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Determining Season of Occupation at Tranquility Farm, Maine Using Oxygen Isotopes from Mya arenaria

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DETERMINING SEASON OF OCCUPATION AT TRANQUILITY FARM, MAINE USING OXYGEN ISOTOPES FROM *MYA ARENARIA*

By

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An Abstract of the Thesis Presented
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Coastal shell midden archaeological sites uniquely preserve information regarding past human habitation there as well as the about the paleoenvironment. In this study, oxygen isotopes ($\delta^{18}O$) from archaeological *Mya arenaria* shells collected from the Tranquility Farm site in Gouldsboro, Maine were used to determine the site's season of occupation. Modern *Mya arenaria* were collected throughout a calendar year from a nearby clam flat in Jones Cove, Gouldsboro to establish a modern isotopic baseline to which the archaeological shell $\delta^{18}O$ values were compared. The results indicate that the archaeological samples occurred most frequently within the modern monthly winter values ranges. Additionally, this study highlights the challenges of comparing archaeological and modern samples. Determining the season of occupation at Tranquility Farm will contribute to archaeologists' understanding of coastal subsistence and settlement patterns in Maine, and the observations made throughout the isotopic analysis can be used to inform further studies.

ACKNOWLEDGMENTS

In August of 2012, I attended the Abbe Museum's Archaeological Field School at Tranquility Farm in Gouldsboro, Maine. With field supervision from Dr. Arthur Spiess and Julia Gray from the Abbe Museum, I learned about shell middens and the research possibilities they provided. Needless to say, that field experience proved to be a strong catalyst in my future research and career decisions. In addition to providing me with field experience and study materials to sample, the Abbe Museum also provided me funding to process those samples for my master's thesis.

Additional research and travel funding came from the UMaine Graduate Student Government. During my time in the Quaternary and Climate Studies Master's program, my assistantships in the College of Education and Human Development and Department of Communications and Journalism provided me with the opportunity to pursue my graduate education and research as well as develop my skills in researching and teaching. Additional funding provided through *The Lisle W. Bridgham Scholarship* allowed me to travel to the 2018 SAA's conference in Washington D.C. My internship with the USDA's NRCS has provided me with post graduate experience and a flexible work schedule throughout my last semester at UMaine and for that, I am very grateful.

I would like to acknowledge my fellow graduate colleague, Emily Blackwood, for collaborating with me on this project and spending a lot of time digging for clams in all weather conditions. Working together through the challenges our combined thesis research presented has helped me become a more thorough researcher and better problem solver. Dr. Alan Wanamaker and Suzanne Ankerstjerne from Iowa State University Stable Isotope Lab were indispensable by processing shell samples in their lab. Dr. Wanamaker helped from the beginning by facilitating

Emily's and my research visit to his lab, teaching us about this research process, and contributed along the way with interpretations and edits. My committee chair and advisor, Dr. Daniel Sandweiss, has supported me throughout my master's program, helping me to find funding, teaching me how to be a more critical researcher, and providing numerous opportunities to network and grow my skills. Thank you to my other committee members, Dr. Bonnie Newsom, and Julia Gray, for their comments and support throughout this thesis process.

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Chapter 1

INTRODUCTION

Coastal shell midden archaeological sites provide a wealth of information about the people who once occupied them as well as about the environmental conditions during their habitation. Shell middens are stratified accumulations of shells and other debris, such as floral and faunal remains, left from subsistence and habitation activities (Andrus 2011). Many studies focus primarily on the faunal remains recovered from the midden while analyzing the environmental data preserved in the shells is often just a small portion of the study or not thoroughly explored (Belcher 1989; Bourque 1995; Spiess & Lewis 2001).

Middens represent a wide variety of marine resources used by Native people; shellfish exploitation represents a portion of these utilized resources. Throughout Maine, many different species of mollusks are represented in the archaeological record. The shells of the *Mya arenaria*, soft-shelled clam, are particularly common. During the clam's lifetime, it deposits layers of calcium carbonate to form successive growth increments (Claassen 1998). Among the various minerals that make up the growth increments are the oxygen and carbon isotopes incorporated into the shell's hard structures from the surrounding water. Shell growth is variable throughout the year; by studying variability in growth one can determine season of harvest (Leng & Lewis 2016).

While there has been significant research throughout Maine to understand the timing and use of coastal sites, these studies have focused generally on faunal remains and incremental growth analysis of mollusk shells, not on the oxygen isotope signatures preserved within the shells (Sanger 1982; Sanger 1988; Belcher 1989; Belcher 1990; Bourque 1995; Sanger 1996; Spiess & Lewis 2001). Research on relatively deepwater dwelling mollusks in the Gulf of Maine has shown the utility of using oxygen isotopes from shells in paleoclimate reconstructions (Wanamaker 2007; Wanamaker et al. 2008; Wanamaker & Gillikin 2018). This thesis seeks to add to archaeologists' knowledge regarding season of occupation at archaeological sites by testing the viability of using oxygen isotopes from modern and archaeological *Mya arenaria* shells to make seasonality determinations for a shell midden in Maine.

Two theoretical approaches provide a framework for this study: cultural historical and cultural ecological. The goals of this study sit between these two theories, the first of which seeks to reconstruct a sequence of events and changes and the other which largely sees choices influenced by environmental constraints and opportunities (Petersen & Sanger 1991; Webster 1996; Michaels 1996; Webster 2007). This research examines pre-contact land use through an environmental data set influenced by humans.

These data will fill a gap in knowledge of the seasonality and subsistence patterns at Tranquility Farm in Gouldsboro, Maine. Archaeological clam shells collected from various locations throughout the site were analyzed for their unique oxygen isotope values (specifically $\delta^{18}O$). Additionally, I used modern *Mya arenaria* shells collected throughout a calendar year to form an isotopic baseline. The modern collected shells formed monthly ranges of $\delta^{18}O$ values with which the archaeological shells were matched to identify specific monthly or seasonal concentrations *. Determining the season of occupation at Tranquility Farm adds to the knowledge base of seasonality data throughout the state and contributes to archaeologists' understanding of coastal subsistence and settlement patterns.

This thesis is organized into the following chapters: 1.) Introduction; 2.) Background; 3.) Methods; 4.) Results; 5.) Discussion; and 6.) Conclusions.

* This portion of the research was completed in collaboration with fellow University of Maine graduate student Emily Blackwood.

Chapter 2

BACKGROUND

The past environmental conditions for Tranquility Farm site setting are recorded here to contextualize human activities within the environmental setting in which they occurred. Paleoenvironmental conditions discussed in the Environmental Context section include Maine's glacial history, sea level rise in the Gulf of Maine and the Gulf's seawater composition, and changes to biotic communities. Cultural Context is then provided detailing the chronology of Maine's cultural periods: Paleoindian Period, Archaic Period, Ceramic Period, and Contact Period. After providing a broad overview of the environment and cultural history of Maine, the final sections discuss methodologies used to make seasonality determinations, and the Tranquility Farm site's local environmental setting and site history.

Environmental Context

Terrestrial Environment

Research over the past fifty years has contributed to the knowledge of Maine's glacial history (Stuiver & Borns 1975; Davis & Jacobson 1985; Barnhardt et al. 1995; Borns et al. 2004; Hall et al. 2017). The landscape of Maine has been heavily shaped by the advance and retreat of massive glaciers over the course of tens of thousands of years. During the last glacial maximum around 24,000 cal BP, the Late Wisconsinan Laurentide Ice Sheet covered Maritime Canada and New England extending as far as Long Island, New York and along Georges Banks in the Gulf of Maine (Figure 1). The glacier's weight depressed the earth's crust by as much as 150 m 24,000 cal BP. Around 21,000 cal BP a warming climate caused the ice sheet to retreat, liberating the southern New England and the Gulf of Maine from ice (Thompson & Borns 2007).

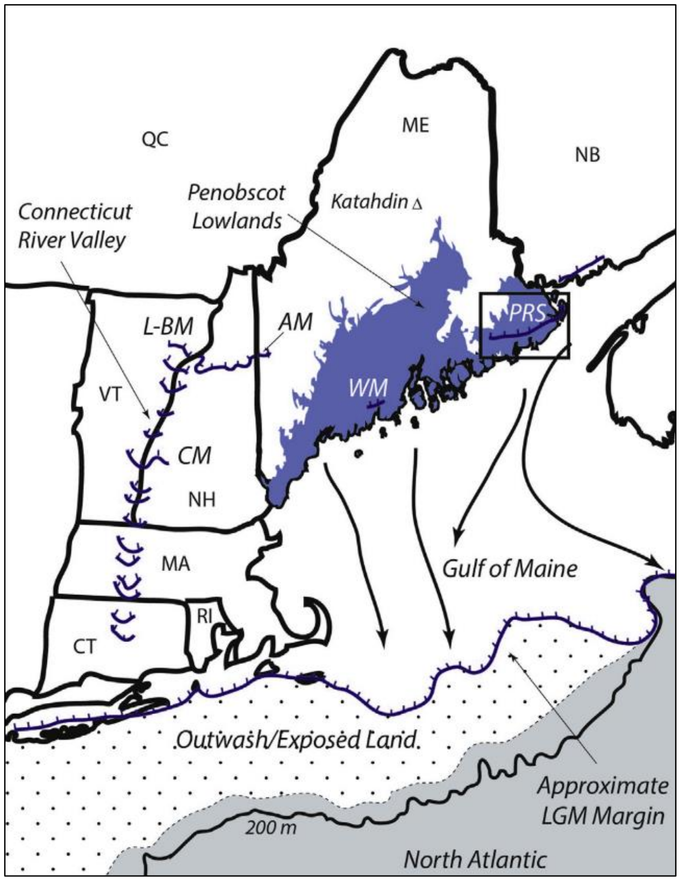

Figure 1. Map showing the LGM margin and marine submergence in Maine (Hall et al. 2017)

Moraines, deltas, and waterlain deposits provide a chronology for the retreat of the ice sheet from the region (Borns et al. 2004). As the ice continued to retreat northwards, the earth's crust remained glacially depressed allowing the ocean to inundate areas of southern Maine and low-lying areas of the interior of the state (Figure 1) (Stuiver & Borns 1975; Thompson & Borns 2007). Maine's sea level curve documents the postglacial changes to the coast's shoreline since the recession of the glaciers (Figure 2) (Kelley et al. 2010). By 12,500 cal BP, Maine had been mostly free from the ice sheet, allowing the earth's crust to rebound. The uplifted crust led to a decrease in relative sea level, pushing the shoreline south as much as 60 m below present (Belknap et al. 2002). A brief period of cooling between 13,000 and 11,500 cal BP, known as the "Younger Dryas Event," may have expanded the ice sheet in Maine by a little, but by 11,000 years ago, it was gone from Maine (Barnhardt et al. 1995; Borns et al. 2004; Thompson & Borns 2007; Lothrop et al. 2016a).

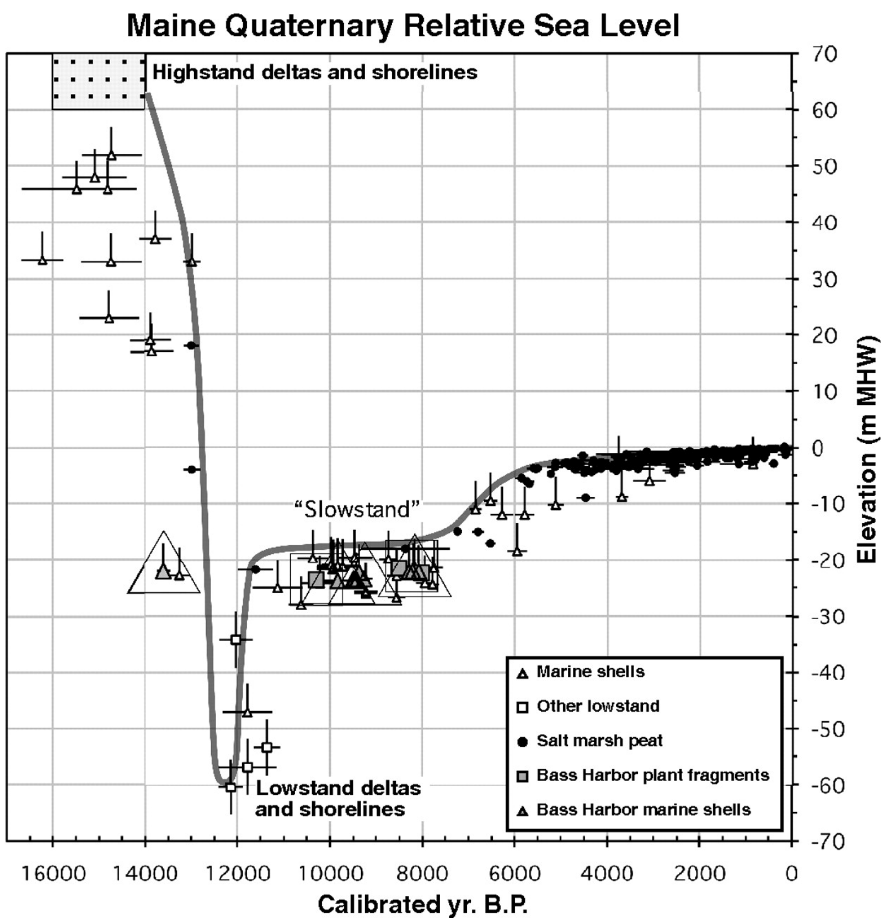

Figure 2. Maine relative sea level curve (Kelley et al. 2010)

The deglaciation of Maine brought about changes in biotic communities. The Younger Dryas is associated with a cooler, drier climate which supported an open tundra-like complex interspersed with spruce woodlands, a prime habitat for migratory caribou herds (Lothrop et al. 2011). By the end of the Pleistocene around 9,500 cal BP, forest communities transitioned to a mixed hardwood-conifer forest indicative of the warmer than present temperatures of the postglacial optimum. Coniferous trees began to increase 2,000 cal BP as conditions cooled to near modern temperatures (Davis et al. 1980; Davis & Jacobson 1985).

Marine Environment

The last 11,400 years, identified as the Holocene, represents a period of relatively stable climate. The climatic changes that have occurred over the past several thousand years in Maine's marine environment can be reconstructed using proxies such as sediment cores and fossilized deep sea mollusks. Oxygen isotope records derived from mollusks from the Gulf of Maine indicate that seawater temperatures over 1,000 years ago were likely 1-2°C warmer than the present-day temperatures (Wanamaker et al. 2008). Warmer temperatures were likely caused by a decrease in Labrador Current transport and a more direct influence from the Gulf Stream in the Gulf of Maine (Marchitto & DeMenocal 2003; Wanamaker 2007; Wanamaker et al. 2008).

Studies in the Gulf of Maine on modern oxygen isotopes ($\delta^{18}O_w$) and salinity composition also provide context for this study. By examining the Gulf of Maine's surficial $\delta^{18}O_w$ and salinity composition, Whitney et al. (2017) determined that there are seasonal differences not only in the temperature of the Gulf of Maine seawater but also in its salinity and $\delta^{18}O_w$. These data indicate a trend towards lower $\delta^{18}O_w$ and salinity in the spring and increasing values throughout the rest of the year (excluding December).

The modern-day Gulf of Maine is home to a wide variety of aquatic species due to nutrient-rich upwelling, strong tides, and cool, Canadian waters. Each spring, a large plankton bloom feeds several smaller fish species such as herring and alewife, which in turn later brings in larger predatory species. These species stay inland until the waters begin to cool once again and they then move to warmer waters. The cold, fall waters then become home to other fish species like larger cod and winter flounder (Spiess 2011: 130-132). Maine's intertidal zones are highly productive and provide habitat for a variety of invertebrate species such as crustaceans and mollusks. Maine has a healthy population of mollusks and several species of clams, *Mya* *arenaria* (soft shell clam), *Mercenaria mercenaria* (hard clam), and *Spisula solidissima* (Atlantic surf clam). These clams live mainly in the intertidal waters buried in the gravel, sand, and mud (Department of Marine Resources 2016).

Cultural History

Paleoindian Period

While it is still widely debated, among the several hypotheses about the route people took to settle the Americas, the most popular is the Bering Land Bridge. This hypothesis states that during the last glacial period a land bridge between modern Siberia and Alaska was exposed due to lowered sea levels (Balter 2008; Waters et al. 2011; Madsen 2015; Halligan et al. 2016; Lothrop et al. 2016b; Braje et al. 2017). Current evidence from DNA suggests that people migrated from Siberia between 30,000 and 13,000 years before present. Narrowing this date even further is the presence of mtDNA suggesting that a dispersion from Beringia by the founding population occurred after 16,600 years BP (Goebel et al. 2008). The exact routes these people took when reaching the American continents is still highly debated, but current publications suggest they took a coastal route from Alaska down to the southernmost point of South America (Braje et al. 2017). In his 2015 paper, Madsen suggests it could have taken between 500 and 2000 years for the people to explore the coastal and possibly inland areas of the American continents.

In their 2011 article, Lothrop et al. identify the Paleoindian period in the New England and Maritime Canada (NEM) to last from 13,000 cal years BP to 10,000 cal BP and break it into three sub-periods distinguished by changes in material culture: Early (~12,900–12,200 cal BP), Middle (12,200-11,600 cal BP), and Late 11,600-10,000 cal BP. Throughout the region, the combination of the ephemeral nature of hunter-gatherer Paleoindian sites and the drastic changes to the coastal landscape has severely limited archaeologists' understanding of coastal Paleoindian peoples. The soils of the NEM are very acidic, which prevents the preservation of organic materials except for calcined bone or burned plant remains or when the acid is buffered by calcium carbonate from midden shells.

Despite the scarcity of organic materials found at these sites, the Paleoindian period peoples' choices in site location and toolkits help shape archaeologists' understandings of Paleoindian subsistence patterns. Typically, Paleoindian period people established their campsites on elevated, well-drained sandy soils in close association to a water source. These locations would have been advantageous for hunting of large game, a practice also suggested by their toolkits of large fluted spear points made from high-quality, fine-grained lithics. Throughout the entirety of the NEM, nearly one-hundred Paleoindian period sites have been located, many of which possess these characteristics (Sanger 2005; Lothrop et al. 2011). Of those sites, the Bull Brook site, in Ipswich, Massachusetts, represents one of the largest Paleoindian sites near the NEM coast (Robinson et al. 2009). Evidence for other Paleoindian period people sites along the coast has most likely been erased by changing sea levels over the past 12,000 years.

Archaic Period

The Archaic period (10,000 to 3,000 BP) is divided into three different sub-periods based on changes in material culture and settlement and subsistence practices: Early (10,000 to 8,000 BP), Middle (8,000 to 6,000 BP), and Late (6,000 to 3,000 BP) (Bourque 2001; Spiess & Mosher 2006). While the technology used by people of the Paleoindian period was broadly similar across large landscapes, the technology used by people of the Archaic period began to differ by region.

These technological variations and shifts are considered to be the result of people adapting to more specific, localized landscapes. Within each of the Archaic period's subdivisions are distinct "traditions" characterized by differences in tools, mortuary practices, and geographical location (Robinson 2006).

Sites representing the Early and Middle Archaic period are scarce in comparison to the Late Archaic period. This scarcity is interpreted, not as a lack of people living throughout the region, but as the result of poor site preservation due to a changing landscape. Artifacts recovered by fishermen along the coast support this hypothesis, but there is still much unknown about this time (Bourque 2001). The Early Archaic period (10,000 to 8,000 BP), is characterized by flaked and groundstone tool technologies. Gouges, adzes, and stone rods were constructed by grinding and pecking granular stone and are thought to indicate an expansion of woodworking technology (Bourque 2001; Robinson 2006)

By the Middle Archaic, marine fishing conditions were becoming more favorable as biological productivity in the Gulf of Maine increased (Bourque 2001). During this time in the Gulf's history, a change in ocean currents, coupled with the lower sea levels, provided habitat for different animals than those currently living in the Gulf today. A few sites have been discovered on islands off the coast indicating that these people were developing seafaring skills with reliable watercraft (Bourque 2001: 44-46). Beginning in the Early Archaic and extending throughout the Middle Archaic period, the Gulf of Maine Archaic Tradition is characterized by a lack of bifacial stone tools, presumably because the people used tools of organic materials such as wood or bone, which would not have preserved in the acidic soils of Maine. Where bifacial stone tools are lacking, the use of ground stone technology in the form of rods, gouges, and slate points becomes more prevalent (Robinson 2006; Spiess & Mosher 2006).

The Late Archaic period (6,000 to 3,000 BP) represents a time with a higher number of sites spread throughout New England and the Canadian Maritimes, which is thought to indicate an increase in population. The Moorehead Phase and Small Stemmed Point Tradition are both representative of the beginning of the Late Archaic before transitioning into the Susquehanna Tradition around 3,700 BP (Bourque 2001). Each of these phases is identified through tool choices such as the ground stone bayonets of the Moorehead Phase and numerous small, stemmed projectile points of the Small Stemmed Point Tradition. The Moorehead Phase is most strikingly represented by elaborate mortuary practices (Robinson 2006).

The most well-known Late Archaic coastal site in Maine is the Turner Farm site on North Haven Island. The Turner Farm site represents one of the few coastal archaeological sites identified to this period. The large stratified shell midden preserved a large number of bones from deer, cod, swordfish, and the shells of clams indicative of a population adapted to both terrestrial and marine environments (Bourque 1995; Spiess & Lewis 2001). While evidence of coastal Archaic period sites is sparse, artifacts from submerged archaeological sites are occasionally recovered by fishing practices. These few artifacts from drowned sites show that coastal sites are largely absent from the record not because they never existed, but rather because they have been erased by post-glacial sea level rise (Kelley et al. 2010).

Ceramic Period

The Ceramic Period (3,050-250 BP) is defined by the presence of pottery in the archaeological record. While undoubtedly Native people had been using cooking and storage containers before the advent of pottery, those vessels were probably made of some organic material such as wood or bark that would not preserve in the archaeological record (Bourque 2001). Throughout Maine, seven Ceramic period subdivisions are used to classify ceramics.

These subdivisions are based on changes in aboriginal ceramic attributes over time (Table 1). The first six of these fall between 3,050 BP and 400 BP and the seventh is considered to be Contact Period from 400 BP to 200 BP (Petersen & Sanger 1991).

Of the three periods in Maine's Native American history, the Ceramic period is the best represented throughout the region. As sea level change became more gradual, the preservation of coastal archaeological sites improved, allowing archaeologists access to rich datasets. Coastal shell middens, with the acid neutralizing properties of calcium carbonate found in mollusk shells, preserves a variety of artifacts rarely seen in the inland sites. Organic remains such as mammal, fish, and bird bones and even plant remains provide not only cultural information for archaeologists but also environmental data (Sanger 2005). With these data from middens, archaeologists have been able to create models for the seasonal movement, subsistence patterns, and use of sites throughout the coast of Maine (Sanger 1981; Kellogg 1987; Sanger 2005).

Contact Period

During the Contact period, Wabanaki people incorporated European-made vessels into their material culture which eventually led to their ceasing to make traditional ceramic containers. The beginning of the Contact period starts around 1500 AD with European voyages to the Gulf of St. Lawrence and Newfoundland. Voyages to the Gulf of Maine were probably infrequent during this century and the European cultural materials found in the archaeological record probably represent the use of trade networks throughout the regions. Historical records offer some insight into the cultural traditions of some tribes, but deciphering which tribes are being described and where geographically they were located is a challenge (Spiess 1995). Where material culture from the Wabanaki becomes scarce or is obliterated by European influences, language and oral and cultural traditions provide context for more recent Native American history in Maine. There has been progress in these interpretations in the extensive ethnographic reports produced by Prins & McBride (2007).

Petersen and Sanger's Ceramic Typology		
Ceramic Period	**Dates**	**Characteristics**
Ceramic Period 1	3,050-2,150 BP	Grit temper paired with impressions made on the inside and the outside using cord or textile wrapped paddle which helped press the coils or slabs of clay together
Ceramic Period 2	2,150-1,650 BP	Elaborately decorated using a stamping tool; interior and exterior of the pots were then smoothed, scraped, or channeled using a toothed implement; characterized by a pseudo scallop shell dentate decoration and rim punctations
Ceramic Period 3	1,650-1,350 BP	Fabric paddling used on the exterior of some pots; inside was smoothed rather than fabric impressed, also have larger toothed dentate and rim punctations
Ceramic Period 4	1,350-950 BP	Cord-wrapped stick dominant decoration technique; towards the end of this period fabric paddled exteriors with smoothed interiors became more popular
Ceramic Period 5	950-650 BP	Fabric impressions continued with the addition of smoothing after impression; the dominant style was vertically placed cord-wrapped stick impressions; temper was predominately organic/shell
Ceramic Period 6	650-400 BP	Very similar stylistically to those produced during CP 5 except with thinner pot bodies
Ceramic Period 7	400-200 BP	Thin walled vessels made with grit temper; exterior treated with incision and fabric paddling; collared rims

Table 1. Table of Ceramic Period chronology based on Petersen & Sanger (1991)

Seasonality

Reconstructing the seasonal movements of native people throughout Maine is important to understanding their past settlement and subsistence patterns. While this thesis focuses on oxygen isotopes from clams shells to assess site seasonality, there are several seasonality proxies that have been used throughout Maine (Sanger 1982; Sanger 1988; Belcher 1989; Belcher 1990; Bourque 1995; Claassen 1998; Spiess & Lewis 2001). Using multiple proxies for seasonality at a site strengthens the validity of the seasonality determination. After assessing seasonality at several sites, regional patterns can be reconstructed by looking at sites which present similar characteristics.

Historically, it was thought that one population of Native Americans occupied the coast during the summer and moved inland for the winter. In his 1982 study, Sanger disputes this model by theorizing two populations, one specialized for inland subsistence and the other for coastal subsistence. The theory postulates that the coastal population moved based on the seasons, favoring the offshore islands in the summer and moving to the coastal mainland during the winter months. The methods for testing this hypothesis by determining seasonality at archaeology sites in Maine are described below.

Analysis of shells collected from archaeological shell middens has been used in numerous studies. Two methods are typically used in such studies: geochemical analysis (oxygen isotopes being the most common) and incremental growth analysis. In this thesis, oxygen isotopes are used to identify the season of use at Tranquility Farm. Other studies in Maine have used incremental growth analysis (Sanger 1982; Belcher 1990; Spiess & Lewis 2001). For this method, shells are cross-sectioned to measure and analyze the organism's internal growth patterns. To do this, mollusks have traditionally been studied using acetate peels where the shell is cross-sectioned, polished, and etched to better show the organism's growth patterns (Claassen 1998). Both of these methods are subject to the natural variations within the shells and can be used with varying results (Claassen 1998). By combining these methods with the other methods described below, archaeologists can complete a more thorough seasonality analysis.

Cultural materials found in shell middens often include faunal remains which are protected from Maine's acidic soils by the calcium in the shells. These remains are used to reconstruct the season of occupation at archaeology sites. By using a method similar to the incremental growth analysis in shells, the growth patterns in mammal teeth can be analyzed as seasonality indicators. Additionally, the stage of eruption and wear of the teeth and development of certain bones can be used to determine the age of the mammal; since most mammals have seasonally specific births, age and death can be a proxy for season. Similar methods prove useful in fishbone analysis, particularly the incremental growth of fish otoliths. A combination of all these methods were used in Spiess & Lewis's (2001) analysis of the Turner Farm site.

Ethnographic resources are also important in making seasonality interpretations. In their extensive ethnography of the Wabanaki of the Mount Desert Island region, Prins and McBride (2007) reconstruct Wabanaki seasonality and subsistence patterns. This reconstruction made use of archaeological data as described above, but also used ethnohistorical and cultural ecological information. These data indicate that, consistent with Sanger's theory, the coast was occupied year-round. Because of their consistent availability, shellfish are identified as a resource that could be used throughout the year, but the ethnographic data indicates they were primarily used during the summer months (Figure 3).

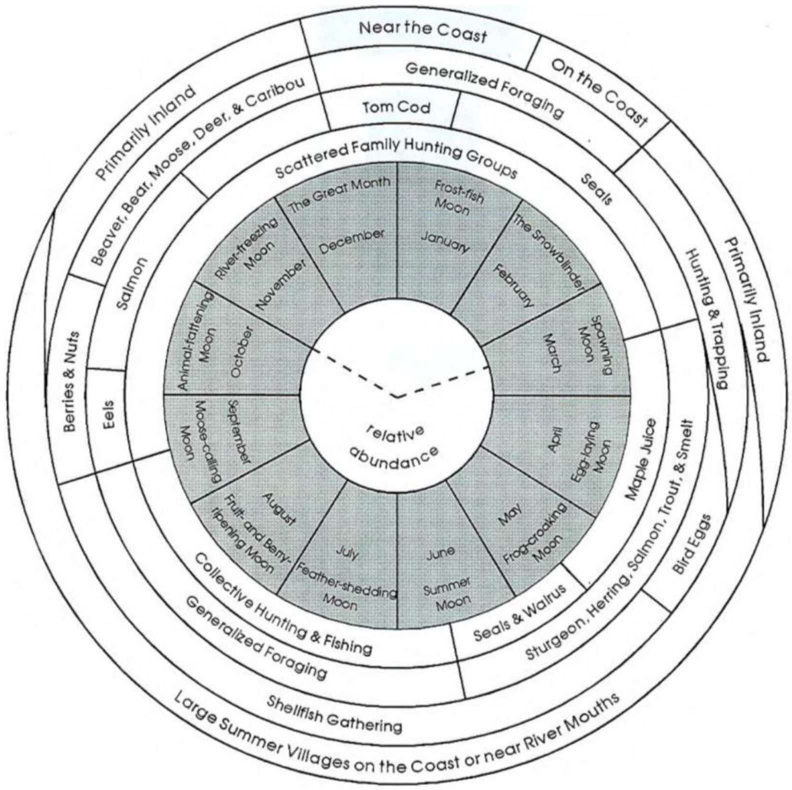

Figure 3. Eastern Wabanaki seasonal hunting and gathering cycle (Prins & McBride 2007a)

Site Background

<u>Site Environment</u>

The Tranquility Farm site is on a peninsula at the mouth of Flanders Bay, in Frenchman Bay, along with the southern shoreline of Schieffelin Point. Two small coves, John Small Cove and Bunker Cove, lie northwest and southeast of the peninsula (Figure 6 and Figure 7). Morancy Stream drains into John Small Cove from several small ponds. The peninsula is underlain by several types of soils, but it is mostly a Hermon-Monadnock complex, a sandy glacial till soil that is somewhat excessively drained (USDA n.d.). This would have made the soil good for farming and historical records and first-hand family accounts show that it was used as farmland (Abbe Museum Staff n.d.).

The Tranquility Farm midden extends approximately 120 m along the shoreline and is approximately 50 m wide. A field covers much of the site, but portions are exposed and eroding into the bay. The middle of the site appears to be eroding faster than the surrounding area; vegetation on either side holds the side embankments in place. The accelerated rate of erosion may be caused by modern human disturbances at the site over the years but may also be due to its location on a small cove surrounded by a rocky outcrop on one side and a forested outcrop on the other. In 1941, excavator Wendell Hadlock described the site as follows:

> It is in a natural basin formed by a ridge of higher ground which makes a half circle about the eastern, northern and western sides of the shell heap. The southern face of the shell heap before excavation, extended to the high water mark on the beach where the extreme high tides have washed into the banks, exposing the horizons of shells. It would seem that this shell heap was an ideal place for an Indian encampment as it was well protected from storms and winds by the high ridge of land (Hadlock 1941:5).

Tranquility Farm is located on the property of the Schieffelin family, who bought the land in 1909 and used it as a family getaway. The 1904 and 1942 United States Geological Survey maps (Figure 4 and Figure 5) of the Bar Harbor region show there is a change in the name of the peninsula from Ash Point to Schieffelin Point. Because of this modern human occupation, the site has been disturbed recently by the moving of a small cottage and construction of a septic system. The midden is covered by a field that is consistently mowed by the Schieffelin family and was once used as farmland. The field has not been plowed in the past forty years according to the landowners, but they have excavated portions of the field to make way for a series of small cabins followed by a septic field and seasonal cottage (Abbe Museum Staff n.d.).

Figure 4. 1904 Historical topo sheet with Schieffelin Point (orange circle; then called Ash Point) (USGS Historical Topographic Map Explorer 1904)

Figure 5. 1942 Historical topo sheet with Schieffelin Point (orange circle) (USGS Historical Topographic Map Explorer 1942)

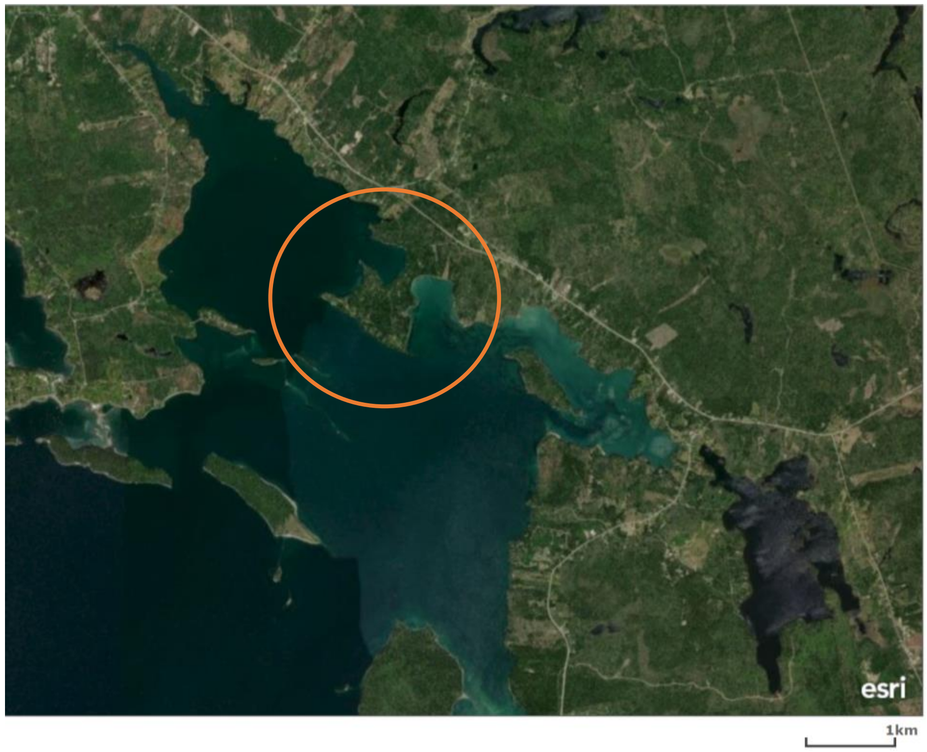

Figure 6. Aerial photograph of Schieffelin Point (orange circle) (Earthstar Geographics 2018)

Figure 7. Topographical Map of Schieffelin Point (orange circle) (National Geographic Society 2013)

Site History

The Abbe Museum's involvement at the Tranquility Farm site has been instrumental in the site's excavations and in building an understanding of shell middens throughout the Frenchman Bay region. For the last eight years, the Abbe Museum has organized and funded excavations at Tranquility Farm. Even before the Abbe Museum was conducting excavations at the site, artifacts from Tranquility Farm were being accessioned into its collection. According to accession catalogs from 1924, Dr. William Schieffelin donated fifteen objects collected from his farmland. In 1929, another fifty objects were donated to the collection by Gouldsboro community members Fletcher and Charles Wood. These brothers collected thousands of objects from the greater Gouldsboro area and donated them to the museum collection.

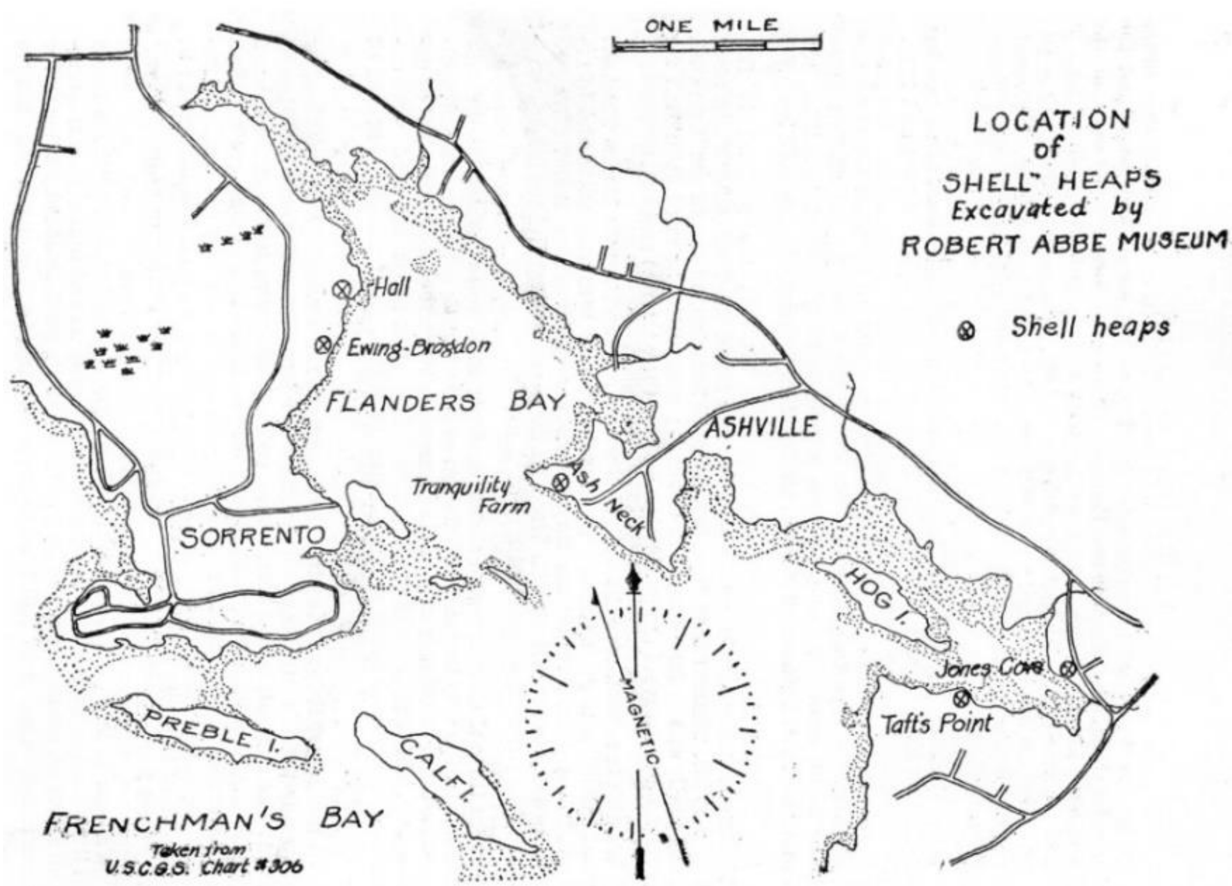

Figure 8. Map of Site from "Three Shell Heaps on Frenchman's Bay" by Hadlock (1941)

The first excavations at Tranquility Farm began in 1931, ended in 1936, and were led by Warren K. Moorehead with Fletcher Wood as an assistant. In a 1931 letter to the Abbe Museum Board of Directors, Wood wrote that museum director Walter B. Smith "…took back quite a collection that has been found in a few days... There is plenty of excavating in the same field for another year" (Abbe Museum Staff n.d.). A detailed account of these excavations and findings was never published, but some of the findings were described in Hadlock's 1941 publication "Three Shell Heaps of Frenchman's Bay." The three shell heaps he refers to are Tranquility Farm, Hall Shell Heap, and the Ewing and Bragdon Shell Heap, all of which are located along Frenchman Bay within a mile of each other (Figure 8). Because of their proximity to each other, the Abbe Museum took a keen interest in excavating and documenting these sites. Hadlock's report details site description, shell midden composition, and a description of the artifacts collected during the excavation.

Figure 9. 1930s Site Excavations at Tranquility Farm (Abbe Museum Collection)

Moorehead's and Wood's excavations produced a large collection of coastal material which was donated to the Abbe Museum for curation. Some of these artifacts included bone harpoons and flutes as well as stone bifaces, drills, pestles, whetstones, and a sandstone pipe. These sites also yielded some more unusual artifacts such as stone pendants, bone combs, and beads, and several small copper implements (Hadlock 1939; Hadlock 1941; Hadlock 1943). While the 1933 through 1938 excavations resulted in 3,851 new accessions to the Abbe Museum, many of the artifacts collected were larger and more distinctive. Screens were not used during excavation, instead, trenches were dug and only the large, "interesting" artifacts were collected (Figure 9). An official report was never written stating the excavation methods used at Tranquility Farm, but the methods appear to be similar to those described in a report written about the Jones Cove Site which was excavated by the same people in 1927. An account of their methods is as follows:

> Digging was begun at the thin edge of the shells nearest the shore and gradually carried up the slope into deeper material. The numerous diggers were spaced several feet apart, and the pits they dug soon uniting formed a long trench, the dirt being shoveled behind them. Thus a perpendicular face of the shell-heap was always exposed from top to bottom. The material looked rather loose but did not crumble as it was pretty well dovetailed together.
>
> After the trench was started, digging was practically done from the bottom up—understoping, miners would term it. Small trowels and hand garden weeders were used for loosening this ancient debris, particular care being exercised where worked objects showed in the trench face. A tough, heavy sod covered the top of the shells and was broken off in chunks as it became undermined (Abbe Museum Staff n.d.).

After these excavations in the 1930s, no additional excavations were carried out for several decades. In 1994, the Abbe returned to the site under the guidance of Rebecca Cole-Will to complete shovel testing and evaluate the site's condition. Shovel testing showed that there were undisturbed portions of the shell midden, but unfortunately other portions of the midden were badly eroding along the bank (Cole-Will 1994). With the discovery of undisturbed portions and the knowledge that the site was being lost, the Abbe Museum decided to renew excavation efforts at the site by implementing a field school in 1995. During this field school, fifteen 1 m by 1 m units were excavated, and several important discoveries were made. The area excavated was dated to the Middle to Late Ceramic period based on diagnostic stone tools and pottery, and a radiocarbon date from a hearth feature dated to 1,240±70 (no lab number identified) (Abbe Museum Staff n.d.). Plant remains were also collected from the hearth feature fill which later were identified by ethnobotanist Nancy Asch Sidell as beechnut shell, seeds of raspberry, Chenopodium, smartweed, wild rye, dewberry, grasses, and wood charcoal from maple, birch, beech, ash, pine, and red oak. The hearth feature was surrounded by a house floor traceable for several meters (Abbe Museum Staff n.d.).

In 1998, another field school was hosted at Tranquility Farm resulting in another fifteen 1 m by 1 m units excavated. These units focused around the edges of the house floor and in one of the units a post mold was uncovered measuring roughly 15 cm across and 18 cm deep, with a rounded bottom and filled with "greasy" material, charcoal, and pebbles. A second hearth feature was also excavated which yielded a concentration of rocker-dentate decorated ceramics. These ceramics have not been assessed to determine where they fit into Maine's chronology of aboriginal ceramics. After this excavation, work at Tranquility Farm was set aside until

Figure 10. Simple bone points from the Tranquility Farm site (Abbe Museum Collection)

2010. From 2010 to 2015 the Abbe hosted its annual field school at the site. These excavations produced a large amount of data that are still being processed.

For my undergraduate honors thesis at Franklin Pierce University, I analyzed a collection of faunal remains collected during the excavations at the Tranquility Farm site. Dr. Arthur Spiess and I identified faunal species from a sample of 431 animal bones and determined if any of the identified species were indicative of a particular season. The remains of the extinct great auk (*Pinguinus impennis*) and sea mink (*Neovison macrodon*) were present in the identified sample and represent species hunted to extinction after European colonization of Maine. All of the extant species identified in this sample represent year-round resources indicating that Tranquility Farm was either occupied throughout the year or that further research was required to better answer this question of site seasonality.

Chapter 3

METHODS

Analysis of the oxygen isotopic composition ($\delta^{18}O$) in calcium carbonate shell material offers a unique glimpse into past environmental conditions by serving as a proxy for water temperature and the oxygen isotopic composition of water ($\delta^{18}O_w$; related to salinity); as temperature and salinity of the water fluctuate throughout the year, so does the value of $\delta^{18}O$ within the composition of the mollusk's shell (Leng & Lewis 2016). Because mollusks build their shells from seawater the isotopic composition of the shell material reflects both seawater temperature and its isotopic composition at formation (Epstein et al. 1953). Often, mollusks produce their calcite or aragonitic shells in visible bands (MacDonald & Thomas 1980) therefore they are good candidates for $\delta^{18}O$ analysis.

In this study, the outermost growth increment from the mollusk shell and/or chondrophore was sampled to capture the $\delta^{18}O$ values preserved in the calcium carbonate from the mollusk's last growth sequence. The Stable Isotope Lab at Iowa State University performed this analysis under the direction of Dr. Alan Wanamaker. In the following sections, I will discuss the collection and laboratory processing methods for the modern and archaeological shells and the modern water samples.

Mollusk Collection

Oxygen isotope ($\delta^{18}O$) analysis of calcium carbonate from mollusk shells is a method used to reconstruct water temperatures. However, the $\delta^{18}O$ of a shell reflects both the seawater temperature and $\delta^{18}O_w$ while the shell was precipitating calcium carbonate (Epstein et al. 1953; Grossman & Ku 1986; Leng & Lewis 2016). This section provides an overview of how modern and archaeological shell samples were obtained for this study, and their locations, times, depths, and sample sizes. The mode of collection for the modern samples of *Mya arenaria* remained consistent throughout the duration of the one-year collection interval; the mode of collection for the archaeological samples was through excavation, which varied in technique across the different excavations.

Archaeological Shell Lab Selection

The archaeological shell samples came from excavations at the Tranquility Farm site by the Abbe Museum Field School between 2010 and 2015. Each field season, 1 m by 1 m units were excavated in 10 cm layers within natural strata. The resulting materials were screened through ¼ in hardware cloth and any cultural materials such as stone tools, pottery, and animal bones were bagged according to their unique site provenience. Approximately ten shells or shell fragments were collected from each quadrant layer in the excavation units, but this is not a representative sample of the midden. When possible, entire shells were collected, but the majority of the shells collected were the hard hinge fragments called the chondrophore. While some whole shells with the intact outer growing margins were saved, the majority of the shells sample in the collection only represent the chondrophore (Spiess 2012; Spiess n.d.).

Collecting methods for shells at Tranquility Farm changed over time. During the first excavations in the 1900s, shells were not collected so these early data could not be used in this study. Excavations during the mid-2000s produced collections of several shells and/or chondrophores for each layer/level and quadrant. This collection resulted in hundreds of shell samples from many locations throughout the site. For this thesis project, shells were selected that were in the same test unit and layer/level as another dateable object or material (e.g., decorated pottery, diagnostic stone projectile points, or a soil sample) (spatial distribution of units displayed in Figure 11). Once shells were selected based on their location characteristics, they were examined individually and selected based on their state of preservation. Shells with an intact chondrophore and ideally an intact outer growing margin were sampled.

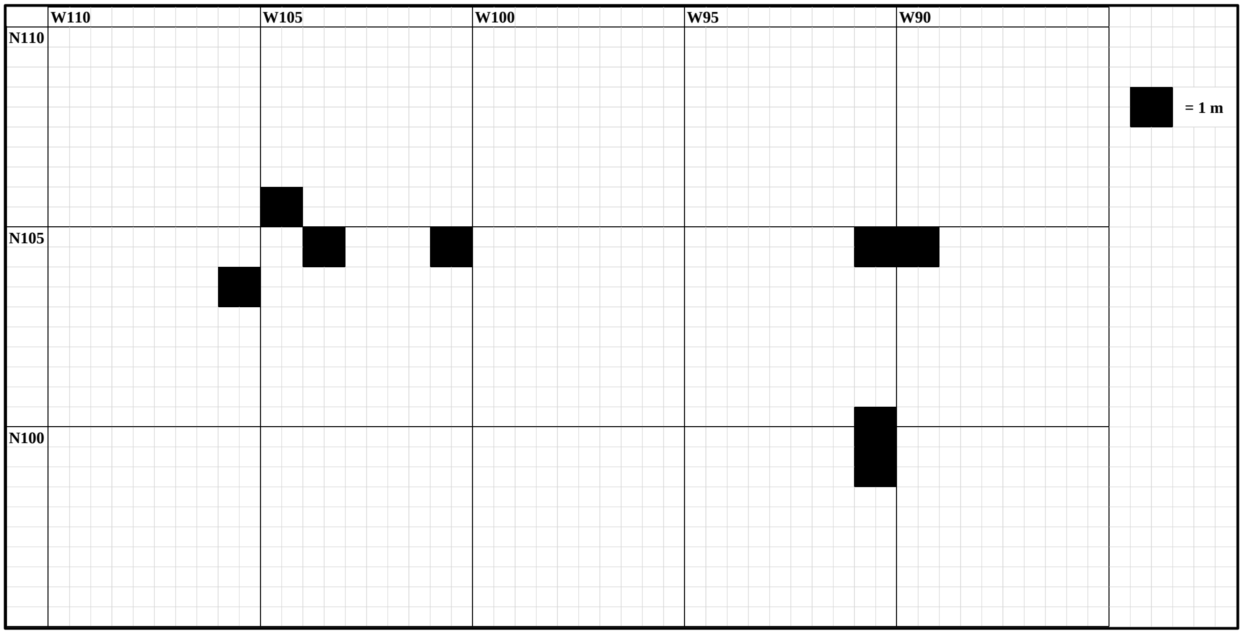

Figure 11. Site map showing units with shells selected for sampling

Modern Shell

The modern collection of shells was assembled in collaboration with fellow University of Maine graduate student Emily Blackwood. Blackwood's thesis research parallels my own but focuses on different sites in Gouldsboro and Machias, Maine. One year (twelve months) of monthly modern samples were collected from mudflats in Jones Cove, near the Tranquility Farm site, to create a comparative oxygen isotope baseline. This baseline was used to compare with the archaeological shell data set to determine when the site was in use. Before each monthly collection, the local Maine Department of Inland Fisheries and Wildlife Game Warden was contacted to obtain permission to collect the samples and to ensure that there were no prohibitory circumstances at the time (e.g., red tide).

Ten to fifteen samples were collected once a month throughout a calendar year. The sample size was chosen to account for potential breakage during transportation and shell preparation and to ensure that enough samples were collected for this study and future work. For the analyses to account for the varying clam sizes seen in the archaeological shell collection, we collected variously sized clams in our modern sample. In the state of Maine, a soft-shell clam must be two inches in size to be harvested, setting a minimum size limit on the collection for this study (Department of Marine Resources 2016). The months of February, March, and October could not be used in this study due to too much sea-ice during the winter months and a red tide closure during the fall.

Once collected, the soft tissues from the shells were removed in two ways. For shells collected during the month of June, soft tissues were removed before leaving the shells to air dry, while those collected during the other eight months were steamed in fresh tap water making the soft tissues easier to remove. These shells were then also air dried. In order to address if cleaning the shells by cooking them in fresh water would alter the isotopic values, ten additional mollusks were collected from Jones Cove. Five of the resulting shells were cleaned by steaming them in fresh water while the other five were cleaned out while raw, rinsed in seawater, and left to dry for several weeks. The results of this test and the implications for the study are addressed below in the results and discussion section.

Modern and Archaeological Shell Laboratory Processing

Emily Blackwood and I continued our collaboration throughout this stage of research. In order to learn the processing methodology, the first set of shell micro mill samples were taken at the Stable Isotope Lab at Iowa State University micro mill lab where Dr. Alan Wanamaker provided guidance for processing methodology. After learning the sampling techniques, additional shells were sampled in Maine at the University of Maine's Archaeology Lab and at the Pontbriand house in Gouldsboro, ME. Before sampling, shells were rinsed with tap water, brushed clean of remaining organic materials, and examined for certain characteristics of their anatomy. For a shell to be selected for sampling analysis, it had to meet one or more of the following criteria:

- Intact outer growing margin – shells that have an intact outer growing margin (no visible damage) are good for assessing the season of harvest, as this is the last increment of growth before death (Figure 12 b).
- Intact chondrophore – the chondrophore accumulates sequential growth matter, like the outer growing margin of the shell, but at a much slower rate; they are naturally tougher than the outer growing margin of the shell and also represent the final increment of growth (Figure 12 a).
- Inter-annual growth increments – these increments can be seen from the umbo to the ventral margin of a shell. Within these increments, annual (yearly) growth lines are distinguishable by size and color; these increments are used to analyze an entire year of growth within a shell (Figure 12 a&b).

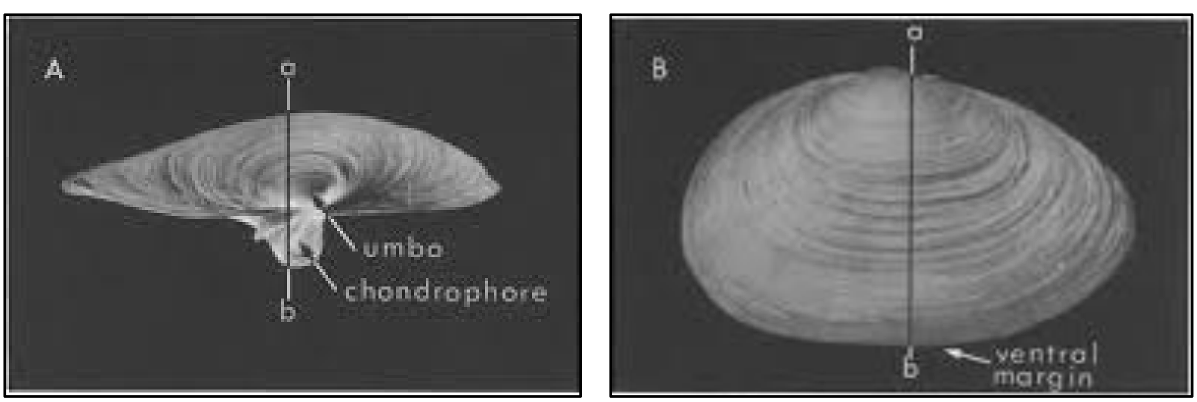

Figure 12. *Mya arenaria* shell anatomy from MacDonald and Thomas (1980)

Within the shells selected for analysis, when possible, the outer growing margin of the shell and the outer edge of the chondrophore from the same valve were sampled. This technique allowed for a comparison between the chondrophore and outer growing margin values obtained from the same organism. Of the three shells selected per level of each unit, one was also selected for interannual growth increment analysis. Within the organism's first seven years of growth the annual growth bands are clearest (MacDonald & Thomas 1980). To ensure a clearly identifiable year was sampled, either the third or fourth year of growth, as judged by the external growth bands, was chosen for sampling. Between five and eight holes were drilled from the beginning of the growth year (designated by a dark band) towards the outer growing margin to the end of the next beginning of growth (another dark band). Given that both modern and excavated shells were used, many of the sampling methods were applied to both collections but occasionally had to be modified if the sample did not contain the necessary elements. For example, some shells met two of the three criteria but due to deterioration of archaeological shell samples in some levels, some levels only had the chondrophore and outer growing margin milled.

A Dremel tool was used to drill into the shell in order to collect samples for analysis. Analysis of calcium carbonate requires such a small amount of material that this tool is an effective instrument of collection. Two different styles of dental bits were used on the Dremel 300 and 3000, a Brasseler USA's 845.11.010 HP Medium Flat End Cylinder Diamond and a Brasseler USA's 801.11.010 HP Medium Round Diamond (Brasseler n.d.). The general steps for completing a sample are as follows:

- Select shells to be drilled
- Record contextual information for data spreadsheet
- Create a sequence of sample vials and label accordingly
- Assess shell for the viability of data collection (see criteria above)
- Use Dremel on lowest speed to ensure that the carbonate sample is not heated, which may potentially alter the isotopic composition

- Mill desired portion of shell over a glass plate
- Collect 0.20-0.40 mg of powder
- Use a razor blade to scrape amount into the glass vial
- Label vial
- Clean the razor blade and glass plate with alcohol to reduce the risk of contamination

<u>Outer Growing Margin</u>

A sample from the outer growing margin was collected using the Brasseler USA's 845.11.010 HP Medium Flat End Cylinder Diamond drill bit. This drill bit is designed to mill very fine sections of the shell ensuring that only one year's worth of growth was collected for testing. The area was assessed for damage and then milled using the Dremel tool on lowest speed in a long, sweeping motion along the length of the shells edge. This technique ensures that only the final growth sections are milled, creating the purest sample this method can allow.

<u>Chondrophore</u>

Milling of the chondrophore followed a similar procedure to the outer growing margin of the shell. Each chondrophore was inspected closely for damage before milling; because the growth increments on this section of the shell are much finer than those of the outer growing margin, this inspection is particularly important for creating a clean sample. Again, using the Brasseler USA's Medium Flat End Cylinder drill bit on a low setting to prevent shell breakage, the Dremel tool was run along as much of the intact sections as possible to gather enough of a sample to analyze.

Figure 13. Chondrophore

Interannual

Drilling the interannual samples varied from the chondrophore and outer growing margin samples. A Brasseler USA's 801.11.010 HP Medium Round Diamond was used to obtain eight consecutive drilling locations throughout one year's growth sequence. The purpose of this procedure was to analyze data throughout a single year of growth within a shell (growth lines are likely deposited monthly) to compare these data to the chondrophore and outer growing margin samples taken from the shells of the same sample group.

Figure 14. Interannual samples indicated with red arrow

Mechanical Processing

A mass spectrometer was used to measure shell $\delta^{18}O$ within each shell sample. The Stable Isotope Lab at Iowa State University uses a ThermoFinnigan Delta Plus XL mass spectrometer attached to a GasBench II with a CombiPal autosampler. This setup produces a long-term precision of ±0.09‰ (1 std dev) for $\delta^{18}O$ (ISU Stable Isotope Lab 2018). International reference standards (NBS-18, NBS-19) were used for isotopic corrections, and to assign the data to the appropriate isotopic scale. Corrections were done using a regression method and isotope results are reported in parts per thousand (per mil, ‰). All the reported $\delta^{18}O$ values were returned via Microsoft Office Excel sheets.

Water Collection and Processing

Samples of marine water were collected from the Jones Cove mudflat in Gouldsboro. This location was used to complement the modern shells collected from the Jones Cove mudflat. The Jones Cove mudflat is in the same tidal bay as Tranquility Farm and also has a freshwater stream emptying into the cove, so it was determined to be a comparable location. Twenty-four water samples were collected over twenty-four consecutive hours starting at 12 pm on September 8, 2017, and ending at 11 am on September 9, 2017. Collecting these samples shows the environmental conditions under which the modern samples grew. Because water samples were not collected alongside the modern shell collections, these samples are not representative of the changes throughout the year in water temperature and oxygen isotopes (Whitney et al. 2017). However, they do capture the variations during several tidal cycles.

Using 50ml sterile plastic vials, a sample of water was collected every hour on the hour for twenty-four consecutive hours in the shallow water close to shore. During this collection, water was collected as far away from freshwater inlets as possible and areas with high sedimentation were avoided. Each vial was filled and rinsed with marine water before being completely submerged in the water where the cap was secured underwater to ensure the purest and fullest sample. Following collection, each vial was labeled with the location, date, and hour of collection. The sample information was recorded in a Microsoft Excel file and all samples stored in a refrigerator to prevent evaporation.

The Iowa State University Stable Isotope Lab was also used to process and prepare these water samples. To prepare our water samples for the machine, we used an Eppendorf pipette with adjustable volume 500-2500Vl to siphon approximately 2 mL of water into a 2 mL vial. This process was repeated for a total of twenty-four water samples. A Picarro L2130-i Isotopic

Liquid Water Analyzer with autosampler and ChemCorrect software was used to test these water samples. Each sample was measured six times with only the last three injections being used to calculate the mean isotopic values to account for memory effects. For every five samples, at least one reference sample (VSMOW2, USGS 48, USGS 47) was used to assign the data to an appropriate isotopic scale and for regression-based isotopic correction. The average isotopic precision was ± 0.07‰ (VSMOW). Each water sample was also tested for its salinity levels using a Vernier LabQuest ll with a chloride sensor.

Chapter 4

RESULTS

In this section, I will review the results of the archaeological shell collection, modern shell collection, and the water samples. The $\delta^{18}O$ values are displayed in parts per thousand (per mil or ‰).

Modern Shells

Modern shells collected during nine different months were analyzed to create a comparative sample for this study. The months of February, March, and October were not included because of unfavorable weather conditions (i.e., too much ice to collect, February, March) or a ban on collecting prevented clams from being harvested (October).

Outer Growing Margin

The outer edges of the modern shells were sampled to create a sequence of data showing the different shell $\delta^{18}O$ values throughout a calendar year. Of the ten to fifteen samples collected for each month, between five and six shells per month were sampled for this analysis, leading to a total of fifty-one shells sampled. This number was then reduced to total forty-six samples after outliers were identified and removed from the data set. Outliers were identified using the box and whisker plot function in Microsoft Excel. These shells were processed through the Mass Spectrometer in different "runs" leading to different analytical uncertainty for each sample. The average analytical uncertainty for each month's samples is displayed in Table 2. Averages and ranges were also calculated for each month. These data will make it easier to compare the archaeological shells, modern chondrophores, and water samples against the modern monthly outer growing margin data.

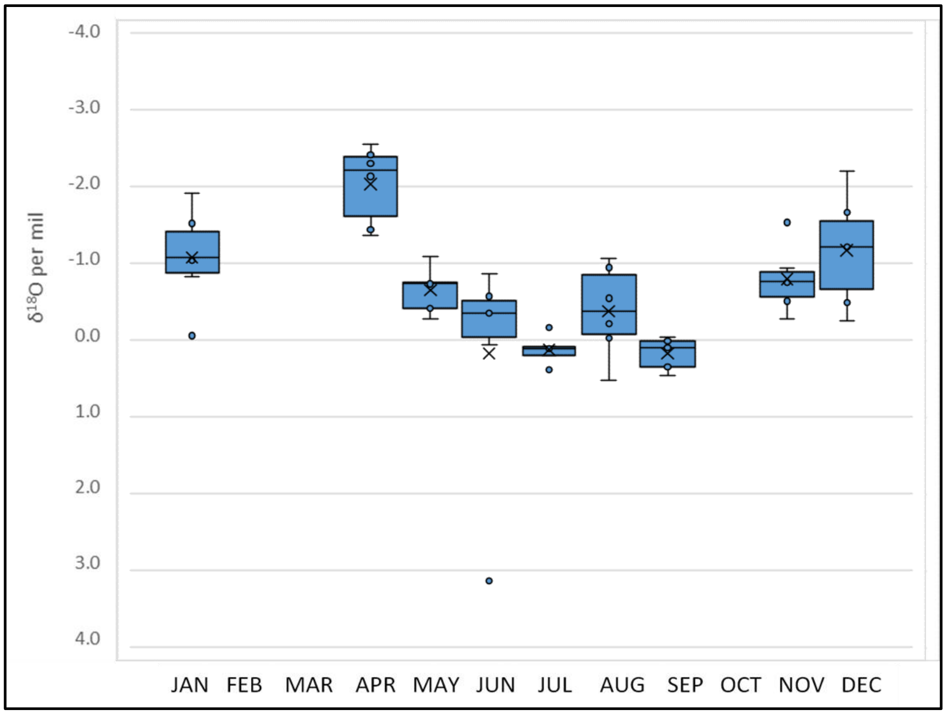

Figure 15. Box and whisker plot displaying the shells from the modern monthly samples

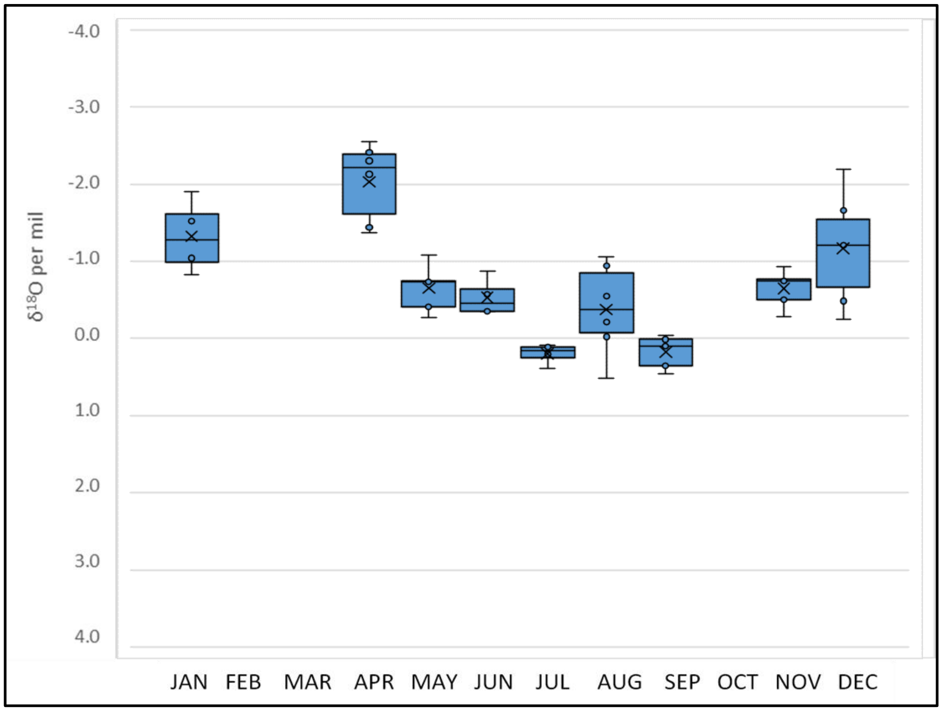

Figure 16. Box and whisker plot, **excluding** the outliers, displaying the shells from the modern monthly samples

Figure 15 shows all the modern monthly data including outliers. The monthly data (outliers removed) displayed in Figure 16 indicates several things about the growth cycles of the sampled soft-shell clams. In both figures, the “x” axis displays the month in which the shells were collected while the “y” axis shows the shell $\delta^{18}O$ values in per mil. Even with the outliers removed from the dataset, there is still a lot of variability within each monthly collection. Figure 16 shows that the months of June, July, September, and November represent the months that have the least amount of variation, with ranges of less than 0.75 per mil. Others, such as August and December, represent months with sample ranges above 1.5 per mil. By referencing Figure 16, we can see that the range of values for December is so broad it covers the same range of values seen in all the other months except June, August, and September.

Even with this inter-month variation, we still can see some clear patterns in terms of seasonal variation are apparent. Since these shells were collected in a climatic zone in which the temperature varies drastically from summer to winter, we would expect to see this seasonal temperature oscillation reflected in the shell’s oxygen isotopic values. Even with the wide ranges within several of the months, we do see a trend of colder values from the shells collected during winter to early spring, warmer values in the late spring to early fall, and a return to cooler values in the late fall to winter. These data combined with the water samples (discussed below) show that the modern collected shells are a reasonable proxy for the observed ocean temperatures.

	January	*February*	*March*	*April*
Mean	1.279	No data collected	No data collected	2.034
Median	1.098			2.218
Range	1.084			1.181
Minimum	0.826			1.367
Maximum	1.910			2.548
Average Analytical Uncertainty	± 0.074‰ (VPDB)			± 0.095‰ (VPDB)
Standard Deviation	0.433			0.508
Number of Outliers	1			0
Total After Outliers Removed	5			6
	May	*June*	*July*	*August*
Mean	0.652	0.535	-0.197	0.379
Median	0.733	0.461	-0.155	0.381
Range	0.810	0.521	0.300	1.583
Minimum	0.276	0.348	-0.390	-0.519
Maximum	1.086	0.869	-0.090	1.065
Average Analytical Uncertainty	± 0.104‰ (VPDB)	± 0.113‰ (VPDB)	± 0.08‰ (VPDB)	± 0.125‰ (VPDB)
Standard Deviation	0.318	0.246	0.137	0.596
Number of Outliers	0	2	1	0
Total After Outliers Removed	5	4	4	6
	September	*October*	*November*	*December*
Mean	-0.177	No data collected	0.647	1.170
Median	-0.100		0.747	1.215
Range	0.497		0.656	1.954
Minimum	-0.459		0.279	0.246
Maximum	0.038		0.936	2.200
Average Analytical Uncertainty	± 0.126‰ (VPDB)		±0.180‰ (VPDB)	± 0.085‰ (VPDB)
Standard Deviation	0.218		0.257	0.725
Number of Outliers	0		1	0
Total After Outliers Removed	5		5	6

Table 2. Modern shell outer growing margin $\delta^{18}O$ descriptive statistics

Chondrophore

The chondrophore makes up a part of the clam hinge and is located on just one valve of the bivalve. This portion of the shell is much harder than the rest of the shell and is formed by very condensed mineral deposits. For the modern shells, one chondrophore from each monthly collection was sampled leading to a sample size of nine shells. Figure 17 graphs the values for each sampled chondrophore (in orange) by month and shell $\delta^{18}O$ value alongside the outer growing margin values (in blue) from the same shell. As with the outer growing margin described above, we would expect to see a seasonal oscillation from cold associated values in the winter to warm associated values in the summer. The values displayed in the chondrophore graph do reflect a seasonal temperature oscillation.

While the chondrophore data reflect a seasonal temperature oscillation, because only one chondrophore per month was sampled there was some uncertainty about how accurately the chondrophore recorded the water temperature as compared with the outer growing margins. In theory, chondrophore and outer growing margin samples taken from the same shells should display similar shell $\delta^{18}O$ values. To test whether chondrophores accurately record temperature, the outer growing margins and chondrophore were sampled from the same valve of the mollusk (Figure 17). Figure 18 shows the chondrophore values (orange) and the monthly means for the outer growing margin values (blue), with error bars of 2 Standard Deviations on either side of the mean. While the chondrophore and outer growing margin follow the same trend lines and the chondrophore values always fell within the two-sigma range of the growing margin values, in several instances the values displayed in a month are drastically different. For example, the chondrophore value for May is 1.7105 per mil while the outer growing margin measurement of the same shell is 0.4129. May is the most drastic example of this disparity, but August, November, and December also display very different values.

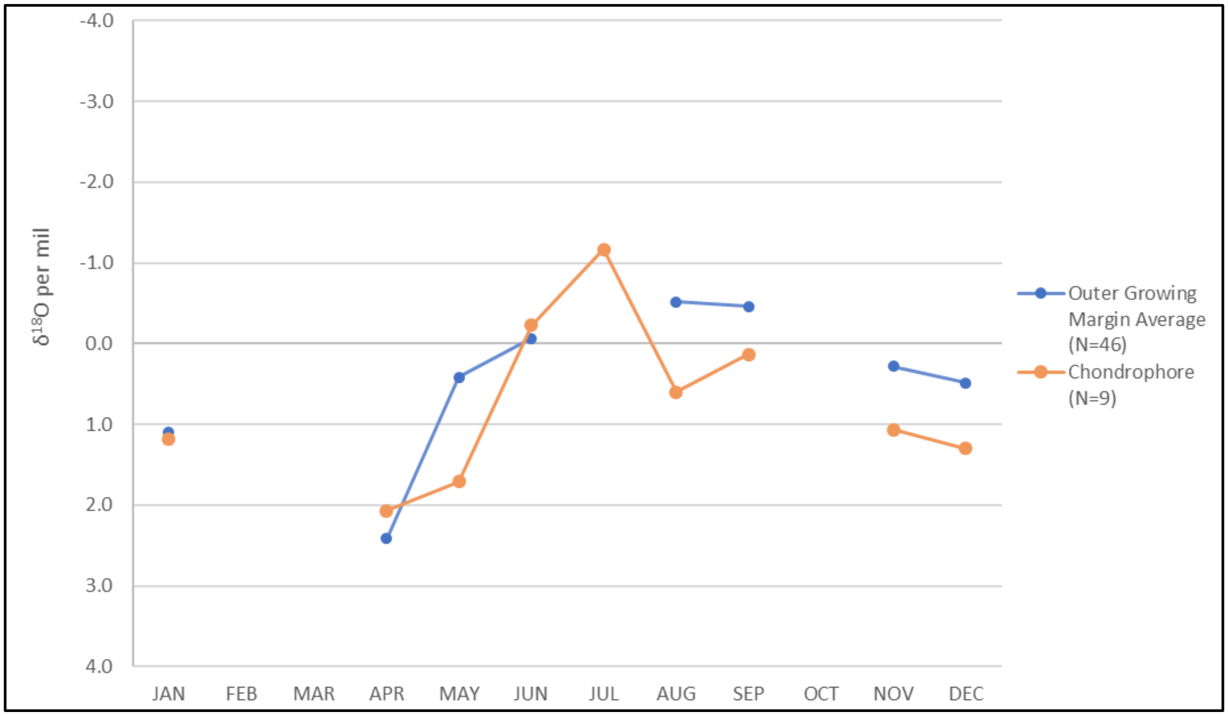

Figure 17. Modern chondrophore samples (orange) and modern outer growing margin from the same shells (blue)

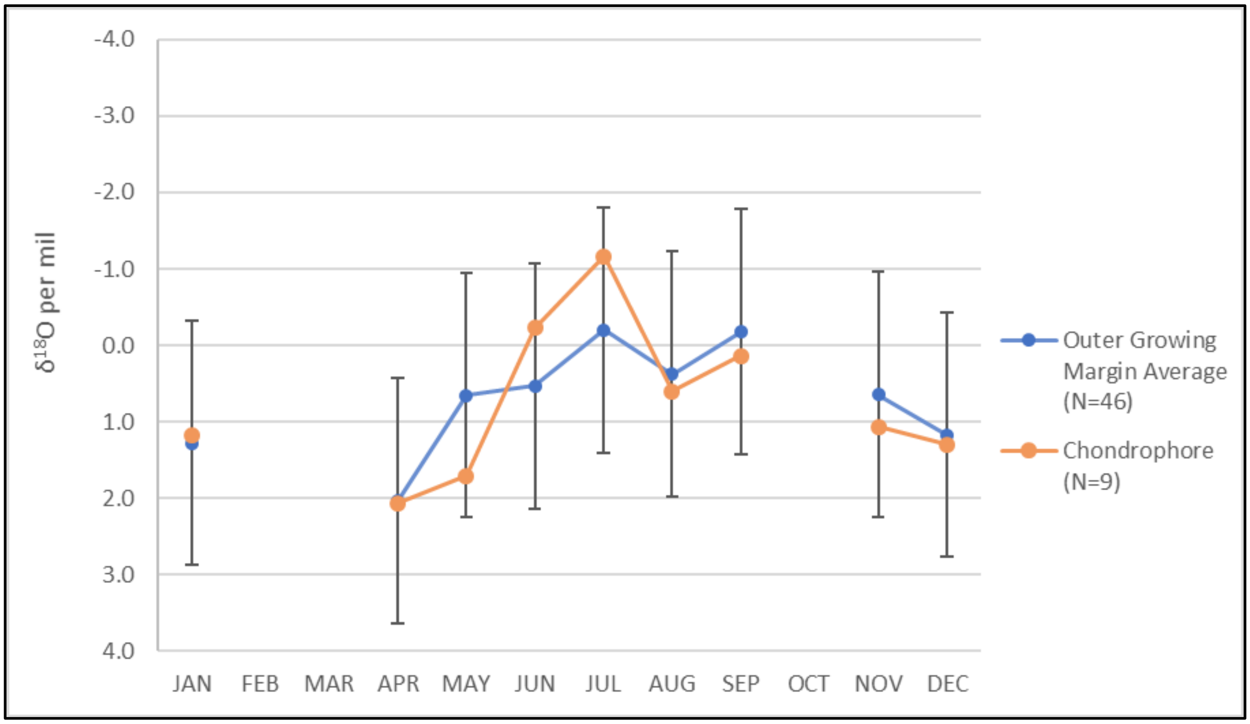

Figure 18. Comparison of chondrophore values per month and monthly outer growing margin average with error bars displaying 2 Standard Deviations

Archaeological Shells

The Tranquility Farm archaeological shells were sampled in three locations: the outer growing margin, the chondrophore, and an interannual sequence. The interannual sequences were not examined as part of this project but are available for reference. On several occasions, a sample shell possessed both an intact outer growing margin and chondrophore, allowing for a comparison between the isotopic values from each portion of the shell.

<u>Outer Growing Margin</u>

The outer growing margin of the archaeological shells was challenging to find given the various levels of preservation among the archived shells. Only shells with a clear final growth increment were selected for sampling. A total of ten archaeological shells from five different excavation units throughout the site at depths ranging from 20-45 cm below the surface were selected for sampling. The shell $\delta^{18}O$ values from the outer growing margin of these shells ranged from 0.0812 to 2.1247 per mil with an average analytical uncertainty (AU) of ± 0.113 (Vienna Pee Dee Belemnite (VPDB).

Archaeological Outer Edge Statistics	
Mean	1.1119
Median	1.1240
Standard Deviation	0.6019
Range	2.0436
Minimum	0.0812
Maximum	2.1247
Count	10

Table 3. $\delta^{18}O$ statistics from archaeological shells with an intact outer growing margin

Study ID	$\delta^{18}O$	AU	Unit	Quad	Level	Below Surface (cm)
TF_0001	**0.081**	± 0.12 (VPDB)	N105 W91	NW	9	69
TF_0017	**1.203**	± 0.11 (VPDB)	N99.5 W92	NW	3	20-30
TF_0026	**1.340**	± 0.11 (VPDB)	N99.5 W92	NW	3	20-30
TF_0027	**0.695**	± 0.11 (VPDB)	N99.5 W92	NW	3	20-30
TF_0028	**1.285**	± 0.11 (VPDB)	N100.5 W92	SW	4	35-40
TF_0034	**0.528**	± 0.11 (VPDB)	N100.5 W92	SW	4	35-40
TF_0036	**1.045**	± 0.11 (VPDB)	N100.5 W92	SW	4	35-40
TF_0044	**0.969**	± 0.11 (VPDB)	N104 W106	NW	8	40-45
TF_0049	**1.848**	± 0.11 (VPDB)	N105 W101	SW	3	25-30
TF_0058	**2.125**	± 0.13 (VPDB)	N105 W101	SW	3	25-30

Table 4. List of archaeological outer growing margin data samples, $\delta^{18}O$ values, and provenience

<u>Chondrophore</u>

At the Tranquility Farm site, chondrophores were preferentially preserved over the whole shells with an intact outer growing margin. Chondrophores were saved over whole shells because there were relatively few intact whole shells and chondrophores are more durable than the outer growing margins. This led to a larger sample size for chondrophores, which have the same growth increments as the full portion of the shell but are more condensed. Thirteen shell chondrophores were sampled from eight different excavation units throughout the site at depths ranging from 25-69 cm below surface. The shell $\delta^{18}O$ values from these shells ranged from 0.1181 to 1.8127 per mil with an average analytical uncertainty (AU) of ± 0.117 (VPDB).

Archaeological Chondrophore Statistics	
Mean	0.6918
Median	0.6472
Standard Deviation	0.4816
Range	1.6946
Minimum	0.1181
Maximum	1.8128
Count	13

Table 5. $\delta^{18}O$ statistics from archaeological chondrophores

Study ID	$\delta^{18}O$	AU	Unit	Quad	Level	Below Surface (cm)
TF_0035	0.815	± 0.11 (VPDB)	N100.5 W92	SW	4	35-40
TF_0037	0.617	± 0.11 (VPDB)	N104 W106	NW	8	40-45
TF_0043	0.783	± 0.11 (VPDB)	N104 W106	NW	8	40-45
TF_0048	1.379	± 0.11 (VPDB)	N105 W101	SW	3	20-25
TF_0059	0.284	± 0.13 (VPDB)	N105 W101	SW	3	25-30
TF_0060	0.318	± 0.13 (VPDB)	N105 W104	SE	3	20-30
TF_0061	0.647	± 0.13 (VPDB)	N105 W104	SE	3	20-30
TF_0045	0.653	± 0.11 (VPDB)	N105 W90	SE	4	no record
TF_0046	0.147	± 0.11 (VPDB)	N105 W90	SE	4	no record
TF_0047	1.813	± 0.11 (VPDB)	N105 W90	SE	4	no record
TF_0010	0.118	± 0.12 (VPDB)	N105 W91	NE	8	50-55
TF_0011	0.499	± 0.12 (VPDB)	N105 W91	NE	8	50-55
TF_0062	0.921	± 0.13 (VPDB)	N106 W105	SW	4	30-40

Table 6. List of archaeological chondrophore data samples, $\delta^{18}O$ values, and provenience

Provenience of Shells

The archaeological shells used in this thesis were selected based on their orientation to other datable objects (i.e. soil sample, decorated pottery) and the quality of the shell. The shells were collected from four different soil layers ranging from 20-69 cm below surface within nine different units. The vertical distribution of shells and their associated $\delta^{18}O$ values does not show any relationship between location and seasonality determination.

Comparison

After establishing the modern shell $\delta^{18}O$ ranges for the outer growing margins sampled from each month, the archaeological outer growing margin and chondrophore $\delta^{18}O$ values were then placed within the monthly modern ranges. Table 7 and Table 8 display the modern monthly ranges on the y-axis and the archaeological $\delta^{18}O$ value and shell ID on the x-axis. When an archaeological shell $\delta^{18}O$ value fell within the modern monthly range, an "X" was placed in the shell's column and the corresponding modern monthly range row. In many cases, an archaeological sample fell in more than one modern range, leading to more than one "X" in an archaeological shell's column. The total number of "X"'s per month is listed in the column on the far right of the figures.

Table 7 displays the total of ten archaeological shell outer growing margins sampled for this study compared to the modern monthly outer growing margin ranges. As noted by the "Total" column, more than half of the archaeological outer growing margin shells fell within the January and December value ranges. The July and September monthly ranges did not have any archaeological shells with comparable values. The other months have between two and four shells falling within their ranges. These data suggest that the archaeological mollusks recovered from Tranquility Farm were probably collected during seasons with cooler water temperatures such as late fall, winter, and early spring. These data will be discussed more fully in Chapter 5.

Table 8 displays where the thirteen archaeological chondrophore samples fall within the modern outer growing margin range. As discussed above, even though the samples are coming from two different parts of the shell, they are both measuring the last growing margin but simply from different portions on the shells. These data are comparable as shown in Figure 18 where the modern chondrophores fall within 2 Standard Deviations of the modern outer growing margin means, but there are still discrepancies between the measurements from these two locations on the shells. Even with these discrepancies, these data are comparable and the results are displayed in the same manner as the outer growing margins above. Once again, the archaeological values primarily fall within the November and December ranges. The months of May and August also represent a high number of archaeological matches. While August appears to have the majority of the archaeological matches, there are some explanations for this apparent over-representation which will be discussed in Chapter 5. As with the outer growing margin comparison above, the months of July and September do not display any archaeological matches.

			Tranquility Farm Archaeological Study ID - Outer Growing Margins										Totals
			TF_0001	TF_0017	TF_0026	TF_0027	TF_0028	TF_0034	TF_0036	TF_0044	TF_0049	TF_0058	10
		δ18O per mil	**0.081**	**1.203**	**1.340**	**0.695**	**1.285**	**0.528**	**1.045**	**0.969**	**1.848**	**2.125**	
Modern Monthly Sample Ranges	JAN	0.826 to 1.910		X	X		X		X	X	X		6
	FEB	No data											
	MAR	No data											
	APR	1.367 to 2.548			X						X	X	3
	MAY	0.276 to 1.086				X		X	X	X			4
	JUN	0.348 to 0.869				X		X					2
	JUL	(-)0.390 to -0.090											
	AUG	(-)0.519 to 1.065	X			X		X	X				4
	SEP	(-)0.459 to 0.038											1
	OCT	No data											
	NOV	0.279 to 0.936				X		X					2
	DEC	0.246 to 2.200		X	X	X	X	X	X	X	X	X	9

Table 7. The data displayed in this table shows where each archaeological outer growing margin $\delta^{18}O$ values falls within the modern outer growing margin $\delta^{18}O$ ranges

			Tranquility Farm Archaeological Study ID - Chondrophores													Totals
			TF 0035	TF 0037	TF 0043	TF 0048	TF 0059	TF 0060	TF 0061	TF 0045	TF 0046	TF 0047	TF 0010	TF 0011	TF 0062	13
		δ18O per mil	**0.815**	**0.617**	**0.783**	**1.379**	**0.284**	**0.318**	**0.647**	**0.653**	**0.147**	**1.813**	**0.118**	**0.499**	**0.921**	
Modern Monthly Sample Ranges	JAN	0.826 to 1.910				X						X			X	3
	FEB	No data														
	MAR	No data														
	APR	1.367 to 2.548				X						X				2
	MAY	0.276 to 1.086	X	X	X		X	X	X	X				X	X	9
	JUN	0.348 to 0.869	X	X	X				X	X				X		6
	JUL	(-)0.390 to -0.090														0
	AUG	(-)0.519 to 1.065	X	X	X		X	X	X	X	X		X	X	X	11
	SEP	(-)0.459 to 0.038														0
	OCT	No data														
	NOV	0.279 to 0.936	X	X	X		X	X	X	X				X	X	9
	DEC	0.246 to 2.200	X	X	X	X	X	X	X	X		X		X	X	11

Table 8. These data displayed in this table shows where each archaeological chondrophore $\delta^{18}O$ values falls within the modern outer growing margin $\delta^{18}O$ ranges

Water Samples

To complement the modern shell collection from Jones Cove, twenty-four water samples were collected over the course of twenty-four hours from Jones Cove in Gouldsboro. These samples were collected to create a profile of shell $\delta^{18}O$ values from the seawater throughout a tidal cycle. The samples were collected in lieu of collecting water samples at the same time as the shell collection throughout the year. By using a modified Grossman & Ku (1986) equation, the $\delta^{18}O$ from the modern collected shells and the $\delta^{18}O$ from the twenty-four hours of water samples can be used to approximate the actual temperature in degrees C. The formula was modified for such a use and is as follows (Dettman et al. 1999; Wanamaker & Gillikin 2018):

$$T\ (°C) = 20.60 - 4.34 * (\delta^{18}O_{aragonite} - (\delta^{18}O_{water} - 0.27))$$

By applying this formula to the data collected for this study, an approximation of the actual water temperature at the time of the mollusks collection could be ascertained. To test the accuracy of these results, they were plotted alongside the actual measured sea surface temperature monthly averages as recorded by the NOAA. The temperatures in the figure below were recorded at the NOAA buoy in Bar Harbor, ME which is the closest buoy to Jones Cove in Gouldsboro, ME (NOAA, 2018). The sample data (displayed in orange) follow the same trend line as the actual temperature in blue. The months of January and August deviate from the actual averages with the observed January temperature being warmer and the observed August temperature being cooler. The other sampled months are generally less than 2 degrees cooler than the observed temperatures.

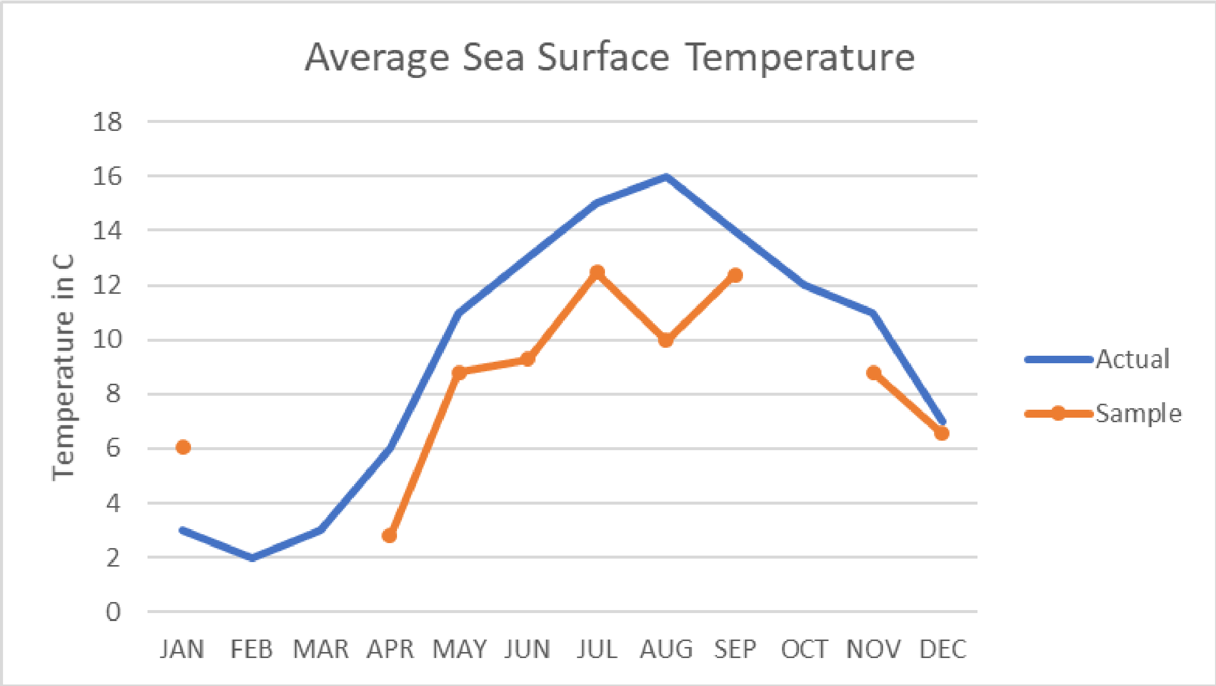

Figure 19. Comparison of the Grossman and Ku derived sample data (orange) and actual average water temperature from Bar Harbor NOAA buoy (blue)

Chapter 5

DISCUSSION

While other studies have been conducted throughout New England and the Canadian Maritimes to determine seasonal movement and subsistence patterns of Native people throughout the region, no published studies have utilized oxygen isotopes from shell middens (Sanger 1982; Belcher 1990; Bourque 1995; Spiess & Lewis 2001). This study attempted to use this technique to determine the season of occupation at the Tranquility Farm shell midden in Gouldsboro, ME. Definitively knowing the season of occupation at archaeological shell middens along the entirety of the coast of Maine contributes to the understanding of the past function of these midden sites as well as the subsistence and settlement patterns of the people who occupied them. This study seeks to establish not only a season of occupation at Tranquility Farm but also to assess the utility of using oxygen isotopes in such determinations.

Results

Seasonality Indicator

In this study, modern shells were collected throughout a calendar year to form a modern baseline of $\delta^{18}O$ values from *Mya arenaria* shells. This modern baseline provided modern $\delta^{18}O$ ranges for each month into which the archaeological shell $\delta^{18}O$ values were placed. After the shells were placed in their appropriate ranges, monthly and seasonal patterns were analyzed. In both the outer growing margin samples and chondrophore samples, the overlap between monthly modern samples made it very difficult to evaluate which months corresponded best with the archaeological samples. Overall, the $\delta^{18}O$ values obtained for the archaeological samples are characteristic of cooler water temperatures which typically appear in the late fall, winter, and early spring. In both the outer growing margin and chondrophore comparisons, the months of November, December, and January display a large number of monthly matches. By looking at Table 7 and Table 8, we can see that these cooler months are more strongly represented than the summer and early fall months.

While this study and Blackwood's concurrent study of Jones Cove and Holmes Point East and West sites may be the first time oxygen isotopes have been used successfully to assess shell midden seasonality in Maine, other techniques have been employed to determine the seasonal of occupation at Maine archaeological sites. The other, more commonly used, method for making season-of-capture determinations from mollusk shells is called incremental growth analysis, wherein the shell is cross-sectioned and the growth patterns are measured and analyzed. This method, like oxygen isotope analysis, is used with varying results. Due to the amount of natural variation in growth patterns between individual organisms, the growth measurement in the analyzed mollusks may display a wide range of values (Claassen 1998). Nonetheless, the growth increment method can be an effective way to determine the season of collection of mollusk shells.

One of the oldest shell middens in Maine, Turner Farm, has been extensively studied to better understand Native people's coastal seasonal and subsistence patterns. The Turner Farm site dates to the Middle and Late Archaic periods. Several proxies for seasonality were examined including mammal bones, fish bones, and *Mya arenaria* incremental growth analysis. A large sample size was used (greater than twenty shells per feature/level analyzed) allowing for shells with irregular or inconsistent growth patterns to be discarded. The results of this study indicate that mollusks were harvested primarily during the late fall, winter, and early spring (Spiess &

Lewis 2001). These results are consistent with the results of this study even though a different method was applied to the shells.

Another example of the incremental growth analysis used on Maine *Mya arenaria* shells comes from the Knox Site on Pell Island. Located off the Isle au Haut in East Penobscot Bay, Maine, this site spans the entirety of the Ceramic Period until its subsequent abandonment in the Late Ceramic period correlated with rising sea levels. Belcher sectioned sixty-eight *Mya arenaria* chondrophores and analyzed their growth development. Contrary to the results of the present research, the cross sections of these shells indicated that the shellfish harvesting occurred during a warm weather occupation from between April and December (Belcher 1989). Although this result is different from the results of my study, both are actually consistent with Sanger's theory that people utilized the offshore islands during the summer and moved to the coastal mainland areas during the cold months (Sanger 1982).

Changes in Seawater Conditions

Through the review of past publications where oxygen isotopes have been used in seasonality determinations elsewhere (Killingley 1981; Bailey et al. 1983; Godfrey 1988), one question continually arises: how is a change in water temperature accounted for? To compare the archaeological shells' $\delta^{18}O$ to the modern collected shells' $\delta^{18}O$ ranges, a change in water temperature from the past to the present must be accounted for. Based on evidence from non-archaeological mollusks and sediment cores, seawater temperatures in the Gulf of Maine 1,000 years ago were estimated to be an average of 1-2°C warmer than the present-day temperatures (Marchitto & DeMenocal 2003; Sachs 2007; Wanamaker et al. 2008; Wanamaker et al. 2011). These data indicate that the water temperature during the modern shell collection for this thesis project was **not** the same as the temperature of the water during the times the archaeological shells were collected.

Having established that the archaeological mollusks were harvested from waters warmer than present-day temperatures, how does this impact the seasonality determination? Disregarding the temperature variation, my thesis data suggest that the mollusks were harvested during seasons when the water temperature was colder (i.e. late fall, winter, and early spring). None of the $\delta^{18}O$ values from the archaeological shells correlate with warmer temperatures characterized as below 0.0 per mil or in the negative numbers. Factoring in warmer average water temperature at the time of collection, the archaeological shells still maintain their cold-season signal. The warmer paleotemperatures, in this case, do not change the outcome of this seasonality analysis and still indicate that the shells were collected during cold water seasons.

Variability of Shell $\delta^{18}O$

Even though my results indicate the seasonal nature of shellfish harvesting at the Tranquility Farm site, these data also serve as a cautionary tale to others who want to use the same methods to assess other shell middens for seasonality. First and most problematic is the large amount of variation that can be seen within the modern monthly shell $\delta^{18}O$. Even with the outliers identified and eliminated, there are several months that display larger than expected shell $\delta^{18}O$ ranges. For example, August values range from (-)0.519 to 1.065 per mil. This range is so broad that it encompasses the same ranges as the May through November samples. When attempting to place the archaeological values in the modern ranges, the months of July and September did not show any matches while August showed a very large number of matches due to this large range. This challenge highlights the need to use larger sample sizes, which would make these data more statistically robust. With a larger sample size, some of the values which expanded the range of August $\delta^{18}O$ values could possibly be identified as outliers and thus excluded from the study.

The use of modern shells as compared with archaeological samples has been done before in other places, with varying results. In her manual on shells in archaeology, Claassen (1998) discusses the utility of using oxygen isotopes in seasonality determinations but cautions archaeologists against using this technique because of its expense and the challenges the method presents. The problems identified in this manual and in other literature on this topic (Bailey et al. 1983; Godfrey 1988; Leng & Lewis 2016; Mette et al. 2018) highlight the same problems discovered in this study.

In his 1981 publication on seasonality of coastal middens in California, Killingley postulates that by using $\delta^{18}O$ profiles from prehistoric mollusks, the actual month of collection can be ascertained. These data were the result of fourteen sampled shells from a variety of mollusk species, the majority of which pointed to a "warm period" of collection. With these data, Killingley made several assumptions. The first of these assumptions is that the shells he sampled are a truly random sample. Killingley's sample was mainly constrained by the number of collected archaeological shells of good enough quality to be analyzed (similar to my study). So, while this sample is the best it can be given the shell quality, it is uncertain if these shells are representative of the population. Another assumption made in Killingley's paper is that the water temperature has remained consistent from the time archaeological shells were harvested to the present when he harvested modern shell to derive reference values. Should this assumption prove to be incorrect, these data would need to be calibrated to the paleo sea surface temperature range to correct this problem. These problems are not specific to the Killingley (1981) study, they are also problems the present research encountered and are discussed in the limitations section.

Just a few years after the Killingley study was published, an overview of the potential and limitations presented by using oxygen isotopes in seasonality determinations was published in *American Antiquity*. Bailey et al. (1983) provide a critique of this method and offer additional guidance to others who may use this method. In addition to the critiques of Killingley's paper that I reviewed above, Bailey et al. (1983) are critical of the ability for oxygen isotopes to show the time of collection down to the month. By collecting modern shells and testing their outer growing margins for the range of $\delta^{18}O$ values, Bailey et al. found that shells collected on the same day from the same geographic location could have different values. These authors suggest this could have two interacting causes; the population of mollusks are not growing at the same rate at the same time and variation in sampling technique. These two challenges presented by Bailey et al. are the exact problems faced in this thesis study.

Research from a site in Australia adds to the literature discussing the challenges of using oxygen isotopes in seasonality determinations. Godfrey (1988) applied a similar technique to the one used in this thesis study wherein monthly modern samples were collected to form a baseline of shell $\delta^{18}O$ values. These modern collected shells were bolstered with the addition of seawater samples taken at the time of mollusk harvest. As in the studies previously discussed and this thesis study, the shell $\delta^{18}O$ values were not always consistent within a monthly collection. Godfrey further investigated this disparity and found a correlation with larger, older specimens and greater variety in $\delta^{18}O$ values within a month. As a result of his study, Godfrey recommended using younger shells to create modern monthly ranges since they yielded more consistent, closer grouped values. While this is a valuable observation, it may not always be applicable to shell midden studies where the sample size and quality of archaeological shells for sampling are limited.

Seeing that other, more seasoned researchers also encounter these same problems shows that the results achieved in this thesis are not entirely due to inexperience but are problems inherent to this methodology. Even with these problems, the available data still point to a cold season use of the Tranquility Farm site. As the aforementioned papers discussed, the ability to narrow this season of occupation down to specific months may be outside of the capabilities of this method. Where the other papers discuss populations of mollusk species endemic to their area of study, this thesis applied these methods to *Mya arenaria* clams from Maine and shows the same variability of shell $\delta^{18}O$ values collected from the same month. These thesis data add to the literature supporting the challenges presented with using mollusks to identify season of occupation at archaeological sites and provide guidance for those who may attempt this method in the future.

Limitations

When interpreting my data, there are several limitations and assumptions that must be accounted for. Some of these have been highlighted above in the previous literature section, while others are unique to the species of shell used and the location from where they were collected. This section will continue to discuss some of the limitations of this research and provide further justification for the results obtained through this research.

Throughout this thesis process, one of the major hurdles to overcome has been the small sample size used to make my determinations. While the entire sample of modern data is over thirty shells, for each monthly range and average, only five or six shells were used. This number was then reduced by using box and whisker plots to identify outliers (Figure 15 and Figure 16). With a larger data set, more outliers could have become apparent and the monthly ranges could have been narrowed. For example, the sample values from the months of August and December have overlapping value ranges when these months should display very different values. A larger data set could lead to more robust monthly averages that are more representative of the actual water temperature values for each modern month. These data do follow the general trend of water temperatures in the Frenchman Bay region but are generally offset from the actual NOAA observed values.

The archaeological samples used in this analysis are the result of a largely non-systematic collection of shells during the Abbe Museum's summer field schools. The shells were initially collected for incremental growth analysis, not for oxygen isotope analysis. The number of samples chosen from each 10 cm layer within each excavation quadrant was not based on any statistical theory. These shells were arbitrarily collected based on the amount of other cultural material being recovered, but excavators were instructed to save approximately ten shells per quadrant layer, preferentially selecting whole shells. The results of this non-systematic sampling method in this study are unknown.

It is also possible that the apparent overlap in values is due to sampling error from the inexperience of the samplers at the time of this study. While the sampling method remained as consistent as possible between shells, Blackwood and I were novices at this process; as the project continued, we were able to refine our sampling skills. In some cases, as in the shells collected during the mollusks' minimal-growing seasons, the amount of calcium carbonate the shell accreted during that period of growth may be so thin that during sampling, the shell's monthly signal was contaminated with the previous month's growth signal. This effect, known as time averaging, could have been more problematic with the chondrophore samples where the monthly signals are more highly condensed than on the outer growing margins.

As noted by Godfrey (1988), mollusks' age seems to have a direct effect on how the individual organisms incorporate oxygen isotopes. By using younger clams for his monthly collection averages, he was able to obtain better consistency between the $\delta^{18}O$ values of different individuals. In this study, the relationship between the size and age of the modern collected *Mya arenaria* and the consistency of its oxygen isotope values in relation to other mollusks from the same monthly collection were not assessed. The size of the clam collected was dictated by the Department of Marine Resources guidelines for shellfish harvesting stating that a clam must measure at least 2 inches. While selecting younger clams might have created a more cohesive data set, these data would not necessarily have been representative of the size and age of archaeological shells. The archaeological shells were also not selected by their size, but by their overall quality of preservation. Limiting the sizes of shells used in this study would have only further limited an already restricted sample. While size/age was not accounted for in this study, the relationship between this and shell oxygen isotope values could be explored in further research.

During the modern shell collection process, the mollusks were cleaned of flesh using one of two methods; steaming in freshwater before cleaning or cleaning at the time of collection followed by drying the shells in the sun. According to ethnographic and archaeological data, clams were either cooked by steaming on large rocks or dried in the sun for storage and later use (Prins & McBride 2007a). There was uncertainty if boiling these shells would significantly alter the oxygen isotopic values preserved in the calcium carbonate of the shell. A study by Müller et al. (2017) tests the chemical alteration of shells by different cooking methods and temperature ranges. Through experimentation with modern collected shells and archaeological remains, Müller et al. suggest that cooking shells by boiling them for a short amount of time should not significantly impact the $\delta^{18}O$ in the shells.

In Müller's study, the shells were boiled in salt water and there is some uncertainty about whether there would be a difference between cooking shells in freshwater or salt water. To test whether this were so, ten additional mollusks were collected from Jones Cove in June of 2018. Five of these whole mollusks were boiled in fresh water and then cleaned by hand, while the other five whole mollusks were cleaned while still raw and the shells left to dry in the sun. The isotopic values from the cooked shells ranged from 1.4667 to 0.8831 parts per mil with an analytical uncertainty of ± 0.25‰ (VPDB). The dried shells showed less variation with their values ranging from 1.4995 to 1.4322 with the same analytical uncertainty of ± 0.25‰ (VPDB). Given the extremely small size of this dataset, it is difficult to say if a statistically significant difference exists between the shell treatment methods. Further testing would be needed to test the significance of difference so, for this thesis, it is assumed that the results would be consistent with those found in Müller et al. (2017).

Even with the limitations presented throughout this study, the data still indicate that the archaeological shells were collected during a cold time of year. The limitations provide room for further experimentation and mainly call for an increase in sample sizes. These data show how complicated it is to make seasonality determinations using oxygen isotopes, but how rewarding it is for the field of research to do so through continued research and experimentation.

Recommendations

Given some of the limitations produced throughout this thesis research process, there are several recommendations for further research. These recommendations would help any researchers using oxygen isotopes to make seasonality determinations at archaeological sites to create a more robust data set and use it more effectively. Even with the challenges this research has presented, these data are still important to the overall understanding of Maine's coastal seasonal and subsistence history.

Some studies using oxygen isotopes to assess seasonality at shell middens base their determinations on very small sample sizes (Killingley 1981). As discussed above in the limitations section, the sample size used in this study is too small. While some outliers were able to be identified and removed from the monthly averages, it is possible that the data sets could be refined by increasing the number of samples. This increase should not only be in the number of outer growing margins used but also in the number of chondrophores. Ideally, the number should be equal, with paired measurements coming from the same valve of the same mollusk to ensure that the values are indeed comparable. Because of the limited number of intact outer growing margins in archaeological samples and the larger number of intact archaeological chondrophores, this will allow for a better direct comparison between sample locations and the obtained $\delta^{18}O$ values.

As mentioned above, there are other methods that can be applied to mollusk shells to make seasonality determinations (Claassen 1998). Incremental growth analysis involves the cross-sectioning of the entire shell or the chondrophore followed by a close examination of the internal structure of the section under a microscope. By "reading" the seasonal bands in the mollusk, a seasonal determination can be made by identifying the final season of growth based on the width of the prior growth bands. One of the recommendations from this study would be to use a combination of the incremental growth analysis and oxygen isotopes in making seasonality determinations. Instead of just observing the pattern of growth increments, precise calcium carbonate samples could be taken from different increments within the shell makeup. For example, instead of just sampling the outer growing margin, successive samples could be taken from the shell going back in its growth sequence for several seasonal cycles. This would result in many samples taken from one shell and strengthen the overall quality of these data by combining two methods of analysis.

As part of this research process, water samples were collected for use in water temperature reconstructions based on the modern collected shells. By using a modified Grossman and Ku formula, the $\delta^{18}O_w$ and the $\delta^{18}O$ from the shell are combined to approximate the water temperature at the time of shell collection (Wanamaker & Gillikin 2018). Ideally, water samples would have been collected during each modern monthly shellfish collection as done by Godfrey (1988). Unfortunately, this was not done as part of this study. For future studies, researchers could more effectively use the Grossman and Ku formula to reconstruct water temperatures and check the accuracy of the mollusk's isotopic equilibrium with the water. As noted by Whitney et al. (2017), the $\delta^{18}O_w$ depends on the time of year so using one measurement does not capture the variation that actually occurs throughout the year.

The constraints encountered during my analysis of the archaeological collections can be used to guide future shell midden excavations and subsequent shell collections. The shell collecting method used by the Abbe Museum during the Tranquility Farm excavations is a good method for constraining the number of shells per layer. From my experiences during the field excavations, the shell collections became secondary to collecting other cultural materials such as stone tools, pottery, and animal bones. By stressing the importance of collecting well-preserved shells throughout the collection process, there would be a greater number of better-quality shells for analysis. Whole shells with intact chondrophores should be saved when possible which would allow for both portions of the shell to be sampled.

As shown throughout the archaeological, environmental, and paleoclimatic literature reviewed in this discussion, using oxygen isotopes preserved in shells from shell middens to make seasonality determinations is a complex process. In this thesis study, monthly modern shell samples were collected to form a calendar year of shell isotope values to which the archaeological values could be compared. Many factors, from paleo-water temperatures to prehistoric cooking techniques, can change the results of the seasonality study, but even accounting for these challenges, the $\delta^{18}O$ values obtained from the archaeological shells still point to a cold-water collection time. While these data can be improved by increasing the sample size and methods used, this conclusion remains consistent with current literature about seasonal occupation on the coast of Maine.

Chapter 6

CONCLUSION

Coastal shell middens represent unique and, unfortunately, endangered cultural resources which preserve cultural and environmental data. Due to the amount of geological changes along the coastlines of Maine, most of the earliest coastal archaeological sites have been erased by post-glacial sea level rise. The majority of the shell middens that have survived are from the Ceramic Period. By using modern and archaeological *Mya arenaria* shells from the Tranquility Farm site in Gouldsboro, Maine, this thesis has attempted to determine season of occupation at the site. While there are already seasonality models for the coast of Maine using other seasonality determination methods (Sanger 1982; Spiess & Lewis 2001), this thesis utilizes stable oxygen isotopes preserved in the hard shells of the clams and adds to archaeologists' understanding of past seasonal movements and subsistence patterns.

As part of this study, modern *Mya arenaria* shells were collected each month for an entire year to form a modern isotopic baseline. The archaeological shells used in this study came from various locations throughout the Tranquility Farm shell midden. Using the modern shell values to create modern monthly ranges of $\delta^{18}O$ values, the archaeological $\delta^{18}O$ values were then placed within the modern monthly ranges. These placements primarily fell into the cold-water seasons of late fall, winter, and early spring. This seasonal interpretation is consistent with current theories regarding the seasonal movement of coastal people and adds a new layer of data to archaeologists' understanding of this topic.

This thesis study also served to test the utility of using a modern collection of shells to interpret the seasonality of archaeological samples. Even with outliers removed from the modern data set, the modern monthly samples still displayed large ranges, with monthly ranges from opposite seasons overlapping. These results aligned with similar studies from around the world and highlight some of the challenges of working with $\delta^{18}O$ values in mollusks. Changes in average seawater temperature from archaeological to modern times presented another challenge. These factors and more were considered during the analysis of these thesis results. In the end, these data serve as a cautionary tale for others wishing to complete a study of this nature.

Because a study using a modern shell baseline is not well represented in current literature, this study provides many suggestions for future work using this method. The most challenging problem throughout this study was the small sample size used to make large-scale site interpretations. A large sample size could have created more cohesive modern monthly ranges and better represented the relationship between the outer growing margins and the chondrophore samples from shells. An increased sample size should also include monthly water samples collected in conjunction with the monthly shell collections to show how accurately the shell $\delta^{18}O$ related to the water $\delta^{18}O$. Finally, using a mixture of incremental growth analysis and oxygen isotopes could more accurately identify the seasonal signal from both modern and archaeological samples.

The results of this study remain consistent with published literature on both seasonality data and oxygen isotope studies on shells. This consistency shows that while there were problems with this analysis, these problems are not only inherent in this method but also can be improved upon in further research. Studying shell middens in Maine is particularly important now because they are endangered resources. Continued investigation of middens by testing different methods to study them, identifying methodological changes, and reaffirming cultural models serves to keep these middens alive even in their time of peril.

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Kate Pontbriand was born in January 1994 in Vernal, Utah. At the time, her parents, National Park Service rangers, worked at Dinosaur National Monument in Dinosaur, Colorado. During her childhood, her parents took jobs in at North Cascades National Park in Stehekin, Washington followed by Acadia National Park in Gouldsboro, Maine. She attended Mount Desert Island High School in Bar Harbor, Maine where she graduated in June 2012. In September 2012, she began her undergraduate studies at Franklin Pierce University (FPU) in Rindge, New Hampshire in the Anthropology Department. During summers, she worked as a seasonal employee at Acadia National Park in their Cultural Resources Division. Kate graduated with honors in May 2016 with a BA in Anthropology, minors in Environmental Studies and Public History, and certificates in Sustainability and Global Citizenship. The following fall she began her graduate work at the University of Maine and Climate Change Institute in their Quaternary and Climate Studies program where she focused in archaeology. At the University of Maine, she held two Graduate Assistantships, during her first year in the College of Education and Human Development and the second year as a TA in the Department of Communications and Journalism. She is a candidate for the Master of Science degree in Quaternary and Climate Studies from the University of Maine in December 2018.