The Impacts of Permafrost Thaw and Social Changes on Bakeapple Picking

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Abstract

Air temperatures are increasing at a faster rate at northern latitudes compared to the global average and consequently, the extent of permafrost has been reduced with impacts on the traditional land based livelihoods of Indigenous communities in the Arctic and Subarctic. Communities are responding to the physical and biological impacts of permafrost thaw amidst ongoing social, economic and political changes. This thesis examines the impacts of permafrost thaw and related social changes on traditional land based livelihoods through the lens of bakeapple berry picking, drawing upon a case study from the community of Cartwright, Labrador. Mixed methods including interviews (n=18), a focus group, participant observation, field surveys (n=62) and analysis of satellite imagery and historical weather data are used to: i) document and characterize ecological changes that are impacting the growth of bakeapples, ii) identify how these changes are affecting communities and how they are responding, and iii) identify and assess social, economic, and political changes that affect how community members interact with and respond to changing conditions. Key findings include that the extent of palsa permafrost features have decreased, and surface water and vegetation have increased over a 12-year period, in a permafrost associated peatland in Cartwright, with likely impacts on the abundance and fragmentation of bakeapple patches. While bakeapple pickers experience changes in seasonality, vegetation growth, and surface moisture at their bakeapple picking grounds, the largest concern of bakeapple pickers is that fewer young families have the capacity to visit the bakeapple picking grounds and to harvest bakeapples. This thesis contributes to the growing literature on how Indigenous communities are being affected by climate change, bringing attention to an understudied region.

Résumé

Les températures de l'air augmentent plus rapidement dans les latitudes nordiques comparées à la moyenne mondiale et, par conséquent, l'étendue du pergélisol a été réduite et a eu des impacts sur les moyens de subsistance des territoires traditionnels des communautés autochtones de l'Arctique et du subarctique. Les communautés réagissent aux impacts physiques et biologiques du dégel du pergélisol au milieu des changements sociaux, économiques et politiques en cours. Cette thèse examine les impacts du dégel du pergélisol et des changements sociaux connexes sur les moyens de subsistance traditionnels à travers le prisme de la cueillette des plaquebières (*bakeapple*), en s'appuyant sur une étude de cas de la communauté de Cartwright, au Labrador. Des méthodes mixtes comprenant des entrevues (n = 18), un groupe de discussion, des observations des participants, des enquêtes sur le terrain (n = 62) et des analyses d'imageries satellite et des données météorologiques historiques sont utilisées pour: i). documenter et caractériser les changements écologiques qui ont une incidence sur la croissance des plaquebières, ii). identifier comment ces changements affectent les communautés et comment elles réagissent, et iii). identifier et évaluer les changements sociaux, économiques et politiques qui affectent la façon dont les membres de la communauté interagissent avec les conditions changeantes et y réagissent. Les principales constatations sont que l'étendue du pergélisol a diminué et que l'eau de surface et la végétation ont augmenté sur une période de 12 ans dans une tourbière associée au pergélisol à Cartwright, ce qui a eu des répercussions sur l'abondance et la fragmentation des parcelles de plaquebière. Tandis que les cueilleurs de plaquebières vivent des changements de saisonnalité, de croissance de la végétation et d'humidité de surface sur le terrains de cueillettes de plaquebières, la plus grande préoccupation des cueilleurs de plaquebières est que moins de jeunes familles ont la possibilité de visiter les terrains de cueillettes de plaquebières et de cultiver des plaquebières. Cette thèse contribue à la documentation grandissante sur la façon dont les communautés autochtones sont affectées par les changements climatiques, attirant l'attention sur une région peu étudiée.

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Preface and Contribution of Authors

This thesis is written in a manuscript style. Chapter III and chapter IV are intended to be stand-alone manuscripts. The following text lists the contributions made by myself, co-authors, and others to each of the chapters and the plans for publications.

Manuscript 1: Environmental Change and the Impact on Bakeapples in Southern Labrador

Authors: Darya Anderson, James, Ford, Margaret Kalacska, Nigel Roulet and Robert Way

This manuscript is being prepared for submission to the journal Sustainability Science. The study design, data collection, analysis and writing were carried out primarily by Darya Anderson. Leslie Hamel served as an invaluable field guide. Robert Way provided guidance and suggestions during study design, data collection, data analysis, and plans to contribute edits to the final manuscript. James Ford was the primary supervisor and provided feedback and guidance during study design, data collection, data analysis, and writing of the manuscript. Margaret Kalacska and Nigel Roulet are committee members who provided guidance during the data analysis and writing of the manuscript.

Manuscript 2: Climate Change and the Vulnerability of Bakeapple Picking as a Cultural Activity

Authors: Darya Anderson and James Ford

This manuscript is being prepared for submission to the journal Ecohealth. The study design, data collection, analysis and writing were carried out primarily by Darya Anderson. Judy Pardy served as research coordinator during data collection. James Ford, the primary supervisor, provided feedback during the study design, data collection, data analysis, and writing of the manuscript.

The reading and writing for chapter I, II, and V was carried out primarily by Darya Anderson with edits and supervision from James Ford.

Chapter 1 Introduction

1.1 Background

Globally, the climate is changing at unprecedented rates largely attributed to the anthropogenic release of greenhouses gases. On average, global air temperatures have increased by 0.85 degrees Celsius (C) over the past century and temperatures are projected to continue increasing with consequent biophysical impacts (IPCC, 2013b). Across Canada, temperatures have risen about 1.7 degrees C and by as much as 3.1 degrees C in the western Canadian Arctic (Environment Canada, 2017). Temperatures are projected to continue increasing over the next century in the Arctic (IPCC, 2013b) with average winter and fall temperatures projected to increase by 4 degrees C in the next three decades (Arctic Monitoring and Assessment Programme, 2017).

Northern Indigenous communities are disproportionately sensitive to climate changes due to habitation in a region undergoing the most dramatic climate change globally, socio-economic disparities, and colonial legacies (Ford, 2012). Historically, Indigenous communities have adapted to natural variability in the climate and continue to adapt to changes (Anisimov et al., 2007; Forbes et al., 2009; Ford et al., 2007; Ford, 2012; Guyot, Dickson, Paci, Furgal, & Chan, 2006; Larsen et al., 2014; Turner & Clifton, 2009; Wenzel, 2009). However, with added social, economic, and political changes, it is more challenging for northern communities with strong links to the natural environment for hunting, fishing, berry picking, travel, and well-being to respond to climate changes (Anisimov et al., 2007; Forbes et al., 2009; Ford, 2012; Ford et al., 2013; Ford, McDowell, & Pearce, 2015; Ford, Lea Berrang-Ford, Malcolm King, & Chris Furgal, 2010; Larsen et al., 2014; Turner & Turner, 2008; Wenzel, 2009).

Specifically, permafrost thaw, accelerated by climate change, is resulting in biological and physical changes that impact northern communities with strong links to the natural environment. The physical impacts of permafrost thaw include changes in topography and hydrology (Allard & Lemay, 2012; Couture & Pollard, 2007; Furgal & Prowse, 2007; Hong, Perkins, & Trainor, 2014; Payette, Delwaide, Caccianiga, & Beauchemin, 2004) with resulting impacts on access to geographic locations, water sources, food storage mechanisms, infrastructure and animal migrations (Amstislavski et al., 2013; Andrachuk & Pearce, 2010; Brubaker, Berner, Chavan, & Warren, 2011; Downing & Cuerrier, 2011; Ford, Ford, et al., 2010; Goldhar, Bell, & Wolf, 2013). Biological impacts of permafrost thaw include changes in vegetation, which impacts animal foraging patterns, and the loss of fish populations due to the draining of permafrost contained lakes (Andrachuk & Pearce, 2010; Andresen & Lougheed, 2015; Downing & Cuerrier, 2011; Fitzgerald & Riordan, 2003; Goldhar et al., 2013).

While there is much research on permafrost thaw in the Arctic and Subarctic, very little of this work examines how the associated biological and physical impacts are affecting traditional land based livelihoods of Indigenous populations. This is particularly relevant for berry picking, an actvity which has cultural and nutritional importance for Canadian arctic and subarctic communities (Downing & Cuerrier, 2011; Fitzhugh, 1999; Kellogg et al., 2010; Murray, Boxall, & Wein, 2005). Over a two to three week window in the summer, families will pick sufficient cloudberries (or bakeapples in Labrador) to store for their winter use, primarly as jam or as fruit (Fitzhugh, 1999). Communities spanning the Canadian north note changes in the time that bakeapples are ripening and increased growth of surrounding vegetation that is impacting bakeapple growth (Downing & Cuerrier, 2011; Guyot et al., 2006; Parlee, Berkes, & others, 2005), although few studies have examined how communities are experiencing and responding to these changes (Parlee & Berkes, 2006; N. Turner & Clifton, 2009).

It is important to consider how permafrost thaw will impact bakeapple growth because the extent of permafrost is decreasing and projected to continue decreasing (Furgal & Prowse, 2007; IPCC, 2013b; Zhang, Chen, & Riseborough, 2006). Permafrost thaw impacts soil moisture conditions and plant communities (Payette et al., 2004; Sannel & Brown, 2010; Sannel & Kuhry, 2011), the ability to access berry picking areas, and it can be expected that permafrost thaw will indirectly impact bakeapple growth. In communities within the discontinuous permafrost zone, the permafrost is not widespread compared to the continuous permafrost zone. As a result, researchers can observe how bakeapple growth varies in areas with and without permafrost to have a better understanding of how future permafrost loss and consequent physical and biological changes will impact the nutritionally and culturally important bakeapple.

1.2 General Problem and Research Questions

With the recognition that climate changes are already occuring and impacting communities, the world is increasingly recognizing the importance of adaptation in addition to mitagation in climate change policy (IPCC, 2014; Khan & Roberts, 2013; Moss et al., 2013; Pielke, Prins, Rayner, & Sarewitz, 2007) . In order to appropriately advance and priotize adaptation actions, vulnerability must be assessed (Smit & Wandel, 2006). Vulnerability can be defined as the susceptibility to harm, and is a function of exposure, sensitivity and adaptive capacity. Exposure is the environmental stimulus and is characterized by its magnitude, duration, frequency and extent; sensitivity refers to the historical and current social, economic, and political traits of the community; and adaptive capacity captures the ability to plan for, address, or cope with the exposure (Bennett, Blythe, Tyler, & Ban, 2016; Ford & Smit, 2004; O'Brien, Eriksen, Nygaard, & Schjolden, 2007; Smit & Wandel, 2006).

There are currently few studies that consider the interaction between physical and social factors that challenge or advance northern communities ability to bakeapple pick. This research will contribute understanding to this gap by identifying and chararcterizing the vulnerability of bakeapple picking in a changing physical and social landscape drawing upon a case study from Cartwright, Labrador.

Specific research objectives include:

1. Document climatic exposures affecting bakeapple picking by identifying the environmental constraints on bakeapple growth and examining if/how these environmental constraints have changed over time.
2. Identify and characterize the factors affecting sensitivity and adaptive capacity to changes in bakeapple picking.
3. Examine the overall vulnerability of bakeapple picking in a changing physical and social landscape.

1.3 Thesis Overview

This thesis is a manuscript based thesis. Chapter 3 and chapter 4 are stand-alone manuscripts. In chapter 3, the exposures or the environmental factors that impact bakeapple growth and how these factors have changed over time will be described. In chapter 4, the key components of sensitivity and adaptive capacity and the interactions between the three components of vulnerability will be identified. In chapter 5, the overall vulnerability considering what is described as the exposure in chapter 3 and as the sensitivity and adaptive capacity in chapter 4 will be described. Also, the larger themes that parallel or contradict vulnerability assessments in other northern communities with land based livelihoods will be highlighted, and the limitations of this study and remaining questions will be identified. Chapter 2 will be a literature review of the impacts of permafrost thaw on communities and land based livelihoods across the Arctic and Subarctic.

Chapter 2 Literature Review

Role of Chapter 2

This chapter begins by reviewing the land based livelihoods literature focusing on Indigenous communities in the Canadian Arctic and Subarctic. First, the discourse around traditional subsistence livelihoods and the impacts of social, economic, and political changes is considered, which informs the study design of the case study elaborated on in chapter 4. Next, the human dimensions of climate change literature, with a focus on permafrost thaw is reviewed. The physical and biological impacts of permafrost thaw are described with examples from communities across the Arctic and Subarctic. Lastly, the impacts of permafrost thaw on harvesting activities is delineated, with a focus on berry picking, which informs the study design and methodology of chapter 3. The details of this impact pathway are elaborated on in chapter 3 via the case study of Cartwright, Labrador.

2.1 Land Based Livelihoods

Traditional subsistence activities of Indigenous communities in the Canadian North includes the harvesting of food and water from the land and sharing of those resources through complex social structures. This process of harvesting and sharing has both cultural and spiritual importance (Natcher, 2009; Nuttall et al., 2005). For example, Indigenous communities in British Columbia harvest edible seaweed and Pacific crabapple with family and the harvest of thimbleberry shoots is preceded by ceremonies (N. Turner & Turner, 2008). For Gwich'in communities, wild (traditional or country) foods, including berries, are considered a gift from the creator (Parlee & Berkes, 2006). Traditional foods are also an important part of diet. For Inuit communities in Nunavut, wildlife harvest surveys show that traditional foods are still a considerable part of the diet at 295 grams per person per day as of 2000 (Wenzel, Dolan, & Brown, 2016). In Nunatsiavut, country foods, including berries, were documented to make up 56% of households' dietary intake (Tait, 2001). The flexibility of traditional subsistence is evidenced by the collection of water from various sources on the land (Daley, Castleden, Jamieson, Furgal, & Ell, 2014; Goldhar et al., 2013) and the harvest and consumption of diverse species (Beaumier, Ford, & Tagalik, 2015; Birket-Smith, 1929; Brice-Bennett, Cooke, Fitzhugh, & Labrador Inuit Association, 1977). Traditional subsistence importantly includes the sharing of the harvest and the process and conditions of sharing are complex and dependent on kinship relationships (Natcher, 2009; Wenzel, 2009). For instance, in Inuit communities, reciprocity of resources is less common and rather the giving and redistribution of food dominates (Kishigami, 2004).

Historically, many arctic Indigenous peoples were semi-nomadic in order to access local resources and to respond to natural ecological variability (Anisimov et al., 2007; Natcher, 2009; Wenzel, 2009). The degree of nomadism varied regionally. For Inuit communities within Nunavut, for example, in the Baffin Island region, sea mammals are a fundamental part of the diet. Resultantly, Inuit moved between a number of coastal hunting sites and, occasionally, inland sites to hunt caribou (Damas, 1988). In the Kivalliq region, the Caribou Eskimo depended largely on the harvest of land animals, berries, freshwater fish and water fowl. They had a more sedentary lifestyle only switching camps to follow the caribou (Beaumier et al., 2015). In contrast, Inuit in the Kitikmeot region were more nomadic (Birket-Smith, 1929). In what is now central Labrador, Inuit also moved between winter settlements to hunt seal and summer accommodations to do fishing, hunting of caribou and birds (Brice-Bennett et al., 1977; Rankin, 2010). In the Sandwich Bay region of central Labrador, the "lifestyle and resource exploitation patterns… were a blend of Innu, Inuit, and European" traditions (Fitzhugh, 1999, p. 143), including trapping and hunting in the winter and then setting potatoes at the start of summer just before moving to fishing stations, as a result of the history of interaction between settlers and Indigenous people in the region. Across regions, the temporary settlements were composed of a large extended family or a group of families (Brice-Bennett et al., 1977; Damas, 1988).

Contact with white southerners and/or white Europeans began at different times and persisted in different ways for arctic Indigenous communities in Canada. For many Inuit, contact with the Canadian Government began in the early 1900s with the fur trade. Pre-1950s the philosophy of the Canadian Government was to keep Inuit dispersed on the land and away from the Hudson's Bay Company posts. It was not until the 1950s that the lifestyle of white southerners was more heavily pushed upon Inuit (Damas, 1988). In contrast, in Labrador, Inuit had contact with the French starting in the early 1700s. Their interactions consisted mostly of trade. It was not until the English came and established permanent settlements in the region in the late 1700s that contact increased and also acculturation took place between the Europeans and Inuit (Auger, 1989; Brice-Bennett et al., 1977; Felt, Natcher, & Procter, 2012; Rankin, 2010).

Arctic and subarctic Indigenous communities have and continue to experience great social, economic, and political changes. For Inuit, these changes started to accelerate in the 1800s with the permanent presence of English in Southern Labrador (Rankin, 2010) and with increased colonialization post 1950s in more northern Inuit communities (Goddard & Sturtevant, 1997). As early as the late 18th century in Labrador, Moravian missionaries encouraged more sedentary lifestyles for Inuit and this had profound impacts on the social structure of communities (Auger, 1989; Brice-Bennett et al., 1977; Dorais, 1980; Natcher, Felt, & Procter, 2012; Rankin, 2010). Additionally, in the late 19th century many Inuit women of Labrador married with English settlers. In the household female sphere, Inuit traditions, such as the types of food prepared, persisted. However, in the male dominated sphere, European influences were more present. By the 19th century, this resulted in the Inuit-Métis culture, or a mix of Inuit and European cultures (Dorais, 1980; Natcher et al., 2012; Rankin, 2010). Similarly, starting in the 1950s, Inuit in Nunavut increasingly moved from the use of non-permanent base camp sites to the inhabitance of permanent communities (Birket-Smith, 1929; Wenzel, 2009) driven by a centralization policy of the Canadian government (Damas, 1988). Specifically, the Canadian government provided education, housing and health care prompting and accelerating centralization (Damas, 1988). Also, in Labrador the delivery of social services, like health care, housing, and schooling by the Canadian government, the US military presence and the resulting jobs, and resource extraction all accelerated the centralization of Inuit into larger communities in the 1960s (Brice-Bennett et al., 1977; Damas, 1988; Felt et al., 2012).

Some arctic Indigenous peoples have been able to secure a land claim recognizing their traditional rights to the land. However, the federal government of Canada has inadequately recognized aboriginal groups in Labrador, starting in 1949 when Newfoundland became the 10th province of the Canadian federation (Felt et al., 2012). The land claims process for Inuit in Labrador began in 1970 and was accelerated by a large mining project in the 1990s. Inuit of Labrador entered into a land claim in 2005. The beneficiaries of this land claim where determined by geographic definitions. As a result, Labrador Inuit outside of these rigid geographic definitions were not beneficiaries of the land claim agreement. This includes Inuit in central and southern Labrador (Felt et al., 2012). In the face of social and political reorganization, Inuit have coped with and continued to engage in subsistence activities (Felt et al., 2012).

Centralization and subsequent economic and social changes have impacted and continue to impact traditional subsistence. Resource extraction, specifically mining, impacts caribou migrations and therefore, harvesting (McDonald, Arragutainaq, & Novalinga, 1997; Rixen & Blangy, 2016). Another example, large scale agriculture and industrial development destroyed important habitats where Indigenous communities in British Columbia used to harvest the clover root vegetable (N. Turner & Turner, 2008). Similarly, the development of a national park displaced Indigenous people in Alaska from the lands that they traditionally harvested wild foods, including berries (Thornton, 1999). Also, permanent dwellings and hunting quotas limit the traditional flexibility of harvesters (Brice-Bennett et al., 1977; Damas, 1988; Ford et al., 2013; McDonald et al., 1997; Wenzel, 2009; White, Gerlach, Loring, Tidwell, & Chambers, 2007). Often, this forces families to depend more heavily on market foods. There is increasing interest and attempts to commoditize country food in northern communities and this sometimes poses challenges to sharing networks, critical to traditional subsistence (Ford, Macdonald, Huet, Statham, & MacRury, 2016; Gombay, 2009; McDonald et al., 1997; Searles, 2016). Additionally, imposed southern ideas of single family houses and wage labor impact social relations and sharing in Inuit communities (Stern, 2005).

The increased cost of equipment and gasoline has made it more difficult for individuals to engage in harvesting resulting in decreased availability of country food (Wenzel, 2009; Wenzel et al., 2016). Also, the extent of harvesting areas has decreased with consequent impacts on the demand on the land and the range of species hunted (Freeman, 1976). Consequently, there is concern that decreased availability of country food will decrease the food security of families (Egeland, Williamson-Bathory, Johnson-Down, & Sobol, 2011) because while Inuit communities currently depend on both country and market foods (Beaumier et al., 2015; Tait, 2001; Wenzel et al., 2016), country food is preferred (McDonald et al., 1997; Statham et al., 2015). Water security is also a growing concern for Inuit communities (Daley et al., 2014; Donihee, 2011; Goldhar et al., 2013). The current political, social, and economic climate is a greater challenge to Inuit trying to engage in traditional subsistence compared to climatic changes at present (Ford et al., 2015; Wenzel, 2009). Communities are able to moderate some of these challenges through traditional sharing networks, flexibility in harvesting practices, and more recently, increased dependence on store bought food (Ford et al., 2008). However, with climate changes, there are added challenges for individuals to engage in traditional harvesting activities (Ford, Smit, Wandel, & MacDonald, 2006).

2.2 Climate Change in the Arctic

2.2.1 Arctic Amplification

Both scientific observations and Indigenous knowledge indicate that the climate is changing rapidly in the Arctic (IPCC, 2013b; Larsen et al., 2014). (IPCC, 2013b)(IPCC, 2013)(IPCC, 2013b)Across the Canadian Arctic, temperatures are warming and precipitation is increasing. Air temperatures in Canada have risen about 1.7 degrees C over the past 67 years and by as much as 3.1 degrees C in the Yukon and Northern British Columbia in the western Canadian Arctic (Environment Canada, 2017). Temperatures are projected to continue increasing over the next century (IPCC, 2013b) with average winter and fall temperatures increasing by 4 degrees C in the next three decades (Arctic Monitoring and Assessment Programme, 2017). A projection of precipitation is more complex but generally, is predicted to increase in the Arctic (Arctic Monitoring and Assessment Programme, 2017) especially in the winter and fall, anywhere from 5% to 70% (Arctic Monitoring and Assessment Programme, 2012). Greening of the Arctic is also occurring and there is evidence of increased shrub growth and decreases in bare ground across sites in the Arctic (Anisimov et al., 2007; Elmendorf et al., 2012; Xu et al., 2013). The implications of climate changes are both: i) physical, including changes in sea ice dynamics, permafrost extent, coastal areas, and ii) biological, including changes in vegetation and wildlife (Anisimov et al., 2007; Furgal & Prowse, 2007; Guo & Wang, 2016; Larsen et al., 2014). With the recognition that climate changes are already occuring and impacting communities, the world is increasingly recognizing the importance of adaptation in addition to mitagation in climate change policy (Ford, 2009; Ford et al., 2007; Ford & Smit, 2004; IPCC, 2014; Khan & Roberts, 2013; Moss et al., 2013; Pielke et al., 2007)

Northern Indigenous communities are disproportionately sensitive to climate changes due to habitation in a region undergoing the most dramatic climate change globally, socio-economic disparities, and colonial legacies (Ford, 2012). Historically, Indigenous communities have adapted to natural variability in the climate and continue to adapt to changes (Anisimov et al., 2007; B. C. Forbes et al., 2009; Ford, 2012; Ford et al., 2007; Guyot et al., 2006; N. Turner & Clifton, 2009; Wenzel, 2009). However, with added social, economic, and political changes, it is more challenging for northern communities with land based livlihoods to respond to climate changes (Anisimov et al., 2007; B. C. Forbes et al., 2009; Ford, 2012; Ford et al., 2013, 2015; Ford, Ford, et al., 2010; N. Turner & Turner, 2008; Wenzel, 2009). As a result, Indigenous communities experience challenges related to infrastructure, traditional subsistence, health, and culture (Ford et al., 2012a; Ford, Bell, & Couture, 2016; Harper, Edge, Schuster-Wallace, Berke, & McEwen, 2011; MacDonald, Harper, Willox, & Edge, 2013; Ostapchuk, Harper, Willox, Edge, & others, 2012). Specifically, permafrost thaw, accelerated by climate change, results in biological and physical changes that impact northern Indigenous communities.

2.2.2 Permafrost Thaw

Permafrost, soil that is below freezing temperatures for two consecutive years, covers the circumpolar Arctic (Ford, Bell, et al., 2016; Furgal & Prowse, 2007). The continuous permafrost zone is at northernmost latitudes where the permafrost "is effectively ubiquitous" (Heginbottom, 2002, p. 627). In contrast, "some proportion of the ground does not contain permafrost" in the discontinuous permafrost zone (Heginbottom, 2002, p. 627). Both external factors, or climate related, and internal factors, or factors related to soil type, vegetation cover, and water content, impact the ground temperature and therefore, permafrost condition (Allard & Lemay, 2012; Annersten, 1964; Zuidhoff & Kolstrup, 2005). Furthermore, permafrost is more susceptible to ground ice if the soil is fine grained or has high organic matter content (Ford, Bell, et al., 2016). Specifically in the discontinuous permafrost zone, variability in snow cover has been found to be a main driver of permafrost distribution (Annersten, 1964; Brown, 1979; Seppälä, 2011). Terrain factors have an important role in permafrost distribution. Critically, permafrost is largely found in peatlands at the southernmost permafrost boundary (Zoltai & Tarnocai, 1975) due to the thermal properties of peat (Brown, 1979; Seppälä, 2011). Peat insulates permafrost because of its low thermal conductivity when it is dry in the summer and its high thermal conductivity when it is moist in the winter (Brown, 1975; Seppälä, 2011). Permafrost in peatlands is associated with specific landforms including peat plateaus and palsas (Zoltai & Tarnocai, 1975). Also, the natural differences in topography and drainage impact the spatial distribution of intact permafrost and thermokarst (thaw pond) creation (Schuur, Crummer, Vogel, & Mack, 2007). Generally, temperature at 20 meters depth is a good indicator of long term change, but other indicators of permafrost degradation include: increased summer thaw, development of taliks, thermokarst terrain, expansion of thaw lakes, active layer detachments, rock falls, destabilized rock glaciers (IPCC, 2013).

With climate change, permafrost associated soils are thawing across the Arctic, and it is projected that by then end of the century permafrost areas at high latitudes will decrease by 48% (Guo & Wang, 2016). Northern Canada is underlain by both discontinuous and continuous permafrost (Furgal & Prowse, 2007). As air temperatures increase across the Canadian Arctic so do soil temperatures (Ednie & Smith, 2010, 2015; S. L. Smith, Burgess, Riseborough, & Mark Nixon, 2005), with records of deep permafrost temperatures increasing since 2008 (Ednie & Smith, 2015) and reductions in the area underlain by permafrost (Furgal & Prowse, 2007; IPCC, 2013b; Zhang et al., 2006). In the Subarctic, there are decreases in the extent of permafrost mounds by as much as a 96% (Bouchard, Francus, Pienitz, Laurion, & Feyte, 2014), concurrent increases in the extent of fen and bog vegetation by as much as 40% in northern Quebec (Payette et al., 2004; Sannel & Kuhry, 2011), and similar increases in fen vegetation by as much as 7.3% per decade in sporadic permafrost peatlands in northern Sweden (Sannel & Kuhry, 2011) in the past half century. About half of the permafrost in the Canadian Arctic and Subarctic is projected to dissapear in the next century with warming air temperatures and where permafrost persists the active layer (seasonal thaw layer) is projected to increase up to 50% in the next half century (Furgal & Prowse, 2007). Under an intermediate representative concentration pathway (RCP) 4.5 scenario, permafrost in Canada is projected to decrease by 45%, and under the RCP 8.5 scenario, all remaining permafrost in Canada is projected to be north of 65 degrees (Guo & Wang, 2016). The consequences of permafrost thaw include changes in hydrogolical connections, water quality, slope instability and land subsidence/thermokarst creation (especially where the permafrost is ice rich) (Allard & Lemay, 2012; Couture & Pollard, 2007; Ford, Bell, et al., 2016; Furgal & Prowse, 2007; Hong et al., 2014), with permafrost degradation impacting vegetation and wildlife (Furgal & Prowse, 2007).

Communities experience and express challenges as a result of permafrost thaw largely related to infrastructure (Ford, Bell, et al., 2016). The integrity of infrastructure is threatened by thawing ice rich permafrost (Andrachuk & Pearce, 2010; Crate & Fedorov, 2013; Nasmith & Sullivan, 2010). Infrastructural damage impacts emotional and mental well being with the threat of relocation (Spinney & Pennesi, 2013). Across communities in Nunavut, Canada, these challenges have been articulated in adaptation action plans (Calihoo & Ohlson, 2008; Calihoo & Romaine, 2010; Hayhurst & Zeeg, 2010; Johnson & Arnold, 2010; Lewis & Miller, 2010; Nasmith & Sullivan, 2010). Community concerns prompted mapping of surficial geology to assess current and future risk to permafrost thaw (Allard et al., 2012; D. L. Forbes, Bell, James, & Simon, 2014; I. R. Smith, 2014; I. R. Smith & Forbes, 2014). Researchers have attempted to further assess soil ice content via coring and ground penetrating radar to better predict the risk of communities to permafrost thaw induced subsidence (Bagnall, Forbes, & Bell, 2015; Government of Nunavut, 2016; Grandmont, Guimet, & Maday, 2011; Leblanc et al., 2011). Meanwhile, communities are seeking to alter permafrost thaw by modifying housing structures, building pipes above ground, using trucks to transport water and sewage, and introducing shoreline protection and culverts to minimize thermal erosion of permafrost (Ford, Bell, & St-Hilaire-Gravel, 2010; Government of Nunavut Department of Environment, 2013). An additional challenge to coping with the infrasturctural damage of permafrost thaw is that current codes, standards and related instruments (CSRI) do not accurately take into account climate changes (Ford et al., 2014; Steenhof & Sparling, 2011). These physical and *also* biological consequences of permafrost thaw will likely impact traditional subsistence activities.

2.3 Impact Pathway of Permafrost Thaw on Traditional Subsistence

Permafrost thaw has diverse impacts on traditional subsistence activities. Displacement of the land surface, as ice rich permafrost thaws, impacts the integrity of trails for accessing hunting areas and berry picking locations (Ford et al., 2010). For instance, increased standing water, as a result of thaw, impacts reindeer migrations in arctic Russia (Amstislavski et al., 2013), and permafrost thaw is likely a factor in observed changes in reindeer and caribou migrations in other northern regions (Amstislavski et al., 2013; Beaumier et al., 2015 & Nasmith & Sullivan, 2010). More freeze thaw cycles also disrupt caribou's ability to forage for lichens in the winter and, therefore, impact the health of the caribou (Andrachuk & Pearce, 2010; Downing & Cuerrier, 2011). Additionally, freshwater fish are impacted by the drainage of once permafrost contained lakes (Andresen & Lougheed, 2015; Fitzgerald & Riordan, 2003; Goldhar, Bell, & Wolf, 2014). Permafrost thaw threatens the integrity of food storage mechanisms (Brubaker et al., 2011; Downing & Cuerrier, 2011), and will likely impact the availability and quality of communities' natural water sources (Andresen & Lougheed, 2015; Brubaker et al., 2011) because of how permafrost thaw impacts hydrological regimes and connections (Christensen et al., 2004; Fitzgerald & Riordan, 2003; Maldonado, Colombi, & Pandya, 2014; Takakura, 2016). In the discontinuous zone, researchers have observed an initial increase followed by a loss of water bodies (Beck, Ludwig, Bernier, Lévesque, & Boike, 2015). Similarly, in boreal peatlands the conditions may become wetter rather than drier with thaw (Camill, 1999; Camill, Lynch, Clark, Adams, & Jordan, 2001). For instance, in Abisko, Sweden, the landscape has become wetter (more thermokarst features) as permafrost has thawed (Johansson et al., 2006). Similarly, in Healy, Alaska, as the ice rich permafrost thaws in the undistrubed tussock tundra, there are changes in the microtopography and as a result, hydrology (Schuur et al., 2007).

Diverse changes in vegetation dynamics have been observed as a result of permafrost thaw, specifically, the deterioration of forests, the loss of grasses, and the loss of shrubs and increase in graminoids (Bubier, Moore, Bellisario, Comer, & Crill, 1995; Camill, 1999; Camill et al., 2001; Chapin et al., 2010; Christensen et al., 2004; Crate & Fedorov, 2013; Johansson et al., 2013; Takakura, 2016). In permafrost associated peatlands in the sporadic permafrost zone, permafrost degradation has been followed with an increase in thermokarsts and fen and bog vegetation (Payette et al., 2004; Sannel & Brown, 2010; Sannel & Kuhry, 2011). Often, in the sporadic permafrost zone, intact permafrost is associated with palsa features and as the permafrost thaws the palsa collapses. There are distinct changes in vegetation between the palsa, which has shrubs, lichen, and sphagnum, and the collapsed palsa, which is dominated by sphagnum, mosses, sedges and forbes (Bubier et al., 1995; Camill, 1999; Camill et al., 2001). While increasing air temperatures and resulting permafrost thaw trigger changes in vegetation, there are concurrent changes in soil moisture and nutrient availability that also impact vegetation abundance (Schuur et al., 2007).

These changes in vegetation impact traditional subsistence activities. For instance, changes in vegetation have impacted the traditional pastoral activities of the Sakha in Siberia, Russia (Takakura, 2016). The loss of lichen has impacts on caribou, and the increase in woody plants has potential impacts on wild berries, both important parts of Inuit diet (Allard & Lemay, 2012). Berries are an important part of the traditional harvest and culture in Indigenous communities across the Arctic and Subarctic (Birket-Smith, 1929; Bunce, Ford, Harper, Edge, & IHACC Research Team, 2016; Downing & Cuerrier, 2011; Fitzhugh, 1999; Kellogg et al., 2010; Murray et al., 2005; Ootoova et al., 2001). Inuit have observed a loss of berries due to shrub encroachment (Downing & Cuerrier, 2011) which also limits access to berry picking areas (Allard & Lemay, 2012). While it is uncertain which factors are impacting the location, abundance, extent, and ripening times of wild berries, Indigenous peoples attribute changes in berries to changes in precipitation (both rain and snow), and tree and shrub growth (Bunce et al., 2016; Cuerrier, Brunet, Gérin-Lajoie, Downing, & Lévesque, 2015; Guyot et al., 2006; N. Turner & Clifton, 2009).

2.4 Conclusion

The literature on traditional subsistence, climate change in the Arctic and Subarctic with a focus on permafrost thaw, and the impacts of permafrost thaw on traditional subsistence were reviewed in this chapter. With rapid climate and social changes in the Canadian Arctic and Subarctic, the vulnerability of traditional subsistence activities of Indigenous communities should be assessed to inform adaptation policies. There is considerable research on how climate change impacts the hunting component of subsistence but less consideration of climate change impacts on wild berry picking. Additionally, there are numerous studies that identify and characterize how vegetation and hydrology changes with permafrost thaw, but a lack of studies that assess how these changes have impacted land based livelihoods, specifically berry picking. The literature reviewed in this chapter lays the foundation for the study design and methodology of chapter 3, where the environmental changes, with a focus on permafrost thaw, that have impacted the berry producing plant, *Rubus chamaemorus*, are identified and characterized, and chapter 4, where the social, economic, and political changes that interact with environmental changes to mitigate or exacerbate the capacity of individuals to participate in bakeapple picking are described.

Chapter 3 Environmental Change and the Impact on Bakeapples in Southern Labrador

Role of Chapter 3

This chapter addresses objective one of the thesis which was to identify the environmental changes that are impacting bakeapple picking. The study design of this chapter draws upon the literature reviewed in chapter 2. The purpose of this chapter is to synthesize the findings of mixed methods to describe how various related environmental changes are impacting the growth of *Rubus chamaemorus.* The results of this chapter inform chapter 4 where I examine the overall vulnerability of bakeapple picking in Cartwright, Labrador to both ecological and social changes.

Abstract

As permafrost degrades there are long term changes in the hydrology and predominate types of vegetation of a landscape. *Rubus chamaemorus* (cloudberry/bakeapple), a culturally and nutritionally important berry for Indigenous communities in the Arctic and Subarctic, grows abundantly in permafrost associated peatlands. The impacts of permafrost thaw on this berry species have not been specifically considered in the literature. A case study approach of the community Cartwright, Labrador is used to i) assess how the abundance of *Rubus chamaemorus* differs between palsa permafrost and no permafrost sites, ii) quantify the change in permafrost features over time, iii) infer how permafrost thaw has impacted *Rubus chamaemorus* growth over time, and iv) identify related changes in temperature, vegetation, and surface water and their potential impacts on *Rubus chamaemorus* growth. We find that the presence/absence of *Rubus chamaemorus* is not significantly dependent on the presence of permafrost but that vegetation assemblages are significantly different between palsa and no permafrost sites. Additionally, we find that palsa features have decreased in a representative permafrost peatland in Cartwright over a 12-year period. The findings of this study heighten our understanding of how an important berry species has been impacted by environmental change and highlights the need for longer term studies to assess how vegetation changes, specifically *Rubus chamaemorus,* with palsa permafrost degradation.

3.1 Introduction

Globally, the climate is warming at unprecedented rates and warming is directly impacting sea ice, snow cover, and permafrost extent in the Arctic (IPCC, 2013b). Permafrost is soil that has been frozen for at least two years with an overlying active layer that seasonally thaws and freezes. In Canada, permafrost is projected to decrease by 45% (Furgal & Prowse, 2007) under an intermediate representative concentration pathway (RCP) 4.5 scenario, and only remain north of 65 degrees under a high end RCP 8.5 scenario by the end of the century (Guo & Wang, 2016).

Permafrost thaw has chemical, biological, and physical implications. One chemical implication is a flux of nutrients into nearby water bodies which can impact water quality, especially on arctic coastlines (Fritz, Vonk, & Lantuit, 2017). Additionally, a physical and biological implication is the redistribution of water in thawing permafrost associated peatlands resulting in increased fen and bog vegetation (Payette et al., 2004). Similarly, permafrost degradation, beneath ponds or lakes, can result in greater soil infiltration, lake drainage, and subsequent fish and other wildlife loss (Fitzgerald & Riordan, 2003; Furgal & Prowse, 2007). Permafrost degradation has physical manifestations in the landscape including ground subsidence, thaw pond formation, coastal erosion, and landslides (Allard & Lemay, 2012; Hong et al., 2014). Permafrost thaw, in turn, is affecting infrastructure across arctic and subarctic regions, including houses and roads, which has prompted local monitoring and action plans to moderate the impacts (Ford, Bell, et al., 2016, 2010; Spinney & Pennesi, 2013). The physical implications of permafrost thaw have additional impacts on the traditional land based livelihoods of Indigenous communities. Permafrost thaw induced land subsidence can impact both caribou or reindeer migrations and hunting trail access (Beaumier et al., 2015; Ford, Bell, et al., 2010; Nasmith & Sullivan, 2010), threatens traditional food storage mechanisms (Brubaker et al., 2011; Downing & Cuerrier, 2011), and has implications for vegetation, such as on wild berries (Allard & Lemay, 2012; Larsen et al., 2014).

In the Subarctic where permafrost is discontinuous, permafrost is often associated with peatlands due to the thermal properties of peat (Brown, 1979; Zoltai & Tarnocai, 1975). In peatlands, permafrost features include peat plateaus and palsas, and are associated with particular vegetation types including, black spruce, shrubs, and lichens (Zoltai & Tarnocai, 1975). Palsas are "mounds of peat with a permanently frozen core" (Seppälä, 2011, p. 370). These palsas are surrounded by unfrozen areas (Roberts & Robertson, 1980). The conditions that promote palsa formation include, a mean annual air temperature that is less than 0 degrees Celsius, low summer rainfall, a thin snow layer, and critically, the presence of peat (Seppälä, 2011; Way & Lewkowicz, 2016). During the winter, in areas that snow has been scoured by wind, frost can penetrate saturated peat. Resultantly, the ground heaves up. The overlaying peat layer insulates the frozen core because of its low thermal conductivity when it is dry in the summer and its high thermal conductivity when it is moist in the winter (Brown, 1975). Each successive winter, water in the peat and possibly, in the underlying fine grained soil freezes and the palsa heaves up further (Seppälä, 2011). The vegetation of undisturbed palsa features through its stages of development includes: shrubs (for example *Empetrum nigrum, Ledum spp., Vaccinium ulginusom)*, lichen, *Sphagnum* spp., and few herbaceous plants, including *Rubus chamaemorus* (Roberts & Robertson, 1980; Zoltai & Tarnocai, 1975). Disturbances such as the construction of roads, warming temperatures, and increasing snow cover can damage the insulating peat layer causing the permafrost to thaw resulting in a collapsed palsa and shifts in vegetation (Roberts & Robertson, 1980; Roberts, Simon, & Deering, 2006).

With permafrost thaw, previous studies describe consequent ground subsidence, wetter conditions, and a transition to wet graminoids and *Sphagnum moss* spp (Camill, 1999; Camill et al., 2001; Christensen et al., 2004; Johansson et al., 2006). Also, with permafrost thaw there is fragmentation of the permafrost palsa/peat plateau dependent vegetation (Christensen et al., 2004). These changes associated with permafrost thaw over the past half century have been quantified with remote sensing techniques. Bouchard et al., (2014) used a historical aerial photograph from 1959 and a Quickbird satellite image from 2006 to identify a decrease in the extent of permafrost features by as much as a 96% in northern Quebec. Sannel and Kuhry (2011) did a time series analysis of thaw pond formation with historical aerial photographs and satellite images of locations across the circumpolar North and were able to quantify increases in fen vegetation by as much as 7.3% per decade in sporadic permafrost peatlands in northern Sweden in the past half century. In a shorter period, from 2004 to 2009, Beck et al., (2015) quantified a decrease in permafrost features by 6% using Quickbird and GeoEye satellite images.

Wild berries, including *Rubus chamaemorus*, grow in permafrost associated peatlands on palsa features (Roberts & Robertson, 1980) and their growth is impacted by precipitation, temperature, soil moisture and the surrounding vegetation (Agren, 1989; Downing & Cuerrier, 2011; Kellogg et al., 2010; Korpelainen, 1994). Because palsa permafrost thaw impacts soil moisture and vegetation, it is likely that permafrost thaw will have implications on *Rubus chamaemorus,* a berry particularly important for Indigenous communities in southern Labrador, Canada. Indigenous communities across the Arctic and Subarctic harvest berries for reasons of both nutritional and cultural importance (Parlee & Berkes, 2005, 2006; Thornton, 1999). Communities express concern for how climate related changes, including increases in temperature and tall erect shrub growth, are impacting wild berry species (Allard & Lemay, 2012; Cuerrier et al., 2015; Downing & Cuerrier, 2011).

Despite the importance of berry picking to Indigenous communities, few studies have examined how permafrost thaw and other relevant ecological changes are affecting berry species consumed by communities (exceptions include Allard & Lemay (2012), Bunce et al., (2016), Cuerrier et al., (2015), Downing & Cuerrier (2011), Kellogg et al., (2010)). This paper contributes to this nascent area of study by examining the differences in *Rubus chamaemorus* (referred to herein as 'bakeapples' consistent with local terminology) on palsa permafrost features and the surrounding areas with no permafrost, and the associated use by Indigenous communities, focusing on southern Labrador, Canada.

3.2 Methods

3.2.1 Study Area

This study was undertaken in collaboration with the community of Cartwright, Labrador, Canada. Cartwright is located in southern Labrador on Sandwich Bay and on the coast of the Atlantic Ocean (Figure 1). The community is in the mid Boreal Forest ecoregion (Roberts et al., 2006), and between 1981-2010 had an average annual temperature of 0 degrees Celsius, experienced average annual rainfall of 616.8 mm and average annual snowfall of 462 cm (Government of Canada, 2017). Cartwright has a population just under 500 individuals according to the Canadian 2016 census, the majority of who have Indigenous ancestry. This community was selected as it is a location of long-term permafrost monitoring stations in palsa peat bogs, with the NunatuKavut Community Council (NCC) and community members expressing interest in the study.

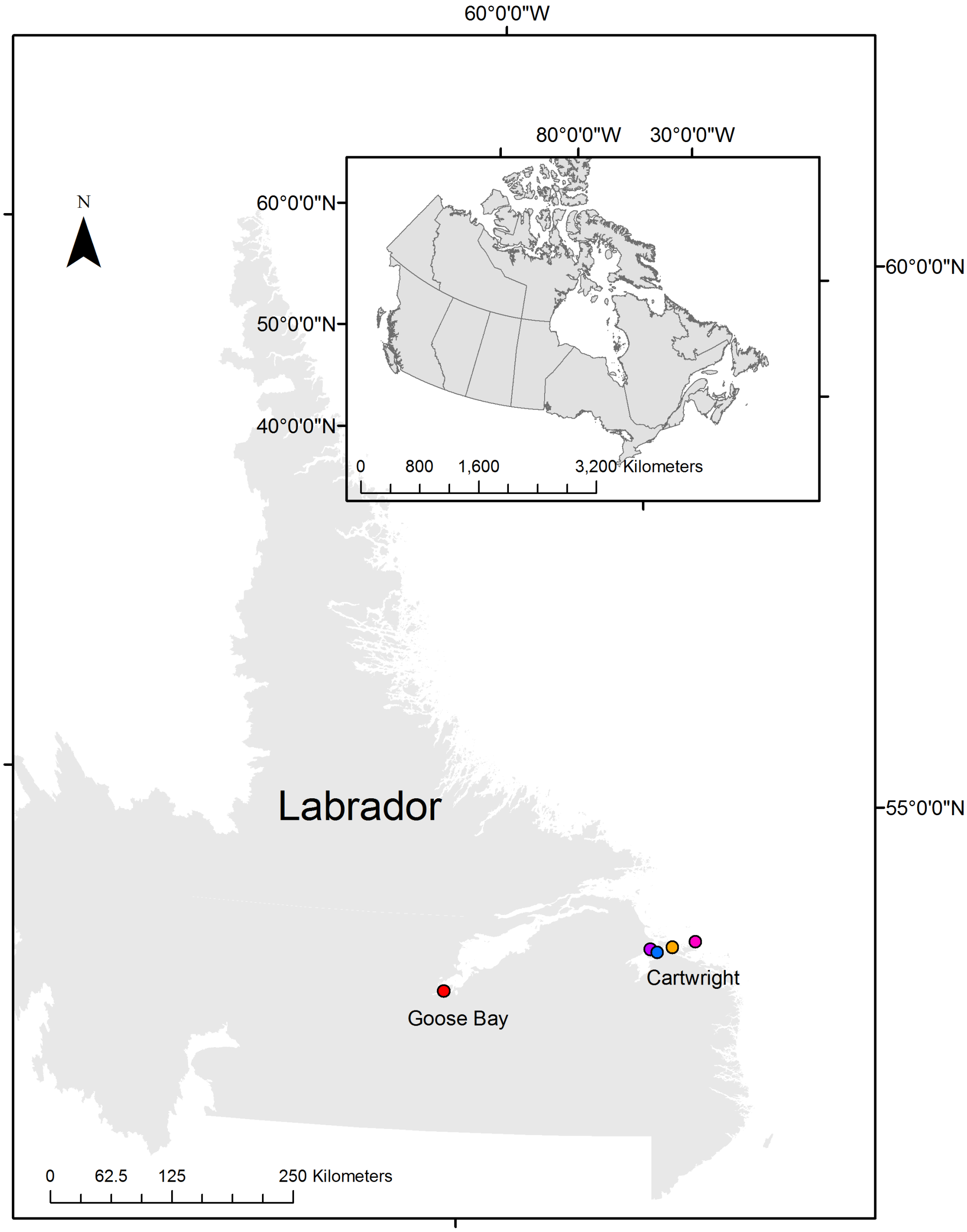


Figure 1: A map of Canada and a zoomed in version of Labrador with Cartwright and Happy-Valley Goose Bay labeled. The four peatlands where data was collected are labeled and include: The Big Marsh in Cartwright (blue point), Main Tickle Point (purple point); Hare Harbor (orange point), Grady (pink dot). Data source: Statistics Canada (2016) for Cartographic Boundary File of Canada and Elections Newfoundland and Labrador (2015) for Labrador shape file.

Cartwright is located at the southernmost boundary of permafrost. The permafrost is classified as sporadic and is limited to palsa features in peatlands. Palsa peat bogs, containing palsa and collapse palsa features, can span from 50 m^2 to 200 km^2 (Zuidhoff & Kolstrup, 2005). The peat in these palsa bogs is about a meter thick. Below the peat is soil with silty sandy texture. The permafrost table is about 60 cm below the surface (Brown, 1979). Palsas are usually between 10 to 30 meters in diameter and can be raised one to seven meters above the ground (Figure 2). The size of palsas differs based on the developmental stage of the palsa; at the initial stage of development, palsas can be as small as 1.5 meters (Roberts & Robertson, 1980; Zuidhoff & Kolstrup, 2005).

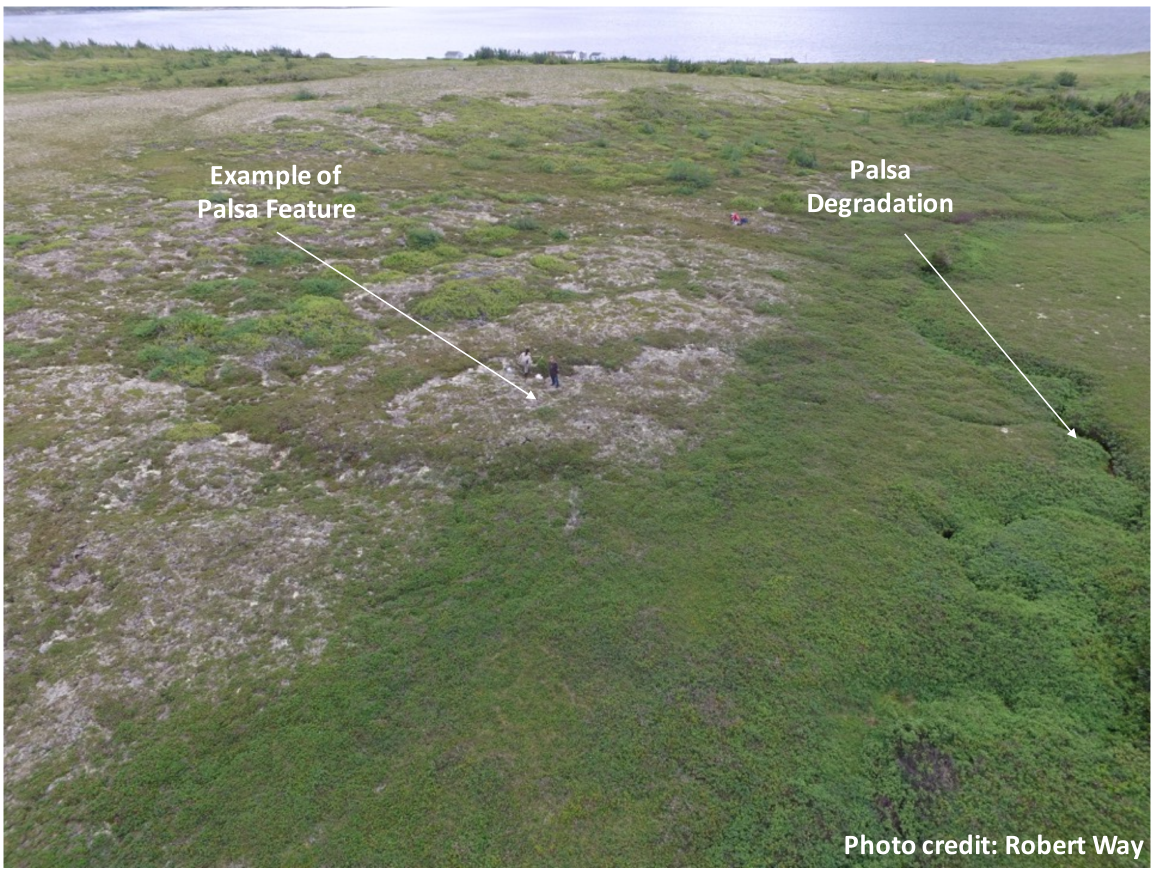


Figure 2: An example of a palsa feature and with probable rapid palsa degradation. Photo credit: Robert Way

These palsa features were first recorded in southeastern Labrador in 1939 (Hustich, 1939) Later in 1979, Brown described the palsa features in Cartwright, Labrador as 2 to 3 meters high with a peat layer about 60 cm to 1.2 meters thick. In more recent investigations, palsa features in

Cartwright, Labrador are described between 0.3-1.3 meters in height with lichen and exposed peat in the drier palsa areas and shrubs and mosses in the surrounding wetter depressions where there is no permafrost (Way, Lewkowicz, & Zhang, 2018). Palsas naturally form and degrade over time (Roberts & Robertson, 1980; Seppälä, 2011). While there is no historical data to assert that the surrounding area with no permafrost used to once have permafrost or be part of a palsa feature, we do know that palsa features have decreased in size in southern Labrador (Brown, 1979; Way et al., 2018) and it is reasonable to infer that as palsa features thaw they will resemble the wetter conditions of the surrounding depressed areas (Supplementary Figure 1) based on the findings of other studies (Camill, 1999; Christensen et al., 2004; Johansson et al., 2006, 2013; Payette et al., 2004)

This study draws from data collected in and within 115 km of Cartwright, Labrador (Figure 1) which was determined by community members' collective knowledge of bakeapple picking spots (Supplementary Figure 2 and Supplementary Table 1). The study focuses on locations on the mainland and the surrounding islands in Sandwich Bay, but community members' had knowledge of the region from Table Bay to Indian Tickle, and the Black Tickle/Batteau area.

3.2.2 Data Collection and Analysis

Mixed methods (Supplementary Table 2) were used to identify how ecological changes have impacted *Rubus chamaemorus* growth. Vegetation surveys and remote sensing techniques were used to infer the impacts of permafrost thaw on *Rubus chamaemorus*. Qualitative methods including focus groups and interviews, were used to characterize other relevant ecological changes, drawing upon the traditional ecological knolwedge (TEK) of community members. The importance of using TEK to document environental change is now widely recognized, providing in-depth, location specific observations of change drawing on generations of continuous enviornmental observations (Huntington, 2011; Laidler, 2006; Riedlinger & Berkes, 2001; Savo et al., 2016). For this study, ethics approval was obtained from McGill University and the NCC prior to data collection.

3.2.2.1 Field Surveys

Field surveys included relevé sampling of 62 plots that spanned four permafrost associated peatlands (Figure 1) and occurred over 4 consecutive days (August 7th through August 10th, 2017). Relevés are a standard method to study vegetation (Causton, 1988; Ellenberg &

Mueller-Dombois, 1974; Podani, 2006). A relevé is, at minimum, a list of present species within the plot (Causton, 1988, p. 56). The purpose of the relevé method is to classify distinct plant communities, identify vegetation gradients, and/or to determine the importance of environmental factors on assemblages of vegetation (Causton, 1988, p. 56). The area of the plot was $1m^2$ based on recommendations for lichen and moss communities (Ellenberg & Mueller-Dombois, 1974). Sample plots were stratified between palsa sites with an active layer and sites with no detectable permafrost within 120 cm of the peat surface. In total, 31 plots were randomly selected on both palsa and no permafrost sites by throwing the quadrat in areas of the peatland with palsa features. 7 palsa and 7 no permafrost plots were selected at Hare Harbor. 8 palsa and 8 no permafrost plots were selected at Grady. 5 palsa and 5 no permafrost plots were selected at Main Tickle Point. 11 palsa and 11 no permafrost plots were selected at The Big Marsh in Cartwright. The number of plots at Hare Harbor, Grady, and Main Tickle Point was limited by the logistics of traveling by boat.

Per plot, species frequency was measured with the Daubenmire scale (Supplementary Table 3), which is a modified version of the Braun-Blanquet scale (Supplementary Table 4) (Ellenberg & Mueller-Dombois, 1974; Thomas et al., 2003). See supplementary methods text 1 for the limitations of the Braun-Blanquet scale compared to the Daubenmire scale.

Elevation, water table, soil water pH, active layer depth (ALD), soil temperature were also measured at each plot because hydrological conditions constrain permafrost presence (Brown, 1979; Camill et al., 2001), and ground temperatures and microtopography are indicators of permafrost degradation (Johansson et al., 2013; Roberts & Robertson, 1980; Way & Lewkowicz, 2016). Soil water samples were collected at no permafrost sites with a syringe connected to a hollow serrated tube. pH was tested in the field with a Hanna [HI98100] pH meter (with a resolution of 0.01pH and an accuracy of plus or minus 0.2 pH) at sites 15, 17, 18, 19, 20, 21, 23, 24, 25 NP and with pH strips at 26 CP through 30 CP due to a loss of the calibration tools (Bubier et al., 1995; Camill, 1999; Glaser, Wheeler, Gorham, & Wright, 1981). Elevation was measured with a hand-held Garmin GPS with a resolution of less than 10 meters. A 120 cm permafrost probe was used to measure ALD. The temperature at ALD and 20 cm above for palsa sites or at 120 cm and 100 cm for sites with no permafrost were taken to check that the frost table had actually been reached by the permafrost probe and as another indicator of possible permafrost degradation (Beck et al., 2015; Way & Lewkowicz, 2015). A limitation of this dataset is that ecological parameters, including water table depth, soil water pH, and temperature were not measured at all relevés because of technical issues with the field equipment at remote sites only accessible by boat.

The purpose of the relevé data is to identify the ecological conditions that constrain *Rubus chamaemorus* abundance in the study region. To determine if *Rubus chamaemorus* was significantly different across palsas and sites with no permafrost, a Fisher's exact chi squared test was used with the stats package in R [1.0.143] (Causton, 1988). Then, a combination of ordination and regression techniques were used to determine if i) distinct vegetation communities are associated with the palsa and no permafrost plots, and ii) ecological gradients explain the differences in vegetation. Unconstrained ordination is commonly used by ecologists to consider the similarities between plant communities at different site types and also, to consider the environmental variables that explain the variation in species (Causton, 1988; Šmilauer & Lepš, 2014). For the unconstrained ordination, non-metric multidimensional scaling (NMDS) was performed with the Vegan package in R [1.0.143]. This method first calculates a dissimilarity matrix between all the objects, in this case using the Bray-Curtis dissimilarity index, and then places those objects in 2 or 3 dimensional space in a way that optimizes the dissimilarity distances calculated (Šmilauer & Lepš, 2014). NMDS is an appropriate method because it only considers rank order data when configuring relevés in the two or three dimensional space (Podani, 2006; Šmilauer & Lepš, 2014). Other possible methods are elaborated on in the supplementary methods text 2. Then, ANOSIM analysis was done with the Vegan package in R [1.0.143] to test whether the dissimilarity between the vegetation of the palsa and no permafrost plots is significantly greater than the dissimilarity within each group (Robert, 2006). Additionally, SIMPER analysis was done with the Vegan package in R [1.0.143] to determine which species are contributing most to dissimilarity between groups (Robert, 2006).

Spearman rank correlation coefficients were calculated with the stats package in R [1.0.143] to determine if the correlations of the environmental variables (elevation, ALD, temperature at max depth and 20 cm above max depth) with the NMDS coordination axes are significant (Causton, 1988). Water table depth and soil water pH were excluded from the analysis because of inadequate sample size (14 plots and 16 plots respectively). Because the temperature variables both had a sample size of 47 and the elevation and ALD had sample sizes of 62 the spearman correlation coefficients and the significance of each spearman rank correlation coefficient were determined separately. The environmental variables with significant correlation coefficients were fitted via regression to the ordination axes using the Vegan package in R [1.0.143] (Oksanen, 2015). The direction of the vector indicates whether the correlation is positive or negative and the magnitude of the vector is proportional to the strength of the correlation (Oksanen, 2015).

3.2.2.2 Remote Sensing

Two images, with multispectral and panchromatic bands, from 2004 and 2016 were received from the DigitalGlobe Foundation. This time period was selected based on the availability of images from satellite sensors with a fine enough spatial resolution to detect palsa features. The 2004 image is from the QuickBird sensor which has a multispectral spatial resolution of 2.62 meters and a panchromatic spatial resolution of 0.65 meters. The 2016 image is from the World View 2 sensor which has a multispectral spatial resolution of 1.84 meters and a panchromatic spatial resolution of 0.45 meters. The spatial resolution of both sensors is fine enough to detect palsa features which are generally 10-30 meters (Zoltai & Tarnocai, 1975) but can be as small as 1.5 meters at the initial stages of palsa formation (Brown, 1979).

The change in palsa features, vegetation, and surface water were assessed in the permafrost associated peatland in Cartwright, called The Big Marsh over the time period from 2004 to 2016 using ENVI 5.4 software. The Big Marsh is a bog with permafrost associated peat mounds, a frost table depth of about 43 to 45 cm, and a maximum permafrost depth of 5.4 meters (Way et al., 2018). This specific peatland was evaluated because it was an overlapping area in the two images, community members reported picking bakeapples there, and I selected palsa and no permafrost plots in this peatland, so I had an understanding of the features to look for in the satellite imagery. The images were already geometrically corrected (DigitalGlobe Foundation, 2016). Therefore, preprocessing included radiometric corrections (Lillesand, Kiefer, & Chipman, 2014), with the radiometric calibration tool available through ENVI 5.4 (Harris Geospatial Solutions, 2018a) and atmospheric corrections (Lillesand et al., 2014), with FLAASH, a commonly used algorithm to eliminate the effects of atmospheric scattering and adsorption on the reflectance values measured at the satellite sensor (Marcello, Eugenio, Perdomo, & Medina, 2016). To ensure that the 2004 and 2016 images were precisely aligned, they were co-registered following the approach of Andresen and Lougheed (2015) who selected 15 tie points with a root-mean-square error (RMSE) of less than 1 meter to align an historical aerial photo with three satellite images of thaw ponds in Alaska. For this study, there were a limited number of identifiable tie points between the 2004 and 2016 images due to a coarser resolution in the 2004 image and little built infrastructure surrounding the peatland, so 11 tie points were used with a final RMSE of 1.90.

For the palsa features, the manual target detection approach used by Beck et al., (2015) and also, Bouchard et al., (2014), who both identified palsas and other degradation features in subarctic Quebec in areas equal to or less than 0.25 km^2, was applied. Additionally, following the approach of Sannel and Kuhry (2011), I used the panchromatic bands with the aid of the multispectral bands to identify palsas. The change in the identified palsa features between 2004 and 2016 was assessed using ArcMap of ArcGIS 10.5.1. Automatic target detection was used to identify any green vegetation and surface water in the 2004 and 2016 images. Vegetation and water were considered because community participants described changes in both, and were not used as proxies for permafrost degradation. First, 0.539405 km^2 subsets of the “Big Marsh” were created within the larger satellite images. Automated target detection was used for vegetation and surface water features, with the Matched Filtering (MF) algorithm, which required a selection of target and rejection spectra in the image (Harris Geospatial Solutions, 2018b). Three algorithms were considered including, MF, mixed tuned matched filtering (MTMF), and adaptive coherence estimator (ACE). The outputs of these three algorithms were visually assessed by comparing the features detected by each algorithm to the original image. The MF and MTMF outputs were similar for vegetation but the MF output more appropriately detected water for the 2004 and 2016 images compared to the MTMF and ACE outputs (Supplementary Figure 3). The ROI separability between vegetation, water, and the other unclassified areas was computed with Jeffries-Matusita separability measures. Jeffries-Matusita separability measures range from (0,2) with a value closer to 2 indicating better separability (Richards & Jia, 2006). All combinations of ROI’s had Jeffries-Matusita separability measures greater than 1 indicating good spectral separability (Supplementary Table 5). Classification accuracy was also computed with three metrics including: the overall accuracy (correctly classified pixels/total number of testing pixels), producer accuracy (pixels correctly classified in one class/, total reference pixels in that class), and user accuracy (pixels correctly classified in a class/total pixels classified in that class) (Richards & Jia, 2006). To do this it is recommended that first, a random sample of 30 to 60 reference pixels are labeled with the appropriate class and then, the labeled reference pixels are compared to the corresponding classified pixels (called the testing pixels) within the image (Richards & Jia, 2006). The user accuracy, which is the chance that a pixel labeled vegetation or water is actually vegetation or water, was 81.82% and 87.50% for the surface water class in 2004 and 2016 respectively, and 100% for the vegetation class in both 2004 and 2016. The producer accuracy and the overall accuracy were lower for both classes meaning that not all vegetation or water reference pixels were classified as vegetation or surface water pixels during the automatic target detection (Supplementary Table 6)

3.2.2.3 Environment Canada Weather Data

Historical weather data was used to separately compare temperatures in the spring (April, May, June) and summer (July and August) over time. There is a weather station in Cartwright that has been collecting climate data, including temperature, since 1934. This data was downloaded and graphed in R [1.0.143]. Vincent, Zhang, Bonsal, & Hogg (2002) suggest that researchers homogenize long term weather datasets, especially if a climate station has been relocated. The weather station in Cartwright has not been relocated, however, a change in nationwide observation times in 1961 affected recorded minimum temperatures, and is a possible concern when doing temperature analysis (Vincent et al., 2012). Thus, a homogenized dataset of monthly mean temperatures for Cartwright was obtained from Vincent et al., (2012) and used to graph mean spring and summer temperatures.

Additionally, daily precipitation data from the weather station in Cartwright was downloaded and graphed in R [1.0.143]. The mean daily precipitation was compared for significant differences over the time period 2004 to 2016 (time frame between the two satellite images) using the stats package in R [1.0.143].

3.2.2.4 Focus Groups and Participatory Mapping

A focus group is a facilitated discussion about a topic of interest (Bedford & Burgess, 2001; Berg, 2001; Cameron, 2000) and was used in this study to inform the location of plot sampling and to modify and develop interview questions. Participants were selected through purposeful sampling (Baxter & Eyles, 1997; Cameron, 2000), where a well-respected community leader identified individuals in the community actively involved in bakeapple picking and with significant knowledge on the activity. These individuals were invited to participate in the focus group which was attended by 3 people and convened at the 50+ club in town (Supplementary

Table 7). The focus group lasted about 1 hour, was recorded, and was organized around a large map of the region.

A participatory mapping activity was used to structure the focus group discussion. Participants were provided a map of the area and asked to identify on the map their bakeapple picking spots and any changes they had observed in the topography, hydrology and vegetation at their bakeapple picking spots (Supplementary Table 8). Participants were also shown pictures of permafrost degradation and asked whether they had observed any similar features. Participants collectively determined how they would use colors to indicate these different aspects of the bakeapple picking grounds (Supplementary Figure 2).The focus group with participatory mapping was advantageous because participants were able to brainstorm collectively and fill in the gaps of each other's knowledge of the bakeapple picking grounds (Cameron, 2000). The focus group data was analyzed by digitizing the annotations that the participants created (Supplementary Figure 2). Geospatial data is not provided with the annotations to safeguard the exact locations of community members' bakeapple picking spots. The annotations were contextualized with notes on participants' explanations and comments during the focus group.

3.2.2.5 Semi-structured Interviews

Semi-structured interviews (n=18) were conducted to identify if and how vegetation, water, the landscape, and the quality and ripening time of the bakeapples has changed and the impacts on bakeapple picking (Supplementary Table 9 and 10). This provided an opportunity to talk more in depth about some of the observations participants mentioned in the focus groups. The duration of the interviews ranged from 30 minutes to an hour. Participants were selected with a purposeful sampling strategy (Baxter & Eyles, 1997), where the same community leader and participants of the focus group identified individuals with rich knowledge and experience of the bakeapple picking grounds, and later with a snowballing strategy, in which interview participants identified more potential participants. For analysis, key themes (see Supplementary Table 11) from the interviews were identified using an open coding process meaning that codes continued to be added as patterns emerged within and between interview transcripts/notes (Cope, 2003; Saldaña, 2013).

3.3 Results and Discussion

The results and discussion are divided into four sections. The first describes the ecological constraints on *Rubus chamaemorus* and the final three describe the changes that have likely impacted the growth on *Rubus chamaemorus* (vegetation growth, a decrease in palsa permafrost features, hydrological changes, and earlier springs and summers).

3.3.1 The Ecological Constraints on the Growth of *Rubus chamaemorus*

Climate and geographic constraints on bakeapple growth were identified by focus group and interview participants. First, the focus group participants highlighted that the best bakeapple picking grounds are only accessible by boat (Supplementary Figure 2), and interview participants confirmed this (Supplementary Table 12). Also, both focus group and interview participants mentioned that the "Big Marsh," on the mainland in Cartwright, used to be a better source of bakeapples for the previous generation. Furthermore, in the focus group discussion, participants emphasized that it is difficult to identify how the growth of bakeapples has changed over time because bakeapple growth is largely impacted by weather. Participants explained that the weather can be variable from year to year and therefore, the growth of bakeapples is variable from year to year.

Interviewees reiterated focus group participants' observation that there is expected variability in the growth of bakeapples from year to year because of variable weather (Supplementary Table 12). In addition, interviewees explained the specific ways in which weather impacts the growth of bakeapples. Firstly, the weather in the spring of the year will impact the bakeapple blossoms. If there is strong wind and or heavy rain then the bakeapple blossoms can be destroyed, which would result in fewer bakeapples that year. Also, the weather in the summer is important because if there are extreme temperatures in the summer the bakeapples will be of a lesser quality. Specifically, if there are extreme warm temperature the berries will dry out and if there are extreme cold temperatures the berries will freeze and be mushy.

Ecological constraints on bakeapples were identified and characterized by interviewees and through field surveys. Interview participants described the optimal ecological conditions for bakeapple growth. Almost all participants explained that bakeapples are found in the boggy areas, but not too wet areas:

> *A lot of the places you pick bakeapples are pretty much wet spots anyways. Not right wet as such but damp… the best areas.* (Leslie Hamel, previously a fisherman, >50 years)

Additionally, more than half (n=11) of the participants explained that bakeapples will likely be larger and more abundant in spots sheltered by the (micro)topography of the landscape and/or surrounding plants.

Field surveys were used to tease out the ecological constraints on where *Rubus chamaemorus* grow. A Fisher's exact chi-squared test of presence/absence of *Rubus chamaemorus* on palsa and collapsed palsa plots showed that the surface cover of *Rubus chamaemorus* is not significantly different between palsa and collapsed palsa plots (Supplementary Table 13 and Supplementary Figure 4). However, through NMDS of the data, it is evident that the palsa (green) and no palsa (blue) vegetation communities diverge (Figure 4). The purpose of NMDS is to visualize the relative position of the plots in a two-dimensional space via comparison of the species surface cover per plot. The closer the position between two plots implies that those two plots are more similar in terms of their species composition. The ANOSIM analysis produced an ANOSIM statistic, R, with a value of 0.226 (with a significance value of 0.001) revealing that the vegetation types between palsa and no permafrost plots are significantly different. The SIMPER analysis revealed that the *sphagnum moss* spp.*, sedge* spp. *Empetrum nigrum, Lichen* spp.*, Rubus chamaemorus, Vaccinium ulginosum, and Ledum groelandiculum* contributed to 70% of the dissimilarity between palsa and no permafrost plots (Table 1).

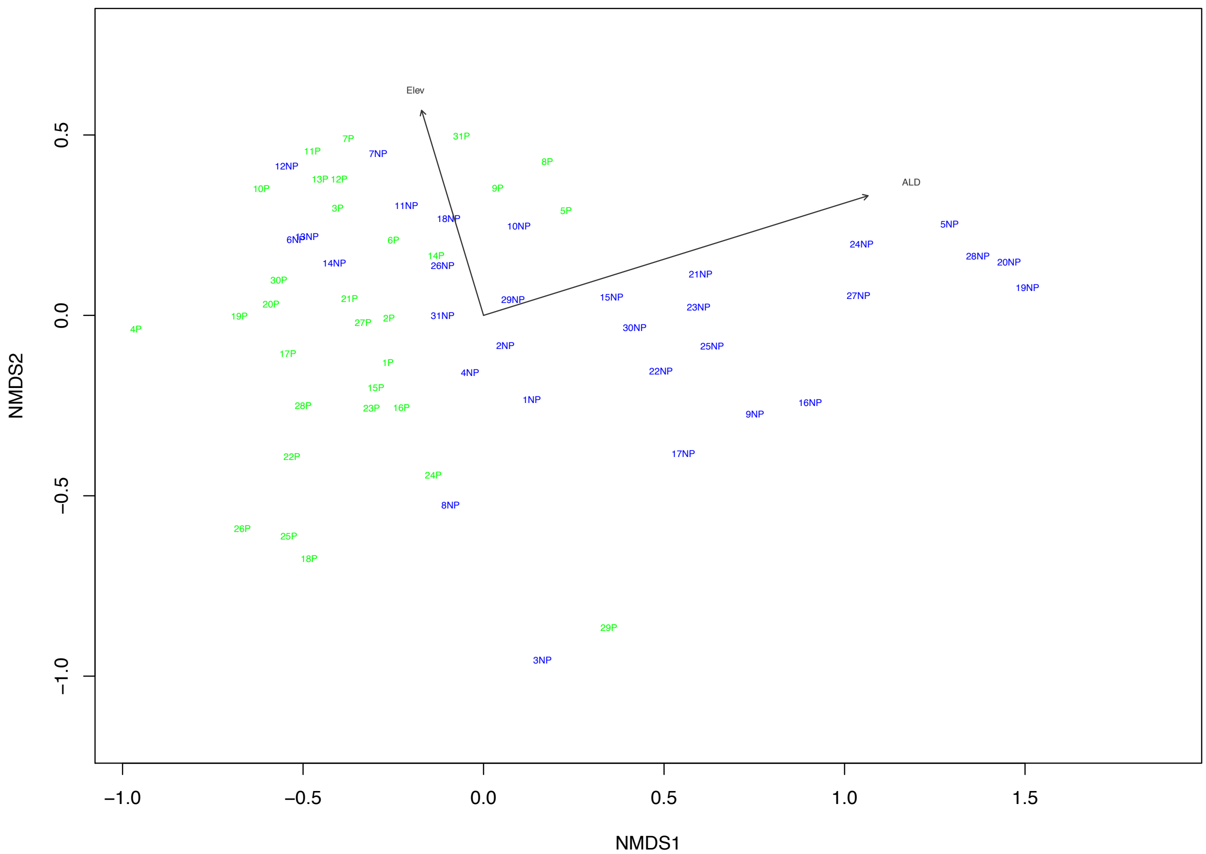


Figure 4: The NMDS of vegetation plot data. Environmental vectors (Elev=elevation, ALD=active layer depth) are overlaid on the NMDS. Palsa (P) sites are in green and no permafrost (NP) sites are in blue.

Table 1: Species in order of contribution to the dissimilarity between palsa and no permafrost plots and the cumulative contribution to dissimilarity shown

Species	Ordered cumulative contribution to dissimilarity
Sphagnum moss spp.	0.12
Sedge spp.	0.23
Empetrum nigrum	0.34
Lichen spp.	0.44
Rubus chamaemorus	0.52
Vaccinium ulginosum	0.58
Ledum groenlandicum	0.64
Bare ground	0.71
Leaf litter	0.76
True Moss spp.	0.81
Vaccinium oxycoccos	0.86
Vaccinium vitis-idaea	0.90
Kalmia polifolia	0.93
Myrica gale	0.96
Drosera sp.	0.98
Picea mariana	0.99
Chamaedaphne calyculata	0.99
Vaccinium myrtilloides	0.99
Larix sp.	1.00

Within the plots classified as palsa, ALDs were heterogeneous and the no permafrost sites visibly varied in water table depth (Table 2). Therefore, I also considered how water table depth, active layer depth, soil water pH, elevation and soil temperature (at max depth and 20 cm above max depth) drive the differences in vegetation between palsa and no permafrost plots. Spearman rank correlation coefficients revealed that ALD was significantly correlated with the first ordination axes and therefore, increases in ALD explain some of the differences in vegetation seen in the palsa plots compared to plots with no permafrost (Table 3). Additionally, elevation was significantly correlated with the second ordination axes and therefore, also explains some of the differences in vegetation between the palsa and no permafrost plots.

Table 2: Mean, standard deviation and 95% confidence interval for the active layer depth of the 31 palsa plots and the water table depth of 16 of the 31 no permafrost plots. A negative water table depth indicates that the water table is above the peat surface.

Plot	Active layer depth (cm) (n=31 palsa plots)	Water Table Depth (cm) (n=16 no permafrost plots)
Mean	52	-15
Standard Deviation	15	9
95% Confidence Interval	(46, 58)	(-10, -20)

Table 3: Spearman Rank correlation coefficients (to two decimal places) and asterisk indicates if significant (p value less than 0.05).

	NMDS axis 1	NMDS axis 2
Elevation (m)	-0.08	0.38 *
Active Layer Depth (cm)	0.66 *	0.16
Temperature at depth (C)	0.25	-0.06
Temperature at depth plus 20 cm (C)	-0.32	-0.28

While bakeapple pickers expect the growth of bakeapples to vary temporally and spatially, there are specific longer term ecological changes discussed during the focus group and/or interviews and also observed via satellite images, field surveys and a historical weather dataset. These longer-term patterns include, vegetation growth, changes in hydrology and changes in the timing of picking, documented in section 3.3.2, 3.3.3, and 3.3.4.

3.3.2 Vegetation Growth at the Bakeapple Picking Grounds

Vegetation has increased and palsa features have decreased with potential impacts on *Rubus chamaemorus* growth. Focus group participants explained that, like other areas in town, the tall erect vegetation, especially willows, has increased in the "Big Marsh," and that the abundance of bakeapples is less in recent years. Focus group participants shared observations of vegetation increasing at two other bakeapple grounds that are only accessible by boat (Supplementary Table 1 and Supplementary Figure 2), but did not observe that this had resulted in less abundant bakeapples. However, six interviewees did explain that vegetation growth at their bakeapple grounds had overcrowded the bakeapples resulting in fewer bakeapples in recent years (Supplementary Table 12).

Through the analysis of two satellite images from 2004 to 2016 it was also observed that the total green vegetation in the "Big Marsh" increased by 21.5% within the permafrost associated peatland. Not only the total area but also the spatial distribution of the vegetation has changed over the 12 years. In 2004, the green vegetation was confined to the boundaries of the peatland. In 2016 the green vegetation encroaches along the boundary of the permafrost associated peatland, and there is more vegetation growth surrounding the surface water bodies and palsa features.

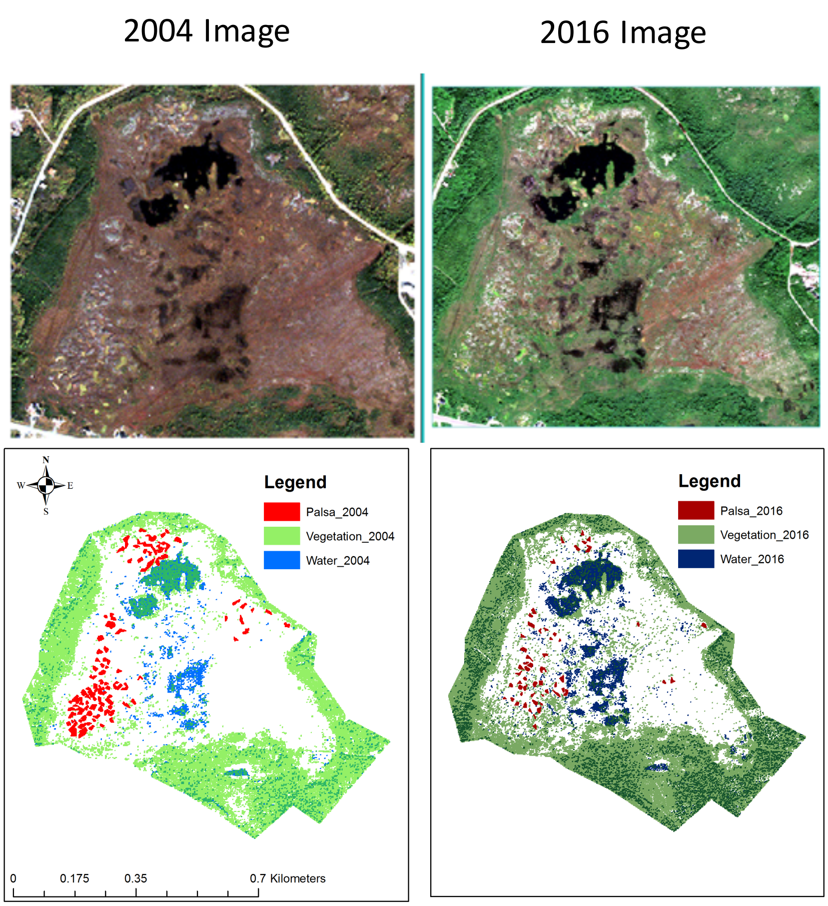


Table 1: Shows area of palsa, vegetation, and surface water in 2004 and 2016, the change in area in m^2, and the percent change between 2004 and 2016.

Feature	Area in 2004	Area in 2016
Palsa	13,200 m^2 2.45%	4,680 m^2 0.87%
Vegetation	166,807 m^2 30.92%	202,803 m^2 37.60%
Surface Water	34,368m^2 6.37%	57,196 m^2 10.60%

Feature	Change in area	Percent change (Change in area/area in 2004)
Palsa	8,520 m^2 decrease	64.5%
Vegetation	35,996 m^2 increase	21.5%
Surface Water	22,828 m^2 increase	66.4%

Figure 5: Quickbird image of region of interest in 2004 (left) and World View 2 image of region of interest in 2016 (right). Target detection of palsa, vegetation, and surface water delineated in 2004 (left with lighter shades of colors) and 2016 (right with darker shades of colors). In areas

where vegetation and water features overlap the vegetation and water shades are both present. The unclassified areas are bare ground (scarce vegetation). Satellite Imagery courtesy of the DigitalGlobe Foundation

The permafrost palsa features decreased by 64.5% over the past 12 years, likely caused by a warmer climate and increased vegetation growth, consistent with trends seen in other permafrost associated peatlands (Bouchard et al., 2014; Christensen et al., 2004; Johansson et al., 2006). With increase in vegetation plant growth, snow is trapped, accumulates, insulates the soil, and results in permafrost thaw (Johansson et al., 2013). While the total area of palsa features has decreased there is an area on the south-eastern side of the peatland where two features have formed. Palsas naturally form and degrade, and it is possible that these two palsa features formed over the 12 years, as the result of tree growth that shifted where snow was collecting. More feasible, is that these features were not detectable in the slightly lower resolution 2004 image. From field surveys (section 3.3.1), it is evident that palsa features are different in vegetation types compared to the surrounding non permafrost areas largely driven by changes in elevation and ALD. It is not directly clear how this decrease in permafrost palsa features in the "Big Marsh" over 12 years has impacted bakeapples, but it has likely contributed to changes in vegetation communities resembling the differences, at present, between the palsa and non permafrost sites.

3.3.3 Changes in Hydrologic Conditions

The changes in surface water in permafrost associated peatlands is likely associated with thawing permafrost and has likely impacted predominant vegetation communities. Two focus group participants observed decreased surface water at the bakeapple grounds and marked two specific spots on the map (Supplemental Figure 2). This observation of drying was confirmed in more in-depth interviews with bakeapple pickers. Seven interviewees observed a drier landscape at their respective bakeapple grounds. Interviewees explained that decreased moisture results in less abundant bakeapples or bakeapples of a lesser quality because the bakeapples dry out. Also, two of these seven participants explained that "cracks" formed in the earth's surface a couple years ago at a popular bakeapple picking spot and a nearby pond had completely drained. During field surveys, I visited the bakeapple picking spot, called Hare Harbor, were these cracks had formed (Figure 2). The bakeapple ground at Hare Harbor is a permafrost associated peatland and the cracks were likely features of permafrost degradation. The area for picking bakeapples is a plateau surrounded by cliffs and the Atlantic Ocean. It is possible that the degradation of permafrost created a way for the water in the small pond to drain. Similar features were seen during field surveys at another popular bakeapple picking spot called Grady (Figure 3), but no focus group participants or interview participants mentioned the cracks at Grady. This is possibly because Grady is further from Cartwright, with people frequenting this area less often than Hare Harbor.

While seven interview participants described the landscape becoming drier at their respective bakeapple picking grounds, satellite imagery showed that the surface water increased at the “Big Marsh” over the time period from 2004 to 2016 by 66.4% (Figure 4). In addition, there was no significant difference (p value 0.7935) in the daily mean total precipitation between 2004 and 2016. In 2004 the daily mean total precipitation was 3.08 mm and in 2016 was 3.20 mm (Supplementary Figure 5). This indicates that the increase in surface water is not attributable to precipitation but rather to the hydrological changes likely associated with permafrost thaw and subsequent ground subsidence. It is expected, that in a low-lying permafrost associated peatland, like the “Big Marsh,” as permafrost thaws the soil will become more saturated; in contrast, in areas with better drained soils the landscape will become drier (Johansson et al., 2013). Field survey sites did not cover all of the bakeapple grounds where participants had observed a drier landscape, but it is possible that these areas are not low-lying areas and therefore, would not become more saturated as permafrost thaws. It is also possible, that bakeapple pickers would tend to avoid the bakeapple grounds that are becoming wetter because increased surface water would result in the bakeapple patches becoming less accessible. Because the surface water in collapsed palsa features is coming from the thawing palsa features, then this implies that some areas are getting drier which parallels community members observations of a drying landscape.

3.3.4 Changes in the Timing when Bakeapples are Ripe

Temperatures are increasing in the late spring and early summer and likely, causing the bakeapples to ripen earlier. Six interview participants noted that bakeapple picking time was a couple of weeks earlier in recent years (~ past decade) compared to their youth (Supplementary Table 12). As youth, five elders described that August was bakeapple picking time, but in recent years families can be picking bakeapples as early as July. Four interview participants explained that this is because the spring and summer were coming earlier and the bakeapples were ripening earlier. However, historical homogenized daily temperature data from the Cartwright weather station do not show a clear warming trend in the late spring (May and June) and summer (July and August) over 8 decades (Supplementary Figure 6a and b). To some degree, participants expect variability in when the bakeapples will be ripe, especially spatially. For example, participants explain that it is expected in the cooler areas, like more distant islands or sheltered spots, for the bakeapples to ripen later (Supplementary Table 12).

3.4 Conclusions

This paper focuses on the ecological changes that are impacting *Rubus chamaemorus* growth. Community members in Cartwright are observing changes in the weather, which some interpret as indicative of longer term climate change with consequent impacts on the ripening time of bakeapples, however statistical trend analysis is needed to determine whether historical weather data confirms observed increases in late spring and summer temperatures. Participants are also observing increases in vegetation and decreases in surface water and hypothesize these changes to be also impacting the abundance and quality of bakeapples. These ecological observations are confirmed by both satellite imagery, which shows the increase in vegetation, a change in surface water. Field surveys show that vegetation types are significantly different across palsa and no permafrost plots driven by elevation and ALD changes. Satellite imagery also reveals a decrease in palsa features. From this, we are able to infer that with continued palsa degradation and subsequent increases in ALD and decreases in elevation, that the vegetation will change and resemble the present vegetation of the surrounding no permafrost areas. Warming temperatures, decreases in palsa features, and increased vegetation are relevant exposures for Indigenous communities who berry pick across subarctic regions.

Bakeapple pickers in Cartwright know the ecological and climatic constraints on bakeapple growth and have mechanisms to cope with variable growth from year to year. Similarly, studies with Indigenous communities in Alaska (Kellogg et al., 2010) and the Yukon (Krebs, Boonstra, Cowcill, & Kenney, 2009) have documented the importance of moderate temperatures and precipitation for berry growth and the understanding that the growth of berries is variable form year to year. Also, previous research has documented the berry harvesting strategies of Indigenous communities in the Northwest Territories in years of less abundant berries, including traveling farther to find berries and sharing knowledge via word of mouth (Parlee & Berkes, 2006). Both Indigenous Alaskan communities and the community of Cartwright express concern that the younger generation is not as interested in the use and knowledge of berries (Kellogg et al., 2010). Consequently, the knowledge of when and where to bakeapple pick and how to deal with variable bakeapple growth may not be learned by younger generations.

There is greater consensus between bakeapple pickers about the impact of weather and season on berry growth, but the impacts environmental changes occurring at decadal scales, like arctic greening and permafrost thaw, on important berry species are less clear. Vegetation growth, changes in hydrology, and permafrost thaw are well documented by other studies in the Subarctic, but the specific connection and focus on bakeapples has not been considered prior to this study. Previous research documents the decrease in permafrost associated features, the increase in thaw ponds at the margins of prior permafrost features, and the increase in the normalized difference vegetation index in the discontinuous permafrost zone of Northern Quebec (Beck et al., 2015; Bouchard et al., 2014; Payette et al., 2004). Also, in another Canadian discontinuous boreal permafrost associated peatland, there are documented increases in sphagnum mosses and forbs when peat plateaus degrade into collapse scars (Camill, 1999; Camill et al., 2001). Similar vegetation gradients have been observed in thawing permafrost associated peatlands in subarctic Sweden (Christensen et al., 2004), with concurrent increases in wetter sites and a decreases in the dry palsa features (Johansson et al., 2006). Communities in Nunavik and Nunatsiavut also describe changing ground temperatures and the resulting permafrost degradation that are "outside the range of previous community experience" (Allard & Lemay, 2012). Because this is the first study, to our knowledge, to focus on the impact of permafrost thaw and related ecological changes on *Rubus chamaemorus* growth, more research is needed to determine if the growth of *Rubus chamaemorus* will be constrained by permafrost thaw in other subartic regions.

Furthermore, bakeapple pickers in Cartwright observe climate and weather changes and the impact on the growth of bakeapples. Other communities are experiencing the impacts of climate changes on nutritionally and culturally valuable plant species. In Nunavik and Nunatsiavut, communities hypothesize that berry growth will be constrained by increases in tall erect shrub cover (Allard & Lemay, 2012; Cuerrier et al., 2015). Inuit communities in Northern

Labrador already observe that some of their important berries are of decreased quality and ripening earlier than past years (Allard & Lemay, 2012; Cuerrier et al., 2015; Downing & Cuerrier, 2011). Similarly, in an Alaskan Native community, changes in the climate are reported as the greatest threat to berry growth by community members (Kellogg et al., 2010). Additionally, in a First Nation community in British Colombia, community members observe that the variability in the weather is beyond their previous experience and that this is impacting their harvest of and drying of edible seaweed (N. Turner & Clifton, 2009). In contrast to observations in Cartwright, one community in Nunavik observed that bakeapples are more abundant with climate changes, unlike other berries that are being constrained by vegetation growth (Cuerrier et al., 2015). For this study in Cartwright, changes in the growth of bakeapples in bogs was only considered because participants described bogs as the best places to pick bakeapples. The Nunavik study that reported an increase in bakeapples considered all the places bakeapples could grow rather than solely considering bogs (Allard & Lemay, 2012). Again, due to local ecological heterogeneity, more research is needed to understand how bakeapple growth will be impacted by climate change in different regions.

Despite these climate related changes, community members did not express concern about not having enough bakeapples because of environmental changes. Community members highlight that they have always been able to get some bakeapples, even in bad years. Community members are more concerned about changes in their economic, social, and political situations that are making it harder to go bakeapple picking with their families and to pass that knowledge to younger generations. This concern is reflected by other Indigenous communities, including Inuit communities (Beaumier et al., 2015), Alaskan Native communities (Kellogg et al., 2010), the Tlingit in Glacier Bay, Alaska (Thornton, 1999) and First Nation communities (N. Turner & Turner, 2008), that harvest plants from the land for food.

Chapter 4 Climate Change and the Vulnerability of Bakeapple Picking as a Cultural Activity

Role of Chapter

This chapter addresses objectives 2 and 3 of the thesis which were to identify and characterize components of sensitivity and adaptive capacity that mediate or magnify the impacts of climate change on bakeapple picking and to describe the vulnerability of bakeapple picking by considering the interactions between environmental and social changes. The study design, described in this chapter, draws upon the literature reviewed in chapter 2. The results of this chapter are organized by the components of vulnerability including, exposure, sensitivity, and adaptive capacity, and draw from 18 semi-structured interviews and participant observation to describe each component. The results of this chapter consider the vulnerability of bakeapple picking with a more holistic view than chapter 3, but do not go into the same depth about environmental changes, specifically permafrost thaw, that have impacted bakeapple berries. The results and discussion of this chapter, in addition to those of chapter 3, inform the discussion on the overall vulnerability of bakeapple picking in chapter 5.

Abstract

In the Subarctic, the traditional subsistence of Indigenous communities is affected by the impacts of climate change in addition to the effects of other social, economic and political changes. Wild berry picking is a component of traditional subsistence, and it has been considered to a lesser degree in the human dimension to climate change literature compared to other aspects of harvesting like hunting. In this study, the vulnerability of bakeapple picking to environmental and social changes is examined in the community of Cartwright, Labrador. Semi-structured interviews and participant observation were used to identify and characterize the components of vulnerability, including: exposure (environmental changes), sensitivity (characteristics of the community like the livelihoods, settlement patterns, technology, cultural values), and adaptive capacity (the ways in which the community responds to environmental changes). Key findings include that seasonality has changed causing the bakeapples to ripen earlier, and there is increased growth of large shrubs in and around bakeapple patches affecting the abundance of bakeapples. Bakeapple pickers have knowledge of their patches and are able to respond to variable bakeapple growth from year to year, but this is increasingly challenging because of changes in summer settlement patterns that place families farther from their traditional bakeapple

patches. Bakeapple pickers overcome the challenge of living further from the bakeapple grounds through utilization of faster boats, the market for bakeapples to offset the costs of picking, and the cultural and nutritional value placed on this berry. Like other communities with land based livelihoods, the harvesters in Cartwright exhibit knowledge of the land and how to respond to environmental variability, but also, express concern that fewer young families are able to go out to the bakeapple grounds and participate in this important cultural activity.

4.1 Introduction

Globally, temperatures are increasing at unprecedented rates with temperature increases amplified in the Arctic. Across Canada, air temperatures have increased by 1.7 degrees Celsius (C) and by 3.1 degrees C in the western Canadian Arctic (Environment Canada, 2017). Indigenous communities are more sensitive to climate changes because of the arctic amplification of climate change, their close relationship with the land, colonial legacies, and concurrent socioeconomic changes (Anisimov et al., 2007; Ford, 2012).

There is an abundance of literature that considers the impacts of climate change on the land based livelihoods of Inuit communities, with a focus on hunting (Ford et al., 2012a). Fewer studies consider the impacts of climate change on the gathering component of land based livelihoods, specifically berry picking (Cuerrier et al., 2015). There are also geographic gaps of research on the human dimensions of climate change (HDCC). The HDCC research has a greater focus in central and eastern Canada, for example in Nunavut and Nunavik (Ford et al., 2012b). There is less research from the perspective of Indigenous people in southern Labrador.

Wild berry picking is an important part of the food subsistence for Indigenous communities in southern Labrador for both nutritional and cultural reasons (Fitzhugh, 1999; Goudie, 1991; Lethbridge, 2007). Individuals consider wild berries, including bakeapples, to be healthier than store bought foods and a tradition that has been passed down for generations. There is a two to three week window, typically in August, when families go bakeapple picking (Fitzhugh, 1999). Bakeapples have specific growing conditions including the soil moisture, precipitation, temperature, surrounding vegetation and sex ratios (Agren, 1989; Downing & Cuerrier, 2011; Kellogg et al., 2010; Korpelainen, 1994). Changes in the climate can impact the ripening time, quality, and abundance of bakeapples (Cuerrier et al., 2015).

In light of the cultural and nutritional value placed on bakeapples and the amplification of climate change in the Arctic, it is important to consider the factors that advance and/or hinder families from going to bakeapple pick. In response to the existing gaps in the literature, the vulnerability of bakeapple picking to climate changes will be identified and characterized with consideration of the concurrent socioeconomic changes, drawing on interviews and participant observations from a case study in Cartwright, Labrador. A contextual vulnerability approach is used (Bennett et al., 2016; Ford & Smit, 2004) to identify both the environmental and socioeconomic factors that are impacting the ability of Indigenous people to engage in bakeapple picking.

4.2. Methodology

4.2.1 Conceptual Approach

This research is structured using a vulnerability approach. Vulnerability can be defined as the "susceptibility to be harmed" (Adger, 2006, p. 269), with vulnerability research seeking to identify and characterize who is vulnerable, to what stresses, and why (Ford and Smit, 2004). The concept of vulnerability has a long history with contributions from various fields, and in the HDCC literature is conceptualized in two major ways, as either outcome vulnerability (or end point vulnerability) or contextual vulnerability (or starting point vulnerability) (Ford, Keskitalo, et al., 2010; O'Brien et al., 2007). With an outcome vulnerability approach, one would consider how a future biophysical hazard acts on a human population, how that population responds, and the left over damage which captures vulnerability (O'Brien et al., 2007; Smit & Wandel, 2006). However, the research presented here draws more heavily from the contextual vulnerability approach.

Contextual vulnerability considers the political, biophysical, social and economic factors that interact to shape vulnerability. Specifically, contextual vulnerability assessments focus on three components of vulnerability: exposure, sensitivity, and adaptive capacity. The exposure is the environmental stimulus and is characterized by its magnitude, duration, frequency and extent. The sensitivity reflects the livelihoods and other social, economic and political characteristics of the community. The sensitivity of a community impacts the significance of the exposure for that particular group. For instance, if there is a landslide caused by permafrost degradation (the exposure), the effect on a community will be dependent on components of sensitivity like the location of settlements, infrastructure, land use, and technology (Smit & Wandel, 2006). Adaptive capacity reflects the potential ability of the community to plan for, address, or cope with the exposure (Bennett et al., 2016; Ford & Smit, 2004; O'Brien et al., 2007; Smit &

Wandel, 2006). For instance, harvestors may bring more gasoline out on the land in preperation for a need to take an alternate trail because of changes in sea ice (Ford et al., 2013). The response to these drivers of vulnerability in turn shapes and changes the initial conditions of vulnerability, and as a result, vulnerability is dynamic (Ford, Keskitalo, et al., 2010; O'Brien et al., 2007; Smit & Wandel, 2006). These components of vulnerability also exist at regional, national, and global scales and impact and shape local exposures and sensitivities (Bennett et al., 2016; Smit & Wandel, 2006). Additionally, there are stimuli that act quickly on a system and others that impact a system slowly and therefore, exposures and sensitivities exist at different temporal scales. For instance, there are slow exposures, like warming air temperatures which occur over decades and have a less immediate recognizable impact compared to that of a flood or other natural disaster. A fast stimulus affecting the sensitivity could be an increase in gas prices that keeps a harvester from going out on the land. Conversely, a slow stimulus is the transition from a semi-nomadic to sedentary lifestyles over decades reducing the extent of harvesting areas (Ford et al., 2013). Assessing vulnerability with this approach requires researchers to engage stakeholders and knowledge holders through approaches such as case studies which allow for participatory methods (Berrang-Ford et al., 2012; Fazey, Pettorelli, Kenter, Wagatora, & Schuett, 2011; Smit & Wandel, 2006).

4.2.2 Case Study Approach

A case study approach is used to consider both the environmental and socioeconomic factors that impact the ability of individuals to berry pick with a focus on those exacerbated by climate change. A case study approach advances deep understandings about the complex factors that interact and impact vulnerability and is appropriate for research questions where there are local and regional differences in vulnerability (Ford, Keskitalo, et al., 2010). After consultations with other researchers in the region, community members, and the NunatuKavut Community Council (NCC), Cartwright, Labrador was selected as the case study community because of the continued cultural importance of bakeapple picking in the community, and concern over climate change impacts expressed by community members.

4.2.2.1 Study Region

Cartwright is located in southern Labrador on the coast (Figure 1). Environment Canada reported that the average annual temperature was 0 degrees Celsius and the average annual precipitation was 616.8 mm of rainfall and 462 cm of snowfall between 1981 and 2010

(Government of Canada, 2017). Sandwich Bay, located adjacent to Cartwright, is fed by three rivers that are important for salmon spawning. The region has great ecological diversity including seals, whale, black bear, polar bear, caribou, wolf, fox, small mammals, waterfowl, marine and freshwater fish, blueberries, crowberries, cloudberries (which locally are called bakeapples), lichen, white and black spruce, Eastern larch, and birch (Natcher et al., 2012; Roberts et al., 2006).

Cartwright has a population just under 500 individuals according to the Canadian 2016 census. The majority of individuals have Indigenous ancestry. Many individuals hold employment at the Labrador Fishermen's Union Shrimp Company Limited where currently, crab is predominately processed from the offshore crab fishery. Historically, there was a cod fishery but cod stocks declined noticeably in the second half of the 20^{th} century and the Canadian government placed an official moratorium on the commercial cod fishery throughout Southern Labrador in 1992. The inland commercial fishery for salmon closed (for other political reasons) a few years after the cod fishery closed (personal communication, August 2017). The population of Cartwright is formed of families from smaller surrounding communities because the provincial government had a centralization program in the 1960's (Lethbridge, 2007). Essentially, Cartwright was serviced with a school, a grocery store, the post, telephone lines, and a road. Without these services provided to nearby communities, many families moved to Cartwright.

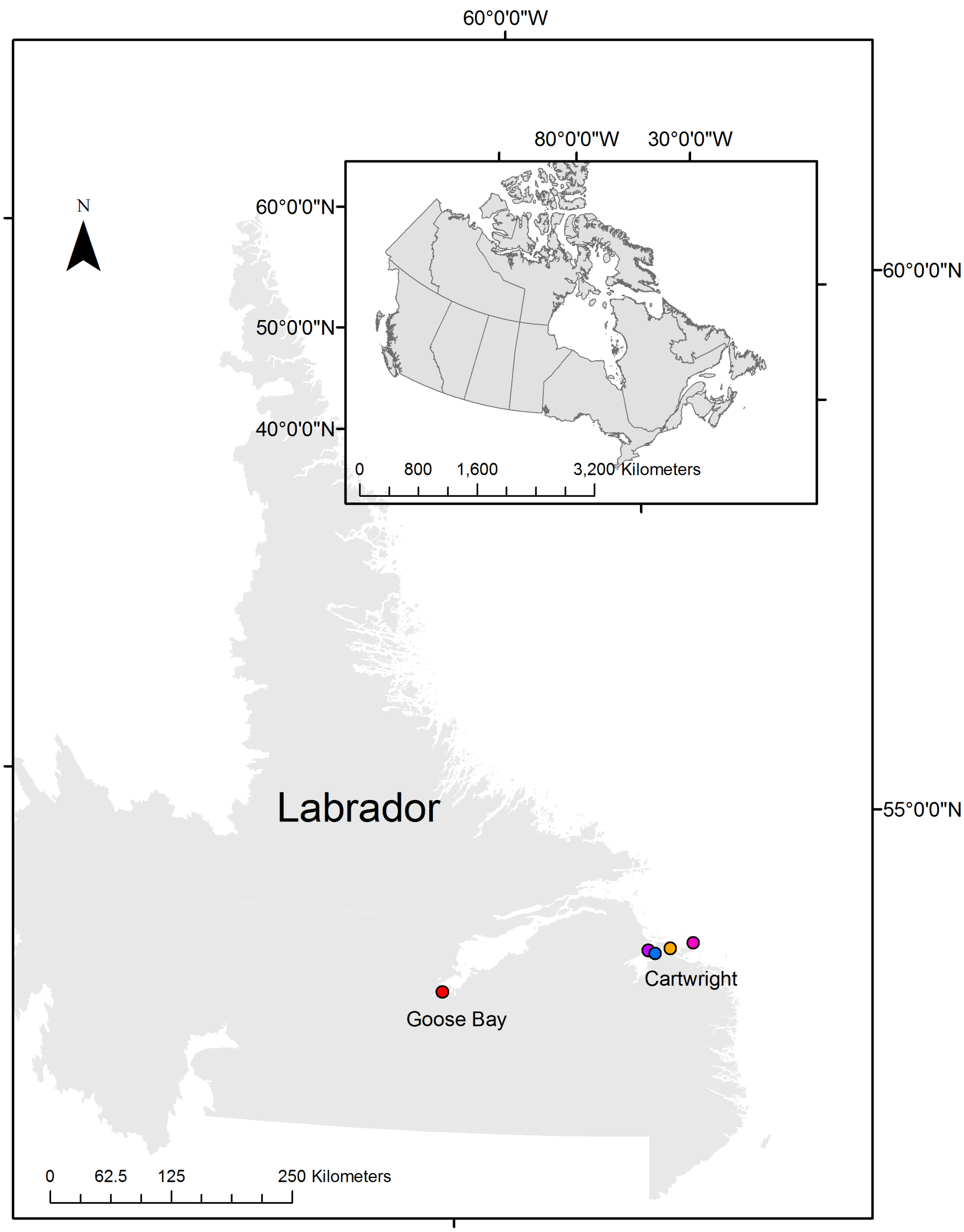


Figure 1: A map of Canada and a zoomed in version of Labrador with Cartwright and Happy-Valley Goose Bay labeled. The purple, orange, and red points mark bakeapple picking spots nearby Cartwright. Data source: Statistics Canada (2016) for Cartographic Boundary File of Canada and Elections Newfoundland and Labrador (2015) for Labrador shape file.

Inuit have had a permanent presence in southern Labrador since the 16th century (Brice-Bennett et al., 1977; Natcher et al., 2012; Rankin, 2010). The French arrived in the early 1700's for whaling and traded with Inuit. The English established a permanent presence in southern Labrador in the late 1700's and many married with the Inuit population (Blake, 2010). Intermarriage resulted in the Inuit-Métis culture (Natcher et al., 2012). The 20th century was a period of denial of Inuit ancestry among the Métis population; it was not till the 21st century that the Métis population in southern Labrador increasingly outwardly identified with their Inuit ancestry (Rankin, 2010). For example, Indigenous individuals in southern Labrador now refer to themselves as the people of NunatuKavut, which is an Inuit word, rather than Métis (personal conversation, August 2018). Labels of ancestry aside, Indigenous communities across southern Labrador have engaged and continue to engage in subsistence livelihoods (Lethbridge, 2007). Inuit in southern Labrador, along with the NCC, are pushing for a land claim to increase their sovereignty (Dombrowski, Habecker, Gauthier, Khan, & Moses, 2016) but they have not yet received a land claim (Brake, 2015).

Traditionally, the Métis in southern Labrador were semi-nomadic. In the winter groups of families settled together (Brice-Bennett et al., 1977) and during the summer families dispersed into single family settlements (Lethbridge, 2007). Families moved between winter settlements to hunt seal and set traps and summer accommodations to fish, hunt caribou, and hunt birds (Brice-Bennett et al., 1977; Lethbridge, 2007; Rankin, 2010). Also, families picked culturally and nutritionally important wild berries: bakeapples, red berries, black berries, blueberries, squash berries, raspberries and dogberries, in the summer (Fitzhugh, 1999). Families will store these wild berries for their winter fruit (Fitzhugh, 1999). Indigenous communities across the Arctic and Subarctic value the health benefits of wild berries (Downing & Cuerrier, 2011). For example, bakeapples are a good source of vitamin C (Arnason, Hebda, & Johns, 1981).

4.2.3 Qualitative Methods

The data collected from interviews and participant observations for this study (elaborated on in 4.2.3.1 and 4.2.3.2) draws upon the traditional ecological knowledge (TEK) of individuals in Cartwright. Traditional knowledge (TK) is the "cumulative body of knowledge, practice, and values acquired through experience and observations on the land or from spiritual teachings and handed down from generation to generation" (Pearce, Ford, Willox, & Smit, 2015, p. 235). TEK is a subset of TK that specifically encompasses knowledge about the environment and human's relationship with it (Pearce et al., 2015; Riedlinger & Berkes, 2001). TEK is growing and dynamic because of increasing experiences on the land and observations of environmental variability (Pearce et al., 2015) . TEK, historically, has been an integral part of the ability of Indigenous communities to safely and effectively live off the land and continues to be a component of adaptive capacity to climate change, and is increasingly valued by researchers seeking to understand how climate change interacts with society (Huntington, 2011; Pearce et al., 2015).

Historical climate related datasets from instruments only go back about a half a century and there are gaps in these datasets (Huntington, 2011; Riedlinger & Berkes, 2001; Savo et al., 2016). In comparison, TEK can go back generations and therefore, can complement and/or fill the gaps of instrumented datasets (Huntington, 2011; Riedlinger & Berkes, 2001; Savo et al., 2016). Additionally, climate data from instruments only collects data from a single point in space and models do not have the spatial resolution to capture regional and local scale differences. In contrast, TEK provides expertise on local and regional scale ecological processes (Laidler, 2006; Riedlinger & Berkes, 2001; Savo et al., 2016). Researchers have also confirmed the general consistency between TEK and modeled climate data with the few mismatches being attributed to different temporal and spatial scales (Savo et al., 2016). The use of TEK has other unique advantages including that it effectively prioritizes research questions, provides insight on how humans are adapting to ecological change, can be a source of daily environmental monitoring, and captures both the human and biophysical impacts of climate change (Huntington, 2011; Laidler, 2006; Savo et al., 2016). At the same time, it is important to recognize that TEK is context specific and that the dataset is biased towards ecological changes, like extreme weather events, that have a more significant impact on individuals' livelihoods (Savo et al., 2016).

Incorporating TEK into research requires heightened engagement with community members and there are recognized best practices including clear two way communication, informed consent, compensation, and appropriate data representation (Huntington, 2011). Researchers can advance the recognition of TEK by being transparent about research methods, comparing observations from TEK to other data sources (like field data, instrumented datasets, satellite imagery, or models), and creating ways to increase access to information between researchers and community participants (Huntington, 2011). For this study, ethics approval was obtained from McGill University and the NCC prior to data collection, outlining the researcher's steps and precautions taken to appropriately engage with the case study community.

4.2.3.1 Interviews

For this study, I conducted 18 semi-structured interviews (Table 1) as the principal method to identify and describe the three components of vulnerability including: exposure, sensitivity, and adaptive capacity. A semi-structured interview is a structured conversation (Dunn, 2000; Longhurst, 2003; Valentine, 1997). Semi-structured interviews are "content focused" compared to structured interviews which are "question focused" (Dunn, 2000, p. 60), and compared to an unstructured interview, the researcher has a "more interventionist" (61) role and the interview is less conversational. The semi-structured interview format was appropriate because it allowed for comparison between interview responses while still permitting for flexibility in the conversation. An interview guide (Dunn, 2000; Valentine, 1997) was used and listed the key themes including: the duration of time an individual has picked for, observations of environmental changes at the bakeapple picking grounds, observations of social change related to bakeapple picking, technological advances and the impacts on bakeapple picking, and the main barriers and reasons for bakeapple picking (Table 2). The interviews lasted between 30 minutes to an hour. A purposive sampling strategy (Baxter & Eyles, 1997) was used to select participants with rich knowledge and experience of bakeapple picking and was implemented with the help of a respected and active community member and then via a snowballing strategy, in which interviewees suggested other potential participants. Interviews were conducted till a saturation of relevant information had been reached.

Table 1: Demographic information of interviewees (n=18)

Demographic	**Number of Participants**
Male	9
Female	9
Over 50 years old	15
Between 30 and 50 years old	3

Table 2: Key themes and sample questions from interview guide

Interview Themes	**Example Questions**

Duration of time an individual has picked for	About how many years have you been bakeapple picking?
Observations of environmental changes at the bakeapple picking grounds	Have you noticed changes in the plant species where you pick bakeapples? What other species of plants do you see around bakeapples picking spots?
	Have you noticed a change in the amount of surface water in the landscape? How much water do you notice in the areas you bakeapple pick?
	How much variability is there from year to year in the abundance and quality of bakeapples?
	What things have effected how good the bakeapples are in a particular year?
	Has the timing of when you go out to pick bakeapples changed from your youth?
Observations of social change related to bakeapple picking	What importance does bakeapple picking have to you currently as an adult and previously as a child?
	What does an average day of bakeapple picking look like now as an adult and previously as a child?
Observations of economic change related to bakeapple picking	Do you sell some of the bakeapples that you pick?
	Have other job opportunities impacted your ability to go bakeapple picking?

Technology advances and impact on bakeapple picking	How do you get to the spots that you bakeapples pick now and how is this different then when you were a youth?
The main barriers and reasons for bakeapple picking	What do you think the greatest barriers to go out bakeapple picking are for you? How have you dealt with this/these barrier(s)?
	What are the main reasons that you go bakeapple picking?

4.2.3.2 Participant Observation

Participant observation is the process of a researcher immersing him/herself in a community and then stepping back to make objective observations (Bernard, 2011). Elements of participant observation were used during diverse interactions with community members and to get a sense of the social structure and physical layout of the community. I kept a journal to record detailed descriptions of my observations over the month that I was in the community. These notes also helped me to assess how my positionality may have change over the course of field work (see section 2.4) (Laurier, 2010).

Participant observation is advantageous because it allows researchers to become more involved in community life and increases trust and rapport between the researcher and community members (Bernard, 2011; Collings, 2009). Importantly, participant observation increases the researcher's cultural competence (Laurier, 2010). A drawback of this method is that the researcher may misinterpret what he/she is observing because what we observe is dependent on our positionality (Collings, 2009; Vidich, 1955). Therefore, it is important for a researcher to recognize how he/she is positioned in the field.

4.2.4 Positionality

Positionality encompasses one's gender, age, citizenship, economic and social status and life experiences and how it affects the research process. Therefore, positionality is dynamic. Positionality influences a researcher's opinions and biases and thus, the research. The researcher should be reflexive, practicing heightened awareness, about how his/her positionality influences how he/she collects and interprets data (Dowling, 2016). However, social scientists recognize that it is difficult to be reflexive and to understand how positionality, power relations, and privilege impact the researcher, researcher participants, and resulting research outputs (Rose, 1997). However, the researcher should attempt to consider his/her positionality with the understanding that knowledge is fragmented and shifting (Cupples, 2002).

In attempt to be reflexive, I considered my positionality before leaving for the field and how my positionality changed in the field. Before leaving for the field, I understood that the questions I was asking were biased towards my research interests. I thought that this meant that a portion of the community would not be interested in my research. I hoped that I could generate interest by engaging local collaboration in the design, data collection, and dissemination of results. I also worried that participants may sense that I am an amateur and position me as inexperienced.

In the community, I was increasingly anxious leading up to the interviews I would conduct. In conversations with community members, I realized that the word interview held some negative connotations and that the word conversation was less intimidating. Despite my anxiety leading up to the interviews, I realized that people did enjoy having conversations about their culture. Also, people invited me back to their house, gave me food to take home, and positively confirmed the research. Some participants did express that the research did not have much importance to them, but they still seemed to enjoy having a conversation about their culture with me. This made me feel that people in the community liked me and trusted me. There were instances where I questioned my role as a researcher in the community. I felt the need to be friends with everyone, but I realized that this was impossible in the time I was there. Rather, I needed to be respectful, honest, and kind and make sure the short time we had together was a good experience.

4.2.5 Analysis

To identify the key components of the vulnerability of bakeapple picking to changes in the physical and social landscape, I coded interviews. First, I created transcripts (Bedford & Burgess, 2001) from the 14 interviews that were recorded. Four interviews were not recorded and I simply coded my interview notes. First, I reread transcripts or the notes, and I made annotations or memos related to the method or context (Cope, 2003; Corbin & Strauss, 2014; Dunn, 2000). If I was unclear about any of the statements in the interview, I checked my understanding by asking follow-up questions of the participant within three weeks of the interview. Based off of the emerging patterns that I noted while annotating the interviews, I created initial codes, called "descriptive codes" (Cope, 2010, p. 446). Then, after deeper reflection of the initial patterns and how they connect to the components of vulnerability being sensitivity, exposure, and adaptive capacity, I developed secondary codes, called "analytical codes" (446). Next, I identified the emerging key themes based on the secondary codes and my knowledge from reading relevant literature (Saldaña, 2013). See supplementary figure 4 for the supplementary table 9 for the larger key themes and more focused analytical codes. The results (section 4.3) focus on the final key themes as drivers of the vulnerability of bakeapple picking.

4.3 Results

4.3.1 The Human Ecology of Bakeapple Picking

In 17 of the 18 interviews, participants said that bakeapple picking is a family activity. Judy Pardy, an active member in the community and a grandmother, shared, "*We did it with our two children from the time we had them till they left and then the grandkids came along and we are still doing it. 46 years of doing that."* In half of the interviews, participants explained that in the past if the men were fishing, then just the women and children would bakeapple pick. Rosetta Howell, an active community member and also a grandmother, explained that bakeapple picking was "*often a Sunday event because that's the only day they didn't fish."* Dwane Burdett, a business owner in Cartwright, described that his extended family meets at their traditional bakeapple picking grounds in August or September. *"There's probably, 10 or 12 people there anyway at the same time of year. We all gather there at bakeapple picking time. It is just a holiday and bakeapple picking*."

Every family has their favorite spots to go bakeapple picking, some spots go back generations and other new ones are discovered by word of mouth. Often, a family keeps the exact location of their favorite picking grounds a secret to protect their supply of bakeapples. There is consensus among all interviewees that the best bakeapple picking areas are out on the islands. Therefore, during bakeapple picking time, usually in August, families travel by boat to their summer homes or islands nearby Cartwright to bakeapple pick. Individuals harvest fewer bakeapples from small patches around town.

Bakeapples are used for special dishes like pies, cheesecakes, and muffins during the holidays. One anonymous male, employed in Cartwright, described a delicious meal with bakeapples: *"Dough boys, the salt beef, and the potatoes and all this stuff and then you have bakeapple jam to go with that. Goood."* For some individuals bakeapples are a part of their daily diet, though this was more common in the past when there was not a grocery store to purchase fruit during the winter. Dwane Burdett shared about his father's love of bakeapples. *"Well my father, he was 97 when he died, he had bakeapples every day. Every day for breakfast he had bakeapples."*

The quantity that a family picks depends on their uses of the bakeapples. Generally, if the family is picking without the intention of selling, a family will pick between five to 15 gallons of bakeapples. If the family is picking with the intention of selling then they might pick anywhere from 20 to 50 gallons of bakeapples depending on the abundance of bakeapples in a particular year. Participants expect the growth of bakeapples to be variable from year to year. Dwane Burdett said, "*Some years there's none nowhere! I've been up there and sometimes you can literally see that the land has an orange glow to it. Like an orange… a big orange carpet."*

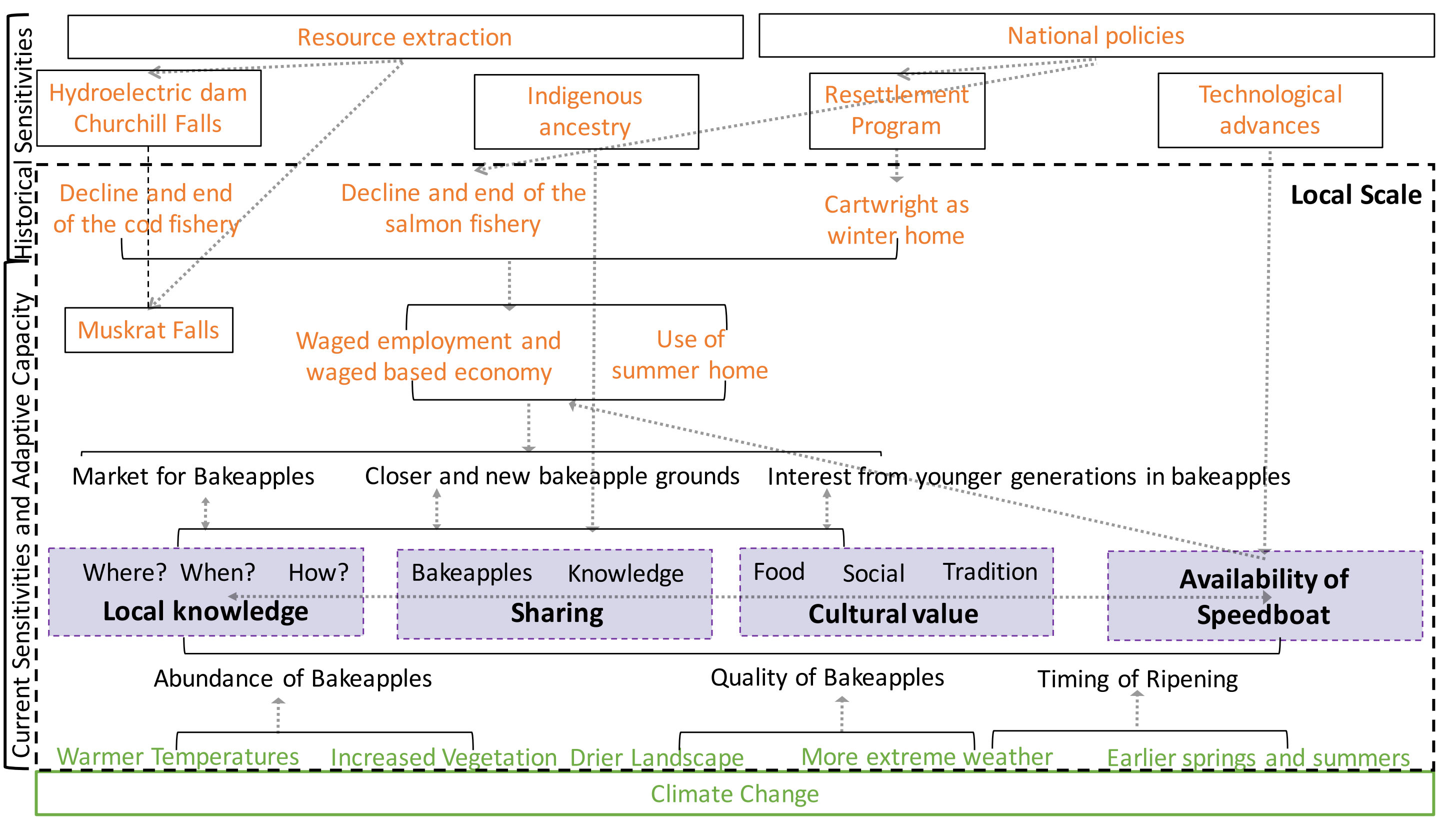
Bakeapple pickers recognize that the variability in the abundance of bakeapples from year to year is largely attributed to weather. About a third of participants emphasized that the weather during the spring and summer of the year is a key factor in the abundance of bakeapples that season. Interviewees explained that in the spring if there are strong winds or rains then the bakeapple blossom can be destroyed because they are particularly sensitive till the shuck has closed in. Rosetta Howell said that "*if there's too much wind the bakeapple blossoms will be blown off before they have a chance to come to anything."* Dave Hamel, an active community member and a bakeapple picker for more than 50 years, reiterated the point, "*you have to have the ideal spring… for the blossoms to fold in… when they turn in the berries is protected then."* Interviewees also explain that the weather during the summer is very important. Extreme temperatures can destroy the bakeapple fruit. As described by Tracy Martin, a bakeapple picker of 20 years who lives and works in Cartwright, the bakeapples are sensitive to weather conditions. She explained, "*if it's too hot they'll kind of burn up… and if it's cold and damp for a while they just won't grow like they should. You'll get a few but they'll be small or spaced apart."*

Families will generally go for day trips or a holiday to the bakeapple grounds from the end of July through September, depending on when the bakeapples are ripe. Largely, interviewees consider this variability to be normal. Leslie Hamel, a grandfather employed in Cartwright and previously a fisherman, explained that "*timing changes almost every year. You might be able to pick bakeapples in the middle of July and most times it is not until the first week* *in August and then from that on the bakeapples ripen."* Almost half of the participants describe how the temperatures in both the spring and the summer will determine the ripening time. With a shorter spring and earlier summer the bakeapples will ripen sooner. Also, about a third of participants explain that the time when bakeapples are ripe depends on location. The bakeapples will ripen as late as early September if the berries are in a sheltered spot where they receive less sun or on an island farther from the mainland.

4.3.2 Exposure

Community members discussed the following ecological changes that are beyond their past experiences and related to the growth of bakeapples. A few interviewees consider the recent variability in weather to be beyond normal (Figure 2). Participants consider the spring temperatures to be warmer in the last decade. However, participants also pointed out that the 2017 spring was colder than usual, which is an exception to this longer term observed trend. Rosetta Howell described how the weather has become more extreme.

> *The berry picking for the bakeapples has changed because the weather has changed. The weather has changed, because it is more windy. A lot of wind. And more stormy. A lot of*



storms. And not, not usual happenings, like last summer being extremely cold the whole summer. And there was still a good berry crop it was just froze because of the frost. Extreme weather conditions are changing the bakeapples. And we go and pick bakeapples and they're intermingled.

Figure 2: A diagram of the vulnerability of bakeapple picking to physical and social changes. The exposures are in green; the adaptive capacities are in purple; the sensitivities are in orange. The local scale is marked with a dotted black square. The current and historical components are indicated on the left of the figure. Arrows show the interactions between different components.

There was greater consensus between interviewees that bakeapples are ripening earlier in the season (Figure 2). Almost half the participants observed that the bakeapples have been ripening earlier than normal in recent years. Participants explained that this change is because of changes in the timing of the seasons. The bakeapples are ripening earlier because the temperatures are warming up earlier in the year. Dave Hamel explained that "*the springs are coming earlier each year and because of that your blossoms are coming out earlier and they are ripening earlier because of that."* A few participants attributed changes in the growth of bakeapples to climate change without the phrase climate change being brought up by the researcher.

A third of participants observed that the bakeapples themselves are changing and that they grow differently (Figure 2). However, the reasons behind the possible change in bakeapple growth were unclear based on the interviews. Specifically, a few participants observed that the way the bakeapples are ripening is more fragmented. Donnie Howell, a Cartwright community member and grandfather, explained that in the past individuals could find large patches of bakeapples all ripe at the same time, but now the patches are more fragmented and the bakeapples are ripening at different times.

But I know that the bakeapples don't grow anymore like they used to years ago. Years ago, when they ripe, you go out into a spot of bakeapples and you just pick, pick, pick. But now when you go you pick a few that's ripe and then you go back a bit later and pick a few more when they are ripe. Why? I don't know. But I do know there is a lot of vegetation growing up that wasn't in some places anyhow.

Similarly, Rosetta Howell reflected on how the bakeapples grew in her childhood compared to now.

> *There are some ripe, some partly ripe, and some overripe where we are picking the bakeapples. When I picked them as a child, when you went berry picking, there were all one thing, all one color, all the one ripeness. You weren't picking 5 or 6 here and 5 or 6 there. There was the whole thing right in front of you. All the same. The same color. The same ripeness. And you know, really thick. And lots of berries.*

10 of the 18 participants noted changes in the landscape at the bakeappple picking grounds. Many participants observed that there are increases in the surrounding larger shrubs at the bakeapple grounds and this vegetation is competing with the bakeapples (Figure 2). For instance, Dave Hamel stated that "*some of the other shrubs seem to be overtaking some of the… places where bakeapples grow.*" Furthermore, in town there has been rapid growth of shrubs, especially willows, in the past five to ten years. This has less impact on bakeapple picking grounds but is consistent with the longer-term trend of increased large shrub and tree growth.

A few participants explained that the landscape is drier (Figure 2) in response to the question: have the water conditions at the spots you pick bakeapples changed? Participants observed this change through small bodies of water in the landscape, ponds and rivers, or by how changes in soil moisture conditions have impacted the kinds of shoes people need to wear to go bakeapple picking. A couple of participants even described how a small pond nearby a popular bakeapple picking ground completely dried up one year after large cracks formed in the landscape.

In addition to these biophysical stressors, socioeconomic changes are impacting where and when families bakeapples pick.

4.3.3 Sensitivity

Before the 1960's, families moved between summer homes, for fishing and bakeapple picking, and winter homes, for trapping and hunting (Fitzhugh, 1999; Lethbridge, 2007). There was a provincial centralization program in the 1960s that moved smaller coastal communities into Cartwright to reduce the cost of servicing the coast, and many families moved their winter home to Cartwright (Figure 2). Consequently, resettlement moved participants further from their summer homes and bakeapple picking grounds, making it harder to cope with variability in the growth of bakeapples.

However, before the moratorium on cod and salmon fishing in the 1990s, many families went to their summer homes around June, out on the islands for fishing and bakeapple picking, and returned to Cartwright around September, for the winter. The salmon fishery was in July and ended just before bakeapple picking time in August. The cod fishery started in August and overlapped with the bakeapple picking time. Families' summer homes were nearby their fishing nets and a short boat ride or walk away from their bakeapple picking grounds.

After the moratorium, families now live and work in Cartwright during the summer and are farther from the bakeapple picking grounds (Figure 2). Rosetta Howell explained,

> *I was a young teenager when the cod fishery was over so life began to change then. So life began to change and peoples' way of life began to change from that day to this. Less and less and less people could make a livelihood from in shore fishing. Taking their families to summer fishing places.*

Few families are able to take a holiday to return to their summer homes, which can be hours away by boat, for bakeapple picking. Families who do take vacations to the bakeapple picking grounds can more easily pick the bakeapples as they become ripe, which happens over the course of a couple of weeks. More commonly, families will take day trips to nearby bakeapple picking grounds, less than a half hour away by boat. Leslie Hamel explained *"that's the way we pick bakeapples. We run off for a few hours and go out for a day or two and come back."* Community members explained that when not all the bakeapples are ripe they have to make multiple day trips back to the same berry patch over the course of a couple of weeks while the bakeapples ripen. It is more challenging for community members, in terms of finances and time, to deal with temporal and spatial variability in the ripening of bakeapples living farther from the bakeapple picking grounds.

Many families no longer find the time to go bakeapple picking. Rosetta Howell said that *"the biggest barriers have been economic because we can't leave in the summer whenever we feel like it. He has to work."* It is difficult to cope with variability in weather with rigid work schedules and increasingly, single men will go to the bakeapple grounds for a couple of hours to pick bakeapples for their family. Despite living farther from their bakeapple picking grounds and having less time, due to work schedules, some families continue to bakeapple pick.

4.3.4 Adaptive Capacity

The speedboat, an upgrade from the row boat and then motor boat, is a part of the community's adaptive capacity because it enables families to travel more quickly and to continue frequenting their bakeapple picking grounds (Figure 2). Rosetta Sainsbury, a bakeapple picker for about 70 years and a grandmother, said "*you jump on your boat and go on and you're there in half the time you were there in a motor boat."* Because the speedboat reduces travel time, individuals can more easily make a trip to a nearby bakeapple picking spot before or after work. The speedboat has also encouraged families to explore new bakeapple picking spots. Cookie Lethbridge, a woman who grew up in Cartwright and now lives in Cartwright during the summers, said that "*you can now go so much faster and so many different places.*" In fact, some participants explain that the motor boat kept people from bakeapple picking at the best spots because of its slower speed compared to the speedboat. For instance, Dave Hamel recounted the times of the motor boat saying that "*the mode of transportation impended more people from going to where the berries were.*" Most families have a speedboat which helps them deal with the temporal and spatial variability of when bakeapples ripen. One year bakeapples might be abundant on a particular island and another year they might not be, and with the speedboat families can quickly negotiate this variability.

Despite the advantages of the speedboat, challenges remain to bakeapple pick including the difficulty of traveling far distances by a boat in old age, high winds which will make the sea too rough to go out on boat, the cost of gasoline, and access to a boat. Leslie Hamel explained, *"getting ashore is always a problem if there is a sea on. Even if there is no wind sometimes you try and land and there's too much sea. So you had to pick your days."* Two participants considered the cost of gasoline to be a barrier to bakeapple picking. A woman, bakeapple picking for almost 70 years, said that she and her husband spend $40 per trip on gasoline and this has made it too expensive to bakeapple pick compared to when she was growing up and could just walk to the bakeapple grounds. Also, two participants expressed that access to a boat was a challenge in the context of not owning a boat and having rented out his boat for work.

The market for bakeapples is a part of the community's adaptive capacity because it helps some individuals to offset the costs of gas to visit the bakeapple picking grounds. Individuals sell as much as 30 gallons of bakeapples to people in Goose Bay, Newfoundland, and also, Cartwright as a source of supplemental income. There is a high demand from both Goose Bay, where bakeapples do not grow and also from Newfoundland, where the bakeapples do not grow as abundantly and as a result, the bakeapples sell for about $80 a gallon. Judy Pardy explained that "*there are only a couple of patches on the island [Newfoundland] that you can find them and so many people love them, so for them $80 for a gallon of bakeapples is well worth it.*" The market for bakeapples is also helpful to individuals in Cartwright who are unable to go out and pick bakeapples due to age, lack of resources (boat and/or cabin at the grounds), time, and/or interest and instead want to purchase bakeapples (Figure 2). In addition to the market for bakeapples, more than half of the interviewees said that they share their extra bakeapples with family and friends, which is also helpful for those individuals who do not have the resources to bakeapple pick. Donnie Howell said that "*if I was going to get rid of any, I would give them away.*"

Local knowledge, based on generations of bakeapple pickers and word of mouth between berry pickers in the community, is a part of the community's adaptive capacity because it captures when and where to bakeapple pick. Participants can start to predict the impact of weather on the ripening of bakeapples in the spring of the year when the bakeapples are blossoming. If temperatures are warming up in the spring, then it is likely the bakeapples will ripen sooner. If temperatures are remaining cold, then it will likely be a late year for the bakeapples. Leslie Hamel said that "*you can pretty well tell in the spring of the year what it's going to be like in the summer for bakeapples.*" Also, through local knowledge and word of mouth, individuals know the best places. Interview participants described the ideal conditions, including soil moisture (described by almost all participants), topography (described by 10 of 18 participants), and the surrounding vegetation (described by half of the participants), for bakeapple growth. Judy Pardy explained that "*we know not to go to certain places if we are looking for bakeapples because chances are slim you are going to get them. Yes, and a lot of that is local knowledge, right?*" Participants described the bakeapple picking grounds as a marsh or bog and explain that there has to be enough moisture for the bakeapples to grow. Participants emphasized that the bakeapples will not grow right in the waterlogged soils of the marsh/bog but in damp soils. Leslie Hamel shared that "*a lot of the places you pick bakeapples are pretty much wet spots anyways. Not right wet as such but damp, the best areas."* In addition, participants repeated that shelter, from both the natural topography and surrounding vegetation, is an ideal growing condition for the bakeapples. Rosetta Howell described the ideal shelter that will provide the bakeapples with moisture and protection from storms.

> *And the kind of land it is kind of sheltered land. So the wind wouldn't be able to get at the blossoms and blow them off before they get a chance to grow into a fruit. It is kind of a sheltered spot. And the sun and the rain can get at it but it is kind of a sheltered place.*

The value placed on bakeapples by individuals is also a part of the community's adaptive capacity because it provides motivation to cope with and adapt to ecological and social changes (Figure 2). Almost all participants explain that the bakeapples are still a valuable part of the diet. Donnie Howell said that "*bakeapple picking has always been a big part of our lives for food. It's been very important."* Interviewees prefer bakeapples over other fruits at the grocery store. An anonymous male participant said that "*whatever is in the grocery stores doesn't matter. We are still going to get bakeapples if we can get them because they were something that we really liked to have, right?*" Interviewees also prefer bakeapples for their nutritional value. Dwane Burdett explained that "*there are a lot of health benefits to bakeapples. They are packed with vitamins."* Participants also enjoy bakeapple picking because they get to be out on the land. Judy Pardy said, *"and for me I love picking berries. I'd just go out and crawl around on the land all day long, you know?"* Participants also pointed out that bakeapple picking is hard work and can be increasingly difficult with age. Some interviewees value the social aspect of bakeapple picking. After a long day of bakeapple picking, the family will meet up for a boil up, which is a picnic with some boiling water for tea. A third of participants continue to bakeapple pick because it is a tradition. Dwane Burdett said*, "that's how our ancestors survived and it just got passed down from generation to generation."* Fewer participants brought up their Inuit ancestry as a reason for bakeapple picking. Rosetta Howell says, *"we are Inuit because of our background. Our grandmothers were Inuit."* However, participants more largely associated bakeapple picking to their Labradorian culture.

A handful of participants observed that younger families are less engaged in bakeapple picking. Dwane Burdett said, "*like I said it is [bakeapple picking] getting done less and less. There are less and less people out on the land.*" Similarly, Judy Pardy explained *"…the ones that have graduated and gone off to university and college. They don't come back. They never got into it like their parents did. Picking the bakeapples. And that kind of a life."* Also, Rosetta Howell says that "*we still try and pick bakeapples every year. But even that families don't do that anymore with their children or grandchildren. You know some do but very few."* The cultural and nutritional value that families currently place on bakeapples is a key component of adaptive capacity and enables families to cope with the increasing challenges to bakeapple pick. However, because an increasing portion of the younger generation places less value on the activity of bakeapple picking and bakeapples as a food source, this may not be a source of adaptive capacity in the future.

4.4 Discussion

The exposures, described by community members in Labrador, parallel observations in other arctic and subarctic communities. Bakeapple pickers explained that variability in the timing and abundance of bakeapples is expected. Some bakeapple pickers observed that the timing of picking has been earlier in the past 10 years largely due to the springs and summers coming earlier. Other Inuit communities have also observed an earlier season for the bakeapples (Downing & Cuerrier, 2011). Some interviewees described how tree and larger shrub growth has encroached on bakeapple patches. First Nation communities in the Yukon and Northwest Territories and Gwich'in communities also are making observations of new shrub and tree species at berry picking spots (Guyot et al., 2006; Parlee & Berkes, 2005). Participants also observed that the berries ripen in a more fragmented way, are less abundant and smaller compared to their youth. A couple of participants attributed these changes to climate change. One bakeapple picker from Cartwright attributed the fragmentation of bakeapple patches and less abundant bakeapples to more extremes in the weather, including precipitation. Other Indigenous communities note changes in the bakeapples themselves. First Nation communities have described precipitation which is resulting in smaller berries and less snow bringing fewer berries (Guyot et al., 2006). In a Gitga'at community in British Colombia, residents have explained that in recent years wild berries (not specifically bakeapples) are scarce and attributed this to heavy rains (N. Turner & Clifton, 2009).

These ecological changes may be experienced in a comparable way by other Indigenous communities with similar components of sensitivity. In Cartwright, bakeapple picking is tied to other harvesting activities, specifically fishing. Similarly, in Gwich'in First Nation communities the harvest of berries and fish occur at the same time (Parlee & Berkes, 2005). Other First Nation communities in British Colombia also harvest important plants, specifically edible seaweed, while fishing for salmon and halibut. As a result, any changes in the fishery have an impact on the harvesting of edible plants. In Cartwright, resettlement had an impact on families' land based livelihoods because resettlement made it more difficult for individuals to travel between their summer homes for fishing and berry picking and their winter homes for trapping and hunting. The sociocultural transformations following resettlement is an example of a slow variable which has resulted in a change in culture and livelihoods over the past half century in Indigenous northern communities (Chapin et al., 2004; Ford et al., 2013). Similar to resettlement in Cartwright, resettlement programs also moved Inuit in Nunavut into permanent communities and ended their semi-nomadic way of living, which limited individuals' ability to access hunting areas (Wenzel, 2009). For instance, now in Igloolik, Nunavut, there are fewer full time hunters and families who live at outposts (small settlements) nearby their traditional hunting grounds. As a result, the extent of harvesting areas and the availability of country food has decreased (Ford & Beaumier, 2011).

The adaptive capacity of families in Cartwright to respond to these ecological and social changes also has similarities and differences with other arctic and subarctic Indigenous communities. New technology enables Indigenous communities, with land based livelihoods, to continue living off the land despite social and environmental change. In Cartwright, the speedboat has enabled families to continue visiting the bakeapple picking grounds. Similarly, the snowmobile allowed individuals in Inuit communities, in Nunavut, to continue hunting despite living farther away from the places they traditionally hunted (Wenzel, 2009). Members within an Gitga'at community, in British Columbia, designed creative technology to dry their seaweed and fish despite increased precipitation (N. Turner & Clifton, 2009).

In Cartwright, the market for bakeapples is a part of the adaptive capacity of the community because it provides supplemental incomes and makes it more affordable for many families to continue bakeapple picking. Community members in Cartwright did not experience that the market for bakeapples has threatened traditional sharing networks with family and friends and similarly, Inuit communities in Greenland have had widespread positive experiences selling country food for 150 years (Ford et al., 2016). In contrast, other Indigenous communities are concerned about the commercialization of traditional foods. For instance, in the Gwich'in settlement region, communities are concerned that commercializing berries will complicate traditional sharing networks and have not expressed an interest to commoditize wild berries (Murray et al., 2005; Parlee & Berkes, 2005). Similarly, some Inuit communities in Nunavut have expressed concerns about the commoditization of country food in terms of traditional sharing networks (Ford, Macdonald, et al., 2016; Searles, 2016). In some communities where traditional foods are already being sold, community members feel a loss (MacDonald et al., 2013).

In Cartwright, the cultural and nutritional value placed on bakeapple picking is also a key component of adaptive capacity. Other studies documented the nutritional value that an Indigenous community in Alaska and an Inuit community in Nunavut also place on bakeapples (Downing & Cuerrier, 2011; Kellogg et al., 2010). However, there is concern in Cartwright that younger families spend less time or no time out on the land bakeapple picking. Other studies document similar concerns within Indigenous communities that traditional knowledge is not being passed to younger generations (Beaumier et al., 2015; N. Turner & Turner, 2008).

4.5 Conclusion

The results of this study highlight some social and physical changes that impact bakeapple picking, from the perspective of Indigenous individuals in Cartwright, Labrador. In Cartwright, individuals described changes in temperatures, vegetation, and the consequent impacts on bakeapples. The impacts of these environmental changes on families' abilities to harvest bakeapples is magnified by socioeconomic impacts, including the closures of the inland fisheries and the resettlement program. However, the speedboat, the market for bakeapples, the cultural and nutritional value families continue to place on bakeapples, and local knowledge all advance families' engagement in bakeapple picking.

Contextual vulnerability to climate change encompasses not only the environmental impacts associated with climate change but the concurrent social, political and economic processes that determine how a particular community experiences climate change (Bennett et al., 2016; Ford & Smit, 2004; O'Brien et al., 2007; Smit & Wandel, 2006). Previous studies have described the contextual vulnerability of the land based livelihoods of Indigenous communities in the Arctic, (Ford et al., 2012a, 2015) and this study does so through the lens of bakeapple picking. This study is intended to advance our understanding of the complex interactions between and the importance of considering exposure, sensitivity, and adaptive capacity. Also, this study aims to draw attention to the importance of bakeapple picking in Cartwright, where little research has been done previously.

Chapter 5 Discussion and Conclusion

5.1 Overview of Thesis

Climate changes are amplified in the Arctic and permafrost thaw is a consequence of a warming climate (IPCC, 2013a). Indigenous communities in the Arctic and Subarctic are already observing the physical impacts of permafrost thaw on infrastructure, draining bodies of surface water, and animal migrations (Allard & Lemay, 2012; Larsen et al., 2014). Previous research identifies the biological impacts of permafrost thaw including changes in vegetation in the discontinuous permafrost zone; however, this research does not focus on how these changes impact northern communities with land based livelihoods (Beck et al., 2015; Bouchard et al., 2014; Payette et al., 2004). Also, there are numerous studies that consider how changes in sea ice and snow are and will continue to impact the hunting component of land based livelihoods, yet there is less consideration in the literature about the impacts of climate change on berry picking (Ford et al., 2012a). This research considers the impact of permafrost thaw on traditional land based livelihoods through the lens of bakeapple picking.

Drawing from the vulnerability science literature (Kates et al., 2001; B. Turner et al., 2003), a contextual vulnerability framework was used to identify and characterize the vulnerability of bakeapple picking to climate changes in a case study community, examining key factors affecting how community members experience and respond to changing conditions. Within this framing, vulnerability is characterized by exposure (the environmental stressor(s)), sensitivity (the social context that makes the exposure relevant), and adaptive capacity (the ability of the human system to respond to the stressor) (Bennett et al., 2016; Ford & Smit, 2004; O'Brien et al., 2007; Smit & Wandel, 2006). In chapter 3, mixed methods were used to identify the biophysical exposures on bakeapple picking with a specific consideration of bakeapple abundance across palsa permafrost and no permafrost sites. Again, the relevance of these exposures is dependent on the sensitivity and adaptive capacity of the case study community. In chapter 4, the interaction of the biophysical exposures with social, political and economic components of sensitivity and adaptive capacity were considered.

5.2 Discussion of Key Findings

The exposures on bakeapple picking include a decrease in palsa permafrost features, an increase in green vegetation, changes in hydrology, and changes in temperature. Focus group and interview participants explained that the representative permafrost associated peatland, The Big

Marsh, used to be a bakeapple picking spot of the previous generation, however, it is considered a poor spot to pick bakeapples at present. Community members observed that at and around The Big Marsh there have been increases in tall erect vegetation. The increase in total green vegetation in the "Big Marsh" was confirmed by two satellite images over a 12-year period. Also, the two satellite images over the 12 year period, revealed decreases in palsa permafrost features and increases in surface water. The decrease in permafrost palsa features has probably contributed to changes in vegetation. This is inferred based on i) the field surveys that show significant differences in vegetation communities between palsa permafrost sites and the surrounding no permafrost areas driven by changes in ALD and elevation, and ii) prior studies that describe collapsed palsa features as a result of permafrost thaw with subsequent increases in surface water, wet graminoids, and *sphagnum moss* spp (Camill, 1999; Camill et al., 2001; Christensen et al., 2004; Johansson et al., 2006). While, community members' observed that spring and summer temperatures were warming and resulting in the bakeapple ripening sooner, increases in spring and summer temperatures were not obvious from plots of homogenized historical weather data from Environment Canada.

The changes in vegetation, surface water, and permafrost palsa features in palsa bogs in Cartwright parallel the findings of other studies. Increased growth of trees and shrubs in Cartwright, is consistent with "arctic greening" being observed across the Arctic and Subarctic (Elmendorf et al., 2012). Also, previous studies in permafrost associated peatlands in the Subarctic have found that with permafrost thaw there are changes in vegetation and decreases in surface water (Beck et al., 2015; Bouchard et al., 2014; Payette et al., 2004). Previous research has also documented Indigenous communities' observations of increased shrub and tree growth blocking out important berry species (Guyot et al., 2006; Parlee & Berkes, 2005). However, this is the first study, of our knowledge, to used mixed methods to specifically consider how permafrost thaw, and other related climate changes, are impacting bakeapples.

The biggest concern community members have in the context of bakeapple picking is not related to climate change but that fewer families are going bakeapple picking. Families continue to value bakeapples both culturally and nutritionally, however, it is more difficult to get to the bakeapple picking grounds as a result of social, political and economic changes, including the provincial centralization program and the closures of the fisheries. However, the speedboat, the market for bakeapples, local knowledge and most importantly, families' love of bakeapples, helps some families to continue going to the bakeapple picking grounds. These findings have parallels and also contrasts with previous research in other communities in the north American Arctic.

Previous research identifies similar concerns, by elders, that the younger generation and young families are spending less time out on the land as a result of social, political, and economic changes that make it more difficult for individuals in Indigenous communities to have land based livelihoods (Beaumier et al., 2015; Kellogg et al., 2010; Thornton, 1999; N. Turner & Turner, 2008) . Also, previous research identified the ways in which technology are contributing to new tools to adapt to environmental variability (N. Turner & Clifton, 2009; Wenzel, 2009). At the same time, greater dependence on technology, like GPS, has also been problematic in the contexts of deskilling and a false sense of security in dangerous conditions and can contribute to increased sensitivity to environmental change (Ford et al., 2013). In contrast to the findings of this study, previous research has documented a concern, in other communities, that the commoditization of country food will threaten traditional sharing networks (Gombay, 2009; Murray et al., 2005; Parlee & Berkes, 2005). However, in Cartwright, community members view the market for bakeapples as a helpful source of supplemental income while still maintaining sharing networks with family, friends, and neighbors. This difference highlights that vulnerability is community specific and that specific components of sensitivity and adaptive capacity cannot be generalized across communities.

5.3 Methodological Contributions

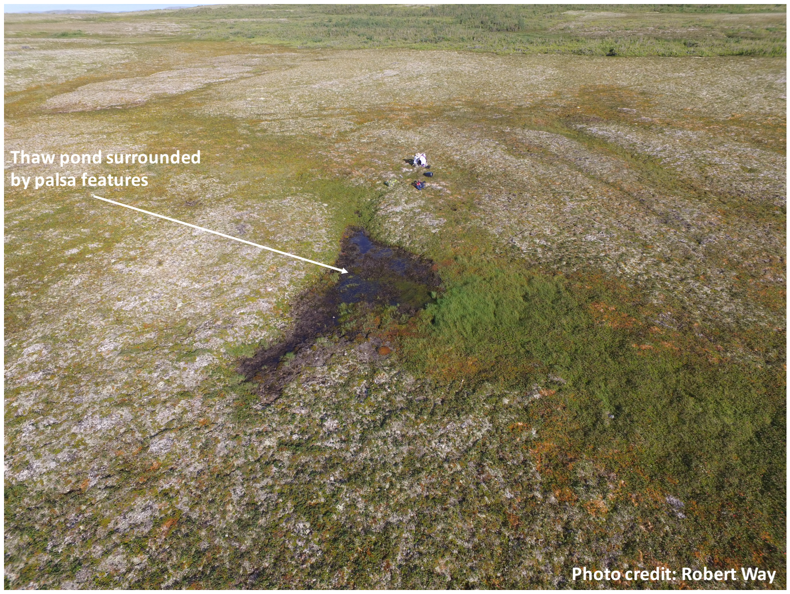
This research considers the biophysical stresses, in addition to, social, political, and economic stresses on the case study community. Compared to research that only considers the biophysical impacts of permafrost thaw on a human system (Fritz et al., 2017), this is a more comprehensive approach to assessing vulnerability because Indigenous communities in the Arctic and Subarctic are more sensitive to climate change impacts, including permafrost thaw, as a result of, not only, the region they inhabit but also their traditional land based livelihoods and a history of colonial legacies (Anisimov et al., 2007; Ford, 2012; Larsen et al., 2014). Additionally, the contextual vulnerability approach takes into account the adaptive capacity of Indigenous communities to respond to environmental variability owing to strong social networks and their TEK (Anisimov et al., 2007; Ford, 2012; Larsen et al., 2014). This research also uses TEK, in addition to other methods, to characterize the exposure component of vulnerability.

There is increasing recognition of the use of TEK in scientific research (Huntington, 2011). However, few studies have actually combined TEK with other instrumented data collection methods (Savo et al., 2016). This research first uses TEK to identify the relevant exposure and then uses instrumented datasets, including field surveys, satellite imagery, and weather data to confirm and further describe ecological changes captured by TEK. The temporal scale is not a constraint in this research because TEK spans generations of bakeapple pickers (Riedlinger & Berkes, 2001). By using TEK in addition to other instrumented datasets, longer term exposures can be identified.

5.4 Limitations and Future Research

In contrast, the spatial scope of this research is limited to the greater region of Cartwright, Labrador. As a result, it is challenging to develop generalizations to other arctic communities. There are parallels (described above) with previous research, however, to make broader generalization about the vulnerability of bakeapple picking to climate changes, more case studies are needed. Bakeapple growth is dependent on a combination of both biotic and abiotic factors (Agren, 1989; Korpelainen, 1994) and, as a result, there is likely local heterogeneity in how climate changes are impacting bakeapples. For instance, in a community in Nunavik residents observe an increase in the abundance of bakeapples (Cuerrier et al., 2015). In addition, the sensitivity and adaptive capacity component of vulnerability reflect traits of the community and therefore, this component will be different within and between regions. Future case studies in Arctic and subarctic communities with different rates of warming, degrees of permafrost degradation, Indigenous backgrounds, engagement in traditional subsistence, levels of commoditization of country food, and predominate livelihoods are necessary to get a broader sense of what is the vulnerability of the activity of bakeapple picking to climate change across the North.

Appendix I: Chapter 3 Supplementary Materials



Supplementary Figure 1: An image of a thaw pond surrounded by palsa features at Hare Harbor

Supplementary Figure 2: The topographic map used by focus group participants with digitized annotations from the focus group. Purple polygons are the nearby bakeapple picking grounds.

Red polygons are areas where permafrost degradation has been observed. Green polygons are areas where vegetation has been changing. Blue polygons are areas where the amount of surface water has been changing. Black dots are the areas where vegetation data was collected.

Supplementary Table 1: Ecological changes discussed during the focus group discussion and corresponding colors of Supplementary Figure 2 map annotations

Ecological Observation	Geographic Context	Number of Participants	Color on Map
Abundant bakeapples	**Sandwich Bay (n=2),** Table Bay to Indian Tickle (n=0)*, Black Tickle and Batteau Areas (n=1)	3	Purple
More vegetation growth	**"Big Marsh",** Packs Harbor, Horse Chops, Black Head	3	Green
Drier landscape	Old Mans Cove, Packs Harbor	2	Blue
Permafrost degradation	Hummock landscape and potential spots of permafrost degradation	3	Red

Supplementary Table 2: Data sources and their respective spatial and temporal extents

Data source	Spatial Extent	Temporal Extent
Interviews	115 km	Generational
Focus Groups	115 km	Generational
Field Surveys	4 peatlands and 62 plots	1 week
Satellite Imagery	0.54 km^2	2004 to 2016
Weather Data	One point	1934 to 2017

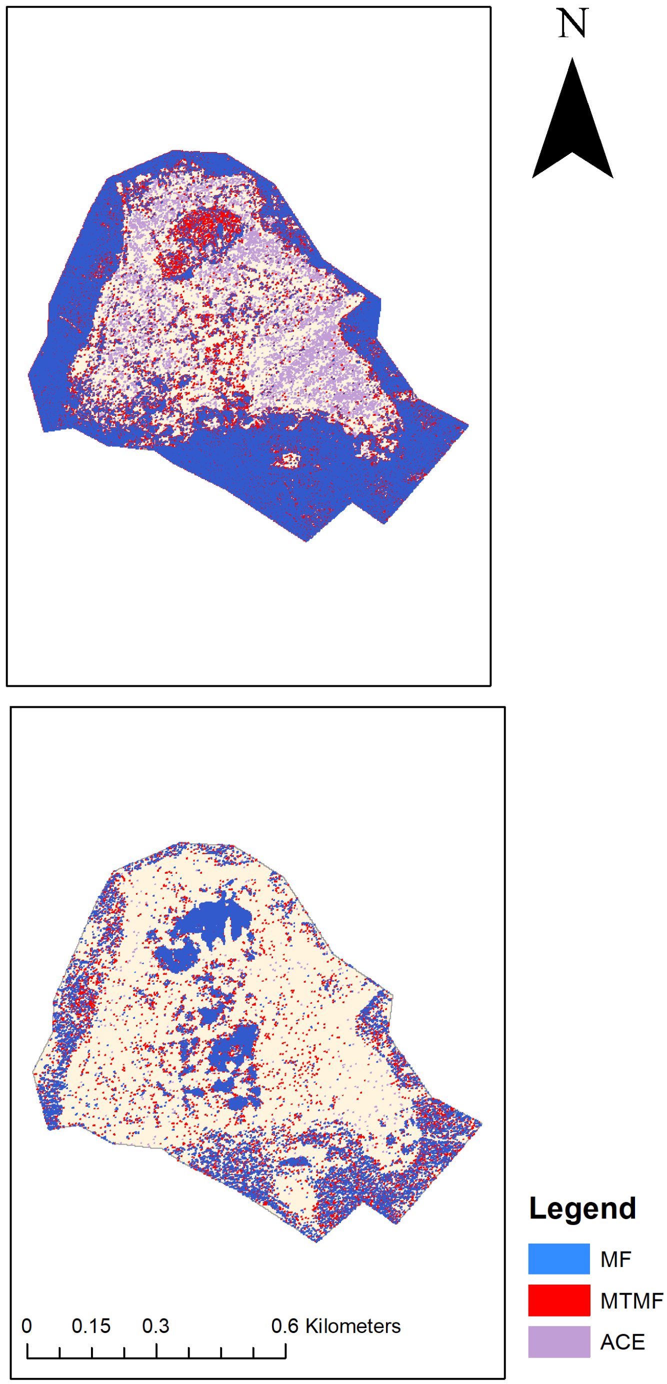
Supplementary Table 3: The Daubemire scale taken from Thomas et al., (2003)

Daubenmire Scale	Corresponding Percentage
6	95-100%
5	75-95%
4	50-75%
3	25-50%
2	5-25%
1	0-5%

Supplementary Table 4: The Braun Blanquet scale copied from Ellenberg & Mueller-Dombois, (1974)

Braun Blanquet Scale	Corresponding Percentage
5	Any number >75%
4	Any, number 50-75%
3	Any number, 25-50%
2	Any number, 5-25%
1	Numerous with up to 5% cover
+	A few with small cover
r	Solitary with small cover

A)



B)
Supplementary Figure 3: A) The outputs of the MF, MTMF, and ACE algorithms for target detection of vegetation above and water below in 2016. B) The outputs of the MF, MTMF, and ACE algorithms for target detection of vegetation above and water below in 2016

Supplementary Table 5: The Jeffries-Mutasita spectral seperability measures for the 2004 classes (vegetation, water, and other) and for the 2016 classes (vegetation, water, and other).

2004 classes	**Jeffries-Mutasita**
vegetation-water	1.35
vegetation-other	1.97
water-other	1.97
2016 classes	
vegetation-water	1.35
vegetation-other	1.98
water-other	1.98

Supplementary Table 6: Classification accuracy metrics (user accuracy, producer accuracy, and overall accuracy shown for 2004 and 2016 surface water and vegetation classifications.

	2004 Water	**2004 Vegetation**	**2016 Water**	**2016 Vegetation**	**2004**	**2016**
User Accuracy	81.82%	100%	87.50%	100%		
Producer Accuracy	84.38%	64.15%	93.33%	48.91%		
Overall Accuracy					71.76%	59.84%

Supplementary Table 7: Demographic information of focus group participants (n=3)

Demographic	Number of participants
Female	3
Male	0
Over 50	3
Under 50	0

Supplementary Table 8: Key themes and questions from the focus group

Focus group themes	Kinds of questions
Bakeapple Picking Spots	Where are the places you know that bakeapples grow?
	Where are some of the places that people in town used to pick at and no longer do?
Ecological changes at bakeapple picking spots	Have you seen changes in the vegetation at the bakeapple picking grounds?
	Have you seen changes in moisture at the bakeapple picking grounds?
Identification of permafrost degradation features	Have you seen any of these examples (from pictures) of permafrost degradation at the bakeapple picking grounds?

Supplementary Table 9: Demographic information of interviewees

Demographic	Number of participants
Male	9
Female	9
over 50 years old	15
between 30 and 50 years old	3

Supplementary Table 10: Questions about ecological changes from the interview guide

Example questions
Have you noticed changes in the plant species where you pick bakeapples? What other species of plants do you see around bakeapples picking spots?
Have you noticed a change in the amount of surface water in the landscape? How much water do you notice in the areas you bakeapple pick?
How much variability is there from year to year in the abundance and quality of bakeapples?
What things have effected how good the bakeapples are in a particular year?
Has the timing of when you go out to pick bakeapples changed from your youth?

Supplementary Table 11: The larger key themes and more specific codes (analytical codes) within both the sensitivity (orange rows) and exposure (blue rows).

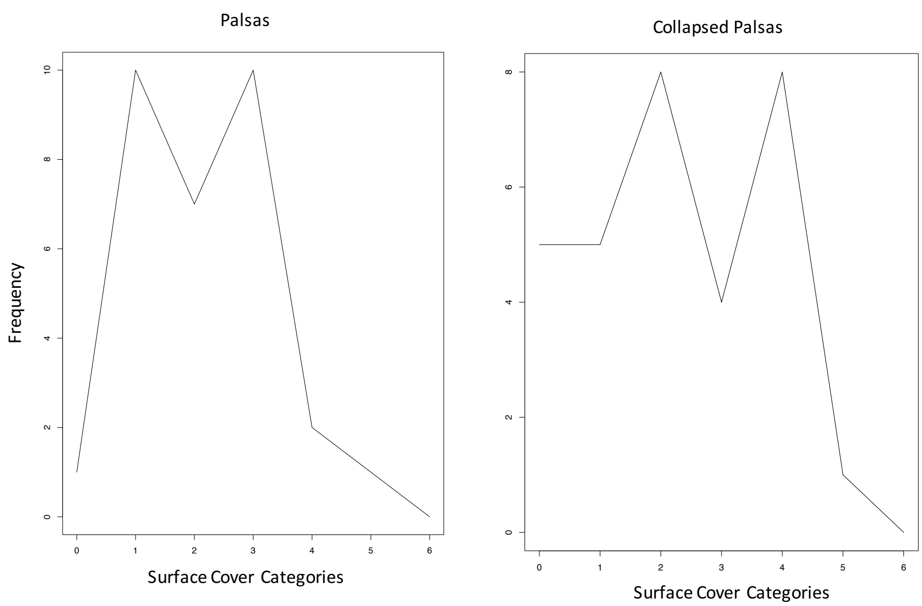
Vulnerability Framing	Themes	Examples of more specific codes
Sensitivity	Livlihoods	Fishery, Market for bakeapples, other jobs
	Diet	Food supply, nutrition
	Social event	Family, Gender, Sharing, Duration, Young people
	Sense of Place	Access, Local Knowledge, Secrecy
	Tradition	Labradorians, Inuit
Exposure	Natural variability in the growth	Spatial variability, Interannual variability, Uncertainty about change beyond natural variability, Human impacts
	Weather and Climate	Ideal for bakeapple growth, Not ideal for bakeapple growth, Ideal for bakeapple pickers, Changing weather
	Natural variability in timing	Window when ripe, Spatial differences in ripening, Variability beyond normal in ripening

Supplementary Table 12: Expected and longer-term variability in bakeapple growth from focus group and interview data

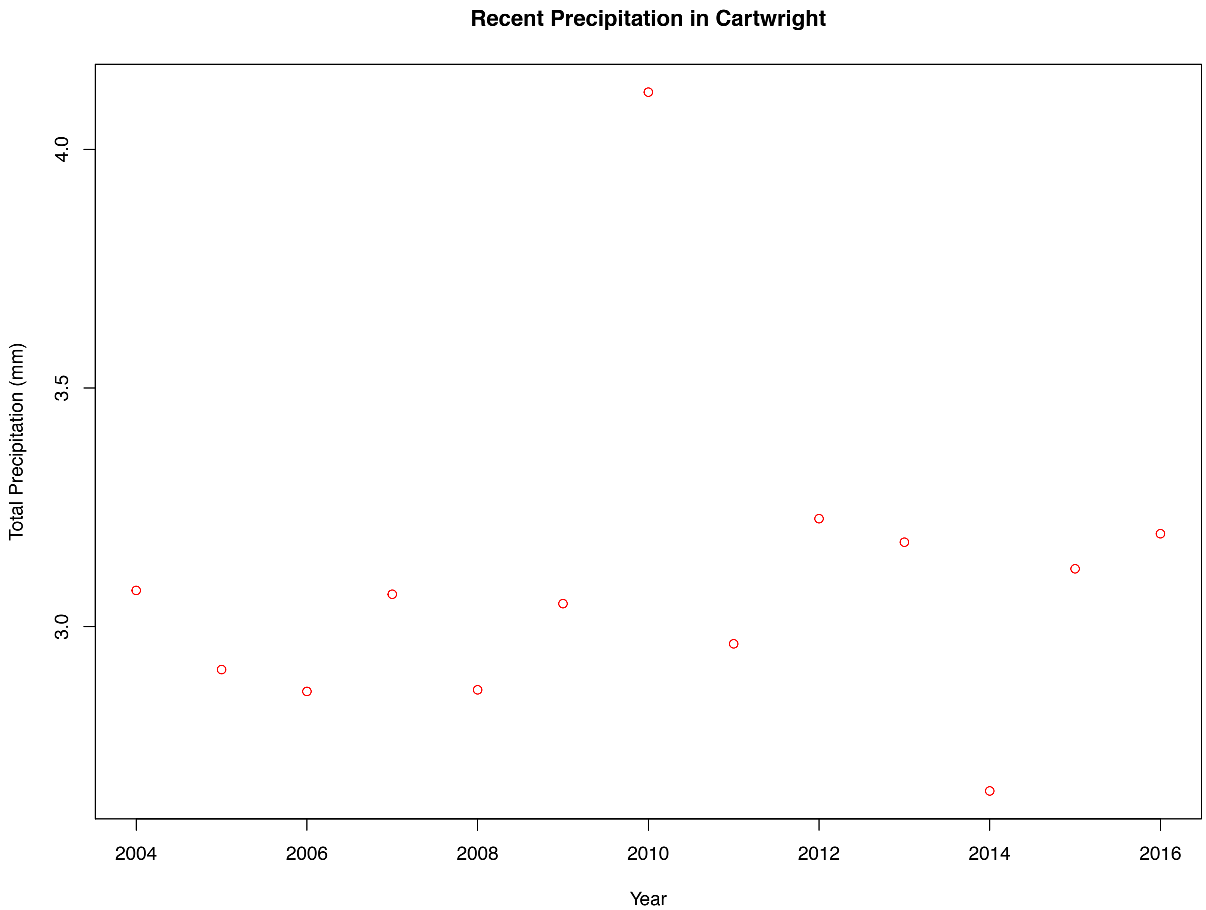
Aspect of Change Related to Bakeapples	Determinates of Expected Variability	Factors Contributing to Longer Term Change
Abundance	• The abundance of bakeapples is susceptible to high winds and/or rains starting in the spring through the summer of the year	• Drying and vegetation growing up resulting in fewer bakeapples • Bakeapples not growing as big or as abundant due to warming temperatures
Quality	• Extreme temperatures can spoil the bakeapple in the spring and summer of the year	• More extreme weather spoiling the bakeapples
Timing	• The temperatures during the spring and summer will determine when the bakeapples are ripe. • Bakeapples in cooler places, including more distant islands and sheltered spots, will ripen later	• Bakeapples ripening earlier because the spring and summers are coming earlier
Geographic Context	• Best spots out by boat but will also get some in town • Dense berry patches in sheltered and moist area	• Fragmentation of bakeapples patches

Supplementary Table 13: Frequencies of surface cover categories for Rubus chameamorus per palsa and collapsed palsa feature type

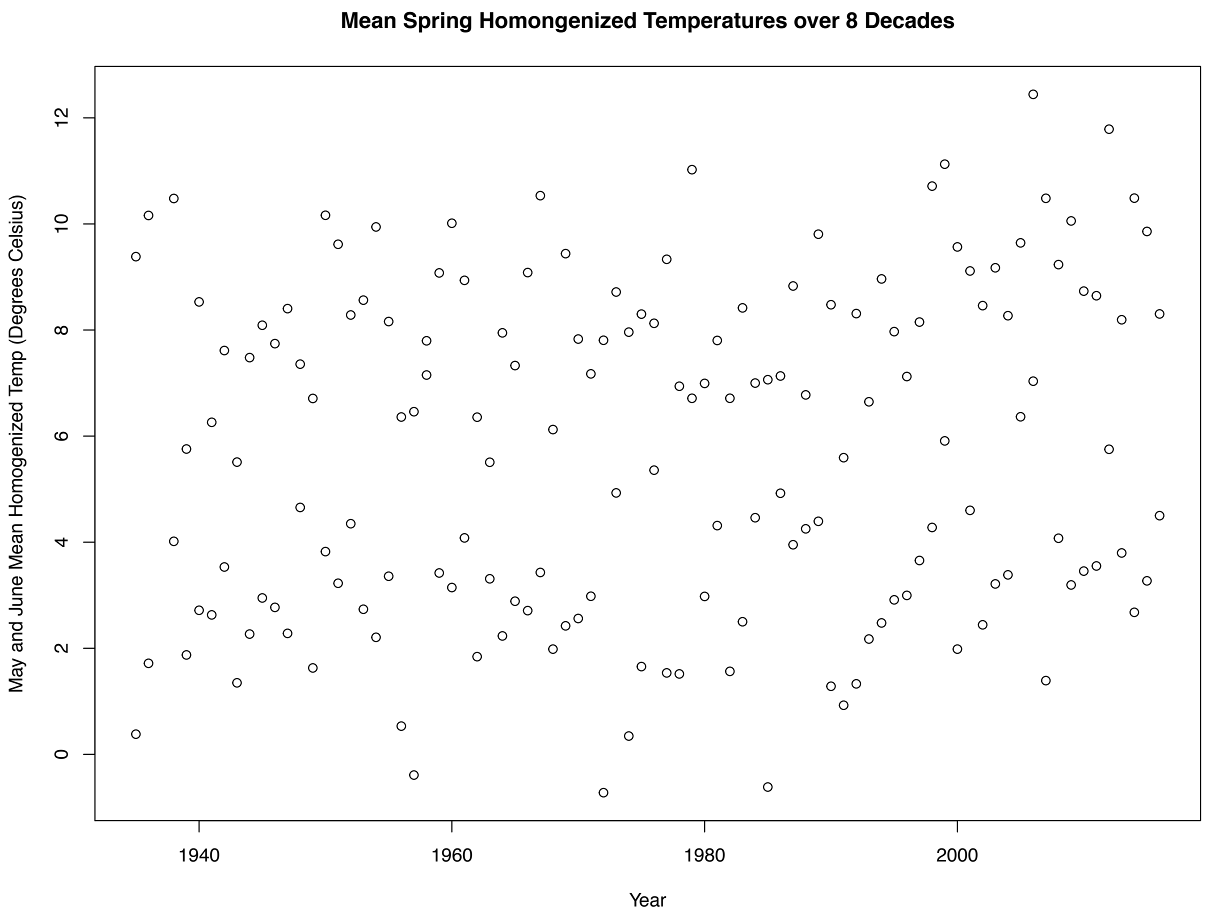
Surface Cover	Absent	Present
Frequency of Bakeapples on Palsa	1	30
Frequency of Bakeapples on Collapsed Palsa	5	26



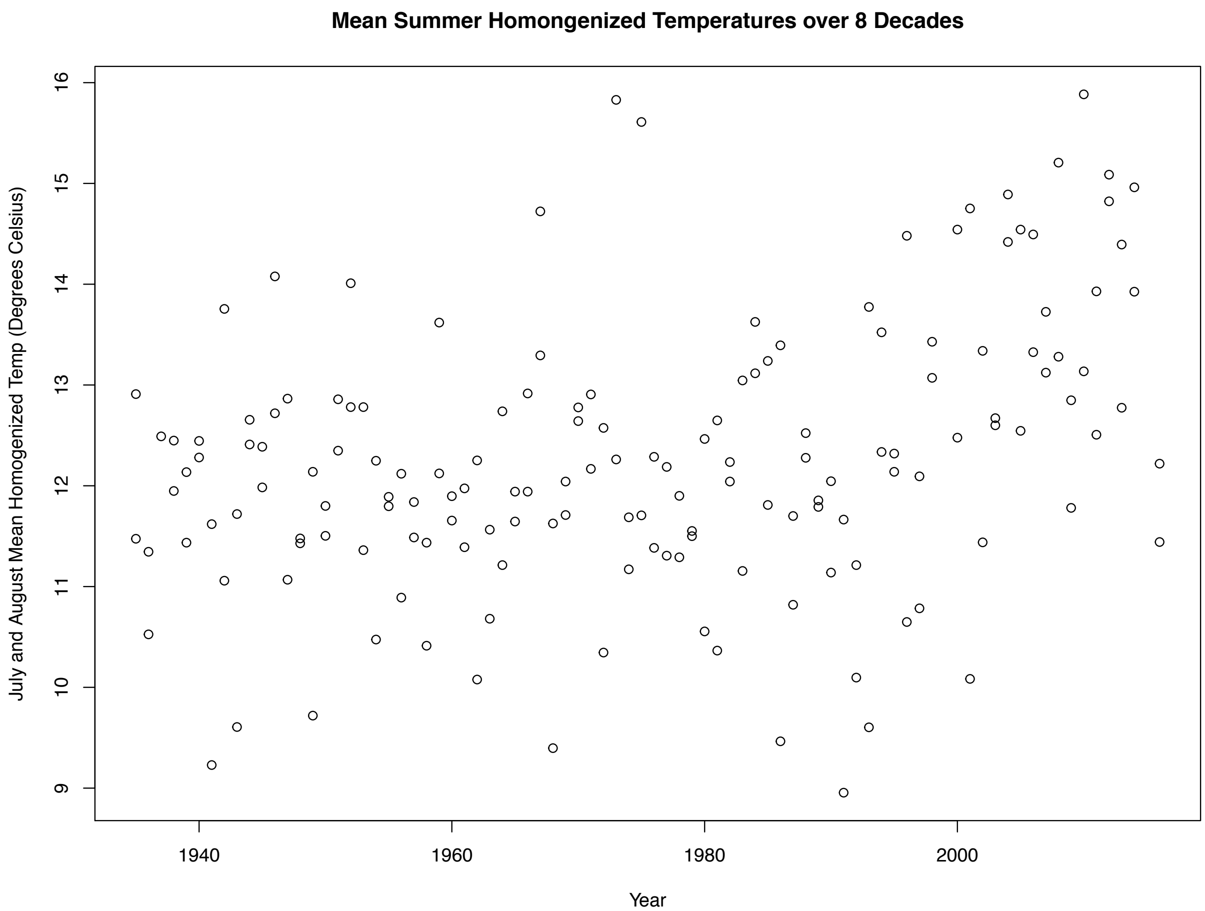
Supplementary Figure 4: Distribution of surface cover categories for bakeapples for palsa sites (left) and no permafrost sites (right)



Supplementary Figure 5: Daily mean total precipitation (mm) over the time period 2004 to 2016


Mean Spring Homongenized Temperatures over 8 Decades
May and June Mean Homogenized Temp (Degrees Celsius)
0
2
4
6
8
10
12
1940
1960
1980
2000
Year

a)



b)

Supplementary Figure 6: A) Mean spring temperatures (May and June) over 8 decades and B) Mean summer temperatures (July and August months) over 85 years.

Supplementary Methods Text 1: The following text elaborates on other possible methods for relevé data collection during field surveys.

The percent cover of relevés is commonly estimated with the Braun-Blanquet method (Camill, 1999; Causton, 1988; Glaser, 1983; Glaser et al., 1981; Wikum & Shanholtzer, 1978). The Braun-Blanquet is a semi-quantitative scale with seven scale values, four which are cover values and three which are abundance values (Supplementary Table 4) (Ellenberg & Mueller-Dombois, 1974). The Braun-Blanquet method is criticized for not being quantitative enough, only having ordinal meaning, and having values that correspond to cover and/or abundance (Podani, 2006). Researchers have suggested various solutions to the inherent limitations of the Braun-Blanquet scale. Some researchers attempt to visually estimate the exact surface cover of all species (Camill, 1999). However, it is difficult to make exact estimates of cover because often species cover is heterogeneous and fragmented within a plot (Thomas et al., 2003). Some researchers have modified the scale by taking the mean of the upper four value ranges, converting r and 1 to arbitrary percentages, and disregarding the lowest category (van der Maarel, 1979). Also, researchers have used an alternative scale, specifically the Daubenmire scale, with six scale values corresponding only to cover not abundance (Thomas et al., 2003). A final option is to only record presence/absence of the vegetation.

Supplementary Methods Text 2: The following text elaborates on other possible methods for data analysis of data collected in field surveys.

Ordination can either be constrained (direct gradient analysis) or unconstrained (indirect gradient analysis) (Causton, 1988; Šmilauer & Lepš, 2014). Constrained ordination considers how the vegetation in relevés varies with specific measured environmental gradients. Redundancy analysis (RDA) and canonical correspondence analysis (CCA) are commonly used constrained ordination methods (Bubier et al., 1995; Šmilauer & Lepš, 2014). Unconstrained ordination searches for any gradient based on the relevé vegetation data (Causton, 1988; Šmilauer & Lepš, 2014). For this research, unconstrained ordination is more appropriate because it is not clear which environmental gradient is predominately driving the differences in vegetation communities.

In all types of unconstrained ordination, species abundances are first plotted in multidimensional space (Causton, 1988; Šmilauer & Lepš, 2014). Then a model is needed to reduce the dimensionality in a way that minimally changes the original spatial relationships in multidimensional space. These models can be linear or unimodal models. Linear models are more appropriate for homogenous data and unimodal models are appropriate for more heterogeneous dataset with longer environmental gradients (Šmilauer & Lepš, 2014). Because the dataset of this study is stratified by palsa and collapsed palsa sites, which have heterogeneous environmental conditions, a unimodal model is appropriate. Correspondence Analysis (CA) or Detrended Correspondence analysis (DCA) both utilize unimodal models (Šmilauer & Lepš, 2014). However, the way that CA represents sites in a reduced dimensional space can be misleading because it does not retain the original spatial relationships. Two of the issues of CA include the following: i) variation is compressed at the extremes of axis 1 and ii) axis two does not correctly account for the variation in axis 1 leading to an “arch effect” (Thomas et al., 2003, p. 86). DCA corrects for some of the misrepresentations of CA, but DCA modifies the data in a complex way (Oksanen, 2015). Non-Metric Multidimensional Scaling (NMDS) is an alternative more straightforward model that uses rank order data to reduce the dimensionality. Specifically, NMDS uses a Bray Curtis distance to reduce the dimensionality of the plots in multidimensional space. Bray Curtis is similar to the widely accepted Sorenson coefficient for presence/absence data because it only considers common species that relevés have during the calculation of the dissimilarity matrix. Ecologists consider the species that plots have in common to be a more insightful comparison than a comparison of total species between plots. For example, methods like principal component analysis (PCA), that uses Euclidean distances to calculate similarity, only compare the total species between plots (Causton, 1988; Šmilauer & Lepš, 2014).

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