IMPORTANCE OF BERRIES IN THE INUIT BIOCULTURAL SYSTEM:

A MULTIDISCIPLINARY INVESTIGATION IN THE CANADIAN NORTH

by

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Abstract

In the Canadian North, the fruits of berry producing species are a highly nutritious source of food available to both animals and humans. Although relatively well-documented in boreal and subarctic environments, little information on the ecology and cultural importance of berry species is available for the Arctic. This research aims to fill that gap using archives, interviews, ecological monitoring as well as remote sensing tools. An overview of the different uses and roles of berry plants and berry picking as reported in close to 200 interviews conducted with Elders and active land users across Inuit Nunangat since the 1980s was compiled. Through extensive fieldwork and remote sensing analyses, local availability and animal consumption of berries were investigated in detail in the vicinity of Arviat, Nunavut. Finally, an overall assessment of berry productivity in the Canadian North was conducted using berry productivity data collected between 2007 and 2015 at 10 sites from Nain, Nunatsiavut, and Kugluktuk, Nunavut, to Alexandra Fiord, Ellesmere Island, Nunavut. Results showed the extensive and intimate knowledge of berry plants throughout Inuit Nunangat; berries were and remain culturally and nutritionally important for Inuit. Detailed landscape analyses in Arviat, revealed the large number of berries produced and the relatively large amount consumed by animals, mainly geese. Nevertheless, animals only eat a marginal portion of the total production at the site. Perceived competition for the resource may be linked to the small number of productive and accessible patches in the vicinity of the community. The analysis of inter-annual and regional variations in berry productivity illustrated that the abundance of berries in the Arctic is comparable or greater to certain forested areas in North America and Fennoscandia. The most productive sites were located in the low Arctic, in dry-mesic sites dominated by semi-prostrate dwarf shrubs. Inter-annual productivity analyses showed the complex interaction of winter and spring precipitation as well as summer temperature on productivity. Overall, this research demonstrates the cultural and ecological importance of berry species across Inuit Nunangat and suggests ongoing impacts of community development, pollution and recent climate change on the quality and availability of this important resource.

Lay summary

Berry species are widespread across Inuit Nunangat but little is known about their place in the socio-ecological system of the region. This study provides an overview of the cultural and nutritional importance of berry plants in 10 Inuit communities, evaluates fruit contribution to animals' diet and presents a preliminary analysis of fruit productivity data collected as part of an ongoing community-based monitoring project in nine Inuit communities and three Arctic research stations. Results demonstrate the importance of berry picking in Inuit culture as well as the prevalence of berries in the diet of both humans and animals. Fruit production is highest in low Arctic regions where the cover of erect shrubs is low and winter conditions are key to understand inter-annual variability. Both the quality and accessibility of berry patches are affected by global climate change and pollution as well as community development.

Preface

Chapters 2-4 are stand-alone manuscripts and for this reason present some repetitions. Chapters 2 and 4 were conceived as part of a collaborative research project. For chapter 2, Greg Henry, Esther Lévesque, Alain Cuerrier and Luise Hermanutz initiated the project. José Gérin-Lajoie, Alain Cuerrier, Laura Siegwart Collier, Megan Gavin, Ancilla Irkok and Kadluk Pingushat conducted interviews. I collected the information in the archives of the Oral History Project. I conceived the idea, analyzed the data and wrote the manuscript for this chapter. Greg Henry, Susan Rowley, José Gérin-Lajoie, Esther Lévesque, Sarah Desrosiers and Alain Cuerrier gave me comments on a first version of the manuscript. I conceived the idea, conducted field work, analyzed the data and wrote the manuscript for Chapter 3. Greg Henry and Nicholas Coops provided technical support throughout the research process and reviewed the manuscript. For Chapter 4, Greg Henry, Esther Lévesque, Alain Cuerrier and Luise Hermanutz initiated the project. Data were collected by a number of graduate students, including myself, as well as José Gérin-Lajoie. I conceived the idea for the chapter, analyzed the data and wrote the manuscript. Greg Henry reviewed the manuscript.

I received a permit from UBC's Behavioural Research Ethics Board (H13-00420) to conduct interviews in Arviat. The methodology and results for those interviews are presented in chapter 2 and 3. The core interviews presented in Chapter 2 received ethical approval from the Université du Québec à Trois-Rivières, Université de Montréal and Memorial University.

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List of abbreviations

AHCCD	Adjusted and homogenized Canadian climate data
CANGRD	Canadian gridded climate data
CAVM	Circumpolar Arctic vegetation map
CCA	Canonical correspondence analysis
Df	Degrees of freedom
IQ	Inuit *Qaujimajatuqangit*
NMDS	Non-metric multidimensional scaling
No.	Number
TEK	Traditional ecological knowledge
Ybp	Year before present

Acknowledgements

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The Faculties and students of the Department of Geography at UBC provided a unique and inspiring environment for my PhD. Under one roof, I discussed gender and indigenous issues as well as mixed model analyses and remote sensing. I came into the Department feeling like a biologist who happened to be working in a Geography Department. I now truly feel like a geographer, not a physical or a human geographer, just a geographer.

As part of this research project, I spent three summers in the Canadian Arctic where I met incredible people who inspired and challenged me. Special thanks to Nicolas Lecomte and Sylvie Lajoie in Igloolik; Kyle Seeley and Jennith Perth in Baker Lake; Shirley Tagalik, the Wellness Center and the Film Society of Arviat; Lisa-Marie Leblanc and Gerry Atatahak in Kugluktuk as well as all to the numerous Elders and students who gave a unique colour to this project. I am grateful to Nash Panniuq and Anne-Laurence Boulanger-Lapointe for their assistance in the field.

This research used data collected since 2008 by a number of researchers across the Canadian Arctic. José Gérin-Lajoie, Alain Cuerrier, Luise Hermanutz, Laura Siegwart Collier and Carmen

Spiech shared their data and helped me understand the specificities of their field site. Special thanks to my fellow lab mates and visiting scholars: Sarah Desrosiers, Alison Cassidy, Esther Frei, Isla Myers-Smith and Virve Ravolainen for Franglish revisions and fruitful conversations. Thanks to my biological family for inspiring perseverance and critical thinking and to my chosen Vancouver and Kelowna families who gave me sparks and energy. I am grateful to my partner, Riley McPherson, who helped with graphic design and offered caring support all along.

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Chapter 1: Introduction

1.1 Literature review

Arctic tundra ecosystems cover ca. 28% of Canada (Walker et al. 2005), and are home to ca. 52,000 people (2011 census; Statistics Canada 2016). Arctic tundra has important variations in climate, flora and fauna. Most differences are found along the latitudinal gradient with lower latitudes having a higher animal and plant diversity which decreases going north along the bioclimate gradient (Figure 1.1; Walker et al. 2005, CAFF 2013). Important differences can also be found longitudinally notably in regards to precipitation and glacial history (Raynolds and Walker 2009).

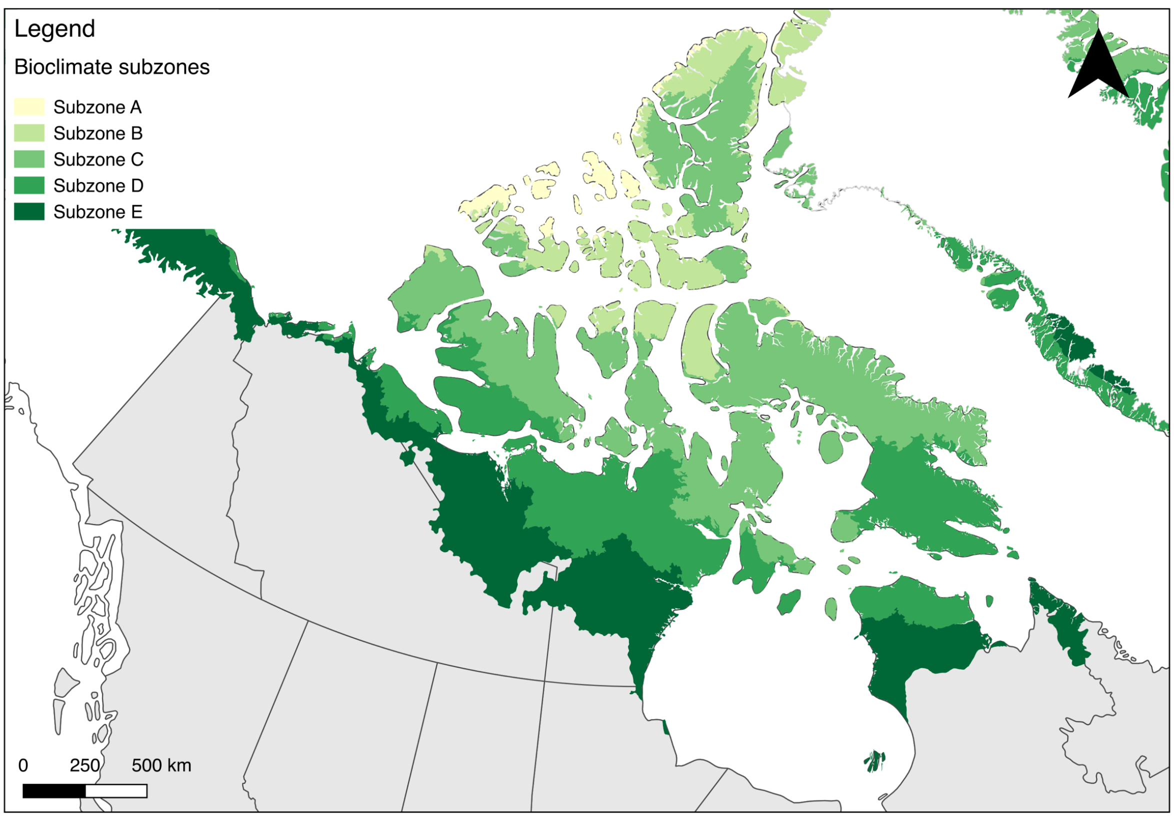

Figure 1.1 Bioclimate subzones in the Canadian Arctic based on the Circumpolar Arctic Vegetation map (Walker et al. 2005).

Like the Arctic landscape, Inuit people are diverse. Current political divisions in Canada recognize four Inuit territories forming Inuit Nunangat: the Inuvialuit Settlement Region (Northwest Territories and Yukon), Nunavut, Nunavik (Quebec) and Nunatsiavut (Newfoundland and Labrador; Figure 1.2). These have some connection to the regions' cultural groups although current borders were created through land claim agreements (Inuit Tapiriit Kanatami 2017). It has been estimated that by the 1950s, 48 distinct cultural groups lived in Nunavut alone (Bennett and Rowley 2004). In Canada, a majority of Inuit communities are located in the Arctic, i.e. north of the tree line, although some are found in the forest-tundra ecotone and others, especially in Nunatsiavut, were established south of the tree line.

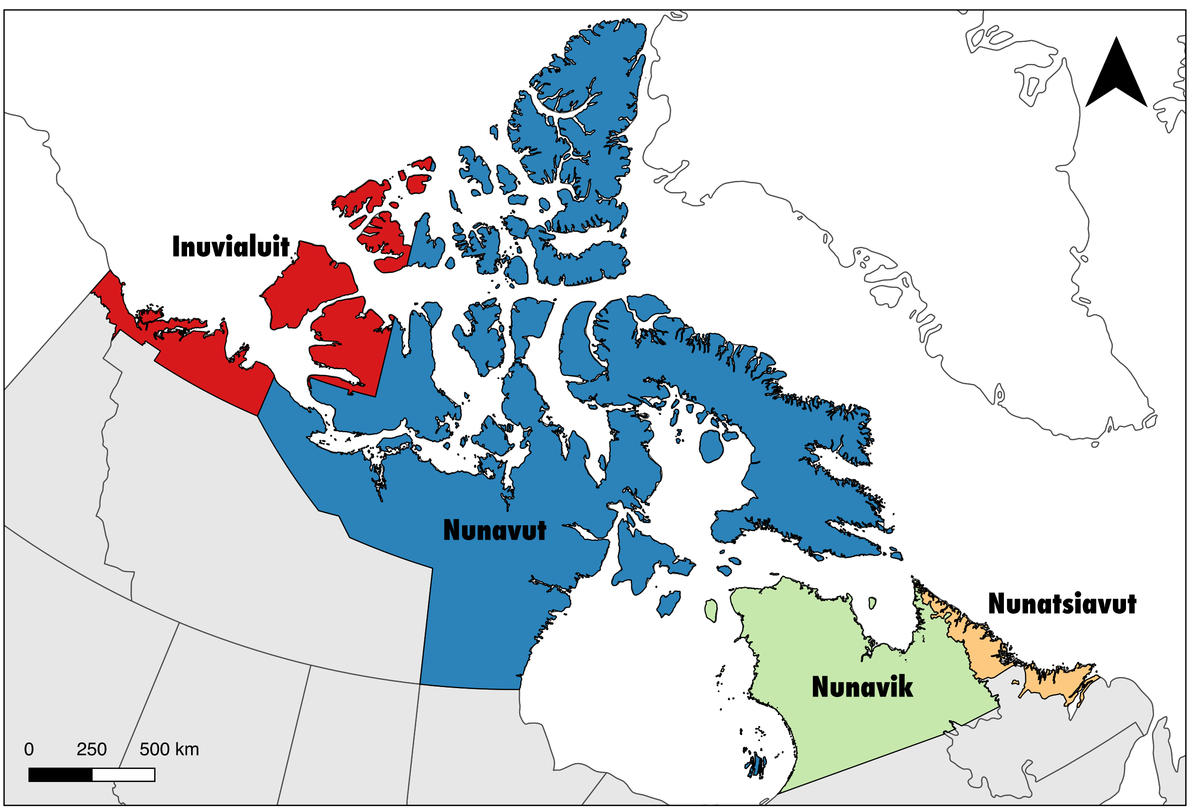

Figure 1.2 Location of the four territories forming Inuit Nunangat.

1.1.1 Arctic vegetation

The latest and most currently accepted environmental division of the Arctic recognizes five bioclimate subzones based on a combination of summer temperature and vegetation (Figure 1.1; Walker et al. 2005). Generally, plant size and diversity decline with latitude. However, important local variations occur due to topographic controls on snow distribution and moisture availability (Walker 2000). Subzones from E to A are roughly aligned from south to north with exception in the Canadian Arctic Archipelago, where most of subzones A and B are found. The tree line forms the southern border of subzone E which is usually composed of 2 to 3 layers of vegetation; mosses, herbaceous/erect dwarf shrubs and low shrubs up to 80 cm. Subzones D, C and B are characterized by two layers of vegetation consisting of a ground cover of moss and lichen overlain by a low and prostrate shrub and/or herbaceous layer. The height of both layers diminishes going north from 5-10 cm, 3-5 cm to 1-3 cm for mosses and lichens and 10-40 cm, 5-10 cm to < 5 cm for shrubs and herbs. Subzone A is mostly barren with a thin layer of moss and lichen as well as scattered herbaceous vascular plants in favorable microsites. Subzones D and E belong to the low Arctic tundra with erect shrubs, while subzones C, B and A correspond to the high Arctic tundra dominated by prostrate vegetation (Bliss 1997).

Many species of tundra plants have wide ranges of tolerance and are found in a variety of habitats (Muc et al. 1988). The shift toward more prostrate shrubs, cushion plants and rosette species going north represents morphological adaptations to cold temperatures, short growing seasons and strong winds (Bliss and Matveyeva 1992). Low temperatures and short growing seasons are associated with slow decomposition and low nutrient content and availability in soil (Chapin et al. 1995). Plants in many tundra areas have access to a limited amount of water during the growing season due to soils that poorly retain water, as well as little summer precipitation (Walsh et al. 2005).

Even though long-distance plant colonization occurs (Alsos et al. 2007), local diversity and ecosystem productivity are still very much influenced by the time since ice retreat after the last glacial maximum ca. 12,000 – 15,000 ybp (Raynolds and Walker 2009). For example, Arctic landscapes located between the Taimyr Peninsula in Russia and the Mackenzie Delta in Canada were not glaciated during the last glacial period and show significantly greater productivity as measured by the Normalized Difference Vegetation Index (NDVI; Raynolds and Walker 2009). This index is a proxy of vegetation productivity, and there is a correspondence between zone and/or time of high NDVI with warm temperature (Jia et al. 2009, Bhatt et al. 2010) and high biomass (Hope et al. 1993, Boelman et al. 2003, Edwards and Henry 2016). Studies in the high Arctic demonstrated that plant colonization followed changes in permanent snow and glacier cover associated with increasing temperature at the end of the Little Ice Age (~150 years BP; Wolken et al. 2008) and that there was a strong link between plant community composition and surface age (Jones and Henry 2003, Moreau et al. 2005).

Processes driving vegetation succession vary across the Arctic with low latitude sites largely influenced by disturbances, such as fires (Payette et al. 1989), insect outbreaks and herbivores (Starfield and Chapin 1996). Toward the high Arctic, classic directional replacement succession is limited by environmental stress which constrains vegetation expansion (Svoboda and Henry 1987). In marginal ecosystems (e.g. bioclimate subzone A), the strong environmental stress may only allow for the maintenance of few species without true succession (Svoboda and Henry

1987). Barriers to succession may be alleviated under milder climatic conditions associated with current climate change and if so, large-scale modification of tundra vegetation could be expected.

1.1.1.1 Ecology of berry producing species

Berries are commonly referred to as small fleshy fruits. In the Arctic, six berry species are commonly found: black and red bearberry (*Arctous alpina* L. Nied. and *Arctous rubra* Rehder & Wilson, Nakai), crowberry (*Empetrum nigrum* L.), blueberry (*Vaccinium uliginosum* L.), cranberry (*Vaccinium vitis-idaea* L.) and cloudberry (*Rubus chamaemorus* L.). Species names follow the classification of the Flora of North America (Flora of North America Editorial Committee 1993+). All species except *R. chamaemorus* (Rosaceae) belong to the Ericaceae family and thrive in poor soil with high carbon to nitrogen ratio (Heikkinen and Mäkipää 2009).

Arctous spp. are commonly found in the low Arctic (Porsild 1957). *Arctous alpina* is a prostrate woody species that produces large (6-9 mm) black-purple fruits. It grows on slopes and ridges as well as imperfectly drained moist or dry areas of Arctic and alpine tundra (Aiken et al. 2003). *Arctous rubra* morphology and ecology are similar to *A. alpina*, but the species produces bright red fruits and is commonly found in calcareous soils and coastal limestone heaths (Flora of North America Editorial Committee 1993+).

Empetrum nigrum is found throughout the Arctic as far north as Ellesmere Island. It is a low woody species with horizontal stems branching extensively to shape plant habit as mat. Leaves are evergreen and needle-shaped; fruits are dark purple to black. *Empetrum nigrum* is shade and drought intolerant and its occurrence is linked to snow cover that provides a drought and frost barrier during the winter (Tybirk et al. 2000).

Vaccinium uliginosum and *V. vitis-idaea* have a circumpolar distribution and range from the forest-tundra ecotone to the high Arctic in sheltered areas. *Vaccinium uliginosum* is a deciduous species that grows on moderately to well-drained flat terrains and slopes. Flowers are pink and bell-shaped; fruits are dark blue. *Vaccinium vitis-idaea* is comparatively smaller with a height of 5-10 cm; its horizontal stems at ground level sometimes form mats. It is an evergreen species that produces white flowers and spherical red fruits. It is often observed growing in well-drained to dry habitats (Aiken et al. 2003).

Finally, *Rubus chamemorus* (Fig.1d) is a perennial forb species with a range restricted to the low Arctic. It prefers moist habitats and is often found around ponds and lakes. Plants produce three circular and cordate hairy leaves and one single orange aggregate fruit at the terminus of a non-branching stem (6-15 cm; Flora of North America Editorial Committee 1993+).

Throughout the year, climatic factors influence the development and reproduction of berry species in different ways. Winter temperature, total precipitation and snow cover may prevent or induce frost injuries and desiccation (Tahkokorpi et al. 2007, Taulavuori et al. 2013). Spring temperature and precipitation as well as cloud cover and wind influence flower bloom and pollinator activity (Jacquemart 1997, Wipf et al. 2009). Summer weather determines the number of pollinated flowers producing viable fruits along with the size of those fruits (Selas et al. 2015). Temperature and precipitation in the year prior, and some suggest two years prior, influence nutrient storage and the formation of flower primordia (Selas 2000, Krebs et al. 2009). Different metrics of plant productivity are also expected to reflect the influence of climate on different portions of the plant life cycle. As such, the abundance of berries is closely linked to reproductive effort (i.e. number of flowers produced) and pollination success, which reflect winter and spring conditions. Alternatively, the biomass of fruits depends on the abundance of berries but also on summer conditions determining fruit development. On the other hand, berry producing species are of different functional types, which may affect their response to climate. For example, evergreen species, such as *E. nigrum* and *V. vitis-idaea*, are less dependent on previous year carbon supplies than deciduous species such as *V. uliginosum,* since overwintering leaves become productive earlier in the season (Karlsson 1985).

Many studies have tried to build models to predict annual berry production. Krebs et al. (2009), using a 12 year dataset for 6 berry species (*Arctous rubra*, *Arctostaphylos uva-ursi*, *Empetrum nigrum*, *Vaccinium vitis-idaea*, *Geocaulon lividum* and *Shepherdia canadensis*) in subarctic Yukon, found temperature and rainfall from the previous two years to be the most significant predictors of fruit productivity. On the other hand, in a six year study in subarctic alpine sites of northern Europe, Shevtsova et al. (1995) found no link between temperature and precipitation and the annual growth and berry productivity of *Vaccinium uliginosum, V. vitis-idaea, V. myrtillus* and *Empetrum nigrum*; annual growth was generally correlated with age and interactions (positive and negative) with neighbouring plants. Using a 40 year dataset of *Vaccinium myrtilloides* berry productivity in Finnish Lapland, Boulanger-Lapointe et al. (2017) showed that productivity is strongly influenced by rodent abundance, insect outbreaks and climate, while the relative importance of each factor depends on herbivore abundance as well as the species adaptation to local environmental conditions. These results showed that the response of berry species to climate is complex and may be strongly dependent on local conditions.

1.1.2 Herbivory in the Arctic

Terrestrial animal species richness decreases with latitude leading a small number of ecologically plastic species, such as rodents, geese and caribou or reindeer, to have a large effect on ecosystem processes at higher latitudes (Callaghan et al. 2013). Herbivore diversity in the Arctic has been linked to plant productivity, as estimated by the NDVI index, as well as July temperature and predator diversity; indicating that abiotic and biotic factors are both important to understand species distribution (Barrio et al. 2016). Plant-based vertebrate food webs are composed of a number of animal guilds (i.e. a group of species with a similar trophic position). Going north along the bioclimate gradient, the number of guilds per food web diminishes and so does the number of species per guild (CAFF 2013). Legagneux et al. (2014) found that large herbivores generally escape predation and their abundance is linked to plant productivity, while small herbivore abundance is largely controlled by predator-prey interactions.

1.1.2.1 Consumption of berries by animal species in the Arctic

Among animals relying on berry producing species are exclusive frugivores, feeding on berries with little impact on the plant integrity, and opportunistic feeders eating both fruits and shoots. In the Canadian Arctic, birds and bears are the main frugivorous groups. Ripened fruits of *Vaccinium* and *Empetrum* species provide Canada geese the energy required for pre-migratory fat deposition and constitute > 40% of their diet in late summer (Sedinger and Raveling 1984, Cadieux et al. 2005). Hupp et al. (2013) using the amount of *E. nigrum* counted before and after the passage of the cackling geese on the Alaska Peninsula in the fall estimated that 30-60% of the annual production was lost to herbivory. Berries may also be important for passerines (Norment and Fuller 1997), shorebirds (McCaffery 1998) and ptarmigan (Weeden 1969). They are a main source of food for grizzly bears (*Ursus arctos*; Ripple et al. 2014) and may be of importance for polar bears (*Ursus maritimus*; Dyck and Kebreab 2009, Rode et al. 2010, Gormezano and Rockwell 2013). Berries represent 14-30% of red fox scat but are a negligible portion of Arctic fox diet (Ehrich et al. 2015).

Even if frugivorous species eat a significant number of berries, they have little impact on plant integrity and may contribute to seed dispersal (Honkavaara et al. 2007). On the contrary, opportunistic feeders can alter community structure and plant composition (Ravolainen et al. 2011). Throughout Arctic and alpine environments, the leaves, buds and fruits of berry shrubs constitute a significant portion of the diet of rodents (Andersson and Jonasson 1986, Selas et al. 2013). In the southern Yukon, Krebs et al. (2010) found that voles rely heavily on *Empetrum nigrum* as a main source of food in winter and microtines may remove up to 40% of bilberry (*Vaccinium myrtillus*) phytomass during pre-peak winters (Andersson and Jonasson 1986).

1.1.3 Changing Arctic environments

1.1.3.1 Climate change

During the last three decades, global average air and ocean temperatures have been unequivocally increasing leading to cascading effects on the global climate (IPCC 2013). In the Canadian Arctic, climate records indicate an overall warming trend dominated by increased winter temperatures on the central and western regions (Serreze et al. 2000). Concomitantly, changes in precipitation have been occurring in winter and spring because of higher atmospheric water vapour content and pole-ward vapour transport (Kattenberg et al. 1996). Between 1950 and 1990 in northern Canada, precipitation increased by up to 20% (Groisman and Easterling 1994). Since the increase in precipitation primarily occurred during winter, it is snow regimes that are affected. However, these changes are accompanied by an overall decrease in the area and duration of snow cover (Serreze et al. 2000). Globally in the Arctic, the area covered by snow in early summer has decreased by 18% since 1966 in response to earlier spring snowmelt (AMAP 2011). Late lying and permanent snow patches are common features in the Arctic and are often the main source of water for the richest and most productive plant communities (Bliss and Matveyeva 1992). Earlier snow melt, if not accompanied by increase in summer precipitation, will have a significant negative impact on vegetation (Boulanger-Lapointe et al. 2014). Similarly, rapid permafrost thaw (Lawrence and Slater 2005) caused a lowering of the soil water table and an increase in active layer depth leading in some areas to a drainage of surface water (Hinzman et al. 2003). Cold permafrost soils have poor decomposition and mineralization; increased temperatures will improve microbial activity and therefore nutrient supply (Sturm et al. 2001a). Finally, glaciers around the Arctic have been melting at an increasingly fast pace (Kohler et al. 2007, Lemke et al. 2007). New areas available for colonization are being released and plants quickly colonize those favourable substrates (Jones and Henry 2003, Breen and Lévesque 2006, Mori et al. 2008).

1.1.3.1.1 Impact of climate change on Arctic vegetation

Moist habitats as well as those dominated by trees and shrubs are the most responsive to the recent increase in temperature (Callaghan et al. 2011); there has been a general infilling of plant community and an increase in the abundance of shrubs, forbs and rushes (Elmendorf et al. 2012). Shrubs are growing at a faster rate, existing shrub patches are infilling, and the shrub line is moving up in altitude (alpine environments) and latitude (Myers-Smith et al. 2015). The transition toward more shrubs involves complex feedback mechanisms such as changes in surface energy exchanges and nutrient availability (Sturm et al. 2001a, Myers-Smith et al. 2011).

Recent studies indicate that local factors are important to understand vegetation response to climate change. Among these factors is herbivore activity; when protected from grazing, experimental plots have a much higher percentage of shrub cover than surrounding vegetation (Post and Pedersen 2008, Speed et al. 2010). Similarly, recurrent forest fires, which are expected to be common features in forest-tundra and low Arctic regions under a warmer climate (Wottom et al. 2010), have been shown to constrain seed availability, leading to possible impacts on forest recovery and expansion (Brown and Johnstone 2012). Results from a tree line dynamics study in Siberia also showed that even if climatic conditions are favourable for tree growth, permafrost might limit seed recruitment and successful tree establishment beyond tree line (Wilmking et al. 2012).

The main effects of climate change on berry species are expected to be winter (Taulavuori et al. 2013) and spring (Wipf et al. 2009) warming combined with a thin layer of snow (Tahkokorpi et al. 2007) that will negatively affect berry productivity and vegetative growth (Aerts 2010, Bokhorst et al. 2011). Cold season warming is associated with early dehardening (i.e. reduced physiological adaptation to cold temperatures), exposure to drought (Rixen et al. 2010, Selas et al. 2015) and frost injuries (Tolvanen 1997). However, a number of Arctic berry species were found to have a high tolerance to ice encasement (i.e. the formation of an ice layer in the snow pack; Preece and Phoenix 2014) as well as spring and summer frost events (Tolvanen 1997, Saarinen and Lundell 2010). *Vaccinium* species may recover vegetatively from frost injury through stimulated shoot elongation, but the number of aborted flower buds increases with the number of frost days after greening (Wipf et al. 2009). Graae et al. (2008) measured compounding effects of warm temperatures during the seed incubation period which favoured germination but increased fungal infection. Finally, *Empetrum* species responded differently to warming in boreal and tundra ecosystems with a weaker response in the latter (Tybirk et al. 2000).

Erect shrubs compete for light and can have a negative impact on growth and productivity of berry plants through shading (Lavallée 2013, Lussier 2016). High phenolic content in leaves of berry species are believed to reduce grazing pressure because of low palatability and digestibility but the concentration of phenolic compounds in leaves is expected to decrease with increased shading (Hansen et al. 2006). Hence, the predicted increase in shrub height and cover in response to climate change may have an overall negative impact on berry shrubs.

1.1.3.2 Community development and global environmental pollution

In the last century, Inuit have experienced major changes in their lifestyle with repercussions for the environment. The transition from nomadic to sedentary life occurred at different times depending on regions and individual families, but most people had settled in communities by the mid-1960s (Tester and Kulchyski 1994). Settlement, but also the arrival of motorized vehicles including all-terrain vehicles, snow machines and motor boats, modified the way people travel on the land and hunt (Myers et al. 2005). As northern communities are expanding and the level of industrial development is increasing, so does anthropogenic impact on the land. Little scientific research has been conducted on the impacts of local sources of pollution on people and the environment in the Canadian Arctic. Popular media have notably reported leaks from sewage water (Nunatsiaq News February 25, 2011) and reduced air quality from dump fires (Rideout July 13, 2001, Varga September 10, 2014). Medeiros et al. (2011) found that water quality is significantly affected by community development. The benthic fauna of two streams influenced by human activities in Iqaluit (Nunavut) shifted toward pollution tolerant taxa and water samples contained elevated levels of nitrogen and phosphorus as well as several metals.

Mineral exploration and mining has steadily increased in the circumpolar Arctic since the beginning of the 20th century with direct impacts on the environment (Lemly 1994, Larsen and Fondahl 2014). The effects of mining extraction and mineral processing on terrestrial and marine ecosystems have been documented in many regions across the Arctic (Kashulina et al. 2003, Elberling et al. 2007). There are a relatively small number of active mines in the Canadian Arctic and little information is available in the scientific literature on their impact on the environment because research has largely been conducted as part of the environmental assessments of mining projects (MacLachlan 1996, CEAA 1997, Golder Associates Ltd. 2013).

Long-range transport introduces a significant number of anthropogenic contaminants to Arctic ecosystems through atmospheric circulation as well as marine and fluvial pathways (Barrie et al. 1992). Atmospheric pollutants largely originating from Eurasia are rapidly transported to the Arctic via dominant wind patterns, while contaminants carried through oceanic currents travel at a much slower pace (MacDonald et al. 2000). Fluvial pathways consisting of northward running rivers transport contaminants originating from both point sources and atmospheric deposition; contaminants in rivers may be greatly enhanced by water flowing from melting glaciers that accumulated atmospheric particles over the years (Domagalski et al. 2016). Contaminants are found everywhere in Arctic air, water and wildlife. They are notably present in large amounts in animals harvested and consumed by northern residents (Oostdam et al. 2005).

1.1.3.2.1 Impact of community development and pollution on vegetation

Besides the obvious destruction of habitats by the construction of infrastructure, the introduction of non-native plant species is one of the main direct effects of increased human presence in the Arctic. A large number of viable seeds are transported to the Arctic on travelers' footwear (Ware et al. 2012) and climate change is expected to facilitate the establishment of propagules (Dukes and Mooney 1999). However, experimental studies in the high Arctic found that environmental conditions other than climate, such as photoperiod and edaphic conditions, may limit exotic plant establishment success (Bjorkman et al. 2017).

Point sources of pollution related to mining activities have a strong local impact that decreases away from the source. Yet, a study conducted near an active diamond mine in the Northwest Territories showed that contaminants could be found in lichens located up to 60 km from the extraction site (Naeth and Wilkinson 2008). Contaminants may also be found in and on plants long after mining activities stop. Concerns about levels of arsenic in berries near abandoned gold mines in the vicinity of Yellowknife led to public concerns and recommendations against harvesting (Davey 1999). However, washed berries were found to have significantly lower arsenic levels than unwashed berries (Godin and Osler 1985) and later studies showed that berries uptake of arsenic is low (Nicholson 1999). Koch et al. (2013) also found that berries accumulate a form of inorganic arsenic that is not readily absorbed by humans.

The concentration of contaminants in vegetation tends to be extremely variable and depends on plant species, plant tissues as well as local soil conditions such as pH (Braune et al. 1999, Elberling et al. 2007). Although mosses and lichens are the most commonly used organisms to study airborne contamination (Thomas et al. 1992, Nash III and Gries 1995, Wilkie and La Farge 2011), contaminants have also been measured in vascular plant species. The studies reviewed described the presence of different contaminants across the Arctic and documented the impact on terrestrial food chains. For example, the distribution of cesium concentrations in lichen, from nuclear weapons testing, along the latitudinal gradient was correlated to original latitudinal deposition, the expired portion of its physical half-life as well as the efficiency of the biotic and abiotic removal process (Hutchinson-Benson and Svoboda 1985). Another study found lead in specimens of *Saxifraga oppositifolia* collected across Ellesmere Island and demonstrated that the Canadian high Arctic received significant amount of the heavy metal from Eurasia (France and Blais 1998). As a last example, Kelly and Gobas (2001) studied the presence of persistent organic pollutants (POPs) in the lichen-caribou-wolf food chain. They showed that specific processes of biomagnification are associated with terrestrial organisms.

1.1.4 Country food in the Canadian Arctic

Country food refers to subsistence-based food obtained through hunting, fishing, and gathering (Searles 2016). It is a meaningful source of food and contributes to mental and physical health in contemporary Inuit communities (Loring and Gerlach 2009, Willox et al. 2012). The consumption of country food is associated with healthier diets (Egeland et al. 2009) and the construction of Inuit identity (Searles 2002), but urban living as well as monetary and time constraints make it increasingly difficult to access (Ford and Beaumier 2011). The income from regular employment is necessary for at least one member of the household to afford the cost of hunting equipment and fuel, however such employment also reduces the time people can spend on the land (Huet et al. 2012, Simard-Gagnon 2013).

Successful hunting and sustainable harvesting by indigenous communities rely on local and traditional ecological knowledge as well as modern tools and equipment. Traditional Ecological knowledge (TEK) is defined as the legacy of thousands of years of adaptation and dependence on the environment passed from generation to generation through oral culture (Huntington et al. 2004). In Canada, Inuit generally used the term Inuit *Qaujimajatuqangit (IQ)* instead of TEK; it is "the Inuit way of doing things: the past, present and future knowledge, experience and values of Inuit Society" (Inuit *Qaujimajatuqanginnut* Task Force 2002). The knowledge and skills needed to harvest country food as well as the social and spiritual dimensions of harvesting activities are all components of IQ.

1.1.4.1 Importance of plants for Inuit

The place of plants in pre-contact Inuit diet is largely unknown. Archaeological evidence has shown that berries may at times have been an important source of nutrients and vitamins (Zutter 2009, Pigford and Zutter 2014). However, most early explorer accounts described Inuit diet as almost exclusively based on animal products, including stomach contents (Stefansson 1914, Mathiassen 1928, Birket-Smith 1929). Stefansson (1922) believed that Inuit started harvesting berries following contact with Euro-Canadians. This view has been criticized for a number of years (Oswalt 1957, Dristas 1987) and an increasing body of research emphasized the significant place of plant resources for food, medicine and material in the Arctic (Black et al. 2008, Cuerrier and Elders of Kangiqsujuaq 2011, Cuerrier and Elders of Kangiqsualujjuaq 2012, Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012).

1.1.4.2 Ethnobotanical knowledge of Arctic berry species

Berry species growing in the Canadian Arctic may also be found across the circumpolar Arctic and in many alpine areas. The use and knowledge of berry species vary across their distribution range according to cultural groups and local abundance. In the Canadian North and Alaska, berry picking has been linked to community wellness (Thornton 1999, Parlee and Berkes 2005, Flint et al. 2011) and sharing practices (Parlee and Berkes 2006, Simard-Gagnon 2013). Estimated annual harvest of berries in northern Alaskan communities range from 6L to 24L/household per species (Murray et al. 2005). Berries are seldom collected for sale and such practices are opposed as they interfere with traditional sharing systems (Murray et al. 2005, Karst and Turner 2011).

Berries used to be picked throughout the year (Bennett and Rowley 2004, Griffin 2009). In winter, people would dig into the snow to find berries and deposit them in a perforated bowl used to drain the snow (Porsild 1953, Ootoova et al. 2001). Some people in the Canadian Arctic use a rake-like tool to collect berries (Joamie and Ziegler 2009), these tools were also commonly used by indigenous people living in alpine areas of British Columbia (Turner et al. 2011). Berries collected at maturity in summer and fall were preserved in the ground and protected by a layer of frozen fat and sealskin (Ootoova et al. 2001) or in a basket made of birch and willow bark (Andre and Fehr 2001). Throughout the Arctic, the most common way to prepare berries is to mix them with seal and caribou fat, and in some region fish, moose and other greens. The most common food preparation is commonly called Eskimo or Inuit ice cream; it is referred to as *agu'tuk* in Alaska (Andre and Fehr 2001), *aluit* in Nunavut (Ootoova et al. 2001) and *suvak* in Nunavik (Cuerrier and Elders of Kangiqsujuaq 2011).

1.1.4.2.1 *Arctous* spp.

Arctous alpina and *Arctous rubra* are found throughout the circumpolar North (Aiken et al. 2003). In North America, *Arctous* spp. and *Arctostaphylos uva-ursis* (L.) Spreng. are all species commonly referred to as bearberry. While only *Arctous* spp. are found beyond the tree line, many Inuit groups lived close to or travelled to the forest thus confusion between the three species may occur.

The berries of *Arctous rubra* may be used to quench thirst if you do not have water (Andre and Fehr 2001). Berries are processed into jams and fresh berries are said to be effective to fight colds (Holloway and Alexander 1990). A strong and tasty tea can be made from the leaves (Ootoova et al. 2001).

The berries of *Arctous alpina* were picked opportunistically when travelling on the land or in years where other berries were not abundant (Oswalt 1957, Cuerrier and Elders of Kangiqsujuaq 2011). They are not generally stored for the winter (Griffin 2009). An Elder from Iqaluit suggested eating the berries before they ripen for a better taste (Joamie and Ziegler 2009). Elders from Kangiqsualujjuaq recommended not eating the berries as they may cause diarrhoea (Cuerrier and Elders of Kangiqsualujjuaq 2012). Leaves and stems may be collected at any time to make tea (Joamie and Ziegler 2009, Cuerrier and Elders of Kangiqsujuaq 2011) although some preferred year old leaves picked in the fall (Avataq Cultural Institute 1984). The tea may help with stomach ache and kidney ailments (Avataq Cultural Institute 1984). Children used the berries as beads to make necklaces or as fake blood (Cuerrier and Elders of Kangiqsujuaq 2011).

1.1.4.2.2 Empetrum nigrum

Empetrum nigrum, crowberry, is often locally referred to as blackberry. The species is widespread in Arctic and alpine habitats around the world (Aiken et al. 2003). In Inuktitut the berries are called *paurngait* meaning “which looks like pauq” because they are black in color like *pauq*, i.e. soot (Ootoova et al. 2001). In the Pacific Northwest the berries are called raven berries by the Haida and the Kitasoo Nations (Turner and Bhattacharyya 2016). Writings from the late 19th century reported that large amounts were picked in southwest Greenland (Porsild 1953).

The berries are largely picked at the end of the summer and to a lesser extent in winter (Porsild 1953). They are eaten with seal (Porsild 1953) or beluga (Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012) blubber or caribou fat (Ootoova et al. 2001). They are used to make *aluit* and can be mixed with alpine bistort root (*Polygonum* spp.) and cooked char (Joamie and Ziegler 2009). They are eaten with pounded dry fish (Andre and Fehr 2001, Whitecloud and Grenoble 2014) or combined with fish or duck liver to make *suvak* (Cuerrier and Elders of Kangiqsualujjuaq 2012, Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012). The berries mixed with seal blubber are good for pain and for people who have an intense appetite (Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012). Nowadays, crowberries are also eaten in jam (Andre and Fehr 2001, Ootoova et al. 2001). In Greenland, fresh berries are used in winter to alleviate depression (Whitecloud and Grenoble 2014). The crowberries were traditionally preserved in seal blubber (Porsild 1953, Ager and Ager 1980).

In certain regions, the whole plant was used to make tea (Oswalt 1957, Cuerrier and Elders of Kangiqsualujjuaq 2012, Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012). The tea was considered an effective medicine for stomach aches, bad colds (Holloway and Alexander 1990, Andre and Fehr 2001) and cataracts (Cuerrier and Elders of Kangiqsujuaq 2011). The leaves were also boiled in water and made into a poultice to soothe pain (Holloway and Alexander 1990).

The stems may be used to clean gun barrels or make mattresses (Ootoova et al. 2001, Cuerrier and Elders of Kangiqsujuaq 2011). Similarly, they make a good pit liner for storage (Griffin 2009). Stems can also be used as fuel, to smoke meat, and when damp to repel black flies (Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012). When boiled, the stems can be used as a colorant for fishnets and to help in bending the wood for building kayaks (Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012). They were attached to puppies' paws to make them stronger (Cuerrier and Elders of Kangiqsujuaq 2011).

1.1.4.2.3 Rubus chamaemorus

Rubus chamaemorus, the cloudberry, also called bake apple in Newfoundland and Labrador (Karst and Turner 2011), is the favorite berry in Arctic Alaska (Ager and Ager 1980). Oswalt (1957) described how these berries were important for the people of Napaskiak in Alaska, where virtually every family went berry picking for two to three days when the berries were ripe. People usually eat them right away, save them for special occasions or give them away as a gift (Andre and Fehr 2001). They are used to prepare *agu'tuk* (Oswalt 1957, Ager and Ager 1980) or *suvak* (Cuerrier and Elders of Kangiqsujuaq 2011). The berries are said to help with diarrhoea and skin troubles (Griffin 2009). They are mixed with seal blubber and stored during fall and winter (Ager and Ager 1980, Griffin 2009). The berries harvested when still red help to sooth stomach ache (Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012). Birket-Smith (1929) reported for the Caribou Inuit, living inland west of the Hudson Bay, that cloudberries were taboo for women in general.

Leaves can be harvested anytime to make tea, but the old leaves are preferred (Cuerrier and Elders of Kangiqsujuaq 2011). The tea helps with sore throat and fevers (Cuerrier and Elders of Kangiqsualujjuaq 2012) as well as gives energy and slakes thirst (Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012).

1.1.4.2.4 Vaccinium uliginosum

Vaccinium uliginosum, the blueberry, is the other favourite alongside the cloudberry for most Inuit. It is said to be the preferred berry in many regions of Alaska (Anderson 1939, Holloway and Alexander 1990) as well as one of the favourite foods of the youth in Sanikiluaq, Nunavut

(Wein et al. 1996). In Inuktitut the blueberry is called *kigutangirnait* meaning “that which causes teeth to be removed” because they leave black spots on the teeth (Ootoova et al. 2001). It is used to prepare jams, pies, muffins and *it’suh*, a traditional Gwich’in dessert prepared with pounded dry fish (Andre and Fehr 2001) or as ingredient to prepare *aluit* (Joamie and Ziegler 2009). It is the best berry for *suvak* and may be eaten with *misiraq*, fermented seal oil (Cuerrier and Elders of Kangiqsujuaq 2011, Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012). The berries are used to treat colds, snow blindness or a voracious appetite (Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012). The berries do not preserve well and are therefore seldom stored for winter (Oswalt 1957, Ager and Ager 1980, Griffin 2009).

The leaves are edible and may be chewed like gum (Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012) or mixed with seal blubber (Cuerrier and Elders of Kangiqsualujjuaq 2012); harvested in the spring they help to soothe runny noses (Whitecloud and Grenoble 2014). The stem and leaves can be boiled to make tea which alleviates cold symptoms (Andre and Fehr 2001) and treats diarrhoea (Cuerrier and Elders of Kangiqsualujjuaq 2012). The branches were used to remove *puja*, gummy blubber, and other stains that ordinary soap could not remove (Ootoova et al. 2001).

1.1.4.2.5 Vaccinium vitis-idaea

The cranberry, *Vaccinium vitis-idaea*, is harvested throughout Arctic and alpine environments (Turner et al. 2011). It is the berry most often used for its medicinal properties. The cranberries are better harvested after the first frost (Cuerrier and Elders of Kangiqsujuaq 2011) or in the spring (Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012). Cree healers believe that cranberry harvested in the spring have optimal medicinal properties (Fraser et al. 2007). The fruit may be eaten whole to treat fatigue, infection, the flu, sore throats and stomach ache (Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012, Mallory and Aiken 2012) as well as fight tooth cavities (Cuerrier and Elders of Kangiqsualujjuaq 2012). The juice may be directly squeezed out of the berry to treat snow blindness and baby's thrush (Cuerrier and Elders of Kangiqsujuaq 2011). A juice prepared by simmering berries is good for kidney problems, colds, digestion and to improve appetite (Andre and Fehr 2001). The fruits are also included in many preparations including *it'suh* (Andre and Fehr 2001) and *agu'tuk* (Oswalt 1957). They can be eaten with seal oil, ptarmigan meat, fish flesh (Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012) as well as fish liver and eggs (Andre and Fehr 2001). Cranberry juice can also be used to dye porcupine quills (Andre and Fehr 2001). Like cloudberries, the cranberries may have been taboo for Caribou Inuit women (Birket-Smith 1929).

The leaves can be eaten fresh (Cuerrier and Elders of Kangiqsualujjuaq 2012) or used for tea (Ootoova et al. 2001). The leaves can help to heal wounds (Whitecloud and Grenoble 2014). In the past the whole plant was used as tobacco (Birket-Smith 1929, Cuerrier and Elders of Kangiqsujuaq 2011).

1.2 Overview and research objectives

Berries are among the most appreciated country food across Inuit Nunangat (Fediuk 2000, Northern Contaminants Program 2003). Food preparations and medicinal properties of these plant resources have been documented in boreal and Arctic environments yet there is a poor understanding of how these uses are linked to the social and cultural value of berries in contemporary Inuit communities. Moreover, we have limited knowledge of the abundance of berries throughout Inuit Nunangat as well as the factors controlling their productivity, availability and accessibility. This research uses a biocultural lens to provide baseline information on berry producing species across Inuit territories. The term “biocultural” stands for the interlinked nature of biology and culture (Maffi and Woodley 2010). In the Inuit biocultural system, berries are a source of nutrients for humans and animals and harvesting berries is a cultural practice. Assessing ecological processes controlling berry availability and productivity while documenting the cultural value will help to inform decisions on land use and traditional activities in the Arctic. In the context of rapid environmental and cultural changes, it will also provide tools to better understand and mitigate the effects of changing conditions.

This project uses new and available data to document the ecology and Inuit *Qaujimajatuqangit* of Arctic berry species. A large portion of this work stemmed from the International Polar Year project entitled *Climate impacts on Canadian Arctic tundra ecosystems: multi-scale and interdisciplinary assessments* (see Henry et al. 2012 for details). Complementary data were collected in the field and in archives as part of this PhD project. The general objective of this research was to provide an overview of the prevalence of berry species across Inuit Nunangat, their importance for the socio-ecological system as well as the factors that may reduce availability. This overview was addressed in three different stand-alone manuscripts (Chapters 2-4). The objectives and some broad predictions of each component of the research are detailed below.

Objective 1: Document the ethnobotanical knowledge of berries, their cultural importance as well as the barriers to their availability as perceived by northern residents.

Inuit throughout the Canadian North have an in-depth knowledge of berry species and berries are consumed in a variety of preparations. Berries and berry picking are an integral part of Inuit culture and berry picking is an important time of the year that contributes to mental well-being and sharing practices. The availability and quality of berries are negatively affected by community development and pollution, recent climate change and animal consumption.

Objective 2: Evaluate the abundance of berries in the vicinity of Arviat and the impact of animal consumption on the availability of berries.

The community of Arviat is surrounded by lakes, wetlands and marshes that have low berry productivity, berries are thus not found in abundance in the vicinity of the community. A large lesser snow geese colony breeds a few kilometers inland from Arviat and birds nesting at higher latitudes use the west coast of Hudson Bay as a staging area in the spring (Kerbes et al. 1990). We thus expect geese to eat a significant portion of the annual production of berries.

Objective 3: Evaluate the abundance of berries across Inuit Nunangat and identify the climatic factors influencing inter-annual productivity.

Berry producing species are widespread across Inuit Nunangat and their productivity is determined by a combination of environmental stress and inter-specific competition. Trees and erect shrubs shade out berry species toward the southern end of the study area, while climatic conditions limit plant growth and reproduction going north along the bioclimate gradient. Berry production has a considerable annual variability and the abundance of berries in a given year is largely influenced by winter and summer temperature and precipitation.

Chapter 2: Berry plants and berry picking: traditions in a changing Arctic

2.1 Introduction

What we define as culturally and economically important for a society determines what is worth being protected or worthy of investment, and what we may consider in political decisions. Colonial history in the Canadian Arctic has silenced the voices of Inuit who did not get to tell their own stories until recently. Documentation of Inuit culture by early explorers and ongoing research in the North have and continue to shape our understanding of Inuit culture and influence political decisions at the national and regional level. A number of authors note that documentation of Inuit culture and environment has and remains focused on hunters' knowledge (Nuttall 1998, Shannon 2006, Dowsley 2015). Such focus emerged for a number of historical and cultural reasons (see among others Hill 2008) and emphasized men's observations of the land (Klein and Ackerman 1995, Desbiens 2010). While it is true that hunting of large terrestrial and marine mammals is at the core of Inuit culture and was central for survival, thus determining seasonal migrations and periods of scarcity (Bennett and Rowley 2004), solely focusing on those activities gives a narrow vision of such a rich culture. Among the numerous plants and plant tissues that have been and remain widely used by Inuit, berries are one of the most commonly harvested today (Ootoova et al. 2001, Black et al. 2008, Nancarrow and Chan 2010). Nevertheless, the cultural importance of berry plants for Inuit in Canada is poorly documented.

Notes on plant usage are sporadically found in early explorers' accounts. While berries are mentioned in a number of stories and songs reported by Boas (1901) from Baffin Island and the Hudson Bay, the author otherwise widely dismissed the importance of berries. Birket-Smith

(1929, p.96) reports for the Central Arctic that "there is so little gathering of berries that it must almost be disregarded." Similarly, Mathiassen (1928, p.207) noted for the Iglulik Inuit (now referred to as the Amitturmiut, Bennett and Rowley 2004) that "very little vegetable food is eaten; it has no part at all in the economy of the people." Stefansson (1914, p.47) believed that in the western Arctic the "proximity to the vegetable-eating Indians of Alaska and not the richness of any given district determines the amount and variety of vegetables used." He also suggested that some groups may only have started picking cloudberries recently (Stefansson 1922). Porsild (1953) reported that although the amount of plant material used is small, northern residents make use of a large number of species. However, Porsild (1953, p.16) also makes a direct connection between "the gathering of roots and berries [...] by women and children," the absence of agriculture and the limited importance of plants for Inuit. The *a priori* assumption that plants are only important for societies involved in agriculture has also served to dismiss the importance of plants for other Indigenous groups in Canada (Turner and Turner 2008).

However, interviews with Inuit Elders conducted in the second half of the 20^{th} century and in the early 2000s demonstrate that berry species have been widely used for food, medicine, fuel and bedding (Kuhnlein and Soueida 1992, Bennett and Rowley 2004, Cuerrier and Elders of Kangiqsujuaq 2011, Cuerrier and Elders of Kangiqsualujjuaq 2012, Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012). Berries have been identified as an important source of food in time of scarcity (Bennett and Rowley 2004) and berry picking has been linked to modern community well-being (Simard-Gagnon 2013, Kugluktukmiut Elders and Youth and Desrosiers 2016). Very limited archeological investigations have looked into plant remains in the Arctic, but a study in northern Labrador found an abundance of berry seeds in the vicinity of human habitations from the 18^{th} century (Zutter 2009).

Country food is an important part of Inuit diet. It is culturally meaningful and contributes to mental and physical health in contemporary Inuit communities (Loring and Gerlach 2009, Willox et al. 2012). The consumption of country food is associated with healthier diet (Egeland et al. 2009) and the construction of Inuit identity (Searles 2002), but urban living as well as monetary and time constraints make this resource increasingly difficult to access (Ford and Beaumier 2011). The income from regular employment is necessary for at least one member of the household to afford the cost of hunting equipment and fuel, however such employment also reduces the time people can spend on the land (Huet et al. 2012, Simard-Gagnon 2013). A recent study in Arviat highlighted that younger generations have not developed a taste for a variety of country food (Beaumier et al. 2015). They therefore have a reduced range of food options available to cope with changing conditions on the land.

In the last century, Inuit have experienced major changes in their lifestyle and environment, and these changes have had direct impacts on land use and harvesting practices. Settlement occurred at different times depending on the regions and individual families but most people had settled in communities by the mid-1960's (Tester and Kulchyski 1994). Settlement and the arrival of snow machines and all-terrain vehicles modified the way people travel on the land and hunt (Myers et al. 2005). In the meantime, the effects of recent rapid climate change were starting to become obvious with many regions experiencing milder winters as well as warmer and drier summers (Gérin-Lajoie et al. 2016). Changing weather conditions made transportation on the land, water and ice increasingly difficult and unpredictable (Krupnik and Jolly 2010, Herman-Mercer et al. 2011, Prno et al. 2011). Annual fluctuations in resource abundance have always occurred, but anthropogenic activities and pollution now also influence the availability and quality of country food (Klein and Vlasova 1992, Abraham et al. 2005, Oostdam et al. 2005, Northrup and Wittemyer 2013).

It is in this context that a major research effort was initiated during the International Polar Year (IPY) to understand the impact of environmental and climate change on Arctic tundra vegetation and the repercussions for people in the North. A special focus of the project was to document the ecology and Inuit *Qaujimanituqangit* of berry plants. A subset of the data collected as part of that project led to the publication of findings related to the knowledge of climate change in Nunavik (Cuerrier et al. 2015) and throughout the Canadian Arctic (Gérin-Lajoie et al. 2016). In this study, I focus on the cultural importance of berry plants and berry picking for Inuit. I aim to document the importance of these plant resources, while highlighting regional differences, changes through time as well as constraints on availability.

2.2 Methods

2.2.1 Study area

During the IPY, interviews were conducted in Kugluktuk, Baker Lake, Pond Inlet and Pangnirtung in Nunavut, Umiujaq, Kangiqsujuaq and Kangiqsualujjuaq in Nunavik as well as in Nain, Nunatsiavut. Researchers from the Université du Québec à Trois-Rivières, Université de Montréal, Memorial University and the University of British Columbia chose field sites based on their ongoing involvement with the communities, geographic spread as well as co-occurring scientific monitoring of berry productivity (Chapter 4). These interviews were the main source of information for this study and will hereafter be referred to as the "core interviews". Complementary interviews were conducted in Arviat in 2015 and archive material was gathered from Igloolik as part of this doctoral research.

A number of Inuit cultural groups used to live across the Canadian North and people travelled extensively (Bennett and Rowley 2004, Aporta 2009). The history of settlement and colonisation varies per region and while it is beyond the scope of this paper to review this history, it is important to note that it has had an impact on people's knowledge and experience of the land as discussed in these interviews. The environment varies across the study area with southern sites generally having a higher animal and plant diversity which decreases going north along the bioclimate gradient (Walker et al. 2005, CAFF 2013). Most Inuit communities are located north of the tree line but some were also established in the forest-tundra ecotone as well as in the boreal forest.

2.2.2 Data collection

The core interviews were conducted by José Gérin-Lajoie, Alain Cuerrier and Laura Siegwart Collier between 2007 and 2010. Interviewees were identified from reports and personal communication with community representatives and local interpreters. People selected were considered local knowledge holders because of the considerable amount of time they spent on the land whether this was ongoing or not. Sessions were conducted in Inuktitut with the help of an interpreter or directly in English depending on the interviewee's preference. The sessions took place in the community and lasted between one and two hours. The number of participants in each community depended on a variety of factors such as availability during the researcher's stay in the community, knowledge of the research project and desire to participate. A sufficient number of people were interviewed to draw recurring themes and observations for each community (i.e. between 9 and 24 interviewees per community) thus fulfilling the requirements of theoretical sampling (Gubrium et al. 2012). A total of 138 people born between 1917 and 1965, 81 women and 57 men, participated in the research (Appendix A). Interview questions were both closed- and open-ended. Specific questionnaires varied somewhat between interviews although the objectives remained the same. During a typical interview, the interviewer(s) conducted a mapping exercise during which the participant(s) indicated their place of birth and the different locations where they lived, hunted and gathered berries. The interview questionnaire was divided into five themes: 1) berries and berry picking activities, 2) abundance and distribution of plants, 3) influence of climate on plants, 4) changes related to animals and 5) human factors related to climate change (see Cuerrier et al. 2015 for details).

In Arviat, interviews were conducted by local youth with my assistance. The interviews were first meant as a training and learning experience for the youth and as such vary in quality. Prior to the interviews, the youth and I discussed vocabulary associated with country food as well as potential questions. It was agreed that the interviews should touch on berries, their uses, where they could be found as well as on the animals that eat them. The youth were encouraged to discuss other subjects that might be linked to the Elders' responses. They conducted the interviews in Inuktitut with four Elders, three women and one man (Appendix A). Their conversations were later translated from the audio recordings. Since we did not reach the requirements of theoretical sampling for this community, the information provided by Elders from Arviat is only used as complementary information and is not included in summary tables.

In 2013, I searched for information on berries in the archives of the Oral History Project (OHP) in Igloolik. The archive consists of transcripts of interviews conducted since the early 80s with Elders from the area around Igloolik on a variety of subjects. A limited number of keywords were first selected and more were added until no more information on plants could be found. The following keywords were used to search for relevant interviews in the database: *kigutangirnnait, kigutangirnaq, paurnngait, paurngait, paurngaqutillu*, berry, berries, edible, medicinal, medicine and plant. The spelling of the Inuktitut words corresponds to the spelling used in the database. A total of 49 interviews were extracted from the database (Appendix B).

2.2.3 Data analyses

The interviews from all communities were transcribed, when needed, and entered into QSR NVivo (QSR International Pty Ltd 2016). I analyzed the data using a thematic content analysis to extract and group the information related to the importance of berry plants and berry picking. The process of coding involved assigning both pre-determined and emergent categories (Brunet et al. 2014). All interviews were read through once and coded to extract major themes and read through a second time to ensure that emergent themes were extracted from all interviews. At the end, the information was organized under the following themes: material culture, periods and methods of harvesting, food preparations, medicinal properties, preservation techniques, roles of berry picking and berries, sharing practices, consumption of berries by animals, and impacts of climate change and community development on berries.

I created a map showing the place of birth of participants of the core interviews and interviewees from Arviat using QGIS (QGIS Development Team 2017). Some informants were born in trading posts or communities, and these locations were easily identifiable. However, a majority of participants were born on the land and the location of their place of birth was based on the maps created during the interview. It was possible to locate the place of birth of most of the informants (120 out of 142 participants). The missing geographical information largely came from Kangiqsujuaq and Kangiqsualujjuaq because maps were not systematically used during interviews in those communities.

The spelling and names of the different berry species were discussed with the interpreters from each community and when available validated from previous work by collaborators on the project. For Kugluktuk (Inuinnaqtun), names are based on extensive discussions with Elders conducted by Sarah Desrosiers in 2016 (Kugluktukmiut Elders and Youth and Desrosiers 2016). For Nunavik (Inuktitut), names followed previous ethnobotanical research conducted by Alain Cuerrier between 2001-2004 (Cuerrier and Elders of Kangiqsujuaq 2011, Cuerrier and Elders of Kangiqsualujjuaq 2012, Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012). For Nain (Nunatsiavut, Inuttut), names followed the spelling from the work by Alain Cuerrier and Luise Hermanutz in Nain and the Torngat Mountains (Cuerrier and Hermanutz 2012). For the Qikiqtaaluk (Nunavut, Inuktitut) names were validated by the interpreters from Nunavut Arctic College during the reviewing process for the book based on the core interviews (Gérin-Lajoie et al. 2016). Even though names have been validated using different sources, different spelling and pronunciation may be in use. Plants Latin names and authorities were validated using the Integrated Taxonomic Information System (ITIS 2017). For simplicity, the common English name will be used throughout the text. When I provide a translation for a word in English, this translation corresponds to the local dialect of the region discussed.

I created a map of the geographic distribution of the most commonly harvested berry species for each community where the core interviews were conducted using QGIS (QGIS Development Team 2017). I did not include the information from Arviat and Igloolik due to the small number of interviewees specifically discussing the subject of berries. The geographic distribution of each berry species is based on Porsild and Cody (1980). A berry species was deemed “commonly harvested” when three or more interviewees from one community mentioned harvesting it.

Finally, based on all the interviews, I compiled a list of the different food preparations, beverages and medicinal uses of berry plants. I also calculated how many times and from which community a certain use was mentioned. When two people were interviewed at the same time, generally spouses, I only counted one mention. Because each interviewee was not asked the same questions and questions were frequently worded differently; these numbers should not be taken as an absolute representation of local knowledge of berry plants. Instead, they serve to demonstrate the widespread uses of berry plants and provide indicators of regional preferences.

2.3 Results and discussion

Interviews provided information on a wide range of subjects linked to personal history, harvesting activities and the environment. For this analysis, I focused on the ethnobotanical knowledge, the cultural and social importance as well as the constraints on the quality and availability of berries. I aim to provide an overview of these topics through time and regions.

A majority of informants were Elders and due to age and reduced mobility did not go out on the land very much anymore. Younger people interviewed were active on the land and considered very knowledgeable of the environment. Informants were born and grew up throughout the Canadian Arctic (Figure 2.1), they moved into a community in their early childhood or later in their life. For a number of them, this transition was gradual with a period during which they lived on the land for parts of the year. All interviewees now permanently live in communities.

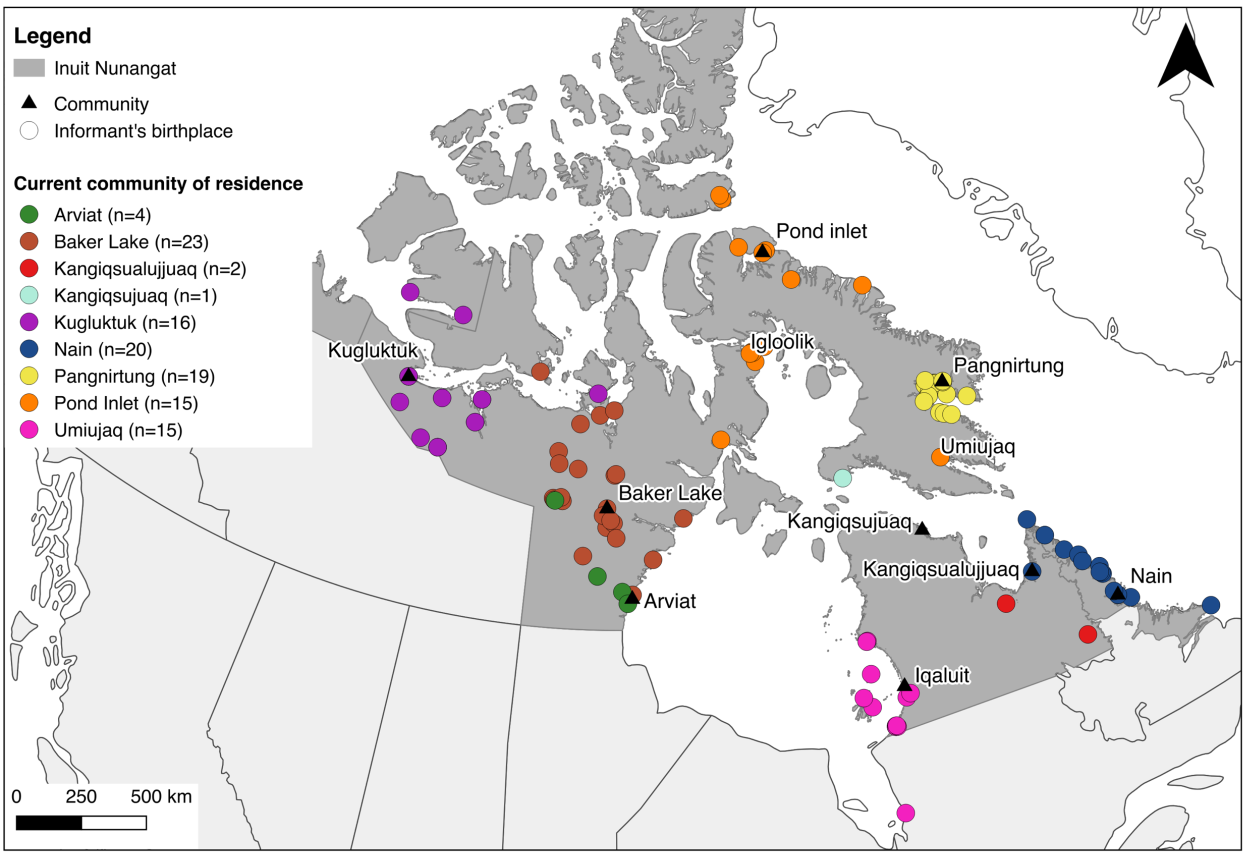

Figure 2.1 Birthplace of informants from the core interviews as well as interviewees from Arviat along with the location and names of the communities where the interviews were conducted throughout Inuit Nunangat.

Informants knew and harvested most berry species present in their area (Figures 2.2 and 2.3). They often had an intimate knowledge of their ecology although some common and local names referred to more than one species (Table 2.1). The most commonly harvested were blueberries (*Vaccinium uliginosum* L. and *V. caespitosum* Michx.), crowberries or blackberries (*Empetrum nigrum* L.) and cloudberries or bake apple (*Rubus chamaemorus* L.). Bearberries (*Arctous rubra* Rehder & Wilson Nakai and *A. alpina* L. Nied.), although present throughout most of the territory, were only commonly harvested by Kugluktukmiut. Local raspberry species (*Rubus arcticus* L. and *Rubus idaeus* L.) were harvested in small amounts in the vicinity of Umiujaq and Nain. Marshberries (*Vaccinium oxycoccos* L.), skunk currants (*Ribes glandulosum* L.) and squashberries (*Viburnum edule* (Michx.) Raf.) were harvested by a small number of people in the vicinity of Nain. Raspberries, skunk currants and squashberries are also present in the vicinity of Kangiqsualujjuaq although these species were not mentioned by informants. Ethnobotanical research conducted by Cuerrier and Elders (2012) in Kangiqsualujjuaq indicated that some residents knew about these species, but they are not commonly harvested because of their low abundance. The different stages of development of the fruit as well as the different parts of the plant have specific names that were known by some of the informants. These would however need further investigations to find appropriate pronunciation and spelling for each region.

Berries were harvested throughout the study area. Preferred berries varied according to personal taste and the most harvested species were usually correlated to local abundance. While the number of berry species declines with latitude (Figure 2.3), the density of berries is highest in subzone D (Walker et al. 2005), where Kangiqsujuaq and Pangnirtung are located (Figure 2.3; Chapter 4). Berries are especially important for people in Umiujaq and Nain, two southern communities with a wide variety of species and productive patches, but also in Pangnirtung, where only three species are found in large abundance.

Figure 2.2 Most common berry species across the study area: a) bearberry (picture taken in the fall), b) crowberry, c) blueberry, d) cranberry and e) cloudberry.

2.3.1 Ethnobotanical knowledge

Most ethnobotanical studies conducted in Arctic North America focused on the knowledge of specific cultural groups. While it is true that regional differences exist, in the case of berry species, there is a vast body of knowledge shared throughout the territory in regards to the harvest, uses and medicinal properties of berry species.

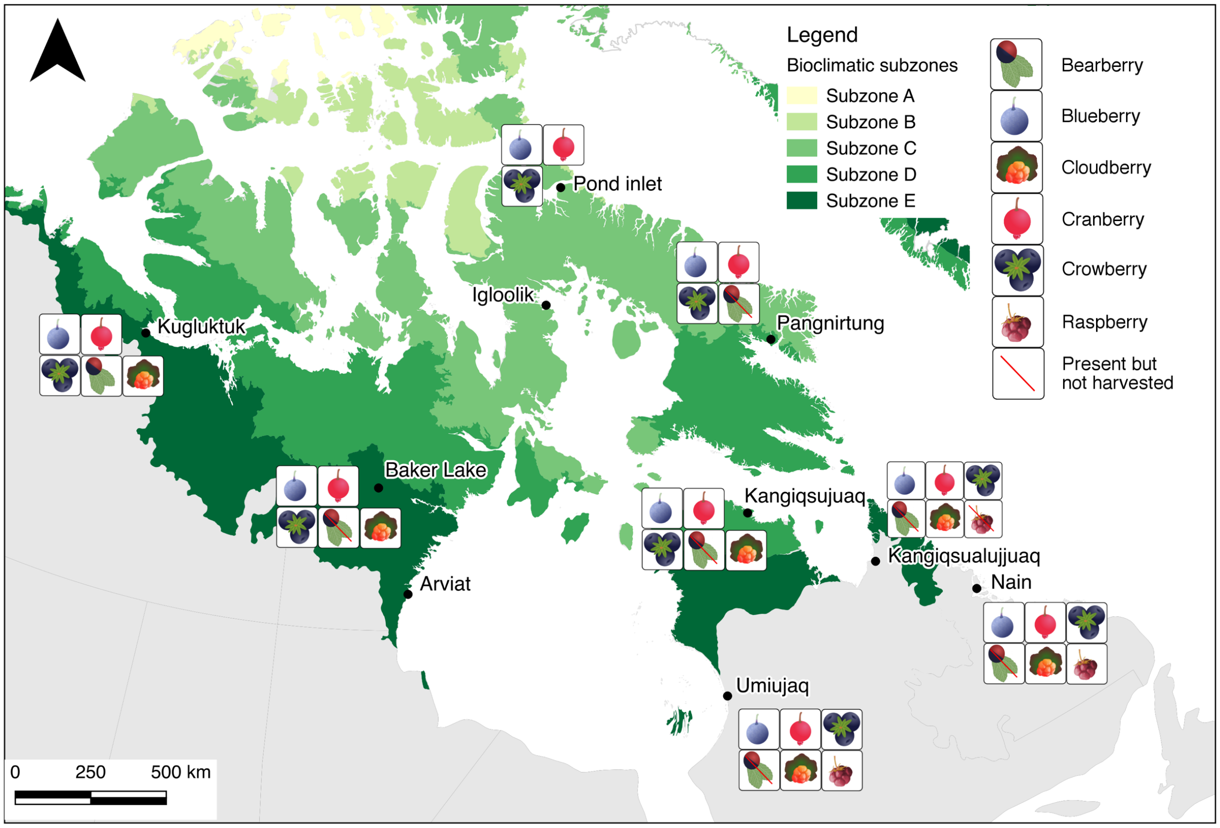

Figure 2.3 Bioclimate subzones: Subzone A- cushion forbs, moss and lichens; subzone B- prostrate dwarf shrubs; subzone C- hemi-prostrate dwarf shrubs; subzone D- erect dwarf shrubs; subzone E- low shrubs (Walker et al. 2005). Kangiqsualujjuaq, Nain and Umiujaq are located in the forest-tundra ecotone. Presence of the six main berry species: unless otherwise mentioned, all berry species are commonly consumed where present. The two bearberry species are represented by the same logo.

2.3.1.1 Timing and methods of harvesting

Very few items of material culture are specifically associated with berry picking. A strainer, used to collect berries during the winter, was mentioned by a small number of informants. A minority of people used berry pickers, a rake-like tool with a short handle. First Nations in montane areas of British Columbia used to make a similar tool for berry picking (Turner et al. 2011), although none of the informants recalled using such instruments in the past. Berries were harvested in buckets, barrels, used coffee tins or whatever container was available. In the past bags made out of caribou or seal-skin were used.

Table 2.1 English common names, scientific names as well as names in the different local dialects for berries across Inuit Nunangat.

Common name	Scientific	Nunavut, Kitikmeot – Inuinnaqtun	Nunavut, Kivalliq-Inuktitut	Nunavut, Qikiqtaaluk-Inuktitut	Nunavik-Inuktitut	Nunatsiavut-Inuttut
Bearberries	*Arctous rubra* and *A. alpina*	kablat	kallat	kallat	kallak or kallaq	kallak (*A. rubra*) kaplaruaq (*A. alpina*)
Blueberry	*Vaccinium uliginosum* and *V. caespitosum*	kigutigirngnat	kigutangiqnaq	kegotangenak	kigutanginnaq or kigutangirnaq	kigutanginnak (*V. uliginosum*) Pungajuk/ kigutanginnakuluk (*V. caespitosum*)
Cloudberry, bakeapple	*Rubus chamaemorus*	aqpik	aqpik	akpik	arpik	appik
Cranberry, lingonberry, redberry, partridgeberry	*Vaccinium vitis-idaea*	kingmingnat	kimminaq	kimminaq	kimminaq	kimminak
Crowberry, blackberry	*Empetrum nigrum*	paun'ngat	paurngaq	paurngaq	paurngaq	paungnak
Skunk currant	*Ribes glandulosum*	NA	NA	NA	mirqualik	mikKulik
Marshberry	*Vaccinium oxycoccos*	NA	NA	NA	NA	kimmnaujak
Raspberry, plumboy, strawberry	*Rubus arcticus* and *R. idaeus*	NA	NA	NA	arpiujaq	apiujak
Squashberry	*Viburnum edule*	NA	NA	NA	urpinisuut	NA

People go berry picking close to the community, in the vicinity of their cabin and plan trips specifically to go berry picking. Most people pick berries during the peak in productivity at the end of the summer before the first frost, which also corresponds to the caribou hunting season, and berry picking was often mentioned alongside caribou hunting. Cranberries are also harvested after the first frost or in the spring as the sour berries become sweeter after freezing. In the past, berries were commonly harvested throughout the year; right when they ripen, under the snow in winter or right after snowmelt in spring. One informant described how they used to put markers on the land before the snow fell in order to find the best patches during the winter.

> *During the winter […] my mother would pick blackberries under the snow. Before it snowed and the land would be freezing, we would build small* inuksuit *near the crowberries. It's easier to pick in the winter because they are frozen and don't break easily.*
>
> \- Elijah Panipakoocho, Pond Inlet

2.3.1.2 Food preparations

Most people eat berries raw, both while picking and immediately after coming back to the community. Blueberries and crowberries are often mixed together. Some people mentioned being warned that they should not eat too many berries, especially crowberries, on an empty stomach because it may cause stomach ache and in extreme cases death. Throughout the Arctic, berries are commonly mixed with fat, blubber, fish, and other greens, and the different preparations are referred to in English as "Eskimo or Inuit pudding" (Oswalt 1957, Andre and Fehr 2001, Joamie and Ziegler 2009). In Nunavut, the dish is called *aluk;* interviewees described preparations including seal blubber, old seal blubber (*puja*), caribou back fat (*tunnuq*) and willow catkins (Table 2.2). In Nunavik, the dish is called *suvaliq* and it is usually prepared with fresh, frozen or dried fish eggs (Table 2.2). Informants from Umiujaq also described how they ate berries with cooked fish in a dish called *auqtuliq* or *qajuatilik* (Table 2.2). Finally, in Nain, interviewees described a dish called *siva* made with fish liver (Table 2.2). Crowberries were most often used in food preparations although cranberries or a mixture of crowberries and blueberries were also used. Saila Kisa from Pangnirtung mentioned that fresh crowberry leaves can be eaten with oil before the plant produces fruits. Blueberry leaves may be eaten fresh and are preferentially harvested when the fruits are turning red. The tip of blueberry roots can also be eaten fresh. Less common recipes combined berries with seal brain and blood as well as with ptarmigan skin and the intestines of caribou and hare.

A modern version of the pudding involves mixing lard and cooking oil instead of wild animal fat. Berries may also be used in baking mixed into bannock or muffin dough. They are eaten with a variety of sweeteners, such as sugar, ice cream and condensed milk. They are also made into jam. A number of Elders mentioned that they like their berries raw or prepared the traditional ways while younger people prefer using store-bought ingredients for making recipes with berries.

Table 2.2 Most common traditional recipes prepared with berries, their ingredients, methods of preparation, as well as the community of residence of the informants and the number of mentions. Abbreviations: IK, Igloolik; KU, Kugluktuk; NA, Nain; PA, Pangnirtung; UM, Umiujaq.

Name	Ingredients	Preparation	Com.	Mentions
Aluk	-Seal blubber -Crowberry and/or blueberry	"[…] just put it [the berries] on seal blubber. You squeeze the blubber and mix it with the oil and just eat it."[1]	NA, PA	8
*Aluk (*name from PA*)*	-Old seal blubber -Crowberry and/or blueberry	"[…] if you leave the seal fat on snow the oil becomes kind of sticky and it becomes *puja*. You collect that and you mix it with crowberries."[2]	PA, UM	2
Aluk	-Old seal blubber -Willow catkins -Crowberry	"Mix the old seal blubber with willow. Just this part [catkin]. You just rub it and mix it with berries." [3]	IK, PA	2
Aluk	-Caribou back fat -Crowberry and/or blueberry or cranberry -opt. seal or cooking oil	"you squash the caribou back fat first and you add a little bit of fat and you add a little bit of water and it gets big and after that you mix it with"[4] the berries.	IK, KU, PA	17
Aluk (PA) *Suvaliq* (UM)	- Crushed dried, frozen or fresh fish eggs -Crowberry and/or blueberry -seal or cooking oil	Arctic char (most common) or cod fish eggs whipped with oil. Berries are added at the end.	PA, UM	10
Auqtuliq or *Qajuatilik*	-Cooked fish (cod, white fish, trout, canned fish) -Old or fresh seal blubber or cooking oil -Crowberry and/or blueberry	"We mix [the berries] with cooked fish and some oil. Cooking oil or seal oil." [5]	UM	8
Siva	-Cod liver or char liver -Seal or cooking oil -Crowberry	"[…] you take that [the liver of the codfish] and just put it in a boiler outdoors in a pan-pot stir and stir and stir, make it really crumbly […] add a lot of oil and mix that in with some crowberries"[6]	NA	3

[1]Jaco Ishulutaq (PA), [2]Pauloosie Veevee (PA), [3]Sowdloo Nakashuk (PA), [4]Daisy Dialla (PA), [5]Moses Novalinga (UM), [6]Christine Baikie (NA)

Beverages may be prepared from the leaves, stems and fruits of berry plants (Table 2.3). Tea can be made from old bearberry leaves, the whole crowberry plant as well as cloudberry leaves. Bearberries and cranberries can be cooked to make juice. In general, berry plants were used to prepare beverages more often when living on the land although two interviewees from Umiujaq still used cooked cranberries for food and medicine. It is unclear if Inuit were drinking tea before contact with Euro-Canadians (Birket-Smith 1929), however this practice seems to have been widespread and very important for some of the informants.

> *What we really depended on were bearberry and prickly saxifrage leaves, they were really part of our survival for tea.* -Inursiq Nashalik, Pangnirtung

Some regional patterns emerged regarding the different food preparations and uses for the fruits and vegetative parts of berry plants. Only in Umiujaq did interviewees mix berries with cooked fish and only in Nain did they combine them with fish liver. Similarly, the leaves of cloudberries were only used for tea by informants from Baker Lake and the leaves of blueberries were only harvested for consumption in Pangnirtung. Each preparation was well known in a region while never mentioned in the others. Local availability of certain ingredients could explain some but not all of these differences. I thus suggest that they represent culinary preferences of different cultural groups that would have lived close to the current communities. It is however important to note that food preparations and uses reported here represent a subset of local knowledge of berries in Inuit Nunangat. Previous work by Cuerrier at al. in Umiujaq, Kangiqsujuaq and Kangiqsualujjuaq (2011, 2012) suggest that interviews focusing on ethnobotanical knowledge may gather a greater wealth of information. Nevertheless, the few mentions of other recipes, notably including parts of the animals not sought after by the younger generation, such as intestines and brain, may be associated to a diminution in the diversity of country food consumed and the erosion of the knowledge associated with these ingredients (Beaumier et al. 2015).

Table 2.3 Beverages prepared from berry plants and fruits, harvesting time and preparations as well as the community of residence of the informants and the number of mentions. Abbreviations: BL, Baker Lake; IK, Igloolik; KJJ, Kangiqsualujjuaq; KU, Kugluktuk; NA, Nain; PA, Pangnirtung; PI, Pond Inlet; UM, Umiujaq.

Part used	Harvest	Preparation	Com.	Mentions
Blueberry leaves	Various periods	Boiled	PA	4
Blueberry	Ripe berries	Cooked	PA	1
Bearberry leaves	Fall, winter, spring	"[…] we would pick the old bearberry leaves to make tea. […] only when they are getting brown"[1]	KU, PA, BL	19
Bearberry fruits	Ripe berries	"My dad used to tell me to pick them up and after I cooked them […] the juice when it cools off it tastes so good."[2]	KU	1
Cloudberry leaves	Fall, winter, spring	"We used to make tea out of those old dry leaves."[3] "When we boil the leaves the second time they turn really good. […] We would still drink the first boil but the second was better."[4]	BL	9
Crowberry plant	Anytime	"Just cut it along with the roots. Boil it there."[5]	IK, KJJ, NA, PA, PO	8
Cranberry fruits	Ripe berries	"We boil those cranberries and they become very delicious. We drink the whole thing that's left in the pot, but it's sour. You can add a little bit of sugar if you prefer."[6]	UM, PA	2

[1]Kate Inuktalik (KU), [2]Alice Ayalik (KU), [3]Toona Iqulik (BL), [4]Lucy Kownak (BL), [5]Lucas A. Etok (KJJ), [6]Viola Napartuk (UM)

2.3.1.3 Medicinal uses

Berries and other parts of the plants are recognized as medicine and may be used to cure specific afflictions (Table 2.4). Cranberry is the species most commonly used for medicine. It may be eaten fresh or cooked to help with cold, nausea, the digestive system, sore throat, thrush, skin conditions as well as lung and respiratory problems. Blueberry leaves may be eaten fresh to help with stomach ache. The blueberries themselves are believed to help when someone loses his/her appetite. Cloudberries may be eaten fresh or cooked to help with heartburn and the digestive system in general. Old bearberry leaves harvested in the spring may be boiled to help with upset stomach and flu. Finally, the smoke produced when burning crowberry plants can help with eye infections.

Pharmaceutical studies have shown that berry species are rich in antioxidants that can ameliorate metabolic disorders such as obesity and type 2 diabetes (see among others Määttä-Riihinen et al. 2004, Taruscio et al. 2004, Ogawa et al. 2008, Harris et al. 2014). These properties were well known by Cree healers (Fraser et al. 2007), although not usually mentioned by informants in this research. The Inuit notion of health is encompassing, and contrary to western medicine, does not focus on the absence of illness or injuries (Ootoova et al. 2001). This was reflected in the interviews by the number of people who considered that berries, like other country food, were good for your health without identifying specific medicinal purposes.

> *When we are sick we have to use berries. If they are frozen, you get them soft and eat them. It will help your body because your body has no sour, you mostly eat meat and all those animal foods. […] It's good for the body, it helps it.* - Lucas A. Etok, Kangiqsualujjuaq

The crowberry plant was used to make tea, the whole plant. [...] It is very nutritious and helps the body in terms of health. It gives you certain nutrients. -Taukie Qappik, Pangnirtung

Health surveys stressed how food insecurity and the consumption of poor quality food are important issues in the Canadian Arctic (Huet et al. 2012). Informants were very much aware that a diet rich in country food, including berries, may alleviate these problems (Kuhnlein and Soueida 1992, Fediuk et al. 2002).

Table 2.4 Medicinal use of berry plants and fruits, harvesting time, preparations and uses as well as the community of residence of the informant and the number of mentions. Abbreviations: KJJ, Kangiqsualujjuaq; KU, Kugluktuk; PA, Pangnirtung; UM, Umiujaq.

Part used	Harvest	Preparation	Use	Community	# mention
Blueberry leaves	Harvest leaves when berries are turning red	Eaten fresh	Stomach ache	PA	1
Blueberry	Ripe berries	Eaten fresh	Loss of appetite	UM	1
Bearberry leaves	Harvest leaves in the spring	Boiled	Upset stomach, flu	KU	1
Cloudberry	Ripe berries	Eaten fresh or boiled	Heartburn, stomach system (general)	KU	1
Cranberry	Ripe berries	Eaten fresh or boiled	Cold, nausea, digestive system (general), sore throat, thrush, skin conditions, lung and respiratory problems (general)	KJJ, KU, UM	13
Crowberry plant	Anytime	Burn the plant	Eye infection	KU	1

2.3.1.4 Preservation

Although many interviewees mentioned that berries could not be preserved during the winter when they were living on the land "because they had no freezer", preservation techniques were described by others. All kinds of containers were used to store berries in the ground such as hide pouches, fish swim bladders and caribou stomachs as well as flour and sugar bags, metal tins and clothes. Berries may be cached with meat or by themselves in cracks covered with moss, on a steep hill between rocks or under the sand close to the beach. In Nain, some people recalled leaving berries in bags hanging from the trees. Mixing berries with animal fat or caribou marrow helps to preserve the fruits and will later provide a more wholesome meal.

2.3.1.5 Other uses of berry plants

Crowberry plants were used throughout the study area as a fuel; the smoke may repel insects and one informant mentioned using it to smoke meat. To a lesser extent, crowberry plants may be used to insulate bedding by placing plants on the ground underneath a hide. Some interviewees from Baker Lake mentioned smoking bearberry leaves when they were living on the land and ran out of cigarettes. It is however unclear if they were referring to *Arctostaphylos uva-ursis* a boreal species, also commonly called bearberry, and often smoked by First Nations (Thornton 1999).

The ethnobotanical knowledge presented here reflects findings from regional studies conducted in Alaska (Oswalt 1957, Ager and Ager 1980), the Northwest Territories (Andre and Fehr 2001), Nunavut (Ootoova et al. 2001, Joamie and Ziegler 2009) and Nunavik (Cuerrier and Elders of Kangiqsujuaq 2011, Cuerrier and Elders of Kangiqsualujjuaq 2012, Cuerrier and Elders of

Umiujaq and Kuujjuaraapik 2012), and makes a strong case for the widespread extent of this knowledge in Inuit communities across Canada.

The different uses and roles of berry plants evolved through time and corresponded to the different needs associated with life on the land and in the community (Figure 2.4). I represented the time "On the land" within the time "In the community" because this time is part of Elders stories and informs their teachings. It is also central to Inuit sense of identity and when spending time on the land, people are more incline to harvest land resources, including berries. Historically, most of the same uses and functions persisted while their relative importance changed. The leaves and stems of berry plants are now seldom harvested for fuel and mattresses; gas stoves have replaced other sources of heat, while plants and hides have been replaced by foam mattresses. Store-bought teas have largely replaced infusions prepared with wild plants, although these may still be used to a lesser extent, e.g. for medicinal purposes. The transition observed in term of the uses and functions of berry plants can also be extended to the social and cultural value of berries and berry picking (Figure 2.4).

2.3.2 Social and cultural value of berries

Throughout the interviews, informants highlighted the reasons why they go berry picking. These were numerous and matched reports for the Gwich'in people in the Northwest Territories (Parlee and Berkes 2005) and Alaska Native communities (Flint et al. 2011). People go berry picking because 1) berries are tasty and nutritious, 2) it is an occasion to spend time on the land, 3) it is an opportunity to spend time with family and friends, 4) it is part of their culture, 5) it contributes to sharing practices and 6) it helps maintain a spiritual relationship to the land. The motivation to go berry picking may then be associated to their contribution to Inuit personal and community well-being as well as cultural preservation.

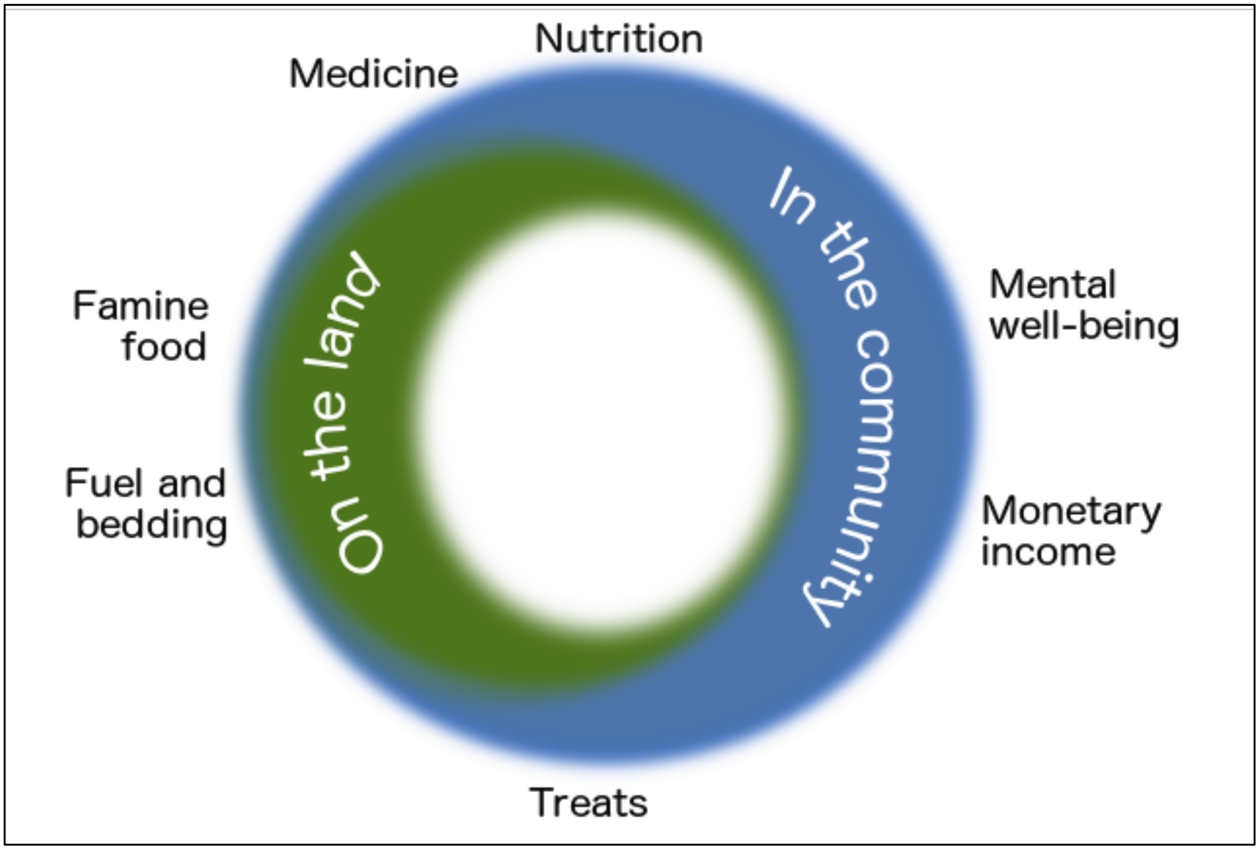

Figure 2.4 Evolution of the uses and functions of berry plants and berry picking through time as symbolized by the time "on the land" and "in the community".

2.3.2.1 Personal well-being

Interviewees described how they enjoyed being out on the land berry picking. Going on the land is calming and it is a unique opportunity to get away from stresses of the community. Berry picking trips provide psychological goods to Inuit women (Dowsley 2015). These may be acquired informally through a family trip or more formally through land-based counselling and ‘healing’ trips. While many go berry picking with their spouse, some informants discussed how berry picking is an opportunity for women to be alone or with their younger kids.

> *I like going berry picking not just to get big pails of berries but because you are out alone. […] Calm and just enjoying yourself. […] Small children, they usually come along but you don’t have to worry that they will go out of sight. They are more free, it’s good therapy.* - Anonymous

Some also described how exciting it is to find a good berry patch when traveling on the land.

> *I remember, I was chasing a caribou. I was tracking it, chasing it and it ended up going to this little ground. I found cloudberries there and I forgot about the caribou. I took my shirt off and started picking. After I finished picking it was really heavy to carry. They were so tasty.*
> -John Ohokak, Kugluktuk

When living on the land with limited or no access to store-bought food, berries brought a welcome change in a diet based on meat and fat. It would notably help to comfort their stomach. Moreover, berries may save lives in times of scarcity and famine. Plants such as berries were used as famine food by indigenous groups throughout North America because they were a reliable source of food when hunting and fishing failed (Turner and Davis 1993, Thornton 1999). The Arctic has a shorter growing season and less productive vegetation, but plants still played an important role during episodes of famine.

That summer the caribou were scarce so we would have to go without meat for extended periods of time so we had to resort to plant[s] and vegetation such as airaq [roots of plants] *and berries*. -Rebecca Irngaut, Igloolik

2.3.2.2 Community well-being and sharing practices

Berry picking is very much a family activity and interviewees remembered picking berries at a young age with their mother. Work by Sarah Desrosiers with middle and high school students in Kugluktuk showed that berry picking is still very much appreciated by youth and some described how it is a unique opportunity to spend time with their family (Kugluktukmiut Elders and Youth and Desrosiers 2016). Although a number of men interviewed were active berry pickers themselves, many described how during a family trip in the fall, women and children may be dropped at a good berry picking patch for the day while men go caribou hunting or fishing. In a context where travelling on the land is expensive, we could hypothesize that this strategy maximises harvesting activities at a lower cost. Good berry patches located further away from the community and that may not otherwise be visited are then available.

Berries are shared with family and friends and to a lesser extent Elders in the community. Berries may be shared because they are available in the household or people may go out expressively to pick berries for Elders. Like they share berries, they also willingly shared the location of berry picking patches. Informants pointed out on the map general areas and specific locations close and far from the community that they may access by all-terrain vehicle, boat and walking. Through informal discussion, it was understood that berries located close to a cabin "belong" to the owner. However, very few people were protective of their berry patches outside of informants from Umiujaq and Nain. In those communities, it was repeatedly mentioned that the best berry picking spots are kept secret and some participants inquired about the confidentiality of the interview. It is not clear why berry patches were more secret in Umiujaq and Nain since local abundance and history of land use are not especially different for those two communities.

Parlee and Berkes (2006) documented common property management practices and rules related to the access of berry picking patches for the Gwich'in in the vicinity of Fort McPherson, NWT. They found rules related to the availability of certain berries as well as traditional family patches. Similarly, Karst and Turner (2011) described how residents of Charlottetown in southern Labrador harvest cloudberries in areas that they used to visit with their parents. In this study, only one interviewee from Nain mentioned that he kept some of his best berry picking spots secret because it was a particularly productive area where his family harvested in the past. In Umiujaq, informants who kept their berry patches secret did not mention that these areas were traditionally used by their family although the question was not specifically asked. Differences between Inuit and First Nations in Canada may be related to the recent history of relocations, meaning that most informants do not currently live where they grew up. However, it may also have to do with a certain relationship to the land that sees slow vegetation growth and long regeneration time obliging people to move often and prevents them from re-using a certain area for a while, thus developing a different sense of ownership. Bennet and Rowley (2004, p.383-384) reported how traditional beliefs associated with land use required people to move in order for the land to replenish and "cool down" after being used for some years. If a camp is occupied for too long the land becomes hot and dangerous. On the other hand, the low population density may have meant that there were enough berries for everyone and it was not worth the effort of protecting patches (Thornton 1999).

Elders from Kugluktuk remembered using berries as a trading good when they did not actively participate in the wage labour market. Otherwise, only in Nain was it often mentioned that berries are now commonly sold between community members. None of the interviewees expressed concerns about the exchange of berries for money and some noted that they may buy berries when they are unable to pick themselves. Even if the subject was only discussed by residents of Nain, observations by collaborators across Inuit Nunangat suggest that this practice is slowly becoming more common. For example, in Nunavik, *suvaliq* is sometime sold at the entrance of the grocery store and it is a treat very much sought after. In this research, informants did not express concern about this practice. However, this topic may need further investigation since the question was not asked directly during the interviews and the exchange of country food for money is a topic of growing concern in the Canadian Arctic and Alaska (Parlee and Berkes 2006, Karst and Turner 2011, Kellogg et al. 2011), where it is believed to disrupt traditional food sharing systems (Searles 2002, Kishigami 2004).

2.3.2.3 Cultural and spiritual dimensions

Berries like other country food are an important part of Inuit culture and contribute to the construction of Inuit identity (Searles 2002). Berries are shared during community feasts and celebrations such as Christmas. Residents of Umiujaq discussed their participation in the annual Blueberry festival, an event appreciated by locals and which attracts people from other communities. Even though people now harvest berries during a short period of time in the fall, they still consider it an important resource and as such, it is part of life and conversations throughout the year.

> *Even today* [March 6th] *some women are thinking about the berries that will grow this summer wishing for rain and sunshine*. -Juusipi Nappaaluk, Kangiqsujuaq

Berry picking is valued as a cultural activity and a berry picking trip may be sought after even if few berries are expected to be found. Going berry picking contributes to cultural continuity (Parlee and Berkes 2005) and as such is a cultural practice. When living on the land, travels were planned according to animal availability; berries were generally picked while travelling or in the vicinity of the camp. This idea of picking berries "on the way to" or in the vicinity of cabins and the community is still very important, but a number of people also talked about making dedicated trips to go berry picking. These berry picking trips seem associated to the cultural value of berries and their place in contemporary Inuit communities and lifestyle.

Finally, little is known about the symbolic place of berries for Inuit. Boas (1901) noted a story where an *Angakok* (i.e. an Inuit shaman) stopped a monster by putting a berry patch in his way; the monster could not help but stop to eat the berries. Similarly, informants reported that you should not eat the berries from a place where there never used to be any because they will make you sick. Moreover, berries, like other non-human agents (see among others Nadasdy 2007, Watson and Huntington 2008), have a salient presence on the land and must be treated with respect (Thornton 1999). In that sense, some interviewees were taught that berries will not grow well if they are not harvested.

2.3.3 Factors affecting the quality and availability of berries

Inuit are very much aware of annual fluctuations in climate, animal populations and plant productivity. These have always occurred and people have had to adapt to survive. In the last century, anthropogenic factors have put increasing pressure on the land with impacts on the productivity, availability and accessibility of berry patches (Kellogg et al. 2010, Flint et al. 2011).

2.3.3.1 Community development and pollution

Informants often contrast their life on the land with the one in the community. Now that they live in communities, they have to go a certain distance to collect berries, which costs money and becomes more difficult with age and reduced mobility.

> *There is an area down beyond this map where I would prefer to collect berries but we don't go often because it is so far and it would cost a lot of money*. -Leopa Akpalialuk, Pangnirtung

Some communities have berry patches in close proximity to habitations, but infrastructure, including houses, sewage lagoons and dumps, as well as traffic from motorized vehicles and dust from the roads may reduce the quality and productivity of those patches. Some also fear the effect of atmospheric pollution due to local sources such as dump fires and global pollution from acid rain. Some informants believed that pollution is changing the taste of berries and others no longer pick in areas directly affected by pollution. Constraints on the accessibility and availability of berries vary by region. Concerns about the quality and quantity of berries due to community development including roads, dumps and sewage facilities came from different communities and did not seem to be linked to the size of the community but may have had more to do with the presence of berries near infrastructure.

Concerns about the impact of mining activities were localized and came from residents of Baker Lake and Nain, two communities located near active mines. Similarly, residents of Kugaaruk, Nunavut, believed that mining exploration affected the taste of animals (Nancarrow and Chan 2010). While exploration permits usually take into account the impact on wildlife, it does not consider potential negative effects on berry patches. In a conversation with a person in charge of issuing exploration permits for mining companies in Nunavut, I was asked if it would be possible to document berry picking patches in order to protect them against exploitation or if such an initiative would be met with criticism. This question pointed to the lack of written accounts on the subject and the difficulty for land use planners to integrate berries in their day-to-day decisions.

2.3.3.2 Consumption and trampling by animals

Berry pickers have to share patches with a number of animal species. Informants explained how all bear species (i.e. black, grizzly and polar bears), geese (greater snow, lesser snow and Canada geese), ground squirrels, hares, partridges, ptarmigans, ravens, seagulls and a number of small birds eat berries. Caribou are not usually believed to eat berries, although trampling by large herds may reduce berry production. Among all those species, informants only expressed concerns about geese. Geese populations have been increasing in the last 50 years due to agricultural changes that provide a readily abundant food source during migration and wintering (Abraham et al. 2005). Although drastic population management measures have been taken, populations are still considered overabundant (Koons et al. 2014) and migrating geese were found to eat 30-60% of the annual crowberry production on the Alaska Peninsula in the fall (Hupp et al. 2013). However, the consumption of berries is much lower in areas not directly located on the southward migration path (Chapter 3). Nevertheless, the effect of geese on berry availability was strongly felt in most of the communities where the core interviews were conducted.

> *There is a lot more Canada geese now. Even when we try to go berry picking, where we know that there usually are berries, if the geese have been there then the berries are usually gone. Some women hate Canada geese. Canada geese they seem to know what's better too. Like us, they intend to pick the better tasting ones. Both the women and the Canada geese want to eat those berries, we are in competition.* -Pauloosie Veevee, Pangnirtung

2.3.3.3 Recent climate change

In Alaska, climate change or fluctuations from year-to-year were identified as the main threats to berries (Kellogg et al. 2010). Informants in this research presented mixed opinions in regards to the effect of climate change on berry productivity. A diminution in snow deposition and summer precipitation was widely observed and some attributed a change in the taste of berries to those drier conditions (Gérin-Lajoie et al. 2016). Downing and Cuerrier (2011) as well as Cuerrier et al. (2015) and Gérin-Lajoie et al. (2016), using data from the core interviews, documented local observations on the increase in shrub cover associated with recent climate change (Myers-Smith et al. 2011, Tremblay et al. 2012, Myers-Smith et al. 2015). They showed that the increase in height and cover of erect shrubs constrains movements on the land and reduces the accessibility of berry patches. It is however unclear from the interviews used in this research if the increase in shrub height and cover has a direct negative impact on berry productivity. In some instances, shrubs are perceived to diminish berry productivity while in others, like during a warm and dry summer, they may provide shade and thus have a positive influence on the quality of the berries. Ecological studies conducted in Umiujaq however showed that the cover and productivity of berry species diminished under erect shrubs suggesting that the impact might be largely negative (Lussier 2016). Moreover, high phenolic content in leaves of berry species are believed to reduce grazing pressure because of low palatability and digestibility but these are expected to decrease with increased shading (Hansen et al. 2006).

2.4 Conclusion

The importance of berries for Inuit was widely dismissed in the early ethnographic literature based on southern bias related to the poverty of the land and the lesser importance given to a non-agricultural activity under the responsibility of women and children. This research demonstrates that berry species were and remain important for Inuit in Canada. Although berries are ripe for a short period of time, they are and were preserved for later use and were harvested throughout the year. Berries and berry picking confer physical, mental and community well-being in Inuit communities. It is a family activity that contributes to cultural preservation and connection with the land. It is still one of the most affordable harvesting activities. When berry patches are present nearby, berry picking can easily be done after a day at work and does not require special equipment. It is an easy way to escape life in the community and connect with the land while providing nutritious food. However, increasing pressure from community development, extended impact of pollution, overabundant geese populations as well as recent climate change may reduce the quality, availability and accessibility of patches.

This study has only skimmed important body of local knowledge in order to provide a strong case for the widespread importance of berries and berry picking throughout Inuit Nunangat. Detailed ethnobotanical studies may reveal an even greater wealth of knowledge (Cuerrier and Elders of Kangiqsujuaq 2011, Cuerrier and Elders of Kangiqsualujjuaq 2012, Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012). Hence, this study should be considered a preliminary investigation. More work is needed to understand the traditional and contemporary place of plants for Inuit in Canada.

Finally, it became obvious during the course of this project that documenting the cultural importance of berry plants and berry picking not only provided a better understanding of Inuit culture, but also might have direct repercussions on land management practices. If good berry patches around the community were known, they could be protected from community and industrial development in order to facilitate access to this important country food. In a context of rapid social and environmental changes in the Arctic, this research will provide some much-needed written account of the cultural and nutritional importance as well as the barriers to the accessibility of berry plants and berry picking for Inuit in Canada.

Chapter 3: Where are the berries and who eats them? Distribution and consumption of berries near Arviat, Nunavut

3.1 Introduction

The fruits of circumpolar berry-producing species possess high nutritional value, benefitting both animals and humans. While they are known to produce a great amount of fruits, the climatic and environmental factors influencing their productivity are poorly understood (Murray et al. 2005, Krebs et al. 2009) especially in the Arctic (Chapter 4). Numerous animal species as well as contemporary Inuit rely on berries as a local source of nutrients and vitamins (Fediuk et al. 2002, Cadieux et al. 2005, Krebs et al. 2010). Berry picking is a traditional activity still largely practiced in Inuit communities and contributes to physical and mental well-being (Chapter 2). As both humans and animals intensively seek berries during a short period of time, conflict over the resource may occur, especially in a context where people have less time to travel on the land and community development is affecting nearby berry patches (Chapter 2). Understanding the variables affecting the availability of berries will contribute to informed decisions on land use and traditional activities in the Arctic.

Berries are found in feces of numerous animal species, but little is known about their prevalence or importance in diets. Ripened fruits of *Vaccinium* and *Empetrum* species provide Canada geese the energy required for pre-migratory fat deposition and constitute > 40% of their diet in late summer (Sedinger and Raveling 1984, Cadieux et al. 2005). Berries may also be important for passerines (Norment and Fuller 1997), shorebirds (McCaffery 1998) and ptarmigan (Weeden

1969). They are a main source of food for grizzly bears (*Ursus arctos*; Ripple et al. 2014), a boreal species whose density in the Arctic has steadily been increasing in the last three decades (Dumond et al. 2015). They may also be of some importance for polar bears (*Ursus maritimus*; Dyck and Kebreab 2009, Rode et al. 2010, Gormezano and Rockwell 2013). Berries represent 14-30% of red fox (*Vulpes vulpes*) scat but are a negligible portion of Arctic fox (*Vulpes lagopus*) diet (Ehrich et al. 2015). The density of red foxes has also steadily been increasing in the Arctic since the beginning of the 20th century (Berteaux et al. 2015). Throughout Arctic and alpine environments, berry species leaves, buds and fruits constitute a significant portion of the diet of rodents (Andersson and Jonasson 1986, Selas et al. 2013). In southern Yukon, Krebs et al. (2010) found that voles rely heavily on *Empetrum nigrum* as a main source of food in winter. While these studies provide some insights as to which animal species eat berries, they leave open the question of the impact of herbivory on resource availability.

Local observations in the North identified caribou and geese as the two main animal guilds that may cause a diminution in the availability of berries for human consumption (Chapter 2, Nancarrow and Chan 2010, Downing and Cuerrier 2011). While caribou are not expected to eat a significant number of berries, trampling, especially in the summer, may alter plant community composition (Kumpula et al. 2011). On the other hand, geese populations have been increasing in the last 50 years due to agricultural changes that provided a readily abundant food source during migration and wintering (Abraham et al. 2005). Although drastic population management measures have been taken, populations are still considered overabundant (Koons et al. 2014). Cackling geese were notably found to eat 30-60% of the annual production of *E. nigrum* during their southward migration on the Alaska Peninsula (Hupp et al. 2013).

As northern communities are expanding and the level of industrial development is increasing, undisturbed berry picking sites are getting more difficult to access. Global sources of pollution such as organochlorines (OCs) and toxic metals (Oostdam et al. 2005) have been extensively studied while local sources, although striking on the land, are poorly documented (Medeiros et al. 2011). These local sources of pollution include leaks from sewage water (Nunatsiaq News February 25, 2011), reduced air quality from dump fires (Rideout July 13, 2001, Varga September 10, 2014) and dust from gravel roads (Chapter 2). Mining activities may also have an impact on the quality of berries in certain regions. While berry species do not readily absorb the arsenic present in contaminated soil (Nicholson 1999), we may expect a different response to other contaminants. Moreover, contaminants are being deposited directly on the fruits where they will remain if not washed (Davey 1999).

In this research, I was interested to understand the spatial distribution of berry and animal species in the vicinity of Arviat, Nunavut. I also wanted to test the hypothesis that animals, mainly geese, eat a significant portion of the annual berry production. Arviamiut, notably through a local organization called the Wellness Center, have a keen interest in promoting the use of local food sources, especially native plants. This research was thus locally relevant while the field location also allowed to test the impact of a resident goose population of intermediate abundance in an area extensively used by local residents.

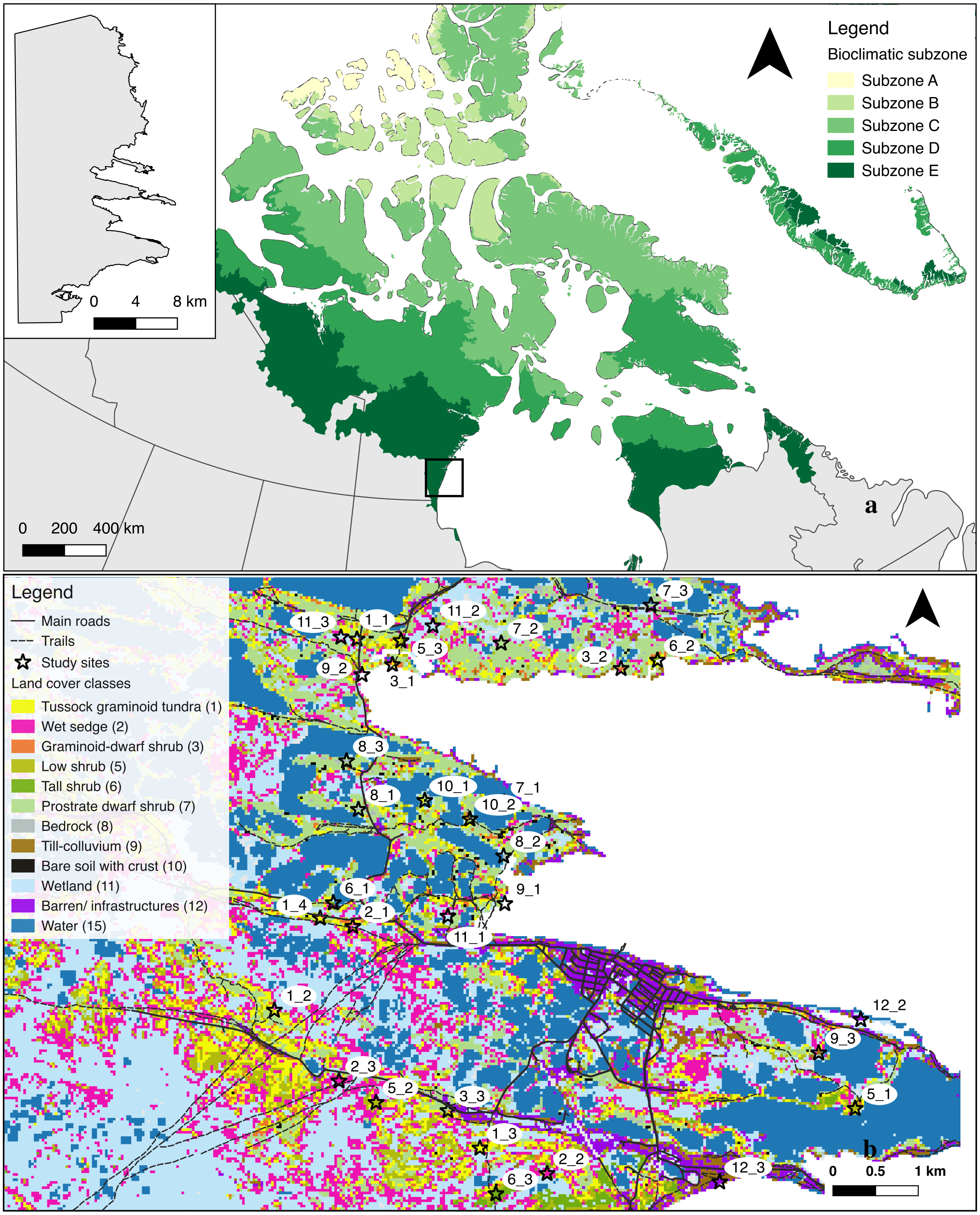

Figure 3.1 a) Location of the municipality of Arviat along the bioclimate gradient in the Canadian Arctic (Walker et al. 2005), inset presents the boundaries of the municipality of Arviat; b) location of the study sites on the 30 m resolution land cover map (Olthof et al. 2009). Roads and trails are based on Pleides-1A at 50 cm resolution and were processed by Community and Government Services of the Government of Nunavut (used under permission).

3.2 Methods

3.2.1 Study site

Arviat is one of the most southerly communities in Nunavut. It is located on the western shore of Hudson Bay, approximately 200 km north of Churchill, Manitoba (Figure 3.1a). The study area is located in subzone E of the Circumpolar Arctic Vegetation map (CAVM; Walker et al. 2005) and characterized by vast areas covered by lakes, marshes and wetlands within a mosaic of drier habitats with low and prostrate dwarf shrubs (Table 3.1). The tree line is located a few kilometers inland and people often travel from the coast to the tree line. A large lesser snow geese colony breeds a few kilometers inland from Arviat and birds nesting at higher latitudes use the West Coast of the Hudson Bay as a staging area in the spring (Kerbes et al. 1990). The colony grazes intensively until mid-August when they begin their southward migration (Kerbes et al. 1990).

3.2.2 Study species

The study focuses on five widespread low Arctic berry species, namely bearberry (*Arctous alpina* L.), crowberry (*Empetrum nigrum* L.), blueberry (*Vaccinium uliginosum* L.), cranberry (*Vaccinium vitis-idaea* L.) and cloudberry (*Rubus chamaemorus* L.; Figure 3.2). Species names follow the classification of the Flora of North America (Flora of North America Editorial Committee 1993+). All species except *R. chamaemorus* (Rosaceae) belong to the Ericaceae family and thrive in poor soil with high carbon to nitrogen ratio (Heikkinen and Mäkipää 2009). *Arctous alpina* is a prostrate woody species that produces large (6-9 mm) dark purple fruits. It is commonly found on slopes and ridges as well as imperfectly drained moist or dry areas of Arctic and alpine tundra (Aiken et al. 2003). *Empetrum nigrum* is found throughout the Arctic as far north as Ellesmere Island. It is a low woody species with horizontal stems branching extensively to shape plant habit as mat. Leaves are evergreen and needle-shaped; fruits are dark purple to black. *Empetrum nigrum* is shade and drought intolerant and its occurrence is linked to snow cover that provides a drought and frost barrier during the winter (Tybirk et al. 2000).

Figure 3.2 Study species: a) *Arctous alpina* (picture taken in the fall), b) *Empetrum nigrum*, c) *Vaccinium uliginosum*, d) *Vaccinium vitis-idaea* and e) *Rubus chamaemorus*.

Vaccinium uliginosum and *V. vitis-idaea* have a circumpolar distribution and range from the forest-tundra ecotone to the high Arctic in sheltered areas. *Vaccinium uliginosum* is a deciduous species that grows on moderately to well-drained flat terrains and slopes. Flowers are pink and bell-shaped; fruits are dark blue. *Vaccinium vitis-idaea* is comparatively smaller with a height of 5-10 cm;

horizontal stems at ground level sometimes form mats. It is an evergreen species that produces white flowers and spherical red fruits. It is often observed growing in well-drained to dry habitats (Aiken et al. 2003). Finally, *Rubus chamaemorus* is a perennial forb species with a range restricted to the low Arctic. It prefers moist habitats and is often found around ponds and lakes. Plants produce three circular and cordate hairy leaves and one single orange aggregate fruit at the terminus of a non-branching stem (6-15 cm; Flora of North America Editorial Committee 1993+).

3.2.3 Data collection

I used the Circa 2000 Land Cover Map of northern Canada at 30 m resolution as a basis for investigations (Olthof et al. 2009). The map is based on orthorectified Circa 2000 Landsat data and covers Canada's land mass north of the tree line. The map has an estimated accuracy of 81.5% (Olthof et al. 2009) and a previous study in the region found good correspondence between the 15 land cover classes (Olthof et al. 2009; Table 3.1) and plant species cover in the field (Spiech 2014). Prior to fieldwork, I selected six points within each of the 15 land cover classes, except for the categories 'Ice-Snow', 'Shadow' and 'Water', in a radius of 10 km of the community following a stratified random strategy. The coordinates of the random points were entered in a GPS prior to field seasons. Fieldwork was conducted in July and August of 2014 and 2015. In the field, I visited each site, conducting an initial survey to locate three plot locations for each land cover class. Sites were chosen according to accessibility and disregarded if they did not correspond with the desired land cover class, if they had experienced major disturbances (i.e. road, excavation, detritus) or were located close to anthropogenic structures such as cabins. There was a minimum of 150 m between each site. In order to sample within a homogenous patch of vegetation, the center of the plot was sometime adjusted but never placed more than 30 m away from the initial coordinates.

When an area suitable for sampling was found, a 20 x 20 m plot was established in a homogenous stand of vegetation. I recorded the coordinates of the four corners, and measured the slope angle and the maximum canopy height. Three random soil moisture measurements were also recorded using a soil moisture probe (HydroSenseII, Campbell Scientific, Edmonton, Canada). Vascular plant, moss, lichen, bare ground and rock cover was assessed using Braun-Blanket cover classes (Braun-Blanquet 1932) in 10 random 70 x 70 cm quadrats within each plot. Berries were collected in random 25 x 25 cm quadrats within the plots following a standardized protocol (CiCAT 2016). Empty quadrats were recorded until 25 quadrats with berries were found for a maximum of 50 quadrats sampled. The number and weight of berries were measured in the days following the harvest and berries were kept cool until weighed.

The abundance of animal feces was recorded on an area of 1 m on each side of a 100 m transect (for a total area of 200 m^2). The transect was located around the edge of the 20 x 20 m plot as well as on a diagonal line of 20 m in the middle of the plot. Animal feces were classified into ten categories easily identifiable in the field: fox, goose, ground squirrel, hare, microtines (vole and lemming), passerine, ptarmigan, tern, white liquid and unknown. Feces were collected in four 70 x 70 cm quadrats located on the corner of the 20 x 20 m plot. If feces of a certain species were found along the transect but not in the quadrats, I collected the feces observed along the transect. Berries and feces were shipped frozen for analyses.

Table 3.1 Description of the 15 land cover classes of the Circa 2000 Land Cover Map of Northern Canada (Olthof et al. 2009) as well as percentage cover of each cover class for the municipality of Arviat.

Classes	Description	% of study area
Graminoid dominated		
1	Tussock graminoid tundra (<25% dwarf shrub)	14
2	Wet sedge (<10% dwarf shrub)	25
3	Moist to dry non-tussock/dwarf shrub tundra (50-70% vegetated cover)	4
4	Dry graminoid prostrate dwarf shrub tundra (70-100% vegetated cover)	0
Shrub dominated		
5	Low shrub (<40 cm; >25% cover)	16
6	Tall shrub (>40 cm; >25% cover)	1
7	Prostrate dwarf shrub (dry substrate with >50% cover consisting of prostrate dwarf shrub)	10
Sparse vegetation		
8	Sparsely vegetated bedrock (2-10% vegetated cover)	1
9	Sparsely vegetated till-colluvium (2-10% vegetated cover)	4
10	Bare soil with cryptogam crust-frost boils (2-10% vegetated cover)	1
Wetlands		
11	Vegetated areas where the water table intersects the land surface all or part of the year	17
Non-vegetated		
12	Barren (<2% vegetation cover)	3
13	Ice/snow	0
14	Shadow	0
15	Water	5

After the first field season, I plotted the location of the sites visited back onto the land cover map to assess if the sampled units corresponded to the land cover classes that were pre-selected. I compared the average cover of the main functional groups (i.e. low shrub, tall shrub, lichen, etc.) present in the plots with their expected cover from the class descriptions. In 2015, I re-sampled the plots from 2014 showing a good correspondence with their land cover class description. In order to account for plots that were wrongly located in the field (i.e. the location of the sampled plot did not correspond to the expected land cover class) or had vegetation cover that did not match their land cover class, I sampled six new plots located following previously described methodology.

In the laboratory, feces and berries were dried in an oven at 100°C for two days. The average abundance of seeds per berry was evaluated using a minimum of 10 berries of each species randomly selected from the samples. The animal feces were successively passed in sieves of 4000 to 250 microns or until no more seeds could be extracted. The seeds were sorted according to the five berry species and all other seeds were discarded. Since it was difficult to distinguish the seeds from *Vaccinium uliginosum* and *Vaccinium vitis-idaea* by visual observation, *Vaccinium* seeds were treated together. I focused laboratory analyses on goose, hare and microtine feces, although I quickly realized that no seed could be found in microtine feces, most probably because berry seeds are too big to be ingested by those species. It is however possible that the small *Vaccinium* spp. seeds were not identified after inspection of the microtine feces because their shape was altered by digestion or during the process of crushing the feces for analysis.

3.2.4 Data analyses

I conducted a canonical correspondence analysis (CCA) with the vegetation cover data as well as soil moisture, slope angle and maximum canopy height as environmental variables. I compared berry and animal abundance for 2014 and 2015 using a paired t-test only on the sites that were sampled in both years. I tested the difference in the abundance of berries and animal species between land cover classes using two linear mixed effect models with the land cover class as fixed effect and the plot as random effect. All statistical analyses were conducted using R software (R Core Team 2016).

I created maps of the abundance of berries and feces for the area of the municipality of Arviat using QGIS (QGIS Development Team 2017). I assigned a mean abundance value (no./m^2) for the abundance of berries and feces to each land cover classes. It was thus assumed that each class corresponds to a specific habitat presenting similar plant and animal composition and abundance. Values for land cover classes 1 (Tussock graminoid tundra), 3 (Moist to dry non-tussock/dwarf shrub tundra), 7 (Prostrate dwarf-shrub), 8 (Sparsely vegetated bedrock) and 10 (Bare soil with cryptogam crust) were pooled due to ecological similarities (see results for details).

I then calculated the total abundance and biomass of berries as well as the abundance of animal feces over the area of the municipality of Arviat. I provided an estimation of the number of animals present over the area based on specific defecation rates and persistence time of feces. Defecation rates vary greatly between waterfowl species and habitat studied. In the literature, values vary from 28 to 160 feces/day, so I used the average value of 100 feces/day for the estimations (Bédard and Gauthier 1986, Krebs et al. 2003, Unckless and Makarewicz 2007). The value of 208 feces/day was used for the defecation rate of hare (Flux 1970). Persistence time of pellets also vary between studies, Klein and Bay (1994) estimated persistence time in the high Arctic from 1 to 6 years depending on soil moisture, while Karels et al. (2004) and Hupp et al. (2013) evaluated that feces from previous years were rarely found in low Arctic and alpine environments. Since feces count largely underestimated the actual number of feces in the field (Bédard and Gauthier 1986), I assumed persistence rate to be one year, i.e. all feces counted were from the current year. Finally, using the average number of berries per feces and the average number of feces in each land cover class, I calculated an estimate of the total number of berries of each species eaten over the area of the municipality of Arviat.

3.3 Results

A total of 45 sites were visited during July and August 2014 and 2015 with 34 sites sampled in 2014 and 33 in 2015 (Figure 3.1b). I excluded five sites that had human infrastructures (i.e. road, cabins, dog houses) as well as two sites that, although homogenous in the field, corresponded to more than one land cover class on the map. In the field, four sites were disregarded because the plant community clearly did not match with the land cover class description. Finally, I disregarded two sites based on the results from the CCA analysis which placed them away from the cluster of sites from the same class, indicating discrepancy in vegetation cover and environmental variables. This left three sampling locations per land cover class, except for class 10 for which we only have two locations.

3.3.1 Vegetation analysis

The CCA biplot pooled study plots according to plant composition along three axes: moisture, slope angle and maximum canopy height (Figure 3.3). The explanatory variables constrained 41% of the total inertia. Sites of land cover class 9 (*Sparsely vegetated till-colluvium)* and 12 (Barren) showed low vegetation cover of species characteristic of sea shores and eskers. Most of the intertidal zone was classified as class 12, while the band of vegetation just above the shoreline was classified as class 9. They both have low soil moisture and class 9 may be distinguished from class 12 by its slightly higher vegetation cover. On the other end of the moisture spectrum were sites of class 2 (Wet sedge) and 11 (Wetlands). In the field, those classes could be differentiated by the bare ground cover which was higher in class 11 and represented areas where water remained present for a significant portion of the growing season. The cover of moss was also significantly lower in class 11. The highest cover of erect shrubs was found on sites of class 6 (Tall shrub), although these were never higher than 40 cm as would have been expected from the land cover class description (Table 3.1). Sites of class 5 were characterized by small areas of sheltered mesic habitats that retained snow later than surrounding areas. The vegetation was dominated by low and prostrate dwarf shrubs and was lush compared to surrounding areas. The other sites, although different in the field, plotted closely to each on the ordination biplot, and they are hereafter referred to as the mesic cluster. On the drier end of the mesic cluster are sites of class 10 (Bare soil with cryptogam crust) characterized by a continuous cover of fructose lichen mostly of black color with a mixture of dwarf shrubs. Sites of class 8 (Sparsely vegetated bedrock) were also quite easily identifiable with a cover dominated by medium size boulders on which were growing an assortment of mainly crustose lichen. However, I rejected the highest number of sites in the field for this class due to misclassification.

The land cover map often had areas with a mixed cover of black and white lichen assigned to class 8. Land cover of class 1 (Tussock graminoid tundra) had a significant cover of low and prostrate shrubs along with sedges. Plots of class 3 (Moist to dry non-tussock graminoid / dwarf shrub tundra) had an intermediate cover of dwarf shrubs growing with lichen and moss. Land cover class 7 (Prostrate dwarf shrub) was characterized by a mixture of moist and dry habitats often along lake margins.

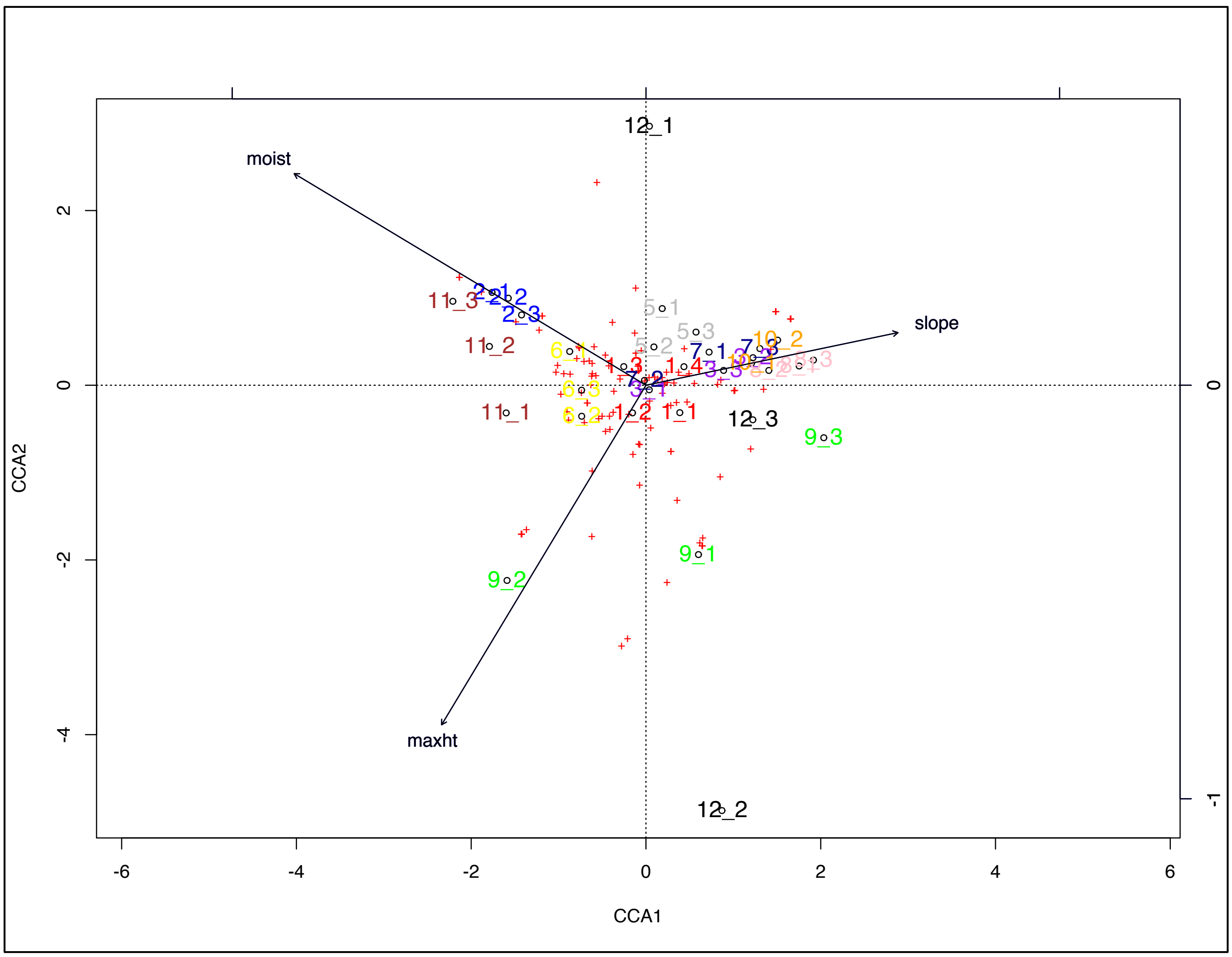

Figure 3.3 Results from the Canonical Correspondence Analysis (CCA) of vegetation cover data with the maximum canopy height (maxht), moisture (moist) and slope angle (slope) as explaining variables. Different colors present different land cover classes; numbers with the land cover class are individual quadrats. Red crosses show the distribution of plant species along the axis.

3.3.2 Abundance and distribution of berries and animal feces

Empetrum nigrum was the most abundant species throughout the region, followed by *Vaccinium vitis-idaea*, *V. uliginosum*, *Rubus chamaemorus* and *Arctous alpina* (Figure 3.4). Berry producing species were found in all land cover classes. Class 5 had the highest productivity with an inter-annual average of 935 (SE=358) berries/m^2 shared mostly between *E. nigrum* and *V. vitis-idaea*. Land cover classes 2, 9 and 11 had the lowest abundance of berries with only 8 (SE=7) to 22 (SE=14) berries/m^2 while the other sites had average abundance ranging between 128 (SE=26) and 242 (SE=67) berries/m^2. Overall, considering all berry species combined on the sites that were sampled in both 2014 and 2015, there was significantly less berries being produced in 2014 than in 2015 (df=114, p=0.002). When looking at the differences between years for each species separately, there was only a significant difference for *V. vitis-idaea* (df=22, p=0.011). Regarding the differences between land cover classes, there was only a significant difference in the abundance of berries between class 5 and all other classes (df=280, p=0.002). The amount of seeds per berries was relatively constant for *A. alpina*, *E. nigrum* with respectively 5 (SE=0) and 9 (SE=0.2) seeds/berry. *Vaccinium* spp. and *R. chamaemorus* showed more variability with, respectively, 12 (SE=2) and 9 (SE=2) seeds/berry.

There was a relatively low diversity of animal feces over the area studied. I found some feces of foxes, ground squirrels, passerines and terns although their number was negligible compared to the abundance of feces from geese, hares and microtines (Table 3.2 and Figure 3.5). Geese clearly dominated the fauna in the vicinity of Arviat with a large number of feces found across land cover classes (0.81-6.33 feces/m^2). The abundance of goose feces was greater in classes 6, 9 and 11 and lower in classes 2 and 8. The abundance of microtine feces was up to 1.02 feces/m^2 in class 6 and the abundance of hare feces was up to 0.05 feces/m^2 in class 9. Overall there were no differences in the abundance of feces between years when considering only the sites that were sampled in both 2014 and 2015 and for all species combined and analyzed separately (df=74, p>0.05). There were no statistical differences in the abundance of animal feces between land cover classes (DF=277, p>0.05).

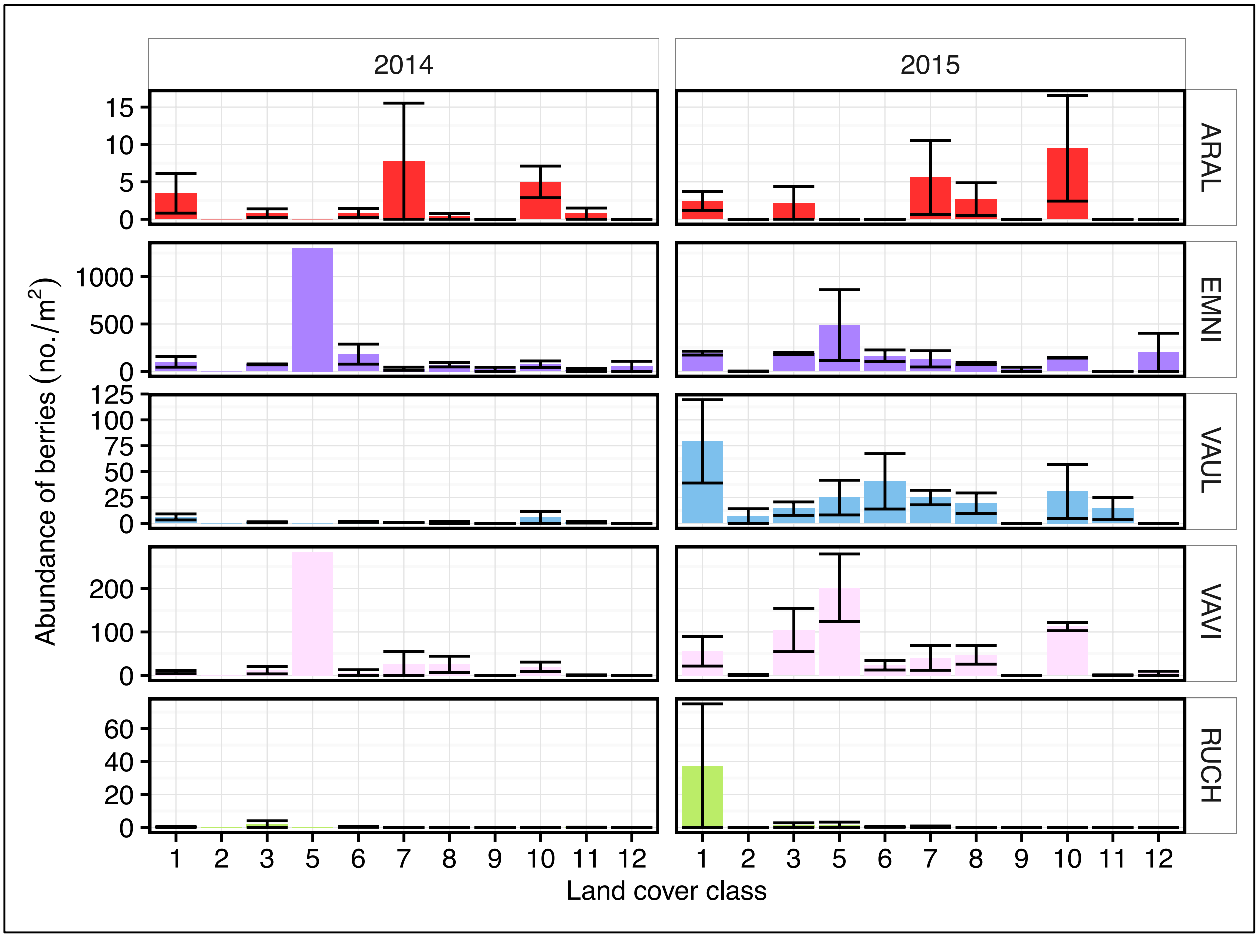

Figure 3.4 Abundance of berries (no./m^2) and associated standard error for the five plant species studied (ARAL: *Arctous alpina; EMNI: Empetrum nigrum; VAUL: Vaccinium uliginosum*; *VAVI: V. vitis-idaea;* RUCH: *Rubus chamaemorus*) for the 2014 and 2015 samplings per land cover class in the vicinity of Arviat, Nunavut. Scale of the y-axis differs between species.

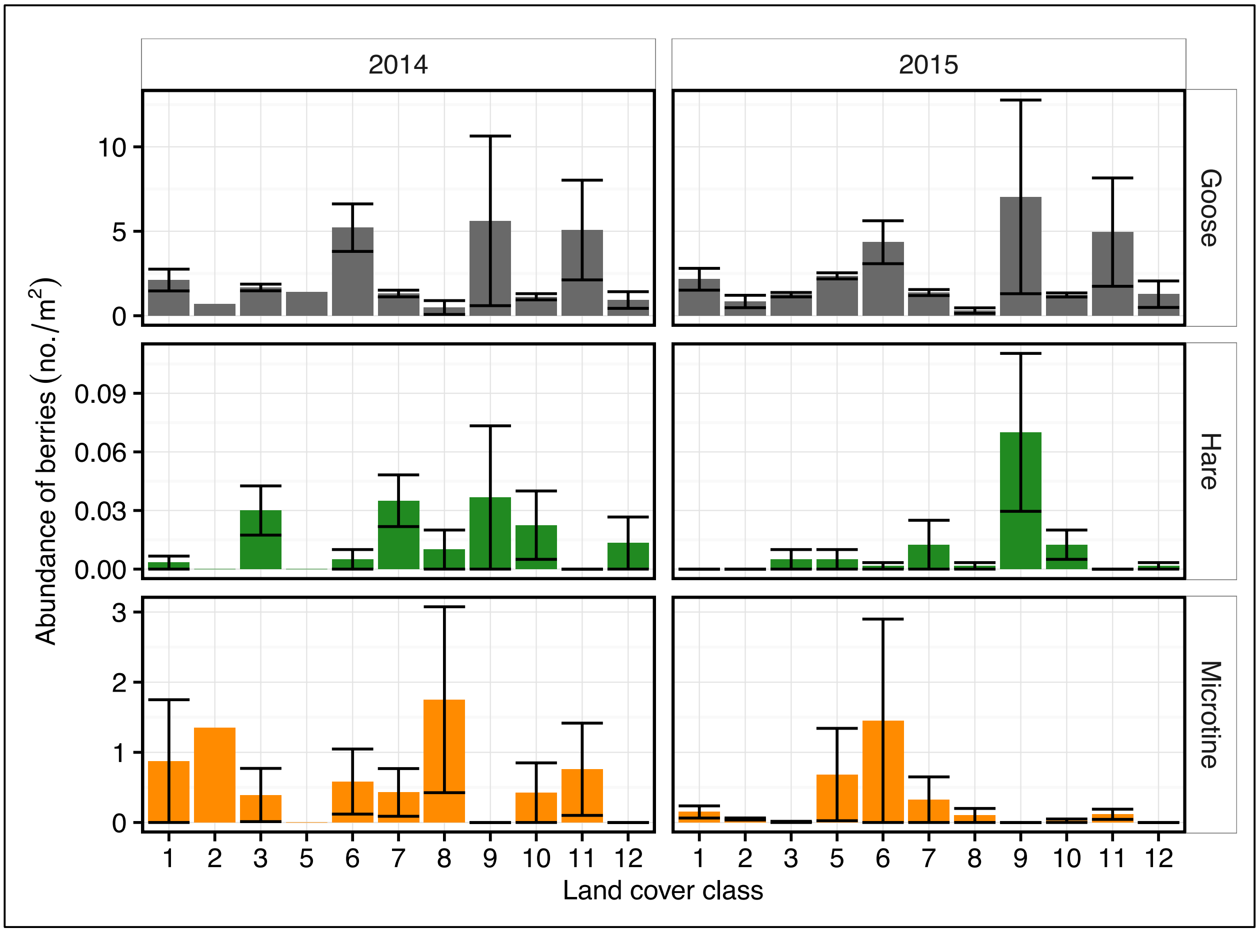

Figure 3.5 Abundance of feces (no./m^2) and associated standard error for the three main group of species recorded (goose, hare, microtine) presented for the 2014 and 2015 sampling per land cover class in the vicinity of Arviat, Nunavut. Scale of the y-axis differs between group of species.

Table 3.2 Average number of feces (no./m^2) and associated standard error for each animal group identified in the field. Symbol '–' indicates that no feces were found and 'tr' means that a trace amount was found (<0.01 feces/m^2).

	Average number of feces (no./m^2)						
	Land cover class						
	2	***5***	***6***	***9***	***11***	***12***	***Mesic***
Fox	tr	tr	tr	-	-	-	tr
Goose	0.81 (0.23)	2.13 (0.23)	4.78 (0.79)	6.33 (3.12)	5.02 (1.84)	1.10 (0.38)	1.42 (0.17)
Ground squirrel	-	tr	-	-	-	-	tr
Hare	-	tr	tr	0.05 (0.02)	-	0.01 (>0.01)	0.01 (>0.01)
Microtine	0.38 (0.28)	0.51 (0.43)	1.02 (0.65)	-	0.48 (0.35)	-	0.43 (0.16)
Passerine	-	-	-	tr	0.02 (0.01)	-	0.01 (>0.01)
Ptarmigan	-	0.01 (0.01)	-	0.03 (0.03)	-	-	0.01 (>0.01)
Tern	-	-	-	-	-	0.04 (0.03)	-
White liquid	-	0.01 (0.01)	-	-	-	0.07 (0.06)	-
Unknown	-	tr	-	-	tr	tr	tr

The small sampling size per land cover class gives little power to the mixed model analyses to test the difference in the abundance of berries and feces across land cover classes. However, I considered that even though it was not statistically possible to distinguish all land cover classes based on the abundance of berries and feces, they still generally represented different plant community types clearly identifiable in the field. Environmental variables, plant species cover as well as the abundance of berries and feces showed clear similarities for land cover classes 1, 3,7, 8 and 10 (i.e. the mesic cluster), I thus estimated that the ecological differences between those land cover classes for the variables studied must be minimal.

Maps of the abundance of berries and feces for the area of the municipality of Arviat show the distribution of berries and animals over the landscape (Figures 3.6 and 3.7). All five berry species were found in abundance in the same general areas indicating that even though each species had a slightly different preference in terms of moisture, they are still within a range of largely mesic sites where the largest abundance of hare feces was also found. Geese feces were largely found in wetter habitats, but were generally abundant throughout the territory. Microtine feces were largely found at an intermediate level of abundance (<0.01-0.51 feces/m^2) throughout the study area.

The total area of land for the municipality of Arviat is 45.5 km^2. The biomass of berries estimated over that area was 16,429 kg (361 g/m^2), 756 kg (17 g/m^2), 461 kg (10 g/m^2), 307 kg (7 g/m^2) and 174 kg (4 g/m^2), respectively, for *Empetrum nigrum, Vaccinium vitis-idaea, Arctous alpina*, *V. uliginosum* and *Rubus chamaemorus*. The total number of feces estimated for the same area was $3.3*10^6$ feces, $2.1*10^4$ feces and $1.1*10^4$ feces respectively for geese, microtines and hare. Based on the estimated defecation rate of 100 feces a day for geese, abundance in the area can be estimated to 33,208 geese-days. Similarly, based on a defecation rate of 208 feces a day for hare, abundance in the area can be estimated to 52 hares-days.

The number of berries per feces was highest in land class 12 and the mesic cluster for geese (Table 3.3). Berry seeds were only found in hare feces collected in in the mesic cluster (Table 3.3). No *R. chamaemorus* seeds were found in hare feces and no seeds of *Arctous alpina* were ever observed in any of the feces. Unfortunately, due to the time intensive laboratory work and because samples were processed after the 2014 field season, which meant that some samples had to be disregarded after sites were excluded from the analysis, there is a low sample size for the number of feces analyzed per species and land cover classes (n=1-7). No herbivory was detected on *A. alpina*, while 5%, 3% and 2% of respectively *R. chamaemorus, Vaccinium spp.*, and *E. nigrum* fruit production was consumed by geese and hares over the area of the municipality of Arviat.

Table 3.3 Average number of berries in the feces of goose and hare and associated standard error per land cover classes for the four berry species or genus identified in the laboratory. Symbol '–' indicates that no seeds were found in the feces of that animal species.

		Number of berries per feces						
		Land cover class						
		2	***5***	***6***	***9***	***11***	***12***	***Mesic***
Goose	*A. alpina*	-	-	-	-	-	-	-
n=21	*E. nigrum*	-	-	0.11 (0.10)	-	0.22 (0.16)	4.30 (3.51)	6.81 (3.52)
	Vaccinium spp.	-	-	0.47 (0.33)	-	0.29 (0.21)	6.53 (5.30)	3.29 (2.99)
	R. chamaemorus	-	-	-	-	-	-	0.17 (0.15)
Hare	*A. alpina*	-	-	-	-	-	-	-
n=5	*E. nigrum*	-	-	-	-	-	-	0.09 (0.08)
	Vaccinium spp.	-	-	-	-	-	-	0.23 (0.10)
	R. chamaemorus	-	-	-	-	-	-	-

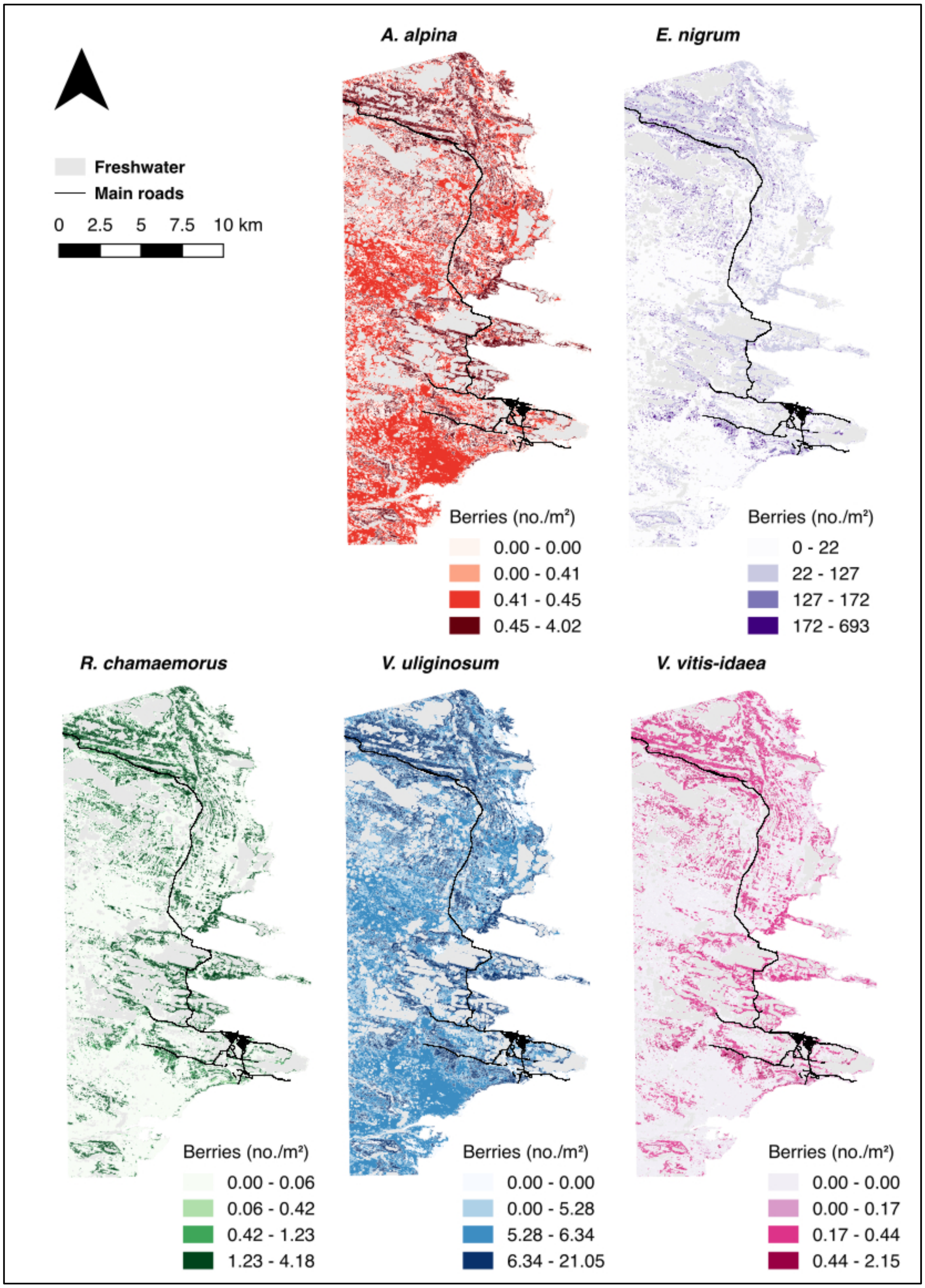

Figure 3.6 Abundance (no./m^2) and distribution of the five berry species studied for the municipality of Arviat based on field surveys and extrapolations from the 30 m resolution land cover map (Olthof et al. 2009). Main roads are based on Pleides-1A at 50 cm resolution and were processed by Community and Government Services of the Government of Nunavut (used under permission). Abundance scale based on Jenks natural breaks method.

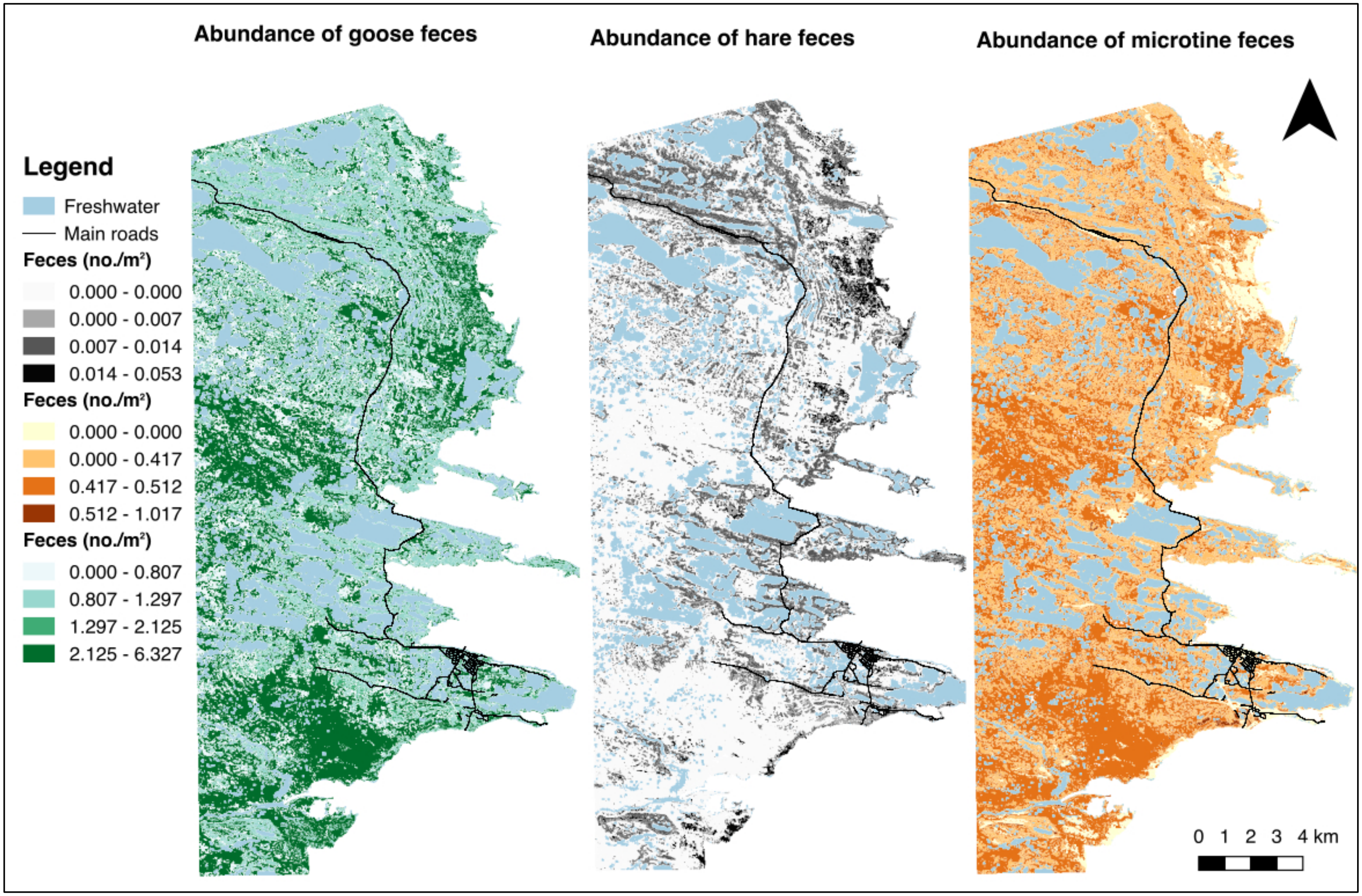

Figure 3.7 Abundance (no./m^2) and distribution of animal feces for the municipality of Arviat based on field surveys and extrapolations from the 30 m resolution land cover map (Olthof et al. 2009). Main roads are based on Pleides-1A at 50 cm resolution and were processed by Community and Government Services of the Government of Nunavut (used under permission). Abundance scale based on Jenks natural breaks method.

3.4 Discussion

Berry species are found throughout the landscape and are more abundant in mesic and to some extent in xeric sites, such as on eskers and bedrock. The vegetation map shows that mesic sites are somewhat limited on the west coast of the Hudson Bay due to large bodies of freshwater and areas covered by wetlands. Probably for this reason, the surroundings of Arviat are not considered by locals to be a prime berry picking area. However, densities of berries in the best patches are similar to elsewhere in the Canadian Arctic (Chapter 4) and higher than values recorded in other low Arctic (Hupp et al. 2013) and boreal locations (Ihalainen et al. 2003, Murray et al. 2005).

The abundance of geese feces in close proximity to the shore as well as in wetlands clearly illustrated the impact of migrating geese in the spring. Although geese are still the most abundant animal species to occupy the land during the rest of the growing season, they do so to a lesser extent. Feces counts only provided a proxy of animal activity and should not be considered an accurate assessment of the actual number of animals present in the field. Bias associated with this methodology includes differences in accuracy between observers, vegetation types (Bédard and Gauthier 1986) as well as inherent visibility issues, such as feces deposit underground or in the water. Nevertheless, animal feces densities in the vicinity of Arviat are very high compared to elsewhere in the circumpolar Arctic (Jónsdóttir et al. 2015). The diversity of animal feces is comparatively low and dominated by avian fauna which may be associated with the proximity to the community and extensive human impact, but also corresponds to generally low diversity of herbivores in the Arctic (Barrio et al. 2016).

Although the low sample size limits the interpretation of the percentage of berries eaten by animals, results provide a general order of magnitude of the impact of animal consumption on berry availability. Overall, 2-5% of the berries produced are being consumed by geese and hares. A number of cautionary remarks are however necessary regarding these data. Values may underestimate total consumption because even though I harvested the fruits when most were ripe, berries are most probably eaten later in the season. The methodology used was also poorly suited to evaluate the impact of grazing by microtines and ground squirrels, and the importance of berries in their diet was most definitely underestimated (Krebs et al. 2010). On the other hand, values may be overestimated because geese could be eating berries from the previous year in the spring on their northward migration and the seeds of those berries would have been present in the feces collected. Values may also overestimate animal consumption because the percentage of berries eaten was calculated on the number of fruit available after animal consumption; the feces and the berries were collected at the same time. Hupp et al. (2013) using the amount of *E. nigrum* counted before and after the passage of the cackling geese on the Alaska Peninsula in the fall estimated that 30- 60% of the annual production was lost to herbivory. Considering that Arviat is not located on the southward migration path of geese, the values presented here fit well with a resident population of geese of moderate abundance.

Field investigations were complicated due to extensive impact of human activities on the land in the vicinity of Arviat. Since mesic habitats are primarily selected for roads and cabins, a significant portion of the best berry picking sites had human infrastructures. This indicates on one hand that our results overestimate the number of berries produced because I did not specifically account for the impact of infrastructures and human activities. On the other hand, it also points to community development and related pollution as additional limiting factors for berry pickers. The compounding effect of increase in goose populations (Abraham et al. 2005) and community development may have an impact on the availability of berries in a context where a limited number of berry patches are easily accessible from the community.

3.5 Conclusion

This study provides the first estimation of the abundance and distribution of berry producing species on the west coast of the Hudson Bay. While preferred habitats for these plant species were relatively well known, results showed the extent to which those are present, accessible and affected by animal and human activities in the vicinity of Arviat. I found that the region has a low diversity of terrestrial animals but hosts a large number of geese throughout the growing season. Geese are moderately abundant during August and berries are relatively abundant in the feces of geese, yet they only eat a marginal portion of the total production, despite the likely underestimation of their consumption of berries. The initial hypothesis that geese eat a significant portion of the annual production of berries was thus not verified. In a context where few productive berry patches are easily accessible, and both humans and geese are preferentially selecting those patches, there may still however be a perceived competition for the resource.

Chapter 4: Climate and environmental drivers of berry productivity in the Canadian North

4.1 Introduction

Berry shrubs are circumpolar species that produce a great abundance of fruits each year, but the climatic and environmental factors influencing their productivity are poorly known, especially in the Arctic. Numerous animal species in the Arctic, as well as contemporary Inuit rely on berries as a local source of nutrients and vitamins (Chapter 2, Fediuk et al. 2002, Cadieux et al. 2005, Krebs et al. 2010). Berry picking is a traditional activity still largely practiced in Inuit communities and it contributes to community well-being and sharing practices (Chapter 2, Simard-Gagnon 2013). A better understanding of the drivers of berry productivity will help to inform decisions on land use and traditional activities in the Arctic.

Indigenous people from the Canadian Arctic and Alaska have been expressing growing concerns about the reliability of berry harvest due to declining abundance and increasing annual variability (Cuerrier et al. 2015, Hupp et al. 2015). Climate change as well as fluctuations in temperature and precipitation from year-to-year were highlighted as posing the greatest risks to local berry resources (Kellogg et al. 2010). Local observations indicated the importance of winter conditions, particularly abundant precipitation in the form of snow as crucial to develop a high yield, high-quality berry harvest, with warmer, drier winters resulting in fewer and less tasty berries (Flint et al. 2011). Moderate summer warmth, sunshine, and adequate precipitation were also seen as essential to the abundance and quality of berries (Kellogg et al. 2010).

Throughout the year, climatic factors influence the development and reproduction of berry species in different ways. Winter temperature, total precipitation and snow cover may prevent or induce frost injuries and desiccation (Tahkokorpi et al. 2007, Taulavuori et al. 2013). Spring temperature and precipitation as well as cloud cover and wind influence flower bloom and pollinator activity (Jacquemart 1997, Wipf et al. 2009). Summer weather determines the number of pollinated flowers producing viable fruits along with the size of those fruits (Selas et al. 2015). Temperature and precipitation in the year prior, and some suggest two years prior, influence nutrient storage and the formation of flower primordia (Selas 2000, Krebs et al. 2009). Different metrics of plant productivity are also expected to reflect the influence of climate on different portions of the plant life cycle. As such, the abundance of berries is closely linked to reproductive effort (i.e. number of flowers produced) and pollination success, which reflect winter and spring conditions. Alternatively, the biomass of fruits depends on the abundance of berries but also on summer conditions determining fruit development.

The main effects of climate change on berry species are expected to be winter (Taulavuori et al. 2013) and spring (Wipf et al. 2009) warming combined with a thin layer of snow (Tahkokorpi et al. 2007) that will negatively affect berry productivity and vegetative growth (Aerts 2010, Bokhorst et al. 2011). Cold season warming is associated with early dehardening (i.e. reduced physiological adaptation to cold temperatures), exposure to drought (Rixen et al. 2010, Selas et al. 2015) and frost injuries (Tolvanen 1997). However, a number of Arctic berry species were found to have a high tolerance to ice encasement (i.e. the formation of an ice layer in the snow pack; Preece and Phoenix 2014) as well as spring and summer frost events (Tolvanen 1997, Saarinen and Lundell 2010). *Vaccinium* species may recover vegetatively from frost injury through stimulated shoot elongation, but the number of aborted flower buds increases with the number of frost days after greening (Wipf et al. 2009). Graae et al. (2008) measured compounding effects of warm temperatures during the seed incubation period which favoured germination but increased fungal infection.

Warming will have differential effects on plant populations depending on local environmental conditions (Elmendorf et al. 2012, Myers-Smith et al. 2015). Soil moisture mediates the effect of temperature with plants growing on moist sites being more sensitive to warming temperature (Elmendorf et al. 2012, Boulanger-Lapointe et al. 2014). Field experiments showed that warming temperatures significantly influence annual growth of *E. nigrum* and *V. vitis-idaea* but plant response is mitigated by species composition and water availability (Shevtsova et al. 1997). Latitude and canopy height (Elmendorf et al. 2012, Myers-Smith et al. 2015) were also found to influence the strength of the response to warming temperatures with, on average, lower latitudes and taller shrubs being more sensitive. Similarly, *Empetrum* species were found to respond differently to warming temperatures in boreal and tundra ecosystems with a weaker response in the later (Tybirk et al. 2000).

Increase in shrub cover has been documented in many Arctic, subarctic and alpine regions and is expected to be one of the major effects of climate change on Arctic terrestrial ecosystems (e.g. Sturm et al. 2001b, Forbes et al. 2010, Tremblay et al. 2012, Myers-Smith et al. 2015). Shrubs are growing at a faster rate, existing shrub patches are infilling, and the shrub line is moving up in altitude in alpine areas and to higher latitudes in Arctic systems (Myers-Smith et al. 2015). Erect shrubs have a negative impact on growth and productivity of berry plants by shading the prostrate and low berry species (Lavallée 2013, Lussier 2016). Moreover, high phenolic content in leaves of berry species are believed to reduce grazing pressure because of low palatability and digestibility but the concentration of phenolic compounds in leaves are expected to decrease with increased shading (Hansen et al. 2006). Hence, even if warming temperatures benefit shrub growth in general, it may have an overall negative impact on berry shrubs.

Berry shrubs, fruits and stems, are known to be important sources of food throughout the year for animals in the Arctic. Ripened fruits of *Vaccinium* and *Empetrum* species provide Canada geese the energy required for pre-migratory fat deposition and constitute > 40% of their diet in late summer (Sedinger and Raveling 1984, Cadieux et al. 2005). Berries may also be important for passerines (Norment and Fuller 1997), shorebirds (McCaffery 1998) and ptarmigan (Weeden 1969). They are a main source of food for grizzly bears (*Ursus arctos*; Ripple et al. 2014), a boreal species whose density in the Arctic has steadily been increasing in the last three decades (Dumond et al. 2015). They may also be of importance for polar bears (*Ursus maritimus*; Dyck and Kebreab 2009, Rode et al. 2010, Gormezano and Rockwell 2013). Berries represent 14-30% of red fox (*Vulpes vulpes*) scat but are a negligible portion of Arctic fox (*Vulpes lagopus*) diet (Ehrich et al. 2015). The red fox is another boreal species whose density has steadily been increasing in the Arctic since the beginning of the 20th century (Berteaux et al. 2015). Throughout Arctic and alpine environments, berry shrubs leaves, buds and fruits constitute a significant portion of rodents' diet (Andersson and Jonasson 1986, Selas et al. 2013). In the southern Yukon, Krebs et al. (2010) found that voles rely heavily on *Empetrum nigrum* as a main source of food in winter. Long-term monitoring studies in Fennoscandia showed that vole abundance, moth outbreaks and climate were all important to understand the productivity of *Vaccinium myrtillus* (Boulanger-Lapointe et al. 2017).

In the context of rapid cultural, environmental and land use changes in the Arctic, an extensive research effort was initiated under the Canadian International Polar Year program, and continued under the ArcticNet (a Network of Centres of Excellence of Canada), to better understand the ecology and Inuit *Qaujimajatuqangit* (IQ) of berries (Henry et al. 2012). In this study, I present the first synthesis of this ongoing research effort that brought together local knowledge holders, schools and scientists to better understand spatial and long-term trends in berry productivity across Inuit Nunangat.

4.2 Methods

4.2.1 Study sites

Berry-monitoring sites were established across Inuit Nunangat in the vicinity of research stations and Inuit communities (Figure 4.1). When possible, sites were established in collaboration with local communities and partnerships with high schools were developed to integrate berry monitoring in science classes. The sites were chosen and established by researchers from the Université du Québec à Trois-Rivières, Memorial University and the University of British Columbia. Plots were chosen based on accessibility, minimum disturbance to local harvesting sites and abundance of berries. Study sites cover three of the four Canadian Inuit territories, namely Nunavut, Nunatsiavut (Newfoundland & Labrador) and Nunavik (Quebec), and extend south to the Northwest Territories. Only prostrate vegetation is found at Alexandra Fiord, Bylot Island and Pond Inlet located in the high Arctic (Bliss 1997) and subzone C of the Circumpolar

Arctic Vegetation Map (Walker et al. 2005). Pangnirtung, Kangiqsujuaq and Iqaluit, located in subzone D, are dominated by prostrate vegetation but tall shrubs grow in sheltered areas. Daring Lake, Kugluktuk and Baker Lake are located in subzone E where there is a mixture of tall and low vegetation. Subzone D and E are also classified as low Arctic (Bliss 1997). Kangiqsualujjuaq, Nain and Umiujaq are located south of the tree line in the forest tundra-ecotone, going away from these communities, inland or to the south, tree cover becomes progressively denser. A total of 25 study plots was established between 2008 and 2011, but analyses were performed on 21 of those plots for which productivity was documented during at least three growing seasons (Table 4.1). A minimum of 8 and a maximum of 21 plots in 5 to 10 sites were sampled every year during that period.

Table 4.1 Establishment date of the sites, number of plots at each study site, number of years during which each site was visited between 2008 and 2015, and number of plots sampled at each site when it was visited. Study sites are presented from north to south.

Sites	Start year	Total no. of plots	No. of years visited	No. of plots sampled each year
Alexandra Fiord	2011	3	5	3
Bylot Island	2009	1	6	1
Pond Inlet	2008	3	6	1-3
Pangnirtung	2008	2	4	2
Kugluktuk	2010	3	5	1-3
Iqaluit	2009	1	7	1
Baker Lake	2009	4	5	1-4
Daring Lake	2008	1	6	1
Kangiqsujuaq	2008	2	5	2
Kangiqsualujjuaq	2008	2	3	2
Nain	2009	6	3	6
Umiujaq	2009	3	3	1-3

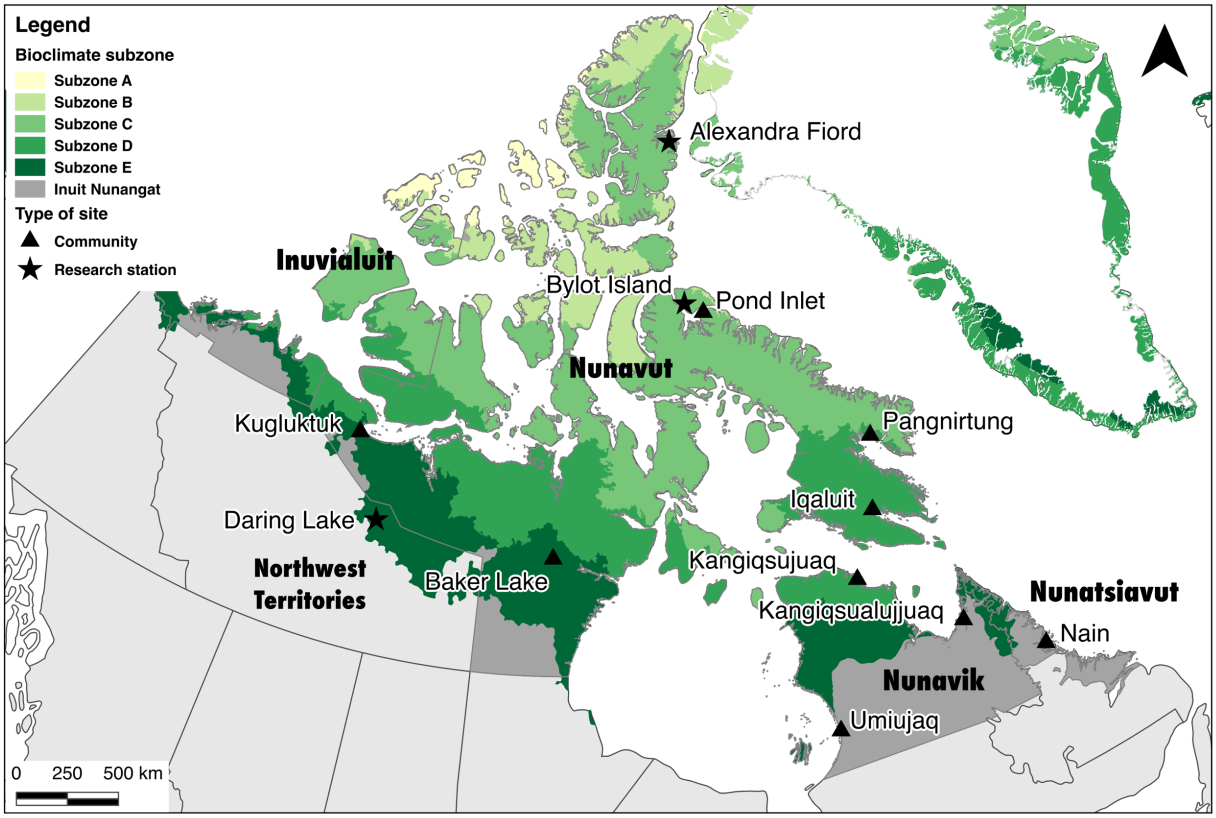

Figure 4.1 Study sites located in three Inuit territories, Nunavut, Nunavik (QC) and Nunatsiavut (NL) and the Northwest Territories. Markers of different shapes indicate the type of site, i.e. community or research station.

4.2.2 Study species

The study focuses on the three most common and widespread berry species in the Canadian Arctic, namely blueberry (*Vaccinium uliginosum* L., Figure 4.2c), cranberry (*Vaccinium vitis-idaea* L., Figure 4.2b) and crowberry (*Empetrum nigrum* L., Figure 4.2a). Species names followed the classification of the Flora of North America (Flora of North America Editorial Committee 1993+). All species are woody dwarf shrubs that belong to the Ericaceae family. They have a circumpolar distribution and range from the forest-tundra ecotone to the high Arctic in sheltered areas. *Vaccinium uliginosum* is a deciduous species that grows on moderately to well-drained flat terrain and shallow slopes. Flowers are pink and bell-shaped; fruits are dark blue. *Vaccinium vitis-idaea* is comparatively smaller with a height of 5-10 cm; horizontal stems at ground level sometimes form mats. It is an evergreen species that produces white flowers and spherical red fruits. It is often observed growing in well-drained to dry habitats. *Empetrum nigrum* is found throughout the Arctic as far north as Ellesmere Island. It is a low woody species with horizontal stems branching extensively to shape plant habit as mat. Leaves are evergreen and needle-shaped; fruits are dark purple to black. *Empetrum nigrum* is shade and drought intolerant; its occurrence is linked to snow cover that provides a drought and frost barrier during the winter (Tybirk et al. 2000). Both *Empetrum* and *Vaccinium* species thrive in poor soil with high carbon to nitrogen ratios (Heikkinen and Mäkipää 2009).

Figure 4.2 Study species: a) *Empetrum nigrum*, b) *Vaccinium vitis-idaea*, c) *Vaccinium uliginosum*.

4.2.3 Field measurements

At each site, except Alexandra Fiord, at least one, but up to six 20 m x 20 m plots were permanently marked. The number of sites or plots surveyed within each site varied annually according to local participation and researchers' visits (Table 4.1). Information on vegetation cover was collected in each plot at the time of establishment using Braun-Blanquet cover classes (Braun-Blanquet 1932) or the point intercept method (Molau and Mølgaard 1996). Berries were collected in 25 random 25 cm x 25 cm quadrats within plots. Empty quadrats were recorded until 25 quadrats with berries were found. The number and weight of berries was measured for each quadrat. At Alexandra Fiord, berries were collected in 30 permanent 25 cm x 25 cm quadrats located 3 m apart along three randomly located transects; the three permanent transects were considered as equivalent to plots at other sites. After fieldwork and laboratory analyses, data were sent to the affiliated university or in Nunavik, uploaded on the *Avativut* portal (http://www.cen.ulaval.ca/avativut/).

4.2.4 Statistical analyses

I used the berry productivity dataset to conduct two main analyses. First, I evaluated the influence of plant species composition and local environmental factors on the abundance of berries, hereafter called the spatial analysis. Second, I modelled the inter-annual variation in the number and weight of berries across study sites in relation to climate, hereafter called the inter-annual analysis. All statistical analyses were conducted using R software (R Core Team 2016).

4.2.4.1 Spatial analysis

To assess environmental differences between plots, I computed a non-metric multidimensional scaling (NMDS) ordination using the plant species data. The plant species cover data measured with Braun-Blanquet classes were standardized to 100 for each quadrat and then averaged per plot. For the point intercept data, the top hits were standardized to the number per 100 per quadrat and then average per plot. The analysis was performed using the metaMDS function in the vegan package (Oksanen et al. 2012). A three-dimensional ordination displayed the least stress and was repeated 100 times to reach the best solution for each NMDS (Legendre and Legendre 1998). The effect of local environmental factors (i.e. altitude, latitude, and cover of erect shrubs, lichens and mosses) on the relative productivity of each berry species per plot (i.e. abundance of berries/species cover) was tested using a linear model.

4.2.4.2 Inter-annual analysis

Climate data were extracted from CANGRD, a gridded dataset with a 50 km resolution. Grids of monthly temperature and precipitation are generated through statistical interpolation using adjusted and homogenized climate data (AHCCD; Environment Canada 2012). These climate data are adjusted for instrument relocation, trace observations, and changes in observing procedures and are therefore the most reliable climate data for Canada.

I fitted a generalized linear mixed model with normal random effects using penalized quasi-likelihood estimation (function glmmPQL, package MASS; Venables and Ripley 2002). I used a negative-binomial distribution for the abundance of berries (count data) and a Gamma distribution with a log link function for the weight of berries (continuous data). To satisfy the requirements of the Gamma distribution, I performed the analyses on all weight values above zero. The abundance and weight of berries for each species (i.e. *Vaccinium uliginosum, Vaccinium vitis-idaea* and *Empetrum nigrum*) were tested against standardized climate variables with the plot and the site as random effects. Even though the detailed abundance per quadrat was known, I used the average per plot to avoid problems related to the very high number of zeros. For *Vaccinium uliginosum*, I conducted two separate analyses, one for the high Arctic sites (i.e. Alexandra Fiord, Bylot Island and Pond Inlet) and one for the low Arctic and forest-tundra ecotone sites (i.e. all the other sites). For *Empetrum nigrum*, I did one analysis because the species was only found in the low Arctic sites. Based on ecological assumptions as well as the literature, the explanatory variables selected were: 1) mean temperature from November to April, 2) mean precipitation from November to April, 3) mean June temperature, 4) mean June precipitation, 5) mean temperature during July and August, 6) mean precipitation during July and August, 7) mean temperature during July and August of the previous year, and 8) mean precipitation during July and August of the previous year. The final models were selected following a backward selection method, i.e. the variables with the lowest fit were successively dropped. Models were validated by visual evaluation of the plotted response and deviance residuals (Zuur et al. 2009). Once the best models were selected I calculated the marginal (R^2m) and conditional R^2 (R2m, package MuMIn, Barton 2016). The marginal R^2 describes the portion of the variance explained by the fixed factors only (equivalent to a linear model) while the conditional R^2 describes the variance explained by both the fixed and random factors (Nakagawa and Schielzeth 2013).

4.3 Results

The data presented in this synthesis are spatially and temporally complex. The sites present a gradient in annual temperatures with temperature during July and August from 0.8°C (Bylot Island) to 11.7°C (Nain; Figure 4.3). Precipitation in June and July and August also presents a clear gradient with a minimum during July-August of 32 mm at Alexandra Fiord and a maximum of 90 mm at Nain. In contrast, winter precipitation (November-April) was similar among sites with the exception of Nain which received a greater amount of snow. The increasing number of missing precipitation data since 2013 is due to the shift in recent years from human observation to automatic meteorological stations in the Canadian Arctic (Ewa Milewska, personal communication).

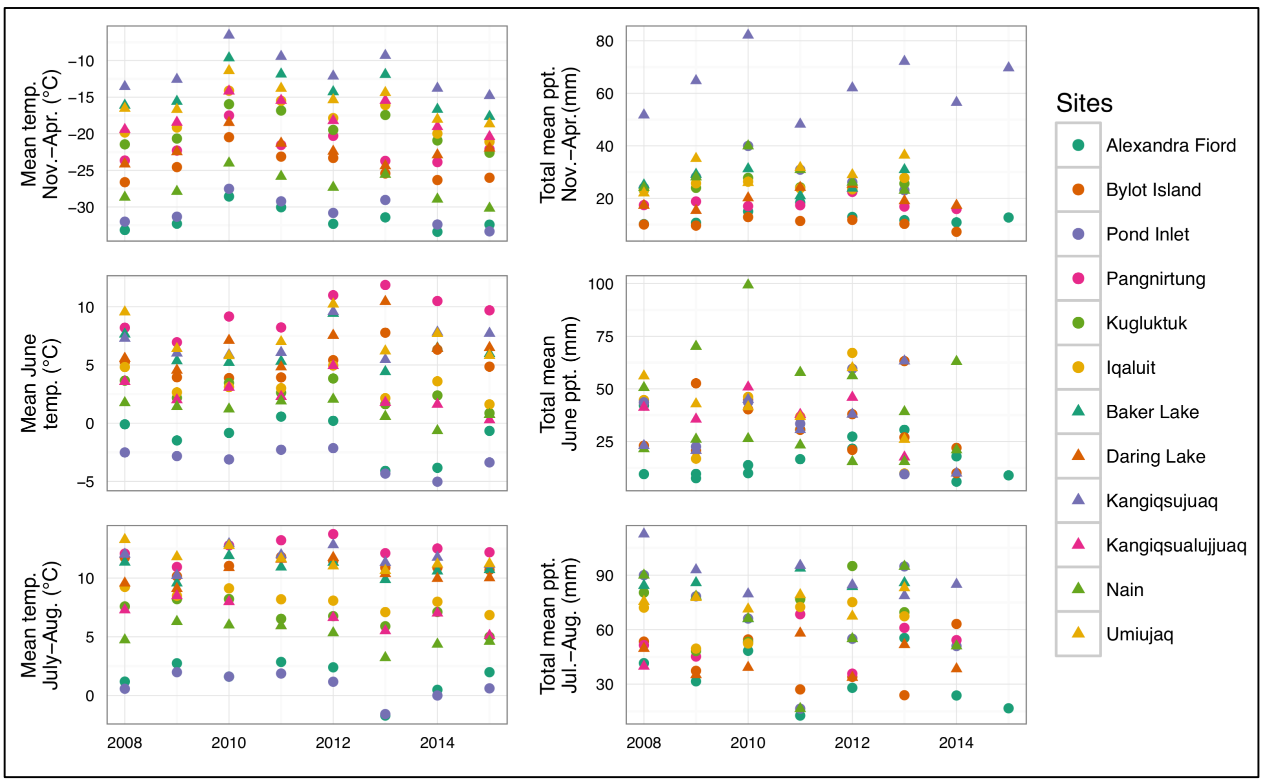

Figure 4.3 Climate data for all study sites and explanatory variables used in the model for the period 2008-2015: Mean temperature from November to April (°C), total precipitation from November to April (mm), total June precipitation (mm), mean June Temperature (°C), mean temperature during July and August (°C), total precipitation during July and August (mm). Study sites are presented in the legend from north to south.

The abundance of fruits in subzone D (Pangnirtung, Kangiqsujuaq and Iqaluit) was much higher than elsewhere with abundance for all species combined of 484 (SE=20), 360 (SE=17) and 361 (SE=16) berries/m^2, respectively (Figures 4.4 and 4.5). Abundance at the other sites varied from 97 berries/m^2 to 225 berries/m^2. Average productivity values per site are generally a good estimation of the abundance of berries in productive patches for those regions however sites where a small number of plots were sampled may be less representative (i.e. Bylot Island, Daring Lake, Iqaluit). Furthermore, values for Alexandra Fiord overestimate regional productivity since at this site only data were collected in permanent quadrats placed on *Vaccinium uliginosum* plants. Inter-annual variability is important at all sites and can have an amplitude from almost zero to 300 berries/m^2 for the same site (Figure 4.6).

4.3.1 Spatial analysis

Non-metric multidimensional scaling (NMDS) ordinations showed four groupings based on plant species composition (Figure 4.7). The first grouping included the high Arctic sites located in subzone C (i.e. Alexandra Fiord, Bylot Island and Pond Inlet) and the second consisted of the sites located in subzone D (i.e. Iqaluit, Kangiqsujuaq and Pangnirtung). The third grouping consisted of the sites located in subzone E (i.e. Daring Lake, Kugluktuk and Baker Lake) with those near the tree line (i.e. Daring Lake and Kugluktuk) placed closer to the fourth grouping which included the sites located in the forest-tundra ecotone (i.e. Kangiqsualujjuaq, Nain and Umiujaq). I obtained similar results when using the plot instead of the site as the grouping factor indicating that even though plots varied in their plant composition and environmental conditions, they are still closely linked to their position along the climatic gradient. The upper portion of the plot presented sites with more standing water and in general, plant species that require greater soil moisture. The only significant correlation between the abundance of berries and environmental variables was a positive link between the cover of lichen and the abundance of *Vaccinium uliginosum* ($p<0.01$). However, this correlation was largely driven by one plot in Umiujaq with a large cover of lichen and high berry productivity. The correlation was no longer significant once I excluded that plot.

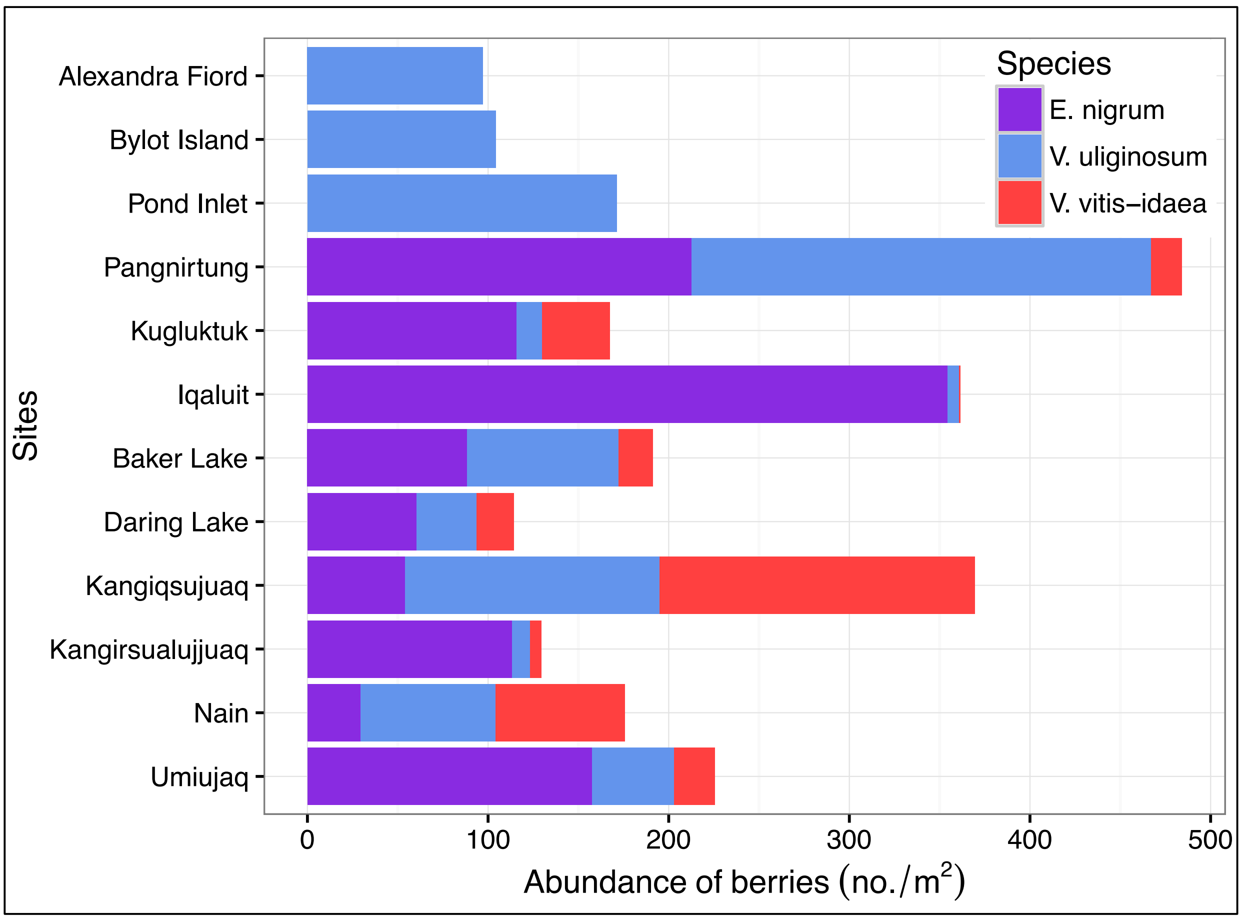

Figure 4.4 Mean abundance of the three berry species at each study site, all years combined. Study sites are presented from south (Umiujaq) to north (Alexandra Fiord).

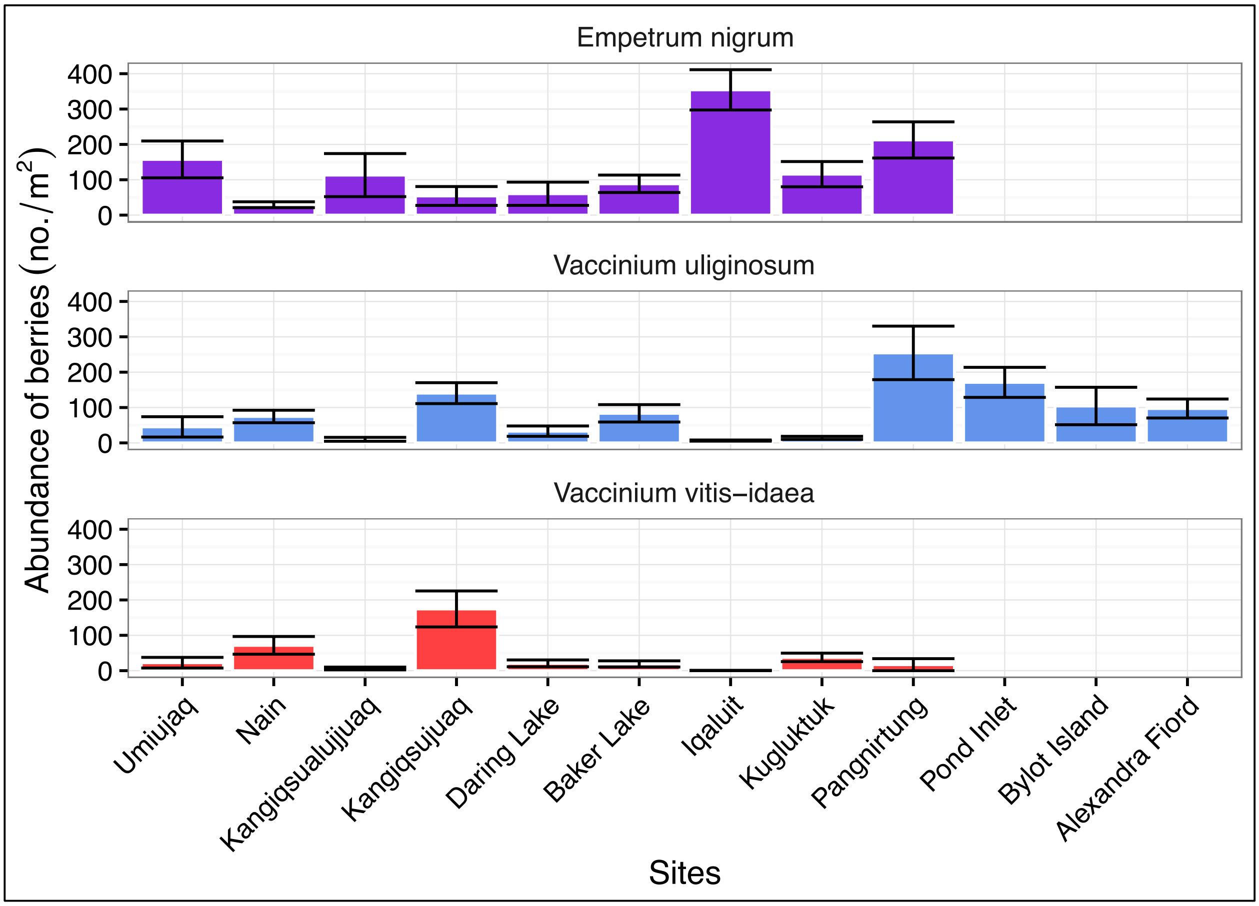

Figure 4.5 Mean abundance (no./m^2) and associated standard error of the three berry species at each study site, all years combined. Study sites are presented from south to north.

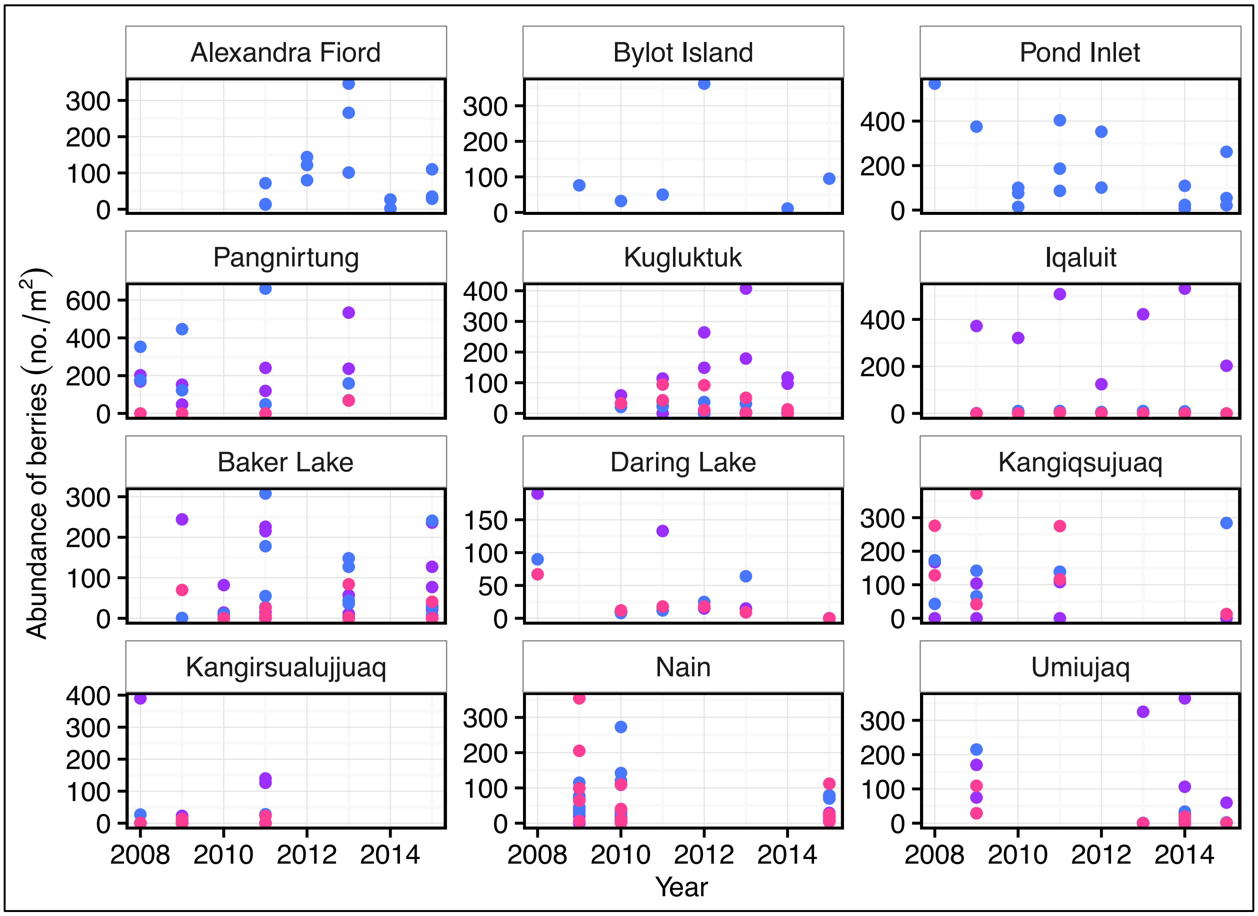

Figure 4.6 Mean abundance (no./m²) of the three berry species between 2008 and 2015 at each study site. Individual points present average per plot and colours represent each species: blue, *Vaccinium uliginosum*; purple, *Empetrum nigrum*; pink, *Vaccinium vitis-idaea*. Study sites are presented from north to south. Scale of the y-axis differs between sites.

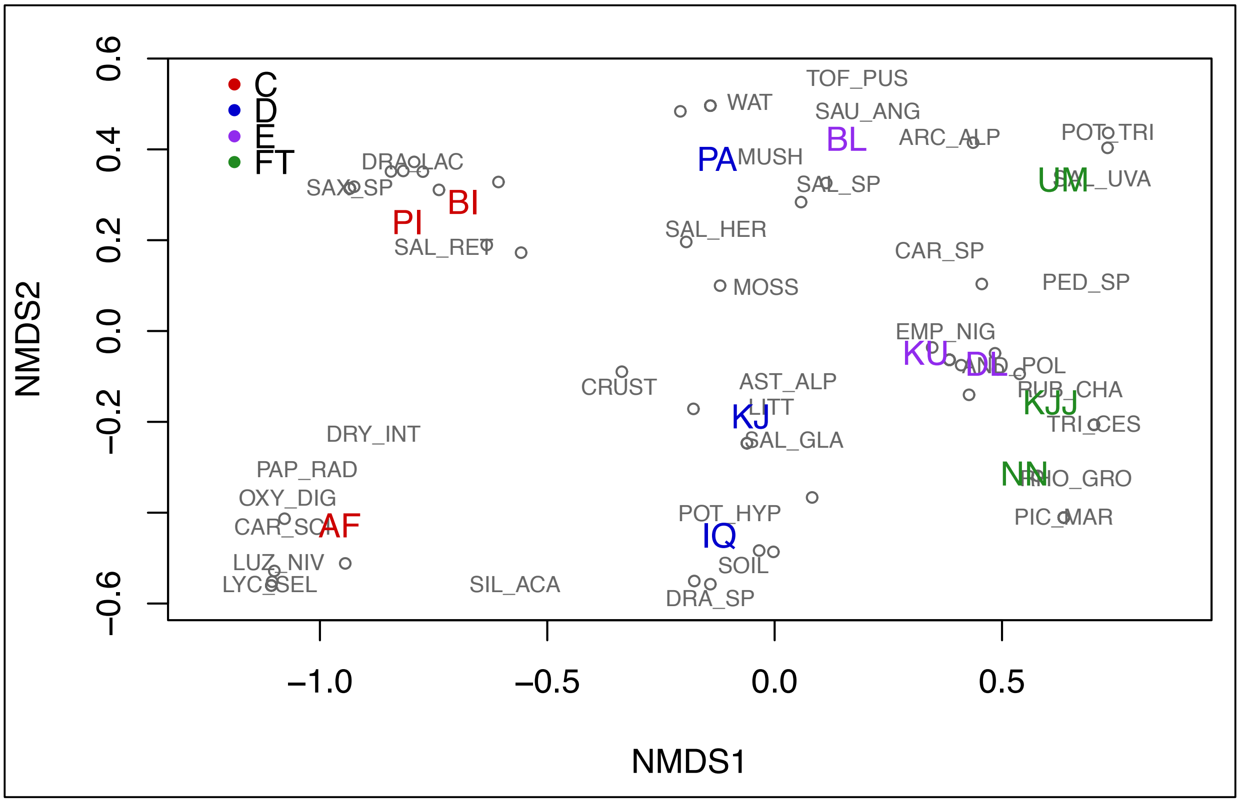

Figure 4.7 Results from NMDS ordination using the plant species cover per site. The abbreviations for the site names correspond to: AF, Alexandra Fiord; BI, Bylot Island; BL, Baker Lake; DL, Daring Lake; IQ, Iqaluit; KJJ, Kangiqsualujjuaq; KJ, Kangiqsujaq; KU, Kugluktuk; NN, Nain; PA, Pangnirtung; PI, Pond Inlet; UM, Umiujaq. The colour of each name represents the CAVM subzone as well as the forest-tundra ecotone (FT).

4.3.2 Inter-annual analysis

The generalized linear models showed the contrasting effects of winter, spring and summer conditions on berry productivity (Table 4.2). The best models for the abundance and weight of *Vaccinium uliginosum* fruits in the low Arctic included a positive effect of the previous year temperature from July and August and current year June precipitation. In the high Arctic, the models selected for the abundance and weight of *V. uliginosum* fruits included a number of variables (Table 4.2). For the abundance of berries, there was a strong positive effect of the temperature from November to April as well as a strong negative effect of the precipitation from November to April. A negative effect of winter precipitation was also found for the weight of *V. uliginosum* fruits in the high Arctic although the slope of the correlation was comparable to the other variables selected. All models for *V. uliginosum* fruits had a similar positive intercept for the random effects “plot” and “site”, except for the weight of berries in the high Arctic, for which the random effects “site” had a marginal value.

The best model for the abundance of *Empetrum nigrum* fruits included a positive influence of temperature during July and August and a negative effect of the precipitation from November to April. The best model for the weight of *E. nigrum* fruits included previous year precipitation during July and August, current year temperature during June, and during July and August, and June precipitation as well as November to April temperature. The random effect “site” had very little explanatory power compared to the “plot” effect for the two analyses. All models presented a large difference between the marginal and conditional R^2. This difference was however smaller when models included a greater number of variables. It was not possible to find significant variables for the abundance and weight of *Vaccinium vitis-idaea* as the low number of observations did not allow models to converge.

Table 4.2 Results from the generalized mixed effect models for the inter-annual analyses with *Vaccinium uliginosum* and *Empetrum nigrum* abundance and weight. All slope variables are significant at p<0.05.

Species		**Random effect intercepts**		**Fixed effects**			
	df	**Site**	**Plot**	**Variables**	**Slope (SE)**	**R^2m**	**R^2c**
Abundance (no./m^2)							
V. uliginosum							
Low Arctic/ forest-tundra	35	0.957	0.856	July-Aug. temp. (t-1)	0.394 (0.136)	0.11	0.82
				June ppt. (t)	0.633 (0.181)		
High Arctic	16	0.540	0.802	June temp. (t)	0.533 (0.167)	0.61	0.88
				July-Aug. temp. (t)	0.683 (0.234)		
				July-Aug. ppt. (t)	0.555 (0.151)		
				Nov.-April temp. (t)	2.543 (0.462)		
				Nov.-April ppt. (t)	-2.534(0.380)		
E. nigrum							
Low Arctic	40	<0.001	2.420	July-Aug. temp. (t)	0.414(0.137)	0.01	0.94
				Nov.-Apr. ppt. (t)	-0.617(0.189)		
Weight (g/m^2)							
V. uliginosum							
Low Arctic/ forest-tundra	34	0.773	0.577	July-Aug. temp. (t-1)	0.333 (0.143)	0.10	0.58
				June ppt. (t)	0.518 (0.185)		
High Arctic	17	<0.001	0.649	July-Aug. temp. (t-1)	0.914(0.222)	0.50	0.78
				July-Aug. ppt. (t-1)	0.801(0.246)		
				June temp. (t)	0.742(0.158)		
				Nov.-April ppt. (t)	-0.945(0.215)		
E. nigrum							
Low Arctic/ forest-tundra	31	<0.001	0.644	July-Aug. ppt. (t-1)	-0.367(0.162)	0.36	0.62
				June temp. (t)	-0.341(0.161)		
				June ppt. (t)	-0.373(0.173)		
				July-Aug. temp. (t)	0.386(0.140)		
				Nov.-April temp. (t)	-0.766(0.188)		

4.4 Discussion

All berry pickers in the North have a theory on the environmental conditions and meteorological factors that make for a good berry year and good berry patch. This knowledge is based on lifelong observations. Quantifying such knowledge in order to discern the drivers of berry productivity above the noise requires a tremendous amount of observations and results from this synthesis are a first step in that direction.

The inter-annual and spatial analyses both pointed to the importance of the bioclimate gradient to understand berry productivity. In the inter-annual analysis, the location of the site was important to understand year-to-year variations in *Vaccinium uliginosum* productivity. In the spatial analysis, based on vegetation cover, sites were grouped according to their position along the bioclimate gradient and the best berry patches did not show similar plant community composition. Moreover, none of the local environmental variables, among the few available, were correlated to berry productivity. These results suggest that there may not be a single local environmental condition or climatic factor that is optimal for berry production throughout the study area. Indeed, studies conducted in alpine and forested areas of Europe showed that climate affects berry species differently depending on the position of the population along the species distribution range (Rixen et al. 2010, Boulanger-Lapointe et al. 2017). While the data available in this study limit site specific interpretations, some insights can be gained from the geographic location of the most productive patches.

At the regional level, sites located in subzone D had higher berry productivity. I hypothesized that this must represent the optimum location within the species distribution range where the balance of interspecific competition, and other biotic interactions, and environmental stressors is minimized (Svoboda and Henry 1987). This hypothesis is reinforced by the comparison with berry productivity data collected within the Gwich'in settlement areas located at the northern extent of the Canadian boreal forest (Murray et al. 2005) as well as in central Finland (Ihalainen et al. 2003). The difference is striking with much higher productivity values found in this study for all three berry species (Table 4.3). Berry productivity data collected near Kluane Lake in Yukon (Krebs et al. 2009) also suggest that productivity for the three study species is higher in the tundra than the boreal forest, however results are not as easily comparable.

Table 4.3 Average berry productivity (g/m^2) for *Vaccinium uliginosum, V. vitis-idaea* and *Empetrum nigrum* in the boreal forest of Canada and Scandinavia as well as in the tundra of the Canadian Arctic (this study). Ranges present variability between sites.

	Average productivity (g/m^2)		
Species	**Boreal forest Canada**	**Scandinavia**	**Tundra Canada**
V. uliginosum	0.02-0.75[1]	NA	0.40-36.30
V. vitis-idaea	0.52-3.49[1]	0.3[2]	<0.01-14.08
E. nigrum	0.04-2.04[1]	NA	4.71-30.22

[1] Murray, G., P. C. Boxall, and W. W. Ross. (2005)
[2] Ihalainen, M., K. Salo, and T. Pukkala. (2003)

In this study, I did not find a direct negative impact of the cover of erect shrubs on berry productivity (although see Lussier 2016). We may expect that the first habitats to suffer from increase in shrub cover due to recent climate change would be those that already have a significant cover of shrubs which will become denser (Myers-Smith et al. 2011). Since sites with high cover of erect shrubs were not selected, it is not surprising that this factor does not stand out. However, the spatial distribution of the most productive sites (in subzone D) supports the hypothesis that berry species are more productive where there are less erect shrubs.

A number of studies have focused on the impact of winter conditions as they are expected to experience major changes under current climate change scenarios (IPCC 2013). Northern residents usually associate a thick layer of snow with high berry productivity (Guyot et al. 2006, Cuerrier et al. 2015). However, Wipf and Rixen (2010) in a meta-analysis of experimental snow manipulation studies found mixed results for the effect of increased snow depth on berry shrub performance. They attributed this variability to the amplitude of change in snow depth as well as plant habitat (i.e. exposed with early snow melt vs late laying snow patches). In this study, I found a negative impact of winter precipitation in all models except for the weight and abundance of *Vaccinium uliginosum* in the low Arctic. Notably, the strongest negative effect of winter precipitation was found in the high Arctic, where delayed snowmelt may be critical on the already short growing season.

However, delayed snowmelt may not alone contribute to the negative impact of winter precipitation on berry productivity. There may be an interaction, not measured in this study, between winter precipitation and temperature. Winter precipitation falling as rain would cause ice-encasement and a thinning of the snow pack without ultimately contributing to spring runoff. On the other hand, the increase in winter precipitation recorded in the Arctic (IPCC 2013) has been associated with stronger winds modifying the distribution and quality of the snow (Gearheard et al. 2010, Gérin-Lajoie et al. 2016). Under these conditions, exposed sites may not accumulate more snow while sheltered areas would get a lot more. In depressions, the negative impact of delayed snowmelt would likely outweigh the benefits of a thick snow layer, such as protection from desiccation in the winter and water input in the spring (Wipf and Rixen 2010). Finally, northern residents have been reporting that snow is melting faster (Gérin-Lajoie et al. 2016), which corresponds with the diminution in the number of days with snow on the ground observed across the Arctic (AMAP 2011). The rapid melting of large snow packs, with potential flooding, would not provide optimal conditions for vegetative growth and flower initiation. Most studies of the influence of winter conditions on berry shrubs have been conducted in the alpine areas of Europe and more evidence from northern Canada and other Arctic areas would be needed to better understand the mechanisms behind the observed response.

Summer and spring temperature affected the number and weight of berries differently depending on latitude. While these results correspond to the scientific literature (Krebs et al. 2009, Selas et al. 2015) and local observations (Kellogg et al. 2010), the large number of variables included in the models limit potential interpretation. There are currently a number of missing values for the precipitation data and those will become available in the spring of 2017 (Ewa Milewska, personal communication), I thus hope to be able to get better models once those data are included in the analyses.

Finally, previous studies of berry shrubs found a significant impact of the abundance of rodents on plant growth and reproduction (Laine 1978, Laine and Henttonen 1983, Callaghan and Emanuelsson 1985, Boulanger-Lapointe et al. 2017) as well as the abundance of berries on rodent populations (Krebs et al. 2010, Selas et al. 2013). Local observations (Chapter 2) and scientific investigations (Hupp et al. 2013) in the Arctic also indicated that geese may consumed a large number of berries. The consumption by animals of berry species leaves, stems and fruits certainly has had an impact on the abundance of berries measured in this study and was a major component of the unexplained variability in the models.

4.5 Conclusion

This research provides a first overview of the distribution and productivity of *Empetrum nigrum*, *Vaccinium uliginosum* and *V. vitis-idaea* in the vicinity of Inuit communities in Canada. From the forest-tundra ecotone to the high Arctic, I found numerous productive berry patches that varied in their respective plant community composition. The greatest berry productivity was observed in subzone D, where the balance of biotic and abiotic conditions must be optimal for the species growth and reproduction. I also observed a significant positive effect of spring and summer temperature and precipitation but a negative effect of winter precipitation.

This study demonstrates the widespread distribution and variability in production of northern berry shrubs and sheds light on some of the climate variables that may influence their productivity. However, the high annual variability that may at least partially be attributed to the influence of local environmental factors and herbivory creates noise that makes it difficult to clearly determine the main drivers of berry productivity. Long-term monitoring will be key to gain a better understanding of the impact of year-to-year fluctuations in climate as well as global climate change on berry productivity.

Chapter 5: Conclusions

Arctic and subarctic terrestrial ecosystems have low plant productivity and are covered by snow for most of the year. Nevertheless, the short growing season provides food and material for animals and people throughout the year. Understanding the place of berries in the Inuit biocultural system is a step towards a better integration of terrestrial socio-ecological systems to our understanding of the North. In this thesis, I used an multidisciplinary approach because neither the ecology nor the cultural importance of berries could be properly understood within the narrow lens of a single field of study. This approach yielded many insights; the ecological information helped to better understand the cultural dimension and local observations complemented ecological monitoring.

5.1 Summary

Ethnobotanical research conducted in the Canadian Arctic (Ootoova et al. 2001, Joamie and Ziegler 2009, Cuerrier and Elders of Kangiqsujuaq 2011, Cuerrier and Elders of Kangiqsualujjuaq 2012, Cuerrier and Elders of Umiujaq and Kuujjuaraapik 2012), the Northwest Territories (Andre and Fehr 2001) and Alaska (Oswalt 1957, Ager and Ager 1980) documented the use of berry species by Inuit in specific regions of the North. This study demonstrated that the knowledge of berry plants is extensive and intimate across Inuit Nunangat (Chapter 2). Berry picking contributes to personal and community well-being through the promotion of culturally meaningful activities on the land. The link between community well-being and berry picking had been documented for the Gwich'in in the Northwest Territories (Parlee and Berkes 2005) as well as for different cultural groups in Alaska (Flint et al. 2011), and I demonstrated that even though

Inuit in Canada predominantly live in less productive environments, berries and berry picking are still an important part of life and culture. However, I found discrepancies between Inuit and other First Nations' groups living in the Canadian North regarding the management practices of berry patches. While residents of communities located in the boreal forest (Parlee and Berkes 2006, Karst and Turner 2011) tend to be protective of their berry patches, this is seldom the case for Inuit in Canada. The place of berries in Inuit culture is however evolving: the quality and accessibility of berries are affected by recent climate change and community development, while availability may be constrained by overabundant goose populations in certain regions.

Detailed field investigations in Arviat demonstrated the widespread distribution of berry species throughout the landscape (Chapter 3). Even though the vicinity of Arviat is not considered to be a prime berry picking area, local abundance of fruits for the municipality of Arviat is still high with estimates of 16,429 kg (361 g/m^2), 756 kg (17 g/m^2), 461 kg (10 g/m^2), 307 kg (7 g/m^2) and 174 kg (4 g/m^2), respectively, for *Empetrum nigrum, Vaccinium vitis-idaea, Arctous alpina*, *V. uliginosum* and *Rubus chamaemorus*. This is the first assessment of the distribution and productivity of berry species at the landscape level for the vicinity of Arviat and among the few evaluations for the Canadian Arctic (Spiech 2014). Local diversity of animal species in the region is low and dominated by avian fauna, especially geese. The abundance of geese is highest in the spring but remained relatively high through the growing season. Geese eat a large number of berries with up to 21 berries/ feces in mesic habitats. While it was known that berries may represent a significant part of geese diet in the fall (Cadieux et al. 2005), we documented the impact on berry availability. Results showed that between 2-5% of the annual berry production is eaten by geese. Comparatively, Hupp et al. (2013) estimated that between 30-60% of *Empetrum* *nigrum* annual production was consumed by cackling geese on their southward migration path in Alaska. The results from this research may then be a good evaluation of the impact of a moderate abundance of geese on the availability of berries. Finally, the observation of large scale impacts of human activities and pollution in the vicinity of the community leads to the hypothesis that perceived competition for the resource may be associated with the relatively small number of berry patches of good quality that are readily accessible.

In regards to the environmental and climatic determinants of berry productivity (Chapter 4), I found that berry species are widespread and productive from the forest-tundra ecotone to the high Arctic with total productivity ranging from 97-484 berries/m^2. The most productive sites, Iqaluit, Kangiqsujuaq and Pangnirtung, were located in the bioclimate subzone D of the CAVM (Walker et al. 2005). I hypothesized that it is in that subzone that the interspecific competition, especially shading by erect shrubs, is minimized while temperature and precipitation remain optimal for fruit production. In accordance with this hypothesis, I found that the density of berries for the same species is much lower in the boreal forest (Ihalainen et al. 2003, Murray et al. 2005). None of the ecological variables available showed a significant correlation with berry productivity and plant community composition was associated with the position along the bioclimate gradient, indicating that productive berry patches have different characteristics depending on the latitude. Large inter-annual variability across and within sites reduced the power of the mixed model analyses to determine the climatic variables driving productivity. However, I observed that spring temperature and precipitation are important for both the number and weight of the fruits, and that winter precipitation has a negative effect on production. These results contribute to a growing literature on the determinants of berry productivity in subarctic and alpine environments (see among others Krebs et al. 2009, Rixen et al. 2010, Selas et al. 2015). This is, however, the first time that such research has been conducted in the Canadian Arctic.

5.2 Overall contribution of this research

The strength of this research lies in the demonstration that berry species are common and produce a lot of fruits in the vicinity of Inuit communities in Canada and for this reason are important for both animals and people. Large inter-annual variability in the abundance of berries has always occurred but concerns related to overabundant geese populations as well as community development and recent climate change increase pressure on the quality and availability of the resource. Constraints on resource availability vary per region and depend on the abundance of animal populations, local impact of climate change and the extent of community and industrial development. The information presented in this thesis demonstrate the widespread distribution and importance of berries and berry picking and may be used to better understand Arctic terrestrial ecosystems and inform decisions on land use in the vicinity of Inuit communities in Canada.

5.3 Future directions

5.3.1 Inuit ethnobotanical knowledge

This research provided an overview of the ethnobotanical knowledge of berries across a number of Inuit communities in Canada. While a small number of studies have been conducted on Inuit ethnobotanical knowledge, much more information could be gained from in-depth regional studies. These would help to understand how local environment and resource availability influence the use of different plant species over time and for different cultural groups. It may also shed light on the use of plants by the younger generation and how it may contribute to food security and cultural preservation in contemporary Inuit communities.

On the other hand, the study of the Inuktitut vocabulary associated with the plant world may help to understand the importance of plants in Inuit culture. Preliminary investigation in Igloolik (Dristas 1987), Kangiqsujuaq (Cuerrier and Elders of Kangiqsujuaq 2011) and Kugluktuk (Kugluktukmiut Elders and Youth and Desrosiers 2016) showed that this knowledge is vast and associated with the morphology and different uses of plants. Very few people still have the knowledge of this vocabulary and it is a time sensitive issue to preserve this vast body of knowledge.

Finally, while reviewing early explorer accounts and interviews, I got a sense that berries may occupy a specific symbolic place in Inuit cosmology. Berries, because they were one of the few sweet treats available before the arrival of store-bought food, are often depicted as an irresistible temptation that can stop monsters and distract hunters. It would be interesting to investigate how this may be elaborated in traditional stories and songs, and its impact on the contemporary perception of berries.

5.3.2 Impact of consumption by animals on resource availability

Different animal species are known to rely on berry shrubs throughout the year. In this study, I evaluated the impact of geese consumption on availability. However, the methodology used provided a poor assessment of the consumption by other species, especially rodents. Since rodents are important in affecting annual berry production and availability in boreal forests and alpine environments (Krebs et al. 2010, Boulanger-Lapointe et al. 2017), we may also expect them to have a significant impact on productivity in the Arctic. A better evaluation of animal consumption would help to understand inter-annual fluctuations in the abundance of berries.

On the other hand, research in Arviat demonstrated that even if berries are a significant part of the diet of geese, consumption may not necessarily have a large impact on resource availability. Research conducted on the southward migration path of cackling geese in Alaska showed that this may not always be the case (Hupp et al. 2013). A better evaluation of the impact of consumption of berries by geese (and other herbivores) on availability throughout the Arctic may be gained from comparing the impact of different goose densities on berry availability.

5.3.3 Climatic and environmental determinants of berry productivity

Long-term monitoring provides precious information on trends that may be masked under inter-annual variability. This study is no exception and continued monitoring will provide more accurate and detailed information on the climatic and environmental drivers of berry productivity from the boreal forest to the high Arctic. A longer time series would allow, among other things, a comparison of the influence of climate in each bioclimate subzone and thus help to determine the impact of local environmental conditions on species response.

Contrary to local observations, I measured a negative impact of winter precipitation on berry productivity. Snow depth measurements would be necessary to understand how regional precipitation data are linked to snow conditions in the field and thus identify the mechanisms behind the observed response.

5.3.4 Impact of community and industrial development on berry patches

Information collected in the interviews as well as field investigations in Arviat indicated that community and mining development have a significant impact on the quality and availability of berry patches. Since I also found that, in most regions, people do not keep their best berry patches secret, land managers may benefit from knowing the location of good berry patches, at least those located close to the community, in order to limit the impact of development projects on this resource.

In conclusion, the biocultural approach adopted in this research allowed us to conduct a first global assessment of the place of berries in the Inuit socio-ecological system. I hope that this research will inform land use planning and contributes to different fields of research in the North. The large number of variables at play would require continued monitoring to understand the shifting cultural importance as well as the productivity and availability of berries in a changing Arctic.

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Appendices

Appendix A. Community of residence, name of interviewees and interviewers as well as year of interview for the core interviews and interviews conducted in Arviat (Chapter 2). Abbreviations: N. B.-L., Noémie Boulanger-Lapointe; A. C., Alain Cuerrier; M. G., Megan Gavin; J. G.-L., José Gérin-Lajoie; A. I., Ancilla Irkok; K. P., Kadluk Pingushat; L. S. C., Laura Siegwart Collier.

Community	**Interviewee**	**Interviewer**	**Year**
Arviat	Elizabeth Alareak Aqiruq Suluk	N. B.-L., M. G., A. I., K. P.	2015
Arviat	Louis Angalik	N. B.-L., M. G., A. I., K. P.	2015
Arviat	Margaret Hannak	N. B.-L., M. G., A. I., K. P.	2015
Arviat	Dorothy Akatsiak	N. B.-L., M. G., A. I., K. P.	2015
Baker Lake	Margaret Amauruq Niviatsiaq	J. G.-L.	2009
Baker Lake	Norman Attungala	J. G.-L.	2009
Baker Lake	Silas Aittauq	J. G.-L.	2009
Baker Lake	Hattie Attutuvaa	J. G.-L.	2009
Baker Lake	Paul Attutuvaa	J. G.-L.	2009
Baker Lake	Vera Avalaa	J. G.-L.	2009
Baker Lake	May Haqpi	J. G.-L.	2009
Baker Lake	Jacob Ikinilik	J. G.-L.	2009
Baker Lake	Winnie Ikinilik	J. G.-L.	2009

Appendix A (continued)

Community	Interviewee	Interviewer	Year
Baker Lake	Janet Ikuutaq	J. G.-L.	2009
Baker Lake	Toona Iqulik	J. G.-L.	2009
Baker Lake	Lucy Kownak	J. G.-L.	2009
Baker Lake	Martin Kreelak	J. G.-L.	2009
Baker Lake	Mary Kreelak	J. G.-L.	2009
Baker Lake	Martha Nukik	J. G.-L.	2009
Baker Lake	John Nukik	J. G.-L.	2009
Baker Lake	Thomas Qaqimat	J. G.-L.	2009
Baker Lake	Elizabeth Quinangnaq	J. G.-L.	2009
Baker Lake	Joan Scottie	J. G.-L.	2009
Baker Lake	Irene Taviniq Kaluraq	J. G.-L.	2009
Baker Lake	Simon Tookoome	J. G.-L.	2009
Baker Lake	Basil Tuluqtuq	J. G.-L.	2009
Baker Lake	Julie Tuluqtuq	J. G.-L.	2009
Baker Lake	Lucy Tunguaq	J. G.-L.	2009
Kangiqsualujjuaq	Betsie Annanack	A.C., J. G.-L.	2007
Kangiqsualujjuaq	Eva Annanack	A.C.	2007
Kangiqsualujjuaq	Johnny George Annanack	A.C.	2007, 2008
Kangiqsualujjuaq	Sarah Pasha Annanack	A.C., J. G.-L.	2007
Kangiqsualujjuaq	Willie Emudluk	A.C.	2007, 2008

Appendix A (continued)

Community	Interviewee	Interviewer	Year
Kangiqsualujjuaq	Lucas A. Etok	A.C.	2008
Kangiqsualujjuaq	Mary Etok	A.C., J. G.-L.	2007
Kangiqsualujjuaq	Tivi Etok	A.C.	2007, 2008
Kangiqsualujjuaq	Susie Morgan	A.C.	2007, 2008
Kangiqsujuaq	Mary Anogak	A.C.	2008
Kangiqsujuaq	Livi Arnaituk	A.C.	2008
Kangiqsujuaq	Nappaaluk Arnaituk	A.C.	2008
Kangiqsujuaq	Minnie Etidloie	J. G.-L.	2007
Kangiqsujuaq	Lizzie Irniq	A.C.	2008
Kangiqsujuaq	Mary Kiatainaq	A.C.	2008
Kangiqsujuaq	Alasie Koneak	A.C.	2007
Kangiqsujuaq	Eva Llimasaut	A.C.	2008
Kangiqsujuaq	Juusipi Nappaaluk	A.C.	2008
Kangiqsujuaq	Lukasi Nappaaluk	A.C.	2008
Kangiqsujuaq	Naalak Nappaaluk	A.C.	2008
Kangiqsujuaq	Pitsiulaq Pinguatuq	A.C., J. G.-L.	2007, 2008
Kangiqsujuaq	Aqujaq Qisiiq	A.C.	2007, 2008
Kangiqsujuaq	Annie Tertiluk	A.C.	2008
Kangiqsujuaq	Mark Tertiluk	A.C.	2008
Kangiqsujuaq	Maata Tuniq	A.C.	2007

Appendix A (continued)

Community	Interviewee	Interviewer	Year
Kugluktuk	John Allukpik	J. G.-L.	2010, 2011
Kugluktuk	Lena Allukpik	J. G.-L.	2010, 2011
Kugluktuk	Martha Ayaligak	J. G.-L.	2010
Kugluktuk	Alice Ayalik	J. G.-L.	2010
Kugluktuk	Kate Inuktalik	J. G.-L.	2010, 2011
Kugluktuk	Roy Inuktalik	J. G.-L.	2011
Kugluktuk	Nellie Kaiyogana	J. G.-L.	2010
Kugluktuk	Mary Kellogok	J. G.-L.	2010
Kugluktuk	Annie Kigiuna	J. G.-L.	2010
Kugluktuk	Laura Kohoktak	J. G.-L.	2010
Kugluktuk	Agnes Kokak	J. G.-L.	2011
Kugluktuk	Joseph Niptanatiak	J. G.-L.	2010
Kugluktuk	Lena Niptanatiak	J. G.-L.	2010, 2011
Kugluktuk	John Ohokak	J. G.-L.	2010
Kugluktuk	Mamie Oniak	J. G.-L.	2010
Kugluktuk	Mark Taletok	J. G.-L.	2010, 2011
Kugluktuk	Martha Taletok	J. G.-L.	2010, 2011
Kugluktuk	Mona Tiktalek	J. G.-L.	2010
Nain	Anonymous	L. S.-C.	2009
Nain	Christine Baikie	L. S. C.	2009

Appendix A (continued)

Community	Interviewee	Interviewer	Year
Nain	Edward Flowers	A.C., L. S. C.	2010
Nain	Louisa Flowers	A.C., L. S. C.	2010
Nain	Julius Ikkusek	L. S. C.	2010
Nain	Elizabeth Ittulak	A.C., L. S. C.	2010
Nain	Sarah Ittulak	L. S. C.	2009
Nain	Verona Ittulak	A.C., L. S. C.	2010
Nain	John Jararuse	A.C., L. S. C.	2010
Nain	Annie Lampe	A.C., L. S. C.	2010
Nain	Annie Lidd	A.C., L. S. C.	2010
Nain	Eli Merkuratsuk	A.C., L. S. C.	2010
Nain	Jacko Merkuratsuk	A.C., L. S. C.	2010
Nain	Julius Merkuratsuk	A.C., L. S. C.	2010
Nain	K Naeme Merkuratsuk	A.C., L. S. C.	2010
Nain	Minnie Merkuratsuk	A.C., L. S. C.	2010
Nain	Martha Okkuatsiak	A.C., L. S. C.	2010
Nain	Timothy Townlay	A.C., L. S. C.	2010
Nain	Ron Webb	A.C., L. S. C.	2010
Nain	Katie Winters	A.C., L. S. C.	2010
Nain	William Winters	A.C., L. S. C.	2010
Pangnirtung	Anonymous	J. G.-L.	2009

Appendix A (continued)

Community	Interviewee	Interviewer	Year
Pangnirtung	Evee Anilniliak	J. G.-L.	2008
Pangnirtung	Leah Akpalialuk	J. G.-L.	2008
Pangnirtung	Leopa Akpalialuk	J. G.-L.	2009
Pangnirtung	Geela Akulukjuk	J. G.-L.	2009
Pangnirtung	Mary Battie	J. G.-L.	2009
Pangnirtung	Daisy Dialla	J. G.-L.	2009
Pangnirtung	Leah Evik	J. G.-L.	2008
Pangnirtung	Ooraika Iseemailee	J. G.-L.	2009
Pangnirtung	Aiga Ishulutaq	J. G.-L.	2009
Pangnirtung	Jaco Ishulutaq	J. G.-L.	2009
Pangnirtung	Leesee Mary Kakee	J. G.-L.	2009
Pangnirtung	Saila Kisa	J. G.-L.	2009
Pangnirtung	Jamasie Mike	J. G.-L.	2008
Pangnirtung	Sowdloo Nakashuk	J. G.-L.	2009
Pangnirtung	Inusirq Nashalik	J. G.-L.	2009
Pangnirtung	Peterloosie Qappik	J. G.-L.	2009
Pangnirtung	Taukie Qappik	J. G.-L.	2009
Pangnirtung	Pauloosie Veevee	J. G.-L.	2009
Pond Inlet	Rhoda Arnakallak	J. G.-L.	2008
Pond Inlet	Ham Kadloo	J. G.-L.	2009

Appendix A (continued)

Community	Interviewee	Interviewer	Year
Pond Inlet	Gamailie Kilukishak	J. G.-L.	2008
Pond Inlet	Mary Kilukishak	J. G.-L.	2008
Pond Inlet	Abraham Kunnuk	J. G.-L.	2009
Pond Inlet	Letia Kyak	J. G.-L.	2009
Pond Inlet	Theresa Koopa Maktar	J. G.-L.	2008
Pond Inlet	Joanasie Muckpa	J. G.-L.	2008
Pond Inlet	Elisapie Ootoova	J. G.-L.	2008
Pond Inlet	Elijah Panipakoocho	J. G.-L.	2008
Pond Inlet	Annie Peterloosie	J. G.-L.	2009
Pond Inlet	Jayko Peterloosie	J. G.-L.	2008
Pond Inlet	Paniloo Sangoya	J. G.-L.	2008
Pond Inlet	Ruth Sangoya	J. G.-L.	2008
Pond Inlet	Qamaniq Sangoya	J. G.-L.	2008
Umiujaq	Lizzie Crow	J. G.-L.	2009
Umiujaq	Willie Kumarluk	J. G.-L.	2009
Umiujaq	Siasi Naluktuk	J. G.-L.	2009
Umiujaq	Viola Napartuk	J. G.-L.	2009
Umiujaq	Moses Novalinga	J. G.-L.	2009
Umiujaq	Joshua Sala	J. G.-L.	2009
Umiujaq	Dinah Tookalook	J. G.-L.	2009

Appendix A (continued)

Community	**Interviewee**	**Interviewer**	**Year**
Umiujaq	Lizzie Tookalook	J. G.-L.	2009
Umiujaq	Alice Tooktoo	J. G.-L.	2009
Umiujaq	Alice Tooktoo Sr	J. G.-L.	2009
Umiujaq	Billy Tooktoo	J. G.-L.	2009
Umiujaq	Charlie Tooktoo	J. G.-L.	2009
Umiujaq	Lucassie Tooktoo	J. G.-L.	2009
Umiujaq	Clara Tumic	J. G.-L.	2009
Umiujaq	Ernest Tumic	J. G.-L.	2009

Appendix B. Interviews from the Oral History Project in Igloolik consulted as part of this research: reference number, name of interviewees and interviewers as well as year of the interview.

Reference no.	Interviewee	Interviewer	Year
IE-017	Michel Kupaaq	Emile Imaruittuq	1987
IE-019	Therese Qillaq Ijjangiaq	Paul Irngaut	1987
IE047	Noah Piugaattuk	Paul Irngaut	1989
IE-068 - 068A	Aipilik Inuksuk	Louis Tapardjuk	1989
IE-095	Aipilik Inuksuk	Eugene Amarualik	1990
IE-108	Rebecca Irngaut	Susan Avingaq	1989
IE-128	Michel Kupaaq	Therese Ukaliannuk	1990
IE-157	Rachael Ujarasuk	Louis Tapardjuk	1990
IE-167	George Kappianaq	Louis Tapardjuk	1990
IE-172	Michel Kupaaq Piugaattuk	Louis Tapardjuk	1991
IE-197	Philip Qipanniq	Louis Tapardjuk	1991
IE-209	Zachariasie Uqalik	Maurice Arnattiaq	1991
IE-240	Therese Qillaq Ijjangiaq	Leah Otak	1992
IE-258	Peter Tatiggat Arnattiaq	Maurice Arnattiaq	1993
IE-277	Noah Piugaattuk	Susan Rowley / Leah Otak	1993
IE-281	Martha Nasuk	Susan Rowley / Leah Otak	1993
IE-305	Catherine Aaluluuq Arnatsiaq	Leah Otak	1995

Appendix B (continued)

Reference no.	Interviewee	Interviewer	Year
IE-327	George Kappianaq	Self-taped	1995
IE-330	George Kappianaq	Self-taped	1995
IE-341	Atuat Akittiq	Marie Lucie Uviluq	1995
IE-349	Sarah Amak&ak Haulli	Lydia Qaunnaq	1995
IE-376	Victor Aqaattiaq	Lazarie Otak	1996
IE-379	Abraham Ulayuruluk	Lazarie Otak	1996
IE-384	Noah Siakuluk	Louis Tapardjuk	1996
IE-388	Therese Qillaq Ijjangiaq	Moati Kunuk	1996
IE-395	Rosie Iqallijuq	Leah Otak	1997
IE-408	George Kappianaq	Self-taped	1997
IE-411	George Kappianaq	Self-taped	1997
IE-426	George Kappianaq	Leah Otak	1997
IE-428	Z. Innuksuk	Leah Otak	1999
IE-429	Rebecca Irngaut	Leah Otak	1999
IE-435	Rosie Iqallijuq	Leah Otak	1999
IE-436	Rachael Uyarasuk	Leah Otak	1999
IE-441	Theresia Taqaugaq	Louis Tapardjuk	2000
IE-442	Nathan Qamaniq	Louis Tapardjuk	2000
IE-453	George Agiaq Kappianaq	Louis Tapardjuk	2000
IE-454	George Agiaq Kappianaq	Louis Tapardjuk	2000

Appendix B (continued)

Reference no.	Interviewee	Interviewer	Year
IE-457	George Agiaq Kappianaq	Louis Tapardjuk	2000
IE-469	Abraham Ulaajuruluk	Louis Tapardjuk	2001
IE-470	Julia Amarualik	Louis Tapardjuk	2001
IE-471	Nathan Qamaniq	Louis Tapardjuk	2001
IE-475	Margaret Sunak Kipsigaq	Louis Tapardjuk	2001
IE-484	Lucien Ukaliannuk	Louis Tapardjuk	2001
IE-485	Lucien Ukaliannuk	Louis Tapardjuk	2001
IE-487	Louis Alianakuluk Utak	Louis Tapardjuk	2001
IE-488	Julia Amarualik	Louis Tapardjuk	2001
IE-489	Margaret Sunak Kipsigaq	Louis Tapardjuk	2001
IE-490	Lucien Ukaliannuk	Louis Tapardjuk	2001
IE-506	Louis Alianakuluk Utak	Louis Tapardjuk	2002