Coastal Landscapes & Indigenous Histories of Shellfish Harvesting in Atlantic Canada: *Mya arenaria* as a new proxy for shellfish harvesting pressure in Port Joli, Nova Scotia.

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A thesis submitted to the School of Graduate Studies In partial fulfillment of the requirements for the degree of

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ABSTRACT

Marine bivalves from archaeological shell middens sites reveal critical information about past environments, harvesting strategies, and human impacts on shellfish populations. However, robust sample sizes are required to develop meaningful interpretations over time and space. Port Joli, Nova Scotia (NS), has the densest concentration of shell midden deposits in Atlantic Canada, dating to ~1600 cal BP. A protocol for rapid-age at-death assessments of *Mya arenaria*, was developed by analysing live-collected *M. arenaria* to establish a baseline for interpreting archaeological shell growth patterns. Rapid-age-at-death assessments of *M. arenaria* reveal insights for both sclerochronological methods and archaeological interpretation. One-hundred archaeological shells were selected from six shell middens to interpret regional trends in shellfish harvesting. Chondrophores were sectioned to 3mm, mounted on slides, polished, and imaged using reflected light at 20x. Each image was analysed by four independent observers to assess: 1) quality of growth lines; 2) shell portion with the clearest lines; 3) relative age; 4) ontogenetic age; 5) season of death. Variation in growth patterns was observed between modern and archaeological specimens, with modern shells having better clarity. Further variation was observed with readability between archaeological sites and variation in the average age between sites, suggesting that some clam beds were harvested more than others. The results also demonstrate the level of experience in sclerochronology will produce more conservative age and seasonality estimates, and that novice readers are more likely to miss-characterize growth patterns.

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Publications

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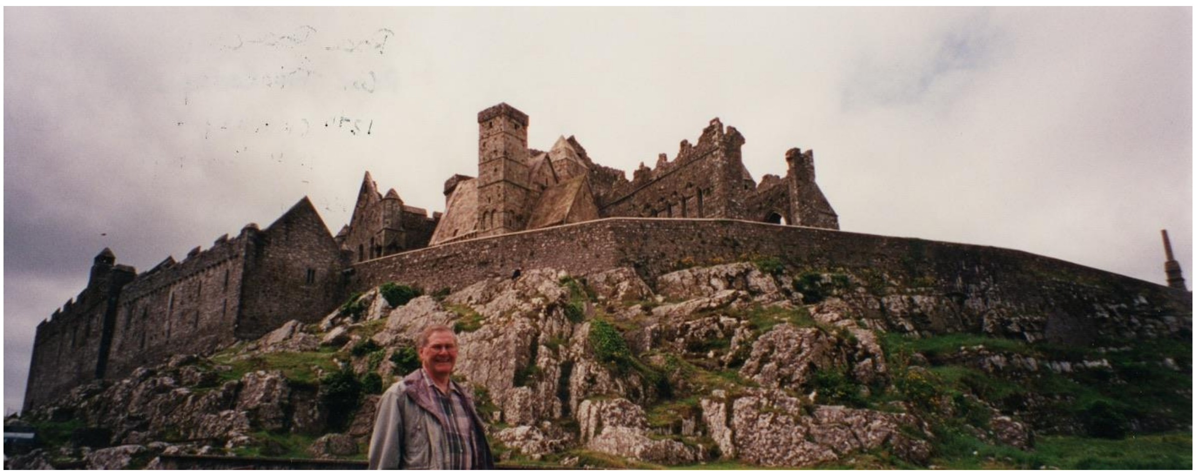

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CHAPTER 1

INTRODUCTION

Shellfish, specifically bivalves, appear in the archaeological record most commonly in the context of shell middens. Archaeological shell midden deposits occur near coastal, riverine, and lacustrine habitats almost worldwide and have been associated with the late Pleistocene and Holocene eras (Andrus 2011; Balbo et al. 2011; Butler et al. 2019). The bulk of a shell midden is made up of the remains of well-preserved accretionary calcium carbonates, like the shells of marine molluscs. These middens act as a record of long-term cultural and environmental archives, as they are homogenous waste deposits, representing human shellfish collection and disposal over long periods of time (Butler et al. 2019).

Shell middens represent a fingerprint of the people who formed them. The contents of shell middens are contingent on several factors, dependent on both the actions of humans and the inconsistencies of the natural environment (Butler et al. 2019). Geographically, the contents of a shell midden are contingent on the local availability of shellfish species (Monks 1981; Claassen 1986; Waselkov 1987). Shell middens are also contingent on the choices of the people who form them; such things as site formation, duration of occupation, population size and purpose all affect the contents of a shell midden (Butler et al. 2019). The contents of shell middens consist of piles of shell and other refuse. However, depending on geography, shell middens can differ greatly in contents throughout the world, as contents are contingent on the availability of local marine and terrestrial animals.

Shells from archaeological midden deposits are a valuable resource for archaeological research when reconstructing past human-environmental relationships, marine resource management and seasonality (Butler et al. 2019). The shells of marine molluscs are useful for examining past environmental changes, as they serve as a source of sequential proxy records of past climate and environmental conditions (Andrus 2011; Butler et al. 2019). Shell middens represent detailed pictures of human environment interaction (Andrus 2011), as shellfish acted as an important food source for Indigenous groups.

This research uses shells of the marine bivalve *Mya arenaria* from six shell midden sites from Port Joli Harbour, Nova Scotia to test this species utility for rapid-age-at-death assessments. This method is a beneficial method for archaeologists for assessing shellfish harvesting pressure of past indigenous groups.

1.1 Sclerochronology and Archaeology

As marine mollusks grow in the ambient environment, new layers of shell are deposited that incorporate oxygen and carbon isotope signatures of the local water at variable growth rates (Hoefs 1973; Shöne et al. 2003; Gröcke and Gillikin 2008; Burchell et al. 2014a; Leng and Lewis 2016). The shells of marine mollusks can be used as proxies for past seasonality and paleoclimate reconstructions (Shöne and Gillikin 2013; Surge and Barrett 2012; Wang et al. 2012; Burchell et al. 2013; Butler et al. 2013; Hallman et al. 2013; Surge et al. 2013; Cannon and Burchell 2017). These environmental proxies are developed using sclerochronology. The term sclerochronology was first used by Buddemeier et al. (1974) to describe the methods used to examine the rate of growth in density bands of hermatypic coral (Oschmann 2008). As defined by a team of sclerochronologists at the first International Sclerochronology Conference in 2007, “sclerochronology is the study of physical and chemical variations in the accretionary hard tissues of organisms, and the temporal context in which they formed”. For marine mollusks, this involves examining internal growth structures that reflect annual, monthly, tidal, daily, or sub-daily increments (Oschmann 2008; Shöne and Gillikin 2013).

The shells of marine mollusks have been of particular focus for sclerochronologists since the field's inception, as they serve as a useful climate and environmental proxy record, as shells record changes in local temperature and oxygen isotope signatures from the ambient water (Urey 1947; Shone and Gillikin 2013). While mollusks are often the focus of sclerochronological study in archaeology, other accretionary hard tissued organisms are used across this field in paleoclimate science, biology, and ecology. Other organisms of such focus are corals and fish otoliths (Shone and Gillikin 2013; Butler et al. 2019).

1.1.2 Shellfish Harvesting Pressure

Incremental growth lines in marine bivalves represent, daily, monthly, seasonal, subannual and annual of a shell (Claassen 1998; Shöne et al. 2003; Shöne et al. 2005). Growth stage profiles can be assessed in marine bivalve shells through sclerochronological analysis to determine growth rate patterns and the relative age-at-death by examining the number of annual, weekly, or daily growth lines in a shell. This involves cross sectioning a shell to examine the incremental growth structures (Cannon and Burchell 2009). Mature and senile (Fig. 3) growth stages are observable through the density of incremental growth lines deposited on the ventral margin of the shell (Cannon and Burchell 2009). Mature growth is evident through broadly spaced; regular incremental growth bands deposited on the ventral margin. Senile shells, however, exhibit irregular small incremental growth bands packed in the ventral margin area of the shell (Claassen 1998; Cannon and Burchell 2009).

Sclerochronological analyses on shells can be used to determine shellfish harvest pressures by identifying the ontogenetic age of the harvested population. Higher shellfish harvesting pressure is seen in the archaeological record through a larger abundance of juvenile shells in the midden deposit, as shellfish growth periods are short due to a high frequency collection strategy.

Similarly, if there exists a low shellfish harvest pressure, there will be a greater abundance of mature and senile shells (Cannon and Burchell 2009).

1.2 The Mi'kmaq of Nova Scotia

This research is situated in the traditional territory of Acadia First Nation. The Mi'kmaq are an Indigenous people of the northeastern coast of North America. The Mi'kmaq are part of the Algonkian-speaking group of Indigenous peoples in Canada and represent the largest Algonkian-speaking population in Eastern Canada (Prins 1996; Hornborg 2008). The Mi'kmaq have inhabited the Atlantic coast of North America for some 13,000 + years and currently have communities in Nova Scotia, Prince Edward Island, New Brunswick, Quebec, Newfoundland, and Maine (Robinson 2014:673; Joudry 2016). It has been estimated that prior to European colonization of North America, there were at minimum around 200,000 Mi'kmaq people inhabiting eastern North America (Paul 2006; Kinnear 2007).

Traditionally the Mi'kmaq had a subsistence economy that had a substantial focus on marine resources (Betts and Hrynick 2022). The Mi'kmaq oriented their settlement patterns to coincide with availability of regional terrestrial and marine food resources (Hornborg 2001: 4). In the historic period, the Mi'kmaq would traditionally establish villages at the mouth of a river to gain access to both marine food resources and transportation routes (Whitehead and McGee 1983; Kinnear 2007). However, settlement could be variable depending on the season. In the historic period, the Mi'kmaq followed a relatively uniform settlement round; in the spring and summer they lived in small villages along the coast and focus on marine resources (Bock 1978; Hornborg 2001; Miller 2004; Kinnear 2007; Pentz 2008). In the fall, the Mi'kmaq would travel upriver to catch migrating fish, including eels, bass, and salmon (Kinnear 2007). In winter, the Mi'kmaq would move into the interior of Nova Scotia, relying on terrestrial game for food (Kinnear 2007).

“The Mi’kmaq view of the world is rooted in our relationship with the other-than-human animals that share our territories"; these are the words of a Mi’kmaq woman who grew up in Nova Scotia when asked by Margaret Robinson to explain how the Mi’kmaq view the natural world (Robinson 2014:673). The Mi’kmaq worldview is built on the ideology that the Mi’kmaq must live in harmony with the natural world, respecting both living and nonliving things (Kinnear 2007:1). According to Kinnear (2007:24), to describe their worldview and their relationship with the land, the Mi’kmaq use the term *Netukulimk*. This term is defined by the Mi’kmaq as a concept that situates their people in using natural resources which have been provided by the “creator” for the self-support and well-being of the nation. (Kinnear 2007:24).

In Mi’kmaq traditional beliefs, it is said that their people originated from *weji-sqalia’tiek*, which translates to “we sprouted from the earth” (Joudry 2016:18). This belief that their ancestors physically originated from the soil of the earth, situates their belief systems to be focussed on relationships with the land and the environment. The Mi’kmaq view themselves as being part of a complex web of relationships that encompasses all the natural world (Kinnear 2007). In this view, the Mi’kmaq see the land and sea as something that cannot be owned or possessed and situated themselves as having no superiority on the land; they lived as equals with animals and all living things.

The relationship between humans and animals is one that is essential to the Mi’kmaq worldview. In most Indigenous groups throughout time, the natural world, including animals, are viewed as highly personal beings, forming a fundamental aspect of the human social and spiritual universe (Hornborg 2001). For the Mi’kmaq, animals are not considered as simply resources for sustenance; rather, they are treated as if they were brothers or sisters; they are equal. This level of equality between the Mi’kmaq and animals is illustrated in their oral histories, as in many of their stories, animals are central conversation partners to humans, and in some cases may even marry each other (Hornborg 2001:59,138). This is illustrated often in Mi'kmaq stories, with ancestors of the Mi'kmaq having kin-based relations with animals.

1.3 Theoretical Approach: Historical Ecology, Landscape Theory and Agency

In this research I use historical ecology, landscape theory and agency theory to understand how past Indigenous groups in Nova Scotia used shellfish as an integral source of sustenance. While these theories ground and inspire this work, this research is primarily focussed on methodology.

Historical ecology situates humans as active agents of environmental change and management (Thompson 2013:3). From viewing humans in this way, as agents of ecological change, humans can be seen as writers of environmental histories (Smith and Wishnie 2000: 496). For this research, situating past Indigenous populations on the coasts of Atlantic Canada in this framework will be essential, as it can aid in understanding how people interacted with their environment and actively managed marine resources. Historical ecology will also help in understanding the ecology of marine bivalves in Atlantic Canada, and how active management of these resources by Indigenous populations would have affected local marine bivalve populations.

One of historical ecology's main foci is on landscapes and seascapes, as they exhibit human actions, natural processes and the continued interaction between humans and the environment (Thompson 2013:4). Additionally, Thompson (2013:5) pointed out that a fundamental goal of historical ecology is to understand exactly how and why humans manipulate the landscape and assess the amount of intentionality in such activity. This will be fundamental to this research, as I will consider why and how Indigenous groups on the coasts of Nova Scotia interacted with the environment and managed specific marine resources, especially shellfish. Historical ecology also ties into aspects of landscape theory, as it aims to understand what kinds of impacts humans have on their landscape (Thompson 2013:5).

A fundamental aspect of this research will be understanding how Indigenous groups in Atlantic Canada interacted with the landscape and utilized certain spaces on the coasts of this region. Through a landscape theoretical approach, I will be able to interpret potential spatial patterns of shellfish harvesting and species distribution across Nova Scotia and the greater Atlantic Canada region. According to Anschuetz et al. (2001:160), a landscape theoretical approach views landscapes as being created through the product of cultural activity. Expanding on this point, Anschuetz et al. (2001:160) state that the landscape, the actual physical spaces people inhabit become transformed through daily [monthly, seasonal] activities. This is particularly relevant to this research as I view shellfish harvesting as a daily activity, where Indigenous communities actively manipulated their landscape to manage marine resources (Cannon and Burchell 2009).

Another aspect of a landscape approach is the role of settlement systems and patterns. This will be a key area of concern in this research, looking at settlement patterns by Indigenous groups in Nova Scotia. One thing to consider when applying a landscape approach to this research is how sea-level change may have impacted settlement patterns in Nova Scotia. As indicated by previous research (Cannon 2000:73) on the Northwest Coast of British Columbia, the distribution of coastal shell midden sites indicated that Indigenous settlement patterns coincided with the gradual decline in relative sea level. This may likely be the case as well on the Atlantic Coast of Canada, as the scarcity of shell midden deposits in the region may be linked to changes in sea level over time.

The third theoretical framework that will shape this research is agency theory. In general, agency theory allows us to explore and ask specific questions about the internal sources of human behavior in the past. As defined by (Barker 2004), agency can be defined as the socially determined capability to act and to make a difference. In other words, human agency constitutes an individual's capacity to act and make change in their life and environment. Applying agency theory to archaeological contexts, allows us to ask questions on human behavior and interpret whether individuals in the past made conscious choices that brought about change in their lives and the environment.

Hunter-fisher-gatherers are active agents on their landscape (Sassaman and Holly Jr. 2011), who would actively harvest and manage specific foods. The active choices of communities that went into resource management play a fundamental role in how shell middens and archaeological sites are formed over time. From interpreting the contents of shell midden deposits from Nova Scotia and implementing an agency approach, I will be able to understand the active choices that may have gone into shellfish harvesting strategies. With agency theory, I can ask questions pertaining to individual taste preferences and the level of availability of specific shellfish species, depending on the abundance of one species of shellfish over other within a shell midden deposit.

CHAPTER 2

SHELL MIDDEN ARCHAEOLOGY IN THE ATLANTIC NORTHEAST

Atlantic Canada encompasses Newfoundland and Labrador, as well as the Maritime provinces of Canada, which includes Prince Edward Island, New Brunswick, and Nova Scotia. Human occupation of Atlantic Canada began approximately 13,000 years ago, when Paleoamerican peoples began populating the Northeastern region of North America following the retreat of the Laurentian continental glacier (Deal 2016). In Atlantic Canada, shell middens have been the subject of archaeological investigations for decades.

The first attention to shell midden deposits in Atlantic Canada came when naturalists from the Nova Scotian Institute of Science investigated two shell middens in Nova Scotia. First at Frostfish Cove in St Margaret's Bay in 1863, and then in Cole Harbour in 1864 (Betts and Hrynick 2021; Deal 2016). The early investigations at Frostfish Cove were published by J.M Jones in the Journal of the Anthropological Society of London in 1864. According to Betts and Hrynick (2021:9), the description of the contents of the Frostfish Cove midden in Jones' (1864) report points to a Maritime Woodland deposit, as the abundance of softshell clam and quahog shells are seen in other Maritime Woodland shell middens along the South Shore of Nova Scotia.

Shell midden archaeology in the Atlantic Northeast continued sporadically into the late nineteenth century through the lead of naturalists. In Nova Scotia, Sir John William Dawson (1878) and George Patterson (1883;1890) completed investigations at Merigomish Harbour. According to Patterson's (1890) report, he noted the presence of shell midden deposits all over the coast of Nova Scotia such as Pictou Harbor, Big Island, Point Betty Island, the Pig Islands, Antigonish Harbor, Tracadie and Tatamagouche to name a few. I am unaware if any of these have been professionally investigated, or even confirmed to exist. Notably, Patterson (1890:238) mentions that he was informed of the presence of shell middens in Port Joli, however he had not confirmed their existence or undertook any excavations. Such early accounts of the abundance of shell middens in the province is interesting considering how little professional work has been done on these deposits. At the time, Patterson spoke with such confidence that these deposits were so abundant to ignore for archaeological purposes, stating that, “I believe that every harbor and the embouchure of every considerable river will be found to exhibit to a greater or less extent such evidence of having been occupied by the people of the stone age” (Patterson 1890:237).

The first professional investigation of shell middens in Atlantic Canada came in 1913 and 1914 when Harlan Smith and William Wintemberg, members of the Geologic Survey of Canada, excavated shell midden deposits at Merigomish Harbour and Mahone Bay in Nova Scotia (Smith and Wintemberg 1929; Betts and Hrynick 2021). According to Smith and Wintemberg’s (1929) report, they identified eighteen shell midden deposits in this area, all of which are dominated by the shells of the softshell clam and to be contemporary with the Mi’kmaq occupation of Nova Scotia.

Following the investigations carried out by Smith and Wintemberg, attention to shell middens in the area waned. Not until the 1950’s did shell middens again attract the attention of archaeologists. In 1957, John Erskine investigated the South Shore of Nova Scotia, an area of the province known to be abundant with shell bearing deposits (Betts and Hrynick 2021). Despite having no professional background in archaeology, Erskine conducted twenty years of investigations on shell middens on the south shore of Nova Scotia (Betts and Hrynick 2021). Specifically, Erskine (1962) excavated over a dozen sites in Port Joli Harbour.

It is important to note that the review of shell midden archaeology in Atlantic Canada and Maine focusses solely on academic research and publications focussing on shellfish from archaeological shell bearing sites and shell middens. This is to say that over the past several decades sites that have contained shellfish and shell midden archaeology along the coasts of the North Atlantic have been the subject of research, however, have had a focus on site formation, settlement, and vertebrate faunal data. Within all the Atlantic Provinces and Maine, shell middens have been, and continue to be the investigated archaeological within cultural resource management and field work.

3.1 Newfoundland and Labrador

Shell midden deposits in Newfoundland and Labrador have had little archaeological research-based attention within the province. Burchell et al. (2018) published the first study to focus on shellfish within archaeological contexts, utilizing stable oxygen isotope analysis on archaeological shellfish in Newfoundland and Labrador. This study examined mussel shells from house middens at an Inuit winter camp to determine seasonality.

3.2 Prince Edward Island

Like Newfoundland and Labrador, shell middens in Prince Edward Island have seen little professional analysis. During the 20th century, and even prior, there were only few references to such deposits in the area. In 1896, Walter J. Fewkes (1896) reported on the finding and excavation of a “prehistoric shell heap” on Prince Edward Island. Some seventy years later, Richard J. Pearson (1966) reported on some archaeological investigations throughout the province with mention of the presence of shellfish within middens and sites. However, no substantial work was done. Since 2000 there has been no published shell midden research focusing on shellfish from the province.

3.3 New Brunswick

Shell midden research in New Brunswick has garnered more attention than any other province in Atlantic Canada. Research in New Brunswick began when George Frederick Matthew conducted large scale excavations of a shell midden at Bocabec Village in 1883 (Betts and Hrynick 2021). Work at the Bocabec Village shell midden would continue until 1905 (Matthew 1884, 1886, 1900; Matthew and Kain 1905). In 1970, Pearson (1970) investigated several shell middens in the St. Andrews area of New Brunswick. The focus of this research was to locate artifacts associated with the Archaic period in New Brunswick, however Pearson (1970) mentions these shell middens to be made up primarily of the shells of the soft-shell clam.

In the past two decades, shell midden research in New Brunswick has been exclusive to the work of archaeologist David Black. Just as David Sanger was a chief figure in shell midden archaeology in Maine, the work of David Black is equally significant in New Brunswick. Black made several noteworthy contributions to shell midden research in New Brunswick in the 1980s and 1990s (Black 1983; Bishop and Black 1988; Black and Whitehead 1988; Black 1991). However, since the turn of the century, shell midden research and publications on such deposits all but halted, until Blair et al. (2017) published a study on a protohistoric shell-bearing site in Birch Cove, New Brunswick. This study reported on preliminary excavations at the site in 2015, which aimed to investigate the cultural transition during the protohistoric period in New Brunswick (Blair et al. 2017). This study primarily described the contents and matrix of the shell midden sites at Birch Cove, as analyses of recovered materials are still ongoing. Since 2017, nothing further has been published on the excavations at Birch Cove.

It is also important to note here that there has been additional work done on shell middens in New Brunswick, although no published study has resulted from such work. Specifically, Katherine Patton at the University of Toronto analyzed shells recovered from the Birch Cove excavations. However, the results of these analyses were presented in a conference paper. This is to say that to discern the full scope of shell midden research in the North Atlantic, researching grey literature and thesis work may be needed moving forward.

3.4 Maine and New England

In Maine, it seems that most of what has been done with shell midden archaeology over the past two decades is primarily reviewing and summarizing previous shell midden research from the mid-late 20th century, particularly that of David Sanger's work (Sanger 1981; Sanger and Sanger 1986; Sanger 1996; Sanger and Sanger 1997). One study that was published in 2017 by Arthur Spiess, summarized the ways shellfish and shell middens have been examined on the coasts of Maine to challenge the assumptions that people have about the role of shellfish in prehistoric coastal subsistence. Specifically, Spiess (2017) discussed the number of studies that had examined the relative abundance of shellfish species in the middens. In this study, Spiess (2017:105) noted that shell middens in Maine have been the subject of archaeological investigations for some 150 years. However, despite this long history of acknowledging these deposits in Maine, Spiess (2017:105) indicates that few sites have been excavated, and that only three studies to have quantified shell material. This lack of tangible archaeological work is puzzling considering the amount of documented shell middens in the region. Consulting the Maine Prehistoric Archaeological Database (MHPC), Spiess (2017:105) reported that there are some 2000 documented shell midden sites along the coast of Maine, with the soft-shell clam (*M. arenaria*) comprising some 95% of shells within these deposits.

The first study to generate new data on shell middens during this period in Maine was published in 2016 when Ambrose et al. (2016) analyzed archaeological shells of the softshell clam from shell middens on Malaga Island, Maine, to determine harvesting strategies of the Malaga Island community from 1860 to 1912. Like previous studies along the Atlantic coasts of North America (Lightfoot and Cerrato 1988; Lightfoot and Cerrato 1989; Cerrato et al. 1991; Lightfoot et al. 1993), this study utilized sclerochronology to examine the internal growth lines in the softshell clam to determine the age of death, and by proxy, age of harvest. To determine the season of harvest in *M. arenaria*, Ambrose et al. (2016) used incremental growth assessment to estimate the amount of expected growth completed in the harvest year.

The second study from Maine was published in 2018 by Miller et al. and contrasts with the previous study in both methods and objectives. Miller et al. (2018) looked at how climate change is increasingly detrimental to the state of shell middens on the coast of Maine, and the coasts of Atlantic North America. They propose that ground penetrating radar would be a less-destructive alternative to excavating these deposits. This study detailed a six-step methodology for utilizing ground penetrating radar at shell midden sites in Maine. To demonstrate their experiments with ground penetrating radar, Miller et al. (2018) report on two case studies that outlined the method's advantages and challenges.

Since there are only two studies to come from Maine since 2000, it is difficult to draw conclusions on patterns of shell midden research in the area. Likewise, these two studies differ considerably, representing two contrasting ways of approaching shell middens, with one being more grounded in geoarchaeological methods (Ambrose et al. 2016), and the other demonstrating how alternative excavation methods can preserve eroding shell midden deposits (Miller et al. 2018).

In 2018 and 2019, two master's theses were completed at the University of Maine that used stable oxygen isotope analysis on both live-collected and archaeological *M. arenaria* shells. Pontbriand (2018) analyzed archaeological *M. arenaria* chondrophores for stable oxygen isotope analysis to determine time of occupation at the Tranquility Farm shell midden in Maine. Live-collected samples were also utilized to determine a baseline for modern isotopic signatures. In total Pontbriand (2018) examined 23 archaeological shells and 46 modern shells. When sampling, both Pontbriand and Blackwood outlined a set of criteria each shell would have to meet to be used for stable oxygen isotope analysis: intact outer growing edge, intact chondrophore and inter-annual growth increments (Pontbriand 2018).

Blackwood (2019) looked at 3 shell midden sites from Maine to infer on the seasonality of each site using oxygen isotope analysis. The sites examined in this study ranged from the Early Woodland Period (3050-2150 BP) to the Middle Woodland Period (2150-650 BP). Blackwood's (2019) analysis consisted of five sample sets: three archaeological and two modern. All five assemblages were subject to stable oxygen isotope analysis. Blackwood (2019) collected 10 to 15 modern samples of *M. arenaria* monthly from tidal mudflats near the three archaeological middens. In total, around 120 to 150 modern shells were analyzed. The archaeological *M. arenaria* shells were selected from three assemblages that were excavated between 2006 and 2014. Across the three archaeological sites, Blackwood (2019) analyzed 133 *M. arenaria* chondrophores.

3.5 Nova Scotia

Considering the extent of documented shell midden deposits in Nova Scotia, these features have received little analysis over the past century (Smith and Wintemberg 1973; Burchell et al.

2014b; Betts et al. 2017; Betts 2019; Betts and Hrynick 2021). The most significant shell midden research in Atlantic Canada in the last twenty years has come from Nova Scotia.

Since the turn of the century, shell middens in Nova Scotia have seen increased attention. Since 2000, four studies have been published and one large scale, community-based excavation. In 2013, Mudie and Lelièvre (2013) published a palynological study on a shell midden from Maligomish Island, one the shell middens identified by Wintemberg in Merigomish Harbour in 1913, to test pollens' utility in interpreting paleoenvironmental conditions in Nova Scotia. This research proves significant to shell midden research in Atlantic Canada, as well as the entire North Atlantic, as it represents the first reference for archaeologists attempting to apply this method to samples in Nova Scotia shell midden deposits (Mudie and Lelièvre 2013:2161). Several years later, Lelièvre (2017) continued research on the Maligomish shell midden by examining the apparent proportional difference in oyster and soft-shell clam within the midden between a thousand-year period.

The focus of shell midden archaeology in Nova Scotia has been on the cluster of sites within Port Joli Harbor, the same sites John Erskine investigated in the late 1950's. The harbor contains 18 identified shell midden deposits, representing one of the densest concentrations of such features in Nova Scotia (Burchell et al. 2014b; Betts et al. 2017). Archaeological investigations in Port Joli began when John Erskine excavated over a dozen sites in the 1950's (Erskine 1962). These early excavations concluded that the harbor was home to an extensive Maritime Woodland occupation (Betts et al. 2017:19). Starting in 2008, an extensive community-based archaeological investigation entitled the E'se'get Archaeology Project, led by Matthew Betts, was undertaken in Port Joli Harbor. The objectives of this project were to define the Maritime Woodland period on

Nova Scotia's South Shore and to highlight the relationship between the Mi'kmaq and the marine ecosystem (Betts et al. 2017:18).

CHAPTER 3

THE SOFT-SHELL CLAM (*MYA ARENARIA*) IN MODERN FISHERIES AND ARCHAEOLOGY

3.1 *Mya arenaria* in Biology and Ecology

The soft-shell clam (*M. arenaria*) is a marine bivalve species that is native to intertidal zones along the coast of the North Atlantic Ocean (LeBlanc and Miron 2005; Ambrose et al. 2016) (Figure 3.1). Distribution of the soft-shell clam ranges from the coast of Labrador to North Carolina (Abgrall et al. 2010; Hicks and Ouellette 2011). The soft-shell clam is most abundant on the shores of New England and Atlantic Canada (Strasser 1999) and is the earliest introduced mollusk species in the North Atlantic shore (Strasser 1999), believed to have invaded the waters of the North Atlantic sometime during the Miocene.

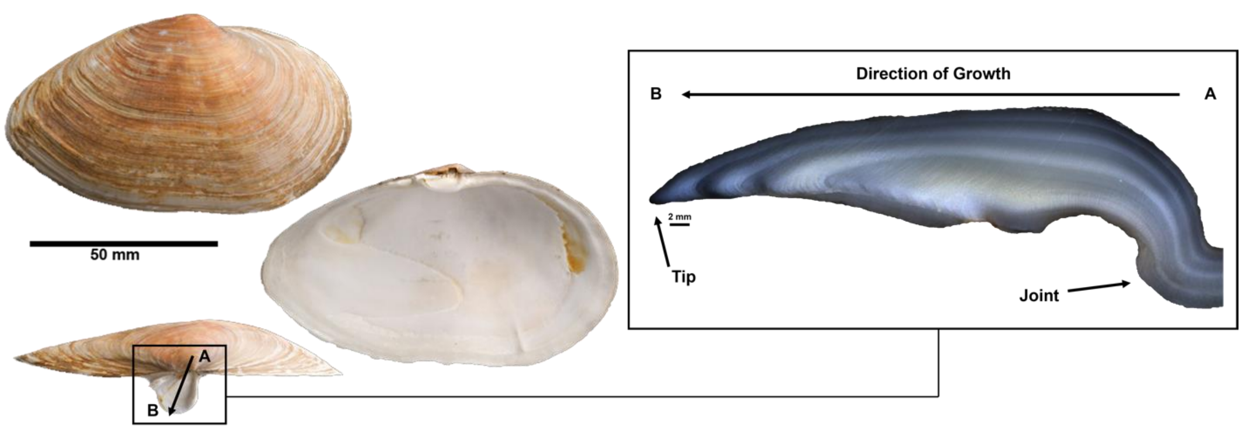

Figure. 3.1. The soft-shell clam (*Mya arenaria*) with chondrophore and cross section indicated.

M. arenaria are found in the intertidal zone in Atlantic Canada at a depth of 9m (Fisheries and Oceans Canada 1996; Abgrall et al. 2010). The distribution and abundance of *M. arenaria* is contingent on several factors, all of which are linked to the local environment. These factors include salinity, temperature, and sediment type (Strasser 1999; LeBlanc and Miron 2005; Hiebert 2015). In terms of salinity, *M. arenaria* is capable of tolerating both brackish water in estuarine environments and full salt water on ocean shores (Hiebert 2015). As Strasser (1999) and Hiebert (2015) indicated, the distribution of *M. arenaria* may be dependent on selective settlement in habitats that contain suitable sediment properties, like the grain size and the presence of sea grass. *M. arenaria* inhabit areas where water temperature is cool, however this species is also capable of tolerating waters below freezing (Hiebert 2015). This explains the abundance and distribution of *M. arenaria* along the North Atlantic coast.

The distribution and abundance of *M. arenaria* has been noted to be affected by several factors. These include predation, nutrient availability, habitat structure, light, salinity, and physical stress (LeBlanc and Miron 2005). The soft-shell clam is a dioecious organism that reach maturity at a length of about 2.5 cm and at an age of two to three years (Hawkins 1985). Like most marine bivalves, the soft-shell clam feeds on microscopic organisms, such as filamentous algae, diatoms, algal fragments, and flagellates floating in the ambient water (Hawkins1985).

The shell of *M. arenaria* can range in size from 2-150 mm, and on average, measure around 50-100 mm (Hiebert 2015). According to calculated growth curves completed by Strasser (1999) for both Europe and North America shells, maximum growth of *M. arenaria* is between 60- and 100-mm. Juvenile shells of *M. arenaria* are normally less than 2-15 mm in length, with sexual maturity occurring when individuals reach a length of 25-35 mm (Hiebert 2015). Hiebert (2015) reported that the shell of *M. arenaria* grows around 110 µm per day, with most of the shell deposition during a period of growth from March to November.

The average lifespan of the soft-shell clam seems to vary depending on geographic location. Reported in Maximovich and Guerassimova (2003:92), the lifespan of *M. arenaria* in the White Sea can range from 4 to 28 years. This differs considerably from the average lifespan of *M. arenaria* on the North Atlantic coast, which Strasser (1999) indicated to be between 10 -12 years. This further demonstrates the significant role geography plays in the growth of the soft-shell clam.

In the Atlantic Northeast *M. arenaria* has two main seasons of growth, an active season from March to November, and a season of slow growth from December to February (Hancock 1982; Hawkins1985). In the spring and summer when water temperatures are warm and there is an increase in food supply, the rate of growth in *M. arenaria* is higher. However, during the winter when water temperature is cold, growth rate decreases so much that growth is negligible (Hancock 1982:5; Hawkins1985). *M. arenaria* growth has been reported to be most rapid when it is young and slows down with age (Feder and Paul 1974; Hawkins 1985; Strasser 1999). Blackwood (2019:24) indicated that *M. arenaria* simultaneously produce two records of their local environment. The first is recorded in the chondrophore and the second is recorded in the ventral margin. The growth stored in the chondrophore produces a more condensed record of growth (Blackwood 2019:24).

Spawning season for the soft-shell clam occurs one to two times annually (Strasser 1999) and is dependent on monthly tidal cycles and water temperature (Abgrall et al. 2010). In the North Atlantic, soft-shell clam spawning begins in June and peaks in mid- July (Hiebert 2015; Abgrall et al. 2010).

Outlined in a study conducted by Hancock (1982), the soft-shell clam experiences variation in the rate of growth throughout the year that is highly correlated to water temperature. According to Hancock (1982), There are two growth seasons in *M. arenaria*, an active period from March to November and a slow period from December to February. In the spring and summer, growth in *M. arenaria* is most rapid, as water temperatures are warmer and food supply is at a maximum (Hancock 1982:12-13). As water temperature decreases, growth in *M. arenaria* slows down to almost a halt.

Previous studies have outlined considerable variation in the growth of *M. arenaria* from different locales. Maximovich and Guerassimova (2003) pointed out that they observed significant differences in average growth rates between mollusks from different locations. This was also evident in previous research conducted on *M. arenaria* from Nova Scotia and Maine by Predham (2019), where internal growth structures between the two collections of the soft-shell clam varied considerably. Additional evidence of geography playing a key role in the growth rate of *M. arenaria* was outlined in Strasser (1999: 315), who pointed out that in Alaska, it took *M. arenaria* 6 to 7 years to reach a size of 51 mm, while it took only 1.5 years to reach this size in Connecticut. During growth, the range of salinity the soft-shell clam requires to survive can vary. Ideally, it thrives in salinity of around 25 to 35 parts pers thousand and at temperatures from 6°C to 14°C (Hawkins 1985).

3.2 *Mya arenaria Modern Fisheries*

3.2.1 Atlantic Canada

In Atlantic Canada, the soft-shell clam is harvested commercially, recreationally, and traditionally, and is the most harvested clam species in the region (Abgrall et al. 2010). Commercial use of the soft-shell clam in Atlantic Canada began in the mid-1800's to supply bait for the Grand Banks fishery (Hawkins 1985). By 1950 a more domestic-based industry had developed, with landings reaching upwards of 10,000 metric tons (Hawkins1985). Today, the soft-shell clam remains an important resource for modern fisheries along the North Atlantic coast. Specifically in the Scotia-Fundy region (Hawkins and Rowell 1984; Beal 2002; Abgrall et al. 2010; Hicks and Ouellette 2011). As outlined in various Department of Fisheries and Oceans reports (Hawkins 1985; Freeman 1997), the commercial fishery of the soft-shell clam in Atlantic Canada and Maine has a complex history, one that has seen many peaks and drastic declines.

3.2.2 Nova Scotia

In Nova Scotia, the soft-shell clam has been harvested commercially since around the turn of the 20th century (Hawkins 1985), with formal catch records from the Department of Fisheries and Oceans dating to the late 1800’s (Chandler et al. 2001). Like other provinces in Atlantic Canada, the harvesting methods of the commercial soft-shell clam industry in Nova Scotia have remained the same since the early days of the commercial fishery, using traditional methods with hand picks and tools (Hawkins 1985; Hicks and Ouellette 2011).

Outlined in Sullivan (2007), the Annapolis Basin region has a rich history of being one of the major focal points of soft-shell clam harvesting in both the modern fishery, as well as a point of indigenous harvesting as well. Sullivan (2007) reports that information regarding the commercial soft-shell clam fishery in the Annapolis Basin pre 20th century is limited. The beginnings of the commercial fishery post-contact in this region of Nova Scotia began sometime during the mid-1800’s (Sullivan 2007). However, at the time, clams were rarely used for sustenance, instead being used for bait.

3.2.3 New Brunswick

In New Brunswick, the soft-shell clam continues to be significant to local fisheries, both socio-economically and ecologically. The soft-shell clam in New Brunswick is of major importance to local ecosystems and commercial and recreational fisheries, however, recent publications have indicated that an increase in harvest pressure has led to decreasing clam stocks (Hicks and Ouellette 2011).

As of 2010, over 600 commercial clam fishing licenses were issued nearly every year in eastern New Brunswick (Abgrall et al. 2010). In 2003, the mean annual landing value of the commercial soft-shell clam fishery in New Brunswick was estimated to be around $700,000 (Fisheries and Oceans Canada 2005; Abgrall et al. 2010). In New Brunswick, clams are still harvested traditionally by locals, by hand or with picks, clam hoes and shovels. As of 2011, the catch limit for the recreational fishery was 100 soft-shell clams per day. Additionally, both the recreational and commercial fishery must only harvest soft-shell clams that are over, or equal to 50 mm in size (Hicks and Ouellette 2011).

3.2.4 Maine

In Maine, the soft-shell clam has been harvested commercially year-round since the mid -1800's and still serves as a highly important commercial resource (Beal 2002). In Maine, commercial harvesting of the soft-shell clam has seen a steady decrease. In 2016, Beal et al. (2016) reported that over the past four decades, the commercial production of *M. arenaria* in Maine has decreased some 75%. Chandler et al. (2001) reported that the pattern of gradual decrease in the past century in soft-shell clam stocks observed in the Bay of Fundy has also been seen in Eastern Maine.

3.3 *Mya arenaria* in Archaeological Studies of Settlement and Subsistence

The shells of *M. arenaria* are composed entirely of calcium carbonate derived from local water (CaCO3; aragonite), making them soft, thin, and fragile (Hiebert 2015; Blackwood 2019). This makes the valves of *M. arenaria* thin-walled and prone to damage, especially along the outer margin (Lightfoot et al. 1993). Therefore, growth patterns are poorly preserved in the valve, making it an unreliable resource for age estimation. This has led to a shift in focus from the outer growing edge which is primarily used for age estimation in most other bivalve species, to examine the growth information stored within the hinge, or the chondrophore, of the soft-shell clam. The history of *M. arenaria* in archaeological contexts is a complex one. While this species did not receive any substantial attention until the 1980's, it has been present in archaeological investigations. As *M. arenaria* have been known to be an important resource for indigenous groups along the coasts of Atlantic Canada to New York, any excavation that occurred at a shell midden along these coasts would have contained the shells of the soft-shell clam. However, it was not until the latter half of the 20th century that this species was given any substantial archaeological attention.

The first use of the soft-shell clam in archaeological studies using incremental growth analysis came in the early 1980's when Barber (1982; 1983) and Hancock (1982) analyzed shells of *M. arenaria* to determine season of harvest at sites in New England. Due to their existence only in hard copy, I had no access to these studies. However, in a review paper published by Lightfoot and Cerrato (1989) on the current state of mollusk growth studies in archaeology along the New England coast, they give mention to what these three studies investigated. According to Lightfoot and Cerrato (1989), the two studies by Barber (1982; 1983) were undertaken at two Maritime Woodland shell midden sites in Massachusetts. Likewise, Hancock's (1982) study examined shells of the soft-shell clam from a Late Woodland shell midden site in Maine. Unfortunately, the specific methods used to examine the growth structures of these shells were not explained in Lightfoot and Cerrato's (1989) study. This study by Lightfoot and Cerrato (1989) is notable as it shows the first focus on the soft-shell clam as a source of seasonality information in Atlantic North American archaeology.

Inspired by the potential shown by previous studies using the soft-shell clam for seasonality, Lightfoot and Cerrato continued their work with *M. arenaria*, refining the ways this shell should be visualized in archaeology. In 1991, Cerrato published the first major investigation into the internal growth structures of the soft-shell clam for archaeological purposes. Outlined in detail in previous research (Predham 2019), Cerrato et al. (1991) analyzed thick sections of *M. arenaria* chondrophore to test its structural utility in preserving tidal and seasonal patterns. While other studies using sclerochronological analysis on mollusks at the time were using the growth lines deposited within the growing edge of the shell, Cerrato et al. (1991) turned their attention to the chondrophore. This study represented the first demonstration of the presence of seasonal growth information stored within the chondrophore of *M. arenaria*. The the methods used for visualization in this study were flawed due to a misunderstanding of internal growth structures within the chondrophore coupled with inadequate image quality. This led to discrepancies in their interpretations of annual growth lines. Despite this, this study still served as a step forward in how we visualize this species using sclerochronology.

The work established in Cerrato et al. (1991) continued in Lightfoot et al.'s (1993) study on *M. arenaria* shells from two shell middens in New York. Lightfoot et al. (1993) built on previous work (Cerrato et al. 1991) that stated the chondrophore must be used when using the shells of the soft-shell clam for sclerochronological analysis. Lightfoot et al. (1993) reported that they found that the most effective method for observing growth patterns in the chondrophore of *M. arenaria.* Lightfoot et al. (1993) stated that preparing sections ground between 80 to 250 microns in thickness was the best way to visualize micro growth within the chondrophore.

While the methods used in these early investigations into the internal growth structures of the soft-shell clam are outdated, they still serve as a benchmark for studies utilizing the soft-shell clam for growth line analysis.

Although *M. arenaria* saw considerable attention from the sclerochronology community in the early 1990's, research on the species in archaeological contexts completely stalled for nearly two decades. In 2014, *M. arenaria* once again gained the attention of both the archaeological and sclerochronological community, with a publication from Meghan Burchell and coauthors on shells of the soft-shell clam from Port Joli, Nova Scotia. This publication was the first of numerous works that would examine the plentiful assemblage of *M. arenaria* shells collected from the many middens at Port Joli as part of the E'se'get archeological project.

Burchell et al. (2014b) examined the micro-growth patterns observed in the chondrophore and stable oxygen isotope analysis to test *M. arenaria*'s utility in estimating seasonality. Reflecting on the previous work of Cerrato et al. (1991) and Lightfoot et al. (1993), Burchell et al. (2014b) aimed to reassess the methods used in these studies for age estimation. While these earlier studies used thin sections for visualizing growth lines, their images were poor and growth lines could not properly be identified. Burchell et al. (2014b) used thick sections instead, producing images that were much clearer, with distinct identifiable annual growth lines present. However, their study faltered here, as their estimation of age of the shells they examined were incorrect due to misinterpreting what defines an annual growth line in the chondrophore of *M. arenaria*. This is seen in their explanation of figure 6 (Burchell et al. 2014: 103), where they show a thick section of a chondrophore that has 19 +/- 2 years of growth. This estimation is incorrect, as this sample only has about six definite annual lines. The reason for their erroneous findings is due to a lack of understanding of the precise information that is stored within the chondrophore. Within the chondrophore of *M. arenaria*, several distinct growth indicators can be observed, such as annual, sub-annual and spawn lines, however, if you are unable to distinguish between these indicators, it can be very difficult to determine an accurate age of a shell. This is the overall pattern seen in the several decades worth of sclerochronological research on *M. arenaria*, a general lack of understanding what exact information is stored within the chondrophore, and how exactly to identify it.

Ambrose et al.'s (2016) study from Maine focused on sclerochronology of the soft-shell clam to generate proxy data on the season of harvest of archaeological shells. Ambrose et al. (2016) used live-collected modern *M. arenaria* to determine the timing and pattern of growth line deposition in this species. In terms of methods, this study made considerable progress when it comes to visualizing growth lines in the soft-shell clam. Ambrose et al. (2016) analyzed both archaeological and live collected modern *M. arenaria* shells from Malaga Island, Maine, to determine harvesting strategies of the Malaga Island community from 1860 to 1912. The Malaga Island shell middens primarily consisted of the shells of the soft-shell clam. Ambrose et al. (2016) utilized annual growth lines in *M. arenaria* to determine time of death, and by proxy, age of harvest. To determine the season of harvest in *M. arenaria*, Ambrose et al. (2016) used incremental growth assessment to estimate the amount of expected growth completed in the harvest year.

Modern *M. arenaria* shells were live-collected nearby Malaga Island in Maquoit Bay, Brunswick, Maine. Archaeological samples were collected from midden deposits at two domestic areas at the Malaga Island site. Contents and matrix of both middens suggest that one deposit was likely from a commercial processing area, due to the abundance of whole-shell and fish remains, while the others matrix points to the household refuse midden. In total, 146 archaeological shells were examined between both midden deposits. Ambrose et al. (2016) suggest that their results indicate that, in future research, changes in harvest location should be considered when considering changes in the size, age, and growth of archaeological shells.

CHAPTER 4

MATERIALS AND METHODS

4.1 Port Joli Harbour Shell Middens

Port Joli Harbour represents the densest concentration of shell midden sites across all of Nova Scotia, containing eighteen identified sites (Betts et al. 2017; Betts 2019). All eighteen of these sites are within only eleven km of coastline and an area of less than 20 km^2 (Betts 2019). Port Joli Harbour has two concentrations of shell middens, one on the eastern shore and another on the western shore. The eastern shore sites are AlDf-1, AlDf-2, AlDf-3, AlDf-4, AlDf-11, AlDf-12, and AlDf-13. The western shore consists of, AlDf-6, AlDf-7, AlDf-8, AlDf-24, AlDf-25, AlDf-26, AlDf-27, AlDf-28, AlDf-30, AlDf-31, AlDf-35. Due to coastal erosion and considerable private development, the shell middens on the eastern shore are highly disturbed and have seen much less archaeological attention (Betts 2019). The western shore on the other hand contains several large shell middens that have seen considerable archaeological attention. The complex of shell middens on the western shore are the focus of this research.

In Betts' (2019) book regarding the entirety of the E'se'get Archaeology Project, Betts describes each site, how it was excavated and the distinct strata and matrix of each deposit. For this research, I will only summarize his reports on the sites that I have used shells from. These include AlDf-8, AlDf-24, AlDf-25, AlDf-30, and AlDf-31.

Upon completion of the E'se'get Archaeology Project and review of each site, Betts (2019:112) created a site typology for distinct shell midden deposits at Port Joli. This typology consists of five distinct shell midden sites. Only three of these distinct midden types are relevant for this research. The first midden type is classified as being "large shell midden mounds" that are categorized as being intensive shellfish processing sites (Betts 2019). These sites are typically greater than 300m2 and sit around 30m of the high-water mark. Betts (2019:112) reports that these middens are unique to Port Joli relative to other shell middens in the Northeast. What makes these deposits so unique is that they consist almost entirely of whole clam shells, with little to no artifacts. Both AlDf-24 and AlDf-25 are examples of these sites.

The second midden type found at Port Joli are classified as “large shell-bearing black soil deposits” and identified as recurring dwelling sites (Betts 2019). These sites contain large quantities of lithic debitage and crushed shell. AlDf-8 is an example of this site type. Site type three is also classified as being a “black soil midden”, however, these sites are much smaller and identified as interior campsites near freshwater, being found between 140 and 400 m from the coastline (Betts 2019). The key difference between the second and third site type is that while they both contain a black soil, site type 3 has very little shell content. Examples of this site type are AlDf-30 and AlDf-31.

4.1.1 AlDf-8

Described by Betts (2019:58), AlDf-8 (Figure 4.1), or Lower Path Lake Brook, is a large mixed organic deposit site with a black soil matrix that contain small amounts of crushed shell, artifacts and animal remains. In comparison to the other large midden sites on the western shore of Port Joli, the shell matrix of AlDf-8 is much less dense (Betts 2019:58). Due to the high frequency of lithic debitage, charcoal and burned materials paired with compact black soil-deposits, Betts (2019:62) surmised that AlDf-8 was a location where multiple wigwam floors had been placed and which had seen intensive interior occupation.

Figure 4.1. AlDf-8 facing northeast. © Matthew Betts, used with permission.

4.1.2 AlDf-24

AlDf-24 (Figure 4.3), known to the Mi'kmaw as Epte'jijg Utju'sn Gta'nogewa, which translates to "warm breeze by the ocean", is possibly the largest intact shell midden site in Nova Scotia (Erskine 1962; Betts 2019:78). AlDf-24 was first archaeologically investigated in 1990 by Stephen Powell as part of a survey for the Thomas Raddall Provincial Park (Betts 2019). This large shell midden sits 50 m from the shore on a low terrace and small headland, lying between two large clam flat beaches (Betts 2019:78). AlDf-24 is made up of four distinct areas: Area A, Area B, Area C and Area D. In the assemblage of shells from Port Joli used in this research, shells from AlDf-24 made up the bulk, with a total of 1224 chondrophores across areas A and C, making up 56% of all chondrophores in this assemblage.

Area A (Figure 4.2), defined as a large, oval shaped, flat-topped shell mound covers over 300 m^2 and is about 20 x 15 in area, making it the largest area identified at AlDf-24 (Betts 2019:78). Despite substantial looting at Area A, this midden yielded substantial stratigraphic and matrix preservation, a matrix that contained significant amounts of large, whole clam shells, so much so that some parts of the matrix had very little soil at all (Betts 2019:82). Reflecting on David Sanger's (1996:523) categorization of a shell-bearing deposit that contains almost entirely large, whole shells, as well as the previous suggestion by John Erskine that AlDf-25 was a "clam drying site", a type of site that is only found at Port Joli Harbour in all of the Maritime Peninsula, Betts (2019:91) concluded that Area A was an intensive, special-purpose area for shellfish procurement at Port Joli for the Mi'kmaw.

Figure 4.2. Excavation of AlDf-24A. © Matthew Betts, used with permission.

Based on a small test pit excavation in 2009, and early observations by John Erskine, the E'se'get Archaeology team concluded that AlDf-24 Area C represented a complex of dwellings (Figure 4.3) (Betts 2019:91). Area C is described as a small, shallow "black soil deposit" that contains a small, highly disturbed shell midden on its eastern margin (Betts 2019:79). This small test pit yielded many artifact-rich layers (Betts 2019:91), that they concluded to indicate the presence of several dwelling features in Area C. Following the initial 2009 test pit excavation, the E'se'get Archaeology team conducted a large-scale excavation of Area C to investigate these dwelling features. Their excavation uncovered two distinct deposits, a small shell midden, and a complex of numerous house floors that contained significant cultural material (Betts 2019:92). Betts (2019:95) suggested that the dense concentration of house floors and artifacts indicates that this site was used for generations by the Mi'kmaq.

Figure. 4.3. Excavation of AlDf-24C. © Matthew Betts, used with permission.

The remaining two areas of AlDf-24 are Area B and Area D (Figure 4.4). Both these areas received much less attention due to being small and containing minimal cultural material. Area B is described as 15 cm deep shallow shell midden with black soil deposits of large amounts of organic, charcoal-rich soil and some finely crushed shell (Betts 2019:78). Area D on the other hand, is not a shell midden at all, rather, it is an undisturbed, small 10 cm deep thin shell-bearing site with dark black soil that contains some sparse, finely crushed shell (Betts 2019:79).

Figure 4.4. A) AlDf-24 facing west, subject is standing on midden. B) AlDf-24 facing southwest, subject is standing on midden C, with D in background. © Matthew Betts, used with permission.

4.1.3 AlDf-25

One of the largest shell middens located on the western shore of Port Joli Harbour is AlDf-25 (Figure 4.5), or Scotch Point. This site sits directly adjacent from a large clam flat and consists of a large kidney shaped mound that rises 1.5 to 2 m above the ground some 35 m from the shoreline (Betts 2019:71). In contrast to other large shell midden sites at Port Joli, AlDf-25 is overgrown with foliage, which as Betts (2019:74) suggested indicates extensive disturbance over time. A focus for the E'se'get Archaeology Project when investigating AlDf-25 was confirming the original report from John Erskine on the site. Upon completion of three field seasons between 1957 and 1962, Erskine (1962; Betts 2019:74) suggested that AlDf-25 was likely the largest undisturbed shell midden site in Nova Scotia. Furthermore, Erskine (1962; Betts 2019:74) described the site as a very large shell midden with "untrampled clam-shells of unusual size". Following excavation of a 1 X 1 test unit, the E'se'get Archaeology team confirmed John Erskine's original findings at AlDf-25, stating the large midden mound at the site is in fact a deep refuse deposit that contained extensive amounts of whole shells, as well as animal bones and pottery, with little to no lithic materials (Betts 2019:78).

Figure 4.5. AlDf-25 facing west. © Matthew Betts, used with permission.

4.1.4 AlDf-30 and AlDf - 31

Both AlDf-30 and AlDf-31 (Figure 4.6) were first investigated by Thomas Raddall during his surveys of the South Shore in the mid-1930's. From 1935 and 1938 Raddall conducted preliminary excavations on both sites, in what he called "Jack's Brook" (Betts 2019:96). AlDf-30 is a unique shell midden to the area, as it sits some 300 m inland from the shore in a dense forest (Betts 2019:96). From 2008 to 2010, two distinct shell mounds within AlDf-30 were excavated and found to contain rich deposits of fragmented and whole shells, animal bones and artifacts surrounded by organic dark soil deposits (Burchell 2014b; Betts 2019). Adjacent to AlDf-30, AlDf-31 also sits some 300 m inland from the shoreline and contains two shell middens amongst black soil deposits (Betts 2019).

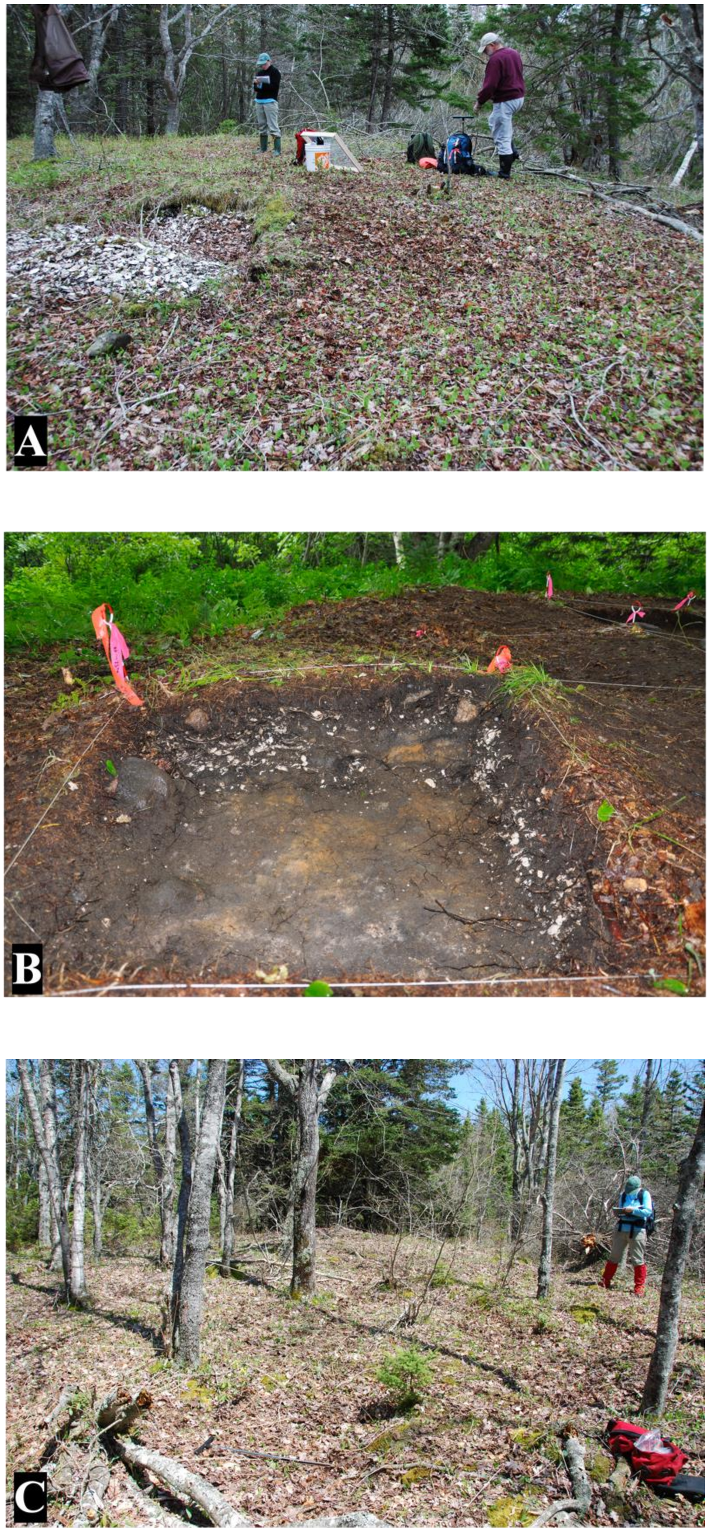

Figure 4.6. A) AlDf-30 facing east. Test Unit A prior to excavation. B) Excavation of AlDf-30 C) AlDf-31 Facing West. © Matthew Betts, used with permission.

4.2 Sample Selection for Rapid-age-at-death Assessment

This collection of *M. arenaria* shells are made up of two different assemblages: an archaeological assemblage from Port Joli, Nova Scotia and live collected shells from Advocate Harbour and Parrsboro, Nova Scotia (Figure 4.7).

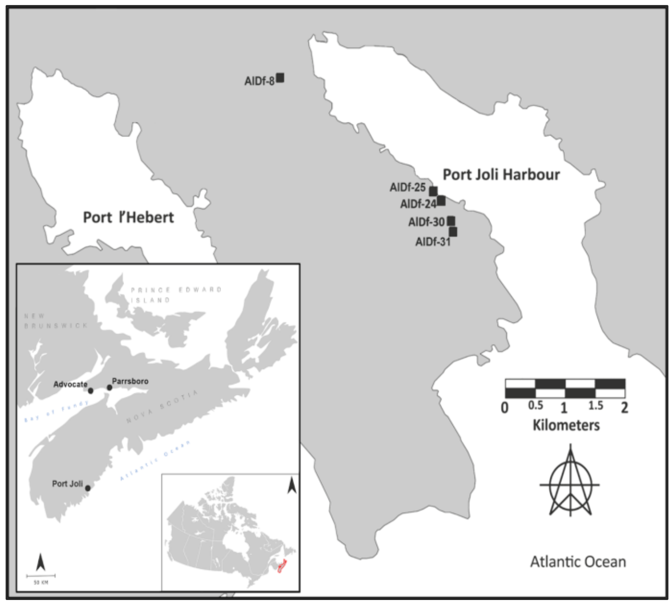

Figure 4.7. Inset map: Map of study area (Nova Scotia, Canada) showing location of archaeological shells (Port Joli) and live collected shells (Advocate and Parrsboro). Primary map: Map indicating shell midden sites used in analysis at Port Joli, NS.

4.2.1 Live-Collected Shells

Live-collected *M. arenaria* were obtained in July 2019 from Advocate Harbour and Parrsboro, Nova Scotia (Table 4.1). Archaeological shells from Nova Scotia came from six sites in Port Joli Harbour and were excavated between 2008 and 2012.

Table 4.1. Live collected date from Advocate Harbour and Parrsboro, Nova Scotia. Shells collected in July 2019.

Site	Samples	Date Collected
Advocate Harbour	32	7 - 29 - 2019
Parrsboro	16	7 - 30 - 2019

4.2.2 Archaeological Sample for Rapid-age-at-death

A total of 100 archeological chondrophores with pristine preservation were selected from multiple layers/depths from six sites: AlDf - 8, AlDf - 24A, AlDf - 24C, AlDf - 25, AlDf - 30 and AlDf - 31 (Table 4.3)

Table 4.2. Total number of chondrophores from each site at Port Joli Harbour, Nova Scotia.

Site	Chondrophores
AlDf - 8	101
AlDf - 24A	476
AlDf - 24C	748
AlDf - 25	290
AlDf - 30	178
AlDf - 31	374
Total	**2167**

4.3 Shell Preparation & Analysis

4.3.1 Preparation & Imaging

Shells were washed in cold water and then cut using a Dremel hand saw (Figure 4.9). Cut valves were then mounted on glass slides using epoxy and cut to 3mm using a Buehler IsoMet 1000 Precision Saw. Sections were then ground and polished on a Buehler MetaServ 250 withSiC Grit (320/P400), SiC Grit (600/P1200) and Texmet Polishing Cloth. Polished chondrophore sections were examined under a ZEISS Axio Zoom.V16 Telecentric Microscope using reflected light under 17 - 22 x magnification.

Figure 4.8. Shells from Port Joli Harbour being washed and prepped for analysis. Photos by the author

CHAPTER 5

RESULTS

To test rapid age-at-death assessments and to test the fidelity of seasonality estimates based on shell growth patterns, four independent observers, trained in sclerochronology, each analyzed 100 shell images from six archaeological sites from Port Joli. By having four different observers, the rate of error can be calculated to better refine analyses using growth patterns in the softshell clam. Observer 1 is a master's student working with *M. arenaria*, Observer 2 has a PhD in isotope sclerochronology and has worked with multiple bivalve species, Observer 3 is a PhD student and has worked with *Saxidomus gigantea* and *Leukoma staminea, and* Observer 4 is a master's student who works with *Crassostrea virginica*. All four observers can make thin and thick sections of bivalve shells and are able to produce high-resolution images of shell growth, but the observers have different expertise in species and sub-speciality of sclerochronology (e.g., geochemistry, seasonality, SEM) (Figure 5.1).

Below the results of rapid-age-at-death assessments are presented using tables and figures to illustrate the variation between all four observers. Data presented here represent the several factors that were considered during rapid-age-at-death assessments. These include: the overall visual quality of shells, the portion of shell counted, season of collection, relative and absolute age. Inter-site data is also presented to demonstrate the variance observed in shells from across all six sites.

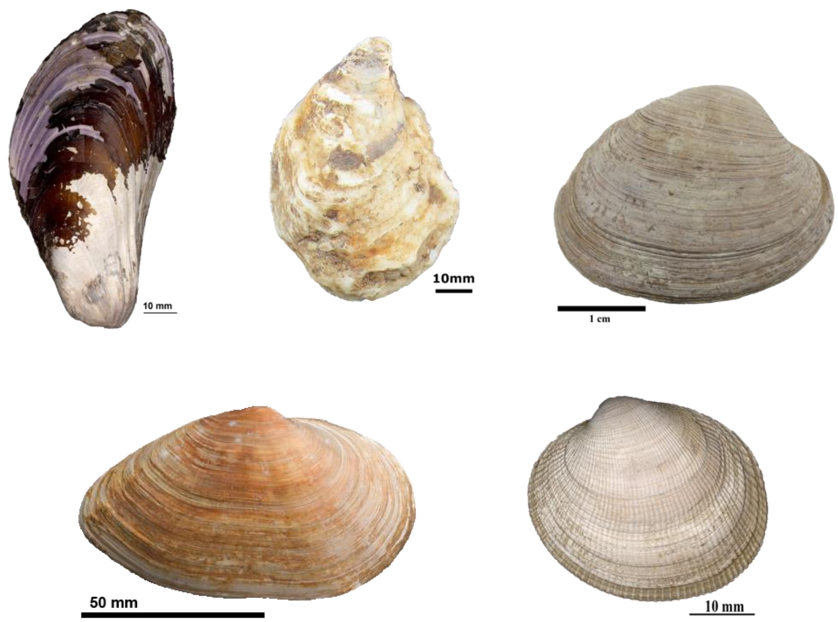

Figure 5.1. Examples of each species of bivalve that all four observers have experience in sclerochronology with. A) *M. arenaria* B) *Saxidomus gigantea* C) *Leukoma staminea* D) *Crassostrea virginica*.

5.1 Evaluating Shell Image Quality and Readability

Overall, the images observed tended to fall into the 'good' and 'fair' category (Table 5.1) (Figure 5.2) (Figure 5.3). When combined, 43% of images were 'good', 41% were 'fair' and 17% were poor. Since most images were considered 'readable' this built confidence in the methods used to prepare the shells for growth line counting.

Table 5.1. Quality of shell Images by observer by number

	Good	Fair	Poor
Obs. 1	45	42	14
Obs. 2	40	36	24
Obs. 3	42	40	18
Obs. 4	45	45	10

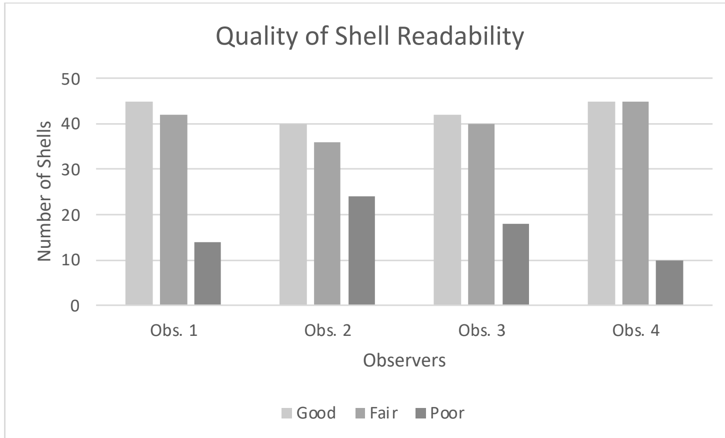

Figure 5.2 Distribution of shell readability quality identified by each observer.

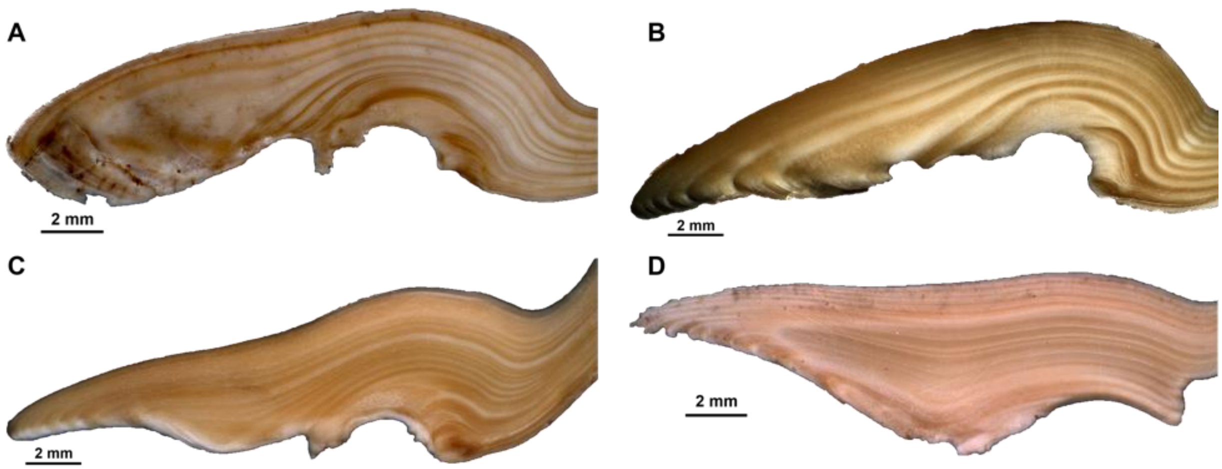

Figure 5.3. Examples of four archaeological thick sections from Port Joli, NS with varying levels of preservation and readable growth structures. A) AlDf-8-11: whole chondrophore with unreadable growth, B) AlDf-24A-25: pristine chondrophore with readable growth at both the direction of growth and the joint axis, C) AlDf-24C-1: some readable growth at the joint axis but not at the direction of growth, D) AlDf-30-1: no readable growth at direction of growth or the joint axis due to poor preservation.

All four observers read most shells at the joint axis, where the growth lines were concentric, and there was less 'noise' from the sub-annual lines that are visible along the growing edge of the chondrophore (Table 5.2) (Figure 5.4) (Figure 5.5). Overall, all observers preferred the joint axis or the counting growth lines. This is surprising when compared to previous studies that used this species for age-estimation where primarily the growing edge was used. There is no discernable pattern between the experience, and the preference for where the growth lines were counted.

Table 5.2. Portion of shell counted (total chondrophore joint axis and growing edge).

	Joint Axis	Growing Edge
Obs. 1	54	17
Obs. 2	70	23
Obs. 3	53	35
Obs. 4	77	19

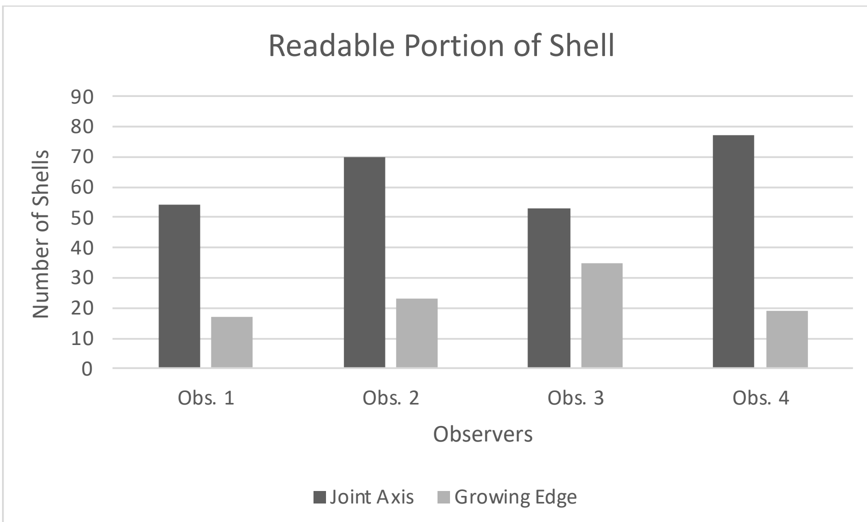

Figure 5.4. Distribution of the portion of shell used to estimate age by each observer.

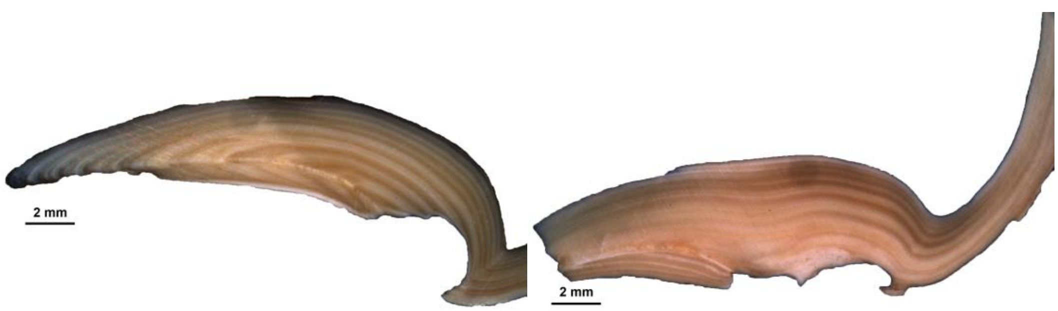

Figure 5.5. Examples of shells with readability only present in the growing edge and the joint axis. Left) AlDf-24A-29 - readability only present in the growing edge. Right) AlDf-24C-10 - readability only present in the joint axis.

5.2 Evaluating Seasonality

Since ~80% of the images were readable, we also tested to see if the four independent observers were able to read seasonal patterns of collection (Table 5.3). This was based on the colouration and distribution of the final area of growth on the growing edge of the shell. Overall, there is a difference between the confidence of observers, indicating that this is not a reliable method for rapid seasonality estimates. Here, we observe the ‘novice effect’, where the least experienced observers were more optimistic with their estimates of seasonality versus the most experienced observer who was more conservative with their estimates. This is likely due to Observer 2 having the most experience validating seasonality through shell growth and stable isotope analysis.

Table 5.3 Seasonality estimates based on shell growth color/line by observer.

	Number of Shells Read
Obs. 1	43
Obs. 2	21
Obs. 3	89
Obs. 4	57

Although not as precise or monthly, or seasonal collection, we also tested if it was possible to identify a warm or cold season of collection based on growth lines (Table 5.4) (Figure 5.6) (Figure 5.7). There are discrepancies between the total number of shells that each observer could read and which temperature they fell into. Overall, ‘warm’ season of collection was identified more frequently than ‘cold’ season of collection by all four observers. Observers 1 and 2 have the most experience with this species, and while the number of ‘cold’ shells is similar (6 and 7, respectively), Observer 1 identified 37 shells as ‘warm’ whereas Observer 2 only identified 14. Again, Observer 3 was the most conservative, and the least conservative estimates were from the reviewers who had not previously worked with this species. This suggests that it's possible to identify warm vs. cold collection, but it is not reliable since only a portion can be 'read' for temperature (e.g., Observer 3 could only read 21/100 shells).

Table 5.4 Warm vs. cold season of collection.

	Warm	Cold	Total
Obs. 1	37	6	43
Obs. 2	14	7	21
Obs. 3	65	24	89
Obs. 4	47	10	57

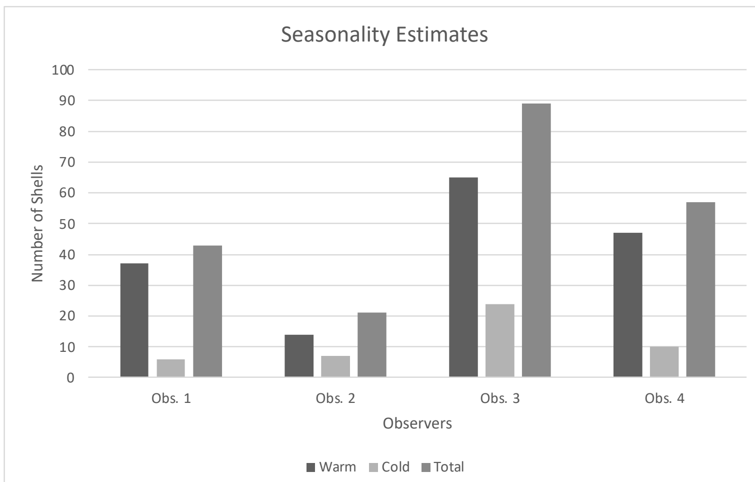

Figure 5.6. Graph showing the distribution of warm vs cold estimates from each observer.

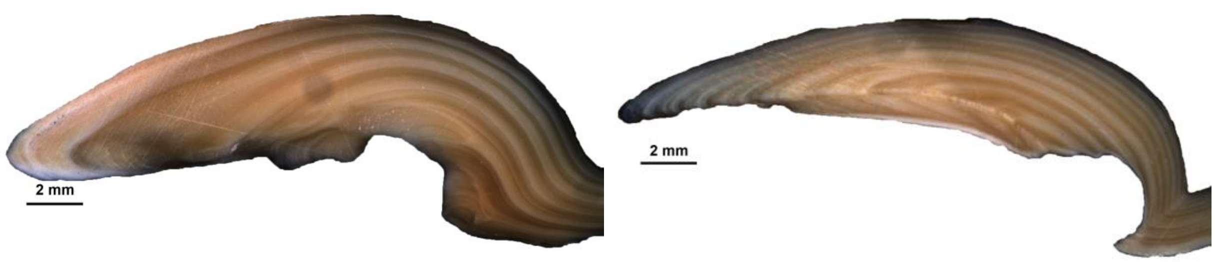

Figure 5.7. Examples of *M. arenaria* thick sections captured during warm and cold seasons. Left) AlDf-24A-19: Example of a shell collected during warm season as the final area of growth on the growing edge is light. Right) AlDf-24A-29: Example of a shell collected during cold season as the final area of growth in the growing edge is dark

5.3 Relative and Absolute Age Estimates

To interpret patterns between sites, observers tested to see how many shells could be read to identify ‘mature’ (younger) or ‘senile’ (older) patterns of growth (Table 5.5) (Figure 5.8) (Figure 5.9). Shells in a ‘juvenile’ phase of growth were noticeably smaller and had less than four visible growth lines. Juvenile shells exhibit dark annual growth lines widely spaced across the thick section of the shell at both the growing edge and joint axis. Mature shells were identified as having four to 10 visible growth lines. characterized by 4 or more annual growth lines. Mature shells look like juvenile, however additional dark annual lines are present. Senile shells are characterized by 10 or more annual growth lines. Senile growth is identified through a clutter of annual growth lines deposited at both the growing edge and the joint axis. Shells that had patterns that did not fit into the categories are classified as ‘unknown’ (Figure 5.8).

Table 5.5. Number of shells in relative age categories by site.

	Juvenile	Mature	Senile	Unknown
AIDf-8	0	52	43	5
AIDf-24-A	0	66	33	1
AIDf-24C	0	49	51	0
AIDf-25	0	39	56	4
AIDf-30	0	36	61	4
AIDf-31	0	32	65	4

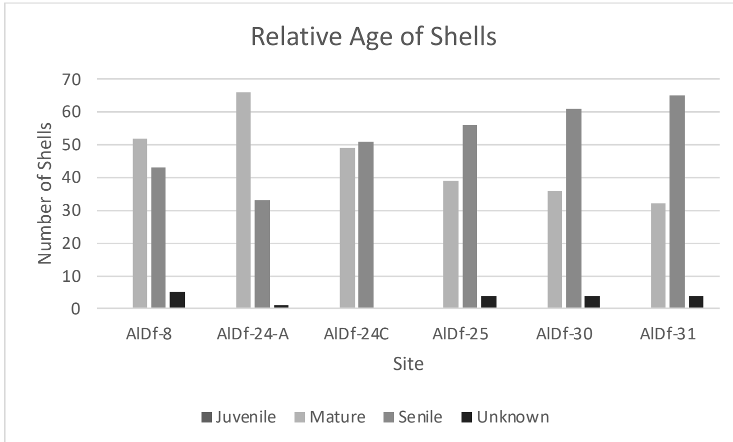

Figure 5.8. Graph showing the relative age distribution across each site.

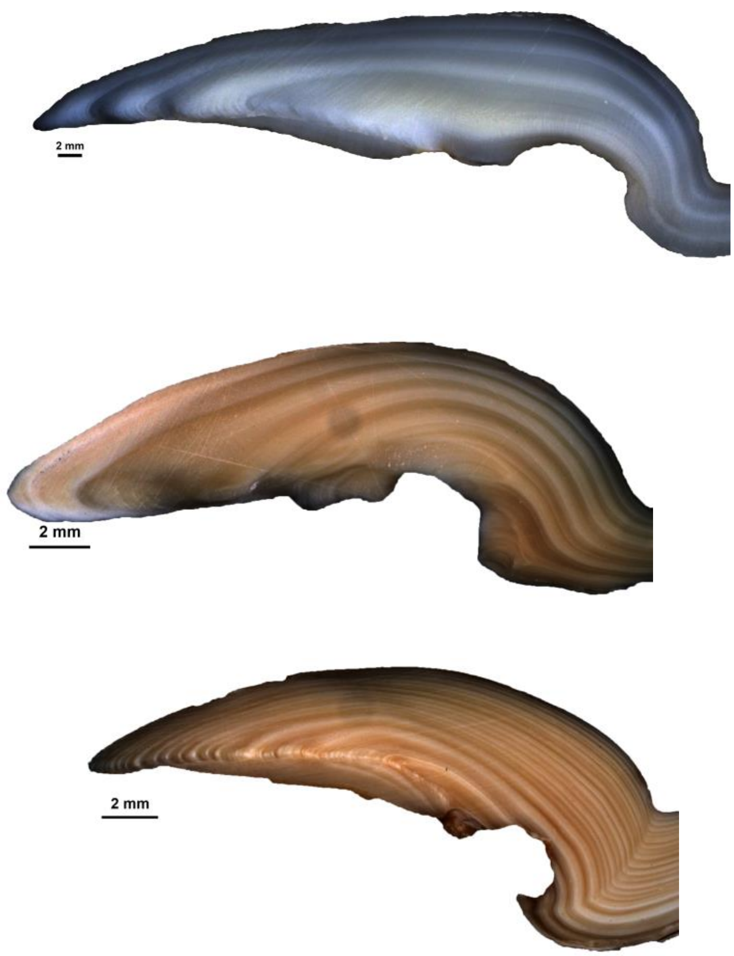

Figure 5.9. Examples of three shells captured at varying ages. Top) Juvenile (live collected July 2019 from Parrsboro, NS), Middle) Mature (AlDf-24A-19), Bottom) Senile (AlDf-24A-39).

The results show that there is no clear pattern between observers' expertise and identifying relative ages of shells. However, there are patterns between the Observers. Observers 2 and 4 identified mature and senile shells similarly. However, it is important to note that reviewers adjusted some of their mature and senile counts after counting lines. Some reviewers relied on the joint axis for counting growth, while others relied on the growing edge, this introduces variables that can influence how someone categorizes a growth line. Overall, it is difficult to reliably identify the distinction between mature and senile shells in *M. arenaria*.

Overall, all four observers had very good agreement with the maximum age, the minimum age, and the overall average age for all shells (Table 5.6). The maximum age had an error of 2.5 years, whereas the minimum age had an error of 1 year. The average age of all shells ranged between 9.41 and 10.39 years.

Table 5.6 Overall average age estimates between four observers.

	Age				**Error**			
	Max	**Min**	**Average**	**Range**	**Max**	**Min**	**Average**	**Range**
Obs. 1	24	4	9.41	20	5	1	1.92	4
Obs. 2	25	3	10.01	22	5	1	1.65	4
Obs. 3	26.5	3.5	10.39	23	5	0	2.5	5
Obs. 4	24	3	9.42	21	5	1	2.19	4

5.4 Results by Individual Sites

To interpret shellfish harvesting and the potential to use rapid age-at-death assessments in Port Joli, four observers assessed the variability in readability, seasonality, relative age, and absolute age across all five sites examined. Site specific patterns can help infer on differences in between sites regarding preservation, growth, and harvest pressure. It is important to identifying any differences in growth patterns between sites as good 'readability' will improve the precision of the age estimate, and subsequently, the interpretation of shellfish use at the site. To determine which site(s) has the best reliability the average percent of ‘good’ vs. ‘poor’ quality shells was calculated.

AlDf-24A has the best quality of readable shells - followed by AlDf-25 (Table 5.7) (Figure 5.10). There is a considerable drop in quality after this with AlDf-24C, AlDf-8, AlDf-31, and AlDf-30. AlDf-24A only had 4% of shells labeled as having poor visual quality. AlDf-30 has the worst quality of readable shells with 43% of shells labeled as poor and essentially unreadable. There are site-specific growth patterns that make shells from some sites ‘easier’ to read. There is a range, where there are some sites with easy readability (AlDf-24C, very poor AlDf-31).

Table 5.7 Overall number of shells classified as ‘good’ or ‘poor’ from each site.

	Good	Poor
AlDf-8	19	23
AlDf-24-A	74	4
AlDf-24C	28	19
AlDf-25	41	21
AlDf-30	11	43
AlDf-31	14	25

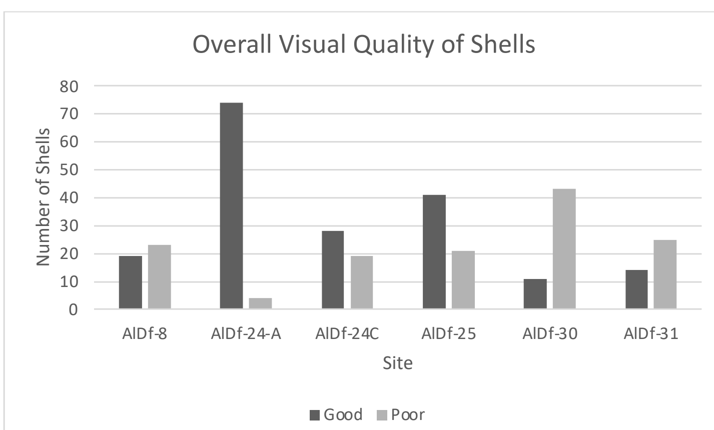

Figure 5.10. Graph indicating the overall quality of shells from each site.

Interpreting the season of collection (warm vs. cold seasons) showed significant variability between observers (Table 5.8). Specifically, between Observers 3 and 4. These observers were less experienced with reading *M. arenaria* lines than Observers 1 and 2. With this in mind, only the seasonality data collected by observers 1 and 2 were used in this assessment. Observers did not include any shells with an unknown season of collection. Only shells with distinct warm and cold markers were counted. Although this reduced the sample of 'readable' shells significantly, there are some consistent seasonal assessments between Observers 1 and 2. However, the reduction in sample sizes does not provide any meaningful results that would determine seasonal patterns of collection. However, site AlD-24A, the site with the best preserved and readable shells, does indicate a pattern of a warm season of collection. Season of collection estimates could not be determined from AlDf-30 and AlDf-31 due to poor preservation of shells, leading to poor image quality.

Table 5.8. Number of shells by site and observer by warm/cold collection.

	AlDf-8		AlDf-24A		AlDf-24C		AlDf-25		AlDf-30		AlDf-31	
	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold
Obs. 1	2	1	33	0	0	3	2	2	0	0	0	0
Obs. 2	0	1	10	4	1	2	3	0	0	0	0	0
Obs. 3	6	4	23	11	17	2	11	5	3	1	5	1
Obs. 4	5	1	16	9	12	0	10	0	2	0	2	0

To understand relative harvest pressure, observers identified shells as juvenile, mature, senile, unknown (Table 5.9) (Figure 5.11). Although there is spread between the observers at some sites for some age classifications (e.g., AlDf-8 OB2 vs OB3 = 22%), the average assessment across all four reviewers can still be used as a rudimentary interpretation of levels of harvest pressure between sites.

Table 5.9 Relative age-at-death based on the average percentage by four observers.

	Juvenile	Mature	Senile	Unknown
AlDf-8	0	52	43	**5**
AlDf-24A	0	66	33	**1**
AlDf-24C	0	49	51	**0**
AlDf-25	0	39	56	**4**
AlDf-30	0	36	61	**4**
AlDf-31	0	32	65	**4**

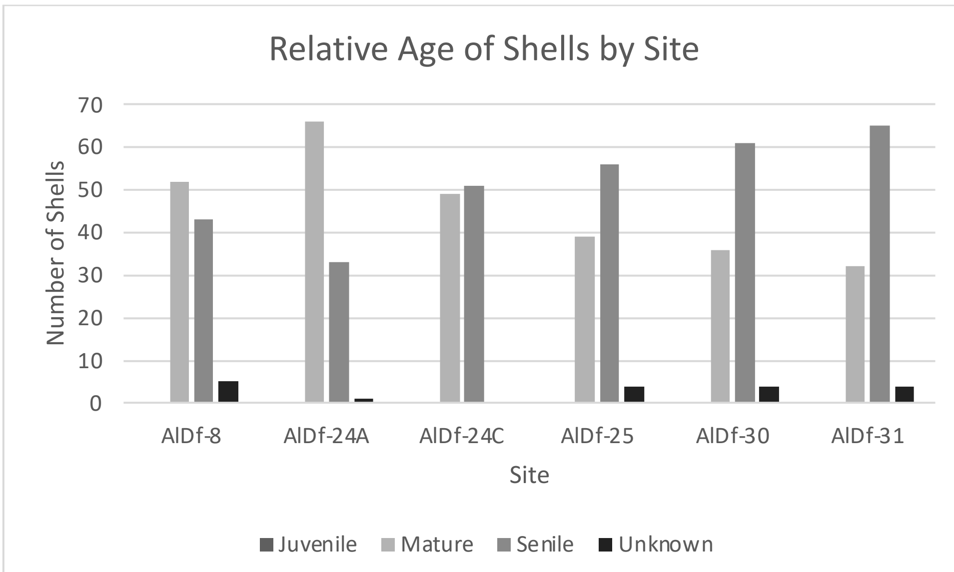

Figure 5.11. Graph showing the relative age distribution of shells from each site.

To refine the relative levels of harvest intensity observed through growth analysis, observers count the individual growth lines and recorded the error. Table 5.10 and Figure 5.12 show a good agreement across all four observers for the average age of the shells from each site, as well as the error.

Table 5.10 Average age distribution by growth line counts, by site and by observer.

	Age	Error
AIDf-8	8.2	1.9
AIDf-24-A	9	1.6
AIDf-24C	10.2	2.2
AIDf-25	11.1	2.1
AIDf-30	9.8	2.5
AIDf-31	11.8	3.1

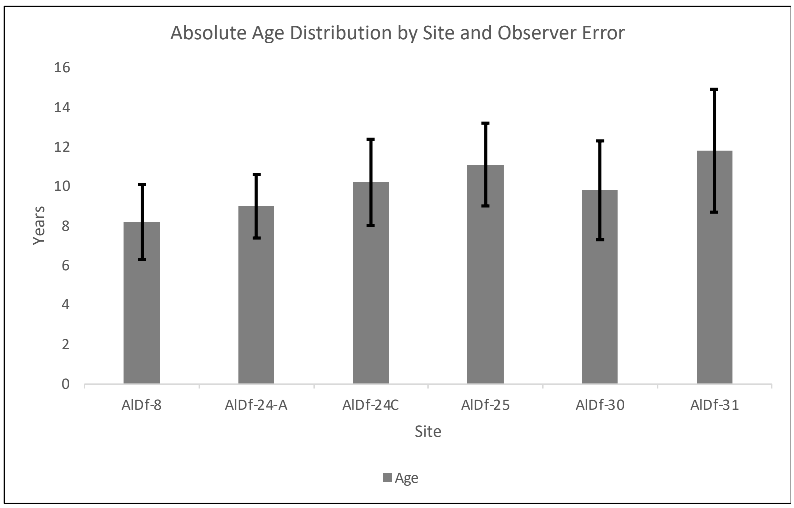

Figure 5.12. Graph showing the absolute age distribution of shells by site with observer error.

CHAPTER 6

DISCUSSION AND CONCLUSION

The results of this thesis demonstrate the ability to use rapid-age-at-death assessments on archaeological specimens of *M. arenaria* to interpret past shellfish harvesting practices. However, several factors must be considered before undertaking such a study. When it comes to the most accurate portion of the shell for growth line analysis, the chondrophore is critical. Due to *M. arenaria* having a thin, and highly fragile shell frequently prevents preservation of whole valves in shell middens; ventral margin (last period of growth) portion of the shell is often absent in archaeological deposits. However, the chondrophore is almost always found intact, therefore, the chondrophore is preferred for assessing age, but not seasonality in *M. arenaria*.

6.1 Diagenesis and Preservation

Variability in the structural quality of *M. arenaria* plays a major role in the ability to reliably prepare and this species for sclerochronological analysis. Large sample sizes are critical for meaningful interpretation. In the assemblage of 100 shells used in this study, shells from sites with poor preservation (AlDf-8; AlDf-30; AlDf-31) contained no readable shells for rapid-age-at-death assessments. This is a problem if sample sizes are limited, as the majority or your samples may end up being unreadable. Therefore, hand picking the most pristine samples from specific sites with ideal preservation is recommended for future studies using *M. arenaria*. For example, the assemblage of shells from AlDf-24 contained many whole clam shells and exhibited the most pristine preservation, which is likely related to the increased density of shell deposition at this site compared to AlDf-30 and AlDf-31.

6.2 Effects of Sample Preparation and Visualization

This research showed that methods for accurately visualizing *M. arenaria* growth records are easily replicated with effective preparation and equipment. Thick sections (3mm) are sufficient for visualizing growth in this species and serves as a cost effective and efficient method for analyzing the large sample sizes needed for meaningful interpretation with *M. arenaria*. Images taken under reflected light reveal growth structures clearly for rapid age-at-death assessments. The difference in visual quality between thick and thin sections was negligible, growth structures were seen clearly and similarly in both (Figure 6.1). This can be a challenge if you are producing a large collection of thin sections, as it is highly time consuming. Thick sections, however, offer a more cost and time effective, sufficient method for visualizing growth in the chondrophore of *M. arenaria*. Overall, thick sections, with powerful digital microscopy are faster, and more reliable than thin sections with transmitted light.

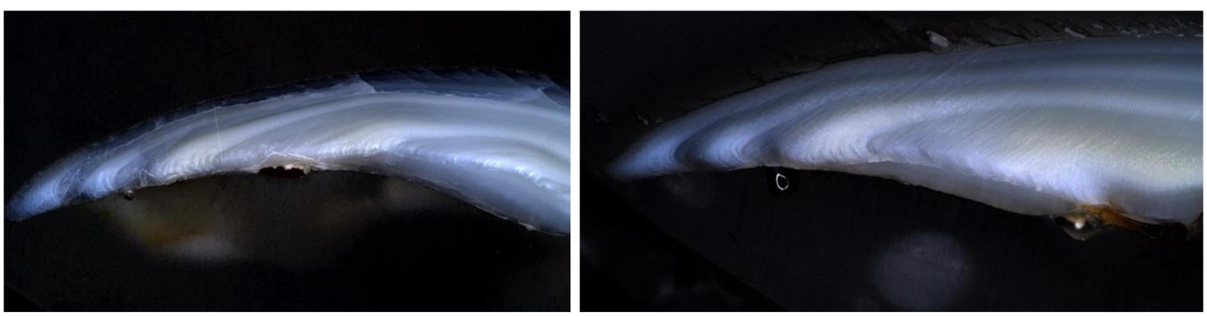

Figure 6.1. Examples of both thin and thick sections of a *M. arenaria* specimen from Parrsboro, NS collected in July of 2019. Left) Live-collected thin section of *M. arenaria* from Parrsboro, NS. Right) Live-collected thick section of *M. arenaria* from Parrsboro, NS. In both sections, clear dark annual lines of growth can be defined and identified.

6.3 Inter-observer variability and Sclerochronology

Inter-observer variability was prevalent throughout the results of rapid-age-at-death assessments. Due to varying degrees of experience with examining *M. arenaria* growth, some shells were interpreted differently by all four observers. Specifically, when estimating seasonality, observers had difficulty confidently identifying warm and cold seasons of collection. This is due to both lack of experience with recognizing the season of capture in *M. arenaria*, as well as issues with preservation. However, when it came to assessing age-at-death, there was significant agreement across all four observers. Considering that two of the observers (3 and 4) had very little experience assessing age in *M. arenaria* at the time of rapid-age-at-death assessments, yet their assessments did, in fact match observers 1 and 2. This is encouraging for future studies that want to employ large-scale rapid-age-at-death assessments on *M. arenaria* using observers with varying degrees of experience with *M. arenaria*.

6.4 Sclerochronology and Age Estimates in *M. arenaria: Relative age vs. Growth Stage*

Ontogenetic age counts for both relative (mature/senile) and absolute age determination are consistent across all four observers. Considering all four observers had varying degrees of experience with sclerochronology, it is conclusive that *M. arenaria* can be used for rapid age-at-death assessment when using a set criterion for identifying annual growth lines for both relative and absolute age determination. However, it is important to note that there are discrepancies when comparing relative age assessments to absolute age assessments. When looking at relative age assessments of *M. arenaria* in this study, it is fair to say that these assessments are accurate, but not precise. *M. arenaria* is not an ideal species compared to *Saxidomus gigantea*, or *Leukoma staminea* (Cannon and Burchell 2009; Kuehn 2018) (Figure 6.2). When assessing relative age, distinguishing between mature and senile shells in *M. arenaria* can be difficult. This is largely due to overall preservation of shells. It is often that near the edges of the joint axis and growing edge, lines get considerably disorderly, and it can be difficult to accurately determine how many distinct annual growth lines are present. This was common in our analysis, as if a shell displayed disorderly lines between the clearly defined growth, an estimate of +/- # was used. Even with high image quality, it can be still difficult to clearly distinguish between mature and senile shells.

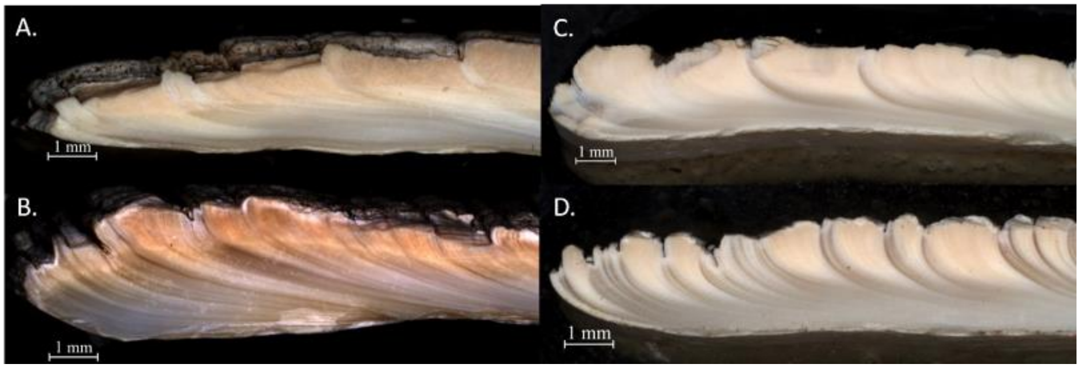

Figure. 6.2. Examples of varying age profiles in the ventral margin of two bivalve species, *Saxidomus gigantea* and *Leukoma staminea*. A) mature growth stage in *L. staminea*, B) senile growth stage in *L. staminea*, C) mature growth stage in *S. gigantea*, and D) senile growth in stage *S. gigantea* (D). Figure modified from Kuehn 2018.

The most reliable method for rapidly assessing the age-at-death of *M. arenaria* is absolute age. Results of rapid-age-at-death assessments showed that observers were able to identify annual growth lines in *M. arenaria* thick sections with confidence (Table 5.6). These assessments will be much more precise, and interpretations of a large sample will be more meaningful.

6.5 Estimating Seasonality

When interpreting seasonality in *M. arenaria* using rapid visual assessments, it was not possible to identify seasons of harvest following previous studies by (Lightfoot et al. 1993; Burchell et al. 2014; Ambrose et al. 2016; Blackwood 2019). The variability in growth patterns between sites was problematic since consistent patterns based on shell growth cannot be identified at this resolution. There is distinct variability present in growth and preservation of shells between all six sites examined. This leads to variability of visual quality in growth lines that then impacts the ability to accurately determine seasonality. Future studies using *M. arenaria* in Port Joli should use shells collected from AlDf-24A, as this site exhibits the most pristine preservation, with observers able to identify season of collection on most shells examined, however, confirmation through stable oxygen isotope analysis is essential to confirm growth patterns at AlDf-24.

6.6 Interpreting Shellfish Harvesting at Port Joli

Results from rapid-age-at-death assessments of *M. arenaria* can contribute to previous interpretations of human activity at sites in Port Joli Harbour and further confirm and validate such interpretation. Patterns of past Mi'kmaq shell fishing harvest pressure can be interpreted based on the varying distribution of ages at each site. However, while confident interpretations can be made at sites with a larger sample size and high quality of specimens, sites that exhibited a lesser quality of preservation and visual quality of *M. arenaria* specimens, interpretations must be cautioned.

Across the six sites from Port Joli Harbour examined here, clear patterns of harvesting pressure can be interpreted based on the relative and absolute age estimates produced from rapid-age-at-death assessments. At sites that were classified as intensive shellfish processing and dwelling sites (AlDf-24A, AlDf-24C and AlDf-25), interpretations can be made in confidence due to high degrees of preservation and visual quality. Likewise, sites that were classified as being interior camps (AlDf-8, AlDf-30 and AlDf-310), interpretations vary due to issues with preservation and visual quality.

Across all sites zero juvenile shells were harvested. As juvenile clams have very little meat, these clams would have been chosen to not be harvest until ample size for maximum sustenance.

From looking at the seasonality and age data produced here as result of rapid-age-at-death of *M. arenaria* shells from Port Joli, interpretations can be made that validate and confirm Betts (2019) hypothesis based on the fauna data collected during the E'se'get Archaeology Project.

6.6.1 AlDf-24A and ALDf-24C

Of all sites examined here, AlDf-24A provides the greatest opportunity for site-specific interpretations based on age-at-death and seasonality assessments due to the highest degree of preservation. AlDf-24A is classified as being an intensive shellfish processing midden, this interpretation from Betts (2019) based on the E'se'get Archaeology Project is confirmed and validated here when considering these results.

At AlDf-24A, 66% of shells were classified as being of mature age. This suggests a higher intensity of harvest pressure at this site. This confirms Betts (2019) hypothesis that based on excavations at the site and the sheer number of whole clams in the matrix, that this site was certainly a high intensity shellfish processing site. This hypothesis is based on the extensive size of the midden deposits at AldF-24A and the occurrence of rapid accumulation within the midden that was confirmed by radiocarbon dates (Betts 2019). The resulting age profile produced here from rapid-age-death assessments confirms this as shells examined from AlDf-24A were mostly mature in age, suggesting intensive harvesting at the site.

Additionally, shells from AlDf-24A almost all fell into the category of warm season of collection. This indicates that this site was used heavily in the spring and summer for harvesting clams. The abundance of warm collected shells present in the assemblage from AlDf24A suggests that people gathered at this specific site in the Harbour during the spring and summer to harvest and process shellfish. It is clear that AlDf-24 was a designated shellfish processing site for the indigenous groups that frequented the south shore in the middle woodland period.

Like AlDf-24A, shells from AlDf-24C exhibited pristine preservation. 51% of shells from AlDf-24C were identified as being senile. As shells from this site are essentially evenly split between mature and senile, it is difficult to draw any concrete conclusions from age data.

However, the presence of more senile shells at the site does align with Betts (2019) description of the site. Betts (2019) outlines that the shell midden at AlDf-24C sits below, and next to the house floor layers, with clear discernible areas of domestic waste deposit. Additionally, stratigraphy of AlDf-24C suggested sequential dwelling surfaces over generations, showing the permanency and long-term use of AlDf-24C as a living space at Port Joli (Betts 2019:95). As AlDf-24C is characterized as a series of dwelling sites, contrasting AlDf-24A which is a clear shellfish processing midden, the presence of many senile shells is customary of a site that is not solely a dedicated space for shellfish collection and process.

Regarding seasonality of the shells from AlDf-24C, almost all shells examined were identified as being captured during the warm seasons. Observers three and four were much more confident in estimating seasonality in shells from AlDf-24C, while observers one and two were very cautious, to the point were combined they only identified season of collection in six shells. This is problematic as observers three and four are the least experienced when it comes to identifying seasonality in *M. arenaria*. Therefore, it is difficult to draw any conclusive interpretations regarding season of capture of the shells collected from AlDf-24C. However, as AlDf-24C is identified as being a dwelling feature related to AlDf-24A, it is likely that shells collected from this site would have been collected in the warm season and consumed in the house floors at this site. This would line up with Betts (2019) hypothesis of AlDf-24C being a dwelling site related to AlDf-24A. Shells were being harvested from the beach, processed, and ate at AlDf-24A, as well as consumed in living spaces, such as AlDf-24C.

6.6.2 AlDf-8, AlDf-25, AlDf-30, and AlDf-31

Looking at the other sites from Port Joli Harbour examined here, it is difficult to assert any interpretation with confidence regarding the seasonality data for sites AlDf-8, AlDf-25, AlD-30, and AlDf-31 as shells from these sites exhibited the least degree of preservation and visual quality, leading to skewed and in some cases, impossible, assessments of season of collection. To validate interpretations of these sites, larger sample sizes is recommended for working with these sites.

At AlDf-8, classified as a large black soil interior camp midden site, preservation was sufficient for interpretation. Shells from this site were split almost evenly between mature and senile ages, with 52% mature, 43% senile and 5% unknown. Even though this is a small sample size, the greater presence of mature shells does indicate a more intensive harvesting pressure for this site. As this is an interior camp site, this suggests that clams were being harvested frequently near this site and brought back to the interior for consumption.

Preservation does however play a role in interpreting seasonality at AlDf-8. Due to such issues with preservation, observers were hesitant to distinctly classify shells from this site as either a warm or cold of capture. While more shells were classified as being collected in the warm season, I would caution asserting any meaningful interpretations based on these data. A larger sample size from this site would be needed for meaningful interpretation of seasonality.

Interestingly, while AlDf-25 is classified as being a large shell midden and categorized as being an intensive shellfish processing site, specimens from this site did not yield results on par with the two sites from AlDf-24. This is likely due to the heavy disturbance within the midden itself and on the surface (Betts 2019). Shells from AlDf-25 were mostly senile with 56% of all shells examined classified as senile. This indicates that despite the classification of this site being a shellfish processing site, shells were not as intensively harvested at this site in comparison to AlDf-24A.

Shells from AlDf-25 primarily were classified as being collected in the warm seasons. However, these data seem to be skewed due to observer inexperience and preservation quality. Observers one and two, who were the more experienced observers with *M. arenaria*, were only able to conclusively identify seasonality in seven shells total. Observers three and four who are less experienced with *M. arenaria* were able to seemingly identify seasonality in almost all shells examined from this site. This suggests that no meaningful interpretations should be drawn from these data.

AlDf-30 and AlDf-31 are both kitchen middens with areas of black soil features that are found secluded from habitation sites (Betts 2019). Of all sites examined from Port Joli Harbour, AlDf-30 and AlDf-31, exhibited the worst levels of preservation. These issues in preservation are reflected in the limited data produced from the shells examined from these sites. Therefore, limited interpretations can be drawn. However, of the shells that were able to be conclusively aged, almost all were senile shells.

This is interesting considering Betts (2019) indicated these sites, especially AlDf-30 exhibited considerable deposits of whole shells. The presence of whole shells should suggest similar preservation to that seen at AlDf-24, however shells from AlDf-30 and AlDf-31 exhibited the worst preservation overall. The reason for this poor preservation is puzzling and no definite conclusion can be made using the age and seasonality data here. It is recommended that future studies investigate these sites further using larger sample sizes.

Like the attempts made at estimating seasonality from shells collected from AlDf-25, shells associated with AlDf-30 and AlDf-31 were essentially all unreadable. Therefore, no meaningful interpretations can be made regarding season of collection for shells from these sites.

6.7 Recommendations for Future Research at Port Joli

To conduct site-level interpretations at Port Joli, future studies must consider the connection between preservation of shells, human activity and shellfish harvesting. Incorporating this into future research design utilizing *M. arenaria* for isotope sclerochronology, seasonality and sea surface temperature reconstruction will validate interpretations on site-level shellfish harvesting patterns.

From rapid age-at-death analysis across six shell middens, clear patterns in preservation and visual quality are exhibited between sites at Port Joli. Shells examined for visual analysis from what Betts et al. (2019) classified as large shell midden mounds (AlDf-24 and AlDf-25), contained the most pristine preservation and visual quality. In contrast, shells examined from black soil middens (AlDf-30 and AlDf-31) were entirely unreadable. This indicates that, soil matrix and site formation play a major role in the preservation of *M. arenaria* post-deposition. Issues of preservation directly correlate to issues in visual quality.

Varying degrees of preservation exhibited in shells between sites suggests that soil matrix plays a key role in a shell's visual quality. Shells from AlDf-24A, which is classified as being a midden unique to the region in that it consists almost entirely of whole clam shells, clearly had the best visual quality. Shells from this site were pristine, with all 35 shells chosen for rapid-age-at-death assessment having perfect preservation for visual analysis. Likewise, shells that were recovered from middens labelled as "black soil middens", showed the worst preservation and visual quality. Shells from black soil middens (AlDf-30 and AlDf-31) were visually unreadable. Black soil middens are highly common along the coasts of Atlantic Canada, the shells from these sites cannot be relied upon for visual analysis. This adds additional importance to the presence of the large shell midden mounds unique to Port Joli, as the shells from these middens are abundant, as large sample sizes are essential for meaningful interpretation of harvest pressure and seasonality studies using *M. arenaria.*

6.8 Conclusion

M. arenaria can be used for rapid assessment of age and can be used to infer on harvest pressure but a sample size of over 100 shells per site is required to be able to interpret the difference between sites with meaningful interpretation. Human activity impacts the ability to use *M. arenaria* in analysis. There is a correlation between visual quality and post-depositional context. It is important to consider that the size of the chondrophore does not always indicate high visual quality, as all live collected samples were much smaller than archaeological shells, yet the live-collected samples displayed pristine visual quality.

When using *M. arenaria* for age at death and seasonality studies, it is imperative to work with a robust assemblage and select the most pristine chondrophores available. In Atlantic Canada this is particularly important as many sites in this region contain the black soil middens mentioned here that lead to poor preservation and poor visual quality. Poor visual quality and inconsistent assessments between observers will lead to skewed interpretations. For future studies using *M. arenaria* at Port Joli, stable oxygen isotope analysis should be employed in future studies to validate the timing of growth line formation and season of shellfish collection.

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APPENDIX I: Additional tables from rapid-age-at-death assessments.

Table 1. Relative age-at-death based on the average percentage by four observers.

	AlDf-8		AlDf-24A		AlDf-24C		AlDf-25		AlDf-30		AlDf-31	
	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold
Obs. 1	2	1	33	0	0	3	2	2	0	0	0	0
Obs. 2	0	1	10	4	1	2	3	0	0	0	0	0
Obs. 3	6	4	23	11	17	2	11	5	3	1	5	1
Obs. 4	5	1	16	9	12	0	10	0	2	0	2	0

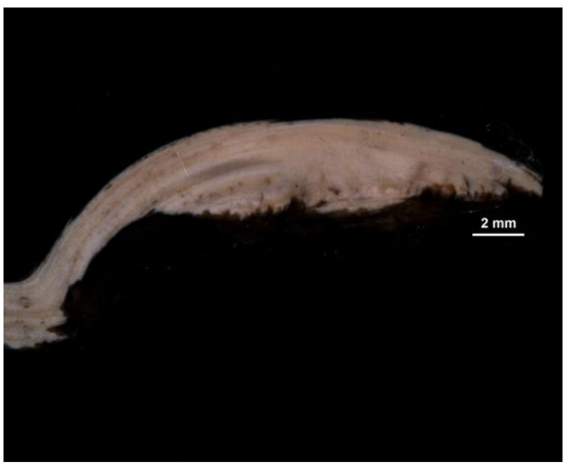
Table 2. Age distribution by growth line counts, by site and by observer.

	AlDf-8		AlDf24-A		AlDf-24C		AlDf-25		AlDf-30		AlDf-31	
	Age	Error	Age	Error	Age	Error	Age	Error	Age	Error	Age	Error
Obs. 1	6.67	1.78	8.69	1.55	9.47	2.11	11.19	1.94	11	2.5	11	2.86
Obs. 2	9.78	1.25	8.74	1.29	10.35	2.15	11.88	1.69	9.67	2	11.71	2.57
Obs. 3	8.18	2.36	9.73	1.94	11.4	2.85	11	2.7	9.93	2.86	13	3.57
Obs. 4	8.3	2.1	9	1.6	9.6	2.6	10.2	2.1	8.4	2.6	11.5	3.3
Average	8.23	1.87	9.04	1.60	10.21	2.43	11.07	2.11	9.75	2.49	11.80	3.08

APPENDIX II: All *M. arenaria* thick sections analyzed for rapid-age-at-death assessments.

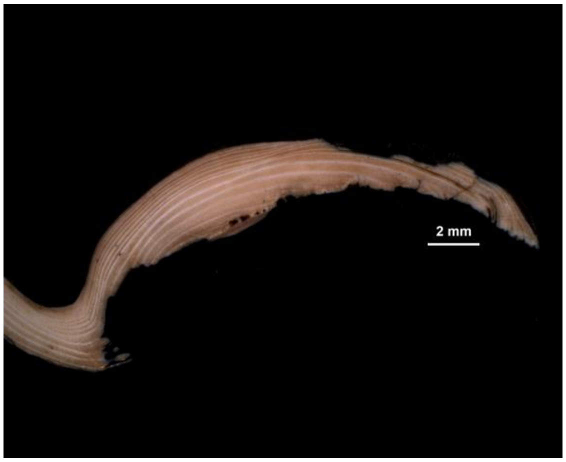
AlDf-8-1

AlDf-8-2



AlDf-8-3

AlDf-8-4



AlDf-8-5

AlDf-8-6

AlDf-8-7

AlDf-8-11

AlDf-8-12

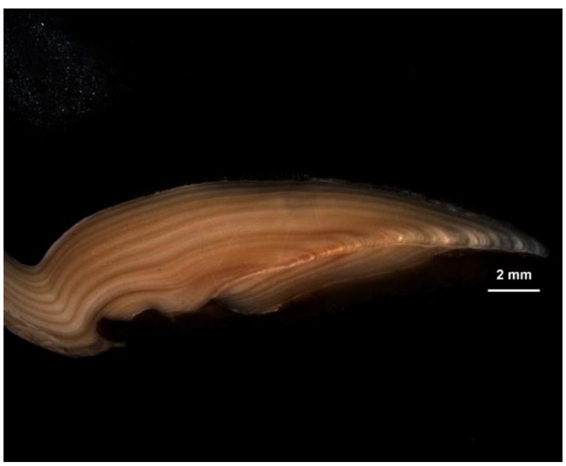
AlDf-8-13

AlDf-8-14

AlDf-24A-1

AlDf-24A-2

AlDf-24A-3



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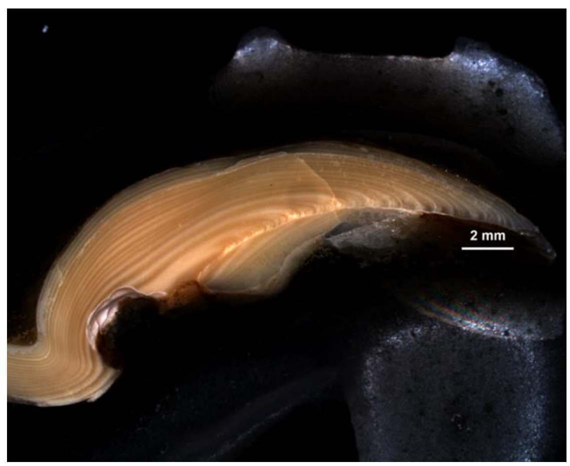
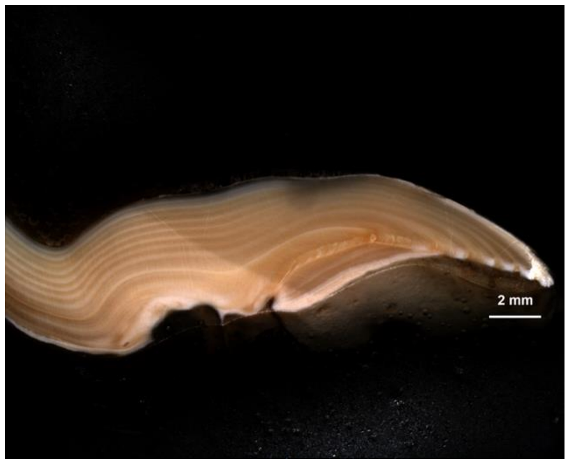


AlDf-24A-5

AlDf-24A-6

AlDf-24A-7

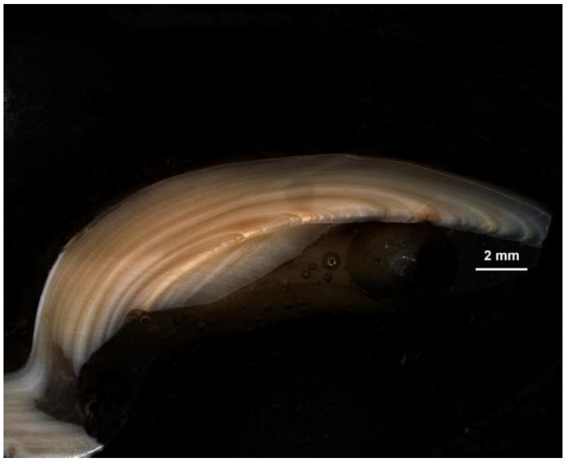
AlDf-24A-8



AlDf-24A-9

AlDf-24A-10

AlDf-24A-11



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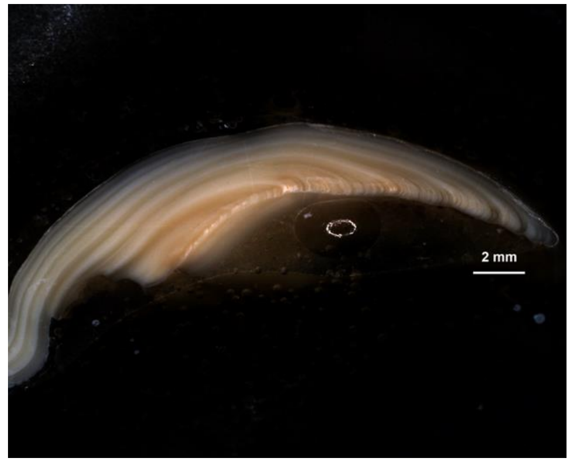

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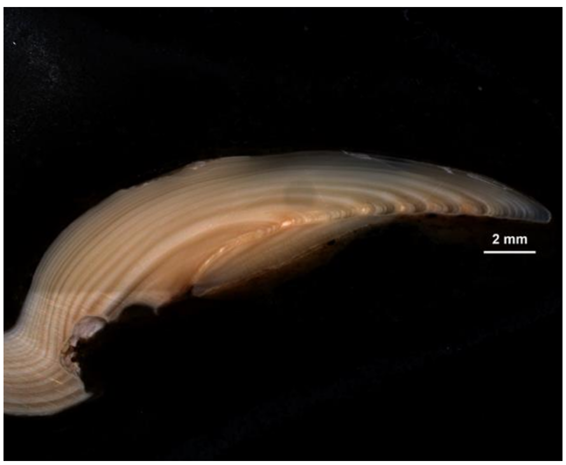
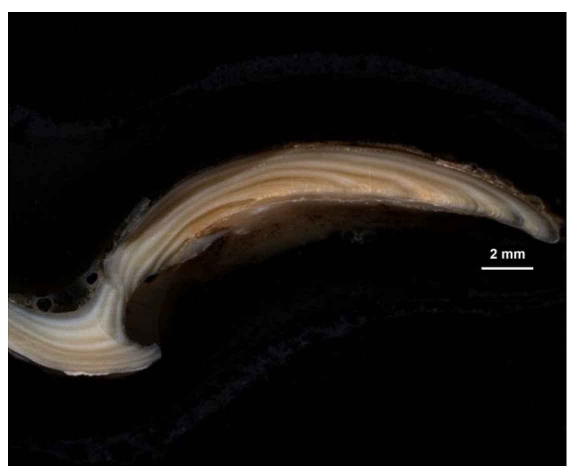


AlDf-24A-14

AlDf-24A-15

AlDf-24A-17



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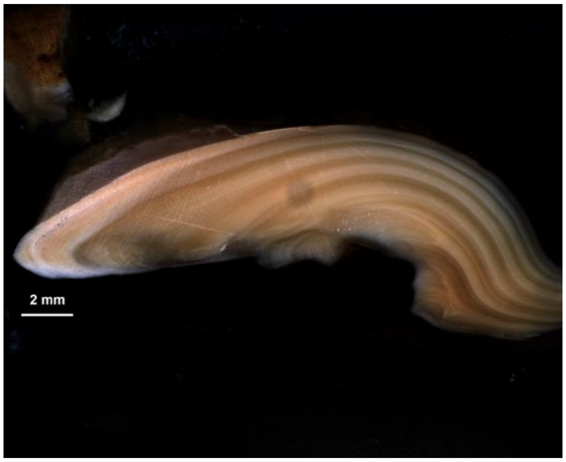

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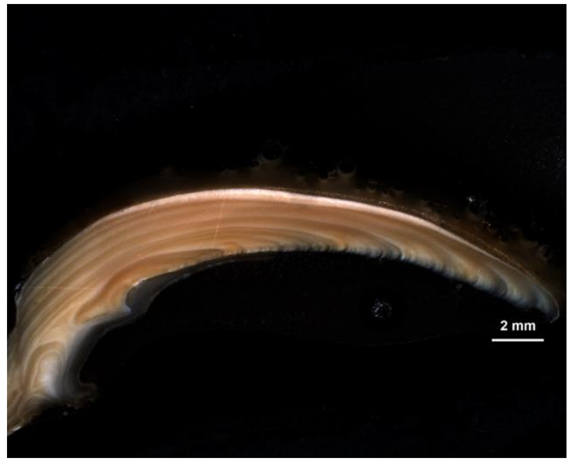

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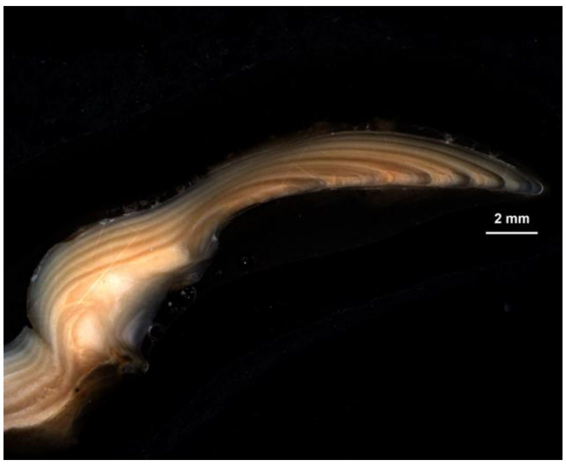


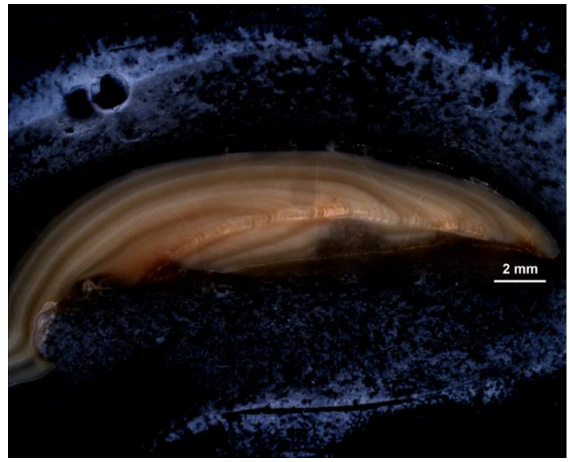
AlDf-24A-22

AlDf-24A-23

AlDf-24A-24

AlDf-24-25

AlDf-24A-26



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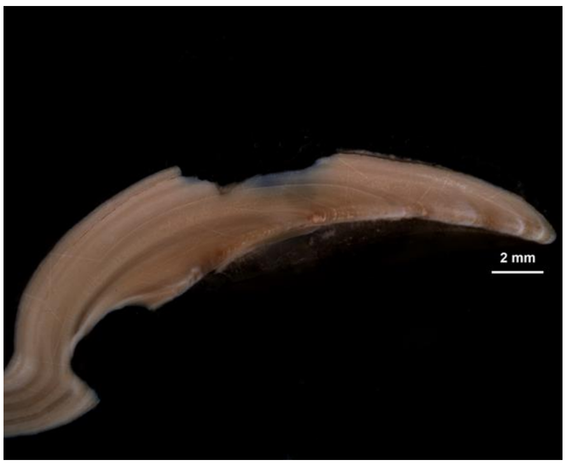

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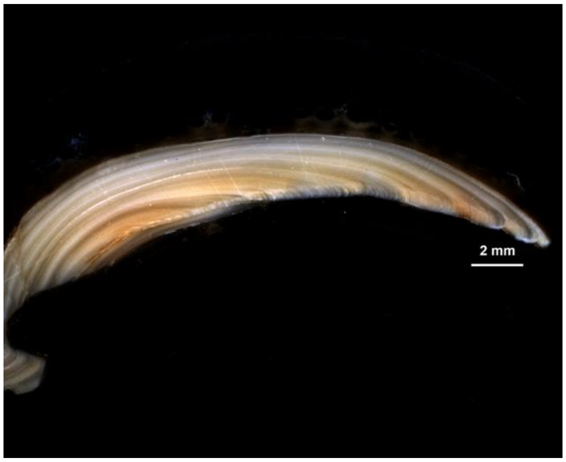
AlDf-24A-29

AlDf-24A-30

AlDf-24A-31



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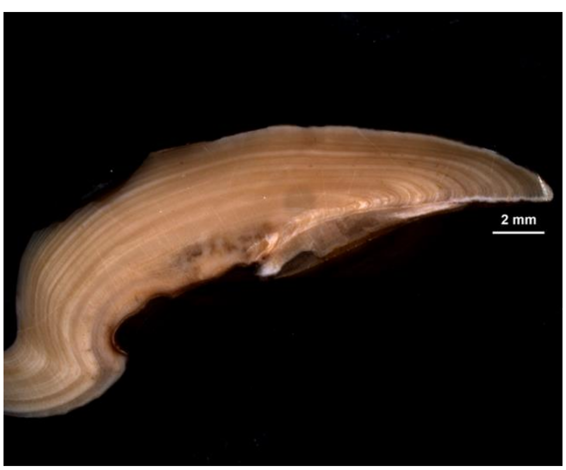
AlDf-24A-33

AlDf-24A-36

AlDf-24A-37

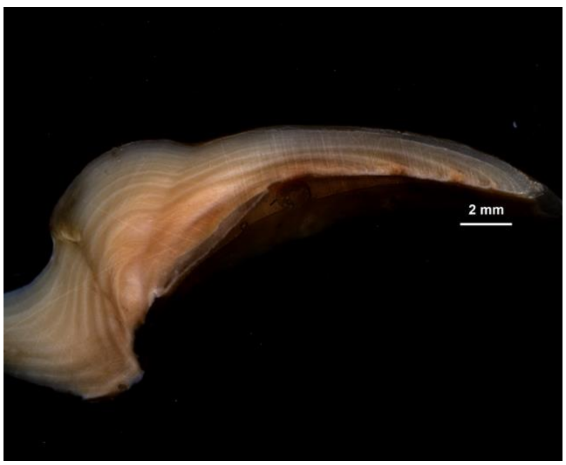


AlDf-24A-38

AlDf-24A-39

AlDf-24C-1

AlDf-24C-2



AlDf-24C-3

AlDf-24C-4

AlDf-24C-5

AlDf-24C-6

AlDf-24C-7

AlDf-24C-8

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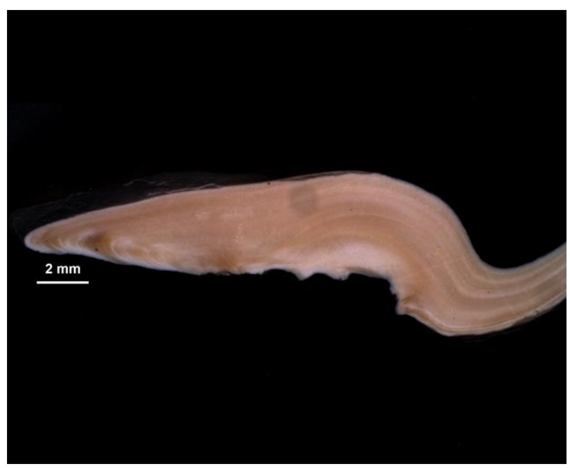
AlDf-24C-10

AlDf-24C-11



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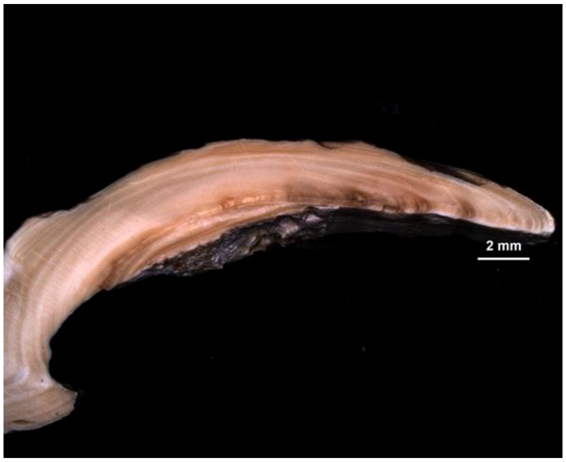

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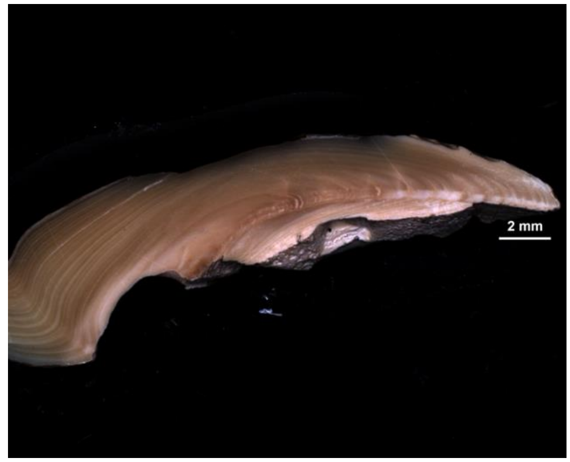

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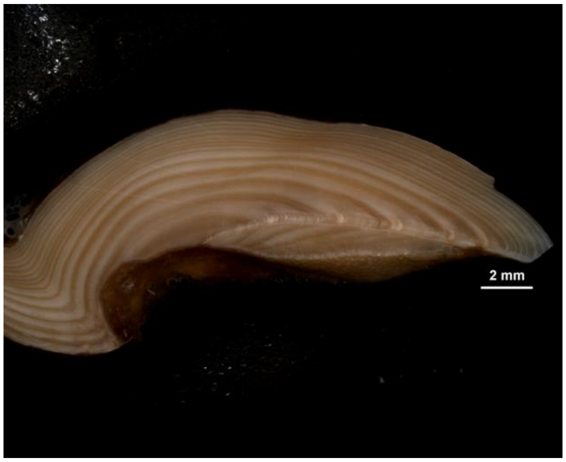
AlDf-24C-17

AlDf-24C-18



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AlDf-24C-21

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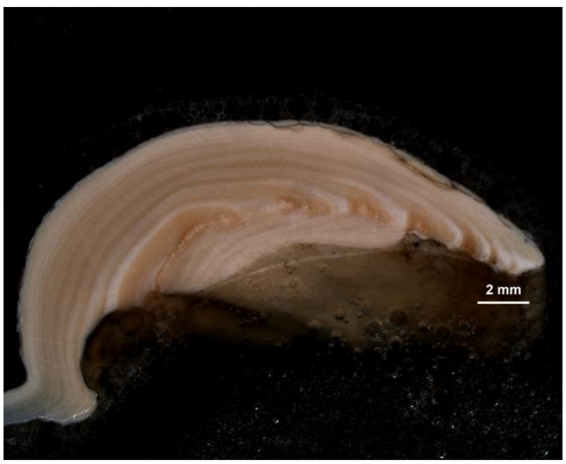

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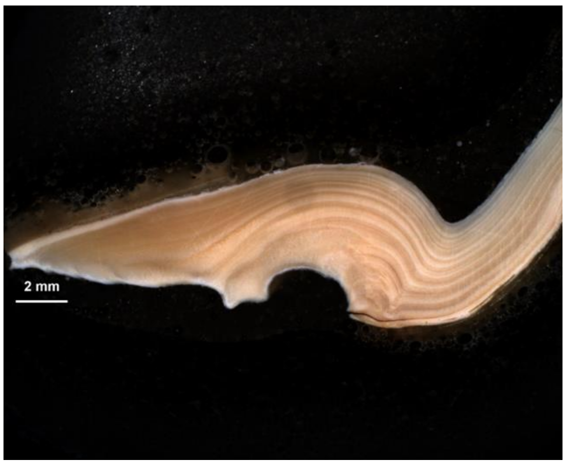

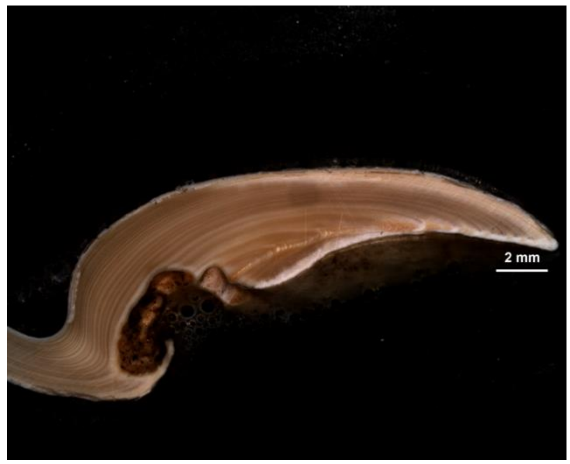

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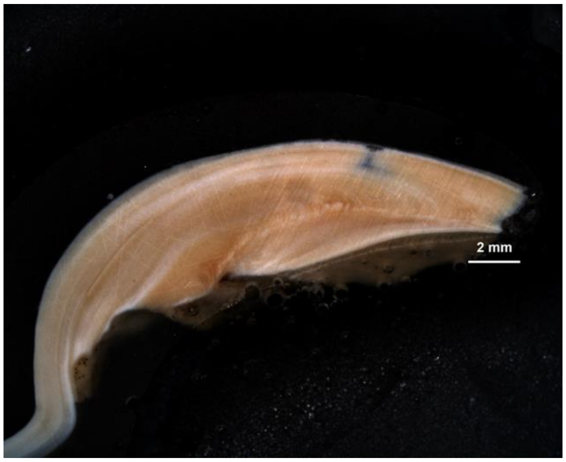
AlDf-25-8

AlDf-25-9

AlDf-25-10



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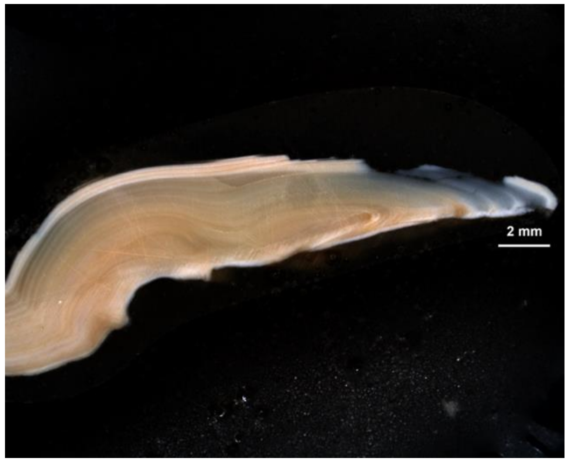

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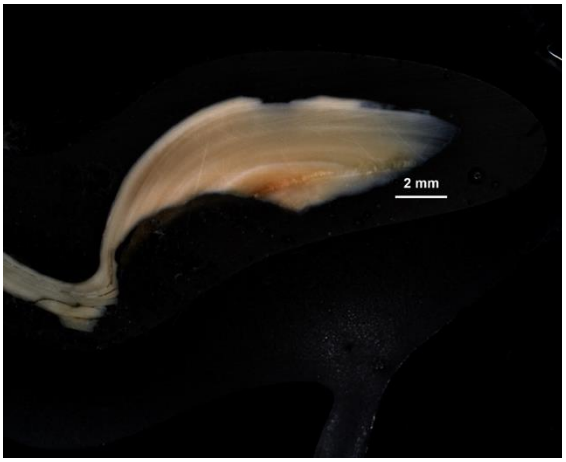

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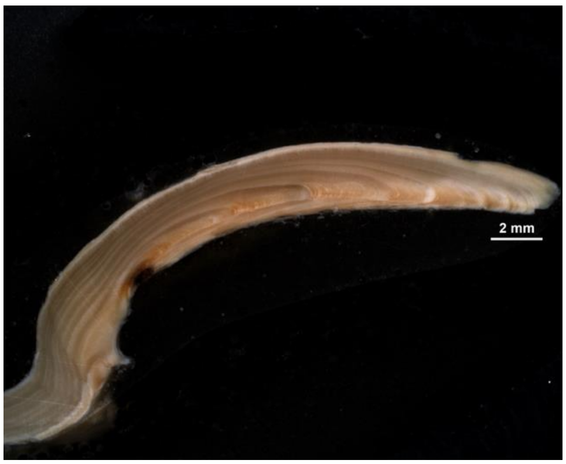
AlDf-25-15

AlDf-25-16

AlDf-25-18

AlDf-25-19



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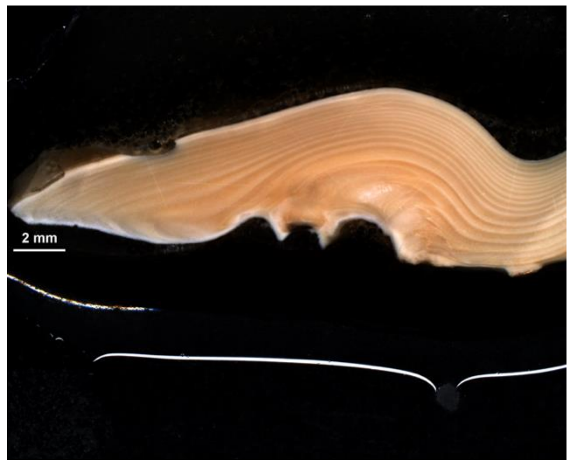

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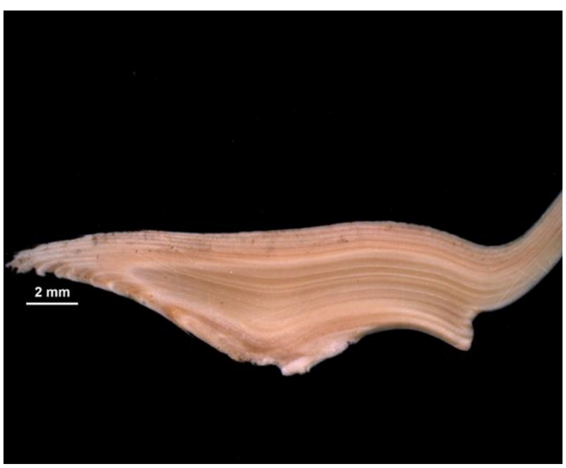
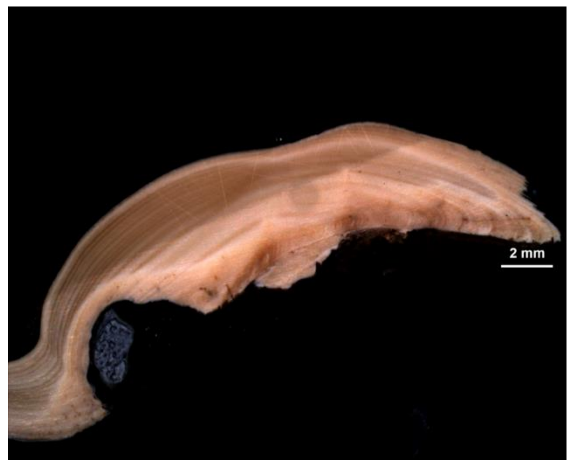


AlDf-30-1

AlDf-30-2

AlDf-30-3

AlDf-30-4



AlDf-30-5

AlDf-30-6

AlDf-30-7

AlDf-31-1

AlDf-31-2

AlDf-31-3

AlDf-31-4

AlDf-31-5

AlDf-31-6

AlDf-31-8