When ‘Perma’ Is No Longer ‘Perma’: Investigating Permafrost Degradation in Churchill, Manitoba

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Abstract

This major paper explores the physical, economic, and cultural consequences of thawing permafrost in Churchill, Manitoba. By analysing a combination of texts and permafrost data, this paper examines how permafrost degradation will reshape Churchill's make up in future years. The research questions I address are as follows: (1) To what extent is permafrost thawing in Churchill, Manitoba? (2) What are the implications of thawing permafrost in Churchill, Manitoba? Specifically: (a) How does thawing permafrost affect economic activity (primarily ecotourism) in Churchill? (b) In what ways does thawing permafrost affect the cultural practices of Churchill's Indigenous population (Chipewyan, Swampy Cree, Métis, Dene, and Inuit)?

Finding suggests that at least a quarter of Churchill's continuous permafrost will degrade in the next fifty years and may completely disappear by the end of the century (Gagnon & Gough, 2005; Gough & Leung, 2002). The extent of this thaw creates a positive feedback loop with Churchill's industries, further threatening the sustainability of the town's activities and ground stability. This paper concludes with recommendations for future research on how to move forward as a town in transition.

Keywords: Periglacial geography, permafrost, Churchill, northern community development, subarctic environments

Foreword

This Major Research Paper is a contribution to, and culmination of two years of studies in the Master of Environmental Studies (MES) program at York University. The guiding document of my MES program was my Plan of Study (POS) which outlines students' area of concentration, learning objectives and learning strategies. I identified three components structuring my area of concentration, which drive this research paper.

Permafrost: Exploring this rapidly changing component of the cryosphere was central to understanding the transition Churchill will soon face. To support this component, I took ENVS 6179 Climate Change: Science and Policy in the Fall of 2018 to better understand current and projected consequences of climate change. In the winter semester of 2019, I took ENVS 5112 Ecology in Environmental Studies to support my understanding of permafrost's role within an ecosystem, as well as ENVS 6182 Quantitative Research Methods to aid in my analysis and understanding of permafrost degradation data. I completed an independent directed study on the topic of periglacial geography with Peter Timmerman in the summer of 2019 and took ENVS 4447 Northern Ecosystems in the fall of 2019.

Churchill: The site of the case study explored in this paper is Churchill, Manitoba, an ecoregion treasure at the junction of the boreal forest, the Arctic tundra, and the Hudson Bay. To support this component, I took ENVS 6115 Ecological Economics in the fall of 2018 to expand my understanding of the environment's importance in Churchill's economy. I also took ENVS 5011 Food, Land and Culture in the fall of 2018 to better understand the subject of Indigenous food sovereignty and traditional land practices, which are threatened as permafrost thaws in Churchill.

I also completed an independent directed study on the history of Churchill with Peter Timmerman in the summer of 2019.

Qualitative Methodologies: Prior to the COVID-19 pandemic, I had planned on conducting semi-structured interviews in Churchill to better understand the implications that thawing permafrost has on daily lives and livelihoods. To develop my understanding of qualitative methodologies, including research design, interview structures, data management and analysis I took ENVS 6183 Qualitative Research Methods and ENVS 6152 Reshaping Research with Aboriginal People in the Winter of 2019. While travel and my research interviews in Churchill were ultimately cancelled, these courses aided in preparing me for literature review.

Overview

Chapter 1 presents the research context that will inform the Major Research Paper. Here I offer fist a history of Churchill, Manitoba and explain the development of the town's industries. Next, I provide an introduction to permafrost and introduce factors that influence its development and global spread.

Chapter 2 focuses on methodology. I outline my research plan and necessary research recalculations after the COVID-19 pandemic.

Chapter 3 examines patterns of permafrost degradation globally and locally in Churchill, before identifying physical factors and consequences of permafrost thaw.

Chapter 4 examines the economic implications of Churchill's permafrost that, starting with the significance of the town's train line, and the train line's importance to the reopening and diversification of Churchill's Arctic port. Next, Churchill's ecotourism activities and their relationship with permafrost are reviewed.

Chapter 5 looks at the cultural implications of Churchill's permafrost thaw, specifically addressing access to hunting and culturally appropriate food.

In the conclusion, I summarize the premises and outcomes of the major paper. I address limits due to insufficient data and provide recommendations for future research.

Key Terms

Active layer: The top layer of permafrost ground that thaws and becomes cryotic with seasonal variability.

Continuous Permafrost: Permafrost zones where 90-100% of the earth contains permafrost.

Cryotic: Soil or rock at temperatures of 0˚C or lower.

Discontinuous Permafrost: Permafrost zones where 50-90% of the earth contains permafrost.

Isolated Permafrost: Permafrost zones with less than 10% permafrost coverage.

Permafrost: Ground with a temperature that remains at or below 0˚C for two or more years.

Sporadic Permafrost: Permafrost zones where 10-50% of the earth contains permafrost.

Talik: A layer of body of non-cryotic ground that occurs in permafrost.

Thermokarst pond: Shallow bodies of water that occur when ice-rich permafrost thaw and release moisture which then occupies the depression formed by the ground settlement

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My education has always been a team endeavour. I am so thankful for the support of my community and am glad for the opportunity to express that here.

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Finally, thank you to Peter who helped guide me through my two years at York, and to Greg for all of his support in this project.

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Chapter 1: Research Context

1.1 History of Churchill, Manitoba

Positioned at the junction of the boreal forest, the Arctic tundra, the Churchill River and the Hudson Bay, Churchill, Manitoba is a Canadian ecoregion treasure. Situated on the 58th parallel north, Churchill and its nearly 1,000 residents are far from any other settlements and can only be reached by plane, train, or boat, as there are no roads leading to Churchill. Despite the size of the town, Churchill holds a big history and a significant presence in Canada.

Figure 1: Location of Churchill, Manitoba
Image retrieved from World Easy Guides (n.d).

1.1.1 Indigenous and First European Contact

1700 B.C – 1620 A.D.

Oral histories recount that the first residents of what is now Churchill were Pre-Dorset peoples, a group of Paleo-Eskimo peoples, around 1700 B.C. (Brandson, 1994). The Pre-Dorset peoples lived a semi-nomadic lifestyle and would travel southward to this area to hunt caribou in the summer and ringed seal in the winter. Around the year 600 B.C. Dorset peoples, successors of the Pre-Dorset peoples, arrived in today's Churchill (Struzik, 2014). The Dorset peoples were members of the Arctic Small Tool tradition (ASTt), a cultural group that developed along the Alaska Peninsula and arctic Canada, who used a distinctive toolkit fitted with a microblade (Brandson, 1994). They were later displaced by the Thule peoples, Inuit ancestors, who arrived from the west around 1000 A.D. (Struzik, 2014) It is believed that by the 1500s the Inuit, Dene and Cree in northern Manitoba had established strong trading networks.

Europeans first made contact with Churchill on September 7, 1619, when a Danish expedition entered the Churchill River on the west coast of the Hudson Bay (Struzik, 2014). The expedition was led by Jens Munk and was made up of 64 men who sought to discover the Northwest Passage. Their two ships, the Unicorn and the Lamprey, were forced to winter in the mouth of the Churchill River and Munk's men succumbed to disease and starvation. Only Munk and two others survived the winter and made it home the following year (Struzik, 2014). A harbour at the mouth of the Churchill River in Hudson Bay was named Munk Harbour in recognition of the explorer.

In 1688 the Hudson's Bay Company attempted to establish their first permanent settlement in Churchill at the same site as where Munk and his crew wintered years before. However, the company temporarily abandoned the project as the post burned down in 1689. The company's second attempt in 1717 proved fruitful and the Hudson's Bay Company opened a log fort post eight kilometers upstream from the mouth of the Churchill River. This placed the post approximately 200 kilometers northwest of the York Factory, another settlement, and Hudson's Bay Company trading post at the mouth of the Hayes River in Manitoba (Selwood, 2012). The intention behind the new post was to "attract the Northern Indians to the fur trade" (Bussidor & Bilgen-Reinart 2002). The post was named the Churchill River Post in honour of Lord Churchill, who later became the first duke of Marlborough (Selwood, 2012). However, in 1718 Governor James Knight, the Chief Factor for the Hudson Bay Company, requested a new name for the post. The Governor and London Committee chose 'Prince of Wales Fort' in honor of the British royal family (Parks Canada, 2017). Trades at the Churchill River Post predominantly involved fur from the Sayisi Dene peoples, and the Europeans relied heavily on the caribou meat at the Sayisi Dene provided (Bussidor & Bilgen-Reinart, 2002). This contact was not without severe consequences for the Sayisi Dene; during the eighteenth century the population of Sayisi Dene peoples throughout the Canadian Northwest was substantially reduced from epidemics of chicken pox, scarlet fever, smallpox, cholera, influenza and the whooping coughs (Bussidor & Bilgen-Reinart 2002). Bussidor and Bilgen-Reinart cite Samuel Hearne as stating that "nine-tenths of the Northern Indians died from diseases introduced by the Europeans" (2002).

The uneasy peace between England and France in the 1720s led to the Hudson Bay Company moving the post, for fear of attack. In 1730 a small peninsula called Eskimo Point at the entrance of the Churchill River was chosen for the new stone post dubbed Prince of Wales Fort II. As the water at the mouth of the river was only 640 meters wide the fort was "considered to be quite defensible" (Parks Canada, 2017). In 1731 twenty-four Englishmen began construction on the new fort which ultimately took more than 40 years to build because of the short building season and sheer size of the fort. In 1782 the French invaded Prince of Wales Fort, greatly outnumbering Samuel Hearne and his 31 men. Hearne and his men surrendered without firing a single shot and were granted passage back to England (Parks Canada, 2017). In 1783 Hearne returned to Churchill to establish a new fort upriver; it became a stable trading post but was never lucrative because of the continuing presence of the Hudson Bay Company. The nature of the fur trade changed over the next several decades; when American whalers began sailing into the Hudson Bay in 1860 their growing interest in polar bears was not for their hides, but rather for sport and huntsman souvenirs (Struzik, 2014) By 1910, non-Indigenous trappers arrived with the intention of harvesting insatiable numbers of pelts. At the demand of the Hudson Bay Company to regulate the fur trade, the federal government passed the North West Game Act in 1917 to prohibit the hunting of some animals and setting limitations for others (Bussidor & Bilgen Reinart, 2002).

The Hudson's Bay Company sold Rupert's Land to Canada in 1870 and soon after signed five different treaties with Indigenous peoples in southern Manitoba. At the time, the government was focusing on opening the prairies for settlement and did not pay considerable attention towards northern Manitoba, as it was considered too harsh for settlement and to not be of much economic value (Bussidor & Bilgen-Reinart, 2002). Therefore, despite repeated requests from northern Indigenous leaders, the process of signing treaties with northern Indigenous peoples did not start for another 30 years.

1.1.2 Military Presence in Churchill

1900 – 1985

By the end of the nineteenth century the idea of creating a shipping harbour in Hudson Bay was becoming popular as a way to have a more direct route to Europe and stake Canadian claim in the Arctic (Gilmore, 2018). Initially in 1912, Port Nelson was chosen to house the new shipping harbour, but the project was abandoned, and Churchill was chosen as the new build-site after the First World War (Bussidor & Bilgen-Renart, 2002). In 1928 the railway finally reached Churchill and a port and grain elevator were built (Bussidor & Bilgen-Reinart, 2002). The port began shipping grain in 1931, primarily to European markets (Gilmore, 2018). The port was dependent on grain from the Canadian Wheat Board, as 90% of the port's business was wheat (Gilmore, 2018). Bussidor and Bilgen-Reinart estimate that employment opportunities at the port brought up to 3,500 men in the summer, while 50 people or less would remain in the winter months to work for the Hudson Bay Company, as Anglican missionaries, or RCMP officers (2002).

The Second World War brought about significant change for the Canadian North. When the United States entered the war in 1941 Churchill became an important strategic zone for the forces. With Canada's permission in 1942 the United States Army Air Corps built the Fort Churchill military centre which included an airstrip and living quarters eight kilometres east of Churchill (Bussidor & Bilgen-Reinart, 2002). The United States Army began their First Army

Test Detachment in 1947, the same year that the Canadian Defense Research Board began a northern laboratory at Fort Churchill to weather test equipment for both militaries (Taylor, 2002). Thousands of military personnel arrived in Churchill at this time, disrupting the wildlife and social relations of the town (Bussidor & Bilgen-Reinart, 2002). After the Second World War the United States Army constructed a Strategic Air Command (SAC) base at Churchill to support northern monitoring stations, and as the military began pulling out of Churchill the airstrip became the town's airport, Churchill Airport (Struzik, 2014). The military formally left Churchill in 1964 (Taylor, 2002).

As military presence dwindled in the 1950s Churchill was actively thought of as a wasteland only suitable for trapping and hunting (Struzik, 2014). This thought brought Churchill to the attention of Canada's Defence Research Board, which added Churchill and surrounding area to a list of sites where 12 Hiroshima-sized atomic bombs might be tested. Ultimately, the atomic bombs were not tested in this area, as it was thought that northern Canada would be too uncomfortable for the scientists involved with the project (Struzik, 2014).

In 1954 the same Defence Research Board built the Churchill Rocket Research Range 23 kilometres outside of Churchill. The military presence at Fort Churchill was a key factor in the selection of the site as the base provided the necessary infrastructure and logistical support and linked the research with the military. However, the location's high aurora activity was another significant motivator (Taylor, 2002). After a brief shut down in 1955, the International Geophysical Year reopened the site from 1956-1958 to use the site to study the upper atmosphere with sub-orbital launches of sounding rockets (Taylor, 2002). The United States

Army later used the site to test sounding rockets and new solid fuel propellant systems before fire destroyed much of the facility in the late 1960s. After a rebuild the Canadian National Research Council used the site during the 1970s and 1980s until its closure in 1985 (Taylor, 2002). Afterwards, the Churchill Northern Studies Centre developed their field station on the rocket range. They now operate year-round with nine full-time staff and four-ten part-time or seasonal employees, and host 100-175 researchers each year (Churchill Northern Studies Centre, 2018).

1.1.3 Relocation of the Sayisi Dene to Churchill

1950 – 1970

The Dene peoples have historically lived in the sub-Arctic region extending north and west from Hudson Bay to the Mackenzie Valley and the Great Bear/Great Slave Lakes (Bussidor & Bilgen-Reinart 2002). "Sayisi" means "the people from the east" in Dene and is the name for the Dene community who lived on the eastern edge. The nomadic Sayisi Dene lived between the open tundra and the tree line along the Churchill River, moving with the caribou herds each winter and summer. Caribou were of great importance: women dried and smoked the meat, fat was used for cooking and lanterns, sinew and hide were used to make clothes, snowshoes, teepees, bones were used as tools (Bussidor & Bilgen Reinart, 2002). In the winter, as many caribou as possible were killed and any carcasses that were not immediately needed would be kept frozen in snow, saved for times of need (Bussidor & Bilgen Reinart, 2002).

As interest grew in northern Manitoba's economic potential at the beginning of the twentieth century the government offered an adhesion to Treaty Five for northern Indigenous peoples to sign. The Sayisi Dene, who were one of the last northern Indigenous peoples to sign the adhesion, signed on August 1, 1910 at Fort Prince of Wales. The treaty was poorly communicated; it contained words and concepts for which the Dene language has no equivalent, like rights, title, privilege, acre, longitude, latitude (Bussidor & Bilgen Reinart 2002). The Sayisi Dene expressed concern over their traditional lifestyles and ability to hunt to which the commissioner, former Methodist missionary Rev. John Semmens, responded "not for many years to come, probably not in the lifetime of any of them, would their hunting right be interfered with" (Bussidor & Bilgen Reinart 2002). The Dominion of Canada then laid claim to the resources of the Sayisi Dene homeland in exchange for a visit by a doctor and five dollars per adult annually (Bussidor & Bilgen Reinart, 2002). The treaty did not have immediate effect on the Sayisi Dene aside from the celebration of Treaty Day each year, where the Sayisi Dene would gather at Fort Prince of Wales near Churchill to celebrate and receive treaty money and some food provisions.

In 1951 the Government of Canada adopted a new Indian Act which openly aimed for assimilation and as early as 1953 plans were being developed to move the Sayisi Dene out of their traditional lands (Bussidor & Bilgen-Reinart, 2002). There was a meeting about the relocation on Treaty Day in July 1956, where the Sayisi Dene were promised more services if they were to move to Churchill (Bussidor & Bilgen-Reinart, 2002). Chief Artie Cheekie responded: "Our people are here because the caribou come here. There are plenty of fish on these connecting lakes and that's why this trading post was built here, to be near us. What is there for us to live on in Churchill?" (Bussidor & Bilgen-Reinart, 2002). Still, a military aircraft arrived on August 17, 1956 to move the Sayisi Dene population from Duck Lake to Churchill. The first flight moved 58 people and 73 dogs, and subsequent army trucks moved the rest of the population of 250-300 people (Bussidor & Bilgen-Reinart, 2002). Chief Cheekie again raised concerns over the relocation with government officials when at a meeting in The Pas a month after the move. Government representatives expressed interest in exploring the North River area for relocation, however its banks flooded in 1957, forcing the community to stay put in Churchill.

By the 1950s, Churchill had developed a stable population of non-Indigenous, Cree, Metis and Inuit peoples who were in Churchill as military personnel, government officials, port and elevator workers, or entrepreneurs. Until their relocation, the Sayisi Dene had been isolated from the Churchill community, and the group quickly ended up in the margins of Churchill's society. The Sayisi Dene were referred to as "Indian Squatters", "a serious Public Health problem", and their dogs were considered a nuisance and rabies threat, so were shot by the RCMP (Bussidor & Bilgen-Reinart 2002). Without dogs, the Sayisi Dene would no longer travel trap lines.

By the summer of 1957, 300 Sayisi Dene were living in Churchill, and in 1958 the Department of Indian Affairs finally built cabins for the community. The neighbourhood, called Camp-10, was built a couple of kilometres from the eastern limits of Churchill, close to the Churchill cemetery. The neighbourhood had no source of fresh water, very little coal and no kindling, an occasional garbage truck, and many difficulties with snowfall, including challenges opening housing doors (Bussidor & Bilgen-Reinart, 2002). Quite notably however, is the proximity of the neighbourhood to the cemetery. The Sayisi Dene greatly respect the spirits of the dead and believe that a burial ground is not to be disturbed. Furthermore, Camp-10 was situated on a polar bear path and no firearms were allowed in the neighbourhood. Bussidor and Bilgen-Reinart explain that poverty, loss, and a sense of powerlessness drove most of the adults at Camp-10 to alcohol (2002). Alcohol abuse and an unfamiliarity with store-bought food and preparation resulted in kids and adults constantly scrounging in the Churchill garbage dump.

In 1966 Indian Affairs began making plans to move the Sayisi Dene to better accommodations in the Churchill area. Indian Affairs chose to build Dene Village five kilometres southeast of Churchill, and styled the new houses on cheap southern, suburban homes. The new neighbourhood was built on muskeg that never drained and according to Phil Dickman, a community development worker, the community was designed in a way to increase interpersonal-tensions as "putting the houses close together has severely aggravated the adjustment problems of people who were accustomed to living out of sight of one another" (Bussidor & Bilgen-Reinart 2002). Bussidor and Bilgen-Reinart stated that "the settlement was like a war zone. In Dene Village, the loud noises of people fighting, and shouting would start in the early evening. It was like a war" (2002). Families began moving to Dene village in the fall of 1967. Death rates accelerated after the move as tuberculosis, malnutrition, house fires, river drownings, beatings/stabbings, sexual assault, and freezing to death were common. Family breakdown and social disintegration also accelerated; the Dene population made up 5% of Churchill's population, but 75% of police activity, and nearly all of the school truancy (Bussidor & Bilgen, 2002). By 1971 families began deciding to move away from Churchill and return to the land, however Bussidor and Bilgen-Reinart acknowledge that the trauma of the forced relocation is long lasting (2002).

1.1.4 Becoming the Polar Bear Capital of the World

1970 – Present

While the Sayisi Dene's housing communities were undeniably extremely rough and poorly planned, Churchill's other residents also experienced poor housing conditions. Struzik explains that these houses were bare-framed shacks "with additions that had been slapped on without any observance to municipal codes" (2014). Water was sent into residential areas and stored in fuel drums, and that the lack of sewage meant that honey buckets, chemical toilets and outhouses were used but often resulted in raw sewage floating down the street during the spring thaw (Struzik, 2014). Heat sources included oil, coal and woodstoves that would not have met safety standards, and Struzik claims that "voluntary firefighters were busier than they would have been in any other rural community" (2014). At this point in time, the 1960s, bear threats were common and bear attacks were not rare (Struzik, 2014). There was a tumultuous relationship between residents of Churchill and the town's bears; the bears were thought of as "rats of the north" and were shot to be killed when they came into town (Struzik, 2014).

It became clear in the 1970s that a plan needed to be implemented to address the polar bear problem. In reflecting on the debate on what to do with the bears, Struzik recounts that it received significant international attention with an estimated 300 million people turned in to listen to the conversation (2014). Many suggested that Churchill's polar bears should be culled, while Churchill's first conservation officer Dale Cross and Brian Davies, the founder of the International Fund for Animal Welfare, suggested that problem bears be airlifted 200 kilometers outside of the community. There were concerns about the amount of money and effort being spent on moving the bears, while other groups were impressed by the humane conservation efforts. Ultimately, as groups such as IFAW were already combatting the Canadian government's 1970 decision to allow Inuit-guided sports hunts in the Northwest Territories and the International Agreement on the Conservation of Polar Bears was still being represented, Operation Bearlift was indeed conducted in 1972 (Struzik, 2014).

In 1975 Churchill was in the final stage of reconstructions to improve upon the town's living conditions. This included the decision that polar bear problem responders should be put into place permanently. One of the recommendations put forward by Roy Bukowsky, a wildlife specialist, suggested that the government lease or purchase a building at Fort Churchill called D-20, a military building due for demolition, so that problem bears could be held there. D-20 was indeed purchased for the coast of a dollar in the summer of 1978 with the condition that the province promised to dismantle it, remove the concrete pad, and landscape the area at the end of its usable life (Struzik, 2014). D-20 opened in 1979 as a polar bear holding facility, often called 'polar bear jail' to support a long-term polar bear management solution.

The relationship between Churchill, its bears, and tourism changed in the 1980s. Struzik states that as far as anyone can remember, the first instance of polar bear tourism was in 1972 when two American journalists arrived in Churchill looking for a chance to take photos (2014). Eventually, Dan Guravich, a freelance photographer from Greenville, Mississippi, approached Len Smith, a Churchill Shell gas station owner, and suggested he build a vehicle to help him get his photography equipment out onto the tundra (Struzik, 2014). Smith then assembled the first version of a Tundra Buggy, which he then called the Tundra Bus, using "a crankcase from a gravel truck, an engine from a snowplough, differentials from a front-end loader, seats from a school bus, and sixty-six-inch crop-spraying tires" (Struzik, 2014). The Tundra Buggy gave Guravich the idea of offering polar bear tours to larger groups, which he pitched to Victor Emanual, the owner of Texas-based Nature Tours Company. Emanuel agreed when the Canadian Department of Tourism offered to support a promotional tour in the autumn of 1980 (Struzik, 2014).

In 1981, National Geographic aired a one-hour show featuring E.G. Marshall and Academy Award winner Jason Robards, which marked a turning point for tourism in Churchill (Struzik, 2014). Soon after, media interest in Churchill's bears skyrocketed. Life Magazine and CBC's Fifth Estate both published pieces on Churchill's tourism, and Guravich and Richard C. Davids' published a book called *Lords of the Arctic*. Bonnie Chartier claims that it was really the National Geographic article that began bringing Churchill residents together in the tourism industry, and that "no one in Churchill really knew much about the tourism industry until National Geographic aired that program" (Struzik, 2014). Struzik writes that the tourism industry brought together non-Indigenous peoples and Cree, Chipewyan, Metis and Inuit entrepreneurs in a unique multicultural way (2014). Churchill's residents had a meeting at the Chamber of Commerce to formally discuss how the media attention could be harvested into a successful economic venture; many of the entrepreneurs made up a brochure for their establishment or tour, and everyone contributed "about $500 so that Penny Rawlings (Arctic Trading Company) could mail the flyers out" (Struzik, 2014). Within a few short years, Churchill's tourists grew from just a few hundred, to 3,000-4,000, to today's numbers of 10,000-14,000 (Struzik, 2014). Churchill is now known as the polar bear capital of the world.

Gilmore suggests that "the entrepreneurs and the researchers and tour guides will continue to keep towns like Churchill alive" (Gilmore, 2018). Indeed, in 2011 when Stephen Harper's Conservatives ended the Wheat Board monopoly, farmers began choosing less expensive shipping companies based in Thunder Bay or Vancouver. The decreasing shipping demand resulted in OmniTRAX closing Churchill's port and freight service in August 2016. Michael Spense, the mayor of Churchill, noted at the time that the port was responsible for 30% of the town's economy, but "luckily, the tourism sector accounts for at least twice that." (Gilmore, 2018). However, this begs the question of how the town so reliant upon ecotourism will fare as global climate change affects the permafrost and ultimately infrastructure and animal patterns their tourism industry so heavily relies upon.

1.2 Introduction to Permafrost

Permafrost is earth that is perennially cryotic, meaning that its temperature remains at or below 0˚C for two or more years (Brown & Kupsch, 1974; Van Everdingen, 1976). The term 'permafrost' was first defined in 1945 by S.W. Muller as shorthand for 'permanently frozen ground' (Brown, 1970), however this definition was later widely dismissed, as it was discovered that the freezing point of water in permafrost terrain may be depressed several degrees below zero, and that water may not be present at all (Brown & Kupsch, 1974). Brown and Kupsch introduced the terms 'cryotic' and 'noncryotic' to periglacial literature in 1974 to solve this major semantic problem (Harris et al., 1988). In this vein, permafrost is not considered 'frozen' and is described as 'thawing' and not 'melting' as it degrades. In addition to the varying quantities of ice, which can range from ice held within soil pores to pure ice many meters thick, permafrost material can consist of rock, sediment, and soil (National Snow & Ice Data Center, 2017). Permafrost is typically overlain by an 'active layer' which is the top layer of permafrost ground that thaws and becomes cryotic with seasonal variability and measures an average of 15-100 cm deep (Harris et al., 1988). The origin of permafrost is not well understood. The Intergovernmental Panel on Climate Change (IPCC) writes: "… Permafrost has not persisted throughout geological time but occurred rather sporadically without a discernable pattern" (1990). However, the majority of present-day permafrost is believed to have formed during the Pleistocene Epoch, ending 11,700 years ago (Brown, 1974) though evidence of permafrost has been dated as far back as 600 million bp (IPCC, 1990). There are two modes of permafrost formation: epigenetic and syngenetic (Vincent et al., 2017). Epigenetic permafrost occurs when pre-existing rock or previously deposited surface deposits become cryotic, typically in periods of significant climate shifts and cooling such as in the Glacial, Neo-glacial, and Little Ice Age periods (Vincent et al., 2017). Whereas syngenetic permafrost involves surface deposits accumulating under extremely cold conditions (Vincent et al., 2017).

Permafrost is classified based on its continuity into four zones: continuous, discontinuous, sporadic, and isolated zones. Continuous permafrost is classified as areas where 90-100% of the earth contains permafrost, and is generally found in areas with mean annual temperatures of less than -6˚C (Anisimov & Reneva, 2006; French, 1999; Lawrence & Slater, 2005). Discontinuous permafrost zones have 50-90% continuity, while sporadic zones have 10-50% continuity (Anisimov & Reneva, 2006; Lawrence & Slater, 2005). Areas with less than 10% permafrost coverage are considered isolated zones (Anisimov & Reneva, 2006; Lawrence & Slater, 2005). Permafrost in continuous zones can reach up to 1500 meters in depth, as seen in parts of Siberia, while permafrost may only be a few meters thick in sporadic and discontinuous areas (Arctic Monitoring and Assessment Programme [AMAP], 2004). There is a clear relationship between climate and the zonation of permafrost zones. In examining this, Shur and Jorgenson (2007) cite three types of climate, as first described by Shur and Ping in 1994: (1) climate favourable to permafrost (permafrost always present); (2) climate neutral to permafrost (permafrost can be present or absent); and (3) climate unfavourable to permafrost (permafrost absent). Shur and Jorgenson explain that climate favourable to permafrost characterizes the continuous permafrost zone, while climate neutral to permafrost characterizes the discontinuous zone (2007).

1.2.1 Factors Influencing Permafrost Distribution

Permafrost's presence is controlled by the energy balance at the ground surface (Canadian Permafrost Association, 2020). Permafrost's thermal regime is influenced by factors such as topography, surface water and groundwater, soil properties, vegetation, and snow accumulation (Jorgenson et al., 2010). Jorgenson et al. write that "There are numerous interactions among these ecological components that can lead to both positive and negative feedbacks to permafrost stability." (2010). The interacting factors affecting permafrost's presence and stability can be categorized into climatic or terrain factors. Harris et al. explain that climatic factors control the temperature and duration of heat on the earth's surface, and include altitude, latitude, longitude, and air mass movement patterns (2017). Terrain factors include vegetation, topography, hydrology, and substrate. Harris et al. write that "The climatic factors are dominant in areas of continuous permafrost, wherein the terrain factors increase in importance as the percentage of ground underlain by permafrost decreased" (2017).

The interaction of these factors direct Shur and Jorgenson's (2007) five patterns of permafrost formation: (1) climate driven permafrost: which develops in the continuous permafrost zone under cool temperatures; (2) climate driven, ecosystem modified permafrost: which develops when the collection of organic maters supports the formation of an ice rich layer, supporting permafrost's development; (3) climate-driven, ecosystem protected permafrost: which is maintained by the ecosystem around it, but could not develop again in the same circumstances; (4) ecosystem driven permafrost: which depends on a number of ecological features; and (5) ecosystem protected permafrost: which could not develop again in the same circumstance.

1.2.1.1 Climatic Factors

Harris et al. first identify latitude as a significant factor that influences permafrost distribution. As latitude determines the range of angles of incidence and solar radiation, it is understood that "the potential amount decreases towards to poles, intensifying cooling in winter, and reduces the effectiveness of the low-angle sun in the summer." (Harris et al., 2017). They explain that altitude affects the distribution of permafrost as air becomes colder with increasing altitude: this is called the lapse rate, and the average near-surface lapse rate is -1.6°/100 m rise in altitude (Harris et al., 2017). Next, they point to the significance of longitude as it influences eastward or westward movement of air masses. Specifically, permafrost distribution is closely related to the Arctic, Antarctic, and polar air masses. Harris et al. write "These air masses are very cold in winter, and the dense cold air spreads out towards the equator until it collides with the subtropical air moving poleward to the maritime Temperate air mass moving eastwards on-shore from the two major oceans. Wherever the cold air masses go for substantial periods in winter, permafrost and glaciers are commonly found" (2017). Cold air runoff winds, produced in mountainous terrain when air meets terrain surfaces, cools, and flows downslope, also affects permafrost's presence (Harris et al., 2017).

1.2.1.2 Terrain Factors

Hydrology is a significant terrain factor in permafrost's presence. Snow cover plays a critical role in permafrost areas for two reasons. First, the presence of snow changes the albedo of the ground surface. The albedo of ground with vegetation is 0.1-03, while ground covered in snow has an albedo of 0.7-0.85 (Harris et al., 2017). The reduced quantity of absorbed radiation keeps underlying ground cool. Harris et al. write: "Snow cover, through its influence on ground temperature can significantly affect permafrost occurrence. In discontinuous and sporadic permafrost areas, snow cover may be the critical local factor determining whether permafrost is present or not" (2017). Second, significant amounts of snow can provide ground insulation to varying results. Thick snow cover can insulate the ground from heat loss, keeping the ground warmer than under snow-free or minimal snow cover conditions. Harris et al. cite a study by Goodrich in 1982 wherein his calculations concluded that "a doubling of the snow cover from 25 to 50 cm increased the mean annual surface temperature by several degrees. Rapid build up of snow in autumn augmented this effect" (2017). In warmer conditions, snow cover can lead to a deepening active layer. Opposingly, in cold environments, snow cover can support the presence of permafrost if the snow cover can persist into the spring or summer. Harris et al. write: "This delay would reduce the amount of warming of the ground that can occur." (2017). Furthermore, there is a complex relationship between rainfall and permafrost. McQuate writes that rain has an underappreciated ability to transport thermal energy into soils, increasing the thawing ability of permafrost landscapes (2019). However, rainfall can also support permafrost's presence in instances where rainfall on snow cover reduces snow's insulating quality (Harris et al., 2017). Harris et al. also note that cloud cover associated with precipitation can also reduce incoming solar radiation (2017)

In flat areas, vegetation plays an important role in permafrost by creating a canopy above the ground's surface and intercepting incoming solar radiation (Jorgenson et al., 2010). Vegetation can also intercept the accumulation of insulating organic matter as well as snow, and can promote transpiration (Harris et al., 2017; Jorgenson et al., 2010). Larger vegetation such as trees provide a significant canopy against snow. Streletskiy et al. report that "increases of 30-45 percent in seasonal snow accumulation have been measured after the removal of evergreen forest cover by clear-cutting at sites across Canada" (2015). Snowmelt is also reduced underneath canopies as snow is protected from incoming solar radiation (Streletskiy et al., 2015). Furthermore, moss plays a significant role in heat exchange as it has a low thermal conductivity in summer and a high thermal conductivity of cryotic material in winter, meaning that moss can generally "facilitate the effective cooling and storage of cold within the permafrost" (Streletskiy et al, 2015). Streleskiy et al. write that in northern Alaska the addition of a 10 cm moss layer resulted in a 15 percent reduction of the active layer thickness and a near 3˚C decrease in the mean summer soil temperature (2015).

Next, topography plays a role in permafrost's presence as it affects the amount of solar radiation reaching the soil surface. In discontinuous permafrost zones topography generally causes permafrost to occur on north facing slopes that receive less direct radiation (Jorgenson et al., 2010). Permafrost is also more commonly found in flat low-lying areas where winter air temperatures are generally colder, and where vegetation has a greater insulating affect (Jorgenson et al., 2010). Topography can also affect snow accumulation and hydrology patterns (Harris et al., 2017).

Soil texture plays a role in vegetation's success, but more importantly affects moisture and thermal properties. Shur and Jorgenson list the three contributing factors to the accumulation of heat in the soil in summer and its loss in winter to be: (1) soil texture on drainage and moisture, (2) moisture on the development of wetland ecosystems and peat accumulation, and (3) soil moisture on thermal conductivity (2007). Wet organic soils typically have permafrost, while silty and clayey soils in low-lying areas often have permafrost, as they tend to be poorly drained and have higher thermal conductivities when cool in winter, than when warm in summer (Jorgenosn et al., 2010; Shur and Jorgenson, 2007). This difference in conductivity results in slower heat penetration in the summer and rapid heat loss in the winter (Jorgenson et al., 2010). Permafrost is rarely found in gravelly soils because they tend to be well drained, with little difference between thermal conductivities when cryotic or non-cryotic (Jorgenson et al., 2010; Shur & Jorgenson, 2007). At the southern boundary of the discontinuous permafrost zone, permafrost can only be found in soils with peat (Shur & Jorgenson, 2007).

Peat soil is unique because it is not of geological origin, rather, it is the product of other organisms and can develop over any soil type given the right hydrology (Shur & Jorgenson, 2007). Peat is a deposit formed by a thick layer of dead plant remains and is formed when vegetable matter decomposes slower than it is deposited. While permafrost and peat exist individually of one another, permafrost peatlands are a key component of the Arctic and subarctic zones of Canada, Denmark, Finland, Norway, Russia, Sweden and the United States (United Nations Environment Programme [UNEP], 2019). A positive feedback loop exists between permafrost and peat: the cold temperature, water-saturation and water stagnation of permafrost allows the accumulation of sediment and prevents it from decaying, thereby creating peat. Peat then insulates permafrost from heat in the summer and helps keep permafrost cool in the winter by becoming wet and cryotic itself (UNEP, 2019).

1.2.2 Permafrost Spread and Extent

Permafrost terrain covers 25% of the earth in the Northern Hemisphere, 37% of which exists in western North America (Anisimov & Nelson, 1996; National Snow and Ice Data Centre, 2017). There is an estimated 16.7 million km^2 of permafrost in northern Eurasia and 10.2 million km^2 in North America (Anisimov & Reneva, 2006). Permafrost cover nearly 65% of Russia and 82% of Alaska's terrain (National Snow and Data Centre, 2017). Subsea permafrost, also known as submarine permafrost or offshore permafrost also exists in the continental shelves of the polar regions. This specific form of permafrost formed during the Pleistocene when the Arctic was almost 20˚C colder, and sea levels were 120-130 m lower (Osterkamp, 2001; Streletskiy et al., 2015). Permafrost was then able to aggrade on the shelves exposed due to low sea levels (Osterkamp, 2001). As subsea permafrost can not form under present climatic conditions it is considered relict permafrost and is beginning to degrade.

The southern limit of permafrost is often represented with the -1˚ C mean annual air isotherm (IPCC, 1990) but permafrost can also be found in the mountain ranges of the South American Andes, on New Zealand's Southern Alps, as well as on Tanzania's Munt Kilimanjaro

(National Snow and Ice Data Center, 2017). Permafrost is also found in the ice-free areas of Antarctica, which the National Snow and Ice Data Center estimates to be about 0.3 percent of the continent's total area (2017).

Figure 2: Permafrost distribution in the Northern Hemisphere
Image retrieved from National Snow & Ice Data Center (2017).

1.2.2.1 Presence in Churchill, Manitoba

In Canada, permafrost can be found beneath approximately 50 percent of the country's land surface, primarily in the Arctic Archipelago, Yukon, Nunavut, and the Northwest Territories. (Harris et al., 1988). In Canada's High Arctic, such as on Ellesmere Island, ground temperatures average as low as -15˚C and permafrost is more than 700 m thick (Canadian Permafrost

Association, 2020). Permafrost has been observed in Canada as far south as the Gulf of St. Lawrence, near Blanc Sablon, Quebec (Canadian Permafrost Association, 2020).

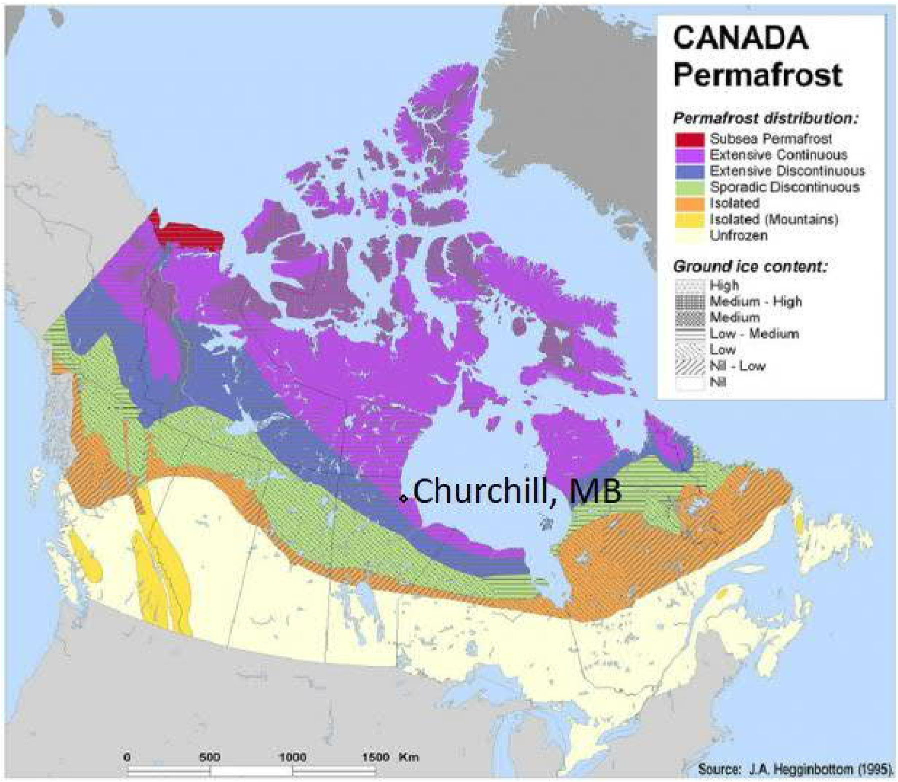

Figure 3: Permafrost distribution in Canada
Image retrieved from Government of Northwest Territories (2014)
and modified to identify Churchill's position.

Churchill, Manitoba rests in the zone of continuous permafrost, where >80% of the area is underlain by permafrost (Heginbottom, 1984). A 1970 study found that Churchill's permafrost is 100-120 feet thick, while Churchill's annual air temperature is 19˚F, and the mean annual ground temperature in Churchill is 27.5˚F-28.9˚F (Brown, 1970). The active layer of Churchill's permafrost is typically less than one meter in depth (Macrae et al., 2014).

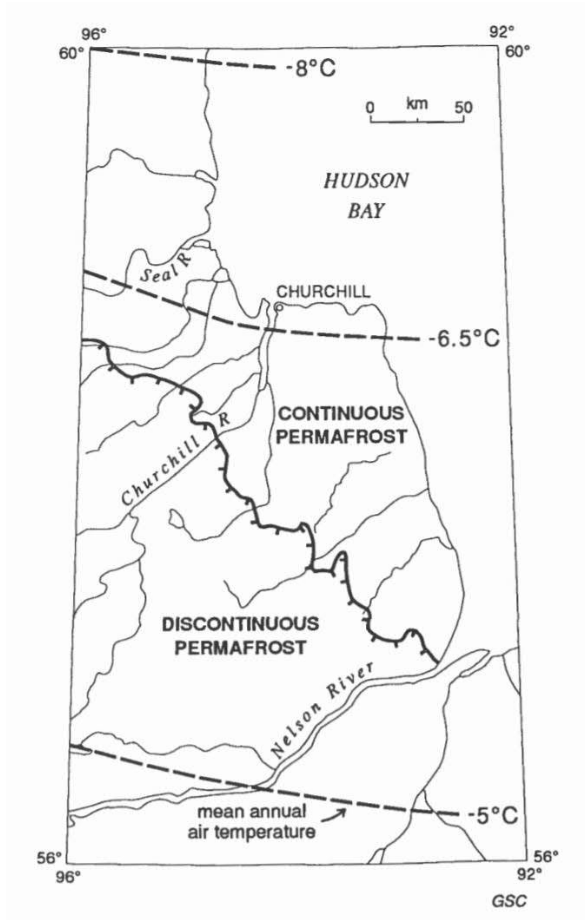

Figure 4: Churchill's position in continuous permafrost
Image retrieved from Dredge & Nixon (1992).

Chapter 2: Methodology

My research plans for this Major Research Paper, as detailed in my Plan of Study (POS) and research proposal, consisted of a thorough literature review as well as fieldwork in Churchill, Manitoba. My literature review was conducted to understand the extent of permafrost presence in Churchill, Manitoba, and to identify the rate and projections of permafrost thaw in that area.

Following the literature review, I had planned to conduct qualitative field research entailing semi-structured interviews in Churchill, Manitoba in May of 2020. I had planned on conducting 20 semi-structured interviews with residents of Churchill to identify: (1) The level of understanding that residents of Churchill already have of permafrost and permafrost's presence in Churchill; (2) The extent to which thawing permafrost has already affected residents' livelihood and/or occupation; (3) The extent to which already thawing permafrost has affected residential accommodations; (4) The extent to which the compromised trainline affected the residents of Churchill in 2017; and (5) The extent to which residents anticipate thawing permafrost to affect them in the future. The semi-structured interview technique best fit my proposed research as it allows for research participants to discuss relevant topics that stray from the interview guide, but still provides comparable data. I proposed transcribing the interviews and analyzing the data through NVivo, which allows for concepts to be coded and categorized into nodes.

2.1 Limitations

The growing COVID-19 pandemic in the spring of 2020 made travel to Churchill not possible for the planned interviews. This decision was made in consideration for my safety and that of research participants, especially given the concerns of my proposed travel from a major city with significant rates of infection to a small isolated community with limited health care resources. This decision was reinforced by research travel restrictions made by York University and the temporary closure of the Churchill Northern Studies Centre. The research for this major paper was then adjusted to consist of a more extensive literature review. This included texts from periglacial geography journals, tourism journals, secondary permafrost data, and case studies from Russia and Alaska.

Chapter 3: Permafrost Degradation

3.1 Global Patterns of Permafrost Degradation

The sustainability of an ecosystem can be understood through its resilience, the capacity of a system to sustain its fundamental function when faced with stress, and vulnerability, the degree to which a system is likely to experience harm due to exposure and sensitivity to a stress (Jorgenson et al., 2010). Jorgenson et al. write that in relation to permafrost resilience is "the capacity to maintain frozen [sic] temperatures and similar ground ice contents and morphologies" (2010). Permafrost's vulnerability, the extent to which it thaws vertically and laterally, is becoming particularly stressed with today's unprecedented rate of climate change.

In 2018 the Intergovernmental Panel on Climate Change issued a special report on the impacts of global warming of 1.5˚C above pre-industrial levels. The report stated: "Human activities are estimated to have caused approximately 1.0˚C of global warming above pre-industrial levels, with a *likely* range of 0.8˚C to 1.2˚C. Global warming is *likely* to reach 1.5˚C between 2030 and 2052 if it continues to increase at the current rate." (2018). Climate change scenarios indicate that this warming will be most pronounced in high latitudes (Nelson et al., 2002). The IPCC states: "Warming greater than the global annual average is being experienced in many land regions and seasons, including two to three times higher in the Arctic." (IPCC, 2018). The effects of climate warming on permafrost is severe. The report alarmed that widespread permafrost thaw is projected to occur in the 21st century as impacted by the significant Arctic warming. There is the potential to lose an estimated 70% of near-surface permafrost by 2100 (IPCC, 2018). Mitigating the degradation is a significant challenge. The IPCC writes: "Even if global warming is limited to well below 2˚C, around 25% of the near 3-4 meter depth permafrost will thaw by 2100… Limiting global warming to 1.5 rather than 2 is projected to prevent the thawing over centuries of a permafrost area in the range of 1.5 to 2.5 million km^2." (IPCC, 2018).

Literature indicates that the depth of permafrost's active layer is already increasing with rising global temperatures, in some cases to the point that permafrost has altogether disappeared in northern environments (Anisimov & Nelson, 1996; Anisimov & Reneva, 2006; Nelson et al., 2002; Shur & Jorgenson, 2007). Since the late 1970s permafrost temperatures have increased on average between 0.5˚C and 2˚C (Streletskiy et al., 2015). Between 2007 and 2016 alone, the average ground temperature in continuous permafrost zones has increased by 0.39˚C, while the average ground temperature in discontinuous permafrost warmed by 0.19˚C (Biskaborn et al., 2019). In the same timeframe mountainous permafrost warmed by an average of 0.19˚C and Antarctic permafrost temperatures rose by 0.37˚C (Biskaborn et al., 2019). Permafrost in the Russian Arctic warmed from 0.5˚C to 2˚C between 1995 and 2015 (Streletskiy et al., 2015). A northward shift in permafrost distribution has also been recorded (Anisimov & Nelson, 1996; Nelson et al. 2002; Streletskiy et al., 2015) as has reduced mechanical strength of permafrost terrain (Anisimov & Reneva, 2006; Shur & Jorgenson, 2007). Permafrost thaw rates rose 200-300% between the periods 1941-1991 and 1995-2002 (Camil, 2005). Permafrost degradation is particularly pronounced in sporadic and discontinuous zones, with significant thawing in these areas recorded since the 1950s (Camil, 2005).

In truth, permafrost degradation is nothing new: climatic transitions between glacial and interglacial periods have always been associated with permafrost change (Streletskiy et al., 2015). In the Late Pleistocene, 20,000-18,000 years before present, permafrost was widespread on exposed continental shelves of the Arctic seas. 12,000-18,000 years before present, France, Germany, Poland, The Czech Republic, Hungary, Ukraine, and the Majority of western Russia, southwestern Siberia, and northern Kazakhstan had permafrost terrain (Streletskiy et al., 2015). Then during the early Holocene, 8,000-6,000 years before present, permafrost disappeared in these European countries, substantially degraded in northern Eurasia, and retreated in North America (Streletskiy et al., 2015). Smaller permafrost boundary retreats took place 3,000 years ago (Streletskiy et al., 2015). However, contemporary permafrost changes are arguably more significant than historic thaws. This is for three reasons: (1) the current rate of climate change is unprecedented; (2) the impact of climate change on permafrost is exacerbated by land use; and (3) there are now substantial populations and settlements in permafrost regions (Streletskiy et al., 2015). Nelson et al. elaborate on the significance on permafrost's thaw, explaining that permafrost provides a record of climate change as it tracks temperature trends over time; acts as a facilitator of further climate change, as it releases greenhouse gases (primarily carbon and methane); and can translate environmental change as it affects natural and human communities (2002). The impacts of permafrost degradation will be explored further throughout this chapter.

As discussed in section 1.2.1 Factors Influencing Permafrost Distribution, permafrost's presence depends on factors extending beyond air temperature. It is important to understand that while rising air temperatures affect permafrost directly to some extent, rising air temperatures significantly affect permafrost in indirect ways. This includes changes in hydrology patterns, snow and organic cover, and vegetation, which will be explore further in this chapter. As Shur and Jorgenson (2007) present, there are four mechanisms of permafrost degradation. First, vertical degradation can occur when there is a lack of protection from the surface ecosystem, an organic insulating layer, with a warmer climate and a positive ground heat flux (Shur & Jorgenson, 2007). Second, the removal of protective insulating vegetation can expose permafrost to a warmer environment, thereby initiating degradation (Shur & Jorgenson, 2007). Third, an influx of heat from adjacent bodies of water and groundwater hydrology can lead to permafrost degradation (Shur & Jorgenson, 2007). Lastly, landscape changes, such as snow and organic cover changes, can support permafrost degradation (Shur & Jorgenson, 2007).

Finally, the process of permafrost degradation should be noted. There are a variety of degradation processes that can occur in stages but will not necessarily include all stages. As listed by Jorgenson et al. (2010) there are eight stages: (1) Active layer degradation involves the active layer deepening as greater quantities of permafrost thaw in summer months; (2) Transient degradation occurs when the transient layer thaws during years with unusually large active-layer thaw; (3) Surface degradation occurs when significant active layer thaw warms surface permafrost; (4) Lateral degradation is caused by surface water, mechanical erosion and bank collapse; (5) Intermediate degradation is caused by the thawing of near surface permafrost creating a talik; (6) Internal degradation is caused by groundwater forming piper or caves; (7)

Complete degradation is when all permafrost is thawed; and (8) Bottom degradation is a bottom-up thawing process that occurs when bottom permafrost thaws from a geothermal heat flux.

3.1.1 Permafrost Degradation in Churchill

Macrae et al. report that between 1943 and 2009 the annual air temperatures in Churchill increased at a rate of 0.02˚C a year, or 0.2˚C a decade, rising a total of 1.02˚C in this time period (2014). However, these records may be conservative as Gagnon and Gough reported that Churchill's mean annual air temperature increased 0.5˚C a decade between 1971 and 2000 (2005). Further, while annual precipitation and rainfall levels were highly variable over the years, a significant increase in precipitation was observed in Churchill between 1943 and 2009 (Macrae et al. 2014). Annual precipitation increased by 1.55 mm per year over this period, 1.47 mm of which was attributed to rainfall (Macrae et al., 2014). Another threat to Churchill's permafrost is an increasing number of wildfires occurring in recent years, which has been attributed to warming and drying climates in boreal forest regions (IPCC, 2018). Fire eliminates the vegetation canopy and moss later, and can remove a portion of the surface peat, which reduces the albedo of the ground surface and reduces or removes the critical insulator and moisture regulator (Richardson et al., 2007). Richardson et al. suggest that lighting strikes, the primary ignition source of fires in the Churchill area, will increase along with the frequency and extent of fires as a result of climatic warming (2007). Furthermore, climate trends point to spring arriving earlier in Churchill while fall arrives later (Flanigan & Van Wagner, 1991). This coupled with rising spring and summer air temperatures in the region could further extend the fire season (Flanigan & Van Wagner, 1991; Richardson et al., 2007).

These changing climate factors have already impacted Churchill's permafrost. Brown reports that the active layer in permafrost has responded to summer air temperatures in Churchill (1978) and Zhang et al. present that the Wapusk National Park just outside of Churchill has had increases in near-surface ground temperature and increase in active layer thickness (2012). Zhang et al. note that in some parts of the park permafrost disappearance has been observed (2012). Warming trends suggest that mean annual air temperatures in northern Manitoba will warm by 3.8-6.8˚C by 2100 (Camil, 2005). With their records Macrae et al. produced models suggesting that Churchill's mean annual temperature will rise from -6.6˚C (1971-2000) to -3.3˚C in 2041-2070, and to -1.4˚C in 2070-2100 (2014). Macrae et al. also project that that annual precipitation will increase in Churchill from 1971-2000 levels by an estimated 18% for the period of 2041-2100, and an estimated 24% for the period of 2070-2100 (2014). They suggest that the 117 ice free days seen between 1971 and 2000 will increase to 127 ice free days for the 2041-2070 period (2014). In modelling permafrost degradation Gagnon and Gough report that the decrease in continuous permafrost in the Churchill area will be between 24-67% for the 2040-2069 period, and 35-100% for the 2070-2099 period (2005). Gough and Leung conduced nine simulations using three different version of the Canadian Centre of Climate Modelling and Analysis general circulation model and all nine simulations, including those that included reduced CO_2 emissions, showed at least a 50% reduction of permafrost in the southwestern Hudson Bay area by 2100 (2002).

3.2 Physical Consequences of Permafrost Thaw

3.2.1 Hydrology

Permafrost has low hydraulic conductivity which results in limited water movement in or out of permafrost terrain and restricts the infiltration of water (Furgal & Powse, 2008). As permafrost thaws two different hydrologic changes may occur. In uplands as the active layer thaws to greater depths surface water will be able to drain into the earth and may leave the top layer of soil dry (Schutte et al., 2019). However, in lowlands thaw can affect ground subsistence and lateral and surface water flow by extension (Schutte et al., 2019). The restricted infiltration results in the creation of wetlands and peatlands in areas of low relief (Furgal & Prowse, 2008; Schutte et al., 2019).

Shallow water bodies are ubiquitous features of Canadian Arctic coastal plains, typically found in the Hudson Bay Lowlands and the Mackenzie River Delta region (Macrae et al., 2014). Within the subarctic environment, shallow pond features are estimated to occupy between 15-50% of the total land areas (Macrae et al., 2014). There are two different types of shallow ponds in the Churchill region of the Hudson Bay: coastal ponds can be found within 10 km of the Hudson Bay coast and were deposited as glaciers melted (Macrae et al., 2014). Ponds further inland are thermokarst features[1], a body of freshwater formed in depressions caused by ice-rich permafrost thawing (Brown & Kupsch, 1974; Jorgenson & Osterkamp, 2005; UNEP, 2019). It should be noted that while coastal ponds may not have been created by permafrost thaw, permafrost may still be present underneath the ponds. The ponds found in the Churchill region of the Hudson Bay range from 30 m to nearly 1 km in diameter (Macrae et al., 2014). The majority

[1] Thermokarst features go by many names in periglacial literature, including thermokarst pond, thermokarst lake, thaw lake, tundra lake, thaw depression, or tundra pond. Thermokarst pond will be used in this paper.

of these ponds are less than a meter in depth and consistently freeze to the bottom in winter (Macrae et al. 2014).

Churchill has historically been an area that experiences a moisture deficit during the post-snowmelt summer months of July-September (Macrae et al., 2014). These late summer and autumn months have therefore typically allowed for these ponds to dry, and as Gagnon and Gough explain "the energy that would otherwise be used to warm the surface is consumed for evaporating the surface water that accumulated on the frozen layer" (2005). However, as noted earlier, a significant increase in precipitation was observed in Churchill between 1943 and 2009, and further rises in precipitation levels are expected to continue as air temperatures also increases (Macrae et al. 2014). Macrae et al. suggest that the retreat of the sea ice cover on the Hudson Bay will contribute to increasing precipitation levels (2014). The increasing air temperatures, lengthening seasons, and increase in precipitation suggest that existing ponds will expand and will spend a greater period of the year as open water (Macrae et al. 2014). The increasing amount of surface water presents a positive feedback that enhances permafrost degradation due to the low albedo and insulating properties of water contributing to warming ground temperatures (IPCC, 1990). Permafrost thaw releasing otherwise frozen water will increase the availability of water to these ponds, and can create new ones, continuing the positive feedback loop (Furgal & Prowse, 2008; IPCC, 1990; Macrae et al., 2014).

3.2.2 Shifting Flora and Fauna Patterns

The permafrost layer is relatively impermeable and acts as a barrier to the movement of water, nutrients, and the deep roots of vegetation (IPCC, 1990). This limits water, nutrient supplies and vegetation to the shallow active layer. This shallow layer, short growing season, and limited soil nutrients resulting from low active layer temperatures and slow rate of decomposition, limit vegetation options in Arctic landscapes (IPCC, 1990). Consequently, Arctic landscapes are typically covered in non-vascular low-lying plants such as a lichen and mosses, shrubs, or few trees with high tolerance for harsh environments, such as black spruce (IPCC, 1990).

Permafrost thaw thickens the active layer, allowing more space for root development, and initiates decomposition leading to a higher nutrient availability in the soil (Schutte et al., 2019). Thawing permafrost also releases moisture, and these factors in conjunction with a lengthening growing seasons and warming air temperatures have led to a shift in Arctic vegetation patterns. Bjorkman et al. suggest that vegetation normally found in southern environments are slowly becoming present in northern communities. Shrubs and herbs now have greater presence in the tundra biome and community height has been rapidly increasing (Bjorkman et al., 2018). Bjorkman et al. estimate that if the observed rate of trait change continues “community height could increase by 20-60% by the end of the century” (Bjorkman et al., 2018). In lowlands such as Churchill, Schutte et al. (2019) and Finger et al. (2016) suggest that the increasing number and extent of thermokarst ponds will result in plant community composition shifting to hydrophilic vegetation with deeper rooting profiles and sedge dominant species. A study in Arctic Abisko, Sweden also found that permafrost terrain transitioning into a waterlogged habitat resulted in taller leafier sedges and fewer small woodier plants and moss (Vining et al., 2016). The study also found that the shift in plant community composition as associated with a loss of plant biodiversity (Vining et al., 2016).

The changing vegetation has implications of its own: changes in the plant growing season can create trophic mismatches, such as in Low Arctic Greenland where "the peak demand for resources by reproductive [caribou] females now falls significantly later than the seasonal peak of resource availability, apparently contributing to reduced production and survival of caribou calves" (Post et al., 2009). Changes in vegetation can also change the movement and spread of Arctic animals. Changing flora and fauna patterns furthermore create positive feedback loops with thawing permafrost. The increase in vegetation for instance reduces the earth's albedo factor and increases snow accumulation, which will insulate the soil temperature and lead to permafrost thaw (Bjorkman et al., 2018). Furthermore, the increased herbivory in certain Arctic areas leads to the trampling of the moss layer: this compacts the layer and insulates and contributes to warming permafrost terrain (Post et al., 2009).

Additionally, animal denning and forage patterns may be impacted by permafrost's relation to peat plateaus. Dyke and Sladen (2010) present that the Northern Hudson Bay lowland contains Canada's largest area of frozen peat plateau bog. This area includes the Wapusk National Park, just outside of Churchill, which contains the country's largest polygonal peat plateau bog and one of the world's largest polar bear denning areas (Dyke & Sladen, 2010; Parks Canada, 2020). Dyke and Sladen write that "Permafrost contributes to the elevation of peat plateaus, allowing the formation of peat banks" (2010). These banks then provide denning habitat for polar bears, while caribou are able to forage on the surface of the plateaus in winter (Dyke & Sladen, 2010). As permafrost thaws these peat banks degrade and collapse, affecting the polar bear denning habitat, and caribou forage patterns (Dyke & Sladen, 2010).

3.3.3 Infrastructure

The majority of infrastructure built on permafrost rely on the bearing capacity of the cryotic ground, often called 'freezing strength,' to support the structures (Streletskiy et al., 2012). However, with present climatic warming the mechanical bearing capacity of permafrost is decreasing as soils are sifting and collapsing, and thermokarst processes are leading to uneven ground settlement (Streletskiy et al., 2012). The increasing soil moisture plays a big role in the uneven terrain, as the ground rises when water freezes and expands, and slumps when the water thaws and contracts (Schreiber, 2018).This threatens Arctic infrastructure of buildings, pipelines, and transportation networks with damage, failure, and collapse. A positive feedback loop exists between these structures with permafrost degradation. The infrastructure's presence on permafrost ground provides additional warming to permafrost, as it gives insulation, reduces the movement of cooling air, and lowers the albedo of that surface. Furthermore, the heating of the building, buried water, sewage, and hydrocarbon pipelines warm surrounding permafrost with their warmth (Prowse et al., 2009). Roads and railways intercept surface and subsurface water flow paths and create obstacles that cause the accumulation of snow: this interception and accumulation provides further insulation and reduces the ground's heat loss, leading to permafrost thaw (Dore et al., 2016).

Infrastructure damage has already been seen in areas of thawing permafrost. When the Qinghai-Tibet Highway, built on permafrost terrain, was upgraded with asphalt in the 1970s, 60 percent of the road developed a thaw layer underneath and by 1995 the permafrost table dropped between 0.16 m and 2.6 m in various areas (Dore et al., 2016). 46% of the roadbed under the Baikal-Amur railroad has been deformed by thawing ground (Streletskiy et al., 2012). Long-term monitoring data from the Seyda-Vorkuta railroad indicate that the annual ground subsidence has increased from 10 to 15 cm in the mid 1970s to 50 cm in the mid-1990s; during the same period the mean permafrost temperature along the railroad increased by 3-4˚C. (Streletskiy et al., 2012). The conditions of runways in Norilsk, Yatusk, Magadan, and other major Siberian cities are also approaching states of emergency (Streletskiy et al, 2012). In many parts of Alaska and Russia pipelines are built above permafrost terrain as to not directly heat the cryotic earth with its warm contents. However, even with this consideration thawing permafrost underneath pipelines resulted in 16 breaks on the Messoyakha-Norilsk pipeline in 2001 (Streletskiy et al., 2012). Streletskiy et al. also report that 35,000 pipeline incidents occur annually in the oil and gas region of West Siberia, 21% of which are thought to be the result of ground instability (2012).

Damage to houses brings concerns to housing security as many Arctic communities are expanding as a result to mineral resource exploration (Streletskiy et al., 2012). In the coal-mining town of Vorkuta, about 40 percent of building have become deformed from changes in the ground, and in Norilsk, the largest city built on permafrost, about 60 percent of the buildings have been damaged by permafrost thaw, and 10 percent of the houses in the city have been abandoned (Schreiber, 2018). Schreiber presents that changing permafrost in Iqaluit is cracking housing foundations and causing houses to sink or tilt (2018). Rapid permafrost shifts make mitigating the damages to houses and other infrastructure more challenging and the cost of bringing necessary materials to these northern communities proves to be a significant limitation. In Iqaluit, the decreasing number of structurally sound homes, the cost of repair, and the cost of other accommodation options have resulted in a perpetually overcrowded homeless shelter (Schreiber, 2018).

Hjort et al. suggest that nearly four million people and 70% of current infrastructure in the permafrost domain are in areas with high potential for thaw of near-surface permafrost (2018). Their results show that one-third of pan-Arctic infrastructure are in regions where thaw-related ground instability can cause severe damage to the build environment (Hjort et al., 2018). Alarmingly, these figures are not reduced substantially even if the climate change targets of the Paris Agreement are reached (Hjort et al., 2018). The Study of Environmental Arctic Change (SEARCH) estimate that Alaska will face $1.6-$2.1 billion in damages due to thawing permafrost between 2015-2099 (n.d). Hjort et al.'s detailed risk assessment identifies Churchill as one of the 'hot spots' for hazard potential, which will be examined further in the next chapter (2018).

3.3.4 Emissions from Permafrost

Carbon has become trapped and built up in permafrost soils over millennia because organic material from dead plants, animals, and microbes are not able to breakdown in permafrost's cool conditions (Turetsky et al., 2019). The UNEP estimates that Arctic and boreal permafrost hold almost twice the amount of carbon in the atmosphere, with stores of approximately 1,600 billion tonnes (2019). However, Lawrence and Slater (2005) suggest that there is 60 to 190 Pg of carbon conserved in Arctic permafrost, meaning that an estimated half of global soil carbon stores are north of the boreal forest. Peatlands specifically are the largest long-term stores of organic carbon of all terrestrial ecosystems (UNEP, 2019). Additionally, mercury bound to organic material is found in permafrost soils: Schuster et al. estimate that permafrost in the Northern

Hemisphere contains 763 Gg of mercury, "nearly twice as much Hg as all other soils, the ocean, and the atmosphere combined" (2018).

As permafrost thaws, microbial decomposers become active and breakdown the materials that have sedimented into permafrost (UNEP, 2019). This organic breakdown emits carbon, methane, and mercury. It is projected that the release of this carbon will transition permafrost regions into carbon sources rather than sinks by 2100 (UNEP, 2019). Turetsky et al. suggest that about 15% of northern soil carbon, an amount of 200 billion tonnes of carbon, will be released in the next three centuries based on current trends (2019). By 2300 they estimate that an additional 60 billion - 100 billion tonnes of carbon could be released from permafrost thawing in lowland lakes and wetlands (Turetsky et al., 2019). The release of this amount of carbon and other greenhouse gases would be devastating and would contribute to a positive feedback loop resulting in further permafrost degradation and carbon release.

The re-emergence of ancient microbes and viruses from thawing permafrost is also possible. Houwenhuyse et al. write that permafrost serves as a natural bank that holds dormant propagules like seeds, eggs, cysts and spores, as well as bacteria and viruses (2017). Houwenhuyse et al. report that a specimen of a giant virus was found in a Siberian permafrost ice core, aged 30,000 years, and two plant viruses have been found in 700-year-old caribou feces preserved in permafrost (2017). The release of anthrax from permafrost terrain in Siberia has been reportedly associated with the death of a 12-year-old Siberian boy, the illness of 100 people, and the death of more than 2,300 reindeer (Goudarzi, 2016). Houwenhuyse et al. estimate that the number of microorganisms trapped in permafrost can range up to 10^8/g of dry soil (2017). While not all released pathogens may pose a risk to communities, the invasion of non-native pathogens could have devastating consequents on plants, animals, and humans (Houwenhuyse et al., 2017).

Chapter 4: Economic Implications of Churchill's Permafrost Thaw

4.1 Dependence on Trainline

As Churchill does not connect to any roads outside of the city, the Winnipeg-Churchill trainline is the only land connection between Churchill and the rest of Canada. Formerly known as the Hudson Bay train, and known as the Northern Spirits train before that, the train covers over 400 km between Winnipeg and Churchill and operates semi-weekly. The trainline acts as a significant lifeline for Churchill as highlighted when rail service stopped in May 2017 due to flooding. Negotiations with the trainline owner OmniTRAX dragged on for months, leaving Churchill a fly-in community until the trainline was repaired and reopened on October 31, 2018 (Hansen, 2018; MacIntosh, 2018).

The halted rail service left Churchill residents with higher living expenses, soaring food costs, and what became the highest gasoline price in all of Canada (Hansen, 2018; MacIntosh, 2018). Fresh produce was most affected by the increased delivery cost, with prices doubling if not tripling (MacIntosh, 2018). For instance, a head of broccoli reached $8.75 (Grabish, 2017) and a bag of cherries reached $16 (Gibson, 2018). Grabish (2017) and Gibson (2018) report that residents of Churchill had to change their diets to compensate for the inaccessible prices, leading to fears of malnutrition. The halted trainline service compounded a pre-existing food insecurity in Churchill. Boerchers et al. write that in northern Manitoba, 75 percent of communities are identified as food insecure, a significant increase to Canada's national average of 15 percent (2015). Boerchers et al. note that food security tends to decrease with the increase of household income and education status and that women are at higher risk for food insecurity than men, which is thought to be a result of women being more likely to be a primary caregiver and are less likely to hunt than men are (2015). In a survey conducted prior to the trainline closure the majority of respondents in Churchill states that they were "unhappy with the quality, price, and selection of the produce available to them." (Boerchers et al., 2015).

Further, in June of 2018 Churchill's propane supply hit critically low levels. Without the trainline, propane ultimately had to be brought in by sea which resulted in significant shipment gaps: propane arrived in October of 2017 and the town's supply was not refuelled again until the middle of July 2018 (Gibson, 2018). As housing units in Churchill are propane heated there was great concern for resident's safety (Gibson, 2018). The tourism industry also suffered with the stalled train service as tourists postponed train journeys and The Arctic Trading Company which sells souvenirs to tourists, was not able to afford bringing in new merchandise by air (Gibson, 2018).

While the trainline has been repaired and is currently operational, projected permafrost degradation in Churchill's continuous permafrost zone threatens the trainline with damage. This is due to ground settlement as well as possible flooding resulting from thermokarst pond development. As seen in other trainlines such as the Baikal-Amur and Seyda-Vorkuta railroads, significant railroad deformations occur with ground subsistence (Streletskiy et al., 2012). As discussed previously, the presence of the trainline supports a positive feedback loop of permafrost degradation as it changes albedo, insulates the ground below, and affects snow accumulation and hydrology patterns (Dore et al. 2016; Streletskiy et al., 2012). The potential for damage and future closures raise concern for food and fuel prices, future tourism, and shipping related transportation should the Arctic port be reopened to a significant capacity.

4.1.1 Reopening the Arctic Port

As discussed in chapter one, the Port of Churchill, Canada's only Arctic port, was closed in 2016 following the dissolvement of the Canadian Wheat Board. OmniTRAX, the American company that owned and closed the port and railway, sold both to the Arctic Gateway Group in 2018. The port then reopened in 2019 with a federal commitment of $117 million supporting both the port and the rail line (MacIntosh, 2018). There is now significant discussion to expand operations at the port. The Arctic Gateway Group's chief executive officer Murad Al-Katib states that the strategic advantage of Churchill's port as North America's only port has not been realized yet (Briere, 2019). Al-Katib foresees the port soon handling 500,000 to 700,000 tonnes of grain (Briere, 2019). It is projected that shipping activity will continue to rise across the Arctic as northern routes become increasingly accessible (IPCC, 2018). Ship and pleasure craft transits through Canada's Northwest Passage have already doubled and quadrupled over the past decade, and the distance travelled by ships in Arctic Canada grew from 365,000 to 920,000 km between 1990 and 2015 (IPCC, 2018). Gough and Gagnon (2005) even suggest that the warmer climate and less frequent ice hazard might result in lower insurance premiums for shipping companies. Expanding operations have already been seen in Churchill: at the time of its closure, the port's business was limited to four months a year when waters were ice free, Briere reports that the shipping season is stretching from mid-May to the end of November (2019). In addition to expanding operations there is discussion for the Port of Churchill to diversify its exports (Hansen, 2018). A Federal-Provincial Task Force on the Future of Churchill published a report in 2013 presenting the idea of exporting bulk potash, of which there are significant quantities in Churchill's catchment area, to Latin and South American markets, particularly Brazil's large agricultural sector. The report also suggest shipping crude oil through the Port of Churchill as there are capacity constraints in North America's pipeline network, and the report relays that producers have expressed interest (Federal-Provincial Task Force on the Future of Churchill, 2013).

The diversification and expansion of activity at the Port of Churchill would bring significant employment and development opportunity to the town. However, the sustainability and safety of these practices are threatened under permafrost degradation, as the at-risk Winnipeg-Churchill trainline may not be able to support transportation to and from ships.

4.2 Ecotourism

Tourism in Churchill is primarily motivated by the ability to see the town's unique ecology, specifically the Hudson Bay's beluga whales, and the polar bears who congregate along the shores of the bay in the fall (Dawson et al., 2009). The majority of the polar bear viewing in Churchill occurs in two protected areas east of the community: Wapusk National Park, and the Churchill Wildlife Management Area (Lemelin & Wiersma, 2007) This ecotourism draws an estimated 6,000-10,000 tourists to Churchill each year, with an approximate 3,000 visitors arriving between mid-October and late November for the optimal bear viewing period (Dawson et al., 2009). Dawson et al. suggest that these numbers are conservative as they do not consider day trip tours that arrive in the morning and leave in the evening, which are growing in popularity with guests chartering private flights from Calgary (2009).

Part of the recent draw to Churchill's ecotourism is the interest and concern over the disappearing north (Lemelin et al., 2010). In recent years travel operators and tour agencies have been recommending vanishing destinations in a tourism trend known as 'doom tourism', 'disappearing tourism', or 'last chance tourism' (Lemelin et al., 2010). Tourists are increasingly seeking to explore endangered sites such as the Great Barrier Reef, the Maldives, and the polar regions (Lemelin et al., 2010). In surveying 334 tourists in Churchill, Dawson et al. found that the majority of individuals travelling to Churchill were strongly motivated by the vulnerability of polar bears and indicated that they wanted to see the bears before they disappeared forever (2009). The same study also interviewed on-site tourists, several of whom acknowledged climate change in their reasoning for travel: "I wanted to see the bears with my daughter because my grandchildren and their children may never know polar bears except in a zoo"; "I'll tell ya, I'm a single mom and I am unemployed but I still took money out of my precious savings to come up here and see the bears before they are all gone"; "I was here seven years ago but I wanted to come up again to show my wife the polar bears before they are gone"; "I thought I better come see the bears because the next time I am in this country they will be all gone" (Lemelin et al., 2010).

Dawson et al. (2009) question how short-term climate change in the next two to three decades will affect tourism numbers in Churchill. They suggest that the longer ice-free periods will increase the period of 'wait time' that polar bears spend around Churchill (Dawson et al., 2009). This may lengthen the viewing season and expand the ecotourism industry. However, they question the health of these bears in such a changing environment: the opportunity to see bears in poor health may deter tourists, or the 'last chance tourism' factor may become stronger (Dawson et al., 2009).

4.2.1 Ecotourism as Means for Asset-Based Development

Literature has highlighted a low quality of living conditions and the underdevelopment of northern Manitoba (Freylejer, 2012; Newton et al., 2000). The population of Churchill has been steadily declining since the 1960s, when military operations were moved out of the community. The population was around 7,000 in 1965 and dwindled to 1,091 by 1996 (Newton et al., 2000). By 2000, unemployment levels in Churchill grew, reaching 21%, in comparison to the province's 8% average (Newton et al., 2000). The Canadian Centre for Policy Alternatives writes that challenges with social and economic development include "paternalistic policies trying to impose development from 'the top down'" (Freylejer, 2012).

The ecotourism industry in Churchill has shown and continues to offer great potential in regional development and economic transition. This can be understood through John McKnight and John Kretzmann's theory of asset-based community development. This form of development involves utilizing the resources, skills, and experiences in a community to move members into action (Hipwell, 2009). Hipwell writes that asset-based community development "holds that community development is likely to result in outcomes of greater profundity and longevity when it is predicated on the identification and utilisation of community strengths or 'assets', which may include collective knowledge, social networks or traditional arts" (Hipwell, 2009). Ecotourism by way of asset-based community development makes space for Churchill's residents to share their understanding and experience of Churchill's environment. This is a particularly significant opportunity for Churchill's Indigenous (Chipewyan, Swampy Cree, Métis, Dene, and Inuit) population to share their traditional knowledge (TK). The opportunity to share this knowledge of Churchill's land and animals in turn benefits Churchill's residents and the town economically.

4.2.2 Ecotourism's Demands and Thawing Permafrost

Dawson et al. (2009) present that traditional resource-use sectors that rely on the environment, such as agriculture and forestry, have been considering the implications of climate change for several decades. However, the tourism industry which also depends on environmental conditions – especially in instances of ecotourism – only just began considering the implications of climate change (Dawson et al., 2009). The understanding of climate change's threats on the tourism sector resulted in the United Nations World Tourism Organization (UNWTO), United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) to name climate change as "the greatest challenge to the sustainability of the global tourism industry in the 21st century" (Dawson et al., 2009).

This threat is certainly true in Churchill, as thawing permafrost threatens the sustainability of the town's tourism. First, as discussed earlier, the threatened trainlines and threatened runways may make transportation a challenge for tourists arriving in Churchill. Further, the lodging and other infrastructure (eg, restaurants, souvenir shops, etc) needed for tour groups also face instability as permafrost degrades. There is also concern that the permafrost ground on which tundra buggies travel to see the polar bears in Wapusk National Park and the Churchill Wildlife Management Area will degrade into thermokarst ponds or other inaccessible landforms.

Of course, due to the positive feedback between infrastructure and permafrost degradation, Churchill's polar bear tourism industry also threatens underlying permafrost through the presence of lodging and transportation infrastructure. While the quantity and movement of the tundra buggies are limited by permits and a set of establish trails created by the military in the 1950s, there is still some concern of movement on delicate permafrost terrain. The compression of permafrost and the vegetation above can influence insulation and permafrost warming by extension. For this reason, The Arctic Monitoring and Assessment Programme reports that "…the number of days per year in which travel on the tundra is allowed under Alaska's Department of Natural Resources has dropped from over 200 to about 100 days in the past 30 years" (2004). As ecotourism makes up more than 60 percent of Churchill's economy (Gilmore, 2018) the economic and developmental results of a permafrost challenged tourism industry would be significant.

Chapter 5: Cultural Implications of Churchill's Permafrost Thaw

5.1 Access to Culturally Significant Foods

According to the 2011 National Household Survey, 51 percent of Churchill's residents identify as Aboriginal, (Chipewyan, Swampy Cree, Métis, Dene, and Inuit) (Statistics Canada, 2013).

The presence of a large Indigenous population in Churchill begs the question of the connection between permafrost terrain and culture, and specifically how this relationship will shift with future degradation.

One concern is the access to culturally significant foods. In a research study on nutrition and consumption habits in Churchill, Boerchers et al. (2015) found that 25 percent of surveyed individuals indicated that they source their meat locally, and 90 percent of respondents indicated that they know someone who hunts. Hunting and foraging, such as for geese, caribou, fireweed, and Labrador tea in Churchill, has a deep connection to Indigenous cultural identity. The Assembly of First Nations Environmental Stewardship Unit (2007) writes: "…there is a deep connection to one's cultural identity and spirituality through the consuming of traditional foods and the events leading up to it... For generations, traditional ecological knowledge, including food species, has been passed down to the younger generations through oral teachings, storytelling, and experiences on the land. Traditional food consumption is deeply rooted in the social and cultural elements of a First Nations' way of life." Further, Boerchers et al. 2015 present that the consumption and access to traditional foods lowers the incidence of food insecurity, and that a diet with traditional foods is found to be more nutritionally dense and sustainable than non-traditional alternatives.

As presented earlier, literature (Dyke & Sladen, 2010; Finger et al., 2016; Schutte et al., 2019; Vining et al., 2016) suggests that as Churchill experiences the development of thermokarst ponds, a thicker active layer, and unstable peat banks, flora and fauna patterns may change. Plant community composition will likely change to hydrophilic vegetation with deeper rooting profiles and sedge dominant species, influencing animal foraging and movement in turn. These changes threaten the access to hunting and culturally significant foods.

Chapter 6: Conclusion

> "The freeze traps life and stops time. The thaw releases it. We can smell the footprints of last fall and the new decomposition of all who perished in the grips of winter. Global warming will release the deeper smells and coax stories out of the permafrost. Who knows what memories lie deep in the ice? Who knows what curses? Earth's whispers released back into the atmosphere can only wreak havoc." (Tagaq, 2018)

It is powerful to imagine that Churchill's permafrost soils have collected the town's history and stores its stories by freezing them in cryotic earth. Churchill's sediment would tell stories of Indigenous settlement, settler colonialism, and the development of the Hudson's Bay Company. The permafrost could recount the development and invasion of the Prince of Wales Fort, a military presence, a rocket range, and the relocation of the Sayisi Dene. More recently the ground would tell stories of Churchill's trainline and Arctic port, and Churchill's development into the polar bear capital of the world. Upon thaw this ground would indeed wreak havoc on the same industries and practices it once supported.

The effects of anthropogenic climate change in Churchill are alarming. Churchill's air temperature is believed to already have warmed 1.5˚C since 1971 (Gagnon & Gough, 2005) and has contributed to an increase of annual precipitation, changes in ice formation, increased incidences of fire, and an earlier spring and later fall arrival (Flanigan & Van Wagner, 1991; Macrae et al., 2014; Richardson et al., 2007). The interaction of these changing factors with Churchill's continuous permafrost zones is resulting in degradation that is expected to thaw a quarter of the ground within the next fifty years (Gagnon & Gough, 2005; Gough & Leung, 2002. This thaw threatens the stability of Churchill's trainline and endangers food security, tourism, and the expansion of Churchill's Arctic port by extension. Infrastructure instability and changing ground features further threaten the sustainability of the tourism industry, which supports a majority of Churchill's economy and development. Recognizing these threats may direct Churchill to a development strategy that empowers longevity and sustainability. This may also provide development strategies useful to other communities facing permafrost change.

6.1 Recommendations for Future Research

Travel restrictions limited the collection of qualitative data for this paper. This hindered some understanding of permafrost's significance in Churchill, particularly in relation to culture and cultural practices. To address the posed research questions more fully, I suggest that qualitative data be collected in future research with the method of semi-structured interviews. This research would help highlight the effects of degradation that Churchill residents have already experienced, residents' particular fears, and a better understanding of the relationship between permafrost and food, and permafrost's place in Traditional Ecological Knowledge.

As it is clear that proactive strategies are needed to protect this town in transition, future research is also recommended to determine which mitigation strategies might work best for Churchill's permafrost thaw. While this paper identified some of the implications of the thaw, it did not provide suggestions on how to prevent it. Various techniques have been used to slow permafrost degradation, including white paint, mulching, stilting buildings, hollow probes, and thermosyphon cooling techniques. Determining the most appropriate method is an important step in constructing Churchill's development strategy.

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