

**Paleodemography of the North American Arctic, Subarctic, and Greenland in Relation to
Holocene Climate and Environmental Change**

Thesis submitted in partial fulfilment of the requirements for the degree of
Master of Science in Geography

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ACKNOWLEDGEMENTS

I would like to first thank Dr. Konrad Gajewski for his unwavering support, guidance, and patience. The amount of time you dedicate to your students is unheard of these days, so I feel extremely fortunate to have had you as a supervisor. I have learned a great deal from you, both inside the classroom as a professor and in the lab as a mentor. Thank you for introducing me to a subject I love so much.

I am especially grateful to my fellow “DHS”, the Laboratory for Paleoclimatology and Climatology members, for over 3 years of moral support and friendship. Our many coffee runs, Friday drinks, and ludicrous discussions about future endeavours will forever be cherished. Amanda, Camille, Karen, Mercedes, Michelle, and Paige, thank you for bringing light into this windowless cave in the sub-basement we call our lab. Fiona, you’ve been a magical part of my life since second-year geomatics class; I’m so glad we’ve been able to share this entire journey. Craig, you’ve kept me grounded through every challenge I’ve faced, and I’m endlessly grateful for you. To all my friends and family, thank you for all your support and encouragement.

To Dr. Elena Ponomarenko and Dr. Matthew Betts, thank you for your valuable insight and the time you have dedicated to this project as committee members. Dr. Ponomarenko, you have been here since the project’s beginnings in my undergraduate thesis; thank you for your continued support. Dr. Betts, your expertise as an archaeologist has been especially valuable to this project. I am also thankful to the Canadian Museum of History for allowing me to use its library’s resources to help me build the Greenland Archaeological Radiocarbon Database. Thank you also to everyone who has contributed to the various databases that have made this project possible.

I extend gratitude to all the professors, staff, and students at the Department of Geography, Environment, and Geomatics with whom I have crossed paths. Thank you for all the knowledge you have shared with me, and for making me feel supported and capable in this department for over seven years. I truly feel at home here. To Café Alternatif and staff, thank you for having fuelled my brain over the course of two degrees. Rest in peace, and may your ghost continue to haunt the basement as a presence unpinning the morale of this department.

This project was funded by an Ontario Graduate Scholarship and an NSERC discovery grant. A final thanks goes to these agencies for their financial support.

ABSTRACT

Human demographic changes in association to environmental fluctuations were studied for the North American Arctic and boreal region. Using the frequency of archaeological radiocarbon dates from the Canadian Archaeological Radiocarbon Database as a proxy for population size, past changes in population density were estimated and quantitatively examined in relation to reconstructions of temperature and sea ice conditions. This was conducted across three spatial scales: the entire area, the four major cultural-environmental regions and sixteen subregions in order to identify both broad-scale and local phenomena. There was a high correspondence between millennial and centennial-scale climate variability and paleodemographic changes across the region, with increasing population density during warmer periods and lower density during cooling episodes. An abrupt Late Holocene cooling (neoglaciation) beginning at 3.9 ka triggered a nearly-synchronous population decline across the region. Cooling temperatures and increased sea ice coverage also influenced large-scale migration patterns of Paleo-Inuit peoples as well as their cultural evolution.

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CHAPTER 1:

Introduction

How climate and environmental change impacted past human populations is a fundamental question in geographical and archaeological research. During the Holocene (11700 years ago to present), a geological epoch characterised by the global expansion of human occupation, climate and environmental changes influenced spatial and temporal patterns of human migration and demographics (e.g., Munoz et al., 2010; Pauketat, 2012; Williams et al., 2015a; Friesen & Mason, 2016; Timmerman & Friedrich, 2016). This has been thoroughly examined in many regions around the world, but research on large-scale human-environment interactions in North America has been limited.

The North American Arctic and Subarctic are of great paleoanthropological interest. Eastern Beringia (Alaska and Yukon) was the first North American region inhabited by people, and served as the entry point for successive migrations into the continent. The rest of the Arctic was the last North American region to be settled by humans, and later saw the disappearance of a widespread culture. Given the relatively harsh environment, climate changes were likely very influential on past societies and cultures in the north (Pilon, 2001; Friesen & Mason, 2016).

One quantitative approach to examine questions about past human-environment interactions is the analysis of paleodemography in relation to paleoenvironmental data. Assuming a larger population would have left more traces of their activities in the archaeological record, the frequency of archaeological radiocarbon dates can be used as a proxy for population size (e.g., Rick, 1987; Chaput & Gajewski, 2016). This paleodemographic estimate can then be compared to reconstructions of past temperatures, sea ice conditions, vegetation, and precipitation.

A few studies have examined local to regional scale paleodemography the North American Arctic or Subarctic (e.g., Potter, 2008; Dyke & Savelle, 2009; Savelle & Dyke, 2014; Tremayne & Brown, 2017), but there has yet to be a quantitative analysis of paleodemography in relation to the paleoenvironment on a large scale. With recent and relatively complete regional paleoenvironmental databases and syntheses from the Arctic and Subarctic regions (e.g., Gajewski, 2015b; Briner et al., 2016; Kaufman et al., 2016), this is now possible.

This thesis aims to answer the following questions:

1. How did populations change through time and space in the North American Arctic, Subarctic and Greenland over the course of the late Pleistocene and Holocene?
2. How did climatic and environmental change influence these demographic changes?

These objectives were accomplished through a data-analytic approach. Using an updated database of archaeological radiocarbon dates, past population sizes from the North were estimated at three spatial scales: sub-continental (the entire North American Arctic and boreal region, including Greenland), regional (Beringia, the Canadian Arctic, Greenland and the boreal forest of Canada), and sub-regional, determined by ecoregion and cultural factors. Population estimates were then compared to reconstructions of past environmental conditions across the same scales. This three-tiered approach enabled the assessment of the scale and regionality of environmental impacts on populations.

Results from this study will contribute to the understanding of the pre-colonial human and environmental history of the north. The study of past human-environment interactions furthermore provides a long timescale perspective with which we can better understand present and future impacts of climate change on human dynamics.

CHAPTER 2:

Literature Review

2.1 Late Glacial and Holocene Paleoenvironments of the North American Arctic, Subarctic, and Greenland

2.1.1 Summary

During the Pleistocene epoch from 2.6 million years ago to 11.7 ka (thousand years before 1950), massive ice sheets covered most of North America and Greenland. At the last glacial maximum (LGM) about 21 ka, sea levels were up to 120 m below present levels (Hoffecker et al., 2016). This exposed vast areas of land such as Beringia, a large region between Russia and Alaska (Hoffecker et al., 2016).

Increasing solar radiation, a result of cyclical changes in the earth's orbit relative to the sun, initiated the long-term melting of the Wisconsinan ice sheet around 18 ka. Ice continued to retreat, punctuated by reversals such as the Younger Dryas Cold Period at 12.9 ka, when the climate abruptly cooled and ice sheets re-advanced. The Younger Dryas ended about 11.7 ka, marking the beginning of the Holocene epoch.

Deglaciation was uneven across space, occurring much earlier in the western part of the continent (Figure 2.1). Due to southerly ocean currents bringing warm air to the North Pacific region, most of Beringia was unglaciated during the Pleistocene. This exposed land was able to absorb more of the increasing solar radiation than the highly reflective ice sheets, enhancing the melt in the adjacent glaciated regions. Around 15 – 14 ka, an ice-free corridor (IFC) opened in the east of Beringia, connecting Beringia to the land south of the two ice sheets. Initially the IFC was regionally inundated, blocking the corridor for up to two millennia. By ~12.6 ka the IFC was several hundreds of kilometres wide and contained a steppe ecosystem. By ~10 ka, boreal forest was established in the region (Pedersen et al., 2016). By about 12 ka, most of northwestern North America was free of ice. It was only around 8 ka that the large remnant ice sheet collapsed in the Northeast.



Figure 2.1. Changing extents of the North American ice sheets throughout the Late Pleistocene and Holocene. Dates are in thousand calendar years before present. The uneven time increments are a result of the calibration from radiocarbon years. Adapted from Dyke et al., 2004.

Generally, the early to mid Holocene was relatively warm and the late Holocene was cool in comparison, a pattern driven in part by an increase and a subsequent decrease in summer insolation and by the changing atmospheric circulation as the remnant ice sheet melted (Miller et al., 2010; Gajewski, 2015b). The warm period is sometimes informally referred to as the “Holocene Thermal Maximum” (HTM) and the late Holocene cooling as “Neoglaciation”.

The spatial variability of century-scale climate changes over the last few millennia in the Arctic remains unclear (Kaufman et al., 2009), but climate syntheses from across the global Arctic and Subarctic suggest a dominant climate pattern during the Common Era. From 1.5 ka to 1.25 ka (450 to 700 CE) it was cooler, with a particularly cold spike around 1.3 ka (675) CE potentially due to volcanic forcing (Nicolle et al., 2018). This is referred to as the “Dark Ages Cold Period”. From 1.05 to 0.9 ka (900 – 1050 CE) it was generally warmer and drier, a period designated the “Medieval Climate Anomaly” or the “Medieval Warm Period”. The “Little Ice Age”, the coldest period of the last 2 millennia, occurred from 0.3 to 0.1 ka (1650 to 1850), and the climate may have also been generally wetter (Kaufman et al., 2009; McKay & Kaufman, 2014; Linderholm et al., 2018). However, global syntheses of the Common Era paleoclimate lack data from the western and central Canadian Arctic Archipelago (e.g., Nicolle et al., 2018), and thus may not be representative of the entire North (Tamo and Gajewski, 2019).

While this climate progression is broadly reflected in the majority of climate reconstructions from across the study region, the timing and intensity of these periods were spatially heterogeneous (Jansen et al., 2007; Nicolle et al., 2018). Physiographic variation and general climate circulation patterns control the regional expression of global climate changes, and in this area, residual ice sheets continued to exert influence on the local to regional climate, as well as the overall climate circulation, particularly in the first half of the Holocene (Miller et al., 2010). As a result, different regions even within the same ecozone (e.g., Arctic) have different paleoclimate histories (e.g., Gajewski, 2015b).

2.1.2 Beringia

A vast, largely unglaciated area spanning from Western Siberia to the Yukon Territory, Beringia is thought to have served as a northern “refugium” for plants and animals during the last glaciation (Hoffecker et al., 2016) (Figure 2.2). Fossil pollen analyses from Russia and Alaska demonstrate that vegetation in Central Beringia during the last glaciation was dominated by *Artemisia* and Poaceae and other herbaceous plants. Some tree species may have also existed there in relatively small numbers (Brubaker et al., 2005). This assemblage has been interpreted as a grassland-type of ecosystem, referred to as the “steppe tundra” or “mammoth-steppe tundra” (Guthrie, 1990; Zazula et al., 2003), as an herb-tundra (Cynwar et al., 1980; Lozhkin et al.,

2011), and as a birch shrub tundra (Elias et al., 1997). While the specific type of ecosystem present in Beringia at this time remains unclear, and may have varied spatially, the abundant fossil record suggests the environment was productive enough to support a substantial population of herbivorous mammals (Elias et al., 1997).

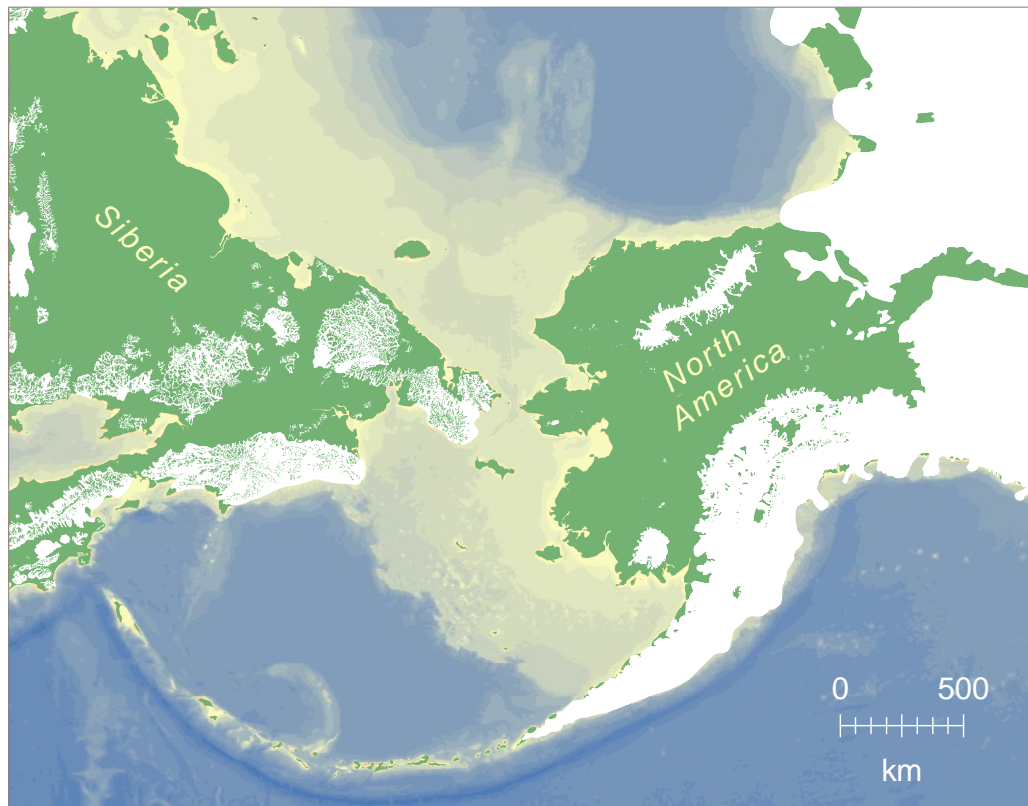


Figure 2.2. Beringia at the last glacial maximum (LGM). The “Bering Strait” refers to the narrow strait between Siberia and Alaska, while “Central Beringia” refers to the large area between Siberia and North America that was below sea level at the LGM. The yellow areas on the ocean bathymetry layer depict the shallow continental shelf, which likely coincide with the extent of the coastlines during the LGM when sea levels were lower.

During deglaciation, global sea levels began to rise, slowly inundating Central Beringia. It is unclear when the Bering Strait, the narrow region where the Pacific and Arctic Oceans meet (Figure 2.2), became submerged. It may have been as early as 13.3 ka (England & Furze, 2008), or as late as 11 ka (Jakobsson et al., 2017). By about 5 ka years ago, global sea levels were similar to the present (Woodroffe et al., 2012).

As the climate warmed during the late glacial, the presence of woody taxa in Beringia increased, and the vegetation became a shrub birch dominated tundra (Anderson et al., 2004; Lozhkin et al., 2011). The climate may have also been wetter at this time (Anderson et al., 2004). Temperatures from the late-glacial into the early Holocene were warmer overall, but appear to have been highly variable. It is unclear whether it was wetter or dryer overall at this time, but it appears that there was significant regional variability in moisture regimes (Viau et al., 2008; Kaufman et al., 2016). Into the early Holocene, a greater number of tree species became established in the region, with *Populus* being the most abundant (Anderson et al., 2004). Boreal forest arrived in the southeastern region by about 10 ka, while shrub tundra replaced *Populus*-dominated deciduous forests in the north (Kaufman et al., 2016). By the mid-Holocene, the magnitude of climatic fluctuations decreased relative to the early Holocene, and plant communities similar to those that exist today in northern and central Beringia became established (Anderson et al., 2004; Viau & Gajewski, 2009; Kaufman et al., 2016). Neoglacial cooling began around 4 – 3 ka (Kaufman et al., 2016), or perhaps earlier (Viau & Gajewski, 2009). Modern vegetation communities of the southern and eastern regions were in place by about 3.2 ka (Anderson et al., 2004).

2.1.3 Subarctic

After about 13 ka, the IFC had widened considerably but most of the Subarctic was still glaciated. By about 10 ka, the west and east coast regions were largely ice-free. Rapid deglaciation followed, and by around 8 ka only a large ice sheet in the northern half of Québec remained, and it disappeared by 5 ka (Dyke, 2004).

The climate evolution across the Subarctic varied across the region (Figure 2.1) (Viau & Gajewski, 2009). Maximum Holocene warmth occurred earlier in the West than in the East, and the HTM occurred as late as 4 – 3 ka in Labrador (Gajewski, 2019). Precipitation was generally out of phase between the West and the East. Québec and Labrador were much drier until the last few millennia of the Holocene, whereas the Mackenzie and Central regions tended to be relatively drier in the Late Holocene (Viau & Gajewski, 2009).

The regional establishment of the boreal forest was also controlled by the spatial pattern of deglaciation. Boreal forest appeared earliest in the west in the Mackenzie region around 9 ka, and latest in Québec and Labrador by 5 ka. In most regions, early Holocene boreal forest was dominated by spruce, usually white spruce. In the southwest margins, this was succeeded by a grasslands phase, while in the southeast a period of temperate forest followed. In the interior forest regions, early boreal forest was succeeded by the modern boreal forest assemblage of spruce, birch, pine, and alder. By 6 – 5 ka, the present composition and extent of the boreal forest was established (Ritchie, 1987).

2.1.4 Canadian Arctic

From the LGM into the Early Holocene, the ice sheets retreated from northwestern North America, but most of northeastern Canada and the Canadian Arctic Archipelago (CAA) remained covered by ice. Around 8 ka large ice sheets still covered northern Québec, the northeastern Northwest Territories, and most of Baffin Island. By about 5 ka only small ice sheets remained in the north and east CAA (Dyke, 2004).

The millennia-scale evolution of the Holocene climate across the Canadian Arctic varied regionally. The Western and Central Arctic experienced a warmer climate until 8 – 7 ka, relatively average temperatures until 4 ka, and then a cooling until near-present. The climate of the Eastern Canadian Arctic warmed until approximately 5.5 ka, cooled rapidly until about 5 ka, and then stabilized relative to the early Holocene. (Gajewski, 2015b). Generally, the high Arctic experienced neoglacial cooling earlier than the southern Arctic (Briner et al., 2016).

Over the Holocene, there were no major changes in vegetation biodiversity in the Arctic – only some relative changes among taxa in response to climate changes. There does not appear to have been a significant lag between changes in the climate and vegetation response. Pollen accumulation rates decreased during the neoglacial cooling, potentially indicating lower plant biomass and/or cover. This decrease of pollen accumulation began around 5 ka in the Western and Central Arctic, and later around 3 ka in the Eastern Arctic (Gajewski, 2015a).

2.1.5 Greenland

From the start of deglaciation to the Mid-Holocene, the Greenland Ice Sheet retreated from the coasts, but did not change substantially in extent. The Greenland Ice Sheet is the only large ice sheet to remain into the late Holocene (Dyke, 2004).

The climate of Northern and Eastern Greenland warmed until about 5.5 ka, cooled for half a millennium, and then remained relatively stable for the Late Holocene. Southern Greenland experienced a relatively late thermal maximum, warming until about 3 ka and cooling thereafter (Gajewski, 2015b). West Greenland warmed until about 5 – 4 ka, and cooled thereafter (Axford et al., 2013; Gajewski, 2015b).

The vegetation history of Greenland is very similar to that of the Canadian Arctic; the biodiversity did not change significantly, but the relative proportion of the taxa shifted somewhat in response to climate changes. Pollen accumulation rates decreased starting around 3 ka, later than much of the Canadian Arctic. Vegetation in southern Greenland did not change significantly throughout the Holocene (Gajewski, 2015b).

2.2 History of Human Occupation in the North American Arctic and Subarctic

In this study, we follow the recommendations of the Inuit Circumpolar Council (ICC) and Friesen (2015) in the designation of certain cultures or archaeological traditions. We use “Paleo-Inuit” to collectively denote the first peoples of the Eastern Arctic who were previously referred to as the Paleo-Eskimo in the Canadian Arctic and Greenland, and the Arctic Small Tool tradition in Alaska. The terms denoting the Paleo-Inuit’s cultural periods and regional variants, such as Pre-Dorset, Dorset, Saqqaq, etc., will still be used. The “Inuit tradition” refers collectively to the Inuit and their ancestors, previously referred to as the Thule. Similarly, “First Nations” replaces Amerind and Indian when referring to the first Indigenous groups to settle the Americas and their ancestors, who are distinct from the Paleo-Inuit and Inuit peoples.

Archaeological information will be divided into three groups based on the archaeological record and physical geography. Archaeology in Eastern Beringia will be referred to as “Beringian”, and will include all archaeological information associated with human activity in Alaska and the

Yukon Territory, regardless of cultural association. Archaeology east of Beringia and generally north of the treeline will be referred to as “Arctic”, and pertains to the Paleo-Inuit and the Inuit tradition. “Subarctic” archaeology will refer to groups within the Subarctic cultural region (roughly coinciding with the Boreal forest boundaries), and will exclude dates within Beringia as well as those pertaining to the Paleo-Inuit and Inuit tradition.

The geographical boundaries in this context are somewhat arbitrary, especially given the mobile nature of most of the ancient peoples in these regions (Sutton, 2011) and the changing biogeography of the ecosystems. Inevitably, there will be some spatial and cultural overlap between the three divisions. For example, the Subarctic and Beringia regions will have considerable cultural overlap, particularly in terms of the Na-Dene peoples (discussed below).

2.2.1 The Peopling of North America

Archaeological, linguistic and genetic information demonstrate that North America’s Indigenous peoples originated from Eastern Asia (Tamm et al., 2007). As Central Beringia was above sea level from the LGM until the early Holocene, it was possible for people to cross from Asia into North America on foot. Although Central Beringia was often referred to as a “Land Bridge”, implying it served just as a pathway for human migration into Eastern Beringia, it is likely that the region was inhabited for a longer period of time (Hoffecker et al., 2016; Tamm et al., 2017). Genetic evidence indicates that there must have been a “standstill” of anywhere from 2400 to 15000 years where people remained physically isolated from their ancestral population in Asia prior to migrating into North America (Tamm et al., 2007; Llamas et al., 2016). Despite a lack of archaeological evidence, it is generally thought that this standstill occurred in the now-submerged area of Central Beringia (Tamm et al., 2007). Further genetic studies indicate that this standstill population consisted of up to a few tens of thousands of individuals (Llamas et al., 2016).

It is unclear precisely when people first entered North America. The Bluefish Caves archaeological site in northern Yukon presents potential evidence of human presence in North America as early as 24 ka (Morlan, 2003; Bourgeon et al., 2017) but the evidence has been questioned (Morlan, 2003). If humans were indeed present at Bluefish Caves at that time, it was

likely used as peripheral seasonal shelter by people venturing from the core in Central Beringia (Bourgeon et al., 2017).

Regardless of contentious early dates, it is evident that that people populated North America in substantial numbers by 14 ka (Bourgeon et al., 2017; Hoffecker et al., 2016). At that time, much of North America was covered by ice, but people had begun occupying south of the ice sheet (Sutton, 2011). It has been debated whether the First Nations migrated south of the ice sheet via the IFC or via the west coast, but increasing evidence supports a west coast route (e.g., Pederson, 2016). As the ice sheets retreated at their southern margins, the newly available land was settled via northward migrations (Sutton, 2011).

It is unclear how many distinct migration events from Central Beringia and Siberia into North America took place, but the sudden appearances of seemingly distinct cultures in the archaeological record, alongside contemporary linguistic and genetic studies, indicate there were several (Achilli et al., 2013; Sutton, 2011; Greenberg et al., 1986). Greenberg (1986) proposed three distinct migration events based on his classification of all modern American Indigenous peoples into the following groups on the basis of linguistic, genetic and dental studies: “Amerind”, “Na-Dene”, and “Eskimo-Aleut”. While this “three-wave model” has formed the basis of several studies (e.g., Bonatto & Salzano, 1997; Achilli et al., 2013; Kitchen et al., 2008), and may broadly describe three major language families of northern Indigenous peoples, others suggest it is too rudimentary of a model (e.g., Bolnick et al., 2004; Rasmussen et al., 2010). Recent work suggests at least 3 migration events from Asia into the Americas via Beringia took place, but it differs from Greenberg’s (1986) original interpretation: the First Nations by ~14 ka, the Paleo-Inuit around 5 ka, and the Inuit at approximately 0.8 ka (Flegontov et al., 2019). Recent evidence also indicates that the ancestors of Na-Dene peoples did not represent a separate migration event of genetically distinct peoples as previously speculated. A genomic analysis of ancient individuals suggests that Na-Dene peoples arose in North America from the mixing of Paleo-Inuit and “Amerind” peoples approximately 5 – 4.4 ka (Flegontov et al., 2019).

2.2.2 Chronology of Human Occupation in Eastern Beringia

As the main entry point for all of the Indigenous peoples of North America, Eastern Beringia has an older and a significantly more complex human history than much of the Western Hemisphere. Despite numerous archaeological, genetic and linguistic studies of past and contemporary Indigenous cultures in the region, there is no consensus on the cultural chronologies of Eastern Beringia (Sutton et al., 2011). While many distinct archaeological complexes have been identified, their designation, cultural affiliation, the relations between them, and their evolution through time is often inconsistent from one study to another, and continues to be debated (Sutton et al., 2011; Friesen & Mason, 2016). The summary presented here represents one interpretation of the evidence, largely based on Sutton (2011) and Friesen & Mason (2016).

The “First Nations” arrived in Beringia by 14 ka, but some groups did not occupy the area for long, migrating south of the ice sheet. Others remained and developed into various Paleoarctic groups. Northern Archaic groups appeared around 6 ka, perhaps originating from groups to the south (Sutton, 2011; Friesen & Mason, 2016).

People of the Eskimo-Aleut linguistic family appeared in Alaska sometime around 9 ka (Sutton, 2011; Maschner, 2016). Those who colonized the Aleutian Islands established the Anangula tradition, and those in the Kodiak Island region became the Ocean Bay tradition. People of the Ocean Bay tradition went through several distinct cultural phases (Kachemak, Koniag) and eventually developed into the contemporary Alutiiq people (Sutton, 2011). The Anangula were replaced by the Aleutian tradition around 4.4 – 4 ka, but it is debated whether the Aleutian tradition evolved from the Anangula or if they originated from a migration westward of people of the Ocean Bay tradition (Maschner, 2016).

The Paleo-Inuit appeared in Alaska on the coast around 5 ka, having arrived from Siberia (Sutton, 2011; Milne & Park, 2016). A genetic analysis of a 4,000-year-old Saqqaq man (a Greenlandic group descended from Paleo-Inuit peoples) revealed Paleo-Inuit are related to modern Eastern Siberian Yuit people and the Aleut people. This suggests the Paleo-Inuit are broadly related to the Eskimo-Aleut linguistic family but diverged in Siberia prior to the first Eskimo-Aleut migration (Rasmussen et al., 2010). Once the Paleo-Inuit arrived in Eastern Beringia, some moved east and colonized the rest of the Arctic as the Pre-Dorset. Some may have mixed Northern Archaic groups which diversified into the various Na-Dene groups

(Flegontov et al., 2019), and others may have remained in Beringia as the Arctic Small Tool tradition (ASTt) and later developed into the Norton tradition. The Norton tradition developed around 3 ka, and evolved into the Ipiutak tradition which lasted from 2 to 1 ka. Some believe the Ipiutak tradition is related to early Inuit tradition, but it is unclear (Sutton, 2011).

2.2.3 Chronology of Human Occupation in the Subarctic

The modern and historic Indigenous peoples of the geographic Subarctic are distinguished linguistically and culturally into two groups: the Athapaskan and the Algonquian. The Athapaskan groups are of the Na-Dene linguistic group and are located in the northwest Subarctic. They may have evolved from the Northern Archaic tradition into the Athapaskans after 3.5 – 3 ka. The ancient Athapaskan groups in the eastern Northwest Territories are referred to as the Taltheilei Tradition (Sutton, 2011).

The first people in the southern and eastern Subarctic were likely descended from the first groups to arrive in North America who migrated south of the ice sheet. As the ice sheets retreated into the Holocene, people migrated northwards into the newly available land. The first people in the forests of the southern and eastern Subarctic are sometimes referred to as the Shield Archaic. Around 2.2 they developed into the Woodland groups, characterized by their use of pottery. These people eventually diversified into the various Algonquian-speaking groups encountered in the Boreal region at European contact (Sutton, 2011).

The first groups to inhabit the east coast maritime regions are known as Maritime Archaic. They arrived as early as 10 ka in Nova Scotia and as late as 5 ka in Newfoundland. From 3.5 to 2 ka, Maritime Archaic populations in many areas declined, and Newfoundland was completely abandoned by 3.2 ka. This decline has been attributed to environmental changes and to the expansion of the Paleo-Inuit from the North and other groups from the South. The Paleo-Inuit first entered Labrador around 3.8 ka, and may have out-competed the Maritime groups or exposed them to new diseases. The Dorset expanded as far south as Newfoundland by 2.8 ka. By this time the Maritime Archaic groups were increasing in population again and eventually they resettled Newfoundland. By 1 ka, the Dorset had disappeared from the region, perhaps a result of climate warming decreasing the success of their seal hunting. The Maritime groups eventually

diversified into the various groups encountered in the region at European contact, including the Cree, Innu, and the now-extinct Beothuk groups (Sutton, 2011; Holly & McCaffrey, 2012).

2.2.4 Chronology of Human Occupation in the Arctic and Greenland

East of Beringia, the human history of the North American Arctic (including Greenland) is shorter, as people first settled the region only after 5 ka, a few millennia after the retreat of the ice sheets. The first people east of the Beringian Arctic were Paleo-Inuit groups, who rapidly expanded across the Arctic all the way to Greenland (Sutton, 2011). This eastward migration may have been motivated by population pressure in Beringia (Tremayne & Winterhalder, 2017), or by the opening of newly available space following the retreat of the glaciers (Sutton, 2011). However, it is unclear why there was a lag between deglaciation and human settlement in the Eastern Arctic. Others have postulated that climate warming was a factor in the Paleo-Inuit migration (Barry et al., 1977), but this is inconsistent with recent paleoclimate records which suggest a cooling at the time (Briner et al., 2016). The first Paleo-Inuit tradition to migrate east of Beringia, referred to as the “Independence I”, settled in the high Arctic on Ellesmere Island and Northwestern Greenland. The “Pre-Dorset” appeared shortly after, settling in the low and middle Arctic. They may have arrived through a separate migration event, although it is debated whether Independence I and the Pre-Dorset represent distinct cultural traditions (Milne & Park, 2016); the Independence I may have been a “specialized northern extension” of the Pre-Dorset people (Sutton, 2011, p. 81). The Pre-Dorset evolved into the Dorset people sometime between 2.8 and 2.4 ka, a transition characterized by a subsistence shift towards marine resources (Ryan, 2016). Some suggest this change resulted from an adaptation to a cooling period, which would have provided superior sea ice conditions for marine hunting (Milne & Park, 2016; Ryan, 2016). The high-Arctic Dorset likely exploited polynyas, open-water areas that typically provide abundant mammal and fish resources. During a colder period around 1.8 – 1.5 ka, the Dorset abandoned the high Arctic and moved as far south as Newfoundland in the East and into the Forest-Tundra transition zone in the West (Sutton, 2011). A colder climate may have increased sea ice extent and/or thickness beyond favourable conditions, perhaps closing polynyas and encouraging the Dorset to migrate south (Ryan, 2016).

The complete disappearance of the Dorset by 0.7 ka (1250 CE) remains one of the biggest questions in Arctic archaeology. This coincided with the arrival of a new group, the Inuit, leading many to suspect the Dorset were pushed out, assimilated, or devastated through warfare by the Inuit. The Inuit appeared to have adopted some Dorset traits (Sutton, 2011), but it is unclear if this is evidence for direct interactions between the two groups, or if the Inuit simply scavenged from abandoned Dorset sites. Inuit oral histories today tell of encounters with a people they call the Tuniiit, which most likely refer to the Dorset. The Inuit recall peaceful interactions at first, but eventually tensions and hostility arose between their ancestors and the Tuniiit (Appelt et al., 2016). It may have been that the Dorset were out-competed and displaced by the Inuit, who had more specialized technology which gave them a competitive advantage in both food procurement and conflict (Friesen, 2016). Alternative theories to explain the Dorset's disappearance include decimation by European diseases resulting from interaction with the Norse, or the inability to adapt to climate changes (Sutton, 2011). The Late Dorset period corresponds to the Medieval Warm Period, and is characterized by the movement of people back into the high Arctic; this suggests changing resource availability resulting from climate change may have contributed to the Dorset's downfall (Appelt et al., 2016).

The Dorset were eventually entirely replaced by the Inuit tradition, a culturally distinct group who emigrated from Eastern Beringia around 1 – 0.7 ka. The reason for their emigration is unclear; population pressure and conflict in Beringia may have been motivation to search for new territory, or perhaps it was a trade expansion related to Norse metals (Sutton, 2011; Friesen, 2016). Changes related to the Medieval Warm Period may have also been factors. A warmer period may have reduced sea ice thickness in colder waters of the central and eastern Arctic ocean; the bowhead whale, an important marine resource to the Inuit, may have migrated eastward in response, encouraging the Inuit to follow (Dyke et al., 1996; Friesen, 2016).

The Inuit were very well adapted to the Arctic. They possessed specialized technology for hunting whales, and were efficient travellers with their use of dog sleds (Sutton, 2011). Their expansion was rapid, and they eventually occupied the entire Eastern Arctic, reaching Greenland by about 0.5 ka (1450 CE). By about 0.5 ka (1450 CE), the Inuit tradition had diversified into the various Inuit, Inuvialuit, and Inupiat groups which exist today (Sutton, 2011).

The human history of Greenland followed a similar trajectory as the rest of the Eastern Arctic, but had its distinctions. Paleo-Inuit peoples may have been first attracted to the region by the presence of the North Water polynya, a large, open-water oasis where Ellesmere Island and Greenland meet which attracted many species of marine mammals and birds (Grønnow, 2016). The first inhabitants of Greenland, who arrived around 4.5 ka, are distinguished into two groups: the Saqqaq in the south and west, and the Independence I in the north. The Saqqaq persisted until about 2.8 ka. Saqqaq may have developed into the Dorset, or were replaced by them (Sutton, 2011). The Independence I population appeared to have fluctuated greatly during their occupation of Northern Greenland, until their eventual abandonment of the high Arctic between 3.5 and 3 ka (Sutton, 2011). People returned to northeast Greenland during a warmer period around 2.5 ka. While this second occupation has traditionally been referred to as Independence II, its relation with Independence I is uncertain, leading some to refer to it instead as the Greenlandic Dorset (Jensen, 2016).

By about 2 ka, Greenland was entirely abandoned (Sutton, 2011). Some attribute this to climate cooling (Schledermann, 1980; Ryan, 2016), but it remains unclear (Jensen, 2016). The Dorset re-inhabited Greenland around 1 ka, but it was not long until they disappeared again, perhaps having been outcompeted by the Inuit. By 0.5 ka, the Inuit had expanded into both the northern and southern portions of Greenland, and eventually diversified into the various Indigenous Greenlandic groups encountered by the Europeans (Sutton, 2011).

2.3 Human-Environment Interactions and Paleodemography

2.3.1 Human-Environment Interactions

The study of past human-environment interactions seeks to understand how people have responded to past environmental changes, and to reveal how, and to what extent, human activity has influenced the environment. This research is the basis of classical geography and is relevant across several disciplines, from natural sciences such as ecology and earth sciences, to social sciences such as anthropology and history.

Environmental change may help explain many patterns and shifts observed throughout human history. Humans do not mechanistically respond to climate changes; rather, they respond and adapt to the secondary effects. Climate changes directly impact ecosystems, which results in changes in vegetation, fauna and water resources on which humans rely on for sustenance (Bigelow & Powers, 2001). These changes exert specific pressures on populations, which in turn may influence cultural shifts (e.g., Munoz et al., 2010), population changes (e.g., Williams et al., 2015), and migrations (e.g., Timmermann & Friedrich, 2016), either directly, and/or indirectly through sociological impacts (i.e., competition and conflict) (e.g., Zhang et al., 2011).

Human-environment interactions in the Arctic and Subarctic have been studied qualitatively and semi-quantitatively in local to regional contexts. In archaeological summaries of the region, the general condition of the climate is often mentioned alongside major events or cultural chronologies (e.g., Sutton, 2011, Friesen & Mason, 2016). In more specific archaeological studies, analyses of the causes of certain events, such as a migration, site abandonment, or cultural change, often discuss environmental changes as a possible factor and/or compare the events to a climate reconstruction (e.g., Betts, 2005; Mudie et al., 2005; Maschner et al., 2009; D'Andrea et al., 2011; Bhiry et al., 2016). With new paleoenvironmental reconstructions, regional paleoclimate syntheses, and relatively complete archaeological databases, we are now able to build upon this research by quantitatively examining the archaeological record in relation to the environment on larger scales.

2.3.2 Paleodemography

One quantitative approach to examine questions about past human-environment interactions is the analysis of paleodemography in relation to climate data. Using a database of archaeological radiocarbon dates, we can estimate past changes in population densities across time and space. This method relies on the assumption that a larger population would leave more traces of their activity on the land, which would be reflected in the archaeological record. The result is a quantitative estimate of past population sizes, which can then be compared to paleoenvironmental reconstructions. Previous studies employing this methodology have demonstrated the influence of paleoenvironmental change on population densities in many regions around the world (e.g., Williams et al., 2008; Munoz et al., 2010; Shennan et al., 2013;

Riris & Arroyo-Kalin, 2019), and a few studies have investigated paleodemography in this area in local to regional contexts, with some qualitative references to paleoenvironmental changes. Potter (2008) first estimated past populations in Central Alaska using the distribution of dated archaeological components. He found population fluctuated in the early Holocene, and attributed climate warming to the initial colonization of the area around 14 ka, the Younger Dryas Cold Period (YD) to a population decline from 14 – 13 ka, and the establishment of spruce forests to a decline from 10 – 9 ka. He noted population increased from 6 ka onwards, suggesting the arrival of new technology as a possible cause. Mullen (2012) used the summed probability distribution of archaeological radiocarbon dates from region of the White River Ash (WRA) deposition to reconstruct paleodemography and found a depopulation following the eastern WRA eruption, and an increase in surrounding populations following the northern WRA eruption. Tremayne & Winterhalder (2017) and Tremayne & Brown (2017) examined paleodemography across Alaska for the last 7 k using the summed probability distribution of archaeological radiocarbon dates. They found populations in the interior of Alaska remained stable throughout much of the Holocene, while those in coastal habitats exhibited a long-term growth trend. They identify a population collapse of the Arctic Small Tool tradition (ASTt) around 3.7 ka, and consider a collapse of caribou populations resulting from the Aniakchak volcanic eruption (first discussed by VanderHoek, 2009) as a potential cause. In the Canadian Arctic, significant work on the paleodemography of Paleo-Inuit populations has been undertaken by Savelle & Dyke (2002, 2009, 2014), Dyke & Savelle (2009), Dyke et al. (2011), Savelle et al. (2012) and Savelle & Dyke (2014). By dating the remains of Paleo-Inuit dwellings, they identified a virtually synchronous Late Holocene boom-and-bust sequence in Paleo-Inuit populations across the Western and Central Arctic. They discuss climate change as a potential factor in the widespread population collapse, but hesitate to accept it as a major contributing factor, citing a lack of evidence. They suggest instead that the initial population “boom” is typical of a population moving into a new, uninhabited territory, and the subsequent “bust” may have resulted from exceeding carrying capacity due to resource overexploitation.

While past population dynamics in Alaska and the Canadian Arctic are beginning to be revealed in regional contexts, paleodemography across most of the Arctic and Subarctic has not been investigated. Moreover, the role of climate and environmental change in influencing large-scale demographic patterns remains unclear.

CHAPTER 3:

Methodology

A data-analytic approach was taken to assess the impacts of environmental change on the size and distribution of past populations in the North. Past population sizes were reconstructed by analyzing the temporal frequency of radiocarbon dates related to human activity and assuming them to be proportional to population. This method relies on the notion that if more people were present in a particular place at a particular time, they would have left more traces of their activity on the land (Rick, 1987; Chaput & Gajewski, 2016). Various biases exist in the data, but we addressed them through previously-developed methods (Williams, 2012). The result was a quantitative estimate of population change through time and space. Estimates of paleodemographic change were then compared to quantitative reconstructions of past climate, sea ice, and other environmental variables.

This analysis was conducted across three spatial scales, beginning with the entire study region and then narrowing down to smaller sub-regions. This approach allowed for the identification of both broad-scale and local phenomena, as well as inter-regional patterns of paleodemographic and paleoenvironmental change. Multivariate data analysis methods were then employed to identify patterns, variation, and associations in and between the paleodemographic and paleoenvironmental reconstructions.

3.1 Study Region Delimitation and Division

This study considered the entire northern portion of North America, from Alaska through to Greenland, and comprising the Arctic and boreal regions. This area was divided into four regions (Figure 3.1) based on eco-climatological characteristics, accounting for the region's archaeological record as necessary:

1. **Beringia** includes Alaska and Yukon, which were largely unglaciated during the Wisconsin glacial period. Beringia served as the entry point for all migration events into North America, and thus has the longest history of human occupation of the study region.

2. **Subarctic** spans the range of the Boreal forest and its transitional ecozones east of Beringia. The Subarctic has generally been inhabited by Dené peoples in the northwest, and other First Nations peoples in the central and eastern areas.

3. **Arctic** encompasses tundra and polar desert environments within Canada, and is characterized by the past and present inhabitancy by Paleo-Inuit and Inuit peoples, respectively.

4. **Greenland** has a broadly similar archaeological history as Arctic Canada, but has a distinct climatology and climate history during the past 10 ka (Gajewski, 2015b).



Figure 3.1. Delimitation of the four regions. The Arctic and Subarctic regions overlap in Newfoundland and Labrador.

These four regions were sub-divided into smaller subregions based on the same criteria (Figure 3.2). Subregions in Beringia are defined by ecozones outlined in Anderson et al., 2004, modified based on the archaeological record. For example, the Kenai Peninsula & Kodiak Island region was likely inhabited by the Ocean Bay people & descendant cultures for its entire history

(Friesen & Mason (eds.), 2016). The Arctic and Greenland subregions are defined by the regional climatological history as reported in Gajewski (2015b). The Subarctic subregions are based on the paleoclimate reconstructions of Viau & Gajewski (2009) with adjustments according to the archaeological record. Their Central Canada region was split into the Northwest Subarctic and the Southwest Subarctic to distinguish between the pre-colonial occupation extents of Dené peoples and First Nations peoples, respectively. The 16 subregions are listed and briefly described in Table 3.1.

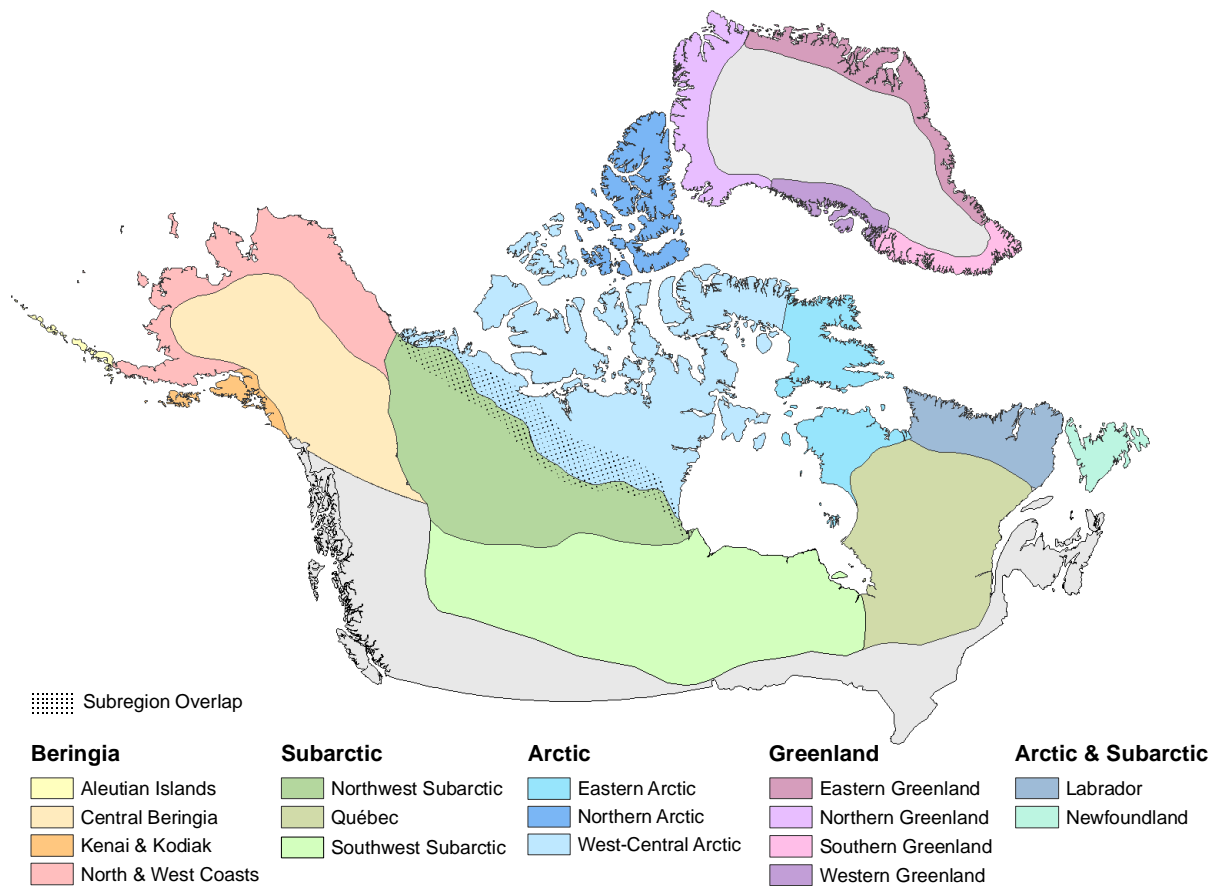


Figure 3.2. Delimitation of the subregions.

There is some overlap between the regions, reflecting the highly mobile nature of the land’s inhabitants as well as the unfixed ecozones and changing climate. For example, in the western forest-tundra transition zone, which shifted in position throughout the Holocene (MacDonald &

Gajewski, 1992; Gajewski & MacDonald, 2004; Gajewski et al., 2007), the Arctic and Subarctic regions overlap (Figure 3.2). Paleo-Inuit and Inuit occupations in this transition zone were included in the Arctic region, while Dené occupations in this zone were placed in Subarctic region. Similarly, archaeological data pertaining to Arctic Peoples in Newfoundland and Labrador were categorized under the Arctic region, while First Nations occupations in the same areas were placed in the Subarctic region.

Vector shapefiles of the overall study region were based on cultural regions outlined by Ubelaker (2006). The Arctic and Subarctic regions were also delimited based on Ubelaker’s delineations, but they were modified to accommodate the spatial distribution of archaeological radiocarbon dates pertaining to Arctic, First Nations, and Dené peoples as discussed above. Beringia and Greenland delimitations were based on shapefiles of geopolitical boundaries. Subregions were manually delineated in relation to maps presented in Anderson et al. (2004), Viau & Gajewski (2009), and Gajewski (2015b), with adjustments based on spatial distribution of archaeological dates where appropriate (i.e., based on cultural association as discussed).

Table 3.1. Subregions and their distinguishing ecological and archaeological characteristics.

Region	Subregion	Characteristics
<i>Beringia</i>	North & West Coasts	Low Arctic vegetation
	Central	Boreal forest
	Kenai & Kodiak	Temperate conifer and boreal forest, Ocean Bay tradition
	Aleutian Islands	Islands off the southwest coast
<i>Subarctic</i>	Northwest Subarctic	Boreal forest and boreal-tundra transition zone, Dené occupations
	Southwest Subarctic	Boreal and boreal-temperate forest transition zone
	Québec	Boreal and boreal-temperate forest transition zone & boreal-tundra transition
	Newfoundland	Boreal forest, First Nations and Paleo-Inuit occupations
	Labrador	Boreal forest and low Arctic vegetation, First Nations, Paleo-Inuit & Inuit
<i>Arctic</i>	West-Central Arctic	Low, middle and high Arctic vegetation
	Northern Arctic	High and middle Arctic vegetation
	Eastern Arctic	Low and middle Arctic vegetation
<i>Greenland</i>	Northern Greenland	High and middle Arctic vegetation, Independence occupation
	Western Greenland	Low and middle Arctic vegetation, Saqqaq occupation
	Southern Greenland	Low Arctic vegetation, Saqqaq occupation
	Eastern Greenland	Low and Middle Arctic vegetation, Independence occupation

3.2 Paleodemography

Changes in population density through time was estimated using the frequency of archaeological radiocarbon dates as a proxy for population size. Adjustments were made to account for sampling bias, taphonomic factors, and radiocarbon date calibration impacts. Paleodemographic reconstructions were generated for the entire study area, the four regions, and the sixteen sub-regions. In the Newfoundland and Labrador subregions, First Nations paleodemography was examined separately from Paleo-Inuit and Inuit paleodemography.

Changes in the spatial distribution of past populations were assessed by plotting the location of radiocarbon records as a function of time. This was conducted for the entire study area, and individually for the four regions.

3.2.1 Radiocarbon Dates

The majority of radiocarbon dates were obtained from the Canadian Archaeological Radiocarbon Database (CARD; <https://www.canadianarchaeology.ca/>). The CARD contains over 40,000 geo-referenced records of radiocarbon dates from archaeological sites across the world. Most records contain details of the archaeological context in which the radiocarbon-dated material was found and of the significance of the find (e.g., paleoenvironmental, paleontological, cultural). Radiocarbon dates were selected by mapping all CARD records using ArcGIS v.10.6.1 (ESRI) and extracting those that fall within the study region or sub-region boundaries as defined above. The initial sample included 4,153 records.

An additional 621 radiocarbon dates and associated information were then manually sourced from the literature to update the database (Appendices A and B). These were compiled following the style of the CARD, with the intention of ultimately submitting them to the database. Two hundred and seventy-four (274) of these records were compiled for Greenland, for which the CARD had none. Three hundred forty-seven (347) new records were collected for the Canadian Arctic, where a significant amount of archaeological material had recently been dated (e.g., Dyke et al., 2011; Savelle et al., 2012; Savelle & Dyke, 2014).

Each of the 4,774 dates was then individually vetted for quality control purposes. Records were excluded if they were not associated with human activity. Following general consensus on the timing of early human migration into North America, dates older than 15 ka were removed (Sutton, 2011; Goebel & Potter, 2016; Potter et al., 2017). Only dates pertaining to Indigenous peoples were included, therefore any Norse or colonial dates were removed. Dates listed as “anomalous” were then reviewed. In the CARD, a date may be flagged as anomalous from suspected sample contamination or dating errors, or when the date is significantly younger or older than the culture or stratigraphic layer to which it is associated. Alternatively, it is possible that some of the dates may have been flagged as anomalous by the author based on available knowledge of the era the excavation was conducted in, which may now be considered out-of-date. CARD contains records of archaeological investigation since the 1950s, and knowledge has certainly advanced since then. Some authors removed these anomalous dates in their studies (e.g., Munoz et al., 2010), while others do not explicitly mention if they were reviewed or not. While there does not appear to be a standard procedure for the use of these dates in population reconstructions, the sample size of dates for this study was deemed sufficiently large, so anomalous dates were removed.

Differences in sampling intensity between archaeological sites was then considered, as this may mask the true demographic signal (Rick, 1987). Sampling biases may arise from differences in funding across archaeological research, enhanced interest in particular time periods and/or places, as well as site inaccessibility. This is commonly addressed by weighting multiple dates from the same site and some defined time period as one single event, referred to as an occupation “episode” (e.g., Peros et al., 2010). In this study, we applied this method but narrowed it down. Dates from the same feature of an archaeological site within 100 calibrated years of each other were averaged and treated as one date, rather than averaging over the entire site. This is to accommodate the difference in size of archaeological sites in this study region, which may range from one artefact to an entire village. A site containing multiple house features reflects the presence of more people than one isolated artefact, which is critical information to retain when reconstructing population sizes. The bracket of 100 years was selected to maximize resolution.

The final dataset included 4029 dates, and these are distributed relatively evenly among the three regions of North America (Table 3.2). Greenland has many fewer dates, but it is not clear if this is due to the smaller area and shorter occupation or incompleteness of the database sample.

Table 3.2. Number of archaeological radiocarbon dates per region and subregion after preliminary quality control and adjusting for sampling bias. Two dates from Greenland had no associated spatial information, so they were not included in any subregion.

Region	Subregion	Dates	Region	Subregion	Dates
Beringia		1459	Greenland		212
	North & West Coasts	742		Northern	63
	Central	409		Western	59
	Kenai & Kodiak	226		Southern	55
	Aleutian Islands	82		Eastern	33
Subarctic		1225	Arctic		1133
	Northwest	221		West-Central	541
	Southwest	455		Northern	137
	Québec	237		Eastern	224
	Labrador	228		Labrador	116
	Newfoundland	84		Newfoundland	115

3.2.2 Radiocarbon Date Calibration

Radiocarbon dates used for spatial analysis and to generate histograms were calibrated using CALIB v.7.0 (Stuiver et al., 2019), while dates used to produce summed probability distributions (SPDs) were calibrated using OxCal v.4.3 (Bronk Ramsey, 1995; Bronk Ramsey, 2001) (discussed in section 3.2.3). Dates made on terrestrial materials were calibrated with the IntCal13 calibration curve (Reimer et al., 2013), while marine dates were calibrated using Marine13 (Reimer et al., 2013).

When calibrating dates made on materials of a marine origin, the marine reservoir effect (MRE) had to be considered. The MRE refers to how marine organisms have different ^{14}C (radiocarbon) levels than contemporaneous terrestrial organisms. This occurs because the ocean absorbs

atmospheric carbon at its surface, and ocean water mixes very slowly. This results in ocean waters being deficient in ^{14}C relative to the atmosphere (Ascough et al., 2005). Therefore, if you measure relative ^{12}C and ^{14}C in both a marine and terrestrial organic substance of the same age, the marine substance will be enriched in ^{12}C and will return a radiocarbon age different than that of the terrestrial material. The average difference in measured age is about 400 ^{14}C years, which is the standard correction applied when calibrating radiocarbon ages of marine materials (Ascough et al., 2005). However, the strength of the MRE differs both globally and with ocean depth. A deviation from the global average MRE of 400 years is referred to as ΔR (Alves et al., 2018). Polar waters have the largest reservoir effect (up to 800 ^{14}C years difference), likely due to sea ice inhibiting ocean-atmosphere air exchange (Ascough et al., 2005). This complicates the correction of radiocarbon ages of Arctic marine materials, which require local ΔR values. This accuracy is important for Arctic archaeology, given its relatively short human history and the abundance of marine materials in its archaeological sites (Ledger et al., 2016). For this reason, some studies exclude all marine radiocarbon dates from their analyses (e.g., Tremayne et al., 2017). There is no standard practice; other studies (e.g., Savelle & Dyke, 2014) retain marine dates and attempt to account for the marine reservoir effect.

A local ΔR value can be applied to each individual sample during the calibration process. Here we used the 14CHRONO Marine Reservoir Correction Database (Reimer & Reimer, 2001), a global database of local ΔR derived from peer-reviewed literature (<http://calib.org/marine/>). For each date, a local ΔR value was calculated using 14CHRONO and applied during calibration. This method is not without shortcomings; ΔR values from a given region in the Arctic still vary widely, so it is challenging to find a truly accurate local ΔR (e.g., Dumond & Griffin, 2002). Nonetheless, we maintain this method is preferable to removing all dates of marine origin, or to applying no local ΔR correction at all.

3.2.3 Paleodemographic Estimates

For the entire North and for the four subregions, summed probability density (SPD) curves were generated using the “Sum” function in OxCal (v4.3.2, <https://c14.arch.ox.ac.uk/oxcal.html>, last accessed May 2019). An SPD is a combination of each individual radiocarbon probability distribution. The advantage of an SPD is that it accounts for the entire range of probability for

each calibrated radiocarbon date, generating a probabilistic population model. The alternative is to use the calibrated median probability calibrated and plot or sum these in some way, but this could be considered less precise, as the distribution of any calibrated date is not normal. Sampling biased was addressed at this point by using the “Combine” function to add and average the calibrated distributions of the radiocarbon dates being combined.

The radiocarbon calibration process can generate false peaks and plateaus in SPDs, which alter the demographic signal. As these “artefacts” are not entirely predictable, there is no standard corrective formula (Williams, 2012; Bronk Ramsey, 2017). Williams (2012) suggests applying a 500-year moving-average smoother after calibration to mask the plateaus or spikes resulting from the calibration process, and this is commonly used (e.g., Kelly et al., 2013). Since moving averages shift the locations of peaks on the curve, we used a local regression instead and ensured a comparable level of smoothing as William’s recommendation.

Due to the lengthy processing time to generate SPDs (each of the five models took several weeks to a month to run), they were not generated for the sixteen subregions. The median probability dates generated with CALIB were used instead, and paleodemography was modelled by plotting a histogram of the frequency of dates through time with 200-year bins. This bin size accounts for the average error of the radiocarbon dates and therefore produces a demographic model with similar results to the SPDs (Figure 3.3). The subregion paleodemographic estimates were also smoothed with a local regression after having been adjusted for taphonomic bias (described below).

3.2.4 Addressing Taphonomic Bias

Due to the natural degradation process of organic matter, as well as progressive destruction of older sites through normal geomorphic processes, older materials are likely under-represented in the archaeological record. These taphonomic processes must be considered or accounted for when examining paleodemography using archaeological information, as population sizes of earlier millennia may be underestimated (Surovell et al., 2009).

The taphonomic degradation of data is commonly accounted for by applying a correction developed by Surovell et al. (2009) (e.g., Perez et al., 2016; Xu et al., 2019), however, the

universal applicability of this equation has been questioned (Williams, 2012; Goldberg et al., 2016). In the Arctic, where the frozen and dry environment favours preservation, a correction may not be required at all. Additionally, soil formation processes are slow in the Arctic; as a result, archaeological finds dating back to the earliest occupations are often on or near the surface and therefore easier to find than buried sites (e.g., Savelle & Dyke, 2009). However, the study area in question also includes regions with a higher risk of loss which may warrant such a correction, such as Boreal forest with its acidic soils and frequent forest fires (Pilon, 2001).

The correction for taphonomic bias was applied to all paleodemographic estimates, however, both the original paleodemographic and the corrected curve will be shown and interpreted. The primary objective of this study was to model the interaction of population growth with environmental change, so the long-term curve is of secondary interest. Curves (b) and (c) in Figure 3.3 depict the original SPD curve for the North and the same curve following adjustment for taphonomic factors, respectively.

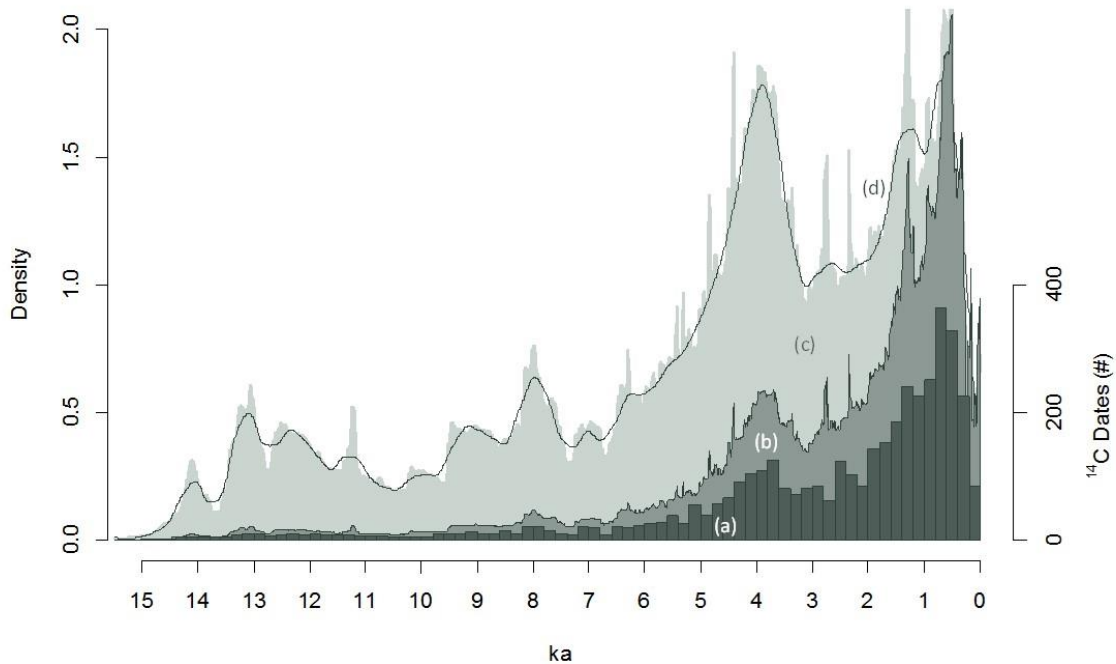


Figure 3.3. Process of converting radiocarbon dates to a summed probability density (SPD) population estimate. (a) Frequency of calibrated archaeological radiocarbon dates from across the North American North in 200-year bins. (b) Raw SPD produced in OxCal (Bronk Ramsey, 1995; Bronk Ramsey, 2001)

by summing individually calibrated radiocarbon distributions. (c) SPD corrected for loss due to taphonomic factors following the method of Surovell et al. (2009). (d) Final SPD smoothed using a loess, following the recommendations of Williams (2012).

3.2.5. The Greenland Archaeological Database

CARD contained no dates from Greenland, therefore the literature of Greenland archaeology was searched and radiocarbon dates were compiled for this study (Appendix A). As this study concerns the paleodemography of Indigenous peoples, Norse dates were excluded. Two hundred and seventy-four (274) radiocarbon dates and associated information (location, cultural association, archaeological context, etc.) were collected (Appendix A). The average radiocarbon date error is 67.8. A description of the origin of the material dated (marine vs. terrestrial) and the cultural association of the dates is presented in Table 3.3.

Table 3.3. Number of radiocarbon dates in the Greenland Archaeological Radiocarbon Database by origin of material dated and by cultural association as prescribed by the author.

Characteristic	Dates (#)
<i>Origin of Material Dated</i>	
Marine	21
Terrestrial	253
<i>Cultural Association</i>	
Dorset	2
Early Paleoeskimo	2
Greenlandic Dorset	37
Independence I	24
Independence II	14
Late Dorset	7
Saqqaq	108
Thule	77
Paleoeskimo or Neoeskimo	1

Saqqaq or Dorset	1
Unknown	1

Records are distributed around the coasts of Greenland (Figure 3.4). Populations were concentrated around the southwest, south, and northeast coasts, and they were highest around 3.8 ka and 0.8 ka (Figure 3.5). The archaeological record suggests the entire island was uninhabited from about 1.7 – 1 ka. Adjusting for sampling bias does not significantly change the temporal distribution of radiocarbon dates (Figure 3.5).

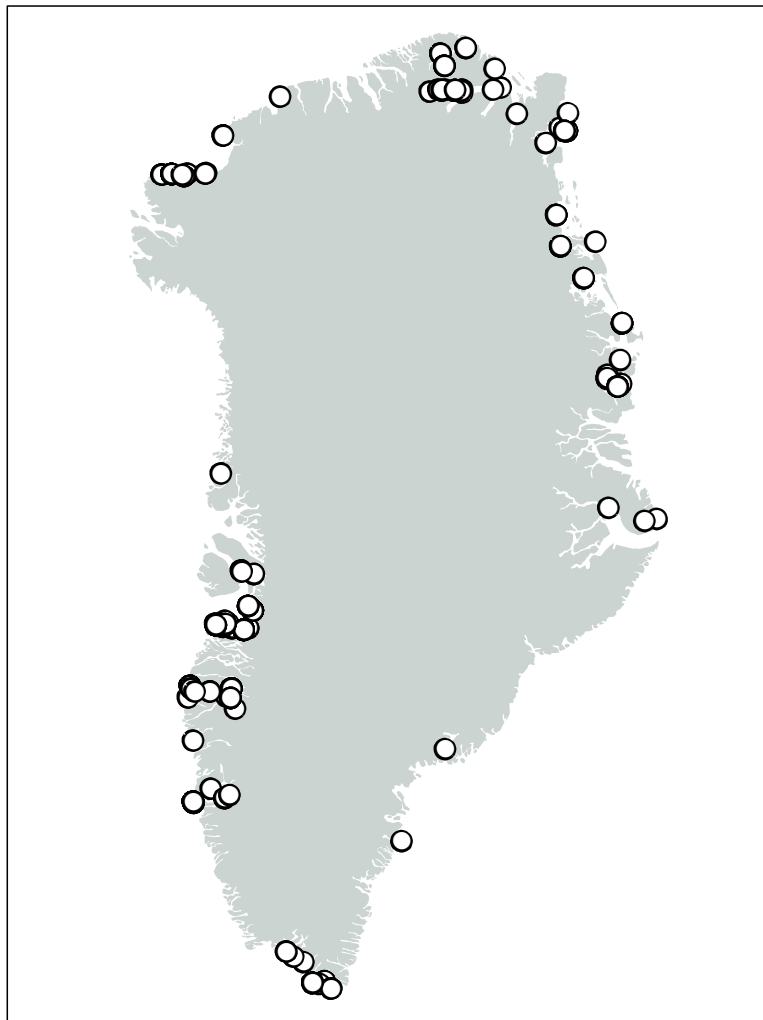


Figure 3.4. Locations of radiocarbon dates from the Greenland Archaeological Radiocarbon Database. One point may represent multiple dates.

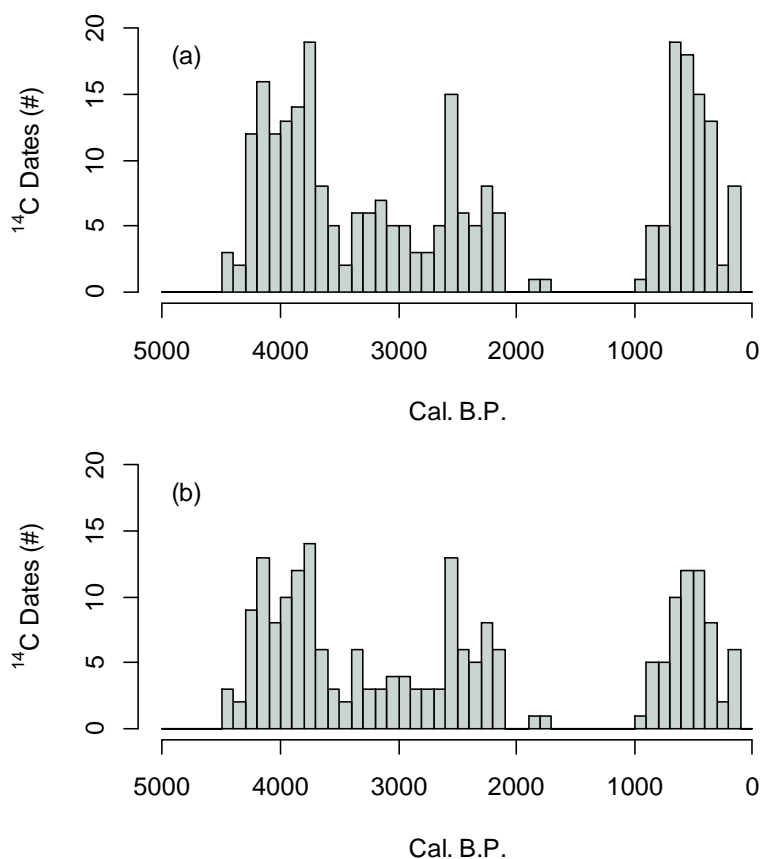


Figure 3.5. Frequency of calibrated radiocarbon dates from Greenland in 100-year bins for (a) the original database and (b) the dataset corrected for sampling bias.

3.2.6 Radiocarbon Dataset Update for the Canadian Arctic

Over the last decade, significant archaeological work had been undertaken in the Canadian Arctic, but the CARD had not acquired these new data. To maximize sample size for this study, the literature was searched and radiocarbon dates from recent publications were gathered (Appendix B). All dates pertaining to the Paleo-Inuit and Inuit were collected. As some Paleo-Inuit groups also lived as far south as Newfoundland at times, all new dates are not necessarily from the Arctic. Three hundred forty-seven (347) radiocarbon dates were collected, with an average dating error of 33 radiocarbon years. Materials of terrestrial origin were more commonly

dated (Table 3.4). Most dates are attributed to the Paleo-Inuit. Some authors did not distinguish between early, middle or late phases of cultural traditions (e.g., “Dorset” may refer to any Paleo-Inuit phase).

Table 3.4. Number of dates in the Canadian Arctic radiocarbon dataset update by origin of material dated and by cultural association as prescribed by the author.

Characteristic	Dates (#)
<i>Origin of Material Dated</i>	
Marine	18
Terrestrial	329
<i>Cultural Association</i>	
Early Pre-Dorset	11
Pre-Dorset	5
Late Pre-Dorset	5
Terminal Pre-Dorset	4
Dorset	179
Early Dorset	2
Middle Dorset	49
Late Dorset	16
Early Groswater	1
Groswater	2
Groswater (transition)	1
Groswater (transition) / Early Dorset	4
Late Groswater	1
Classic Thule	6
Thule	49
Thule-Inuit	2
Innuinait	8
Dorset or Thule	2

Sites are mainly concentrated in the low and central Arctic, while a few are located in Newfoundland and Labrador (Figure 3.6). The frequency distribution of radiocarbon dates through time suggests population was high around 4 ka, low between 3 and 2 ka, and then high for the last 2 k (Figure 3.7a). This interpretation remains the same after the dataset is adjusted for sampling bias (Figure 3.7b). Three records date between 7 and 6 ka (Figure 3.7a), but these were flagged as anomalous in the publication(s), so they were removed for the quality-controlled dataset.

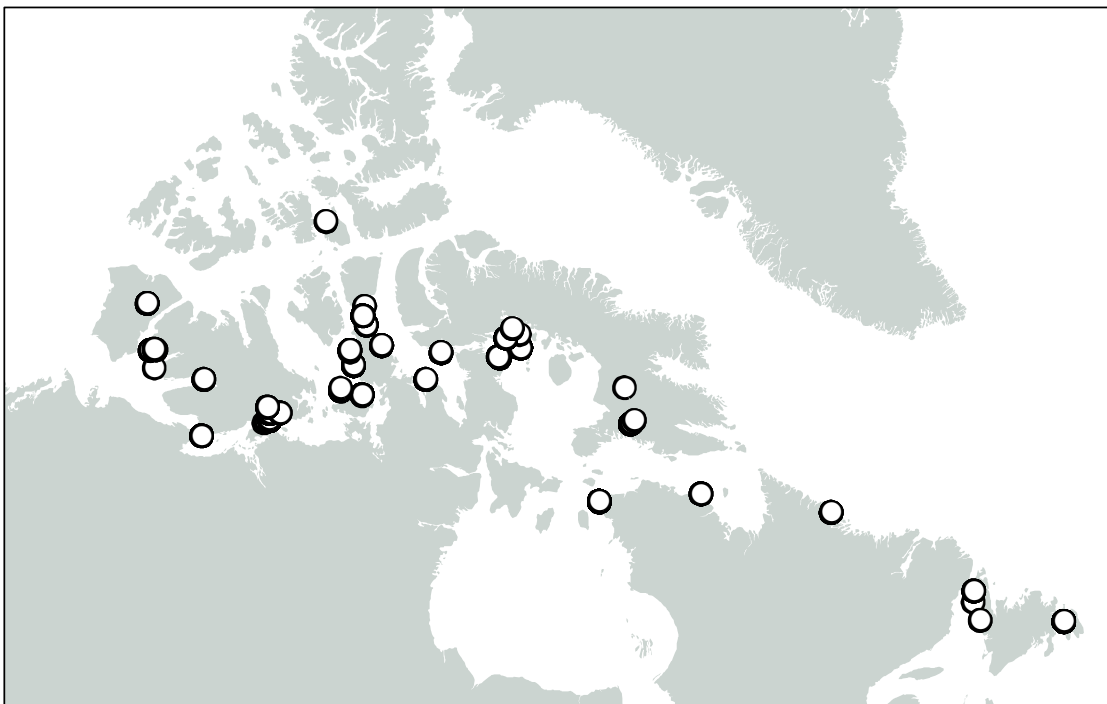


Figure 3.6. Locations of the new collection of radiocarbon dates from the Canadian Arctic. One point may represent multiple dates.

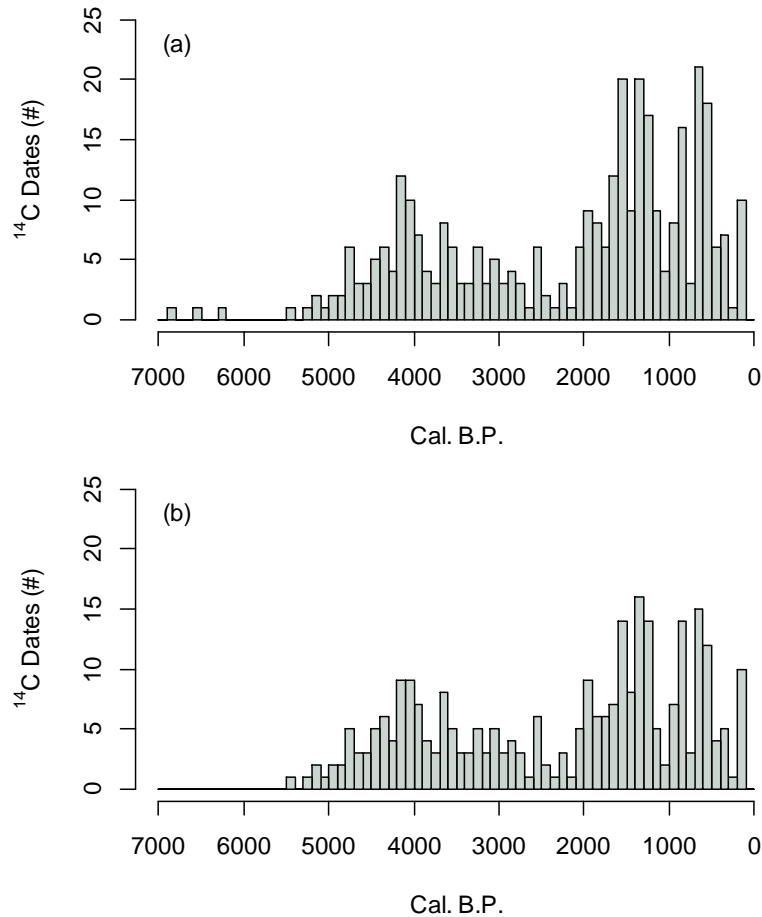


Figure 3.7. Frequency of calibrated radiocarbon dates from the Canadian Arctic in 100-year bins for (a) the original dataset and (b) the dataset after having anomalous dates removed and having been corrected for sampling bias.

3.3 Paleoenvironmental Data

Paleoenvironmental data was obtained from peer-reviewed literature and standard databases NOAA Paleoclimatology (<https://www.ncdc.noaa.gov/paleo>; last accessed July 2019), PANGAEA (<https://www.pangaea.de/>; last accessed July 2019), and the Arctic Holocene Climate Proxy Database (AHCPD) (Sundqvist et al., 2014) (Table 3.5). A time-series of the extents of land ice through time was produced by calculating the geometry of shapefiles of late Pleistocene and Holocene ice extents by Dyke (2004) in ArcGIS for every 1000 radiocarbon years.

Table 3.5. Paleoenvironmental data used in this study.

Record	Variable	Unit	Proxy	Source	Lat.	Long.	Region	Reference(s)
<i>Individual Series</i>								
Agassiz Melt	Temp.	Summer Melt (%)	Ice Melt	Ice	80.70	-73.10	Ellesmere Island	Vinther et al., 2009; Sundqvist et al., 2014
Agassiz Temp.	Temp.	Mean Annual Temp. Anomaly (°C)	δ18O and Ice Melt	Ice	80.70	-73.10	Ellesmere Island	Lecavalier et al., 2017
GRIP	Temp.	δ18O	δ18O	Ice	72.01	-37.63	Central Greenland	Vinther et al., 2006 Sundqvist et al., 2014
Bass Pond	Temp.	Max. Summer Surface Water Temp. (°C)	Chironomid	Lake	50.72	-57.37	Newfoundland	Rosenburg et al., 2005
Deltasø	Temp.	July Air Temp. (°C)	Chironomid	Lake	76.76	-67.61	Northwest Greenland	Axford et al., 2019
Lac Aurélie	Temp.	August Temp. Anomaly (°C)	Chironomid	Lake	50.42	-74.23	Central Québec	Bajolle et al., 2018
North Lake	Temp.	Mean July Air Temp. Anomaly (°C)	Chironomid	Lake	69.24	-50.03	West Greenland	Axford et al., 2013
GGC19	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	72.16	-155.51	Beaufort Sea	de Vernal et al., 2013
HLY0501	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	72.69	-157.52	Beaufort Sea	de Vernal et al., 2013
HU021TW	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	58.37	-57.51	Labrador Sea	de Vernal et al., 2013
HU015	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	61.3	-71.06	Hudson Strait	de Vernal et al., 2013
HU008	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	77.27	-74.32	Northwest Greenland	de Vernal et al., 2013
MD2227	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	58.21	-48.37	South Greenland	de Vernal et al., 2013
JM1207	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	68.1	-29.35	East Greenland	de Vernal et al., 2013
Arc-3	Sea Ice	IP ₂₅ flux (µg/cm ² yr ⁻¹)	IP ₂₅	Marine	74.27	-91.11	Central CAA	Belt et al., 2010
Arc-4	Sea Ice	IP ₂₅ flux (µg/cm ² yr ⁻¹)	IP ₂₅	Marine	69.18	-100.70	South CAA	Belt et al., 2010
Arc-5	Sea Ice	IP ₂₅ flux (µg/cm ² yr ⁻¹)	IP ₂₅	Marine	69.00	-106.57	South CAA	Belt et al., 2010
<i>Regional Averages</i>								
Arctic	Temp.	Mean July Temp. (°C)	Pollen	Lakes				Gajewski, 2015b
Greenland	Temp.	Mean July Temp. (°C)	Pollen	Lakes				Gajewski, 2015b
Beringia	Temp.	Mean Annual Temp. Anomaly (°C)	Pollen	Lakes				Viau et al., 2008
Boreal	Temp.	Mean July Temp. Anomaly (°C)	Pollen	Lakes				Viau & Gajewski, 2009
Northwest	Temp.	Mean July Temp. (°C)	Pollen	Lakes				This study
Southwest	Temp.	Mean July Temp. (°C)	Pollen	Lakes				This study
<i>Other</i>								
Insolation	Insolation	July Insolation at 65°N (W/m ²)						Berger & Loutre, 1991; Berger & Loutre, 1999.

This study relies primarily on pollen data to represent the terrestrial paleoclimate, as there is a complete set of regional pollen-based climate reconstructions from across the study region (Viau et al., 2008; Viau & Gajewski, 2009; Gajewski, 2015b; Gajewski, 2019). These reconstructions reflect summer (July) temperature. For Beringia, because the regional seasonal reconstruction has been questioned (Viau et al., 2008), we are using the reconstruction of mean annual temperatures. An average pollen-based climate reconstruction to represent the entire study region was calculated by averaging the regional averages of Viau et al. (2008), Viau & Gajewski (2009), & Gajewski (2015b). The Mackenzie series from Viau & Gajewski (2009) was excluded from this calculation because the area was already represented in the Beringia reconstructions of Viau et al., (2008). For regions where there are no or few pollen-based climate reconstructions, chironomid-based reconstructions were used, which also represent summer temperatures. δ¹⁸O and summer melt records from ice cores were included to represent long-term climate changes.

Dinocyst and IP₂₅ records from ocean sediment cores were used as reconstructions of past sea ice. Insolation and volcanic eruptions were included as climate forcing variables.

Regional paleoenvironmental averages did not exist for several subregions, so they were generated by averaging individual series from the area. For the Southwest and Northwest Subarctic subregions, individual pollen-based climate reconstructions from Gajewski et al. (in preparation) were averaged. A new regional average for the Eastern Arctic was computed based on Gajewski (2015b), but excluding Sermiut from Greenland and two older diagrams from Baffin Island. A regional sea ice curve for the Canadian Arctic was calculated by linearly interpolating, standardizing, and averaging the Arc-3, Arc-4, and Arc-5 series (Belt et al., 2010). One for Greenland was made by averaging the HU008, JM1207, and the MD2227 series (de Vernal et al., 2013), and one for the Beaufort Sea region of Beringia was calculated using the GGC19 and the HLY0501 series (de Vernal et al., 2013).

3.4 Principal Components Analysis

Principal components analyses (PCA) were conducted in R v.3.5.0 (R Core Team, 2018) using the “Vegan” package v.2.5-3 (Oksanen et al., 2018) to summarize the paleoclimatic and paleodemographic histories across the study region. A PCA describes the variance within a dataset and highlights synchronicities and oppositions between different series. When conducted on a dataset of time series, a PCA typically will identify the long-term trend and significant departures from the trend.

Separate PCAs were conducted on the subregional paleoclimate series and subregional paleodemographic estimates. For the paleodemographic dataset, the series adjusted for taphonomic impacts were used. For the paleoclimate PCA, one climate record for each subregion was included. When a subregion had multiple climate reconstruction options, the series with the highest sampling resolution and/or the longest record was selected. Constrained by the limited lengths of several climate records, all series for the PCA were truncated to the span of 6900 – 200 B.P. Results from the environmental and demographic PCAs were compared to assess the relation between dominant patterns in the study region’s paleoclimate and population history.

CHAPTER 4:

Holocene Paleodemography of the North American Arctic and Subarctic in relation to Paleoenvironmental Change

Key Words

Climate change, paleoecology, paleoclimate, archaeology, neoglaciation, 4.2 event, North America, boreal forest, tundra, Greenland

4.1 Introduction and Background

Climate change has had a significant influence on human history throughout the Pleistocene and Holocene. Major changes in temperature and precipitation regimes have influenced large-scale human activities, including migration events (e.g., Timmermann & Friedrich, 2016; Friesen et al., in press), population booms and busts (e.g., Williams et al., 2008; Kelly et al., 2013; Riris & Arroyo-Kalin, 2019), societal collapses (e.g., Douglas et al., 2015), cultural changes (e.g., Munoz et al., 2010), and agricultural developments (e.g., Wohlfarth et al., 2016; Warden et al., 2017). For North America, a few studies have revealed how ancient populations fluctuated in size in response to the impacts of climate changes (e.g., Munoz et al., 2010; Kelly et al., 2013), but this has not been thoroughly investigated in the Arctic and Subarctic regions.

One quantitative method to identify how environmental changes have affected past societies is the analysis of paleodemography in relation to climate data. Past changes in population densities across time and space can be estimated using a database of archaeological radiocarbon dates. This method relies on the assumption that a larger population would leave more traces of their activity on the land, which would be reflected in the archaeological record (e.g., Rick, 1987; Chaput & Gajewski, 2016). The result of this approach is a quantitative estimate of relative population density through time, which can then be compared to paleoenvironmental reconstructions.

A few studies have examined paleodemography in the North American Arctic or Subarctic. For example, Paleo-Inuit population were found to have declined around 3.9 ka (1000 years before

present, where present is defined as 1950 CE) in most areas surveyed in western and central Canadian Arctic (Savelle & Dyke, 2002, 2009; Dyke & Savelle, 2009; Dyke et al., 2011; Savelle et al., 2012; Savelle & Dyke, 2014). They postulate that the population decline resulted from resource-overexploitation following rapid population increase, and that climate changes were not necessarily a factor. Tremayne & Winterhalder (2017) and Tremayne & Brown (2017) noted a decline of the Arctic Small Tool tradition (ASTt) in Alaska around 3.7 ka, potentially a result of the decimation of caribou populations which may have followed the Aniakchak volcanic eruption (VanderHoek, 2009).

These studies have demonstrated the utility of a paleodemographic approach, but there has yet to be a quantitative analysis of paleodemography in relation to paleoenvironmental data across the entire North American Arctic and Subarctic. With the significant advances made over the last decade in the study of northern paleoenvironments, this is now possible. Multi-proxy paleoenvironmental databases have been assembled (e.g., Sundqvist et al., 2014), regional paleoclimate syntheses have been published (e.g., Vialou et al., 2008; Vialou & Gajewski, 2009, Gajewski, 2015b, Briner et al., 2016, Kaufman et al., 2016), and summaries of past sea ice conditions have been completed (Belt & Vare, 2010; de Vernal et al., 2013; Hole & Macias-Fauria, 2017). A key finding from this work is that different regions within the same modern ecozone (e.g., Arctic, Subarctic) have different climate histories (Gajewski, 2015b; McKay & Kaufman, 2018). Understanding the spatio-temporal dynamics of the paleoclimate is fundamental to the investigation of large-scale human-environment interactions.

4.2 Methods

We examined the impacts of paleoenvironmental change on past populations across the North American Arctic, Subarctic, and Greenland (hereafter referred to as “the North”). This region extends from the northernmost limits of Greenland to the southern extents of the Boreal forest, and spans from the East coast of Greenland to the Aleutian Islands in Alaska.

We took a data-analytic approach to analyse the impacts of climate and environmental change on past population sizes and their spatial distribution. Using the Canadian Archaeological Radiocarbon Database (CARD; www.canadianarchaeology.ca), we estimated past population

sizes from the North at three spatial scales: sub-continental, regional, and sub-regional. Population estimates were then compared to reconstructions of past environmental conditions across the same scales. This three-tiered approach allowed us to assess the scale and regionality of environmental impacts on populations.

In terms of paleoenvironmental variables, this study is primarily concerned with temperature. Variations in average temperatures result in changes in vegetation, fauna and water resources on which humans rely on for sustenance. In this study, the temperatures were primarily estimated from pollen assemblages, and thus are a reflection of the overall environment and available resources. In Arctic environments, sea ice is also an important consideration, as it affects the harvest of sea mammals, staple foods for Arctic peoples (Friesen, 2016). As sea ice is not exclusively a function of temperature, it is important as an independent variable.

4.2.1 Regional Delimitation

We divided the North into four regions based on eco-climatological characteristics, accounting for the region's archaeological record as necessary (Figure 1). "Beringia" includes Alaska and the Yukon Territory. It was largely unglaciated during the last glaciation, and has the oldest history of human occupation in the Americas. The "Subarctic" region spans the range of the Boreal forest and its transitional ecozones east of Beringia. The "Arctic" region includes the tundra and polar desert environments within Canada occupied by Paleo-Inuit and Inuit peoples. This region will therefore include some dates from Newfoundland and Labrador, as Arctic peoples inhabited the area for several millennia.

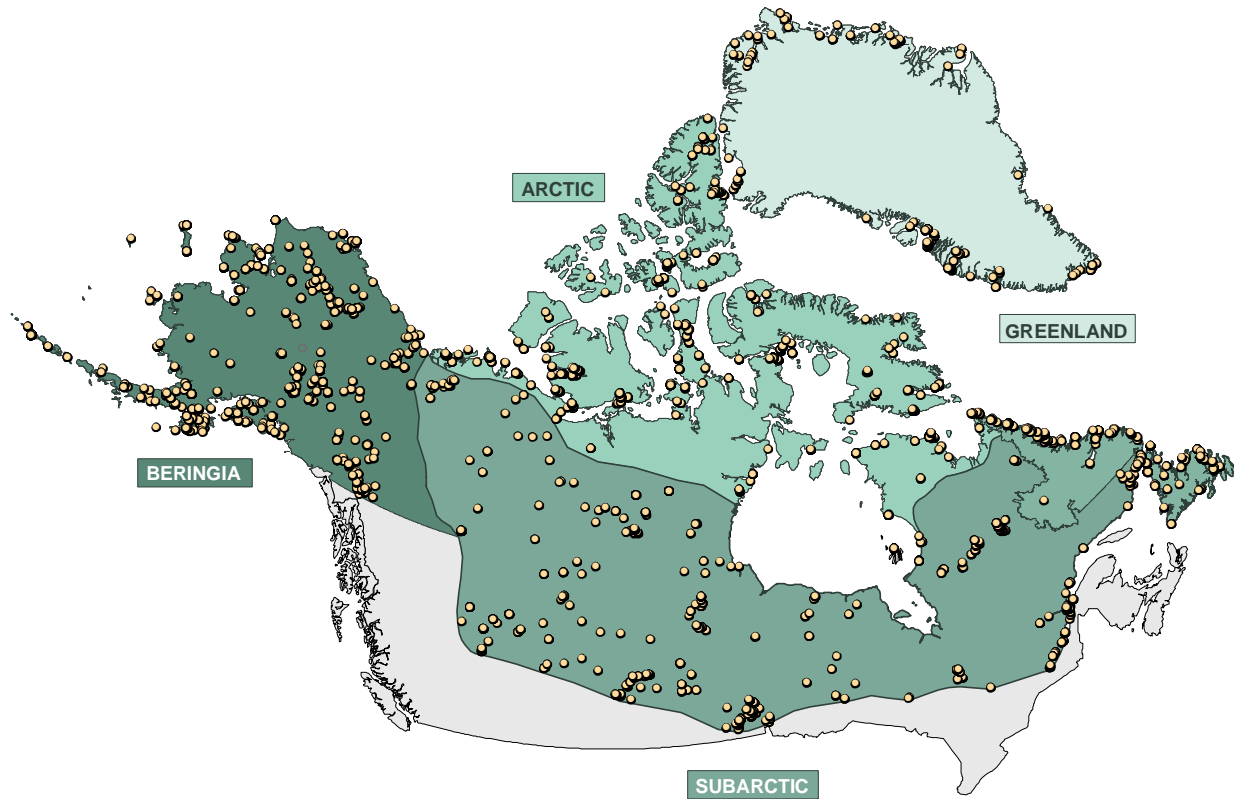


Figure 4.1. Study area and its four regions. The Arctic and Subarctic regions overlap in Newfoundland and Labrador. Points represent archaeological radiocarbon dates, although a single point may represent multiple dates.

Greenland was treated as a separate region for this analysis. Although Greenland has a similar archaeological history as the Arctic, we are separating them because the paleoclimate history of Greenland is distinct from that of the Canadian Arctic (Gajewski, 2015b). A database of cultural radiocarbon dates from Greenland was prepared for this study, although the sample size is small in comparison to the Canadian Arctic (212 vs. 1133 in the final datasets).

Each region was further divided into subregions, for a total of 16 (Figure 2). These also reflect ecological and climatological zones, while being constrained by the archaeological record. Beringia is divided into the coastal zone (North & West Coasts), interior forest (Central), and temperate forest in the south (Kenai & Kodiak). Subregions in the Arctic and Greenland are defined by the regional climatological history as reported in Gajewski (2015b). The Subarctic subregions are based on the paleoclimate reconstructions of Viau & Gajewski (2009) with some

modifications; we divided the Central Canada climate region into the Northwest Subarctic and the Southwest Subarctic to distinguish between the pre-colonial occupation extents of Dené peoples and First Nations, respectively.

In the forest-tundra transition zone, the West-Central Arctic and Northwest Subarctic subregions overlap. Paleo-Inuit and Inuit occupations in this transition zone were included in the West-Central Arctic subregion, while Dené occupations in this zone were placed in the Northwest Subarctic subregion.

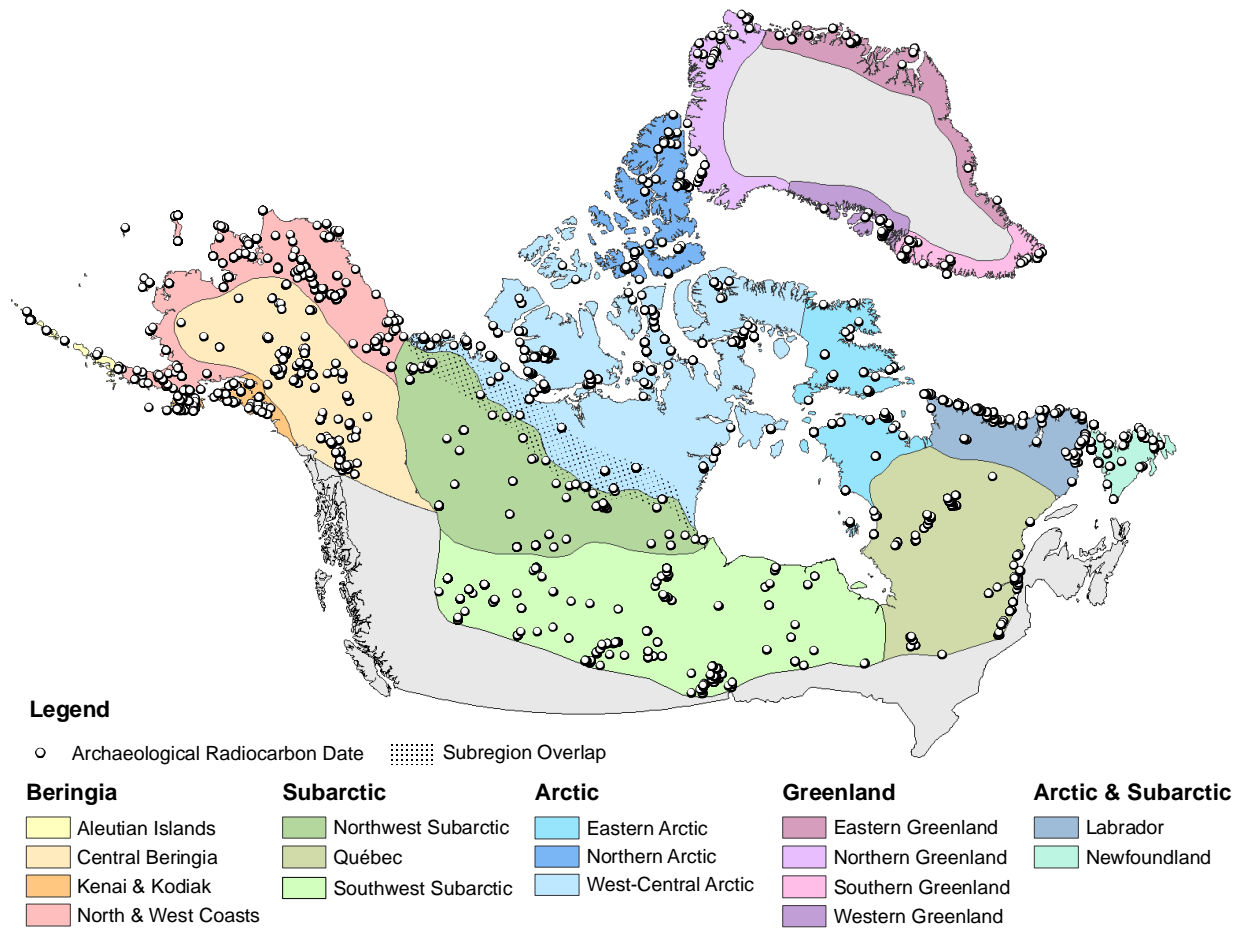


Figure 4.2. Location of subregions. Points represent archaeological radiocarbon dates. A single point may represent multiple dates.

4.2.2 *Paleodemography*

We used radiocarbon dates from archaeological sites as a proxy for past human population size (Rick, 1987). Most radiocarbon dates ($n=4153$) were obtained from the CARD. Additional radiocarbon dates were compiled from the literature for Greenland ($n=274$), from which the CARD had none, and for the Canadian Arctic ($n=347$), where a significant amount of archaeological study had been recently done (e.g., Dyke et al., 2011; Savelle et al., 2012; Savelle & Dyke, 2014).

Records from CARD were excluded if they were not associated with human activity, or if they were flagged as being anomalous (e.g., due to sample contamination). Following consensus on the timing of initial human occupation in Beringia, dates older than 15 ka were also excluded (Goebel & Potter, 2016; Potter et al., 2017). Only dates pertaining to Indigenous peoples were included. To account for sampling bias, which may alter the demographic signal (Rick, 1987), dates from the same feature of a site within 100 calibrated years of each other were averaged and treated as one date. After these adjustments, our final dataset included 4029 dates; 1459 dates are in Beringia, 1225 in the Subarctic, 1133 in the Arctic, and 212 in Greenland.

Summed probability density (SPD) curves were generated in OxCal v.4.3 (Bronk Ramsey, 1995; Bronk Ramsey, 2001) using the Sum function. Dates were calibrated at this stage. Radiocarbon dates used to generate histograms and conduct spatial analysis were calibrated using CALIB v.7.0 (Stuiver et al., 2019). In both instances, the IntCal13 calibration curve (Reimer et al., 2013) and the Marine13 calibration curve (Reimer et al., 2013) were used for materials of a terrestrial and marine origin, respectively. A local marine reservoir correction (ΔR) was applied to dates of marine materials. Local ΔR values were calculated uniquely for each marine date using the 14CHRONO Marine Reservoir Correction Database (<http://calib.org/marine/>) (Reimer & Reimer, 2001).

To remove false peaks and valleys in the SPDs resulting from the calibration process (Williams, 2012), the SPDs were smoothed in R using a loess function. Demographic curves for the subregions are presented as histograms with bin-widths of 200 years. We only interpret results up to ~1800 CE, as there is a reduced use of radiometric dating on more modern archaeological contexts (Rick, 1987).

A final consideration is the loss of archaeological sites through time due to taphonomic processes. Older occupations are more likely to be under-represented in the archaeological record, as older sites have had more time to be eroded or weathered. In a paleodemographic reconstruction, this may underestimate population sizes of earlier millennia. This is commonly accounted for by applying a correction developed by Surovell et al., (2009) (e.g., Perez et al., 2016; Xu et al., 2019). We applied this correction to all of our paleodemographic estimates, but as the universal applicability of this correction has been questioned (e.g., Williams, 2012; Goldberg et al., 2016), both the original and corrected curves will be shown and interpreted.

4.2.3 Paleoenvironmental Data

Paleoenvironmental data was obtained from peer-reviewed literature and standard databases NOAA Paleoclimatology (<https://www.ncdc.noaa.gov/paleo>; last accessed July 2019), PANGAEA (<https://www.pangaea.de/>; last accessed July 2019), and the Arctic Holocene Climate Proxy Database (AHCPD) (Sundqvist et al., 2014). Records from pollen, chironomid, and ice cores were used to represent the terrestrial paleoclimate, while dinocyst and IP₂₅ records from ocean sediment cores were used as reconstructions of past sea ice.

We are relying primarily on pollen data for paleoclimate reconstructions, as there is a complete set of regional pollen-based climate reconstructions from across the study region (Viau et al., 2008; Viau & Gajewski, 2009; Gajewski, 2015b; Gajewski, 2019). These reconstructions reflect summer (July) temperature. For Beringia, where the seasonal reconstruction has been questioned (Viau et al., 2008), we are using the reconstruction of mean annual temperature. As there are no pre-existing regional averages for the Southwest and Northwest Subarctic subregion, we generated our own by averaging individual reconstructions from Gajewski et al. (in preparation). A new regional average for the Eastern Arctic was computed based on Gajewski (2015b), but excluding Sermiut from Greenland and two older diagrams from Baffin Island. We produced a regional sea ice curve for the Arctic by standardizing and averaging the Arc-3, Arc-4, and Arc-5 series (Belt et al., 2010), one for Greenland by averaging the HU008, JM1207, and MD2227 series (de Vernal et al., 2013), and one for the north & west coasts subregion of Beringia by averaging GGC19 and the HLY0501 series (de Vernal et al., 2013).

Table 4.1. Paleoenvironmental data used in this study.

Record	Variable	Unit	Proxy	Source	Lat.	Long.	Region	Reference(s)
<i>Individual Series</i>								
Agassiz Melt	Temp.	Summer Melt (%)	Ice Melt	Ice	80.70	-73.10	Ellesmere Island	Vinther et al., 2009; Sundqvist et al., 2014
Agassiz Temp.	Temp.	Mean Annual Temp. Anomaly (°C)	δ18O and Ice Melt	Ice	80.70	-73.10	Ellesmere Island	Lecavalier et al., 2017
GRIP	Temp.	δ18O	δ18O	Ice	72.01	-37.63	Central Greenland	Vinther et al., 2006 Sundqvist et al., 2014
Bass Pond	Temp.	Max. Summer Surface Water Temp. (°C)	Chironomid	Lake	50.72	-57.37	Newfoundland	Rosenburg et al., 2005
Deltasø	Temp.	July Air Temp. (°C)	Chironomid	Lake	76.76	-67.61	Northwest Greenland	Axford et al., 2019
Lac Aurélie	Temp.	August Temp. Anomaly (°C)	Chironomid	Lake	50.42	-74.23	Central Québec	Bajolle et al., 2018
North Lake	Temp.	Mean July Air Temp. Anomaly (°C)	Chironomid	Lake	69.24	-50.03	West Greenland	Axford et al., 2013
GGC19	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	72.16	-155.51	Beaufort Sea	de Vernal et al., 2013
HLY0501	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	72.69	-157.52	Beaufort Sea	de Vernal et al., 2013
HU021TW	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	58.37	-57.51	Labrador Sea	de Vernal et al., 2013
HU015	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	61.3	-71.06	Hudson Strait	de Vernal et al., 2013
HU008	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	77.27	-74.32	Northwest Greenland	de Vernal et al., 2013
MD2227	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	58.21	-48.37	South Greenland	de Vernal et al., 2013
JM1207	Sea Ice	Mean Annual Concentration	Dinocyst	Marine	68.1	-29.35	East Greenland	de Vernal et al., 2013
Arc-3	Sea Ice	IP ₂₅ flux (µg/cm ² yr ⁻¹)	IP ₂₅	Marine	74.27	-91.11	Central CAA	Belt et al., 2010
Arc-4	Sea Ice	IP ₂₅ flux (µg/cm ² yr ⁻¹)	IP ₂₅	Marine	69.18	-100.70	South CAA	Belt et al., 2010
Arc-5	Sea Ice	IP ₂₅ flux (µg/cm ² yr ⁻¹)	IP ₂₅	Marine	69.00	-106.57	South CAA	Belt et al., 2010
<i>Regional Averages</i>								
Arctic	Temp.	Mean July Temp. (°C)	Pollen	Lakes				Gajewski, 2015b
Greenland	Temp.	Mean July Temp. (°C)	Pollen	Lakes				Gajewski, 2015b
Beringia	Temp.	Mean Annual Temp. Anomaly (°C)	Pollen	Lakes				Viau et al., 2008
Boreal	Temp.	Mean July Temp. Anomaly (°C)	Pollen	Lakes				Viau & Gajewski, 2009
Northwest	Temp.	Mean July Temp. (°C)	Pollen	Lakes				This study
Southwest	Temp.	Mean July Temp. (°C)	Pollen	Lakes				This study
<i>Other</i>								
Insolation	Insolation	July Insolation at 65°N (W/m ²)						Berger & Loutre, 1991; Berger & Loutre, 1999.

4.2.4 Data Analysis

All analyses were completed in R v.3.5.0 (R Core Team, 2018) and maps were made in ArcMap v.10.6.1 (ESRI). Principal components analyses (PCA) were conducted on the paleodemography and the paleoclimate data in R using the “Vegan” package v.2.5-3 (Oksanen et al., 2018). The paleodemographic curves corrected for taphonomic bias were used for this analysis. Data were resampled to 100-year intervals using linear interpolation. One paleoclimate record for each subregion was included in the paleoclimate PCA, and for subregions with multiple climate reconstruction options, we selected the series with the highest sampling resolution and/or the longest record. For the paleodemography PCA, First Nations and Paleo-Inuit groups were treated as independent records in both Newfoundland and Labrador. Constrained by the limited paleoclimate record lengths, all series for both PCAs were truncated to 6900 – 200 B.P. Results from each PCA were compared to assess the relation between dominant patterns in the region’s paleoclimate and population history.

4.3 Results

4.4.1 Sub-Continental Paleodemography and Paleoenvironments

From the initial arrival of peoples into North America at 14 ka until about 9 ka, population density was low (Figure 4.3a). After ~6 ka, population density rapidly increased, reaching an initial peak at 3.9 ka. Population density decreased until 3.1 ka, slowly increased until about 1.9 ka, followed by a second rapid increase until 0.7 ka. Correcting for taphonomic loss retains all of these features, but the corrected curve suggests that the population at the 3.9 ka peak was as large as population at the 0.7 ka peak. It also suggests that the magnitude of the subsequent population decline was much larger.

Periods of population growth are associated with expansion into new, previously uninhabited regions (Figure 4.4). Between 10.5 to 8 ka, populations were expanding east and south. Similarly, an increase in the rate of Mid-Holocene population growth beginning at 5 ka coincides with the migration of people into the mid-high Arctic (>70°N).

During the late glacial, summer insolation was increasing but the average climate across the continent remained relatively cool. Population density increased prior to the Younger Dryas (YD; 12.9 – 11.7 ka), reaching an initial maximum centered at 13.1 ka (Figure 4.3a), but decreased during the YD period. Although the YD is clearly shown in the GRIP ice core record (Figure 4.3c), and there is strong evidence it cooled at this time in south Beringia, it may not have cooled in Central and Northern Alaska (Kokorowski et al., 2008).

In the Early Holocene (11.7 – 8.2 ka), insolation was at its maximum (Figure 4.3g), and temperatures were high or rising. Population density remained low as large ice sheets persisted, so there was little land available for expansion. At the beginning of the Mid-Holocene, the Laurentide ice sheet collapsed, leading to a brief cold period and stabilization of the overall climate. During the Mid-Holocene (8.2 – 4.2), pollen-based reconstructions suggest temperatures were at their Holocene maximum (Figure 4.3b), and this coincided with a period of major population growth. Gradual neoglacial cooling characterised the late Holocene, but it does not appear to be associated with demographic changes at this scale.

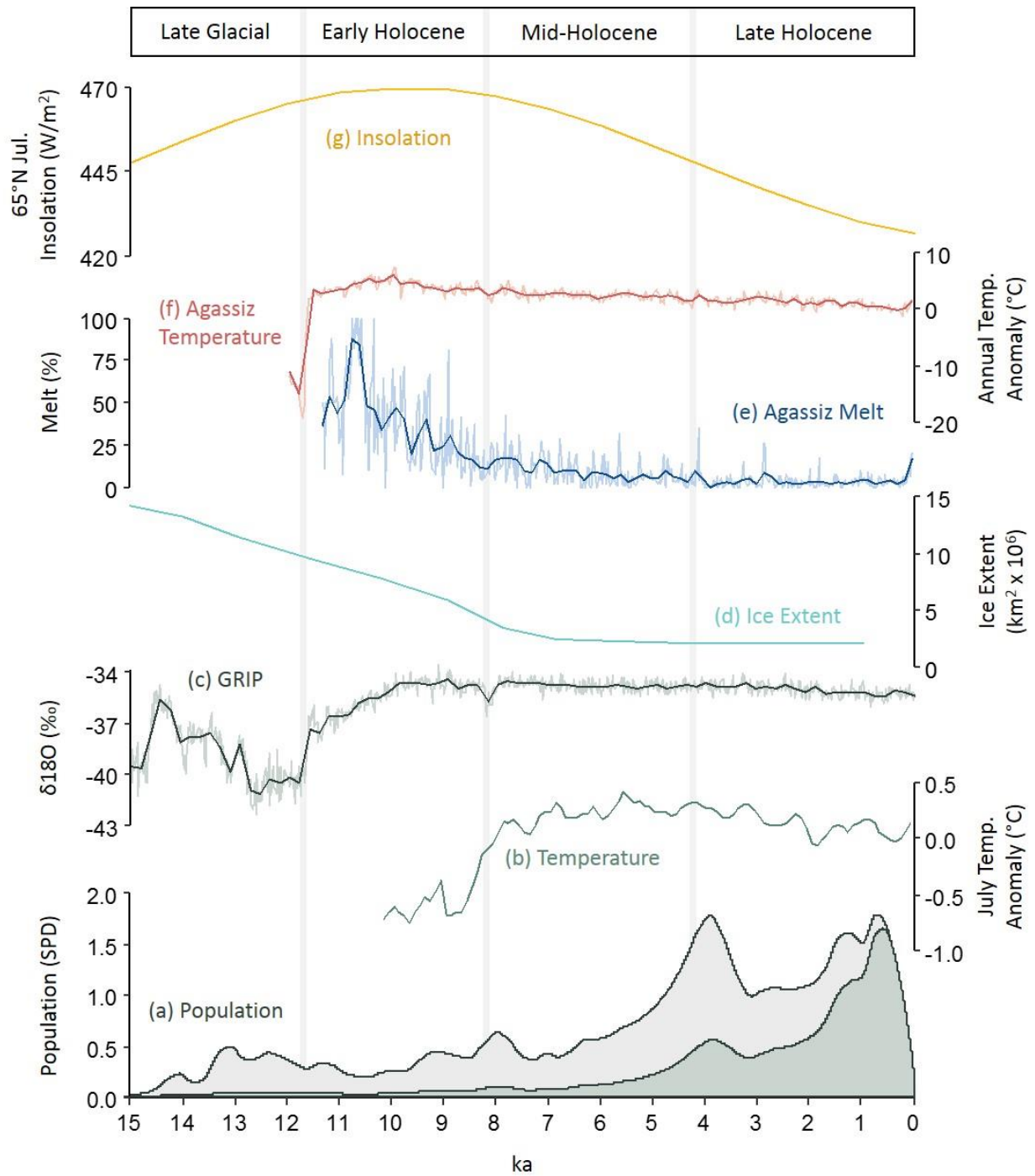


Figure 4.3. Population density estimate of northern North America in relation to climate forcings and paleoenvironmental reconstructions over the last 15,000 years. (a) SPD of archaeological radiocarbon dates for the North American North. The lighter curve has been adjusted for taphonomic loss following Surovell et al., 2009, and the darker curve in the forefront represents the unadjusted curve. (b) Pollen-based July temperature anomaly reconstruction for the entire North American Arctic & Subarctic calculated from individual regional reconstructions from Viau et al., 2008, Viau & Gajewski, 2009, & Gajewski, 2015b. The Mackenzie series

from Viau & Gajewski (2009) was excluded because the area was already represented in the Beringia reconstructions of Viau et al., 2008. (c) Oxygen isotope record from GRIP ice core (Vinther et al., 2006; data from Sundqvist et al., 2014). (d) Extent of north American ice sheets calculated from shapefiles from Dyke, 2004. (e) Estimated melt percentage and (f) temperature from Agassiz ice core on Ellesmere Island (Lecavalier et al., 2017). (g) Insolation at 65°N (Berger & Loutre, 1991 & 1999).

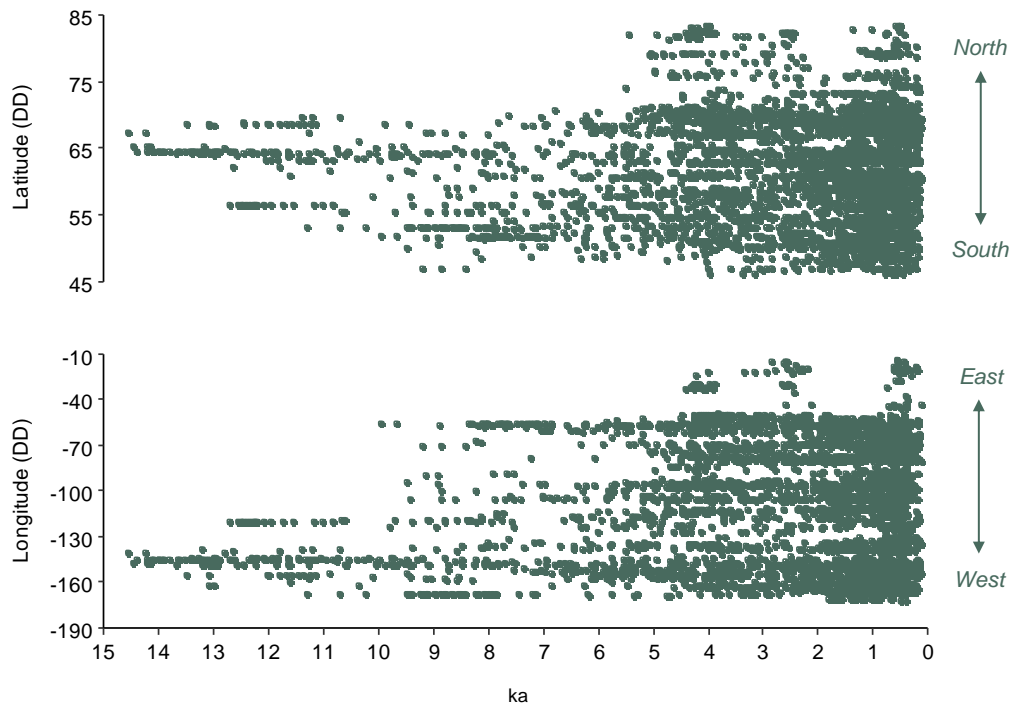


Figure 4.4. Archaeological radiocarbon dates from across the North American North as a function of latitude (top panel) and longitude (bottom panel) in decimal degrees (DD).

4.4.2 Regional Paleodemography and Paleoenvironments

Each region has a unique paleodemographic history, but there are some inter-regional synchronicities (Figure 4.5). All regions except Greenland underwent expected long-term population growth. Population density increased everywhere before the Late Holocene, but then decreased around the beginning of the Late Holocene. By 2 ka, population was increasing again except for Greenland, which was abandoned from ~2 – 1 ka. Large deviations from the long-term trend of population growth are positively associated with temperature, and/or negatively related to sea ice concentration in the Arctic and Greenland.

Beringian population remained relatively constant at low levels from initial occupation at ~15 ka to the Mid-Holocene (8.2 ka), although there were some fluctuations (Figure 4.5a). At ~7.3 ka, population density began a long-term increase. This growth trend increased in slope around 4.7 ka. Population decreased starting at ~3.8 ka, and remained lower until it began rising again at ~2.3 ka. While the corrected SPD and the original both illustrate this pattern, the corrected SPD suggests that population density in the late glacial and Early Holocene was much higher.

Beringia was warmest during the Early Holocene, but average temperatures were fluctuating greatly on centennial to millennial timescales. Beringia's population density was also fluctuating but sustained no long-term growth trend at this time. Population density was higher during warmer periods and decreased during cooling periods in the Early Holocene. Between 8.2 – 7 ka the climate cooled, coincident with a decrease in population. After 7 ka the magnitude of temperature fluctuations were smaller relative to earlier millennia. The decreased magnitude of climate oscillations coincided with long-term population growth.

The Subarctic may have been populated before the Holocene (11.7 ka) (Figure 4.5b), although only one archaeological site provides evidence of this migration (Fladmark & Driver, 1988). People expanded into newly available land after 10 ka as ice sheets were retreating (Dyke, 2004) (Figure 4.6). Population density remained low in the Early Holocene (Figure 4.5b), but increased right before the Mid-Holocene. Population continued to increase throughout the Mid-Holocene. Population density began decreasing around 3.9 ka, until a recovery at 2.2 ka, which was followed by a large increase until the colonial era. The population curve corrected for taphonomic loss suggests population density was much higher in the Mid-Holocene, and that the Late Holocene decrease in population was more severe.

Subarctic paleodemographic trends correspond closely with climate variations. In the Early Holocene, when climate fluctuations were of a relatively great magnitude, population density remained low. From 8.5 ka onwards, population increased during warm periods, and decreased during cooling periods.

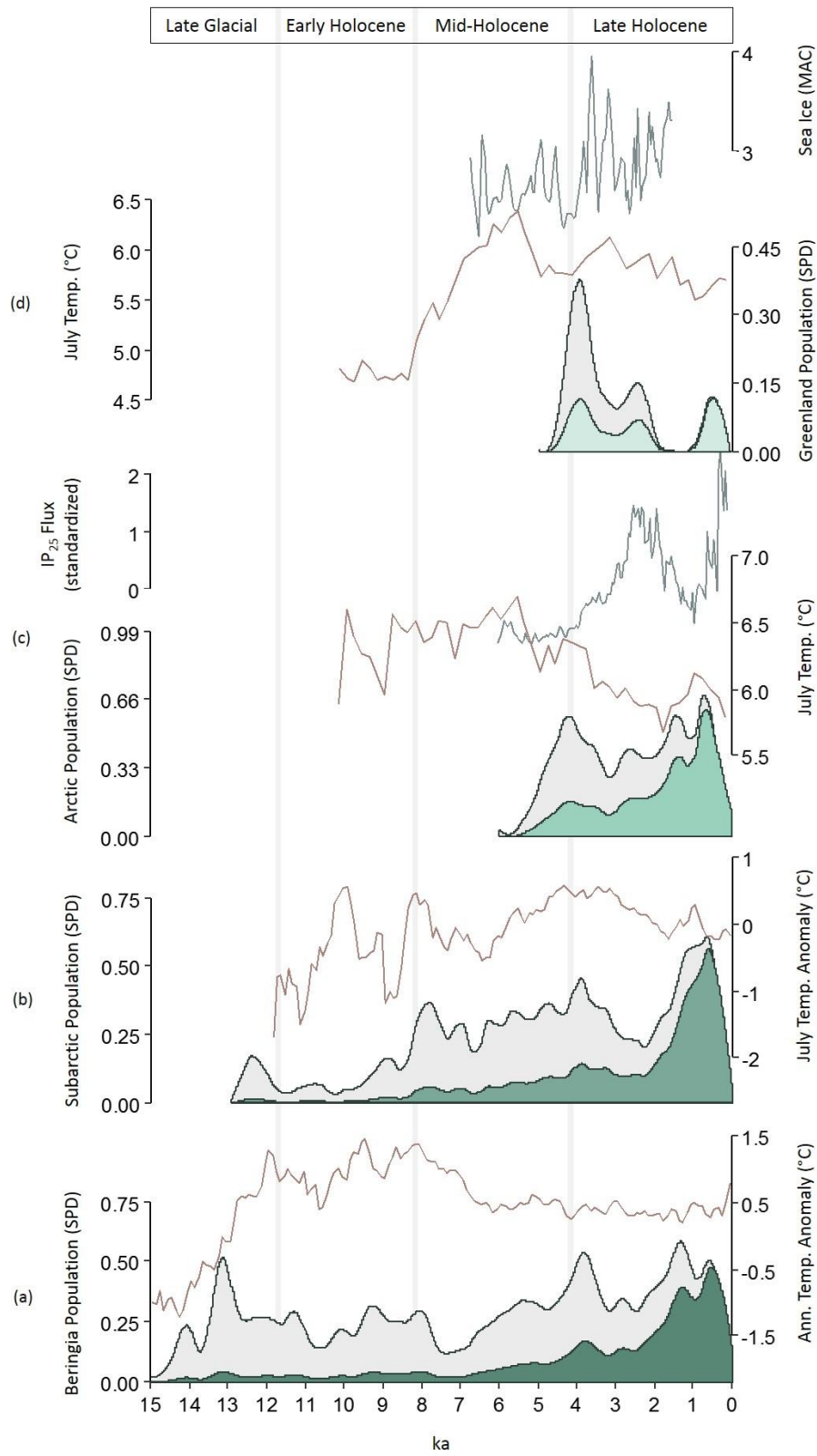


Figure 4.5. Summed probability distribution (SPD) plots representing population density for (a) Beringia, (b) Subarctic, (c) Arctic, and (d) Greenland regions. Grey density plots in the background

depict the SPDs which have been adjusted for taphonomic loss following Surovell et al. (2009), while the green plots in the forefront are uncorrected. Y-axis limits for population densities have been adjusted individually for each plot, so the height of peaks are not comparable between plots. Temperatures are represented by brown lines. July temperature anomalies in (a) and (b) are averages computed from regional climate series from Viau et al. (2008) and Viau & Gajewski (2009), respectively. Mean July temperature series in panels (c) and (d) are averages computed from regional climate series from Gajewski (2015b). Grey-blue series represent sea ice. The Arctic sea ice curve in (c) is a standardized and averaged series from Belt et al. (2010) while the Greenland curve in panel (d) is an average of three series from de Vernal et al. (2013).

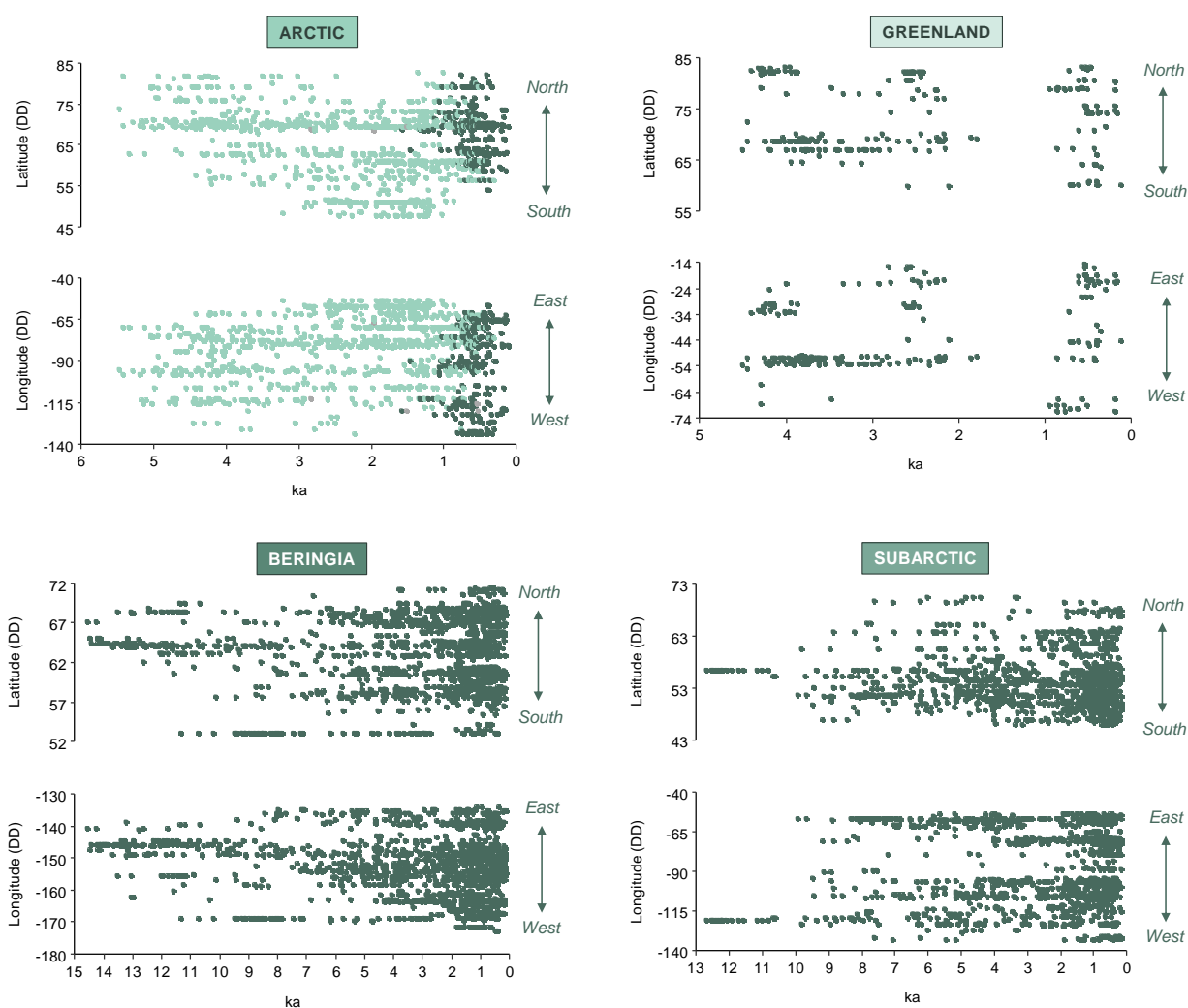


Figure 4.6. Archaeological radiocarbon dates from the Arctic, Greenland, Beringia, and Subarctic as a function of latitude (top) and longitude (bottom) (decimal degrees, DD). Each plot has a different x-axis span. In the Arctic plot, light green points represent Paleo-Inuit dates, while dark green points reflect Inuit dates.

The Arctic radiocarbon record suggests human presence in the region by ~5.5 ka (Figure 4.5c), although the earliest dates are controversial due to concerns about the accuracy of dating early Pre-Dorset sites (Friesen, 2016; Milne & Park, 2016). Regardless, people appeared to have spread rapidly across the Arctic (Figure 4.6). Population density increased until about 4.2 ka, and then declined until approximately 3.2 ka. Population increased thereafter, with some fluctuations. From ~3 to 1 ka, populations had shifted south, abandoning Ellesmere Island and settling as far south as Newfoundland & Labrador. After 1 ka they returned to the former range from the Low to High Arctic, and soon after the Inuit expanded across the Arctic (Figure 4.6) (Friesen, 2016). Adjusting for taphonomic bias suggests early populations increased at a more rapid rate, and that the relative peak around 4 ka was as high as the peak closer to present.

There are notable differences between the spatial patterns of occupation of the Paleo-Inuit and that of the Inuit (Figure 4.6). The region between ~65 – 68°N, corresponding to the coastal region of mainland Nunavut and northeastern Baffin Island, was seemingly never occupied by the Paleo-Inuit, but was later settled by the Inuit. Conversely, the Inuit never settled further south than 50°N, in contrast to the Paleo-Inuit during their occupation of Newfoundland.

The Arctic was warmest from about 9 – 6 ka, but the timing of peak warmth varied from region to region (e.g., Gajewski, 2015b), and it remained unpopulated during this time. People migrated into the region as the Arctic began a long-term cooling, but population reached its first peak during a brief warm period. Sea ice conditions were relatively low at this time. Resumed cooling and increasing sea ice coincided with a decline in population density from 4.2 to 3.2 ka. Population levels recovered while climate cooling and sea ice growth continued. During the coldest period from 3 – 1 ka, Paleo-Inuit populations shifted south (Figure 4.6). Warming and decreasing sea ice ~1.5 ka corresponded with accelerated population growth and a return to the High Arctic.

Greenland's first inhabitants arrived around 4.7 ka (Figure 4.5d). Population density increased until 3.9 ka, and then decreased until 3 ka, as seen in the Canadian Arctic. Population density recovered thereafter until about 2.4 ka, when it declined again. Between about 1.8 and 1.1 ka, Greenland appeared entirely abandoned. People returned around 1 ka, and population density increased rapidly towards the present. In this region, correcting for taphonomic bias makes major

changes to the interpretation of relative population size, suggesting that Greenland's initial population maximum was almost three times higher than its most recent population peak.

When averaged across the entire coastal region, Greenland's warmest temperatures occurred during the Mid-Holocene, and after about 6 ka the climate began to cool. However, there are significant regional climatic differences, discussed below (Gajewski, 2015b). People settled in Greenland shortly after this cooling began, but while sea ice concentration remained low. A first maximum of sea ice around 3.7 ka coincided with Greenland's first major decrease in population density. Population increased around 2.7 ka after sea ice concentration decreased. Greenland was abandoned as cooling continued and sea ice reached a second maximum, and re-occupation occurred around 1 ka as the climate began to warm slightly.

4.4.3 Subregional Paleodemography and Paleoenvironments

Paleodemography

A principal components analysis summarizes the paleodemographic trends across the subregions. The first principal component (Figure 4.7a and b) explains 30% of the variance and depicts a long-term increase in the population. This component also highlights a peak in population density centered on 4 ka and a subsequent decline starting ~3.7 ka that is observed in most areas. The subregion negatively loaded on this component, First Nations Labrador, (Figure 4.7a) lacks a positive long-term trend.

The second principal component explains 19% of the variance and distinguishes between the different modes of recovery after the Late Holocene population decrease identified in component 1 (Figure 4.7c). Regions positively loaded on this component, such as Paleo-Inuit Newfoundland and Labrador, generally underwent population growth or had higher population density between 3-2 ka. In the case of the Eastern Arctic, and the North & West Coasts and Kenai-Kodiak regions of Beringia, this indicates a more rapid recovery. Regions negatively loaded, including the West-Central Arctic, Northern Arctic, Western and Southern Greenland, and First Nations of Newfoundland and Labrador, exhibit a continuation of population decline or the maintenance of low population levels during this time. This component also highlights the opposing population

dynamics of the First Nations and the Paleo-Inuit in Newfoundland and Labrador: when First Nations population declined, Paleo-Inuit population increased.

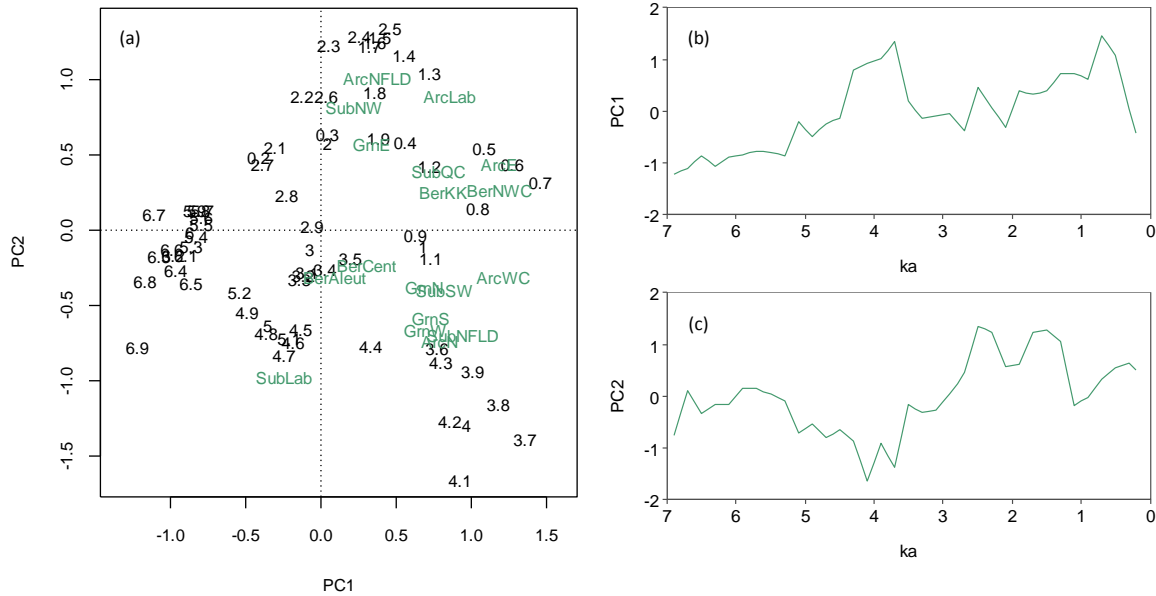


Figure 4.7. Principal components analysis for the subregional paleodemography. (a) Biplot, (b) scores of the first principal component through time, and (c) scores of the second principal component through time.

Paleoclimate

The first component of a PCA of the paleoclimate data explains 37% of the variance (Figure 4.8a and b), and depicts a long-term cooling trend with some high-frequency fluctuations (Figure 4.8b). The few regions strongly loaded positively on the first component (Southern Greenland, Labrador) experienced a long-term warming trend until their comparatively late thermal maximum at ~4 – 3 ka. The second principal component, which explains 20% of the variance, reveals the medium-frequency climate changes superimposed on the long-term background cooling (Figure 4.8c). Regions negatively loaded on this component, such as Southwest Beringia (encompassing both the Aleutians and the Kodiak & Kenai subregions), West-Central Arctic, and Newfoundland, generally were more stable in temperature or cooling slightly during the Mid-Holocene, cooling from ~4 ka until ~2 ka, and warming thereafter. Regions highly positively loaded on this component, such as the Northwest Subarctic, experienced an earlier

cooling period ~5 ka and a second one after 2 ka. Others, such as Southern Greenland, Labrador, and the Eastern Arctic remained warmer between ~4 – 3 ka but cooled after.

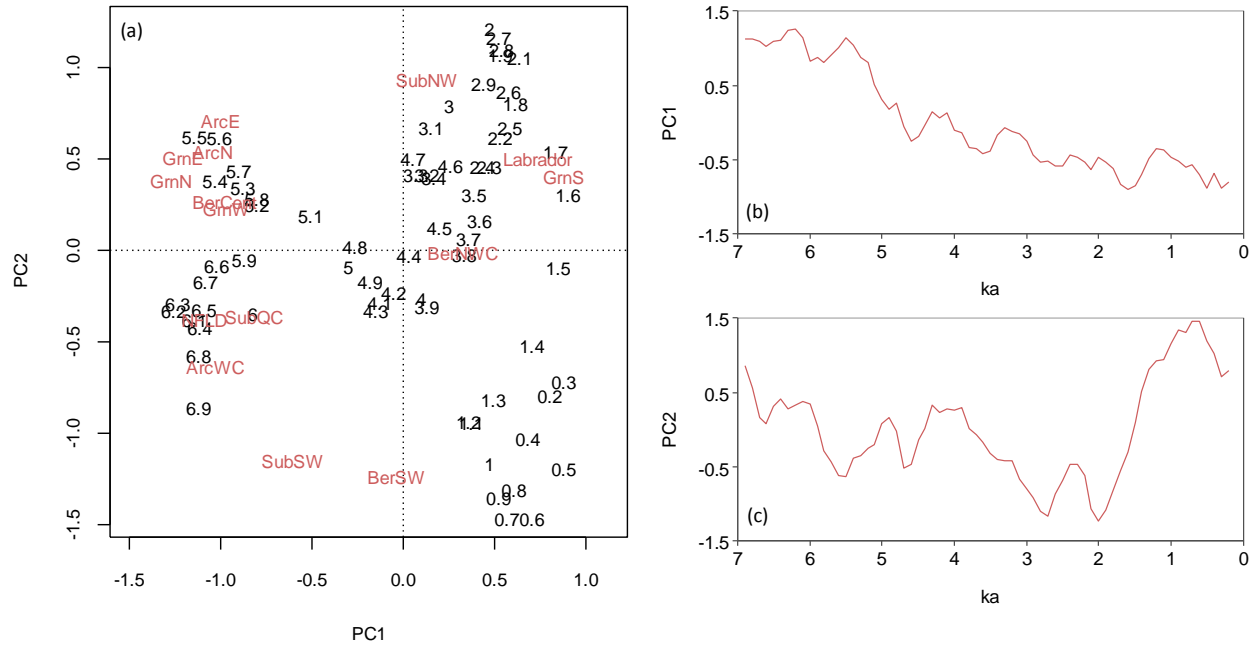


Figure 4.8. Principal components analysis for the subregional paleoclimate. (a) Biplot, (b) scores of the first principal component through time, and (c) scores of the second principal component through time. The y-values of (b) and (c) have been flipped to orient higher temperatures as higher values and vice-versa.

The second component of the climate PCA reveals major climatic fluctuations which are associated with periods of major population growth and decline, which are in turn reflected on both the first and second principal components of the paleodemographic PCA (Figure 4.9). A cooling that began ~3.9 ka in most regions just preceded the population crash at ~3.7 ka, although given the various errors in the dating, these may have been simultaneous. Warming after 2 ka occurs in tandem with population growth in southern Beringia, the Southwest Subarctic, Québec, Newfoundland, and the West-Central Arctic.

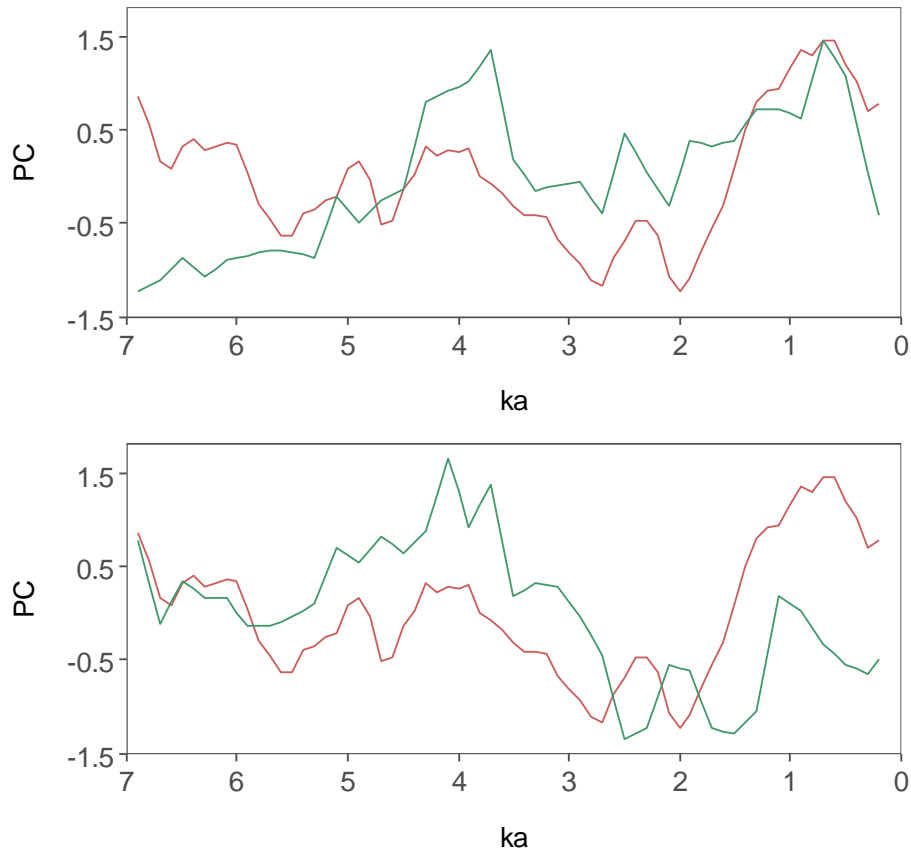


Figure 4.9. Scores of the first (top) and second (bottom) principal components of the paleodemography PCA (green) compared to the scores through time of the second principal component of the paleoclimate PCA (red). The y-values of the climate scores have been flipped to orient positive temperature anomalies as higher values. The y-values of the second component of the paleodemography PCA has been flipped to highlight the positive association between the paleoclimate and the subregions that are negatively loaded on the second component.

Beringia

The demographic history of Beringia differs by subregion (Figure 4.10). Population density in the coastal regions increased earlier and faster than population density in the interior Central region. When corrected for taphonomic loss, the curve for the Central region suggests population did not increase in the Late Holocene, and that it was highest in the Late Pleistocene and Early Holocene (Figure 4.10b). Similarly, population in the Aleutians did not increase in the long-term,

and the curve corrected for taphonomic bias suggests population was highest between ~10 – 8 ka (Figure 4.10c).

In the coastal subregions, population density tended to increase during longer-term warming periods. In the North & West Coasts subregion, the population increase from 4.5 – 3.7 ka reflects the establishment of the ASTt (Figure 4.10a). This coincided with an increase in temperature and a decrease in sea ice concentration. From 3.7 – 3.3 ka, the ASTt population rapidly decreased, coinciding with climate cooling, increasing sea ice, and the Aniakchak volcanic eruption (Vanderhoek & Nelson, 2007). In the Kenai & Kodiak subregion (Figure 4.10d), a population decline coincided with the 4.01 ka Jarvis Creek Ash eruption (Begét et al.,1991). In Central Beringia, population density increased during the cooling of the Mid- to Late-Holocene, but decreased briefly after the 1.15 ka WRAe eruption (Clague et al.,1995; Mullen, 2012).

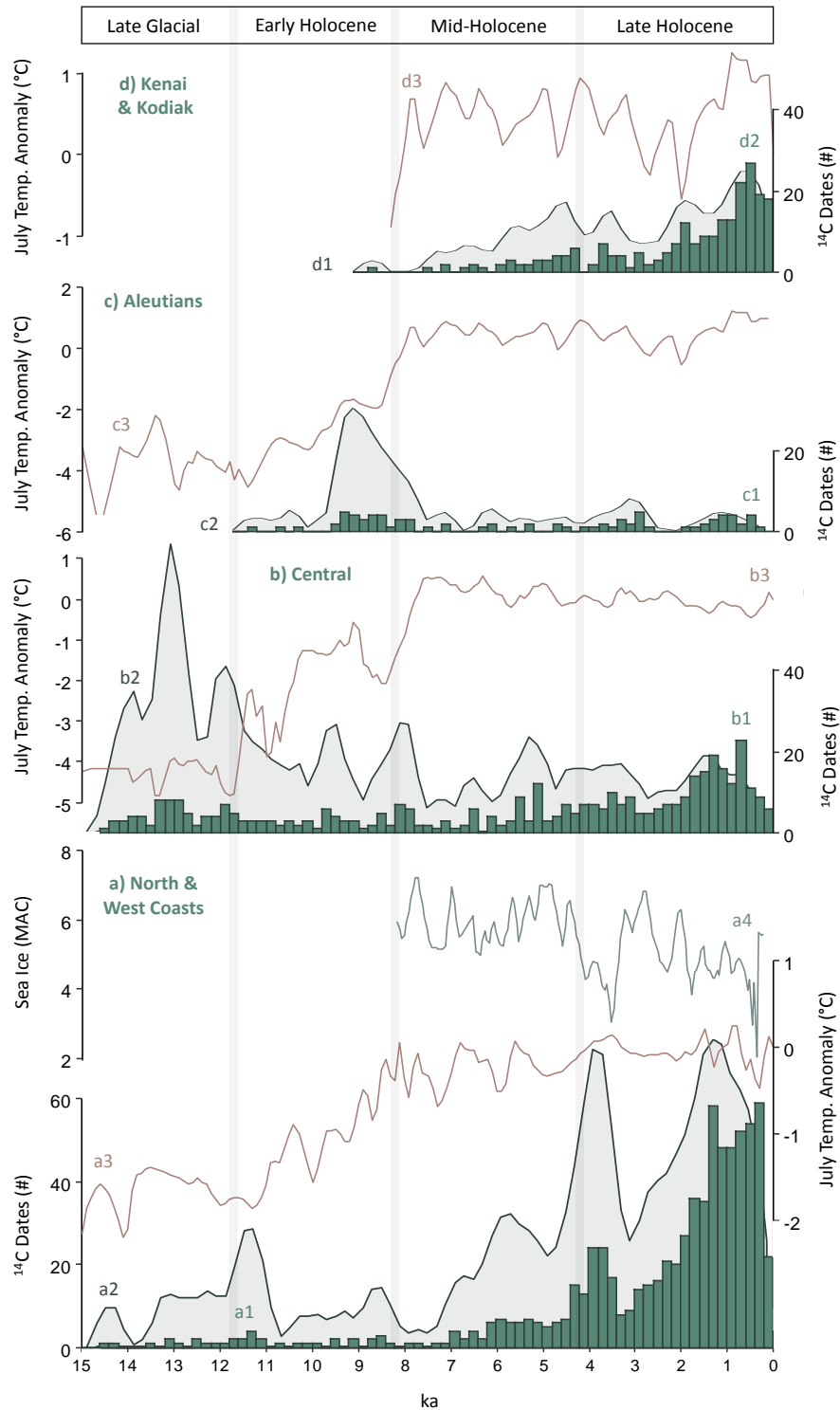


Figure 4.10. Paleodemography vs. paleoclimates of Beringian subregions. For their respective sub-regions: (1) Frequency of calibrated radiocarbon dates. (2) Frequency of dates corrected for taphonomic bias. (3) Mean July temperature anomaly (Viau et al., 2008). (4) Mean annual concentration (MAC) of sea ice in the Beaufort sea. This series is an average of the GGC19 and HLY0501 reconstructions from de Vernal et al. (2013).

Subarctic

In the Southwest Subarctic, the initial arrival of people seems to have immediately followed local deglaciation (Dyke, 2004). Population density underwent a long-term growth from about 10 ka to present (Figure 4.11a). Population decreased from about 3.9 – 2.2 ka before increasing to a maximum around 1 ka. When corrected for taphonomic effects, the curve suggests the Early Holocene population size was comparable to that of the Late Holocene.

In the Northwest, population density initially peaked at 5.5 ka, decreasing thereafter and remaining at low density until about 2.6 ka (Figure 4.11b). Population increased and then generally remained high thereafter, except for a decrease just before 2 ka and a second decrease coinciding with the 1.15 ka WRAe eruption. Correcting for taphonomic loss suggests population was as high at 5.5 ka as it was in the latter half of the Late Holocene. In Québec, the record is restricted to the Mid- and Late Holocene, as it was the last area to be clear of Laurentide ice. Population density was very low until ~3.4 ka (Figure 11.4c). Population decreased after this initial peak and remained low until about 1.2 ka, and then increased thereafter.

In each Subarctic subregion, population growth was positively associated with temperature. Other high-intensity events also influenced population growth, such as deposition of extensive volcanic ash at 1.15 ka over a wide area of southern Yukon and adjacent areas, which caused a brief decrease in population (Mullen, 2012).

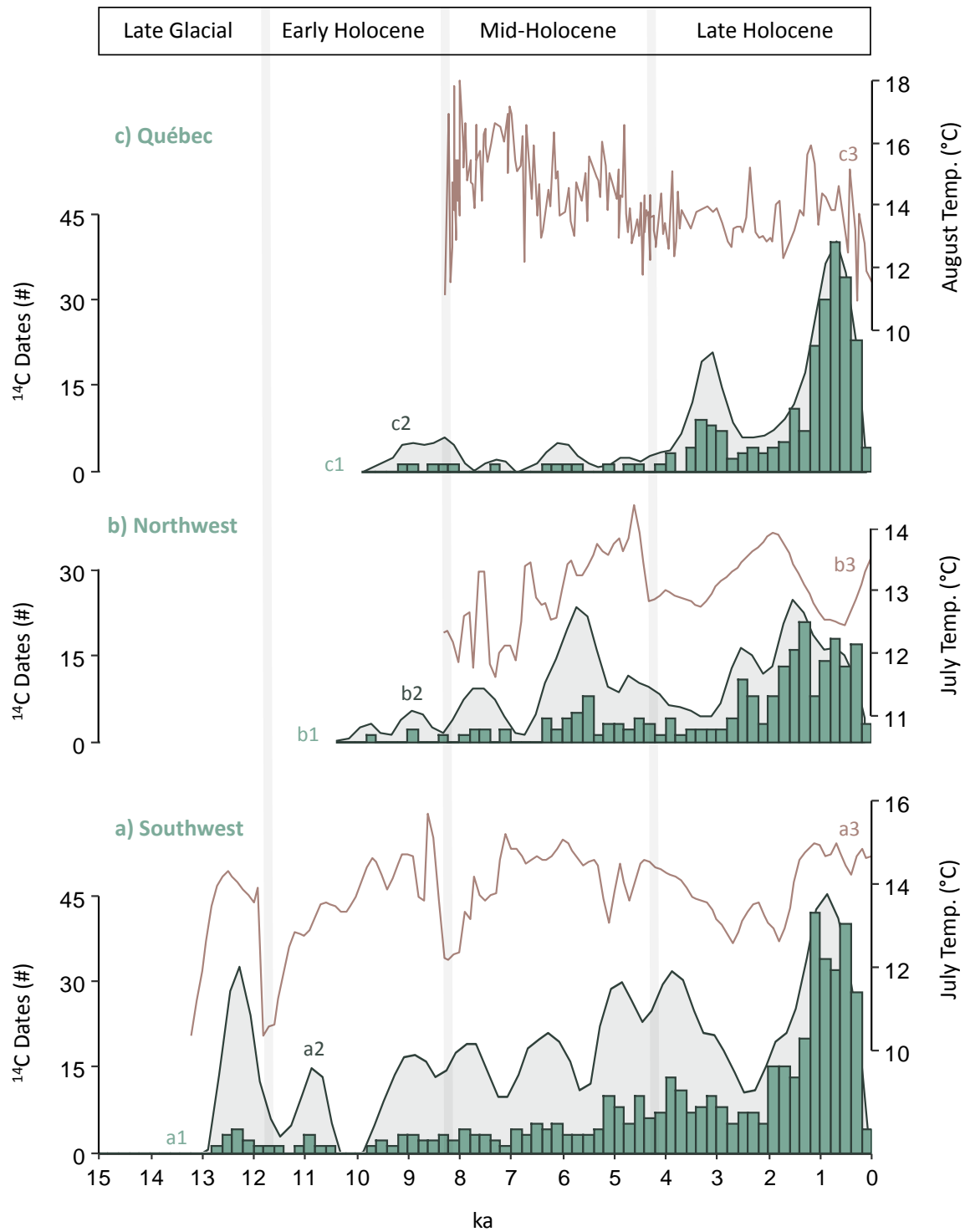


Figure 4.11. Paleodemography and paleoclimate of the three Subarctic subregions: a) Southwest Subarctic, b) Northwest Subarctic, and c) Québec. For their respective sub-regions: 1) Frequency of calibrated radiocarbon dates, 2) frequency of dates corrected for taphonomic bias, and 3) summer temperatures. A3 and b3 were generated for this study, and c3 is from Bajolle et al. (2018).

Arctic

The population histories of the Arctic subregions all exhibit the same general pattern: initial colonization of the Paleo-Inuit around 5 ka followed by rapid increase in population density, a population crash around the beginning of the Late Holocene, and a second major population increase after 1 ka as a result of the Inuit expansion (Friesen, 2016b) (Figure 4.12). Population in the Eastern Arctic recovered from the crash more rapidly (Figure 4.12c), while in the other Arctic regions population density remained low for a few millennia before beginning to increase again. In all subregions, correcting for taphonomic loss suggests population levels in the first few millennia of occupation were higher than populations of the last 1 ka.

People settled in the West-Central Arctic when the climate was warmer and sea ice conditions were relatively low (Figure 4.12a). Population density decreased in the Late Holocene during a time of decreasing temperatures and increasing sea ice, and subsequently increased beginning around 2 ka with increasing temperatures and decreasing sea ice. In the Northern Arctic, population was low from about 4 – 1.5 ka during a period of increased sea ice conditions. The Agassiz ice core temperature reconstruction and pollen-based temperature reconstructions (Figure 4.12b) suggest temperatures here were decreasing over the ~5 ka of occupation. In the Eastern Arctic, population and climate are negatively associated; population was generally higher during colder periods, and the Paleo-Inuit population (~pre – 0.8 ka) was highest when sea ice was at its maximum (Figure 4.12c).

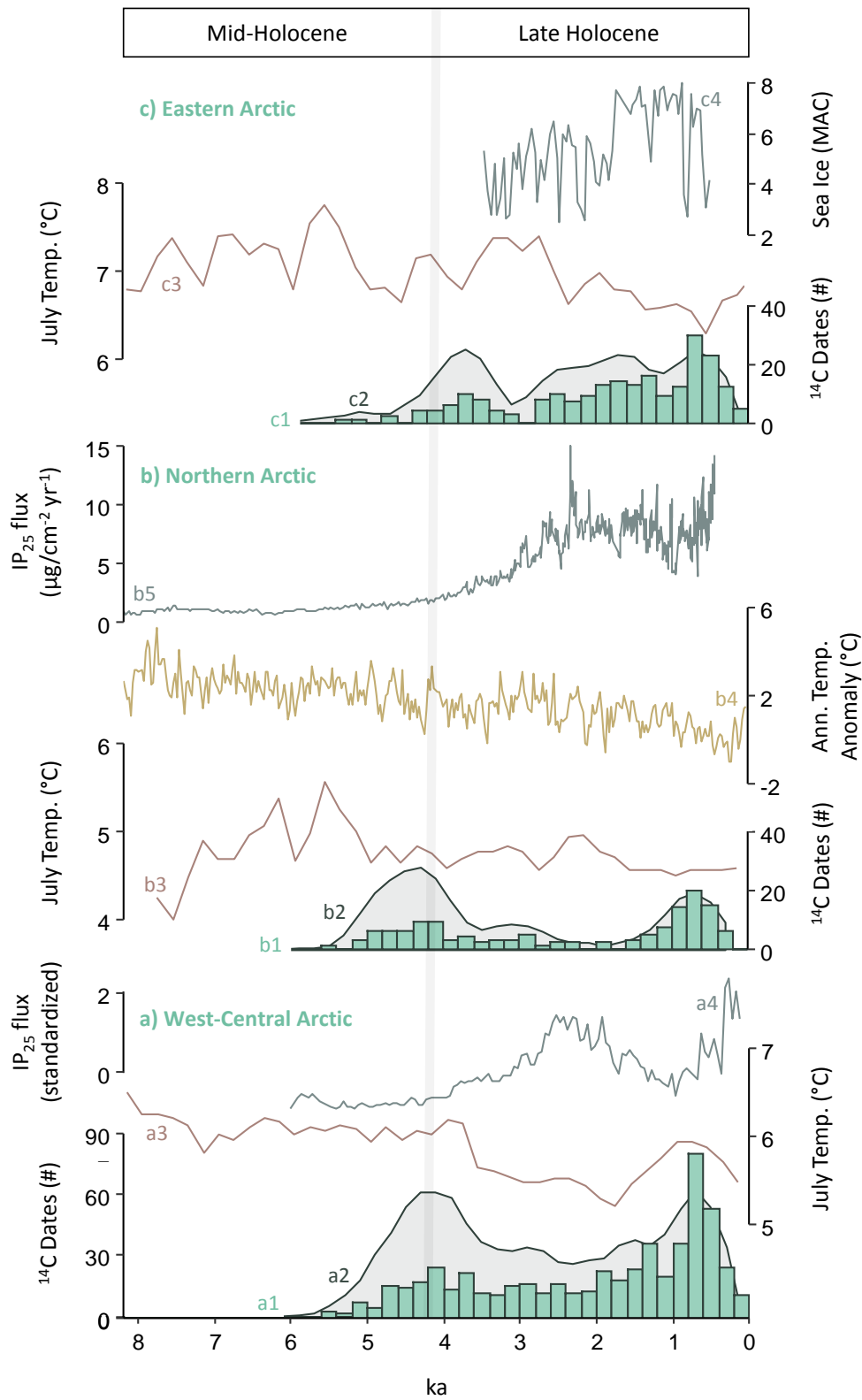


Figure 4.12. Paleodemography and paleoclimate of the Arctic subregions: a) West-Central Arctic, b) Northern Arctic, and c) Eastern Arctic. For their respective sub-regions: 1) Frequency of calibrated

radiocarbon dates, 2) frequency of dates corrected for taphonomic bias, and 3) mean July temperatures (Gajewski, 2015b). Curve b4 represents the annual temperature anomaly reconstructed from the Agassiz ice core (Lecavalier et al., 2017). A4 is an average of the Arc-3, Arc-4, Arc-5 IP₂₅ series, while b5 depicts the Arc-3 series from Belt et al. (2010), and c4 represents mean annual concentration (MAC) of sea ice from the HU015 series from de Vernal et al., 2013.

Greenland

In Northern, Western, and Southern Greenland, population density first peaked around 4 ka, and subsequently declined a few centuries later (Figure 4.13). In Northern and Western Greenland, population recovered around 2.5 ka. In Southern Greenland, the population continued to decline at this time (Figure 4.13c), while in Eastern Greenland population density reached its first peak around 2.3 ka (Figure 4.13d). Population density subsequently declined in all regions, and Greenland was abandoned everywhere by 1.6 ka. After 1 ka people returned to Greenland except the Western subregion (Figure 4.13b). Populations across Greenland were generally higher during warmer periods with lower sea ice. Around the abandonment of Greenland, temperatures were decreasing in the North, West, and East, while sea ice was increasing everywhere.

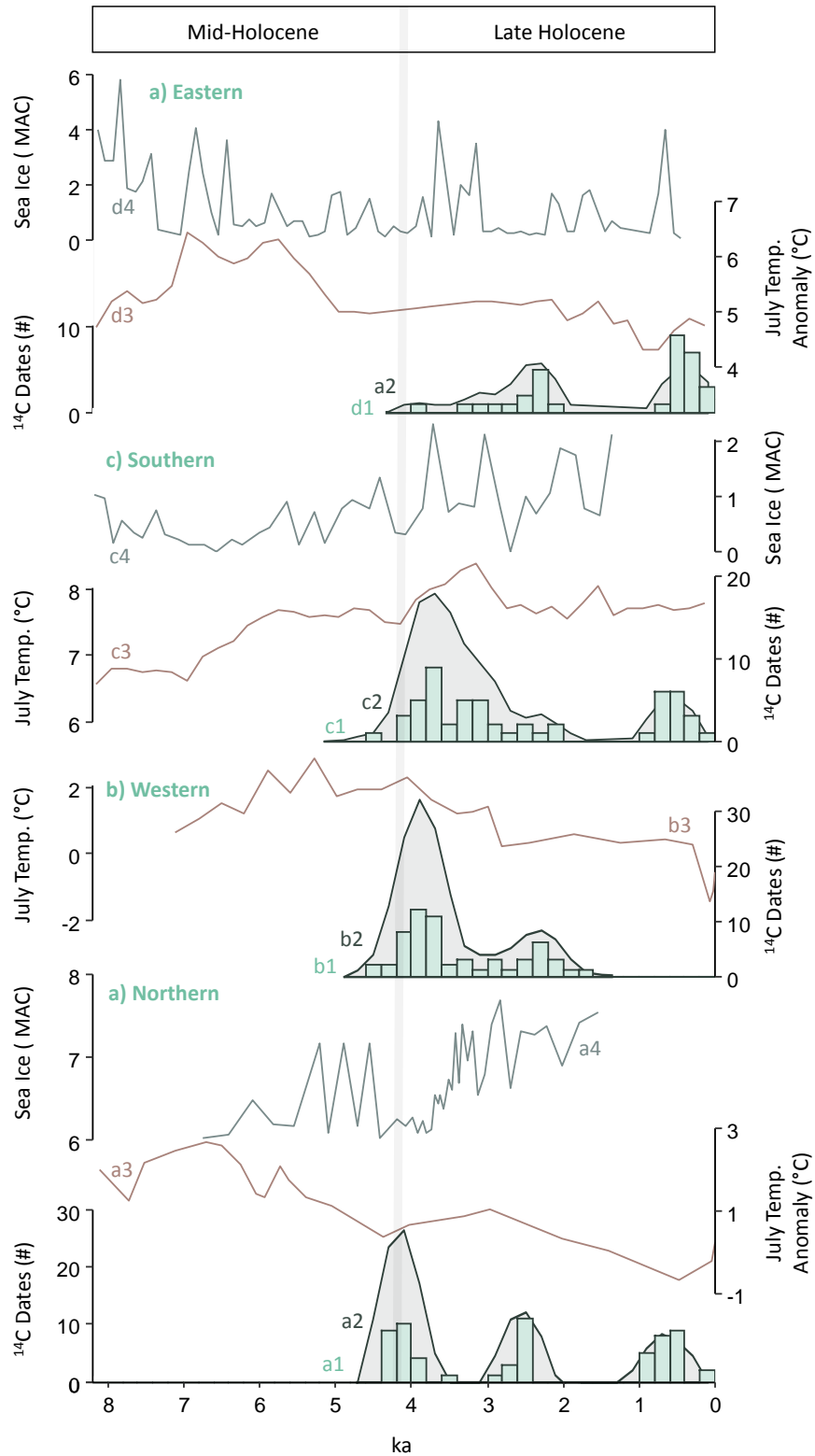


Figure 4.13. Paleodemography and paleoclimate of the Greenland subregions: a) Northern Greenland, b) Western Greenland, c) Southern Greenland, and d) Eastern Greenland. For their respective sub-regions: 1)

Frequency of calibrated radiocarbon dates, 2) frequency of dates corrected for taphonomic bias, 3) July temperatures, and 4) mean annual concentration (MAC) of sea ice from de Vernal et al. (2013). A3 represents lake Deltasø July temperature anomaly reconstruction from Axford et al. (2019), while a4 depicts the North lake series by Axford et al. (2013). C3 and d3 are regional averages from Gajewski et al. (2015b).

Newfoundland & Labrador

First Nations groups were the earliest inhabitants of Newfoundland and Labrador, settling in Labrador perhaps as early as 10 ka and Newfoundland around 6 ka (Figure 4.14). Paleo-Inuit groups expanded into these areas after 4.5 ka. The Paleo-Inuit co-existed with the Maritime Archaic in Labrador for several centuries, but while Paleo-Inuit population increased around 3 ka, the Maritime Archaic decreased. In Newfoundland, the arrival of the Paleo-Inuit coincides with the disappearance of the Maritime Archaic. The arrival of the Inuit in Labrador in the past 1 ka coincided with decreasing First Nations population. The First Nations population was positively associated with temperatures, while the Paleo-Inuit and Inuit population was negatively associated.

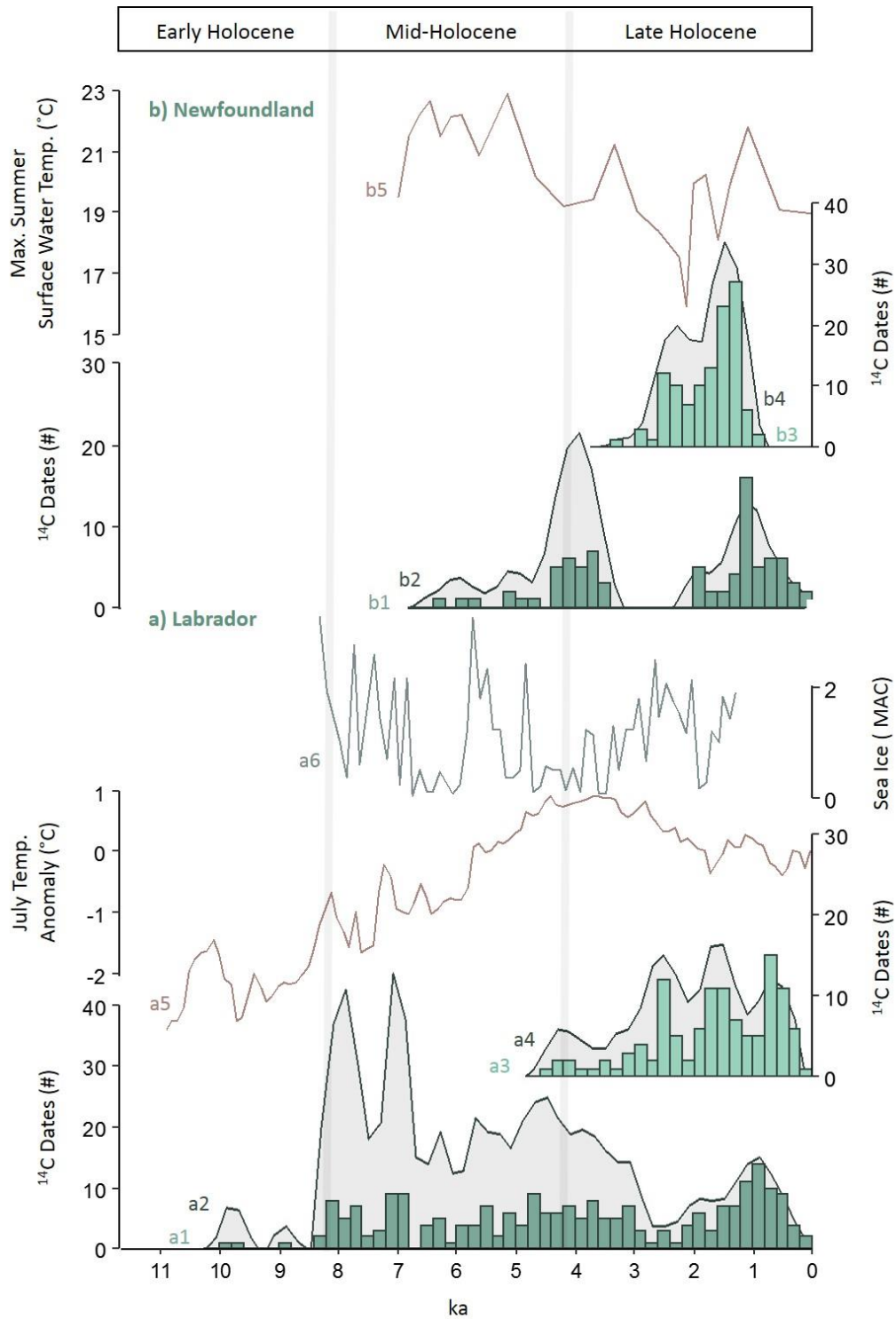


Figure 4.14. Paleodemography and paleoclimate of a) Labrador and b) Newfoundland. A1 and b1 show the frequency of calibrated radiocarbon dates related to First Nations peoples, while a3 and b3 depict radiocarbon dates pertaining to Paleo-Inuit and Inuit peoples. A2, a4, b2, and b4 depict the frequency of dates corrected for taphonomic bias. A5 illustrates July temperature anomalies from Viau & Gajewski

(2009). A6 is from de Vernal et al. (2013) and represents sea ice in the Labrador Sea, and b5 is from Rosenberg et al. (2005) and reflects summer temperatures.

4.4 Discussion

The North is often portrayed as a marginal region where survival is challenged by a harsh environment offering minimal resources (Sutton, 2011; Friesen & Mason, 2016). Accordingly, one might expect the region to have a history of more highly variable population levels. However, the reconstructed paleodemographic curve shows typical long-term growth over the Holocene (Figure 4.3). Although past population density in the north fluctuated in response to climate variability, including the disappearance of people over a large region for a period of time, overall, the expected long-term demographic increase over the course of the Holocene was observed. This shows that the populations could maintain themselves and continually adapt to the environment, in spite of setbacks of several timescales due more severe climates in one region or another.

The rate of long-term population growth across the region remains unclear, however, until the nature of taphonomic processes in both Arctic and boreal regions is better understood. We applied a taphonomic correction, as it is a standard procedure in reconstructing paleodemography, and because it increases the visibility of small fluctuations in the earlier demographic curves. However, it is likely that the correction is not universally applicable across the study region. For example, the nature of the archaeological record in the Arctic does not support the interpretation of early Paleo-Inuit populations being as high as, or higher than, late Paleo-Inuit and subsequent Inuit population levels (M. Betts, personal communication, December 13, 2019). The correction certainly overestimates loss in the Arctic, where frozen and dry conditions encourage preservation. Additionally, soil formation processes are slow in the Arctic; as a result, archaeological finds dating back to the earliest occupations are often on or near the surface and therefore easier to find than deeply buried sites (e.g., Savelle & Dyke, 2009). As a consequence, we propose that the uncorrected population model is probably more accurate in the Arctic. Conversely, this correction is more suitable for the Boreal region, where acidic soils and frequent forest fires are less favourable for preserving organic materials (Pilon, 2001), although the presence of continuous or discontinuous permafrost may again reduce

taphonomic loss in some areas. In the Subarctic and Beringian regions, we suspect that the true long-term trend of population growth is likely somewhere between the corrected curve and the raw data (Figure 4.3). Since the main purpose of this study was to investigate the impact of higher frequency environmental change on paleodemography, we leave both curves in the figures, although we feel the uncorrected curves are more reasonable.

Around the beginning of the Late Holocene (3.9 ka), there was a widespread, nearly synchronous decline in population density across the Arctic and Subarctic. Previous research has identified this decrease in smaller regions within the Arctic, such as with the ASTt in Beringia (Tremayne & Winterhalder, 2017; Tremayne & Brown 2017) and the Paleo-Inuit in the central Canadian Arctic (e.g., Savelle et al., 2012, Savelle & Dyke, 2014). Our results link this continental-scale population decline to decreasing temperatures and increasing sea ice, which would have negatively impacted subsistence success. The cooling northern climate – neoglaciation – is associated with a major shift in the global climate which defines the start of the Late Holocene at 4.2 ka (Walker et al., 2018). Environmental changes at this time have been linked to significant societal impacts in many regions of the world (e.g., Walker et al., 2018), predominantly in lower latitudes; our analysis suggests societal impacts of the Late Holocene climate transition may have been more global in nature than previously recognized.

The cooling climate was also a driver of major spatial patterns of occupation, particularly with the Paleo-Inuit. From ~3 – 1 ka, corresponding to a time of high sea ice and lower summer temperatures, there were almost no radiocarbon dates north of 75°N, indicating Ellesmere Island was abandoned (Figure 4.6). Increased sea ice may have resulted in the closing of polynyas – open water areas surrounded by sea ice – thereby reducing the availability of sea mammal resources in high Arctic regions (Schledermann, 1980; Ryan, 2016). Around the same time, Paleo-Inuit groups shifted further south into Labrador and then into Newfoundland (Figure 7). Although a very cold high Arctic with greater sea ice appeared to have been unfavourable for the Paleo-Inuit, they thrived in the comparatively less harsh climate of both Newfoundland and Labrador while the Maritime Archaic were apparently unable to withstand the impacts of decreasing temperatures (Renouf, 1999; Rosenberg et al., 2005).

In Greenland, the archaeological record suggests people were entirely absent from the island between 2 ka to 1 ka. It is not well understood why Greenland was abandoned at this time

(Jensen, 2016), but it has been linked to the cooling climate and the general Paleo-Inuit abandonment of the high Arctic (Schledermann, 1980; Ryan, 2016). Our analysis, which identifies continued cooling and increasing sea ice at this time, supports this explanation. Additionally, our paleodemographic reconstruction indicates that a population decline lasting ~400 years preceded the abandonment of Greenland. Further archaeological study is required to determine if Greenland's Paleo-Inuit groups died out in-situ, or if the decreasing survival rates eventually motivated people to migrate out of Greenland.

The changing Late Holocene climate was also directly influential in cultural change. In the Arctic, the transition from Pre-Dorset to Dorset occurred from 2.8 – 2.5 ka, and is characterized by a subsistence shift towards marine resources (Ryan, 2016). Paleoenvironmental records indicate sea ice in the Canadian Arctic was at its pre-Little Ice Age maximum at this time (Belt et al., 2010; Belt & Vare, 2010). Greater sea ice extents and thickness in the low and middle Arctic regions would have increased the abundance of species such as ringed seals and walruses, providing a more prolific resource base for the Dorset. Early Dorset settlement patterns and technologies also reflect improved adaptations to increased sea ice and colder conditions (Ryan, 2016). It is also possible that the marine resource intensification characterizing the development of the Norton tradition from the ASTt ~3 ka in Beringia (Tremayne & Brown, 2017) may have been related to increasing sea ice concentration, which presumably would have increased the abundance of certain marine mammals. While neoglaciation initially decimated early Paleo-Inuit populations, their descendants successfully adapted to the colder climate.

Across the north, population density was generally positively correlated with temperature during the Holocene, suggesting that warmer temperatures provided superior access to resources. There are some exceptions, however, and the nature of the population-temperature relationship did not always remain positive as time progressed. For example, although Paleo-Inuit population density decreased in response to neoglaciation, population eventually stabilized and began to increase in size despite continued cooling and increasing sea ice. This reflects successful adaptation to changing environmental conditions, as discussed above. In other cases, the relationship to temperature was negative, where populations increased during cool periods. This is observed with the Paleo-Inuit populations of Newfoundland and Labrador, likely because the local climate is comparatively mild, and climate cooling in this region would have increased the abundance of

sea-ice dependent species such as ringed seals (Woollett et al., 2000). A negative population-temperature association is also observed in the Eastern Arctic subregion. In this area, populations recovered from the Late Holocene population decline more quickly than other Arctic populations, so it is possible that population dynamics alone or population-environment relationships differed in this region.

Although our sample includes radiocarbon dates from across the entire region (Figures 4.1 & 4.2), there is some degree of spatial sampling bias that hampers spatial analysis of populations on a finer scale. Locations of dates generally reflect accessibility, and archaeological sites in some remote areas are likely under-represented. The Subarctic in particular is spatially under-sampled; the largest archaeological projects have resulted from fossil fuel and hydroelectric infrastructure developments (Pilon, 2001), which is apparent in the spatial distribution of sites. For example, in northern Québec, a set of dates roughly lined up east-west follow the Trans-Taiga road constructed for hydroelectric projects. While there are no dates north or south of the road for several hundred kilometers, this certainly represents the lack of infrastructure rather than a lack of archaeological sites. Nevertheless, even small samples of dates seem to be sufficient to estimate past populations (Peros et al., 2010; Chaput et al., 2015).

There is some suggestion that the Late Holocene population crash identified here extended beyond the North American Arctic and Subarctic. Population declines around this time are discernable in the frequency distribution of calibrated archaeological radiocarbon dates of the Plateau, Great Basin, Southwest, Plains, and Northeast cultural regions (Chaput & Gajewski, 2016). Munoz et al. (2010) and Kelly et al. (2013) identified population declines around the same timeframe in the northeastern United States and the Bighorn Basin in Wyoming, respectively. To determine exactly how widespread this population collapse was, further paleodemographic study in other North American regions in relation to regional paleoclimate estimates is required.

4.5 Conclusions

There was a long-term increase in the population of Northern North America during the past 15 ka, although the intensity of the change depended on the region. The settlement of new areas permitted the growth of population, in addition to increased density in areas previously

populated, although the relative increase is still uncertain. However, there is a clear correspondence between millennial and centennial-scale climate changes and population changes across the North American Arctic and Subarctic. The positive association between population density and temperature was not discernable when averaged across the study region, but it was evident at the regional and sub-regional scale. Population histories differed somewhat by region, but a major population decline beginning ~3.9 ka associated with decreasing temperatures and increasing sea ice was almost ubiquitous across the Arctic and Subarctic.

Our results illustrate the importance of analyzing regionally-appropriate paleoenvironmental data in relation to the archaeological record. Previous paleodemographic studies tend to use the $\delta^{18}\text{O}$ record from Greenland Ice Cores (e.g., GRIP; Vinther et al., 2006) to represent climate across the globe (e.g., Stevens & Fuller, 2015; Jørgensen, 2018; Broughton & Weitzel, 2018), but these data do not represent global Holocene climate and thus are not applicable everywhere. The progression of the Holocene climate varied by region, and there were significant differences in the timing and intensity of climatic periods or events (Kaufman et al., 2004; Gajewski, 2015b; McKay et al., 2018). The various Greenland ice core $\delta^{18}\text{O}$ series have identified large-scale global interglacial-glacial cycles in sea level and local temperature, but on smaller timescales they only represent climate on top of the Greenland Ice Sheet. They do not necessarily even record the Holocene coastal climates in all regions of Greenland, which vary regionally (Gajewski, 2015b). Fortunately, climate reconstructions are increasingly available, and for many regions, it is now possible to produce regional climate averages from the individual series.

The Late Holocene epoch is defined by a significant change in the climate regime (Walker et al., 2018), and in the North American Arctic and Subarctic, this manifested as a shift to a cooler climate. The 4.2 transition is thought to have had major effects on societies in lower latitudes (e.g., Weiss, 2017; Blanco-González et al., 2018; Guo et al., 2018), and here we have presented evidence that it also had significant impacts in northern latitudes. The nearly-synchronous collapse of populations across the entire North American north triggered by neoglacial cooling is another cautionary tale of the consequences of rapid climate change.

CHAPTER 5:

Conclusions

The dynamics of ancient human-environment interactions in many regions around the world are increasingly becoming clear (e.g., Williams et al., 2008; Douglas et al., 2015; Warden et al., 2017; Riris & Arroyo-Kalin, 2019), but this has not been thoroughly investigated in North America. Since early archaeological research in the Arctic and Subarctic, it has been surmised that environmental changes were influential on past populations in these relatively harsh environments (Friesen & Mason, 2016). However, comprehensive inquiry on large-scale human-environment dynamics in the north was previously limited by a lack of data. With relatively recent advances in the study of northern paleoenvironment (e.g., Sundqvist et al., 2014; Gajewski, 2015b; Briner et al., 2016) as well as the creation of CARD, a large database of archaeological radiocarbon dates, it is now possible to quantitatively examine past human-environment interactions in the north.

Here we investigated the impacts of past environmental changes on ancient populations in the North American Arctic and Subarctic through a data-analytic approach. Past population sizes across three spatial scales were estimated and the spatial distribution of populations at the continental and regional scale were examined. Population dynamics were compared to reconstructions of past temperature and sea ice. Results indicate that population density fluctuated over the course of the Holocene, but increased overall. Population histories differed somewhat by region and subregion, but major periods of population growth and decline tended to be synchronous across the entire study region. Population increased almost everywhere from ~5 – 4 ka, decreased between ~4 – 3 ka, and increased over the last millennium. There was generally high correspondence between millennial-scale changes in population density and climate in all regions and subregions. Population density generally increased during warming periods and declined during cooling periods. In the Arctic, Greenland, and northern coastal Beringia, population declines also coincided with increasing sea ice.

Neoglacial cooling at the beginning of the Late Holocene coincided with a continental-scale decline in population density. Continued neoglacial cooling is associated with the abandonment of the high Arctic from ~3 – 1 and the migration of Paleo-Inuit groups into Newfoundland and

Labrador. Greenland was completely abandoned from approximately 2 - 1 ka following a millennia of climate cooling and increasing sea ice.

The positive association between temperature and population density was not discernable when the paleoclimate and paleodemography were averaged and summed, respectively, across the entire study region, but it was evident at the regional and sub-regional scale. Analysis at the sub-regional scale revealed the positive association between temperature and population density where the regional scale did not (e.g., in Mid- to Late Holocene Beringia). These findings emphasize the importance of using regionally-appropriate paleoclimate reconstructions when analyzing climate change in relation to the archaeological record, and of conducting this type of analysis at multiple spatial scales.

While we addressed loss due to taphonomic factors by applying the correction of Surovell et al. (2009) to the paleodemographic estimates, the necessity of this in all environments is unclear. In permafrost environments such as the Arctic and Greenland, it is likely not necessary. However, it is probably required to some extent for Boreal forest regions such as the Subarctic and central Beringia. The development of environment-specific taphonomic corrections would be useful to understand the true rate of long-term population growth in any region.

Though the primary goal of this study was to reconstruct relative population density, our results provide an opportunity to estimate absolute population numbers. One could infer this information by assessing our paleodemographic reconstructions in relation to estimates of Indigenous population size at the time of European contact, as well as genetic-based estimate of past population numbers. An analysis of site frequency in relation to the number of dates may also provide insight into absolute population numbers.

Although both absolute population numbers and the rate of long-term population growth remain unclear, our results clearly reveal climatic change mediated population growth throughout the Holocene. Most notably, neoglacial cooling at the beginning of the Late Holocene precipitated a continental-scale decline in population density. To reveal the full spatial extent of this population crash, further investigation of paleodemography in relation to the paleoenvironment across North America is required.

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APPENDIX A

Greenland Archaeological Radiocarbon Database Bibliography

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APPENDIX B

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