2018-09-19

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Edwards, T. (2018). The Role of Avifauna in Paleodiet Reconstruction: An Arctic Case Study (Doctoral thesis, University of Calgary, Calgary, Canada). Retrieved from https://prism.ucalgary.ca. doi:10.11575/PRISM/33052

http://hdl.handle.net/1880/108699

UNIVERSITY OF CALGARY

The Role of Avifauna in Paleodiet Reconstruction: An Arctic Case Study

by

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A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

GRADUATE PROGRAM IN ARCHAEOLOGY

CALGARY, ALBERTA

SEPTEMBER, 2018

Abstract

This thesis explores the importance of birds in paleodietary reconstruction based on stable isotope analysis, using faunal remains from Arctic contexts as a case study. In the Arctic, migratory birds and their eggs have been important seasonal resources for hunter-gatherer populations, and while evidence of their utilization in the faunal record is apparent, their use is less clear from the isotopic record.

Zooarchaeological analysis was carried out on a large sample of bird remains from Pre-Dorset and Dorset sites located on the Knud Peninsula of Ellesmere Island to assess bird hunting and processing amongst Paleo-Inuit groups. A subset of these archaeological bird remains were analyzed to determine the variation in avian isotopic signatures which was expected to differ from terrestrial and sea mammal isotopic signatures. An experimental study was carried out to test the assumption that the spacing between avian tissues (bone collagen, muscle, fat, and feathers) differs from tissue spacings in mammals. Linear mixing models were then used to estimate diet based on new tissue spacing data and isotope data from archaeological bird bone collagen. These results were compared to previous studies of Arctic paleodiet.

Zooarchaeological analysis of the avifaunal remains suggests that Pre-Dorset and Dorset groups on the Knud Peninsula preferentially hunted eider ducks, and birds were heavily processed for human consumption. Bird bones were also used in tool production. Stable isotope analysis of various tissues from ducks fed a controlled diet indicates that avian tissue spacings differ from those of mammals by up to 2‰, especially for stable carbon isotopes. Results from the stable isotope analysis of archaeological avifaunal samples demonstrate that birds have variable isotopic signatures that reflect dietary preferences, migratory routes, and reproductive strategies. Finally, the inclusion of avian-specific tissue spacing values and isotopic signatures for birds and their eggs in linear mixing models for Arctic hunter-gatherers demonstrates that birds and their eggs can be detected isotopically and that these additions can alter our interpretations of the role of birds and eggs in human paleodiet.

Acknowledgements

This dissertation would not have been possible without the endless support of my supervisor, Dr. M. Anne Katzenberg. She has guided me through every part of this journey with great wisdom and dedication. Her door was always open, and I could always count on her for feedback and advice. She was my role model at the beginning of my career, and I am beyond lucky to now call her my mentor. I am a better bioarchaeologist because of Dr. Katzenberg.

I also want to thank my supervisory committee members, Dr. Warren Wilson and Dr. Peter Dawson. Dr. Wilson has pushed me to always consider multiple lines of evidence and to seek a deeper understanding of human adaptation and evolution. Dr. Dawson has inspired my appreciation of the Arctic and the people that call it home. Both have shown an unmatched enthusiasm for my research and endeavours. My committee members, Dr. Matthew Walls and Dr. Christyann Darwent, also provided helpful advice and suggestions that improved the final manuscript measurably.

Thank you to Dr. Karen McCullough for allowing me to work with the avian faunal remains from the Knud Peninsula archaeological sites. Dr. McCullough was also a great source of information during the initial stages of my research. I would also like to thank Stephen Taylor and the team at the Isotope Science Laboratory at the University of Calgary for running all my stable isotope samples over the years. A special thanks to Adam Benfer for creating the maps used in this dissertation.

I am also grateful for all my wonderful lab mates, especially Adrianne Offenbecker, Cynthia Kwok, Nicki Engel, Courtney McConnan-Borstad, and Emily Peschel. They always had great ideas and were always willing to help. I would also like to thank Kris Russell-Markin for

her assistance throughout the years. I made many friends along the way, and I could always count on them for advice, support, and a beer. Lindsay Amundsen-Meyer, Adam Benfer, Ashley Nagel, Margie Patton, Colleen Hughes, and Lance Evans were the best friends that an archaeologist could ask for.

This research was made possible through numerous funding sources. These sources include Master's and Doctoral scholarships from the Joseph-Armand Bombardier Canada Graduate Scholarships Program administered by the Social Sciences and Humanities Research Council (SSHRC), Queen Elizabeth II scholarships from the Government of Alberta, the Dissertation Research Grant from the University of Calgary, and the John C. Carter Endowment for Archaeological Research administered by the Department of Anthropology and Archaeology at the University of Calgary.

My family and friends have been my greatest cheerleaders. My parents have supported this dream from the beginning. They have always encouraged my curiosity and made sure that I had everything I needed to succeed. I would also like to thank my grandmother for her bravery, foresight, and love over the years. Finally, I am incredibly fortunate to have had unwavering love and support from the very start of my journey. My husband, Ian Edwards, has been caring, supportive, and understanding throughout the entire process. He was my rock during the toughest moments.

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ASTt	Arctic Small Tool tradition
NISP	Number of Identified Specimens
MNI	Minimum Number of Individuals
%C	Percentage of carbon in the sample
%N	Percentage of nitrogen in the sample
C:N	Carbon to nitrogen ratio

Chapter One: General Introduction

For the greater part of human history, hunting and gathering has been the main method of food acquisition for our species. Hunting and gathering food items allowed humans to survive, spread, and occupy most of the regions of the world. Hunter-gatherers, therefore, have a wide variety of foraging practices as a result of their environment and cultural interactions (Kelly, 2007, p. 6). Understanding variability in food practices and the strategies employed by hunter-gatherers is, therefore, a key component in learning about human nutrition and health in anthropology.

Beyond anthropology and archaeology, hunter-gatherer subsistence strategies may have further-reaching implications regarding metabolic diseases and nutrition transitions in modern populations. Many Indigenous populations are going through an extreme nutrition transition, from traditional foods to mass-produced market foods. Amongst Arctic groups, researchers find that many people still consume traditional foods such as caribou (*Rangifer tarandus*), fish, and seal, however, younger generations are consuming more commercially-produced foods compared to older individuals partly due to the loss of traditional knowledge about how to procure food from the environment (Mead, Gittelsohn, Kratzmann, Roache, & Sharma, 2010). The rate of obesity has also increased amongst many Canadian Arctic communities from 1970 to 1992, and as of 2010, obesity rate and the risk for chronic disease amongst Canadian Arctic populations are higher than the Canadian national average, and this can be attributed to the poor nutrient density in many commercially-produced foods (Kuhnlein, Receveur, Soueida, & Egeland, 2004; Nash et al., 2012; Sharma, 2010). The commercially-produced foods that are used consistently and most frequently across the Canadian Arctic are typically higher in carbohydrates, fat, and sugars compared to traditional foods such as meat and fish (Kuhnlein & Receveur, 2007; Kuhnlein et al., 2004). The negative health effects attributed to the nutritional transition in Arctic communities highlights the idea that traditional hunting and gathering practices amongst Arctic communities are a vital behavioural adaptation to their environment. An in-depth understanding of past Arctic subsistence strategies is therefore crucial to help researchers and the medical community to tackle modern disease and illness in northern communities.

This thesis examines the interpretive consequences of including birds in paleodietary reconstruction using stable isotope analysis. Archaeological sites from the eastern Canadian Arctic are used as a case study in this thesis. Arctic hunter-gatherers are unique because they mainly rely on fat and protein from animals for the bulk of their diet. The animals exploited by past Arctic groups varied depending on seasonal availability, climatic fluctuations, and cultural food preference, and archaeological research strives to understand this variation in Arctic hunter-gatherer dietary strategies. An important component of past Arctic hunter-gatherer diet is the contribution of small animals, including birds. Birds and their eggs were utilized by many past and present Arctic populations based on ethnographic accounts and can be easily caught and collected in large aggregations during the spring and summer. Birds would have also provided skin, feathers, and bones to produce goods, thereby also increasing their economic value. Finally, the place of birds in Arctic-hunter-gatherer cosmology and ritual also impacts their utility to human groups. Arctic hunter-gatherers are therefore an ideal group to study when trying to understand the impact of adding birds to paleodietary reconstruction using stable isotope analysis because they were likely including a considerable and therefore detectable proportion of birds in their diet.

1.1 Nutritional Background for Arctic Hunter-Gatherers

Humans, including Arctic hunter-gatherers, require three macronutrients fat, protein, and carbohydrates, and various micronutrients, including vitamins A, B_6, B_{12}, C, K, D, and E, thiamin, riboflavin, niacin, and folate, and minerals such as calcium, iron, zinc, magnesium, copper, phosphorus, potassium, and selenium for proper growth and maintenance of body systems (Institute of Medicine of the National Academies, 2011). The nutrients that are most important concerning diet are those that cannot be synthesized by the human body and therefore must be obtained through food, the essential nutrients. The three macronutrients are considered essential because they provide the energy that is needed by the body to maintain proper function. Other examples of essential nutrients include vitamin A, vitamin C, vitamin E, calcium, and iron. Another class of nutrients, termed conditionally essential nutrients, are also important regarding diet. These nutrients are defined as those that are normally synthesized within the body in adequate quantities, however, due to certain circumstances also need to be supplemented in the diet (Chipponi, Bleier, Santi, & Rudman, 1982). One example of a conditionally essential nutrient is vitamin D, which is synthesized by the skin through sun exposure (ultraviolet radiation) but must be supplemented in the diet for populations that do not receive adequate sun exposure (Holick, 2007). There is, therefore, a complex relationship between dietary adaptations and the environment in order for humans to meet their nutritional requirements.

Arctic hunter-gatherers are unique, however, in their reliance on animals to provide most of the necessary dietary requirements. Muscle, fat and, organs from animals are nutrient-dense and provide the macronutrients and micronutrients needed for survival (Kuhnlein, Chan, Leggee,

& Barthet, 2002; Kuhnlein & Receveur, 2007). Although plants are seasonally available in the Arctic, they do not form a large proportion of Arctic hunter-gatherer diet. The abundance and distribution of animals, therefore, limit human nutrition in the Arctic. Most of the animals hunted by Arctic groups, including marine and terrestrial mammals and birds, are also migratory due to seasonal temperature change and food availability (Crawford, 2014). Past Arctic hunter-gatherers, therefore, relied on seasonal movements that would allow them to hunt different animals available at key locations throughout the year. Storage of food would also help to buffer the effects of seasonal food availability.

Traditionally hunted animals were able to provide the nutrients necessary for the survival of Arctic hunter-gatherer groups for thousands of years. Important components of this diet, as documented ethnographically and archaeologically, are migratory birds and their eggs. Given the same quantity of meat, ducks provide comparable amounts of protein and fat to seals, caribou, and muskox (*Ovibos moschatus*) (Kuhnlein et al., 2002). During large spring and summer migrations of birds to the Arctic, birds and their eggs could provide Arctic hunter-gatherers with an additional source of protein and fat. Incorporating birds and their eggs into models of past diet can, therefore, help archaeologists understand the nutritional significance of these food items and how that may affect interpretations about subsistence strategies and seasonal movement of human groups.

1.2 Research Goals and Objectives

The ultimate goal of this dissertation was to understand how the inclusion of birds in paleodietary reconstruction can affect interpretations generated through zooarchaeological and stable isotope analysis. The first research objective to achieve this goal was to explore the faunal evidence from Arctic archaeological sites to identify the use of avifauna. If birds were being hunted and consumed by past Arctic hunter-gatherers, then there would be evidence of these processes in the zooarchaeological record because materials such as avian bone are often preserved through time. Avifaunal remains from Pre-Dorset and Dorset archaeological sites located on the Knud Peninsula of Ellesmere Island were examined to identify predominant bird species, patterns of butchering and processing, and possible hunting seasons for avifauna. This information would also help to inform later paleodietary reconstructions using stable isotope analysis.

The second research objective was to determine if the incorporation of birds into past Arctic hunter-gatherer diet would have any impact on the stable isotope signatures of Arctic hunter-gatherers. If birds were an important resource in Arctic hunter-gatherer diet, then the stable carbon and nitrogen isotope ratios of Arctic hunter-gatherers would be reflective of this dietary resource because stable isotopes serve as natural tracers for diet. This research objective was addressed in three steps. The first step was to test the assumption that stable isotope spacing values for avifauna are the same as those for mammals. Isotopic spacing values for bone collagen, muscle, fat, and feathers were determined for a species of duck (*Anas platyrhynchos*) fed a steady and monotonous diet. This allows us to understand the discrimination factors in stable carbon and nitrogen isotopes across different avifaunal tissues due to metabolic processes. These spacing values could then be compared to those of mammals to examine if this long-held assumption in stable isotope analysis of archaeological human remains is valid.

The second step in this research objective was to analyze a large sample of archaeological avifaunal remains to determine if there is variability in avifaunal stable carbon and nitrogen isotope ratios due to their unique life histories and if avifaunal stable isotope signatures are distinct enough from those of mammals to be detected using stable isotope analysis. A subsample of the avifaunal remains from the Knud Peninsula assemblages was analyzed using stable carbon and nitrogen isotope analysis. A larger sample size of one hundred and one bird bones were analyzed to include avian species within the marine, terrestrial, and freshwater ecosystems and to encompass the possible variety in stable isotope signatures resulting from diverse food sources, migratory routes, and reproductive strategies.

The final step in this research objective was to use linear mixing models to determine if avian-specific spacing values and avifaunal stable isotope signatures, including those from eggs, have any impact on the paleodietary reconstruction of Arctic hunter-gatherer diet using stable isotope analysis. Linear mixing models were generated for various past Arctic groups using avian-specific spacing values and a greater representation of avian isotopic signatures to evaluate the effect that these values have on the paleodietary reconstruction of Arctic hunter-gatherers.

1.3 Archaeological Context

The primary study area for this dissertation is the Knud Peninsula region of Ellesmere Island. Zooarchaeological analysis and stable isotope analysis were conducted on bird remains from these Ellesmere Island sites. Stable isotope data from faunal remains recovered from the Mackenzie Delta were also included in this dissertation as additional animal isotopic signatures for the linear mixing models in Chapter 8.

The Knud Peninsula is located on the eastern coast of Ellesmere Island. It is bounded by Flagler Bay to the north, Hayes Fiord to the south, and Buchanan Bay in the Nares Strait to the east (see Figure 1.1). There are numerous polynyas, or open water areas, around the Knud Peninsula making it an attractive area for human groups (Schledermann & McCullough, 2003). This area of Ellesmere Island may have also served as an essential travel route for past human groups moving from Greenland to the Central Arctic (Schledermann, 1990). This is, therefore, a key area to look at Paleo-Inuit populations and their various migrations to and from Greenland.

The materials used in this dissertation came from a series of excavations run by Drs. Peter Schledermann and Karen McCullough on the central eastern coast of Ellesmere Island between the years of 1977 to 1982 and 1987 to 1988. The goal of their research was to explore prehistoric population movements between the Canadian Arctic and Greenland. In the process of exploring this question they also discovered that the Bache Peninsula and the regions surrounding it on Ellesmere Island also served as long-term settlement sites for numerous Arctic hunter-gatherer groups. This dissertation focusses on the Pre-Dorset and Dorset archaeological sites identified on the Knud Peninsula and the Baculum site just below it. The zooarchaeological collection from these sites was useful for this dissertation because it contained a large number of bird bones from a variety of different species, and Paleo-Inuit groups, including the Pre-Dorset and Dorset, are known to hunt birds at other locations in the Arctic and this data would serve as important comparative material (i.e., Gotfredsen & Møbjerg, 2004; Hodgetts, Renouf, Murray, McCuaig-Balkwill, & Howse, 2003; Milne & Donnelly, 2004). Knud Peninsula archaeological site locations can be found in Figure 1.2.

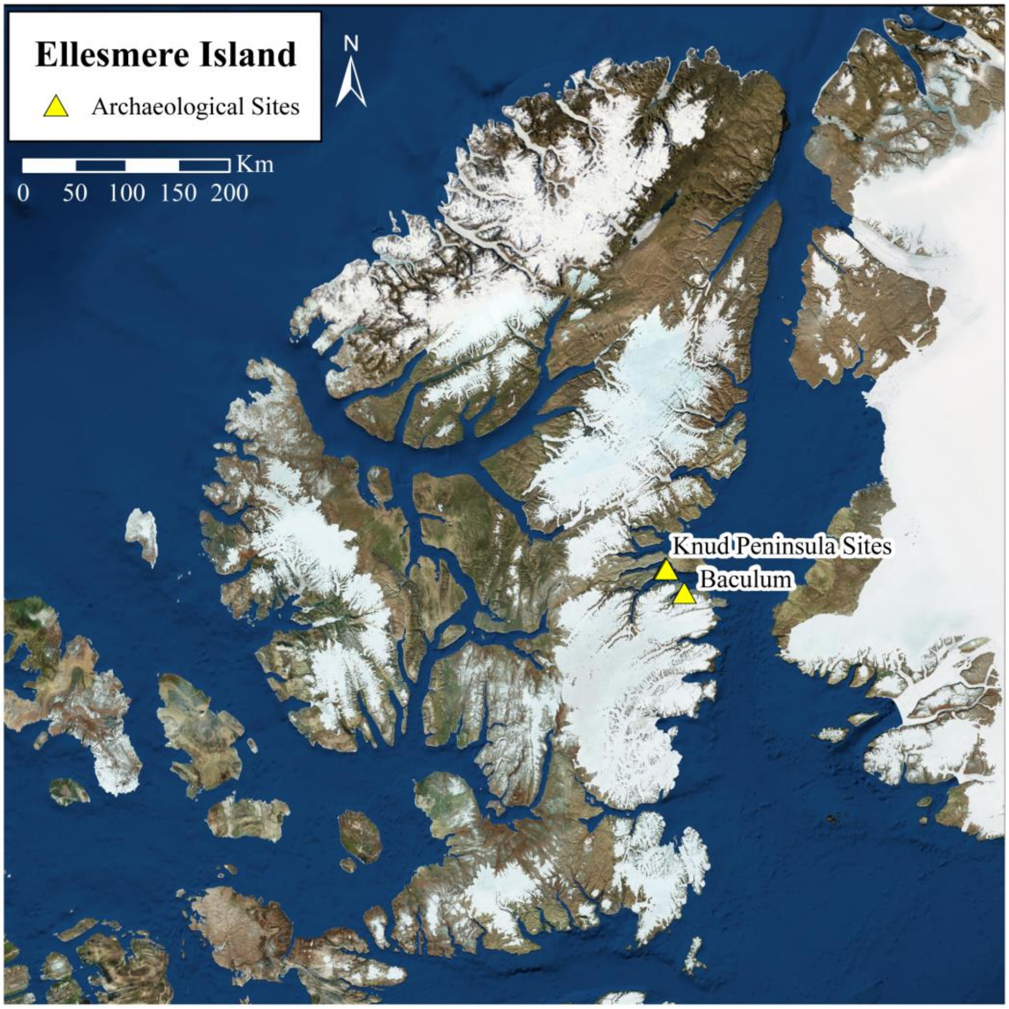

Figure 1.1 Location of Knud Peninsula sites and the Baculum site on Ellesmere Island. Map Courtesy of Adam Benfer. ArcGIS 10.4 software (http://www.esri.com/sofware/arcgis) was used to generate the figure. Service layer credits: Esri, ArcGIS Online, TerraColor (Earthstar Geographics), and the GIS User Community.

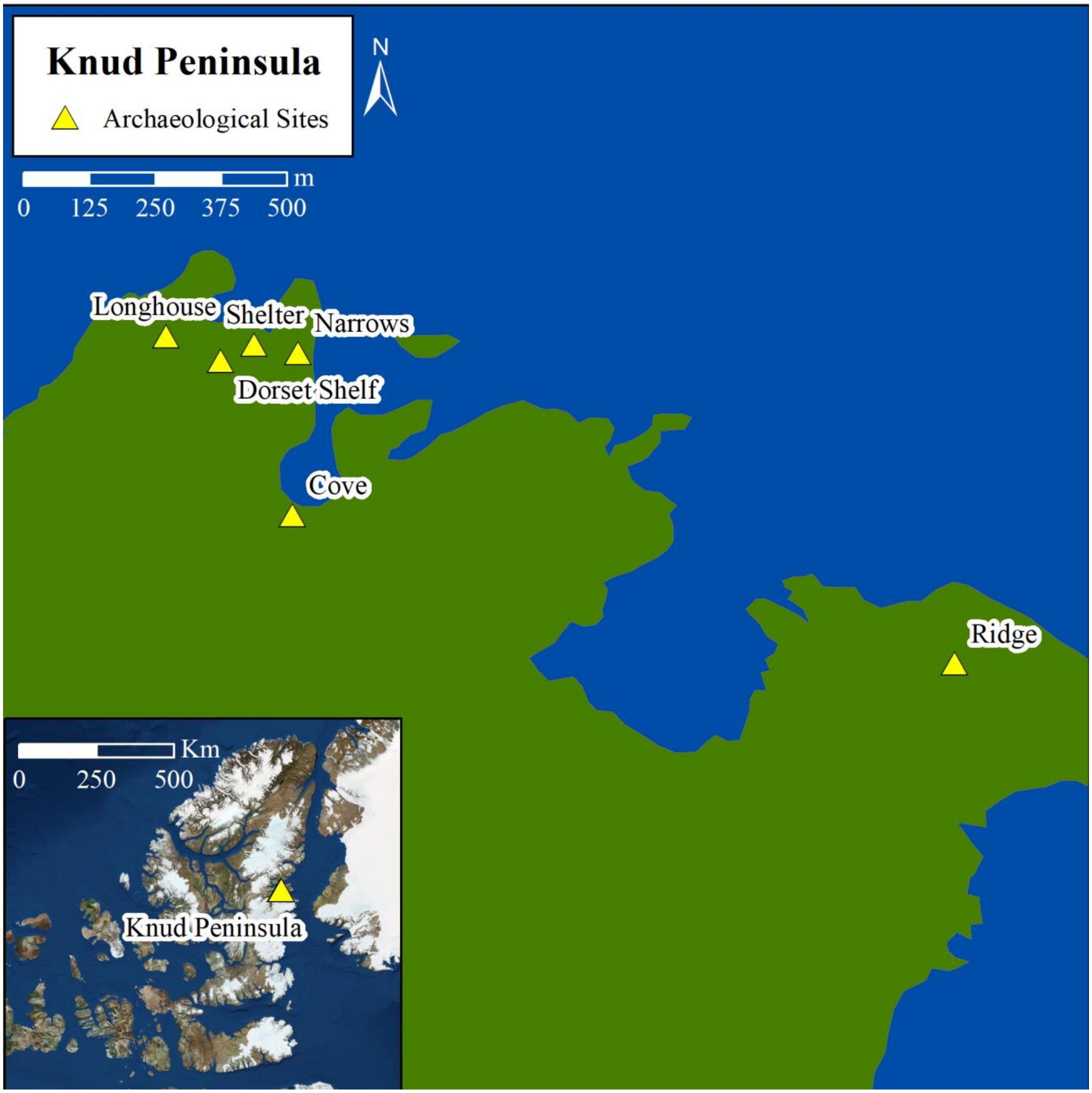

Figure 1.2. Location of Knud Peninsula sites on East Ellesmere Island. Map Courtesy of Adam Benfer. ArcGIS 10.4 software (http://www.esri.com/sofware/arcgis) was used to generate the figure. Service layer credits: Esri, ArcGIS Online, TerraColor (Earthstar Geographics), and the GIS User Community.

In addition to the avifaunal samples from the Knud Peninsula, comparative stable isotope data for faunal remains from the Kuukpak site in western Canada were also used. The stable isotope values for the Kuukpak site in the Mackenzie Delta were previously obtained for a joint project between Dr. M. Anne Katzenberg from the Department of Archaeology and colleagues from the Department of Biology and Department of Geology at the University of Calgary. The project was part of the Outer Mackenzie River Delta Human Ecology Project. These faunal samples were collected from Kuukpak Area 1, House 1 located on the Mackenzie River Delta, and are dated to approximately A.D. 1500 (see Figure 1.3). Though these materials are more recent than those from Ellesmere Island, the large number of faunal remains analyzed provides useful comparative data. The isotopic signatures from these faunal remains were used in the linear mixing models in Chapter 8.

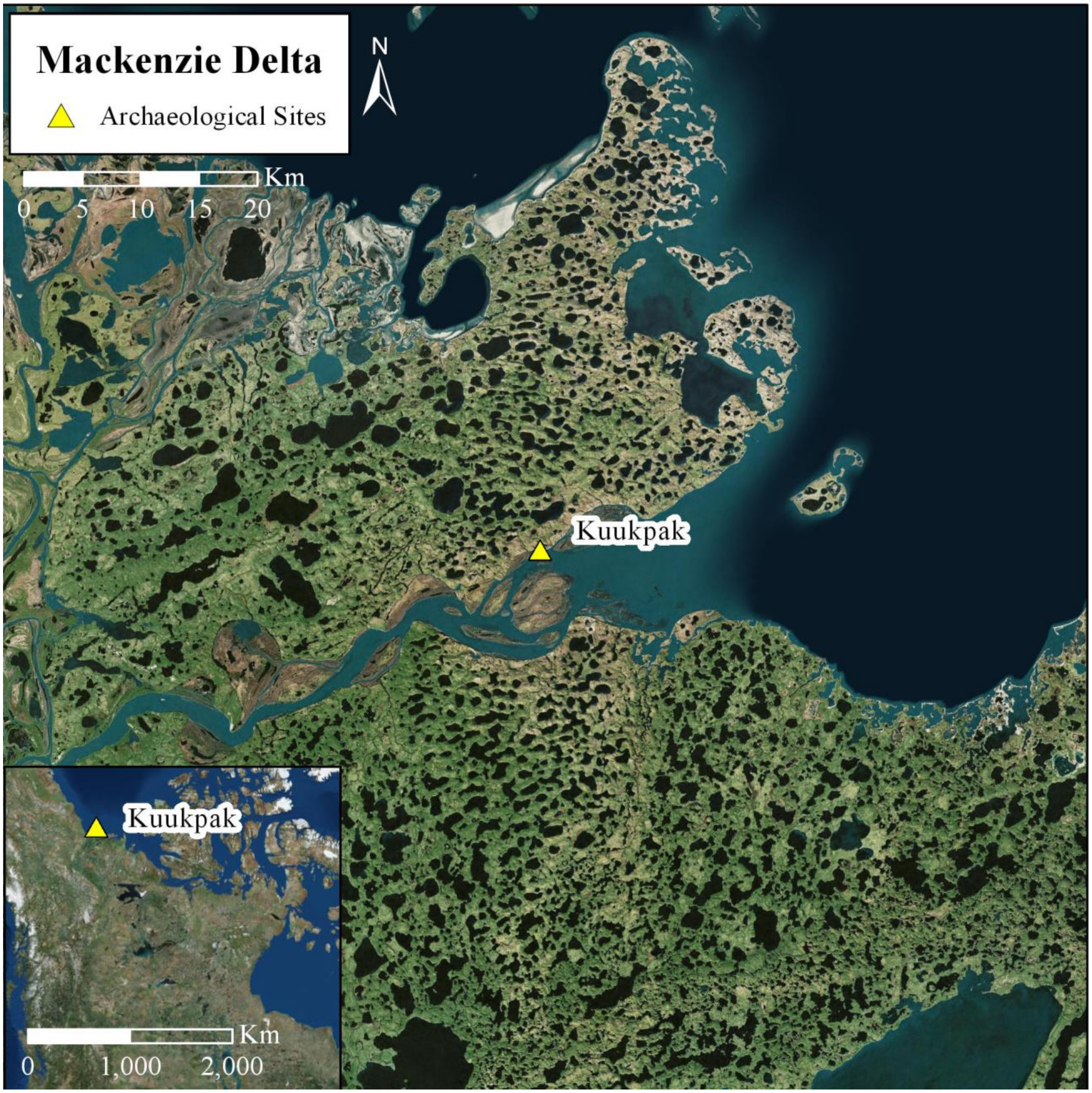

Figure 1.3. Location of the Kuukpak site in the Mackenzie Delta, Canada. Map Courtesy of Adam Benfer. ArcGIS 10.4 software (http://www.esri.com/sofware/arcgis) was used to generate the figure. Service layer credits: Esri, ArcGIS Online; TerraColor (Earthstar Geographics) 1999; Vivid - Alaska (Digital Globe) 2009, 2010, 2011, 2012, 2013, 2014, 2015; Vivid - Canada (Digital Globe) 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016; Vivid - USA (Digital Globe) 2012, 2013, 2014, 2015, 2016; and the GIS User Community.

1.4 Dissertation Outline

This dissertation contains nine chapters. Chapter 2 provides background information on the climate, geography, and primary ecosystems of Ellesmere Island, the main location of the archaeological sites used in this thesis. It also summarizes the subsistence strategies of Paleo-Inuit groups, namely Denbigh Flint Complex, Independence I, Pre-Dorset, Saqqaq, and Dorset populations.

Chapter 3 is a survey of the different roles that birds have played in the resource strategies of northern hunter-gatherers. Both ethnographic and archaeological evidence are used to explore how birds served various purposes for Arctic groups. Birds were not only important in the diet of Arctic hunter-gatherers; they also provided raw materials for bone tools, clothing, and household items. Birds also played an important symbolic role in the shamanic universe of many northern hunter-gatherer groups.

Chapter 4 provides a summary of stable isotope analysis in paleodietary reconstruction, with a focus on stable carbon and nitrogen isotopes. This chapter describes how stable isotope analysis allows researchers to determine the plant foods at the base of the food web, intake of marine versus terrestrial versus freshwater foods, and the trophic level of an organism. Conditions that may affect the analysis and interpretation of stable isotope results such as metabolic routing, preservation, and migration are also addressed. Finally, the current state of research on paleodietary reconstruction of Arctic hunter-gatherer diet using stable isotope analysis is discussed. Stable carbon and nitrogen isotope ratios of animals that were likely included in Arctic hunter-gatherer diet are also provided.

Chapter 5 contains the zooarchaeological analysis of avian faunal remains from seven archaeological sites located on or near the Knud Peninsula of Ellesmere Island. A total of 1661 bird bones were included within the analysis. The bird species present were quantified using Number of Identified Specimens (NISP) and Minimum Number of Individuals (MNI) and were analyzed for evidence of human activity, cut marks, age and sex, and degree of preservation. The bird bones were well-preserved and had clear evidence of human activity in the form of spiral fractures, cut marks, bite marks, and tool processing. Eider ducks (*Somateria* sp.) make up most of the assemblage. A small number of bones belonging to female birds and juvenile birds were identified, but the assemblage consisted mainly of adult birds that were likely male. Pre-Dorset and Dorset groups located on the Knud Peninsula therefore preferentially hunted adult eider ducks during the late summer months.

Chapter 6 determines if avian diet-to-tissue and tissue-to-tissue spacings in stable isotope analysis are different from the mammal spacing values typically used in paleodietary reconstruction. Current spacing values available in the ecological literature are provided for both mammals and birds. Many of these values are geared towards ecological research and mainly include diet-to-tissue spacings, and the isotopic spacing between bone collagen and other tissues is rarely addressed. Noting this lack in the literature, stable carbon and nitrogen isotope analyses were performed on the muscle, fat, feather, and bone collagen tissues from mallard ducks (*Anas platyrhynchos).* Stable carbon and nitrogen isotope analyses were also carried out on the duck feed to provide diet-to-tissue spacing values that can be compared to current ecological research. The stable carbon and nitrogen isotope analyses of these tissues show that there are notable differences between the spacing values between birds and mammals, especially for stable carbon isotope ratios.

Chapter 7 provides stable carbon and nitrogen isotope ratios for 101 bird bone collagen samples recovered from the Knud Peninsula area archaeological sites. Migratory birds have unique life histories compared to marine and terrestrial mammals due to their ability to move between distinct habitats. Stable carbon and nitrogen isotope ratios for bird bone collagen may, therefore, differ from the values obtained from mammals. A total of 13 different bird species were analyzed to determine the possible range in stable isotope ratios for arctic birds. Isotopic signatures for the different bird species appear to separate into three distinct groups: birds with low stable carbon and nitrogen isotope ratios representative of a terrestrial signature, birds with intermediate stable carbon and nitrogen isotope ratios, and birds with elevated stable carbon and nitrogen isotope ratios reflective of a high trophic level marine diet.

Chapter 8 explores the effect of avian-specific spacing values on paleodietary reconstruction of Arctic hunter-gatherer diet using stable isotope analysis and linear mixing models. Linear mixing models allow researchers to estimate the proportions of the main food items incorporated into a consumer’s subsistence strategy. These models were therefore used in this chapter to evaluate the impact that birds, eggs, and bird-specific spacing values have on human isotopic signatures. Linear mixing models were created using stable carbon and nitrogen isotope ratios from Arctic hunter-gatherers and arctic prey species currently published in the bioarchaeological and ecological literature and the stable isotope ratios of bird bone collagen and bird-specific isotopic spacing values determined in this thesis. In all the models, bird-specific spacing values change the proportion of birds that were likely included in the diet of Arctic hunter-gatherers, with the percentage of birds increasing in the diet of Arctic hunter-gatherers in three out of five models. Egg isotopic signatures were also calculated to determine their impact on models of human paleodiet. Theoretical bone collagen stable carbon and nitrogen isotope ratios were also calculated for Paleo-Inuit groups using faunal percentages published in the zooarchaeological literature, published isotopic signatures for faunal remains, and bird bone collagen stable isotope ratios and bird-specific spacing values reported in this dissertation.

Chapter 9 summarizes the findings from this dissertation and notes the most significant contributions to paleodiet research. The main objectives and the resulting conclusions are re-stated. Future directions for research, including further consideration and stable isotope analyses of bird eggs, continued experimental research into tissue spacing values of different bird species, and increased samples sizes of bird remains in paleodietary research are also discussed.

Chapter Two: Study Area and Archaeological Background

Hunter-gatherers in the Arctic have adapted to extreme climates with generally low temperatures, and low biodiversity but with a high number of individuals for the species that are present (Jonasson, Callaghan, Shaver, & Nielsen, 2000). Human groups in the Arctic rely on the seasonal availability of migratory terrestrial and marine animals since climate and weather patterns can fluctuate to a larger degree compared to temperate environments. Not all past human groups adapted in the same way across the Arctic. This dissertation will utilize the range of subsistence strategies adopted by the first human populations known to migrate and occupy locations across the North American Arctic, the Paleo-Inuit, as a case study. This chapter will provide geographic and ecological information for Ellesmere Island, the main study area, and archaeological background for Paleo-Inuit groups.

2.1 Boundaries of the Arctic

Past circumpolar populations, the focus of this research, include human groups north of the Arctic Circle from Siberia, Alaska, the Canadian Arctic, and Greenland. Where relevant, groups from the Subarctic are also discussed since cultural groupings are not defined by modern geographical boundaries and groups may share some cultural attributes. The Arctic study area can be defined as the northern latitudinal areas of the earth (the Arctic Circle is located at 66° north of the Equator) where there is permafrost, with temperatures throughout the year that never reach above 21°C (Maxwell, 1980). Due to the permafrost in these Arctic regions, there is also little vegetation, and the Arctic and the Subarctic regions can be separated based on the tree line

(Maxwell, 1980). This general definition of the Arctic, however, does not capture the variation in both climate and geography from Siberia to Greenland. The Arctic is subject to seasonal fluctuations, and even areas within the same general region can have remarkably different weather patterns and ecology. This definition of the Arctic also does not consider climatic changes through time. This demarcation therefore only serves as a guideline for this dissertation, and where necessary, human cultural groupings take precedence over geographical definitions since this research is focused on northern hunter-gatherers.

2.2 Study Area

2.2.1 Ellesmere Island

Most of the research discussed in this dissertation is based on Paleo-Inuit sites located in the Knud Peninsula region of Ellesmere Island, Canada. The Knud Peninsula is located on the east coast of central Ellesmere Island. Ellesmere Island is the largest and northernmost island in the Canadian Arctic Archipelago. Islands of the Canadian Arctic Archipelago north of Lancaster Sound fall within the category of polar desert or semi-desert and are classified as part of the High Arctic (Svoboda & Freedman, 1980).

2.2.1.1 Geography

2.2.1.1.1 Terrestrial Landscape

Ellesmere Island is one of the most mountainous islands in the Canadian Arctic Archipelago. Mountain ranges are found over most of the island, intercepted by narrow passages, fiords, and inlets (Dick, 2001). The main mountain ranges include the Grant Land mountains in the north, the Princess Margaret range in the west, the Victoria and Albert mountain ranges, and the Prince of Wales mountain ranges in the east (Bell, 1992). Numerous glaciers also cover the Ellesmere Island landscape, and ice caps cover all of the major mountain ranges (Bell, 1992; Koerner, 2002). One of the largest ice caps on the island is the Grant Land ice cap located on top of the Grant Land mountains in the northwest quadrant (Bell, 1992; Dick, 2001). Two ice fields cover most of east-central Ellesmere Island, and the east coast is rugged and mountainous with elevations up to 2000 meters and steep fiords that drop off into the ocean (Henry, Freedman, & Svoboda, 1986; Oakey & Damaske, 2004). Together, the mountain ranges and glaciers limit the movement of humans and animals on the island.

There are, however, areas on the island that are considered lowlands and are more hospitable to plant and animal life. One such rare area is Sverdrup Pass, which runs east to west in central Ellesmere Island, from the Bache Peninsula in the east to Irene Bay in the west. It is in between two ice fields to the north and south and is largely ice-free (Henry et al., 1986). Other lowlands on Ellesmere Island include areas around Alexandra Fiord, Cañon Fiord, Princess Marie Bay, and Irene Bay, the Hazen plateau, the Knud Peninsula, Bache Peninsula, the Fosheim Peninsula and Cook Peninsula (Bell, 1992; Henry et al., 1986).

2.2.1.1.2 Marine Landscape

Ellesmere Island is situated in the Arctic Ocean, bounded by the Robeson Channel, the Kane Basin, and Smith Sound in the east, Eureka Sound in the west, the Arctic Ocean in the north, and Jones Sound in the south. The coastline of central-eastern Ellesmere Island is complex and can vary from steep-sided fiords to lowland areas (Henry et al., 1986; Oakey & Damaske, 2004). There are also numerous peninsulas along the eastern coastline. The northeast coastline is somewhat less steep and irregular compared to the central-eastern coastline. The northern coast of Ellesmere Island is home to the unique ice shelves that extend into the Arctic Ocean. Occasionally, these ice shelves will break off and form ice islands in the sea (Dick, 2001). The western coastline is described as a “low-rolling landscape” (Henry et al., 1986, p. 78) compared to the eastern coast.

The bathymetry of the Kane Basin and Smith Sound in the east varies from 200 meters to 500 meters, with increasing depths in the Smith Sound region (Oakey & Damaske, 2004). The southwest continental shelf off of Ellesmere Island reaches depths up to 2000 meters deep and the continental shelf to the north breaks at approximately 250 to 400 meters and reaches up to depths of 1650 meters (Johnson, Grantz, & Weber, 1990).

Most of the sea is frozen in the Arctic for a majority of the year, except for a few notable areas called polynyas. Polynyas remain ice-free throughout the year because of prevailing northerly winds and south-flowing currents that clear away any forming ice (Stirling, 1980). The most predominant polynya around Ellesmere Island is the North Water polynya, located in the Smith Sound, east of Ellesmere Island. The North Water polynya is surrounded by pack ice to the north and south, and land-fast ice to the east and west, along the coasts of Greenland and Ellesmere Island (Tellman, Born, & Acquarone, 1999).

2.2.1.1.3 Freshwater Bodies

Ellesmere Island is home to the largest lake north of 76° latitude, Lake Hazen (England, Kershaw, LaFarge, & Bednarski, 1981). Today, Lake Hazen is located within Quttinirpaaq National Park and is an important, protected ecosystem (England et al., 1981). Lake Hazen is a drainage basin for the Grant Land Ice Cap located to the north of the lake. The Ruggles River also connects Lake Hazen to the sea, providing a migration route for arctic char (*Salvelinus alpinus*).

Many lakes in the High Arctic can remain frozen for most of the year, for example, Upper Dumbbell Lake located north of Lake Hazen. They are usually formed through glacial activity. The movement of former ice sheets can create depressions that are eventually filled with snow and glacial melt. Moraine lakes and kettle lakes can also form as a result of retreating glaciers leaving ice deposits around the former margin. Deglaciation of the Arctic over time has also lead to isostatic rebound of the land, and some previously low-lying areas have filled with water, rebounded, and are now lakes (Mackay & Løken, 1974).

Many smaller lakes on Ellesmere Island, such as Tuborg Lake or numerous unnamed lakes are a result of glacial advance trapping seawater at the head of fiords or post-glacial uplift trapping seawater at the bottom of fiords. Meltwater from glaciers and snow eventually decrease the salinity of the water in these areas, turning them into freshwater lakes (Hattersley-Smith, Keys, Serson, & Mielke, 1970). Numerous streams are also formed on the island due to glacial outwash (Bentham, 1941).

2.2.1.2 Climate

Climate on Ellesmere Island can be highly variable based on location. Seasonal temperature changes vary between coastal and inland locations and at different altitudes. Coastal sites are somewhat buffered to extreme temperature changes during the winter and summer compared to inland sites, which have colder winters and warmer summers (England et al., 1981). Northern Ellesmere Island, however, tends to have colder summers and longer periods of snowfall due to the effects of the Arctic Ocean (Bell, 1992). Certain locations on western Ellesmere Island, such as the Fosheim Peninsula, are somewhat protected from the cold Arctic Ocean air by the mountain ranges and can have summer temperatures as high as 13° C (Bell, 1992).

Coastal locations also have increased precipitation compared to inland locations, though Ellesmere Island is still classified as a polar desert and precipitation at coastal sites is still lower than sites further south (England et al., 1981). Precipitation at inland sites on Ellesmere Island can be extremely low, averaging one centimeter per year at some locations (England et al., 1981). Most of the precipitation seen on Ellesmere Island is in the form of snow (Bell, 1992). The Canadian Arctic Archipelago sees approximately 260 to 300 days of snow cover since melting occurs in late June or July and moderate snowfall begins as early as September (Barry & Hare, 1974).

In the last 20 years, rapid climate change has increasingly been documented by Arctic researchers and Ellesmere Island has been the focus of many climate studies. Earlier studies examined the calving of ice shelves on the coasts of Ellesmere Island. Ice shelves are platforms of ice flowing from a glacier that extend past the coastline and onto the ocean surface, and the northern coast of Ellesmere Island has the last remaining ice shelves in Canada. Unfortunately, ice shelves calve faster and in larger portions due to rising temperatures and these calving events are some of the first indications of rapid climate change (Copland, Mueller, & Weir, 2007). Ice shelves have experienced ice break-up for approximately the last 5500 years, but satellite imagery has shown that they have never calved at the magnitude seen in the 20th and 21st centuries (England et al., 2008).

Annual average surface temperatures in the High Arctic have also increased by 3.2°C from 1972 to 2007 based on observations at Eureka, Ellesmere Island. The greatest increases in temperature over the years was observed in the winter and autumn seasons (Lesins, Duck, & Drummond, 2010). Along with this increase in surface temperatures, surface wind speeds also decreased during the autumn, winter, and spring seasons, and precipitable water increased by 10% year-round across this time span (Lesins et al., 2010). Both the evidence from calving ice shelves and instrumental observations at Eureka are supported by reconstructions of Holocene air temperatures using ice cores from the Agassiz ice cap on Ellesmere Island. Stable oxygen isotope analysis of ice cores indicates that modern air temperatures are approximately 4°C warmer than pre-industrial temperatures and that these temperatures are the highest they have ever been in the last 7000 years (Lecavalier et al., 2017). The preponderance of evidence from various locations on Ellesmere Island indicate that although climate can be variable across the island and through time, rapid climate change and increasing temperatures are occurring at an accelerated rate in the Arctic. Warming temperatures, changes in wind speeds, precipitation, and ice cover both on land and water immediately impact animal and human ecology in the Arctic.

2.2.1.3 Ecology

2.2.1.3.1 Marine Ecosystem– Open Water

The marine ecosystem surrounding Ellesmere Island can be extremely productive, even though the surface is frozen over during the winter. Marine food webs tend to be more complex than terrestrial food webs, due to the large variety of organisms near the base of the food chain. Phytoplankton and ice algae serve as the primary producers in polar regions (Hobson et al., 2002; Hobson & Welch, 1992). Organisms that feed near the bottom of the food web in Arctic marine ecosystems include numerous species of zooplankton, crustaceans, and mollusks (Hobson et al., 2002; Hobson & Welch, 1992). Marine fish found around Ellesmere Island include arctic cod (*Boreogadus saida*), arctic char (*Salvelinus alpinus*), blue catfish (*Ictalurus furcatus*), sculpins (Cottoidea), thorny skates (*Amblyraja radiata*), snailfish (Liparidae), lumpfish (*Cyclopterus lumpus*), and wolffish (Anarhichadidae) (Hobson et al., 2002; Walters, 1953). Arctic char (*Salvelinus alpinus*) are anadromous, traveling to freshwater to spawn (Ebbin, 2005).

Sea mammals found around Ellesmere Island include beluga whales (*Delphinapterus leucas*), bowhead whales (*Balaena mysticetus*), narwhals (*Monodon monoceros*), killer whales (*Orcinus orca*), walrus (*Odobenus rosmarus*), bearded seal (*Erignathus barbatus*), and ringed seal (*Phoca hispida*). Within the marine ecosystem of Ellesmere Island, and the Arctic in general, we also see animals that exploit the marine food web but live on land. These animals include polar bears (*Ursus maritimus*) and certain species of birds, such as ducks and geese (Anatidae), gulls (Laridae), loons (Gaviidae), jaegers (Stercorariidae), and plovers (Charadriidae) that prefer marine foods (Gray, 1995).

2.2.1.3.2 Marine Ecosystem– Polynyas

Polynyas are a special ecosystem within the Arctic. These areas become a hotspot for marine life, especially in the mainly barren High Arctic. Secondary polynyas do not remain open for the whole year but have earlier spring ice break up compared to other frozen areas (Schledermann, 1980). These secondary polynyas are also attractive locations for Arctic life (Born, Teilmann, Acquarone, & Riget, 2004). The North Water polynya supports a high level of primary productivity (i.e., phytoplankton), making it one of the most productive areas in the Arctic (Hastrup, Mosbech, & Grønnow, 2018; B. Klein et al., 2002; Stirling, 1980).

Marine mammals will often overwinter in and around polynyas, and polynyas provide food for many migratory birds and marine mammals. Ringed seals, for example, will remain near the North Water polynya, located in the Smith Sound between Ellesmere Island and Greenland, for the entire year and utilize different areas depending on the season. They will spend most of the winter underneath the land-fast and pack ice surrounding the polynya but will come onto the ice for molting during the spring (Born et al., 2004). Polynyas are especially favourable to younger seals because there is a larger area for them to easily surface and breathe after diving for prey (Tellman et al., 1999). Belugas (*Delphinapterus leucas*), bearded seals (*Erignathus barbatus*), bowhead whales (*Balaena mysticetus*), narwhal (*Monodon monoceros*), and walrus (*Odobenus rosmarus*) are also known to overwinter in the North Water polynya (Heide-Jørgensen, Sinding, Nielsen, Rosing-Asvid, & Hansen, 2016; Heide-Jørgensen et al., 2013).

Birds present on Ellesmere Island and attracted to polynyas include brant (*Branta bernicla*) and snow geese (*Chen caerulescens*), old squaws (*Clangula hyemalis*), common

(*Somateria mollissima*) and king eiders (*Somateria spectabilis*), thick-billed murres (*Uria lomvia*), dovekies (*Alle alle)*, gyrfalcons (*Falco rusticolus*), plovers (Charadriidae), turnstones (Scolopacidae), parasitic (*Stercorarius parasiticus*) and long-tailed jaegers (*Stercorarius longicaudus*), glaucous (*Larus hyperboreus*), herring (*Larus argentatus*), ivory (*Pagophila eburnea*), and Sabine's gulls *(Larus sabini*), red phalaropes (*Phalaropus fulicarius*), and kittiwakes (*Rissa* sp.). All of these birds are migratory and utilize different areas along the Ellesmere Island and Greenland coastlines such as beaches, rocky outcrops, and slopes as their breeding and nesting grounds (Snyder, 1957). Fish, mollusks, crustaceans, seaweed, and invertebrates in and around the polynyas provide a rich resource base for these migratory birds (Snyder, 1957).

2.2.1.3.3 Terrestrial Ecosystem

The polar desert environment of Ellesmere Island coupled with the mountainous and complex geography is limiting on terrestrial life. Productivity in the polar desert region is concentrated in the lowlands, also referred to as lowland oases, which are warmer and have favourable moisture conditions for life (Svoboda & Freedman, 1980). The area surrounding Lake Hazen, the Hazen plateau, on the northern end of Ellesmere Island is an example of a lowland oasis. Lowland oases on Ellesmere Island typically have the greatest vegetation cover and contain plants such as arctic willow (*Salix arctica),* forbs, grasses, sedges, and shrubs (Henry et al., 1986).

Terrestrial mammals found on Ellesmere Island include muskoxen (*Ovibos moschatus*), Peary caribou (*Rangifer tarandus pearyi*), arctic wolves (*Canis lupus arctos)*, gray wolves

(*Canis lupus*), arctic foxes (*Vulpes lagopus*), short-tailed weasels (*Mustela erminea*), polar bears (*Ursus maritimus*), arctic hare (*Lepus arcticus*), and collared lemmings (*Dicrostonyx groenlandicus*) (England et al., 1981; Gray, 1995). Terrestrial animals also include birds such as rock ptarmigan (*Lagopus muta*), snowy owls (*Bubo scandiacus*), and snow buntings (*Plectrophenax nivalis*) that nest on land and feed on terrestrial resources.

The complex terrestrial landscape of Ellesmere Island can limit the movements of terrestrial mammals such as muskoxen and caribou. Muskoxen and caribou are mainly found in lowland oases such as the Hazen Plateau, Sverdrup Pass, Fosheim Peninsula, and the northwestern coastline of Ellesmere Island (Henry et al., 1986; Petersen, Manseau, & Wilson, 2010). Muskoxen are the largest herbivores in the Arctic, and they are found across the Arctic in Alaska, Canada, and Greenland (Crawford, 2014). Peary caribou (*Rangifer tarandus pearyi*), a subspecies of caribou, are principally located on the islands of the Canadian Arctic Archipelago, and even within this range they are limited in number due to geographic isolation, and in recent years, hunting, and pressure from industrialization (Gunn, Miller, & Thomas, 1981; Petersen et al., 2010). The number of Peary caribou on Ellesmere Island is low compared to more southern islands in the Canadian Arctic Archipelago, and their distribution on the island is also clustered (Petersen et al., 2010).

2.2.1.3.4 Freshwater

Freshwater environments in the Arctic are limited in terms of life compared to rivers and lakes in temperate and tropical environments. Arctic freshwater environments can also be highly variable from ice-capped lakes that only support microbial life to extremely productive lakes and rivers that support surrounding wildlife.

Ice-capped lakes can support algae and zooplankton such as copepods. The primary productivity of such lakes is limited by the availability of nutrients such as nitrates and phosphates. Productivity can also fluctuate depending on ice cover, light penetration, and depth below the surface (Apollonio & Saros, 2014).

Larger lakes, such as Lake Hazen, support more diverse life forms. Lake Hazen is classified as an oligotrophic lake due to its low accumulation of nutrients and fewer phytoplankton and zooplankton compared to other lakes. It is, however, still home to arctic char (*Salvelinus alpinus*) and numerous benthic invertebrates (Köck et al., 2012). The area surrounding Lake Hazen is also protected from cold winds from the Arctic Ocean by the Garfield Mountain Range to the north and is a polar oasis home to various terrestrial plants and animals (Köck et al., 2012). Fish in the lake are an important food resource for many of the animals on the Hazen Plateau.

2.2.1.4 Cultural Sequence of the Knud Peninsula, Ellesmere Island

The sites analyzed in this dissertation belong to Pre-Dorset and Dorset groups. Pre-Dorset and Dorset groups are classified as Paleo-Inuit groups. A brief outline of Paleo-Inuit groups and their subsistence strategies will be provided in the next section of this chapter. This outline will provide an idea of the range of subsistence strategies in these populations and will help to situate the findings from this research in the broader pattern of dietary adaptations amongst the Paleo-Inuit.

2.3 Dietary Strategies of Paleo-Inuit Groups

Paleo-Inuit groups include groups that belong to the Arctic Small Tool tradition and the Dorset culture. Paleo-Inuit groups have also been referred to as Paleoeskimo or Palaeoeskimo in the past, but these designations are problematic due to the name "Eskimo" not being a self-designation by the Inuit. This dissertation will, therefore, follow T. Max Friesen's (2015) suggestion to use Paleo-Inuit to refer to groups belonging to the Arctic Small Tool tradition and Dorset culture along with the names of the regional variants of the Arctic Small Tool tradition to avoid confusion.

The Arctic Small Tool tradition (ASTt) was present in the North American Arctic from approximately 4500 BP to 2600 BP. Arctic Small Tool tradition sites are found in Arctic Alaska, the Canadian Arctic, and Greenland, and ASTt groups are likely descendants of populations from Siberia, such as the Bel'kachi (Ackerman, 1998; Giddings, 1964). The Arctic Small Tool tradition was first coined by William Irving to help classify groups across the Arctic that had similar small, flaked stone tools (W. N. Irving, 1964). Currently, ASTt groups are classified into four variants: the Denbigh Flint Complex located in Alaska, the Pre-Dorset located in the Canadian Arctic, Independence I located in the High Arctic in Canada and Greenland, and the Saqqaq in Greenland. ASTt groups are not believed to be related to current Inuit groups or their ancestors, the Thule (see Figure 2.1) (Raghavan et al., 2014; Rasmussen et al., 2010). Their initial migration across the Arctic from Alaska to Greenland pre-dates that of the Thule by over 3000 Years.

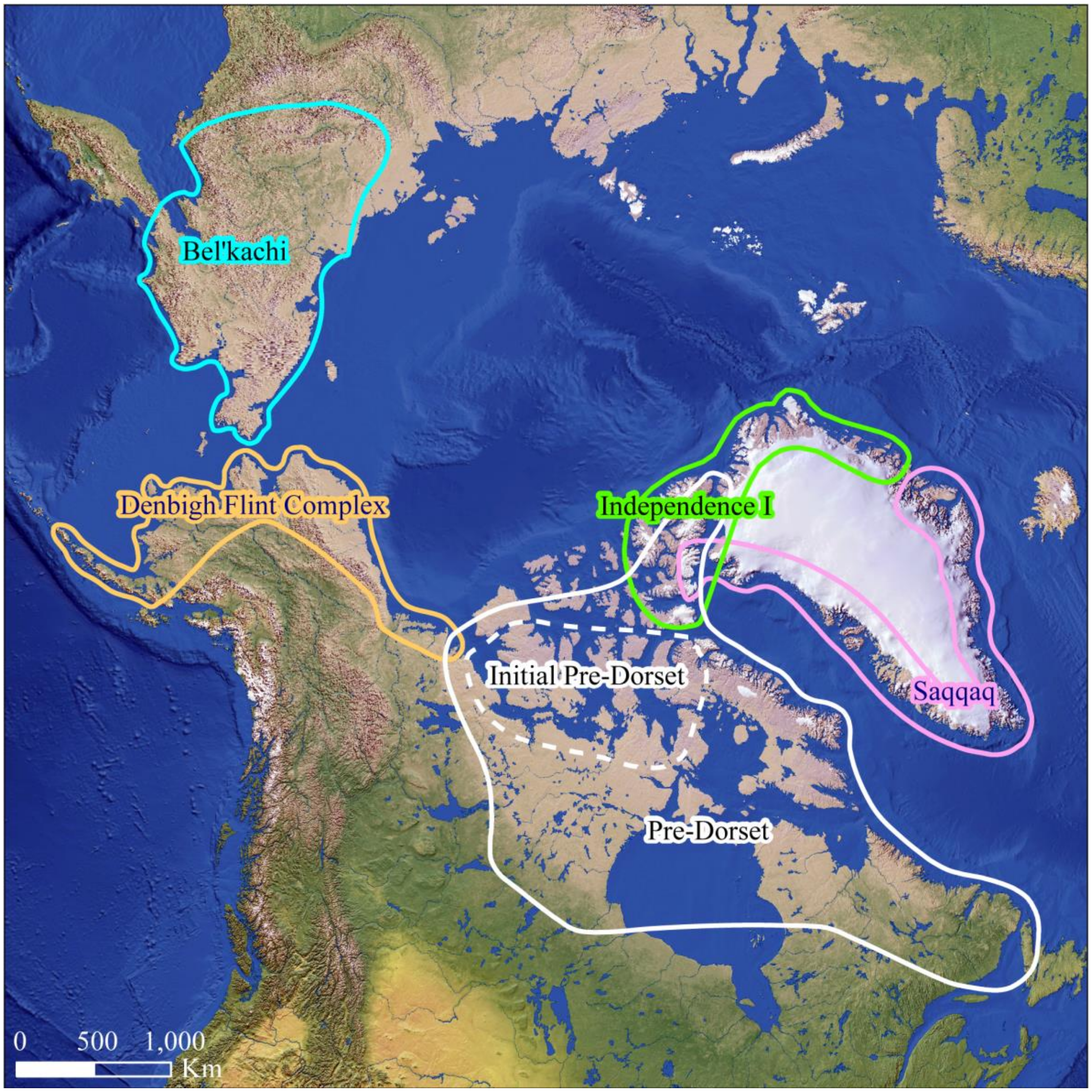

Figure 2.1. Distribution of Arctic Small Tool tradition groups and the Bel'kachi in the Arctic. Map Courtesy of Adam Benfer. Redrawn after Matthew Walls and T. Max Friesen (2016). ArcGIS 10.4 software (http://www.esri.com/sofware/arcgis) was used to generate the figure. Service layer credits: Natural Earth (Free vector and raster map data @ naturalearthdata.com).

Arctic Small Tool tradition groups are believed to be quite conservative across the range of groups from Alaska to Greenland (Gotfredsen & Møbjerg, 2004). Most of the toolkits of ASTt groups are similar, with spalled burins and small sideblades and endblades (microblades) appearing at most ASTt sites. Their toolkits also provide evidence that they could hunt both marine and terrestrial animals proficiently.

2.3.1 Denbigh Flint Complex

The Arctic Small Tool tradition (ASTt) first appears in the archaeological record of the North American Arctic with the Denbigh Flint Complex in Alaska. The earliest sites in Alaska belonging to the Denbigh Flint Complex are dated to approximately 4500 BP (Slaughter, 2005). However, they were likely present in the area earlier than this date. Sites associated with related ASTt groups located in Eastern Canada and Greenland have been radiocarbon dated to 4400 cal BP (Cox, 2003; Grønnow & Jensen, 2003; M. Meldgaard, 2004) and the likely path of ASTt migrants was from west to east, with their likely origins being in Siberia. It is unlikely that ASTt groups could make it from Alaska to Eastern Canada and Greenland in that short of a period (Friesen, 2016). Unfortunately, mainland Alaska suffers from poor preservation of organic materials for radiocarbon dating, and currently, only one Denbigh Flint Complex site (Kuzitrin Lake) predates 4500 BP by approximately 200 years (Harritt, 1994). This date has, however, been questioned by some archaeologists due to the large standard deviation associated with the radiocarbon date and possible stratigraphic mixing during excavation and recovery (Harritt, 1994; Odess, 2003).

Denbigh Flint complex sites have been located from Norton Sound in western Alaska to the Mackenzie River Delta in the Northwest Territories of Canada (Tremayne & Rasic, 2016). Denbigh Flint complex sites have been located both inland and along the coast of Alaska, with the earliest known sites, with the exception of Kuzitrin Lake, located on the coast (Tremayne, 2015). The timing of maritime hunting by the Denbigh Flint complex is uncertain and highly debated. It is unclear whether Denbigh Flint Complex groups arrived in Alaska from Siberia with a fully-developed maritime hunting adaptation or if that was an adaptation to the new environment in North America (Ackerman, 1998; Giddings & Anderson, 1986; Maxwell, 1980; McGhee, 1996). Site location, select sites with faunal remains, preserved lipids, and the presence of non-toggling harpoon heads in the toolkit of Denbigh Flint Complex groups however, supports the idea that they were maritime hunters by 4500 cal BP (Buonasera, Tremayne, Darwent, Eerkens, & Mason, 2015; Dumond, 1987; Giddings, 1964; Giddings & Anderson, 1986; Tremayne, 2011, 2015; Tremayne & Winterhalder, 2017). The actual number of faunal remains reported for coastal sites is low, however, and some terrestrial sites, like the Matcharak Lake site in Alaska, yield far larger faunal collections (Tremayne, 2011). Faunal remains found at the few inland Denbigh sites mainly include caribou supplemented with Dall sheep (*Ovis dalli*), porcupine (*Erethizon dorsatum*), marmot (*Marmota broweri*), arctic ground squirrels (*Urocitellus parryii*), ptarmigan, ducks, geese, and freshwater fish (W. N. Irving, 1964; Odess, 2003; Tremayne, 2011). The people of the Denbigh Flint Complex were therefore likely skilled marine and terrestrial hunters.

2.3.2 Pre-Dorset

By 4400 BP, Arctic Small Tool tradition (ASTt) groups were present in the Canadian Arctic (Cox, 2003). Pre-Dorset is the designation given to ASTt groups generally located in Low Arctic Canada, from the Mackenzie Delta to Baffin Island (McGhee, 1978). Pre-Dorset sites have also been found on Ellesmere Island (Schledermann, 1978b, 1990). Pre-Dorset subsistence strategies are variable. Although seals appear to be the most important food resource at many sites, the Pre-Dorset were also very adept at hunting caribou (*Rangifer tarandus*), migratory birds, fish, and other mammals (Bocherens et al., 2016; Gordon, 1996; LeBlanc, 1994; Maxwell, 1985; McAvoy, 2014; McCartney & Helmer, 1989a; Milne & Donnelly, 2004; Schledermann, 1990). Diet varied regionally, and Pre-Dorset sites have been identified at both coastal and inland locations (Darwent, 2001; Murray, 1999).

The faunal remains recovered from three sites in the Truelove Lowland on Devon Island, for example, show that the remains of small seals (most likely ringed seals (*Phoca hispida*)), bearded seal, and walrus make up 55 to 80% of the assemblages, while terrestrial mammals such as caribou and muskoxen account for 12 to 30% of the assemblages, and birds make up the rest of the assemblage, at 5% or less of the NISP (McCartney & Helmer, 1989). It is therefore argued that Pre-Dorset populations on Devon Island hunted terrestrial mammals mainly for raw materials such as hide, furs, antlers, and bone. Sea mammals instead, made up most of the food resources for the Devon Island Pre-Dorset. This may be a regional adaptation to sparse and clustered populations of terrestrial mammals on the islands of the Canadian Arctic Archipelago. Sea mammals were likely a more stable source of food (McCartney & Helmer, 1989).

In comparison, the Igloolik site located in the Foxe Basin shows that caribou played an even smaller role in the Pre-Dorset diet in this area. Ringed seals make up 80 to 90% of the faunal assemblage for Pre-Dorset occupations at the Igloolik site (Murray, 1996). The Pre-Dorset occupation at Igloolik was likely seasonal due to the presence of ephemeral tent rings and a lack of storage features (Murray, 1996). This does, however, demonstrate that Pre-Dorset subsistence practices varied regionally and the importance of marine versus terrestrial resources to Pre-Dorset groups was dependent on season and availability of resources.

Pre-Dorset populations also took advantage of seasonal migrations of birds during their harvest of resources. The Mosquito Ridge site, located on southern Baffin Island, yields a high number of geese remains (85% of the NISP) in conjunction with a large amount of lithic debitage and stone tools (Milne & Donnelly, 2004). This site was also occupied multiple times. The Pre-Dorset in this area were therefore likely taking advantage of the annual spring migration of geese, while also acquiring lithic raw material from the area (Milne & Donnelly, 2004). This procurement of *specific* resources, geese and lithic raw materials, from a known location is also consistent with Binford's (1980) description of a collector subsistence-settlement system. Given the widespread distribution of Pre-Dorset populations, there is evident regional variation in subsistence strategies amongst the Pre-Dorset compared to other Arctic Small Tool tradition groups.

2.3.3 Independence I

The High Arctic variant of the Arctic Small Tool tradition (ASTt), referred to as the Independence I culture, has also been dated to approximately 4350 BP. The High Arctic includes the islands of the Eastern Canadian Arctic near the Nares Strait region, extending to Peary Land in northeast Greenland. Unfortunately, preservation of organic remains at many Independence I sites in the Canadian Arctic is poor, and often lack faunal remains for dietary reconstruction. Independence I sites in Arctic Canada are, however, usually located near polynyas, which may suggest marine-based subsistence strategies (Helmer, 1991; McGhee, 1979; Schledermann, 1990). Where faunal remains are preserved, ringed seals appear to be the most important to

Independence I groups in Canada, and bearded seal, walrus, polar bear, and seabirds were also incorporated into the diet (McGhee, 1979).

Independence I sites at Pearylandville and Deltaterrasserne in Greenland are luckily better preserved than most. Independence I groups in Greenland were more specialized terrestrial hunters compared to Independence I groups located in Canada. Muskox remains are the most abundant in Peary Land, with remains from arctic hare, fox, ptarmigan, and brant geese making up the rest of the assemblage (Darwent, 2003).

2.3.4 Saqqaq

Saqqaq is the designation given to the Greenlandic variant of the Arctic Small Tool tradition (ASTt). First described by Jørgen Meldgaard (1952), the Saqqaq were the first human group to occupy western Greenland in 4350 BP (Larsen & Meldgaard, 1958; M. Meldgaard, 2004). Like the Pre-Dorset, the Saqqaq exploited all available food resources, and they had a toolkit to match. Both toggling and tanged harpoon heads were used to hunt sea mammals, along with lances, and possibly sealing nets of baleen (Grønnow, 1997; M. Meldgaard, 2004). Fragments of a wooden kayak-like frame have also been recovered from Qeqertasussuk, suggesting that marine game may have also been hunted from a kayak-like vessel on open water (Grønnow, 1994; M. Meldgaard, 2004). Bird spears, fishing spears, bow and arrow, and baleen line snares were also used by the Saqqaq to obtain a range of resources, including birds, fish, caribou, and small mammals (Grønnow, 1994; M. Meldgaard, 2004).

Faunal assemblages from two Saqqaq sites, both on the west coast of Greenland, have been analyzed extensively: the Qeqertasussuk site in Disko Bay and the Nipisat site. 50% of the faunal remains recovered from the Qeqertasussuk site, located in Disko Bay, consisted of seal bones, with the dominant species being harp seal (*Pagophilus groenlandicus*) (Grønnow, 1994; M. Meldgaard, 2004). Bird bones represent the other 39% of the faunal assemblage, followed by other marine and terrestrial mammals, fish, and mollusks (Grønnow, 1994; M. Meldgaard, 2004). A temporal analysis of the faunal remains recovered from Qeqertasussuk shows that reliance on mammals versus birds fluctuates through time and the importance in harp seal (*Pagophilus groenlandicus*) increases between 2400 BC and 1700 BC (M. Meldgaard, 2004). Seals were mainly hunted during the winter and spring, using toggling harpoons, and throwing harpoons from boats, and nets (M. Meldgaard, 2004). Birds were hunted from spring through late fall, with numerous species, including gulls, ducks, geese, and fulmars, being recovered from Saqqaq sites at Disko Bay (Andreasen, 1998; M. Meldgaard, 2004).

A somewhat different assemblage is seen at the Nipisat site, located to the southeast of Qeqertasussuk. Mammals, including seals, caribou, and small amounts of porpoise, whale, walrus, arctic fox, and arctic hare, make up 51.2% of the total faunal assemblage at Nipisat. Birds, including various species of ducks, geese, gulls, auks, fulmars, and shearwaters, make up 46.4% of the total assemblage. Finally, fish, including cod and arctic char, make up 2% of the total faunal assemblage (Gotfredsen & Møbjerg, 2004). Caribou remains constitute approximately 50% of the mammal assemblage, and were the most important animal to the population at Nipisat, according to meat yield (Gotfredsen & Møbjerg, 2004). Adult caribou were preferred at Nipisat and hunting likely took place during the late summer and fall. Seals make up 42% of the mammal assemblage, with the common seal and the harp seal (*Pagophilus groenlandicus*) being the most important species. Unlike at Qeqertasussuk however, seals at the Nipisat site, based on the age distribution and elements present, were hunted during the summer and fall, with young seals being the main target (Gotfredsen & Møbjerg, 2004). Gulls and eiders were the most important birds to the economy at Nipisat, and they were hunted during the spring and summer, using bird darts, gull hooks, snares, or simply taken by hand in the case of unfledged young. Eggs were likely also collected (Gotfredsen & Møbjerg, 2004). The Saqqaq of Qeqertasussuk and Nipisat, therefore, had different seasonal rounds and exploited marine and terrestrial animals in different quantities although they were both located on the coastal islands of west Greenland. This regional variation in subsistence strategies is similar to the pattern seen amongst Pre-Dorset groups.

2.3.5 Dorset

First identified by Diamond Jenness in 1925, the Dorset culture was present in the Canadian Arctic from 2600 BP and until 820 BP in limited areas such as the Iqaluktuuq region of southeastern Victoria Island (Friesen, 2004; Helmer, 1991). Dorset sites have been identified across most of the Canadian Arctic and into west Greenland, Peary Land, and northeast Greenland (Jensen, 2006; McGhee, 1978). Dorset culture is often separated into three time periods: the early, middle, and late or terminal Dorset (Maxwell, 1985). Dorset groups are considered Paleo-Inuit groups but are not a part of the Arctic Small Tool tradition. There is a consensus in the archaeological community that the Dorset culture is related to and emerged from the Pre-Dorset culture; however, there is debate regarding why there was a cultural shift, the timing, the geographical extent, and the relationship between the Dorset culture and other Arctic Small Tool tradition groups (Taylor, 1959, 1968). Two models have been proposed to address this “Dorset Problem”: the Core Area model and the Regional Centers or Mini Cores model (Helmer, 1991; Maxwell, 1976; Taylor, 1959, 1968).

The Core Area model, developed in the mid-1970s, posits that there is cultural and biological continuity between Pre-Dorset and Dorset groups in the core area of the Foxe Basin, northern Hudson Bay, Hudson Strait, and Baffin Island regions throughout time. During warmer climatic periods, the Pre-Dorset population would push out into more marginal areas, and during colder climatic periods the population would contract back to the core area. Over time, regional adaptations would be brought back to the core area, leading to an eventual cultural change from Pre-Dorset to Dorset (Maxwell, 1976). This model places the environment as the driver for cultural change, and this eventually led to some criticism regarding the lack of agency attributed to Paleo-Inuit groups. Increased excavation and research also revealed that there was cultural continuity in so-called marginal or fringe areas such as Labrador and Ellesmere Island, and fluctuations in population in the Foxe Basin core area (Bielawski, 1988; Cox, 1978; Helmer, 1991; Savelle & Dyke, 2014; Schledermann, 1978a, 1978b, 1990).

Due to the criticisms and inconsistencies leveled at the Core Area model, the Regional Centers or Mini Cores model was developed to better accommodate the changing archaeological data (Helmer, 1991). The Mini Cores model posits that there is a continuous exchange of ideas, traits, and populations between the regional centers of the central, eastern, and High Arctic, including Labrador, Ellesmere Island, and the previous core area of the Foxe Basin, northern Hudson Bay, Hudson Strait, and Baffin Island region. Some of the regional centers also have interactions with Independence I and Saqqaq groups that may lead to unique adaptations and traits (Cox, 1978; Schledermann, 1990). This continuous exchange of ideas across diverse regions eventually led to the transition from Pre-Dorset to Dorset.

During the shift from Pre-Dorset to Dorset, there is a shift in subsistence strategies from the land-sea approach of the Pre-Dorset to one more reliant on marine foods. This subsistence shift is reflected in settlement pattern, faunal assemblages, and the toolkit of the Dorset. Dorset harpoon heads come in two different sizes to exploit both smaller marine mammals such as seals, and larger marine mammals such as walrus, narwhal, and beluga (Taylor, 1968). Walrus bone is also present in many early Dorset middens, which is a significant shift away from earlier Paleo-Inuit assemblages (Maxwell, 1976; Murray, 1999; Taylor, 1968). Their ice-adapted technologies such as the ice crampons, sled runners, and snow knives show that they were successful at navigating and hunting on the sea ice and may have hunted seals directly from their breathing holes (Spiess, 1978).

Polynyas, such as the North Water located between Ellesmere Island and Greenland, continued to be important seasonal locations from the Arctic Small Tool tradition through to Late Dorset times. Archaeological sites along the coast of both Ellesmere Island and Greenland adjacent to the Smith Sound were occupied by Paleo-Inuit groups for up to 2000 years. Notable, however, is a hiatus in site occupation on the east coast of Ellesmere Island adjacent to the North Water between the Early Dorset and the Late Dorset (between approximately 500 B.C. and A.D. 700) (Schledermann, 1990). Re-occupation of the Knud Peninsula by the Late Dorset coincides with a warming period known as the Medieval Warm period (Dahl-Jensen et al., 1998; Darwent, 2004). The importance of polynyas to the seasonal round of Dorset groups also further emphasizes the increasing reliance on marine resources such as walrus, seals, and waterfowl (Gotfredsen, Appelt, & Hastrup, 2018; Schledermann, 1990).

Even with the intensification of marine hunting amongst Dorset groups, they possessed the tools and implements necessary to hunt terrestrial mammals, birds, and fish and would also settle at inland areas (Milne, Park, & Stenton, 2012). They are not believed to have used the bow and arrow. However, caribou and muskox could be hunted with thrusting harpoons and lances (McGhee, 1978). There is also some indication that the Dorset may have exploited more fish and birds through time at certain sites. For example, the Dorset were found to increase their hunting of birds and fishing compared to the hunting of harp seal (*Pagophilus groenlandicus*) at the site of Phillip's Garden in Newfoundland. The percentage of harp seal from the Dorset assemblages at Phillip's Garden goes from 96.1% of the NISP, in the earlier assemblages, to 70.8% in the later assemblage, meanwhile, the percentage of fish and birds increases (Hodgetts et al., 2003). This subsistence shift may coincide with a period of local climatic warming due to atmospheric circulation patterns (Hodgetts et al., 2003).

Late Dorset groups also display a variety of subsistence strategies that differ from earlier Arctic Small Tool traditions and the Early and Middle Dorset. Though the strategies differ somewhat according to their location, the Late Dorset appear to undergo intensification in hunting pursuits. At the site of Iqaluktuuq, Victoria Island, the Late Dorset increased their hunting of arctic char and caribou, the two principal animals available in the area. The greater number of char and caribou recovered from Late Dorset middens at Iqaluktuuq also coincides with an increase in settlement density during the twelfth century A.D. (Friesen, 2009). At the site of Cape Grinnell in northwest Greenland, the Late Dorset appeared to broaden their subsistence base, with greater proportions of birds, fish, foxes, hares, walrus, caribou, and muskox in their diet compared to later Thule groups at the site who incorporated more seal into their diet. Resource use intensification amongst Late Dorset groups has been attributed to a variety of causes including climate change and the arrival of the Thule in the eastern Canadian Arctic and Greenland (Friesen, 2004; Maxwell, 1985; Park, 1993).

2.3.6 Dorset-Thule Transition

One of the longest-standing topics of debate amongst Arctic archaeologists is the eventual disappearance of Dorset populations across the Arctic, and their replacement by the group ancestral to modern-day Inuit, the Thule. Genetic evidence from the Canadian Arctic and Greenland indicate that the Dorset were completely replaced by Thule groups and the mtDNA data from the two groups show no genetic admixture (Raghavan et al., 2014). Two main arguments are typically posited by archaeologists for the demise of the Dorset: pressure from foreign groups such as the Thule, and population collapse due to environmental and ecological conditions. Regarding the first theory, researchers have posited that the Thule, with their sophisticated technology, including such things as drag floats, allowed them to hunt larger sea mammals such as the bowhead whale (*Balaena mysticetus*), likely out-competed the Dorset (Maxwell, 1984). This argument rests on evidence that the two populations had contact with each other in the eastern Arctic. Radiocarbon dates for Dorset and Thule sites however, do not definitively place them in similar regions at the same time, as more recent considerations of radiocarbon dates in the Arctic place the Thule migration into the eastern Arctic during the thirteenth century, which is two centuries later than previously thought (Friesen & Arnold, 2008; McGhee, 2009). Thule groups also often preferred to utilize sites previously occupied by the Dorset and perhaps even salvaged Dorset artifacts such as harpoons; therefore, artifact assemblages that contain artifacts diagnostic of both Dorset and Thule groups also do not provide irrefutable evidence of cultural contact (Park, 1993, 2000).

The second theory posits that Dorset groups suffered from catastrophic population collapse prior to the arrival of the Thule in the eastern Arctic. The reason for the collapse is not clear in the archaeological record; however, some archaeologists suggest climatic changes that would have negatively impacted the seasonal availability of key species to Dorset subsistence strategies, such as the harp seal (*Pagophilus groenlandicus*) (Bell & Renouf, 2008; Tuck & Pastore, 1985). The disruption in the availability of prey species may have resulted in the abandonment of sites, such as the Phillip's Garden site in Newfoundland, that were important to Dorset social networks (Bell & Renouf, 2008). Dorset populations were likely small and could not recover once social networks were disrupted, resulting in eventual population collapse. The debate regarding Dorset-Thule succession in the eastern Arctic remains polarizing, although advances such as mtDNA analysis may provide a better picture in the future.

2.3.7 Summary

The subsistence strategies of Arctic Small Tool tradition (ASTt) groups appear to be a balance between marine and terrestrial food resources. They likely started out as skilled marine hunters that would also incorporate terrestrial resources seasonally as they moved from Alaska into the eastern Arctic based on the limited data from Denbigh Flint Complex and Independence I groups. With migration into different parts of Arctic Canada and Greenland, ASTt populations continued to increase their hunting of marine mammals, which is evident in the assemblages recovered from Pre-Dorset and Saqqaq sites. Marine mammals may have provided a more stable food resource compared to terrestrial mammals, whose distribution could vary and fluctuate in areas like the High Arctic. Regional and seasonal variation in subsistence strategies of course still existed between groups; however, there is a clear shift to a priority for marine mammals by the time of the Dorset culture.

Unfortunately, the archaeological record for subsistence strategies amongst Paleo-Inuit groups is sparse for many parts of the Arctic and is often reliant on lithic toolkits and site location instead of faunal remains. Many Denbigh Flint Complex and Independence I sites lack well-preserved faunal remains, and the degree in which faunal remains have been studied for Pre-Dorset, Saqqaq, and Dorset sites varies between researchers and archaeological projects. Continued research and different techniques such as stable isotope analysis will hopefully uncover more information regarding the varying subsistence strategies of Paleo-Inuit groups.

Chapter Three: Bird Use amongst High-Latitude Hunter-Gatherers

Birds and their eggs were essential resources for past hunter-gatherers, from supplemental sources of food to significant symbolic figures, and their exploitation can be traced back through time and across the globe. Many hunter-gatherer groups actively monitored seasonal movements of birds, both as a source of food and as seasonal and environmental markers. This chapter explores how birds were used by past hunter-gatherer groups, with a focus on northern groups, including their symbolic importance. There is a focus on northern hunter-gatherers because the Arctic was and is a popular summer breeding location for many different species of migratory birds and northern groups are the focal point of this dissertation. Both ethnographic and archaeological evidence are included to provide a comprehensive picture of bird use amongst hunter-gatherers.

3.1 Ethnographic Evidence

3.1.1 Diet

3.1.1.1 Meat

The most important role that birds played amongst hunter-gatherers was as a source of food. Birds and their eggs can be essential sources of protein and fats, especially during periods when larger animals are not yet present (Uspenskii, 1984). Ethnographic accounts of various Arctic hunter-gatherer groups have indicated that migratory birds arrive in the Arctic during spring, which can be a very tumultuous period. Spring is often a time of food shortage, as food stores for the winter have been depleted, and larger mammals have not yet moved into primary hunting locations (R. K. Nelson, 1969). The massive influx of migratory birds during this period is therefore crucial in replenishing food stores, and for providing a fresh and varied source of protein and fat. Birds are also exceptionally easy to hunt during their molting period in the spring and summer, where they lose many of their flight feathers and are therefore unable to fly.

The importance of mass harvesting migratory bird species is exemplified by hunter-gatherer groups that continued to harvest birds even after the introduction of sophisticated hunting technology such as firearms that allow them to hunt larger animals. The High Arctic Inughuit in Canada and Greenland, for example, continued to hunt dovekies or little auks (*Alle alle)* using traditional methods even after the re-introduction of the bow and arrow and eventually firearms (Johansen, 2013). The hunting of dovekies by the Inughuit was originally assumed to be a response to the loss of sophisticated hunting technology such as the bow and arrow and fishing leisters (Holtved, 1967). These previous assumptions, however, did not account for the fact that up to millions of pairs of dovekie arrive in the Thule district of Greenland to breed every summer and hundreds could be caught at a time with traditional hunting nets (Johansen, 2013). Ethnographers have observed that the Inughuit continued to hunt small migratory birds with nets even when they had access to firearms. These birds could then be eaten right away or stored in sealskin bags and fermented for several months (Holtved, 1967; Vaughan, 1991, 1992). Birds were fermented whole in sealskin bags and were easily plucked and skinned after the fermenting process and eaten without any further preparation. The millions of dovekies and their eggs were, therefore, a reliable source of food for the Inughuit over the summer months into the fall and winter if stored properly and continued to be a favoured hunting adaptation even after the re-introduction of other hunting technologies into these groups.

The nutritional quality and variety that birds may provide to hunter-gatherers should also be considered. A proper balance of macronutrients, fat, protein, and carbohydrates, is necessary for survival and reproduction. Many migratory birds are available in the Arctic during the spring and summer, for example, ducks, geese, and gulls, and they can be very fatty just before egg-laying begins. Duck meat is comparable to seals, caribou (*Rangifer tarandus*), and muskoxen (*Ovibos moschatus*) in terms of protein and fat content (Kuhnlein et al., 2002).

Bird meat, organs, and eggs also contain essential nutrients such as calcium, iron, zinc, vitamin C, vitamin B_{12}, folate, thiamin, and riboflavin (Hockett, 2007; Kuhnlein et al., 2002). These essential nutrients, coupled with the fatty meat available from birds have been posited as a contributing component in increased fertility amongst some hunter-gatherer groups (Hockett, 2007). Hockett (2007) argues that a diversified diet, that includes smaller animals such as birds and rabbits, better provides the macro and micronutrients that are necessary for reproduction and healthy development of a fetus compared to a diet that relies on just a limited number of large mammals. Dietary diversity may provide adequate nutrient intake for growth and reproduction as the likelihood that all essential nutrients are included in the diet increases with the inclusion of different food items (Arimond & Ruel, 2004; Ruel, 2003).

Hunting birds and egg collection could also be undertaken by all members of the community, in contrast to larger mammals that required hunting groups consisting mainly of men. The collection of eggs and hunting of small game serves to reinforce social roles within the hunter-gatherer community and provides children with a way to contribute to food acquisition. Jenness (1922, p. 105) for example, describes the Copper Inuit children as the only individuals who will collect the eggs of geese, ducks, and loons during the spring. Bird hunting may also be an opportunity for young hunters, especially boys, to practice hunting in a low-risk situation. Nelson (1969, p. 159) describes, for example, that Alaskan men, women, and children carried bolas with them during the seasonal waterfowl migration. Nelson (1969, p. 98) also describes the young boys of Wainwright hunting ptarmigan flocks with light rifles. Amongst the Koyukon, women were mainly in charge of obtaining small game and making and maintaining snares for animals such as ducks and geese (R. K. Nelson, Mautner, & Bane, 1982). Small game provisions provided by women during the spring was especially important for the camp, as this was traditionally the time of food shortages (R. K. Nelson et al., 1982).

Hunting large animals was also riskier and yielded less success than often assumed. Sea mammal hunting in the Arctic, for example, often requires more than one hunter and ideal environmental conditions. Hunting seals on the sea ice can be particularly precarious for the hunter since the safety of the hunter is reliant on his knowledge and accurate assessment of sea ice conditions (Gearheard et al., 2013; R. K. Nelson, 1969). Hunting smaller animals such as birds may, therefore, be a safer and more reliable food source for hunter-gatherer groups.

Hunter-gatherer groups have devised various methods to hunt and catch birds to increase their food yield. Arrows, bolas, and bird darts were utilized by the Inuit, Yupik, Inupiat, and Beothuk to hunt birds out of the air (Howley, 1915; R. K. Nelson, 1969; R. K. Nelson et al., 1982). Bolas and bird darts were especially favoured because they stun the bird and prevent it from flying for easy capture without damaging the bird’s skin. The skin could then be used to make clothing and items such as bags. Bolas were constructed by wrapping rope or sinew around pieces of ivory or stone. Once thrown at a bird, the stones or ivory balls would wrap around the bird upon contact and bring the bird to the ground (R. K. Nelson, 1980). In more recent times, guns have become a popular choice for hunting birds (R. K. Nelson, 1969, p. 154).

Ethnographic accounts of bird hunting have also described the use of snares and nooses. Bird snaring has been documented for the Copper Inuit, Alaskan Natives, and the Inughuit (Holtved, 1967; Jenness, 1922; Ostermann, 1952; Sabo, 1991). Snares were typically placed in areas of high bird traffic, such as along the coastline or around nests, and would trap the birds' feet as they walked past (Holtved, 1967, p. 113; Ostermann, 1952). Snares could also be used to loop around the birds' necks as they were feeding (Ostermann, 1952, p. 115). Snares were often made of materials such as sinew or baleen (Ostermann, 1952, p. 115).

Nets were often used to collect large groups of flying birds by numerous hunter-gatherer groups such as the Inughuit, the Yupik, the Lummi, the Salish, the Tlingit, the Cup'ig, and the Nunivak Islanders (Barnett, 1955; Brandt, 1943; Hoffman, 1990; Oberg, 1973; Stern, 1934). Nets could be used with large accumulations of migratory birds and simply held up by hunters to catch birds flying by, or with sophisticated drives where birds were directed towards waiting nets. The former situation is seen with the Inughuit, where two hunters would set up a net to catch the thousands of dovekies flying by in the Thule district (Holtved, 1967). The Hooper Bay Inuit practiced a system of nets and bird drives (Brandt, 1943). Nets could also be placed over ditches that were known to be feeding grounds for birds and lowered on either end once the birds were under the net (Oberg, 1973). Bird nets were constructed from materials such as baleen and sinew and in more recent times twine and rope (Hoffman, 1990).

Hunter-gatherers have also devised clever traps and strategies to catch birds. Bird pounds, stone enclosures, decoys, bird calls, and traps have all been described in the ethnographic literature (Brandt, 1943; Nappaaluk, Frost, Saladin d'Anglure, Nappaaluk, & Avataq Cultural

Institute, 2014). In one ingenious example amongst the Lummi and the Salish of the Northwest Coast, fishing weirs were used primarily for catching fish, but the hunting groups would also wait until birds were attracted to the trapped fish and obtain them both (Monks, 1987). Birds were also trapped with nets, snared, or speared as they were eating herring trapped in tidal traps on the beach (Barnett, 1955; Stern, 1934, p. 41). A similar situation has been described for the Haida and Tlingit of the Forrester Islands in Southeast Alaska, where puffins, attracted to the fishing bait and the salmon around the islands, were easily caught by fishermen (Moss, 2007).

3.1.1.2 Eggs

Eggs of local breeding bird populations provided another easily accessed food resource. Eggs are rich in protein and calories and are easy to obtain. Amongst the Inughuit, egg collection begins in June, and the eggs of all migratory bird species including geese, ptarmigan, and ducks were taken (McEachern, 1978). Thousands of eggs were collected from numerous species, and hunters would average approximately 70-79 eggs each (McEachern, 1978). Egg collection has also been described for the Beothuk, where they would obtain canoes full of eggs from Funk Island. The Beothuk would make an annual trip to Funk Island for the sole purpose of collecting eggs (Howley, 1915, p. 48). Many hunter-gatherer groups in the Arctic and North America, such as the Tlingit, the Inuit, and the Inupiat also practice egg collection, especially during the summer months (Jenness, 1922; D. R. Klein, 1966; R. K. Nelson, 1969; R. K. Nelson et al., 1982; Oberg, 1973).

Eggs can also be stored and preserved. In the Arctic, eggs were frozen for later consumption (Ekblaw, 1919). Eggs were also boiled, or egg yolks could be dried and stored in seal intestines, similar to the preservation method for dovekies amongst the Polar Inughuit (Holtved, 1967). The drying and powdering of eggs was also practiced by the Beothuk and historical hunter-gatherers of Newfoundland (Kristensen, 2011). Eggs were boiled until the yolks were very hard, dried in the sun, and then could be easily powdered, and the Beothuk would add the powdered egg to broths and other meat dishes (Howley, 1915, p. 246). The Beothuk were also known to bake “egg cakes” in the sun or put eggs in a pudding along with seal fat and liver, and this pudding was eaten during times of scarcity (Howley, 1915, pp. 33–34).

3.1.2 Other Uses

In addition to their dietary importance, birds also provided raw materials, such as bones for tools, feathers for decorative use, and skin for clothing. These resources, together with the dietary resources discussed previously, increased the value of birds to hunter-gatherers. Bird skin is often not considered a resource for making clothing compared to the hide from large mammals; however, numerous Arctic groups use bird skin as a valuable waterproof material for clothing. The skins of geese and ducks were typically preferred by Arctic groups to produce parkas. Amongst the Ungava Inuit of the Belcher Islands, eider duck skin was used to fashion parkas for the entire family and smaller items such as footwear or accessories (Oakes, 1990). Even the skins from smaller birds, such as dovekies, would be used for clothing. The Inughuit, for example, would use dovekie skins to make inner coats. Dovekie skins were also used as washcloths (Holtved, 1967). The Nunivak Islanders would also produce parkas from the skins of murres and puffins (Hoffman, 1990; Pratt, 1990).

Household items could be fashioned out of bird bones, feathers, skins, beaks, and wings. Bird bones could be made into needles, needle cases, whistles or bird calls, beads, and decorative items. The hollow long bones of birds made them easy to work into needles, needle cases, whistles, and beads. Feathers of birds were used for various purposes including arrow fletching, decoration, down fill, bandages, cleaning, and even a type of chewing gum. The Ungava Inuit utilized eider duck wings to fashion brooms, and their down was used to make bandages or chewing gum when mixed with blood and fat (Oakes, 1990). Goshawk feathers were used to fletch the arrows of the Noatak Inupiat (Hall, 1969).

The use of bird beaks and wings has also been documented in the ethnographic literature. Bird beaks and feet were used by the Nunivak Islanders as decorative elements for clothing (Hoffman, 1990). Bird wings were used as small brooms for cleaning out the home or even as ceremonial items. The feet of eider ducks were also used by the Ungava Inuit as small water containers for short trips (Oakes, 1990).

3.1.3 Environmental Monitoring

Since many birds are migratory, their movement patterns and presence at sites could signal seasonal changes to hunter-gatherer groups. The arrival of migratory birds in the Arctic in the spring was often a time of excitement and hope for hunter-gatherers (R. K. Nelson, 1969, 1980, 1983). Like other important animals to Arctic hunter-gatherers, birds are highly observed by human groups, and bird movement patterns can indicate things such as wind direction and conditions on the water. Many northern groups also have names for all the bird species that migrate to or fly by their sites and can even duplicate their bird calls (L. Irving, 1958). This extensive naming of birds indicates that northern hunter-gatherer groups meticulously observe and keep track of the birds in their area.

Comparing the ethnographic record through time can provide researchers with indications regarding climate change and resulting changes to bird populations. In her work regarding climate change and Indigenous knowledge, Fox (2002), found that many elders that she spoke to from Baker Lake, Nunavut indicated that the migratory bird populations that used to be abundant at known areas in the past, are present in fewer numbers or do not travel to those locations altogether. They also note that many of the migratory birds that still fly to the area are smaller and that species that were never seen in the past, such as the robin, are now being spotted. Similar observations have also been recorded at Nain, Banks Island, and Sachs Harbour (Furgal, Martin, & Gosselin, 2002; Jolly et al., 2002). From this detailed ecological knowledge that is passed on through generations, researchers can track bird species through time in the Arctic and identify the impact of climate change on migratory bird populations.

Evidence of past hunter-gatherer groups monitoring movement patterns of birds is also found in recent databases that document place names. For example, the Inuit Heritage Trust has compiled place name data for numerous locations in Nunavut that are now all searchable on Google Maps. Place name data is also available for the community of Arviat, Nunavut on the Arctic IQ website (Arviat Archaeology and Oral History Project, 2012). Named places are areas of significance that have been identified by elders and individuals from Indigenous groups that relate to hunting localities, geographical markers, areas of historical significance, and areas that have been mentioned in old stories and myths. The use of place names highlights the close connection between Arctic hunter-gatherers and their environment (Lyons et al., 2010). Using place names, we can locate key breeding sites of birds such as eider ducks, geese, and kittiwakes that were known to local Inuit groups and were utilized for egg harvesting and hunting (Inuit Heritage Trust Place Names Program, 2016).

3.1.4 Symbolic Importance

Many hunter-gatherer groups, especially in Arctic and sub-Arctic regions, practiced some form of shamanism, animism, or totemism. Central to these belief systems is a complex and intimate relationship between people, their environment, and the animals in that environment. Shamans have a Siberian origin. However, this worldview that includes a very close connection between humans, animals, and their environment is seen in similar forms across many hunter-gatherer societies (Balzer, 1996; Peoples, Duda, & Marlowe, 2016; Stutley, 2002). The term shamanism has therefore been applied to the religious practices of most hunter-gatherer groups. Shamanic ritual is mainly curative; however, environmental and ecological information can be passed on through shamanic practice (Balzer, 1996; Ostermann, 1952, p. 130). Shamans can convey hunting locales, safe camping sites, and productive travel routes after performing spirit travel.

Hunter-gatherer groups that practice shamanism often view the world as having multiple realms. Most groups typically have three divisions, the upper world, the world where humans live, and the underworld, although there may be further subdivisions depending on the culture. Due to the birds' ability to fly, hunter-gatherer groups often viewed them as important animals that could travel between these worlds and they were often seen as shamanic guides and helpers. Waterfowl, especially, were seen as special creatures that could move between all three realms because of their ability to fly and their ability to swim. (Kristensen & Holly, 2013; Mannermaa, 2008a, 2008b; Morrow & Volkman, 1975). The upper world is typically associated with the sky, while the underworld is often associated with water. Amongst numerous Siberian hunter-gatherer groups, such as the Sakha and the Evenki, shamans often invoked bird spirit guides during shamanic séances to help them travel to the upper and lower worlds (Balzer, 1996). Shamans would also gain the qualities of their bird spirit guide during séances, for example, if their spirit guide is an eagle, they would gain the extraordinary eyesight and endurance often associated with eagles (Balzer, 1996).

An essential part of hunter-gatherer society is story-telling. Myths and stories are often passed down through generations, and they can convey information such as religious beliefs, morals, landmarks, and environmental and ecological information. Birds are often featured within hunter-gatherer myth and shamanic narrative from Siberia to many groups in North America (Balzer, 1996; Morrow & Volkman, 1975). Myths and shamanic narratives contain a variety of bird species including ravens, eagles, loons, hawks, cranes, swans, wood grouse, larks, cuckoos, and sandpipers (Balzer, 1996).

3.2 Archaeological Evidence

3.2.1 Diet

3.2.1.1 Meat

Archaeologists must rely on items that are preserved in the archaeological record to make inferences about bird hunting and bird collection in the past, and they can use ethnographic sources to understand what the artifacts are and the pattern of behaviour that may have created this record. Therefore, compared to ethnographic evidence, the hunting of birds and the collection of their eggs is less visible in archaeological research. The International Council for Archaeozoology (ICAZ) Bird Working Group deserves a special mention, however, for the expertise that they have devoted to studying bird remains in archaeological contexts. The ICAZ Bird Working Group was initiated by Arturo Morales-Muniz, a Spanish zoologist, in 1991, and now includes archeologists, zooarchaeologists, zoologists, and ornithologists from across the world.

Faunal remains provide the principal evidence for bird exploitation by past hunter-gatherers. Similar to the analysis of mammal remains, bird bone distribution, abundance, element representation, cut marks, breakage patterns, and burn marks can provide the archaeologist with valuable information regarding bird hunting and processing patterns. Birds most often recovered from Arctic archaeological sites are ducks, geese, and auks (Casperson, 2012; Gotfredsen, 1997; Gotfredsen & Møbjerg, 2004; Kristensen & Curtis, 2012; M. Meldgaard, 2004; Milne & Donnelly, 2004). These birds are some of the largest migratory species available in the Arctic, and they all provide fatty meat that was likely desirable to Arctic hunter-gatherers.

An emerging pattern seen in the archaeological record of northern hunter-gatherers is the exploitation of birds at key breeding sites during the summer along with lithic tool manufacture. Faunal assemblages dominated by bird remains and in association with significant accumulations of stone tools and lithic debitage have been recovered at sites in Newfoundland and southern Baffin Island for two distinct hunter-gatherer groups, the Cow Head and Early and Late Recent Indian people on Newfoundland and the Pre-Dorset on Baffin Island (Kristensen & Curtis, 2012; Milne & Donnelly, 2004). These sites do not contain identifiable structures and were likely occupied seasonally during the summer or early fall. Multiple features such as hearths and accumulations of fire-cracked rock suggest that these sites were repeatedly occupied over the years (Kristensen & Curtis, 2012). Small rings of cobble along with lithic debris and stone tools were also found on a cobble beach at the Newfoundland site that may have been used as bird-hunting blinds (Kristensen & Curtis, 2012). The combination of bird hunting and lithic manufacture was likely highly efficient for hunter-gatherers as they could maintain, repair, and produce stone tools as they were waiting at hunting blinds (Binford, 1978). With the Pre-Dorset of Baffin Island, the intersection between a nearby lithic source and a known breeding area for migratory birds was a valuable location during their seasonal movements (Milne & Donnelly, 2004). This archaeological evidence, therefore, supports the observations from ethnographic research that suggests northern hunter-gatherers incorporated the breeding sites of migratory birds into their seasonal round. These studies also demonstrate the value of an in-depth analysis of bird faunal remains.

In rare cases, the archaeological record can provide evidence of bird species that were hunted in the past but have become extinct. Remains of the great auk, for example, have been recovered at numerous sites bordering the North Atlantic, including Canada and Greenland, but are no longer present today (Montevecchi & Tuck, 1987). Numerous great auk bones have been recovered from burials associated with the Maritime Archaic culture in Newfoundland and Labrador. Great auk remains were also recovered at archaeological sites associated with the Dorset and Beothuk (Montevecchi & Tuck, 1987). The extinction of the great auk was likely due to the mass harvesting of both birds and eggs by Europeans. (Gaston & Jones, 1998; Howley, 1915).

In addition to zooarchaeological analysis, stable isotope analysis of faunal remains can also provide valuable information regarding hunter-gatherer subsistence strategies. Currently, there has been little focus on stable isotope analysis of bird bones from an archaeological context, though limited stable isotope values from bird remains have been incorporated into human dietary reconstructions. There have only been two studies that have focussed exclusively on stable isotope ratios of bird remains in an archaeological context (Giardina, Neme, & Gil, 2014; Grupe & Mekota, 2005), but many have included values from bird remains found in the archaeological site or recovered from comparable environments (i.e., Coltrain, Hayes, & O'Rourke, 2004; Hard & Katzenberg, 2011; Katzenberg, 1989; D. E. Nelson, Møhl, Heinemeier, & Arneborg, 2012; etc.). There is also extensive stable isotope analysis of birds in the ecological literature, but the focus is often on migratory patterns or dietary adaptations of living birds (Hobson, 1995, 2005; J. F. Kelly, 2000; Moody, Hobson, & Gaston, 2012). The ecological studies reveal, however, that there is extensive variation in bird stable isotope values due to variability in environmental conditions, dietary niches, migration, reproduction, and body condition (Cherel, Hobson, & Weimerskirch, 2000; Hobson, Alisauskas, & Clark, 1993; Hobson, Gilchrist, & Falk, 2002; Moody et al., 2012). A better understanding of bird isotopic values can provide valuable information for the reconstruction of past human dietary adaptations.

The presence of lithic artifacts can also indicate bird hunting. Though many implements such as nets and snares are only preserved in exceptional conditions, net weights, bird darts, bola balls, and stone points will remain in the archaeological record. Bird darts made of ivory, bola balls fashioned from animal ribs or ivory, and a needle used to pierce bird wings for transport were recovered by Rasmussen in the western Arctic during the Fifth Thule Expedition from 1921 to 1924, and these findings were summarized by Mathiassen in 1930. Snares made from baleen were also obtained by Rasmussen at Point Barrow (Mathiassen, 1930). The archaeological collections from the Western Arctic collected by Rasmussen mainly belong to Thule and Birnirk populations, and what Rasmussen and Mathiassen refer to as the later Western Eskimo culture, but who are now referred to as the Inuit. Gull hooks made of wood, bird dart prongs made of bone and ivory, and bola weights made of antler were also found at Thule sites in the North Bay region of southern Baffin Island (Sabo, 1991). Blunt arrowheads, weights, bola weights, and bird spear prongs have also been recovered in association with numerous remains from willow ptarmigan at the site of Kangiguksuk in Alaska (Hall, 1969).

3.2.1.2 Eggs

Eggshells have received even less attention within archaeological research. Lack of research may be due to the fact that egg shells are difficult to assign to species without the use of DNA analysis or peptide mass fingerprinting (Oskam et al., 2011; Stewart, 2013). Archaeological and museum collections therefore only go as far as separating eggshells from other remains and artifacts. Eggshells are also often recovered at archaeological sites in small fragments, and the best recovery method, according to Keepax (1981), is wet sieving, which is not practiced in many excavations. Eggshells recovered from middens or with evidence of burning are likely due to the consumption of eggs by humans. Unfortunately, eggshells have only been studied extensively in a few studies, and these studies are mainly focused on the identification of eggshells to the species level (i.e., Oskam et al., 2011, 2012; Stewart et al., 2014).

3.2.2 Other Uses

Archaeological evidence of birds being used for resources other than food is very limited and often relies on the assumption that if the bird was caught for food, parts that were not eaten would also be utilized. Certain artifacts that are preserved in the archaeological record such as bone needles, bone beads, and other bone implements support this assumption. Butchering patterns which leave their marks on bone may also provide clues about how birds were used in addition to subsistence. In exceptional preservation conditions, feathers are also preserved in the archaeological record (Dove, Hare, & Heacker, 2005).

Bird bone needles, awls, and needle cases have been identified in the archaeological collection of the Thule from southern Baffin Island. A cod jigging hook fashioned out of seal bone and attached small bird beaks was also described from the same group (Sabo, 1991). Needles made from bird bone have also been found at the Amaknak site in the Aleutian Islands (Serjeantson, 2009, p. 214).

Cut marks on specific areas of certain elements can indicate the processing of birds for resources other than food. Processing birds for their skin leaves characteristic cut marks on the skull and pelvis, for example (Lefèvre & Laroulandie, 2014). The removal of feathers has also been hypothesized based on cut marks on certain regions of bird long bones, specifically striae on the humerus, ulna, and carpometacarpus (wing bones) related to disarticulation and removal of the skin (Peresani, Fiore, Gala, Romandini, & Tagliacozzo, 2011).

An over-representation of certain bird bone elements at archaeological sites may also indicate that birds may have been processed for resources other than food. If birds are being hunted and used solely for subsistence, we might expect most skeletal elements to be present in equal numbers, or elements from areas with the greatest amount of meat to be present in higher numbers at archaeological sites (Gumiński, 2005). Cut marks on bones from meat-rich portions (i.e., coracoid and scapula of the pectoral area or the pelvis and femur) of the bird would also be expected (Peresani et al., 2011). Bird faunal remains would also be mainly found in middens or in and around cooking areas at the site. Differential preservation of elements may affect the proportions of elements present, but all elements would still be expected at an archaeological site if birds were being brought back whole for processing (Gumiński, 2005; Lefèvre & Laroulandie, 2014).

There may be a differential representation of elements if bones are being worked into tools or decorative items such as awls, needles, and beads, or if certain elements are being traded as raw materials. Lefèvre and Laroulandie (2014), for example, found that fewer radii and ulnae of several bird species were recovered from the hunter-gatherer-fisher site of Offing 2 in southern Chile (4200 – 2500 B.P.) compared to other bird elements. They propose that these elements were being traded as raw materials since these bones have been recovered in higher numbers at nearby sites and differential preservation cannot completely account for the missing bones.

3.2.3 Environmental Monitoring

Bird bones are a unique seasonality indicator in the archaeological record. Bird bones are hollow, except for the long bones of female birds during the breeding and laying period. Female birds will develop medullary bone within their long bones to serve as a calcium reserve for their eggs (Rick, 1975). For migratory birds in the Arctic, the presence of medullary bone in bird faunal remains indicates that they were hunted during the spring and summer, during the birds' typical breeding period. The drawback of this method to determine seasonality is that it relies on the medullary bone being exposed and is only useful if the medullary bone has been revealed through butchering and/or taphonomic processes.

The movement of birds may also be associated with the presence of specific tools or implements. The presence of lunate crescents at numerous North American Paleoindian archaeological sites, for example, has been linked to the major flyways of migratory birds. Chipped stone lunate crescents are often recovered from archaeological sites near ancient wetland areas across the Far West of the United States (Moss & Erlandson, 2013; Sanchez, Erlandson, & Tripcevich, 2016). The use of lunate crescents is unclear; however, several researchers have proposed that they were hafted transversely with the concave side facing outwards and were used to strike birds to immobilize them without damaging their skin and feathers. The natural reaction for a bird once struck is to become immobilized and fall to the ground. There is morphological variability amongst lunate crescents, which also suggests that they may have had multiple uses (Moss & Erlandson, 2013). A decrease in the use of lunate crescents amongst Paleoindians is also correlated with an expansion northward of available breeding grounds for migrating bird species such as geese. The extension northward was possible after the terminal Pleistocene with the melting of the Laurentide ice sheet at approximately 8000 BP (Moss & Erlandson, 2013). The presence of birds and the tools used to hunt them at a site can, therefore, lead to a further understanding of seasonality and broad patterns of climate change.

3.2.4 Symbolic Importance

Archaeological evidence of the spiritual importance of birds amongst human groups is mainly in the form of art and iconography. The artistic representations of birds preserved in the archaeological record include rock art and figurines or statues carved into materials like stone, bone, or antlers. Depictions of birds in rock art may go as far back as the Upper Paleolithic at Hoit-Tensker Agui cave in the Altai mountains of Mongolia and the Grotte Cosquer in Marseille, France (Eastham & Eastham, 1995; Okladnikov, 1972 in Kubarev & Zabelin, 2006).

Multiple studies have found however that some archaeological sites contain more bones from the wings of birds compared to other elements and that they are found in suspected ceremonial or burial contexts. Birds may be associated with burials because of the belief that birds could travel between worlds within the shamanic universe (Kristensen & Holly, 2013). Pendants fashioned from bird humeri and tubular bone beads made of bird ulnae and radii have been recovered from numerous Late Mesolithic and Early Neolithic burials in Sweden and Latvia (Mannermaa, 2008a). Wing bones (carpometacarpi and wing phalanges) of the Eurasian jay have also been recovered with three male burials at Zvejnieki, Latvia. The wing of the Eurasian jay is a deep blue colour, and the colour along with the wing itself may have held symbolic meaning to this hunter-gatherer group. The association of the wing bones with just three male burials also suggests that these individuals may have been seen as special or important within the community (Mannermaa, 2013).

Caribou bone pendants, depicting bird anatomy such as feathers and feet, have also been recovered from Beothuk settlements in Newfoundland, Canada. Caribou bone pendants are typically associated with burials. However, looting is a problem in this area, and archaeological context can be unclear (Kristensen & Holly, 2013). Burial sites for the Beothuk are often located on small coastal islands that also serve as rookeries for migrating birds. Settlement sites are not found on these small islands. The association of the bird rookeries and Beothuk burial sites further supports the connection between birds and burial of the dead amongst the Beothuk. Birds may serve as spiritual messengers that aid in the transformation between life and death amongst the Beothuk (Kristensen & Holly, 2013). A loon skull and numerous loon ivory carvings have also been recovered from Ipiutak burials on the northwest coast of Alaska. It has also been proposed that loons served as supernatural guardians or guides to the underworld amongst the Ipiutak (Morrow & Volkman, 1975).

3.3 Conclusion

The importance of birds and their eggs to the diet of hunter-gatherers is becoming increasingly evident, and they are ubiquitous in human diet through time. Ethnographic research on northern hunter-gatherers reveals that migratory birds were hunted using numerous methods, that their eggs were extensively collected and that these food items were crucial during periods of food scarcity. This is supported by archaeological evidence in the form of various preserved implements used to hunt birds, faunal remains, and artistic depictions. In addition to food, birds provided raw materials to produce bone tools, household goods, skins for clothing, and feathers for decorative elements. As such, the movement of birds was extensively tracked by northern populations, and they remain as seasonal indicators for modern Arctic people. Birds were also significant figures in the shamanic universe of many northern hunter-gatherer groups; they were thought to be able to travel through the different realms of the shamanic universe because of their ability to fly. Depictions of birds can be found in shamanic art, and the remains of birds are sometimes found associated with human burials. Together, ethnographic and archaeological research demonstrate the close connection between Arctic hunter-gatherers and birds and the multitude of roles that birds played in day-to-day life in the Arctic.

Chapter Four: The Use of Stable Isotope Analysis in Paleodietary Reconstructions of Arctic Hunter-Gatherers

The use of stable isotope analysis in paleodietary reconstructions has spanned nearly 40 years. Although well-established, developments in method and interpretation are still ongoing. Stable isotope analysis has been used to identify the introduction of maize agriculture to past populations, determine marine versus terrestrial diets, and discover dietary shifts, along with many other applications. With continued research, bioarcheologists are recognizing the variability and complexity not only in human diet but in the ecology of the food resources as well. Ecological research has helped bioarcheologists to understand the sources of variability that can affect dietary reconstructions and is, therefore, a valuable resource for future developments in stable isotope analysis of human paleodiet.

As this dissertation explores the contribution of avian resources to the diet of past populations using stable isotope analysis as a tool, this chapter will provide a summary of stable isotope analysis in paleodietary reconstruction and avian ecology, with a focus on stable isotopes of carbon and nitrogen.

4.1 What are stable isotopes?

Isotopes are atoms of an element that have the same number of electrons and protons but a different number of neutrons. Due to the different number of neutrons in the nucleus, isotopes of the same element have different atomic masses. For many elements, the lighter isotope form, for example, carbon-12, is much more abundant in nature compared to the heavier isotope, carbon-13. Stable isotopes, unlike radioactive isotopes, do not decay over time and therefore stable isotopes can serve as natural tracers of diet. Stable isotopes are passed from food items to the consumer, with metabolic processes associated with digestion and tissue synthesis causing fractionation.

4.2 Sources of Variation

4.2.1 Fractionation and Mixing

The differences in atomic mass between the different isotopes of an element lead to varying rates of chemical reaction. Lighter isotopes tend to react slightly faster than their heavier counterparts, and the heavier isotopes often form stronger bonds within molecules (Fry, 2006; Sulzman, 2007). Differences in reaction time and reactivity for chemical processes due to mass differences between isotopes are also known as isotope effects. Isotope effects lead to differential distributions of the lighter versus the heavier isotope in the source versus product compounds in chemical reactions (Sulzman, 2007). This is referred to as fractionation. Variation in stable isotope distributions across different plants and animals is further produced through the process of mixing, which is the incorporation of different sources of food and nutrients with varying stable isotope ratios into the tissues of the organism. Fractionation and mixing are therefore responsible for the variation we see in the distribution of stable isotopes within the environment (Fry, 2006).

4.2.2 Metabolic Processes and Tissue Turnover

Once food is consumed and digested, dietary macronutrients such as fat, protein, and carbohydrates, are differentially incorporated into the body tissues of the organism. With each physiological process or metabolic step, there is the potential for fractionation. These processes, therefore, lead to differences between the stable isotope values of the consumer versus the diet and between different tissues. These differences are often referred to as spacing values, enrichment values, or discrimination factors to reflect the numerous processes involved in isotopic routing from food items into body tissues (Martínez del Rio, Wolf, Carleton, & Gannes, 2009). This dissertation will mainly use spacing values when referring to diet-to-tissue and tissue-to-tissue differences in isotopic ratios.

A series of controlled feeding studies helped to identify the routing of macronutrients into mammalian tissues. Stable carbon isotopes in bone collagen are mainly derived from the protein portion of the diet, while stable carbon isotopes in bone carbonate are derived from blood bicarbonate and therefore all components of the diet (protein, carbohydrates, and fat) (Ambrose & Norr, 1993; Tieszen & Fagre, 1993). Because of the metabolic and tissue formation processes, tissues become enriched or depleted in the heavier isotope in relation to the diet. The stable carbon isotope ratio of bone collagen is elevated by approximately 3.5 to 5‰ compared to the diet and by approximately 1.4 to 3.4‰ for stable nitrogen isotope values (Ambrose & Norr, 1993; DeNiro & Epstein, 1978, 1981; Schoeninger & DeNiro, 1984; van der Merwe & Vogel, 1978).

The difference in stable isotope ratios between bone components and other tissues must also be accounted for by bioarchaeologists. Ecological researchers can analyze many different tissues, including those that are naturally shed, since live animals can be used. Archaeologists are limited to the tissues that remain preserved for hundreds or thousands of years, namely bones and teeth, and sometimes hair. To accurately reconstruct diet, bioarchaeologists must then account for the bone to tissue differences in stable isotope ratios since tissues like muscle and fat were consumed by past populations instead of bone. These values are available in the ecological literature, though they are more well-established for mammals compared to other animal classes. The bone collagen to muscle tissue spacing most commonly used for human dietary reconstructions for stable carbon isotope values is approximately -3 to -4‰, and +0‰ for stable nitrogen isotope values (Ambrose & Norr, 1993; DeNiro & Epstein, 1978, 1981; Tieszen & Fagre, 1993). Increasing work in ecological research is, however, finding that enrichment values may vary between tissues for different classes of animal (Vanderklift & Ponsard, 2003). The values established for mammals are the ones predominantly used in archaeological studies regardless of animal class. The assumption that mammals and birds have similar isotopic spacing values will be tested in this dissertation.

Biological tissues, not only incorporate macronutrients in different proportions but also at different rates. The time it takes for a tissue to reflect dietary changes is referred to as turnover time or rate. It has been studied in the ecological literature using diet-switch experiments where tissues are sampled sequentially from animals that have been switched between two isotopically distinct diets, often from a C_3 to a C_4 based diet. Turnover rates are reported as half-lives using a negative exponential decay model. Turnover rates vary by species, but generally, tissues that are more metabolically active such as blood or liver have a faster turnover rate compared to tissues such as muscle or bone. Turnover rates for stable carbon isotopes in gerbil tissues were ranked from fastest to slowest in the following order: liver > fat > muscle > brain > hair, with liver tissue having a half-life of 6.4 days and hair having a half-life of 47.5 days (Tieszen, Boutton, Tesdahl, & Slade, 1983). Turnover rates for stable carbon isotopes in Japanese quails tissues were ranked from fastest to slowest in the following order: liver > blood > muscle > bone collagen, with liver tissue having a half-life of 2.6 days and bone collagen having a half-life of 173.3 days (Hobson & Clark, 1992a). By measuring the carbon-14 content of human bone collagen from individuals with ages at death spanning 40-97 from the Melbourne Femur Collection, and correlating these measurements with the bomb curve (changes in atmospheric carbon-14 content due to nuclear bomb testing), Hedges and colleagues (2007) determined that human bone collagen retains the isotopic record of diet for a period over ten years. Turnover rates for different tissues can, therefore, affect the level of dietary interpretation. Tissues with faster turnover such as blood or hair provide information regarding short-term diet, whereas tissues such as bone collagen, when sampled, may represent the combined isotopic signatures from the diet over a period of years.

4.3 Standards and Delta Notation

The absolute differences in isotope compositions can vary largely across different elements, but the lighter isotope of an element is usually far more abundant than the heavier isotope, and the absolute ratio of the heavier to lighter isotope often results in a very small number. Delta notation converts these very small isotopic values into larger numbers, within the range of -100 to +100‰, making them easier to communicate. The stable isotope ratios of the sample are therefore always compared to a standard with a known composition. The ratio of ratios produced by comparing the sample to the standard is calculated using the equation below:

$$\delta^{H}X = [(R_{SAMPLE}/R_{STANDARD} - 1)] \text{ x } 1000$$

X= Element
H= Heavy isotope mass of that element
R = Ratio of heavy isotope to light isotope

Delta values are reported in parts per thousand or permil (‰). International standards are used for comparability between laboratories; however, individual labs often have their own standards that are run routinely to ensure comparability between runs (Katzenberg, 2008). The international standards for stable carbon and nitrogen isotopes are PeeDee Belemnite (PDB), now ViennaPeeDee Belemnite (VPDB), and air (AIR), respectively. Standards have a δ value of 0‰ since the standard is compared to itself in the equation stated above.

4.4 Dietary Analysis and Ecological Applications

4.4.1 Dietary Reconstruction

Dietary studies using stable isotope analysis often focus on stable carbon and nitrogen isotopes. Paleodietary reconstruction using stable isotope analysis has been ongoing within bioarchaeology for many years and the questions addressed are increasingly complex. There is recognition that numerous sources of variation exist in the isotopic signatures of humans and their prey. Studies using stable isotope analysis that hope to reconstruct a food web for an organism, both within the ecological and bioarchaeological literature, typically sample the target species under study and possible prey items available in the environment, or if they are looking to produce a generalized food web for a particular habitat, will sample as many organisms as possible.

Bioarchaeological studies are however limited by the remains preserved within an archaeological site. This often means that only bones and teeth are available for analysis and that the prey species present are the ones that were brought back to the site and processed in a way that would leave these tissues preserved within the area. Excavation and research biases may also mean that certain species of prey are more likely to be sampled than others. Usually this means that larger mammals are sampled more frequently compared to smaller animals such as birds, fish, and small mammals, though this is not always the case. It is also harder to reconstruct broader food webs beyond what is being consumed by humans since many of the remains at archaeological sites are a direct result of human activity.

Ecological dietary studies utilizing stable isotope analysis often have similar goals to paleodietary research, but they are not limited to the tissues preserved in the archaeological record. Stable isotope analysis allows for the determination of the food items incorporated into the tissues of organisms and can reveal dietary patterns that are not easily observed by ecologists, for example, it can be difficult for ecologists to observe the feeding behaviour of smaller animals that hide or fly away. Stable isotope analysis of multiple tissues with different turnover rates can also provide valuable information regarding temporal changes in diet.

4.4.2 Plant Consumption and the Base of the Food Web

Stable carbon isotope analysis can help to indicate the plant foods utilized at the base of the food web because plants have different degrees of discrimination against the heavier ^{13}C isotope based on their photosynthetic pathway. Plants can follow one of three pathways for carbon fixation during photosynthesis: C_3, C_4, or the CAM pathway (Bender, 1971; Hatch & Slack, 1966; Hatch & Slack, 1967). C_4 plants, primarily grasses such as maize that are adapted to an arid climate, typically have higher stable carbon isotope ratios compared to C_3 plants, since the C_4 pathway is less discriminatory against the heavier ^{13}C isotope during carbon dioxide uptake as an adaptation to hot and dry environments (Hatch & Slack, 1966; Hatch & Slack, 1967; van der Merwe, 1982). C_4 plants, therefore, have stable carbon isotope ratios within the range of -9‰ to -16‰, whereas C_3 plants, typically trees, woody shrubs, etc., have stable carbon isotope ratios within the range of -20‰ to -35‰ (Bender, 1971; O'Leary, 1988; van der Merwe & Vogel, 1978; Vogel & van der Merwe, 1977). In contrast to plants that utilize the C_3 pathway or the C_4 pathway, CAM plants, generally succulents, are highly water efficient and can perform carbon dioxide fixation both during the day and at night through two different pathways, and therefore have stable carbon isotope ratios in between the ranges of C_3 and C_4 plants (DeNiro, 1987; O'Leary, 1988).

4.4.3 Trophic Level

Stable nitrogen isotope ratios can indicate the trophic level at which an organism is feeding. Stable nitrogen isotope ratios increase with successive trophic levels due to the stepwise enrichment of the heavier ^{15}N isotope in organisms as they feed at higher trophic levels (Minagawa & Wada, 1984; Schoeninger & DeNiro, 1984). Trophic levels will increase by approximately 3-4‰ for each successive trophic level (Minagawa & Wada, 1984; Schoeninger & DeNiro, 1984). Enrichment occurs between each trophic level due to excretion of nitrogenous waste. The level of discrimination against the heavier stable nitrogen isotope during waste excretion varies between classes of organisms; however, there is generally discrimination against the heavier isotope during the production of urea, uric acid, or ammonium (Minagawa & Wada, 1984). The discrimination against the heavier isotope during the production of urea, uric acid, or ammonium means that more of the lighter isotope, ^{14}N, is lost relative to ^{15}N during excretion and body tissues become relatively enriched in ^{15}N, and this enrichment is passed up the food chain once the organism is consumed by a predator (Minagawa & Wada, 1984).

Consumption of legumes, or nitrogen-fixing plants, can lead to lower stable nitrogen isotope values. Nitrogen-fixing plants can obtain nitrogen from the air through a symbiotic relationship with rhizobium bacteria and therefore have a stable nitrogen isotope ratio closer to the AIR standard or 0‰. Plants other than legumes obtain nitrogen from the soil in the form of ammonia or nitrate and have elevated $\delta^{15}N$ values compared to legumes (Shearer & Kohl, 1978).

4.4.4 Marine versus Freshwater versus Terrestrial Food Webs

Stable carbon and nitrogen isotope ratios can be used to identify whether an organism is feeding on a marine versus a terrestrial food web. In terms of stable carbon isotope analysis, many animals consuming food from a marine food base tend to have elevated stable carbon isotope ratios compared to organisms consuming food from a terrestrial food base (Chisholm, Nelson, & Schwarcz, 1982; Tauber, 1981). This is due to the different sources of carbon at the base of the food chain, dissolved marine bicarbonate with a stable carbon isotope ratio of 0‰ for the marine ecosystem compared to atmospheric carbon dioxide with a stable carbon isotope ratio range of -8‰ to -6‰ for terrestrial ecosystems (Chisholm et al., 1982; Tauber, 1981). The isotopic separation for marine versus terrestrial diets can, however, be obscured if individuals consuming foods from a terrestrial food web are also consuming significant amounts of C_4 plants which also have elevated stable carbon isotope signatures (Chisholm et al., 1982; Tauber, 1981).

Stable nitrogen isotope analysis in addition to stable carbon isotope analysis can potentially solve this problem. Individuals eating marine foods also tend to have elevated $\delta^{15}N$ values (Schoeninger, DeNiro, & Tauber, 1983). This elevation in $\delta^{15}N$ values is mainly due to the greater number of trophic levels in marine food webs (Cabana & Rasmussen, 1996), and the tendency of humans to consume the animals near the top of the food chain in marine ecosystems, such as high trophic level fish, seals, and other marine mammals. Primary producers in marine environments also have elevated stable nitrogen isotope values (up to 8‰) compared to terrestrial primary producers, which leads to elevated stable nitrogen isotope values in consumers of marine foods (Coltrain et al., 2004).

Stable nitrogen isotope values for individual animals within the marine ecosystem can vary, however, due to many factors. Primary producers in the marine ecosystem can include algae, phytoplankton, and autotrophic bacteria. Consuming these primary producers, are a variety of crustaceans, mollusks, and zooplankton, which are then consumed by a multitude of predators including fish, marine mammals, birds, and humans. The marine food web is therefore often more complex compared to terrestrial food webs.

The distinction between marine versus freshwater versus brackish environments is less clear cut. The main source of carbon for marine ecosystems is dissolved bicarbonate, which has a $\delta^{13}C$ value of 0‰, whereas freshwater ecosystems have several sources of carbon including bicarbonate, solubilized CO_2, and dissolved organic and inorganic carbon (Katzenberg, 2008). There is variation in the isotopic composition of these different sources of carbon, especially in the dissolved organic and inorganic carbon sources, leading to isotopic variation in the plants available in the freshwater ecosystems (Fry & Sherr, 1989). There is, however, systematic variation in δ^{13}C values dependent on water depth, with plants in shallower waters having more positive δ^{13}C values than benthic plants, and this relationship is passed up the food chain (Katzenberg, McKenzie, Losey, Goriunova, & Weber, 2012; Katzenberg & Weber, 1999; Vander Zanden & Rasmussen, 1999).

Stable nitrogen isotope ratios can also vary between organisms within the freshwater environment. Again, the variation in stable nitrogen isotope ratios is observed in the lower trophic levels of freshwater food webs and these differences are passed up through the food chain. Zooplankton, for example, have been found to have niche partitioning within a single water body, where different zooplankton species will consume different species of phytoplankton, microzooplankton, etc. compared to each other. Zooplankton can, therefore, appear as primary or secondary consumers based on their stable nitrogen isotope ratios (Driscoll, Bootsma, & Christiansen, 2015). Seasonal variations in stable nitrogen isotope ratios have also been observed for zooplankton in lakes, and this variation may be due to preferential uptake of nitrate with the lighter isotope of nitrogen by phytoplankton and other plants in the lake environment, and the increase of this activity in the summer months (Syväranta, Hämäläinen, & Jones, 2006). These differences in stable carbon and nitrogen isotope ratios at the lower trophic levels of the freshwater food web are subsequently passed up the food chain to consumers such as fish. There is, therefore, greater variation in isotopic values of freshwater organisms than previously thought.

4.4.5 Migration

Movement of animals can also affect stable carbon and nitrogen isotope signatures as food items may change or have varying isotopic signatures in different environments. Stable isotope analysis provides the advantage of not having to re-capture species for tagging in comparison to traditional migratory analyses (Rubenstein & Hobson, 2004). Migratory birds are a special prey item when it comes to paleodietary reconstruction because they spend most of their lives traveling between habitats that may be very isotopically distinct. Ecologists can collect blood and feather samples from birds with relatively little harm to the animals. The two tissue samples also provide different temporal scales for analysis, with the feathers representing a longer formation period that likely reflects wintering grounds in terms of isotopic signatures, while blood has a fast turnover rate and will have an isotopic signature reflective of the summering ground.

Within avian ecology, the question of whether migratory birds use endogenous reserves from nutrients acquired at the wintering habitat (capital breeders) or exogenous resources at the summer habitat (income breeders) to produce eggs has also been successfully explored using stable isotope analysis (Federer, Hollmén, Esler, & Wooller, 2012; Gauthier, Bêty, & Hobson, 2003; Hobson, Hughes, & Ewins, 1997; Hobson, Jaatinen, & Öst, 2015; Morrison & Hobson, 2004). The stable isotope ratios of egg or chick tissues can allow researchers to estimate the nutrient sources during breeding. Ecologists have found that capital versus income breeding varies by bird species, for example, snow geese (*Chen caerulescens*) were found to be capital breeders, relying on the maize consumed in their wintering grounds for reproduction, while some of the High Arctic waders, such as plovers (Charadriidae) and sandpipers (Scolopacidae), are income breeders that rely on invertebrates available in their summering grounds for reproduction (Klaassen, Lindstrom, Meltofte, & Piersma, 2001; R. I. G. Morrison & Hobson, 2004). Differences in isotopic signatures across migratory habitats and variation in resource allocation to reproduction make birds a unique class of animal when it comes to stable isotope analysis. Compared to mammals that are limited in the habitats that they can exploit, birds can potentially have widely differing stable carbon and nitrogen isotope ratios even within the same genus.

4.4.6 Mixing Models

The major drawback of using stable isotope analysis for dietary research is that multiple food items can have similar isotopic signatures and the overlap of isotopic signatures can make it difficult to determine the exact foods and the quantities that were being consumed. One way that researchers have attempted to address this problem is by using mixing models to help determine the possible combinations of food items.

The most commonly used mixing models in stable isotope analysis are linear mixing models. Standard linear mixing models are based on mass balance equations, which simply mean that combinations of possible sources and their proportions are combined to conserve mass balance for all the isotopes analyzed. Mass balance is achieved when the total isotopic composition of the inputs matches the outputs in a system. The mass balance equation used for standard linear mixing models is provided below and is based on the equation put forward by Schwarcz (1991).

$$\delta J_D = f_A \, \delta J_A + f_B \, \delta J_B + f_C \, \delta J_C$$

$$\delta K_D = f_A\,\delta K_A + f_B\,\delta K_B + f_C\,\delta K_C$$

$$1 = f_A + f_B + f_C$$

J = 1^{st} Stable Isotope
K = 2^{nd} Stable Isotope
A = 1^{st} Source
B = 2^{nd} Source
C = 3^{rd} Source
D = Mixture
f = Source Proportion

The computer program IsoSource (Phillips & Gregg, 2003), used in this dissertation, utilizes standard linear mixing models and the mass balance equation provided above. With standard linear mixing models, unique solutions can only be generated for n+1 sources when n isotopes are being analyzed; this means that for a typical dietary model looking at both stable carbon and nitrogen isotopes, unique solutions can only be generated for three sources (food items). The IsoSource program, however, allows for the prediction of source proportions for >n+1 sources. The Isosource program generates numerous combinations of sources and their proportions that still maintain mass balance in small increments of each source proportion. These small increments, typically around 1% to 2% are referred to as source increments in the IsoSource program, and the value is entered by the user, with greater source increments being entered when there are greater uncertainties in the isotopic values of the sources (food items) or mixture (consumer). The user also inputs a small tolerance value, often between 0.1‰ and 0.5‰, which represents the acceptable variation between the resulting isotopic value from the various sources and proportions calculated by IsoSource and the isotopic signature of the mixture. Once the isotopic signatures of the likely sources and the mixture, the source increment, and the tolerance value are entered, IsoSource provides various summary statistics such as the mean, minimum, and maximum proportions of each source and the distribution of potential source proportions. It is recommended that the ranges of source proportions for each source are reported in the academic literature instead of a single value, such as the mean, to not overstate the likelihood of the proportions for each source (Phillips & Gregg, 2001, 2003). IsoSource therefore only provides the range of possibilities for source proportions and not a definitive result.

Mixing models, therefore, provide a wide range of possible dietary items and their proportions based on the end consumer stable isotope ratios and the values provided for potential dietary items. Interpretations from mixing models, whether for ecological or archaeological studies, are therefore best made with supporting evidence. Different lines of evidence, such as the distribution of faunal remains at the site, ethnographic information, and availability of potential prey items, allow the researcher to narrow down the possible combinations of food items. Mixing models work best if the possible dietary items have distinct stable isotope ratios from each other (Phillips & Gregg, 2003). If multiple food items share similar isotopic signatures, they can be combined during the analysis, with the caveat that the source proportion generated through the calculations is for the combined resources and it may not be possible to differentiate them during the interpretation phase.

Mixing models also rely on accurate spacing values for diet-to-tissue spacings and tissue-to-tissue spacings entered by the researcher to minimize error during analysis and interpretation (Phillips & Gregg, 2001). The stable isotope ratios of the bone collagen obtained from prey items in the archaeological record are not directly indicative of the actual diet of the human groups since they were more likely consuming muscle and fat from the animal. Diet-to-tissue spacings and tissue-to-tissue spacings must therefore also be incorporated into the mixing model.

4.4.7 Preservation

Archaeological studies utilizing stable isotope analysis are further complicated by the problem of preservation and diagenesis. The integrity of bone collagen is subject to its burial environment, and it may degrade or become contaminated through time. Procedures for evaluating the integrity of bone collagen and for removing contaminants are well-established (Ambrose, 1990). Researchers evaluate the physical integrity and appearance of the bone collagen sample as well as look at the carbon:nitrogen (C:N) ratio and %carbon (%C) and %nitrogen (%N) in the sample to determine if the bone collagen is well-preserved. A C:N ratio of 2.9 to 3.6 for bone collagen is considered to be well-preserved (DeNiro, 1985). The percentage yield of bone collagen after extraction can also be used to help evaluate the integrity of the collagen. Collagen makes up approximately 22-25% of the weight of fresh bone, and minimum collagen yield percentages between or greater than 1% and 3.5% have been suggested as indicators of acceptable bone preservation for stable isotope analysis (Ambrose, 1990; van Klinken, 1999).

4.5 Stable Isotope Ecology of the Arctic

Stable isotope analysis has been used in numerous studies on Arctic ecology; however, dietary reconstructions of past human groups in the Arctic using stable isotope analysis have been relatively lacking compared to temperate regions. A summary of the current stable isotope research on Arctic hunter-gatherer dietary strategies and relevant ecological reconstructions are provided below. Stable isotope ratios of potential prey for Arctic hunter-gatherer groups are also provided in Tables 4.6 through 4.11. Included in these tables are all the available stable carbon and nitrogen isotope ratios from animal bone collagen recovered from Arctic archaeological sites along with isotopic signatures from two ecological studies (Hobson, Fisk, et al., 2002; Hobson & Welch, 1992). The two ecological studies were included because they provided stable isotope ratios for a wide range of animals in the Arctic marine food web. Animal stable isotope ratios are organized in the following manner: terrestrial mammals, porpoise and whales, marine sea mammals not including whales and porpoise, freshwater and anadromous animals, marine echinoderm and fish, and birds. This organization allows for the comparison of various species within the marine, terrestrial, and freshwater ecosystems and demonstrates the variation that can be seen within and between species. Also, note that the number of isotopic signatures available for marine and terrestrial mammals is greater than those available for fish and birds.

4.5.1 Aleutian Islands

One of the earlier isotopic studies of Arctic hunter-gatherer diet was an addition to radiocarbon dating of human skeletal remains from the Aleutian Islands. Coltrain and colleagues (2006) were trying to determine radiocarbon dates and provide preliminary dietary reconstructions for 80 burials recovered by Aleš Hrdlička in the late 1930s. The objective was to test Hrdlička's hypothesis of a population replacement scenario of the Paleo-Aleut people on Umnak Island by Neo-Aleut groups at 1000 BP based on cranial measurements completed in the 1940s.

The researchers found that the Paleo-Aleut had mean stable carbon and nitrogen isotope values that indicated a diet consisting of lower-ranked and smaller packaged resources such as sea otter, sea urchin, plankton-feeding seabirds, as well as harbour seals (*Phoca vitulina*), which are a near-shore resource. The Neo-Aleut had slightly elevated stable nitrogen isotope values and slightly lower stable carbon isotope values compared to the Paleo-Aleut (see Table 4.1). The revisions completed in 2010 by Coltrain were based on previous cataloging discrepancies, and some values obtained from stable carbon and nitrogen isotope analysis were revised, but her conclusions remained the same as those reached in 2006. Unfortunately, neither of these studies included isotopic values for faunal bone collagen as part of the paleodietary reconstruction.

Study	Cultural Group	Time Period	Tissue	n	$\delta^{13}C$	$\delta^{15}N$
Coltrain et al. 2006	Paleo-Aleut	3594 - 285 cal. B.P.	Bone Collagen	34	-12.3 ± 0.5	19.3 ± 0.7
	Neo-Aleut	1060 - 283 cal. B.P.	Bone Collagen	46	-12.6 ± 0.4	20.3 ± 0.8
Coltrain et al. 2010	Paleo-Aleut	3400 - 400 cal. B.P.	Bone Collagen	41	-12.3 ± 0.5	19.5 ± 0.9
	Neo-Aleut	800 - 400 cal. B.P.	Bone Collagen	39	-12.7 ± 0.4	20.3 ± 0.7

Table 4.1. Human bone collagen stable carbon and nitrogen isotope ratios from paleodietary research on past Aleutian populations.

Byers and colleagues (2011), using the data presented in Coltrain's 2010 research, argued that the genetic drift theory regarding the two distinct cranial configurations in populations of the Aleutian Islands was not supported by recent evidence of dietary shifts, genetic differences, and the introduction of new mortuary practices by 1000 BP. They argued that the stable carbon and nitrogen isotope ratios obtained for the Paleo-Aleut versus the Neo-Aleut were different enough to indicate a major dietary shift (Byers et al., 2011). In addition to this re-interpretation of the human bone collagen data, Byers and colleagues (2011) also provided comparative faunal stable isotope ratios to contribute to the paleodietary analysis; however, they did not include any birds in their analysis (see Tables 4.6 to 4.11). Birds have been recovered from faunal assemblages in the Aleutian Islands and were likely included in the Aleutian diet (R. S. Davis & Knecht, 2010; Maschner, Mason, & McGhee, 2009). Faunal remains from the Aleutian Islands have also been analyzed using stable isotope analysis by Misarti and colleagues (2009) as part of a larger study into changes in the marine ecosystem of the northeast Pacific using animal bone collagen from archaeological middens.

4.5.2 Alaska

Following a similar vein to the research conducted on human skeletal remains from the Aleutian Islands, isotopic signatures from human skeletal remains from Alaska were first analyzed as additions to ancient DNA research. Coltrain (2010) performed stable carbon and nitrogen isotope analysis and accelerator radiocarbon dating on 23 individuals from the three sites of Port Moller, Mink Island, and Brooks River on the Alaskan Peninsula (see Table 4.2). In contrast to the Aleutian studies, this study had a greater emphasis on understanding the complexity of pre-European adaptations on the Alaskan Peninsula, and therefore there was a greater emphasis on dietary strategies. Coltrain (2010 determined, using stable isotope analysis, that there was a uniform reliance on high trophic level marine foods amongst the three sites because of the elevated stable carbon and nitrogen isotope ratios; however, there was also significant intersite variability (see Table 4.2). The intersite variation was due to different amounts of terrestrial versus marine foods in individual diet at the three sites (Coltrain, 2010).

The individuals at the Brooks River site were likely consuming the greatest quantity of terrestrial foods compared to the individuals at the Mink Island site who were likely consuming the least amount of terrestrial foods (Coltrain, 2010). Coltrain (2010) does, however, make the point that the small sample size is not reflective of all the subsistence strategies on the Alaskan Peninsula and that faunal analysis needs to be carried out at these sites as well for these conclusions to be more accurate. When the stable isotope ratios were compared to those obtained from the Aleutians, the eastern Aleutians showed more positive δ^{13}C and δ^{15}N values than all three of the Alaskan Peninsula sites. Coltrain (2010) argues that populations from the eastern Aleutians were, therefore, consuming larger quantities of high trophic level marine fauna than the populations on the Alaskan Peninsula. Again, this study lacked comparative faunal stable isotope ratios for paleodietary reconstruction.

In 2013, Britton and colleagues performed a more in-depth paleodietary analysis of Norton and Thule groups on the Bering Sea coast of Alaska through the stable isotope analysis of hair keratin from hair collected at the Nash Harbor and Nunalleq sites. The hairs collected were from domestic debris and were not from a mortuary context. They found that the Norton population at the Nash Harbor site had elevated stable carbon and nitrogen isotope ratios compared to the Thule at Nunalleq and that they were likely consuming protein exclusively from high trophic level marine sources such as seals or piscivorous (fish-eating) seabirds and seabird eggs (see Table 4.2). Serial sampling of the hair samples from Norton groups also shows that they had more intra-hair variation indicating that their diet may have varied seasonally. Based on the stable isotope ratios obtained from the hair samples collected from the Thule era Nunalleq site, Britton and colleagues (2013) concluded that the Thule were consuming a mixed diet of fish, terrestrial herbivores, and marine mammals. Hair collected from the Thule site also had less intra-hair variation, which meant that they had an isotopically homogenous diet over the course of approximately ten months. In 2016, Britton and colleagues published additional data on 51 strands of hair collected from Thule house floors at the Nunalleq site (see Table 4.2). Again, Britton and colleagues (2016) concluded that the Nunalleq Thule were consuming a mixed diet that consisted mainly of high trophic level marine protein with the possible addition of sea fish, shellfish, salmon, and some terrestrial protein such as caribou (*Rangifer tarandus*). With the increased sample size, however, they were able to identify variation in stable isotope ratios within and between hair samples, indicating seasonal dietary variation and differences in subsistence practices between individuals at the site. Additional faunal bone collagen stable isotope ratios from the Nunalleq site were also provided by McManus-Fry and colleagues (2016).

One of the most recent paleodietary analyses of past Arctic hunter-gatherer groups was performed by Coltrain and colleagues in 2016. They analyzed 54 human bone collagen samples from the Nuvuk cemetery site in northwest Alaska for stable carbon and nitrogen isotope ratios and AMS radiocarbon dates (see Table 4.2). The comparative faunal stable isotope ratios used in this research came from lipid-extracted muscle from modern animals and included ringed seal (*Phoca hispida*), bearded seal (*Erignathus barbatus*), walrus (*Odobenus rosmarus*), cod, salmon, smelt, flounder, whitefish, bowhead whale (*Balaena mysticetus*), beluga whale (*Delphinapterus leucas*), barren ground caribou (*Rangifer tarandus groenlandicus*)s, and polar bear (*Ursus maritimus*). The elevated human bone collagen stable nitrogen isotope ratios suggest that the Thule at Nuvuk were high-level marine predators, however, their mean stable carbon isotope ratio was depleted relative to Aleutian groups and may indicate some incorporation of terrestrial animals into their diet. These results are somewhat contradictory, but the researchers also found that these mean stable isotope ratios were very close to the values obtained for polar bears in the region. Polar bears almost exclusively consume marine mammals. The relatively lower stable carbon isotope ratios for the Nuvuk Thule samples were therefore thought to be due to the admixture of terrigenous (terrestrial-based) carbon in estuarine and near-shore Beaufort Sea food webs (Coltrain et al., 2016). The terrigenous carbon comes from freshwater runoff containing organic sediments into the sea. The Nuvuk Thule were likely consuming ice-adapted seals that fed near the shore and would, therefore, have elevated stable nitrogen isotope ratios but somewhat lower stable carbon isotope ratios. Caribou, bowhead whale, and fish were very minor contributions to Thule diet at the Nuvuk site.

Study	Cultural Group	Time Period	Tissue	n	$\delta^{13}C$	$\delta^{15}N$
Britton et al. (2013)	Norton	1750 ± 40 cal BP	Hair Keratin	4	-14.5 ± 0.5	19.3 ± 1.0
	Thule	650 ± 40 cal BP - 290 ± 30 cal BP	Hair Keratin	6	-15.7 ± 0.4	16.0 ± 1.4
Britton et al. (2016)	Thule	650 ± 40 cal. BP – 182 ± 37 cal. BP	Hair Keratin	57	-15.7 ± 0.4	16.5 ± 1.1
Coltrain (2010)	Brooks River	1484-381 cal. BP	Bone Collagen	9	-15.0 ± 0.3	17.4 ± 0.5
	Port Moller	3547-1388 cal. BP	Bone Collagen	7	-13.8 ± 0.7	18.6 ± 2.5
	Mink Island	666 - 292 cal. BP	Bone Collagen	7	-13.1 ± 0.4	18.9 ± 0.7
Coltrain et al. (2016)	Nuvuk Thule	AD 975 - 1885	Bone Collagen	54	-14.1 ± 0.8	20.5 ± 1.1

Table 4.2. Stable carbon and nitrogen isotopes of human tissue from paleodietary research on past Alaskan populations.

4.5.3 Western Canadian Arctic

Only one stable isotope study has been published on the paleodietary reconstruction of an Arctic hunter-gatherer group in the western Canadian Arctic. The study was conducted by Bocherens and colleagues in 2016. They analyzed one human bone collagen sample from a Pre-Dorset individual from the Umingmak site on Banks Island (see Table 4.3) along with faunal remains recovered from the same site except for one bone collagen sample from a modern polar bear skull. The goal of the research was to determine the contributions from marine, terrestrial, and freshwater foods to the diet of Pre-Dorset hunter-gatherers. They found that the Pre-Dorset individual had a predominantly marine diet with an approximate freshwater and terrestrial component from 10% to 40% of the overall diet. These isotopic results are consistent with the mixed marine and terrestrial/freshwater subsistence strategies proposed for Pre-Dorset groups in the zooarchaeological literature (i.e., McCartney & Helmer, 1989; Murray, 1996).

Study	Cultural Group	Time Period	Tissue	n	δ^{13}C	δ^{15}N
Bocherens et al. (2016)	Pre-Dorset	2470 - 2207 cal. B.C.	Bone Collagen	1	-17.2	18.7

Table 4.3. Human bone collagen stable carbon and nitrogen isotope ratios from paleodietary research on past Western Canadian Arctic populations.

4.5.4 Eastern Canadian Arctic

The earliest paleodietary reconstruction of Arctic hunter-gatherer diet using stable isotope analysis was completed by Coltrain and colleagues in 2004. Their research focused on human skeletal remains from Sadlermiut and Thule groups in the Eastern Canadian Arctic. The goal of their research was to determine the importance of whales to the diet of Thule groups. Based on the stable carbon and nitrogen isotope values obtained from bone collagen (see Table 4.4) and linear mixing model results, Coltrain and colleagues, in 2004, concluded that the Thule were hunting bowhead whales although seals remained the most important dietary resource. In comparison, the Sadlermiut most likely did not hunt whales and were instead exploiting seal and seabirds. The researchers also noted that there was also increased individual variation within the Thule samples suggesting that there were possible status differences, likely based on whaling success. In 2009, Coltrain introduced 75 new samples to the previous 81 samples studied in 2004 to include more samples from the Classic Thule period which were mainly absent in the first study. With the larger sample size, stable carbon and nitrogen isotope analysis and AMS radiocarbon dating revealed that the Sadlermiut appeared to be incorporating increasing amounts of higher trophic level marine taxa into their diet over time. The Thule from both the sites of Kamarvik and Silumiut were less reliant on high trophic level marine foods but instead relied on caribou, ringed seal, and some bowhead whale. Coltrain (2009) also concludes that whaling seemed to increase in importance amongst the Thule between approximately AD 1400 to AD 1600/1700 and both Thule sites seemed to have been abandoned by the mid-17th century. The work of Coltrain and colleagues (2004) and Coltrain (2009) also demonstrates that temporal trends in marine food intake can be detected using stable carbon and nitrogen analysis, with the caveat of a large sample size spanning a broader time period.

Paleodietary reconstruction for Eastern Canadian Arctic populations also benefits from extensive ecological research that establishes a picture of the marine food web in this region. Research has been carried out on Arctic marine food webs, by ecological researchers such as

Hobson and Welch (1992) and Hobson and colleagues (2002). The goal of both these studies was to establish a detailed food web, from particulate organic matter to large marine mammals, for the Barrow-Strait-Lancaster Sound region of the Northwest Territories and the North Water region of northern Baffin Bay, respectively. In the study carried out by Hobson and Welch (1992), analyzed samples included zooplankton, benthic organisms, copepods, mysid, particulate organic matter, marine birds, fish, seals, whales, and polar bears. While the later study carried out by Hobson and colleagues (2002) included samples of ice algae, particulate organic matter, zooplankton, macrozooplankton, fish larvae, benthic amphipods, fish, seabirds, seals, beluga whales, narwhal (*Monodon monoceros*), and bowhead whales. Based on the stable nitrogen isotope trophic enrichment value of 3.8‰ between predator and prey, as determined by Hobson and Welch (1992), both studies show that there are at least five trophic levels within the Arctic marine food web, however both of these studies also emphasize the complexity of the Arctic marine ecosystem and that trophic positions of marine organisms are not fixed and can vary based on age, seasonality, and migration. For example, seals may have different trophic positions depending on age, and walrus and bearded seals are known to be migratory in regions such as the Barrow Strait-Lancaster Sound and will, therefore, have varying stable isotope values based on areas of different isotopic composition (Hobson and Welch, 1992). The variations in stable isotope values seen for animal species that are potential prey species for humans, such as seal and walrus, should, therefore, be accounted for in archaeological investigations.

Study	Cultural Group	Time Period	Tissue	n	$\delta^{13}C$	$\delta^{15}N$
Coltrain et al. (2004)	Sadlermiut	AD 1308-1890	Bone Collagen	19	-13.3 ± 0.3	20.9 ± 0.5
	Kamarvik Thule	AD 1158-1664	Bone Collagen	30	-14.3 ± 0.4	18.2 ± 1.5
	Silumiut Thule	AD 1063-1679	Bone Collagen	32	-14.5 ± 0.3	17.5 ± 1.1
Coltrain et al. (2009)	Sadlermiut	AD 1414 - 1896	Bone Collagen	26	-13.1 ± 0.4	20.3 ± 0.7
	Kamarvik Thule	AD 1293-1678	Bone Collagen	15	-13.9 ± 0.4	17.7 ± 1.0
	Silumiut Thule	AD 1287 - 1700	Bone Collagen	34	-14.4 ± 0.4	16.4 ± 1.0

Table 4.4. Human bone collagen stable carbon and nitrogen isotope ratios from paleodietary research on past Eastern Canadian Arctic populations.

4.5.5 Greenland

Isotopic studies of past diet amongst Greenland inhabitants were the topic of a special issue in the Journal of the North Atlantic published in 2012. Nelson and colleagues (2012) presented the first extensive dietary study using stable isotope analysis on the Greenland Thule in this journal issue. The researchers sampled 65 Thule individuals from 14 Greenland sites, which were organized into northwest, southwest, southeast, and northeast divisions (see Table 4.5). Nelson and colleagues (2012) concluded that the populations from each division were exploiting distinct patterns of resources even though all groups were heavily reliant on marine protein. Individuals from the northwest and southwest regions appear to be consuming large amounts of seal and some amounts of beluga or narwhal (Nelson et al., 2012). There was little faunal comparative data from the southeast region, but based on the human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values, they had similar diets to those of the southwest region. The northeast region was the only region mentioned to have some contribution from terrestrial resources such as caribou.

Study	Cultural Group	Time Period	Tissue	n	$\delta^{13}C$	$\delta^{15}N$
Nelson et al. (2012)	NW Thule	AD 1450 – 1650	Bone Collagen	11	-13.2 ± 0.3	21.3 ± 0.8
	SW Thule		Bone Collagen	26	-12.6 ± 0.4	19.2 ± 0.6
	SW tip Thule		Bone Collagen	5	-13.4 ± 0.3	19.3 ± 0.4
	SE Thule		Bone Collagen	5	-13.6 ± 0.2	19.4 ± 0.6
	NE Thule		Bone Collagen	18	-15.3 ± 0.5	18.3 ± 1.1

Table 4.5. Human bone collagen stable carbon and nitrogen isotope ratios from paleodietary research on past Greenland hunter-gatherer populations.

Region	Tissue	Caribou		Muskox		Dog		Hare		Sources
		$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	
Alaska	Bone Collagen	-18.4 ± 0.4	2.4 ± 0.7							Britton et al. 2013
Alaska	Bone Collagen	-18.0 ± 1.8	1.8 ± 0.5					-21.3 ± 1.4	2.9 ± 0.9	McManus-Fry et al. 2016
W. Canada	Bone Collagen					-16.2 ± 1.5	16.7 ± 1.3			Mackenzie-Grieve et al. 2005
W. Canada	Bone Collagen	-18.9 ± 0.4	2.4 ± 0.9	-20.9 ± 0.3	2.7 ± 1.1			-22.5	1.3	Bocherens et al. 2016
E. Canada	Bone Collagen	-17.1 ± 0.3	2.8 ± 0.3	-18.3 ± 0.9	3.7 ± 1.3					Coltrain et al. 2004
E. Canada	Bone Collagen	-20.7 ± 0.9	2.0 ± 0.5	-20.8 ± 0.3	2.6 ± 1.0			-21.7 ± 1.0	4.2 ± 2.3	Katzenberg and Krouse n.d.
E. Greenland	Bone Collagen	-19.3 ± 0.1	1.5 ± 0.2	-20.2 ± 0.1	2.8 ± 0.2					Nelson et al. 2012
W. Greenland	Bone Collagen	-18.2 ± 0.1	2.0 ± 0.2							Nelson et al. 2012

Table 4.6. Faunal bone collagen stable carbon and nitrogen isotope ratios of Arctic terrestrial mammals.

Region	Tissue	Porpoise		Beluga Whale		Narwhal		Bowhead Whale		Baleen Whale		Whale		Sources
		$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	
Aleutian Is.	Bone Collagen	-13.1 ± 0.3	16.2 ± 1.2									-13.5 ± 0.6	15.4 ± 1.6	Byers et al. 2011
Alaska	Bone Collagen	-12.3	15.5	-12.9 ± 0.2	19.5 ± 1.3							-13.5 ± 0.7	18.5 ± 0.7	McManus-Fry et al. 2016
W. Canada	Bone Collagen			-13.0 ± 0.4	18.9 ± 0.8									Mackenzie-Grieve et al. 2005
E. Canada	Bone Collagen							-14.8 ± 0.3	15.1 ± 0.9					Coltrain et al. 2004
E. Canada	Muscle			-18.1 ± 0.5	16.6 ± 0.6	-18.0 ± 0.4	15.8 ± 0.7							Hobson and Welch 1992
E. Canada	Muscle			-17.6 ± 0.1	16.9 ± 0.2	-18.2 ± 0.03	16.0 ± 0.1	-18.2 ± 0.3	13.2 ± 0.7					Hobson et al. 2002
W. Greenland	Bone Collagen			-12.6	16.1	-12.6	16.1			-14.4 ± 0.3	12.6 ± 0.8			Nelson et al. 2012

Table 4.7. Stable carbon and nitrogen isotope ratios of porpoises and whales in the Arctic.

Region	Tissue	Sea Otter		Stellar Sea Lion		Harp Seal		Ringed Seal		Bearded Seal		Harbour Seal		Hooded Seal		Fur Seal		Walrus		Study
		δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	
Aleutian Is.	Bone C.	-12.2 ± 0.7	12.2 ± 0.9	-13.8 ± 0.7	16.6 ± 1.1			-12.4 ± 0.5	17.7 ± 0.9	-12.1 ± 1.0	17.4 ± 1.1	-12.8 ± 0.6	16.3 ± 1.7			-13.7 ± 1.5	17.3 ± 1.7			Byers et al. 2011
Aleutian Is.	Bone C.	-11.9 ± 0.8	14.5 ± 1.4	-13.1 ± 0.7	18.4 ± 1.4							-12.2 ± 0.8	17.1 ± 1.7			-13.6 ± 1.4	16.1 ± 2.4			Misarti et al. 2009
Alaska	Bone C.			-11.1	20.3			-13.4 ± 1.0	18.3 ± 0.9	-12.8 ± 1.0	17.4 ± 1.0	-12.8 ± 0.6	19.6 ± 1.0					-12.5 ± 0.4	14.5 ± 0.2	McManus-Fry et al. 2016
W. Canada	Bone C.							-15.3 ± 1.0	17.9 ± 1.0	-15.0 ± 1.2	18.4 ± 0.5	-15.3 ± 1.0	17.9 ± 1.0							Mackenzie-Grieve et al. 2005
E. Canada	Bone C.							-13.9 ± 0.7	17.2 ± 1.0	-14.2 ± 0.4	15.9 ± 0.7							-14.0 ± 0.2	13.9 ± 2.3	Coltrain et al. 2004
E. Canada	Muscle							-17.3 ± 0.7	17.3 ± 1.1	-16.6 ± 0.5	16.8 ± 0.2							-17.8 ± 0.3	12.5 ± 0.6	Hobson and Welch 1992
E. Canada	Muscle							-18.3 ± 0.1	17.5 ± 0.2	-16.6 ± 0.3	16.8 ± 0.1							-17.8 ± 0.1	12.5 ± 0.3	Hobson et al. 2002
E. Greenland	Bone C.					-15.7 ± 0.2	11.8 ± 0.9	-15.2 ± 0.1	14.3 ± 0.6											Nelson et al. 2012
W. Greenland	Bone C.					-14.3 ± 0.2	14.5 ± 0.2	-14.1 ± 0.2	16.6 ± 0.4	-12.6 ± 0.2	13.5 ± 1.0	-12.6 ± 0.1	17.0 ± 0.3	-13.6 ± 0.2	15.8 ± 0.3			-12.7 ± 0.1	11.7 ± 0.3	Nelson et al. 2012

Table 4.8. Stable carbon and nitrogen isotope ratios of Arctic marine mammals other than porpoise and whales (Bone C. is the abbreviation for bone collagen).

Region	Tissue	River Otter		Salmon		Burbot		Inconnu		Broad Whitefish		Lake Trout		Least Cisco		Arctic Cisco		Lake Whitefish		Northern Pike		Sources
		δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	δ^{13}C	δ^{15}N	
Aleutian Is.	Bone C.			-15.0 ± 0.2	11.6 ± 1.2																	Byers et al. 2011
Aleutian Is.	Bone C.			-15.2 ± 1.4	11.5 ± 1.7																	Misarti et al. 2009
Alaska	Bone C.	-22.4	12.5	-16.0 ± 1.0	13.6 ± 1.9																	McManus-Fry et al. 2016
W. Canada	Bone C.					-21.3 ± 2.1	12.5 ± 1.3	-20.6 ± 1.5	14.7 ± 1.8	-22.6 ± 1.8	9.4 ± 0.3	-22.5 ± 1.1	13.0 ± 1.1	-20.0 ± 0.3	9.3 ± 0.3	-23.3 ± 0.9	10.5 ± 0.6	-20.5 ± 1.1	9.6 ± 0.1	-20.9 ± 2.6	13.0 ± 2.0	Mackenzie-Grieve et al. 2005

Table 4.9. Stable carbon and nitrogen isotope ratios of Arctic freshwater and anadromous animals (Bone C. is the abbreviation for bone collagen).

Region	Tissue	Sea Urchin		Pacific Cod		Arctic Cod		Near Shore Fishes		Sources
		$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	
Aleutian Is.	Bone Collagen	-13.2 ± 0.7	9.2 ± 0.9	-12.2 ± 0.7	16.9 ± 1.1			-11.2 ± 0.7	14.5 ± 1.4	Byers et al. 2011
Aleutian Is.	Bone Collagen			-12.5 ± 1.0	16.1 ± 1.2					Misarti et al. 2009
E. Canada	Muscle	-16.5 ± 0.3	9.9 ± 0.3			-18.9 ± 1.0	15.2 ± 0.7			Hobson and Welch 1992
E. Canada	Muscle	-15.7 ± 1.6	8.3 ± 0.5			-19.3 ± 0.1	14.0 ± 0.2			Hobson et al. 2002

Table 4.10. Stable carbon and nitrogen isotope ratios for a marine echinoderm and marine fish in the Arctic.

Region	Tissue	Common Eider		Geese		Duck		Glaucous Gull		Thick-billed Murre		Black-Legged Kittiwake		Dovekie		Arctic Loon		Yellow-billed/Common Loon		Parasitic Jaeger		Red-Throated/Pacific Loon		Sources
		$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	
Alaska	B. C.					-21.5 ± 2.9	8.3 ± 0.5																	McManus-Fry et al. 2016
W. Canada	B. C.							-19.9 ± 1.8	17.3 ± 1.7							-20.3 ± 7.8	13.6 ± 2.7	-12.7 ± 1.0	17.1 ± 0.3	-15.0 ± 1.9	16.0 ± 1.5	-13.6 ± 0.8	17.0 ± 1.3	Mackenzie--Grieve et al. 2005
W. Canada	B. C.			-19.4 ± 1.1	6.8 ± 0.7																			Bocherens et al. 2016
E. Canada	B. C.	-12.9 ± 0.6	16.3 ± 0.6																					Coltrain et al. 2004
E. Canada	Muscle							-17.6 ± 0.5	17.0 ± 0.9	-18.4 ± 0.6	15.8 ± 0.7	-18.3 ± 0.7	15.4 ± 0.9											Hobson and Welch 1992
E. Canada	Muscle							-18.8 ± 0.3	16.2 ± 0.3	-19.9 ± 0.04	14.1 ± 0.1	-19.3 ± 0.1	13.7 ± 0.2	-18.7 ± 0.2	11.3 ± 0.3									Hobson et al. 2002
W. Greenland	B. C.									-16.1 ± 0.2	14.6 ± 0.5													Nelson et al. 2012

Table 4.11. Stable carbon and nitrogen isotope ratios for Arctic birds (Bone C. is the abbreviation for bone collagen).

4.6 Summary

The use of stable isotope analysis in dietary reconstruction can aid in identifying plant base, trophic level, terrestrial versus marine resource use, marine versus freshwater resources, and more. Interpretation of stable isotope values must however also include factors such as metabolism, environment, and preservation. Mixing models have therefore been created to help researchers manage the numerous sources and variation in these sources that contribute to the isotopic signatures of consumer tissues. Mixing models, however, still rely on a sound ecological and archaeological understanding of the samples and their background.

This dissertation will include stable isotope values for both modern and archaeological bird remains. Analyses of modern and archaeological remains pose different sets of considerations and challenges and a holistic approach must be taken for both. As the end goal of this dissertation is to understand how the addition of birds will impact models of paleodiet generated by stable isotope analysis, an understanding of how stable isotope analysis can contribute to dietary reconstruction is needed.

Current paleodietary research on Arctic populations using stable isotope analysis was also discussed in this chapter, and it must be noted that smaller animals such as fish and birds play a very small role in these studies. Most of the studies only included one species of bird in their analyses, and if mixing models were used, the birds would have identical tissue spacing values to mammals. The rest of this dissertation, therefore, explores whether this approach, when it comes to the incorporation of birds into past human diet, is sufficient.

Chapter Five: Zooarchaeological Analysis of Bird Bones recovered from Pre-Dorset and Dorset sites on the Knud Peninsula, Ellesmere Island

5.1 Introduction

Paleo-Inuit groups (4500 to 820 BP) practiced a broad subsistence strategy that enabled them to migrate across the Arctic. Migratory birds served as a reliable and easy option within Paleo-Inuit dietary adaptations (Gotfredsen & Møbjerg, 2004; T. B. Johansen, 2013; M. Meldgaard, 2004). Archaeological reconstructions of bird use are, however, limited for Paleo-Inuit groups. Only recently have some archaeologists focused on the detailed zooarchaeological analysis of bird remains from Paleo-Inuit sites. These studies have revealed that Paleo-Inuit groups incorporated birds into their seasonal rounds in meaningful and strategic patterns (Gotfredsen & Møbjerg, 2004; M. Meldgaard, 2004; Milne & Donnelly, 2004; Monchot, Thompson, Patenaude, & Houmard, 2016). Zooarchaeological analysis of bird remains can, therefore, provide valuable information regarding species preference, butchering patterns, and resource use. Careful examination may also reveal patterns of tool manufacturing from bird bone. This information ultimately informs researchers regarding the resources that contribute to the seasonal movements and dietary adaptations of Paleo-Inuit groups. Zooarchaeological analysis of avian faunal remains is principally included in this dissertation to determine the preferred bird species hunted by Paleo-Inuit groups on the Knud Peninsula of Ellesmere Island, but this analysis may also reveal patterns in bird hunting and processing practices of Paleo-Inuit groups.

5.2 Site Information

The faunal remains analyzed in this study come from Pre-Dorset and Dorset sites located on the Knud Peninsula, Ellesmere Island, Canada (see Figure 5.1). The Knud Peninsula is located on the eastern coast of Ellesmere Island. It is bounded by Flagler Bay to the north, Hayes Fiord to the south, and Buchanan Bay to the east. There are numerous secondary polynyas, areas of sea ice that experience earlier spring break up, around the Knud Peninsula making it an attractive area for human groups (Schledermann & McCullough, 2003). This location is also part of the Sverdrup pass, an ice-free corridor running east to west in the central region of Ellesmere Island. Sverdrup pass is, therefore, a principal migratory route for terrestrial mammals, increasing the attractiveness of the area to human groups.

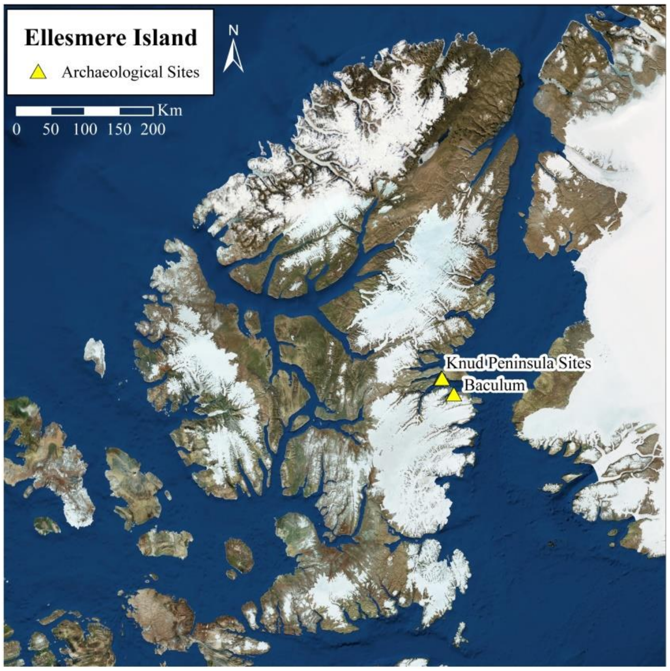

Figure 5.1. Location of Knud Peninsula sites and the Baculum site on Ellesmere Island. Map Courtesy of Adam Benfer. ArcGIS 10.4 software (http://www.esri.com/sofware/arcgis) was used to generate the figure. Service layer credits: Esri, ArcGIS Online, TerraColor (Earthstar Geographics), and the GIS User Community.

This area of Ellesmere Island may have also served as an essential travel route for past human groups moving from Greenland to the Central Arctic and vice versa (Schledermann, 1990). Freezing of the Nares Strait, which runs between Ellesmere Island and Greenland, would have allowed human groups to cross this somewhat narrow stretch of ocean (Grønnow & Sørensen, 2006; Schledermann, 1990). The Knud Peninsula and nearby Bache Peninsula contain evidence of occupation by Independence I, Saqqaq, Pre-Dorset, Dorset, Thule, and possible transitional groups. This is, therefore, a key area to look at Paleo-Inuit populations and their various migrations to and from Greenland.

The materials used in this dissertation came from a series of excavations run by Drs. Peter Schledermann and Karen McCullough on Ellesmere Island between the years of 1977 to

1982 and 1987 to 1988. The sites included in this study come from the Ridge site, the Longhouse site, the Baculum site, the Dorset Shelf site, the Shelter site, the Narrows site, and the Cove site. Only avian faunal remains were included in the zooarchaeological analysis because avifaunal remains needed to be identified for the subsequent stable isotope analysis in this dissertation. The exclusive analysis of avian faunal remains, however, can also reveal important class-specific hunting and butchering patterns that can later be compared to research completed on other animals. The analysis of various species of birds is also useful for future research as these species are also found at other locations in the Arctic. The site information provided below comes from Peter Schledermann's *"Crossroads to Greenland: 3000 Years of Prehistory in the Eastern high Arctic"* (1990), and all faunal percentages are based on Number of Identified Specimens (NISP).

5.2.1 Ridge Site (SgFm-6)

The Ridge site is a multi-component site, approximately 100 meters by 120 meters, including Pre-Dorset Complex features and several Thule tent rings and remains of caches. The Ridge site is located on the shores of the Flagler Bay polynya on the north side of Knud Peninsula. Many of the features excavated at the Ridge site appear to belong to a later period during the Pre-Dorset (3440 ± 50 BP) (Schledermann, 1990). Faunal remains are dominated by the remains of seals, with bird remains being the second most abundant. Caribou (*Rangifer tarandus*), arctic hare (*Lepus arcticus*), arctic fox (*Vulpes lagopus*), and walrus (*Odobenus rosmarus*) bones were also recovered from the Ridge site.

5.2.2 Longhouse Site (SgFm-3)

The Longhouse site is located on the northeast end of the Knud Peninsula and is one of the richest sites in the area, archaeologically. It is a multi-component site, approximately 140 square meters, with a Late Dorset communal longhouse approximately 45m in length being its principal feature (1150 ± 60 BP) (Schledermann, 1990). The Longhouse site also contains components from Late Pre-Dorset and Early Dorset occupations. Within the communal structure, seal bones and bones from migratory waterfowl make up most of the faunal assemblage. Most of the faunal remains used in this research come from the interior of the communal structure; however, there are a few remains from the exterior, a hearth feature, and a winter house.

5.2.3 Baculum Site (SfFl-1)

The Baculum site is an early Dorset site located on a ridge to the east of the Twin Glacier Valley outwash plain and is approximately 140 meters by 100 meters (2780 ± 140 BP) (Schledermann, 1990). The site is situated near the sea, in an area of known secondary polynya development and features small caches, two tent ring outlines, and two activity areas. Seal bones make up most of the faunal assemblage followed by walrus and bird bones. The faunal assemblage also includes a few bones from arctic fox, polar bear (*Ursus maritimus*), and canid species.

5.2.4 Dorset Shelf Site (SgFm-18)

The Dorset Shelf site is located on the Knud Peninsula, in between the Shelter site and the Longhouse site, is approximately 40 square meters, and 9 to 10 meters above sea level. This site is also near the polynya, and likely belongs to the Early Dorset or transitional Late Pre-Dorset to Early Dorset period based on the simple flaking technique present on lithic artifacts at the site. Seals make up approximately 60% of the faunal assemblage, while 31% of the remains are from birds, which is greater than most of the sites in the area.

5.2.5 Shelter Site (SgFm-17)

The Shelter site is approximately 80 meters by 40 meters, and 100 meters northeast of the Longhouse site. Again, this site is situated near the polynya, and it also had the advantage of having protection against southeast winds. The main feature at the site is a Late Dorset rectangular communal structure. This site did not yield very many faunal remains, though bird remains dominate the assemblage at 48.4%, followed by small seal bones at 19.4%.

5.2.6 Narrows Site (SgFm-12)

The Narrows site is located in between the Shelter site and the Cove site on the Knud Peninsula. It is a multi-component site, approximately 140 meters by 280 meters, with features from both the Dorset and Thule cultures. The site also contains a Late Dorset communal structure. 243 bones were recovered from inside of the communal structure, with 82.3% of those bones coming from birds and 12% from seals. A few polar bear and walrus bones were also recovered.

5.2.7 Cove Site (SgFm-5)

The Cove site is approximately 160 meters by 60 meters and located 200 meters east of the Longhouse site and on an old beach terrace. The Cove site is also a multi-component site with both Late Dorset and Thule features. The Cove site also contains a Late Dorset communal structure, although the size of the communal structure at the Cove site is much larger than the structure at the Narrows site. Faunal remains are also more abundant at the Cove site, with approximately 62% of the assemblage consisting of bird bones. Arctic hare, arctic fox, lemming (*Dicrostonyx groenlandicus*), polar bear, walrus, muskox (*Ovibos moschatus*), fish, and seal remains were also recovered at the Cove site.

5.3 Zooarchaeological Analysis of Bird Faunal Remains

Zooarchaeological and taphonomic analysis of avifaunal remains has received considerably less attention compared to the study of remains from mammals. Significant steps have been made in the last two decades to fill in this research (i.e., Gilbert, Savage, & Martin, 1996; Grupe & Peters, 2005; Serjeantson, 2009), however, there are still gaps in our knowledge regarding differential preservation, patterns of processing and butchering of birds, and variation in zooarchaeological evidence for past human groups in different environments.

Element representation, especially the ratio of upper limb to lower limb bones, is a notable topic within the zooarchaeological analysis of birds. Element representation has been used to address the problem of differential preservation and cultural versus natural deposition of bird faunal remains. Ericson (1987) has proposed that wing bones are highly under-represented in anthropogenous faunal collections, while natural accumulations of bird faunal remains have a higher ratio of wing bones to lower limb bones. The under-representation of wing bones at archaeological sites is thought to be due to the preference for meat-rich regions of birds, typically the lower limbs, by humans (Ericson, 1987). Further research by Livingston (Livingston, 1989), however, suggests that limb ratios for bird faunal remains at archaeological sites may be dependent on the species present since limb robusticity varies between waders and birds of prey for example. Differential preservation of bird limb bones based on the main mode of locomotion has been both supported and rejected by other studies (Bovy, 2002; Cruz, 2007).

Contrary to Ericson's (1987) predictions, researchers have noted an abundance of wing bones compared to lower limb bones at certain archaeological sites (Bovy, 2002, 2012; Mannermaa, 2008a). The abundance of wing bones at archaeological sites is usually attributed to ritual practice or symbology since the wings of birds have comparably less meat than the lower limbs, and therefore their presence does not line up with the use of birds for food. Bird wings may also have significance within the shamanic universe for hunter-gatherers because of the belief that birds can act as spiritual guides due to their ability to fly (Balzer, 1996; Kristensen &

Holly, 2013). Element representation in bird faunal remains thus remains a compelling topic within zooarchaeology.

Age and sex determination for avifaunal remains is difficult. There is limited sexual dimorphism for many species, and sex determination is reliant on the presence of medullary bone (Serjeantson, 2009). Medullary bone is only present in females during the period just before egg-laying. Medullary bone accumulates in the long bones of females before breeding as calcium storage for egg production. This also makes the presence of medullary bone a unique indicator of seasonality since many migratory birds have a strict schedule for breeding (Rick, 1975). Medullary bone is spongy in appearance but is denser than the trabecular bone found in the long bones of mammals. Unfortunately, medullary bone can only be observed if the long bone is broken to expose the medullary cavity.

Age determination for bird faunal remains is equally challenging. Birds grow at a much faster rate compared to mammals and lack common age indicators such as dental eruption (Serjeantson, 2002). Age determination for bird faunal remains is therefore reliant on the recovery and identification of unfused epiphyses and epiphyseal fusion. Juvenile diaphyses also have a rough, porous appearance. Skeletal maturity has not been fully explored for birds, although it appears to take place around the time of fledging and this timing varies between bird species (deFrance, 2005; Serjeantson, 2009). The archaeological recovery of bird epiphyses is rare, but diaphyses with unfused epiphyses have been recorded (Gotfredsen, 1997).

Evidence of processing and butchering of bird bones is somewhat similar to the patterns left on mammal bones (Serjeantson, 2009). Human activity on bird bones is mainly in the form of cut marks, burning, and bite marks or tooth punctures. Consistent fracture patterns on select elements can also indicate human processing, for example, long bones often have patterns of spiral fracturing if they were broken to expose the nutrient-rich marrow. Bird bones are hollow and are especially convenient for marrow extraction. Spiral fracturing on bird bones for marrow extraction leaves clean margins and is at an oblique angle (Mannermaa & Storå, 2006; Weisler & Gargett, 1993).

Cut marks are the most obvious evidence for human processing of faunal remains, but the identification and interpretation of cut marks can be difficult. Cut marks, for example, may resemble damage due to excavation or post-depositional processes such as root etching or gnawing (Lyman, 1994b, p. 297). Weathering and post-mortem processes in the burial environment can also destroy or obscure cut marks. Cut marks can be classified into three main purposes including dismembering, flesh removal, and skinning (Serjeantson, 2009). Dismembering of a bird carcass typically leaves deep cuts around areas of articulation or muscle and ligament attachments, flesh removal can leave smaller, striated cut marks, and skinning can sometimes leave cut marks on the skull and pelvis of birds (Lefèvre & Laroulandie, 2014; Monchot et al., 2016; Serjeantson, 2009). Cuts located on the wing bones of birds (humerus, ulna, radius, carpometacarpus, and phalanges) have also been interpreted as cut marks resulting from skin and feather removal (Peresani et al., 2011).

Processing of bird bones for tools and implements can leave characteristic breakage patterns. Grooving patterns resulting from the manufacturing of bird bone needles has been described by Monchot and colleagues (2016) for bird faunal remains recovered from Dorset sites at Nunavik. A humerus and a tibiotarsus were used to produce needles at the Nunavik sites. Grooves were present at the sites on the bones where the needle was detached from the bulk of the long bone. Grooving was found at the distal end of the tibiotarsus (Monchot et al., 2016). Bird bone needles and manufacturing waste from the production of bird bone needles have also been recovered from Nipisat, a Saqqaq site in Greenland (Gotfredsen & Møbjerg, 2004).

Human bite marks are characterized by their ovular shape compared to the round shape resulting from rodents and canines. Crushing of the surrounding bone and within the bite mark are also characteristic of human bite marks (Laroulandie, 2002). Bone damage caused by carnivores is usually in the form of round puncture marks and gnawing at the ends of long bones (Binford, 1981).

5.4 Sample and Methods

The total number of bird bones examined for all seven sites was 1661 bones with 581 bones from the Cove site, 510 bones from the Longhouse site, 324 bones from the Dorset Shelf site, 142 bones from the Narrows site, 65 bones from the Baculum site, 26 bones from the Shelter site, and 13 bones from the Ridge site.

Bones were identified as specifically as possible given preservation and presence of diagnostic features. The comparative zooarchaeology collection located in the Department of Anthropology and Archaeology at the University of Calgary and the Virtual Zooarchaeology of the Arctic Project (VZAP) database were used to identify the faunal remains. Consideration of species distribution in and around Ellesmere Island was also used as a reference. Bird species ranges were based on modern distributions obtained from http://www.iucnredlist.org ("The IUCN Red List of Threatened Species," 2017) and various bird surveys on Ellesmere Island (i.e., Nettleship & Maher, 1973; Trefry, Freedman, Hudson, & Henry, 2010). In many cases, due to the similarity between duck species, the species identified has the most similarities to the comparative collections, but the sample may be from several closely related species, such as the common eider (*Somateria mollissima*) and the king eider (*Somateria spectabilis*).

Number of Identified Specimens (NISP) and Minimum Number of Individuals (MNI) were calculated for the collection of bird faunal remains. NISP and MNI were determined for each species (in some cases to the genus level) for each site. NISP was determined with a count of the number of specimens for each identifiable genus or species and element. MNI was calculated using the element with the greatest number of specimens identifiable to genus or species while accounting for side and fracturing (Lyman, 1994a).

Skeletal representation of wing bones compared to leg bones and bones of the pectoral girdle was also calculated for each site and the total collection. Wing-to-leg ratio and pectoral girdle-to-wing ratio were calculated using formulas provided by Monchot and colleagues (2016). Bones of the wing include the humerus, ulna, and radius, bones of the leg include the femur and tibiotarsus, and bones of the pectoral girdle include the coracoid and scapula. The following are the formulas used in the calculations for wing-to-leg ratio and pectoral girdle-to-wing ratio:

% Wing (Wing-to-Leg Ratio) = NISP Wing/ (NISP Leg + NISP Wing) x 100

% Pectoral Girdle = NISP Pectoral Girdle/ (NISP Wing + NISP Pectoral Girdle) x 100

Weathering was classified based on Behrensmeyer’s (1978) stages of bone weathering. Bird bone weathers in a similar pattern to mammalian bone, with the exception that bird bone tends to crack through the cortical bone before flaking of the external surface occurs (Behrensmeyer, Stayton, & Chapman, 2003).

Age and sex were determined when possible and were based on epiphyseal fusion for age determination and the presence of medullary bone for sex determination. Lack of epiphyseal fusion was recorded when observed. Long bones with a particularly spongy appearance were also noted. The presence of medullary bone was recorded when observed. Medullary bone is only visible if the bone has been fractured near the shaft, exposing the medullary cavity, or if the bones were sectioned for stable isotope analysis.

Evidence of human activity on the bones was classified into evidence of burning, butchering, and consumption. Blackening and calcination were both considered evidence of burning on the bones. Evidence of butchering included spiral fracturing, cut marks, and in some cases, repeated breakage patterns in the same area for certain elements. Human consumption included evidence of human bite marks or chewing. Bite marks and gnawing created by canines and rodents were considered separately from human bite marks.

5.5 Results

5.5.1 Species Present

Bones could be identified to the class Aves based on the appearance of internal struts in the marrow cavity, which are not present in mammal bones (Darwent & Foin, 2010; Driver et al., 2011). Unfortunately, many of the bird bones were heavily processed and could not be identified past the class level. Long bones were often missing both ends likely due to marrow extraction and therefore lacked diagnostic features. The majority of identifiable bones, however, came from ducks and geese. Ducks, unfortunately, are one of the hardest remains to identify down to the species level. The next most abundant species present in the collection were brant geese (*Brant bernicla).* Other birds in the faunal collection included birds from the cormorant genus (*Phalacrocorax),* the arctic tern (*Sterna paradisaea),* the glaucous gull *(Larus hyperboreus),* the snow goose (*Chen caerulescens),* pintail ducks (*Anas acuta),* thick-billed murres (*Uria lomvia*), black-legged kittiwakes (*Rissa tridactyla*), parasitic jaegers (*Stercorarius parasiticus*), rock ptarmigan (*Lagopus muta*) and birds from the phalarope (*Phalaropus*) genus (see Table 5.1). Masses of the identified bird species are also provided in Table 5.2.

	NISP	**MNI**
Pintail Duck	11	4
Brant Goose	28	7
Snow Goose	3	2
Eider Duck	203	35
Dovekie	5	2
Thick-Billed Murres	6	5
Glaucous Gull	8	2
Black-Legged Kittiwake	7	2
Arctic Tern	3	2
Parasitic Jaeger	6	3
Cormorant	4	3
Phalarope	2	1
Rock Ptarmigan	2	1
Raven	1	1

Table 5.1. Total NISP and MNI for identifiable bird species from all Knud Peninsula sites.

Bird	Male Mass (g)	Female Mass (g)	Species Mass (g)
King Eider	1668	1567	
Common Eider	2218	1915	
Brant Goose	1293	1224	
Northern Pintail	1006	887	
Glaucous Gull	1855	1497	
Black-Legged Kittiwake			365-400
Thick-Billed Murre	802-1180	734-1140	
Parasitic Jaeger	413	478	
Dovekie	147-200	145-167	
Great Cormorant	3240	2630	
Snow Goose	2744	2517	
Arctic Tern			86-127
Rock Ptarmigan	521	550	
Common Raven			1097

Table 5.2. Mass of bird species identified at Knud Peninsula sites based on modern samples.

* Bird masses were obtained from Dunning (2008)

There are no postcranial skeletal features that separate common eiders from king eiders (Gotfredsen & Møbjerg, 2004). Size can sometimes be used to separate the two species, but there is considerable overlap for the two species in the postcranial skeleton. Common eiders are slightly larger than king eiders, but often only by millimeters (M. Meldgaard, 2004, p. 102). Given the location of the sites on Ellesmere Island and the modern range for eider migration, the eider ducks recovered are likely king eiders, though climatic changes through time may have affected the ranges of eider ducks in the past. Many of the bones are also on the smaller size range for common and king eider, which would be consistent with the identification of king eider. The identifications in this dissertation are kept at the genus level for eider ducks because exact measurements for long bones were not taken due to the high level of processing and fracturing of long bones. There were also no identifiable cranial bones recovered from eider ducks thus a definitive classification could not be made.

5.5.2 NISP and MNI

Eider ducks made up the majority of the identifiable species at every Knud Peninsula archaeological site. The Cove site yielded the greatest variety of bird species but had comparatively fewer eider ducks compared to the Longhouse and Dorset Shelf sites for both the NISP and MNI calculations. The Shelter and Ridge sites yielded the least number of identifiable remains for NISP and MNI respectively. NISP and MNI values can be found for each site in Tables 5.3 to 5.9:

	NISP	**MNI**
Pintail Duck	3	1
Brant Goose	10	2
Snow Goose	1	1
Eider Duck	40	5
Dovekie	3	1
Thick-Billed Murre	5	4
Glaucous Gull	6	1
Black-Legged Kittiwake	7	2
Parasitic Jaeger	5	2
Rock Ptarmigan	2	1
Raven	1	1

Table 5.3. NISP and MNI for bird species at the Cove site.

	NISP	MNI
Pintail Duck	3	1
Brant Goose	16	3
Eider Duck	47	6
Dovekie	2	1
Glaucous Gull	2	1
Arctic Tern	1	1
Phalarope	2	1
Parasitic Jaeger	1	1

Table 5.4. NISP and MNI for bird species at the Longhouse site.

	NISP	MNI
Pintail Duck	5	2
Brant Goose	1	1
Snow Goose	2	1
Eider Duck	78	13

Table 5.5. NISP and MNI for bird species at the Dorset Shelf site.

	NISP	MNI
Brant Goose	1	1
Eider Duck	24	6
Cormorant	4	3
Arctic Tern	2	1

Table 5.6. NISP and MNI for bird species at the Narrows site.

	NISP	MNI
Eider Duck	3	2
Thick-Billed Murre	1	1

Table 5.7. NISP and MNI for bird species at the Baculum site.

	NISP	MNI
Eider Duck	3	2

Table 5.8. NISP and MNI for bird species at the Shelter site.

	NISP	MNI
Eider Duck	8	1

Table 5.9. NISP and MNI for bird species at the Ridge site.

5.5.3 Element Representation

Of the 1661 bird faunal remains recovered, 1299 of the bones were identifiable to element. Of the 1299 bones identifiable to element, 289 of those bones could be identified to at least the genus level. Tibiotarsi are the most abundant long bones recovered from all the Knud Peninsula sites, while the hyoid, pygostyle and quadrate are the least represented (see Table 5.10).

Element	NISP
Carpometacarpus	18
Coracoid	92
Cranium	23
Femur	78
Furcula	62
Humerus	108
Hyoid	3
Mandible	61
Phalanges	70
Pygostyle	3
Quadrate	3
Radius	66
Rib	225
Scapula	64
Sternum	78
Synsacrum	20
Tarsometatarsus	66
Tibiotarsus	153
Ulna	39
Vertebra	67
Unidentifiable	362

Table 5.10. NISP for the elements recovered from all sites.

For the comparison of wing bones to leg bones and bones of the pectoral girdle, ratios vary between sites (see Table 5.11). The ratios calculated for the entire collection do, however, deviate from the ratios expected if the complete skeleton of birds were present at the archaeological sites.

	Wing-to-leg ratio				Pectoral girdle-to-wing ratio	
	Wing (NISP)	Leg (NISP)	%Wing		Pec. Girdle (NISP)	% Pec. Girdle
Expected for Complete Skeleton	8	6	57.14		4	33.33
Cove	68	43	61.26		36	34.62
Longhouse	51	46	52.58		42	45.16
Dorset Shelf	69	87	44.23		48	41.03
Narrows	17	12	58.62		15	46.88
Baculum	1	25	3.85		12	92.31
Shelter	4	2	66.67		1	20.00
Ridge	3	5	37.50		2	40.00
Grand Total	213	220	49.19		156	42.28

Table 5.11. Wing-to-leg ratio and pectoral girdle-to-wing ratio for combined bird species.

5.5.4 Age and Sex

A scapula from an unidentified bird was recovered from the Dorset Shelf site with an unfused proximal epiphysis, a left tibiotarsus from a brant goose from the Dorset Shelf site had an unfused proximal epiphysis, and the epiphyseal line was still present on the proximal end of a left scapula of an eider duck from the Longhouse site. Long bone diaphyses with a rough, spongy appearance were also noted for 56 of the bird bones. Medullary bone was observed in a left coracoid and a left scapula belonging to eider ducks from the Narrows site, a left coracoid from an eider from the Dorset Shelf site, and a right scapula from an eider and a left tibiotarsus from an unidentified bird from the Longhouse site.

5.5.5 Preservation

Preservation for the entire collection was comparably good, with weathering at stages 0 to 2 for a majority of the bird faunal remains, although remains from the Dorset Shelf site displayed further stages of weathering (Stages 3 and 4). Cortical bone appearance and the presence of smaller elements such as ribs and phalanges indicate that the overall preservation was decent for archaeological sites on the Knud Peninsula. The bird faunal remains were however highly fragmented due to spiral fracturing. Most of the bones were the expected beige or tan colour, but some of the bones were also stained a darker brown colour or were bleached white. There was minimal carnivore or rodent disturbance to the faunal remains as only four of the bird bones display evidence of carnivore or rodent bite marks.

5.5.6 Evidence of Butchering and Human Manipulation

Evidence of butchering on the avian remains mainly consisted of spiral fractures on long bones, although cut marks were also present on the ends of numerous long bones. Spiral fracturing was recorded for 28% of the bird bones (467 of the 1661 bird bones). Spiral fractures were mainly found on humeri and tibiotarsi followed by femora, ulnae, and radii (see Plate 5.1). Cut marks were recorded on 1% of the bird bones (18 of the 1661 bird bones). Cut marks were identified on coracoids, scapulae, humeri, radii, femora, and tibiotarsi, and were often toward the proximal and distal ends. Some of these cut marks were shallow, clustered, and facing in the same direction, which is consistent with marks typically left during de-fleshing of an animal. Deeper cut marks identified on areas such as the posterior side of the medial condyle of the tibiotarsus are identified as disarticulation cuts. Evidence of burning was also recorded for 3% of the bones in the collection (54 of the 1661 bird bones). Human bite marks were identified on one duck coracoid at the Cove site. The bite mark is ovular, and there is associated crushing of the bone both in and around the bite mark (see Plate 5.2).

Plate 5.1. Spiral fracture on the proximal end of tibiotarsus of *Somateria* sp.

Plate 5.2. Possible human bite mark on the coracoid shaft of *Somateria* sp.

In addition to the spiral fractures observed on bird long bones, certain elements, such as the coracoid, display consistent patterns of breakage. The distal ends of coracoids were broken for 28 out of 92 coracoids (30%), with many of the fractures located on the lateral distal end as seen below (Plate 5.3).

Plate 5.3. Coracoid of *Somateria* sp. with fracturing of the lateral distal end.

Some of the bones analyzed display evidence of processing of bird bones for tools. Three tibiotarsi from the Cove site show evidence of modification by humans beyond the processing of birds for consumption, two of the modified bones are from species other than the eider duck, and the final tibiotarsus is unidentifiable to species. The tibiotarsi of a thick-billed murre and a rock ptarmigan were possibly used in needle manufacturing (note the thin and tapered bone fragment in Plate 5.4 and the notching and grooves in Plate 5.5), while the tibiotarsus of an unidentified species was possibly fashioned into a whistle (see Plate 5.6). These modified bones are also not finished tools but appear to be discarded after manufacturing or due to breakage.

Plate 5.4. Possible needle pre-form fashioned from tibiotarsus of *Uria lomvia*.

Plate 5.5. Notched tibiotarsus of *Lagopus muta* as a result of needle manufacturing.

Plate 5.6. Possible whistle fashioned from a bird tibiotarsus.

5.6 Discussion

The majority of the identifiable bird faunal remains recovered from the Pre-Dorset and Dorset sites on the Knud Peninsula belong to the eider duck genus. The presence of medullary bone and a limited number of juvenile duck bones indicates that eider ducks were likely being hunted in July and August, after the breeding period, based on modern-day nesting behavior of king eiders (Ogilvie, 2005). The limited number of juvenile remains also indicates that they preferentially hunted adult ducks. Although egg shells were not recovered, the large number of bird bones recovered from the Knud Peninsula sites likely means that eggs were also collected by Pre-Dorset and Dorset groups.

The hunting of ducks and geese is also seen at other Paleo-Inuit sites, though with notable differences. Eider ducks and brant geese were also the preferred subsistence birds for some Saqqaq and Dorset groups (Gotfredsen, 1997; Gotfredsen & Møbjerg, 2004; Monchot et al., 2016). Although the Saqqaq at Nipisat also exploited greater numbers of thick-billed murres and guillemots for their diet compared to the Pre-Dorset and Dorset on the Knud Peninsula. The Dorset site (KcFs-2) on Nunavik also yielded a higher number of thick-billed murres compared to eider ducks (Monchot et al., 2016). The faunal remains from the Pre-Dorset site on Baffin Island, Mosquito Ridge, were predominantly composed of snow geese (Milne & Donnelly, 2004). The variation in bird species seen in just these few archaeological sites belonging to Paleo-Inuit groups illustrates the broad and flexible subsistence strategies that allowed the Paleo-Inuit to migrate and colonize across the Arctic. Though species preference may be related to the availability of bird species, the range of bird species exploited demonstrates that Paleo-Inuit groups incorporated the birds that were in their environment whenever possible.

The element representation seen at the Knud Peninsula sites is somewhat different compared to the sample recovered from Dorset sites in Nunavik. There was a notable lack of bones of the pectoral girdle (coracoid and scapula) at the Tayara site while the Knud Peninsula sites, except the Shelter site, had pectoral girdle-to-wing ratios above the expected value. While the Cove, Narrows, and Shelter sites had wing-to-leg ratios above the expected ratio, the overall ratio for the entire collection was below the expected ratio. The Dorset sites at Nunavik all show wing-to-leg ratios above the expected ratio. The element representation at the Knud Peninsula sites, therefore, suggests that whole birds were likely transported back to the site for processing and consumption. There does not appear to be a clear differential representation of elements, other than the lack of cranial and axial bones, though these are comparably thinner than the long bones of birds and are more likely to be fragmented and destroyed.

Based on the large number of long bones with spiral fracturing, as well as the presence of burning and cut marks on the bones, the bird faunal remains were likely a result of human consumption and processing. Though burning and cut marks were present on several of the bird bones, the percentage was very low (3% and 1% respectively). The lack of cut marks in association with the large number of long bones with spiral fracturing may indicate that the birds were simply processed by hand with very little use of stone tools. The low incidence of burning found on the bird bones suggests that birds were likely processed and consumed raw or boiled and not roasted. Another explanation that accounts for the lack of burning and cut marks on the bird bones is that these birds were cached and fermented, similar to the practices of the Polar Inughuit (Ekblaw, 1919; Holtved, 1967; T. B. Johansen, 2013). The fermentation process softens the meat and bones of the birds making it possible to eat the bird whole, including bones (Maxwell, 1985). This practice amongst the Polar Inughuit traditionally uses dovekies with smaller bones, so the use of larger birds such as the eider duck may result in the disposal of larger bones since they may not be as soft. This may help to explain why larger bones such as the humerus have been preserved within this collection. Some birds may have been eaten fresh, right after capture, while the majority of the birds were cached and fermented for the winter, which may also help to explain the low incidence of cut marks.

Spiral fracturing is found mostly on the humeri and tibiotarsi. These bones are typically the longest and have a greater circumference compared to other long bones in birds. Their length and size are therefore associated with the greatest amount of marrow. Spiral fracturing on these bones is therefore consistent with marrow extraction by Pre-Dorset and Dorset groups. Marrow extraction and consumption likely occurred for both fresh and fermented birds; however, the fracture pattern of long bones that have been fermented is unknown, but they may resemble fresh bone since it is not dry and brittle.

Breakage of the lateral distal end of the coracoid in many of the remains shows that this area may have been a disarticulation point for butchering. The coracoid articulates with the furcula, scapula, and sternum, and serves to support the humerus. The distal end of the coracoid is attached to the sternum in birds and is also the most delicate feature of this element. It would, therefore, be the area most likely to break during disarticulation of the pectoral girdle from the sternum or body of the bird. Further experimental work with disarticulation of modern birds may clarify this breakage pattern seen on the coracoid.

The presence of bird bones with human modification unrelated to subsistence practices indicates that the Dorset were also manufacturing bone needles out of bird bone. This is consistent with the practice seen at other Dorset sites and Saqqaq sites. The possible bird bone whistle within this collection is also compelling. Bird bone whistles are rare within the archaeological record and very few if any have been reported for Dorset groups. Items fashioned from bird bones were, however, only identified for the Cove site. This may be because the Cove site had the largest collection of bird bones compared to the other sites. The presence of waste from bird bone tool manufacturing and the bird whistle at the Cove site may also be associated with the large communal structure.

5.7 Conclusion

The bird faunal remains recovered from the Knud Peninsula illustrate that the Pre-Dorset and Dorset in this area selectively hunted eider ducks during the spring and summer. The birds were highly processed to yield as much meat and marrow as possible. Birds may have also been stored and fermented for winter consumption. Though birds cannot replace the importance of marine and terrestrial animals in Paleo-Inuit diets, they are a reliable resource that is likely easier to capture. The variety of birds exploited between different Paleo-Inuit groups illustrates that they actively incorporated birds into their seasonal rounds. This study demonstrates the range of information that can be uncovered through the detailed zooarchaeological analysis of bird remains.

Chapter Six: Variability in Isotopic Tissue Spacing Values for *Anas Platyrhynchos*

6.1 Introduction

The use of stable isotope mixing models is now common practice for paleodietary reconstructions. Isotopic mixing models help researchers to determine the possible proportions of sources (food items) contributing to a mixture (diet). Isotopic mixing models, however, rely on stable isotope values entered by the user for the subject of study (human bone collagen), the possible sources (faunal bone collagen) contributing to the resulting stable isotope value, and spacing/offset values between diet and tissues and between tissues (bone collagen to flesh). Spacing values are needed because stable isotopes from the diet are re-distributed to tissues of the consumer disproportionately due to metabolic processes. They are especially important for paleodietary reconstruction because the bioarchaeologist is often limited to reconstructing diet from materials preserved in the archaeological record, namely bone. Humans, however, mainly consume the fat and muscle of animals, and the isotopic signatures from these tissues differ from the signatures obtained from bone collagen. Isotopic offset values allow the researcher to calculate the muscle and fat stable isotope ratios of prey species from bone collagen.

The diet-to-tissue and tissue-to-tissue spacings have been investigated for mammals by multiple researchers (Ambrose & Norr, 1993; DeNiro & Epstein, 1978, 1981; Tieszen et al., 1983; Tieszen & Fagre, 1993; Vogel, 1978) but not as extensively for other classes of animals, such as birds. Some information regarding avian tissue spacings is available in the ecological literature (i.e., Hobson, 1995; Hobson & Clark, 1992b; Mizutani, Fukuda, Kabaya, & Wada, 1990); however, this issue has not been explored within the bioarchaeological literature, and often not from a tissue-to-tissue spacing perspective. Ecologists have different goals than bioarchaeologists, and they are mainly concerned with understanding avian metabolism and resource use during migration and breeding. Ecologists also prefer to analyze tissues that are easily collected and processed with minimal impact on the animals, for example, feathers and blood are easily collected, do not injure the animal, and can be analyzed with very few or no processes or treatments. Stable isotope analysis used in paleodietary reconstruction still relies on spacing values determined for mammals regardless of the animal classes included in the study. The assumption that spacing values are similar amongst all animal classes has not been tested in the bioarchaeological literature. The lack of avian-specific values can, therefore, lead to misinterpretation regarding the contribution of birds to the diet of past populations if these values differ from mammal values. This research will test the hypothesis that dietary and tissue spacing values for mallard duck (*Anas platyrhynchos)* bone collagen, muscle, fat, and feathers differ from those of mammals and will determine if spacing values are required for different animal classes. Meta-analyses in the ecological literature show that there are meaningful differences in diet-to-tissue spacings for animals from different classes that may be a reflection of these variabilities in physiology (Becker, Newman, Inglis, & Beissinger, 2007; Vanderklift & Ponsard, 2003).

6.2 Birds in Stable Isotope Analysis

The need for tissue spacing values in stable isotope research was recognized in the bioarchaeological and ecological literature during the late 1970s and early 1980s and a number of researchers explored tissue spacing values through laboratory and field experiments to address this problem (DeNiro & Epstein, 1978, 1981; Vogel, 1978). Where bioarchaeologists required tissue-to-tissue spacing values due to the limited tissues recoverable in the archaeological record, ecologists placed emphasis on diet-to-tissue spacings because they were interested in how dietary isotopic signatures were routed to different animal tissues.

Stable isotope analysis in dietary reconstruction progressed, but paleodietary researchers continued to question some of the assumptions that were being made at the time, especially the assumption that the isotopic values of our tissues are a direct indication of our diet. They were also unsure of the relationship between the nutrients consumed and how these would be re-distributed to different tissues (i.e., bone collagen versus muscle). Researchers during this period were especially interested in the difference between stable carbon isotope ratios of bone collagen and bone carbonate and the macronutrients that were routed to these tissues. Controlled dietary experiments were carried out on rats and mice. Researchers found that bone collagen stable isotope values are mainly reflective of the protein portion of the diet, while bone carbonate gave a better indication of whole diet (Ambrose & Norr, 1993; Tieszen & Fagre, 1993). During this process, isotopic offset values between bone collagen and bone carbonate were reported for rats and offset values between bone collagen and muscle were reported for mice (Ambrose & Norr, 1993; Tieszen & Fagre, 1993). Research regarding offset values as it applies to paleodietary studies, unfortunately, dropped off at this point. Paleodietary studies have therefore continued to use these offset values established for mammals during reconstruction and in mixing models.

Separate diet-to-tissue and tissue-to-tissue spacing values need to be determined for birds because they form an entirely different class than mammals, and thus have different evolutionary histories and physiological adaptations. Physiological differences between birds and mammals, especially ones that relate to digestion and excretion, can mean that nutrients are routed to tissues differently between the two classes resulting in different stable isotope enrichment values.

Avian diet-to-tissue spacing values are valuable if a researcher is trying to determine the dietary items in avian diet. Bioarchaeologists are more concerned with tissue-to-tissue spacing values because we are trying to determine the isotopic value of avian muscle from avian bone collagen. Tissue-to-tissue spacing values are limited but have been established for some mammals and have only been addressed in the ecological literature for birds in one study (Refer to Tables 6.1 and 6.22). As the values in Tables 6.1 and 6.2 indicate, tissue spacing values can vary by approximately one permil for the same tissues in different mammal species, especially for stable carbon isotope ratios. Less tissue-tissue spacing data is available for stable nitrogen isotope ratios; however, with the values available, it is evident that tissue spacing values can also vary by approximately one permil.

	Δ Collagen-Muscle (‰)	Δ Collagen-Fat (‰)	Δ Collagen-Hide (‰)	Δ Collagen-Keratin (‰)
Ungulates (Vogel 1978)	+2.3	+7.9	+0.6	
Mice (Tieszen and Fagre 1993)	+2.25			
Pig (Nardoto et al. 2006)	+1.1 ± 1.6			
Wolf (Fox-Dobbs et al. 2007)	+1.5 ± 0.7			+0.4 ± 0.8
Primates (Crowley et al. 2010)	+1.0 ± 1.1			+0.9 ± 1.1
Northern fulmars (Thompson and Furness 1995)	+2.8			+1.6

Table 6.1. Stable carbon isotope tissue-to-tissue spacing values for mammals and one species of bird in the current literature.

	$\Delta_{\text{Collagen-Muscle}}$ (‰)	$\Delta_{\text{Collagen-Fat}}$ (‰)	$\Delta_{\text{Collagen-Keratin}}$ (‰)
Pig (Nardoto et al. 2006)	+0.9 ± 0.6‰		
Wolf (Fox-Dobbs et al. 2007)	-0.5 ± 0.8		+0.3 ± 0.7‰
Primates (Crowley et al. 2010)	-0.1 ± 1.0‰		+0.8 ± 0.9‰

Table 6.2. Stable nitrogen isotope tissue-to-tissue spacing values for mammals in the current literature.

Avian diet-to-tissue spacings are still discussed here because the preponderance of ecological data is on diet-to-tissue spacings, and these data serve as important comparative data to demonstrate any differences between bird and mammal isotopic signatures. As stated above, most of the ecological research regarding bird diet-to-tissue spacings in stable isotope analysis has been carried out on feathers (Refer to Table 6.3). Feathers are readily available and can be collected with minimal stress on the animal, thus making it an ideal tissue for ecological research, which is often concerned with the routing of nutrients to various tissues to address research questions about migration and metabolism.

To date, there have only been two studies within the ecological literature that include bone collagen in their diet-to-tissue spacing analyses and calculations. Neither of these studies included birds from the family Anatidae, which includes birds such as ducks and geese. Values for ducks and geese may be especially important for bioarchaeological research because they were often hunted by hunter-gatherer groups and provide greater quantities of meat and fat compared to other birds.

Bird	**Bone Collagen**		**Muscle**		**Feathers**	
	δ^{13}C (‰)	**δ^{15}N (‰)**	**δ^{13}C (‰)**	**δ^{15}N (‰)**	**δ^{13}C (‰)**	**δ^{15}N (‰)**

Bird	Bone Collagen		Muscle		Feathers	
	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Great Cormorant[1] (Mizutani et al. 1991)	+2.5	+3.9	+2.1	+2.4	+3.6	+3.6
Black-Tailed Gull (Mizutani et al. 1992)					+3.6 ± 0.5	+5.3 ± 0.8
Nankeen Night Heron (Mizutani et al. 1992)					+3.2 ± 0.4	+4.2 ± 0.3
Great White Egret (Mizutani et al. 1992)					+3.1 ± 0.4	+3.9 ± 0.2
Grey Heron (Mizutani et al. 1992)					+3.4 ± 0.6	+4.3 ± 0.4
Scarlet Ibis (Mizutani et al. 1992)					+3.8 ± 0.3	+4.5 ± 0.4
White Ibis (Mizutani et al. 1992)					+2.5 ± 0.5	+4.3 ± 0.5
Flamingo (Mizutani et al. 1992)					+3.6 ± 0.6	+5.6 ± 0.3
Great Cormorant (Mizutani et al. 1992)					+3.8 ± 0.5	+3.7 ± 0.6
Humboldt's Penguin (Mizutani et al. 1992)					+2.9 ± 0.2	+4.8 ± 0.5
Domestic Chicken (Hobson and Clark 1992)	+0.8 ± 1.2	+1.5 ± 0.1	+0.3 ± 0.3	+0.2 ± 0.2	-0.4 ± 0.02	+1.1 ± 0.1
Japanese Quail (Hobson and Clark 1992)	+2.7 ± 0.4	+2.5 ± 0.4	+1.1 ± 0.5	+1.0 ± 0.1	+1.4 ± 0.6	+1.6 ± 0.1
Ring-billed Gull (Hobson and Clark 1992)	+2.6 ± 1.1	+3.1 ± 0.2	+0.3 ± 0.4	+1.4 ± 0.1	+0.2 ± 1.3	+3.0 ± 0.2
Subantarctic Skua[3] (Thompson & Furness, 1995)					+3.0	+0.4
Broad-billed Prion[2,3] (Thompson and Furness 1995)					+2.5	+4.3
Common Murre[2,3] (Thompson and Furness 1995)					+1.0	+3.3
Arctic Tern[3] (Thompson and					+2.1	+3.4

Bird	Bone Collagen		Muscle		Feathers	
	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Furness 1995)						
Great Cormorant (Bearhop, Waldron, Votier, & Furness, 2002)					+2.3	+4.2
Great Skua (Bearhop et al. 2002)					+2.1	+4.6
Dunlin (Evans Ogden, Hobson, & Lank, 2004)			+1.9	+3.1		
King Penguin (Cherel et al. 2005)					+0.1	+3.5
Rockhopper Penguin (Cherel et al. 2005)					+0.1	+4.4
Common Murre (Becker et al. 2007)					+1.9 ± 0.3	+3.7 ± 0.2
Spectacled Eider (Federer, Hollmén, Esler, Wooller, & Wang, 2010)					+3.2 ± 0.2	+5.6 ± 0.3
California Condor[2] (Kurle et al., 2013)					+0.4 ± 0.4	+3.1 ± 0.1

Table 6.3. Literature values for diet-to-tissue spacings for avian bone collagen, muscle, and feathers.

[1] Lipids not removed from tissues
[2] Data from chicks
[3] Diet values based on regurgitated food or stomach contents. All other bird samples had controlled diets.

The two studies that include bone collagen do however indicate that there may be differences in diet-to-tissue spacings of birds, specifically for bone collagen, compared to mammals. Hobson and Clark (1992b) demonstrated that there were lower diet-to-tissue spacing values in birds compared to mammals when looking at stable carbon isotopes and that there is variability in the diet-to-tissue spacings in different species of birds. They found that the bone collagen diet-to-tissue spacings for stable carbon isotopes for three different species of birds varied from +0.8 to +2.7‰ (Hobson & Clark, 1992b); while DeNiro and Epstein (1978) determined that bone collagen diet-to-tissue spacings for mice varied from +3.5 to +4.4‰. Mizutani and colleagues (1991) also report a similar diet-to-tissue spacing for cormorants, a type of seabird, with an average enrichment of +2.5‰ for stable carbon isotope ratios between diet and bone collagen.

Though they did not find differences in diet-to-tissue spacing values in birds compared to mammals for stable nitrogen isotopes, Hobson and Clark (1992b) suggest that there may be variation with further experimentation and a larger sample size due to the differences in how birds and mammals excrete nitrogenous waste. This finding was supported by the meta-analysis completed by Vanderklift and Ponsard (2003), which found that the biochemical form of nitrogen excretion and nutritional status were the main sources of variation in $\delta^{15}N$ enrichment among 134 estimates from controlled studies of diet to consumer $\delta^{15}N$ enrichment. Birds produce uric acid instead of urea, which is produced by most mammals. The level of discrimination against the heavier isotope during the production of urea versus uric acid may differ. Bone collagen diet-to-tissue spacings for stable nitrogen isotopes varied from +1.5 to +3.1‰ for birds (Hobson & Clark, 1992b), and from +1.4 to +3.4‰ for mice (DeNiro & Epstein, 1981). Mizutani and colleagues (1991) however, found that the average enrichment between diet and bone collagen for cormorants was +3.9‰ for stable nitrogen isotope ratios, which is slightly elevated compared to mammals and the bird values reported by Hobson and Clark (1992b).

Due to the variability in both dietary and tissue enrichment values documented by previous ecological studies, it is imperative that dietary reconstruction using stable isotope analysis in bioarchaeology recognize and test the possible variation in the diet-to-tissue and tissue-to-tissue spacings in birds. Further comparative studies considering different bird tissues are also encouraged within the ecological literature.

6.3 Samples and Methods

Since the goal of this research was to determine dietary spacing values for various avian tissues, it was important to obtain bird samples with a known dietary source that could also be analyzed to control for as many variables as possible. For this purpose, ducks were obtained from a local supplier who could also supply the feed used for the ducks. These birds were food-grade, prepared for sale for human consumption (i.e., plucked, cleaned, etc.), and frozen by the time of purchase by the researcher. Unfortunately, eggs could not be obtained for analysis because the food-grade ducks provided by the farm were not egg-laying ducks, and the egg-laying ducks could not be obtained from this farm. The ducks used for food and the ducks used for laying eggs were also of different species.

All the ducks used in this research were from the same flock and were therefore of the same age. These ducks were also all fed the same type of feed. Ducks were chosen for sampling because waterfowl were commonly eaten by hunter-gatherers. Though wild ducks would better reflect the dietary items that hunter-gatherers would have obtained, numerous variables such as diet, body condition, and age would not be controlled for. By controlling for these variables, the variation in isotopic signatures between tissues would be more reflective of actual differences in metabolic activity between tissues.

The following tissues were chosen for sampling: muscle, fat (n=10), bone collagen (n-10), and feathers (n=9). Both lipid-extracted muscle (n=10) and muscle with lipids (n=10) still present were included in the analyses. Analyzing lipid-extracted muscle, muscle with lipids, and fat allows for the analysis of individual tissue types, as well as for the analysis of what past human groups were most likely eating. Bone collagen was analyzed because this tissue is often the only tissue still present in the archaeological record for stable isotope analysis. Finally, feathers were chosen for analysis because feathers are often analyzed within the ecological literature, and would, therefore, provide comparative data for avian dietary spacing values.

Feathers, muscle, fat, and bone were obtained from frozen food-grade Grimaud Pekin hybrid ducks (*Anas platyrhynchos)* from Leduc, Alberta[1]. Duck feed was also provided for stable isotope analysis by the same supplier. Feathers from the same flock came from the collection of feathers naturally moulted and recovered from their barns. It was not possible to obtain feathers directly from the sampled ducks since they were cleaned and processed in another facility separate from the supplier. All the ducks were fed the same diet; therefore, little variability due to diet is expected between animals in terms of stable isotope ratios for individual feathers. All tissue samples were stored frozen until ready for processing and analysis.

6.3.1 Muscle and Fat Tissue Samples

Samples of muscle with visible fat were dissected from frozen birds. All muscle and fat tissues came from the legs of the birds since this section was also used to obtain the tibiotarsus

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[1] Duck and feed samples came from Greens Eggs and Ham Food Artisans in Leduc, Alberta

bone samples. Samples included muscle samples with lipids removed, muscle and lipid samples, and fat samples. Lipids are defined as biological substances that are soluble in organic solvents, not soluble in water, and contain long-chain hydrocarbon groups (Kates, 1972). Within an organism, lipids are often referred to as fat, although this is usually referring to fatty tissue and not the chemical substance. The chemical procedures used in this research are designed for total lipid extraction; therefore, lipids will be the favoured term for this dissertation; however, fat may be used to describe preferred dietary items or visible tissues within an organism.

Muscle tissues were divided into two batches, one where lipids were extracted and one with lipid still in the samples. For the lipid-extracted muscle, visible fatty tissue was removed from the muscle using a scalpel. The muscle samples were cleaned with double distilled water, and then dried at 60°C in an oven for 48 hours and powdered with mortar and pestle. Lipids were extracted from the powdered, dried muscle using a 1:2 solution of chloroform and methanol, and a vacuum filter (Bligh & Dyer, 1959). Lipid-extracted muscle samples were then rinsed again with double distilled water and air-dried. Muscle samples with lipid still present were cleaned with double distilled water, dried at 60°C in an oven for 48 hours and powdered using mortar and pestle.

Fat samples were dissected from duck tissue samples using a scalpel. Fat samples were then cleaned with double distilled water and freeze-dried in a Virtis Benchtop 3L Benchtop freeze drier. Freeze-drying minimizes the amount of liquid in the sample for easier sectioning and placement into tin cups for analysis in the mass spectrometer.

6.3.2 Bone Collagen

Bone samples were also dissected from frozen birds, specifically from the leg portion to target the tibiotarsus. The tibiotarsus was chosen for analysis due to its large size which would ensure an adequate sample size for stable isotope analysis. Bone collagen samples were prepared for stable isotope analysis in the Bone Preparation Lab in the Department of Archaeology at the University of Calgary.

For the processing of bone tissue prior to stable isotope analysis, muscle and other tissues such as ligaments and the periosteum were removed using a scalpel. Bones were split using a Dremel rotary tool to remove marrow and to section the bone into small pieces. The bones were also cleaned using sonication in double distilled water prior to collagen extraction. Collagen extraction was completed based on Judith Sealy's method for collagen extraction from archaeological bone with an added step for lipid extraction and no sodium hydroxide soak to remove contaminants due to the sample being fresh and not archaeological (Sealy, 1986). Cleaned bones were demineralized in 1% hydrochloric acid for 24 to 48 hours per wash, with the number of washes varying due to the size of the sample. Demineralization is complete when signs of a chemical reaction are no longer present, for example, the solution is clear and colourless, and there are no bubbles present on the surface of the bone and in the solution. The collagen pseudomorph of the bone would also be spongy or soft when probed with a stirring rod once demineralization was complete. Once the bones were demineralized, and only the collagen pseudomorph was left, lipids were extracted from the collagen using a 24-hour soak in a solution of 500 ml of methanol, 250 ml of chloroform, and 200 ml of water as per a modified methodology outlined by Howland and colleagues (2003). Samples were rinsed with double distilled water then freeze-dried in a Virtis Benchtop 3L Benchtop freeze dryer and ground to a powder using a Spex 6750 freezer mill.

6.3.3 Feathers

Feathers were prepared according to the protocol established by previous ecological studies. Feathers were washed with a 2:1 chloroform to methanol solution twice, followed by multiple rinses with double distilled water to remove lipids and debris as per the procedure outlined by Cherel and colleagues (2005). Lipids need to be removed prior to stable isotope analysis because lipids are depleted in ^{13}C compared to proteins and carbohydrates (Post et al., 2007). Since stable isotope analysis of the fat tissue was already being carried out in this project, the analysis of feathers was to target the keratin protein. Once feathers were cleaned and dry, small sections were cut, avoiding the rachis, and homogenized as suggested by Bontempo and colleagues (2014).

6.3.4 Duck Feed

Commercial duck feed mainly includes grains such as barley and oats, corn, and soybean meal. The duck feed used in this research was in pelletized form. Duck feed (n=5) was powdered and homogenized using mortar and pestle and kept in a desiccation cabinet until further analysis using the mass spectrometer.

6.4 Stable Isotope Analysis

Stable isotope analyses, using the mass spectrometer, were carried out in the Isotope Science Laboratory in the Department of Physics and Astronomy at the University of Calgary. Tissue samples were analyzed on a ThermoFisher Delta V Plus mass spectrometer interfaced with a varioISOTOPE CHNOS elemental analyzer to obtain $\delta^{13}C$ and $\delta^{15}N$ values, as well as carbon to nitrogen ratios and percentage carbon and percentage nitrogen to evaluate the integrity of the tissue samples. The results of the stable isotope analysis are reported using δ notation relative to the VPDB standard for carbon and the AIR standard for nitrogen. Machine error is within 0.2‰ for both stable carbon isotopes and stable nitrogen isotopes.

All tissue samples were weighed to 1 mg on a microbalance and placed into tin cups for the auto-sampler connected to the elemental analyzer and subsequently the mass spectrometer. All tissue samples except for the fat samples were combusted in the elemental analyzer with 30 seconds of oxygen gas exposure, with a sample dilution of 78%. Fat samples were combusted with 90 seconds of oxygen gas exposure, with a sample dilution of 78%. Ninety seconds of oxygen gas exposure ensured that the fat sample would be completely combusted within the elemental analyzer.

6.5 Statistical Analysis

Differences in stable carbon and nitrogen isotope ratios between tissue types and tissue type and diet were evaluated using one-way analysis of variance (ANOVA). This statistical analysis accounts for both differences between tissue types as well as differences within tissue types. Data normality was verified with the Shapiro-Wilk test, with p-values for all tissue types above 0.05. Two-way t-tests were used to determine the difference between means of specific tissue types and duck feed, and standard variation was calculated using the pooled data since equal variances were established using Levene's test during the ANOVA analysis. Homogeneity of variance was verified if the p-value of the Levene's test is above 0.05. All statistical analyses were performed using SYSTAT 13 Version Number 13.00.05.

6.6 Results

The averages for stable carbon isotope ratios were -22.3‰ ± 0.2‰ for lipid extracted muscle, -23.1‰ ± 0.2‰ for muscle with lipid still present, -26.4‰ ± 0.4‰ for fat samples, -21.4‰ ± 0.3‰ for bone collagen, and -21.1‰ ± 0.3‰ for feathers. The stable carbon isotope ratios ranged from -25.8‰ to -25.0‰, with an average of -25.3‰ ± 0.3‰, for duck feed (see Table 4).

The average stable nitrogen isotope ratios were 5.7‰ ± 0.3‰ for lipid extracted muscle, 5.3‰ ± 0.2‰ for muscle with lipid still present, 5.5‰ ± 0.8‰ for fat, 5.1‰ ± 0.2‰ for bone collagen, and 6.2‰ ± 0.7‰ for feathers. The stable nitrogen isotope ratios ranged from 3.2‰ to 3.9‰, with an average of 3.5‰ ± 0.3‰, for duck feed (see Table 6.4).

The one-way analysis of variance (ANOVA) for stable carbon isotope ratios had a p-value of less than 0.05 indicating that there were statistically significant differences in stable carbon isotope ratios between tissue types and tissue type and diet. A p-value of less than 0.05 was also obtained for stable nitrogen isotope ratios; however, an outlier fat sample and an outlier feather sample were excluded from the analysis. These samples had to be excluded to satisfy the assumptions of data normality and homogeneity of variance for the one-way analysis of variance. Both the excluded samples had elevated stable nitrogen isotope ratios, approximately 1-2‰ above the average for all analyzed tissues. The other tissues analyzed from the same individual as the outlier fat sample did not have elevated stable nitrogen isotope ratios. The mean diet-to-tissue spacings and mean tissue-to-tissue spacings are therefore the result of the analysis of nine fat samples and eight feather samples. The ranges for stable carbon and nitrogen isotope ratios for all tissue types and diet-to- tissue spacings are summarized in Table 6.4. The mean tissue-to-tissue differences in stable carbon and nitrogen isotopes are summarized in Table 6.5.

	Muscle (n=10)	**Muscle and Fat (n=10)**	**Fat (n=9)**	**Bone Collagen (n=10)**	**Feathers (n=8)**
δ^{13}C Range (‰)	-22.5 to -22.0	-23.4 to -22.8	-26.9 to -26.0	-22.1 to -21.0	-21.5 to -20.7
Mean Diet-to-Tissue Spacing for δ^{13}C (‰)[1]	**3.0 ± 0.3**	**2.2 ± 0.3**	**-1.2 ± 0.4**	**3.9 ± 0.4**	**4.2 ± 0.3**
δ^{15}N Range (‰)	5.3 to 6.0	4.9 to 5.7	4.6 to 5.7	4.8 to 5.6	5.2 to 6.6
Mean Diet-to-Tissue Spacing for δ^{15}N (‰)[1]	**2.1 ± 0.3**	**1.7 ± 0.3**	**1.7 ± 0.4**	**1.6 ± 0.3**	**2.4 ± 0.5**

Table 6.4. Ranges for stable carbon and nitrogen isotope ratios for avian tissues and associated diet-to-tissue spacing means.

	Bone Collagen to Muscle	**Bone Collagen to Muscle+Fat**	**Bone Collagen to Fat**	**Bone Collagen to Feather Keratin**
Δ^{13}C (‰)	+1.0 ± 0.2	+1.7 ± 0.3	+5.1 ± 0.3	-0.3 ± 0.3
Δ^{15}N (‰)	-0.5 ± 0.2	No difference	No difference	-0.8 ± 0.4

Table 6.5. Mean Differences in Stable Carbon and Nitrogen Isotope Ratios Between Bone Collagen and Other Tissues.

6.7 Discussion

6.7.1 Tissue-to-Tissue Spacing Values

Knowledge of enrichment values between tissues of the same animal is necessary for all paleodietary reconstructions because researchers are limited to tissues that are preserved within the archaeological record. Tissue-to-tissue spacing values have only been reported for one species of bird, northern fulmars, in the ecological literature (Thompson & Furness, 1995), and avian-specific values have not been applied to mixing models in the paleodietary literature. The stable carbon isotope tissue enrichment values for bone collagen versus muscle, fat, and keratin of *Anas platyrhynchos* were lower compared to values reported for some mammals by at least 1‰ (Tieszen & Fagre, 1993; Vogel, 1978). The stable carbon isotope bone collagen to muscle spacing for *Anas platyrhynchos* was also lower compared to values obtained from northern fulmars. The bone collagen to muscle spacing value for *Anas platyrhynchos* was similar to the values reported for pigs, wolves, and primates, but not to mice, which is the value often used in paleodietary reconstructions, while the bone collagen to keratin spacing value for stable carbon isotopes was less than values reported in the ecological literature thus far (See Table 6.6).

Tissue-tissue spacing values for bone collagen to fatty tissues have only been determined for ungulates by Vogel (1978), and the values determined for *Anas platyrhynchos* indicates that the spacing value can range up to 2‰ between classes for stable carbon isotopes. Fatty tissues represent a calorie-rich source of nutrients for human groups and maybe an important food source that should be considered in isotopic mixing models. The bone collagen to fat and bone collagen to fatty muscle tissue spacing values reported for *Anas platyrhynchos* here, therefore, provide researchers with this necessary information.

	Δ Collagen-Muscle (‰)	Δ Collagen-Fat (‰)	Δ Collagen-Hide (‰)	Δ Collagen-Keratin (‰)
Ungulates (Vogel 1978)	+2.3	+7.9	+0.6	
Mice (Tieszen and Fagre 1993)	+2.25			
Pig (Nardoto et al. 2006)	+1.1 ± 1.6			
Wolf (Fox-Dobbs et al. 2007)	+1.5 ± 0.7			+0.4 ± 0.8
Primates (Crowley et al. 2010)	+1.0 ± 1.1			+0.9 ± 1.1
Northern fulmars (Thompson and Furness 1995)	+2.8			+1.6
Ducks (This study)	+1.0 ± 0.2	+5.1 ± 0.3	n/a	-0.3 ± 0.3

Table 6.6. Stable carbon isotope tissue-to-tissue spacing values for mammals and one species of bird in the current literature.

Compared to mammals, the stable nitrogen isotope collagen to muscle spacing for *Anas platyrhynchos* was similar to values reported for wolves, but the spacing between collagen and keratin for *Anas platyrhynchos* was less than all mammals (See Table 6.7).

	$\Delta_{\text{Collagen-Muscle}}$ (‰)	$\Delta_{\text{Collagen-Fat}}$ (‰)	$\Delta_{\text{Collagen-Keratin}}$ (‰)
Pig (Nardoto et al. 2006)	+0.9 ± 0.6‰		
Wolf (Fox-Dobbs et al. 2007)	-0.5 ± 0.8		+0.3 ± 0.7‰
Primates (Crowley et al. 2010)	-0.1 ± 1.0‰		+0.8 ± 0.9‰
Ducks (This study)	-0.5 ± 0.2	No difference	-0.8 ± 0.4

Table 6.7. Stable nitrogen isotope tissue-to-tissue spacing values for mammals in the current literature.

The tissue-tissue spacing values reported for *Anas platyrhynchos* deviate from some of the values for mammals by up to 2‰. Tissue spacing values in paleodietary research are based on values established for mammals, regardless of animal class. Differences in tissue-to-tissue spacings between classes can, therefore, introduce uncertainty into stable isotope mixing models, and the use of class-appropriate values can improve the accuracy of said models (Phillips, 2012).

6.7.2 Diet-to-Tissue Spacing Values

The diet to bone collagen enrichment values for both stable carbon and nitrogen isotopes obtained in this study were lower than the values previously reported for mammals in the ecological literature. This is consistent with the findings of Hobson and Clark (1992b) regarding stable carbon isotope enrichment values; however, they found comparable enrichment values with mammals for stable nitrogen isotopes. The difference in diet-to-tissue spacing values between mammals and birds further supports the idea that spacing values can vary between different classes of animals.

Offset values for ducks, as determined through this study, were therefore different than the values for mammals that have been reported in the ecological literature. The values obtained for this study support the conclusion reached by Vanderklift and Ponsard (2003), that stable isotope enrichment values for taxonomically similar animals should be used when reconstructing diet. This is especially relevant for archaeological studies that have, up to this point, utilized mammal values for all animal classes during dietary reconstruction. Further studies exploring the dietary and tissue spacing values of other members of the Anatidae family are also encouraged in future studies to add comparative data to the stable isotope literature.

6.8 Conclusion

Tissue-to-tissue spacing values determined for *Anas platyrhynchos* differed by as much as 2 permil compared to values established for mammals, and therefore the values that are currently being used for paleodietary reconstructions regardless of animal class. These differences and the ones discussed in this research demonstrate that variation exists in terms of tissue spacing values between birds and mammals. Class-appropriate enrichment values are therefore needed within dietary research utilizing stable isotope analysis. This approach provides simple offsets for reconstructing past diet and minimizes the error introduced by the researcher when using mixing models. Future dietary reconstructions within the bioarchaeological literature should, therefore, take this variation into account and try to use enrichment values that are more class-appropriate.

Chapter Seven: Stable Carbon and Nitrogen Isotope Ratios of Archaeological Bird Remains from Knud Peninsula, Ellesmere Island

7.1 Introduction

Stable isotope analysis is now a staple in the toolkit of many archaeologists and ecologists when reconstructing diet. Accurate interpretation of subsistence strategies in past human populations relies on a complete survey and analysis of available and likely dietary items in the environment. In most cases, these samples come from the faunal remains recovered at the archaeological site. Modern faunal remains may sometimes be included in the stable isotope analysis if the environmental conditions are demonstrably like the past environment. Unfortunately, archaeological excavation and preservation at archaeological sites are biased toward large animals. Larger bones are more readily preserved through time and are easier to recover during the excavation process. This can lead to further biases in stable isotope analysis as larger bones are more likely included in the study, and smaller animals may be less represented during the interpretation of the results. This study will, therefore, look at a large sample of bird bones from Pre-Dorset and Dorset sites on the Knud Peninsula of Ellesmere Island to determine the stable carbon and nitrogen isotope ratios of Arctic birds. The large sample of avifaunal stable isotope signatures allows us to determine if the few bones typically included in paleodietary reconstruction are representative of the larger sample, and this data can also be compared to the isotopic signatures of arctic mammals to see if birds can be detected isotopically in past human diet.

7.2 Site Information

Seven sites from the Bache Peninsula region on Ellesmere Island were included in this study: the Dorset Shelf site (SgFm-18), the Longhouse site (SgFm-3), the Narrows site (SgFm-12), the Cove site (SgFm-5), the Baculum site (SfFl-1), the Ridge site (SgFm-6), and the Shelter site (SgFm-17). These sites were mainly occupied by Dorset groups; however, some of the sites, such as the Ridge, Longhouse, and the Dorset Shelf sites also contain Pre-Dorset components. Pre-Dorset groups belong to the Arctic Small Tool tradition and are also classified as a Paleo-Inuit group. Paleo-Inuit groups are known to utilize a broad subsistence strategy that incorporates the mammals, birds, fishes, and plants available in their environment. The reconstruction of Paleo-Inuit dietary adaptations relies mainly on zooarchaeological analysis and the tools recovered from archaeological sites. To date, the stable isotope analysis of faunal remains from Paleo-Inuit sites has only been completed for one site in the western Canadian Arctic and geese were the only birds analyzed. Though this study does not look at all the faunal remains recovered from the Knud Peninsula archaeological sites, the thorough analysis of the bird remains provides a comprehensive picture of the avian dietary ecology and marine versus terrestrial diets in the area.

7.3 Stable Isotope Analysis of Archaeological Bird Remains

Stable isotope analysis of avifaunal remains from archaeological sites has received less attention compared to the study of mammal remains. Stable isotope ratios for bird remains have been included in dietary reconstructions for past human groups; however, the sample size is often low. Migratory birds are special prey items that deserve more attention when it comes to paleodietary reconstruction because they spend most of their lives traveling between habitats that may be very isotopically distinct. Migration between their summer and winter locations and the range of ecosystems that birds can, therefore, exploit means that they may have distinct and variable isotopic signatures compared to marine and terrestrial mammals that are more limited in their range of habitat choice. For example, eider ducks will consume food from both the freshwater and marine ecosystems during their reproductive period in the Arctic, whereas a ringed seal (*Phoca hispida*) is limited to foods from the marine ecosystem. Long-distance migrations, as well as reproductive demands, can also affect the birds' physical condition, placing them under nutritional stress. Hobson and colleagues (1993) found that Ross' geese nesting in the Arctic, had decreased body, muscle, liver, and abdominal fat mass from arrival in the Arctic through to the egg incubation period. This nutritional stress also corresponded with elevated stable nitrogen isotope ratios for geese muscle and liver tissues. Migratory birds may, therefore, be a potential human food source with elevated stable nitrogen isotope ratios.

The aggregation of large numbers of migratory birds in the Arctic during the summer also makes them potentially important food resources for Arctic hunter-gatherers. Unfortunately, little is known regarding the variation in stable isotope ratios of bird remains recovered in the archaeological record. To date, there have only been two stable isotopic studies that look exclusively at the faunal remains of birds or their eggs (Giardina et al., 2014; Grupe & Mekota, 2005). Grupe and Mekota (2005) analyzed the bird faunal remains of goshawk, pintail ducks, mallard ducks, white front geese, grey geese, rooks and cranes from the Neolithic Pestenacker site in Bavaria. They were able to distinguish between herbivorous, omnivorous, and carnivorous birds, and notably found that pintail ducks could vary in their stable nitrogen isotope values by up to one trophic level between individuals (Grupe & Mekota, 2005). They also noted the complications in interpreting stable isotope values for migratory birds since they could exploit different areas with varying isotopic signatures.

Giardina and colleagues (2014) analyzed the rhea eggshells from archaeological sites in southern Mendoza, Argentina. The authors used stable oxygen and carbon isotope analysis to determine the spatial distribution of rhea eggshells, if this distribution was related to human mobility, and if rhea eggs in human diet would result in elevated stable carbon isotope signatures. They found that the stable oxygen isotope ratios of eggshells could help to determine their origin, and therefore identify where human groups were obtaining the eggs and if they would transport them to different sites. The stable carbon isotope ratios for the eggshells were, however, variable and likely did not contribute to the elevated stable carbon isotope values seen in the human groups in that area (Giardina et al., 2014).

In contrast, birds have been analyzed extensively in the ecological literature. Ecologists are interested in their dietary ecology, migration patterns, reproductive strategies, and nutrient allocation during egg-laying (i.e., Cherel et al., 2000; Hobson, 1993, 1995, 2005; Hobson et al., 1997; Lott, Meehan, & Heath, 2003; Moody et al., 2012; Rubenstein & Hobson, 2004). Feathers, blood, muscle, fat, and liver isotopic ratios are routinely analyzed, but bone collagen has only been included in a few studies due to the added sample preparation time needed for bone collagen (Cherel et al., 2000; Hobson & Clark, 1992b). Obtaining bone collagen for stable isotope analysis also requires the sacrifice of the animal, compared to blood and feathers which can be obtained with little impact on the animal. Chapter 6 explored the isotopic spacing values between bone collagen and other tissues in birds to address this gap in the literature. The controlled feeding study in Chapter 6 established tissue spacing values for one species of duck fed a steady and monotonous diet in a controlled environment. This chapter will look at the variation in isotopic values between different species of birds in the archaeological record. Research on wild bird populations helps to elucidate the variation seen in avian isotopic values due to variables such as migration, breeding, dietary variation in different habitats, and physiological changes. Since birds such as the thick-billed murre (*Uria lomvia*) and eider ducks (*Somateria* sp.) have been identified as significant seasonal dietary resources to numerous Paleo-Inuit groups, the variation in their isotopic values can affect the dietary reconstructions of these populations.

7.4 Ecology of Birds Recovered from Knud Peninsula Sites

Identification for bird species was determined in the zooarchaeological analysis discussed in Chapter 5. The ecological and environmental conditions for these birds are based on modern research. Bird remains analyzed for this study included birds from the eider duck genus (*Somateria* sp.), northern pintail ducks (*Anas acuta*), brant geese (*Brant bernicla*), snow geese (*Chen caerulescens*), glaucous gulls (*Larus hyperboreus*), thick-billed murres (*Uria lomvia*), parasitic jaegers (*Stercorarius parasiticus*), black-legged kittiwakes *(Rissa tridactyla*), arctic terns (*Sterna paradisaea*), dovekies (*Alle alle*), rock ptarmigan (*Lagopus muta*), cormorants (*Phalacrocorax* sp.), and gulls/auks (*Charadriiformes*). Based on the species distribution described in Chapter 5, the bird species most likely included in the diet of Pre-Dorset and Dorset populations on the Knud Peninsula were eider ducks followed by brant geese. The other species analyzed, such as the thick-billed murres and the snow geese, were also included in the analysis because these are known food items for other Paleo-Inuit groups and were likely still eaten when caught but they were not preferred foods at these sites. The inclusion of all the identifiable bird species from the Ellesmere Island sites also provides a complete picture of the avian dietary ecology on the Knud Peninsula, including both marine and terrestrial isotopic signatures.

7.4.1 King Eider (*Somateria spectabilis*)

King eider ducks winter in the area along the North Water Polynya near western Greenland, as well as along the east coast from Newfoundland down to Maine (Abraham & Finney, 1986; Lyngs, 2003). They arrive at their summer breeding grounds in the High Arctic in early June (Parmelee & MacDonald, 1960). King eiders prefer to nest approximately 50 to 100 kilometers inland from the coast near tundra pools and marshes, but also on the dry tundra (Ogilvie, 2005; Parmelee & MacDonald, 1960; Snyder, 1957). Egg-laying begins in late June and reaches its peak in July (Parmelee & MacDonald, 1960). Drakes will move to the coast as soon as egg-laying begins, and females and their young will travel to the coast in late August or early September once the young have fledged (Parmelee & MacDonald, 1960).

King eiders are principally divers and will forage for their food on the bottom of the coastal or intertidal zone. Their preferred marine foods include crustaceans, mollusks, and echinoderms (Cottam, 1939). During the summer, the king eider diet is more varied and can also include invertebrate larvae and plants such as sedges and eelgrass (*Zostera* sp.) (Johnsgard, 2016; Ogilvie, 2005). They will also include food from freshwater environments, especially during the breeding period when they move inland.

7.4.2 Common Eider (*Somateria mollissima*)

Common eiders winter in Newfoundland, the Gulf of St. Lawrence, and in western Greenland (Abraham & Finney, 1986). They arrive in High Arctic Canada in late May or early June and nest shortly after. The preferred nesting habitat of the common eider is in rock-sheltered grassy areas, in proximity to marine foods (Johnsgard, 2016; Snyder, 1957). Egg incubation takes approximately one month and another two months for the hatchlings to be fully fledged (Cooch, 1965). As with the king eiders, males leave for the coast shortly after egg-laying. Once hatched, the ducklings learn how to dive for food in intertidal pools and feed mainly on invertebrates during this period (Johnsgard, 2016).

The diet of common eiders is similar to that of king eiders, with a preference for mollusks, supplemented by crustaceans, echinoderms, insects, some fish such as sticklebacks, and crowberries (Dementiev & Gladkov, 1967). Common eiders are also diving ducks that like to forage during low tide in the coastal zone.

7.4.3 Northern Pintail (*Anas acuta*)

Northern pintail ducks winter in the United States, in areas close to large bodies of water, such as western Washington, central California, the Texas-Louisiana Gulf Coast, and the Chesapeake Bay region (Hestbeck, 1993). They arrive at their breeding grounds in the Arctic during early spring (Lyngs, 2003). Pintail ducks prefer to nest under cover of rushes, grasses, and low scrub bushes. They have the most extensive distribution of any waterfowl species across the northern hemisphere and are very opportunistic in their choice of breeding habitat (T. Fox, 2005). They will take advantage of freshwater, saline, or brackish wetlands. They have a diet of midges, snails, slugs, and earthworms. During laying, females will also eat fairy shrimp if available in nearby wetlands (T. Fox, 2005).

7.4.4 Brant Geese (*Branta bernicla*)

Brant geese breeding on Ellesmere Island spend their winters in Ireland and use Greenland as a staging area along their migratory route in the spring (Boertmann, Mosbech, & Frimer, 1997). Brant geese arrive in the High Arctic in early June and reach their peak hatching period in mid-July. They prefer to nest on the open tundra away from the coast to avoid predation. Their diet consists of mosses, upland forbs, and sedges while nesting on the tundra, and they move to coastal wet meadows after hatching to take advantage of the sedges and grasses in that area (Boyd, 2005). During migration, they prefer salt marshes and coastal grasslands, especially areas with *Zostera* sp. seagrasses (Boyd, 2005).

7.4.5 Snow Geese (*Chen caerulescens*)

Similar to brant geese, snow geese prefer the tundra environment, especially near lakes and rivers (Snyder, 1957). Snow geese have a winter range in the northeastern United States and use southern Quebec as a staging area in the spring before they migrate to the Arctic for breeding (Gauthier et al., 2009; Souchay, Gauthier, Lefebvre, & Pradel, 2015). They arrive at Ellesmere Island in early June, but their nesting patterns can be sporadic, and some sexually mature adults will not mate at all upon arrival (Parmelee & MacDonald, 1960). Snow geese are terrestrial herbivores and prefer foods such as alpine foxtail, *Maydell oxytrope*, a legume, chickweed (*Stellaria media*) leaves, and alpine bistort (*Persicaria vivipara*) bulbs available on the tundra. Grasses, water sedges, and arctic willow (*Salix arctica*) are also incorporated into their diet (Gauthier, 1993).

7.4.6 Glaucous Gulls (*Larus hyperboreus*)

Glaucous gulls breeding in the eastern Canadian Arctic likely spend their winters near the North Water polynya by southwest Greenland since they try to avoid areas of heavy ice cover (Boertmann, Lyngs, Merkel, & Mosbech, 2004). They arrive at Ellesmere Island in late May and prefer to nest on ledges and cliffs near the sea (Parmelee & MacDonald, 1960). Glaucous gulls have a varied diet, but they mainly prey on other animals and fish. They have been observed attacking and stealing food from other birds, preying on the fledglings of snow geese, fishing for sculpins at sea, and scavenging animal carcasses (Parmelee & MacDonald, 1960; Snyder, 1957).

7.4.7 Thick-Billed Murres (*Uria lomvia*)

Thick-billed murres spend their winters along the coast from southwest Greenland down to the coast of eastern Canada surrounding the Labrador Sea and start to move north towards their breeding grounds in May (Lyngs, 2003; Salomonsen, 1969). They breed on cliffs near the ocean during the summer on Ellesmere Island (Snyder, 1957). They do not have nests and eggs are simply laid on bare rock. The incubation period is 29 to 35 days, and both parents take turns incubating the egg (Gaston & Jones, 1998). Chicks are fledged after a month and follow their parents to hunt in the sea.

Thick-billed murres are pelagic hunters, but prefer shallower dives due to their smaller size and resulting decreased oxygen storage capacity (Croll, Gaston, Burger, & Konnoff, 1992). They mainly prey on marine fishes, such as arctic cod (*Boreogadus saida*) and sculpins, and invertebrates (Gaston & Jones, 1998; Hobson, Gilchrist, et al., 2002).

7.4.8 Parasitic Jaegers (*Stercorarius parasiticus*)

Parasitic jaegers, also referred to as arctic skuas, arrive in the Arctic in early June from wintering grounds likely located in South America and southern Africa and occupy coastal regions all but during the breeding season (Olsen & Larsson, 1997). They like to nest on the tundra near freshwater, and in low and flat grassy areas (Snyder, 1957). Parasitic jaegers prefer fish and crustaceans during the non-breeding season, but once they move onto the tundra, they will eat berries, insects, eggs, rodents, and even other birds (Andersson & Götmark, 1980). They are also kleptoparasites, which means that they will steal food from other birds if given a chance (Arnason, 1978).

7.4.9 Black-Legged Kittiwakes (*Rissa tridactyla*)

Black-legged kittiwakes winter around the northern portions of the Atlantic Ocean, ranging from Nova Scotia, Newfoundland, and Labrador to western Europe and travel to their Arctic breeding grounds in April and May (Lyngs, 2003). They breed on rocky coasts and cliffs and will nest on cliff ledges (Baird, 1994; Snyder, 1957). Unlike other gulls, they strictly prefer marine foods (Baird, 1994). Stable isotope analyses of breeding colonies around the North Water Polynya indicate that they eat zooplankton, tertiary fish such as the arctic cod, and small crustaceans (Hobson, Gilchrist, et al., 2002). Observational studies have also shown that they prefer to stay near the surface when foraging for fish and will also catch smaller fish such as herring (Suryan et al., 2002). Chicks were also fed more fish compared to adults, placing them at one trophic level higher than adult kittiwakes (Hobson, Gilchrist, et al., 2002).

7.4.10 Arctic Terns (*Sterna paradisaea*)

Arctic terns have the longest migratory route of the birds discussed here. The majority of the arctic tern population migrate between the Arctic and Antarctic every year, with key staging areas in northwest Europe, West Africa, equatorial Africa, and South Africa along the way (Lyngs, 2003). They travel to the High Arctic in the spring and arrive in late May (Snyder, 1957). They prefer aquatic areas, both marine, and freshwater, and will place their “scrapes”, shallow depressions for their eggs lined with some rocks and plant debris, in the sand, gravel bars, or moss (Snyder, 1957). Arctic terns hunt near the surface of the water column, and prefer fish and crustaceans, though they may also eat small squids and amphipods (Mallory, Boadway, Davis, Maftei, & Diamond, 2017; Parmelee & MacDonald, 1960; Weslawski, Stempniewicz, & Galaktionov, 1994).

7.4.11 Dovekies (*Alle alle*)

Dovekies, or little auks, winter in Nova Scotia and Newfoundland (Lyngs, 2003). They mainly breed on the west side of Greenland and are only caught in the Canadian High Arctic when they are passing through on their migratory route through Baffin Bay during the spring and summer (Lyngs, 2003; Snyder, 1957). Dovekies prefer to nest on cliffs or talus slopes (Norderhaug, 1980; Snyder, 1957). Egg incubation takes approximately one month, and unlike the eiders, males and females are both responsible for incubation and chick-rearing (Norderhaug, 1980). Chicks are fledged after about one month and make their way to the sea.

Dovekies are also diving seabirds. They are mainly planktivorous with a preference for copepods (Harding et al., 2009). They are very efficient foragers and are thought to use filter-feeding to increase their copepod intake (Harding et al., 2009). Adult dovekies also include crustaceans and arctic cod in their diet (Bradstreet, 1982). They are pelagic hunters for most of the year but prefer drift ice in Canada and Greenland during the summer (Snyder, 1957).

7.4.12 Rock Ptarmigan (*Lagopus muta*)

The habitat of rock ptarmigan includes barren highlands, rock deserts, ravines, and mountainous slopes (Snyder, 1957). They are smaller than the willow ptarmigan but occupy a more extensive range within the Arctic. Unlike many of the migratory birds discussed, they are more abundant and clustered on west-central Ellesmere Island during the fall instead of spring and summer, opting to nest scattered apart across the tundra and flocking together after chicks have fledged (Parmelee & MacDonald, 1960). In the southern parts of the High Arctic, rock ptarmigan populations may be resident, while further north, populations will migrate to southern regions of Ellesmere Island or Greenland (Lyngs, 2003). Their nests are similar to those of the arctic tern in that they are just shallow depressions in the ground lined with items such as rocks, feathers, and leaves (Snyder, 1957). Rock ptarmigan are terrestrial herbivores and will eat willow buds, berries, and leaves of forbs and shrubs when available (Weeden, 1969).

7.4.13 Great Cormorant (*Phalacrocorax carbo*)

The great cormorant, also known as the common cormorant, is the most likely species of cormorant recovered from the Knud Peninsula, though the remains could not be identified to species. Remains of the great cormorant have been recovered from archaeological sites in southwest Greenland (Gotfredsen & Møbjerg, 2004). They are not known breeders on Ellesmere Island but may have been caught by hunter-gatherers as they were flying through the area or stopping for food and rest. Great cormorants arrive at their breeding grounds around the coast of Greenland in April and May and spend their winters in the areas surrounding the Open Water region between Ellesmere Island and Greenland (Lyngs, 2003).

The great cormorant is a diving duck that prefers foraging for fish, for example, arctic cod, on the continental shelf (Grémillet et al., 2001; R. Johansen, Barrett, & Pedersen, 2001). Studies have found that cormorant will capture smaller fish during the summer while opting for larger fish during the winter to increase their foraging efficiency (Čech, Čech, Kubečka, Prchalová, & Draštík, 2008; R. Johansen et al., 2001).

7.5 Sample and Methods

7.5.1 Sample Preparation and Isotopic Analysis

One hundred and one avian bones were included for stable isotope analysis of the faunal remains from Ellesmere Island with species representation as indicated in Table 7.1. The sampling strategy was to maximize the number of bird species and the number of individual birds per species. Unfortunately, for some species, only one sample was analyzed because the number of identifiable faunal remains suitable for stable isotope analysis for those species was very low.

Site	n	Birds Analyzed
Dorset Shelf	20	Eider Duck, Snow Goose, Duck sp.
Longhouse	17	Eider Duck, Brant Goose, Glaucous Gull, Dovekie
Narrows	16	Eider Duck, Arctic Tern, Cormorant sp., Duck sp.
Cove	22	Eider Duck, Northern Pintail Duck, Brant Goose, Snow Goose, Glaucous Gull, Rock Ptarmigan, Black-Legged Kittiwake, Parasitic Jaeger, Gull/Auk sp.
Baculum	12	Eider Duck, Thick-billed Murre, Duck sp.
Ridge	9	Eider Duck, Duck sp.
Shelter	5	Eider Duck, Duck sp.

Table 7.1. Birds analyzed in this study organized by site.

The faunal remains from Ellesmere Island were processed following the demineralization procedure for isolating bone collagen outlined by Judith Sealy (1986). Bones were first sectioned with a Dremel tool to produce smaller pieces of bone that would be easier and faster to demineralize. These sectioned bone samples were then cleaned using double-distilled water in a sonicator. Clean samples were demineralized through a series of soaks in dilute (1%) hydrochloric acid. Samples were submerged in the dilute hydrochloric acid for 24 to 48 hours at a time until the bone samples were fully demineralized. Bone samples were fully demineralized once all signs of a chemical reaction (i.e., bubbling, discolouration of the acid solution) ended, the sample was soft and spongy, and in some cases, translucent. Demineralized samples were soaked in a 0.125M sodium hydroxide solution for 20 to 24 hours to remove humic acids from the burial environment that may have contaminated the sample. Bone collagen samples were rinsed to neutrality before being lyophilized in a Virtis Benchtop 3L Benchtop freeze dryer. Dried samples were then homogenized using a Spex 6750 freezer mill.

Stable isotope analysis of the prepared samples was performed in a ThermoFisher Delta V Plus mass spectrometer interfaced with a varioISOTOPE Carbon, Hydrogen, Nitrogen, Oxygen, and Sulfur (CHNOS) elemental analyzer in the Isotope Science Lab in the Department of Physics and Astronomy at the University of Calgary. Stable carbon and nitrogen isotope ratios were obtained, as well as carbon to nitrogen ratios and percentage carbon and percentage nitrogen to evaluate the integrity of the tissue samples. The results of the stable isotope analysis are reported using δ notation relative to the VPDB standard for carbon and the AIR standard for nitrogen. Machine error is within 0.2‰ for both stable carbon isotopes and stable nitrogen isotopes.

7.5.2 Bone Collagen Preservation

Preservation of bone collagen for stable isotope analysis is often assessed using atomic carbon to nitrogen (C:N) ratios. DeNiro (1985) has suggested an atomic C:N ratio range of 2.9 to 3.6 as indicating well-preserved bone collagen for stable isotope analysis as this range is closest to the atomic C:N ratio of fresh bone collagen. Collagen carbon and nitrogen content, or %C and %N, and collagen yield have also been identified as indicators of preservation (Ambrose, 1990; van Klinken, 1999). Well-preserved bone collagen has a % carbon (%C) of approximately 35% and a % nitrogen (%N) of around 11% to 16% (van Klinken, 1999). Ambrose (1990) has also suggested a minimum collagen yield of 3.5% for well-preserved collagen, while van Klinken (1999) has proposed a minimum collagen yield of 1%; collagen makes up approximately 22% of the weight of fresh bone. Grupe and colleagues (2009) however, have found that C:N ratios do not always correlate with collagen yield, and samples with atomic C:N ratios greater than 3.6 but less than 4.0 still had isotopic values consistent with corresponding samples with atomic C:N ratios between 2.9 and 3.6.

Carbon to nitrogen ratios for the modern-day ducks analyzed in Chapter 6 were approximately 3.5, which is on the upper range of the acceptable C:N ratios determined for bone collagen. The modern-day ducks were frozen immediately after processing at the butcher and were therefore not subject to contamination from a burial environment. Many of the archaeological samples analyzed in this study had atomic C:N ratios that were greater than 3.6. Samples with atomic C:N ratios below 4.0 were still included in the calculation of species means and statistical analyses following the example of Grupe et al. (2009). These samples were still included in the analysis because collagen yield, %C, and %N satisfied the criteria for well-preserved collagen as outlined by Ambrose (1990) and van Klinken (1999). The %C and %N values for these samples were also similar to the values obtained for fresh bone collagen obtained from mallard ducks analyzed in Chapter 6. The isotopic ratios obtained from these samples were within the ranges obtained for the samples with atomic C:N ratios between 2.9 and 3.6 from the same species.

7.5.3 Statistical Analysis

Differences in stable carbon and nitrogen isotope ratios between the various bird species were evaluated using one-way analysis of variance (ANOVA) when possible. One-way analysis of variance compares the differences between the means of several groups to determine statistical significance, provided that the conditions of normality and homogeneity of variances are met. P-values below 0.05 indicate that there are significant differences between groups. Data normality was assessed using the Shapiro-Wilk test, with p-values above 0.05 indicating normality. Homogeneity of variance was evaluated using Levene's test, with p-values above 0.05 indicating homogeneity of variance. ANOVA was also used to determine if there were significant differences in stable carbon and nitrogen isotope ratios between the eider duck remains from different sites. Only the stable isotope ratios of eiders ducks were compared between archaeological sites because this was the only species that was present at all the Knud Peninsula archaeological sites.

The one-way analysis of variance was used for assessing the difference in stable carbon isotope ratios between the unidentified duck/goose remains, and the eider duck remains. The Mann-Whitney *U* test was used for analyzing the stable nitrogen isotope ratios between the unidentified duck/goose remains and the eider duck remains. The Mann-Whitney U test was used because the stable nitrogen isotope values for the unidentified duck/goose remains, and eider duck remains did not have equal variances. Species with a sample size less than three were not included in any statistical analyses. All statistical analyses were performed using SYSTAT 13 Version Number 13.00.05.

7.6 Results

The δ^{13}C, δ^{15}N, C to N ratios, %C, %N, and collagen yield are presented for all the samples analyzed in Table 7.2.

Sample ID	**Site**	**Species**	**Element**	**δ^{13}C**	**δ^{15}N**	**%C**	**%N**	**Atomic C:N**	**Collagen Yield (%)**
SgFm5-128	Cove	*A. acuta*	R. Scapula	**-15.2**	**18.8**	46.2	14.8	3.6	15.0
SgFm3-414	Longhouse	*A. alle*	R. Humerus	**-17.1**	**15.8**	45.5	14.7	3.6	11.8
SfFl1-33	Baculum	Anatidae	L. Tibiotarsus	**-16.1**	**14.1**	46.1	14.7	3.7	21.1
SfFl1-57	Baculum	Anatidae	R. Tibiotarsus	**-15.0**	**14.1**	46.1	14.7	3.7	16.0
SfFl1-10	Baculum	Anatidae	R. Tibiotarsus	**-16.6**	**13.2**	40.9	12.2	3.9	18.1
SfFl1-13	Baculum	Anatidae	L. Tibiotarsus	**-16.9**	**11.1**	44.9	13.5	3.9	13.5
SfFl1-15	Baculum	Anatidae	L. Tibiotarsus	**-16.5**	**11.0**	44.0	13.5	3.8	14.0
SfFl1-22	Baculum	Anatidae	R. Tibiotarsus	**-17.0**	**11.4**	45.1	13.7	3.8	11.8
SfFl1-23	Baculum	Anatidae	L. Femur	**-15.1**	**14.6**	44.8	13.9	3.8	14.2
SfFl1-4	Baculum	Anatidae	R. Tibiotarsus	**-15.7**	**14.3**	43.1	12.9	3.9	12.6
SgFm18-186	Dorset Shelf	Anatidae	L. Coracoid	**-15.4**	**14.5**	45.3	13.6	3.9	16.1
SgFm18-284	Dorset Shelf	Anatidae	L. Coracoid	**-15.6**	**15.1**	43.6	13.9	3.7	15.2
SgFm12-14	Narrows	Anatidae	R. Tarsometatarsus	**-15.4**	**14.6**	45.7	14.4	3.7	16.4
SgFm6-3	Ridge	Anatidae	R. Femur	**-15.8**	**14.1**	42.7	13.3	3.8	10.7
SgFm6-8	Ridge	Anatidae	L. Femur	**-19.6**	**6.5**	45.9	14.6	3.7	15.8
SgFm6-10	Ridge	Anatidae	R. Tibiotarsus	**-14.7**	**13.2**	46.9	15.3	3.6	10.5
SgFm17-2	Shelter	Anatidae	L. Tibiotarsus	**-14.9**	**13.7**	46.7	14.8	3.7	14.4
SgFm17-8	Shelter	Anatidae	Tibiotarsus	**-15.4**	**13.9**	43.8	14.2	3.6	16.8
SgFm5-388	Cove	*B. bernica*	L. Scapula	**-17.6**	**5.9**	46.4	16.5	3.3	26.2
SgFm5-387	Cove	*B. bernicla*	R. Scapula	**-17.7**	**6.0**	45.9	16.2	3.3	14.2
SgFm5-42	Cove	*B. bernicla*	L. Humerus	**-17.8**	**10.4**	47.0	15.6	3.5	10.9
SgFm3-116	Longhouse	*B. bernicla*	R. Tibiotarsus	**-14.7**	**14.5**	46.7	15.5	3.5	19.4
SgFm3-192	Longhouse	*B. bernicla*	R. Scapula	**-17.6**	**6.6**	45.7	15.0	3.6	14.6
SgFm3-7	Longhouse	*B. bernicla*	R. Scapula	**-11.4**	**8.4**	45.7	15.8	3.4	13.1
SgFm3-68	Longhouse	*B. bernicla*	R. humerus	**-21.2**	**5.6**	46.5	15.3	3.5	14.7
SgFm3-69	Longhouse	*B. bernicla*	L. Coracoid	**-12.9**	**8.1**	46.7	15.0	3.6	28.2
SgFm3-74	Longhouse	*B. bernicla*	L. Scapula	**-11.6**	**8.5**	45.0	14.7	3.6	17.1
SgFm5-484	Cove	*C. caerulescens*	R. Coracoid	**-18.4**	**5.8**	46.6	15.5	3.5	18.8
SgFm18-177	Dorset Shelf	*C. caerulescens*	L. Coracoid	**-22.5**	**6.3**	45.7	14.2	3.8	19.7
SgFm5-16	Cove	*Charadriiformes*	R. Humerus	**-14.8**	**18.8**	46.6	15.1	3.6	15.4
SgFm5-493	Cove	*L. hyperboreus*	L. Scapula	**-14.9**	**18.8**	45.4	14.4	3.7	18.5
SgFm5-547	Cove	*L. hyperboreus*	R. Coracoid	**-15.3**	**18.9**	44.0	13.7	3.7	14.2
SgFm5-555	Cove	*L. hyperboreus*	R. Scapula	**-14.7**	**18.9**	45.6	14.7	3.6	19.2
SgFm3-225	Longhouse	*L. hyperboreus*	L. coracoid	**-15.7**	**18.0**	44.4	13.2	3.9	14.7
SgFm3-226	Longhouse	*L. hyperboreus*	1st phalanx, 2nd digit	**-15.1**	**20.8**	46.5	15.0	3.6	18.6

Sample ID	Site	Species	Element	δ^{13}C	δ^{15}N	%C	%N	Atomic C:N	Collagen Yield (%)
SgFm5-175	Cove	*L. muta*	R. Tibiotarsus	**-21.3**	**2.9**	46.2	15.1	3.6	20.0
SgFm12-7	Narrows	*Phalacrocorax* sp.	R. Carpometacarpus	**-12.2**	**14.4**	43.2	14.0	3.6	14.2
SgFm12-11	Narrows	*Phalacrocorax* sp.	R. Carpometacarpus	**-14.9**	**14.6**	46.6	15.4	3.5	11.5
SgFm12-90	Narrows	*Phalacrocorax* sp.	R. Carpometacarpus	**-14.7**	**13.9**	47.5	15.5	3.6	16.1
SgFm5-213	Cove	*R. tridactyla*	R. Coracoid	**-14.2**	**19.0**	45.5	14.7	3.6	21.3
SgFm12-65	Narrows	*S. hirundo*	L. Coracoid	**-18.1**	**12.5**	45.6	15.6	3.4	23.0
SgFm12-74	Narrows	*S. hirundo*	L. Humerus	**-18.0**	**13.3**	44.9	15.7	3.3	18.3
SgFm5-170	Cove	*S. parasiticus*	R. Humerus	**-15.2**	**19.2**	47.0	15.4	3.6	15.2
SgFm5-331	Cove	*S. parasiticus*	R. Humerus	**-15.9**	**18.6**	46.2	14.9	3.6	10.9
SgFm5-346	Cove	*S. parasiticus*	R. Scapula	**-16.4**	**19.2**	45.4	14.8	3.6	16.2
SgFm5-365	Cove	*S. parasiticus*	L. Carpometacarpus	**-15.0**	**19.1**	44.5	14.5	3.6	13.5
SgFm5-470	Cove	*S. parasiticus*	R. Carpometacarpus	**-15.6**	**18.2**	46.9	15.4	3.6	17.0
SfFl1-38	Baculum	*Somateria* sp.	L. Tibiotarsus	**-15.1**	**14.0**	45.0	14.1	3.7	13.2
SfFl1-27	Baculum	*Somateria* sp.	L. Tibiotarsus	**-15.1**	**14.4**	46.0	14.2	3.8	10.8
SfFl1-39	Baculum	*Somateria* sp.	L. Femur	**-14.7**	**14.1**	43.0	13.8	3.6	15.0
SgFm5-271	Cove	*Somateria* sp.	R. Coracoid	**-14.8**	**13.8**	46.3	16.5	3.3	16.5
SgFm5-222	Cove	*Somateria* sp.	R. Humerus	**-15.4**	**12.8**	45.1	14.2	3.7	16.5
SgFm5-124	Cove	*Somateria* sp.	R. Coracoid	**-14.3**	**12.8**	46.8	16.2	3.4	17.5
SgFm5-290	Cove	*Somateria* sp.	R. Coracoid	**-15.0**	**14.1**	46.1	15.1	3.6	14.0
SgFm5-482	Cove	*Somateria* sp.	R. Coracoid	**-15.1**	**13.8**	47.2	15.0	3.7	17.9
SgFm5-6	Cove	*Somateria* sp.	R. Coracoid	**-14.2**	**14.3**	44.3	14.6	3.6	10.5
SgFm18-173	Dorset Shelf	*Somateria* sp.	L. Humerus	**-15.5**	**14.6**	42.2	13.9	3.5	18.1
SgFm18-141	Dorset Shelf	*Somateria* sp.	L. Coracoid	**-16.0**	**12.4**	46.7	15.0	3.6	20.4
SgFm18-176	Dorset Shelf	*Somateria* sp.	L. Coracoid	**-15.0**	**14.3**	46.5	14.7	3.7	17.5
SgFm18-179	Dorset Shelf	*Somateria* sp.	L. Coracoid	**-16.1**	**12.7**	46.6	14.5	3.8	20.0
SgFm18-158	Dorset Shelf	*Somateria* sp.	L. Scapula	**-15.1**	**14.7**	46.2	14.9	3.6	15.0
SgFm18-167	Dorset Shelf	*Somateria* sp.	L. Scapula	**-15.0**	**12.9**	47.2	15.0	3.7	17.1
SgFm18-197	Dorset Shelf	*Somateria* sp.	L. Coracoid	**-15.1**	**15.2**	45.8	14.1	3.8	13.5
SgFm18-320	Dorset Shelf	*Somateria* sp.	L. Coracoid	**-15.1**	**13.9**	46.9	14.9	3.7	18.0
SgFm18-269	Dorset Shelf	*Somateria* sp.	L. Humerus	**-14.8**	**14.6**	46.5	14.7	3.3	12.6
SgFm18-143	Dorset	*Somateria* sp.	L. Scapula	**-16.3**	**12.2**	46.2	16.1	3.7	20.5

Sample ID	Site	Species	Element	**δ^{13}C**	**δ^{15}N**	%C	%N	Atomic C:N	Collagen Yield (%)
	Shelf								
SgFm18-210	Dorset Shelf	*Somateria* sp.	L. Scapula	**-15.7**	**14.5**	45.5	15.7	3.4	23.5
SgFm18-211	Dorset Shelf	*Somateria* sp.	L. Scapula	**-15.8**	**12.7**	45.9	15.5	3.5	10.4
SgFm18-31	Dorset Shelf	*Somateria* sp.	L. Coracoid	**-14.6**	**13.9**	46.4	15.8	3.4	15.6
SgFm18-164	Dorset Shelf	*Somateria* sp.	L. Coracoid	**-15.2**	**12.7**	46.0	15.3	3.5	19.0
SgFm18-38	Dorset Shelf	*Somateria* sp.	L. Coracoid	**-15.5**	**13.2**	46.8	16.2	3.4	18.4
SgFm18-150	Dorset Shelf	*Somateria* sp.	L. Coracoid	**-14.8**	**14.3**	45.4	15.8	3.4	15.6
SgFm18-175	Dorset Shelf	*Somateria* sp.	L. Coracoid	**-15.5**	**14.6**	45.9	15.9	3.4	19.4
SgFm3-93	Longhouse	*Somateria* sp.	R. Humerus	**-13.5**	**12.8**	46.4	16.5	3.3	15.9
SgFm3-230	Longhouse	*Somateria* sp.	R. Scapula	**-16.9**	**13.5**	46.2	14.8	3.7	14.6
SgFm3-403	Longhouse	*Somateria* sp.	R. Tibiotarsus	**-14.8**	**14.6**	45.4	15.1	3.5	11.9
SgFm3-465	Longhouse	*Somateria* sp.	R. Humerus	**-14.3**	**14.1**	47.5	15.7	3.5	13.3
SgFm3-213	Longhouse	*Somateria* sp.	R. Scapula	**-14.8**	**12.4**	46.4	16.0	3.4	24.0
SgFm3-404	Longhouse	*Somateria* sp.	R. Humerus	**-14.6**	**15.8**	45.7	14.1	3.8	16.5
SgFm3-410	Longhouse	*Somateria* sp.	R. Scapula	**-15.9**	**12.6**	44.6	14.2	3.7	20.0
SgFm3-411	Longhouse	*Somateria* sp.	R. Scapula	**-15.0**	**13.8**	46.8	15.2	3.6	14.8
SgFm12-95	Narrows	*Somateria* sp.	L. Scapula	**-14.3**	**14.6**	46.7	15.4	3.5	13.3
SgFm12-91	Narrows	*Somateria* sp.	L. Coracoid	**-14.3**	**14.6**	44.1	14.4	3.6	11.5
SgFm12-2	Narrows	*Somateria* sp.	L. Scapula	**-15.6**	**13.5**	46.8	15.4	3.5	19.2
SgFm12-120	Narrows	*Somateria* sp.	L. Coracoid	**-15.0**	**13.1**	46.6	16.1	3.4	19.0
SgFm12-8	Narrows	*Somateria* sp.	L. Coracoid	**-15.6**	**13.8**	45.9	14.7	3.6	13.5
SgFm12-15	Narrows	*Somateria* sp.	R. Coracoid	**-15.7**	**13.5**	46.0	14.7	3.7	15.7
SgFm12-63	Narrows	*Somateria* sp.	L. Scapula	**-14.6**	**13.4**	47.1	15.3	3.6	19.7
SgFm12-73	Narrows	*Somateria* sp.	L. Scapula	**-14.6**	**13.1**	47.3	15.7	3.5	15.3
SgFm12-92	Narrows	*Somateria* sp.	L. Coracoid	**-15.3**	**14.3**	47.1	15.4	3.6	16.9
SgFm12-94	Narrows	*Somateria* sp.	L. Scapula	**-15.3**	**14.6**	45.4	15.0	3.5	23.3
SgFm6-2	Ridge	*Somateria* sp.	L. Coracoid	**-15.1**	**12.9**	45.5	15.9	3.3	17.3
SgFm6-11	Ridge	*Somateria* sp.	R. Coracoid	**-14.9**	**14.6**	46.3	15.1	3.6	14.9
SgFm6-1	Ridge	*Somateria* sp.	L. Humerus	**-15.0**	**15.1**	46.6	15.0	3.6	11.6
SgFm6-6	Ridge	*Somateria* sp.	L. Tarsometatarsus	**-15.0**	**14.5**	46.0	15.1	3.6	16.2
SgFm6-7	Ridge	*Somateria* sp.	R. Humerus	**-13.7**	**14.1**	47.1	15.0	3.7	16.0
SgFm6-15	Ridge	*Somateria* sp.	L. Tibiotarsus	**-15.4**	**15.6**	46.2	14.5	3.7	11.9
SgFm17-1	Shelter	*Somateria* sp.	R. Coracoid	**-15.4**	**13.4**	45.6	15.5	3.4	21.1
SgFm17-9	Shelter	*Somateria* sp.	R. Humerus	**-14.5**	**14.6**	47.1	15.5	3.5	18.3

Sample ID	Site	Species	Element	$\delta^{13}C$	$\delta^{15}N$	%C	%N	Atomic C:N	Collagen Yield (%)
SgFm17-21	Shelter	*Somateria* sp.	R. Humerus	**-16.1**	**13.5**	45.6	14.4	3.7	19.1
SfFl1-37	Baculum	*U. lomvia*	R. Tibiotarsus	**-15.7**	**16.2**	42.7	12.7	3.9	16.2

Table 7.2. Stable carbon and nitrogen isotope values from bird skeletal remains recovered from the Knud Peninsula sites. Atomic C:N ratios, %C, %N, and collagen yield percentage are also included.

Mean and standard deviation were determined for all species with a sample size of two or more (see Table 7.3). Mean and standard error for all bird species with a sample size of two or greater are also represented graphically, and species with a sample size of one are also plotted on the same graph for comparison (see Figure 7.1). Cormorants have the most elevated stable carbon isotope ratios, while snow geese and rock ptarmigan have the most depleted stable carbon isotope ratios. Glaucous gulls have the most elevated stable nitrogen isotope values, while rock ptarmigan have the most depleted stable nitrogen isotope values.

Species	**NISP**	**MNI**	**Mean δ^{13}C (‰)**	**δ^{13}C Range (‰)**	**Mean δ^{15}N (‰)**	**δ^{15}N Range (‰)**
Northern Pintail*	1	1	-15.2	-15.2	18.8	18.8
Duck/Goose	15	10	-15.7 ± 0.7	-17.0 to -14.7	13.5 ± 1.3	11.0 to 15.1
Brant Goose	9	4	-16.4 ± 3.5	-21.2 to -11.4	7.3 ± 1.6	5.6 to 10.4
Snow Goose	2	2	-20.5 ± 2.9	-22.5 to -18.4	6.0 ± 0.4	5.8 to 6.3
Eider sp.	54	29	-15.1 ± 0.6	-16.9 to -13.5	13.9 ± 0.9	12.2 to 15.8
Dovekie	1	1	-17.1	-17.1	15.8	15.8
Gull/Auk*	1	1	-14.8	-14.8	18.8	18.8
Glaucous Gull	5	2	-15.1 ± 0.4	-15.7 to -14.7	19.1 ± 1.0	18.0 to 20.8
Black-Legged Kittiwake	1	1	-14.2	-14.2	19.0	19.0
Arctic Tern	2	1	-18.1 ± 0.1	-18.1 to -18.0	12.9 ± 0.6	12.5 to 13.3
Parasitic Jaeger	5	2	-15.6 ± 0.6	-16.4 to -15.0	18.9 ± 04	18.2 to 19.2
Thick-Billed Murre	1	1	-15.7	-15.7	16.2	16.2
Rock Ptarmigan*	1	1	-21.3	-21.3	2.9	2.9
Cormorant sp.	3	3	-13.9 ± 1.5	-14.9 to -12.2	14.3 ± 0.4	13.9 to 14.6

Table 7.3. Mean and range of stable carbon and nitrogen isotope ratios for bird faunal remains from Knud Peninsula sites.

*Means were not calculated for species with a sample size of one.

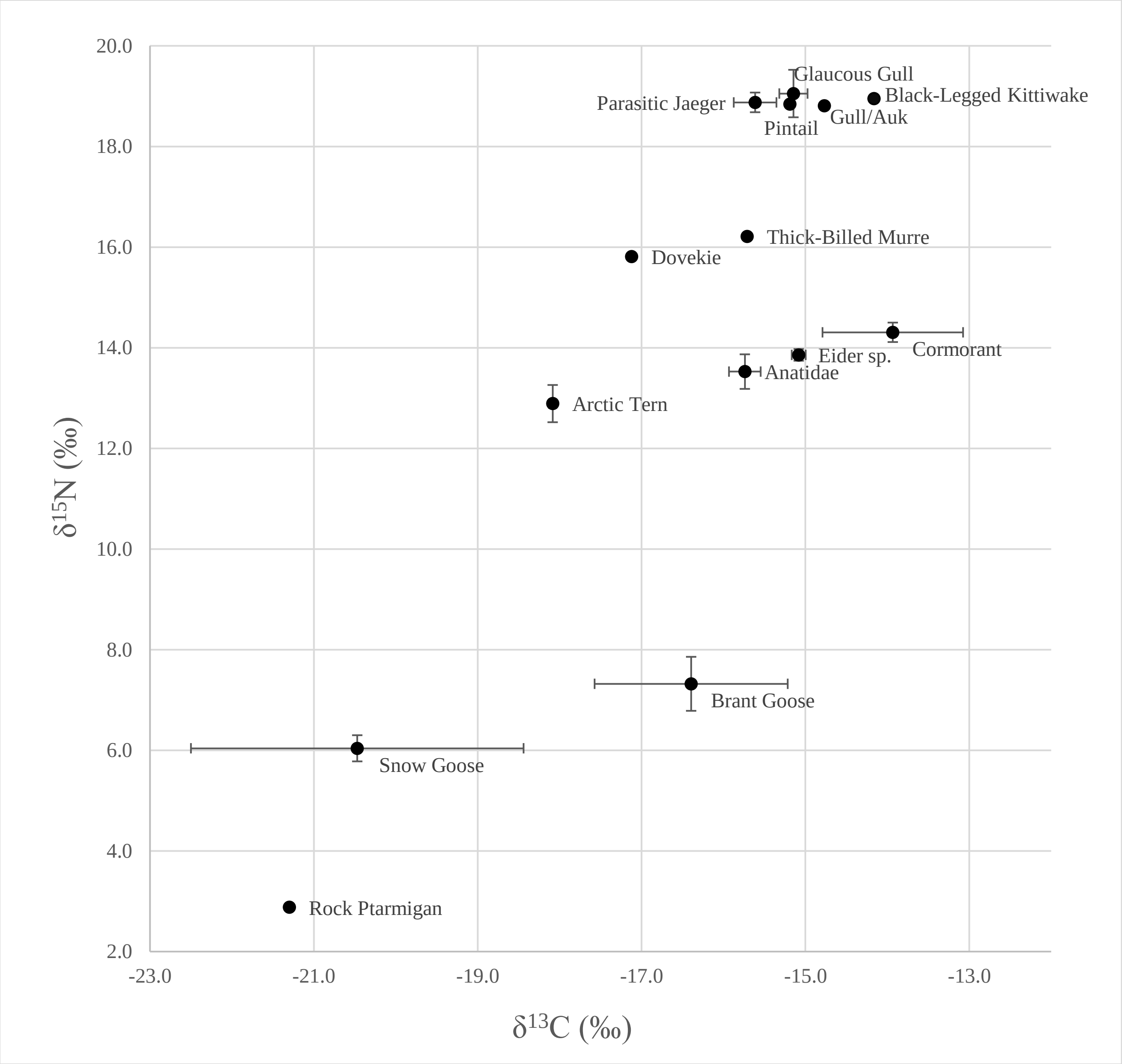


Figure 7.1. Mean and standard error of stable carbon and nitrogen isotope ratios of archaeological bird remains from Knud Peninsula.

The ANOVA test indicated that there were significant differences between the various species of bird faunal remains recovered from the Knud Peninsula when the brant geese were omitted from the analysis (p-value = 0.023). Three of the brant geese values were outliers, and therefore they did not satisfy the requirement for normality and equality of variances for the ANOVA test. The three brant geese values were, however, still included within the mean calculations and the discussion because the variation in isotopic signatures still reflects dietary differences within the species. There were significant differences in stable carbon isotope ratios between the unidentified duck/goose remains, and the eider duck remains (p-value = 0.001), but not for the stable nitrogen isotope ratios (p-value = 0.694). The one-way analysis of variance (ANOVA) for eider remains from the seven sites showed that there were no significant differences for stable carbon and nitrogen isotope values for eider duck remains from different sites (δ^{13}C p-value= 0.099, δ^{15}N p-value= 0.6570).

7.7 Discussion

7.7.1 Isotopic Signatures of Birds from Eastern Ellesmere Island

The stable carbon and nitrogen isotope values of the bird faunal remains appear to separate into three groups: birds with terrestrial herbivore signatures which are comparatively depleted in the heavier isotopes of carbon and nitrogen (geese and ptarmigan), birds with intermediate stable carbon and nitrogen isotope ratios (eiders, auks, cormorants, and the arctic tern), and birds enriched in the heavier isotopes of carbon and nitrogen that reflect a higher trophic level marine diet (gulls, jaeger, and pintail duck). These groupings are consistent with their known diets, except for the kittiwake and the northern pintail.

Snow geese, brant geese, and ptarmigan are all terrestrial herbivores. Eider ducks feed mostly within the marine ecosystem. Thus, they have elevated δ^{13}C values, but their stable nitrogen isotope ratios are not as elevated as those of gulls because they consume foods at a lower trophic level such as mollusks and echinoderms instead of prey items such as fish or other birds. The unidentified ducks/geese are isotopically similar to the eider ducks and likely have a similar diet. The auks (thick-billed murre and dovekie) are also enriched in the heavier isotopes of carbon and nitrogen in comparison to the eiders because they are known to incorporate more fish, such as arctic cod, into their diet. Cormorants are intermediate in terms of stable nitrogen isotope ratios between eiders and auks. Though they also eat fish such as arctic cod, similar to the auks, they may be slightly depleted in the heavier isotope of nitrogen compared to the auks because they tend to hunt closer to shore and may, therefore, be obtaining smaller fish. Smaller cod are known to take smaller prey potentially from lower trophic levels resulting in lower stable nitrogen isotope ratios for cormorants (Hobson & Welch, 1992). This is also consistent with the known pattern of cormorants feeding on smaller fish during the summer.

The gulls and jaegers are mainly marine predators, but they will also hunt other birds, steal food from other birds, or feed on carcasses. They thus have the most elevated stable carbon and nitrogen isotopes compared to the values obtained for other species. The one unidentified Charadriiformes sample likely belongs to a species of gull based on the elevated δ^{13}C and δ^{15}N values.

The stable nitrogen isotope ratio of the black-legged kittiwake is elevated compared to the values obtained by Hobson and colleagues (2002) for adult kittiwakes. It is possible that the value obtained in this study is from a younger kittiwake, however. Fledgling kittiwakes were found to have stable nitrogen isotope ratios consistent with one trophic level above adult values due to greater consumption of arctic cod by hatchlings. Since the value obtained here was from bone collagen, the longer turnover time of bone compared to muscle, which was analyzed by Hobson and colleagues (2002), may mean that the stable nitrogen isotope ratio may still reflect juvenile values.

The elevated stable nitrogen isotope value obtained for the lone northern pintail sample was unexpected based on their dietary preference of various invertebrates. They are however opportunistic in their choice of habitat which may lead to variation in their isotopic values (Cloern, Canuel, & Harris, 2002). Plants in different wetland environments can have differing stable nitrogen isotope values due to variation in dissolved inorganic nitrogen, the microbial processes such as nitrification/denitrification taking place, and algal uptake (Cloern et al., 2002). Saline wetlands can have plant δ^{15}N values of up to 17.4‰, while freshwater plants may have a δ^{15}N value as low as 0.7‰ and these differences are passed up the food chain (Cloern et al., 2002). The elevated δ^{15}N value of the northern pintail may be due to increased exploitation of foods in saline or brackish environments. This finding may also be consistent with Grupe and Mekota's (2005) analysis of pintail ducks which found that they could vary by up to one trophic level based on their stable nitrogen isotope values.

The range of stable carbon isotope ratios for brant geese and snow geese were greater than that of the other avifaunal remains. This range may be due to smaller samples sizes, but it may also be due to the variety of plant food sources. Compared to birds feeding within the marine system, geese are limited by the shorter growing season in the Arctic and plant availability on their migratory route. Stable carbon isotope ratios can vary for plants in different environments and due to variables such as water stress, temperature, and nutrient depletion (Tieszen, 1991; van der Merwe, 1982). Variation in habitats occupied by geese during migration may, therefore, lead to a wide range of variation in their isotopic signatures.

The stable isotope analysis of bird remains from Pre-Dorset and Dorset sites on the Knud Peninsula, therefore, demonstrate that birds potentially consumed by these groups have a broad range of isotopic values that are reflective of their unique dietary strategies and habitat selection. Birds may vary in their isotopic values due to opportunistic hunting strategies, age, and food availability. Though it is important to not overstate the importance of birds in the diet of past Arctic hunter-gatherers, the isotopic variation in economically-valued birds should be considered in dietary reconstructions. For example, the remains of the two most abundant species at these archaeological sites, the eider duck and the brant goose, have highly differing stable carbon and nitrogen isotope ratios. Brant geese also have greater variation in their $\delta^{13}C$ values, which may be overlooked with small sample sizes. These differences are increasingly crucial in dietary reconstructions if birds are being stored for consumption during the winter and may, therefore, contribute to a more substantial proportion of the diet.

One last notable finding is the small range of variation in isotopic signatures for eider ducks across the seven sites. The statistical analysis indicated that there were no significant differences in stable carbon and nitrogen isotope ratios for eider ducks between the different sites. The seven sites, however, span the period between Pre-Dorset and Late Dorset occupations which is approximately 2000 years (Schledermann, 1990). There were also significant climatic shifts during this period, such as the Medieval Warm period during the Late Dorset site occupation. This may, therefore, indicate that the avian paleoecology for this region, at least for eider ducks, was relatively stable from approximately 3400 BP to 1100 BP despite climatic shifts that may have impacted human occupation. A larger sample size of bird faunal remains for stable isotope analysis therefore also provides valuable data for comparison with ecological studies of modern birds. Researchers can track changes in dietary niches of birds through time. These data are especially relevant for bird conservation studies that seek to understand the notable drop in the number of migratory birds breeding at certain sites (S. E. Davis, Nager, & Furness, 2005).

7.8 Conclusion

This study is the first to report stable carbon and nitrogen isotope ratios for a large sample of archaeological bird remains in the Arctic. Isotopic values were reflective of different dietary strategies, life history, and habitat selection and were therefore variable and could only be understood with an increased sample size. Increasing zooarchaeological analysis of Paleo-Inuit groups demonstrates that birds formed an essential seasonal resource at various sites, and the variability in the values obtained here may play a role in the dietary reconstructions of these populations. Isotopic values obtained from archaeological bird remains can also provide valuable comparative data for ecological research. Taken together with the avian-specific spacing values determined in Chapter 6, the stable isotope signatures obtained from archaeological bird remains demonstrate that not only do avian tissue spacings differ from those of mammals, but that stable isotope ratios from wild birds are highly variable and reflective of their unique life histories. Variability in avian stable isotope ratios may mean that birds can have isotopic signatures that are distinct from mammals thus making it possible to detect them in the diet of hunter-gatherers when using stable isotope analysis. This variability in avifaunal stable isotope ratios must also be considered when attempting to reconstruct past Arctic diets.

Chapter Eight: The Effect of Bird Isotopic Values and Bird-Specific Spacing Values on Linear Mixing Models of Past Arctic Hunter-Gatherer Diet

This chapter seeks to quantify the effect of birds on Arctic hunter-gatherer diet and evaluate the addition of avian-specific spacing values to linear mixing models. Linear mixing models based on values obtained from previous isotopic studies on past Arctic diet were used to test the impact of avian-specific spacing values on stable isotope reconstructions of past human diet. Bird-specific spacing values were also used in mixing calculations for various Paleo-Inuit groups to examine if these spacing values will result in changes to human bone collagen stable isotope ratios. These exercises will ultimately determine if the addition of birds, eggs, and bird-specific spacing values into isotopic models has any effect on analysis and interpretation of human paleodiet.

8.1 Linear Mixing Models

Bioarchaeologists need a variety of ways to determine the quantity of certain food items being consumed to reconstruct past diet. Stable isotope values from the consumer and prey items do not provide a complete picture on their own. Mixing models were therefore created to serve as a tool for researchers to estimate the proportions of sources that combine to create a resulting mixture. The first mixing models and those most often used are linear mixing models. Regarding dietary reconstructions using stable isotope analysis, linear mixing models allow researchers to estimate the proportion of dietary sources with unique stable isotope ratios that result in a given stable isotope ratio or mixture in the consumer. An example relevant to this dissertation would be the proportions of marine versus terrestrial food items that would contribute to the resulting stable carbon and nitrogen isotope ratios in an Arctic hunter-gatherer group.

This dissertation will use a standard linear mixing model and the IsoSource computer program (version 1.3). Standard linear mixing models operate using the following mass balance equations derived from Schwarcz's (1991) work:

$$\delta J_D = f_A\, \delta J_A + f_B\, \delta J_B + f_C\, \delta J_C$$

$$\delta K_D = f_A\, \delta K_A + f_B\, \delta K_B + f_C\, \delta K_C$$

$$1 = f_A + f_B + f_C$$

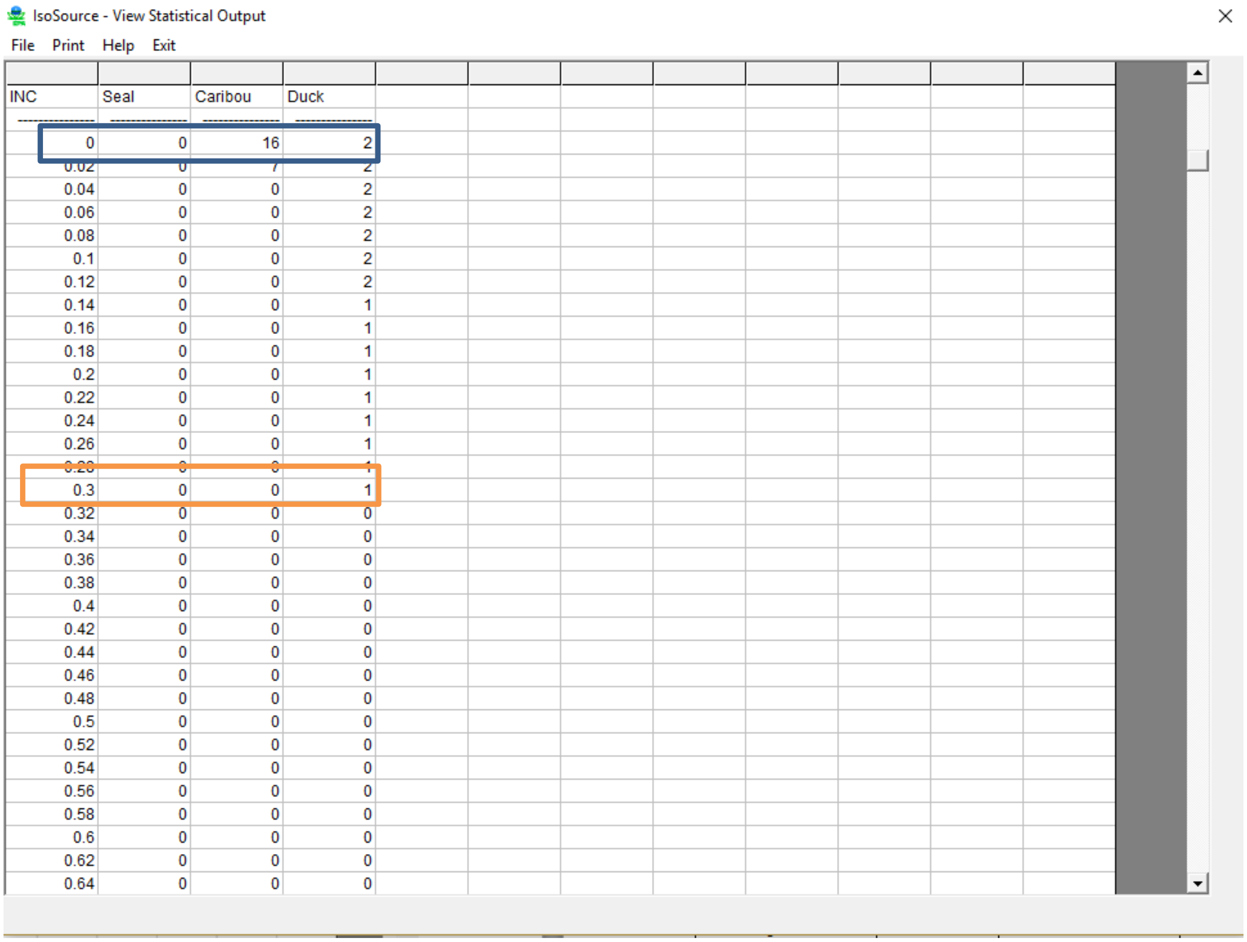
This set of equations represents three sources and their proportions in a two isotope system, where δJ_D and δK_D represent the isotopic signatures of the mixture, $\delta J_{A,}$ $\delta J_{B,}$ $\delta J_{C,}$ $\delta K_{A,}$ $\delta K_{B,}$ and δK_C represent the isotopic signatures of the sources, and f represents source proportions. Unique solutions can only be generated for n+1 sources in n isotope systems, as these are linear equations. A theoretical example is provided below:

$$\delta^{13}C_{human} = \%_{seal}\,(\delta^{13}C_{seal}) + \%_{caribou}\,(\delta^{13}C_{caribou}) + \%_{duck}\,(\delta^{13}C_{duck})$$

$$\delta^{15}N_{human} = \%_{seal}\,(\delta^{15}N_{seal}) + \%_{caribou}\,(\delta^{15}N_{caribou}) + \%_{duck}\,(\delta^{15}N_{duck})$$

$$1 = \%_{seal} + \%_{caribou} + \%_{duck}$$

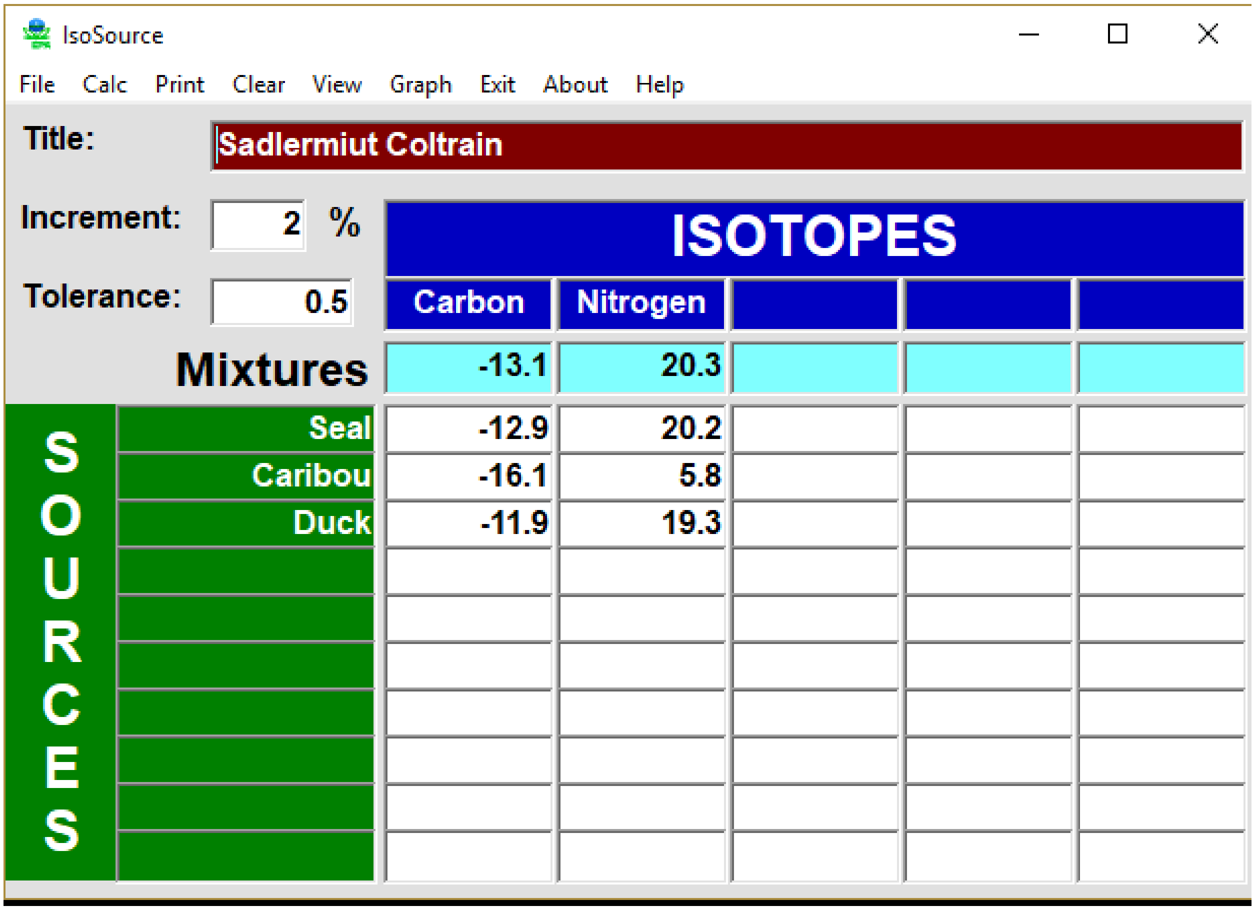
The IsoSource program, which will be used in this dissertation, however, finds the feasible combinations of source proportions for systems with >*n*+1 sources by creating possible combinations of sources that maintain mass balance in the mixture in small increments (referred to as the source increment), typically around 1-2% (Phillips & Gregg, 2003). For example, if a source increment of 2% is set, IsoSource will calculate all the possible combinations of the sources entered that will combine to equate to the measured isotopic ratio of the consumer in increments of 2% for each source (i.e., 2% seal, 4% caribou, 94% duck). The following figure (Figure 8.1) shows a sample output from IsoSource which displays the 2% source increments on the far left-hand side, followed by the number of times that each food source could be incorporated into the model to add up to the resulting measured human value with the corresponding source proportion. An example is shown in the orange box, where there is only one instance where ducks, if they made up 30% of the human diet, would result in the measured stable isotope ratios for human bone collagen as entered in the model. The example in the blue box shows that there are 16 scenarios where caribou (*Rangifer tarandus*) do not need to be included in the calculation, and the proportions of seals and ducks is enough to add up to the measured human values, and 2 scenarios where ducks do not need to be included in the calculation, and the proportions of seals and caribou is enough to add up to the measured human values. Please note that these are not the same scenarios and that IsoSource is simply tallying up the instances where the source proportions of each food item can add up to result in the measured human values. Also according to this IsoSource output, ducks can only make up a maximum of 30% of the human diet because there is no feasible proportion of ducks that would result in the measured human stable isotope ratios after the 30% source increment.



INC	Seal	Caribou	Duck
0	0	16	2
0.02	0	7	2
0.04	0	0	2
0.06	0	0	2
0.08	0	0	2
0.1	0	0	2
0.12	0	0	2
0.14	0	0	1
0.16	0	0	1
0.18	0	0	1
0.2	0	0	1
0.22	0	0	1
0.24	0	0	1
0.26	0	0	1
0.28	0	0	1
0.3	0	0	1
0.32	0	0	0
0.34	0	0	0
0.36	0	0	0
0.38	0	0	0
0.4	0	0	0
0.42	0	0	0
0.44	0	0	0
0.46	0	0	0
0.48	0	0	0
0.5	0	0	0
0.52	0	0	0
0.54	0	0	0
0.56	0	0	0
0.58	0	0	0
0.6	0	0	0
0.62	0	0	0
0.64	0	0	0

Figure 8.1. Output from IsoSource showing 2% source increments and the number of times that the food sources could add up to result in the measured human isotopic ratio with the corresponding proportion (source increment).

The possible combinations of sources are compared to the resulting mixture isotopic signature within a small tolerance value (referred to as the mass balance tolerance), which is often between 0.1‰ and 0.5‰. A tolerance value of 0.5‰ would mean that the resulting mixture from the various combinations of sources can range within 0.5‰ of the measured ratio, so if an individual has a measured stable nitrogen isotope ratio of 18.0‰, the resulting mixtures calculated by IsoSource need to fall between 17.5‰ and 18.5‰. Source increments and tolerance values are entered manually into the software, and both values should increase if there is uncertainty regarding the sources (i.e., spacing values, variability) (see Figure 8.2).



Title: Sadlermiut Coltrain

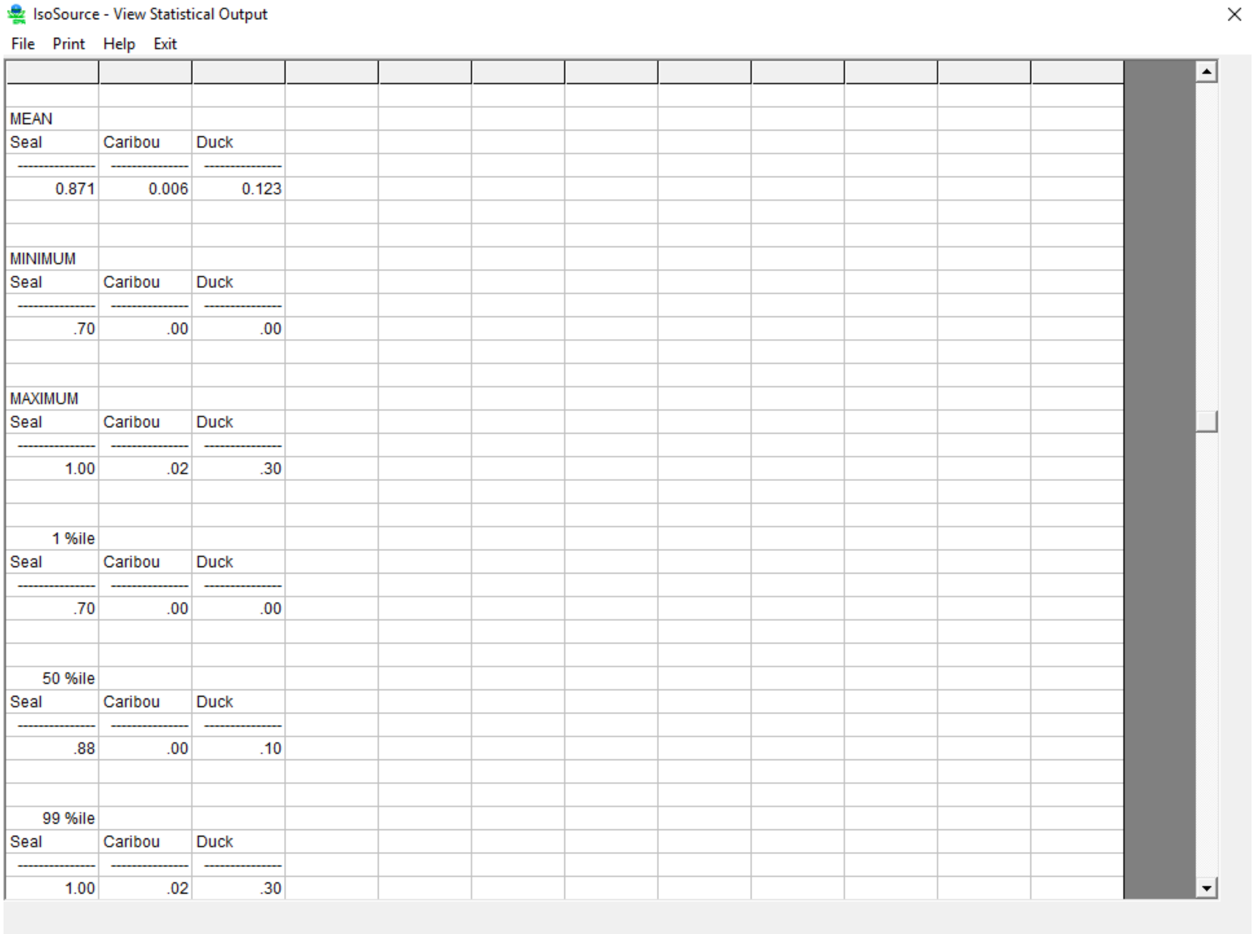
Increment: 2 %

Tolerance: 0.5

	Carbon	Nitrogen			
Mixtures	-13.1	20.3			
Seal	-12.9	20.2			
Caribou	-16.1	5.8			
Duck	-11.9	19.3			

Figure 8.2. Screenshot of IsoSource program showing the data input screen. Stable carbon and nitrogen isotope ratios entered to the right of the Mixtures title are the ratios measured for human bone collagen.

IsoSource compiles all the possible combinations that satisfy mass balance and are within the mass balance tolerance of the mixture and creates a distribution of all the feasible solutions with minimum and maximum source proportions and percentile ranges for source proportions. Mean source proportions are also provided, but it is recommended that ranges are reported to highlight that the source proportions supplied in IsoSource are within a range of possible source proportions and not unique values (Phillips & Gregg, 2003) (see Figure 8.3). On occasion, IsoSource will not be able to calculate any feasible solutions. This indicates that one or more of the isotopic values used for either the sources or mixture is incorrect, missing, or does not belong within the model, for example, the isotopic signature of an animal species recovered from an archaeological site is included in a human dietary mixing model, however, this animal was not used as food at the site.



```
MEAN
Seal          Caribou       Duck
------------  ------------  ------------
       0.871         0.006         0.123


MINIMUM
Seal          Caribou       Duck
------------  ------------  ------------
         .70           .00           .00


MAXIMUM
Seal          Caribou       Duck
------------  ------------  ------------
        1.00           .02           .30


      1 %ile
Seal          Caribou       Duck
------------  ------------  ------------
         .70           .00           .00


     50 %ile
Seal          Caribou       Duck
------------  ------------  ------------
         .88           .00           .10


     99 %ile
Seal          Caribou       Duck
------------  ------------  ------------
        1.00           .02           .30
```

Figure 8.3. Sample statistical output provided by IsoSource showing mean, minimum, and maximum proportions for each food source. Percentile ranges for source proportions are also provided, and these will be the favoured values for this dissertation.

Standard linear mixing models can also be presented graphically using a mixing polygon or diagram. Sources and mixtures are plotted in a scatter plot with the isotope systems on each axis (i.e., stable carbon and nitrogen isotopes). When sources are connected by lines to form a mixing polygon, the mixture should fall very close to or within the mixing polygon. If the mixture is not within or very close to the mixing polygon, IsoSource will likely not produce any results. The lines of the mixing polygon represent the extreme possible stable isotope ratios of an individual consuming these foods. The isotopic signature for the consumer will fall closer to the food items that they are eating in greater quantities. For example, in Figure 8.4, the human stable isotope ratios fall closer to food items 1, 2, and 4. Therefore this individual was likely consuming more of these food items, with a lesser contribution from food item 3. If the human value was too far outside of the polygon, however, there might be a food item that was not accounted for by this model. This graphical representation of the mixing model does not take into account variability like the IsoSource program; therefore if the human value still falls close to the mixing polygon (approximately 0.5‰), results are still likely. It is also worth noting that the values used in the mixing diagrams and entered into IsoSource are average stable isotope ratios for the consumer and food items. Stable isotope ratios for food items may also need to be converted to account for the tissue that is commonly eaten (i.e., muscle and fat) and the tissue that is preserved in the archaeological record (i.e., bone collagen). Mixing diagrams are mainly used to verify if the source values are feasible, but they are also a quick way to understand the results generated by IsoSource.

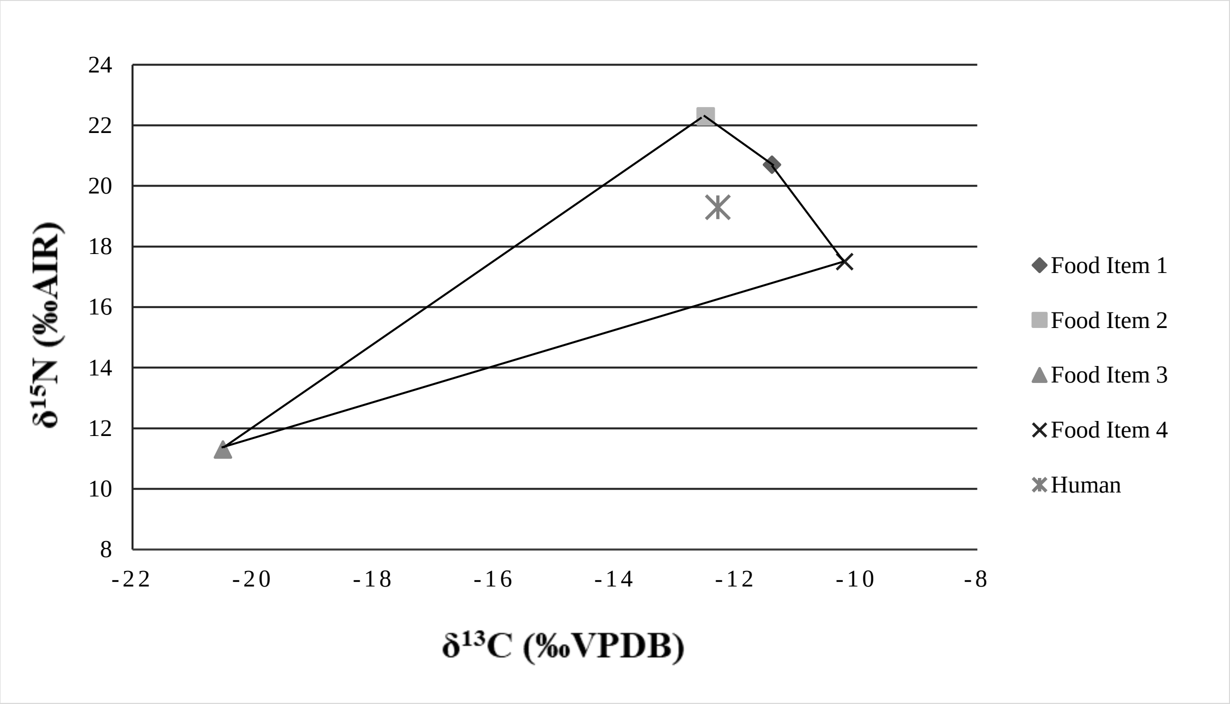


Figure 8.4. A theoretical example of a linear mixing diagram.

The sources, mixture, and their isotopic signatures are all determined and entered into mixing models by the user. Paleodietary reconstruction using mixing models, therefore, relies on additional lines of evidence, such as faunal analysis, to inform the researcher about the dietary items that were most likely consumed by the group. Often, there are also too many food sources with overlapping isotopic values that can hamper the interpretation of linear mixing models. Phillips and Gregg (2003) have therefore suggested that sources with very similar isotopic ratios be combined in IsoSource, for example, if ringed seals (*Phoca hispida*) have very similar isotopic values to Pacific cod (*Gadus microcephalus*) (within 1-2‰), the value of ringed seal or Pacific cod can be used to represent both in IsoSource, as IsoSource will unlikely be able to differentiate the two sources individually. This does mean, however, that during interpretation of the IsoSource results, the two sources cannot be distinguished, so if there is a maximum of 20%

of ringed seal or Pacific cod in the human diet as determined by IsoSource, there is no way to determine the individual proportions of each of these food resources isotopically, and this is where combined data from zooarchaeological analysis and stable isotope analysis is critical in paleodietary reconstruction.

Paleodiet researchers are further restricted by what is preserved in the archaeological record. As described in Chapters 4 and 6, faunal bone collagen stable isotope ratios from likely prey animals must also be converted to stable isotope ratios for muscle and fat, as these are the tissues that are being consumed by humans. An additional trophic level enrichment factor must also be added to the converted bone collagen stable isotope ratios to account for the trophic level shift from prey to human bone collagen. The resulting stable isotope ratio after these calculations is the end value that is entered into IsoSource for the source values (see Figure 8.5).

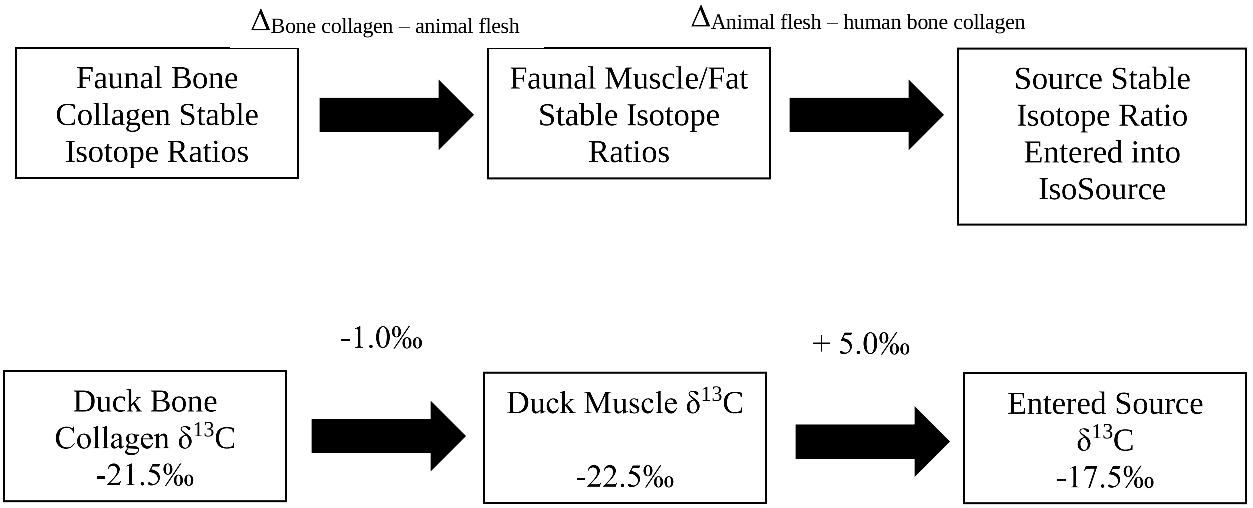


Figure 8.5. Steps outlining conversion of faunal bone collagen stable isotope ratios into values used in mixing models for human diet.

8.2 Linear Mixing Models Applied to Current Research

To determine the effect of duck-specific spacing values on paleodietary reconstruction using linear mixing models, the bird-specific spacing values for lipid-extracted muscle and fatty muscle presented in Chapter 6 were compared to the uniform spacing values used by Coltrain (2009), with the exception of one study (Bocherens et al., 2016), in ISOsource. Coltrain (2009) used an overall stable carbon isotope spacing value of +1‰ and overall stable nitrogen isotope spacing value of +3‰ for all faunal remains. Uniform spacing values for all faunal remains regardless of animal class, as used by Coltrain (2009), is the common practice in paleodietary reconstructions. Separate spacing values from faunal bone collagen to faunal flesh and from faunal flesh to human bone collagen were not provided by Coltrain (2009). Therefore only the overall spacing values are used in the models with uniform spacing values for all animals.

In addition to the linear mixing models with uniform spacing values for all faunal remains as described above, this chapter will also include linear mixing models with spacing values specific to birds. This chapter will use the enrichment value between animal flesh and human bone collagen of +5‰ for stable carbon isotope ratios (Ambrose & Norr, 1993; van der Merwe & Vogel, 1978) and +3‰ for stable nitrogen isotope ratios (Schoeninger & DeNiro, 1984) for the models with bird-specific spacing values. The bird-specific spacing values between bird bone collagen and bird flesh as determined in Chapter 6, and which will be used in this chapter are provided in Table 8.1.

	$\Delta^{13}C$	$\delta^{15}N$
Bird Muscle	-1.0	+0.5
Bird Muscle+Fat	-1.7	+0.0

Table 8.1. Bird-specific spacing values to convert bird bone collagen stable carbon and nitrogen isotope ratios to bird muscle and bird muscle and fat stable carbon and nitrogen isotope ratios.

The linear mixing model program, IsoSource, was used for all the mixing models in this study. A source increment of 2% and a mass balance tolerance of 0.5‰ were used for all models to account for uncertainties in tissue spacing values and source variability. All stable isotope ratios for human bone collagen were obtained from previous studies conducted on past Arctic human populations and the individual studies used are outlined in the following sections. Stable isotope ratios from faunal bone collagen were obtained from the corresponding studies where possible. If the studies on human bone collagen did not include data from faunal remains, stable isotope ratios from faunal bone collagen were used from studies in a similar geographical area. Archaeological samples were prioritized over modern samples to reduce uncertainty from accounting for the Suess effect and dietary changes through time, for example, the use of agricultural fields by migrating birds such as geese would result in differing isotopic values for modern versus pre-agricultural samples. The Suess effect refers to the shift in atmospheric CO_2 to a $\delta^{13}C$ value approximately 1.2‰ lower than pre-industrial values due to the burning of fossil fuels (Friedli, Lötscher, Oeschger, Siegenthaler, & Stauffer, 1986). Linear mixing models were created for archaeological studies from the Aleutian Islands, Alaska, Western Canadian Arctic, Eastern Canadian Arctic, and Greenland to include a wide geographical area that would cover the diverse ecosystems of the Arctic. This was done to evaluate the scale of the effect that bird-specific spacing values might have on Arctic populations eating different combinations of food from marine, terrestrial, and freshwater sources.

8.2.1 Aleutian Islands – Paleo-Aleut

The first linear mixing models created were for human bone collagen samples from 34 Paleo-Aleut individuals analyzed by Coltrain and colleagues in 2006. The study carried out by Coltrain and colleagues in 2006 was focussed on radiocarbon dating with only a brief mention of diet, and therefore did not include faunal bone collagen samples. Stable isotope ratios for faunal bone collagen from Aleutian archaeological sites were later obtained by Byers and colleagues in (2011) and included samples from ringed seal, bearded seal (*Erignathus barbatus*), harbour seal (*Phoca vitulina*), near-shore fishes, and Pacific cod. Linear mixing models were not used in either study to determine the potential food sources in Paleo-Aleut diet.

The archaeological study by Knecht and Davis (2008) on the Amaknak Bridge site was consulted in this dissertation to determine the animals that were likely being consumed by Paleo-Aleut groups. As a result, ringed seal, fur seal (*Callorhinus ursinus*), common murre (*Uria aalge*), large duck, Pacific cod, and near-shore fish were determined to be the most likely food items in Paleo-Aleut diet. The stable isotope values for ringed seal, common murre, large duck and near-shore fish were used in linear mixing models (see Table 8.2). Values for fur seal and Pacific cod were very similar to values for ringed seal in the region and were therefore grouped with the ringed seal, as is suggested by Phillips and Gregg (2003). Stable isotope ratios were not obtained for common murres and ducks in Byers and colleagues' 2011 study and were therefore derived from other research (see Table 8.2).

Animal	Sample	Source	$\delta^{13}C$	$\delta^{15}N$
Seal/Pacific Cod	Bone Collagen	Byers et al. 2011	-12.4	17.7
Common Murre	Bone Collagen	Szpak et al. (2009)	-13.5	19.3
Large Duck	Bone Collagen	McManus-Fry et al. 2016	-21.5	8.3
Near-Shore Fish	Bone Collagen	Byers et al. 2011	-11.2	14.5
Human (Paleo-Aleut)	Bone Collagen	Coltrain et al. 2006	-12.3	19.3

Table 8.2. Stable carbon and nitrogen isotope ratios for species included in Paleo-Aleut mixing models and their sources.

Linear mixing models of Paleo-Aleut diet, therefore, included isotopic values for common murres, large ducks, seal/Pacific cod, and near-shore fish. It is worth noting again that only the stable isotope ratios of birds change between the different models due to the changes in spacing values, stable isotope ratios of all other animals remain the same between the three Paleo-Aleut models (see Tables 8.3 and 8.4).

Aleutian Islands (Common Murre)	Measured Value (‰)		ΔAnimal Collagen - Animal Flesh (‰)		ΔAnimal Flesh - Human Collagen (‰)		Total Offset (‰)		Corrected Value (‰)	
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Coltrain (2009)	-13.5	19.3					+1.0	+3.0	-12.5	22.3
Muscle Spacing (This Dissertation)	-13.5	19.3	-1.0	+0.5	+5.0	+3.0	+4.0	+3.5	-9.5	22.8
Muscle+Fat Spacing (This Dissertation)	-13.5	19.3	-1.7	0	+5.0	+3.0	+3.3	+3.0	-10.2	22.3

Table 8.3. Spacing values for common murres (*Uria aalge*) used in Paleo-Aleut mixing models (Animals other than birds maintain the total offset from Coltrain (2009) for all mixing models).

Aleutian Islands (Large Duck)	**Measured Value (‰)**		**ΔAnimal Collagen - Animal Flesh (‰)**		**ΔAnimal Flesh - Human Collagen (‰)**		**Total Offset (‰)**		**Corrected Value (‰)**	
	$\delta^{13}C$	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**
Coltrain (2009)	-21.5	8.3					+1.0	+3.0	-20.5	11.3
Muscle Spacing (This Dissertation)	-21.5	8.3	-1.0	+0.5	+5.0	+3.0	+4.0	+3.5	-17.5	11.8
Muscle+Fat Spacing (This Dissertaion)	-21.5	8.3	-1.7	0	+5.0	+3.0	+3.3	+3.0	-18.2	11.3

Table 8.4. Spacing values for large ducks used in Paleo-Aleut mixing models (Animals other than birds maintain spacing values from Coltrain (2009) for all mixing models).

With the application of bird-specific spacing values to the mixing models, the proportion of common murres and large ducks likely included in Paleo-Aleut diet increases (See Table 8.5). The mixing diagrams (Figures 8.6 to 8.8) show that the bird-specific spacing values place the common murre and large duck more in line with the measured Paleo-Aleut value thereby increasing the likelihood that they were included in Paleo-Aleut diet. This increase of birds in Paleo-Aleut diet is also seen in the statistical output from IsoSource, where the feasible combinations for common murres and ducks increase across all percentiles once bird-specific spacing values were used for the linear mixing models. The use of uniform spacing values for all species, therefore, underestimates the proportion of birds in Paleo-Aleut diet.

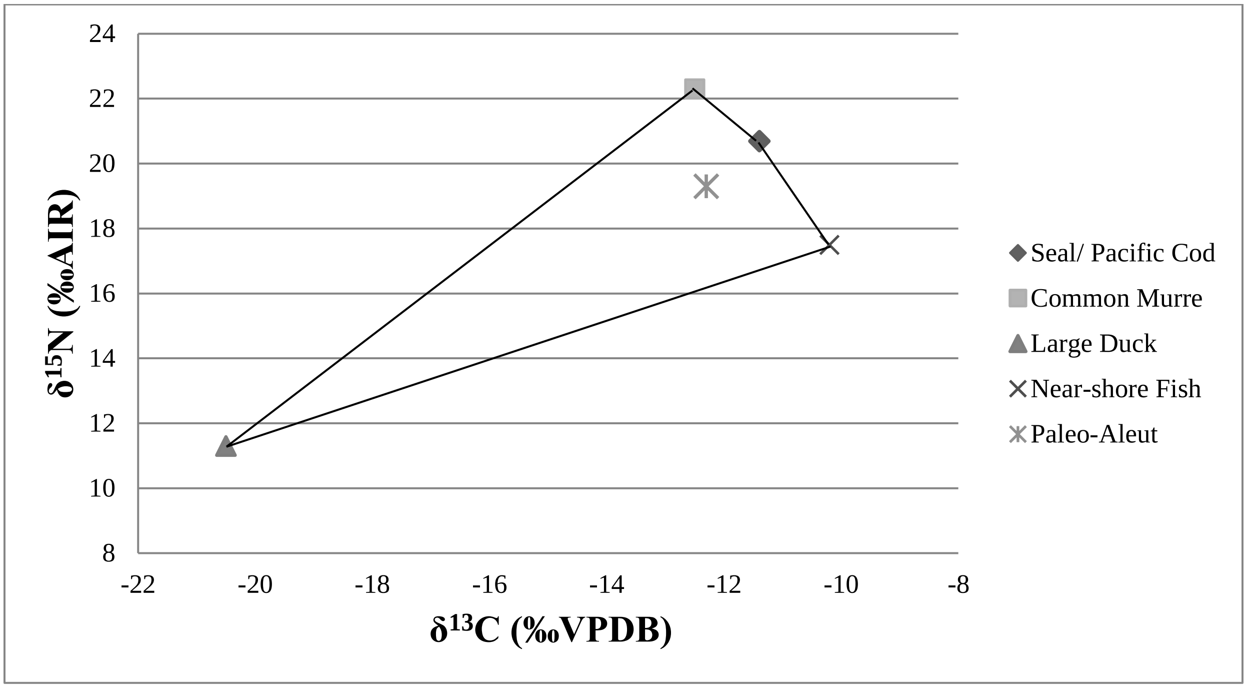


Figure 8.6. Paleo-Aleut linear mixing diagram with uniform spacing values for all faunal species.

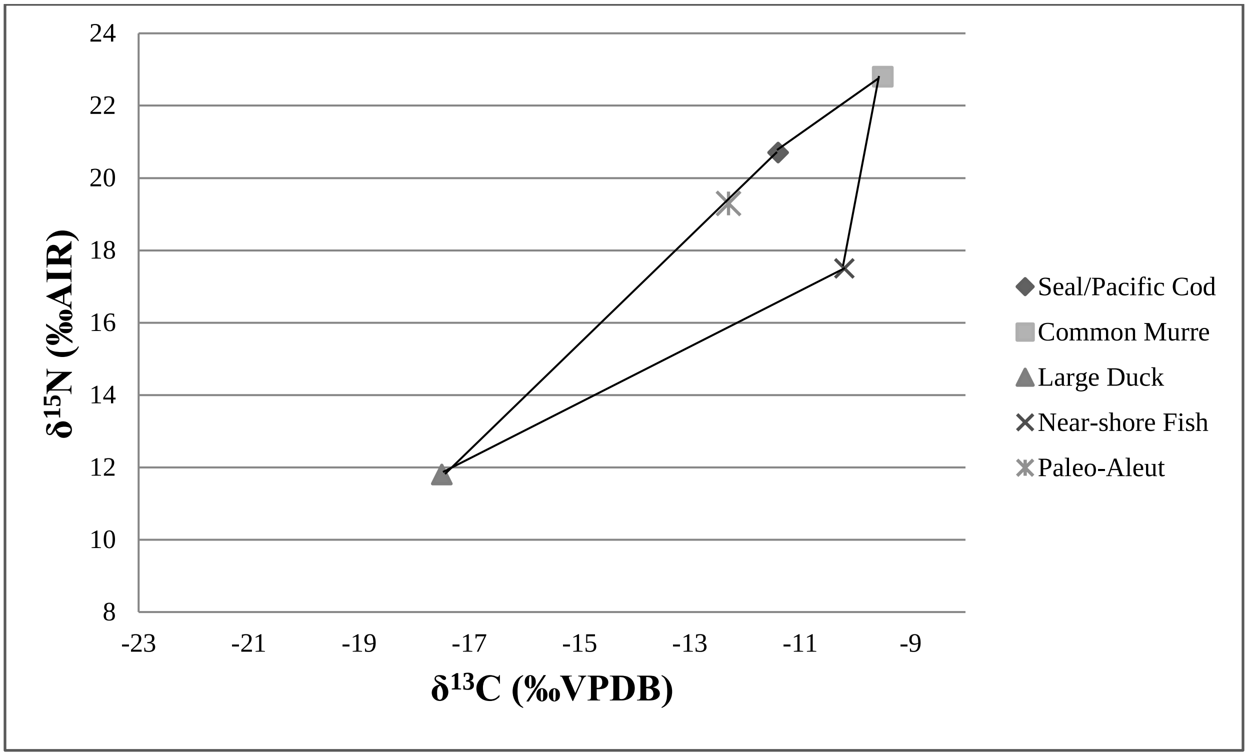


Figure 8.7. Paleo-Aleut linear mixing diagram with spacing values for seal and fish from Coltrain (2009) and lipid-extracted muscle spacing values for birds as determined in Chapter 6.

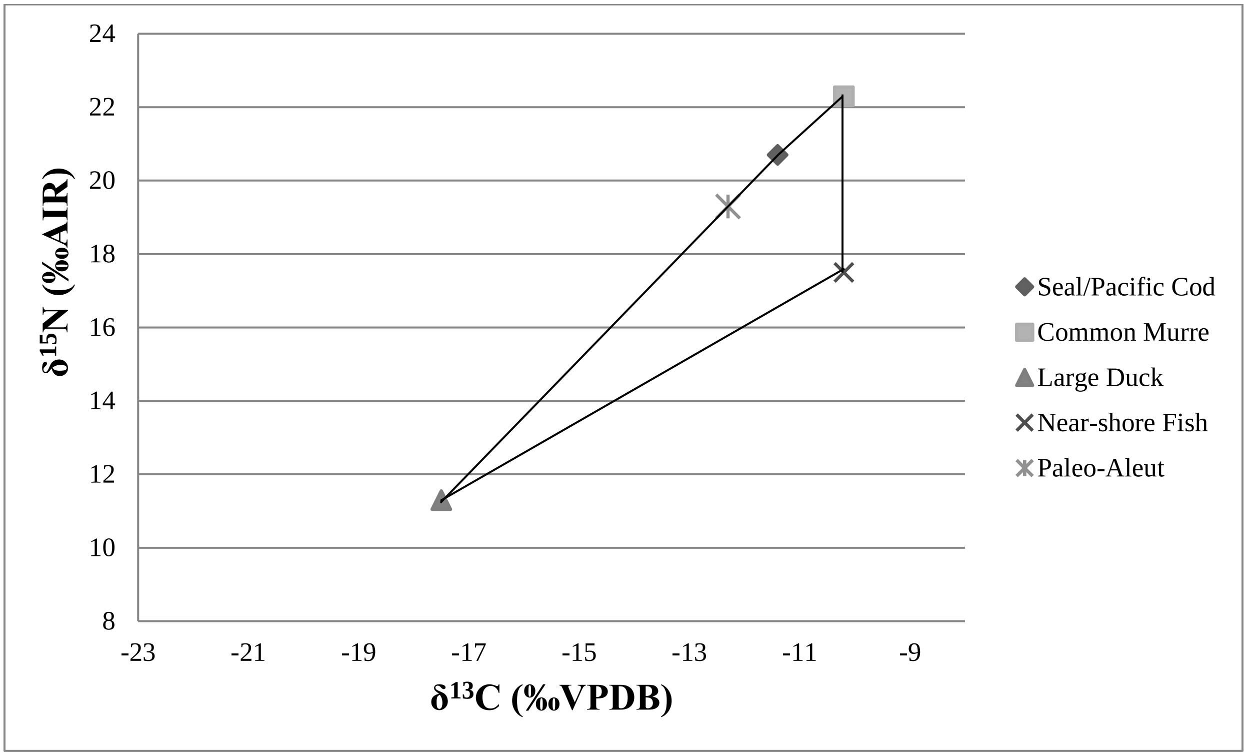


Figure 8.8. Paleo-Aleut linear mixing diagram with spacing values for seal and fish from Coltrain (2009) and muscle+fat spacing values for birds as determined in Chapter 6.

Spacing Reference	Animal	1st Percentile	50th Percentile	99th Percentile
Coltrain 2009	Seal/Pacific Cod	0.00	0.38	0.84
	Near-shore Fish	0.00	0.26	0.48
	Common Murre	0.00	0.24	0.56
	Large Duck	0.06	0.10	0.16
Muscle Spacing Values (This Dissertation)	Seal/Pacific Cod	0.00	0.46	0.84
	Near-shore Fish	0.00	0.06	0.22
	Common Murre	0.00	0.26	0.66
	Large Duck	0.10	0.20	0.34
Muscle+Fat Spacing Values (This Dissertation)	Seal/Pacific Cod	0.00	0.40	0.84
	Near-shore Fish	0.00	0.08	0.24
	Common Murre	0.00	0.32	0.72
	Large Duck	0.10	0.18	0.28

Table 8.5. IsoSource statistical outputs for Paleo-Aleut mixing models.

8.2.2 Alaska – Thule

The study by Coltrain and colleagues (2016) on bone collagen from Thule individuals at the Nuvuk site was used to create linear mixing models for past hunter-gatherer diet in Alaska. A total of 54 human bone collagen samples were analyzed in that study. Coltrain and colleagues (2016) also examined diet using a Bayesian mixing model, but they utilized modern muscle samples for potential food items. In order to determine the dietary items most likely eaten by the Nuvuk Thule, the mixing models in this section were made based on Morrison's (1983) analysis of faunal remains from the Nuvuk site. Ringed seal made up most of the assemblage, followed by caribou and birds. Bird species within the assemblage included common eider (*Somateria mollissima*), geese, and gulls. Faunal bone collagen values used for the mixing models in this dissertation were obtained for the appropriate species from other studies with the closest geographical proximity to the Nuvuk site in Alaska to maintain consistency with the other linear mixing models used in this dissertation. The animals included in the Alaskan Thule mixing models were ringed seal, caribou, eider duck (*Somateria* sp.), gull, and goose. The stable isotope ratios used for the linear mixing models for the Alaskan Thule reconstruction are listed in Table 8.6.

Animal	Sample	Source	$\delta^{13}C$	$\delta^{15}N$
Ringed Seal	Bone Collagen	McManus-Fry et al. 2016	-13.4	18.3
Caribou	Bone Collagen	McManus-Fry et al. 2016	-18	1.8
Eider Duck	Bone Collagen	Coltrain et al. 2004	-12.9	16.3
Gull	Bone Collagen	Mackenzie-Grieve et al. 2005	-19.9	17.3
Goose	Bone Collagen	Bocherens et al. 2016	-19.4	6.8
Human (Thule)	Bone Collagen	Coltrain et al. 2016	-14.1	20.5

Table 8.6. Stable carbon and nitrogen isotope ratios for species included in Alaskan Thule mixing models and their sources.

Three different mixing models were generated, one with uniform spacing values for all species based on spacing values obtained from Coltrain (2009) (see Figure 8.9), one model with a bird-specific spacing value from bird bone collagen to bird muscle as determined in chapter 6(see Figure 8.10), and one model with a bird-specific spacing value from bird bone collagen to bird muscle and fat as determined in chapter 6 (see Figure 8.11). The spacing values used and the resulting bird isotopic values entered in IsoSource are provided in Tables 8.7, 8.8, and 8.9.

Alaska (Glaucous Gull)	Measured Value (‰)		ΔAnimal Collagen - Animal Flesh (‰)		ΔAnimal Flesh - Human Collagen (‰)		Total Offset (‰)		Corrected Value (‰)	
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Coltrain (2009)	-19.9	17.3					+1.0	+3.0	-18.9	20.3
Muscle Spacing (This Dissertation)	-19.9	17.3	-1.0	+0.5	+5.0	+3.0	+4.0	+3.5	-15.9	20.8
Muscle+Fat Spacing (This Dissertation)	-19.9	17.3	-1.7	0	+5.0	+3.0	+3.3	+3.0	-16.6	20.3

Table 8.7. Spacing values for glaucous gulls used in Alaskan Thule mixing models (Animals other than birds maintain spacing values from Coltrain (2009) for all mixing models).

Alaska (Common Eider)	Measured Value (‰)		ΔAnimal Collagen - Animal Flesh (‰)		ΔAnimal Flesh - Human Collagen (‰)		Total Offset (‰)		Corrected Value (‰)	
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Coltrain (2009)	-12.9	16.3					+1.0	+3.0	-11.9	19.3
Muscle Spacing (This Dissertation)	-12.9	16.3	-1.0	+0.5	+5.0	+3.0	+4.0	+3.5	-8.9	19.8
Muscle+Fat Spacing (This Dissertation)	-12.9	16.3	-1.7	0	+5.0	+3.0	+3.3	+3.0	-9.6	19.3

Table 8.8. Spacing values for common eiders used in Alaskan Thule mixing models (Animals other than birds maintain spacing values from Coltrain (2009) for all mixing models).

Alaska (White-fronted goose)	Measured Value (‰)		ΔAnimal Collagen - Animal Flesh (‰)		ΔAnimal Flesh - Human Collagen (‰)		Total Offset (‰)		Corrected Value (‰)	
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Coltrain (2009)	-19.4	6.8					+1.0	+3.0	-18.4	9.8
Muscle Spacing (This Dissertation)	-19.4	6.8	-1.0	+0.5	+5.0	+3.0	+4.0	+3.5	-15.4	10.3
Muscle+Fat Spacing (This Dissertation)	-19.4	6.8	-1.7	0	+5.0	+3.0	+3.3	+3.0	-16.1	9.8

Table 8.9. Spacing values for white-fronted geese used in Alaskan Thule mixing models (Animals other than birds maintain spacing values from Coltrain (2009) for all mixing models).

The use of bird-specific spacing values in these mixing models increases the proportion of gulls included in the Alaskan Thule diet across all percentiles, while the proportion of ducks in Alaskan Thule diet decreases across all percentiles, and the proportion of geese in Alaskan Thule diet remains the same in all three models (see Table 8.10). The bird-specific spacing values place the gull isotopic signature closer to that of the Thule, thereby increasing the likelihood that they were included in Alaskan Thule diet (see Figures 8.9 to 8.11). The possibility that eider ducks were included in Alaskan Thule diet decreases with bird-specific spacing values because their isotopic signature moves further away from that of the Thule. The proportion of geese in Alaskan Thule diet does not change across the three models because their isotopic signature is very similar to that of the terrestrial caribou, and the Alaskan Thule signature indicates that they were consuming very high proportions of marine foods, and terrestrial foods likely played a very negligible role in their diet. The use of bird-specific spacing values, in this case, indicates that the relative importance of certain bird species may be confused with the traditional model of using uniform spacing values for all species. Under the traditional model, eider ducks may have appeared more important to Alaskan Thule diet, while under the model with bird-specific spacing values, gulls take up greater importance in Alaskan Thule diet.

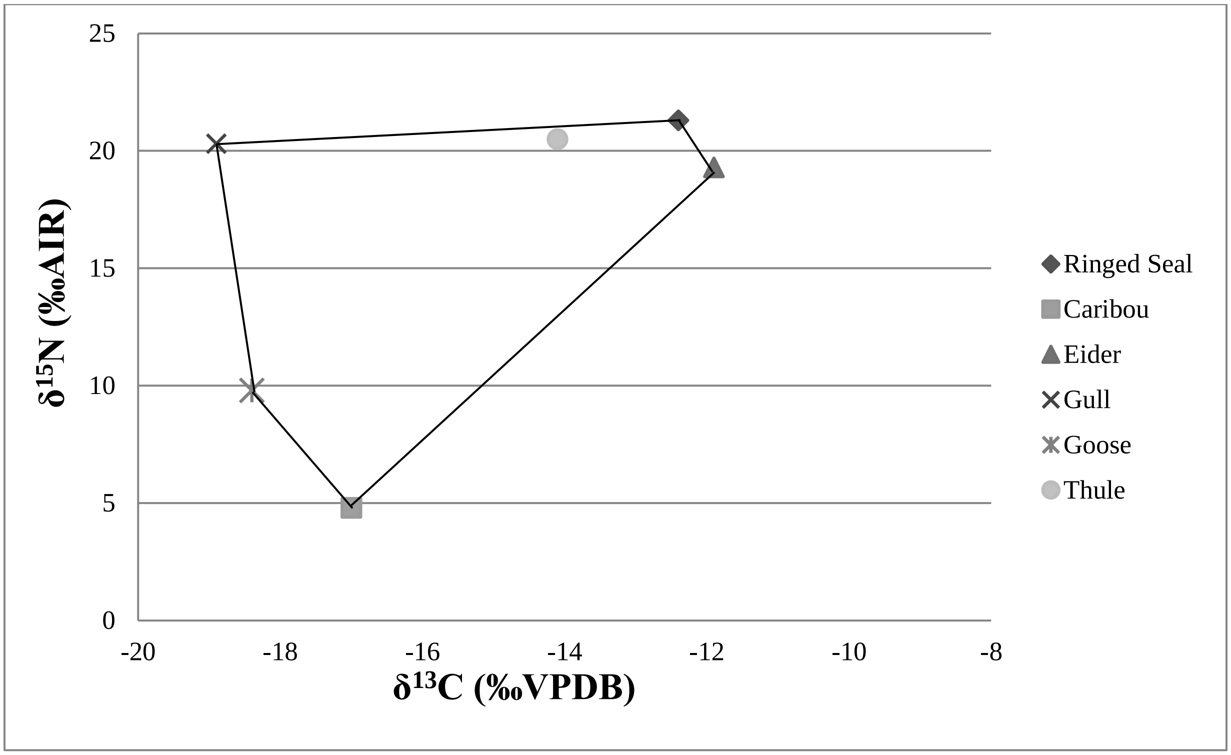


Figure 8.9. Alaskan Thule linear mixing diagram with spacing values from Coltrain (2009).

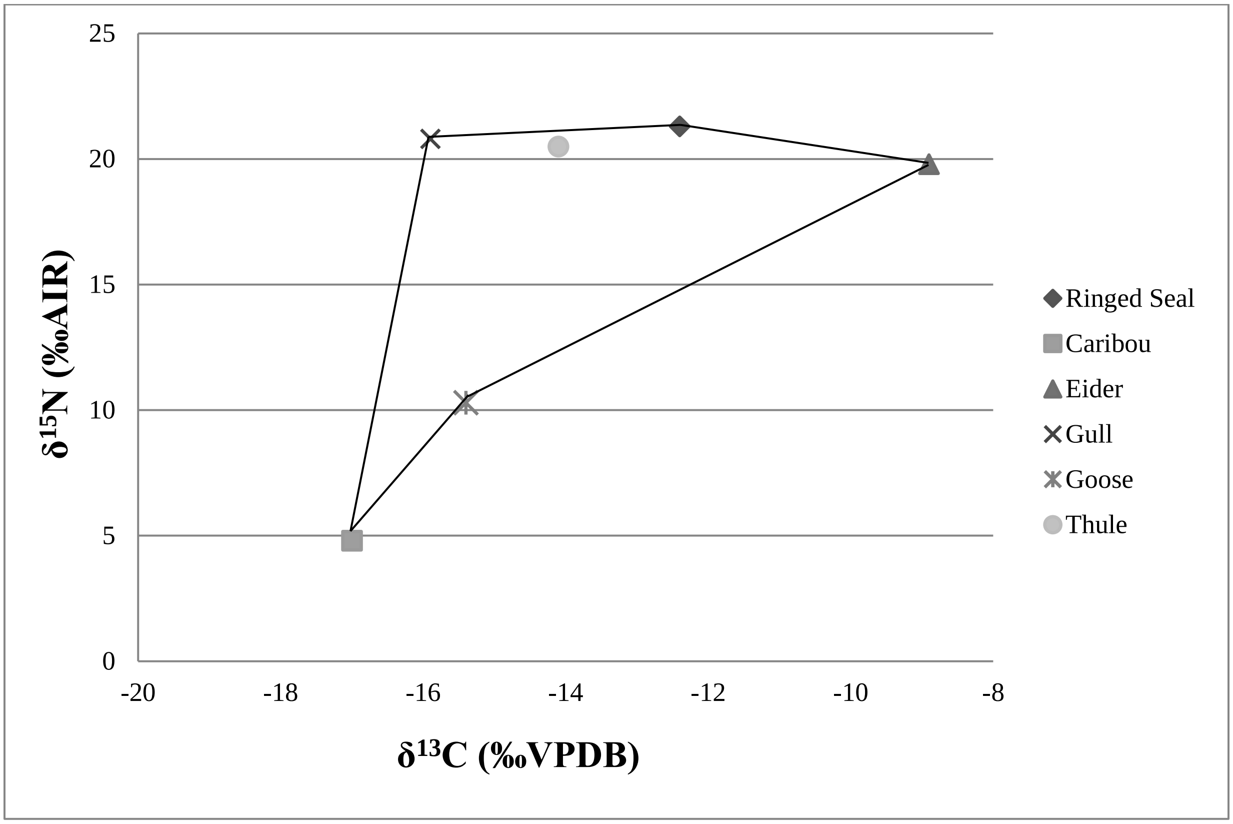


Figure 8.10. Alaskan Thule linear mixing diagram with spacing values for seal and caribou from Coltrain (2009) and lipid-extracted muscle spacing values for birds as determined in Chapter 6.

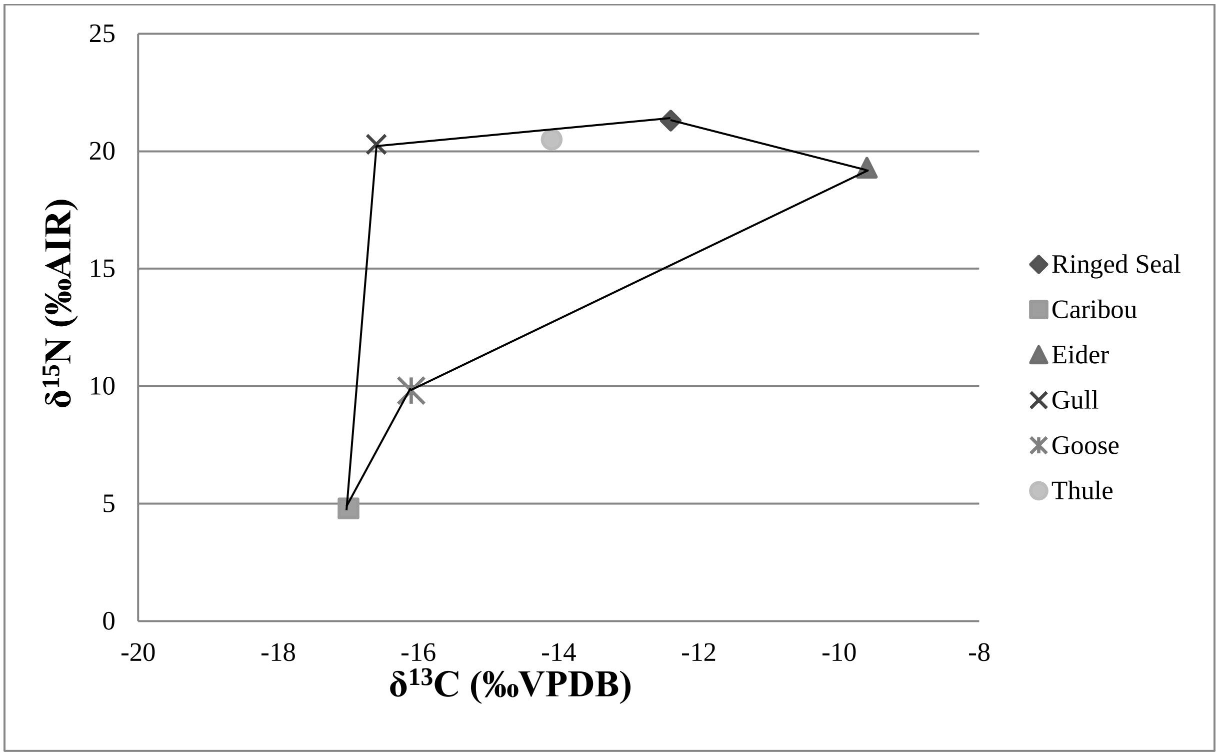


Figure 8.11. Alaskan Thule linear mixing diagram with spacing values for seal and caribou from Coltrain (2009) and muscle+fat spacing values for birds as determined in Chapter 6.

Spacing Reference	Animal	1st Percentile	50th Percentile	99th Percentile
Coltrain 2009	Ringed Seal	0.22	0.60	0.80
	Caribou	0.00	0.00	0.06
	Gull	0.12	0.24	0.34
	Duck	0.00	0.12	0.48
	Goose	0.00	0.02	0.08
Muscle Spacing Values (This Dissertation)	Ringed Seal	0.00	0.32	0.64
	Caribou	0.00	0.02	0.06
	Gull	0.30	0.54	0.76
	Duck	0.00	0.10	0.30
	Goose	0.00	0.02	0.08
Muscle+Fat Spacing Values (This Dissertation)	Ringed Seal	0.06	0.46	0.70
	Caribou	0.00	0.00	0.04
	Gull	0.24	0.42	0.66
	Duck	0.00	0.08	0.34
	Goose	0.00	0.02	0.08

Table 8.10. IsoSource statistical output for linear mixing models of Alaskan Thule diet.

8.2.3 Western Canada – Pre-Dorset

Linear mixing models were created for the western Canadian Arctic using data from Bocherens and colleagues' study from 2016 on Pre-Dorset diet. Their study only included stable carbon and nitrogen isotope values for one Pre-Dorset individual, but faunal bone collagen values were included for a Bayesian mixing model. Bocherens and colleagues (2016) included faunal bone collagen values for caribou, muskox (*Ovibos moschatus*), skua, and geese, however, whitefish values were based on modern muscle samples, and seal values were estimated using whitefish values. A total offset value of 1.1‰ for stable carbon isotopes and 3.8‰ for stable nitrogen isotopes was used for the faunal remains in their study.

For this dissertation, whitefish and ringed seal bone collagen stable isotope values were based on data collected by Mackenzie-Grieve and colleagues (2005) from the Kuukpak site on the Mackenzie Delta. Mixing models were created using the whitefish values provided by Bocherens and colleagues (2016); however, they did not yield any results. Due to this reason and to maintain consistency between the various mixing models in this dissertation, the archaeological values for both ringed seal and broad whitefish (*Coregonus nasus*) from the Mackenzie Delta were used in the following mixing models. Stable isotope ratios for caribou, muskox, skua, geese, whitefish, and ringed seal were used for the Pre-Dorset linear mixing models in this dissertation (see Table 8.11). This is also the only study where total offset values of 1.1‰ for stable carbon isotope ratios and 3.8‰ for stable nitrogen isotope ratios were used for the uniform spacing value for all animals instead of the spacing values used by Coltrain (2009) to maintain most of the conditions used in Bocherens and colleagues' (2016) study.

Animal	**Sample**	**Source**	**δ^{13}C**	**δ^{15}N**
Caribou	Bone Collagen	Bocherens et al. 2016	-18.9	2.4
Muskox	Bone Collagen	Bocherens et al. 2016	-20.9	2.7
Skua	Bone Collagen	Bocherens et al. 2016	-20.1	12.9
Geese	Bone Collagen	Bocherens et al. 2016	-19.4	6.8
Whitefish	Bone Collagen	Mackenzie-Grieve et al. 2005	-22.6	9.4
Ringed Seal	Bone Collagen	Mackenzie-Grieve et al. 2005	-15.3	17.9
Human (Pre-Dorset)	Bone Collagen	Bocherens et al. 2016	-17.2	18.7

Table 8.11. Stable carbon and nitrogen isotope ratios for species included in Pre-Dorset mixing models and their sources.

Three different mixing models were generated, one with uniform spacing values for all species based on spacing values obtained from Bocherens and colleagues (2016) (see Figure

8.12), one model with a bird-specific spacing value from bird bone collagen to bird muscle as determined in chapter 6 (see Figure 8.13), and one model with a bird-specific spacing value from bird bone collagen to bird muscle and fat as determined in chapter 6 (see Figure 8.14). The spacing values used and the resulting bird isotopic values entered in IsoSource are provided in Tables 8.12 and 8.13.

W. Canadian Arctic (Geese)	**Measured Value (‰)**		**ΔAnimal Collagen - Animal Flesh (‰)**		**ΔAnimal Flesh - Human Collagen (‰)**		**Total Offset (‰)**		**Corrected Value (‰)**	
	δ^{13}C	**δ^{15}N**	**δ^{13}C**	**δ^{15}N**	**δ^{13}C**	**δ^{15}N**	**δ^{13}C**	**δ^{15}N**	**δ^{13}C**	**δ^{15}N**
Bocherens et al. (2016)	-19.4	6.8					+1.1	+3.8	-18.3	10.6
Muscle Spacing (This Dissertation)	-19.4	6.8	-1.0	+0.5	+5.0	+3.0	+4.0	+3.5	-15.4	10.3
Muscle+Fat Spacing (This Dissertation)	-19.4	6.8	-1.7	0	+5.0	+3.0	+3.3	+3.0	-16.1	9.8

Table 8.12. Spacing values for geese used in Pre-Dorset mixing models (Animals other than birds maintain spacing values from Bocherens et al. (2016) for all mixing models).

W. Canadian Arctic (Skua)	**Measured Value (‰)**		**ΔAnimal Collagen - Animal Flesh (‰)**		**ΔAnimal Flesh - Human Collagen (‰)**		**Total Offset (‰)**		**Corrected Value (‰)**	
	δ^{13}C	**δ^{15}N**	**δ^{13}C**	**δ^{15}N**	**δ^{13}C**	**δ^{15}N**	**δ^{13}C**	**δ^{15}N**	**δ^{13}C**	**δ^{15}N**
Bocherens et al. (2016)	-20.1	12.9					+1.1	+3.8	-19.0	16.7
Muscle Spacing (This Dissertation)	-20.1	12.9	-1.0	+0.5	+5.0	+3.0	+4.0	+3.5	-16.1	16.4
Muscle+Fat Spacing (This Dissertation)	-20.1	12.9	-1.7	0	+5.0	+3.0	+3.3	+3.0	-16.8	15.9

Table 8.13. Spacing values for skua used in Pre-Dorset mixing models (Animals other than birds maintain spacing values from Bocherens et al. (2016) for all mixing models).

Unlike the previous mixing models, once bird-specific spacing values were used in the mixing models, the possible proportions of both geese and skua in Pre-Dorset diet decreased compared to the mixing model with uniform spacing values for all animals (see Table 8.14). Figures 8.13 and 8.14 show that geese and skua isotopic signatures move further away from the Pre-Dorset signature once bird-specific spacing values were used. The proportions of ringed seal and whitefish, however, increased once the bird-specific spacing values were used. This is a significant result because bird-specific spacing values not only affect the interpretation regarding birds in human diet, but it will also influence the possible proportions of other animals in human diet because the source proportions must sum up to 100%.

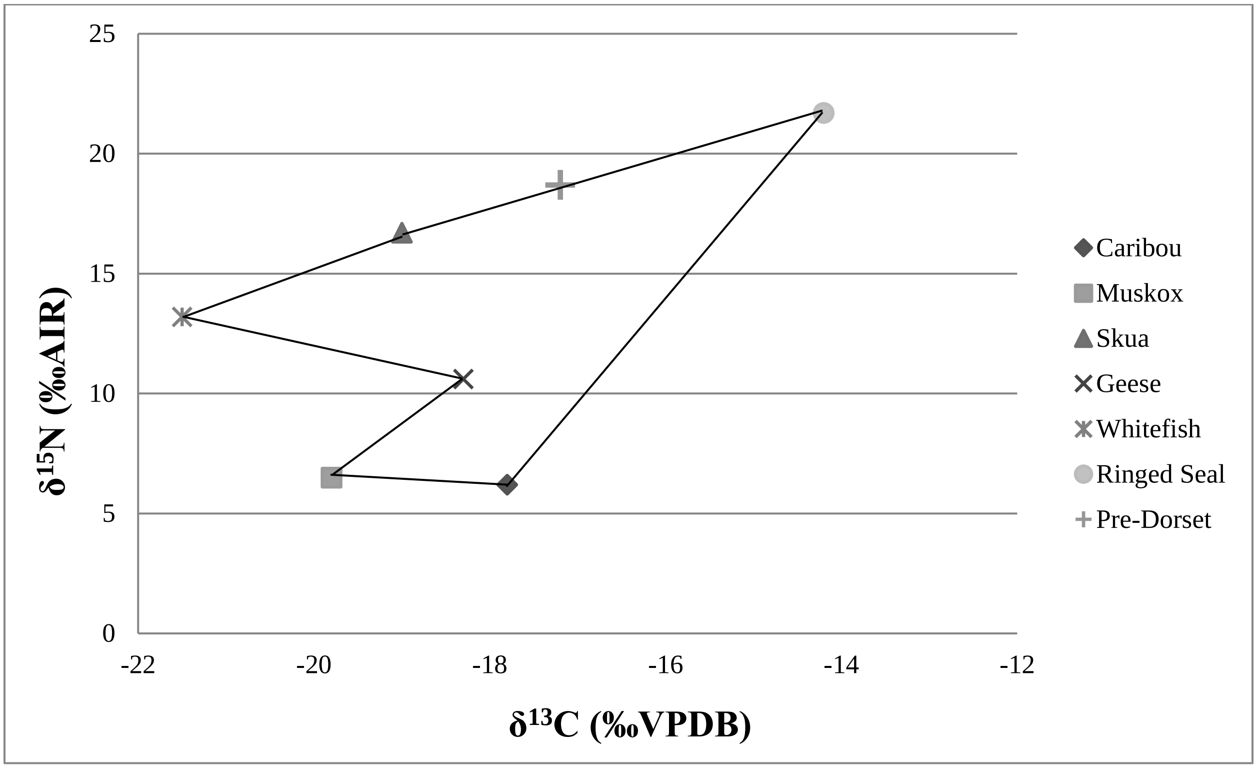


Figure 8.12. Pre-Dorset linear mixing diagram with spacing values from Bocherens et al. (2016).

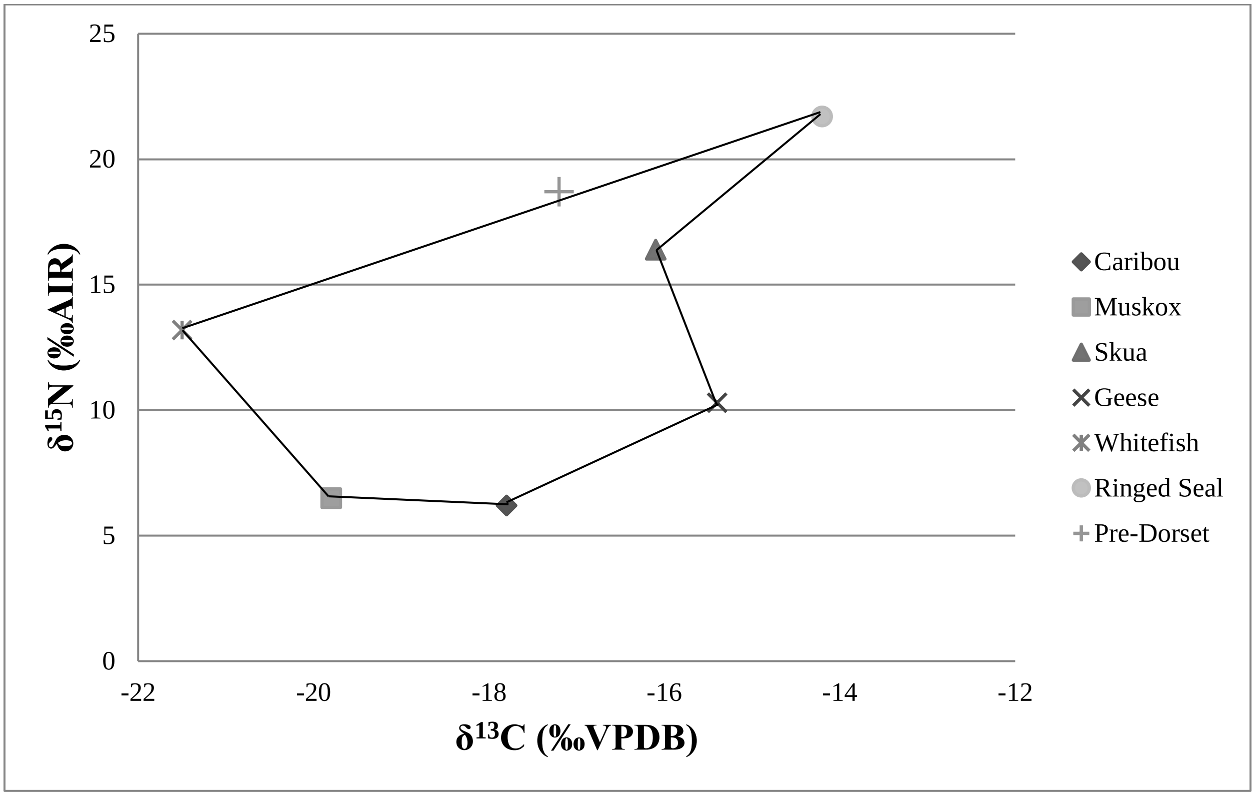


Figure 8.13. Pre-Dorset linear mixing diagram with spacing values for caribou, muskox, whitefish, and ringed seal from Bocherens et al. (2016) and lipid-extracted muscle spacing values for birds as determined in Chapter 6.

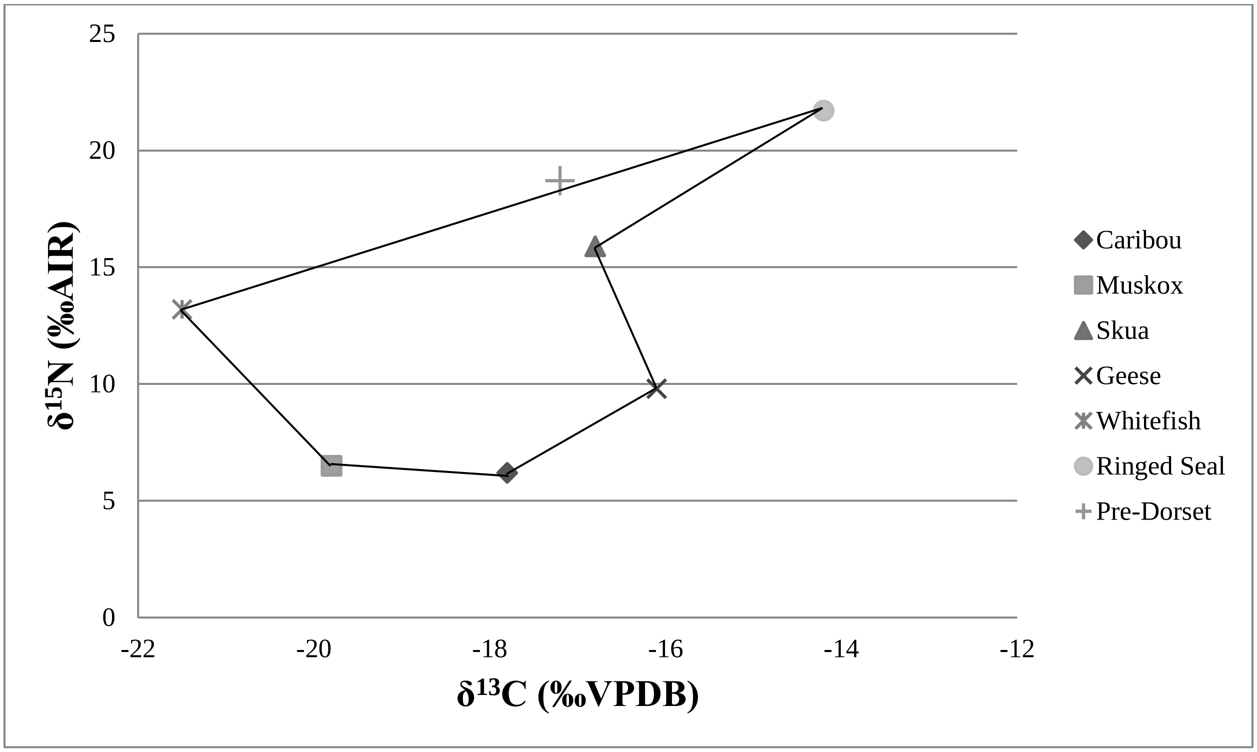


Figure 8.14. Pre-Dorset linear mixing diagram with spacing values for caribou, muskox, whitefish, and ringed seal from Bocherens et al. (2016) and muscle+fat spacing values for birds as determined in Chapter 6.

Spacing Reference	Animal	1st Percentile	50th Percentile	99th Percentile
Bocherens et al. 2016	Caribou	0.00	0.00	0.04
	Muskox	0.00	0.00	0.06
	Whitefish	0.00	0.12	0.36
	Ringed Seal	0.36	0.50	0.64
	Skua	0.00	0.34	0.60
	Goose	0.00	0.02	0.10
Muscle Spacing	Caribou	0.00	0.00	0.02
	Muskox	0.00	0.00	0.04
	Whitefish	0.30	0.34	0.38
	Ringed Seal	0.54	0.60	0.64
	Skua	0.00	0.02	0.12
	Goose	0.00	0.00	0.04
Muscle+Fat Spacing	Caribou	0.00	0.00	0.02
	Muskox	0.00	0.00	0.04
	Whitefish	0.28	0.34	0.38
	Ringed Seal	0.54	0.60	0.64
	Skua	0.00	0.04	0.16
	Goose	0.00	0.00	0.04

Table 8.14. IsoSource potential solutions for Pre-Dorset mixing models using different spacing values for birds.

8.2.4 Eastern Canada – Sadlermiut

Mixing models were created for eastern Canadian Arctic populations using data from Coltrain and colleagues' (2004) and Coltrain's (2009) study on Sadlermiut, Thule, and Proto-historic individuals from eastern Canada. For this dissertation, only Sadlermiut individuals were included in the mixing models as they appeared to have the highest proportion of birds in their diet compared to other groups based on the original study (Coltrain et al., 2004). Sadlermiut stable isotope ratios were based on Coltrain's updated study (2009), which included 25 human bone collagen samples. These studies also included linear mixing models to help reconstruct paleodiet. The linear mixing models for the analysis in this dissertation were therefore directly based on the values used in the original research except for the models with bird-specific spacing values (see Table 8.16). The animals included in the original studies and for the linear mixing models in this dissertation were seal, caribou, and duck, and their stable isotope ratios are provided in Table 8.15.

Animal	**Sample**	**Source**	**δ^{13}C**	**δ^{15}N**
Seal	Bone Collagen	Coltrain et al. 2004	-13.9	17.2
Caribou	Bone Collagen	Coltrain et al. 2004	-17.1	2.8
Duck	Bone Collagen	Coltrain et al. 2004	-12.9	16.3
Human (Sadlermiut)	Bone Collagen	Coltrain 2009	-13.1	20.3

Table 8.15 Stable carbon and nitrogen isotope ratios for species included in Sadlermiut mixing models and their sources.

Three different mixing models were generated, one with uniform spacing values for all species based on spacing values obtained from Coltrain (2009) (see Figure 15), one model with a bird-specific spacing value from bird bone collagen to bird muscle as determined in chapter 6 (see Figure 16), and one model with a bird-specific spacing value from bird bone collagen to bird muscle and fat as determined in chapter 6 (see Figure 17). The spacing values used and the resulting bird isotopic values entered in IsoSource are provided in Table 16.

	Measured Value (‰)		**ΔAnimal Collagen - Animal Flesh (‰)**		**ΔAnimal Flesh - Human Collagen (‰)**		**Total Offset (‰)**		**Corrected Value (‰)**	
	$\delta^{13}C$	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**
Coltrain (2009)	-12.9	16.3					+1.0	+3.0	-11.9	19.3
Muscle Spacing (This Dissertation)	-12.9	16.3	-1.0	+0.5	+5.0	+3.0	+4.0	+3.5	-8.9	19.8
Muscle+Fat Spacing (This Dissertation)	-12.9	16.3	-1.7	0	+5.0	+3.0	+3.3	+3.0	-9.6	19.3

Table 8.16. Spacing values for ducks used in Sadlermiut mixing models (Animals other than birds maintain spacing values from Coltrain (2009) for all mixing models).

The possible proportion of duck in Sadlermiut diet decreases once bird-specific spacing values were used in the linear mixing models (see Table 8.17). The duck isotopic values become more distinct from the seal values and further away from the Sadlermiut isotopic signature once bird-specific spacing values were applied. Therefore the Sadlermiut values were more likely due to greater consumption of seals (see Figures 8.16 and 8.17). Though the incorporation of bird-specific spacing values into linear mixing models decreases the proportion of duck possible in Sadlermiut diet, this result emphasizes the idea that these spacing values can better separate bird isotopic values from other potential food items making dietary reconstruction more accurate.

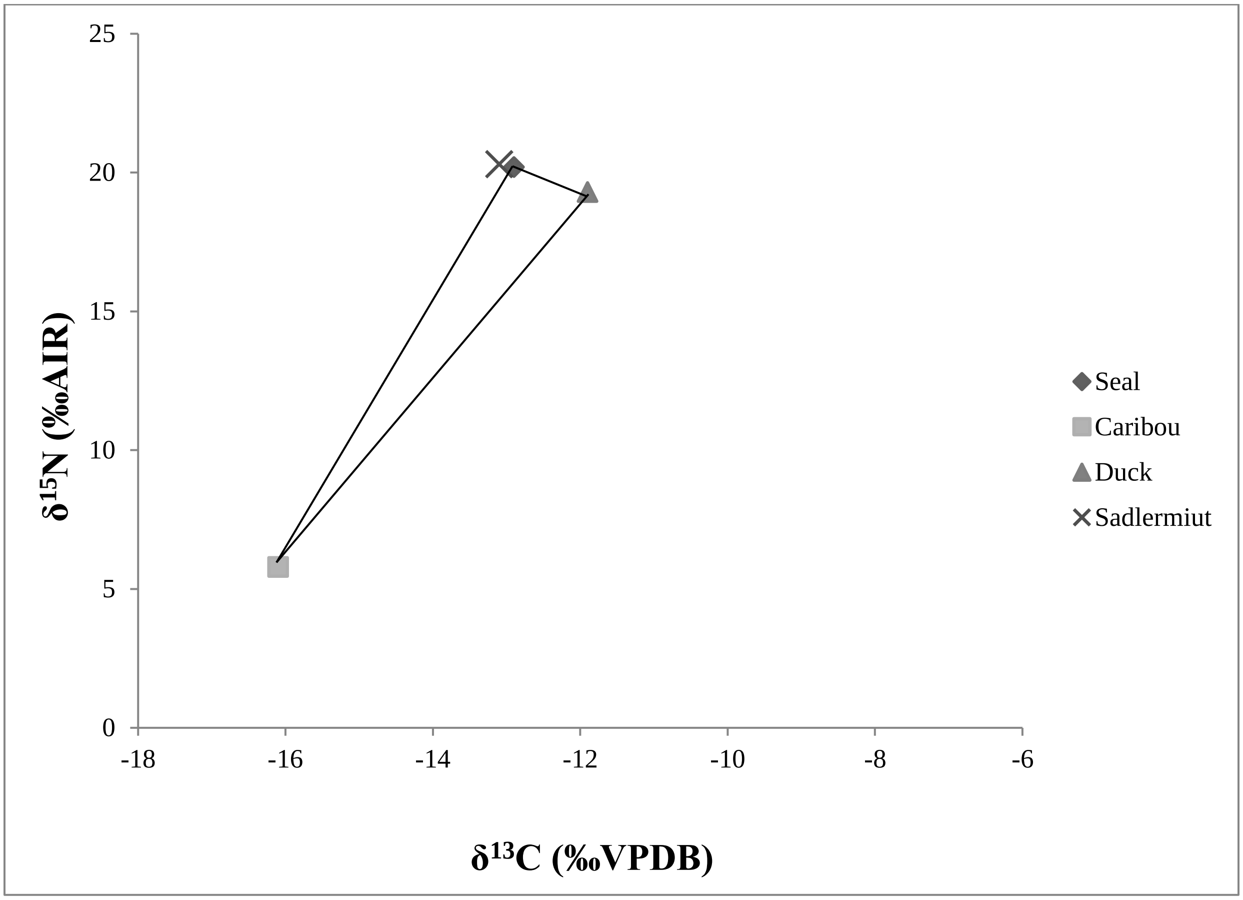


Figure 8.15. Sadlermiut linear mixing diagram based on stable isotope ratios and spacing values from Coltrain (2009).

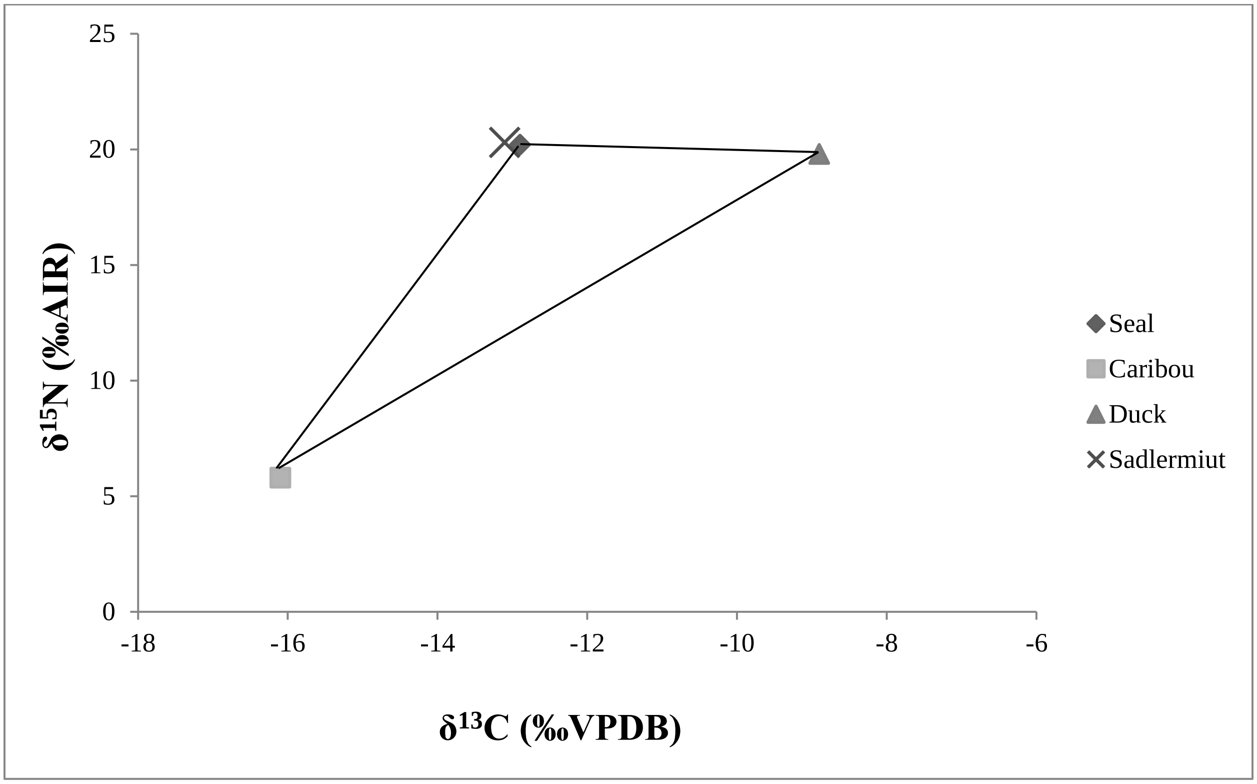


Figure 8.16. Sadlermiut linear mixing diagram with spacing values for seal and caribou from Coltrain (2009) and lipid-extracted muscle spacing values for ducks as determined in Chapter 6.

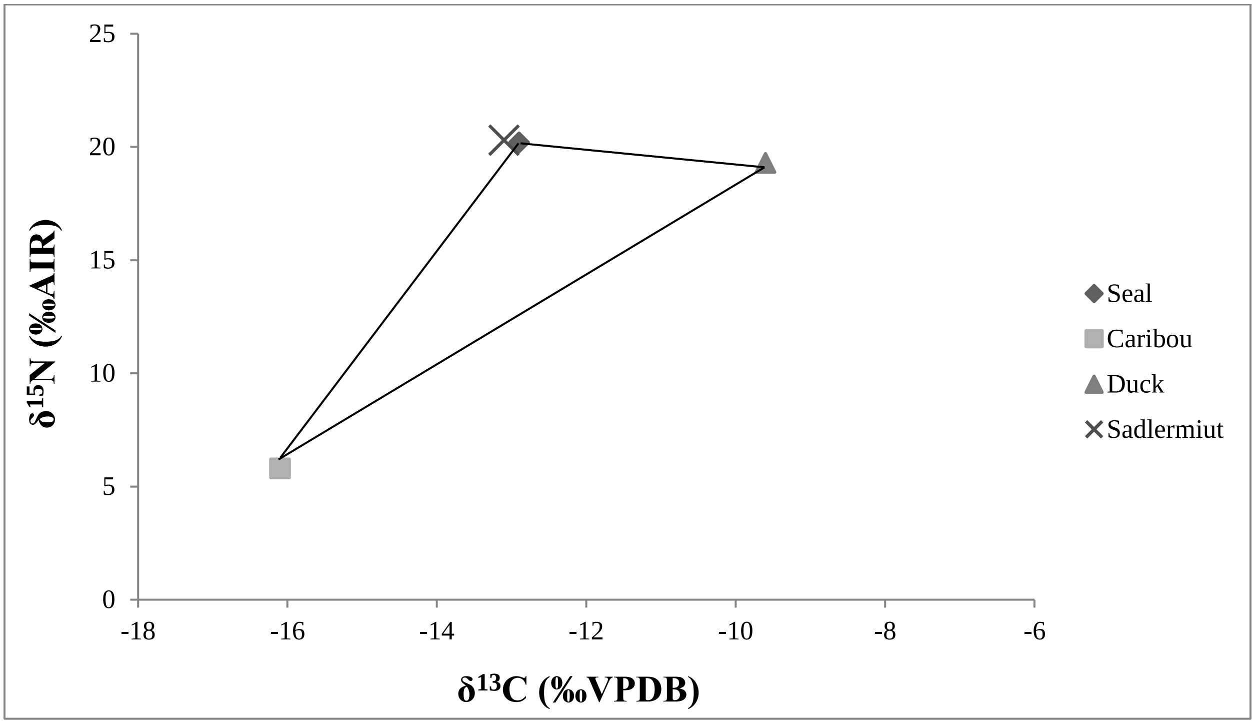


Figure 8.17. Sadlermiut linear mixing diagram with spacing values for seal and caribou from Coltrain (2009) and muscle + fat spacing values for ducks as determined in Chapter 6.

Spacing Reference	Animal	1st Percentile	50th Percentile	99th Percentile
Coltrain 2009	Seal	0.70	0.88	1.00
	Caribou	0.00	0.02	0.02
	Eider Duck	0.00	0.10	0.30
Muscle Spacing Values (This Dissertation)	Seal	0.90	0.96	1.00
	Caribou	0.00	0.02	0.02
	Eider Duck	0.00	0.04	0.08
Muscle+Fat Spacing Values (This Dissertation)	Seal	0.88	0.94	1.00
	Caribou	0.00	0.02	0.02
	Eider duck	0.00	0.04	0.10

Table 8.17. IsoSource potential solutions for Sadlermiut mixing models using different spacing values for birds.

8.2.5 Greenland – Thule

Mixing models were created using data for 26 Thule individuals from the southwest side of Greenland that were analyzed by Nelson and colleagues (2012). All faunal bone collagen stable isotope values also came from Nelson and colleagues' (2012) study, but no mixing models were used for analysis and interpretation as part of that research. The faunal remains were recovered from the same archaeological site as the human remains and included the likely dietary items. The animals entered as part of the Greenland Thule linear mixing models in this dissertation include ringed seal, bearded seal, caribou, baleen whales, and thick-billed murres (*Uria lomvia*) (see Table 8.18).

Animal	Sample	Source	$\delta^{13}C$	$\delta^{15}N$
Ringed Seal	Bone Collagen	Nelson et al. 2012	-14.1	16.6
Bearded Seal	Bone Collagen	Nelson et al. 2012	-12.6	13.5
Caribou	Bone Collagen	Nelson et al. 2012	-18.2	2.0
Baleen Whales	Bone Collagen	Nelson et al. 2012	-14.4	12.6
Thick-billed Murres	Bone Collagen	Nelson et al. 2012	-16.1	14.6
Human (Thule)	Bone Collagen	Nelson et al. 2012	-12.6	19.2

Table 8.18. Stable carbon and nitrogen isotope ratios for species included in Greenland Thule mixing models and their sources.

Three different mixing models were generated, one with uniform spacing values for all species based on spacing values obtained from Coltrain (2009) (see Figure 8.18), one model with a bird-specific spacing value from bird bone collagen to bird muscle as determined in chapter 6 (see Figure 8.19), and one model with a bird-specific spacing value from bird bone collagen to bird muscle and fat as determined in chapter 6 (see Figure 8.20). The spacing values used and the resulting bird isotopic values entered in IsoSource are provided in Tables 8.19.

Greenland (Thick-Billed Murre)	**Measured Value (‰)**		**ΔAnimal Collagen - Animal Flesh (‰)**		**ΔAnimal Flesh - Human Collagen (‰)**		**Total Offset (‰)**		**Corrected Value (‰)**	
	$\delta^{13}C$	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{13}C$**	**$\delta^{15}N$**
Coltrain (2009)	-16.1	14.6					+1.0	+3.0	-15.1	17.6
Muscle Spacing (This Dissertation)	-16.1	14.6	-1.0	+0.5	+5.0	+3.0	+4.0	+3.5	-12.1	18.1
Muscle+Fat Spacing (This Dissertation)	-16.1	14.6	-1.7	0	+5.0	+3.0	+3.3	+3.0	-12.8	17.6

Table 8.19. Spacing values for thick-billed murres used in Greenland Thule mixing models (Animals other than birds maintain spacing values from Coltrain (2009) for all mixing models).

The possible proportion of thick-billed murres in the diet increased in the 50th and 99th percentiles, with only slight decreases in proportion for other species, once bird-specific tissue spacing values were applied to the mixing models (see Table 8.20). After bird-specific spacing values were used in the mixing models, thick-billed murre isotopic ratios were more similar to those of seals, whales, and the Thule individuals, therefore increasing the possible proportion of birds in the Thule diet (see Figures 8.19 and 8.20). It is important to emphasize again that linear mixing models do not provide us with exact proportions but with ranges of possible source proportions. Because thick-billed murre stable isotope ratios were more similar to those from the Thule individuals, once bird-specific spacing values were used, there was a greater chance that more birds were incorporated into Thule diet than predicted with models using uniform spacing values for all species. This result provides evidence that linear mixing models that utilize uniform spacing values for all species in the diet can underestimate the proportion of birds in the diet.

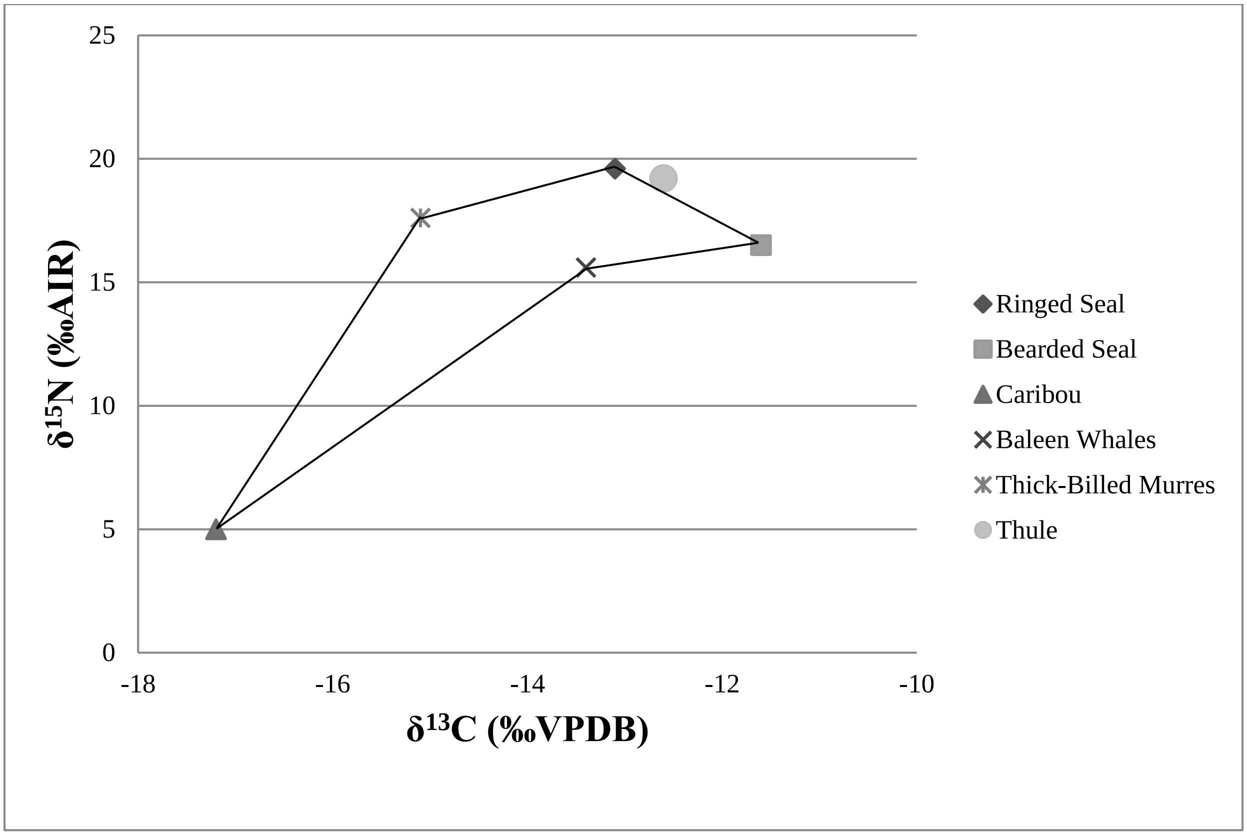


Figure 8.18. Greenland Thule linear mixing diagram with spacing values from Coltrain (2009).

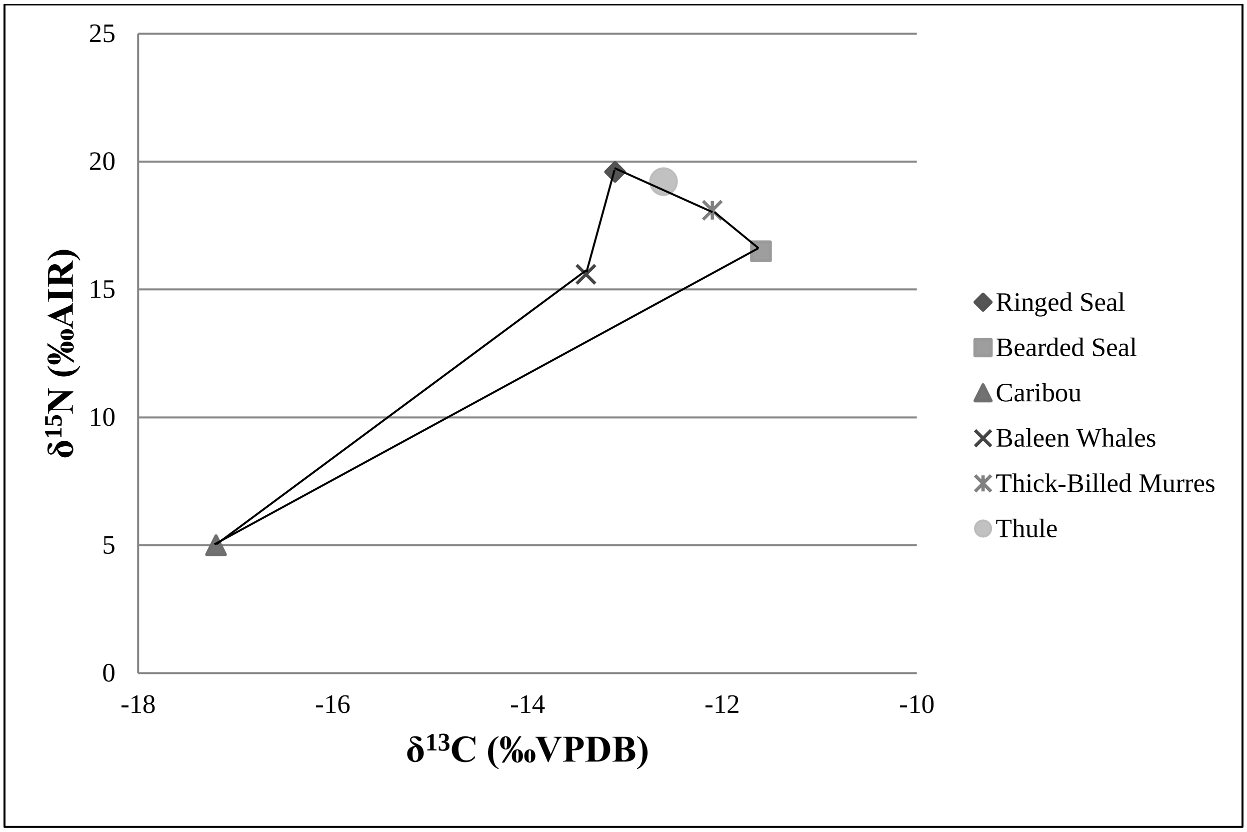


Figure 8.19. Greenland Thule linear mixing diagram with spacing values for seals, caribou, and baleen whales from Coltrain (2009) and lipid-extracted muscle spacing values for birds as determined in Chapter 6.

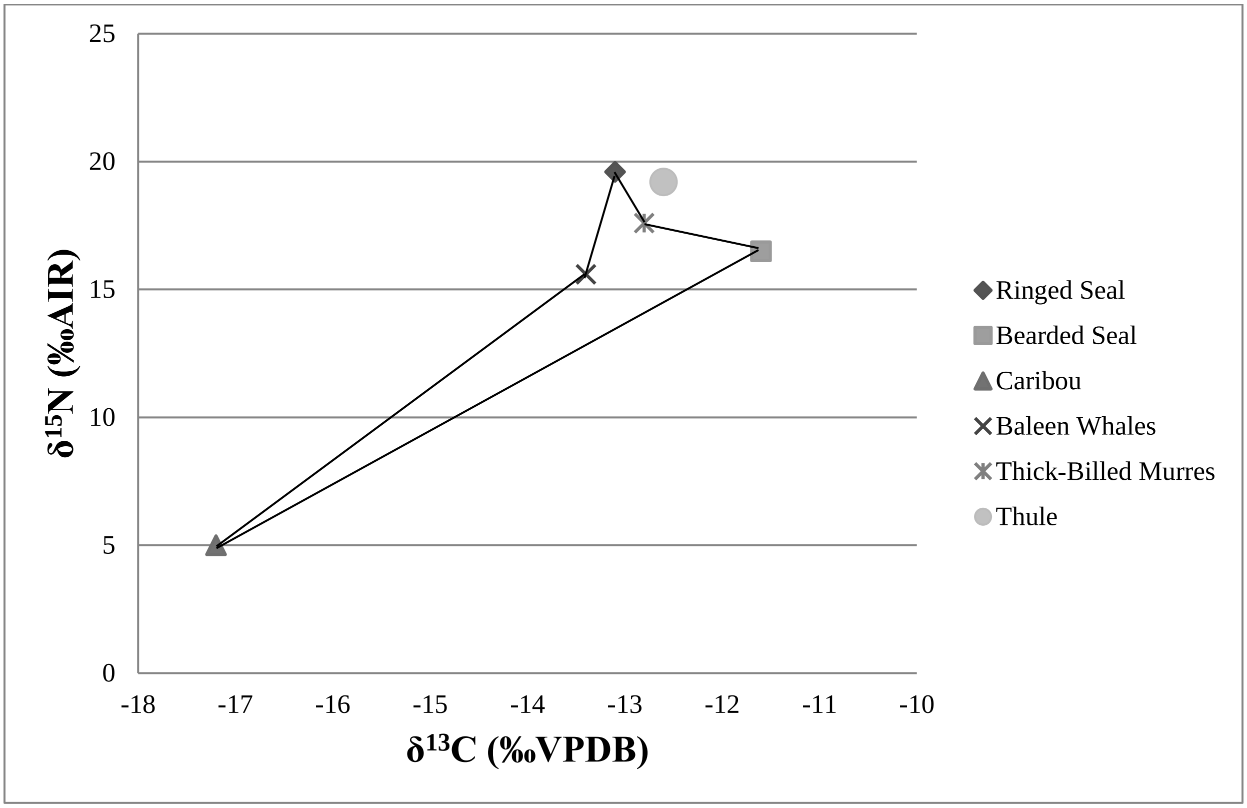


Figure 8.20. Greenland Thule linear mixing diagram with spacing values for seals, caribou, and baleen whales from Coltrain (2009) and muscle+fat spacing values for birds as determined in Chapter 6.

Spacing Source	Animal	1st Percentile	50th Percentile	99th Percentile
Coltrain 2009	Ringed Seal	0.68	0.80	0.96
	Bearded Seal	0.02	0.12	0.26
	Caribou	0.00	0.00	0.02
	Baleen Whales	0.00	0.04	0.16
	Thick-Billed Murres	0.00	0.02	0.12
Muscle Spacing (This Dissertation)	Ringed Seal	0.48	0.74	0.94
	Bearded Seal	0.00	0.06	0.24
	Caribou	0.00	0.00	0.02
	Baleen Whales	0.00	0.04	0.16
	Thick-Billed Murres	0.00	0.12	0.50
Muscle+Fat Spacing (This Dissertation)	Ringed Seal	0.60	0.76	0.94
	Bearded Seal	0.00	0.06	0.24
	Caribou	0.00	0.00	0.02
	Baleen Whales	0.00	0.04	0.16
	Thick-Billed Murres	0.00	0.10	0.36

Table 8.20. IsoSource potential solutions for Greenland Thule mixing models using different spacing values for birds.

8.2.6 Contribution of Eggs to Arctic Hunter-Gatherer Diet

If little is known about how bird-specific spacing values can affect paleodietary reconstruction then even less is known regarding how isotopic signatures of eggs can affect paleodietary reconstruction. In fact, only one study has attempted to reconstruct how eggs may have contributed to past human diet using stable isotope analysis (Giardina et al., 2014). Unfortunately, that study focuses on recovered rhea (*Rhea pennata*) eggshells, and it is unclear how the isotopic values of the yolk and albumen (egg whites) were calculated from the egg shells and factored into human diet. The isotopic signatures of the tissues preserved in the archaeological record (avian bone collagen or, rarely, egg shells) must again be converted to the isotopic signatures of the tissues being eaten (yolk and albumen). Unfortunately, the isotopic spacing between avian bone collagen and egg yolk and albumen could not be explored in Chapter 6 of this dissertation because the ducks used in that analysis were not the same species as the egg-laying ducks at the farm from which the samples came.

Limited data is also available from the ecological literature. As stated in Chapter 6, the ecological literature has mainly focused on diet-to-tissue spacing for birds, and this also includes eggs. Researchers have established diet-to-tissue ratios for egg components because they are interested in the nutrients that are routed to eggs from the female bird. Because they are not limited to certain tissues for analysis, blood, muscle, and feathers have been favored for analysis compared to bone collagen (i.e., Federer, Hollmén, Esler, & Wooller, 2012; Hobson, 1995; Polito, Fisher, Tobias, & Emslie, 2009).

There is also an added hurdle to calculating isotopic signatures for eggs from bird tissues. Different bird species have different strategies for allocating resources to eggs. Some birds are capital breeders, they allocate food stores accumulated from the wintering grounds and along the migratory route to the production of eggs, while others are income breeders, and they use the resources at the summer breeding site to produce eggs. This means that the isotopic spacing values between eggs and bird tissues may vary between bird species, where some species will have eggs that are reflective of the foods available at the breeding grounds and others will have eggs that are more reflective of the female’s body tissues (Gauthier, Bêty, & Hobson, 2003; Hobson, Jaatinen, & Öst, 2015; Schmutz, Hobson, & Morse, 2006).

This hurdle is not insurmountable but requires many different steps. Similar procedures are carried out in ecological studies trying to determine if certain bird species are capital or income breeders. For example, Gauthier and colleagues (2003) and Hobson and colleagues (2015) have modeled what snow goose (*Chen caerulescens*) and common eider (*Somateria mollissima*) egg components would have for isotopic signatures if the species were principally capital or income breeders. Isotopic spacing values between diet and egg components have been determined by Federer and colleagues (2012) for spectacled eiders (*Somateria fischeri*). Isotopic spacing values between bird muscle and egg components have been estimated by Gauthier and colleagues (2003) using Hobson's (1995) discrimination factors for a carnivore model of peregrine falcons (*Falco peregrinus*) feeding on Japanese quail (*Coturnix japonica*), and the reasoning that the spacing value between endogenous protein reserves and egg proteins would be similar to the spacing value between exogenous protein sources and egg proteins in falcons (see Table 8.21).

Nutrient Source	Egg Component	Δ^{13}C (‰)	Δ^{15}N (‰)	Source
Lipid-free Diet	Lipid-free Yolk	+2.2	+4.2	Federer et al. (2012)
Lipid-free Diet	Albumen	+1.9	+3.5	Federer et al. (2012)
Maternal Muscle	Yolk	0	+3.4	Hobson (1995)
Maternal Muscle	Albumen	+0.9	+3.4	Hobson (1995)

Table 8.21 Isotope spacing values used in mixing models to estimate the exogenous (lipid-free diet) and endogenous (maternal muscle) contributions to egg tissues.

These studies, however, have the stable isotope ratios for the food items of the bird species while paleodietary reconstructions do not. Luckily, diet-to-tissue spacing values for birds were determined in Chapter 6, and we can work backward from the bone collagen data to obtain approximate stable isotope ratios for bird diet (see Table 8.22).

	Δ^{13}C (‰)	**Δ^{15}N (‰)**
Bone collagen to diet spacing	-3.9	-1.6

Table 8.22. Bird bone collagen to diet spacing as determined in Chapter 6.

For simplicity, the linear mixing model parameters for the Greenland Thule will be used in the following theoretical model that includes eggs from thick-billed murres. Two models will be included, one where thick-billed murres are capital breeders, and the egg isotopic signatures are reflective of endogenous sources and one where thick-billed murres are income breeders, and egg isotopic signatures are reflective of exogenous sources or the food sources available on the breeding grounds. It is worth noting here that the exploration of resource allocation strategies in birds using stable isotope analysis is ongoing within the ecological literature and the strategies of most bird species are not well-established. For example, this question has not been addressed for thick-billed murres; thus two models are provided here for thick-billed murres to account for both possibilities. These additional steps could be avoided if resource allocation strategies for a given species are already established within the ecological literature.

8.2.6.1 Linear mixing model for Greenland Thule with eggs from income-breeding thick-billed murres

In order to calculate stable isotope ratios for the diet of thick-billed murres (exogenous sources), the bone collagen values obtained by Nelson and colleagues (2012) must be converted to diet values using the avian bone collagen to diet spacings determined in Chapter 6.

$$\delta^{13}C_{diet} = \delta^{13}C_{bone\ collagen} + (-3.9‰)$$

$$\delta^{13}C_{diet} = -16.1 + (-3.9‰)$$

$$\delta^{13}C_{diet} = -20.0‰$$

$$\delta^{15}N_{diet} = \delta^{15}N_{bone\ collagen} + (-1.6‰)$$

$$\delta^{15}N_{diet} = 14.6 + (-1.6‰)$$

$$\delta^{15}N_{diet} = 13.0‰$$

The stable carbon and nitrogen isotope ratios for thick-billed murre diet can then be converted to the isotopic signatures for egg components using the spacing values from Federer and colleagues (2012) (see Table 8.23).

$$\delta^{13}C_{yolk} = \delta^{13}C_{diet} +2.2‰$$

$$\delta^{13}C_{yolk} = -20.0‰ + 2.2‰$$

$$\delta^{13}C_{yolk} = -17.8$$

$$\delta^{15}N_{yolk} = \delta^{15}N_{diet} + 4.2‰$$

$$\delta^{15}N_{yolk} = 13.0‰ + 4.2‰$$

$$\delta^{15}N_{yolk} = 17.2‰$$

$$\delta^{13}C_{albumen} = \delta^{13}C_{diet} + 1.9‰$$

$$\delta^{13}C_{albumen} = -20.0 + 1.9‰$$

$$\delta^{13}C_{albumen} = -18.1‰$$

$$\delta^{15}N_{albumen} = \delta^{15}N_{diet} + 3.5‰$$

$$\delta^{15}N_{albumen} = 13.0‰ + 3.5‰$$

$$\delta^{15}N_{albumen} = 16.5‰$$

Egg component	**$\delta^{13}C$ (‰)**	**$\delta^{15}N$ (‰)**
Lipid-free Yolk	-17.8	17.2
Albumen	-18.1	16.5

Table 8.23. Resulting stable carbon and nitrogen isotope ratios for egg components after spacing values from Federer et al. (2012) are applied to converted dietary values.

The stable carbon isotope spacing of +5.0‰ (Ambrose & Norr, 1993; van der Merwe & Vogel, 1978) and stable nitrogen isotope spacing of +3.0‰ (Schoeninger & DeNiro, 1984) for the difference between animal tissue and human bone collagen can then be applied to the isotopic signatures of the egg components to obtain the values that will be entered into the linear mixing model.

Egg component	δ^{13}C (‰)	δ^{15}N (‰)
Lipid-free Yolk	-12.8	20.2
Albumen	-13.1	19.5

Table 8.24. Stable carbon and nitrogen isotope ratios of egg components as entered into IsoSource.

These values were then entered into the existing linear mixing model for Greenland Thule diet with bird-specific spacing values for lipid-extracted muscle to evaluate the impact of eggs from an income-breeding thick-billed murre on paleodietary reconstruction of Thule diet.

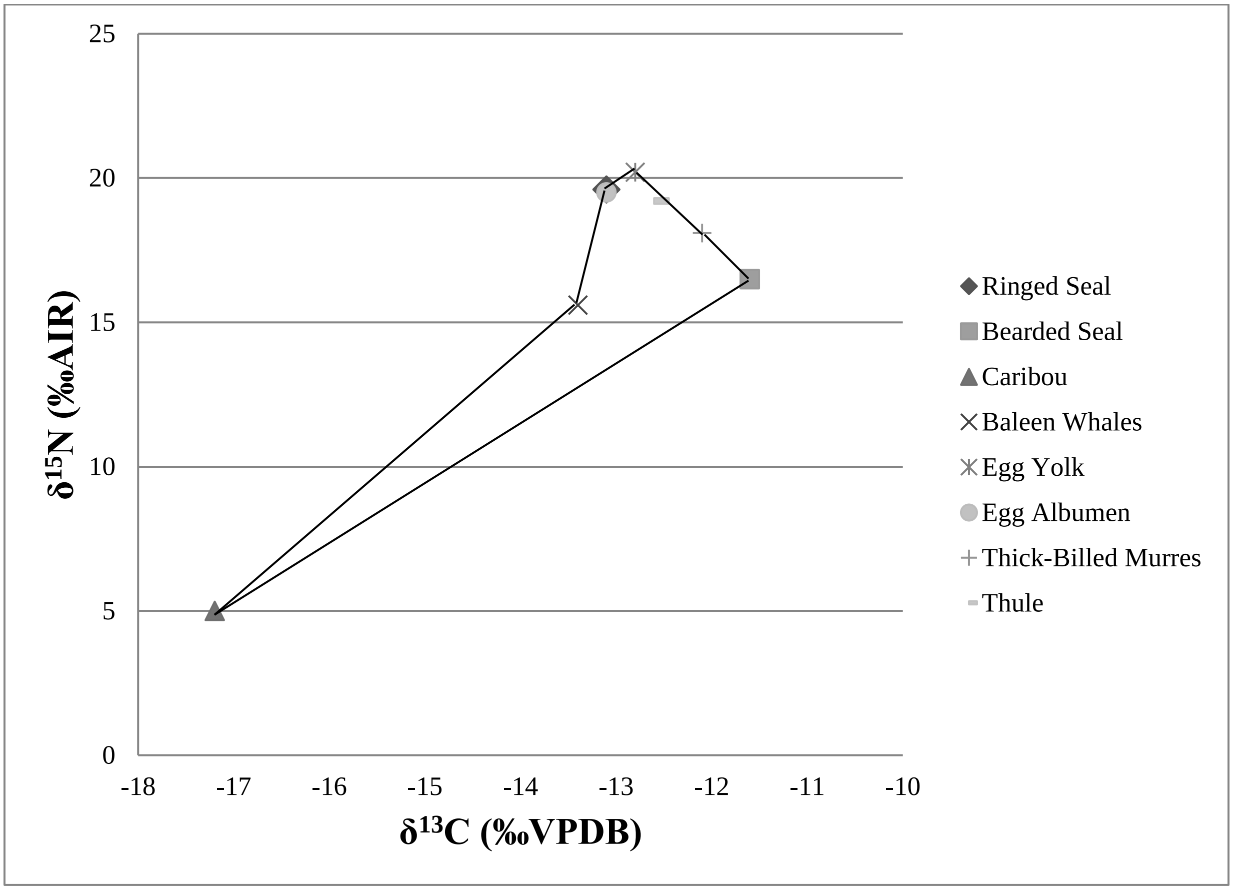


Figure 8.21. Greenland Thule mixing diagram with bird-specific spacing values for lipid-extracted muscle and isotopic signatures for egg yolk and albumen from income-breeding thick-billed murres.

	Animal	1st Percentile	50th Percentile	99th Percentile
Muscle Spacing	Ringed Seal	0.00	0.18	0.72
	Bearded Seal	0.00	0.06	0.26
	Caribou	0.00	0.00	0.04
	Baleen Whales	0.00	0.04	0.20
	Thick-Billed Murres	0.00	0.10	0.46
	Egg Yolk	0.00	0.28	0.74
	Egg Albumen	0.00	0.18	0.72

Table 8.25. IsoSource potential solutions for the Greenland Thule mixing model with bird-specific spacing values for lipid-free muscle and egg yolk and egg albumen stable isotope ratios for income-breeding thick-billed murres.

The mixing diagram generated from the added data show that egg yolk and egg albumen values for income-breeding thick-billed murres are similar to the isotopic signatures of ringed seal within the model (see Figure 8.21). Because the stable isotope ratios of egg yolk and albumen are clustered around the isotopic signatures of ringed seal, bearded seal, baleen whales, thick-billed murres, and the Thule, the potential solutions generated through IsoSource show that egg yolk and albumen were likely consumed in Greenland Thule diet. Note that the proportions of ringed seal, bearded seal, baleen whales, and thick-billed murres also increase in the 99th percentile, likely because these sources are now harder to separate from each other with the addition of egg yolk and albumen values from income-breeding thick-billed murres, and any combination of these food items could result in the isotopic signature of the Greenland Thule (see Table 8.28). In this model, the isotopic signatures of eggs are therefore very similar to marine mammals and birds and it is hard to distinguish the actual contribution of eggs to the diet of the Greenland Thule. This does, however, mean that even if Arctic hunter-gatherer groups were incorporating a significant amount of eggs in their diet, this fact might be obscured if only sea mammals are considered during isotopic modeling. The importance of multiple lines of evidence during paleodietary reconstruction cannot be understated in these cases.

8.2.6.2 Linear mixing models for Greenland Thule with eggs from capital-breeding thick-billed murres

A similar procedure is used to estimate the effect of eggs from capital-breeding thick-billed murres on the paleodietary reconstruction of Greenland Thule groups. The only difference is that the stable isotope ratios for egg yolk and albumen are determined using bird muscle values instead of bird diet values and the spacing values between avian muscle and egg components as provided by Hobson (1995). The first step is to convert the bird muscle values determined for thick-billed murres in section 8.2.5 into stable carbon and nitrogen isotope ratios for egg yolk and albumen using the spacing values determined by Hobson (1995) (see Table 8.26).

$$\delta^{13}C_{yolk} = \delta^{13}C_{muscle} + 0.0‰$$

$$\delta^{13}C_{yolk} = -12.1‰ + 0.0‰$$

$$\delta^{13}C_{yolk} = -12.1$$

$$\delta^{15}N_{yolk} = \delta^{15}N_{muscle} + 3.4‰$$

$$\delta^{15}N_{yolk} = 18.1‰ + 3.4‰$$

$$\delta^{15}N_{yolk} = 21.5‰$$

$$\delta^{13}C_{albumen} = \delta^{13}C_{muscle} + 0.9‰$$

$$\delta^{13}C_{albumen} = -12.1 + 0.9‰$$

$$\delta^{13}C_{albumen} = -11.2‰$$

$$\delta^{15}N_{albumen} = \delta^{15}N_{muscle} + 3.4‰$$

$$\delta^{15}N_{albumen} = 18.1‰ + 3.4‰$$

$$\delta^{15}N_{albumen} = 21.5‰$$

Egg component	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Yolk	-12.1	21.5
Albumen	-11.2	21.5

Table. 8.26. Resulting stable carbon and nitrogen isotope ratios for egg components after spacing values from Hobson (1995) were applied to converted dietary values.

The stable carbon isotope spacing of +5.0‰ (Ambrose & Norr, 1993; van der Merwe & Vogel, 1978) and stable nitrogen isotope spacing of +3.0‰ (Schoeninger & DeNiro, 1984) for the difference between animal tissue and human bone collagen can then be applied to the isotopic signatures of the egg components to obtain the values that will be entered into the linear mixing model (see Table 8.27).

Egg component	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Yolk	-7.1	24.5
Albumen	-6.2	24.5

Table 8.27. Stable carbon and nitrogen isotope ratios of egg components as entered into IsoSource.

The mixing diagram for Greenland Thule diet created using the additional stable isotope ratios for egg yolk and albumen for capital-breeding thick-billed murres produces a different picture compared to the diagram with egg yolk and albumen from income-breeding birds. The isotopic signatures for the egg components from income-breeding thick-billed murres are clustered around the stable isotope ratios for ringed seal, bearded seal, baleen whales, thick-billed murres and the Thule samples, whereas for the capital-breeding eggs, these components had distinct isotopic signatures (see Figure 8.22).

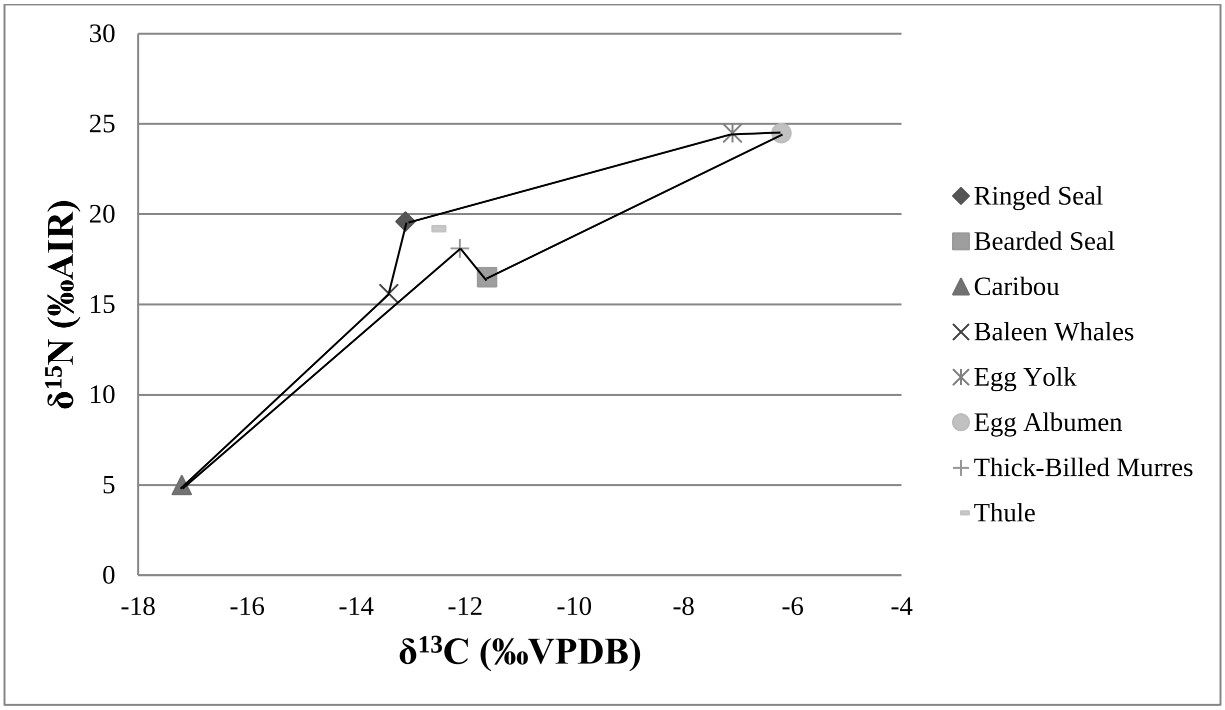


Figure 8.22. Mixing diagram for Greenland Thule diet with bird-specific lipid-free muscle spacing values and stable isotope ratios for egg components from capital-breeding thick-billed murres.

The mixing diagram generated from the added data show that egg yolk and egg albumen values for capital-breeding thick-billed murres are very distinct from the isotopic signatures of all the other animals within the model, including the thick-billed murres (see Figure 8.21). The Thule signature remains near the isotopic value for ringed seal, bearded seal, and thick-billed murres. The potential solutions generated by IsoSource, however, show a slightly different interpretation regarding diet compared to the model excluding eggs (see Table 8.25). Compared to the model excluding eggs, the proportion of ringed seal and thick-billed murres decrease slightly in the 99th percentile and the possible proportions of egg yolk and egg albumen are at 18% and 14% in the 99th percentile. This indicates that eggs may have been included in Greenland Thule subsistence strategies, if only to supplement the diet and these proportions can still be detected during stable isotope analysis. This is a significant finding because this is the first time that the incorporation of eggs in human diet has been successfully modeled for any Arctic hunter-gatherer group.

	Animal	1st Percentile	50th Percentile	99th Percentile
Muscle Spacing	Ringed Seal	0.38	0.60	0.84
	Bearded Seal	0.00	0.04	0.24
	Caribou	0.00	0.02	0.10
	Baleen Whales	0.00	0.06	0.30
	Thick-Billed Murres	0.00	0.08	0.46
	Egg Yolk	0.00	0.06	0.18
	Egg Albumen	0.00	0.04	0.14

Table 8.28. IsoSource potential solutions for the Greenland Thule mixing model with bird-specific spacing values for lipid-free muscle and egg yolk and egg albumen stable isotope ratios for capital-breeding thick-billed murres.

The results of the two linear mixing models for Greenland Thule groups with the incorporation of stable isotope ratios for egg components demonstrates that further exploration of how eggs can affect paleodietary reconstruction is a worthy pursuit. In many ways, these results are theoretical because the resource allocation strategies for thick-billed murres are not well-established in the ecological literature and stable isotope partitioning between bird body tissues and eggs is not well understood. The spacing values used here represent the two extremes of purely income versus capital breeding birds, however, realistically, birds may mobilize resources from both endogenous and exogenous sources towards the production of eggs and strategies may change based on food availability (Hobson et al. 2015). Nonetheless, these results demonstrate that the inclusion of eggs in past human diet can be estimated using stable isotope analysis. This also highlights the importance of continued experimental research within bioarchaeology and ecology when it comes to stable isotope analysis so that we can continue to address more complex and nuanced research problems.

8.3 Linear Mixing Models and Dietary Reconstruction of Paleo-Inuit Diet

As demonstrated in the examples above, bird-specific spacing values and the incorporation of birds into the diet of Arctic hunter-gatherers can affect the interpretation of stable isotope results. To further explore the potential impact of birds on the isotopic ratios of Paleo-Inuit populations, theoretical stable carbon and nitrogen isotope ratios were calculated for Denbigh Flint Complex, Independence I, Saqqaq, Pre-Dorset, and Dorset groups using faunal percentages already published in the archaeological literature and regional stable isotope ratios for prey animals where possible. Where the linear mixing models in the previous section provided possible source proportions for prey items, this exercise estimates how the stable carbon and nitrogen isotope ratios of human bone collagen may change when birds and avian-specific tissue spacing values are included in paleodietary reconstruction.

The spacing values determined in Chapter 6 were compared to spacing values used by Coltrain (2009) by substituting these values into mass balance equations to determine the impact of avian-specific spacing values on the isotopic signatures of Paleo-Inuit groups. This is, therefore, a very simplified model and a theoretical exercise to determine the impact of tissue spacing values specific to birds on paleodietary reconstruction and may not represent the entire diet or seasonal round of Paleo-Inuit groups. Stable isotope ratios for human bone collagen were calculated using the following equation (Phillips, 2001; Schwarcz, 1991):

$$\delta J_D = f_A\, \delta J_A + f_B\, \delta J_B + f_C\, \delta J_C$$

$$\delta K_D = f_A\, \delta K_A + f_B\, \delta K_B + f_C\, \delta K_C$$

$$1 = f_A + f_B + f_C$$

Linear mixing models provide unique solutions for only $n + 1$ sources, with n representing the number of isotopic tracers. Because most dietary studies using stable isotope analysis, including this dissertation, include stable carbon and nitrogen isotope ratios, the equation is limited to three dietary sources for this research. A full outline of how these calculations were made will be provided in the following Denbigh Flint Complex example.

8.3.1 Denbigh Flint Complex – Alaska

To reconstruct stable carbon and nitrogen isotope ratios for interior Denbigh Flint Complex groups, Tremayne's (2011) study on zooarchaeological remains from Matcharak Lake, Alaska was used as a reference for the most likely dietary items and the proportions of these animals in Denbigh Flint Complex diet. This study was used for reference because it includes a large number of faunal remains, which is rare for Denbigh Flint Complex sites. The source proportions used for the calculations are as follows:

Caribou 98%

Ptarmigan 1%
Freshwater Fish 1%

The stable carbon and nitrogen isotope ratios for the faunal species, along with their sources, are listed in Table 8.29. Freshwater fish include species such as burbot (*Lota lota*), trout (Salmoninae), and pike (Esocidae). The isotopic values for each species of fish were very similar according to research by Mackenzie-Grieve and colleagues (2005) on faunal remains from the Mackenzie Delta; therefore the stable carbon and nitrogen isotope values for burbot (*Lota lota*) were used to represent all three species.

Animal	**Sample**	**Source**	**δ^{13}C**	**δ^{15}N**
Caribou	Bone Collagen	McManus-Fry et al. 2016	-18.0	1.8
Ptarmigan	Bone Collagen	This Dissertation	-21.3	2.9
Freshwater Fish	Bone Collagen	Mckenzie-Grieve et al. 2005	-21.3	12.5

Table 8.29. Stable carbon and nitrogen isotope ratios for species included in mixing calculations for Denbigh Flint Complex human bone collagen values and their sources.

To determine what the theoretical stable isotope signature of a Denbigh Flint Complex individual consuming these foods, in these proportions, would be if uniform spacing values were used, the following conversions and calculations were made.

Resulting faunal stable isotope signatures after uniform spacing values applied:

Caribou δ^{13}C
(-18.0‰) + 1.0‰ = -17.0‰

Ptarmigan δ^{13}C
(-21.3) + 1.0‰ = -20.3‰

Freshwater Fish $\delta^{13}C$
$(-21.3) + 1.0‰ = -20.3‰$

Caribou $\delta^{15}N$
$(1.8‰) + 3.0‰ = 4.8‰$

Ptarmigan $\delta^{15}N$
$(2.9‰) + 3.0‰ = 5.9‰$

Freshwater Fish $\delta^{15}N$
$(12.5‰) + 3.0‰ = 15.5‰$

Mass balance equations with corrected faunal stable isotope signatures:

$\delta^{13}C$
$(0.98)(-17.0‰) + (0.01)(-20.3‰) + (0.01)(-20.3‰) = -17.1‰$

$\delta^{15}N$
$(0.98)(4.8‰) + (0.01)(5.9‰) + (0.01)(15.5‰) = 4.9‰$

Resulting isotopic signature of a Denbigh Flint Complex individual consuming caribou, ptarmigan, and freshwater fish in their corresponding source proportions if uniform spacing values are used for all faunal remains:

$\delta^{13}C = -17.1‰$
$\delta^{15}N = 4.9‰$

The theoretical stable isotope signature of a Denbigh Flint Complex individual consuming the same foods as above, but calculated using a bird-specific spacing value from bone collagen to muscle is shown in the following conversions and calculations.

Resulting faunal stable isotope signatures after bird-specific bone collagen to muscle spacing values are applied:

Caribou $\delta^{13}C$
$(-18.0‰) + 1.0‰ = -17.0‰$

Ptarmigan $\delta^{13}C$
$(-21.3) - 1.0‰ + 5.0‰ = -17.3‰$

Freshwater Fish $\delta^{13}C$
$(-21.3) + 1.0‰ = -20.3‰$

Caribou $\delta^{15}N$
$(1.8‰) + 3.0‰ = 4.8‰$

Ptarmigan $\delta^{15}N$
$(2.9‰) +0.5‰ + 3.0‰ = 6.4‰$

Freshwater Fish $\delta^{15}N$
$(12.5‰) + 3.0‰ = 15.5‰$

Mass balance equations with corrected faunal stable isotope signatures:

$\delta^{13}C$
$(0.98)(-17.0‰) + (0.01)(-17.3‰) + (0.01)(-20.3‰) = -17.0‰$

$\delta^{15}N$
$(0.98)(4.8‰) + (0.01)(6.4‰) + (0.01)(15.5‰) = 4.9‰$

Resulting isotopic signature of a Denbigh Flint Complex individual consuming caribou, ptarmigan, and freshwater fish in their corresponding source proportions if bird-specific bone collagen to muscle spacing is applied to the mass balance equation:

$\delta^{13}C = -17.0‰$
$\delta^{15}N = 4.9‰$

The theoretical stable isotope signature of a Denbigh Flint Complex individual consuming the same foods as above but calculated using a bird-specific spacing value from bone collagen to muscle and fat is shown in the following conversions and calculations.

Resulting faunal stable isotope signatures after bird-specific bone collagen to muscle and fat spacing values are applied:

Caribou $\delta^{13}C$
$(-18.0‰) + 1.0‰ = -17.0‰$

Ptarmigan $\delta^{13}C$
$(-21.3) - 1.7‰ + 5.0‰ = -18.0‰$

Freshwater Fish $\delta^{13}C$
$(-21.3) + 1.0‰ = -20.3‰$

Caribou $\delta^{15}N$
$(1.8‰) + 3.0‰ = 4.8‰$

Ptarmigan $\delta^{15}N$
$(2.9‰) +0.0‰ + 3.0‰ = 5.9‰$

Freshwater Fish $\delta^{15}N$
$(12.5‰) + 3.0‰ = 15.5‰$

Mass balance equations with corrected faunal stable isotope signatures:

$\delta^{13}C$
$(0.98)(-17.0‰) + (0.01)(-18.0‰) + (0.01)(-20.3‰) = -17.0‰$

$\delta^{15}N$
$(0.98)(4.8‰) + (0.01)(5.9‰) + (0.01)(15.5‰) = 4.9‰$

Resulting isotopic signature of a Denbigh Flint Complex individual consuming caribou, ptarmigan, and freshwater fish in their corresponding source proportions if bird-specific bone collagen to muscle and fat spacing is applied to the mass balance equation:

$$\delta^{13}C = -17.0‰$$
$$\delta^{15}N = 4.9‰$$

The results of the calculations are seen in Table 8.30. Because ptarmigan represent only 1% of the diet of Denbigh Flint Complex groups, the bird-specific spacing values did not affect the resulting human bone collagen stable isotope ratios. The difference of 0.1‰ in stable carbon isotope ratios is less than is seen for machine error (approximately 0.2‰) and is therefore negligible.

Denbigh Flint Complex	**Uniform Spacing (Coltrain, 2009) (‰)**	**Lipid-Extracted Muscle Bird Spacing (‰)**	**Muscle + Fat Bird Spacing (‰)**
$\delta^{13}C$	-17.1	-17.0	-17.0
$\delta^{15}N$	4.9	4.9	4.9

Table 8.30. Resulting Denbigh Flint Complex human bone collagen values from mixing calculations using different spacing values for birds.

8.3.2 Independence I – Eastern Canadian High Arctic

The faunal analysis completed by Darwent (2003) was used to calculate the possible stable isotope ratios for bone collagen of Independence I groups. Her report from the Adam C. Knuth site was used because it contained a greater number of bird remains. In contrast, the

Pearylandville site only contains approximately 1% bird remains, and the results from those calculations would be very similar to those from the Denbigh Flint Complex site of Matcharak Lake. Though these are significant findings in terms of dietary reconstruction, they would not allow for the testing of bird-specific spacing values in mixing equations under different conditions (i.e., do human bone collagen values change if bird-specific spacing values are used in mixing equations that include only terrestrial animals when different proportions of birds in the diet are considered?). Stable isotope ratios for all included species are listed in Table 8.31.

The following animals and their source proportions were used for the Independence I bone collagen stable isotope ratio calculations:

Ptarmigan 18%
Hare 10%
Muskox 72%

Animal	Sample	Source	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Ptarmigan	Bone Collagen	This Dissertation	-21.3	2.9
Hare	Bone Collagen	Katzenberg and Krouse, (n.d.)	-21.7	4.2
Muskox	Bone Collagen	Bocherens et al., 2016	-20.9	2.7

Table 8.31. Stable carbon and nitrogen isotope ratios for species included in mixing calculations for Independence I human bone collagen values and their sources.

The results from the mixing calculations are presented in Table 8.32. With the increase to 18% ptarmigan in the mainly terrestrial diet of Independence groups at the Adam C. Knuth site, the addition of bird-specific spacing values can change the stable carbon isotope ratio of human bone collagen by up to 0.5‰. There was no significant change in stable nitrogen isotope ratios. This is a notable finding because all three of the species included in the calculation are terrestrial animals and have similar isotopic ratios. This suggests that bird-specific spacing values can have a significant effect on human bone collagen stable isotope ratios even if the groups were consuming isotopically similar foods.

Independence I	Uniform Spacing (Coltrain, 2009) (‰)	Lipid-Extracted Muscle Bird Spacing (‰)	Muscle + Fat Bird Spacing (‰)
δ^{13}C	-20.1	-19.5	-19.6
δ^{15}N	5.9	6.0	5.9

Table 8.32. Resulting Independence I human bone collagen values from mixing calculations using different spacing values for birds.

8.3.3 Pre-Dorset and Dorset - Ellesmere Island

Paleodietary reconstruction is based on a theoretical diet for Pre-Dorset and Dorset groups utilizing the North Water polynya, and three of the prey animals that were the most predominant in the faunal remains from the Knud Peninsula sites: seal, walrus (*Odobenus rosmarus*), and eider duck (*Somateria* sp.) (Schledermann, 1990). Proportions are based on the two sites with the least and greatest bird remains recovered (the Baculum and Narrows site, respectively) to determine how much proportion of birds in the diet may impact human bone collagen values. The stable carbon and nitrogen isotope ratios for the included species are listed in Table 8.33. The source proportions used in the calculations for each site are provided below:

Baculum site

Seal 60.6%
Walrus 20.7%
Eider Duck 18.7%

Narrows site

Seal 13.3%
Walrus 2.2%
Eider Duck 84.5%

Animal	Sample	Source	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Hooded Seals	Bone Collagen	Nelson et al. 2012	-13.6	15.8
Walrus	Bone Collagen	Nelson et al. 2012	-12.7	11.7
Eider Duck	Bone Collagen	This Dissertation	-15.1	13.9

Table 8.33. Stable carbon and nitrogen isotope ratios for species included in mixing calculations for Pre-Dorset/Dorset human bone collagen values and their sources.

The results of the calculations are provided in Table 8.34. The results from the Baculum site can be compared to those from the Adam C. Knuth site (Independence I) to examine marine versus terrestrial diet because the proportion of birds in the diet was similar, but unlike at the Adam C. Knuth site, the animals from the Baculum site belong to the marine system. Even with the predominantly marine diet at the Baculum site, there was a similar change in stable carbon isotope ratios when bird-specific spacing values are used to calculate human bone collagen values. Again, there is also little change in stable nitrogen isotope ratios. This suggests that bird-specific spacing values have similar effects on human bone collagen values in both marine and terrestrial dietary systems.

With an increase to 84.5% of birds in the diet at the Narrows site, there was a change of up to 2.5‰ for stable carbon isotope ratios and 0.4‰ for stable nitrogen isotope ratios once bird-specific spacing values were applied to the mixing equations. These results suggest that there is a greater change in human bone collagen values if there is a higher proportion of birds in the diet and bird-specific spacing values are used.

Pre-Dorset	**Uniform Spacing (Coltrain, 2009) (‰)**	**Lipid-Extracted Muscle Bird Spacing (‰)**	**Muscle + Fat Bird Spacing (‰)**
Baculum Site			
δ^{13}C **δ^{15}N**	-12.7 17.6	-12.1 17.7	-12.3 17.6
Narrows Site			
δ^{13}C **δ^{15}N**	-13.8 17.1	-11.3 17.5	-11.9 17.1

Table 8.34. Resulting Pre-Dorset/Dorset human bone collagen values from mixing calculations using different spacing values for birds.

8.3.4 Saqqaq - Greenland

Finally, human bone collagen stable isotope ratios for Saqqaq populations were calculated using proportions provided in Gotfredsen and Møbjerg’s (2004) faunal analysis of the Nipisat site. Gotfredsen and Møbjerg’s (2004) study was used because it included birds from different species and a careful analysis of faunal remains from different phases of the Nipisat site. This allowed for calculations based on various species of birds and accounted for temporal changes at a single site. Because only three species could be included in the calculations at a time, different combinations of harbour seal (*Phoca vitulina*), harp seal (*Pagophilus groenlandicus*), gull, eider duck, and caribou were used in the calculations (see Table 8.35). The stable carbon and nitrogen isotope ratios for all species are provided in Table 26. Source proportions for each phase at the Nipisat site are provided below:

Phase 2

Seal 28%
Caribou 19%
Bird 53%

Phase 3

Seal 33%
Caribou 22%
Bird 45%

Animal	**Sample**	**Source**	**δ^{13}C (‰)**	**δ^{15}N (‰)**
Harbour Seal	Bone Collagen	Nelson et al. 2012	-12.6	13.9
Harp Seal	Bone Collagen	Nelson et al. 2012	-14.3	14.5
Caribou	Bone Collagen	Nelson et al. 2012	-18.2	2.0
Eider Duck	Bone Collagen	This Dissertation	-15.1	13.9
Gull	Bone Collagen	This Dissertation	-15.1	19.1

Table 8.35. Stable carbon and nitrogen isotope ratios for species included in mixing calculations for Saqqaq human bone collagen values and their sources.

The results of the mixing calculations are provided in Table 8.36. There was an increase in stable carbon isotope ratios for human bone collagen for all cases when bird-specific spacing values were used in the mixing calculations and a minimal increase in stable nitrogen isotope ratios when lipid-extracted muscle bird spacing values were used. There were negligible differences when eider duck or gull values were used, or when harbour seal or harp seal values were used (less than 0.2‰ difference). The most considerable difference between the two phases was 0.3‰ for stable carbon isotope ratios when the lipid-extracted muscle bird spacing values were used in the calculation. The 8% difference in the proportion of birds in the diet between the two phases was therefore not significant enough to affect the human bone collagen values.

Saqqaq	**Uniform Spacing (Coltrain, 2009) (‰)**	**Lipid-Extracted Muscle Bird Spacing (‰)**	**Muscle + Fat Bird Spacing (‰)**
Phase II (Eider + Harbour Seal)			
δ^{13}C **δ^{15}N**	-14.0 15.5	-12.4 15.8	-12.8 15.5
Phase II (Gull + Harbour Seal)			
δ^{13}C **δ^{15}N**	-14.0 18.3	-12.4 18.7	-12.8 18.3
Phase II (Eider + Harp Seal)			
δ^{13}C **δ^{15}N**	-14.5 14.8	-12.9 15.1	-13.2 14.8
Phase II (Gull + Harp Seal)			
δ^{13}C **δ^{15}N**	-14.5 17.6	-12.9 17.8	-13.2 17.6
Phase III (Eider + Harbour Seal)			
δ^{13}C **δ^{15}N**	-14.0 15.3	-12.6 15.5	-12.9 15.3
Phase III (Gull + Harbour Seal)			
δ^{13}C **δ^{15}N**	-14.0 17.6	-12.6 17.9	-12.9 17.6
Phase III (Eider + Harp Seal)			
δ^{13}C **δ^{15}N**	-14.5 14.5	-13.2 14.7	-13.5 14.5
Phase III (Gull + Harp Seal)			
δ^{13}C **δ^{15}N**	-14.5 16.8	-13.2 17.0	-13.5 16.8

Table 8.36. Resulting Saqqaq human bone collagen values from mixing calculations using different spacing values for birds.

8.4 Summary

To determine the utility of bird-specific spacing values, as determined in Chapter 6, to the interpretation of isotopic results and ultimately to dietary reconstruction using stable isotope analysis, bird-specific spacing values were applied to existing isotopic studies of past Arctic human groups and dietary models of Paleo-Inuit groups. Mixing models based on existing studies demonstrated that bird-specific spacing values often separated birds isotopically from other common dietary items of Arctic groups and can change the proportion of birds contributing to human diet. In three out of the five studies presented, the proportion of certain birds in the human diet increased when bird-specific spacing values were used, while the proportion of birds in the human diet decreased in the remaining two studies when bird-specific spacing values were used. These results indicate that when spacing values specific to birds are used in linear mixing models, the proportion of birds in human diet changes in all cases. These changes can, therefore, affect the way that researchers interpret the role of birds in human diet.

Two linear mixing models for Greenland Thule diet were also created with the incorporation of egg yolk and egg albumen into the models. Two models were created to account for the differing resource strategies that are possible amongst bird species, the first one is for income breeders, where food acquired from the breeding grounds is preferentially allocated to egg production, and the second one is for capital breeders, who allocate nutrients from body stores accumulated at the summer grounds and along the migratory route to egg production. These two strategies could potentially result in differing egg isotopic signatures. Stable isotope ratios of egg components were calculated using existing stable isotope ratios from bone collagen and both the tissue spacing values calculated in Chapter 6 of this dissertation and tissue spacing values published in the ecological literature. The resulting linear mixing models show that the inclusion of eggs in past human diet can be detected using stable isotope analysis, though in some cases the isotopic signatures of eggs are obscured by the stable isotope ratios of other animals.

The theoretical stable isotope values calculated for the various Paleo-Inuit groups paints a similar picture to the linear mixing models. When bird-specific spacing values were incorporated into the equations, stable carbon isotope ratios for human bone collagen could change by over 2‰. This is greater than the value typically seen for machine error (approximately 0.2‰) and is therefore relevant for paleodietary reconstruction. Bird spacing values also affected human bone collagen stable isotope ratios in a similar manner for both marine and terrestrial dietary systems.

Bird-specific spacing values, therefore, have a significant impact on linear mixing models and therefore interpretation of past diet when using stable isotope analysis. Throughout the process of creating mixing models, there was also a need for isotopic values for birds and their eggs. Often, bird isotopic values had to be substituted in from other studies, which could introduce error into mixing models. Because these models indicate that bird isotopic values can affect paleodietary reconstruction, smaller animals, such as birds, that are relevant to the diet should be included in more isotopic research.

Chapter Nine: Final Discussion and Conclusions

9.1 Research Outcomes

Hunter-gatherer subsistence strategies have been of interest to anthropologists since the late nineteenth century. Since then, we have started to recognize the variation present in all aspects of hunter-gatherer life, including diet. Insight into this dietary variation may be especially relevant today in the context of nutritional transitions and the negative health effects associated with switching from a traditional hunter-gatherer diet to a modern one consisting of more processed foods high in carbohydrates. Arctic hunter-gatherers are unique because the Arctic growing season is very limited and therefore their traditional diet mainly consists of animal fat and protein. One key component of Arctic hunter-gatherer diet is smaller animals such as birds. Small animals are safer to hunt, may be more reliable regarding availability, and can also provide other resources such as skins, feathers, and bones. Migratory birds may be especially crucial to Arctic hunter-gatherers because they arrive in the Arctic in large numbers during the spring when food stores for the winter have been depleted. Not only could these birds be hunted, but their eggs could also be easily collected and would provide an additional protein source. Because of this emphasis on animals, zooarchaeology and stable isotope analysis are the most direct methods in understanding past Arctic hunter-gatherer subsistence strategies. It is unclear, however, how the incorporation of birds and their eggs into stable isotope analysis will affect interpretations regarding paleodiet. The ultimate goal of this dissertation was therefore to understand the interpretive consequences of including birds in paleodietary models.

The first research objective of this dissertation was to explore the faunal evidence from Arctic archaeological sites to identify the use of avifauna. If birds were being hunted and consumed by past Arctic hunter-gatherers, then there would be evidence of these processes in the zooarchaeological record because materials such as avian bone are often preserved through time. These patterns and processes would also help to inform paleodietary reconstructions when using stable isotope analysis. For this dissertation, avifaunal remains from Pre-Dorset and Dorset archaeological sites on the Knud Peninsula of Ellesmere were analyzed because a large number of bird bones were recovered, allowing for a more in-depth analysis, and there is some comparative data available regarding bird hunting and butchering amongst Paleo-Inuit groups. The zooarchaeological analysis of bird remains from the Knud Peninsula archaeological sites revealed that eider ducks (*Somateria* sp.), followed by brant geese (*Branta bernicla*), were the most preferred birds in the diet of Pre-Dorset and Dorset groups on the Knud Peninsula. The extensive spiral fracturing on the bird bones, along with cut marks and consistent breakage patterns show that birds were brought back to the settlements whole and were heavily processed to extract all the meat and bone marrow possible from the carcasses. Comparatively few female and juvenile bones were identified within the assemblage, which suggests that Pre-Dorset and Dorset groups on the Knud Peninsula mainly hunted adult male birds during the late summer months. Although egg shells were not recovered, given the hunting of birds during the summer months, bird eggs were likely taken as well. Bird bones were also being used for items such as needles and whistles, further increasing their utility to Paleo-Inuit groups. The picture established here regarding bird use amongst Pre-Dorset and Dorset groups is similar to previous patterns seen at other Paleo-Inuit sites; however, the preferred bird species appears to vary depending on location.

The second research objective was to determine if the incorporation of birds into past Arctic hunter-gatherer diet would have any impact on the stable isotope signatures of Arctic hunter-gatherers. If birds were an important resource in the diet of Arctic hunter-gatherers, then the stable carbon and nitrogen isotope ratios of Arctic hunter-gatherers would be reflective of this dietary resource because stable isotopes serve as natural tracers for diet. To explore the contribution of birds to the diet of Arctic hunter-gatherers using stable isotope analysis, the assumption that isotopic spacings for mammals are similar to the isotopic spacings for birds had to be tested first. Stable isotope analysis of muscle, fat, bone collagen and feathers from *Anas platyrhynchos* fed a consistent and monotonous diet, which was also analyzed, demonstrated that diet-to-tissue and tissue-to-tissue spacing values for birds differed from those for mammals, especially for stable carbon isotope ratios. Stable carbon isotope tissue-to-tissue spacings for birds differed by as much as 2‰ compared to spacings for mammals. Diet-to-bone collagen enrichment values for birds were also less than the values previously reported for mammals. The difference in tissue spacing values between birds and mammals, as demonstrated through this research, indicate that paleodietary reconstructions using stable isotope analysis should consider different classes of animals and their associated stable carbon and nitrogen isotope spacing values.

Building on the results from the experimental analyses, stable carbon and nitrogen isotope analyses were also carried out for one hundred and one bird bone collagen samples from the archaeological sites on the Knud Peninsula of Ellesmere Island. This was completed to determine if avifaunal isotopic signatures also differ from mammal isotopic signatures due to the unique life histories of migratory birds. Stable isotope analysis of a larger sample of wild birds can also reveal how avian isotopic signatures may be affected by migration, body condition, reproductive status, food availability, and habitat variation. The stable isotope analysis of archaeological bird bone collagen showed that birds could have a wide range of isotopic values. The thirteen bird species analyzed fell into three general categories including birds with lower stable carbon and nitrogen isotope ratios reflective of a terrestrial diet, birds with intermediate stable carbon and nitrogen isotope ratios, and birds with elevated stable carbon and nitrogen isotope ratios indicative of high-trophic level marine predators. Certain bird species such as the brant geese and snow geese (*Chen caerulescens*) also had a wide range of possible stable carbon isotope ratios that may be reflective of terrestrial plant foods obtained from a variety of environments. The variability in stable isotope ratios across and sometimes within bird species highlights how birds may have isotopic signatures distinct from mammals and the need for increased sample sizes of bird remains in paleodietary reconstruction.

Finally, stable isotope ratios of birds and their eggs, along with bird-specific spacing values were used to generate numerous linear mixing models for Arctic hunter-gatherer groups to determine if the addition of avian-specific spacing values and a greater representation of avifaunal isotopic signatures will impact dietary reconstruction for these groups. In all the linear mixing models, when bird-specific spacing values were used, the proportion of birds included in the diet was different compared to traditional linear mixing models with uniform spacing values for all food items. Eggs were also successfully identified in the diet of Arctic hunter-gatherers using linear mixing models. Linear mixing equations were also used to calculate theoretical stable carbon and nitrogen isotope ratios for various Paleo-Inuit groups. Once bird-specific spacing values were added to the equations, the resulting stable isotope ratios for human bone collagen would change by up to 2‰. These results suggest that the addition of birds, eggs, and avian spacing values in paleodietary research using stable isotope analysis may lead to more accurate interpretations regarding the role of birds in Arctic hunter-gatherer diet. These findings also support the hypothesis that if birds were a substantial dietary resource for Arctic hunter-gatherers, then their isotopic signatures would be reflective of this food item.

When the zooarchaeological evidence and the results of the stable isotope analyses are combined, the picture of avian resource use amongst Arctic hunter-gatherers becomes more nuanced. The results from the zooarchaeological analysis in this dissertation add to the bigger picture of Paleo-Inuit bird hunting practices. Though bird hunting and processing practices appear to be similar amongst Paleo-Inuit groups, the species they choose to exploit at different sites highlights the flexibility of Paleo-Inuit hunting strategies. Paleo-Inuit groups appear to prefer larger species such as ducks, geese, and gulls, but these species are hunted in different relative proportions across various Paleo-Inuit sites. For example, the Pre-Dorset at the Mosquito Ridge site on Baffin Island predominantly hunted snow geese (Milne & Donnelly, 2004), whereas the Pre-Dorset at the Knud Peninsula sites on Ellesmere Island predominantly hunted eider ducks. Paleo-Inuit groups were also likely incorporating different species of birds in their diet at different locations during their seasonal round. For example, Paleo-Inuit groups could consume eider ducks (*Somateria* sp.) around the Knud Peninsula but also dovekies (*Alle* alle) from the west coast of Greenland if they were able to travel across the Smith Sound during periods of heavier ice cover.

Because Arctic hunter-gatherers groups, such as the Paleo-Inuit, may be incorporating various bird species in their diet, research using stable isotope analysis should also account for this variation. Chapter 7 of this dissertation demonstrated that birds such as eider ducks and snow geese have very different isotopic signatures; eider ducks have isotopic signatures indicative of marine dietary strategies, while geese have isotopic signatures indicative of terrestrial dietary strategies. If only one bird species is included during paleodietary reconstruction, which is often the case, then we may not be accounting for a dietary resource that has an isotopic signature reflective of an entirely different environment. As shown in Chapter 8, when avifaunal isotopic signatures are combined with avian-specific spacing values in paleodietary reconstructions, human isotopic signatures could vary by up to 2‰. Though this difference in human isotopic signatures does not seem very large, the results generated by IsoSource, when avifaunal isotopic signatures and avian spacing values are incorporated, indicate that the proportion of birds in human diet can be miscalculated by up to 48% if avian-specific spacing values are not considered (see skuas in Table 8.14).

The potential ability to identify eggs in past human diet using stable isotope analysis of bird bone collagen can also aid in paleodietary reconstruction. Egg consumption by past Arctic hunter-gatherers has largely been assumed because of the ethnographic record, but archaeologists have not tested this assumption. Using avian-specific spacing values, as determined through this research and values provided in the ecological literature, archaeologists can begin to explore the contribution of eggs to human diet.

9.2 Ongoing Research and Future Directions

The conclusions in this dissertation addressed some untested assumptions regarding birds and their eggs in paleodietary reconstruction, but there are still research avenues beyond the scope of this thesis. Chapter 6 provided diet-to-tissue and tissue-to-tissue spacing values for ducks and Chapter 8 explored how these spacing values would affect paleodietary reconstructions, however, the tissue-to-tissue spacing values for eggs required numerous steps and assumptions that could introduce error into mixing models. Tissue spacing values between avian tissues and eggs could not be determined within this dissertation because eggs could not be acquired for the ducks that were used for the experimental analyses in Chapter 6. The isotopic spacing between avian body tissues and egg components is also not well understood within the ecological literature. A logical next step for research in this area would be to continue stable isotope analyses on various avian and egg tissues, with an emphasis on bone collagen, to determine spacing values amongst different bird species.

Increasing the number of thorough zooarchaeological analyses of bird faunal remains will also provide valuable comparative data for hunting and butchering practices, species preferences, and bone tool use. For example, the high proportion of coracoid bones with similar breakage patterns on the distal end were noted for the Knud Peninsula faunal assemblages, but this pattern has not been identified elsewhere. Increasing comparative data and butchering experiments carried out on bird remains could, therefore, provide clues regarding the causes for this breakage pattern. Increasing zooarchaeological research on bird remains may also spur more researchers into including bird remains within their isotopic studies.

Finally, although this is an easy and over-used research direction in concluding statements, the need for more avifaunal isotopic signatures in paleodietary research was a constant issue within this dissertation. As demonstrated in Chapter 7, the stable isotope ratios for birds can vary widely between and sometimes within bird species, but many paleodietary studies only include a small number of bird values and often only from one bird species. Though many hunter-gatherer groups likely prefer one species of bird, Chapter 5 shows us that they will include other birds in their diet and that their subsistence strategies may change depending on prey availability. Chapter 8 also illustrates how the inclusion of more than one bird species in linear mixing models can influence the resulting interpretation of the relative importance of various bird species (see Section 8.2.2). Including a greater number of bird remains in future paleodietary reconstructions using stable isotope analysis would, therefore, go a long way in addressing this problem. Since migratory birds utilize a variety of habitats as part of their migratory route, an increase in stable isotope analysis of avifaunal remains may also provide researchers, within both archaeology and ecology, with a better picture regarding geographical differences in avifaunal isotopic signatures.

9.3 Research Significance

These conclusions support the addition of birds to paleodietary models to improve the accuracy of interpretations of hunter-gatherer subsistence strategies. Paleo-Inuit groups, for example, had distinctive ways of hunting and butchering birds and preferences for specific bird species depending on their environment. Linear mixing models generated for Arctic hunter-gatherer groups with the addition of stable isotope ratios from birds and their eggs and avian-specific spacing values also impacted possible proportions of birds in human diet and thereby the role that birds may have played in past hunter-gatherer subsistence strategies. Together, these lines of evidence help to address the utility of a food resource in past human diet that has often been under-studied.

The identification of birds and their eggs in the diet of Arctic hunter-gatherers helps to address only one portion of the overall diet of these human groups, but the significance lies in our ability to start recognizing the role of smaller animals in human subsistence strategies. Hunter-gatherers have a wide variety of food procurement practices and being able to detect yet another facet, their exploitation of birds and small animals, adds to the mosaic that anthropologists have been working to understand since the late nineteenth century. By including food items such as birds and their eggs into existing models of hunter-gatherer subsistence strategies, we can make these models more robust, and we are better equipped to understand hunter-gatherer variation.

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Appendix A

Stable carbon and nitrogen isotope ratios for all tissues and samples analyzed to determine avian spacing values in Chapter 6.

Duck #	**Muscle δ^{13}C**	**Muscle + Fat δ^{13}C**	**Bone Collagen δ^{13}C**	**Fat δ^{13}C**	**Muscle δ^{15}N**	**Muscle + Fat δ^{15}N**	**Bone Collagen δ^{15}N**	**Fat δ^{15}N**
1	-22.3	-22.9	-21.6	-26.9	6.0	5.7	5.3	5.7
2	-22.3	-22.9	-21.4	-26.0	5.9	5.5	5.1	7.7
3	-22.3	-23.3	-22.1	-26.4	5.8	5.2	5.1	5.3
4	-22.0	-22.8	-21.0	-26.1	6.0	5.3	5.2	5.3
5	-22.2	-23.1	-21.0	-26.1	5.9	5.3	5.6	5.3
6	-22.4	-23.0	-21.4	-26.9	5.8	5.2	5.3	5.6
7	-22.5	-23.3	-21.4	-26.5	5.6	5.4	5.3	5.2
8	-22.5	-23.4	-21.4	-26.5	5.3	5.1	4.9	4.6
9	-22.4	-23.1	-21.3	-26.9	5.4	5.1	5.0	5.0
10	-22.5	-22.9	-21.2	-26.2	5.3	4.9	4.8	5.1

Feather δ^{13}C	**Feather δ^{15}N**
-21.5	5.4
-21.1	7.6
-21.5	5.2
-20.9	6.0
-20.8	6.6
-21.1	5.9
-21.1	6.3
-21.1	5.9
-20.7	6.5

Feed δ^{13}C	**Feed δ^{15}N**
-25.1	3.4
-25.3	3.5
-25.0	3.9
-25.8	3.8
-25.3	3.2