Tuktu Past, Present, and Future: State of Torngat Mountains Caribou and their Forage in a Changing Environment

by

Alexandra Johnson

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Caribou (*Rangifer tarandus*) populations are in decline across Canada, making this charismatic species a major conservation concern. For Inuit of Northern Labrador and Quebec, caribou are a cultural keystone species with nutritional, cultural, and spiritual value. Inuit have long been aware that the Torngat Mountains Caribou (TMC) population is distinct from the overlapping George River Caribou (GRC) herd, but this distinction has only recently been recognized by federal and provincial governments. Therefore, limited TMC specific data are available. The objective of this thesis is to summarize existing information on the TMC, identify knowledge gaps, and contribute to the growing body of research on the TMC. One threat facing the TMC is climate change. Arctic warming has resulted in shrub expansion in Eastern Canada's tundra which, in turn, has negatively impacted lichens, an important caribou food source. This study investigates changes to caribou forage availability due to ambient and experimental warming at two tundra sites located within the range of the TMC in Nunatsiavut, Labrador. The main questions we address are: 1) What proportion of total vegetation is suitable caribou forage and how has this changed with time and experimental warming? 2) Which forage species are most impacted by recent climate change? To answer these questions, we analyzed vegetation data collected over a 14-year period within the TMC's range. Permanent, control and warming plots were established at Nakvak Brook and Torr Bay in 2007 and 2009 respectively and re-sampled every 3-6 years. From these vegetation data, we identified species of high, medium, and low caribou forage quality based on published literature. We then modelled the observed changes in forage availability. Results of this study found that caribou are more likely to be forage limited in the winter than during the summer. Consistent with shrub expansion, we found that birch, and ericaceous shrub species increased with time at Torr Bay. Conversely, we found that willow species declined in abundance at Nakvak Brook. We did not find that lichen species were significantly affected by time or warming at either of our sites. Our research provides valuable insight into recent changes in caribou forage availability for the TMC. This knowledge will help to inform appropriate conservation and management measures so that the TMC can continue to persist and contribute to the social-ecological resilience of northern communities.

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Table of Contents

List of Figures

List of Tables

Chapter 1 : Introduction and Background Information

Caribou (*Rangifer tarandus*; Tuktu) populations are in decline across Canada, making this charismatic species a major conservation concern. For Inuit and First Nations living in Canada's North, caribou are an important cultural and subsistence species. Inuit have deep enduring relationships with caribou developed throughout thousands of years of traditional and cultural practices (Allard et al., 2012; Borish et al., 2021; Cunsolo et al., 2020; Snook et al., 2020; Wilson et al., 2014). Recent declines in caribou populations have had major cultural, social, physical, and emotional implications for Northern communities. The ability to hunt caribou is crucial for Inuit cultural continuity, sense of identity, and northern food security (Cunsolo et al., 2020; Snook et al., 2020; Ungava Peninsula Caribou Aboriginal Round Table, 2017). Therefore, the long-term preservation of caribou is a high priority.

Reasons behind the rapid decline in many caribou populations across Canada are still somewhat uncertain but a number of threats have been identified. According to scientific and Inuit Knowledge, major threats include habitat loss or disturbance, predation, disease, resource limitation, climate change, and hunting (COSEWIC, 2017, Species At Risk Public Registry, 2019; Wilson et al., 2014). Human induced threats to caribou such as habitat degradation and climate change are only expected to increase with time adding further pressure to already struggling herds. More research will be required to better understand how caribou will be affected by climate change so that appropriate management measures are taken.

Climate change is expected to impact both caribou movement patterns and access to forage (Côté et al. 2012). Late freeze and early ice thaw on lakes and rivers has been shown to influence caribou migration (Leblond et al., 2015), while increased abundances of insects affect the amount of time caribou spend foraging (Bradley et al., 2005; Russell et al., 1993). Warming is also expected to cause 'trophic mismatch' between calving and peak forage availability (Post & Forchhammer, 2008) and warmer winter temperatures can cause ice layers to form on the snowpack making it harder for caribou to dig for food (Tyler, 2010). Moreover, climate change is expected to have major impacts on the availability of summer and winter forage although the precise effects of warming are still open to debate.

Over the past few decades, Arctic warming has triggered dramatic changes in vegetation composition and biomass across tundra landscapes (Elmendorf et al., 2012; Fraser et al., 2011; Sturm et al., 2001). Research has shown that deciduous shrubs such as birch (*Betula* spp.), willow (*Salix* spp.) and alder (*Alnus* spp.) species are increasing in abundance and cover across the Arctic (Ackerman et al., 2018; Bjorkman et al., 2018; Davis et al., 2020; Elmendorf et al., 2012; Sturm et al., 2001). Two decades worth of monitoring found that shrubs exhibited the greatest rate of expansion in warm and moist tundra regions while cold regions were more resistant to shrub expansion (Elmendorf et al., 2012). One detected consequence of greater shrub cover has been a reduction of lichen abundance and diversity (Alatalo & Annika, 2017; Chagnon et al., 2019; Fraser et al., 2014). Reduced lichen cover could have significant consequences for caribou whose winter diet is composed of more than 50% lichen (Joly & Cameron, 2018). Summer forage availability is also expected to change with shrub expansion. During the summer months, caribou forage on leaves of deciduous shrubs (Denryter et al., 2017; Ehlers et al., 2021; Webber et al., 2022). Greater shrub cover may therefore increase summer caribou forage assuming it is palatable shrub species that are increasing.

Torngat Mountains National Park (Tongait KakKasuangita SilakKijapvinga; TMNP) located in Nunatsiavut, Northern Labrador, is experiencing widespread environmental change. Over the past 30 years, mean summer and winter temperatures have increased by 2.0°C/decade and 0.5°C/decade respectively in the broader Nunatsiavut and Nunavik regions, with temperatures expected to rise another 2-8°C by the end of the century (Barrette et al., 2020). Thawing permafrost (Way & Lewkowicz, 2016), declines in caribou (Bergerud et al., 2008; COSEWIC, 2017), and rapid shrub expansion (Davis et al., 2020; 2021) have all been documented. Notably, shrub cover has increased dramatically in TMNP's low-latitude valley bottoms where shrubs have displaced wet vegetation (Davis et al., 2021). Furthermore, studies have analyzed radial growth patterns in shrubs in Northern Labrador and found that radial growth is strongly correlated with warming trends and shrub expansion in this region (Davis et al., 2020; Larking et al., 2020). TMNP, first established in 2005 as a Park Reserve, was created to protect the region's great cultural and ecological value (Parks Canada, 2010). Furthermore, TMNP may become an important refuge for species shifting northward to due to climate change (Berteaux et al., 2018). Caribou may very likely be one of those species since the North-eastern Quebec-Labrador Peninsula, where TMNP is situated, is predicted to be the only winter, spring, and summer habitat still suitable for the George River Caribou by as early as 2040 (Sharma et al., 2009).

TMNP has historically been home to two herds of caribou, the Torngat Mountains Caribou (TMC), and the George River Caribou (GRC). The TMC are a small population of around 1,300 mountain caribou that remain in the Torngat Mountains year round changing elevations to escape predators and poor conditions (Couturier et al., 2010; 2015; 2017). Conversely, the GRC are a migratory herd that undertakes large seasonal migrations across most of the Quebec-Labrador Peninsula, and at times their calving grounds fell within TMNP (Bergerud et al., 2008). Historically, the GRC herd has been quite large with population sizes in the hundreds of thousands, today however their population size has declined to the low thousands and their range has shrunk to no longer overlap with the TMC population (Bélanger et al., 2019; Couturier et al., 1996; Government of Newfoundland and Labrador, 2018). Currently, both the TMC population and the GRC herd are classified as 'Endangered' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) but have yet to be listed under the Canadian Species at Risk Act (SARA) (COSEWIC, 2017).

The TMC were only recently recognized by federal and provincial governments as their own designated population (COSEWIC, 2011), although Inuit have long been aware that the TMC are distinct from the GRC (Wilson et al., 2014). Prior to 2011, the TMC were legislatively considered part of the larger GRC herd and had been paid little attention (COSEWIC, 2011). Since their designation they have been the focus of three population surveys (Couturier et al., 2015; 2017), an Inuit Knowledge study (Wilson et al., 2014), and a habitat selection study (Bélanger et al., 2019). Despite recent interest, TMC are still understudied, and data limited in comparison to other caribou herds in Canada. Data deficiencies have been identified by COSEWIC, Parks Canada, and local Inuit communities as a limitation for understanding and managing this population (COSEWIC, 2017; Wilson et al., 2014)**.**

My research aims to summarize existing information on the TMC, identify knowledge gaps, and contribute to the growing body of knowledge necessary for their long-term management. My thesis is divided into four chapters; Chapter 1 introduces my topic and provides the rationale and context for my research, Chapter 2 is a literature synthesis for Parks Canada on the state of caribou in TMNP, Chapter 3 is a quantitative examination of vegetation data collected in the Torngat Mountains to explore the effects of climate change on caribou forage, and Chapter 4 concludes my thesis by synthesizing ideas and providing a number of potential future research directions . Chapters 1 and 4 are written in first person singular as they introduce and conclude my thesis while Chapters 2 and 3 are written in first person plural as they are co-authored. My Chapter 2 was co-authored by Andrew Trant (Univeristy of Waterloo) and Darroch Whitaker (Parks Canada), and Chapter 3 was co-authored by Emma Davis (University of Waterloo), Luise Hermanutz (Memorial University), Laura Siegwart Collier (Parks Canada), Tom Knight (Parks Canada), and Andrew Trant.

On its own, Chapter 2 is intended as a report for Parks Canada summarizing the current state of knowledge on caribou in TMNP. The objective of this chapter is to compile and synthesize all existing information on the TMC from Inuit Knowledge and scientific research. This chapter also highlights some challenges related to the management of the TMC as these caribou are a meaningful part of a complex social-ecological system. Finally, we identify several knowledge gaps important for the management of the TMC and provide suggestions for how to address them. We intend for this chapter to be used by Parks Canada to inform staff on the state of the TMC and to bring together data from multiple fields of study into one document that can be referenced during the development of future TMC management plans.

In Chapter 3, we build on previous research that found climate change had a significant impact on vegetation composition and abundance in TMNP (Davis et al., 2020; 2021). Our study contributes to the limited knowledge on the effects of climate change on caribou forage availability by asking the following questions:

1) What proportion of total vegetation is suitable summer and winter caribou forage and how has this changed with time and experimental warming in mountainous coastal tundra?

2) Which forage species are most impacted by recent climate warming?

We answer these questions by analyzing vegetation data collected in the Torngat Mountains over a 14-year period. Permanent control and warming plots were established at Nakvak Brook and Torr Bay in 2007 and 2009, respectively, and re-sampled every 3-6 years. From these vegetation data, we identify species of high, medium, and low caribou forage quality. We then used Generalized Linear Mixed Models (GLMMs) to analyze the effects of time, experimental warming, and subsite on the abundance of caribou forage at our sites.

The Torngat Mountains are a complex social-ecological system with many rights holders and stakeholders involved in the management of ecological and cultural resources. TMNP was first established as Torngat Mountains National Park Reserve in 2005 with the enactment of the Labrador Inuit Land Claims Agreement (LCA) (Parks Canada, 2014). TMNP lies within the traditional territories of the Labrador Inuit and Nunavik Inuit in Quebec and therefore operates under both the

Labrador Inuit LCA and the Nunavik Inuit LCA (Parks Canada, 2010). From these LCAs, the Torngat Mountains Cooperative Management Board (TMCMB) was established with representatives from the Nunatsiavut Government (Labrador Inuit), the Makivik Corporation (Nunavik Inuit), and Parks Canada. The role of the TMCMB is to provide advice on research priorities and the park's management plan (Parks Canada, 2018). The TMCMB combines both Inuit Knowledge and scientific approaches to establish research and monitoring strategies in the park (Lemelin et al., 2016). Another important player in the management of TMNP is the Torngat Wildlife and Plants Co-management Board (TWPCB), which consists of members appointed by the Nunatsiavut Government, the Government of Newfoundland and Labrador, and the Canadian Government. The TWPCB is responsible for the establishment of Total Allowable Harvest limits, and recommends conservation, management, and monitoring measures for plants and wildlife in the Labrador Inuit Settlement Area including TMNP (Torngat Wildlife, Plants & Fisheries Secretariat, n.d.). The management model applied in TMNP allows for collaboration between multiple rightsholders and different levels of government. This approach ensures that multiple perspectives and ways of knowing are considered in the management of natural resources in TMNP including the TMC.

Caribou are an important part of Northern Labrador's social-ecological system. Caribou hold irreplaceable value for Inuit in Labrador who have co-existed with caribou for thousands of years developing cultural practices and a breadth of knowledge relating to caribou (Borish et al., 2021). Recent declines in caribou have already triggered cultural losses and ecological grief (Cunsolo et al., 2020). Therefore, efforts must continue to be made to protect caribou in Labrador. Data gaps have been identified as a management limitation for the TMC. My master's thesis summarizes existing information on the TMC and contributes new information on the impacts of climate change to caribou forage availability in the Torngat Mountains. My findings provide valuable insight into the how caribou may become forage limited in the future. This knowledge can be used to inform appropriate conservation measures. A greater understanding of how climate change could impact the TMC will enable appropriate management so that they can continue to contribute to Inuit culture and Northern resilience.

Chapter 2: Summary of Knowledge on the Torngat Mountains Caribou Population

2.1 Caribou in Canada

Caribou (*Rangifer tarandus*) have a circumpolar distribution across boreal, montane, and arctic environments (COSEWIC, 2011). Caribou are highly adapted to cold and snowy environments with specialized heat exchange systems in their nasal passages and a thick fur coat (Geist, 1998). Additionally, caribou are able to meet the majority of their energetic needs by feeding on fruticose lichen during the fall and winter when leafy shrubs and fresh grasses are not present (Schaefer et al., 2016). Generally, caribou are considered a lichen specialized species. Four decades of research has found that lichens make up more than 50% of migratory artic caribou's winter diets (Joly & Cameron, 2018) and Inuit Knowledge describes fruticose lichen as being a common food source for caribou year-round (Wilson et al., 2014). Although lichens are an important component of a caribou's diet, their yearly diets are more generalized and shift with vegetation abundance (Denryter et al., 2017; Ehlers et al., 2021; Webber et al., 2022). During the winter, when there are limited forage options lichen is the primary food source (Bergerud, 1972; Gauthier et al., 1989; Thomas & Hervieux, 1986). Then in the spring, diet composition shifts to be sedge dominant (Bergerud, 1972; Gauthier et al., 1989). As fresh shoots begin popping up in the early summer caribou focus their attention to nutrient rich young leaves of deciduous shrubs (Denryter et al., 2017; Ehlers et al., 2021; Webber et al., 2022).

Caribou are a member of the deer family (Cervidae) and exhibit the most variation in morphology, ecology, and behaviour of all species in this family (Geist, 1998). This high variation in intraspecific characteristics is thought to be a result of the wide range of environments where this species is found (Thomas & Everson, 1982). Cold and snow adapted characteristics become more distinct in the northerly sub-species with Peary caribou in the Queen Elizabeth islands having a shorter muzzle and lighter coloured fur than the more southern barren-ground caribou on the central Boothia Peninsula (Thomas & Everson, 1982). Variations in size, shape, and movement have also been found between caribou herds of migratory, montane, and sedentary ecotypes (Couturier et al., 2010). Increased population densities and migration have been found to negatively impact caribou body size with migratory caribou being smaller than sedentary caribou (Couturier et al., 2010).

Only one species of caribou exists globally (called reindeer in Europe and Asia) however a multitude of subspecies and ecotype designations are recognized to capture the diversity of this species (COSEWIC, 2011). Currently, there are 12 distinct designatable units (DUs) of caribou recognized in Canada. These units are based on known differences in subspecies, ecotypes or population groupings and are further assessed using genetic, morphological, and behavioural differences (COSEWIC, 2011).

In Canada, caribou are divided into three main subspecies based on their appearance, habitat, and behaviour. These three subspecies are Peary, barren-ground, and woodland (Species At Risk Public Registry, 2019). The Peary caribou are the smallest and lightest-coloured of the 3 groups while woodland caribou are the largest and darkest-coloured, barren-ground caribou are found somewhere in between. Peary caribou are isolated to the islands of the Canadian Arctic Archipelago while Woodland caribou are distributed across Canada's boreal and mountain ecosystems, and barren-ground caribou are found in northern Canada's tundra from Alaska to Baffin Island. Woodland caribou and barren-ground caribou also exhibit clear behavioral differences. Woodland caribou are non-migratory, however mountainous woodland herds will move to higher or lower elevations based on the season. Barren-ground caribou are migratory and will migrate large distances seasonally following predictable migration routes (Species At Risk Public Registry, 2019). It should be noted that not all populations of caribou in Canada can be easily categorized into these three groups, some populations exhibit characteristics of more than one ecotype (Species At Risk Public Registry, 2019).

2.1.1 Threats to Caribou in Canada

Caribou are a conservation concern across Canada as most populations are currently in decline. Of Canada's 12 DUs, 1 DU has been assessed as 'Extinct', 6 as 'Endangered', 3 as 'Threatened', and 2 as 'Special Concern' (Species At Risk Public Registry, 2019). The reasons behind the rapid decline in many caribou populations globally are complex, with a large number of threats identified. Major threats include top-down drivers such as predation and hunting, as well as bottom-up drivers like resource limitations, and habitat change (COSEWIC, 2017; Gunn et al., 2011). Furthermore, climate change, and habitat loss are impacting the ways that caribou can utilize the landscape. (COSEWIC, 2017, Species At Risk Public Registry, 2019). Wolves and bears are the biggest non-human predators of caribou globally. Wolf abundance has been found to play a major role in whether caribou recruitment exceeds caribou mortality. Caribou populations begin to decline when wolf numbers exceed 6.5 per 1000 km^2 (Bergerud, 1988). For the mountain caribou in south-eastern British Columbia, predation is a major cause of declining caribou numbers. In south-eastern British Columbia, excessive caribou predation by wolves is a result of growing moose numbers (Seip, 2008). Growth in moose populations is being driven by improved moose habitat from forestry activities (Seip, 2008). This example demonstrates the impacts of both top-down predation and bottom-up habitat changes to caribou survival.

Climate change is another major threat to caribou. In the Arctic, and Sub-arctic, warming conditions are resulting in increased shrub growth and consequently decreased lichen abundance (Alatalo & Annika, 2017; Chagnon et al., 2019; Myers-Smith et al., 2011). Warming is also expected to cause a 'trophic mismatch' where early springs could desynchronize calving and peak forage abundance (Post & Forchhammer, 2008). Furthermore, a warming climate may increase the prevalence of biting insects, parasites, and consequently diseases in caribou (Bradley et al., 2005; Hoberg et al., 2008). A greater abundance of insects could also adversely impact the amount of time caribou spend foraging (Russell et al., 1993). Finally, rain or warm temperatures in the winter can cause snow icing which is when a layer of ice forms on top of the snow pack (Tyler, 2010). Snow icing events can have catastrophic effects on caribou as the ice prevents them from digging to the ground level to access forage. In November of 2013, a rain on snow event resulted in massive reindeer mortality on the Yamal Peninsula, Russia (Forbes et al., 2016).

2.2 Cultural Significance of Caribou

Certain species play an especially important role in the lives of the people who rely on them, this causes them to shape cultural identity. These species are described by Garibaldi and Turner (2020) as cultural keystone species. For the Inuit of Nunatsiavut and Nunavik, caribou are a cultural keystone species as they are a vital economic, cultural, and nutritional resource (Wilson et al., 2014). Labrador Inuit and caribou have co-existed for thousands of years. The Nunatsiavut Government, who represent Labrador Inuit, have stated that "the cultural, social and physical survival of Labrador Inuit depended on their ability to hunt and gather caribou" (Ungava Peninsula Caribou Aboriginal Round Table, 2017). For the Inuit of Nunatsiavut and Nunavik, caribou have always played a critical role in their livelihoods providing meat, and resources for clothing, tools, and artwork (Cunsolo et al., 2020; Ungava Peninsula Caribou Aboriginal Round Table, 2017).

Nain and Kangiqsualujjuaq are fly-in communities, with no road access. This makes them especially vulnerable to food insecurities. In Nunatsiavut, 46% of families have reported to be food insecure (Allard and Lemay, 2012). Country food – plants and animals hunted or gathered from the land – make up a considerable portion of Nunavik and Nunatsiavut residents' diets, however, many country foods are harder to find and hunt today (Allard and Lemay, 2012). Caribou were identified as the main species that has become harder to hunt, and in 2013 the Government of Newfoundland and Labrador issued a total hunting ban (Government of Newfoundland and Labrador, 2013; Wilson et al., 2014). This decline in caribou and loss of hunting is having negative social and economic implications for northern communities (Allard and Lemay, 2012; Wilson et al., 2014).

Caribou are important not only for northern food security but also for the intergenerational transfer of knowledge. Inuit youth learn hunting skills and hide preparation at an early age by watching and following family members. There is concern from Inuit across Nunatsiavut that with the loss of caribou there will also be a loss of knowledge and a disruption to thousands of years of traditional and cultural practices (Allard and Lemay, 2012; Borish et al., 2021; Cunsolo et al., 2020; Wilson et al., 2014). The recent decline in caribou and access to hunting in Northern Labrador has had major implications for food security and cultural continuity but has also led to physical, mental, emotional, and spiritual impacts (Borish et al., 2021; Cunsolo et al., 2020). Inuit in Labrador have deep and enduring connections to caribou and this loss has triggered ecological grief (Cunsolo et al., 2020).

2.3 Torngat Mountains Caribou

The Torngat Mountains Caribou (TMC) population are part of the woodland caribou subspecies (*Rangifer tarandus caribou*) (COSEWIC, 2011). Inuit have long been aware that the TMC population is distinct from the neighboring George River Caribou (GRC) herd (Wilson et al., 2014), but this distinction has only recently been acknowledged by government and scientists (COSEWIC, 2017; Couturier et al., 2010; Schaefer and Luttich, 1998). The TMC were first recognized as their own DU in 2011. Prior to 2011 they were considered part of the neighbouring Eastern Migratory Population which includes the GRC herd (COSEWIC, 2011). The GRC herd will be discussed in detail in a later section of this report.

Although the TMC and the GRC overlapped in the most southern portion of the TMC's range, the TMC are considered a significantly discrete unit (Couturier et al., 2015; COSEWIC, 2011). The

TMC differ from the Eastern Migratory Population by both morphology and movement behavior (COSEWIC, 2011). Individuals from the TMC are found to be larger than individuals from the migratory George River herd. This is thought to be a result of the George River population having larger population numbers (Couturier et al., 2010). The TMC also differ in their movement patterns. The TMC are classified as mountain ecotype which means that they do not undertake large scale migrations but instead use elevational movements to escape predators and poor conditions (Couturier et al., 2015; Couturier et al., 2010). This is different from the migratory caribou ecotype which undertakes large seasonal migrations of thousands of kilometers (Couturier et al., 2010). Additionally, TMC are said to taste different from GRC which has been attributed to GRC being leaner from their migratory behaviour (Wilson et al., 2014).

The TMC are considered a conservation concern and were assessed as ‘Endangered’ in 2016 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2017). The reason for this designation was that existing population data and Traditional Knowledge indicated a recent population decline and small population numbers (COSEWIC, 2017). Additionally, the population decline was expected to continue as the main threats facing this population had not been alleviated (COSEWIC, 2017). The 2017 COSEWIC assessment and status report for the Torngat Mountains Caribou assigned the population a ‘high’ threat score. This report identified hunting, and climate change effects to be the biggest threats facing the TMC. Climate change is expected to impact habitat quality and resource availability for caribou. Climate induced arctic-greening is increasing the presence of shrubs in tundra environments, shrubs have been found to outcompete lichens thus reducing the availability of winter caribou forage (Alatalo & Annika, 2017; Chagnon et al., 2019). Some of these shrubs even have antibrowsing defenses which prevent caribou from accessing them as a food source (COSEWIC, 2017; Fauchald et al., 2017; Myers-Smith et al., 2011). In an Inuit Traditional Knowledge report, local Inuit hunters identified increasing predator populations, increasing hunting pressure, habitat degradation, and climate change as the main threats facing the TMC (Wilson et al., 2014).

2.4 Torngat Mountains Caribou Population History

Limited population data exist for the Torngat Mountains Caribou (Couturier et al., 2015). This is because the TMC was only first assessed as its own distinct population by the Canadian federal government in 2011 (COSEWIC, 2011). The existing population data consist of a controversial, 1980 reconnaissance survey and two systematic aerial surveys conducted in 2014 and 2017 (Belanger & Henaff, 1985; Couturier et al., 2017; Couturier et al., 2015). The results of the 1980 survey indicated a TMC population of around 5,000 individuals (Belanger & Henaff, 1985) though the results of this survey have been questioned since it was not completed systematically and there is a high probability that some individuals from the neighbouring George River herd were included (COSEWIC, 2017; Couturier et al., 2015). The more recent surveys were completed using aerial line transect distance sampling over the entire range of the TMC. Distance sampling techniques were then complemented with the Lincoln-Petersen technique for population estimates. The results of the aerial surveys found an estimated population size of 930 individuals in the spring of 2014 (CI: 616-1453) and an estimated population size of 1,326 individuals in 2017 (CI:912 – 1,986) (Couturier et al., 2017; Couturier et al., 2015). A third aerial survey was conducted in the spring of 2021, a report of the surveys findings has yet to be released but generally the results show that the TMC population has continued increasing since the initial 2014 survey (M. Purcell, personal communication, April 4, 2022).

The existing TMC population data suggest that the population has undergone a decline of 80% from 1980 to 2014 but has since experience an increase of 13% from 2014 and 2017. This recent increase is in contrast with the declining numbers of other caribou herds across the Quebec-Labrador Peninsula. In addition to the increasing population, high levels of recruitment were found in both the 2014 and 2017 surveys suggesting population growth (Couturier et al., 2017). Although recent census data suggest that the population is growing, scientists are still concerned about this population since a population of around 1,000 individuals is small compared to past populations of neighbouring herds (COSEWIC, 2017; Couturier et al., 2017). Additionally, the neighbouring George River herd has in the past 3 decades experienced a major decline. This is a concern for the Torngat Mountains caribou population as they are exposed to similar environmental conditions as the George River herd especially in the southern portion of their range.

2.5 Torngat Mountains Caribou Population Complexities

The lack of historical population data for the TMC has been identified as a major limitation for appropriately listing and managing this population (Wilson et al., 2014; COSEWIC, 2017). The TMC was evaluated by COSEWIC in 2016 as ‘Endangered’. This listing recommendation was due to low population numbers of 698 mature individuals in 2016 and evidence of a 80% population decline since the 1980’s (COSEWIC, 2017). For a species, or sub-species, to be listed under the federal

Species at Risk Act, COSEWIC's recommendation must be approved by Canada's Minister of Environment and Climate Change (Government of Canada, 2016). Currently, the Torngat Mountains Caribou population is under review by the Minister, but a decision has yet to be made whether the TMC will be listed under the Species at Risk Act (Species At Risk Public Registry, 2019). The Minister could alternatively decide not to list the population, send the matter back to COSEWIC for more information, or decide that a better management option exists outside of the federal listing process (Government of Canada, 2016).

If the TMC becomes listed under the federal Species at Risk Act it will have significant consequences for the harvest of TMC as the act prohibits the killing or harming or listed wildlife (Species At Risk Act Section 32). The Nunatsiavut Government is publicly opposed to the federal listing of TMC stating that the 1980's baseline estimate of 5,000 individuals is inaccurate and not supported by scientific fact or Traditional Knowledge. The Nunatsiavut Government suggests that the TMC population should continue to be managed by the Nunatsiavut Government and the Makivik Corporation (Nunavik Inuit), collectively, as they are the traditional users of the TMC (Nunatsiavut Government, 2018).

Currently, a hunting moratorium is in place for all caribou from the George River herd. This moratorium was enacted in 2013 by the Province of Newfoundland and Labrador and was initially scheduled to last for 5-years, however, a review by the province concluded that the ban should continue (Government of Newfoundland and Labrador, 2013; Nunatsiavut Government, 2020). This ban has brought mixed emotions for Labrador Inuit. Many Inuit miss being able to practice an important cultural activity while others hope that the ban will conserve caribou for future generations to use (CBC, 2018). This caribou hunting moratorium has since extended to all caribou in Labrador including the TMC. Currently Inuit beneficiaries can exercise their land claim rights to hunt caribou in Torngat Mountains National Park (D. Whitaker, personal communication, 2020) but this right could be impacted if the TMC become listed under Species At Risk Act (SARA) legislation. Many community members feel that a hunting ban is too blunt of a management technique and would prefer to see a more holistic approach taken where an occasional caribou can be harvested for cultural purposes such as teaching younger generations how to hunt (Borish et al., 2021; Snook et al., 2020; Wilson et al., 2014).

Historical TMC population trends are also crucial for setting appropriate management targets. The omission, or lack of historical population trends typically results in overly optimistic assessments of conservation status and recovery targets that are lower than historical population sizes (Mcclenachan et al., 2012). Grace et al. (2019) argue that species recovery targets should focus on more than just short-term increases in abundance. Recovery targets should aim to restore species to their full ecological roles and indigenous ranges determined by historical baseline data (Akçakaya et al., 2018; Grace et al., 2019). The benefit of applying baseline data derived from historical ecology or palaeoecology to current conservation efforts is that it limits the effects of shifting baseline syndrome (Grace et al., 2019; Pauly, 1995). Shifting baseline syndrome is the gradual shift in the accepted baseline of a species as each new generation has a different memory of what that species used to be like (Pauly, 1995). The consequence of shifting baselines is the use of inappropriate reference points and species overexploitation (Pauly, 1995). Historical baselines are commonly used to set population target levels in ecological restoration (Sanderson, 2006). The restoration to historical baselines however should not focus on a specific point in time but rather a "natural range of variability" (Landres et al., 1999). Management using natural variability relies on knowledge of past conditions and processes to guide management (Landres et al., 1999). In the case of the Torngat Mountains Caribou, population trends derived from trampling scars could be used to better understand historical population sizes and fluctuations to inform conservation targets (Morneau & Payette, 1998; see Appendix C).

2.6 George River Caribou Herd

Another caribou herd whose range extended into TMNP is the George River Caribou (GRC) herd. Although this herd does not currently migrate into the Torngat Mountains, its historical spring migration route extended as far North as Alluviaq Fjord on the Quebec side of the peninsula and Komaktorvik Fjord on the Labrador side (Couturier et al., 1996; Government of Newfoundland and Labrador, Unpulished Data). Historically, the smaller TMC population shared most of its seasonal range with the larger GRC herd except during the winter when the GRC herd migrated South (Couturier et al., 2010). GRC are considered part of the Eastern Migratory population along with the Leaf River herd, the Cape Churchill herd, and the Southern Hudson Bay herd (COSEWIC, 2017). The GRC's yearly range extends through most of Labrador and Northern Quebec, spanning both sides of Ungava Bay (Bergerud et al., 2008; Sharma et al., 2009). GRC have been assessed by COSEWIC as

‘Endangered’ and are currently under a hunting ban, that was enacted in 2013 by the Government of Newfoundland and Labrador (COSEWIC, 2017; Government of Newfoundland and Labrador, 2013).

The GRC herd is well known in the conservation world for having suffered a 99% population decline since the 1990’s, one of world’s largest known ungulate population crashes (Couturier et al., 2015). The herd peaked around 1993 with an estimated population size of 776,000 animals (Couturier et al., 1996), then declined to 385,000 animals in 2001 (Couturier et al., 2004), 14,200 animals in 2014 (QC Government and NL Government, unpublished data), and finally down to 5,500 individuals in 2018 (Government of Newfoundland and Labrador, 2018). This massive decline, although very concerning, is only part of the story.

Inuit Knowledge and scientific studies are in agreeance that migratory caribou herds in North America tend to experience cyclic population fluctuations (Ferguson et al., 1998; Gunn et al., 2011; Wilson et al., 2014; Zalatan et al., 2006). The GRC’s peak population size of almost 800,000 individuals was not the norm for this herd and was likely a much larger population than the landscape could sustain. Based on historical records, the GRC were thought to have reached previous highs of approximately 400,000 animals between 1750-1820 (Bergerud et al., 2008). Aerial surveys conducted in the 1950’s found the GRC to be experiencing a population low of an estimated 2,000 animals (Banfield & Tener, 1958), but then increased to 15,000 caribou in 1958 (Bergerud, 1967). The GRC, along with other migratory herds have experienced significant population fluctuations over time (Ferguson et al., 1998; Gunn et al., 2011). That however does not mean that the GRC’s current low population size is not of concern. Over the past several decades, the GRC herd has been faced with far greater threats than ever before. The COSEWIC report (2017) for the Eastern Migratory population lists habitat loss due to mining, illegal hunting, and climate change as threats facing the GRC. These threats are only expected to increase with time (COSEWIC, 2017). A holistic management approach involving collaboration between Inuit communities and all levels of government must be taken to ensure the survival of the GRC herd (Wilson et al., 2014).

2.7 Co-operative Management in Torngat Mountains National Park

TMNP was first established as Torngat Mountains National Park Reserve in 2005 with the enactment of the Labrador Inuit Land Claims Agreement. In 2008 it became TMNP when the Nunavik Inuit Land Claims Agreement came into effect (Parks Canada, 2014). Although TMNP falls entirely within Labrador, it lies within the traditional territories of the Labrador Inuit and Nunavik

Inuit of Quebec. This means that the park operates under two land claims agreements (the Labrador Inuit LCA and the Nunavik Inuit LCA) and two Inuit Impact and Benefit agreements (The Labrador Inuit Park Impacts and Benefits Agreement and the Nunavik Inuit Park Impacts and Benefits Agreement) (Parks Canada, 2010). The outcome of the Labrador IIBA for Torngat Mountains National Park was the payment of 1 million dollars to the Nunatsiavut government to help Inuit take advantage of business opportunities related to the park, the establishment of a cooperative management board, and provisions for ongoing traditional land use (Government of Newfoundland and Labrador, 2005).

Through the Land Claims Agreements and Inuit Impacts and Benefits Agreements the Torngat Mountains Cooperative Management Board (TMCMB) was established. The TMCMB is made up of equal representation from all partners; 2 representatives from the Nunatsiavut Government, 2 representatives from the Makivik Corporation, and 2 Parks Canada representatives (Lemelin et al., 2016). Together the partners appoint one independent chairperson. Currently all Torngat Mountains board member are Inuit (Lemelin et al., 2016). The role of the board is to provide advice on “research priorities, visitor access to and use of the park, removal of carving stone, changes to the national park boundary, economic opportunities and the management plan” (Parks Canada, 2018). The TMCMB is involved in the management of resources within the park including caribou (Parks Canada, 2010). The board’s mandate is to provide advice to the Federal Minister, but they can also provide park management advice to the Torngat Wildlife and Plant Co-Management Board, the Torngat Joint Fisheries Board, the Makivik Corporation, and the Nunatsiavut Government (Parks Canada, 2010).

One unique program developed through the Labrador Inuit Park Impact and Benefits agreement was the creation of Base Camp. Base camp was piloted by Parks Canada but is now entirely Inuit run through the Nunatsiavut Group of Companies (Parks Canada, 2014). Base Camp is located just outside of TMNP southernmost boundary on Saglek Bay, 225 kilometers from Nain, the closest community. Base Camp operates as a starting point for trips into the park. They facilitate interpretation tours about Inuit culture, provide skilled guides, and help scientists orchestrate research. Base Camp provides economic opportunity to remote communities and increases Inuit presence in the park (The Torngats, 2019).

2.8 Knowledge Gaps

One outcome of this literature review has been the identification of two major knowledge gaps surrounding our understanding of the TMC population. The first, and biggest knowledge gap is the lack of historical population data for the TMC. This lack of population data have been identified through Inuit Knowledge and scientific research as a major limitation for appropriately listing and managing this population (COSEWIC, 2017; Wilson et al., 2014). Long-term TMC specific data are limited because the population was only recently recognized by federal and provincial governments as distinct from the neighbouring GRC herd (COSEWIC, 2011). We suggest that this knowledge gap be filled using dendrochronological techniques outlined in Morneau & Payette (1998 & 2000) and Zalatan et al. (2006), where caribou trampling scars are collected and dated to estimated caribou population trends on the landscape. A detailed description of our recommended sampling strategy in TMNP can be found in Appendix C.

The second knowledge gap we identified was a lack of knowledge surrounding habitat use and interactions between the TMC population and the GRC herd during periods of range overlap. Historically, the TMC herd shared most of its seasonal range with the larger GRC herd except during the winter when the GRC herd was further south (Couturier et al., 2010). The recent population decline of the GRC has resulted in a range contraction so that they no longer overlap with the TMC herd (Bergerud et al., 2008). A greater understanding of how these two herds utilized habitat during periods of overlap would provide insight into the degree of contact between the herds and thus help us to understand what effects the current lack of overlap might have on the TMC. To fill this knowledge gap, we suggest that existing satellite collar data from the years when the herds overlapped be used to analyze habitat selection for each herd. The resource selection function is the most common approach for identifying habitat selection patterns from satellite collaring data (Manly et al., 2002; Northrup et al., 2013). Further details on our recommended methodology can be found in Appendix C.

Chapter 3: Impacts of Climate Warming on Caribou Forage Availability in the Torngat Mountains, Labrador

3.1 Introduction

Canada's Arctic and Subarctic are experiencing dramatic environmental change, with Arctic surface air temperature anomalies occurring at more than double the average global rate (Ballinger et al., 2020). Consequences of warming Arctic air temperatures include sea ice loss, glacial melt, permafrost thaw, and changes in vegetation growth and composition (Elmendorf et al., 2012; Koven et al., 2013; Lawrence et al., 2008; Meredith et al., 2019). These changes have serious implications for the people, plants, and wildlife who inhabit the North (Meredith et al., 2019).

Arctic warming is accompanied by the expansion of deciduous shrubs into tundra landscapes (Fraser et al., 2014; Sturm et al., 2001). Increases in shrub biomass, abundance, and cover across Arctic ecosystems have been colloquially termed "shrubification"(Myers-Smith et al., 2011). Evidence of shrubification has been identified through Inuit Knowledge (Cuerrier et al., 2015; Siegwart Collier, 2020; Wilson et al., 2014), historical photographs (Sturm et al., 2001), remote sensing (Davis et al., 2020; Fraser et al., 2011), dendrochronology (Ackerman et al., 2018; Larking et al., 2021), and vegetation surveys (Bjorkman et al., 2018; Elmendorf et al., 2012). A major consequence of shrubification is that greater shrub cover can shade out lichens, reducing lichen abundance and species richness (Alatalo & Annika, 2017; Chagnon et al., 2019; Elmendorf et al., 2012; Fraser et al., 2014). A loss of lichen abundance has serious ramifications for caribou (*Rangifer tarandus*) whose winter diets are generally composed of greater than 50% lichens (Heggberget et al., 2002; Joly & Cameron, 2018; Thomas & Hervieux, 1986; Webber et al., 2022). Conversely, important spring and summer caribou forage, such as birch (*Betula* spp.), willow (*Salix* spp.), and ericaceous (*Vaccinium* spp.) shrub species, are expanding with climate warming (Denryter et al., 2017; Ehlers et al., 2021; Webber et al., 2022).

Despite significant complexities surrounding the effects of climate warming on the abundance of caribou forage, a full analysis of these effects has yet to be completed. In this study, we investigate changes to caribou forage availability due to ambient and experimental warming at two tundra sites located within the range of the Torngat Mountains Caribou (TMC) population in Nunatsiavut, Labrador (Canada). The objective of our study is to address the following questions: 1) What proportion of total vegetation is suitable summer and winter caribou forage and how has this changed with time and experimental warming in mountainous coastal tundra? And 2) Which forage species are most affected by recent climate warming? To answer these questions, we analyze point-frame vegetation data collected during a 14-year study within Torngat Mountains National Park (*Tongait KakKasuangita SilakKijapvinga* in Inuktitut). Based on Arctic warming and shrub expansion trends, we expect to see an increase in summer caribou forage since deciduous shrubs are primary summer forage. Furthermore, we expect to see a decline in winter forage since lichens are primary winter forage and shrubs have been found to outcompete lichen.

Over the past three decades, the migratory George River caribou (GRC) herd, whose range extends into the Torngat Mountains, has experienced a drastic population decline from 770,000 caribou in 1993 (Couturier et al., 1996) to 5,500 caribou in 2018 (Government of Newfoundland and Labrador, 2018). Additionally, recent population surveys of the Torngat Mountains caribou population showed small but increasing population numbers (~1,326 caribou in 2017) (Couturier et al., 2017; Couturier et al., 2015). Due to low herd sizes, a hunting ban was implemented severely impacting Inuit wellbeing and cultural continuity (Borish et al., 2021; Cunsolo et al., 2020; Snook et al., 2020). For Inuit of Northern Labrador and Quebec, caribou are a cultural keystone species with intangible value far beyond being a food source (Borish et al., 2021; Garibaldi & Turner, 2004). Understanding and co-managing these herds in the face of a rapidly changing Arctic will be crucial for the long-term prosperity of caribou and Inuit.

3.2 Study Sites

Data collection took place at two study sites in Northern Labrador, Canada. The two sites, Torr Bay (58.46° N 62.82° W; 40 m above sea level) and Nakvak Brook (*Pitukkik* in Inuktitut) (58.64° N, 63.35° W; 420 m above sea level) are located in or near the southern portion of Torngat Mountains National Park (Figure 1). These study sites were established in 2009 and 2007 respectively and have been re-sampled periodically to monitor vegetation change in the region. The area surrounding Torr Bay has been identified as an especially important caribou hunting ground for Inuit (Wilson et al., 2014).

The Torr Bay site was established in a mesic, low-shrub, tundra environment, and is characterized by deciduous shrub species with very little lichen cover. Study plots are distributed on both sides of a river valley. The shrub canopy is dominated by dwarf birch (*Betula glandulosa* Michx;

Avaˆ laKiak) with some willow species (*Salix herbacea* L.; Dwarf willow, and *S. arctica* Pall; UKaujak; Arctic willow) while the ground cover is composed mainly of dwarf ericaceous shrubs (*Vaccinium uliginosum* L.; Kigutanginnak; Bog bilberry, *V. vitis-idaea* subsp. *minus* L.; Kimminak; Redberry, *Empetrum nigrum* L.; Paungak; Crowberry, *Rhododendron tomentosum* L.; Mamaittukuluk; Marsh Labrador tea, and *R. groenlandicum* Oeder.; MamaittuKotet; Labrador tea). The Nakvak Brook site is flatter, more open, and has far less shrub cover than the Torr Bay site. Nakvak Brook is primarily composed of low-tundra vegetation and exposed rock. The shrub canopy at Nakvak Brook is dominated by prostrate *Salix sp.* (*S. arctica, S. herbacea, S. pedicellaris* Pursh.; Bog willow, and *S. uva-ursi* Pursh.; Bearberry willow) with some dwarf birch and bog bilberry present. Ground cover in the dry areas tends to have a greater abundance of lichen (*Cladonia* spp., *Flavocetraria* spp., and *Stereocaulon* spp.) and evergreen shrubs, whereas mosses and graminoids are more common in wet areas. Visual observations (L. Hermanutz) and limited soil moisture measurements at the site suggest that wet areas have undergone a drying trend in the last decade.

Atmospheric reanalysis data (ERA5; Hersbach and others 2020), downscaled to the location of our two sites, indicate that mean temperatures of the coldest and warmest months are -22 °C (February) and 9 °C (August) at Torr Bay, and -25 °C (February) and 8 °C (July) at Nakvak Brook. Mean winter and summer regional temperatures have increased by 2.0 °C/decade and 0.5 °C/decade respectively over the past 30 years (Barrette et al., 2020). The entire region is underlain with extensive discontinuous permafrost (Way & Lewkowicz, 2016).

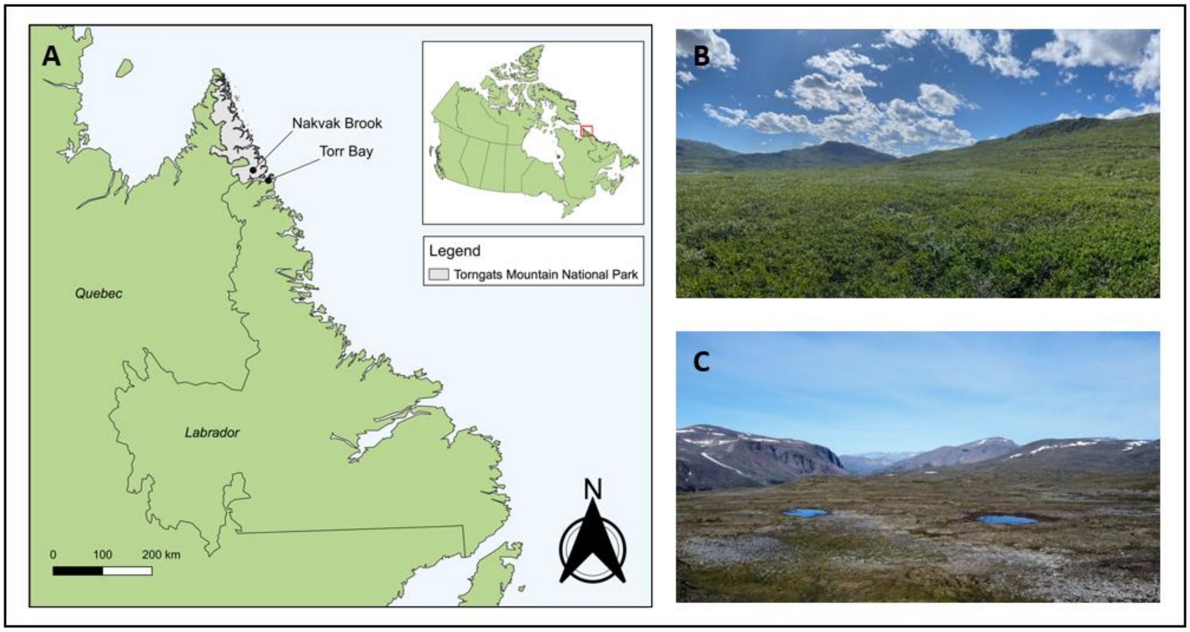

Figure 1. A) A map of the study sites in Labrador, Canada **B)** Torr Bay study site, and **C)** Nakvak Brook study site.

3.3 Methods

3.3.1 Study Design

Study sites were established at Torr Bay and at Nakvak Brook during the summers of 2009 and 2007/2008 respectively. Site establishment was conducted by Luise Hermanutz, Laura Siegwart Collier, Alain Cuerrier, John Jacobs, Darroch Whitaker, Rodd Laing, Paul McCarney, Gary Baikie, Judy Rowell, Brittany Cranston, and Julia Wheeler. This dataset was provided to us by Luise and Laura. This same dataset has been used in other publications by Davis et al. (2020) and Siegwart Collier (2020). At each site, paired experimental warming and control plots were established (Torr Bay, N = 30; Nakvak Brook, N = 19). The Torr Bay plots were equally dispersed across the East and West facing slopes on either side of Torr Bay Pond over an area of $1.8km^2$, while the Nakvak Brook plots were divided between wet and dry subsites over an area $0.36km^2$. Plots were resampled in 2011 and 2016 at Torr Bay, and in 2010, 2015, and 2021 at Nakvak Brook to understand the effects of ambient and experimental warming on vegetation composition and abundance.

Study design and data collection methods followed the protocols developed for the International Tundra Experiment (ITEX; https://ibis.geog.ubc.ca/itex/). Data on changes in plant composition and abundance were collected through point-frame vegetation surveys. The point-frame plots at Torr Bay measure 70 cm x 70 cm, while those at Nakvak Brook measure 1 m x 1 m. Vegetation data were collected using a gridded frame with 10 cm grids, resulting in 70 and 100 data collection points per plot, respectively for Torr Bay and Nakvak Brook. During the point-frame process, at each intersect, the height and species identification for species making contact with the point-frame pin were recorded, so more than 70 or 100 plants could be listed for each plot. Plants and lichens were identified to species level whenever possible; however, some could only be identified to genus, or lifeform type. Generally, most monocots and dicots were identified to the species level, but mosses and lichens were trickier to identify and were more commonly identified to genus.

To monitor changes in vegetation resulting from tundra warming, open top warming chambers (OTCs) were erected (one per paired plot) to warm vegetation and shelter it from the wind, also moderating diurnal heat loss. OTC chambers are considered an appropriate analogue for regional climate warming (Hollister & Webber, 2000), and are estimated to increase mean daily summer air temperatures by 1.5°C and soil temperatures by 1.0°C (Elmendorf et al., 2012). At our Torr Bay site, OTCs were found to raise mean soil temperatures by approximately 1.5-2°C above the control plot temperatures (Siegwart Collier, 2020). The Climate Atlas of Canada (2019) projects that mean summer temperatures will increase 1.5°C by the year 2050 in this region of Labrador, therefore, OTCs are an appropriate tool to replicate climate warming in our study.

Furthermore, greater soil moisture availability has been found to affect plant response to climatic warming (D. Ackerman et al., 2017; Myers-Smith et al., 2015). To account for the effects of soil moisture on plant growth and abundance, Nakvak Brook plots were evenly split between a representative sample of wet and dry subsites. Wet plots were identified as having saturated soil and/or some standing water, while dry plots had no standing water and dry soils.

3.3.2 Ranking Caribou Forage Species

To assess changes in caribou forage abundance, we had to first identify which vegetation species found in our plots were of high, medium, and low caribou forage quality. To do this, we reviewed the literature on caribou forage and used papers that identified forage types to the species or genus level. These papers were then included in our rank calculations. In total, 20 papers were included (See list in

Appendix B). Species ranks of 0, 1, and 2 were assigned to each species listed in caribou forage papers. A rank of '0' was assigned to species that were avoided by caribou, a rank of '1' for species that caribou ate but were not selected for, and a rank of '2' was assigned for preferred forage species. Ranks were based on each species' proportional abundance in rumen, scat, or visual forage recordings in comparison to other species in each study. Final summer and winter forage ranks were assigned from the table based on the most common ranking a species received. Any species that were identified in our plots but did not appear in the forage literature assumed a rank of '0' (i.e., not an important forage species). For verification of findings, final ranks were shared with Luise Hermanutz, Tom Knight, Andrew Trant, and Darroch Whittaker all experts on the region.

3.3.3 Analyses

To answer our first research question: what proportion of total vegetation is suitable summer and winter caribou forage and how has this changed with time and experimental warming? We first created a table comparing the proportional abundance of vegetation from each forage class (0,1,2) in our control plots across study years. We then applied Generalized Linear Mixed Models (GLMMs) to evaluate how the abundance of preferred, edible, and avoided forage types have changed with time and experimental warming at both sites. We also used GLMMs to answer our second research question: which forage species are most affected by recent climate warming? In this analysis, we modeled the effects of time and experimental warming on the abundance of six high quality forage genera. In our study, abundance is defined as the total count of each species per site.

3.3.3.1 Proportional Abundance of Forage Ranks

We evaluated the proportional abundance of each forage rank (0, 1, 2) in our control plots to infer what forage availability might look like across the landscape. Only control plots were included in this calculation, as they represent the greater landscape which is exposed to ambient warming. We calculated proportional abundance of each forage rank by simply summing the vegetation counts for each forage rank category (0, 1, 2) and dividing them by the total vegetation count in the control plots. We used this approach for summer and winter forage ranks, and at both Torr Bay and Nakvak Brook study sites.

3.3.3.2 Statistical Analyses

We used GLMMs to analyze the effects of time (2009 vs 2016 and 2010 vs 2021), experimental warming (OTC vs Control), and subsite (East facing vs West facing and Wet vs Dry) on the abundance of caribou forage. We chose to use mixed models as our study design involved repeat sampling of the same plots at multiple points in time. Repeat measurements of the same plots are not independent and must be accounted for in the model (Elmendorf et al., 2012; Zuur et al., 2009). Mixed effect models are an appropriate choice for datasets that violate independence since they consider both fixed effects and random effects (Zuur et al., 2009). In such datasets, the unit for which repeat measurements are taken (plot, site, etc.) is commonly included in the model as a random effect so that it's impacts are still considered in the model despite not being one of the variables of interest (Bolker et al., 2012; E. Davis et al., 2020; Elmendorf et al., 2012).

GLMMs were used to evaluate how the abundance of preferred, edible, and avoided forage types have changed with time and experimental warming at both sites. We also used GLMMs to assess how the abundance of specific high quality forage genera have changed with time and experimental warming at the two sites. In both analyses, abundance was the response variable of interest. In the forage genera models we considered only 6 (*Carex, Betula, Vaccinium, Salix, Cladonia,* and *Stereocaulon)* of the 11 preferred caribou forage genera since 5 of the genera (*Alectoria*, *Cetraria, Equisetum*, *Flavocetraria,* and *Gowardia*) did not have sufficient data to run the GLMMs ($X < 250$ cumulative occurrences for both sites). In addition to the six selected genera, we also chose to include a general lichen model, which included all lichen species found in our plots. We included a lichen model because we were concerned that the *Cladonia* and *Stereocaulon* models alone would not fully capture the lichen abundance at our sites, since many lichens could not be identified to the species level or had a low abundance. Lichens are a very important forage group for caribou especially in the winter, so we wanted our results to fully capture lichen availability.

All generalized linear mixed models were analyzed in R version 4.1.2 (R Core Team, 2021) using package glmmTMB (Magnusson et al., 2016). Effect plots were constructed using packages SjPlot (Lüdecke, 2021), and ggplot2 (Wickham, 2016).

3.3.3.2.1 Model Selection

Since we had a large number of models to build for both forage ranks (N = 12) and forage genera (N = 14), and models could consist of various combinations of main effects, distributions, and model types, we decided to adopt a model selection approach taken by Brooks et al., 2017. This approach fits data to GLMMs with each combination of main effects, distribution, and model type and then uses the Akaike Information Criteria (AIC) to compare the fit of the various model options.

To select appropriate model parameters for the forage rank and genera level analyses, we first fit GLMMs, and zero-inflated GLMMs to the dataset with log-linked Poisson and negative binomial distributions. We chose to test both distributions as count data tend to be over-dispersed (Zuur et al., 2009). We ran zero-inflated models for the genus level analyses as there were many plots where a genus was absent resulting in high counts of zero. An excess number of zeros could negatively impact our model's fit so although we were not directly interested in the probability of receiving excess zeros (i.e., we did not care why a plant was not there) we applied a zero-inflated model to improve the fit of our conditional models. Furthermore, each model type and distribution we tested also contained different combinations of interaction functions for the three fixed effects (Treatment, Year, and Subsite). Every model included abundance as the response variable and plot as a random effect.

For the forage rank GLMMs, a total of 6 models were run for each seasonal forage rank (N=6) for each site. We did not consider zero-inflated models as an option for the forage rank models since an excess number of zeros did not appear in any histograms of the count data. For the preferred forage genera models, 16 models were considered for each preferred forage genus at the Torr Bay site and 12 models were run for each preferred forage genus at the Nakvak Brook site. More model options were included for Nakvak Brook since we expected the wet/dry subsite to have a stronger influence on genera abundance than the east facing/west facing subsite effect at Torr Bay, so subsite was always included in the Nakvak Brook models.

We then used the AIC to compare the models. We identified the models with the 3 lowest AIC values for each forage rank and for each genus. We then selected the model that best fit the majority of ranks or genera (Appendix A Tables 4 & 5). We decided to apply the same model for all ranks and for all genera at each site so that we could compare results across ranks, and between genera. In total, this left us with the possibility of using 4 different model structures in our analysis.

Since our treatment plots at time zero are expected to be the same as our control plots at time zero (i.e., the warming treatment had not yet been applied), we did not expect to find any significant results from our treatment (OTC) main effect. Regardless, we chose to include treatment as a main effect in order to determine interaction effects, which identify how abundance is changing through time in treatment plots compared to control plots. This decision is in line with the hierarchy principle that dictates insignificant terms should be included in the model if they help to satisfy the goals of the experiment (Montgomery et al., 2005).

3.4 Results

3.4.1 Preferred Caribou Forage Species

Through an extensive literature search (Appendix B), and confirmation with experts, we identified 14 preferred winter, and 21 preferred summer, forage species at our sites (Table 1). This literature search highlighted the importance of lichens, especially *Cladonia* spp., as a winter food source (Bergerud, 1972; Gauthier et al., 1989; Thomas & Hervieux, 1986), while leafy deciduous species such as birch, willow, and blueberry made up a large portion of a Caribou's summer diet (Denryter et al., 2017; Ehlers et al., 2021; Webber et al., 2022). A caribou's spring diet was found to have a high composition of sedge species (*Carex* spp.) (Bergerud, 1972; Gauthier et al., 1989).

Table 1. Preferred caribou forage species in the Torngat Mountains Region of Labrador, Canada, as identified through an extensive literature search and expert knowledge (see methods section for details on how this table was generated).

Winter Forage Species	Summer Forage Species
Alectoria ochroleuca	*Alectoria ochroleuca*
Cetraria islandica	*Betula glandulosa*
Cladonia arbuscula	*Carex bigelowii*
Cladonia deformis	*Carex rariflora*
Cladonia mitis	*Carex rotundifolia*
Cladonia rangiferina	*Cetraria islandica*
Cladonia stellaris	*Cladonia arbuscula*
Cladonia uncialis	*Cladonia deformis*
Equisetum arvense	*Cladonia mitis*
Flavocetraria cucullata	*Cladonia rangiferina*
Flavocetraria nivalis	*Cladonia stellaris*
Gowardia nigricans	*Equisetum arvense*
Stereocaulon spp.	*Flavocetraria cucullata*
Vaccinium vitis-idaea	*Flavocetraria nivalis*
	Salix arctica
	Salix glauca
	Salix herbacea
	Salix pedicellaris
	Salix uva-ursi
	Vaccinium uliginosum
	Vaccinium vitis-idaea

3.4.2 Proportional Abundance of Forage Ranks

The proportional abundance of avoided, edible, and preferred forage found in the study's control plots showed that the forage rank with the greatest proportional abundance in the summer is the preferred forage rank while in the winter it is the edible but not preferred forage rank for Torr Bay and the avoided forage rank for Nakvak Brook (Table 2). Overall, the proportional abundance of preferred winter caribou forage is much lower than the proportion of preferred summer forage. The only significant change in preferred forage abundance with time is the Torr Bay site change in proportion of preferred winter forage from 2009 to 2016 ($p < 0.01$). However, despite a lack of statistical significance, the proportional abundance of preferred summer and winter caribou forage appears to be increasing with time at both sites and for both seasons (Table 2; Appendix A Tables 10 & 11). The proportion of avoided summer and winter forage declined significantly from 2009 to 2016 at Torr Bay (p < 0.001; p < 0.01; Table 2; Appendix A Tables 10 & 11) while at Nakvak Brook the proportion of avoided summer forage and edible winter forage declined from 2010 to 2021 (p < 0.001; p < 0.05; Table 2; Appendix A Tables 10 & 11).

Table 2. Proportional abundance of avoided, edible, and preferred summer and winter forage in Control plots at Torr Bay and Nakvak Brook, Labrador, comparing first (2009, 2010) and last survey times (2016, 2021).

	Torr Bay				Nakvak Brook			
	Summer		Winter		Summer		Winter	
Rank	**2009**	**2016**	**2009**	**2016**	**2010**	**2021**	**2010**	**2021**
Avoided	0.04***	0.02***	0.14**	0.10**	0.35***	0.23***	0.61	0.62
Edible	0.32	0.28	0.65	0.65	0.07	0.12	0.29*	0.24*
Preferred	0.64	0.70	0.21**	0.25**	0.57	0.64	0.09	0.14

Starred values show significant change in proportion with time (***p < 0.001; **p < 0.01; *p < 0.05)

3.4.3 Model Selection

The most parsimonious model for forage rank at both Torr Bay and Nakvak Brook was the negative binomial GLMM with treatment, year, and subsite as main effects and an interaction term for treatment and year (Table 3). The most parsimonious preferred forage genera model at Torr Bay was the zero-inflated Poisson GLMM that allowed genera counts to vary with treatment, year, and their interaction. Subsite was not included as a main effect. For Nakvak Brook the most parsimonious model was found to be the non-zero-inflated negative binomial GLMM that allowed genera counts to vary by treatment, year, subsite, and treatment year interaction.

Table 3. Model parameters and distributions used in each statistical analysis.

Analysis	Model Type	Model Equation	Distribution
Torr Bay Forage Rank	GLMM	(Encounters ~ TRTMT*YEAR + SUBSITE + (1|PLOT))	Negative Binomial
Nakvak Brook Forage Rank	GLMM	(Encounters ~ TRTMT*YEAR + SUBSITE + (1|PLOT))	Negative Binomial
Torr Bay Preferred Forage Genera	Zero-inflated GLMM	(Encounters ~ TRTMT*YEAR + (1|PLOT))	Poisson
Nakvak Brook Preferred Genera	GLMM	(Encounters ~ TRTMT*YEAR + SUBSITE + (1|PLOT))	Negative Binomial

3.4.4 Forage Rank GLMMs

Analysis of point-frame data in relation to the three caribou forage ranks (preferred, edible, and avoided) found that with time, avoided forage (both summer and winter) abundance declined at Torr Bay ($t_{2016} = -0.83$; $p < 0.001$ and $t_{2016} = -0.24$; $p < 0.01$; Figure 2; See Appendix A Tables 6-9 for full model parameter estimates), with avoided winter forage abundance declining more in the OTC plots than in the control plots ($t_{OTC*year} = -0.32$; $p < 0.01$). Preferred winter forage abundance increased with time at Torr Bay ($t_{2016} = 0.26$; $p < 0.001$) and more so in the control plots than in the OTC plots ($t_{OTC*year} = -0.33$; $p < 0.01$). At the Nakvak Brook site, avoided forage (both summer and winter) also declined in abundance with time ($t_{2021} = -0.82$; $p < 0.001$ and $t_{2021} = -0.37$; $p < 0.05$), but there were no significant changes in preferred forage abundance.

Subsite level factors (East facing/West facing, and Wet/Dry) were also found to have a significant effect on forage abundance. At Torr Bay, preferred summer forage species were more abundant in the West facing plots ($t_{west} = 0.40$; $p < 0.001$; Figure 2), while edible but not preferred summer species were favoured in the East facing plots ($t_{west} = -0.55$; $p < 0.01$), and edible but not preferred winter species were favoured in west facing plots ($t_{west} = 0.28$; $p < 0.001$). Moisture levels had a strong influence on forage abundance at Nakvak Brook. Avoided summer and winter forage along with preferred summer forage species were all more abundant in wet than dry plots ($t_{wet} = 0.68$; $p < 0.001$; $t_{wet} = 0.83$; $p < 0.001$; $t_{wet} = 0.57$; $p < 0.001$). Alternatively, preferred winter forage was significantly more abundant in dry plots rather that wet plots ($t_{wet} = -3.39$; $p < 0.001$), which can be attributed to lichens, a key winter forage class, favouring dry areas.

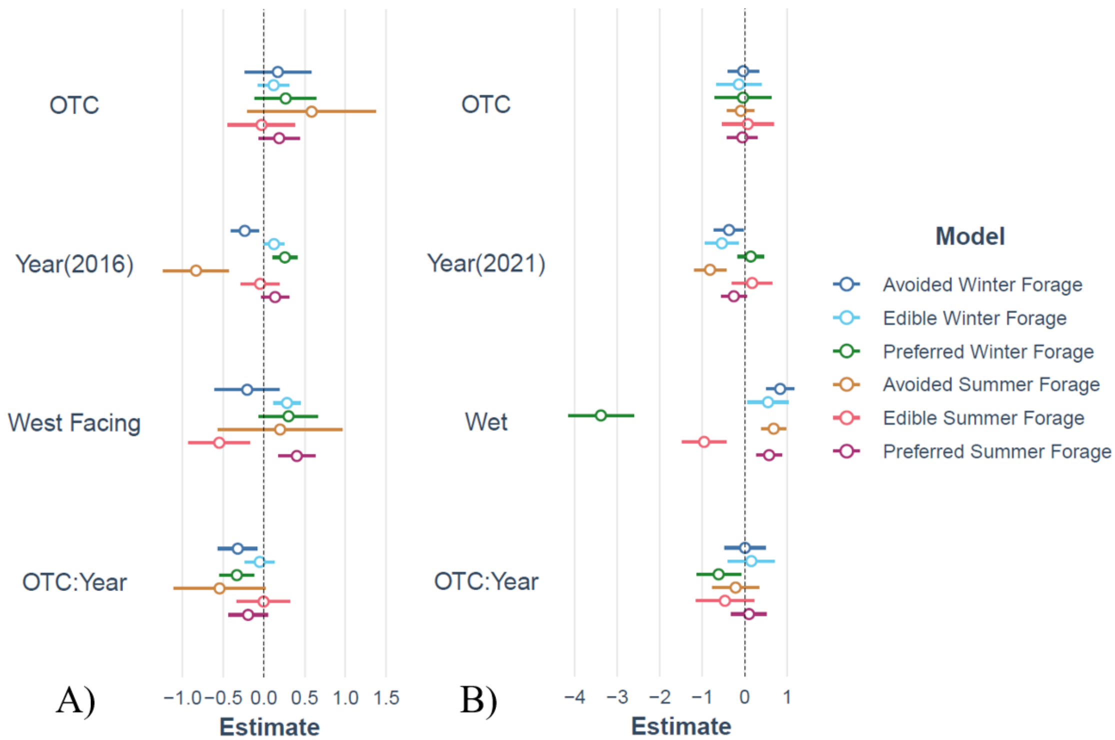

Figure 2. A generalized linear mixed model (GLMM) showing the effects of OTC treatment, year, subsite, and year*treatment interactions on the abundance of avoided, edible, and preferred summer and winter forage types at Torr Bay (**A**) and Nakvak Brook (**B**). Control plots, the 2010 (**A**) and 2009 (**B**) surveys, and dry and east facing plots are the baseline categories that the effects are measured against. Significant effects have 95% confidence interval bars that do not overlap with zero.

3.4.5 Forage Genera GLMMs

To better understand changes in preferred forage with time we analyzed six preferred forage genera (*Carex*, *Betula*, *Vaccinium*, *Salix*, *Cladonia*, and *Stereocaulon*) using GLMMs. Our genera level zero-inflated Poisson GLMMs for the Torr Bay site showed increased abundances of both *Betula* and *Vaccinium* species with time ($z_{2016} = 0.35$; $p < 0.001$; $z_{2016} = 0.19$; $p < 0.001$; Figure 3). *Betula* experienced a greater increase in OTC plots while *Vaccinium* experienced a greater increase in control plots ($z_{OTC*\mathrm{time}} = 0.28$; $p < 0.01$; $z_{OTC*time} = -0.21$; $p < 0.001$). There were no significant changes in abundance with time for *Carex, Salix, Cladonia, Stereocaulon*, and 'lichen'.

At the Nakvak Brook site we applied a non-zero-inflated negative binomial GLMM. We found that *Salix* species declined in abundance from 2010 to 2021 ($b_{2021} = -0.28$; $p < 0.001$; Figure 3). This change in abundance appears to be driven by a decline in *S. herbacea* over time. No significant changes in abundance with time were found for the other five forage genera, nor pooled lichen species. Plot moisture class (wet/dry) played a significant role in genera abundance. *Carex* was more abundant in wet plots than dry plots ($b_{wet} = 2.13$; $p < 0.001$), while *Cladonia*, *Stereocaulon*, and lichens are more abundant in dry plots ($b_{wet} = -3.42$; $p < 0.001$; $b_{wet} = -4.49$; $p < 0.001$; $b_{wet} = -3.66$; $p < 0.001$).

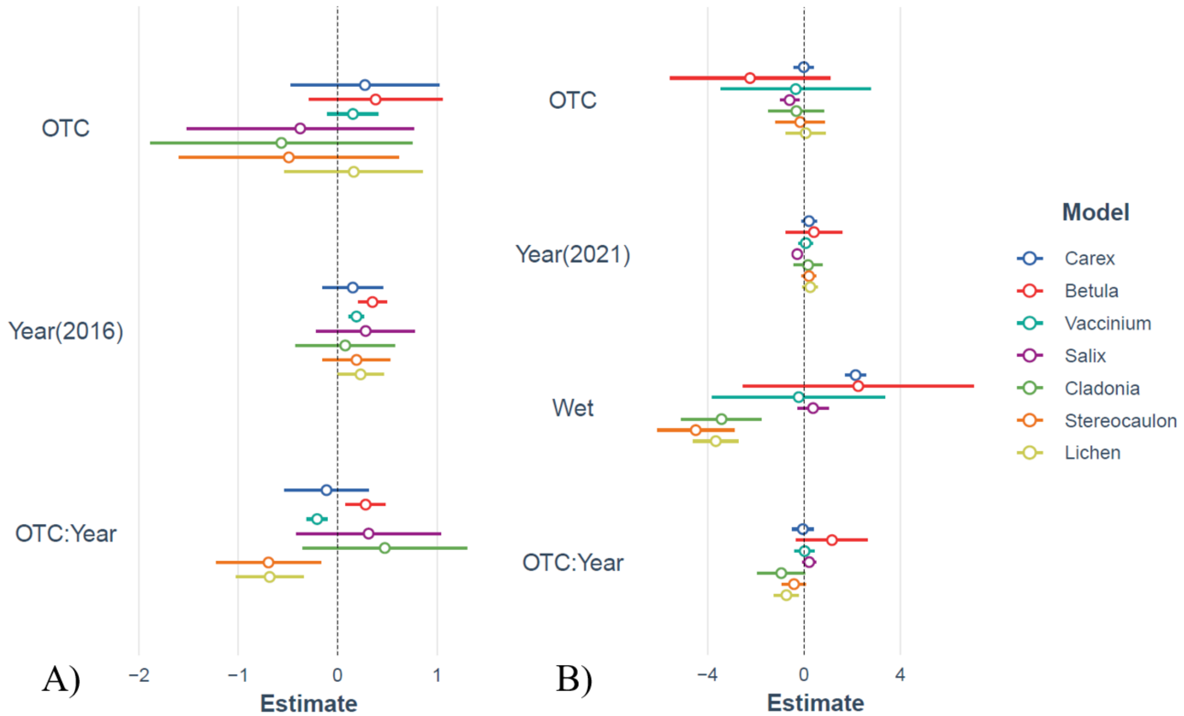

Figure 3. A generalized linear mixed model (GLMM) showing the effects of OTC treatment, year, subsite, and year*treatment interactions on the abundance of 6 genera of preferred caribou forage and lichen at Torr Bay (**A**) and Nakvak Brook (**B**). Control plots, the 2010 (**A**) and 2009 (**B**) surveys, and dry and east facing plots are the baseline categories that the effects are measured against. Significant effects have 95% confidence interval bars that do not overlap with zero.

3.5 Discussion

Caribou in Northern Labrador have immeasurable cultural and resource value to Inuit living in Nunatsiavut and Nunavik. Massive population declines of the George River Caribou (GRC), and consistently low TMC population sizes have resulted in far fewer caribou roaming the Torngat Mountains. Not only do low population sizes make caribou especially vulnerable to predation and hunting, but climate change is also expected to pose a major threat (COSEWIC, 2017). With climate warming, an increased shrub presence across the Arctic is anticipated to further reduce lichen abundance, which would have major consequences for caribou survival and health. Our study looks at the effects of warming on the availability of high-quality caribou forage to determine how caribou may become forage limited in the future.

Our study found that the proportional abundance of preferred winter caribou forage was far lower than the proportional abundance of preferred summer forage at both Torr Bay and Nakvak Brook. In the most recent Torr Bay survey (2016), 70% of total vegetation was preferred summer forage, while only 25% of the available vegetation was preferred winter forage. Similarly, at Nakvak Brook in 2021, 64% of the total vegetation was preferred summer forage and 14% was preferred winter (Table 2). This finding would suggest that caribou are more likely to be forage limited in the winter than during the summer months, within this range.

Other studies also found caribou to be more forage limited during the winter, however these studies found forage limitations were a result of small winter ranges, or limited suitable forage sites resulting in greater caribou concentration and over grazing of lichens (Bergerud, 1963; Heggberget et al., 2002). Moreover, the availability of high-quality winter forage is only expected to decline with climate change (Alatalo & Annika, 2017; Chagnon et al., 2019). As growing conditions become increasingly favourable for shrubs, they will continue to expand across the tundra and outcompete lichens (Elmendorf et al., 2012; Myers-Smith et al., 2011). Limited winter forage availability could have serious implications for caribou since winter is when caribou face the highest thermoregulation costs and demands for fetal growth (Parker et al., 2005). Furthermore, winter forage limitations could influence caribou movement patterns. Schmelzer & Otto (2003) found evidence of range drift in the GRC herd, when an area was overgrazed in a previous year, caribou shifted their migratory patterns to avoid those areas the subsequent year. The TMC are a non-migratory mountain caribou population, they do however display elevational movement patterns to escape predators and poor forage conditions (Couturier et al., 2015; Couturier et al., 2010). Inuit Knowledge says that when caribou food runs out, the caribou will move to find other food (Wilson et al., 2014). Therefore, winter forage limitations could cause changes in TMC movements. Our two study sites, Torr Bay and Nakvak Brook fall within the winter range of the TMC and the historic range of the GRC (Bélanger et al., 2019; Bergerud et al., 2008; Couturier et al., 2015; Schaefer & Luttich, 1998).

At our Torr Bay site, we found increases in abundance of *Betula* and *Vaccinium* species over the duration of our study (Figure 3). This result supports our hypothesis that we would see increased shrub abundances consistent with shrubification. Other long-term studies from Quebec and Alaska which looked at the effects of warming on vegetation change also found similar patterns (Ropars & Boudreau, 2012; Sturm et al., 2001). Traditional Knowledge also notes a recent increase in shrub abundance in the Torngat Mountains (Cuerrier et al., 2015; Siegwart Collier 2020; Wilson et al., 2014). However, at a global scale, recent syntheses document vegetation responses to climate change are not uniform across the Arctic (Elmendorf et al., 2012; Myers-Smith et al., 2015, 2020).

A global synthesis of two decades of ecological monitoring (ITEX) found that shrubs exhibited the greatest rate of expansion in warm tundra regions particularly in moist to wet areas while cold regions were more resistant to shrub expansion (Elmendorf et al., 2012). The Circumpolar Arctic Vegetation Map (Walker et al., 2005) classifies Northern Labrador as part of bioclimate subzone E, which is the warmest of the 5 Arctic subzones, categorized by mean summer temperatures of 10-12°C, taller shrubs, 80-100% vascular plant cover, and a closed canopy (Walker et al., 2005). It is in subzones D and E that Elmendorf et al. (2012) expect future climate-induced shrub expansion to be the greatest. This is supported by our finding that *Betula* and *Vaccinium* species have increased in abundance. Contrarily, we found that *Salix* species declined in abundance over the 11 years at our Nakvak Brook site (Figure 3). One possible explanation for this finding is that in recent years, we have observed visible drying of wet areas at the Nakvak Brook site. This drying trend could be negatively impacting *Salix* expansion since willow species tend to grow in moister environments. Furthermore, our results showed that avoided summer forage declined at both sites over time. This decline appears to be driven by reductions in moss abundance at both sites. At Torr Bay moss declines were primarily experienced by *Polytrichum* and *Aulocomium* while *Sphagnum*, *Aulocomim*, *Dicranum*, *Pogonatum*, *Drepanocladus* all decreased drastically at Nakvak Brook (See Figure 6 in Appendix A). Similar to *Salix*, declines in moss species were likely driven by drying of wet sites, but could also have been affected by the encroachment of shrubs, especially at the Torr Bay site where birch and ericaceous species increased in abundance.

Similar to findings from Davis et al. (2021), Elmendorf et al. (2012), and Myers-Smith et al. (2015), our results showed that vegetation abundance was strongly influenced by soil moisture availability. Our Nakvak Brook plots were split between wet and dry areas. We found that preferred winter forage was significantly more abundant in dry plots while preferred summer forage was far more abundant in wet plots. The greater abundance of preferred winter forage in dry plots can be explained by our findings that *Cladonia, Stereocaulon*, and the lichen functional group were significantly more abundant in dry plots. Additionally, we found that *Carex* was far more abundant in wet plots which could partially explain the greater abundance of preferred summer forage in wet plots.

Tundra areas with higher soil moisture have been found to exhibit greater climate sensitivity to warming thus experiencing greater shrub expansion (Davis et al., 2021; Elmendorf et al., 2012; Myers-Smith et al., 2015). A remote sensing study of Torngat Mountains National Park by Davis et al. (2021) found that 28.8% of raster pixels classified as wet vegetation in 1985/89 transition to shrub vegetation pixels by 2015/19 while only 1.4% and 3% of dry and non-vegetated pixels underwent a similar transition. Furthermore, decreased soil moisture from experimental warming coincided with community turnover from sedge and grass dominated meadow to birch and ericoid dominated heath communities (Scharn et al., 2021). Climate change is expected to impact moisture availability across the Arctic as permafrost thaws and snow melt occurs earlier in the year (Scharn et al., 2021). In Northern Labrador, the maximum precipitation is predicted to increase across the region over the next 30 years (Climate Atlas of Canada, 2019). Additionally, Davis et al. (2021) found that the total amount of wet vegetation in TMNP increased over time with most gains coming from the dry vegetation class. It is clear from climate forecasts (Climate Atlas of Canada, 2019) and our own soil moisture data that soil moisture regimes in Northern Labrador are and will continue to be impacted by climate change. Moreover, a greater proportion of shrub and wet vegetation cover is expected in the region. Consequently, we would expect this to increase the availability of summer caribou forage while decreasing the availability of winter forage as the region continues to experience warming.

A surprising result from our study was that neither experimental warming nor ambient warming (time factor in models) had any significant effects on *Cladonia*, *Stereocaulon*, nor the 'lichen' functional group at either site. Based on results of previous studies (Alatalo & Annika, 2017; Chagnon et al., 2019; Elmendorf et al., 2012), we expected that lichens would have declined with time and warming as a result of greater competition with shrubs. A lack of change in lichen abundance could be explained by the presence of an opposing signal to climate change. A recent study by Andruko et al. (2020) looked at decadal growth rates of dwarf birch in the low arctic and found that across multiple habitat types dwarf birch growth was enhanced. However, since warming trends were found to be limited at these sites, Andruko et al. (2020) suggested that increased birch growth could be explained by reduced browsing from recent caribou herd declines. Our study region, the Torngat Mountains, also recently experienced a release from browsing pressure. In the early 1990's, the GRC herd was experiencing a population boom of approximately 800,000 individuals (Couturier et al., 1996) but, by 2018 this number dropped to around 5,500 individuals (Government of Newfoundland and Labrador, 2018). This massive population decline has resulted in a contraction of the GRC range. Subsequently, they no longer migrate into the Torngat Mountains (Bergerud et al., 2008), leading to a massive reduction of ungulate browsing on the landscape. With reduced browsing pressure, we would expect to see high quality forage species such as lichens rebounding. This would create opposing signals; climate change negatively impacts lichen abundance while reduced browsing benefits their growth. Reduced browsing could have also had an affect on shrub growth; however lichens are very slow growing and unlike shrubs do not experience compensatory growth so we would expect this signal to be stronger for lichens (Champagne et al., 2012; Pegau, 1968). With our current dataset, we do not have enough information to separate climate change and reduced grazing signals, but this is a potential avenue for future research.

It is evident that over the past several decades, shrub abundance has been increasing across the Arctic (Bjorkman et al., 2018; Elmendorf et al., 2012; R. H. Fraser et al., 2011; Sturm et al., 2001). This rapid shrub expansion resulting from Arctic warming has been shown to negatively impact lichens, a key winter forage species for caribou (Alatalo & Annika, 2017; Chagnon et al., 2019; Fraser et al., 2014). On the other hand, preferred summer caribou forage availability is on the rise as deciduous shrubs such as *Betula glandulosa* and *Vaccinium uliginosum* become more abundant. Although quantities of summer caribou forage are expected to increase with warming, forage quality may be diminished. Warming has been found to reduce the nutritional value and digestibility of caribou forage shrubs by decreasing nitrogen content and increasing phenolics in plant tissues (Turunen et al., 2009; Zamin et al., 2017). Furthermore, a study by Vowles et al. (2017) found that non-palatable evergreen shrubs are spreading faster than palatable deciduous shrubs since deciduous shrub expansion is inhibited by caribou browsing. This result would suggest that climate induced shrub expansion is not only limiting winter forage availability, but with time it may also limit summer forage as evergreen shrubs increase in abundance. From our point-frame dataset, we found that at both Torr Bay and Nakvak Brook there was a significant increase in the abundance of *Rhododendron* spp. We also found that at Nakvak Brook, the only site where *Harrimanella hypnoides* L. was present, it increased in abundance, while *Empetrum nigrum*, only present at Torr Bay, showed no change in abundance (See Table 12 & Figure 5 in Appendix A).

Not only has Arctic warming been shown to influence the availability of caribou forage, but it is also impacting caribou in several other ways. Climate change is expected to cause a 'trophic mismatch' where the timing and calving misaligns with forage availability (Post & Forchhammer, 2008). Furthermore, climate change is causing later freezing and earlier breakup of ice on lakes and rivers (Magnuson et al., 2000) which has had consequences for caribou migration patterns (Côté et al. 2012). Finally, an increasing occurrence of rain on snow or snow icing events caused by warming temperatures (Tyler, 2010). Warm temperatures or rain can cause a layer of ice to form on top of the snowpack which prevents caribou from being able to dig to the ground layer to access forage. A rain on snow event which took place in November of 2013 has been linked to massive reindeer mortality on the Yamal Peninsula, Russia (Forbes et al., 2016). Climate change is predicted to cause an 89% decline in suitable caribou habitat in North America over the next 60 years (Yannic et al., 2014). In Labrador and Quebec, spring and summer ranges suitable for the GRC are predicted to shrink to just the northeastern section of the Quebec-Labrador Peninsula over the next 30-50 years (Sharma et al., 2009). Without stronger policies and international action to reduce green house gas emissions, climate change will continue to change the Arctic threatening caribou survival. A loss of caribou would have immense consequences for Inuit wellbeing as caribou are a cultural keystone species.

3.6 Conclusion

Understanding caribou forage availability is necessary for the long-term conservation of caribou in Northern Labrador. Our study found that the proportion of total vegetation suitable for caribou was far higher in the summer months than during the winter months at both study sites. This result suggests that caribou are more likely to be forage limited in the winter than during the summer. Therefore, dry, lichenous, windblown areas optimal for winter foraging should be prioritized for conservation. Furthermore, we found an increase in preferred winter forage abundance from 2009-2016 at Torr Bay and declines in avoided summer forage at both sites over time. In general, we did not find that experimental warming had a greater effect on vegetation abundance than ambient warming (time factor). Finally, we found that birch, willow, and ericaceous preferred forage species are experiencing the most changes in abundance, while lichen species were not significantly affected. Understanding how specific forage species are expected to change with warming will help to predict how caribou may become forage limited in the future, especially if population sizes begin to rebound. Results of this study are specific to the species assemblages found in TMNP. However, methods applied in this study could easily be transferred to other ITEX vegetation datasets to assess caribou forage abundance in different regions. Our research provides valuable insight into recent changes in caribou forage availability for the TMC. This knowledge will help to inform appropriate conservation and management measures so that the TMC can continue to persist and contribute to the social-ecological resilience of northern communities.

Chapter 4: Conclusion and Future Directions

The objective of my research was to summarize existing information on the Torngat Mountains Caribou (TMC), identify knowledge gaps, and contribute to the growing body of research on the TMC. The TMC were only recently designated by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as their own designatable unit, distinct from the George River Caribou (GRC) herd (COSEWIC, 2011). Therefore, knowledge gaps still exist in our understanding of this population. One significant gap is that we did not know how climate change would impact the availability of caribou forage in the Torngat Mountains. Previous work in this region found evidence of widespread shrub expansion, especially in wet areas (Davis et al., 2020; 2021). These results, when considered alongside evidence that shrub expansion negatively impacts lichen abundances could have serious implications for caribou that rely on lichens, especially as a winter food source (Alatalo & Annika, 2017; Chagnon et al., 2019). Another study looked at the effects of warming on caribou forage quality and found that warming negatively impacted the nutritional value and digestibility of several important forage species (Zamin et al., 2017). My thesis builds from these previous studies to assess the effects of warming on the availability of summer and winter caribou forage in the Torngat Mountains.

My first research question was what proportion of total vegetation is suitable summer and winter caribou forage and how has this changed with time and experimental warming? Our results showed that the proportion of total vegetation suitable for caribou was far higher in the summer months (57-70% of total vegetation) than during the winter months (9-25% of total vegetation) at both sites and across all study years (Table 2). This result suggests that caribou are more likely to be forage limited in the winter than during the summer. Additionally, we found a significant increase in preferred winter forage with time at the Torr Bay site (Figure 2). My second research question looked at which forage species were most impacted by recent warming? We hypothesized that our findings would show an increase in summer caribou forage abundance, and a decline in winter forage abundance over time, and with warming, consistent with the effects of Arctic shrubification. To an extent, our results supported our hypothesis. As predicted, we saw an increase in two important summer caribou forage genera, birch and ericaceous shrubs, at Torr Bay (Figure 3). Additionally, the proportion of preferred summer forage appeared to increase at both sites with time, but this increase was not always statistically significant. We did not however expect to see the decline in willow abundance at Nakvak

Brook that we found (Figure 3) and we did not see any significant changes in abundances of lichens, an important winter forage, throughout the study (Figure 3). We theorize that the decline in willows at Nakvak Brook is due to an observed drying of the site over time. Furthermore, we suspect that we did not see a decline in lichen abundances because lichen populations are still recovering after being released from GRC grazing pressures.

Our study provides valuable insight into how caribou forage is being impacted by climate change, and during which seasons caribou are more likely to be forage limited. I expect that the implications of our research will become more significant with time. The most recent, published, population estimate for the TMC is 1,326 animals (Couturier et al., 2017) and since the GRC herd's range no longer extends into the Torngat Mountains, 1,326 is the total number of caribou living in the Torngat Mountains. Since there are very few caribou currently living in the Torngat Mountains, it is unlikely that they will become forage limited in the near future, even with the effects of climate change. Understanding and addressing the effects of climate change on caribou forage will however be important in the long run. TMC population sizes have continued to increase since their initial population survey in 2014 (Couturier et al., 2017; 2015; M. Purcell, personal communication, April 4, 2022). Additionally, a 2020 survey of the GRC herd found that the population had increased for the first time in more than 25 years (Government of Newfoundland and Labrador, 2020). If these two populations continue to grow, forage would once again become a limiting factor in the Torngat Mountains. Moreover, as climate change continues to impact vegetation in the Torngat Mountains National Park (TMNP), it is expected that the North-eastern Quebec-Labrador Peninsula, where TMNP is located, will be the only suitable winter, spring, and summer habitat remaining for the GRC by as early as 2040 (Sharma et al., 2009). This would put even greater pressure on forage species in TMNP, especially lichens. Future research could build from our findings to determine the number of caribou the landscape can sustainably support so that caribou herds can be managed accordingly.

A limiting factor on my thesis was the COVID-19 pandemic. Not being able to visit my field sites due to COVID-19 travel and research restrictions limited my understanding of the broader ecosystems and made it more challenging for me to draw conclusions about which natural processes could have influenced our findings. Fortunately, I was able to rely on the expertise of Andrew Trant, Luise Hermanutz, and Laura Siegwart-Collier who collected the vegetation point-frame data and have all visited the Torr Bay and Nakvak Brook sites multiple times. Additionally, I was lucky to be part of a field team that traveled to Southern Labrador in the summer of 2021 to collect vegetation and drone data in the Pinware Hills region near Red Bay. Spending a month in Pinware Hills, a tundra ecosystem, allowed me to learn the different tundra species in Labrador and to better understand the species assemblages.

My initial thesis plan was to investigate historical TMC population trends using dendrochronology. To carry out this thesis, I would have had to travel to TMNP to collect caribou trampling scars. Unfortunately, just as we were planning our field season the pandemic hit so we had to cancel our travel plans. I then spent the majority of the second year of my master's figuring out what data already existed for the TMC and what questions I could answer using these existing datasets. Throughout my master's program I developed three project proposals, each centered around knowledge gaps for the TMC population. Of the three proposed projects, it was the third project that I carried through to completion and the results of this study are presented in Chapter 3 of my thesis. The other two projects I was unable to complete due to COVID-19, and issues with acquiring government data within the required timeframe. Those two proposals are included in their original form in Appendix C of my thesis and are available for other students or Parks Canada staff to complete if desired.

In short, the objective of my first thesis project was to reconstruct historical TMC population trends by dating caribou trampling scars. The purpose of this project was to address the lack of long-term population data available for the TMC. To reconstruct historical population trends, I would have applied dendrochronological techniques developed by Morneau & Payette (1998; 2000) where shrub roots and stems with visible caribou trampling scars are collected across the landscape. These trampling scars can then be dated by counting the number of growth rings since the scarring event. The number of scarring events occurring per year is a good indicator of caribou activity levels (Morneau & Payette, 1998). The non-linear scar frequency data can be modeled with generalized additive models to assess changes in caribou abundance. A detailed description of my proposed sampling strategy can be found in Appendix C.

While developing sampling methods for my initial thesis project, I needed to know where within TMNP the TMC and GRC historically overlapped. A study by Belanger et al. (2019) determined the annual degree of overlap between the two herds but did not identify the locations of overlap or whether the two herds shared habitat during periods of overlap. This led to my second research proposal which aimed to shed light on the level of interaction between the TMC and the GRC during periods of overlap. To do this, I planned to acquire satellite collar data from the provincial governments of Newfoundland and Labrador and Quebec for both the TMC and GRC. With that caribou collar data, I would have conducted resource selection functions for each caribou herd within the region of overlap to identify habitat selection patterns (Manly et al., 2002; Northrup et al., 2013). Based on their habitat selection patterns, I could have determined whether the two herds were selecting for similar or different habitat types during overlap to predict the level of interaction the herds may have had. This information would be useful for management purposes as it would provide managers with an idea of how habitat selection by the TMC has been influenced by range overlap with the GRC and give insight into potential impacts the loss of overlap may have had. A detailed proposal for this project is also included in Appendix C.

Next steps to build off my thesis work, would be to address the two knowledge gaps I have identified; 1) a lack of historical population data for the TMC and 2) limited knowledge about whether the two herds interacted during periods of range overlap. These research gaps could be tackled by Parks Canada or future master's students. Tangible contributions of my thesis include a summary of existing scientific research and Inuit Knowledge on the TMC population, identification of knowledge gaps for the TMC and proposed projects to fill them, the first comprehensive list of preferred caribou forage species present in the Torngat Mountains, and finally a greater understanding of how caribou could become forage limited in the future. I plan to communicate the results of my thesis by sending a report of Chapter 2 to Parks Canada, publishing Chapter 3 in a scientific journal, creating an infographic of my Chapter 3 results to distribute, writing a summary of my thesis for the Nunatsiavut Government and the Torngat Mountains Cooperative Management Board, and presenting my results at the Labrador Research Forum in May 2022. I hope that with greater knowledge and informed management, the TMC can continue to persist and contribute to the social-ecological resilience of Nunatsiavut communities.

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Appendix A: Supplementary Material

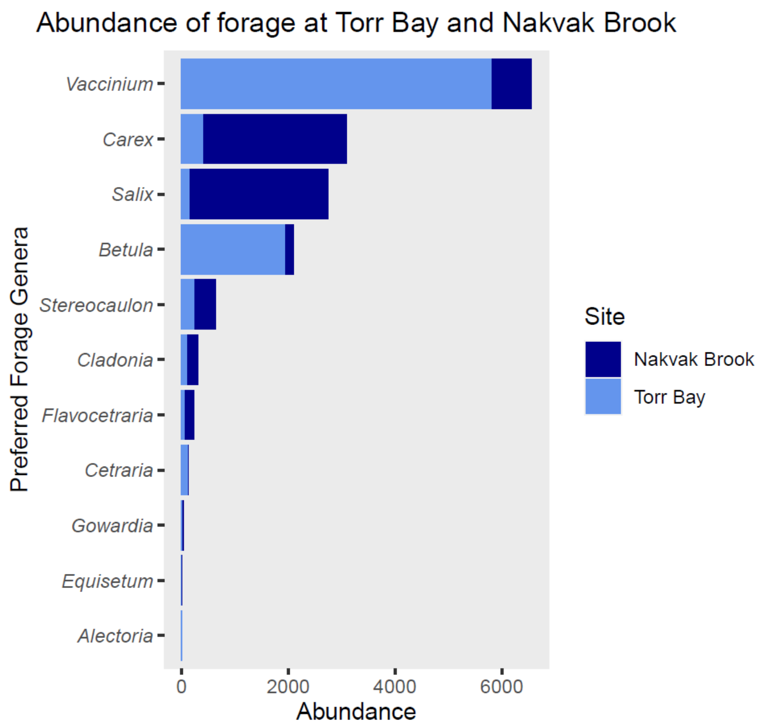

Figure 4. Abundance (genera count) of all preferred forage genera at Torr Bay (2009 & 2016) and Nakvak Brook (2010 & 2021), Labrador, Canada.

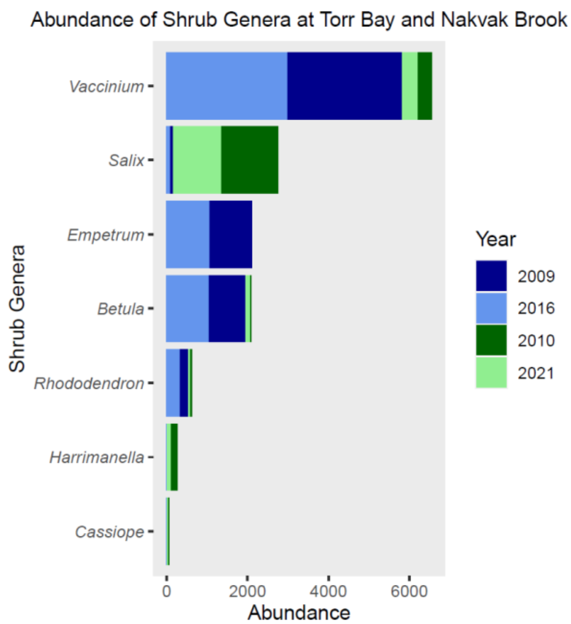

Figure 5. Abundance (genera count) of shrub genera at Torr Bay (2009 & 2016) and Nakvak Brook (2010 & 2021), Labrador, Canada.

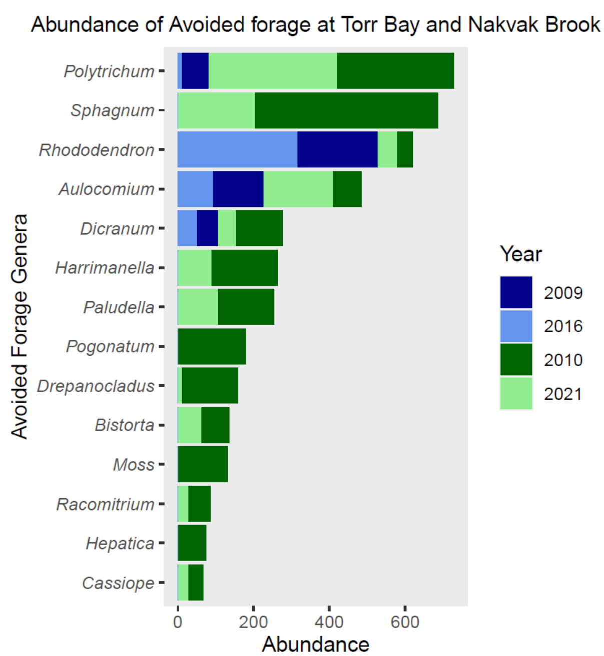

Figure 6. Avoided forage genera abundance (genera count) at Torr Bay (2009 & 2016) and Nakvak Brook (2010 & 2021), Labrador, Canada

Table 4. Generalized linear mixed models were applied to forage rank data using 12 different combinations of main effects, distributions, and model types. The AIC values for each of these 12 model variations were calculated. The models with the 3 lowest AIC values (most parsimonious) are displayed in the table, highlighted values correspond to the selected model applied across all genera at each site.

	Nakvak Brook			Torr Bay		
Rank	1	2	3	1	2	3
0 summer	nb2	nb3	nb1	nb1	nb2	p1
1 summer	nb2	nb3	nb1	nb2	nb1	nb3
2 summer	nb2	nb3	nb1	nb3	nb2	nb1
0 winter	nb2	nb3	nb1	p1	nb1	p2
1 winter	nb3	nb2	nb1	nb3	p3	nb2
2 winter	nb2	nb3	p3	nb2	nb1	nb3

Table 5. Generalized linear mixed models were applied to forage genera data using 14 different combinations of main effects, distributions, and model types. The AIC values for each of these 14 model variations were calculated. The models with the lowest AIC values (most parsimonious) are displayed in the table, highlighted values correspond to the selected model applied across all genera at each site.

	Nakvak Brook			Torr Bay				
	1	**2**	**3**	**1**	**2**	**3**	**4**	**5**
Carex	nb2	nb1	zinb2	zip2	zinb2	zinb4	zip4	zip1
Betula	zinb2	nb1	nb2	nb3	p3	zip4	nb2	nb1
Vaccinium	vnb2	nb1	zinb2	zinb3	zinb4	zinb5	zip3	zip1
Salix	nb3	nb2	nb1	zip1	zip4	nb2	zip2	zip3
Cladonia	p3	nb3	zip3	p4	p2	p1	nb2	nb4
Stereocaulon	p3	p1	nb1	p4	p1	zip4	nb1	zinb4
Lichen	nb3	nb1	zinb3	nb4	nb1	zinb4	p4	zinb1

Table 6. Parameter estimates for glmm models of caribou forage rank classifications at Torr Bay, Labrador, Canada.

	Avoided Winter Forage	Edible Winter Forage	Preferred Winter Forage	Avoided Summer Forage	Edible Summer Forage	Preferred Summer Forage
OTC	0.27	0.12	0.21	0.59	-0.03	0.19
	(0.22)	(0.12)	(0.28)	(0.40)	(0.21)	(0.13)
YEAR(2016)	-0.27 *	0.03	0.22 **	-0.83 ***	-0.05	0.14
	(0.11)	(0.10)	(0.08)	(0.21)	(0.12)	(0.09)
West Facing	-0.32	0.18	0.36	0.20	-0.55 **	0.40 ***
	(0.21)	(0.09)	(0.28)	(0.39)	(0.19)	(0.11)
OTC:YEAR	-0.33 *	-0.05	-0.33 **	-0.54	-0.00	-0.19
	(0.15)	(0.14)	(0.11)	(0.29)	(0.17)	(0.12)
nobs	120	120	120	120	120	120
sigma	0.97	8.92	1.26	0.63	5.37	7.10
logLik	-390.22	-575.42	-459.44	-235.73	-503.39	-578.90
AIC	794.44	1164.84	932.88	485.45	1020.78	1171.80
BIC	813.95	1184.35	952.39	504.97	1040.29	1191.32
df.residual	113.00	113.00	113.00	113.00	113.00	113.00

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Table 7. Parameter estimates for glmm models of caribou forage rank classifications at Nakvak Brook, Labrador, Canada.

	Avoided Winter Forage	Edible Winter Forage	Preferred Winter Forage	Avoided Summer Forage	Edible Summer Forage	Preferred Summer Forage
OTC	-0.04	-0.14	-0.04	-0.09	0.07	-0.06
	(0.19)	(0.27)	(0.34)	(0.16)	(0.31)	(0.18)
Year(2021)	-0.37 *	-0.54 **	0.14	-0.82 ***	0.17	-0.26
	(0.18)	(0.20)	(0.16)	(0.19)	(0.24)	(0.15)
Wet	0.83 ***	0.55 *	-3.39 ***	0.68 ***	-0.96 ***	0.57 ***
	(0.17)	(0.25)	(0.39)	(0.15)	(0.27)	(0.16)
OTC:Year	0.00	0.15	-0.62 *	-0.22	-0.47	0.10
	(0.25)	(0.28)	(0.27)	(0.28)	(0.35)	(0.21)
nobs	76	76	76	76	76	76
sigma	24.17	13.17	2.97	12.46	6.75	16.89
logLik	-390.84	-336.46	-188.98	-328.80	-252.60	-387.96
AIC	795.68	686.92	391.97	671.60	519.20	789.92
BIC	811.99	703.23	408.28	687.91	535.52	806.24
df.residual	69.00	69.00	69.00	69.00	69.00	69.00

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Table 8. Parameter estimates for glmm models of preferred caribou forage genera at Torr Bay, Labrador, Canada.

	Carex	Betula	Vaccinium	Salix	Cladonia	Stereocaulon	Lichen
OTC	0.27	0.38	0.15	-0.38	-0.57	-0.49	0.16
	(0.38)	(0.34)	(0.13)	(0.58)	(0.67)	(0.56)	(0.35)
YEAR(2016)	0.15	0.35 ***	0.19 ***	0.28	0.08	0.19	0.23
	(0.16)	(0.07)	(0.04)	(0.25)	(0.25)	(0.17)	(0.12)
OTC:YEAR	-0.11	0.28 **	-0.21 ***	0.31	0.47	-0.70 *	-0.68 ***
	(0.22)	(0.10)	(0.05)	(0.37)	(0.42)	(0.27)	(0.17)
nobs	119	119	119	119	119	119	120
sigma	1.00	1.00	1.00	1.00	1.00	1.00	1.00
logLik	-259.74	-389.99	-511.72	-159.20	-122.25	-191.78	-293.98
AIC	531.48	791.98	1035.44	330.41	256.50	395.55	599.96
BIC	548.15	808.66	1052.11	347.08	273.17	412.22	616.68
df.residual	113.00	113.00	113.00	113.00	113.00	113.00	114.00

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Table 9. Parameter estimates for glmm models of preferred caribou forage genera at Nakvak Brook, Labrador, Canada.

	Carex	Betula	Vaccinium	Salix	Cladonia	Stereocaulon	Lichen
OTC	-0.01	-2.24	-0.35	-0.60 **	-0.32	-0.16	0.07
	(0.21)	(1.69)	(1.59)	(0.20)	(0.59)	(0.52)	(0.42)
Year(2021)	0.20	0.41	0.07	-0.28 **	0.16	0.20	0.25
	(0.16)	(0.59)	(0.15)	(0.10)	(0.30)	(0.15)	(0.16)
Wet	2.13 ***	2.25	-0.22	0.37	-3.42 ***	-4.49 ***	-3.66 ***
	(0.22)	(2.44)	(1.83)	(0.32)	(0.85)	(0.81)	(0.47)
OTC:Year	-0.05	1.16	0.02	0.21	-0.95	-0.42	-0.73 **
	(0.23)	(0.75)	(0.21)	(0.15)	(0.50)	(0.25)	(0.26)
nobs	76	76	76	76	76	76	76
sigma	7.33	3.13	1.01	2.20	1.99	0.45	2.40
logLik	-299.86	-57.32	-145.09	-320.97	-107.93	-122.34	-178.57
AIC	613.71	128.64	304.19	655.94	229.86	258.67	371.13
BIC	630.03	144.96	320.50	672.25	246.17	274.99	387.45
df.residual	69.00	69.00	69.00	69.00	69.00	69.00	69.00

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Table 10. Parameter estimates for glmm models of caribou forage rank classifications in the control plots at Torr Bay, Labrador, Canada. Models include only as a fixed effect and plot as a random effect.

	Avoided Winter Forage	Edible Winter Forage	Preferred Winter Forage	Avoided Summer Forage	Edible Summer Forage	Preferred Summer Forage
Year(2016)	-0.27 **	0.03	0.22 **	-0.84 ***	-0.05	0.15
	(0.10)	(0.10)	(0.08)	(0.23)	(0.12)	(0.08)
nobs	60	60	60	60	60	60
sigma	0.83	9.28	0.95	1.03	5.81	5.12
logLik	-193.85	-286.65	-227.50	-113.41	-253.69	-286.65
AIC	395.70	581.31	463.01	234.81	515.37	581.31
BIC	404.08	589.68	471.38	243.19	523.75	589.68
df.residual	56.00	56.00	56.00	56.00	56.00	56.00

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Table 11. Parameter estimates for glmm models of caribou forage rank classifications in the control plots at Nakvak Brook, Labrador, Canada. Models include year as a fixed effect and plot as a random effect.

	Avoided Winter Forage	Edible Winter Forage	Preferred Winter Forage	Avoided Summer Forage	Edible Summer Forage	Preferred Summer Forage
Year(2021)	-0.36	-0.51 *	0.15	-0.74 ***	0.09	-0.27
	(0.19)	(0.21)	(0.11)	(0.20)	(0.26)	(0.17)
nobs	38	38	38	38	38	38
sigma	28.50	14.95	0.77	14.90	8.48	21.08
logLik	-200.86	-170.55	-106.18	-171.74	-133.13	-197.44
AIC	409.73	349.11	220.36	351.47	274.27	402.88
BIC	416.28	355.66	226.91	358.02	280.82	409.43
df.residual	34.00	34.00	34.00	34.00	34.00	34.00

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Table 12. Parameter estimates for glmm models of unpalatable evergreen shrub species at **A**) Torr Bay and **B**) Nakvak Brook.

A)

	Empetrum	Rhododendron
OTC	-0.19	0.06
	(0.67)	(0.66)
YEAR(2016)	0.11	0.39 *
	(0.12)	(0.16)
OTC:YEAR	0.05	0.08
	(0.17)	(0.24)
nobs	119	119
sigma	2.58	0.75
logLik	-370.69	-245.69
AIC	753.39	503.39
BIC	770.06	520.06
df.residual	113.00	113.00

*** p < 0.001; ** p < 0.01; * p < 0.05.

B)

	Harrimanella	Rhododendron
OTC	0.68	1.82
	(0.47)	(1.43)
Year(2021)	-0.99 **	1.08 *
	(0.36)	(0.44)
Wet	-3.32 ***	-3.86 *
	(0.79)	(1.59)
OTC:Year	0.37	-1.45 **
	(0.54)	(0.55)
nobs	76	76
sigma	2.24	0.41
logLik	-111.63	-62.81
AIC	237.27	139.62
BIC	253.58	155.93
df.residual	69.00	69.00

*** p < 0.001; ** p < 0.01; * p < 0.05.

Appendix B: List of studies used to determine caribou forage ranks for vegetation species

Bergerud, A. T. (1972). Food habits of Newfoundland caribou. *The Journal of Wildlife Management*, *36*(3), 913–923.

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Appendix C: Proposed Projects to Address Two Knowledge Gaps for the Torngat Mountains Caribou

Combining Western Science and Traditional Ecological Knowledge to Reconstruct Historical Torngat Mountains Caribou Populations

Introduction. Caribou (*Rangifer tarandus*) populations are in decline across Canada, making this charismatic species a major conservation concern. For the Inuit of Northern Labrador and Quebec, caribou are a cultural keystone species (Garibaldi & Turner, 2004) and provide a vital economic, cultural, and nutritional resource (Cuerrier et al., 2012). Inuit have long been aware that the Torngat Mountains Caribou (TMC) population is distinct from the migratory George River Caribou herd (Wilson et al., 2014), but this distinction has only recently been recognized by federal and provincial governments (COSEWIC, 2011). Therefore, limited long-term TMC specific population data are available. The available quantitative population data suggest that the TMC experienced a significant population decline of around 80% since the 1980's and remains low (Bélanger & Le Henaff, 1985; Couturier, S.D. Wood, B. and Snook, 2017; S Couturier et al., 2015). Traditional ecological knowledge (TEK) also suggests a population decline (Wilson et al., 2014). For these reasons, the TMC were assessed as 'Endangered' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2016 (COSEWIC, 2017). If COSEWIC's recommendation is accepted and the TMC become federally listed, Inuit would lose their harvesting rights (COSEWIC, 2017). This would have negative impacts to the resilience of northern social-ecological systems (Cuerrier et al., 2012). The lack of historical population data for the Torngat Mountains Caribou has been identified as a limitation for understanding and managing this population by COSEWIC, Parks Canada, and local Inuit communities.

Research Questions. To accurately assess the population status of the TMC, we need to know the historical population trends. To do this, I will ask the following questions: 1) What are the historical TMC population sizes? 2) How has this population varied through time? and 3) What does Inuit Traditional Ecological Knowledge tell us about TMC population changes?

Methods. To answer these questions, I will follow established dendrochronological methods to reconstruct historical caribou population sizes (Morneau & Payette, 1998, 2000; Zalatan et al., 2006). As caribou travel through an area, their hooves damage the roots and stems of shrubs underfoot, and leave easily identifiable scars (Morneau & Payette, 1998, 2000). I will collect shrub root and stem samples with visible trampling scars along caribou trails to use as a proxy for caribou activity. Shrub rings will be used to date the scars which will provide a long-term set of annual data. Sampling will take place in the Northern portion of the TMC's range where no overlap occurs with the neighbouring George River population. To select appropriate sampling locations, I will consult in situ with Inuit Knowledge holders. I will collect a minimum of 250 trampling scars from each site as this sample size was found to adequately represent the age structure of scars for a sampling location (Morneau & Payette, 1998). In the Trant Eco-cultural Legacy Lab at the University of Waterloo, samples will be thin-sectioned, stained, and examined under a microscope to determine the year and frequency of scars. The frequency of scars over time will be calibrated using existing population data to reconstruct historical population size and trends. In other locations, TEK has effectively informed caribou habitat models and broadened understanding on population distributions (Polfus et al., 2014; Polfus et al., 2016). Therefore, I will review existing TEK literature on the TMC population and I will consult with Inuit Knowledge Holders to add breadth to our understanding of the TMC's range and population trends. The project was co-developed in collaboration with Parks Canada and local Inuit communities. Preliminary data from 882 samples was collected at 3 sites in the Torngat Mountains during the summer of 2018, additional samples will be collected during future summer field work.

Significance of Research. My transdisciplinary research will provide valuable insight into the historical population size and fluctuations of the TMC which will help to inform and define appropriate conservation and management targets. With more informed management, the TMC can continue to persist and contribute to the social-ecological resilience of northern communities.

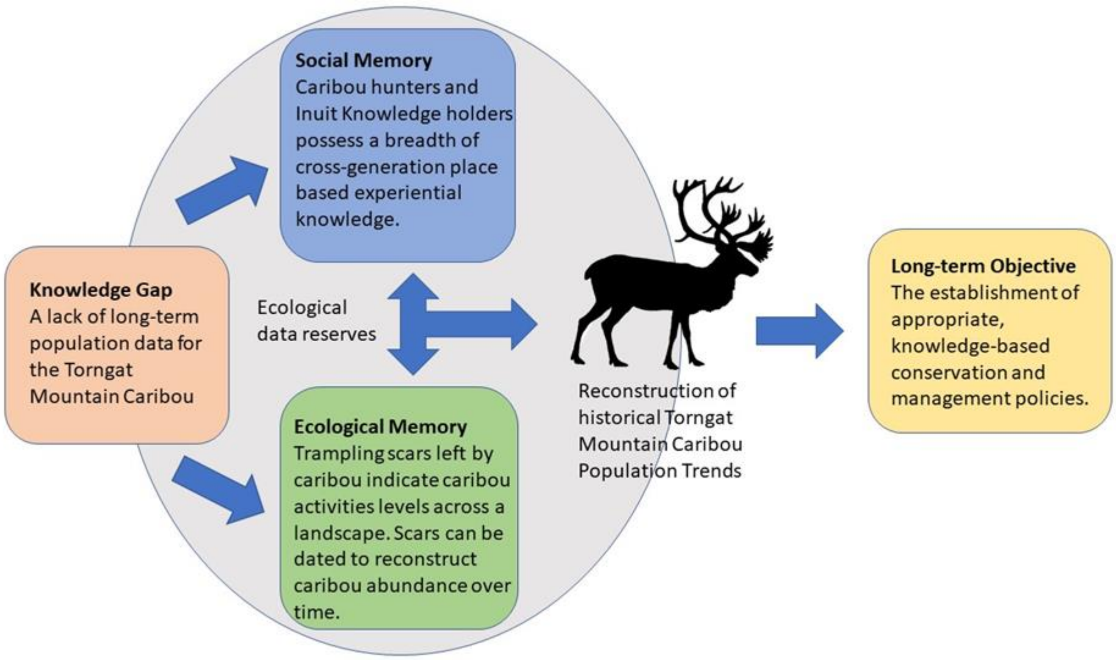

Figure 7. A theoretical framework of my proposed research to reconstruct historical Torngat Mountains Caribou populations trends.

Research Methods and Methodologies

4.1.1.1 Sampling strategies

Method: Targeted site selection using habitat suitability models

To select sampling sites, I will first conduct a habitat suitability analysis to determine which areas within the Torngat Mountains are most suitable for caribou (i.e., more suitable to caribou will mean a greater presence of caribou trails) and are accessible for sampling. I will use ArcGIS to build the habitat suitability model. Habitat suitability models have successfully been used to target field sampling of invasive plant species (Crall et al., 2013), and rare plant species (Guisan et al., 2006), while habitat suitability indices have been used to identify optimal Peary caribou habitat in the Canadian Arctic Archipelago (Jenkins et al., 2019).

The layers that I will include in my habitat suitability model for Torngat Mountains Caribou are an elevation model, a landcover layer (veg type, rock, water), an ecozone layer, Inuit Knowledge caribou summer range maps (Wilson, 2014), and George River caribou range maps. I will use these layers to identify areas within the Torngat Mountains where caribou are most likely to have been during previous summer months (scarring occurs during snow free months), areas where the TMC do/have not overlapped with the George River caribou herd, and areas that are accessible for sampling. Jenkins et al., (2019) found that landcover type was the most important variable in determining Peary caribou presence with Peary caribou preferring grass-lichen-moss and barren-lichen-moss landcover types. Therefore, I will assign lichen landcover classes a higher weighting in my model.

Method: Stratified transect sampling

My habitat suitability model will inform the selection of 6-8 sampling sites; this number of sampling sites will capture landscape diversity while also factoring in the high cost of accessing sites. I will target areas that are likely to have/ have had high caribou presence. When species are rare, it is reasonable to use habitat suitability models for targeted sampling since standard sampling methods such as simple or stratified random sampling will be highly inefficient (Guisan et al., 2006; Rushton et al., 2004). Additionally, previous caribou trampling scar studies used targeted sampling to avoid areas with dense trampling and thus high tree mortality (Morneau & Payette, 1998), and to target areas that were identified by Elders as having high Caribou presence (Zalatan et al., 2006).

For this study, caribou trails will act as sampling transects. Three transects will be selected at each sample site based on the covariate of interest (trail age or trail ecosite). Presence-absence data will be collected along a 100m stretch of each transect. The total number of exposed shrub roots and stems crossing the trail will be counted along with the number of these roots and stems with trampling scars. Absence data tell us how many shrubs were available to be trampled at each site which then allows us to compare caribou abundance between sampling sites. Presence-absence data will also allow me to include covariates into statistical models. In addition to collecting presence-absence data, all trampling scars found on the 100m sections of transect will be collected. At each site we will aim to collect between 200-250 scars as this number of scars was found to adequately represent the age structure of scars for a sampling location (Morneau & Payette, 1998).

<u>Two potential sampling approaches:</u>

1. **Covariate = Caribou trail age**

Caribou trails will be categorized by caribou trail age, age will be determined based on the level of vegetation re-growth on the trails. This will be determined by percent cover. Consideration will be taken to account for different vegetation re-growth rates at lower elevation or wetter sites.

<u>Trail age classes:</u>

Recent/new = <25% veg cover

Medium = Between 25-50% veg cover

Old = >50% veg cover

At each sampling site, one trail from each age class will be identified and presence absence data and trampling scars will be collected.

2. **Covariate = Caribou trail ecosite**

The benefit of sampling based on ecosite type is that it allows us to target areas where there is more likely to be older shrubs growing. Shrubs growing in areas where they have greater access to water are more likely to be older and therefore provide a longer record (S. Payette, personal communication, March 2020). This method would be more difficult to orchestrate since using the caribou trails as transects would not work as well when sampling at edges.

<u>Ecosite types:</u>

- Snow patch edge
- Lake/river edge
- Flat open
- Slope

4.1.1.2 Dendrochronological trampling scar methods

Dendrochronological methods have long been used to recreated historical environmental conditions. Measurements of ring-width and dates of tree scars can produce a broad variety of information such as years since past fires (González, 2005), frequency of debris flows (Owczarek, 2010), changes in climatic conditions (Ma et al., 2016), and ungulate browsing histories (Peterson, 1994; Vila et al., 2004). A method developed by Morneau and Payette (1998) demonstrates the use of trampling scars left by caribou hooves to reconstruct historical caribou population trends. This method uses the number of caribou trampling scars occurring per year as an indicator of the intensity of caribou activity on the landscape (Morneau & Payette, 1998). Trampling scars are collected from caribou trails and can be dated based on the number of growth rings since the scarring event (Kaennel & Schweingruber, 1995; Morneau & Payette, 1998). This method has been successfully applied to caribou herds in Quebec-Labrador (Morneau & Payette, 2000) and in the Northwest Territories (Zalatan et al., 2006).

Collected trampling scars will be brought to the Trant Ecological Legacy lab at the University of Waterloo to be processed. Scars will be thin sectioned using a microtome, stained, and placed on a microscope slide. For every scar slide made, an associated cross-sectional shrub slide will be made of the unscarred region of the same shrub root or stem. These unscarred cross sections will be used to help date scars with incomplete ring growth. The age of trampling scars will be determined by counting the number of growth rings that have occurred since the scar (count the rings on the woody lobes surrounding the scars). Cross dating techniques will be applied to make sure that scar aging is done accurately (Filion et al., 1986). The dendrochronological methods used in previous caribou trampling scar studies will be used for reference (Morneau & Payette, 2000; Morneau & Payette, 1998; Zalatan et al., 2006)

4.1.1.3 Expected data

<u>Count data</u>

- Number of scars occurring over time.
    - Response variable (Y) = number of scars
    - Explanatory variable (X) = Years (~1980-2020)

<u>Presence-absence data</u>

- Number of shrub roots and stems crossing the trail with and without trampling scars.
    - Binary (0 = absent and 1 = present)

4.1.1.4 Generalized Additive Models

I will apply Generalized Additive Models (GAMs) to my trampling scar data to assess historical Torngat Mountains Caribou population trends. The application of GAMs will allow me to see the 'peaks' and the 'valleys' in the data and therefore make it possible to infer when TMC population sizes were at their highest and lowest. The GAM function is similar to the Generalized Linear Model (GLM) function of $Y = \alpha + \beta x + \varepsilon$, where Y is the response variable (# of scars), X is the explanatory variable (year of scar), α is the Y-intercept, β is the slope of the regression line, and ε is the associated error (Zuur et al., 2009; Hastie & Tibshirani, 1990). The difference between a GLM and a GAM function is that in the GAM function the βx component becomes f(x) so $Y = \alpha + f(x) + \varepsilon$. Where the βx component describes the slope of a straight line, the f(x) component acts as a smoothing curve which smooths the regression to capture directional changes in the data points (Zuur et al., 2009; Hastie & Tibshirani, 1990). A GAM model will be able to capture the full range of my count data better than a GLM and can be modified to account for assumptions that are not met.

4.1.1.5 Traditional Ecological Knowledge (TEK) component

The objective of my research is to integrate ecological methods with Traditional Ecological Knowledge to obtain a wholistic understanding of caribou populations trends over time. TEK is to be collected using a semi-structure interview approach with questions that tie caribou population sizes to stories, measurable points in time, and hunting technologies used. The interview questions will draw on techniques used in a study conducted by Eckert et al. (2018) which used Indigenous Knowledge to extend historical baselines for yellow rockfish.

<u>Some sample questions are:</u>

Q. Since you have been hunting Torngat Mountains Caribou, are there any hunting trips that stand out to you? When did this trip occur? What made it especially memorable? (Prompts: saw/harvested especially high or low numbers of Caribou? Difficult weather conditions?)

Q. Do you remember years/periods of high harvest? What hunting techniques/tools were you using?

Q. Have you heard about periods of feast or famine from older generations? Do you have a general sense of when these times were?

Comparison of Habitat Selection by the Torngat Mountains Caribou and the George River Caribou During Periods of Range Overlap

Introduction. Caribou (*Rangifer tarandus*) populations are in decline across Canada, making this charismatic species a major conservation concern. Caribou are a vital cultural, nutritional, and economic species for the Inuit of Northern Labrador and Quebec as well as the Crees of Eeyou Istchee, the Naskapi Nation of Kawawachikamach, and the Innu Nation (Snook et al., 2020; Ungava Peninsula Caribou Aboriginal Round Table, 2017). Inuit have long been aware that the sedentary Torngat Mountains Caribou (TMC) population is distinct from the migratory George River Caribou (GRC) herd (Wilson et al., 2014), but this distinction was only formally recognized by the federal government in 2011 (COSEWIC, 2011). The TMC's recent designation, along with the remoteness of their range has resulted in the TMC being under-represented in research with limited long-term population data available.

An additional challenge for acquiring data on the TMC is that there were significant portions of the TMC range that overlapped with the GRC range (Bélanger et al., 2019; Couturier et al., 2015). Range overlap was greatest during the 1990's when GRC population sizes peaked, this overlap occurred primarily during the summer and fall months (Couturier et al., 2017). Since the 1990's the George River herd experienced a population decline of over 99% with the population dropping from nearly 800 000 individuals in 1993 (Couturier et al., 1996) to 5 500 individuals in 2018 (Government of Newfoundland and Labrador, 2018). This massive population decline has resulted in a contraction of the GRC range and subsequently the area of overlap with the TMC range (Bergerud et al., 2008). Competition between the two herds for habitat and/or resources may have played a role on resource selection by caribou. There is however limited knowledge about how these two herds interacted during periods of range overlap.

Previous studies have used satellite collar data to assess resource selection for the TMC (Bélanger et al., 2019) and habitat use for the GRC (Schmelzer & Otto, 2003). However, to date no studies have used satellite collar data to compare resource use of individuals from both herds in regions of overlap. Greater knowledge surrounding the habitat use of these two herds during overlap will provide insight into the degree of contact between the herds. It will also help us to understand how significant of a role the GRC range expansion played on the TMC.

Research Questions. To better understand the level of interaction between the TMC and the GRC during periods of overlap I will ask the following questions: 1) To what extent have the TMC and GRC experienced range and habitat overlap? 2) During periods of range overlap, did individuals from the TMC and GRC use the same habitat?

Required data. To answer these questions, I will require satellite data for the TMC and the GRC. The data I am requesting access to collar data from all individuals belonging to the TMC, as well as satellite collar data from all GRC individuals that have spent time in the historical TMC range outlined in Bélanger et al. (2019) or within 100km of their range. For these individuals I will require year-round satellite locations. I will also need to know what type of collar was used to track each caribou. The years of interest for this study are 1988-2017. I will require data outside of the years where there is overlapping collar data for both herds since the collared overlap range alone will not provide enough data points for my analysis. Therefore, I will need extend my study to look at all individuals who have spent time in the known overlap range rather than just the collared overlap range.

Table 13. Pre-existing collar data for caribou in Torngat Mountains National Park.

Data Type	Number Collared	Source
TMC satellite collar data 1997-1999 and 2011-2017	86 Caribou	Government of Newfoundland and Labrador and Government of Quebec
GRC satellite collar data 1988-2017	1651 Caribou	Government of Newfoundland and Labrador and Government of Quebec
TMC satellite collar data 1988-1997	6 Caribou - females only	Government of Newfoundland and Labrador and Government of Quebec Schaefer and Luttich, 1998

Methods. To better understand how individuals from the TMC and the GRC overlapped spatially, we need to assess how they used their habitats during periods of overlap. The most common method for identifying habitat selection patterns from satellite collaring data is the resource selection function (RSF) (Manly et al., 2002; Northrup et al., 2013). Typically, RSFs are applied with a used versus available framework in which environmental covariates in locations used by the animal are compared to environmental covariates at random locations deemed to be available (Manly et al., 2002; Northrup et al., 2013). From these data, the relative probability of use by caribou can be modeled for each environmental covariate (Manly et al., 2002). RSFs have been applied to determine the effects of human disturbance and habitat loss on migratory caribou in Quebec and Labrador (Plante et al., 2018), and have also been used to assess wolf and caribou spatial overlap in Banff and Jasper National Parks (Whittington et al., 2011).

We will use collar data from Torngat Mountains caribou and from George River caribou to conduct a Resource Selection Function for each herd. The environmental covariates that we plan to include are land cover class, eco zone, elevation, aspect, slope, and distance to water. Map layers for these environmental variables have been collected from the North American Land Change Monitoring System (NALCMS), the Canadian Governments open data source, Parks Canada, or have been modeled using ArcGIS. The data will be fit to several models using R version 4.0.2 to determine which model best explains the data (R Core Team 2020). A generalized linear mixed model with a binomial distribution was the model chosen to estimate RSFs in a previous TMC habitat selection study (Bélanger et al., 2019). Once an RSF has been applied to each caribou herd for the given period, we will compare which environmental covariates were selected by each herd to determine if habitat preferences align. Additionally, we intend to use the GRC collar data to estimate the total number of GRC individuals moving into the TMC range each year from 1988- 2017. This estimate, along with habitat preferences for both herds will give us a better idea of how likely or how often interactions between individuals from the two herds occurred.

Outcomes and Deliverables. Our research will provide valuable insight into interactions between the TMC and the GRC during periods of range overlap. A greater understanding of how these two herds used resources in the overlap zone will indicate how much contact they may have had. This information is useful for management purposes as it provides managers with an idea of how habitat selection by the TMC has been influenced by range overlap with the GRC herd. The results of this study will also provide insight into what potential impacts the loss of overlap may have and allow for targeted sampling during future TMC studies. With more informed management, the TMC can continue to persist and contribute to the social-ecological resilience of northern communities