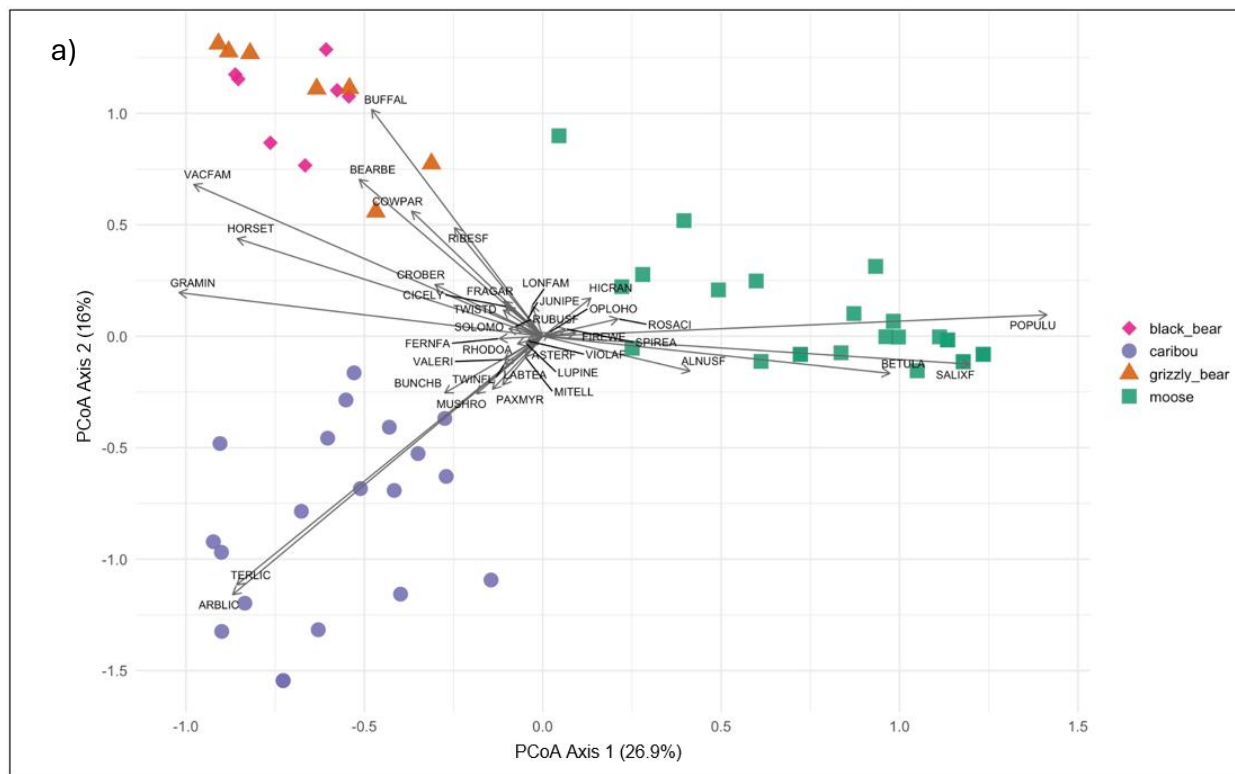
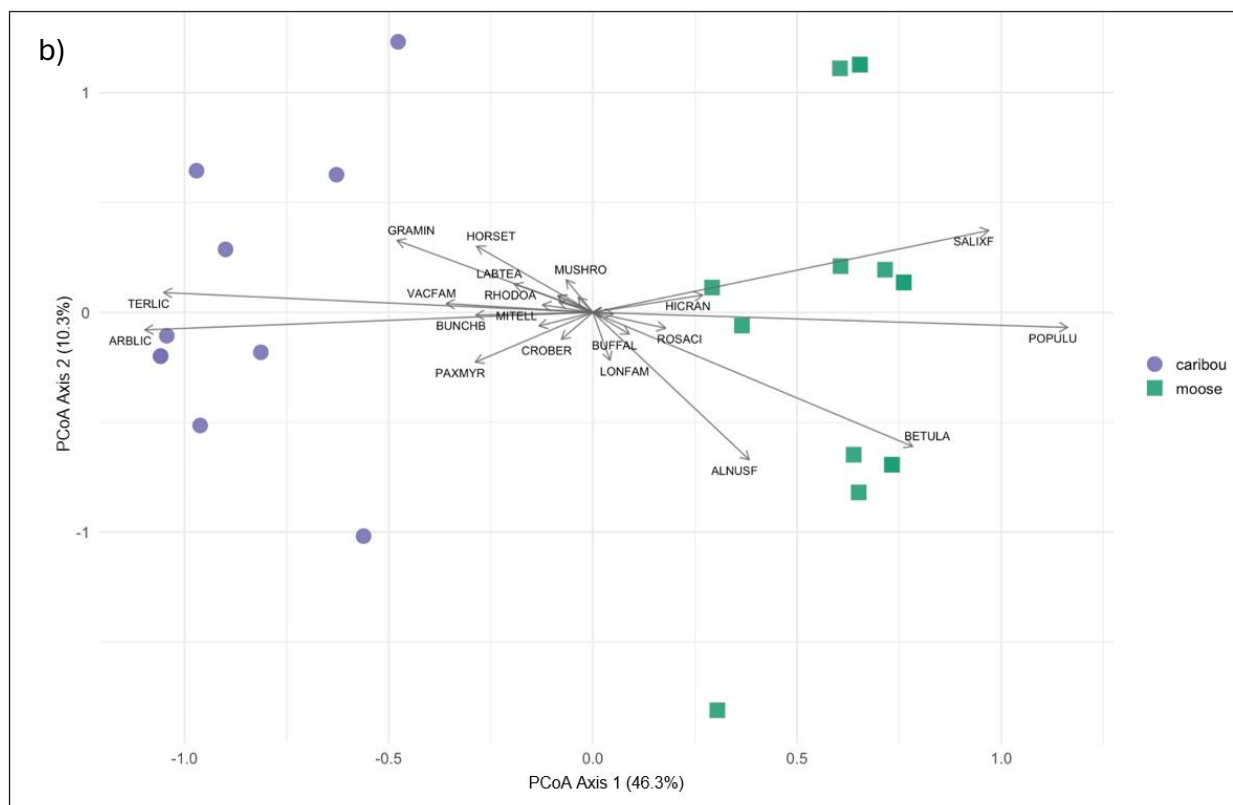
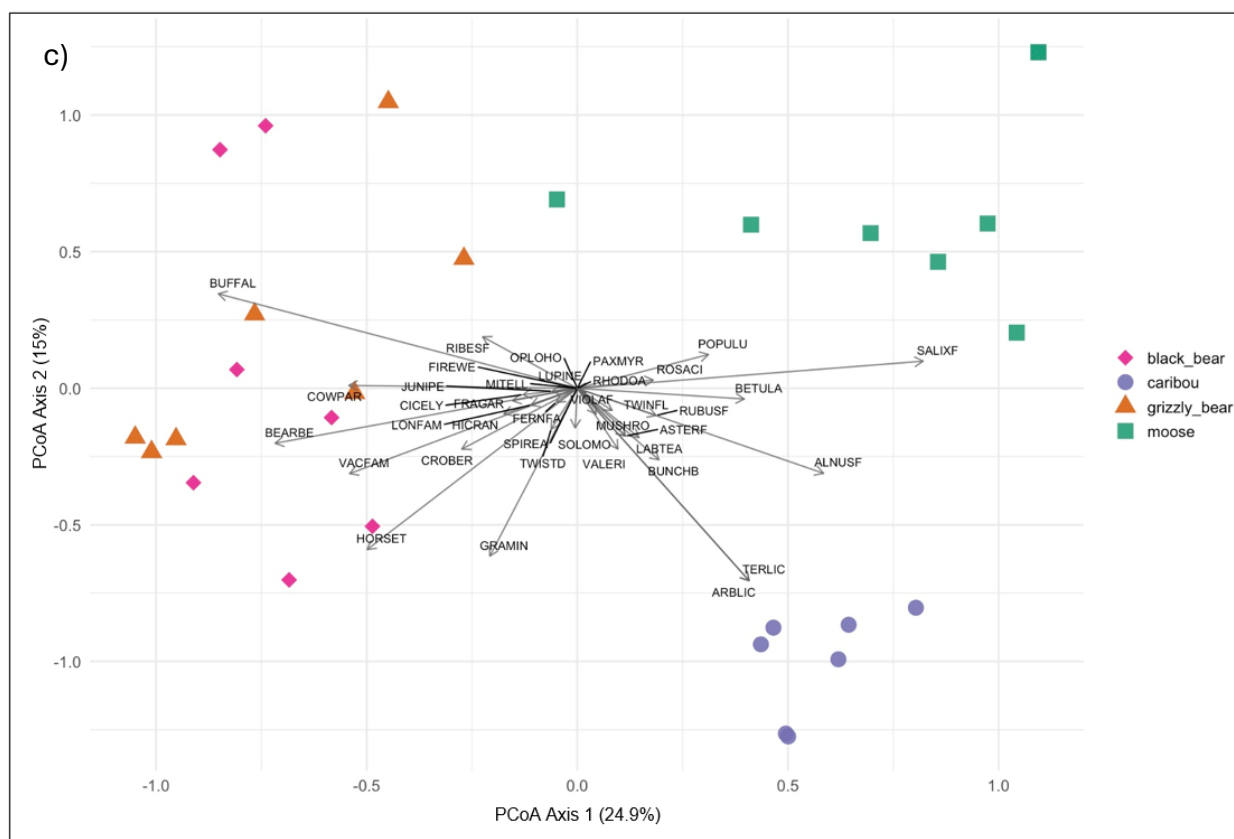


Figure 11

a) Principal Coordinates Analysis using Jaccard distance of dietary partitioning across all seasons between caribou (whudzih, *Rangifer tarandus caribou*), moose (duni, *Alces alces*), black bears (sus, *Ursus americanus*) and grizzly bears (shas, *Ursus arctos*) in Ulkatcho territory, west-central British Columbia. Each shape represents a single dietary review when all sampled vegetation in Ulkatcho is available. Plant codes designed to increase interpretability for community dissemination (Appendix 3).



(b) Principal Coordinates Analysis of dietary partitioning between selected wildlife in winter.



(c) Principal Coordinates Analysis of dietary partitioning between selected wildlife in summer.

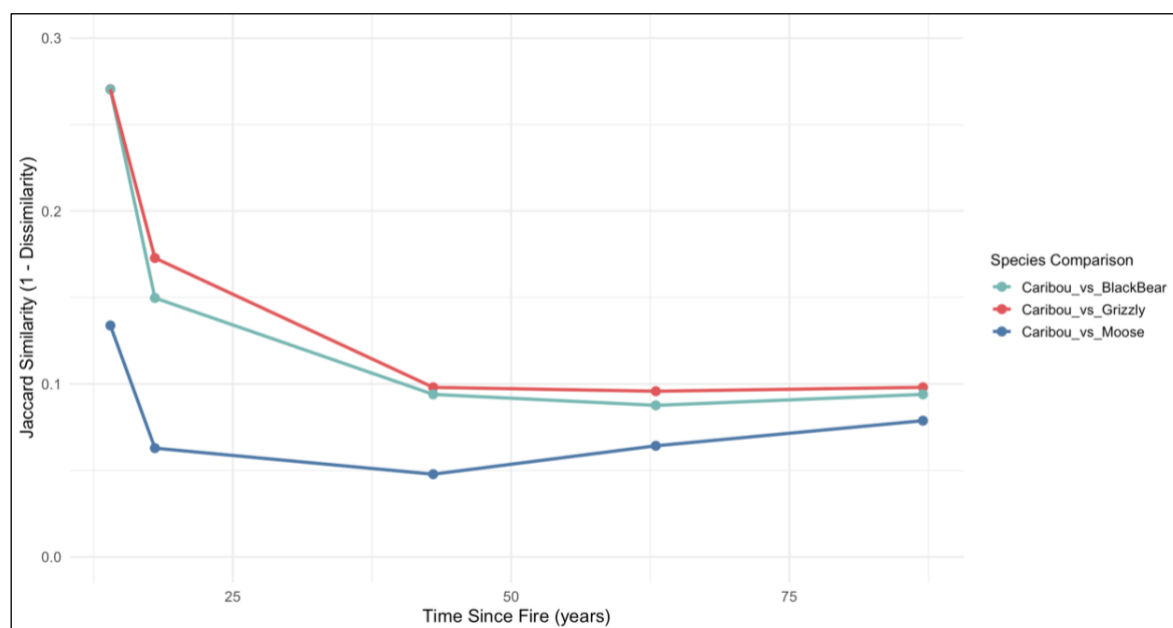


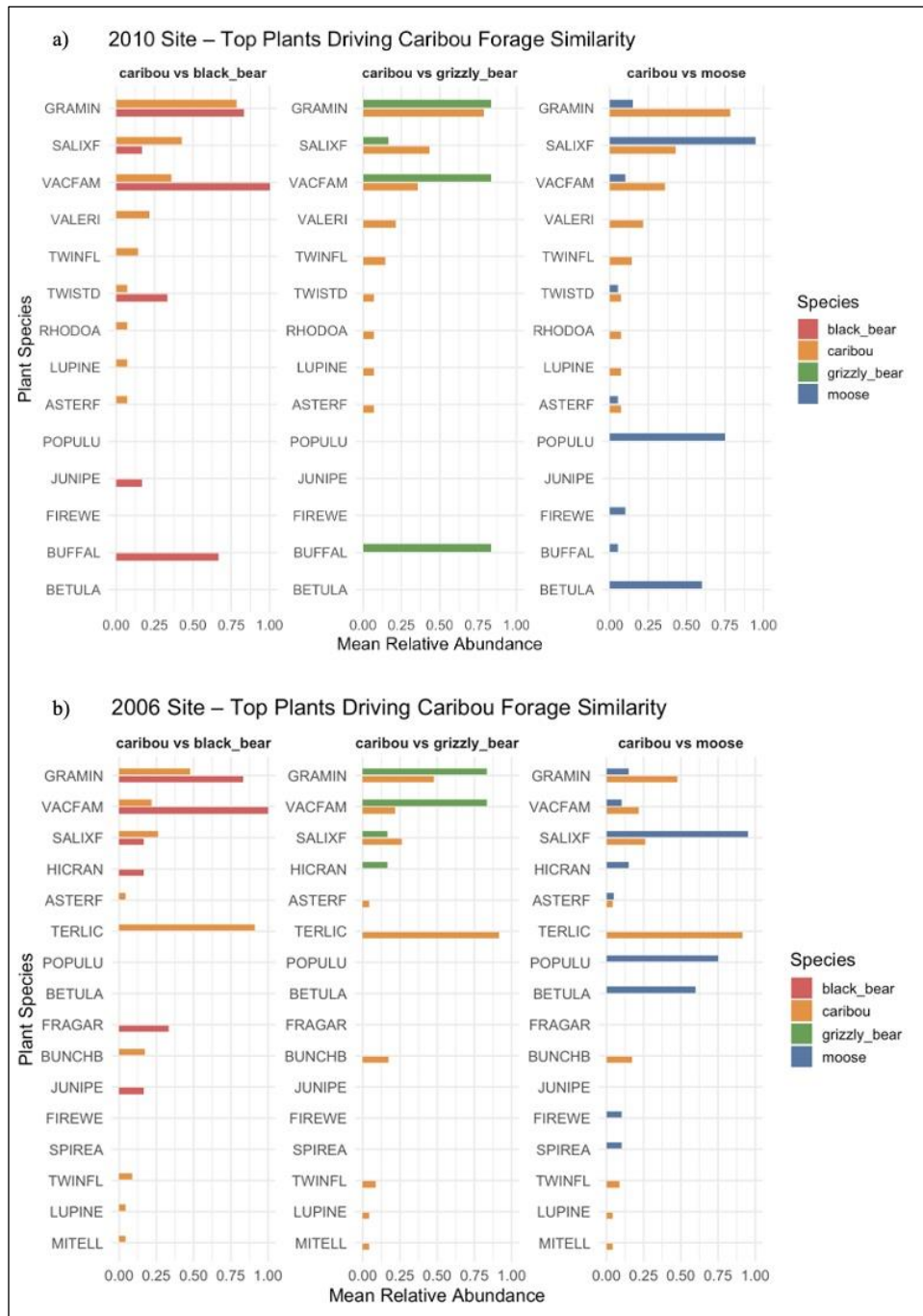
Figure 12

Dietary niche overlap between caribou (whudzih, *Rangifer tarandus caribou*), moose (duni, *Alces alces*), black bear (sus, *Ursus americanus*) and grizzly bear (shas, *Ursus arctos*) following stand-replacing wildfire in Ulkatcho territory, west-central British Columbia. Each point represents Jaccard similarity (1 – dissimilarity) of dietary niche between caribou and other wildlife when only plants sampled at each historical fire are available.

Table 5

Summary of Jaccard dissimilarity results of dietary niche between caribou and selected wildlife at each sampled historical fire in Ulkatcho territory, west-central British Columbia.

Jaccard Dissimilarity Between Species			
Fire Year	Caribou vs Moose	Caribou vs Grizzly Bear	Caribou vs Black Bear
1937	0.921268	0.901967	0.906039
1961	0.935803	0.904244	0.912405
1981	0.952214	0.901984	0.906054
2006	0.937134	0.827208	0.850311
2010	0.866236	0.729563	0.729776



Wildlife Forage Recovery

The likelihood of presence of several summer caribou forage was greatest at recent burns (<20 years) (Figure 15a) and were negatively associated with increasing TSF: *Aster* spp., willow and blueberry (Table 6). Twinflower (*Linnaea borealis*) showed a significant positive association with increasing TSF (Table 6). Bunchberry and *Viola* spp. did not show statistically significant trends (Table 6). For caribou winter forage, all caribou lichens showed significant positive associations with TSF (Table 7; Figure 15). Falsebox (*Paxistima myrsinites*) is also an important winter forage for caribou and showed a positive association with TSF, however was only found at one site (Fire Year: 1937) and should be interpreted with caution (Table 7). For moose forage, willow and graminoids were negatively associated with TSF (Table 6; Figure 15b). Other moose forage species, including k'i (birch, *Betula* spp.), t'ughus (trembling aspen, *Populus* spp.), and highbush cranberry (*Viburnum edule*) did not exhibit significant changes (Table 6). For black bear forage, blueberry and graminoids showed significant declines (Figure 15c), while bearberry and soapberry displayed a significant positive association with increased TSF (Table 6). 'indzi chun (strawberry, *Fragaria* sp.) showed no significant trend. Trends in grizzly bear forage mirrored those of black bears, with *Rubus* spp. exhibiting a non-significant decline over TSF (Figure 15d; Table 6).

Moose Activity

The model for moose pellet presence revealed a significant negative relationship between pellet presence and TSF, suggesting that moose activity was greater in recently burned sites (<20 years) compared to older burns (Figure 16).

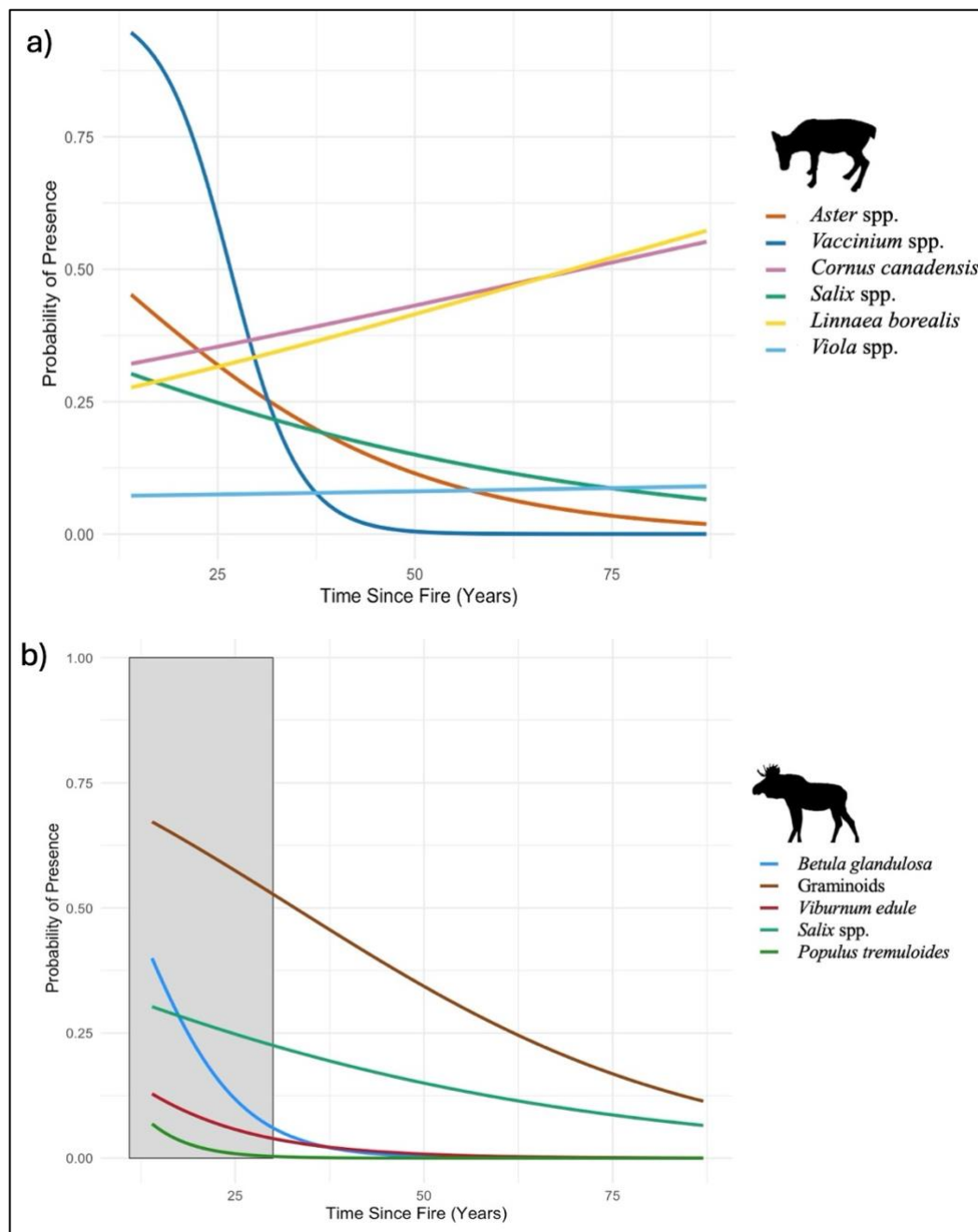
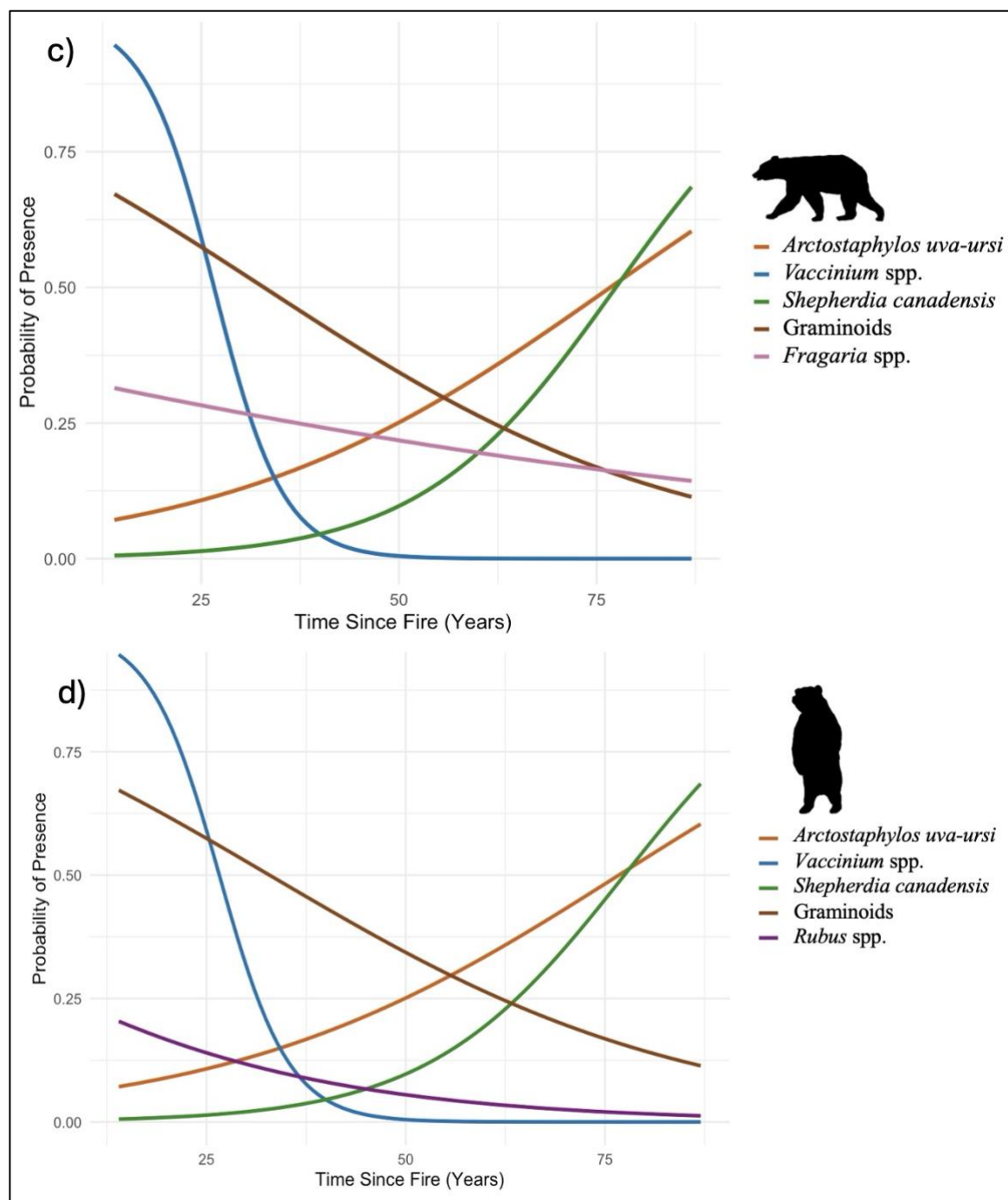


Figure 14

a) Predicted probability of presence of summer caribou (whudzih, *Rangifer tarandus caribou*) forage after stand-replacing fire in Ulkatcho territory, west-central British Columbia. Recovery curves from binomial Generalized Linear Models of plant species presence/absence against time since fire. Each colored line represents a different plant species known to be consumed by caribou. b) Predicted probability of summer moose (duni, *Alces alces*) forage after stand-replacing fire. Grey bar indicates years of greatest moose selection of post-burn habitat (11-30 years), based on Maier *et al.* (2005).



c) Predicted probability of summer black bear (sus, *Ursus americanus*) forage after stand-replacing fire in Ulkatcho territory. d) Predicted probability of summer grizzly bear (shas, *Ursus arctos*) forage after stand-replacing fire in Ulkatcho territory.

Table 6

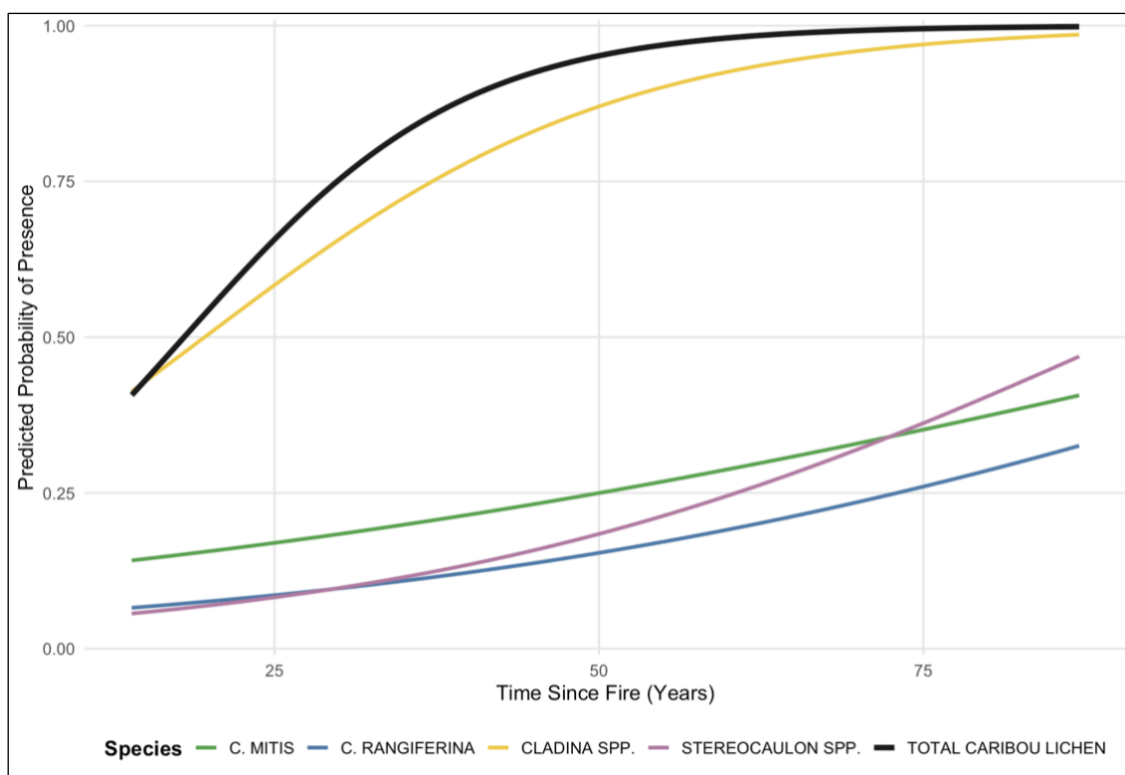
Summary of Wald results of the effect of time since fire on the probability of presence of key plant forage for caribou, moose, black bear and grizzly bear in Ulkatcho territory, west-central British Columbia.

Species Name	Estimate	Std_Error	Z_value	P_value
Caribou				
<i>Aster</i> spp.	-1.4	0.44	-3.16	0.002
<i>Cornus canadensis</i>	0.36	0.22	1.63	0.104
<i>Salix</i> spp.	-0.68	0.33	-2.04	0.042
<i>Viola</i> spp.	0.09	0.39	0.23	0.819
<i>Vaccinium</i> spp.	-6.23	1.82	-3.42	< 0.001
<i>Linnaea borealis</i>	0.47	0.22	2.09	0.036
Moose				
Graminoids	-1.03	0.27	-3.77	< 0.001
<i>Betula</i> spp.	-3.97	2.21	-1.8	0.072
<i>Populus</i> spp.	-5.17	8.19	-0.63	0.528
<i>Salix</i> spp.	-0.68	0.33	-2.04	0.042
<i>Viburnum edule</i>	-2.19	1.64	-1.33	0.183
Black Bear				
<i>Vaccinium</i> spp.	-6.23	1.82	-3.42	< 0.001
<i>Fragaria</i> spp.	-0.38	0.27	-1.39	0.164
Graminoids	-1.03	0.27	-3.77	< 0.001
<i>Arctostaphylos uva-ursi</i>	1.11	0.29	3.87	< 0.001
<i>Shepherdia canadensis</i>	2.22	0.54	4.1	< 0.001
Grizzly Bear				
<i>Vaccinium</i> spp.	-6.23	1.82	-3.42	< 0.001
Graminoids	-1.03	0.27	-3.77	< 0.001
<i>Arctostaphylos uva-ursi</i>	1.11	0.29	3.87	< 0.001
<i>Shepherdia canadensis</i>	2.22	0.54	4.1	< 0.001
<i>Rubus</i> spp.	-1.12	0.58	-1.94	0.052

Table 7

Summary of Wald results for the effect of time since fire on the likelihood of presence of winter caribou forage found in Ulkatcho territory.

Species Name	Estimate	Std_Error	Z_value	P_value	Notes
<i>Cladonia rangiferina</i>	0.03	0.01	3.34	<0.001	n/a
<i>Cladonia mitis</i>	0.02	0.01	2.99	0.003	n/a
<i>Cladina</i> spp.	0.06	0.01	5.33	<0.001	n/a
<i>Stereocaulon</i> spp.	0.04	0.01	4.66	<0.001	n/a
<i>Paxistima myrsinites</i>	0.19	0.06	n/a	0.0013	Firth-adjusted; rare. Interpret with caution.

**Figure 15**

Predicted probability of presence of caribou (whudzih, *Rangifer tarandus caribou*) winter lichen forage following stand-replacing wildfire in Ulkatcho territory, west-central British Columbia. Each line represents predicted likelihood of presence from binomial Generalized Linear Models of species presence/absence against time since fire. Each colored line represents a different terrestrial lichen species group. Bolded black line represents the recovery of total terrestrial caribou lichens combined.

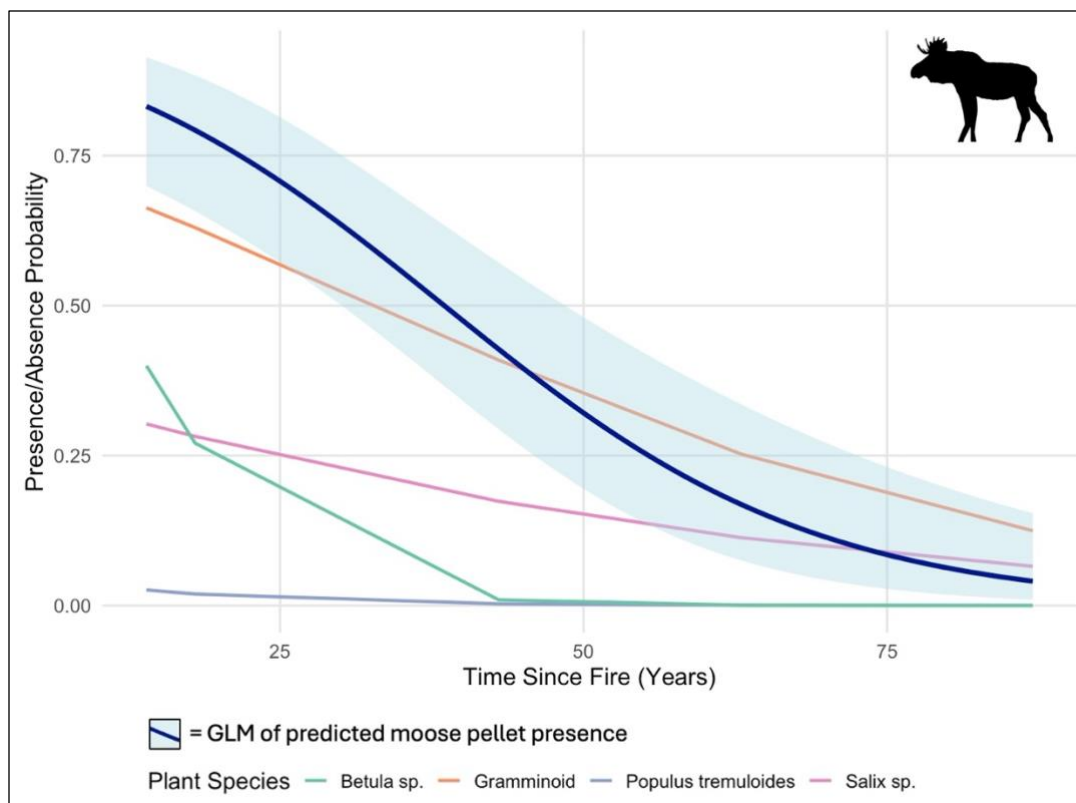


Figure 16

Predicted probability of moose pellet presence following stand-replacing fire in Ulkatcho territory, west-central British Columbia. Plotted alongside the recovery of key moose forage identified from a dietary literature review. Bolded blue curve represents the predicted likelihood of presence of moose pellets from a binomial Generalized Linear Model (GLM) of moose pellet presence/absence against time since fire. Non-bolded lines represent the predicted likelihood of presence of key moose forage from binomial Generalized Linear Models species presence/absence against time since fire.

Discussion

Caribou, moose and bears display high dietary partitioning in Ulkatcho

The strong dietary partitioning between caribou and sympatric herbivores in Ulkatcho (Table 4; Figure 11) is indicative of species that have coevolved under high competition pressure (Connell, 1980). Understanding of this interspecies relationship, especially between moose and caribou, is embedded in Ulkatcho knowledge systems and is pertinently explained by Bella Leon: “caribou don’t like moose, move separately”. Although caribou may not be fully cognizant of complex ecological relationships like apparent competition, at an individual scale they may avoid moose habitat because of its association with wolves (Avgar *et al.* 2015), a learnt behavior that may be related to the experience of individual animals (Derguy *et al.*, 2025). It is also well established that spatial patterns of caribou migration (Bergerud and Page 1987; Seip, 1992) and resource selection (Boer, 2007) reduce caribou interactions with moose, a pattern we found in Ulkatcho with low dietary overlap between each species (Figure 11; Table 4). Given that caribou mortality from predation is often greatest where habitat overlaps with moose (Peters *et al.*, 2013; Christopherson *et al.*, 2019), the ability of caribou to respond cognitively to predation risk may be key in the species’ ability to adapt to increases in disturbance (Derguy *et al.*, 2025), such as wildfire.

Stand-replacing fire causes greater dietary niche overlap between caribou, bears and moose at recent burns compared to older burns, although this effect is marginal

Our models found recent burns (<20 years) resulted in higher similarity in dietary niche between caribou and moose, black bears and grizzly bears in Ulkatcho compared to older burns (Figure 12; Table 5). This effect was marginal (Jaccard distance < 0.2), however suggests that

fire plays some role in determining the availability of key forage for selected wildlife. Further spatial analysis is needed here to understand if greater overlap in dietary niche at recent burns (despite being marginal) translates to increased space-use overlap between species, or whether caribou in Ulkatcho prioritize lower predation risk over forage availability (Gustine *et al.*, 2006; Avgar *et al.*, 2015).

Greater overlap in dietary niche at recent burns was driven by the increased likelihood of willow presence for caribou and moose, blueberries for caribou and bears, and graminoids for all of moose, caribou and bears (Figure 13). Dietary niches were also more similar at recent burns due to the delayed recovery of niche forage for caribou and bears. For caribou, lichens and twinflower (both significant) and bunchberry (non-significant) did not recover until later post-fire successional stages. Bearberry and soapberry (both significant) displayed a similarly delayed recovery and represent niche foods for both black bears and grizzly bears. The relative absence of these niche foods at recent burns contributed to more overlap in dietary niche in the model. Interestingly, the occurrence of fire in our models caused general caribou dietary niche to become more similar with black bears and grizzly bears, whereas it was more similar with moose when all sampled vegetation was available (Table 5; Figure 12). Although this effect was marginal relative to the high Jaccard dissimilarity scores, it demonstrates the role of fire in restricting and promoting the growth of certain vegetation, and subsequently the availability of key forage for different wildlife.

Summer caribou forage is greater in recent burns

Although lichens are important for caribou throughout the year (Cichowski, 1993; Apps and Dodd, 2017; Webber *et al.*, 2022), caribou can exhibit flexible and unspecialized food habits

when vascular plant forage is available (Bergerud, 1972). Recovery models of summer caribou forage found the likelihood of blueberry, willow and *Aster* spp. presence to be greatest at recently burned sites (<20 years; Figure 15a) and to be negatively associated with increasing TSF (Table 6). This suggests that stand-replacing fire may temporarily increase the availability of key summer forage for caribou in the study area. Specifically, newly emergent willow foliage likely provides caribou with a digestible source of protein in summer when energy demands are typically higher, especially for lactating females that experience significant increases in protein requirements compared to winter (Barboza and Parker, 2008; Denryter *et al.*, 2018). In stand-replacing fires where canopy is removed, willow may establish shortly after fire (Lyon and Stickney, 1974; Johnstone *et al.*, 2021; Kiel *et al.*, 2023). Despite being fire-tolerant however, many willow species are shade-intolerant (Ruggirello *et al.*, 2023) and are often outcompeted in later successional stages, a trend we found in Ulkatcho with a decline in the probability of willow presence after 20 years post-fire (Figure 15a). Blueberry meanwhile is another important summer forage for caribou (Edwards and Ritcey, 1960; Bloomfield, 1979; Denryter *et al.*, 2017) and may provide a key source of energy and protein in late summer and fall (Thomas and Hervieux, 1986) as herds enter the rut. Blueberry is also an important cultural plant for the Ulkatcho people and the relationship between ‘ilhtsul chun (blueberry plant) and fire in the territory is well known. Leona Toney, a member of UFN, remembers watching her parents use fire to promote blueberry growth. “...used to do it with blueberries, huckleberries. Never say much about it, our parents did it. Food for all winter.” We found blueberry presence to be greatest in early post-fire stands (<20 years; Figure 15a), with the species known to exhibit a vigorous growth response to fire due to the removal of above ground competition and the survival of underground rhizomes (Tirmenstein, 1991). *Aster* spp. and graminoids meanwhile

likely provide caribou with additional sources of protein in spring and early summer (K. Denryter, personal communication, 2025).

The higher likelihood of presence of willow, blueberry, aster and graminoids in recent burns may explain the findings of Apps and Dodd (2017), who found caribou in the Itcha-Ilgachuz herd to be more likely to select recent burns in summer. Our results indicate that stand-replacing fire may provide a temporary increase in the likelihood of presence of key summer forage for caribou in the study area (Figure 15a). Despite this, willow, blueberry and graminoids also represent key foods for moose and bears (Figure 13), and increases in these specific vegetation types could lead to increased spatial overlap with animals associated with greater caribou mortality, especially near summer calving grounds.

Moose activity in recent burns and the possible impacts on adjacent caribou calving grounds

The effects of increased fire frequency and size on moose populations in Ulkatcho is key to understanding mechanisms of apparent competition in the territory. We found moose pellet presence, an index of moose activity (Härkönen and Heikkilä, 1999), to be greatest in recent burns and to be negatively associated with TSF (Figure 16). This suggests that moose may be benefitting from, and are selecting for, recent burns in the study area, likely due to increases in the quality and availability of forage at these sites (Lord and Kielland, 2015). The proximity of these recent burns to caribou calving grounds also raises important questions about the effects of fire-mediated increases in moose activity near sensitive caribou habitat.

We found evidence of moose activity at an 18-year-old burn at the calving grounds of the Itcha-Ilgachuz caribou herd. Caribou calves are more vulnerable to wolf predation in the weeks immediately following their birth (Adams *et al.*, 1995; Gustine *et al.*, 2006) and high moose

activity nearby may lead to greater caribou mortality (Peters *et al.*, 2013). Compounding this, caribou calving grounds may not have adjusted to recent increases in black bear abundance (Pinard *et al.*, 2011). We found high likelihood of presence of key black bear and grizzly bear forage within the calving ground burn, notably blueberry, *Fragaria* spp. and graminoids (Figure 15c and 13d), alongside signs of bear activity (scat). With low calf survival a major limiting factor for caribou recovery (Lamb *et al.*, 2024), our results indicate that a recent burn at a calving ground may provide key vegetation forage for moose and bears (Figures 13b, 13c, and 13d), the presence of which may limit caribou calf recruitment. At the same time however, our results suggest that recent burns may temporarily provide lactating caribou with access to key protein through the higher likelihood of presence of willow, blueberry, *Aster* spp. and graminoids (Figure 15a; K. Denryter, personal communication, 2025). It remains uncertain whether lactating cows in the Itcha-Ilgachuz herd are actively foraging in this burn however, with female caribou studied to display greater risk aversion towards predation (Derguy *et al.*, 2025) at the expense of forage quality (Gustine *et al.*, 2006).

At a broader scale, the Itcha-Ilgachuz herd is displaying a unique population-level response to wildfire compared to all other herds in BC. Since the 1980's, the herd's annual migration distance has increased substantially (14 kilometers per decade), possibly in response to increases in wildfire activity across their range (Lamb *et al.*, 2025). Despite this, the herd continues to display high fidelity towards their traditional calving grounds (Gharajehdaghipour, unpublished map). This is likely due to a combination of (1) historical separation from wolves and moose in this area (Bergerud and Page, 1987; Pinard *et al.*, 2011), (2) the emergence of high-quality forage immediately before calving (Cameron *et al.*, 2020), and (3) social cues of migration between females (Torney *et al.*, 2018), driven by a spatial memory of (1) and (2) (Cameron *et*

al., 2020). My findings provide preliminary insights into the effects of fire on both (1) separation from predators at calving grounds and (2) the availability of key forage species at calving grounds. Specifically, although caribou calving grounds are historically effective at facilitating avoidance of wolves and moose through elevational separation, fire may be decreasing spatial separation between these animals by providing increased likelihood of key moose forage in nearby burns (Figure 15b). Further, recent burns may also be providing key vegetation forage for black bears, a predatory species that calving grounds may not have adjusted to (Figure 15c; Pinard *et al.*, 2011). Grizzly bears are also opportunistic predators of caribou calves (Young and McCabe, 1997) and may also be attracted to the increased likelihood of key forage at recent burns near calving grounds, namely blueberries and graminoids (Figure 15d). At the same time however, our findings indicate that recent burns have the potential to temporarily provide lactating cows with access to key protein (Figure 15a). Here I suggest spatial analysis is needed to understand how caribou, moose and predators in the Itcha-Ilgachuz herd range are using this specific burn. During fieldwork we saw one caribou female with calf approximately 1200m south of the burn perimeter. This calf was between 69 and 103 days old and had surpassed the period in which wolf predation is greatest (Gustine *et al.*, 2006). Recent wolf reductions in the Itcha-Ilgachuz herd range (Appendix 4) would require future analysis on the effects of fire on apparent competition and predation at calving grounds to implement controls where wolf reductions have not occurred.

Integration and overpowering of Ulkatcho ecological knowledge in statistical modelling

The dataset we selected for ordination combined 15 Ulkatcho oral accounts into four data points, compared to 48 data points from Western literature. This was done as incomplete dietary

reviews in Jaccard distance models tend to be biased towards higher dissimilarity (Alroy, 2015), a result of false absences of actual forage use. Despite this, Ulkatcho ecological knowledge provided the most spatially accurate forage information for each wildlife species in the study area. Although aggregated, these accounts enhanced the ecological relevance of our models. Had our meetings with Ulkatcho Elders and band members emphasized the breadth of forage for selected wildlife, we may have been able to retain more individual oral accounts within modelling. In doing so, we would have further strengthened the ability of our models to “walk on two legs” (Dickson-Hoyle *et al.*, 2022). Nonetheless, our methods provide a case study in integrating Indigenous knowledge systems with Western statistical approaches, and we stress the importance of including traditional ecological knowledge in all aspects of caribou management (Parlee and Caine, 2018).

Limitations

Our data is restricted by the limited number of fires sampled per age class and may be subject to site-specific conditions (Russell and Johnson, 2019). Soapberry (*Shepherdia canadensis*) for example was hypothesized to be present in early successional stands after fire (Hamer, 1996) but was only recorded in older burns (Figure 15c and 13b; Table 6). Our models did not capture the effects of soil moisture, soil type, slope or elevation, all of which are critical variables in determining the presence and abundance of vascular plants (Haughian and Burton, 2015). Climate may also be especially important in the study area. Gertie Capoose, a UFN member, explained how forests in Ulkatcho “have soapberry but it’s too dry”, a reference to recent periods of drought that may be influencing plant growth in the territory. Similar concern about the impact of warm temperatures was also voiced by Corinne Cahoose. “During the heat

dome, that was the first time there were no glaciers on the mountains...ancestors never had to experience that. Wondered what their parents would say... about caribou foraging...in the heat dome. There was hardly any berries.” These accounts indicate that changes in climate could be influencing vegetation growth in Ulkatcho, however our models failed to capture this.

Furthermore, burn severity should be considered when understanding wildlife response to post-fire vegetation communities (Brown *et al.*, 2017). My sampling methods assumed fire to be a binary and homogenous event, although we did find evidence of stand-replacing fire derived from tree cores at all sampled sites, indicating some degree of homogeneity (tree ages were consistently aged within five years of the stand mean). The difference between presence and abundance must also be considered when analyzing binomial presence/absence recovery models. Simply, high likelihood of presence does not necessarily translate to high abundance or biomass. For example, *Cladina* spp. lichens were frequently recorded in burn plots (Figure 15) however often at small percentages likely to be of little benefit to foraging caribou.

Without defecation and decay rates, and DNA profiling, moose pellet counts are not a reliable indicator of moose abundance or density (Härkönen and Heikkilä, 1999; Loosen *et al.*, 2022) and require calibration with other density data (such as GPS collaring and aerial surveys) to achieve reliable estimates (Moll *et al.*, 2022). Despite this, pellet counts provide an inexpensive and non-invasive method of understanding moose use of habitat (Moll *et al.*, 2022) and can be used as an index of moose activity in an area (Härkönen and Heikkilä, 1999). We advise future studies to capture moose activity using similarly non-invasive methods to respect the Ulkatcho people’s right to subsistence.

Conclusions

I posit that fire plays an instrumental role in determining the availability of key forage for caribou, moose, black bears and grizzly bears in Ulkatcho territory (Figure 15). Fire also causes increased forage similarity between these sympatric herbivores, especially at recent burns (Figure 12). I encourage further research to investigate whether increases in forage similarity caused by fire translates to increased spatial overlap between wildlife in this area.

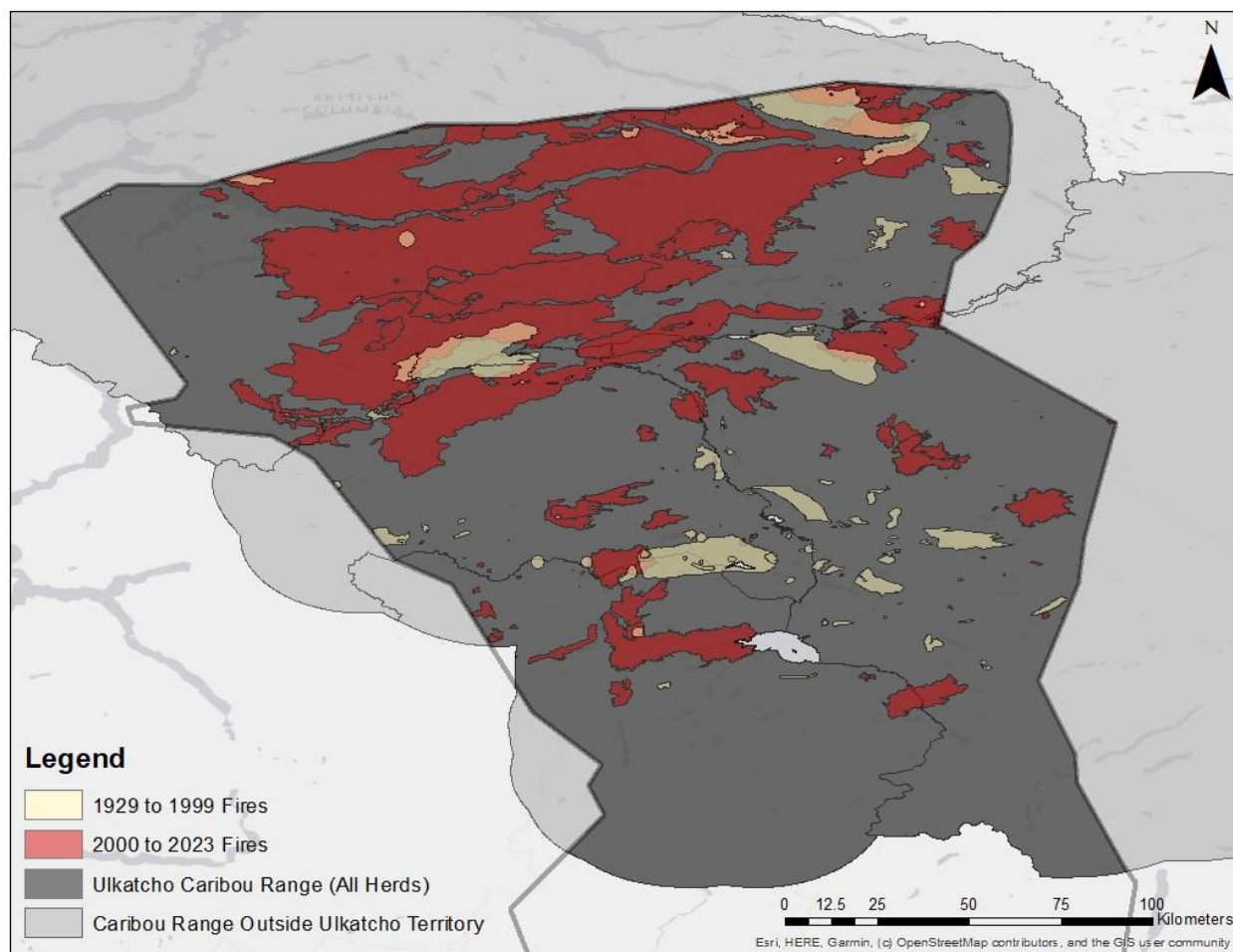
Our results also show that recent (<20 years) stand-replacing burns in Ulkatcho lodgepole pine forests can provide caribou with important summer caribou forage (Figure 15a; Denryter *et al.*, 2017). Increases in the availability of these specific plants however may come with increased risk of encountering predators due to the importance of willow, blueberry and graminoids for bears and moose (Figure 13). Our finding of greater moose activity in recent burns (Figure 16) also furthers our understanding of caribou-moose-fire dynamics and raises concerns about the impacts of a recent burn at the calving grounds of the Itcha-Ilgachuz caribou herd. We emphasize here the importance of considering black bear and grizzly bear forage, alongside moose activity, at burns that occur near calving grounds.

Finally, our study demonstrates the importance of integrating traditional ecological knowledge into all aspects of caribou management (Parlee and Caine, 2018). Knowledge from Ulkatcho Elders and band members provided the most spatially accurate forage information for selected wildlife in Ulkatcho. This facilitated strong collaboration between Indigenous and non-Indigenous knowledge systems and created a framework to better understand the relationships between fire, caribou, moose and bears in Ulkatcho territory.

Acknowledgments

The authors of this study, who are of European descent, recognize the inability of the English language to communicate the ecological knowledge described in this paper. Only Dakelh can effectively transmit the ecological relationships present within Ulkatcho territory. Out of respect for this, we use the Dakelh names for each plant and animal species when its presence in Ulkatcho is first referenced. We use the English name thereafter to allow comparison with studies that occurred outside of Ulkatcho territory. We wish to thank all members of the Ulkatcho Community. Funding for this project was provided by BC Parks Living Labs, Ulkatcho Community, Mitacs, and a NSERC Discovery Grant to Harvey.

Appendix 1



Between 2000 and 2023, 32% of caribou range in Ulkatcho territory, west-central British Columbia, burned. In the 80 years between 1919 and 1999, this figure was 6.5%. Fire polygons obtained from the Canadian National Fire Database. Caribou herd boundaries obtained from the British Columbia Provincial Caribou Recovery Project.

Appendix 2

Community Meeting Discussion Questions

1. How important are caribou to the Ulkatcho?
2. What do the Ulkatcho use caribou for?
3. What are the threats to caribou survival in Ulkatcho?
4. What do caribou eat?
5. Do caribou in Ulkatcho prefer ground or tree lichens?
6. What makes good caribou habitat?
7. Where do caribou in Ulkatcho go in winter?
8. How large did the herds used to be?
9. What is the relationship between moose and caribou?
10. What do the caribou need to return to historical population sizes?

Appendix 3

The following six-letter plant codes were used to increase the interpretability of results during community dissemination:

Identifier Code	Species English Common Name	Dakelh Name	Latin Name
SALIXF	Willow	k'idlih	<i>Salix</i> spp.
PAXMYR	False box		<i>Paxistima myrsinites</i>
VACFAM	Blueberry/Huckleberry	'ilhtsul	<i>Vaccinium</i> spp.
LONFAM	Honeysuckle		<i>Lonicera</i> spp.
RUBUSF	Raspberry/Thimbleberry		<i>Rubus</i> spp.
ROSACI	Prickly rose		<i>Rosa acicularis</i>
BUFFAL	Buffaloberry/Soopolallie	nawus	<i>Shepherdia canadensis</i>
LABTEA	Labrador tea	yak'unulh'a	<i>Ledum groenlandicum</i>

Identifier Code	Species English Common Name	Dakelh Name	Latin Name
HICRAN	Highbush cranberry		<i>Viburnum edule</i>
ARBLIC	Arboreal lichen	dahgda	<i>Bryoria</i> spp. and <i>Alectoria</i> spp.
TERLIC	Terrestrial lichen		<i>Cladonia</i> spp., and <i>Stereocaulon</i> spp.
MUSHRO	Mushroom	benidzo	Various fungi spp.
CROBER	Crowberry		<i>Empetrum nigrum</i>
ASTERF	Aster family		<i>Asteraceae</i> spp.
BUNCHB	Bunchberry	chasli mai	<i>Cornus canadensis</i>
TWINFL	Twinflower		<i>Linnaea borealis</i>
HORSET	Horsetail		<i>Equisetum</i> spp.
GRAMIN	Graminoids		
FERNFA	Ferns		
RIBESF	Gooseberry	‘indawuz	<i>Ribes</i> spp.
RHODOA	Rhododendron		<i>Rhododendron</i> <i>albiflorum</i>
VALERI	Sitka valerian		<i>Valeriana sitchensis</i>
LUPINE	Lupine		<i>Lupinus</i> spp.
MITELL	Mitrewort		<i>Mitella</i> spp.
ALNUSF	Alder	k’us	<i>Alnus</i> spp.
VIOLAF	Violet		<i>Viola</i> spp.
SOLOMO	False solomon’s seal		<i>Smilacina racemosa</i>
TWISTD	Twisted stalk		<i>Streptopus</i> spp.
COWPAR	Cow parsnip		<i>Heracleum maximum</i>
BEARBE	Bearberry/Kinnikinnick	dunih	<i>Arctostaphylos uva-</i> <i>ursi</i>
JUNIFE	Common juniper		<i>Juniperus communis</i>
FRAGAR	Wild strawberry	‘indzi chun	<i>Fragaria</i> spp.
CICELY	Sweet cicely		<i>Osmorhiza</i> spp.
BETULA	Birch	k’i	<i>Betula</i> spp.
POPULU	Poplar/Aspen/Cottonwood	t’ughus	<i>Populus</i> spp.
SPIREA	Birchleaf spirea		<i>Spiraea betulifolia</i>
FIREWE	Fireweed		<i>Chamerion</i> <i>angustifolium</i>
OPLOHO	Devil’s club		<i>Oplopanax horridus</i>

Appendix 4

An intensive government wolf cull in the Itcha-Ilgachuz herd range has seen a 75% wolf reduction since 2019 (Caribou Recovery Program, 2024). In 2023 the highest calf recruitment rate for the Itcha-Ilgachuz herd since the 1980's was recorded (24.2%; Caribou Recovery Program, 2024).

References

- Adams, L.G., Singer, F.J., & Dale, B.W. (1995). Caribou calf mortality in Denali National Park, Alaska. *The Journal of Wildlife Management*, 59(3), 584-594.
<https://doi.org/10.2307/3802467>
- Alroy, J. (2015). A new twist on a very old binary similarity coefficient. *Ecology*, 96(2), 575–586. <https://doi.org/10.1890/14-0471.1>
- Apps, C., & Dodd, N. (2017). Caribou habitat modelling and evaluation of forest disturbance influences across landscape scales in west-central BC. Ministry of Forests, Lands and Natural Resource Operations.
- Avgar, T., Baker, J. A., Brown, G. S., Hagens, J. S., Kittle, A. M., Mallon, E. E., McGreer, M. T., Mosser, A., Newmaster, S. G., Patterson, B. R., Reid, D. E. B., Rodgers, A. R., Shuter, J., Street, G. M., Thompson, I. D., Turetsky, M. R., Wiebe, P. A., & Fryxell, J. M. (2015). Space-use behaviour of woodland caribou based on a cognitive movement model. *Journal of Animal Ecology*, 84(4), 1059–1070. <https://doi.org/10.1111/1365-2656.12357>
- Ballard, W. B. (1992). Bear predation on moose: A review of recent North American studies and their management implications. *Alces*, 162-176
<https://www.alcesjournal.org/index.php/alces/article/view/1805>
- Ballard, W. B. (1994). Effects of black bear predation on caribou—A review. *Alces: A Journal Devoted to the Biology and Management of Moose*, 30, 25–35.
- Barboza, P. S., & Parker, K. L. (2008). Allocating protein to reproduction in Arctic reindeer and caribou. *Physiological and Biochemical Zoology*, 81(6), 835–855
<https://doi.org/10.1086/590414>
- Bergerud, A. T. (1972). Population dynamics of Newfoundland caribou (Wildlife Monograph No. 35). The Wildlife Society.
- Bergerud, A.T. (1974). Decline of caribou in North America following settlement. *Journal of Wildlife Management*, 38(4), 757-770. <https://doi.org/10.2307/3800042>
- Bergerud, A. T. (1996). Evolving perspectives on caribou population dynamics, have we got it right yet? *Rangifer*, 16(4), 95–116. <https://doi.org/10.7557/2.16.4.1225>
- Bergerud, A. T. (2000). Caribou. In S. Demarais & P. R. Krausman (Eds.), *Ecology and management of large mammals in North America* (pp. 658–692). Prentice Hall.
- Bergerud, A. T., & Page, R. E. (1987). Displacement and dispersion of parturient caribou at calving as antipredator tactics. *Canadian Journal of Zoology*, 65(7), 1597-1606.
<https://doi.org/10.1139/z87-249>

- Boertje, R. D., Gasaway, W. C., Grangaard, D. V., & Kelleyhouse, D. G. (1995). Grizzly bear predation rates on caribou calves in northeastern Alaska. *The Journal of Wildlife Management*, 59(3), 505–512. <https://doi.org/10.2307/3802102>
- Bloomfield, M. I. (1979). The ecology and status of mountain caribou and caribou range in central British Columbia (Master's thesis). University of Alberta.
- Boer, A. H. (2007). Interspecific relationships. In A. W. Franzmann & C. C. Schwartz (Eds.), *Ecology and management of the North American moose* (pp. 337–349). University Press of Colorado.
- British Columbia Ministry of Forests. (2022). Best Management Practice Guide for Fuel Treatment: Central Plateau Fire Weather Zone. Government of British Columbia. https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/wildfire-status/prevention/fire-fuel-management/fuels-management/central_plateau_fire_weather_zone_for_review.pdf
- Brown, C. L., Brinkman, T. J., Tape, K. D., & Kundel, H. L. (2017). The influence of snow cover on resource selection by moose (*Alces alces*) in Alaska. *PLOS ONE*, 12(4), e0173883. <https://doi.org/10.1371/journal.pone.0173883>
- Cameron, M. D., Joly, K., Hepler, J., & Kielland, K. (2020). Pronounced fidelity and selection for average conditions of calving area suggestive of spatial memory in a highly migratory ungulate. *Frontiers in Ecology and Evolution*, 8, 564567. <https://doi.org/10.3389/fevo.2020.564567>
- Caribou Recovery Program. (2023). British Columbia caribou herds population estimates: 2023 update. https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/wildlife-wildlife-habitat/caribou/bc_caribou_herds_population_estimates.pdf
- Christopherson, R. J., Redhead, R., Schaefer, J. A., & Witten, E. (2019). Changes in moose habitat use following industrial development in northeastern Alberta. *Global Ecology and Conservation*, 20, e00767. <https://www.sciencedirect.com/science/article/pii/S2351989419301428>
- Ciarniello, L. M., Boyce, M. S., Heard, D. C., & Seip, D. R. (2005). Denning behavior and den site selection of grizzly bears along the Parsnip River, British Columbia, Canada. *Ursus*, 16(1), 47–58. [https://doi.org/10.2192/1537-6176\(2005\)016\[0047:DBADSS\]2.0.CO;2](https://doi.org/10.2192/1537-6176(2005)016[0047:DBADSS]2.0.CO;2)
- Cichowski, D. (1993). Seasonal Movements, Habitat Use, and Winter Feeding Ecology of Woodland Caribou in West-Central BC. <https://www.for.gov.bc.ca/hfd/pubs/Docs/Mr/Lmr/Lmr079.pdf>
- Cichowski, D. (2015). Tweedsmuir-Entiako Caribou Population Status and Background Information Summary.

https://a100.gov.bc.ca/pub/acat/documents/r55188/TweedsmuirCaribouPopulationStatusandBackgroundInf_1542742511092_2741941772.pdf

- Connell, J. H. (1980). Diversity and the coevolution of competitors, or the ghost of competition past. *Oikos*, 35(2), 131–138. <https://www.jstor.org/stable/3544421>
- Darimont, C. T., Paquet, P. C., Reimchen, T. E., & Crichton, V. (2005). Range expansion by moose into coastal temperate rainforests of British Columbia, Canada. *Diversity and Distributions*, 11(2), 235–239
- Demarchi, M. W. (2003). Migratory patterns and home range size of moose in the central Nass Valley. *Northwest Naturalist*, 84, 135–145.
- Denryter, K. A., Cook, R. C., Cook, J. G., & Parker, K. L. (2017). Foraging ecology of woodland caribou in boreal and montane ecosystems of northern British Columbia. *Journal of Wildlife Management*, 81(2), 316–325. <https://doi.org/10.1002/jwmg.21194>
- Denryter, K. A., Cook, R. C., Cook, J. G., Parker, K. L., & Gillingham, M. P. (2018). Nutritional values of habitats for woodland caribou during summer. NRESi Research Extension Note No. 12. University of Northern British Columbia. <https://www.unbc.ca/sites/default/files/sections/nres-institute/nresiren12denryteretal.pdf>
- Derguy, L., Leblond, M., & St-Laurent, M.-H. (2025). Living in fear: How experience shapes caribou responses to predation risk. *Ecosphere*, 16(1), e70155. <https://doi.org/10.1002/ecs2.70155>
- Dickson-Hoyle, S., Ignace, R. E., Ignace, M. B., Hagerman, S. M., Daniels, L. D., & Copes-Gerbitz, K. (2022). Walking on two legs: A pathway of Indigenous restoration and reconciliation in fire-adapted landscapes. *Restoration Ecology*, 30(4), e13566. <https://doi.org/10.1111/rec.13566>
- Edwards, R. Y., & Ritcey, R. W. (1960). Foods of caribou in Wells Gray Park, British Columbia. *The Canadian Field-Naturalist*, 74(1), 3–7.
- 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*, 89(5), 419–434. <https://doi.org/10.1139/z11-025>
- Gharajehdaghpour, T. (n.d.). [*Unpublished map of Itcha-Ilgachuz calving locations*]. Unpublished data.
- Government of BC. (2018). Itcha-Ilgachuz and Rainbow Caribou Herd Population and Habitat Information. https://a100.gov.bc.ca/pub/acat/documents/r54951/ItchaandRainbowcaribouherdinformation_1541116628869_1116541210.pdf

- Greuel, R. J., Degré-Timmons, G. É., Baltzer, J. L., Johnstone, J. F., McIntire, E. J. B., Day, N. J., Hart, S. J., McLoughlin, P. D., Schmiegelow, F. K. A., Turetsky, M. R., Truchon-Savard, A., van Telgen, M. D., & Cumming, S. G. (2021). Predicting patterns of terrestrial lichen biomass recovery following boreal wildfires. *Ecosphere*, 12(4), e03481. <https://doi.org/10.1002/ecs2.3481>
- Gurarie, E., Hebblewhite, M., Jonsen, I. D., Frair, J., & Börger, L. (2011). A framework for modelling range shifts and animal movement: A latent variable approach. *Oecologia*, 165(2), 233–246. <https://link.springer.com/article/10.1007/s00442-010-1883-y>
- 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. [https://doi.org/10.2193/0084-0173\(2006\)165\[1:CSOWCI\]2.0.CO;2](https://doi.org/10.2193/0084-0173(2006)165[1:CSOWCI]2.0.CO;2)
- Hamer, D., & Herrero, S. (1987). Wildfire's influence on grizzly bear feeding ecology in Banff National Park, Alberta. In *Bears: Their Biology and Management* (Vol. 7, pp. 179–186). International Association for Bear Research and Management. <https://doi.org/10.2307/3872624>
- Hamer, D. (1996). Buffaloberry [*Shepherdia canadensis* (L.) Nutt.] fruit production in fire-successional habitats of Banff National Park, Alberta. *Journal of Range Management*, 49(6), 520–529.
- Härkönen, S., & Heikkilä, R. (1999). Use of pellet group counts in determining density and habitat use of moose (*Alces alces*) in Finland. *Wildlife Biology*, 5(4), 233–239. <https://doi.org/10.2981/wlb.1999.028>
- Hebblewhite, M., Whittington, J., Bradley, M., Skinner, G., Dibb, A., & White, C.A. (2007). Conditions for caribou persistence in the wolf-elk-caribou systems of the Canadian Rockies. *Rangifer*, 27. <https://doi.org/10.7557/2.27.4.322>
- Hebda, R. J., Turner, N. J., Birchwater, S., Kay, M., & The Elders of Ulkatcho. *Ulkatcho Food and Medicine Plants*. Williams Lake, BC: Progressive Printers Inc.
- Holt, R. D. (1977). Predation, apparent competition, and the structure of prey communities. *Theoretical Population Biology*, 12(2), 197–229. <https://www.sciencedirect.com/science/article/pii/0040580977900429>
- Hummel, M., & Ray, J. C. (2008). *Caribou and the North: A shared future*. Dundurn Press.
- Johnson, C. A., Mumma, M. A., & McLoughlin, P. D. (2022). Evidence for scale-dependent use of refuges by caribou following disturbance. *Ecography*, 45(2), 165–177. <https://nsojournals.onlinelibrary.wiley.com/doi/epdf/10.1111/j.1600-0587.2012.07733.x>

- Johnson, K. G., & Pelton, M. R. (1980). Environmental relationships and the denning period of black bears in Tennessee. *Journal of Mammalogy*, 61(4), 653–660.
<https://doi.org/10.2307/1380310>
- Johnson, C. J., Santomauro, D., & Fondahl, G. (2012). Historical-ecological evaluation of the long-term distribution of woodland caribou and moose in central British Columbia. *Ecosphere*, 3(5), Article 37. <https://doi.org/10.1890/ES11-00371.1>
- Johnstone, J. F., Baltzer, J. L., Day, N. J., Hollingsworth, T. N., Mack, M. C., & Turetsky, M. R. (2021). The influence of postfire recovery and environmental conditions on vegetation community composition in boreal forests. *Ecosphere*, 12(9), e03605.
<https://doi.org/10.1002/ecs2.4605>
- Joly, K., Chapin, F. S., & Klein, D. R. (2016). Winter habitat selection by moose in a northern boreal forest in Alaska: Effects of landscape composition and structure. *Forest Ecology and Management*, 366, 51–59. <https://doi.org/10.1016/j.foreco.2016.02.004>
- Jorgensen, A. (2021). Wildlife forage recovery following boreal wildfire (Master's thesis). Wilfrid Laurier University.
- Key, C. H., & Benson, N. (2006). Landscape Assessment (LA) ground measure of severity, the composite burn index; and remote sensing of severity, the normalized burn ratio. In D. C. Lutes et al. (Ed.), *FIREMON: Fire effects monitoring and inventory system*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
<https://doi.org/10.2737/RMRS-GTR-164>
- Kiel, M. J., Buma, B., & Whitman, E. (2023). Short-interval reburns alter understory plant communities in high-elevation forests of Glacier National Park, Canada. *Forest Ecology and Management*, 527, 120571. <https://doi.org/10.1016/j.foreco.2023.120571>
- Kuehn, C. (2014). A Second North American hot-spot: Pleistocene volcanism in the Anahim Volcanic Belt, west-central British Columbia (Doctoral thesis, University of Calgary, Calgary, Canada). PRISM Repository.
<https://hdl.handle.net/11023/1936https://doi.org/10.11575/PRISM/25002>
- Lamb, C.T., Williams, S., Boutin, S., Bridger, M., Cichowski, D., Cornhill, K., DeMars, C., Dickie, M., Ernst, B., Ford, A., Gillingham, M.P., Greene, L., Heard, D.C., Hebblewhite, M., Hervieux, D., Klaczek, M., McLellan, B.N., McNay, R.S., Neufeld, L., Nobert, B., Nowak, J.J., Pelletier, A., Reid, A., Roberts, A.-M., Russell, M., Seip, D., Seip, C., Shores, C., Steenweg, R., White, S., Wittmer, H.U., Wong, M., Zimmerman, K.L., & Serrouya, R. (2024). Effectiveness of population-based recovery actions for threatened southern mountain caribou. *Ecological Applications*, 34(4), 2965, <https://doi.org/10.1002/eap.2965>
- Lamb, C. T., Steenweg, R., Serrouya, R., Hervieux, D., McNay, R. S., Heard, D. C., McLellan, B. N., Shores, C., Palm, E., Giguere, L., Hubner, J., Polfus, J., Klaczek, M., Crosland, N., White, S., Russel, M., & Ford, A. (2025). The erosion of threatened southern mountain

- caribou migration. *Global Change Biology*, 31(3), e70095. [https://doi.org/10.1111/gcb.70095:contentReference\[oaicite:8\]{index=8}](https://doi.org/10.1111/gcb.70095:contentReference[oaicite:8]{index=8})
- 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(4), 1078–1087. <https://doi.org/10.1111/1365-2664.12658>
- Legendre, P., & Gallagher, E. D. (2001). Ecologically meaningful transformations for ordination of species data. *Oecologia*, 129(2), 271–280. <https://doi.org/10.1007/s004420100716>
- Loosen, A. E., Devineau, O., Zimmermann, B., & Mathisen, K. M. (2022). The importance of evaluating standard monitoring methods: Observer bias and detection probabilities for moose pellet group surveys. *PLOS ONE*, 17(7), e0268710. <https://doi.org/10.1371/journal.pone.0268710>
- Loranger, A. J., Bailey, T. N., & Larned, W. W. (1991). Effects of forest succession on populations of moose *Alces alces* in south-central Alaska. *Wildlife Biology*, 17(3), 261–267.
- Lord, R., & Kielland, K. (2015). Effects of variable snowpack on forage availability and nutrition for moose (*Alces alces*) in Alaskan boreal forests. *Forest Ecology and Management*, 358, 1–9. <https://doi.org/10.1016/j.foreco.2015.08.043>
- Lyon, L. J., & Stickney, P. F. (1976). Early vegetative succession following large northern Rocky Mountain wildfires. In *Proceedings of the Tall Timbers Fire Ecology Conference* (Vol. 14, pp. 355–373). Tall Timbers Research Station.
- Maier, J. A. K., Ver Hoef, J. M., McGuire, A. D., Bowyer, R. T., Saperstein, L., & Maier, H. A. (2005). Distribution and density of moose in relation to landscape characteristics: Effects of scale. *Canadian Journal of Forest Research*, 35(9), 2233–2243. <https://doi.org/10.1139/x05-110>
- McLaren, A. A. D., Jamieson, S. E., Bond, M., Rodgers, A. R., & Patterson, B. R. (2021). Spring diet of American black bears (*Ursus americanus*) in a moose (*Alces alces*)–woodland caribou (*Rangifer tarandus caribou*) system in northern Ontario, Canada. *Canadian Journal of Zoology*, 99(8), 721–728. <https://doi.org/10.1139/cjz-2020-0263>
- McLellan, B. N., & Hovey, F. W. (1995). The diet of grizzly bears in the Flathead River drainage of southeastern British Columbia. *Canadian Journal of Zoology*, 73(4), 704–712. <https://doi.org/10.1139/z95-082>
- McClelland, C. J. R., Coops, N. C., Kearney, S. P., Burton, A. C., Nielsen, S. E., & Stenhouse, G. B. (2020). Variations in grizzly bear habitat selection in relation to the daily and seasonal availability of annual plant-food resources. *Journal of Wildlife Management*, 84(4), 693–706. <https://doi.org/10.1016/j.jcoinf.2020.101116>

- Moll, R. J., Poisson, M. K., Heit, D. R., Jones, H., Pekins, P. J., & Kantar, L. (2022). A review of methods to estimate and monitor moose density and abundance. *Alces*, 58, 31–49. <https://alcesjournal.org/index.php/alces/article/view/1881>
- Mueller, C., & Boulanger, J. (2013). Chilcotin Coast Grizzly Bear Project: Grizzly bears in the Tatlayoko Valley and along the upper Chilko River, Final report. The Nature Conservancy of Canada & The Wilburforce Foundation. https://static1.squarespace.com/static/5fb40f142378085d51c56743/t/603810c43a2b0832e8b30005/1614287051220/CCGrizzlyBearProject_final+report_Dec1_2013+%281%29.pdf
- Mumma, M. A., Gillingham, M. P., McNay, R. S., & Boutin, S. (2024). Fire-mediated habitat change drives moose population dynamics in boreal forests. *Ecological Applications*, 34(1), e2873. <https://doi.org/10.1002/eap.2873>
- Oksanen, J., Simpson, G. L., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O'Hara, R. B., Solymos, P., Stevens, M. H. H., Szoecs, E., Wagner, H., Barbour, M., Bedward, M., Bolker, B., Borcard, D., Carvalho, G., Chirico, M., De Caceres, M., Durand, S., Evangelista, H. B. A., FitzJohn, R., Friendly, M., Furneaux, B., Hannigan, G., Hill, M. O., Lahti, L., McGlinn, D., Ouellette, M.-H., Ribeiro Cunha, E., Smith, T., Stier, A., Ter Braak, C. J. F., & Weedon, J. (2022). *vegan: Community Ecology Package (Version 2.6-4)* [R package]. <https://CRAN.R-project.org/package=vegan>
- Parks, S., Holsinger, L., Voss, M., Loehman, R., & Robinson, N. (2018). Mean composite fire severity metrics computed with google earth engine offer improved accuracy and expanded mapping potential. *Remote Sensing* 10(6), 879. <https://doi.org/10.3390/rs10060879>
- Parlee, B., & Caine, K. (2018). *When The Caribou Do Not Come: Indigenous Knowledge and Adaptive Management in the Western Arctic*. UBC Press.
- Peters, W., Hebblewhite, M., DeCesare, N., Cagnacci, F., & Musiani, M. (2013). Resource separation analysis with moose indicates threats to caribou in human altered landscapes. *Ecography*, 36(4), 487–498. <https://doi.org/10.1111/j.1600-0587.2012.07733.x>
- Pigeon, K. E., Nielsen, S. E., Stenhouse, G. B., & Côté, S. D. (2014). Den selection by grizzly bears on a managed landscape. *Journal of Mammalogy*, 95(3), 559–571. <https://doi.org/10.1644/13-MAMM-A-137>
- Pinard, V., Dussault, C., Ouellet, J.-P., Courtois, R., & Fortin, D. (2012). Calving rate, calf survival rate, and habitat selection of forest-dwelling caribou in a highly managed landscape. *Journal of Wildlife Management*, 76(1), 189–199. <https://doi.org/10.1002/jwmg.217>
- Poole, K. G., Serrouya, R., & Stuart-Smith, K. (2007). Moose calving strategies in interior montane ecosystems. *Journal of Mammalogy*, 88(1), 139–150. <https://doi.org/10.1644/06-MAMM-A-127R1.1>

- Raine, R. M., & Kansas, J. L. (1990). Black bear seasonal food habits and distribution by elevation in Banff National Park, Alberta. In *Bears: Their Biology and Management* (Vol. 8, pp. 297–304). International Association for Bear Research and Management. <https://doi.org/10.2307/3872932>
- Reynolds, P. E., & Garner, G. W. (1987). Patterns of grizzly bear predation on caribou in northern Alaska. *International Conference on Bear Research and Management*, 7, 59–67. <https://doi.org/10.2307/3872608>
- Ruggirello, M. C., Kurkowski, T. A., Tobalske, C., & Nelson, C. R. (2023). Fire increases shrub dominance in boreal forests by altering willow resprouting and recruitment. *Forest Ecology and Management*, 541, 121009. <https://doi.org/10.1016/j.foreco.2023.121009>
- Russell, K. L. M., & Johnson, C. J. (2019). Post-fire dynamics of terrestrial lichens: Implications for the recovery of woodland caribou winter range. *Forest Ecology and Management*, 434, 1–16. <https://doi.org/10.1016/j.foreco.2018.12.033>
- Schwartz, C. C. (1992). Reproduction, natality, and growth of moose: A review. *Alces*, 28, 165–184. <https://www.alcesjournal.org/index.php/alces/article/view/1063>
- Schwartz, C. C. (1997). Reproduction, natality, and growth. In A. W. Franzmann & C. C. Schwartz (Eds.), *Ecology and management of the North American moose* (pp. 141–171). Smithsonian Institution Press.
- Seip, D. R. (1992). Factors limiting woodland caribou populations and their interrelationships with wolves and moose in southeastern British Columbia. *Canadian Journal of Zoology*, 70(8), 1494–1503. <https://cdnsiencepub.com/doi/10.1139/z92-206>
- Sharp, H. S., & Sharp, K. (2015). *Hunting caribou: Subsistence hunting along the northern edge of the boreal forest*. University of Nebraska Press. <https://doi.org/10.2307/j.ctt1d9nhpn>
- Thomas, D. C., & Hervieux, D. P. (1986). The late winter diets of barren-ground caribou in north-central Canada. *Rangifer*, 6(2), 305–310. <https://doi.org/10.7557/2.6.2.1275>
- Tirmenstein, D. A. (1991). *Vaccinium angustifolium* (low sweet blueberry). In U.S. Department of Agriculture, Forest Service, Fire Effects Information System (FEIS). Retrieved April 25, 2025, from <https://www.fs.usda.gov/database/feis/plants/shrub/vacang/all.html>
- Torney, C. J., Berdahl, A., Meekan, M. G., & Bode, M. (2018). Inferring the rules of social interaction in migrating caribou. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 373(1746), 20170385. <https://doi.org/10.1098/rstb.2017.0385>
- Ulkatcho First Nation. (n.d.). Our history. Ulkatcho First Nation. Retrieved July 5, 2025, from <https://www.ulkatcho.ca/>

- Webber, Q. M. R., Ferraro, K. M., Hendrix, J. G., & Vander Wal, E. (2022). What do caribou eat? A review of the literature on caribou diet. *Canadian Journal of Zoology*, 100(3), 197–207. <https://doi.org/10.1139/cjz-2021-0162>
- Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. Springer-Verlag. <https://ggplot2.tidyverse.org>
- Wittmer, H., Sinclair, A., & McLellan, B. (2005). The role of predation in the decline and extirpation of woodland caribou. *Population Ecology*, 144, 257-267. <https://doi.org/10.1007/s00442-005-0055-y>
- Young, D. D., & McCabe, T. R. (1997). Grizzly bear predation rates on caribou calves in northeastern Alaska. *The Journal of Wildlife Management*, 61(4), 1056–1066. <https://doi.org/10.2307/3802102>

Chapter 4: CONCLUSIONS

Across western Canada, caribou have long persisted in fire-influenced landscapes (Bergerud, 1974; Klein, 1982), yet our understanding of how fire affects caribou habitat remains complex and often fragmented. Historically, in lodgepole pine forests, fire has played an important role in resetting ecological succession, periodically restoring open forest conditions that allow for abundant lichen growth (Coxson and Marsh, 2001) and suitable sightlines for caribou to detect predators (Apps and Dodd, 2017). However, as wildfire regimes change, our study in Ulkatcho territory suggests that fire can simultaneously create and constrain habitat opportunities for caribou. Understanding how caribou navigate post-fire landscapes in Ulkatcho is essential for developing effective conservation strategies. Here our study provides Ulkatcho First Nation with baseline data and ecological patterns to guide their management of caribou in an uncertain future. In this research, we investigated caribou habitat and fire dynamics across temporal scales, providing new insight into the interactions between lichen recovery and forest structure in lodgepole pine forests. We also laid the foundations for future research on the links between fire, dietary niche overlap and predation risk, a complex relationship that will become clearer with further integration of Western scientific tools and Ulkatcho ecological knowledge.

Our findings indicate that post-fire winter habitat recovery for caribou in lodgepole pine forests may not be solely a function of lichen regeneration (Figure 8). While terrestrial lichen cover recovered within as little as ~60 years of stand-replacing fire, lodgepole pine stand structure remained significantly denser than habitat of known caribou selection for decades after (Figure 8). High tree stem densities can limit visibility, mobility, and predator detection, all of which are important factors in caribou habitat selection (Thomas *et al.*, 1996; Wilson *et al.*, 2023). These findings have direct implications for habitat restoration and fire management: if

caribou avoid structurally dense stands despite high forage availability, then recovery timelines based solely on lichen abundance may not fully represent habitat suitability. Our findings here suggest that thinning treatments could be explored as a possible method to accelerate structural recovery, however -- such is the complexity of relationships between lichen, vascular plants and mosses (Haughian and Burton, 2015) -- this could have detrimental effects on lichen recovery if canopy cover is opened too soon after disturbance (Goward *et al.*, 2022). Future research should assess how thinning treatments, and the opening of canopy cover, affect the delicate interactions between understorey vegetation. If an optimal thinning window can be identified, in which thinning both stimulates terrestrial lichen growth and allows for more open stem densities, our results suggests that this could be an effective tool to support the accelerated recovery of suitable caribou habitat.

Our findings also reveal how fire may influence the interactions between caribou and other herbivores and predators. In early post-fire environments, we found greater dietary overlap of caribou with moose and bears (Figure 12; Table 6), driven by the early recovery of important shared forage such as willow, blueberry, and graminoids (Figure 13). These plant species act as key summer forage for caribou (Denryter *et al.*, 2017), especially lactating females (Denryter *et al.*, 2018; K. Denryter, personal communication, 2025) but may also attract moose (Figure 15b, Loranger *et al.*, 1991; Lord and Kielland, 2015) and bears (Figure 15c and 13d) into recently burned areas. This may have significant implications for predator-prey dynamics and the role of apparent competition in caribou decline in Ulkatcho. Specifically, increased moose abundance in recent burns may indirectly support greater predation pressure on caribou by leading to increased wolf encounters (Peters *et al.*, 2013), particularly near sensitive habitat such as calving grounds.

Here our results require further spatial analysis on the use of recent burns by caribou, moose, bears and wolves in Ulkatcho territory to better understand how these dynamics play out.

Given that the Itcha-Ilgachuz calving grounds are located within Itcha-Ilgachuz Provincial Park, and that BC Parks currently enacts a limited response to wildfires within park boundaries, the predicted increase in fire near sensitive alpine calving grounds presents unique challenges for fire management decision-makers in the future. If spatial models suggests that fire near calving grounds has a detrimental effect on calf survival by proxy of increased apparent competition, BC Parks may need to adopt measures that suppress fires occurring near sensitive calving grounds within provincial parks. For fires outside of BC Parks, a broader approach may also involve the BC Wildfire Service. For example, caribou calving grounds could be treated as ‘high value’ layers in wildfire GIS models which triggers the need for fire suppression, similar to how human infrastructure is characterized as high priority for protection. This of course raises philosophical questions about the role of fire suppression in tampering with natural disturbance cycles, although these approaches could be applied specifically to high-elevation and alpine wildfires near habitat that does not have a history of fire activity. Further complicating this is our finding that fires near calving grounds may temporarily increase availability of key summer forage for parturient and lactating caribou (Figure 15a). This again demonstrates the need for spatial analysis to investigate how caribou are responding to and using this burn near the calving grounds, especially females.

Research in other regions of Canada suggests that caribou can demonstrate behavioral flexibility in response to disturbance (Avgar *et al.*, 2015; Derguy *et al.*, 2025). Their avoidance of moose habitat, potentially due to learned associations with predation risk (Derguy *et al.*, 2025), supports the need for management frameworks that consider not only habitat quality and

quantity, but also caribou perceptions of risk (Avgar *et al.*, 2021). Avoidance of high-risk landscapes, even when forage is abundant, should inform the holistic assessment of caribou habitat. Here, spatial models of caribou use in Ulkatcho territory could be improved by incorporating predator risk layers and movement data from other species, while also using our data on the recovery of important forage species.

Environment and Climate Change Canada (ECCC) define the recovery goal for southern mountain caribou as to achieve self-sustaining populations in all local population units within their current distribution, to the extent possible (Environment Canada, 2014). This research supports this goal and provides co-produced knowledge with Ulkatcho First Nation to support the recovery of southern mountain caribou in Ulkatcho territory. The results from this study can be used to inform the management of post-fire caribou habitat in lodgepole pine stands in southern mountain caribou range and demonstrate the importance of considering stand density in winter habitat assessments.

Our efforts to integrate Ulkatcho ecological knowledge into habitat modelling improved the ecological and spatial accuracy of our results. Specifically, knowledge from Elders and community members identified areas of important caribou habitat and key vegetation forage for caribou, moose and bears in Ulkatcho territory. This integration increased the power of statistical modelling, although the inherent biases of the models we selected still leaned towards Western scientific approaches. This research may therefore act as a case study for future research to provide ideas on how to integrate Indigenous knowledge systems in caribou research. For example, the use of Dakelh linguistics and qualitative efforts to ‘Think Like A Caribou’ (TLAC) allowed for greater engagement between field researchers and the land, plants and animals of Ulkatcho. These efforts received positive feedback from Ulkatcho youth and community

members, and our TLAC methods in particular provided a unique, caribou-centric perspective of lichen recovery in post-burn forests (Figure 6). Moving forward, we argue that research and policy in caribou conservation must meaningfully incorporate Indigenous knowledge systems (Parlee and Caine, 2018), not just as validation tools, but as key components to understand caribou habitat and behavior. We recommend that future efforts to recover caribou in Ulkatcho territory be co-designed with UFN from the outset and include dedicated methods for integrating Ulkatcho ecological knowledge into data collection, results and decision-making.

In summary, our research contributes several key findings: (1) stand-replacing fires cause long recovery trajectories for winter caribou habitat, with lichen recovery occurring before structural suitability in lodgepole pine forests; (2) recent burns alter dietary overlap between caribou and moose and bears, which may have important impacts on predation risk for caribou; (3) burns occurring at or near calving grounds have the potential to increase the availability of key spring and summer foods for caribou, especially lactating females, however this may come with increased predation risk in a sensitive habitat; and (4) Indigenous knowledge systems offer invaluable insight into both caribou habitat and caribou behavior. Combined, our findings illustrate the complex relationships between fire and caribou and provide UFN with data to support their management of caribou in an increasingly uncertain future.

As fire regimes change, adopting a holistic understanding of caribou and their habitat has become increasingly important, quite simply as caribou themselves possess a holistic and complex understanding of their environment. Central to our understanding of caribou and fire relationships should be the recognition that fire plays a natural and important role in the regulation of habitat for many caribou (Klein, 1982), especially in lodgepole pine forests (Goward, 1999; Coxson and Marsh, 2001). Caribou across their North American distribution

have shown a remarkable ability to survive and adapt to extreme conditions, however, are now faced with a landscape that is rapidly becoming out of balance with their habitat needs. We posit that an approach to habitat that considers stand structure, forage quality, species interactions, and Indigenous knowledge, alongside the role of fire as a natural and not always detrimental process, will allow for deeper understanding of this complex and threatened species.

References

- Apps, C., & Dodd, N. (2017). Caribou habitat modelling and evaluation of forest disturbance influences across landscape scales in west-central BC. Ministry of Forests, Lands and Natural Resource Operations.
- Avgar, T., Baker, J. A., Brown, G. S., Hagens, J. S., Kittle, A. M., Mallon, E. E., McGreer, M. T., Mosser, A., Newmaster, S. G., Patterson, B. R., Reid, D. E. B., Rodgers, A. R., Shuter, J., Street, G. M., Thompson, I., Turetsky, M. J., Wiebe, P. A., & Fryxell, J. M. (2015). Space-use behaviour of woodland caribou based on a cognitive movement model. *Journal of Animal Ecology*, 84(4), 1059–1070. <https://doi.org/10.1111/1365-2656.12357>
- Bergerud, A. T. (1974). Decline of caribou in North America following settlement. *Journal of Wildlife Management*, 38(4), 757–770. <https://doi.org/10.2307/3800042>
- Coxson, D. S., & Marsh, J. (2001). Lichen chronosequences (postfire and postharvest) in lodgepole pine (*Pinus contorta*) forests of northern interior BC. *Canadian Journal of Botany*, 79(12), 1449–1464. <https://doi.org/10.1139/b01-127>
- Denryter, K. A., Cook, R. C., Cook, J. G., & Parker, K. L. (2017). Straight from the caribou's mouth: Dietary monoterpenes and their implications for a declining boreal ungulate. *Canadian Journal of Zoology*, 95(12), 885–895. <https://doi.org/10.1139/cjz-2016-0114>
- Denryter, K. A., Cook, R. C., Cook, J. G., Parker, K. L., & Gillingham, M. P. (2018). Nutritional values of habitats for woodland caribou during summer. NRESi Research Extension Note No. 12. University of Northern British Columbia. <https://www.unbc.ca/sites/default/files/sections/nres-institute/nresiren12denryteretal.pdf>
- Derguy, L., Leblond, M., & St-Laurent, M.-H. (2025). Living in fear: How experience shapes caribou responses to predation risk. *Ecosphere*, 16(1), e07155. <https://doi.org/10.1002/ecs2.70155>
- Environment Canada. (2014). Recovery strategy for the woodland caribou, Southern Mountain population (*Rangifer tarandus caribou*) in Canada. https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/rs_woodland%20caribou_bois_s_mtn_0614_e.pdf
- Goward, T., Coxson, D. S., Gauslaa, Y., Esseen, P. A., & Resler, L. M. (2022). Stand openness predicts hair lichen (Bryoria) abundance in the lower canopy, with implications for the conservation of Canada's critically imperiled Deep-Snow Mountain Caribou (*Rangifer tarandus caribou*). *Forest Ecology and Management*, 512, 120148. <https://doi.org/10.1016/j.foreco.2022.120148>

- Haughian, S. R., & Burton, P. J. (2015). Microhabitat associations of lichens, feathermosses, and vascular plants in a caribou winter range, and their implications for understory development. *Botany*, 93(4), 221–231. <https://doi.org/10.1139/cjb-2014-0238>
- Klein, D. R. (1982). Fire, lichens, and caribou. *Journal of Range Management*, 35(3), 390–395. <https://doi.org/10.2307/3898658>
- Loranger, A. J., Bailey, T. N., & Larned, W. W. (1991). Effects of forest succession on populations of moose *Alces alces* in south-central Alaska. *Wildlife Biology*, 17(3), 261–267.
- Lord, R., & Kielland, K. (2015). Effects of variable snowpack on forage availability and nutrition for moose (*Alces alces*) in Alaskan boreal forests. *Forest Ecology and Management*, 358, 1–9. <https://doi.org/10.1016/j.foreco.2015.08.043>
- Parlee, B., & Caine, K. (2018). When the caribou do not come: Indigenous knowledge and adaptive management in the Western Arctic. UBC Press.
- Peters, W., Hebblewhite, M., DeCesare, N., Cagnacci, F., & Musiani, M. (2013). Resource separation analysis with moose indicates threats to caribou in human altered landscapes. *Ecography*, 36(4), 487–498. <https://doi.org/10.1111/j.1600-0587.2012.07733.x>
- Thomas, D. C., Barry, S. J., & Alaie, G. (1996). Fire-caribou-winter range relationships in northern Canada. *Rangifer*, 16(2), 57–67. <https://doi.org/10.7557/2.16.2.1198>
- Wilson, S. F., Nudds, T. D., Green, P. E. J., & de Vries, A. (2023). Effect of forest understorey stand density on woodland caribou (*Rangifer tarandus caribou*) habitat selection. *Canadian Journal of Forest Research*, 53(8), 1012–1023. <https://doi.org/10.1139/cjfr-2023-0105>