2022

The Decline of Lake Superior's Woodland Caribou: A Historical GIS Analysis

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THE DECLINE OF LAKE SUPERIOR’S WOODLAND CARIBOU:

A HISTORICAL GIS ANALYSIS

By

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A THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In Environmental and Energy Policy

MICHIGAN TECHNOLOGICAL UNIVERSITY

2022

This thesis has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Environmental and Energy Policy.

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Acknowledgements

Thank you to my advisor Dr. Nancy Langston for believing in and supporting me throughout my thesis process. I would also like to thank Dr. Casey Huckins and Dr. Valoree Gagnon for their time and support throughout the writing process. Thank you to Brian McLaren, Gordon Eason, Arthur Rodgers, Mac Squires, Allen Bisset, and Chief Duncan Michano for taking the time to speak with me on caribou recovery in the Lake Superior region. Thank you to the Great Lakes Research Center's Geospatial Research Facility's Daniel Lizzadro-McPherson and Bob Cowling for their planning and technical assistance throughout the HGIS analysis. Thank you to all of my graduate student colleagues; without their friendship and support, I would not be where I today. Finally, thank you to my friends and family in Houghton and at home for believing in me and continuing to emotionally support me throughout my graduate career. National Science Foundation grant #1902012 (PI Dr. Nancy Langston and Co-PI Dr. Casey Huckins) funded this research.

Acknowledgment of Land and Life

This research study is set in the *Ojibwe Gichigami* ("Ojibwa's Great Sea", Lake Superior). Included are areas that are now in present-day Michigan, Minnesota, Wisconsin, and Ontario. We recognize that this bioregion is the ancestral, traditional, and contemporary lands and waters of many Indigenous nations including the Anishinaabeg (Ojibwe) peoples. Some of these groups include the *Nezaadiikaang* (Lac des Mille Lacs), *Animkii Wajiw* (Fort Williams), *Opwaaganasiniing* (Red Rock Indian Band), *Kiashke Zaaging Anishinaabek/ Gayaashki-Zaagiing Anishinaabeg* (Gull Bay), *Namegosi-zaaga'igan* (Namaygoosisagagun), Whitesand, *Bingwi Neyaashi* (Bingwi Neyaashi Anishinaabek), *Biinjitiwabik Zaaging Anishnaabek*, *Pawgwasheeng/ Baagwaashiing* (Pays Plat), *Animbiigoo Zaagi'igan* (Lake Nipigon Ojibway), *Nishnawbe Aski/ Matawa* (Aroland), Long Lake #58, *Ginogaming, Biigtigong Nishnaabeg* (Ojibways of the Pic River), *Netmizaaggamig Nishnaabeg/ Netamising Zagigun* (Pic Mobert), *Michipigodong/ Mishibikwadinaang* (Michipicoten), Chapleau Ojibwe, *Wapiscogamy* (Brunswick House), *Gitigan-Ziibi* (Garden River), *Obaajiwan* (Batchewana), *Baawiting Anishinaabeg* (Sault Ste. Marie), *Gnoozhekaaning* (Bay Mills), *Gakiiwe-wenaning* (Keweenaw Bay), *Gete-gitigaaniwininiwag* (Lac Vieux Desert), *Waaswaaganing* (Lac du Flambeau), *Mashkiiziibii* (Bad River), *Miskwaabiikaang* (Red Cliff), *Nagaajiwanaang* (Fond du Lac), and *Gichi-onigamiing* (Grand Portage). These Indigenous peoples were and are the region's original caretakers and knowledge holders. We recognize their generations of contributions to the stewardship and governance of the world's largest freshwater ecosystem. Additionally, we take the time to acknowledge all our more-than-human kin that make their homes in this region and have done so since time immemorial.

The acknowledgment statement is a dynamic, living text that is to be embodied; therefore, this version of our statement is subject to change based upon new experiences, new awarenesses, and new conversations with Indigenous knowledge keepers and others. Ultimately our goal is to honor the land and the people who have been its stewards since time immemorial and continue to do so in the present. We recognize the imperfection of our thinking and writing and the standpoint and positions that we embody when doing so. The positions presented in our writing are our own understanding of this wicked problem and do not represent the official positions of any specific group or individuals from the groups mentioned above.

Abstract

Lake Superior's woodland caribou have been declining since the early 1800s. This thesis asks: why? We hypothesize that as settlers expanded into the region, industrial development in woodland caribou habitat reduced woodland caribou persistence. Using an Historical Geospatial Information System (HGIS) analysis, we find that historical mining and railroad infrastructure are associated with woodland caribou extirpation, while wetlands and protected areas are associated with caribou persistence. We also conducted a stakeholder synthesis of the region to help understand diverse perspectives within and between advocacy coalitions that take different positions on the most effective caribou restoration policies. Beliefs on recovery options vary broadly. However, there are overlaps among individual beliefs that can lead to compromises on recovery policy. Policymakers should take away that while there may appear to be no easy solution to this wicked problem, there do appear to be areas of common ground on woodland caribou recovery can be found. Listening to and including diverse stakeholders is key to future recovery efforts.

1 LAKE SUPERIOR WOODLAND CARIBOU

1.1 POSITIONALITY STATEMENT AND CONTRIBUTION TO THE RESEARCH PROJECT

I am Jordan Kelley, an early career wildlife ecologist and master's student in Environment and Energy Policy at Michigan Technological University. I am a U.S. citizen who grew up in central Maine, the place I call home. I am a descendent of European settlers who lives and works within the ancestral, traditional, and contemporary lands and waters of the Ojibwe people. My knowledge is informed by the human and more-than-human beings who have called this land home since time immemorial. It is also informed by my research into environmental history and the use of spatial mapping as a tool to better understand the past. I am passionate about the recovery of woodland caribou and would love for my work to make a difference in the future of the Lake Superior discontinuous population. I believe that caribou are our kin and urge that others consider them in the same way. My goal as a continual learner and scholar is to better understand socio-ecological aspects of conservation problems to promote listening and inclusion of stakeholders to increase the potential for success in future recovery efforts.

This research is part of a larger NSF-funded project on the historical ecology of migratory species in the Lake Superior basin. The thesis uses the pronoun "we" to describe research that was supervised by Dr. Langston and Dr. Huckins, with data gathering assisted by a variety of participants on the project. Data on caribou were collected by Jordan Kelley. HGIS layers were gathered by Austin Johnson, Madeline Webb, Zachary Hough-Solomon, and Robert Cowling. Daniel Lizzadro-McPherson served as consultant for the HGIS structure and data queries. Analyses and writing were conducted by Jordan Kelley.

1.2 INTRODUCTION

Rangifer tarandus caribou (woodland caribou) are a threatened sub-species of migratory caribou that are now mostly found in the boreal forests of northern Canada. Once the most widely distributed of all North American deer species, in the north woods they ranged from Maine south to Massachusetts and west to Minnesota. They are now entirely extirpated from the United States (Environment and Climate Change Canada, 2019; Langston, 2021). In Canada, more than 70% of subpopulations are declining and no longer self-sustaining without human intervention (Environment and Climate Change Canada, 2018).

Across the upper Great Lakes region, woodland caribou have been lost from Michigan, Minnesota, and Wisconsin, except for a small remnant population of Lake Superior caribou that remains on two islands in Lake Superior and potentially some individual stragglers Ontario along Lake Superior's north shore (Figure 1 and 8). After woodland caribou in the upper Great Lakes faced near-extinction in 2018, a series of translocation efforts to wolf-free islands in Lake Superior gave this small population the possibility of survival, but the policy options for restoration remain controversial.

The decline of Lake Superior's woodland caribou was first noted in the early to mid-1800s, before modern biological surveys were in use (Herman, 2002; Allison, 2003). While abundant research now documents stressors such as predation, human infrastructure development, and habitat loss for modern populations, these current stressors do not necessarily explain the reasons for initial population decline.

The three chapters of this thesis explore possible reasons for historical declines of woodland caribou in the Lake Superior region and examine stakeholder positions on possible recovery options. Chapter 1 describes woodland caribou ecology and explores Indigenous peoples and caribou relationships. The chapter then examines reasons for woodland caribou declines, with a focus on the Lake Superior region. The chapter concludes with an argument that the loss of Indigenous lands and growth of the European settler population in the region were both important in woodland caribou decline.

Figure 1. Lake Superior discontinuous population of woodland caribou in Ontario, Canada as of March 2018 (Ontario Ministry of Natural Resources and Forestry, 2018).

Chapter 2 discusses creation of an Historical Geographic Information System (HGIS) that allows us to test alternate hypotheses about the reasons for historic woodland caribou decline in the Lake Superior region. In the HGIS, we overlay early observations of changes in woodland caribou locations with HGIS data layers documenting changes in historic human infrastructure development. We use this HGIS to test hypotheses about ecological refugia and infrastructure development factors associated with historic woodland caribou population decline. Understanding the history of decline of woodland caribou in the Lake Superior region is essential for understanding the potential implications of future management policies and development in caribou habitat.

Chapter 3 describes the history of the translocation and recovery efforts that have taken place to protect this isolated population since the 1980s, and then analyzes the policy options for sustaining them into the near future. These individuals now make up the southern extent of woodland caribou range in the upper Great Lakes region. They have particular importance because recent research shows that they may be genetically distinct from more northern populations (McWhirter, 2022).

1.3 ECOLOGY OF WOODLAND CARIBOU

In the Lake Superior basin, as well as across North America, Euro-American invasions, settler population growth, and displacement of Indigenous nations from their ancestral lands were associated with the decline in woodland caribou. The caribou researcher Thomas Bergerud documented woodland caribou ranges shifting northward in the late 19th and 20th centuries, as settler infrastructure development fragmented the southern portions of their habitat (Bergerud, 1974) (Figure 5).This helped esperate the contiguous populations of woodland caribou in northern Ontario from the Lake Superior population, creating a discontinuous zone where no breeding populations persist between the northern populations and the isolated Lake Superior population. Woodland caribou from the Lake Superior discontinuous population currently have a fragmented distribution (Figures 1 and 7). Woodland caribou still range in northern Ontario from Lake Nipigon north, while an estimated 50-60 caribou persist on rocky islands in the north of Lake Superior and along small portions of the lake’s northern coastline (Fletcher, 2022).

Woodland caribou are a subspecies of caribou, *Rangifer tarandus caribou*. Caribou are members of the Cervidae (deer) family, which also includes deer (*Odocoileus virginianus*), moose (*Alces alces*), and elk (*Cervus canadensis*) in North America (Burt, 1972). The name “caribou” is of Algonquian origin and means a ‘pawer’ or ‘scratcher’ describing a common winter practice of using its hooves to dig in the ground for food (Upham 1920, Fashingbauer 1965). There are seven subspecies of caribou: barren ground caribou (*Rangifer tarandus groenlandicus*), Grant’s caribou (*Rangifer tarandus granti*), Peary caribou (*Rangifer tarandus pearyi*), reindeer (*Rangifer tarandus tarandus*), Svalbard reindeer (*Rangifer tarandus platyrhynchos*), and forest reindeer (*Rangifer tarandus fennicus*) (Boyce, n.d). Eurasian reindeer are different subspecies of caribou than are found in North America but are still members of the same species (Riis, 1938).

Caribou have short, thick legs with heavy wide set muzzles. Their legs are longer in proportion to their body size than those of moose allowing for travel through deep snow. They typically weigh from 110 to 220 kg (Nature Canada, 2018), making them larger than white-tailed deer but smaller than both elk and moose. Their hooves are quite large for their body mass (ten centimeters wide by 18 centimeters long) with deep clefts. They average six and a half square centimeters of foot support for every kilogram of body weight, a ratio four times greater than that of the moose (Riis, 1938). Their antlers are large and branch uniquely “by having frontally emphasized, flat-beamed antlers,” (Geist, 2007) which is different from antlers of other Cervidae. Both males and females grow antlers, which is also unique for the deer family, although females have slightly smaller and narrower sets of antlers (Riis, 1938) (Figure 2).

Their hoof size and shape allow them to move through deep snow, bogs, wetlands, over rocky coastlines, and swim. These traits help to reduce the risk of predation. In winter, woodland caribou use their hooves as snowshoes, allowing them to run vast distances in deep snow (Langston, 2021). Caribou can also traverse rocky coastlines and islands in Lake Superior. Thomas Bergerud (1984) found that woodland caribou would swim to and from small offshore islands to escape nearby wolf predation.

Caribou can store heat and chemical energy in the form of a broad band of marrow-like fat that lies across their backs and rears that aids in protection against the cold (Paul Riis, 1938). These traits allow for the caribou to be mobile even in severe winters, enabling them to follow food throughout the year.

The digestive systems of woodland caribou facilitate a switch from nutrient-rich grasses during the summer to winter use of mosses and lichens from the ground and trees. Mosses and lichens make up smaller portions of other ungulates diets (Riis, 1938; Schmidt-Nielson, 1975; Cumming, 1992). Cervids use microbial fermentation inside of their rumen to break down cellulose and synthesize proteins from lower-quality foods (Schmidt-Nielson 1975, Cumming, 1992). The diets of woodland caribou populations vary depending on the local species composition of vegetation. Woodland caribou in Newfoundland forage on ericaceous shrubs throughout the year, which consist of ¼ of their winter diets. During the spring, broad-leaved evergreen and deciduous shrubs and sedges are important forage items. Deciduous shrubs, reindeer lichens (*Cladonia spp.*), and fungi make up the majority of their diets. Reindeer lichens continue to be the most important food source in Autumn for these populations. In winter arboreal lichens and evergreen shrubs make up the majority of their diets (Bergerud, 1972). Newfoundland caribou populations use sedges, fungi, deciduous shrub leaves, and aquatic macrophytes at higher rates than populations do in Ontario (Bergerud, 1972; Thompson et al., 2013).

In Ontario, woodland caribou populations rarely forage on ericaceous shrubs. Reindeer lichens are common forage during all seasons, making up almost 50% of their diets in summer and around 70% in winter. Graminoids are consumed in all seasons but provide an important food source during the spring. Shrubs tended to be consumed mostly in the spring. In summer, caribou forage on more forbs than in other seasons. Threeleaf false lily of the valley (*Maianthemum trifolium*) was the most common forb consumed (Thompson et al., 2013). By specializing in lichens as major foods, caribou have overlapping ecological niches with only a few other animals, such as red-backed voles (*Clethrionomys gappen*) (Martell, 1981; Cumming, 1992).

Woodland caribou make use of large ranges of habitat throughout the year. Cumming and Beange (1987) found that winter ranges of herds in Ontario averaged around 390 km^2. Seasonal ranges between woodland caribou herds vary. In Manitoba, woodland caribou had ranges of around 250 km2 in winter, 100 km2 in spring, 13 km in summer, and 70 km2 in fall (Shoesmith and Storey, 1977; Cumming, 1992). A mountain dwelling herd in Alberta annually used a range of 400-800 km2 (Edmonds, 1988; Cumming, 1992).

Caribou undertake the longest migrations of any land mammal on earth, with barren ground caribou migrating from 3 kilometers up to 40 kilometers per day and up to 5000 kilometers each year (Thompson, 1978; Fancy et al., 1989; Ferguson and Elkie, 2003). Woodland caribou migrate as well, but their seasonal migrations are generally shorter but vary in length. Some populations in Ontario have been observed migrating 80 kilometers. However, these observations were after human infrastructure and development began to cut off migration routes (Langston, 2021). Some populations have significant daily movements, up to 11 kilometers each day (Harrington & Veitch, 1991; Bergman et al., 2000; Ferguson and Elkie, 2004). These migrations can be up to 80 km between summer and winter ranges (Moison, 1956; Edwards and Ritcey, 1959; Cumming and Beange, 1987), although some populations of woodland caribou remain in relatively the same area year-round (Darby and Pruitt, 1984; Cumming and Beange 1987; Cumming 1992).

The major phases of annual migrations take the animals from spring/summer calving grounds to fall rutting locations, and then to wintering areas. In September and October, rutting typically begins, leading to the fall calving season (Cumming, 1992). As snowfall begins accumulating, woodland caribou begin a more direct migration back to their high-fidelity wintering areas (Edmonds, 1988; Ferguson and Elkie, 2004). Caribou movement from wintering areas to summer calving grounds begins in April as the snow starts tomelt. Woodland caribou do most of their migratory movement during the night. Then in the winter, they seek the shelter of woodlands for shelter against the snow and wind. Woodland caribou in Labrador have been observed cycling through former feeding grounds every third or fourth year while visiting more distant feeding grounds in the years between (Hind, 1863). In winter, caribou move in small groups of about 20 or fewer individuals in woodlands, but in summer it has been suggested that they aggregate into larger groups to overwhelm predators with greater numbers, leaving potential predators with an overwhelming amount of prey options (Bergerud, 1971; Parker, 1972; Cumming, 1975; Cumming, 1992).

To survive the harsh weather that comes with winters in the northern boreal forests of Canada, woodland caribou select special wintering areas. The habitat type of these areas differ widely across the continent, however. In Ontario, caribou prefer to winter in stands of open jack pine (*Pinus banksiana*) and well-spaced black spruce (*Picea mariana*) stands, which are also often associated with wetlands. Caribou in Ontario tend to return to the same wintering areas with high fidelity year after year (Cumming and Beange, 1987). They select locations for abundant food options and predator avoidance (Cumming, 1992). Caribou move using frozen lakes and wetlands where snow is less deep to conserve energy (Stardom, 1975). To search for food in the winter, woodland caribou search for twigs, tree lichens, and ground lichens by digging through snow up to one meter deep (Vandal and Barrette, 1985; Edmonds and Bloomfield, 1985). The

Algonquin name “caribou” meaning a ‘pawer’ or ‘scratcher’ refers to this winter-feeding behavior (Upham, 1920; Fashingbauer ,1965). Caribou may dig up to 800 food craters per 0.4 ha, because they will eat nearly 5 kg of lichens and twigs each day during the winter (Bergerud, 1976; Holleman et al., 1979).

Climate change poses threats to woodland caribou. In Ontario, summer temperatures are expected to increase by 4-5℃ over the next 100 years. Forest fires are expected to increase over this period and decrease the total remaining amount of old-growth forests available for woodland caribou habitat (Racey, 2005). This change in forest composition may lead to an increased risk of disease and predation. White-tailed deer and moose may find more favorable conditions, leading to northward shifts overlapping caribou habitat (Barber et al., 2018). As winter rain becomes more common, ice can form over ground lichens, blocking caribou access to lichens and leading to increased winter starvation.

Figure 2. *Rangifer tarandus caribou* (woodland caribou) Photo by: USFW Pacific Region

1.4 INDIGENOUS PEOPLES AND CARIBOU

Before European colonists came to the region, Indigenous peoples were caretakers of the land and the caribou. Indigenous peoples came into the Lake Superior region following caribou populations that expanded north after the last ice age (Langston, 2021). Both the Anishinaabe and the Northern Lake Superior Meti were here before the time of European settlement. Bones have been found at ancient Indigenous settlements in southeastern Michigan that are 11,000 years old (Langston, 2021). Hunting structures have been discovered under Lake Huron dating back almost 10,000 years where ancient caribou would migrate across a land bridge (O'Shea et al., 2014). Reliance on woodland caribou for survival throughout this long history has intricately woven Indigenous cultures with caribou populations.

Woodland caribou play essential roles in their forested ecosystems in the cultural practices of Indigenous communities throughout the boreal region. As the Wildlife Conservation Society states (n.d.), "Caribou are an important resource for Indigenous peoples, a prey species for carnivores and omnivores, such as bears and wolves, and a critical source of nutrients for the soil in areas where they forage in large numbers.". Indigenous peoples have relied on many resources from woodland caribou. According to historical documentation, Indigenous peoples depended on caribou for "providing sweet dried meat for winter and tasty marrow to spread on bannock, like butter or jam. They had also yielded hide for tents, moccasins, gloves, and leggings, babiche for lacing snowshoes, and antlers for tools such as ice chisels" (Cox, 2018). In most areas, they were abundant enough that Indigenous families could go out for the day and count on finding a caribou for food somewhere along the way. In events of starvation, Anishinaabeg elders would call on the caribou spirits to save their community from hunger and even track game in their sleep (Langston, 2021).

Indigenous peoples formed kinships with woodland caribou over thousands of years since the retreat of the glaciers. However, kinships do not form by chance. They are an entirely human construct referring to relationships between beings. "Kinning revolves around an ethical question: how to rightly relate? (Van Horn et al. [Ch. 1], 2021)" The Anishinaabe viewed deer, moose, and caribou as gentle beings. The Ojibwe Clan System recognized the strengths and responsibilities of clans using animal totems. The hoof clan were known for caring for the community by providing housing and recreation. They were often poets and pacifists in these communities. The Adik (caribou) totem is common among the Ojibwa and Oji-Cree north of Lake Superior. "A prominent family from this totem from the Grand Portage area relocated to La Pointe and produced the chiefs Mamongazeda and Waubojeeg. Later members of this branch became leaders at Sault Ste. Marie" (Benton-Banai, 2015).

Anishinaabeg culture is respectful towards the land and more-than-human-beings around them because they know that they rely on the health of world around them to survive themselves. The term *edbesendowin* translates to humility. The Anishinaabe use e*dbesendowin* to remind themselves that humans are not more important than any other being and to not put themselves above other beings to keep the world balanced (Van Horn et al. [Ch. 14], 2021). This way of thinking is termed reciprocity. Reciprocity involves viewing more-than-human-beings as having intrinsic value, rather than just instrumental value to their survival as a community. It also involves the concept of responsibility to maintain balance in the world around them, so that the same will be available for future generations (Kari-OCA 2, 2012; Whyte et al., 2016) The Indigenous peoples of this region have applied these ways of thinking to their relationships with woodland caribou since time immemorial.

Indigenous peoples were the sole human inhabitants of this land until early European settlers began settling in the region. Between 1836 and 1854 Anishinaabe communities throughout present-day Michigan, Wisconsin, and Minnesota were pressured to cede much of the territory that they had historically inhabited (Figure 3 and 4). Indigenous communities on the north shore of Lake Superior (present-day Ontario, Canada) ceded lands in 1850 as part of the Robinson Superior Treaty. Through these treaties, Indigenous groups maintained the ability to hunt, fish and gather on their ancestral territories. They also maintained reservations for their communities to live on and annuity payments to the Indigenous groups (Stone, 2014). Indigenous land loss and European settler colonialism both coincided with initial woodland caribou decline, suggesting that they may have influenced woodland caribou populations.

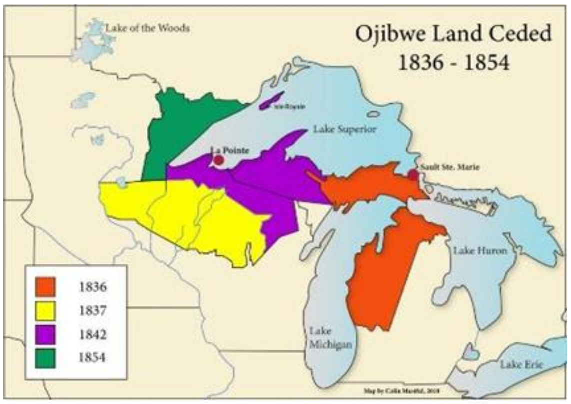

Figure 3. Ceded lands of the Anishinaabeg colorized according to the applicable treaty. Map created by Colin Mustful (Mustful, 2020).

Figure 4. Area on the north shore of Lake Superior included in the Robinson- Superior Treaty (RSMIN, 2016).

1.5 DISCUSSION OF BROAD REASONS FOR DECLINES

A variety of factors have contributed to the decline of woodland caribou in the upper Great Lakes. Settler colonialism in particular brought ecological changes to woodland caribou habitat. Current research shows that industrial development associated with mineral extraction, timber production, transportation networks, hydroelectric development can stress caribou populations by fragmenting habitat and altering migration routes (Bergerud, 1974; James and Staurt-Smith, 2000; Nellmann et al., 2001; Dyer et al. 2002; Mahoney and Schaefer, 2002; Weir et al., 2007; Boan et al., 2011; Herrmann et al., 2014; Cox, 2018). In the past, infrastructure development may affected caribou populations through community compositional change, increased predation, and increased risk of disease.

One of the earliest sources of decline for these animals was overhunting from the time of early settlers through the early 20th century. Like many other game species of this time, woodland caribou were over-hunted by the influx of European immigrants into their range (Bergerud, 1974). Initially, there were few regulations limiting hunting, either for domestic use or for commercial use (Bergerud, 1974). As recreational hunters began thinning out woodland caribou populations, European settlers noticed wildlife declines and placed protections on woodland caribou (Langston, 2021). However, these laws targeted Indigenous communities, in part because many settlers resented that Indigenous communities had retained hunting rights in their treaties (Langston, 2021). Early conservation laws had little effect as woodland caribou continued their decline (Langston, 2021).

As settlers moved into the caribou's habitat range, they also brought with them more industrial development, extractive industries, and landscape alteration. This meant more roads, bigger buildings, and powerlines which all fragmented caribou habitat. Continuing habitat fragmentation decreased the size of available caribou habitat and increased the area of developed land between fragments (Hansen, 2001) Development also disrupted historical migration paths of the caribou.

One form of infrastructure development that may have been a significant factor in caribou decline is the development of railroad systems. Railroads began traversing Ontario around the turn of the 20th century and effectively separated the continuous population in northern Ontario from the discontinuous population along Lake Superior. In Ontario, observations of woodland caribou began declining between the north shore of Lake Superior and the north shore of Lake Nipigon after the construction of the National Transcontinental Railway between 1908 and 1912 (deVos and Peterson, 1951). Linear disturbances such as railroads, roads, power transmission corridors, and seismic lines fragment woodland caribou habitat and allow easier predator access into their habitat (James and Staurt-Smith, 2000). Gray wolves actively use railroads and other linear disturbances during predation. Railroad lines are often hundreds of kilometers long and are fairly flat, unobstructed passageways. Using such linear disturbances allows wolves to efficiently traverse rough terrain, wetlands, and deep snow, where woodland caribou had found refugia from predation (Latham et al., 2011). Researchers have shown that caribou avoid these linear disturbances in places where predators are actively using them (James and Staurt-Smith, 2000; Dyer et al., 2002; Williamson-Ehlers, 2012).

Another form of human infrastructure that negatively impacts woodland caribou are hydroelectric dams and the infrastructure built to accommodate them. Woodland caribou typically avoid large areas around hydroelectric infrastructure construction sites in the short term. Caribou avoid these sites long-term at closer distances than during construction (Mahoney and Schaefer, 2002). Additionally, linear disturbances like power transmission corridors are associated with hydropower development, potentially compounding the effects of the dam infrastructure (Scurrah and Schindler, 2010). Hydropower development is reducing woodland caribou range, disrupting migration timing, and reducing population density around areas of development.

A third example of human infrastructure is mining and the infrastructure required to transport products and workers. Mining affected a larger area than just the mine footprint itself. Transportation corridors must be constructed to accommodate human infrastructure development, and these create physical barriers to migration. The increased presence of humans in woodland caribou habitat reduces the use of nearby high-quality forage (Herrmann et al., 2014). Mines are associated with caribou avoidance of up to 6 km during construction and 4 km during operation. This effect is most noticeable during calving seasons but is present year-round (Weir et al., 2007).

In woodland caribou boreal forest habitat, logging has replaced fire as the main forest disturbance, causing major compositional changes from conifer to hardwood and mixedwood forest stands (Carelton and MacLellan, 1994; Boan et al., 2011). Logging has led to lower dominance of coniferous forests than historically (Whittle et al., 1997; Boan et al., 2011).

Forest compositional changes from undisturbed old-growth coniferous forests to fragmented mixedwood stands negatively impact caribou, but this brings about a cascade of ecological changes that cause caribou decline. These changes often benefit other species because the altered habitat now has become closer to their ideal habitat type. In areas that have been recently logged there are more early successional forest stands with favorable forage for moose and white-tailed deer (Boan et al. 2011). Gray wolves increase population density in areas that have been recently logged. In areas of British Columbia gray wolf populations increased in their study areas as moose populations increased. This caused woodland caribou populations to in turn decline due to increased opportunistic wolf predation in the area (Bergerud and Elliott, 1986; Bergerud, 2018).

Predation is an essential part of food webs in healthy ecosystems. Woodland caribou make up an important food resource for apex predators. Nutrient cycling occurs as caribou consume food sources and leave fecal matter behind for use by decomposers, insects, and small organisms.

The most important proximate source of woodland caribou loss is wolf predation (Bergerud, 2018). However, wolf predation is not the ultimate cause of caribou decline.

As boreal forests were logged in the 1800s, moose and white-tailed deer began to expand their range northward into the southern portions of Ontario. They preferred the composition of freshly logged areas, as mixed hardwood forests were often the first successional stage after logging. Moose and white-tailed deer began expanding into former caribou territory, causing overlap between the populations. Wolves predate on both moose and deer and also expanded their territories north as their primary prey populations increased. As moose, white-tailed deer, gray wolf, and woodland caribou ranges began overlapping, caribou became another easily available food option. Woodland caribou are particularly vulnerable to wolf predation compared to moose and white-tailed deer. Moose have the ability to physically defend themselves from predators, while white-tailed deer can out-reproduce most predation pressures caused by wolves (Langston, 2021). Woodland caribou are not able to physically defend themselves from wolves and they do not reproduce fast enough to negate the effects of predation. Caribou have been shown to disperse deeper into their habitat in the presence of wolves (Bergerud, 1974). Wolves use these linear disturbances and habitat fragments to gain easier access deep into caribou habitat, making predation easier. Caribou are left with more and more fragmented habitat, limiting their possible escape options.

The expansion of moose and deer has also caused diseases like meningeal brain worm (*Paralephostrongylus tenuis*) to become more prevalent in woodland caribou habitat. White-tailed deer rarely die from meningeal brain worm and are common vectors of this parasite. Meningeal brain worm can be passed on to woodland caribou very easily (Anderson, 1972). Meningeal brain worm causes neurological symptoms to woodland caribou once they become infected and is almost always fatal (Anderson and Strelive, 1968; Cumming, 1992).

Pre-1900 time period:

We used three time periods in this analysis that coincided with key infrastructure and ecological changes in the region. Before 1900, European settler immigration into the upper Great Lakes coincided with the decline of woodland caribou and their associated range shifts. Before 1850, there were few European settlements in northern Ontario. Indigenous peoples lived throughout the region, mostly in relatively small groups except near trading posts. By 1851, urban developments were expanding into the southern Ontario and Toronto regions (Figure 5). This was just before European settlers began moving to follow the timber industry and establish agricultural lands farther west. Logging operations began mostly in the northern U.S. forests at this time, bringing workers and infrastructure development in the region.

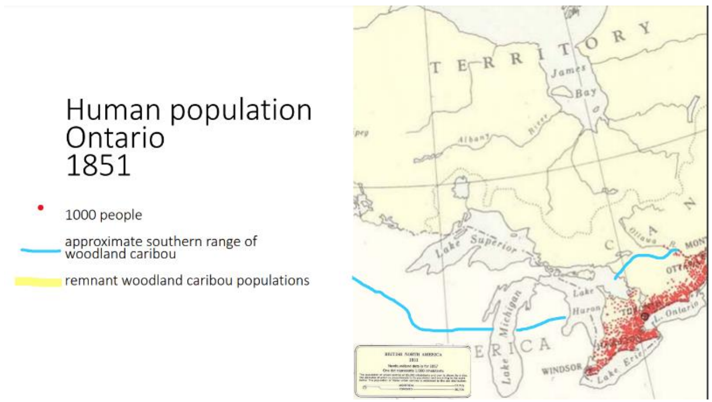

Figure 5. Approximate woodland caribou southern range in the upper Great Lakes region in 1851 and human population centers (Harris and Matthews, 1987; Langston 2021).

1900-1950 Time Period

By the turn of the 20th century in Ontario, woodland caribou populations along the southern extent of their range began becoming extirpated, pushing the southern extent of their range northward. Small populations persisted in northern Minnesota, along the north shore of Lake Superior, and southeast to the Sudbury region of Ontario (Figure 6). Industries like mining and logging for pulp began expanding across the Canadian shore of Lake Superior. In the U.S., mining, logging, and transportation networks continued expanding. Transcontinental railroads were completed at this time, bisecting the north shore of Lake Superior. The European settler population grew significantly to keep up with industrial labor demands. This caused new settlements to develop along the north shore of Lake Superior, near the Lake of the Woods, and around Sault Ste. Marie. During this time, woodland caribou populations became discontinuous from northern ones, with remnant herds in Red Bog, Minnesota, along Canadian shore, and on small offshore islands (Figure 6).

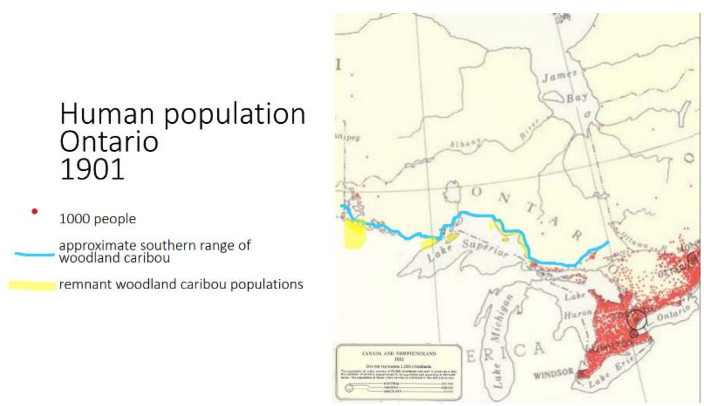

Figure 6. Approximate woodland caribou southern range in the upper Great Lakes region in 1901 and human population centers (Harris and Matthews, 1987; Langston 2021).

Post 1950 Time Period

By 1951 (Figure 7), the southern extent of the continuous northern woodland caribou population extended south from Hudson's Bay to Lake Nipigon. A discontinuous range developed between Lake Nipigon and the north shore of Lake Superior. Caribou were sometimes observed moving through this area but had become increasingly rare. Some survived on the north shore and avoided predation by swimming from the shore to islands offshore. Stable populations were only found on a few small islands after this point. This time period captures the post-World War II industrial boom in the region. Logging for the paper industry intensified across Ontario's southern boreal forests. The Trans-Canada highway was completed across the north shore of Lake Superior, bringing more settlers and tourists into the region. Protected areas such as national and state/provincial parks began to be created to meet the demand for recreation of residents and tourists. Hydroelectrical development began on large scales to meet the power needs of the paper industry and the growing population. The European settler population continued to grow, and towns continued to be created throughout parts of northern Ontario that had traditionally been Indigenous territory, bringing more industrial development to these regions (Figure 7).

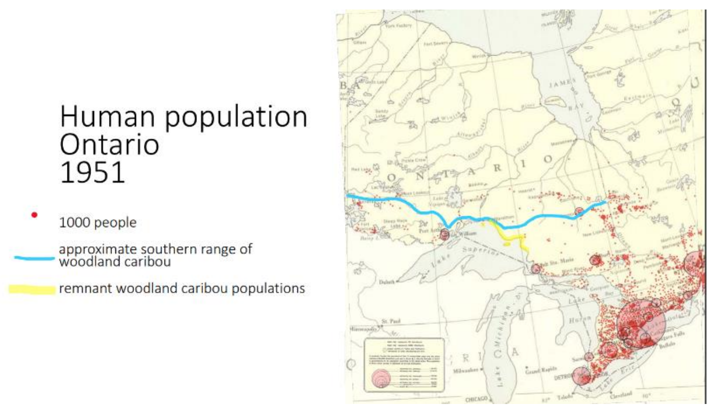

Figure 7. Approximate woodland caribou southern range and human population centers in Ontario, 1951 (Harris and Matthews, 1987; Langston 2021).

By 2022, while woodland caribou had declined across the southern extent of their historic range, a few populations persisted. The Lake Superior discontinuous woodland caribou population has two confirmed woodland caribou herds on islands, in addition to a small mainland population. The first island population is on the Slate Islands archipelago in northern Lake Superior, just off the coast of Terrace Bay, Ontario. The second island population is found on Caribou Island, 64 km from the mainland in Canadian waters (Figure 8).

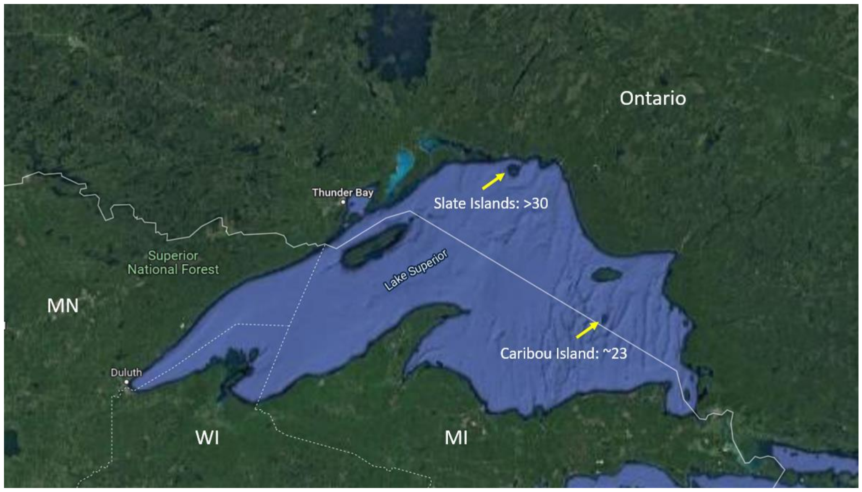

Figure 8. Current locations of Lake Superior woodland caribou populations confirmed as of spring 2022. A small mainland population may also exist.

1.6 CONCLUSION

Woodland caribou have been declining in the great Lake Superior region since the early to mid-1800s. We hypothesize that the loss of Indigenous lands in the region, combined with the growth of the European settler population and associated infrastructure, were important factors in initial woodland caribou decline. As European settlers expanded their settlements and footprint in North America, they brought significant infrastructure and landscape alteration. Mines, hydroelectric dams, logging, and linear disturbances like railroads, roads, power transmission corridors, seismic lines, and oil pipelines all fragmented caribou habitat. Additionally, they led to community compositional changes that have allowed for the northern expansion of moose and white-tailed deer ranges to where they now overlap the southern range of woodland caribou. Gray wolves primarily prey on moose and with-tailed deer bringing opportunistic predation threats to caribou along their southern range. Wolves opportunistically use these linear disturbances to access and prey on woodland caribou where their range overlaps, leading to declines in woodland caribou populations along their southern range boundary. These combined changes have resulted in localized woodland caribou extirpations at the southern portions of their range.

2 HISTORICAL GIS ANALYSIS OF DECLINE

2.1 INTRODUCTION

This chapter describes the creation and analysis of our Historical Geospatial Information System (HGIS). Enhancing current woodland caribou recovery efforts requires a better understanding of the influential factors that led to their historical decline. woodland caribou (*Rangifer tarandus*) began declining in the Lake Superior region during the mid to late 1800s (Bergerud 1974, de Vos and Peterson 1951, see Chapter 1). Due to the early time of initial decline, researchers know little about the initial drivers of decline or the full extent of woodland caribou range pre-decline. Recent research shows that current infrastructure development and landscape alteration fragments woodland caribou habitat and creates linear disturbances that predators use to penetrate more easily into these fragments (James and Stuart-Smith 2000, Newton et al. 2017). But current studies do not necessarily tell us *why* populations declined so rapidly before the 20th century. In this research, we create a Historical Geographic Information System (HGIS) to test hypotheses about infrastructure development, geographical refugia, and the extirpation of woodland caribou populations over more than a century in the Upper Great Lakes region.

Mines and transportation networks may both stress woodland caribou populations (deVos and Peterson, 1951; James and Staurt-Smith, 2000; Latham et al., 2011; Herrmann et al., 2014) Weir shows that woodland caribou avoided venturing within four km of mining sites, and most caribou avoided sites within six km of active mines (Weir et al. 2007). Similarly, linear transportation infrastructure on the landscape, such as roads, trails, pipelines, and railways, allows predators easier access to caribou because they may stretch for hundreds of kilometers across a snowy or boggy landscape. Because woodland caribou are better suited to traveling in wetlands, bogs, and deep snow than are their predators, they had been able to escape some predation pressure, particularly during calving, by retreating to wetlands, rocky coastlines, and areas with deep snow. Modern infrastructure development provides wolves and other predators easier access to woodland caribou refugia (James and Stuart-Smith, 2000).

Although caribou do not require wetlands as habitat, for example for calving or foraging, wetlands may offer refugia from predation pressure, particularly during calving. Reports from European colonists in the late 19th and early 20th centuries mention a possible link between wetlands and caribou refugia. Early observers noted that as settler development increased, woodland caribou fled from European hunters and other predators into wetlands (Langston 2021). Recent research confirms these anecdotal reports, showing that caribou select for wetland habitats, largely for predator avoidance (Terry and Wood 1999, Johnson et al. 2002).

Because national, state, provincial parks, federal protected areas, and conservation reserves reduce industrial infrastructure and may lessen human predation pressure, researchers have suggested that protected may aid with woodland caribou persistence (Vors et al. 2007). However, while protected areas aid in persistence, researchers argue that additional measures need to be taken to ensure self-sustaining populations

(Brashares, 2010). In the upper Great Lakes region, protected areas were not initially established to conserve woodland caribou, but 1913 (Land Information Ontario n.d.), they have restricted some logging, mining, roadbuilding, and other industrial development that may have benefited caribou populations.

This chapter discuss our hypotheses for this analysis, the methods of data collection, creation of the HGIS, the GIS layers included in our analysis, the methods of our analysis, the results of our HGIS analysis, and provide a discussion on what these results mean and lessons for woodland caribou recovery that can be taken away from it. The conclusion argues that future development in woodland caribou habitat should take into account the historic effects of mines, railways, wetlands, and protected areas.

2.1.1 Hypotheses

In this study, we created an HGIS (Historical Geographical Information System) using data from three time periods (pre-1900; 1901-1950; 1951-modern) to test the following hypotheses:

a. Historic woodland caribou populations were less likely to persist over time in areas with greater mine and railroad densities.
b. Historic herds in closer proximity to mining sites and railways were less likely to persist over time.
c. Woodland caribou populations were more likely to persist in locations with a greater percentage of wetlands and protected areas

2.2 METHODS

2.2.1 Overview:

First, we created an HGIS database collating archival evidence of woodland caribou populations. We organized the HGIS into three time periods that captured major periods of change in woodland caribou: pre-19th century; 1900-1950; post-1950 to modern. We mapped change over time in woodland caribou populations in the Upper Great Lakes region across these 3 time periods. Within each time period, we mapped mine locations, km of railroads, protected area acreage, and wetland acreage

The first time period (pre-1900) dates from initial observations by early European settler and explorer records to 1900. This time period captures European invasion into the Upper Great Lakes region and shows the beginning of industrialization in the Lake Superior region. The second time period (1901-1950) captures industrial development within this region related to World Wars I and II. Within this time period, mining and railroads continued to be constructed around the Lake Superior region to meet wartime demands. Wildlife studies began to become more common and better data became available on woodland caribou in the region during this time. The final time period (post-1951) captures the post-World War II era, when energy development, industrial forestry, and mining intensified and settler population in the region boomed (Langston, 2021). This time period also captures better data including scientific surveys and studies on woodland caribou as they continued to decline and rescue efforts began.

2.2.2 MAPPING HISTORIC CARIBOU POPULATIONS:

Documented observations from the pre-1900 era were the most difficult to find and access. Therefore, it is hard to know precisely where caribou herds were before their decline began. We gathered as much archival data from this period as possible to construct a database of woodland caribou observations in the Lake Superior region. The Covid-19 global pandemic made it impossible to visit archives in person. Therefore, to gather woodland caribou records, we searched online archives including the Library of Congress, newspaper.com, academic articles, and hunting reports to gain information about where caribou had previously been. We included observations for the Lake Superior region (Michigan, Wisconsin, Minnesota, and Ontario. Archival data can be difficult to verify, but such data provide one of the few ways to understand the range of wildlife before the 20th century. Another way to understand historic populations is through archaeological evidence. However, because of the relatively recent decline of caribou in the region, there are few archeological studies available documenting their locations. We did incorporate archeological evidence into the pre-1900 time period where such data existed.

We entered each archival observation into an Excel file, including the specific location of the observation, the source of the observation, estimates of population abundance if present in the source, and additional notes about habitat that might have been present. For each recorded observation, we recorded as specific a location as we could derive from the source. If we could not determine a point location for the observation, then we noted the general location as specifically as we could determine from the context of the records. The year of the observation was also recorded along with the number of caribou present in each observation, if available. We included information about the authors of the record and the record's source. We continued searching for observations until the searches found only replicate data and no new observations. The result was a database with 384 recorded sightings of caribou in the region.

After data gathering was complete, we created a Historic Geospatial Information System (HGIS) by importing the woodland caribou database observations into ArcGIS Pro. As mentioned above, we had geographically referenced each observation with specific location data, and then we entered these data sources as point data. For more generalized observation locations, we calculated centroid points in the middle of the county, island, or general area given in the record. If multiple records referred to the same locations, we overlaid them on top of each other.

2.2.3 Infrastructure and ecological feature GIS layers:

We then searched for available open-source GIS layers created by other researchers that were available on sources like Dataverse, OntarioGeoHub, USGS, and more to represent the independent variables: mine locations and dates of opening; railways, wetlands, and protected areas. The mines layer included mines in Ontario and the US states and was obtained from the USGS. While some mines may have been present in the pre-1900 period, this database only included mines from the 1900-1950 time period on.

Previous research has shown that woodland caribou herds avoid areas where mines are in operation (Weir et al., 2007; Herrmann et al., 2014). We tested the results of mines in operation during the period of interest, as well as cumulative sites of mining operation up until that time period. This was done to test the effects of mining infrastructure that lasts even after closure of mining operations. Cumulative mining effects might be present due to residual roads, infrastructure, or pollution that remained at these early mining sites, possibly affecting woodland caribou for decades after mining closure. We hypothesized that cumulative mines and mines in operation negatively affect woodland caribou persistence.

For Ontario, we mapped railways for each time period, using data obtained from Dataverse (Penfound and Vaz, 2020). Railway layers were available for the United States, but the majority of their railway infrastructure was constructed during our first time period. There were too few observations to test the effects of rail pre-1900.

We could not find sources to construct layers showing historic distributions of wetlands in northern Ontario that quantified change over time. Therefore, we mapped the distributions of current wetlands and bogs in Ontario, but we were not able to capture loss of wetlands from earlier time periods. This layer was obtained from Ontario GeoHub and was created by the Ontario Ministry of Natural Resources and Forestry (MNRF, n.d). Using this modern layer will not cause an overestimation of wetlands through history due to the filling of wetlands in these areas throughout the 1800s and 1900s (Langston, 2021). The use of this wetland layer might underestimate their historic effect on woodland caribou.

We constructed a protected areas layer that included provincial protected areas, federally protected areas, and conservation reserves in Ontario from the 1900-1950 period to 2020. Because Ontario began designating protected areas in northern Ontario in 1913 with the establishment of Quetico Provincial Park and only a few additional parks by 1950 (Land Information Ontario n.d.), there were no protected lands in the earliest time periods. Provincial and Federal protected areas began being created in northern Ontrario post-1950 (Land Information Ontario n.d.) In the U.S., woodland caribou had largely disappeared by the time protected areas were established, so we focused the protected area analysis on the Ontario side.

We developed an additional GIS layer based on maps from deVos and Peterson (1951). Between 1944 and 1950, deVos and Peterson gathered sight records of woodland caribou in Ontario (Figure 1).

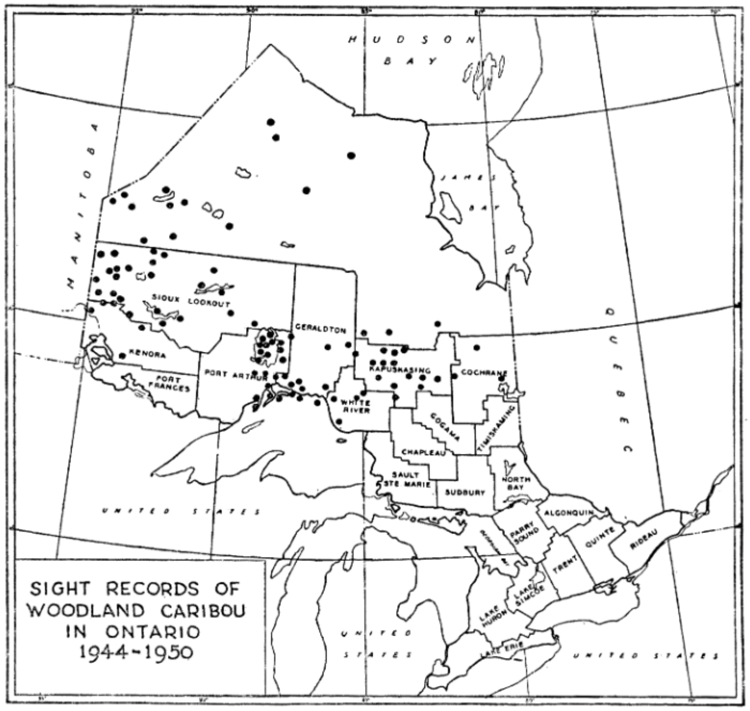

FIG. 1.—Map of Ontario showing the organization of Provincial Forest Districts and the distribution of sight records of woodland caribou made during the years 1944 to 1950.

Figure 1. Sight records of woodland caribou in Ontario from 1944-1950 (deVos and Petterson, 1951).

Of particular importance for our analysis were the data that deVos and Peterson gathered in the late 1940s on woodland caribou herd locations and population abundance (Figure 2 and Figure 3). Data from their second figure were based on interviews deVos and Peterson conducted in 1948 and 1949 with Indigenous communities, hunters, trappers, and game wardens across northern Ontario. This map shows locations of herds that had been recently extirpated after World War II and locations of herds that were still persisting by 1949. Data we extracted from these maps offered a snapshot of Ontario woodland caribou populations before the post World War II infrastructure boom in northern Ontario.

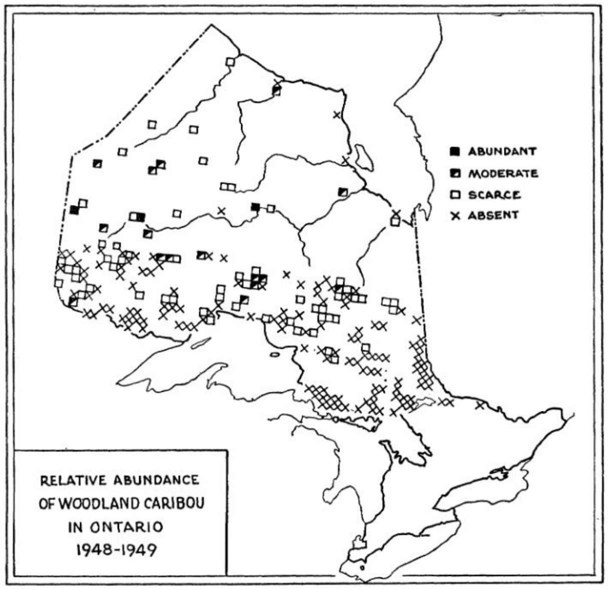

FIG. 2.—Map of Ontario indicating an estimation of relative abundance of woodland caribou based on the 1948 and 1949 regular annual questionnaires of the Royal Ontario Museum of Zoo ogy.

Figure 2. Relative abundance of woodland caribou throughout Ontario and locations of recently extirpated herds. Data gathered from surveys of hunters, trappers, Indigenous communities, and game warden during 1948-1949 (deVos and Peterson, 1951).

FIG. 3.—Map of Ontario indicating an estimation of the 1948–1949 trends in woodland
C caribou populations.

Figure 3. Map depicting the population dynamics and trends of herds in Ontario at the time based on interview data from 1948-1949 (deVos and Peterson, 1951).

To incorporate deVos and Peterson's data into our HGIS analysis, each map was georeferenced using ArcGIS Pro. The maps were then overlaid and adjusted manually to ensure as much accuracy as possible. We transformed each square into a centroid point.

Since these maps were originally hand drawn, it is difficult to pinpoint the exact location of each square within an estimated 10 km range.

For the analysis, we collated abundance data from deVos and Peterson Figure 2 into two categories: recently extirpated and persisting. For the purposes of our analysis, we code caribou herds as persisting if deVos and Peterson categorized them as scarce, moderate, or abundant and "recently extirpated" if deVos and Peterson categorized them as "absent." We collated data into two categories in order to test for possible differences in cell attributes using Mann-Whitney U- Tests (described below).

When mapping layers, we selected either point or line features to represent the location of that layer most accurately. These features were quantified for analysis using tools in ArcGIS Pro. To compare woodland caribou observations and infrastructure changes over time, we first added a uniform grid with cell sizes of 50 km X 50 km over the study area, defined as the historic range of woodland caribou observations (Figure 4). We assigned a unique identifier to each grid cell, allowing us to analyze changes over time in woodland caribou persistence and infrastructure. We chose a 50 km cell size for two reasons: first, because woodland caribou in this region appear to migrate less than this distance. Second, because of potential inaccuracies in geolocating precise locations, a 50 km cell size seemed reasonable.

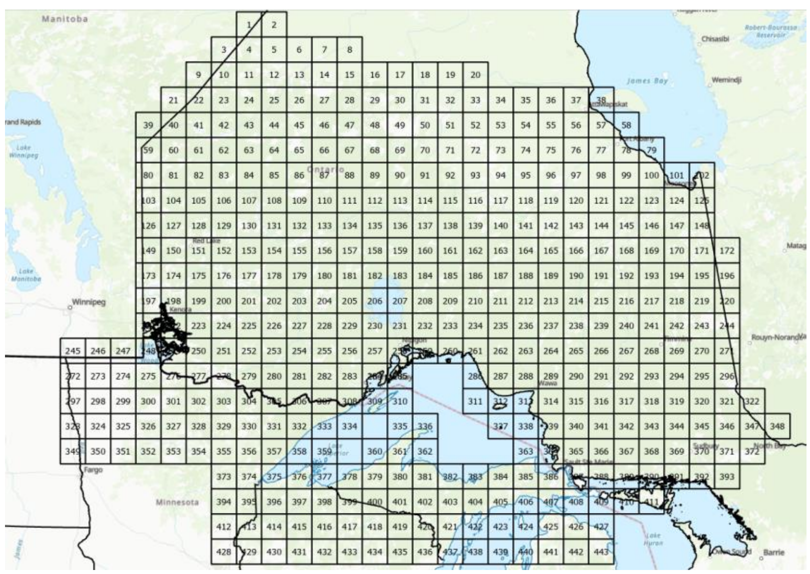

Figure 4. Map of Study area with the grid of 50x50 km cells used for the analysis of GIS layers.

Other HGIS studies have created buffers around each independent variable's location and then compared dependent variables within that buffer (Eedy, 1995). We chose not to use buffers, however, because we know that our observations do not fully capture caribou locations and abundance, particularly during the first time period. We were also concerned that the use of buffers could have led to pseudoreplication where mine buffers overlap each other.

The total habitat area available to woodland caribou in each cell was calculated by overlaying the province of Ontario over the study grid and removing any excess grid area that was not included within the boundaries of the province. On the U.S. side, the study area was manually limited to places where the oldest woodland caribou observations were most common pre-1900. Tools within ArcGIS Pro were used to quantify the area of each new study cell to determine the total available woodland caribou habitat present in square kilometers. Area in grid cells outside the borders of Ontario, Minnesota, Michigan, and Wisconsin was omitted.

For each cell in each time period, we used ArcGIS Pro tools to quantify the infrastructure and ecological features present in each cell and count woodland caribou observations. We began by calculating the amount of suitable area available to be used by woodland caribou inside each grid cell. We then calculated the total area of protected areas in each cell during each time period and then calculated the fraction of each cell area in protected lands for each time period. We determined the area of wetland features present within each grid cell in square kilometers and divided that area by available area to calculate the fraction of each cell in wetlands or bogs. For each time period and each cell, we calculated the number of mines during that particular time period, as well as the cumulative mine counts at the end of each time period. We calculated the total kilometers of railways present in each grid cell for each time period as well.

Next, we quantified the historic observations of woodland caribou. We began by using the GIS tools to calculate the frequency of observations and the number of caribou observed in each cell during each time period. We then compared cells across each time period, marking cells where caribou were present in one time period, but not in the next, to determine localized areas of possible extirpation. We then determined the proximity of woodland caribou observations to the closest of each of our independent variables.

2.3 ANALYSES

For exploratory statistical analyses, we compared mean ecological and infrastructure values (of mines, railways, protected areas, and wetlands) in the 1900-1950 time period, between cells that had recently extirpated herds and cells with persistent herds.

Within the post-1950 time period, we explored differences between cells that had herds that persisted into this time period, versus cells that had caribou present in an earlier time period but extirpated in the final time period. This analysis put grid cells with any persisting caribou into the persisting category even if another herd within that same cell had been extirpated. Next, we compared the second and third time periods to each other to determine if there were differences between cells with persistant herds and cells with extirpated herds. For these analyses, data for the independent variables was taken from the final time period. These analyses do not include the first time period due to insufficient data. If a cell had both caribou observations persisting and reports of extirpation in the same grid cell, we included that cell in both the persisting and extirpated columns.

Using the 1948 and 1949 caribou location data that we extracted from DeVos and Peterson (1951), we conducted a proximity analysis, comparing herds that persisted with herds that had recently become extirpated. We hypothesized that herds that had recently become extirpated were likely to be closer to operational mines and closer to the nearest railway, and further from wetlands and protected areas than herds that were persisting. We also compared herds that were increasing in 1948/1949 with herds that were decreasing. We hypothesized that herds that were decreasing were likely to be closer to operational mines, and further from wetlands and protected areas, than herds that were increasing.

Using 1948/1949 herd location data extracted from DeVos and Peterson, we predicted that cells where caribou had recently been extirpated would have significantly more cumulative mines, operational mines, and kilometers of railway than cells where caribou were persisting during the 1900-1950 time period. Finally, we compared cells where caribou were decreasing compared to cells where they were increasing during 1948/1949, hypothesizing that we would find significantly more operational mines, cumulative mines, and kilometers of railway in cells with decreasing herds.

Analyses were conducted using Mann-Whitney U-Tests in Excel. This test was chosen because all of our observational data was collated into two categories: herds that were persisting during a given time period and herds that had recently become extirpated. The Mann-Whitney U Test is a non-parametric test appropriate for data that is not normally distributed. It allows comparison of median values between two independent groups to determine statistical correlations between the two (LaMorte, 2017). We used $p \leq 0.05$ for statistical significance.

2.4 RESULTS

2.4.1 MINING EFFECTS

We predicted that woodland caribou populations were less likely to persist over time in cells with greater mine densities, and that herds in closer proximity to mining sites were less likely to persist over time.

Using 1948/1949 herd location data extracted from DeVos and Peterson (1951), we found that there were significantly fewer cumulative mines in cells where caribou were persisting in 1948/1949 ($M=2.12$, $n=60$) than in cells where caribou were extirpated ($M=5.38$, $n=85$); $z= 2.16$, $p= 0.015$). There were also significantly fewer operational mines in cells where caribou were persisting ($M=1.23$, $n=60$) compared to cells where they were absent/extirpated ($M=2.73$, $n=85$); $z= 1.02$, $p= 0.027$.

We also tested the effects of proximity to persisting and extirpated caribou herds using data extracted from DeVos and Peterson (1951). We found that caribou herds that were persisting were almost twice as far from an operational mines ($M=60.54$ km, $n=75$) compared to herds that had been extirpated ($M=33.22$ km, $n=136$); $z= -3.57$, $p= 0.0002$.

To test the hypothesis that herd decline between the three time periods was associated with settler infrastructure from the 1900-1950 to the post-1950 time period, we analyzed change over time in each cell during the time periods. First we compared the

1900-1950 time period to the post-1950 time period. We found that there were significantly fewer cumulative mines present in cells where caribou had persisted across the two time periods (M= 28.17, n=35) than in cells where caribou had become extirpated by the post-1950 time period (M= 20.183, n=153); z= -2.37, p= 0.009. There were also significantly fewer number of operational mines present in cells where woodland caribou were persisting (M= 28.17, n=35) during the post-1950 time period than in cells where they became extirpated from the 1900-1950 time period (M= 20.18, n=153); z= -2.66, p= 0.004.

We compared cells with persistent herds in the post-1950 time period, with cells that had herds present in any period but not the modern period. We hypothesized that there would be more cumulative and operational mines present in cells where caribou had been present in past time periods but were extirpated by the post-1950 time period than in cells where caribou were persisting post-1950.

2.4.2 RAILWAY EFFECTS

We hypothesized that historic woodland caribou populations were less likely to persist in cells with greater railway densities, and that historic herds in closer proximity to railways were less likely to persist over time. To test the hypothesis that railways were associated with caribou decline, we used 1948/1949 data extracted from DeVos and Peterson (1951). We compared the mean kilometers of railways in cells with persistent herds to the mean kilometers of railways in cells with extirpated herds. We found that there were significantly less kilometers of rail present in cells where caribou were persisting (M=38.592 km, n=60) than cells where caribou had become extirpated/absent (M=55.531 km, n=85); z= 2.24, p= 0.01.

We also tested the effects of proximity to persisting and extirpated caribou herds using 1948/1949 data extracted from DeVos and Peterson (1951). Cells where caribou were persisting were significantly further away from the closest railway (M=67.59 km, n=75) than cells where herds had been extirpated by this time (M=18.96 km, n=136); z= -2.52, p= 0.006.

To test the hypothesis that herd decline across the three time periods was associated with infrastructure development, we analyzed change over time in each cell during the time periods. Comparing the 1950 time period to the post-1950 time period, we found that cells with persistent caribou herds had significantly fewer kilometers of railway present (M=27.66, n=35) than cells with extirpated herds (M=88.4, n=152); z= 4.1, p< 0.00001.

Next, we compared cells with persistent herds in the post-1950 time period, with cells that had herds present in any period but not the modern period. There were significantly fewer kilometers of railway in cells with persistent herds, compared to cells with extirpated herds in the post-1950 time period (M=46.16, n=35). There were significantly more kilometers of railway in cells with extirpated herds (M=83.4, n=173); z= 2.2, p=0.013.

2.4.3 WETLAND EFFECTS

We hypothesized that woodland caribou were more likely to persist in areas with greater percentages of wetlands. Our specific prediction was that cells with persistent herds contained higher fraction of wetlands than cells with extirpated herds. Using the fraction of wetland habitat present in each cell in 2020, we compared caribou observational data in the post-1950 time period to the 1900-1950 time period. We found that there were significantly larger fraction of wetlands in cells where caribou persisted (M=0.33, n=35) than cells where caribou became extirpated from the second to the third time period (M=0.23, n=153); z= -2.21, p=0.014.

2.4.4 PROTECTED AREA EFFECTS

We hypothesized that woodland caribou populations were more likely to persist in locations with a greater percentage of protected areas. Our specific prediction was that cells with herds that persisted had a higher fraction of protected areas than cells where herds became extirpated. Using the fraction of each cell in protected area, we compared the post-1950 time period to the 1900-1950 time period. Cells with persistent herds had a higher fraction of protected area (M= 0.25, n=35), compared to cells with herds that had become extirpated between the second to third time period (M= 0.08, n=153); z= -5.06, p< 0.00001.

2.5 DISCUSSION

Our results support the hypotheses that historic mining and railway infrastructure were associated with woodland caribou decline in the Upper Great Lakes region between 1900 and 2000, while wetlands and protected areas were associated with woodland caribou persistence. From 1890-1940, mining was in the middle of its most productive period. Mining had been ongoing since the beginning of the 19th century; however, this was a period of unprecedented extraction (Republic of Mining, 2010). Our analyses show that woodland caribou were less likely to persist in closer proximity to open mines, supporting the hypothesis that historic mining was associated with woodland caribou population declines.

The deVos and Peterson (1951) data from the late 1940s were core to our analyses, because they captured data from interviews and surveys across Ontario, just before mining and logging industries expanded in the post-war boom. It would be impossible to gather data like this now because any observers from that time have since died. This study found that woodland caribou were significantly less likely to persist in cells with high rail densities and in closer proximity to railways. These results corroborate historic reports from the early 1900s that as railways expanded, caribou retreated north of Lake Nipigon (deVos and Peterson, 1951). Woodland caribou may have retreated because railways can potentially increase predation pressures for several reasons: first, hunters supplied railway construction crews with fresh meat, often from caribou herds. Second, recreational hunters used the railways for easier access to caribou herds, planning hunting vacations via railway to an area that, before railways, had been quite expensive to reach (Langston 2021). Third, railways are relatively linear features on the landscape that offer wolves and other predators easier access to caribou herds (James and Staurt-Smith, 2000; Dyer et al., 2002; Latham et al., 2011; Williamson-Ehlers, 2012; Newton et al. 2017).

In this study, cells with higher fractions of their area in wetlands were associated with woodland caribou persistence. These results are consistent with 18th and 19th-century archival observations that, as development and hunting pressures increased, woodland caribou sought wetlands as refugia from predators (Langston, 2021). Wetlands have been declining in Ontario since the early 1800's when colonial settlers began expanding into the region in favor of industrial development and agriculture. As a result, Ontario is estimated to have lost roughly 68% of its historical wetlands (Penfound and Vaz, 2022). This study was unable to analyze the effects of historic wetland loss due to the lack of available digitized data. However, we can be confident that we are not overestimating the historical effects of wetlands in the region due to the majority of the decline happening pre-1950 (Penfound and Vaz, 2022).

Our analysis of the impact of protected areas shows that protected areas have been associated with woodland caribou persistence since 1950. However, initial caribou declines took place well before the majority of protected areas were established in the region post-1950 (Land Information Ontario n.d.). Protected areas only began being established in the area in our 1900-1950 time period, with most being established in our post-1951 period. Our data suggests that even though protected areas were established late in terms of caribou decline, protected areas may still aid in woodland caribou persistence. This might suggest that habitat recovery is taking place after the protection of some of these areas and that they offer valuable refugia from population stressors. Prioritization of the establishment of protected areas in suitable woodland caribou habitat could help maintain persisting populations in these areas.

Some limitations of this study were that there were no available digitized data showing the extent of forestry, pulp mills, or forest conversion available to analyze as part of this study. The increase in forest harvest throughout the 1800s caused forest compositional changes (Carelton and MacLellan, 1994; Whittle et al., 1997; Boan et al., 2011). These changes in species composition then lead to increased predation (Bergerud and Elliott, 1986; Bergerud, 2018). Data on roads and dams in the region was also insufficient, which was unfortunate because roads and dams have been shown in recent studies to negatively affect woodland caribou survival by increasing avoidance behaviors and increasing predator access (James and Staurt-Smith, 2000; Mahoney and Schaefer, 2002; Scurrah and Schindler, 2010). This study cannot shed light on the historical impact of roads and logging.

Another limitation of this study was the difficulty in finding specific caribou population records for the pre-1900 time period. We searched online archives extensively, yet most records we found were vague observations rather than population counts. When in-person archives make historic archive records once again available, testing hypotheses about factors associated with the earliest declines may be possible.

Online archives did not provide specific data on changing predator populations or human predation pressure throughout history. Each of these is thought to have caused major declines in woodland caribou populations through time. Future analyses comparing human predation and wildlife predation changes could lead to a more detailed understanding of historic woodland caribou decline in the Lake Superior region.

While the closure of in-person archives almost certainly means some relevant observations were not included in this analysis, the size of the database suggests that it captures key moments in regional woodland caribou decline. A large enough number of observations was required for each time period to capture every place in our study area during the time period of interest where woodland caribou observations were being recorded in some form. It is impossible to ever truly know the full extent of where caribou were or the exact population dynamics present in each population, because until the 1940s or 1950s there were few surveys of caribou populations. There were also fewer people living in this region when caribou first began to decline, and there were places within our study area where records could not be found. This means that the absence of an observation of early woodland caribou does not mean caribou were not present. Such limitations are common in HGIS analyses.

Some unknowns that this HGIS analysis framework could be used for are to analyze the effects of roads, seismic lines, pipelines, and transmission corridors to gain a better understanding of possible associated drivers of decline or recovery. Our observational HGIS database could be expanded upon to better test possible causality and gain a more nuanced understanding of historic stressors, which can be used to inform woodland caribou recovery policies.

2.6 CONCLUSION

In conclusion, this study used an HGIS to test the historic effects of key human development and potential refugia on woodland caribou persistence in the Lake Superior region. We hypothesized that:

a. Historic woodland caribou populations were less likely to persist over time in areas with greater mine and railroad densities.
b. Historic herds in closer proximity to mining sites and railways were less likely to persist over time.
c. Woodland caribou populations were more likely to persist in locations with a greater percentage of wetlands and protected areas

The HGIS was created using historic woodland caribou observations in the region. Online sources like newspapers, online archives, journal articles, governmental documents and more were used to create this historic observational database. Layers indicating key human development and potential refugia were overlaid. Analyses were conducted using Mann-Whitney U-Tests to compare differences in areas were caribou were persisting versus where they had been recently extirpated.

This study shows that the presence of mines and railroads was associated with historic woodland caribou extirpations. Caribou were less likely to persist the closer they were in proximity to mines and rails. Wetlands and protected areas were positively associated with woodland caribou persistence.

Our results suggest that infrastructure development may not be appropriate in woodland caribou habitat. As infrastructure from logging, mining, and energy industries expands into northern Ontario, caribou populations might face intensified stressors. Restricting development in caribou habitat might be necessary for population recovery. Our results also suggest that prioritizing the protection of wetlands and establishing new long-term protected areas in suitable woodland habitat might benefit persistence of woodland caribou.

3 STAKEHOLDER SYNTHESIS AND RECOVERY OPTIONS

3.1 INTRODUCTION

Addressing challenges associated with current woodland caribou recovery efforts are as much about social dynamics as they are about ecology. Chapter 3 describes the history of the translocation and recovery efforts that have taken place to protect the Lake Superior woodland caribou population since the 1980s. We then explore potential recovery options available for sustaining Lake Superior woodland caribou into the future.

A synthesis of stakeholder perspectives was conducted in the region to better understand the diversity of perspectives on woodland caribou recovery options. By better understanding the perspectives of stakeholders in the region, areas of overlap in beliefs on caribou recovery can be identified. This creates room for policy compromises to be made on woodland caribou recovery in the Lake Superior region. Inclusion of diverse groups is vital in recovery planning and processes is vital for finding these areas of compromise and working out a recovery solution.

3.2 METHODS

To conduct this stakeholder synthesis, I conducted seven semi-structured interviews with different stakeholders across the Canadian shore of Lake Superior in August 2021. Each interview lasted for approximately one hour.

I initially identified key stakeholders interested in woodland caribou recovery options in Ontario. This list is incomplete because it is impossible to identify and discuss every possible group that holds a stake in woodland caribou recovery, but it is representative of the major groups identified through this synthesis. The stakeholders include First Nations in Canada, retired ministry biologists, hunters, environmentalists, Environment and Climate Change Canada, Species at Risk Canada, Ontario Ministry of Natural Resources and Forestry, the timber industry, the mining industry, and hydroelectric industry.

In August 2021, I conducted semi-structured interviews with seven people in Ontario associated with different stakeholder groups. During these interviews, I asked stakeholders questions regarding their opinions and beliefs towards woodland caribou recovery efforts in the Lake Superior region. This included questions about past and proposed future recovery efforts. When written consent was granted, I recorded interviews with VoiceMemo on an iPhone. Notes were also recorded during each interview and expanded upon when reviewing recordings.

I transcribed the interviews by hand and stored the digital voice files in a secure location, along with copies of the transcriptions (after making anonymous the interviews with people who had requested anonymity). I then reviewed and coded the transcriptions, searching for themes that reflected the values and beliefs of stakeholders. I extracted quotes from the interviews that illuminated stakeholder perspectives and collated these quotes. A literature review was performed to further identify stakeholders in the region and better understand each group's beliefs on woodland caribou recovery. The literature review consisted of news articles, public statements, journal articles, white papers from both provincial and federal governmental sources, and other available online sources.

Data gathered from interviews with stakeholders and the literature review were used to synthesize the diversity of beliefs that exist both within common groups of stakeholders, as well as between individuals that may share some other beliefs. I identified perspectives that stakeholders have in common, and perspectives that stakeholders differ on.

3.3 LAKE SUPERIOR CARIBOU RECOVERY CONTEXT

Lake Superior has played a special role in woodland caribou persistence in the upper Great Lakes region. Its rocky shores and island safe-havens have been essential to maintaining this small genetically distinct population of caribou (McWhirter, 2022). Woodland caribou are a threatened subspecies of caribou in Ontario (Environment and Climate Change Canada, 2019). However, for the Lake Superior discontinuous population of caribou, this label does not accurately represent their current localized situation. In the Lake Superior region, they have been teetering on the brink of extirpation for almost 50 years. They continue to survive only because of human intervention in the form of recovery efforts that have taken place since the 1980s.

Woodland caribou roamed south of Lake Superior in mainland Michigan and Wisconsin until 1912 at the latest (Gogan and Cochrane, 1994; Langston, 2021). They survived on Isle Royale until at least 1926, and observers noted that wintering herds from Thunder Bay would frequently seek shelter on the island (Baker, 1983). In the United States, woodland caribou survived the longest on the western shore of Lake Superior in Minnesota. Langston (2018) describes the extensive recovery efforts that wildlife agencies made in Minnesota's Big Bog region between 1935 and 1954. Having numbered in the thousands a few decades previously, there only remained three lone females by 1937 making the last resident population in the region functionally extirpated (Fashingbauer, 1965). This led to the first translocation of woodland caribou in the United States. The Red Lake Wildlife Refuge secured the necessary funds from the federal government to reintroduce woodland caribou from a healthier population in Canada to the Red Lake herd that was now functionally extirpated. In 1938, ten caribou were captured 100 miles north of Prince Albert, Saskatchewan with the help of Indigenous trappers from the Montreal Lake Post and transported back to Minnesota (Fashingbauer, 1965 and Langston, 2021).

This translocation effort ultimately failed due to multiple mistakes made at the time. The first issue was that when these caribou were moved, there was only one adult male and one adult female included in the group. This meant that even if all three remaining females had survived, there would only be one breeding male ready to go. If anything were to happen to this male, then they would have to hope one of the younger males survived long enough to reach reproductive maturity for another chance at recovery (Eason [Personal Communication], 2021). Additionally, a fenced-off area of about 480,000 acres was established to protect the remaining woodland caribou from poaching, thought to be a major cause of decline at the time (Fashingbauer, 1965). Poaching was typically blamed on Indigenous groups in the Red Lake area, so a fence was constructed between the caribou range and the reservation the (Langston, 2021). By 1946, there was no sign of living caribou to be found in this region other than the very occasional wanderers that would venture just south of the Canadian border into Minnesota into the early 1980s (Fashingbauer, 1965).

On the north shore of Lake Superior, woodland caribou began declining south of Lake Nipigon during the onset of construction of the Canadian National Railway in 1918. This rail line eventually transected the region between the southern shore of Lake Nipigon and the northern shore of Lake Superior. The Ontario woodland caribou population remained continuous south to the north shore of Lake Superior and Pukaskwa National Park until 1950 and possibly even into the early 1960s. By the 1960s, caribou were surviving in the Slate Islands Provincial Park, Pic Island and Neys Provincial Park, Pukaskwa National Park, and in three small bands on the inland north shore of Lake Superior (Bergerud, 1989; Gogan and Cochrane, 1994).

By the 1980s, Lake Superior's population of woodland caribou appeared to be threatened with imminent extirpation. In an attempt to bolster this population, wildlife biologist Gordon Eason in the Ontario Ministry of Natural Resources division in Wawa devised an ambitious set of woodland caribou translocations. In 1982, biologists moved eight caribou from the Slate Islands Provincial Park to Michipicoten Island, 16 km off the coast. This would be the most successful of this series of translocations, with the caribou population increasing to over 1000 individuals in 30 years. Between 1984 and 1986, biologists moved eight caribou to Montreal Island, 5 km off the coast. When wolves arrived on the Slate Islands in 1994, the caribou population was unable to persist (Eason, 2011).

In 1986, biologists moved three more caribou (2 cows and 1 bull) from the Slate Islands to Leach Island, 5 km off the mainland. The bull left the island, leaving only cows and calves on Leach Island, causing the Leach Island subpopulation to become functionally extirpated (Eason, 2011). In 1989, biologists tried to reestablish the mainland woodland caribou population by translocating 39 caribou from the Slate Islands to Gargantua Point in Lake Superior Provincial Park on the northeast end of Lake Superior. The Slate Island subpopulation was successful for almost 20 years, but ultimately became extirpated in 2009. The most likely reason was higher wolf predation than recruitment. The ministry made additional efforts to reintroduce caribou to St. Ignace Island (in 1985) and the Terrace Bay mainland (in 1984). These translocations failed as well, with all caribou dying over two years (Eason, 2011).

While many of these translocations at this time were unsuccessful, Michipicoten Island and the Gargantua Point translocations were successful enough to maintain a self-sustaining Lake Superior woodland caribou population on the Slate Islands, Micipicoten

Island, and in Lake Superior Provincial Park. By 2009, woodland caribou had become extirpated from Lake Superior Provincial Park along the mainland and were only being sustained on Michipicoten Island with a few potential individual stragglers on the mainland.

As of 2010, woodland caribou were present within the Lake Superior watershed in several places: in the Nipigon subwatershed, along a small section of coast on the mainland, and several islands. However, during the winter of 2014, a polar vortex weather event created enough ice on Lake Superior that wolves from the mainland were able to traverse the ice and reach both the Slate Islands and Michpicoten Island. By 2014, wolves on the Slate Islands eliminated all but two male caribou, causing the Slate Island subpopulation to become functionally extirpated again. Wolves soon vanished from the islands, either starving after their prey was gone or else moving back to the mainland.

On Michipicoten Island the wolves increased to approximately twenty individuals by 2018. This rapid growth threatened to eliminate the last stronghold of woodland caribou in the region (Fletcher, 2022). Groups such as Gordon Eason's coalition of retired Ministry of Natural Resources biologists, the Michipicoten First Nation, and concerned citizens around Ontario, persuaded the Ontario Ministry of Natural Resources and Forestry to allow the translocation of woodland caribou from Michipicoten Island to predator-free islands. Eight caribou were moved to the Slate Island Provincial Park, where they joined the two bulls that had survived on the islands after the wolves arrived in 2013.

The remaining six were translocated to Caribou Island, 13 km offshore (Fletcher, 2022). Caribou had historically been present on this island, according to records of Alexander Henry's 1760-1776 travels in this region where he noted killing 13 caribou and finding fairly fresh skeletons on the island (Langston, 2021; Henry and Quaife, 1921). Caribou Island had also been one of the first translocation efforts in the region when managers with a private game preserve brought in six woodland caribou from Newfoundland in the 1930s (Eason, 2011).

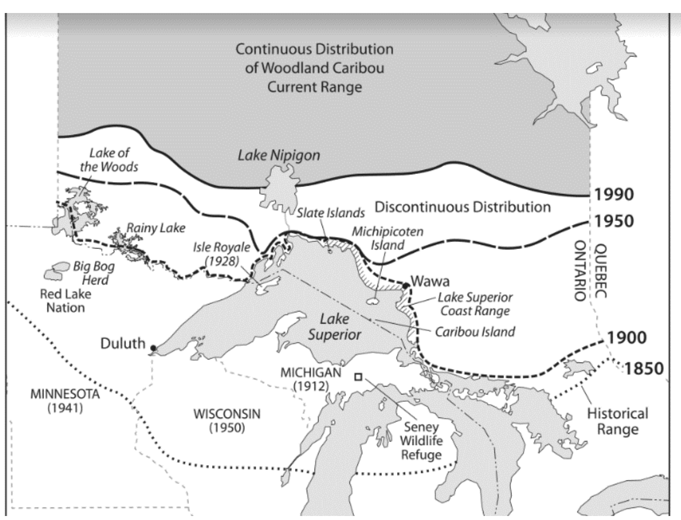

Figure 1. Historic Range map of Woodland caribou in the Lake Superior region; from Langston (2021); map drawn by Bill Nelson.

As of spring 2022, biologists have estimated that 30 caribou are on the Slate Islands and 23 are currently on Caribou Island (Fletcher, 2022). There are thought to potentially be a few individual stragglers still persisting along the mainland (Environment and Climate Change Canada, 2019). Woodland caribou in the Lake Superior population decreased from ~ 1,100 individuals in 2014 to between 50 and 60 individuals in 2022. While this does not quite represent recovery, woodland caribou in the Lake Superior discontinuous population have been able to persist in the face of immense population stressors due to these translocations.

Gordon Eason and Brian McLaren argue that maintaining the small number of caribou that survived these intense predation efforts is essential because these caribou were both physically and genetically fit enough to survive these events. For a self-sustaining Lake Superior woodland caribou population to be possible, these genetics must be maintained and passed onto future generations of caribou if they are to be fit enough to survive in this region (personal communication, 2021, with Eason and McLaren). If the Lake Superior discontinuous population were to become extirpated, their unique genetic diversity would be lost as well. Gene flow in this population has been restricted to human movements of caribou between subpopulations. Maintaining this unique gene pool that has been developed over many generations of caribou that have persisted immense population pressures could aid in future generations of caribou as they continue to face unpredictable population pressures (Drake et al., 2018). No other population of woodland caribou in Canada would be able to replace this genetic diversity because none of them have been subjected to the same evolutionary pressures. Caribou brought from northern Ontario, Newfoundland, or other populations would not have the same genetic advantages that caribou in the Lake Superior discontinuous population have.

Inbreeding depression is also a threat to the isolated subpopulations within the Lake Superior discontinuous population. When populations get too small, alleles are more likely to become fixed within populations, reducing genetic variation within a population, and making it more homogenous. This decreases the population’s ability to survive changes that may occur in the future and increases their risk of extirpation (Brown et al. 2009)

3.4 POLICY OPTIONS FOR CARIBOU RECOVERY

The interviews and literature review identified four policy alternatives for maintaining viable woodland caribou populations in the Lake Superior region. These alternatives include: wolf culls; continued translocations from source populations; moose or deer culls; habitat restoration. Finally, some stakeholders favor the “do nothing” or “let nature take its course” policy of allowing woodland caribou to become extirpated in the region.

Alternative 1: Wolf Culls

Wolf culls are particularly controversial. Advocates argue that culling the wolves in areas where caribou are experiencing high levels of habitat degradation and fragmentation can help to reduce the levels of predation that woodland caribou are facing throughout Canada (Bergerud, 2018). Bergerud's research has shown that wolf densities of greater than 6.5 to 8 wolves per 1000 km^2 in the Lake Superior region has been associated with declines in caribou populations. Caribou mortality and recruitment become roughly equal with this density of predators. This is referred to as the stabilizing density where caribou are generally able to maintain their population levels with stabilizing recruitment of calves of around 15 percent of the population, balancing out adult caribou mortality (Bergerud, 1980; Bergerud and Elliott, 1986; Thomas, 1992; Lessard, 2005; Bergerud [Ch.7], 2018).

However, there is a substantial public debate over the use of wolf culls as management tools. Wolf management policies and politics often encompass a variety of sociopolitical issues that turn seemingly simplistic conservation decisions into multidimensional conflicts between different stakeholder groups (Nie, 2001). Some cultural conflicts that often arise in carnivore conservation are "preservation versus use of resources, recreation-based economies versus extraction-dependent economies, urban versus rural values, and states' rights versus federalism" (Primm and Clark, 1996; Nie, 2001). This sociopolitical context is particularly influential when combined with endangered species management because these other intertwining issues elevate the species of concern into an important and almost symbolic position making any problems concerning their management more difficult to solve (Yaffee, 1994a; Yaffee, 1994b; Nie, 2001). As political scientist Martin Nie writes about wolf recovery programs: "Conservation problems at their root are people problems… they are not fundamentally questions of science, rather questions founded on values, ethics, and politics" (Nie, 2001).

British Columbia approved a series of wolf culls in the winter of 2019-2020, justifying them through a controversial study led by Robert Serrouya (Langston, 2021). This study argued that penning to protect pregnant female caribou and culling wolves was necessary to enact adaptive management in the short term because habitat restoration takes too long to save these caribou populations alone (Serrouya et al. 2019). Other scientists disagreed arguing that this assumption was made due to an important statistical error (Harding et al., 2020). The conservative government of British Columbia interpreted Serrouya's 2019 study to mean that they could cull wolves in the area instead of working on designating areas for habitat protection and restoration. 150 wolves were killed in an area of roughly 80-100 woodland caribou as a result. This did little to help this population recovery and only allowed them to persist in the region (Langston, 2021). This wolf culling effort shows that dealing with the proximate source of decline is not enough to stem the ultimate sources of woodland caribou decline which are habitat fragmentation and degradation due to human industrial development.

Wolves are one small piece in large complex ecological processes. Wolf management is not just about wolves but encompasses the management of ungulate populations like woodland caribou, native flora pressures from these populations, and many of their complex biological relationships and ecological cycles that we may not yet fully understand requiring more balanced management regimes (Nie, 2001).

Views on wolf management vary from stakeholder group to group and even between individual stakeholders within these groups. Therefore, there is no one way to generalize the views of these groups. Past research into the sociopolitical human dimensions of wolf management suggests that rural communities are often particularly resistant to wolf management. Rural residents may view wolf recovery efforts as federal overreach into their region that could result in the enaction of more strict federal lands management. Environmentalists also hold very diverse views. Some view predator management as a useful tool for achieving certain conservation goals, while others feel that human interference with wolves would disturb what they perceive as the balance of nature.

Indigenous communities play a particularly complex role in caribou and wolf management in the Lake Superior basin, with different bands along the north shore of Lake Superior taking different positions on recovery options. Two bands, the *Biigtigong Nishnaabeg* (Ojibways of the Pic River) and the *Michipigodong/ Mishibikwadinaang* (Michipicoten), support active translocation efforts and urge continued investments in woodland caribou recovery. Other bands to the west, according to informants, are less interested in active caribou recovery, and prefer to focus on moose management and forestry operations. Other bands like the *Opwaaganasiniing* (Red Rock Indian Band) seem to support more passive restoration options because of local investments in forestry and preference for moose hunting. Each First Nation band determines its own role and stance on wildlife management issues. Many settlers assume that most bands would hold relatively similar views on species conservation, but just like individuals within a group, each band has unique goals and cultural values leading to diverse views on management (Nie, 2001). The diversity of views continues to the individual level within Indigenous communities. Even though individuals are part of the same overall group, they carry their own views that might differ from the majority.

Alternative 2: Translocation

The second alternative policy is translocation to either reintroduce populations to areas where they historically lived or bolster smaller populations that are at risk of extirpation (Scott et al., 2005; Armstrong & Seddon, 2008). Translocations involve capturing and transporting caribou from a stable population and transferring them to a viable area, where they are released. These translocations require surveying the area to determine why caribou might have left, determining if there is a possibility of successful reintroduction into the area, surveying the stable caribou population to determine whether a small group of caribou can be taken from it, and monitoring the translocated population after they have been moved and released (Decesare et al., 2010). Translocations can help increase genetic variation within small populations of caribou by providing an artificial source of immigration into a small population.

Translocations are an aggressive conservation option that can cost significant sums. While some environmentalists see translocations as too controlling, others view translocation as more viable than wolf culls, due to the lack of societal support for predator control (Garrott et al., 1993; Bruskotter et al., 2009; Decesare et al., 2010). This is especially true in national parks (Serrouya and Wittmer, 2010; Decesare et al., 2010).

Alternative 3: Moose and Deer Culls

The third policy alternative is the culling of moose and deer in woodland caribou habitat (Serrouya, 2013). Commercial logging, wildfires, and climate change have changed the composition of vegetation in many portions of historic caribou habitat so that there are smaller shrubs. This has made these areas more hospitable to moose and deer, who use these types of vegetation as a food source. This combined with species compositional changes due to climate change allows for moose and deer to move into these areas quickly because of their ability to reproduce faster than woodland caribou.

Wolves, which are a major predator of both moose and deer, have followed them as they have expanded their range. This has caused caribou to become more heavily preyed upon by wolves. "In multi-ungulate systems, wolf densities are commonly fifteen to twenty-five wolves/1,000 km^2" (Messier, 1994). In Bergerud and Elliot's 1986 paper they documented that the decline of caribou in British Columbia occurred when the moose population increased, which brought higher wolf populations to northern British Columbia. (Bergerud and Elliott, 1986; Bergerud, 2018).

Unlike moose and deer who have defensive behaviors for fighting or running away from wolves, caribou are only able to move to areas where the wolves do not live to avoid predation or use special habitat features such as rocky mountains and shorelines (Bergerud et al., 1984) If there is not enough space or specialize habitat features caribou become much easier prey than moose or deer resulting in prey switching (Bergerud, 1985). Bergerud argues that even in the absence of deer, caribou populations cannot sustain themselves when there are more than 10 wolves per 1,000 km^2 (Bergerud, 1985).

Additionally, deer and moose harbor diseases such as meningeal brain worms that are "highly pathogenic to caribou" (Anderson, 1972). Meningeal brain worm (*Paralephostrongylus tenuis*) is not fatal to White-tailed deer (*Odocoileus virginianus*) resulting in populations carrying high rates of these parasites that are relatively harmless to them. However, they can pass this parasite on to moose (*A. alces*) and woodland caribou through the consumption of contaminated feed plants near deer feces. Meningeal brain worm causes neurological issues and is invariably fatal once passed to these species (Anderson and Strelive, 1968; Cumming, 1992).

With climate change, if more deer move into woodland caribou range, we can expect to see more cases of meningeal brain worm in caribou. Bergerud and Mercer found that caribou introductions were likely to fail in areas where white-tailed deer are currently present or have been recently present. Caribou introductions failed on Anticosti Island, Cape Breton, Red Lake, and Mt. Katahdin partially because woodland caribou spring habitat overlapped with that of white-tailed deer resulting in meningeal brain worm infections in the woodland caribou populations (Bergerud and Mercer, 1989).

Culling moose and deer in areas near caribou habitat might help decrease wolf predation and help prevent the spread of meningeal brain worm to caribou. This culling could be organized by wildlife managers but carried out by regular citizens through expanded hunting permitting. It would allow people to hunt moose and white-tailed at higher rates to achieve woodland caribou conservation goals in localized settings. However, many local community members along the Canadian shore of Lake Superior oppose deer and moose culls because hunts for those deer species bring valuable economic development to their communities.

Alternative 4: Restoration

The fourth policy alternative involves habitat restoration and protection through the removal of forestry roads, railways, transmission corridors, and other linear disturbances that fracture woodland caribou habitat or the limitation of new linear development in woodland caribou habitat. Linear disturbances bisect forests and other portions of woodland caribou habitat. This causes habitat loss and fragmentation where that habitat is no longer a large continuous space, but now it has been broken into two or more patches of habitat that are separated by these linear disturbances.

Linear disturbances such as these allow for easier predator access to caribou. In areas where gray wolf habitat overlaps with caribou habitat, they often are more likely to use anthropogenic linear disturbances than natural ones to more easily access prey like ungulates (Newton et al., 2017). This results in increased predation risk by caribou that are closer to linear disturbances (James and Staurt-Smith, 2000). Caribou typically avoid linear disturbances at an increased distance due to this risk (Nellemann et al., 2001; Dyer et al., 2002; Latham, 2009; Williamson-Ehlers, 2012). By removing some of these linear disturbances and working to decrease future development of linear features in woodland caribou habitat, vegetation could regrow connecting fractured habitat over time, and predators will no longer have a human-made advantage in preying upon woodland caribou.

Alternative 5: Do nothing; allow nature to take its course

The final policy alternative is to stop trying to rescue fragmented woodland caribou populations and allow them to be extirpated in the Upper Great Lakes. Some advocates see this as “letting nature take its course,” while others belief limited conservation resources should be focused on species with a greater chance of survival. In particular, if woodland caribou are likely to be driven extinct by climate change, as some observers believe, then investing efforts into their short-term survival appears pointless (Langston, 2021).

3.5 SYNTHESIS OF STAKEHOLDER PERSPECTIVES

In this section, we describe the policy views of different stakeholders in woodland caribou conservation within the Lake Superior region, to help understand stakeholder beliefs. We explore shared core beliefs and divergent beliefs, and identify specific areas where groups agree on common perspectives.

We found that stakeholders generally advocate for either passive restoration beliefs or active restoration beliefs (Table 1). Those with primarily active restoration beliefs generally favors active translocations, with the possibility of predator or moose/white-tailed deer culls where appropriate. Those with primarily passive restoration beliefs oppose habitat restoration as a recovery option but agree that translocations can be necessary under certain conditions. Many within this belief group favor the option of doing nothing for the time being. Their perspectives on possible woodland caribou recovery options are worth considering to better understand potential key considerations for policymakers. Individuals within these common belief groups have different individual beliefs depending on the recovery option being proposed.

Table 1. Primary beliefs of stakeholders within the Lake Superior woodland caribou subsystem.

Primary Beliefs	Passive Recovery	Active Recovery
Wildlife conservation in general is valuable	Yes	Yes
Lake Superior caribou are on the verge of extirpation	Yes	Yes
Canada should invest more in Lake Superior recovery efforts	No	Yes
Caribou should be reestablished on Michipicoten Island	No	Yes
A mainland population should be reestablished on the North Shore	No	Yes
Undisturbed migration corridors should be established linking Lake Superior caribou to the continuous populations	No	Yes
We should accept defeat with this woodland caribou population and move on from decades of failed recovery efforts	Yes	No
Sufficient scientific data exists to confirm that Lake Superior caribou are genetically distinct from other populations	No	Yes

Wolf culls are extremely contentious management tools and debate over their use differs greatly inside coalitions. Environmentalists have mixed feelings on their use with some arguing that sacrifices must be made to meet specific species conservation goals, while others feel that nature should take its course and that we should not harm another important ecological species for caribou conservation. When we spoke with a group of retired Ontario Ministry of Natural Resources and Forestry employees, they argued that wolf culls were viable tools shown to be useful in localized management scenarios.

However, they also stressed the importance of not simply relying on predator control because wolves are only the proximate source of the decline. To effectively encourage recovery, they argue that wolf culls need to be used in combination with other management tools to tackle the ultimate causes of decline (Interviews, 2021).

Chief Duncan Michano of the *Biigtigong Nishnaabeg* (Ojibways of the Pic River) First Nation expressed frustration with inaction on wolf culls after they have gotten onto the Slate Islands in 1994 and Michipicoten Island in 2017. He explained that people in his community view wolf culls as a viable and often essential management tool in some situations. He argues that “relocation simply pushes the problem from one area to another where there might already be established wolf communities with their territorial ranges. By moving additional wolves into already established wolf territories, you cause ecological problems there too” (Personal Interviews, 2021). He continues “There must be policies for wolf management in place on islands with isolated populations, wolves cannot be allowed to stay on these islands when they make it out to them (Personal Inerview, 2021). He also stressed that wolves should not be demonized when “humans are ultimately responsible for the situation that caribou populations are in (Personal Interview, 2021).

Translocations are generally the least controversial of the four proposed recovery management options. The active restoration coalition broadly supports the use of translocations to suitable recovery sites. Many parties including hunters and even industry members support translocations as well. The group of retired ministry biologists expressed that they would like to see translocations continue even in the absence of predator pressures because of the islands that these caribou are on act like natural pens. After so many years in a predator-free environment, these caribou populations will exceed the carrying capacity of these small islands leading to starvation for the entire population. They would like to see woodland caribou translocated from the Slate Islands and Caribou Island moved back to Michipicoten Island and potentially reestablish a mainland population in Pukaskwa National Park before their carrying capacities are reached.

Chief Michano echoed these hopes saying that “ Pukaskwa National Park is the least disturbed portion of the north shore and it has had time for its forest to age (Personal Interview, 2021) since it was incorporated. and added that he would like to see Indigenous communities gain access to a limited hunt to help maintain cultural ties and promote Indigenous interest in woodland caribou conservation once self-sustainable populations have been established.

Business interests such as NextBridge Infrastructure have recently shown interest in using translocations to offset the potential impacts of twinning hydro lines north of Lake Superior in woodland caribou habitat. They proposed funding a series of three translocations. The first would move caribou to the area where they are doing the construction to bolster any remaining mainland stragglers. The second would move caribou back to Michipicoten Island where they had thrived until wolves crossed on an ice bridge. This would need to wait until all wolves are off the island. The third translocation would fund a coastal mainland translocation around Pukaskwa National Park (Bisset, 2022).

Even though NextBridge Infrastructure proposed to fund these projects, the Ontario Ministry of Natural Resources and Forestry (MNRF) and Species at Risk Canada declined to allow these translocations to take place, stating the need for a full environmental assessment process. While they forbade the two proposed mainland translocations, the Ministry did agree to allow NextBridge to fund a single translocation of caribou back to Michipicoten Island in late 2022 (Bisset, 2022). The Ministry supports translocations but says that its primary goal is to maintain the Lake Superior woodland caribou population where they have been in recent history (Ontario Woodland Caribou Recovery Team, 2008). Re-establishing a population on Michipicoten Island seems to be their priority. The apprehension to agree to re-establishing three populations most likely comes down to limited time and too few resources available to handle such a lofty series of reintroduction attempts. Current Ministry biologists argue that Michipicoten may not be the best place for re-establishment of caribou because of secondary prey sources available for predators on Michipicoten Island that are not present on other islands like the Slate islands. Retired ministry Biologist Gordon Eason argues that this is not a significant issue and that the more pressing matter is “to reestablish another population in the region to limit the effects of exceeding the carrying capacities on the Slate Islands and Caribou Island (Personal Communication, 2021).” Before this can happen all wolves need to be confirmed to be gone on Michipicoten to ensure possible success.

White-tailed deer and moose culls are an uncommon, but proposed recovery option for woodland caribou (Serrouya, 2013). Most Indigenous communities do not approve of these methods of management because many individuals within these remote northern communities still rely on hunting for sustenance. Many are not willing to sacrifice their current hunts of deer and moose, because it might be years before a woodland caribou population could be hunted. Many settler hunters feel the same way about this issue and are happy to hunt to the moose and white-tailed deer populations available to them currently. Brian McLaren argues that “more lenient hunting restrictions could allow greater moose and white-tailed deer control by managing them at the sub-unit level and offering government funded boat or helicopter trips to encourage participation by hunters (Personal Interviews, 2021). This could encourage increased hunting of these species to meet specified management goals for woodland caribou inside a sub-unit.

Habitat restoration and protection in woodland caribou habitat is highly controversial. Industry groups oppose against this management tool because it would lead to economic losses in the short term and limited growth potential in the long term. The group of retired ministry biologists supports habitat restoration and protection. However, they are aware that the provincial and federal governments are under financial pressure from industry groups to compromise on these issues. Chief Michano proposes that habitat restoration must occur on a smaller scale for a future translocation to the mainland around Pukaskwa National Park to be successful. He argues that “hiking trails and water boating trails along the shoreline must be eliminated or managed in a way that will decrease both human and predator access to woodland caribou along the shoreline (Personal Interview, 2021)" that they will need to use the many offshore rocky islands as escape refugia. The Ontario Ministry of Natural Resources and Forestry supports habitat restoration, but not necessarily the removal of existing infrastructure due to political pressures faced by other stakeholders (Ontario Woodland Caribou Recovery Team, 2008). Stakeholders like Brian McLaren "would like to see continued use of wildlife overpasses across the Transcanada Highway and restoration of conifer forests along the north shore" (Personal Interview, 2021).

Chief Duncan Michano of the *Biigtigong Nishnaabeg* (Ojibways of the Pic River) explained that his community and the *Michipigodong/ Mishibikwadinaang* (Michipicoten) were "working together to create management plans for woodland caribou on each First Nation's respective territorial claim" A major goal of these co-created conservation plans is to address infrastructure in these areas that has allowed for increased predation access by predators. This is an example of two stakeholder groups working together without the prompting of government processes to work for the recovery of woodland caribou in the Lake Superior region. Chief Michano would like to see "Indigenous parks established in the region where land is set aside for conservation purposes (Personal Interview, 2021). This would allow First Nation's in the region to play a more active role in woodland caribou recovery.

3.5.1 DISCUSSION AND CONCLUSION

This stakeholder synthesis shows the diversity of beliefs between stakeholders involved in woodland caribou recovery in the Lake Superior region. However, even among like thinking groups there are individual belief differences that can allow for compromises to be made on Lake Superior woodland caribou recovery.

Woodland caribou in the Lake Superior discontinuous population currently only consists of 50-60 individuals spilt between the Slate Islands and Caribou Island. These caribou have only been able to persist to this point because humans have intervened using emergency translocations that have allowed the population to persist. These caribou are currently nearing the estimated carrying capacities of these islands, threatening them with potential starvation. Additional translocations will be required to other suitable caribou habitat in the region to avoid this.

The support of stakeholders is key to ensure future population recovery actions are taken. However, not all stakeholders in the region want to see recovery options occur and each stakeholder holds different beliefs on each recovery option. A stakeholder synthesis was conducted to better understand these beliefs and how they differ between stakeholders. Semi-formal interviews with stakeholders were conducted along Lake Superior's north Shore. A literature review was also performed to add to the understanding of stakeholders in the region.

The findings of our stakeholder synthesis help to illustrate some of the complex beliefs that stakeholder in the Lake Superior region have on available woodland caribou recovery options. Although no easy solutions for this problem exists, this synthesis reveals areas of potential compromise between stakeholders who are often in opposition when it comes to beliefs on whether they primarily support passive or active restoration.

For future recovery efforts to take place, compromises are going to have to be made between stakeholders possessing traditionally opposing beliefs. We urge the Ontario Ministry of Natural Resources and Forestry, Species at Risk Canada, and Environment and Climate Change Canada to include these stakeholders as much as possible in future recovery planning and efforts. By effectively listening to and incorporating the beliefs and concerns of stakeholders into future management strategies compromises can be made enabling a possible route for the future recovery efforts for the Lake Superior discontinuous population of woodland caribou.

In conclusion, this thesis has explored factors associated with the historic decline of woodland caribou in the Lake Superior region. An HGIS analysis was performed to better understand historic influences of mining, railways, wetlands, and protected areas on woodland caribou persistence. A stakeholder synthesis was conducted to complement this historic understanding of caribou decline, by synthesizing the beliefs of stakeholders in the region on recovery options available for future recovery efforts.

Some of the key points to take away from this thesis are that the loss of Indigenous land and subsequent growth of European settler populations in the region was core to woodland caribou's initial decline in the early to mid-1800s. Our HGIS analysis indicates that mining sites and railway networks have historically been associated with woodland caribou extirpation, while protected areas and wetlands were statistically associated with caribou persistence. Finally, the stakeholder synthesis has shown that areas of compromises might be found between key stakeholders within the region.

Wildlife managers and policy makers should consider the results of this HGIS analysis when future mining or railway development are proposed within woodland caribou habitat. At high densities these have been historically bad for caribou persistence. Wetlands should be prioritized for protection and restoration within caribou habitat because these have historically been key refugia for caribou. Parks and protected areas have been historically associated with caribou persistence. Finally, stakeholders in the region must be included if compromises are to be made enabling future recovery efforts aimed at helping the Lake Superior woodland caribou population persist.

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Figure 2.1 “Sight Records of Woodland Caribou in Ontario 1944-1950” by de Vos and Peterson. Via- de Vos, A., & Peterson, R. L. (1951). A Review of the Status of Woodland Caribou (Rangifer caribou) in Ontario. *Journal of Mammalogy*, *32*(3), 329–337.

Figure 2.2: “Relative Abundance of Woodland Caribou in Ontario 1948-1949” by de Vos and Peterson. Via- de Vos, A., & Peterson, R. L. (1951). A Review of the Status of Woodland Caribou (Rangifer caribou) in Ontario. *Journal of Mammalogy*, *32*(3), 329–337.

Figure 2.3: “Trends in Population of Woodland Caribou in Ontario 1948-1949” by de Vos and Peterson. Via- de Vos, A., & Peterson, R. L. (1951). A Review of the Status of Woodland Caribou (Rangifer caribou) in Ontario. *Journal of Mammalogy*, *32*(3), 329–337.

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