DUAL-BIVALVE PROXY ANALYSIS OF SHELLFISH HARVEST INTENSITY, SEASONALITY, AND PALAEOTEMPERATURE IN POWELL RIVER, BRITISH COLUMBIA

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B.A. Memorial University of Newfoundland, 2018

A Thesis

submitted to the School of Graduate Studies

in partial fulfilment of the requirements for the degree of

Master of Arts in Archaeology

Memorial University of Newfoundland

August 2021

St. John’s, Newfoundland and Labrador

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ABSTRACT

This thesis investigated the seasonality and intensity of shellfish harvesting and past sea surface temperature in Powell River, British Columbia, in the traditional territory of the Tla'amin First Nation. This is the first study to use two species of bivalve *Saxidomus gigantea* and *Leukoma staminea* as proxies for past cultural practices and environment. This is also the first study to use high-resolution stable oxygen isotope sclerochronological analysis for interpreting past subsistence and settlement patterns in the Powell River region.

Seven archaeological shell midden sites were examined to interpret shellfish harvest intensity using sclerochronological measurements of 644 shells from seven shell middens. The results showed that overall, there a consistent, and intense pattern of shellfish harvesting for both species. The only notable site-level difference is at the village site DlSd-11, where the *S. gigantea* shells examined showed a higher relative harvest intensity whereas the *L. staminea* shells showed a lower relative harvest intensity.

High-resolution stable oxygen isotope sclerochronological analysis was used to examine three live-collected *L. staminea* shells from the Sechelt Inlet in Sechelt, British Columbia. The results showed that the species *L. staminea* can be used to interpret the season of capture, although palaeotemperature calculations are affected by changes in salinity. The calculated temperature of the live-collected *L. staminea* shells had a range of 5.1-18.9°C whereas the measured temperature was 5.7-20.4°C. Five *S. gigantea* and five *L. staminea* shells from the defensive lookout site DlSd-1 in Powell River, British Columbia were analyzed for seasonality. The results showed a difference between species for the interpreted season of collection. All five of the *S. gigantea* were collected during the spring. Two of the *L. staminea* shells indicated collection in the spring, one shell indicated either spring or summer collection, one shell indicated summer collection, and the last shell indicated an autumn or winter collection. The combination of $\delta^{18}O_{shell}$ data, with other lines of archaeological evidence, and ethnohistorical records indicate that the site was inhabited during the spring and likely used throughout the year by the ancestral Tla'amin.

The dual proxy analysis showed that the use of two provides insight into the overall history of shellfish harvesting. In this case, the use of two species shifts the interpretation from a single season of site use to year-round by looking at both species of bivalves. Further, the growth increment analysis affirmed a consistent pattern of intensive shellfish harvest in this region.

ACKNOWLEDGEMENTS

Thank you to Dr. Meghan Burchell for her expert supervision, kindness, and support throughout the entire process of my thesis. Thank you for creating an interesting and challenging experience that made me work harder and strive for excellence in my research and writing. You have encouraged me to be the best version of myself.

Thank you to Dr Megan Caldwell, Dr Chris Springer and the Simon Fraser University Archaeology Department for providing the archaeological shell materials and field report.

Thank you to the Tla'amin Nation for their permission for this research.

Thank you to the Shíshálh Nation for their permission to work on their land.

Thank you to Dr. Terence Clark for inviting me to be a part of his 2019 field crew. Thank you to the University of Saskatchewan 2019 field school for helping me with data collection and being so welcoming to their group. Thank you to Dr. Nadine Hallmann for her expert advice and guidance with palaeotemperature calculations. Thank you to Samantha Werry for her assistance in sorting the shells for this thesis. Thank you to Bryn Tapper for teaching me how to make credible and accurate maps.

Thank you to Dr. Joanne Potter for letting me learn how to prepare and run shell carbonate samples for analysis.

Thank you to my lab group including Ian Predham, Marisa Dusseault, Julia Brenan, and Jenn Wilkins, among others for the kindness and support throughout the course of my thesis.

Thank you to John Kuehn for helping to clean and count shells. Thank you to Beth Kuehn for her assistance in photo editing and graphic creation. Thank you to all my friends and family for their love, encouragement, and support.

Thank you to the Social Sciences and Humanities Research Council of Canada and the Department of Archaeology who funded my research. Thank you to the Canada Foundation for Innovation for providing funding for the instrumentation used in my research.

Thank you to my thesis examiners Dr. Evan Edinger and Dr. Amy Prendergast for their insightful comments and critiques.

CHAPTER 1

INTRODUCTION

1.1. SHELL MIDDEN ARCHAEOLOGY

Shell middens occur in coastal areas and have been discovered around the world (Andrus 2011). Shell middens are refuse deposits containing at least fifty percent marine refuse, including fish, gastropod and bivalve shell remains (Bar-Yosef Mayer 2005). The shells that are most often discovered and used archaeologically from shell middens come from the phylum Mollusca (mollusks) and, more specifically, the class Gastropoda (gastropods) that include a variety of limpets and snails and the class Bivalvia (bivalves) comprised of a broad diversity of organisms including clams, mussels, and oysters among others (Claassen 1998). Shell middens are unique sources of archaeological information due to the preservation that the shells provide for other materials (Claassen 1991). Bivalve shells are formed of calcium carbonate, which is alkaline and therefore counteracts the acidity of ground soil, allowing for the preservation of the shells and other materials that the middens sometimes contain (Karleskint et al. 2013). Shells in middens also act as protection for additional materials as they are hard and will prevent breakage from crushing of more fragile material remains (Muckle 1985). Shell middens are densely packed and interlocking deposits that can also prevent the loss of material culture by coastal erosion (Andrus 2011). As such, shell middens are important aspects of archaeological sites that can provide a lot of information both from the shells they contain, and the other material culture remains that they preserve and protect.

1.1.2. Shell Midden Archaeology in British Columbia

Prior to 2009, most of the archaeological evaluations of the shell middens in coastal British Columbia were for the interpretation that the past indigenous societies practiced shellfish collection as a form of subsistence and only used as an addition to other archaeological work and interpretations (Moss and Cannon 2011). The archaeology practiced on the west coast was often focused on fishing practices and technologies, with a primary focus on the salmon fisheries (Cannon et al. 2008). The research focused on placing shellfish harvesting in the understanding and interpretation of the past indigenous populations' subsistence and settlement practices (Moss 1993). Since 2009, archaeological shell middens sites on the north and central coasts of British Columbia have been analyzed to interpret the past's cultural and environmental conditions (Cannon and Burchell 2009; Hallmann et al. 2009). Subsequent years found further investigations into shellfish harvest intensity, the season of capture, and palaeotemperature reconstruction for all coastal British Columbia (Burchell 2013; Burchell et al. 2013a, b, c; Cannon and Burchell 2016; Hallmann et al. 2013; Leclerc 2018; Sparrow 2016). These studies used the bivalve clam species *Saxidomus gigantea* (Deshayes 1839) as a proxy for interpreting subsistence practices, settlement patterns, and palaeoclimate conditions.

A combination of sclerochronology and high-resolution stable oxygen isotope analysis was used to determine the growth stages of the clams at the time of their collection to interpret relative harvest intensity, the season of capture, and to estimate past sea surface temperatures (SST) (Burchell et al. 2013a, b, c; Cannon and Burchell 2009, 2016; Hallmann et al. 2009; 2013; Leclerc 2018; Sparrow 2016). The north coast shell midden sites are located in the vicinity of the Dundas Islands Group and Prince Rupert Harbour in the traditional territory of the Coast Tsimshian First Nation (Burchell et al. 2013a; Hallmann et al. 2009; 2013) (Fig. 1.1.). The central coast shell midden sites are located in the Fitz Hugh Sound area in the traditional territory of the Heiltsuk First Nation (Burchell et al. 2013b, c; Cannon and Burchell 2009, 2016). The south coast shell midden sites are located within the regions surrounding the Salish Sea in the traditional territory of the Central Coast Salish (Sparrow 2016), the Tsawout and Tseycum First Nations (Burchell 2013; Hallmann et al. 2009), and the Shíshálh First Nation (Leclerc 2018). In this study, seven shell midden sites are examined from the Powell River region on the southern coast of British Columbia, in the traditional territory of the Tla'amin First Nation.

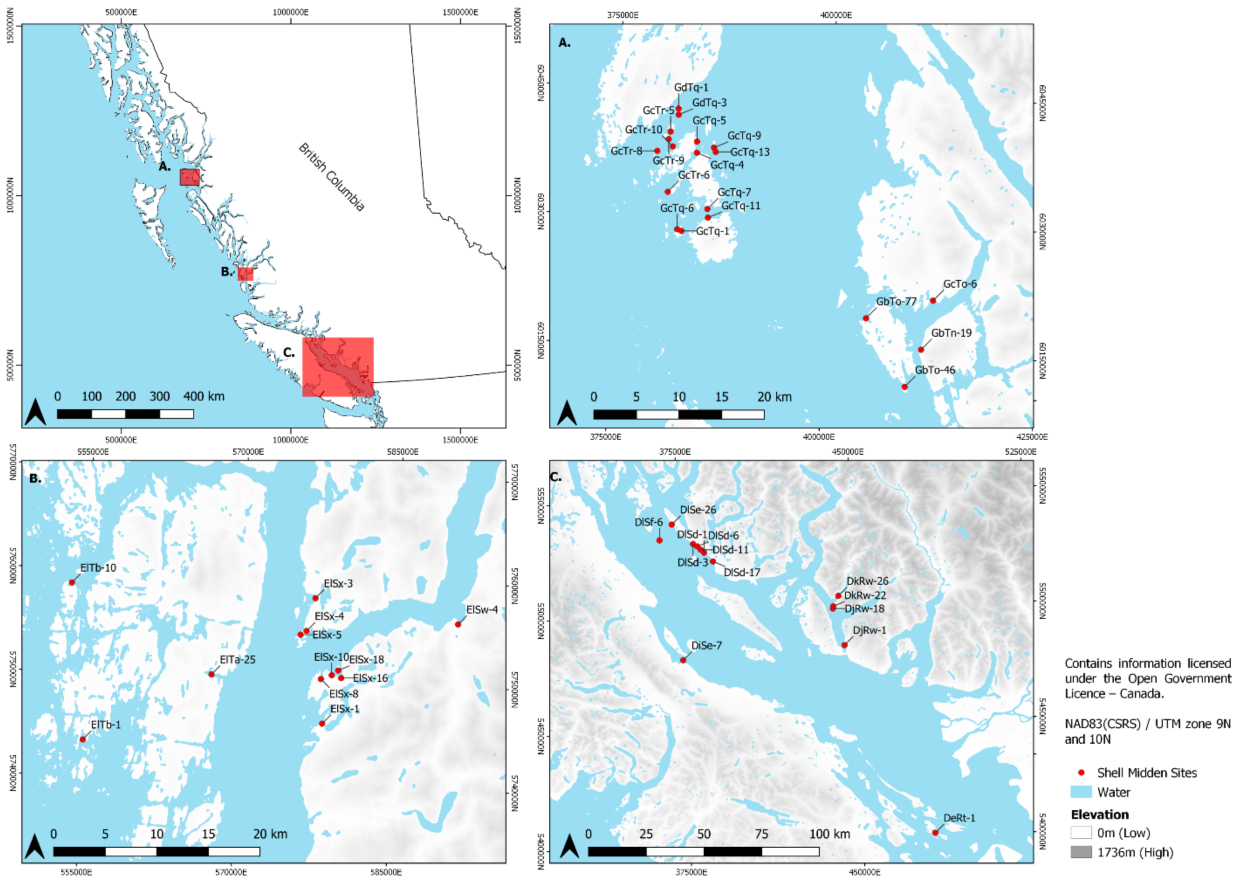

Figure 1.1 Map of shell midden sites on the north, central, and southern coasts of British Columbia to interpret shellfish harvesting pressure, seasonality and estimate PSST. A. Shell midden sites in the Dundas Islands Group and Prince Rupert Harbour, (Burchell et al. 2013a; Hallmann et al. 2009; 2013). B. Shell midden sites examined on the central coast of British Columbia (Burchell et al. 2013b, c; Cannon and Burchell 2009, 2016). C. Shell midden sites examined on the southern coast of British Columbia (Burchell 2013; Hallmann et al. 2009; Leclerc 2018; Sparrow 2016).

This study uses two species of bivalves, *S. gigantea* and *Leukoma staminea* (Conrad 1837), as proxies for shellfish harvest intensity, the season of capture, and to estimate past sea surface temperatures. The method used for interpreting shellfish harvest intensity is sclerochronology, specifically growth stage analysis, as outlined by Cannon and Burchell (2009). Six hundred forty-four shells were examined from seven shell midden sites excavated as part of the joint Simon Fraser University – Tla'amin First Nation Archaeology and Heritage Stewardship Project between 2009 and 2013. Five of the seven sites are identified as defensive sites (DlSd-1, DlSd-3, DlSd-6, DlSd-17, and DlSe-26), one site is identified as a village site (DlSd-11), and one a campsite (DlSf-6) (Springer et al. 2013). For the interpretation of the season of collection and the estimation of past sea surface temperatures, high-resolution stable oxygen isotope sclerochronological analysis was used on three live-collected *L. staminea* shells collected from the Sechelt Inlet in July of 2019. Another five *S. gigantea* and five *L. staminea* shells from the archaeological shell midden site DlSd-1 were analyzed using the same methodology to interpret the season of shellfish collection and past SST.

1.2. RESEARCH OBJECTIVES

This MA research uses the biogeochemical analysis of the shell components from seven shell midden sites located in the Powell River region on the south coast of British Columbia in the traditional territory of the Tla'amin First Nation to interpret the subsistence practices and settlement patterns of the occupants of the sites.

There were four original research objectives:

1. To interpret the shellfish harvest intensity exhibited at seven shell midden sites located in the Powell River region of British Columbia.

2. To test if there is a significant difference in the shellfish harvest intensity between the two species examined (*Saxidomus gigantea* and *Leukoma staminea*) at seven shell midden sites from Powell River, British Columbia.

3. To test the feasibility of using high-resolution stable oxygen isotope analysis on the clam species *Leukoma staminea* to interpret seasonality of harvest and palaeothermometry calculation.

4. To test the use of a multiproxy approach for stable oxygen isotope analysis to interpret seasonality of harvest for shell midden analysis in British Columbia.

1.3. STRUCTURE OF THESIS

This is a manuscript style thesis, where chapters 2 and 3 are prepared as manuscripts. Chapter 1 is an introduction to the thesis and explains the research objectives and background of methods and geographic region.

Chapter 2, '*Leukoma staminea* (Conrad 1857) as a new proxy for evaluating shellfish harvest intensity on the Pacific Northwest Coast: A Case Study from Powell River British Columbia' uses growth stage analysis of both *S. gigantea* and *L. staminea* shells from seven shell midden sites in the Powell River region on the south coast of British Columbia, in the traditional territory of the Tla'amin First Nation. A total of 644 shells were examined to determine if they were collected at the mature or senile growth stage. M. Burchell provided the shell materials, funding, and assisted with editing. This paper is the first to use the bivalve clam species *L. staminea* for this analysis and compare the results for both species for each site to see if there is an agreement between species for the interpreted relative harvest intensity.

Chapter 3, 'A Dual Proxy Bivalve Approach for Interpreting Past Sea Surface Temperatures and Seasonality from Shell Midden Sites' is a paper that uses high-resolution stable oxygen isotope sclerochronological analysis of three live-collected *L. staminea* shells from the Sechelt Inlet in July of 2019 and 10 shells (five of *S. gigantea* and five *L. staminea*) from the archaeological shell midden site DlSd-1 at Gibson's Beach in Powell River, British Columbia. This study tests the feasibility of using oxygen isotopes from the species *L. staminea* as a proxy for the season of capture and palaeotemperature estimation by first testing live-collected specimens. The same methodology is then applied to 10 archaeologically collected shells. This paper is the first to use *L. staminea* as a proxy for seasonality and past sea surface temperatures. M. Burchell provided the shell materials, funding, and assisted with editing.

CHAPTER 4 is a conclusion that summarized the conclusions, discusses pan-regional variation, and discusses avenues for future research.

1.4. BACKGROUND LITERATURE

1.4.1. Shell Midden Archaeology in British Columbia

Shell midden analysis in British Columbia was first published in 1903 by H. I. Smith. Smith evaluated shell mounds from the Fraser River Valley as part of the Jessup North Pacific Expedition (Smith 1903). Little archaeological analysis occurred until the middle of the twentieth century (Carlson 1970). In 1966 the Archaeological Society of British Columbia was founded, which led to increased archaeological surveys and excavations in the province (Carlson 1970). These lead to the discovery of several shell midden heaps along the coast (Carlson 1970). The majority of the shell mounds' evaluations were for the interpretation of indigenous societies' shellfish collection as a form of subsistence and only used as an addition to other archaeological work and interpretations (Moss and Cannon 2011). Most often, the archaeology practiced on the Pacific Northwest Coast was focused on fishing practices and technologies, with a primary focus on the salmon fisheries (Cannon and Yang 2006; Cannon et al. 1999; Cannon 2000a, b; Coupland 1988; Matson 1992; Moss and Cannon 2011; Prince 2011; Speller et al. 2005). The research focused on placing shellfish harvesting in the understanding and interpretation of the past indigenous populations' subsistence and settlement practices (Brewster and Martindale 2011, Lepofsky and Caldwell 2013, Monks 2011, Moss and Cannon 2011). The research conducted was generally more focused on the other zooarchaeological and cultural artifacts discovered within the shell midden matrices (Ames 2005, Clarke and Clarke 1980, Moss and Cannon 2011). These included other faunal remains, including fish as well as marine and terrestrial mammal bones, and cultural discards such as tools and vessels including harpoon points, fishing gorges, net weights, and parts of fish hooks (Brewster and Martindale 2011, Caldwell 2015, Lepofsky and Caldwell 2013; Moss and Cannon 2011, Prince 2011). The shell middens also sometimes contained human interments (Brown 2003; Cannon 2000b; Cannon et al. 1999; Moss and Cannon 2011). The shell middens were mainly researched for possible cultural practices and traditions, but not through sclerochronological analysis (Cannon et al. 2008). Marine bivalve remains were viewed only as evidence that shellfish had been collected and used as a food resource and, as such, were placed into the larger frame of resource procurement (Moss and Cannon 2011).

Research in British Columbia has exhibited a further refinement upon previous shell midden research, with investigations into the best site sampling strategies and screening techniques (Cannon 2000b) and palaeothermometry estimates (Hallmann et al. 2009, Burchell et al. 2013b). The use of growth lines to interpret shellfish harvesting intensity (Cannon and Burchell 2009) and the use of high-resolution stable oxygen isotope sclerochronology to find the exact point within a season that a particular shell was harvested (Hallmann et al. 2013, Burchell et al. 2013c) was developed for this region. Lunar daily growth increment (LDGI) analysis to interpret the growth exhibited on a tidal basis was used to identify the period within a season that a particular shell was collected (Hallmann et al. 2009) was employed with significant effect. All shell midden biogeochemical analysis that has occurred in British Columbia to date has focused on the analysis of one clam species: *Saxidomus gigantea* (common name butter clam).

1.5. MARINE BIVALVES IN ARCHAEOLOGICAL INTERPRETATION

1.5.1. Bivalve Growth & Formation

Bivalves grow through the absorption of macronutrients from their surrounding environment (Reitz and Shackley 2012). Marine shells grow through the secretion of calcium carbonate that they absorb from their surrounding environment, which they then add to the distal or marginal portion of their shells (Reitz and Shackley 2012). Bivalve shells are secreted in three layers: the nacreous layer, the prismatic layer, and the periostracum (Fig. 1.2.). The periostracum is the outermost layer and is composed of a conchiolin protein that forms a hardened surface for the shell. Both the nacreous and prismatic layers are composed of calcium carbonate but have different crystalline structures, where the nacreous layer is always composed of aragonite whereas the prismatic layer can be aragonitic or calcitic depending on the species (Claassen 1998; Karleskint 2013). The prismatic layer contains the environmental information used to determine the shell's age and seasonality (Claassen 1998).

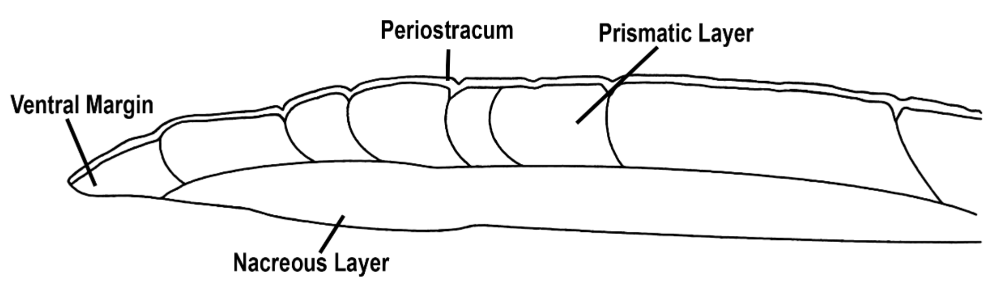

Figure 1.2 Illustration of bivalve shell layers. The outermost layer is the periostracum, the middle layer is the prismatic layer, and the innermost layer is the nacreous layer. The ventral margin is where shell material is added as the bivalve grows.

Shell growth depends on the animals' surrounding environment due to the availability of resources needed for its survival, which is displayed through the cycling of growth increments and growth lines (Reitz and Shackley 2012) (Fig. 1.3.). Generally, the growth increments are displayed in favourable conditions when the animals' preferred temperature, salinity, macronutrients, and food are available. In contrast, growth lines occur when conditions are less favourable resulting in a slower and more compact period of growth (Claassen 1998). When the temperature and salinity are too high or too low, then calcium carbonate levels are not available for the shell's growth (Andrus 2011).

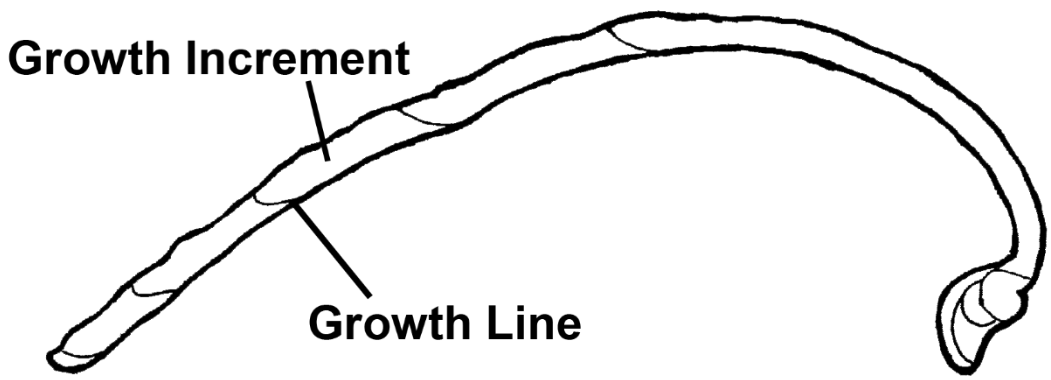

Figure 1.3 Illustration of *S. gigantea* shell cross-section displaying growth lines and growth increments.

1.5.2. Shellfish Harvest Intensity using Sclerochronology

Sclerochronology is the study of the physical and chemical changes in the hard tissues of bivalve and gastropod shells as well as red algae which occur through the animals' life as it ages. Growth profiles of marine shells are species-dependent and are affected by climatic conditions and changes, including seasonal influxes of fresh water, temperature changes, food availability, and many others. Sclerochronology is a method that examines shell growth patterns that are used in growth stage analysis. There are three main growth stages that are easily identified. Juvenile shell growth is visible as it is when shell growth occurs at the highest rate, meaning that there are very few visible growth cessations (growth lines) (Claassen 1998). Mature growth also shows fast growth, but it is marked by evenly spaced regular growth increments and lines and continues up to and includes the ventral margin (Cannon and Burchell 2009: 1051). Senile growth is the slowest growth stage and is marked by the close and numerable incremental growth banding closely packed at the shell's ventral margin (Cannon and Burchell 2009: 1051) (Fig. 1.4.).

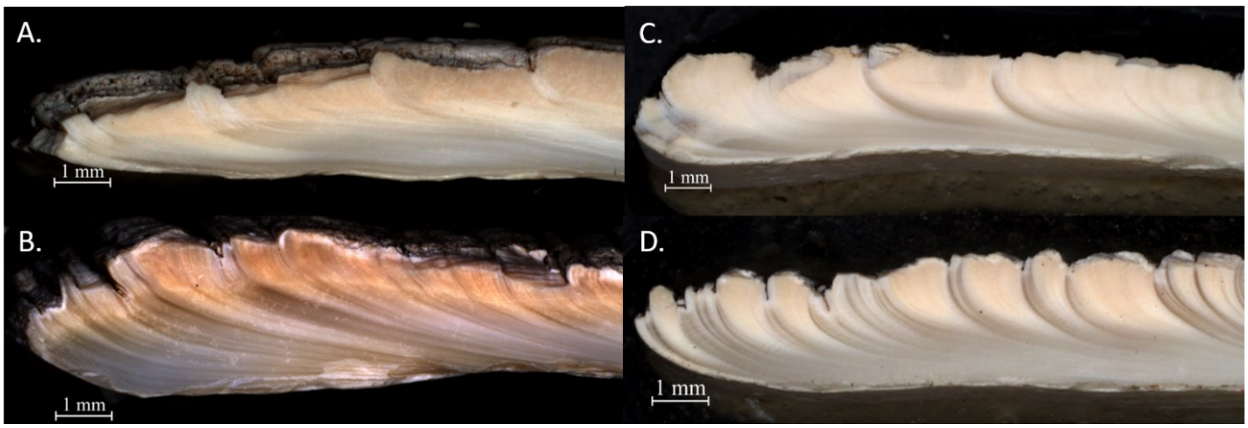

Figure 1.4 Ventral margin of bivalve shell cross-sections of mature growth stage *L. staminea* (A), senile growth stage *L. staminea* (B), mature growth stage *S. gigantea* (C), and senile growth stage *S. gigantea* (D).

Sclerochronology can also be used to estimate the approximate growth stage of a clam at harvest. Research conducted by Cannon and Burchell (2009) identified that shells' growth profiles could be interpreted to indicate the harvest pressure exerted upon a shellfish population in a particular area. Their research showed that a site with a majority of mature growth stage shells in a shell midden indicated a high harvest intensity and that shell midden sites that contained a majority of senile growth shells in a collection reported a low harvest intensity (Cannon and Burchell 2009). Their research has then been applied to sites throughout coastal British Columbia. This MA research is the first time that sclerochronological analysis is applied to the shells from the Powell River region to examine the relative shellfish harvest pressures exerted on this area's shellfish population.

On the north coast of British Columbia, shellfish harvest intensity is higher at long-term village sites and lower at short-term campsites (Burchell et al. 2013a). Conversely, on the central coast of British Columbia, research showed that the sites with a higher harvest intensity were short-term campsites and that longer-term village sites showed a lower shellfish harvest intensity (Burchell et al. 2013b, c; Cannon and Burchell 2009, 2016). Research conducted on the south coast of British Columbia showed little difference between short-term campsites or long-term village sites and that all sites exhibited higher relative harvest intensity (Leclerc 2018).

1.5.3. Stable Oxygen Isotope Analysis of Marine Calcareous Organisms

Stable oxygen isotope ($\delta^{18}O$) values found in calcareous organisms (such as mollusks and coral) can be used as a proxy for the reconstructing of sea surface temperatures (SST) where the organism lived (Epstein et al. 1953; Gillikin et al. 2005; Hallmann et al. 2009). Stable oxygen isotope analysis is done by extracting carbonate from the shells and determining the shell's stable oxygen isotope levels at the time of its harvesting (Hallmann et al. 2009). Stable oxygen isotopes in marine water are affected by the local environment, particularly by the temperature and salinity, and more so by the freshwater influxes from rivers and tributaries, as well as from the significant seasonal influxes from ice melt and precipitation that occur seasonally (Burchell et al. 2013b). Stable oxygen isotopes also vary according to space and time, so determining local conditions (Gillikin et al. 2005; Hallmann et al. 2009).

Generally, when the temperature is lower and salinity is higher, the stable oxygen isotope values are more positive. They can point to the colder winter season. In contrast, when the temperature is higher and salinity is lower, the stable oxygen isotope value is more negative and points to the warmer summer months (Hallmann et al. 2009). By joining stable oxygen isotope analysis with sclerochronology, the exact point in a season that a shell was harvested can be interpreted, which provides information as to the settlement occupation in the area as well as the particular season of the resource procurement of shellfish (Burchell et al. 2013b). Stable oxygen isotope analysis can also be used in estimating past sea surface temperatures. The Böhm et al. (2000) equation was used in this study to reduce error in the calculation for aragonitic organisms.

1.6. STUDY AREA

The archaeological shell midden sites analyzed by this MA research are located mostly on the mainland side of the Salish Sea (Strait of Georgia) on the southern coast of British Columbia in proximity to the city of Powell River. The materials used in this study come from previously excavated shell midden sites in the traditional territory of the Tla'amin First Nation (Fig. 1.5).

1.6.2. Ecology

These seven sites span two distinct biogeoclimatic zones known as the Coastal Western Hemlock (CWH) and the Coastal Douglas-fir (CDF) zones. My MA research also focuses on shellfish and what they can tell us about archaeological sites and their occupants. The clam species that I analyze in my research come from the intertidal zone of coastal British Columbia, which has an ecological system of its own and is highly affected by the Salish Sea (Strait of Georgia). The archaeological shell midden sites DlSd-1 (Gibson's Beach), DlSd-6 (Klehkwannum), and DlSd-17 (Willingdon Beach) are located in the Coastal Western-Hemlock biogeoclimatic zone. The archaeological shell midden sites of DlSd-3, DlSd-11 (Sliammon Reserve (IR1)), and DlSf-6 (Savary Island) are in the Coastal Douglas-fir biogeoclimatic zone, and DlSe-26 (Rasmussen Bay) straddles both the CWH and CDF zones. Swik'als (Sechelt Band Lands no.3) in Sechelt, British Columbia, where the live collected samples of the littleneck clam were collected, falls within the CDF biogeoclimatic zone.

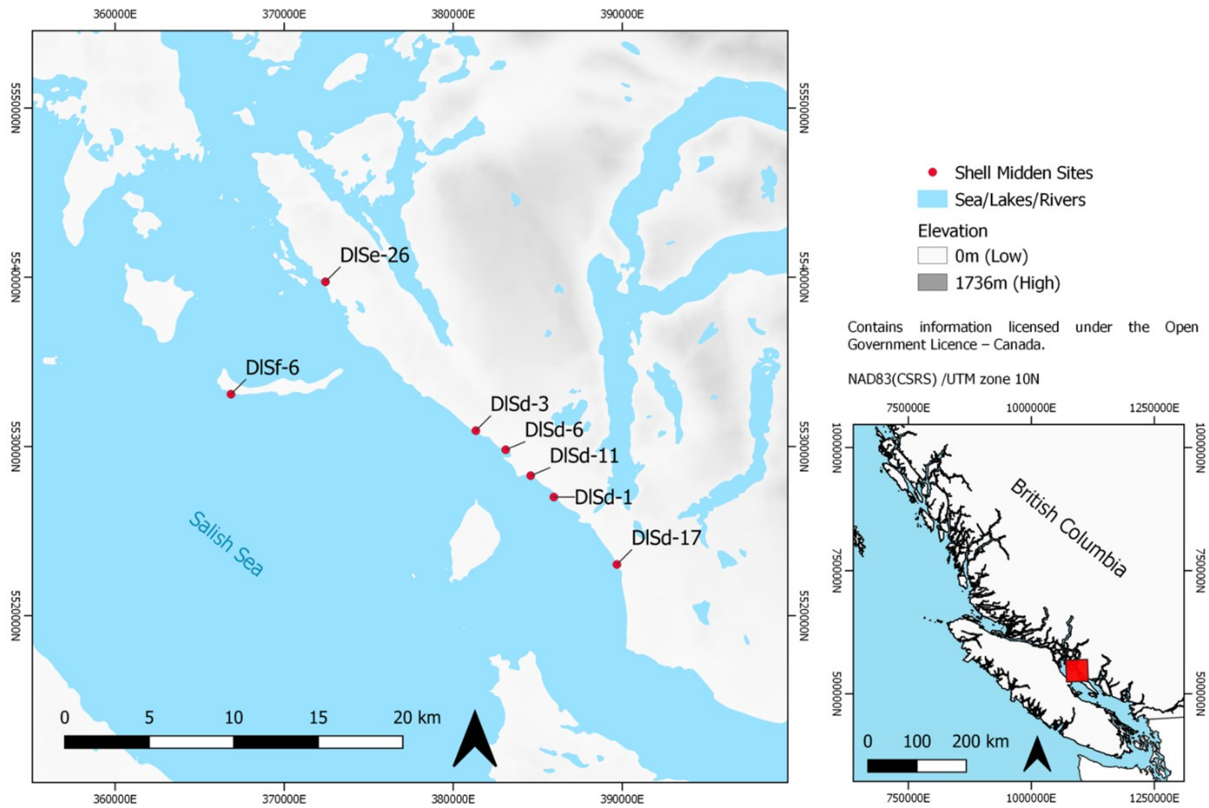

Figure 1.5 Map of archaeological shell midden sites examined in the Powell River in the traditional territory of the Tla'amin First Nation.

1.6.2.1. Coastal Douglas-fir Biogeoclimate Zone

The Coastal Douglas-fir (CDF) biogeoclimate zone ecosystems are greatly influenced by the temperate climate conditions found in this region (Nuszdorfer et al. 1991; Springer et al. 2013) and is one of the smallest ecological zones in British Columbia (Centre for Forest Conservation Genetics 2020). The CDF zone covers the southeastern part of Vancouver Island, several islands in the Salish Sea, and a small mainland portion. This zone is highly affected by its proximity to the Pacific Ocean and exhibits mild winters with a lot of precipitation and long summers with lots of sun and warm temperatures (Centre for Forest Conservation Genetics 2020). The CDF biogeoclimate zone covers approximately 0.25 million hectares and begins at an elevation of 0m and ends at 265m with a mean annual temperature of 9.8°C with a range of 3.4-16.9°C (Centre for Forest Conservation Genetics 2020). For the CDF biogeoclimate zone there is a mean annual precipitation of 1038mm (Centre for Forest Conservation Genetics 2020). Much of the forest in the CDF zone is regrowth with small pockets of old-growth forests (Centre for Forest Conservation Genetics 2020, Nuszdorfer et al. 1991).

1.6.2.2. Coastal Western Hemlock Biogeoclimate Zone

The Coastal Western Hemlock biogeoclimatic zone covers much of coastal British Columbia and occurs in low to moderate elevations and is bordered by the Mountain Hemlock zone at higher elevations and by the Coastal Douglas Fir zone in the south (Centre for Forest Conservation Genetics 2020). The CWH zone's climate is moderate, with cool summers and mild winters (Centre for Forest Conservation Genetics 2020). The CWH biogeoclimatic zone is considered the rainiest biogeoclimatic zone in British Columbia (Pojar et al. 1991). The CWH biogeoclimatic zone contains twenty subzones (Centre for Forest Conservation Genetics 2020). The subzone, which includes the archaeological sites examined in my MA research, is the Very Dry Maritime CWH (Centre for Forest Conservation Genetics 2020; Pojar et al. 1991). The subzone covers approximately 0.45 million hectares and begins at an elevation of 1 m and ends at an elevation of 523 m with a mean annual temperature of 9.3°C and an annual temperature range of 2.4-17.0°C and mean annual precipitation of 1427 mm (Centre for Forest Conservation Genetics 2020). The CWH biogeoclimatic zone is considered an old forest and is highly productive and a structurally complex coniferous forest zone (Centre for Forest Conservation Genetics 2020).

1.6.2.3. Salish Sea Intertidal Zone

The intertidal zone is the coastal areas covered by ocean water at high tide and exposed at low tide (Karleskint et al. 2013). The animals and plants that have their habitat in the intertidal zone are highly adaptive species as a portion of each day they are exposed to numerous elements, including air, wind, sun, rain, and seawater (Georgia Strait Alliance 2015). In the intertidal zone, plants and animals are continually exposed to changes in their environment, including changes in temperature, salinity, moisture, and wave action (Karleskint et al. 2013). This study area has a hard substrate exhibiting a rocky shore habitat (Karleskint et al. 2013). The intertidal zones of rocky shores have vertical zonation that include the upper, middle, and lower intertidal zones, classified based on the amount of time the area is out of the water (Karleskint et al. 2013). The environmental conditions affect the types of animals that can inhabit each of the zones, based on their ability to adapt to the ever-changing environment (Karleskint et al. 2013). The Salish Sea has a mean water temperature in January of 4-6°C and in July of 12-18°C, indicating a range of roughly 4-18°C (Davenne and Masson 2001).

1.7. ARCHAEOLOGICAL SITES IN THE POWELL RIVER REGION

The seven shell midden sites examined in this study were excavated as part of the joint Simon Fraser University - Tla'amin First Nation Archaeology and Heritage Stewardship Project from 2009-2013 under permit number 2009-0132. Five of the seven sites examined are identified as defensive lookout sites (DlSd-1, DlSd-3, DlSd-6, DlSd-17, and DlSe-26), one site is identified as a village (DlSd-11) and one as a campsite (DlSf-6) (Table X).

Table 1.1 The Borden numbers, site names, settlement occupation types, and radiocarbon dates for the seven shell midden sites in the Powell River region. The first set of dates had a Delta-R correction of 422+/-50 BP using the northern hemisphere marine calibration on CALIB 7.0 and reported by Springer et al. (2013). The second set of dates had a Delta-R correction of 198+/-98 BP from the 10 closest points from the Marine20 database and calibrated using IntCal20.

Borden Number	Site Name	Occupation Type	Date (cal. BP)	
			2-sigma cal. BP (P=95%) CALIB 7.0	2-sigma cal. BP (P=95%) IntCal20
DlSd-1	Gibson's Beach	Defensive	436-75	1065-797
DlSd-3	Malaspina Inlet	Defensive		
DlSd-6	Klehkwannum	Defensive	499-312	1063-965
DlSd-17	L'yjiwmixw	Defensive	444-129	1061-920
DlSe-26	Rasmussen Bay	Defensive	513-294 and 491-287	1270-1000 and 1179-978
DlSd-11	Teeshoshum	Village	538-316	1277-1073
DlSf-6	Kayaykwon	Campsite	1687-1386	2682-2346

1.7.2. Subsistence and Settlement Patterns of the Ancestral Tla'amin

The settlement pattern of the ancestral Tla'amin was based on proximity to resources, particularly fish and shellfish, and defensibility (Angelbeck 2009; Springer et al. 2013). Most larger settlement sites, such as villages, were positioned in areas with reasonable proximity to marine food resources (Springer et al. 2013; Springer and Lepofsky 2020). The location of larger settlements was also chosen for protection from elements and from view (Angelbeck 2009; Springer et al. 2013; Springer and Lepofsky 2020). A significant concern for the ancestral Tla'amin was the defensibility of their territory, which involved the construction of smaller settlements in near proximity to the larger settlements to serve as defensive sites such as trench embankments, lookouts, and redoubts (Angelbeck 2007, 2009; Moss and Erlandson 1992; Springer and Lepofsky 2020). These smaller settlements aided in the protection of the larger settlements and took advantage of the proximity to the ocean regarding the use of marine resources for subsistence (Angelbeck 2009; Caldwell 2015; Jackley 2013; Johnson 2010; Springer et al. 2013; Springer and Lepofsky 2020).

Lookout sites were common for areas surrounding main settlement locations, such as the village sites. As these lookout sites were occupied with helping protect settlement sites from attack, there was a need for food throughout the site's occupation. There is evidence to suggest that food was brought to these sites and supplemented through clam harvesting and fishing at the sites (Angelbeck 2007, 2009; Moss and Erlandson 1992; Springer and Lepofsky 2020). Coastal lookout sites were generally located on bluffs that provided a large viewshed and relatively close to settlements (Angelbeck 2009; Springer and Lepofsky 2020). Lookout sites were commonly located in areas where clams would be a readily available food resource, which would account for the higher relative harvest pressure exerted at these sites.

The shell midden excavations for the sites located in the Powell River region indicate a reliance on marine resources, emphasizing herring and shellfish (Springer et al. 2013). The herring fishery was necessary as the territory of the Tla'amin First Nation lacks larger river systems that would allow for heavier subsistence on salmon but has many areas that are key spawning areas for herring. Archaeological evidence from the shell middens excavated in the Tla'amin territory support this as there is a relatively higher quantity of herring bones (Springer et al. 2013). Another key resource in the subsistence practices of the ancestral Tla'amin is shellfish, with larger quantities of the clam species *L. staminea* found incorporated in shell middens for both large and small settlements (Springer et al. 2013). Though the growth stage analysis of the *L. staminea* shells from the sites examined in this study show that the relative harvest intensity was higher, archaeological research and ethnographic evidence suggest that the ancestral Tla'amin did practice resource management strategies that prevented over-harvesting

(Caldwell 2015; Lepofsky and Caldwell 2013; Springer et al. 2013). The ancestral Tla'amin used the manipulation of their landscape, including the creation of clam gardens, to create better habitats for shellfish, which would have allowed for an increase in the shellfish populations to prevent the depletion of this resource (Augustine and Dearden 2014; Caldwell 2015; Deur et al. 2015; Groesbeck 2014; Lepofsky and Caldwell 2013; Smith et al. 2019; Springer et al. 2013; Toniello et al. 2019).

Zooarchaeological analysis of the Powell River region found that there was a heavy reliance on marine resources for subsistence. Chisholm (1986) used stable carbon isotope analysis on human bone collagen of individuals from Powell River and found that the, overall, past diet consisted of 90% marine-based protein. Further, the shell middens examined found that the middens at larger settlements had more diverse contents, including fish, shellfish, marine mammals, and terrestrial mammals, but with a heavier reliance on herring, salmon, butter clams, and littleneck clams (Springer et al. 2013). The middens excavated at smaller settlements found that the faunal remains were primarily shellfish with a heavier reliance on littleneck clams and fish and only some instances of mammals or birds (Springer et al. 2013). Ethnographic evidence supports the dependence on marine resources, emphasizing fish, clams, and sea urchins for diet (Angelbeck 2009; Caldwell 2015; Chisholm 1986; Jackley 2013; Johnson 2010; Lepofsky and Caldwell 2013; Springer et al. 2013, 2018; Springer and Lepofsky 2020).

CHAPTER 2

Leukoma staminea (Conrad 1857) As A New Proxy for Evaluating Shellfish Harvest Intensity on The Pacific Northwest Coast: A Case Study from Powell River, British Columbia

ABSTRACT

Previous research has used only one species of bivalve, *Saxidomus gigantea*, as a proxy to interpret relative harvest intensity in coastal British Columbia. This study tests the feasibility of a second bivalve species, *Leukoma staminea* as a second proxy for growth stage analysis and the interpretation of shellfish harvest intensity. A total of 664 shells were analyzed: 322 *S. gigantea* shells and 322 *L. staminea* shells from seven archaeological shell midden sites for the Powell River region of British Columbia in the traditional territory of the Tla'amin First Nation. A site with a majority of mature growth stage shells indicates higher relative harvest intensity, whereas a site with a majority of senile growth stage shells indicates lower relative harvest intensity. The growth stage analysis showed that there is a difference in relative harvest intensity between the two bivalve species tested. The *S. gigantea* shell analysis results showed agreement with previous studies, where all site types exhibit higher harvest intensity. The *L. staminea* shell analysis results showed a difference in harvest intensity between site types.

Keywords: Sclerochronology, Growth Stage Analysis, Harvest Intensity, Shellfish Harvesting

2.1. INTRODUCTION

Previous sclerochronological and geochemical research on the Pacific Northwest Coast used *Saxidomus gigantea* (butter clam) to investigate sea surface temperature (SST) (Burchell et al. 2013a; Hallmann et al. 2009; 2013), harvesting patterns and seasonal collection (Burchell et al. 2013 a; b; c; Cannon and Burchell 2009; 2016; Leclerc 2018; Sparrow 2016). These studies established protocols for high-resolution analysis, but also critical information on marine bivalve growth rates along the entire coast. *L. staminea* is found frequently in the same depositional contexts and intertidal zones as *S. gigantea*, and at times dominate shell midden assemblages (e.g. Burchell 2013; Leclerc 2018). Other sclerochronological research that has been completed in coastal British Columbia has used bivalve shell growth and size to interpret the human environmental relationship (Toniello et al. 2019; Smith et al. 2019).

Shell middens in British Columbia are composed of many shellfish species including butter clam, horse clam, littleneck clam, cockles, barnacles, mussels, whelks, and urchin (Burchell 2013; Cannon and Burchell 2009; Cannon et al. 2008; Coupland et al. 1993; Leclerc 2018). Recent studies (Cannon and Burchell 2009; Burchell et al. 2013b; Leclerc 2018) noted regional- and site-specific shellfish harvesting strategies. This is the first study of shellfish harvesting intensity in the Powell River region, and also the first study to use both *Leukoma staminea* and *S. gigantea* to interpret shellfish harvesting. Previous studies examining shell midden sites around the Salish Sea indicate that both *S. gigantea* and *L. staminea* were abundantly available and were a reliable and easily harvested food source (Moss 1993; Groesbeck et al. 2014; Toniello et al. 2019). Clam harvesting has been examined to interpret cultural resource management strategies used to sustain this valuable food resource (Caldwell 2015; Groesbeck et al. 2014; Lepofsky and Caldwell 2013; Smith et al. 2019; Toniello et al. 2019). On the Pacific Northwest Coast there is both ethnographic and archaeological evidence indicating that clams were culturally valued (Augustine and Dearden 2014; Cannon et al. 2008; Deur et al. 2015; Groesbeck et al. 2014; Moss 1993), although they are frequently undervalued in archaeological analyses.

This study uses growth increment analysis of *S. gigantea* and tests *L. staminea* as an additional proxy to understand past human-environmental interactions in the Powell River region, in the traditional territory of the Tla'amin First Nation ~1000 years ago.

2.1.2. Background and Study Area

The sites examined are from current Sliammon territory and include a village site (DlSd-11), a campsite (DlSf-6) located on the southwest coast of Savary Island, and five other shell midden sites in the Powell River region on the southern coast of British Columbia in the traditional territory of the Tla'amin First Nation (Fig. 2.1.). The shells were collected from excavation units and shovel test pits during the fieldwork associated with the Simon Fraser University – Tla'amin First Nation Archaeology and Heritage Stewardship Project that took place between 2009 and 2013 (Springer et al. 2013).

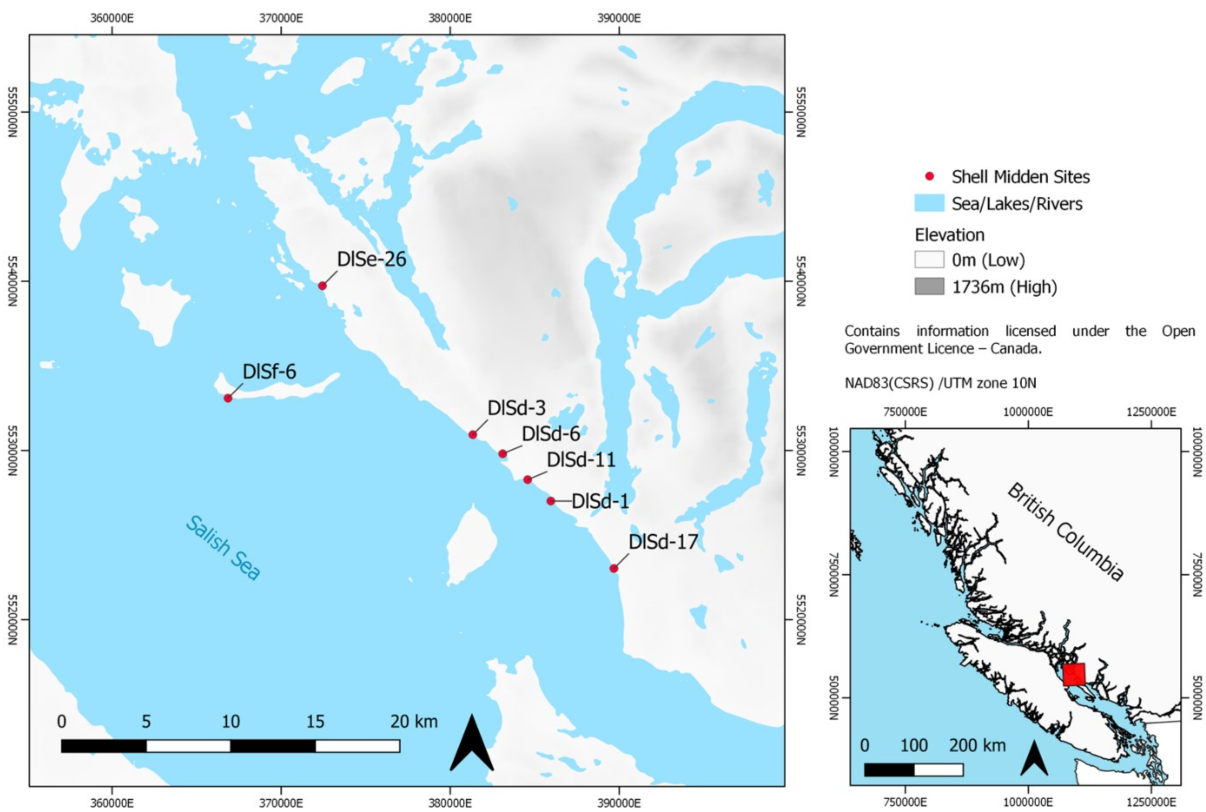

Figure 2.1 Map showing location of seven shell midden sites (DlSd-1, DlSd-3, DlSd-6, DlSd-11, DlSd-17, DlSe-26, and DlSf-6) near Powell River, British Columbia in the traditional territory of the Tla'amin First Nation.

2.1.3. Subsistence and Settlement Patterns of the Ancestral Tla'amin

Springer et al. (2013) noted that larger settlements have larger and more stratified middens that contain key resource species which include salmon, herring, butter clams and littleneck clams as well as other fish, shellfish, and marine and terrestrial mammals. At smaller sites, the middens are more primarily composed of shellfish, specifically *L. staminea*, as well as some fish and rarely mammals or birds (Springer et al. 2013). Both archaeological research and ethnographic records state that the ancestral Tla'amin relied heavily on marine resources for diet with particular emphasis on herring and shellfish as primary resources (Angelbeck 2009; Caldwell 2015; Chisholm 1986; Jackley 2013; Johnson 2010; Lepofsky and Caldwell 2013; Springer et al. 2013, 2018; Springer and Lepofsky 2020).

The settlement pattern of the ancestral Tla'amin was based on proximity to resources, particularly fish and shellfish, as well as defensibility (Angelbeck 2009; Springer et al. 2013). Most larger settlement sites, such as villages, were positioned in areas that had good proximity to marine food resources, protection from the elements, and from view (Angelbeck 2009; Springer et al. 2013; Springer and Lepofsky 2020). A major concern for the ancestral Tla'amin was the defensibility of their territory, which involved the construction of smaller settlements in near proximity to the larger settlements to serve as defensive sites such as trench embankments, lookouts, and redoubts (Angelbeck 2007, 2009; Moss and Erlandson 1992; Springer and Lepofsky 2020). These smaller settlements aided in the protection of the larger settlements and took advantage of the proximity to the ocean for use of marine resources for subsistence (Angelbeck 2009; Caldwell 2015; Jackley 2013; Johnson 2010; Springer et al. 2013; Springer and Lepofsky 2020).

2.1.4. Bivalve Shell Growth

Bivalve shell growth occurs continually through the addition of shell material, made from calcium carbonate to the growing edge of the shell (Karleskint et al. 2013). Bivalve shell growth reflects the environmental conditions in the habitat of the animal and is affected by water temperature, salinity, sediment type, currents, and valve opening times (Claassen 1998:25). When conditions are favourable, meaning that the environmental conditions are in a tolerable range and there is good availability of food, the growth is lighter in colour and is termed a growth increment (Andrus and Crowe 2000; Cannon and Burchell 2009). When conditions are less favourable, the growth rate slows, and the colouration of growth is darker and called a 'growth line' (Andrus and Crowe 2000).

Bivalve shell growth rates change throughout the lifespan of the animal. The growth rate changes the number and quantity of growth lines and growth increments within the shell and can be used to identify a growth stage of a clam (Claassen 1998). The fastest growth occurs during the juvenile growth stage, followed by more even sequential growth during the mature growth stage, and the slowest growth occurring during the senile growth stage (Claassen 1998).

2.1.5. Bivalve Growth Increment Analysis

Bivalve shell growth can be analyzed through high-resolution (micro-scale) and low-resolution (macro-scale) (Burchell et al. 2013a; Milano et al. 2017; Prendergast et al. 2017; Purroy et al. 2018). Low-resolution growth stage analysis examines the macro changes that occur on an annual or seasonal period, whereas high-resolution growth stage analysis is focused on the micro-scale fluctuations that occur on a daily and even tidal basis (Burchell et al. 2013a; Hallmann et al. 2009, 2013). Following the protocols outlined in previous studies of shellfish harvesting intensity (e.g. Burchell et al. 2013b; Cannon and Burchell 2009; Leclerc 2018), the macro-growth scale is sufficient to determine the growth stage in which a shell was harvested.

The initial study of shellfish harvest pressure in British Columbia focused on the analysis of nine shell middens from the central coast of British Columbia in the traditional territory of the Heiltsuk First Nation (Cannon and Burchell 2009). Cannon and Burchell (2009) demonstrated that the incremental growth stages of *S. gigantea* shells can be used to determine the age of the clams at harvest and that the relative proportions of one growth stage over another can be interpreted to identify the harvest intensity of shellfish. Cannon and Burchell (2009) found that sites that had a majority of mature growth stage clam shells were interpreted as exhibiting higher harvest intensity, whereas sites that had a majority of senile growth stage clam shells were interpreted as exhibiting a lower relative harvest intensity. Their research showed that a majority of senile growth stage clam shells is indicative of a lower harvest intensity as the harvesters waited until the clams had reached their maximum level of growth before collection and as such were practicing restraint with regards to the collection and selection of this food resource (Cannon and Burchell 2009). The research also showed that conversely, the shell midden sites that had a majority of mature growth stage clam shells had a higher harvest intensity (Cannon and Burchell 2009).

Subsequent studies also used the growth of *S. gigantea* as a proxy for relative shellfish harvest intensity for shell midden sites on the north, central and southern coast of British Columbia (Burchell et al. 2013b; Cannon and Burchell 2016; Leclerc 2018; Sparrow 2016). *Leukoma staminea* is another commonly recovered bivalve species and is commonly found in the same context as *S. gigantea*, and in some cases, *L. staminea* dominates archaeological shell midden assemblages (Leclerc 2018).

2.2. MATERIALS AND METHODS

Archaeological shells for this study were collected from either excavation units or shovel test pits during Archaeological Field schools from Simon Fraser University as part of the Simon Fraser University - Tla'amin First Nation Archaeology and Heritage Stewardship project, 2009-2013. The contents of the shell middens were previously cleaned, sorted, and catalogued as part of Caldwell's (2015) PhD thesis, completed at the University of Alberta.

Saxidomus gigantea (butter clam) and *L. staminea* (littleneck clam) shells were collected from seven shell midden sites in the Powell River region on the southern coast of British Columbia in the traditional territory of the Tla'amin First Nation. Five of the seven archaeological shell midden sites (DlSd-1, DlSd-3, DlSd-6, DlSd-17, DlSe-26, DlSd-11 and DlSf-6) examined are designated as defensive lookout sites, one of the sites is identified as a campsite (DlSf-6), and one is a village site (DlSd-11) (Springer et al. 2013) (Table 2.1).

Table 2.1 The Borden numbers, site names, and settlement occupation types for sites in the Powell River region. The dates have a Delta-R correction of 198+/-98 BP from the 10 closest points from the Marine20 database and calibrated on IntCal20.

Borden Number	Site Name	Occupation Type	Date (cal. BP)
DlSd-1	Gibson's Beach	Defensive	1065-797
DlSd-3	Malaspina Inlet	Defensive	
DlSd-6	Klehkwannum	Defensive	1063-965
DlSd-17	L'yjiwmixw	Defensive	1061-920
DlSe-26	Rasmussen Bay	Defensive	1270-1000 and 1179-978
DlSd-11	Teeshoshum	Village	1277-1073
DlSf-6	Kayaykwon	Campsite	2682-2346

A total of 664 bivalve shells and shell fragments (n=322 *S. gigantea*; n=322 *L. staminea*) were analyzed from seven shell midden sites. The methods presented in Cannon and Burchell

(2009) to prepare shells and observe growth stages were followed. These data are comparable to other studies of shellfish harvesting pressure using this method on the Pacific Northwest Coast. Cannon and Burchell (2009) analyzed a total of 593 *S. gigantea* shells from nine archaeological sites on the central coast of British Columbia in the territory of the Heiltsuk First Nation.

For this study, to understand the relative harvest pressure at each site over time, bivalve shell samples were selected from different stratigraphic levels. Where possible, whole shells were selected for use in analysis. To assess shellfish harvesting pressure between the sites, a subsample of 50 shells of both *S. gigantea* and *L. staminea* were selected from each site. Two of the seven sites (DlSd-3 and DlSd-11) did not have 50 shells of each species, therefore all available shell fragments were used.

Shells were cut using a Dremel rotary tool perpendicular to the growth lines to reveal the shell's inner structure (Fig. 2.2.). Each specimen was then ground and polished using the Buehler Eco-Met variable speed grinder/polisher with 600 and 1000 SiC grit powder, and last polishing with 1µm Al2O3 colloidal solution. Shells were cleaned in an ultrasonic cleaner between each grinding and polishing step.

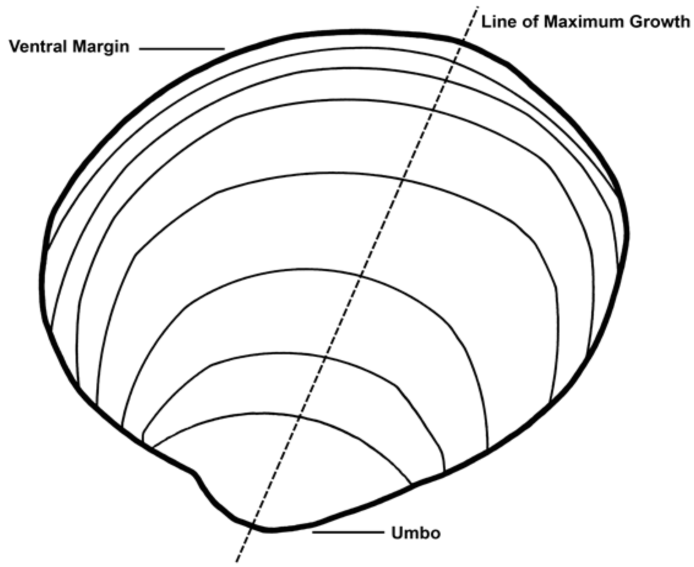

Figure 2.2 Illustration of a *S. gigantea* shell displaying ventral margin, umbo and cut line.

Each shell was assigned a growth stage only if the growth structure was clearly visible as either juvenile, mature, or senile and the shells without a discernible growth structure being labelled as uncertain. Juvenile shell growth is visible as it is the period in which shell growth occurs at the highest rate, meaning that there are very few visible growth cessations (growth lines) (Claassen 1998). Mature growth also shows fast growth, but it is marked by evenly spaced regular growth increments and lines continuing up to and including the ventral margin (Cannon and Burchell 2009: 1051). Senile growth is the slowest growth stage and is marked by the close and numerous incremental growth banding closely packed at the ventral margin of the shell (Cannon and Burchell 2009: 1051). The uncertain category included the shells that did not fit into any of the other categories as their growth banding was unclear and the observers could not confidently identify what growth stage the shell was exhibiting. To refine growth stage assessments, the analysis relied on inter-observer variability, of the author and a colleague, to assess the error in assignment categories of ‘juvenile’, ‘mature,’ senile’ and ‘uncertain’.

2.3. RESULTS

Like *S. gigantea*, *L. staminea* shows a clear division between the upper prismatic layer and the lower nacreous layer and shows very distinct growth lines that are ideal for reliable and fast growth stage identifications (Fig. 2.3.).

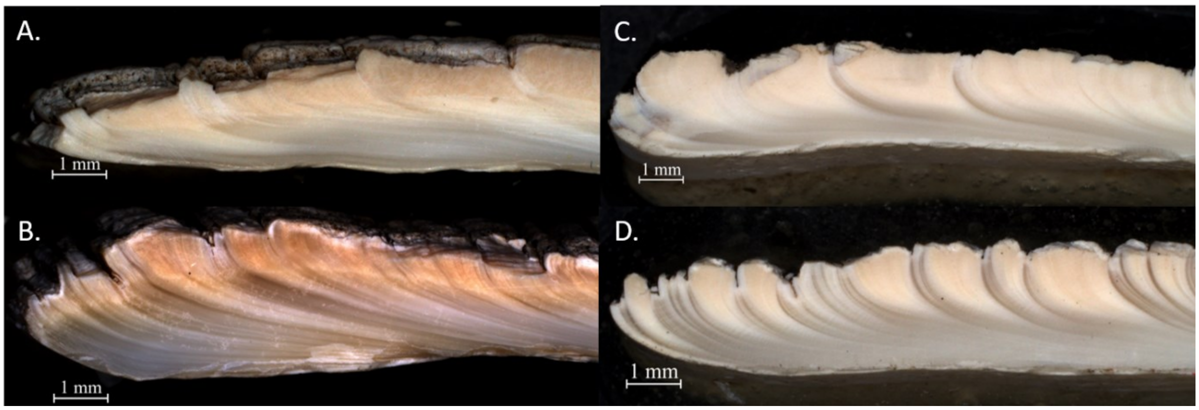

Figure 2.3 Examples of mature growth *L. staminea* (A), senile growth *L. staminea* (B), mature growth *S. gigantea* (C) and senile growth *S. gigantea* (D).

2.3.2. Harvesting Rates

2.3.2.1. *Saxidomus gigantea*

Overall, 53% of the *S. gigantea* shells were in a mature stage of growth, 34% in senile, 5% in juvenile and 8% in uncertain. When examined by site, (DlSd-1), was the only one with a higher percentage of senile shells (50% senile, 28% mature) (Table 2.2.) and DlSd-6, had an even distribution between mature (46%) and senile (48%).

The majority of defensive sites, DlSd-3, DlSd-17 and DlSe-26 had more mature (DlSd-3: mature 52% senile 29%; DlSd-17: mature 66% senile 30; DlSe-26: mature 48% senile 36%) shells, suggesting a more intensive rate of harvest than at site DlSd-1 (Fig. 2.4.). The village site, DlSd-11 also showed a pattern of mature (51%) harvesting over senile (32%) growth clam harvesting. The camp site had the highest proportion of mature (80%) compared to senile shells (12%).

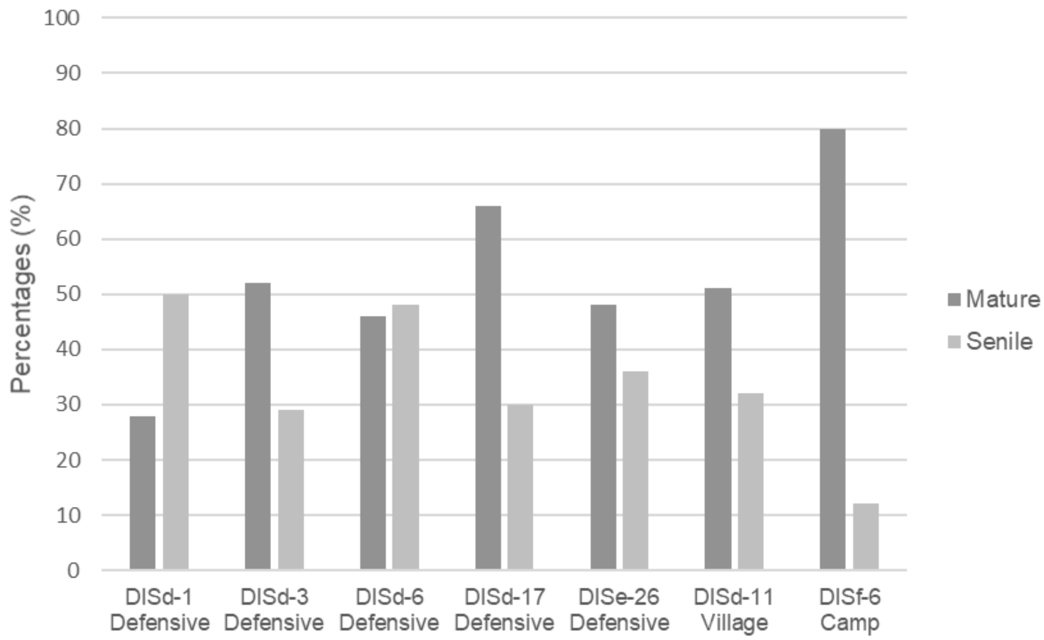

Figure 2.4 Relative proportions of mature and senile growth stage *S. gigantea* shell sections by site.

Table 2.2 The number and percentage of senile- and mature-growth stage *S. gigantea* shell sections and the juvenile and uncertain growth-stage shell sections observed at sites in the Powell River vicinity.

Site	Site Type	Growth Stage Category							
		Juvenile		Mature		Senile		Uncertain	
		n	%	*n*	%	*n*	%	*n*	%
DlSd-1	Defensive	5	10	14	28	25	50	6	12
DlSd-3	Defensive	3	10	16	52	9	29	3	9
DlSd-6	Defensive	1	2	23	46	24	48	2	4
DlSd-17	Defensive	1	2	33	66	15	30	1	15
DlSe-26	Defensive	4	2	24	48	18	36	3	2
DlSd-11	Village	1	8	21	51	13	32	6	6
DlSf-6	Camp	0	0	40	80	6	12	4	8

2.3.2.2. *Leukoma staminea*

Overall, 63% of *L. staminea* shells were mature, 29% senile, 1% juvenile and 7% uncertain. When examined by site, the majority of the sites examined showed a clear preference for the collection of mature growth *L. staminea* shells (Fig. 2.5.). All of the defensive sites, DlSd-1 (mature 74%, senile 16%), DlSd-3 (mature 68%, senile 27%), DlSd-6 (mature 74%, senile 24%), DlSd-17 (mature 64%, senile 30%) and DlSe-26 (mature 62%, senile 18%) had a higher majority of mature growth clam shells collected (Table 2.3.) The campsite, DlSf-6, also showed a preference for the collection of mature growth clam shells (66%) over senile growth clam shells (24%). The only exception was the sole village site (DlSd-11), where there is a higher majority of senile growth clam shells collected (60%) over the smaller proportion of mature growth clam shells collected (34%).

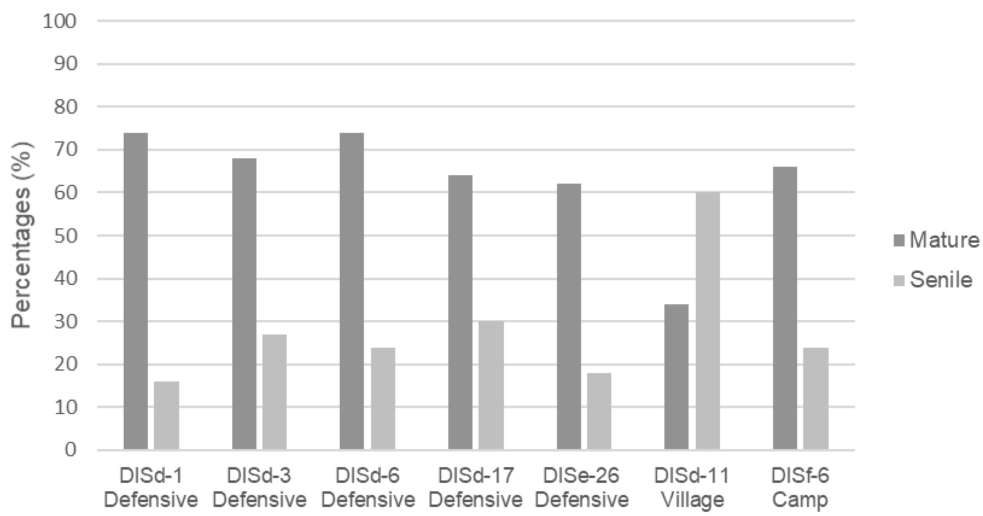

Figure 2.5 Relative proportions of mature and senile growth stage *L. staminea* shell sections by site.

Table 2.3 The number and percentage of senile- and mature-growth stage *L. staminea* shell sections and the juvenile and uncertain growth-stage shell sections observed at sites in the Powell River vicinity.

Sites	Site Type	Growth Stage Category							
		Juvenile		Mature		Senile		Uncertain	
		n	%	*n*	%	*n*	%	*n*	%
DlSd-1	Defensive	1	2	37	74	8	16	4	8
DlSd-3	Defensive	0	0	15	68	6	27	1	5
DlSd-6	Defensive	0	0	37	74	12	24	1	2
DlSd-17	Defensive	1	2	32	64	15	30	2	4
DlSe-26	Defensive	2	2	31	62	9	18	8	4
DlSd-11	Village	1	4	17	34	30	60	2	16
DlSf-6	Camp	2	4	33	66	12	24	3	6

2.4. DISCUSSION

2.4.1. Inter-site variability

There was no significant difference in the patterns of harvest intensity between the seven sites examined. Most of the sites examined in this study exhibit higher relative harvest intensity as the majority of the shells examined, of both species, were collected at the mature growth stage. The only two exceptions are the defensive site, DlSd-1, that had a higher percentage of senile growth stage *S. gigantea* shells (28% mature and 50% senile), and the village site, DlSd-11, that had a higher percentage of senile growth stage *L. staminea* shells (34% mature and 60% senile). The results show that for defensive sites, there is generally a higher relative harvest intensity of shellfish. Lookout sites were common for areas surrounding main settlement locations, such as the village site DlSd-11. As these lookout sites were occupied in order to help protect settlement sites from attack, there was a need for food throughout the occupation of the site. There is evidence to suggest that food was brought to these sites and supplemented through clam harvesting and fishing at the sites (Angelbeck 2007, 2009; Moss and Erlandson 1992; Springer and Lepofsky 2020). Coastal lookout sites were generally located on bluffs that provided a large viewshed and relatively close to settlements (Angelbeck 2009; Springer and Lepofsky 2020). Lookout sites were commonly located in areas where clams would be a readily available food resource, which would account for the higher relative harvest pressure exerted at these sites.

The results also show a difference between species for the relative harvest intensity for the village site DlSd-11, where *S. gigantea* indicates higher harvest intensity with a majority of mature growth shells (51% mature, 32% senile) and *L. staminea* indicates lower harvest intensity with a majority of senile growth shells (34% mature to 60% senile). Finally, the results show that the campsite, DlSf-6, shows higher relative harvest intensity for both species examined.

Defensive sites have a higher proportion of *L. staminea* harvested in the mature growth stage compared to *S. gigantea*. In contrast, the camp and village sites show a higher proportion of mature growth stage *S. gigantea.* At first glance, this could suggest a species-specific harvesting pattern, but with only one village and one campsite, few definitive conclusions can be made.

2.4.2. Species Variability in Harvest Intensity

When considering which species was harvested more intensively, it is critical to consider the lifespan and development of both species of bivalves. The higher percentage of mature growth stage *S. gigantea* shells may be due to the differing growth rates between the two species. *L. staminea* has a life span of ~14 years and reaches the senile growth stage at around four to five years (Gillespie and Bourne 1998; Harbo 2001). *S. gigantea* has a lifespan of ~20 years and, on the south coast, reaches the senile growth stage at five to six years (Burchell et al. 2013b; Harbo 2001). A faster growth rate should result in senility at an earlier age indicating potentially more intensive harvest than the data might suggest (Burchell 2013b:167). Since *S. gigantea* spends a longer period of time in the mature growth stage, it is probable that more mature growth stage clams would be collected.

The relative harvest intensity of shellfish in coastal British Columbia changes over space and time (Burchell et al. 2013 a, b; Cannon and Burchell 2009, Leclerc 2018). Shellfish harvesting strategies can depend on season, availability, diet preferences, territorial ownership among others. Though shell midden sites can be located in proximity to each other, the use of those shell middens can span generations and groups. The ecology of the area can change the availability of shellfish and the safety of eating shellfish. Land ownership can also cause changes in the rate of shellfish collection and consumption. Cannon and Burchell (2009) identified reasons that one site may have had a higher harvest intensity over another including environmental and ecological concerns. For example, ownership or control over the resources available in a particular location can affect the rate of harvest by controlling who can collect shellfish from that location. In order to protect that resource and ensure its longevity, the individual or family group prevents over-harvesting of particular resources (Augustine and Dearden 2014; Cannon and Burchell 2009; Groesbeck et al. 2014; Smith and Wishnie 2000). This is supported by ethnographic data from previous research detailing the history of territorial ownership of clam beds in the coastal regions of British Columbia (Moss 1993; Trosper 2002; 2009; Turner 2005).

2.5. CONCLUSION

The results of this study show that a multi-proxy approach to shell midden analysis provides more ecologically specific information pertaining to past human interactions with shellfish beds. As more species are incorporated into these kinds of analysis, it has the potential to change archaeological interpretations of shellfish harvesting. Our work provides new insights into the shellfish harvesting strategies of the ancestral Tla'amin. Increasing the number of villages and camps analyzed would provide insights into site-specific harvesting patterns.

2.6. ACKNOWLEDGEMENTS

Funding for this project was provided by research grants to Dr M. Burchell from the Social Sciences and Humanities Research Council of Canada (SSHRC) and Canada Foundation for Innovation (CFI). The authors would like to thank Dr M. Caldwell, Dr C. Springer and the Simon Fraser University Archaeology Department for providing the archaeological shell materials and field report. Samantha Werry is thanked for her assistance in analysis.

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CHAPTER 3

A Dual Proxy Bivalve Approach for Interpreting Past Sea Surface Temperatures and Seasonality from Shell Midden Sites

ABSTRACT

Stable oxygen isotope ($\delta^{18}O$) analysis, combined with sclerochronology, is a powerful tool that can precisely determine the season of shellfish collection, and by proxy, the season of archaeological site occupation. These data can also be used to reconstruct past sea surface temperatures and interpret the palaeosalinity of local ocean water. This study uses $\delta^{18}O_{shell}$ and sclerochronology to test the feasibility of the oxygen isotopes of the marine bivalve species *Leukoma staminea* (littleneck clam) as a new proxy for the season of shellfish collection and past sea surface temperature (SST) on the Pacific Northwest Coast of North America. We analyzed live-collected specimens of *L. staminea* from Sechelt, British Columbia, and compared the results to archaeological shells excavated from a shell midden at Powell River, British Columbia, in the territory of the Tla'amin First Nation (1065 to 797 cal. BP). We combine these results with a sample of *Saxidomus gigantea*, a well-studied bivalve, interpret seasonal patterns of shellfish collection, and by proxy, archaeological site occupation. Our results show that *L. staminea* can be used as a proxy for SST. However, the calculated palaeotemperatures indicated that, like *S. gigantea*, the occurrence of freshwater influxes and variable changes in salinity greatly affect temperature calculations. Using two species as environmental proxies, we garner more information on intertidal zone conditions and evaluate if one species is a more reliable recorder of past salinity and SST.

Keywords: Sclerochronology, Stable Oxygen Isotopes, Shell Middens, Seasonality, Sea Surface Temperature, Shellfish Harvesting

3.1. INTRODUCTION

Stable oxygen isotope ($\delta^{18}O$) values found in calcareous organisms (such as mollusks and coral) can be used as a proxy for reconstructing sea surface temperatures (SST) of where the organism lived (Epstein et al. 1953; Gillikin et al. 2005; Hallmann et al. 2009). This study tests the feasibility of using oxygen isotopes of the littleneck clam *Leukoma staminea* (Conrad 1837) as a new proxy for seasonality and SST for the southern coast of British Columbia. *L. staminea* is commonly found throughout archaeological shell middens on the Pacific Northwest Coast and can serve as a valuable tool to understand past patterns of archaeological seasonality, shellfish harvesting, and site occupation.

Previous research established the bivalve species *Saxidomus gigantea* (Deshayes 1839) as a reliable proxy for SST and seasonality. Although this is a common species, it does not appear in all shell middens, and some sites are dominated by *L. staminea* (Leclerc 2018, Springer et al. 2013). A multi-proxy analysis for past SST allows for either confirmation of data or the ability to analyze the strength and weaknesses of the proxies involved (Lotter 2003; Mann 2002). A multi-proxy approach allows for a greater spectrum of species to be incorporated into interpretations, providing more robust seasonality interpretations. This is critical for using seasonality to infer patterns of seasonal site occupation. If the season of collection differs between species, not only would that indicate that the season(s) of occupation may be broader than the original interpretation, it may also point to seasonal preference in species collection.

Patterns of seasonal shellfish harvesting using high-resolution isotope sclerochronology have been completed on the north, central and southern coasts of British Columbia in the ancestral territories of the Coast Tsimshian, Heiltsuk, and Shíshálh First Nations (North: Hallmann et al. 2013; Central: Burchell et al. 2013a, b, c; South: Leclerc 2018). These studies have shown regional and cultural variation in seasonal patterns that contradict the ethnographic records of settlement and seasonal shellfish harvesting trends. These studies have also shifted perceptions about the beginning of sedentism in large, permanent villages (Burchell et al. 2013a). This study uses high-resolution stable oxygen isotope sclerochronology of two bivalve species as proxies to examine past SST and seasonality in the ancestral territory of the Tla'amin First Nation. The interpretation of the season of shellfish harvesting allows for a better understanding of the seasonal changes of site occupation and subsistence patterns of the past.

3.1.2. Marine Bivalve Growth and Stable Oxygen Isotopes

Bivalve shells are secreted in three layers; the nacreous layer, the prismatic layer, and the periostracum. The periostracum is the outermost layer and is composed of a conchiolin protein that forms a hardened surface for the shell. Both the nacreous and prismatic layers are composed of calcium carbonate but have different crystalline structures (Karleskint et al. 2013). The prismatic layer contains the environmental information used to determine the age and seasonality of the shell (Claassen 1998). The prismatic layer of a shell encodes the climatic conditions from the time the shell was formed, notably the $\delta^{18}O_{shell}$ values of the water in which the shell lived. Through the careful collection of the shell carbonate material from the outermost edge of the shell and the subsequent layers of deposition of the shell, a seasonal curve in the fluctuation of the levels of $\delta^{18}O_{shell}$ levels in the water can be determined, and the season of capture of the shell can be interpreted (Burchell et al. 2013b).

The calcium carbonate that forms bivalve shells comes in two crystalline structures, calcite and aragonite. The crystal structure of bivalves is determined by their species and habitat and can change from calcite to aragonite, or vice versa, due to the process of cooking or fossilization (Milano et al. 2016). The majority of freshwater mollusks, oysters, and mussels are composed of calcite crystals, whereas marine clam shells are generally composed of aragonite crystals (Claassen 1998). Both *S. gigantea* and *L. staminea* shells are composed of aragonite.

In the right environmental circumstances, there is a strong relationship between the $\delta^{18}O_{shell}$, $\delta^{18}O_{water}$, sea surface temperature, and salinity (Gillikin et al. 2005; Hallmann et al. 2009; Klein et al. 1997; Schöne and Gillikin 2013). When the water temperature is higher and salinity is lower (in summer), oxygen-18 is more negative, whereas when the temperature is lower and salinity is higher (in winter), oxygen-18 in the water is more positive (Hoefs 2004).

When the $\delta^{18}O$ is sequentially collected along the axis of growth of a calcareous shell, a seasonal change in $\delta^{18}O_{shell}$, temperature, and salinity can be interpreted (Burchell et al. 2013b).

Previous studies of $\delta^{18}O_{shell}$ from *S. gigantea* from the Pacific Northwest Coast showed that salinity greatly influences past SST reconstructions (Burchell et al. 2013b; Gillikin et al. 2005; Hallmann et al. 2009). Hallmann et al. (2009) noted that SST measurements were overestimated by ~6°C on Pender Island on the southern coast of British Columbia and by ~8°C in Alaska, United States of America. Burchell et al. (2013b) found that the reconstructed temperature had a range of ~21°C for the Fitz Hugh Sound on the central coast of British Columbia. In contrast, the region's measured temperature had a range of ~7°C (Burchell et al. 2013b).

3.1.3. Study Area and Archaeology

Archaeological shells were obtained from a shell midden excavation at Gibson's Beach in Powell River, British Columbia, in the traditional territory of the Tla'amin First Nation. This site, DlSd-1, was excavated as part of the 2009 to 2013 field schools as part of the joint Simon Fraser University - Tla'amin First Nation Archaeology and Heritage Stewardship project. DlSd-1 is identified through Tla'amin oral histories as a defensive or "bunker" site (Springer et al. 2013). DlSd-1 is located on the eastern side of the Salish Sea and is approximately 74.75 km NW of the Swik'als site. (Fig. 3.1.). DlSd-1 is part of the Coastal Western Hemlock biogeoclimatic zone and has a mean annual precipitation of 1427 mm (Centre for Forest Conservation Genetics 2020).

Archaeological and ethnographic evidence for the ancestral Tla'amin indicates a reliance on marine resources for subsistence (Angelbeck 2009; Caldwell 2015; Chisholm 1986; Jackley 2013; Johnson 2010; Lepofsky and Caldwell 2013; Springer et al. 2013; 2018; Springer and Lepofsky 2020). The middens excavated at larger settlement sites, such as a village, show more diet diversity, including fish, shellfish, marine mammals, and terrestrial mammals (Springer et al. 2013). However, both the large settlements and smaller settlements show a heavier reliance on herring and the littleneck clam (Springer et al. 2013). Paleoethnobotanical analysis of the shell midden sites DlSd-6 and DlSd-7, ~4 km NW of DlSd-1, suggests an early to late summer occupation period (Jackley 2013).

Figure 3.1 North wall of excavation unit 2 at site DlSd-1, showing dense shell midden (photo by Megan Caldwell) (Springer et al. 2013).

To test the feasibility of using oxygen isotopes of *L. staminea* shells for reconstructing seasonality and past SST, we obtained live-collected specimens of *L. staminea* shells from Swik'als (Sechelt Inlet), British Columbia, in the traditional territory of the Shíshálh First Nation (Fig. 3.2.). Swik'als is located in the Coastal Douglas-Fir biogeoclimate zone and is part of an estuarine environment at the end of the Sechelt Inlet. The estuarine environment of the Swik'als site means that throughout the day, there is a notable seasonal change in the temperature $\delta^{18}O$ value and salinity of the water. In the Coastal Douglas-Fir biogeoclimate zone, there is roughly

1038 mm of recorded precipitation each year, and ice and snowmelt which is run-off into the Sechelt Inlet (Centre for Forest Conservation Genetics 2020).

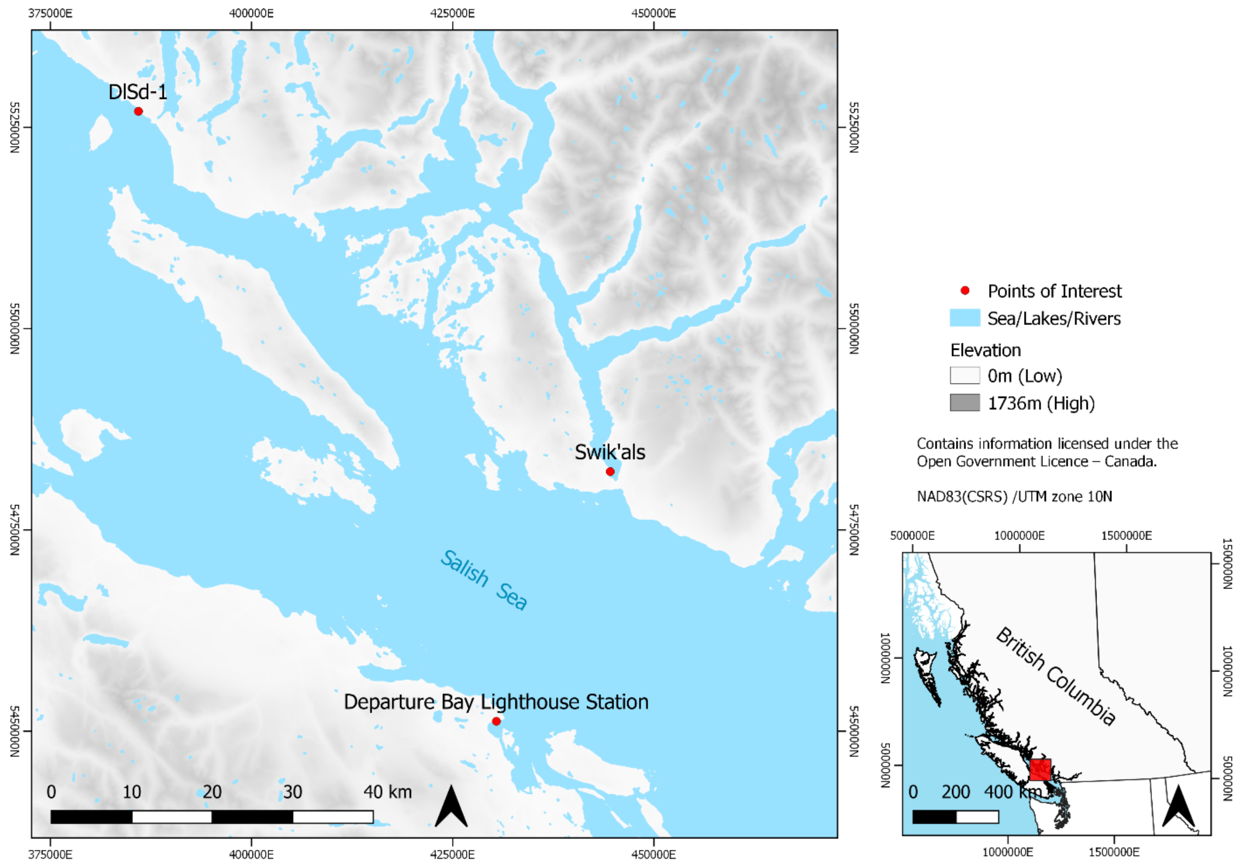

Figure 3.2 Map displaying the location of the live-collection site of *L. staminea* at Swik'als in Sechelt, British Columbia, archaeological shell midden site DlSd-1 in Powell River, British Columbia, and the Departure Bay Lighthouse Station used for climate data located in Nanaimo, British Columbia.

Ideally, the live-collected *L. staminea* shell samples would have been from the same geographic region; however, the environmental and ecological factors are very similar for the two locations. Both Swik'als (Sechelt Inlet) and DlSd-1 (Powell River) are located ~75 km apart and are both affected by the Salish Sea's coastal current and have similar climates and environments. Both sites are also within biogeoclimate zones that receive a relatively large amount of yearly precipitation (1038 mm and 1427 mm, respectively). We recognize that the small variations between the two locations cause limitations and consider this in our interpretations.

3.2. MATERIALS AND METHODS

L. staminea can be found in the intertidal zone on the west coast of North America, from northern Alaska to northern Mexico, and can grow to 13 cm in length (Lamb and Hanby 2005). *S. gigantea* is found from southern Alaska to central California along the West coast of North America (Lamb and Hanby 2005). *L. staminea* and *S. gigantea* burrow into rocky or sand-mud bottoms on the intertidal zone (Harbo 2001). *L. staminea* buries themselves up to 10cm into the substrate, whereas *S. gigantea* can be found up to 30cm below (Harbo 2001). *L. staminea* lives to approximately ~14 years, and *S. gigantea* lives to around ~20 years (Harbo 2001).

Live-collected *L. staminea* shells were obtained at low tide on July 15th, 2019, from the intertidal zone within Sechelt Inlet located at Swik'als (Sechelt Band Lands No. 3) archaeological site, DiRw-42. To identify seasonal shellfish harvesting and test the potential variability between shellfish species, five *L. staminea* shells and five *S. gigantea* shells were selected from various excavated shell midden levels from site DlSd-1. The shells were selected for seasonality analysis based on the preservation, completeness of the ventral margin shell, and growth stage. Mature shells were preferred since they maintain a year-round growth pattern. To capture the temporal span of the site, shells were selected from various levels within the shell midden matrix (Table 3.1.). Prior to analyzing the archaeological shells for $\delta^{18}O_{shell}$ analysis, they were analyzed with a Bruker Alpha II FTIR spectrometer with a reflection module that confirmed the archaeological shells had not undergone diagenesis.

Table 3.1 Archaeological shells from site DlSd-1 with depths and number of shell carbonate samples taken.

ID	Species	Provenience	# of samples
DlSd-1-L29	*L. staminea*	10-20 cm	15
DlSd-1-L38	*L. staminea*	30-40 cm	15
DlSd-1-L14	*L. staminea*	0-10 cm	15
DlSd-1-L15	*L. staminea*	0-10 cm	15
DlSd-1-L21	*L. staminea*	10-20 cm	15
DlSd-1-B23	*S. gigantea*	10-20 cm	15
DlSd-1-B16	*S. gigantea*	30-40 cm	15
DlSd-1-B24	*S. gigantea*	0-10 cm	15
DlSd-1-B25	*S. gigantea*	0-10 cm	15
DlSd-1-B18	*S. gigantea*	30-40 cm	15

3.2.2. Sclerochronological Analysis

To determine the growth stage as being in a 'mature' or 'senile' stage of growth, polished cross-sections were examined under a Zeiss AxioZoom.V16 Telecentric Microscope. Shells that exhibited many small incremental growth lines near and including the shell's ventral margin were interpreted as senile growth. Shells that displayed regular, evenly incremental growth lines up to and including the ventral margin were interpreted as mature growth stage (see Cannon and Burchell 2009; Claassen 1998) (Fig. 3.3.).

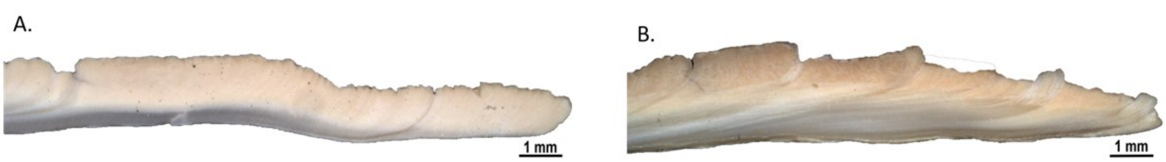

Figure 3.3 Mature specimens of *S. gigantea* (A) and *L. staminea* (B).

3.2.3. $\delta^{18}O_{shell}$ Analysis

The shells were prepared following the methods outlined by Burchell et al. (2013b). The shells were first cut along the line of maximum growth using a Dremel rotary tool with a diamond blade. One half of the shell was then mounted onto a glass slide using Hillquist Thin Section Epoxy. A 3 mm thick section of each shell was then cut with a Buehler Isomet low-speed saw with a 0.4 mm diamond wafering blade. The 3 mm thick section was then ground and polished using the Buehler Eco-Met high-speed grinder polisher with 600 and 100 SiC grit powder, with the last polishing using 1 µm Al2O3 colloidal solution. The shells were cleaned in an ultrasonic cleaner between each step.

To observe multiple years of growth and seasonal variation, each shell had 15 micro-milled samples at the ventral margin and ten micro-drilled samples. A total of 59 shell carbonate samples were obtained from three live collected shells to identify contemporary measurements of $\delta^{18}O$ (Fig. 3.4.). The archaeological shells had ten micro-milled shell carbonate samples and five micro-drilled shell carbonate samples. A total of 150 shell carbonate samples were collected from ten clam shells from site DlSd-1, 75 from 5 *L. staminea* shells, and 75 discrete samples from five archaeological *S. gigantea* shells. The slowest, most recent growing part of the shell, located at the ventral margin, was micro-milled using a 1 mm diamond-coated cylindrical drill bit (model no. 835104010). The samples started directly at the ventral margin and moved along the axis of growth in ~100 µm consecutive steps following the contours of the growth pattern. After the 15 samples were micro-milled, the following ten samples were micro-drilled in the faster-growing portion of the shells. The micro-drilling was completed using a 300 µm conical drill bit (model no. H52104003). The distance between drill points was between 400-600 µm. This allowed the capture of annual variation but at a lower resolution. A higher sampling strategy at the ventral margin is necessary to understand the seasonal signal of $\delta^{18}O_{shell}$ to interpret the final season of growth (before capture) and interpret the climatic conditions within the shell's habitat.

Figure 3.4 Isotope sampling location for live collected *L. staminea.* The lines represent the micro-milling locations, and the dots represent the micro-drilling locations. A) L3, B) L8, C) L9.

Samples for $\delta^{18}O_{shell}$ weighed between 150-250 μg using a Mettler Toledo AT21.Comparator analytical balance. Shell carbonate samples were processed in a Thermo Scientific Gas Bench II in The Earth Resources Research and Analysis Facility (TERRA) at the Memorial University of Newfoundland. The isotope data were calibrated against CBM ($\delta^{18}O$ = -8.55‰) NBS-19 ($\delta^{18}O$ = -2.20‰) and MUN-CO-1 internal standard (δ18O = -13.4‰) at a 1σ external reproducibility of 0.09 for oxygen. The $\delta^{18}O_{shell}$ values are expressed relative to the international VPBD (Vienna Pee Dee Belemnite) standard and are presented as parts per mil (‰) using the formula:

$$\delta^{18}O = [(^{18}O/^{16}O)_{sample}/(^{18}O/^{16}O)_{standard} - 1] * 1000$$

The aragonitic palaeotemperature equation from Böhm et al. (2000) was used to estimate the temperature using $\delta^{18}O_{shell}$ data from the live collected *L. staminea* clam shells.

$$T(℃) = (20.2 \pm 0.2) - (4.42 \pm 0.10) * (\delta^{18}O_{shell} - \delta^{18}O_{water}); \text{ for } 3° < T < 28°$$

3.2.4. Interpreting Shell Seasonality

To interpret the season of collection from archaeological shells, $\delta^{18}O_{shell}$ results were interpreted in association with the formation of growth lines in the shell. The cyclical (sub-annual/seasonal) variation in $\delta^{18}O_{shell}$ can be used to determine the season of collection (e.g., Burchell et al. 2013b; Hallmann et al. 2013; Leclerc 2018). We followed Burchell et al. (2013b: 13-15) model for interpreting shell seasonality, depending on how $\delta^{18}O_{shell}$ varies with distance from the last phase of shell growth.

(1). If there is a complete sinusoidal curve, the season is established based on the position of the ventral margin with respect to the curve and the growth pattern.

(2) If the $\delta^{18}O_{shell}$ value at the ventral margin approaches the most negative value exhibited by the sinusoidal curve of the shell, the season of collection is interpreted as summer. Conversely, if the $\delta^{18}O_{shell}$ value at the ventral margin approaches the maximum value exhibited by the sinusoidal curve, then the season of collection is interpreted as winter.

(3). If the $\delta^{18}O_{shell}$ becomes more positive with distance from the ventral margin, it indicates a colder collection (autumn to winter).

(4). If the $\delta^{18}O_{shell}$ decreases with distance from the ventral margin, this indicates a warmer season of collection (spring to summer).

3.3. RESULTS

3.3.1. $\delta^{18}O$ Analysis of Live-Collected Shells

The results of the three live collected shells show that *L. staminea* grows in seasonal cycles similar to previous studies of *S. gigantea* from the central region of the Pacific Northwest

Coast (e.g., Gillikin et al. 2005; Hallmann et al. 2009). Combined, the data from the three live-collected shells have $\delta^{18}O_{shell}$ values ranging from -4.04‰ to -1.78‰, (Table 3.2.) which results in a temperature range of 5.1°C - 18.9°C.

Table 3.2 $\delta^{18}O$ analysis results of the live-collected *L. staminea* shells collected from the Swik'als site in Sechelt, British Columbia. $\delta^{18}O$ results reported in parts per mille (‰).

Lab ID #	# of Samples	# Years Sampled (approx.)	Growth stage	Max	Min	Range	Ventral Margin
3	24	3	Mature	-1.78	-4.04	2.26	-2.86
8	10	<1	Mature	-2.27	-3.66	1.39	-2.27
9	25	7	Senile	-2.88	-3.9	1.02	-2.95

3.3.2. Temperature Reconstruction

To calculate temperature, the relationship between $\delta^{18}O_{water}$ and salinity was plotted using data collected from Swik'als in July 2019 and data collected by Leclerc (2018) in the surrounding areas. For paleoclimate reconstructions, it is most often assumed that the $\delta^{18}O_{water}$ value is equal to the $\delta^{18}O_{shell}$ value of the calcite organism. For the $\delta^{18}O_{water}$ vs. salinity relationship calculation, data from this study and others completed in the same study area (Leclerc 2018) were used (Fig. 3.5.). This graph shows that the relationship between $\delta^{18}O_{water}$ and salinity for this region is:

$$\delta^{18}O_{water} = -0.61*S+3.53 \qquad R2=0.42$$

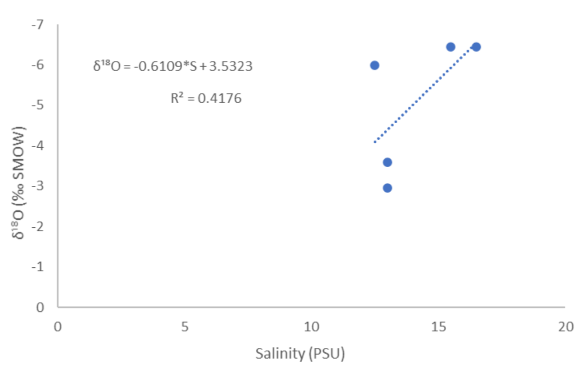

Figure 3.5 $\delta^{18}O$ values of seawater values plotted against salinity to determine the regression formula to estimate δ18O SMOW for Swik'als. $\delta^{18}O_{water}$ values in parts per mille (‰) and salinity reported in practical salinity units (PSU).

This relationship results in a calculated $\delta^{18}O_{water}$ value of -4.40‰. For all three live-collected shells, there is a temperature range from 5.1- 18.9°C.

3.3.3. Statistical Analysis of Live-Collected Shell Data

A Kruskal-Wallis statistical test was performed to understand the difference between the δ18Oshell results from shells in different stages of growth (mature vs. senile). The Kruskal-Wallis statistical test was used because of the differing number of samples for each of the three shells, as this test allows for these variants. The Kruskal-Wallis test results between all three shells showed a significant difference between the $\delta^{18}O_{shell}$ results for all three *L. staminea* clam shells tested (H=7.39, p=0.0248, α=0.05). A subsequent Kruskal-Wallis test also showed that there was no significant difference in the $\delta^{18}O_{shell}$ results for shells 3 and 8 (H=0.451, p=0.117, α=0.05), a significant difference between $\delta^{18}O_{shell}$ results for shells 3 and 9 (H= 6.934, p=0.008455, α=0.05) and that there was a significant difference between $\delta^{18}O_{shell}$ results for shells 9 and 8 (H=4.432, p=0.511, α=0.05).

To examine the difference between measured and observed temperatures, we compared our reconstructed temperatures to the measured temperature collected from the Departure Bay Lighthouse station in Nanaimo, British Columbia. A chi-square test revealed no significant difference between the calculated temperature from shell carbonate versus the measured temperatures obtained from the Departure Bay Lighthouse showed no significant difference ($X2$=1.98, p-value=0.15939, α=0.05).

3.3.4. PSST and Archaeological Seasonality of DlSd-1, Powell River

The data from the $\delta^{18}O_{shell}$ analysis of the five archaeological *L. staminea* shells were used in the Böhm et al. (2000) palaeotemperature equations with the following results. The overall maximum calculated temperature was 26.7°C, a minimum temperature value of 5.3°C with a resulting range of 21.4°C.

Table 3.3 Archaeological $\delta^{18}O_{shell}$ values, seasonality results, and calculated temperatures for *L. staminea* and *S. gigantea* from Powell River, British Columbia.

		δ18Oshell (‰)				Season of Collection	Temperature (°C)		
ID	Species	Max	Min	Range	Ventral Margin		Max	Min	Range
DlSd-1-L29	*L. staminea*	-1.45	-4.03	2.58	-3.01	Spring/ Summer	18.6	6.5	12.1
DlSd-1-L38	*L. staminea*	-1.20	-5.83	4.63	-2.76	Spring	26.7	5.3	21.3
DlSd-1-L14	*L. staminea*	-1.33	-5.81	4.48	-4.16	Spring	26.6	5.9	20.6
DlSd-1-L15	*L. staminea*	-1.37	-5.75	4.38	-5.08	Summer	26.3	6.1	20.2
DlSd-1-L21	*L. staminea*	-2.30	-4.55	2.25	-2.76	Fall/ winter	20.9	10.3	10.6
DlSd-1-B23	*S. gigantea*	-1.74	-6.76	5.02	-3.76	Spring	30.9	7.8	23.1
DlSd-1-B16	*S. gigantea*	-2.00	-7.01	5.01	-3.68	Spring	32	9	23
DlSd-1-B24	*S. gigantea*	-2.26	-6.07	3.81	-3.35	Spring	27.7	10.1	17.6
DlSd-1-B25	*S. gigantea*	-2.08	-4.94	2.86	-3.63	Spring	22.6	9.3	13.3
DlSd-1-B18	*S. gigantea*	-1.38	-6.21	-4.83	-4.56	Spring	28.4	6.1	22.2

The resulting data from the $\delta^{18}O_{shell}$ analysis of five *S. gigantea* shells from the archaeological shell midden site of DlSd-1 were used in the Böhm et al. (2000) palaeothermometry equation. The results of the calculations are displayed in Table 3.3. The overall maximum calculated temperature was 32.0°C, a minimum value of 6.1°C with a range of 25.9°C.

Overall, the maximum $\delta^{18}O_{shell}$ value of the archaeological *L. staminea* shells was -1.20‰, a minimum value of -5.83‰ with a range of 4.63‰. The seasonality interpretation results show three of the five shells collected in the spring, one in the summer and the other in a colder season (fall/winter). The overall maximum $\delta^{18}O_{shell}$ value of the archaeological *S. gigantea* shells was -1.38‰, the minimum was -7.01‰ with a range of 5.63‰. All five of the *S. gigantea* shells are interpreted to have been collected in the spring.

A one per mil (‰) change in the $\delta^{18}O_{shell}$ value implies a 4.42°C temperature change of ambient water. This study used the Böhm et al. (2000) equation instead of the Grossman and Ku (1986) equation to reduce the error in the calculated temperature. A further consideration is the precision error of the mass spectrometer, resulting in an average error of 0.5°C. A reconstructed $\delta^{18}O_{water}$ value of -4.40‰ was used for temperature reconstruction. The resultant calculated temperature for the live-collected shells recorded an annual SST range of 5.1 - 18.9°C. The archaeological *L. staminea* shells showed an annual SST range of 5.3 - 26.7°C, and the archaeological *S. gigantea* shells indicated an annual SST range of 6.1 - 32.0°C. The SST data from the nearest monitoring site at the Departure Bay lighthouse station from January 1 - December 31, 2019, had a yearly maximum SST of 20.4℃, a minimum of 5.7℃, and a range of 14.7℃. The results of the paleotemperature calculations of the archaeologically collected shells show a change in temperature from the current day of ~0.4 - 11.6℃.

Seasonality from the ten archaeological shells from site DlSd-1 in the Powell River region of British Columbia indicates a preferential collection period during the spring season. All five of the *S. gigantea* shells are interpreted for spring collection, and two of the *L. staminea* shells show a season of collection of spring, and another indicates spring/summer. One of the *L. staminea* shells indicated summer collection and the final *L. staminea* shell analyzed indicated colder time of collection in either late autumn or early winter. These results show a preference for the season of shellfish collection in the spring, with some harvesting also occurring in the summer and into the autumn. To determine if there is a seasonal difference in species collection, more samples from *S. gigantea* and *L. staminea* need to be analyzed. Although the sample of ten archaeological shells is small, this pattern of spring harvesting emphasis is consistent with other patterns of seasonality shellfish harvesting in coastal British Columbia. Leclerc (2018) noted that the majority of shellfish harvesting on the south coast of British Columbia occurred in the spring. Burchell et al. (2013a) noted that most shellfish harvesting occurred in the spring followed by autumn for the central coast. Hallmann et al. (2013) found that shellfish harvesting occurred more evenly throughout the spring, autumn, and winter on the northern coast. Although there are similar seasonal patterns, these data must be interpreted within the specific temporal and historical context and not conflated as a broad-regional trend.

3.4. DISCUSSION

The results of the $\delta^{18}O$ analysis of the three *L. staminea* clam shells tested in this study show that this species can be used for palaeotemperature calculations and analysis. As the results show, there were viable $\delta^{18}O$ values collected from all three shells within the expected ranges for $\delta^{18}O$ values of carbonate organisms from an estuarine environment. The temperature calculations using the Böhm et al. (2000) palaeotemperature equation showed that the resulting temperatures fall within the normal ocean temperature range for the study area. Leclerc (2018) examined three live-collected *S. gigantea* shells from three locations, Salmon Inlet, Highland Point, and Storm Bay, that are in close proximity to the Swik'als site examined in this study (13.8 Km, 23.4 Km, and 20.1 Km, respectively). The salinity and water temperature data were recorded at the time of shell collection in July of 2015. $\delta^{18}O_{shell}$ values of butter clams were notably more negative, with values of maximum -2.6‰, minimum -6.45‰, and a range of 4.25‰ attributed to the lower salinity found in this part of the inlet system.

The $\delta^{18}O_{shell}$ profiles of the three *L. staminea* clam shells tested showed no agreement between shell #3 and shell #9 and no agreement between shell #9 and shell #8, but that there was a similar profile for the results of shell #3 and shell #8. A likely reason for shell #9 not having a matching $\delta^{18}O_{shell}$ to either of the other shells is due to shell #9 being of senile growth stage, whereas shell #3 and shell #8 were both mature growth stage. This is significant as when clam shells reach the senile growth stage, the growth rate becomes much slower, and so much more time, up to and including years, are compacted into a smaller proportion of shell. When the shell carbonate is collected from a senile growth stage clam, a much longer period of time is encapsulated in the material than when sampling a mature growth clam shell. The $\delta^{18}O_{shell}$ results from a senile growth stage clam will thus show a time-averaging effect whereby the same sample size will represent more time. Time-averaging causes the $\delta^{18}O_{shell}$ profile to be confused and ultimately of little use in palaeothermometry, as the exact annual and sub-annual climatic conditions cannot be reliably determined (Gillikin et al. 2005).

The $\delta^{18}O_{shell}$ analysis of *L. staminea* shell #3 and #8 shows good agreement in their seasonal profiles. The agreement showed the importance of using only mature growth *L. staminea* clam shells when using stable oxygen isotope analysis of clam shells to avoid the time-averaging effect discussed above. Though the statistical analysis between *L. staminea* clam shell #3 and #8 showed that the $\delta^{18}O_{shell}$ results were significantly different, the fact that their seasonal profiles matched is much more critical for correlating $\delta^{18}O_{shell}$ results with palaeotemperature calculations.

3.4.2. Palaeotemperature

The resulting calculated temperature data was then compared to temperature data from the Departure Bay Lighthouse station, located approximately 34 Km southwest from Swik'als, between January 1 to December 31, 2019. The yearly sea surface temperature range at Departure Bay was 11.8°C between 5.7 to 20.4°C.

The results of the paleotemperature calculations highlighted a critical issue for palaeothermometry, and that is having reliable and accurate $\delta^{18}O_{water}$ values for the specific time and location where a bivalve shell is collected for stable oxygen isotope analysis. As Gillikin et al. (2005) note, the $\delta^{18}O_{water}$ value is crucially dependent upon the salinity profile for a specific location and is greatly dependent on the season and the effects of freshwater influxes caused by precipitation, evaporation, and ice melt. To add to the difficulty of determining the relationship between $\delta^{18}O_{water}$ and salinity for this analysis, the shells were collected at the end of the Sechelt Inlet and less than half a kilometer (489 m) from Cook's Creek (a freshwater source). Therefore, the location is an estuarine environment with constant extreme shifts in the levels of salinity, temperature, and $\delta^{18}O_{water}$ throughout each day, season, and year. The study area also falls within the Coast Douglas-fir biogeoclimatic zone of coastal British Columbia, which has an average yearly precipitation of 1038mm (Centre for Forest Conservation Genetics 2020). A large amount of precipitation, estuarine environment, and location proximal to a freshwater source all contribute to a larger than normal range in the $\delta^{18}O_{shell}$ results for live-collected *L. staminea* clam and helps to explain the variation in temperature calculations.

Reconstructed SST of live-collected *S. gigantea* from Pender Island (Hallmann et al. 2009) reported a minimum temperature of 5.9°C (~158 km SE from us) is in good agreement with our minimum reported values for both modern and archaeological values. A contributing factor to the variation and accuracy in reconstructing temperature is salinity variations, resulting in reconstructed SST overestimation of up to 7°C (Hallmann et al. 2009). A further complication is due to the interpretation of $\delta^{18}O_{shell}$ results. Generally, the colder winter months show a more positive $\delta^{18}O$ signal, and the warmer summer months show a more negative signal. The complication arises because the seasonal influxes of freshwater caused by increased precipitation and snow and ice-melt can cause more negative $\delta^{18}O$ signals out of the summer season. The more negative $\delta^{18}O$ value caused by freshwater then causes unusually high calculated SST, which is unlikely to have occurred.

3.4.3. Seasonality and Settlement

The archaeological shell stable oxygen isotope analysis sample size was limited (n=10) compared to other studies from this region (e.g. Burchell et al. a, b, c; Cannon and Burchell 2009, 2016; Hallmann et al. 2009). The sample of 10 shells from DlSd-1 showed a consistent pattern of seasonal collection for *S.* gigantea, and a varied pattern of multi-season collection for *L. staminea*. Cannon and Burchell (2016) note that a smaller sample size can be useful in interpreting the trends of seasonal shellfish collection for a particular site. As such, the sample of 10 shells analyzed at this site can be interpreted as representative of the general shellfish harvesting pattern for DlSd-1.

Seasonality results for the *S. gigantea* shells examined in this study indicate spring as the season of capture. *Leukoma staminea* shells show a more diverse season of capture where two shells are interpreted as spring, one shell indicates late spring to early summer, one shell indicates summer, and the last shell shows autumn or winter season of capture. The site DlSd-1 is identified as a lookout defensive site (Springer et al. 2013). Archaeological and ethnographic evidence states that these sites were used to help protect the larger settlement sites in the area (Angelbeck 2009; Springer and Lepofsky 2020). Subsistence in these locations depended on food transported from the larger settlements and supplemented by shellfish (Angelbeck 2007, 2009; Moss and Erlandson 1992; Springer and Lepofsky 2020). Springer et al. (2013) also note that the smaller settlements also showed herring as a main source of subsistence. Herring is generally captured during spawning seasons, and for the Pacific Northwest Coast, spawning occurs in the spring and autumn (Hay and McCarter 2015). The paleoethnobotany analysis completed at site DlSd-6 and DlSd-7 located in close proximity to DlSd-1 suggest an early to late summer occupation (Jackley 2013). $\delta^{18}O$ analysis indicated that the defensive lookout site of DlSd-1 was occupied during the spring and that there were likely more seasons of occupation, as evidenced by the range of seasonal signals from the *L. staminea* shells. The archaeological, ethnographical, zooarchaeological, paleoethnobotanical, and $\delta^{18}O$ evidence shows that interpreting the season of site occupation is a complex process that can indicate different seasons of site occupation. When all the evidence is placed together, a broader range in seasonal occupation is indicated and can result in a re-evaluation of our understanding of the seasonal round of settlement occupation.

3.5. CONCLUSION

The results of this study show that the *L. staminea* clam can be used for palaeothermometry calculations. The clear seasonal variations in $\delta^{18}O$ values shown through this analysis demonstrate that this clam species can be used as a proxy for palaeoenvironmental conditions and can provide insights into past climate conditions for the coastal areas of British Columbia. This analysis also demonstrates how the environmental changes due to an estuarine environment, high precipitation, and proximity to a freshwater source affect the temperature, salinity, and $\delta^{18}O$ values for a specific location. The results of this analysis showed how critical it is to understand the environmental changes and conditions within a study area to fully understand the data collected.

3.5.2. Future Research

To better understand the spatial and temporal changes in the seasonality of shellfish collection and past SST changes for the inter-site variability, radiocarbon dating individual shells would be required. Specific dates for each shell would indicate if the shellfish collection occurred within the same time period or if the shells are from separate depositional periods. Shell midden stratigraphy cannot generally be relied upon to determine depositional layers as subsequent use of the refuse deposit, and later site disturbances can result in a degree of mixing of the shells within (Claassen 1991; Muckle 1985). As a result, the only way to truly determine the age of the shells is to perform radiocarbon dating analysis on each shell examined.

A further avenue for future research would be to examine sub-annual patterns of temperature and salinity using minor element (Mg/Ca, Sr/Ca) analysis (Gillikin et al. 2006; Gillikin et al. 2019; Klein et al. 1997; Schöne and Gillikin 2013). The Klein et al. (1997) study in the Puget Sound (~288 Km SE) found that using $\delta^{18}O$ and minor element analysis resulted in a mean annual SST of ~7°C, which is ~5°C lower than their measured mean annual SST of 11.6°C. The use of both $\delta^{18}O$ and minor element analysis could result in refining the results of calculated SST with the possibility of reducing the risk of overestimation due to changes in salinity and effects of freshwater influxes.

Another avenue for future research is for temperature, salinity, and $\delta^{18}O_{water}$ data to be regularly collected in estuarine environments for the coastal regions of British Columbia for more accurate information in these locations. Having these data available would allow for more accurate calculations for paleotemperature research. Another research opportunity would be to analyze the *L. staminea* clam shells from other archaeological sites to perform paleotemperature calculations for other coastal regions of British Columbia.

3.5. ACKNOWLEDGEMENTS

Funding for this project was provided by research grants to Dr M. Burchell from the Social Sciences and Humanities Research Council of Canada (SSHRC) and Canada Foundation for Innovation (CFI). The authors would like to thank Dr M. Caldwell, Dr C. Springer and the Simon Fraser University Archaeology Department for providing the archaeological shell materials and field report. We would also like to thank Marisa Dusseault for her assistance with the FTIR spectroscopy. Dr. Joanne Potter is thanked for her assistance with the operation of the mass spectrometer at the TERRA research facility at Memorial University of Newfoundland.

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CHAPTER 4

CONCLUSION

4.1. SUMMARY

This thesis presented the interpretations of shellfish harvesting intensity, the season of harvest, and palaeotemperature estimation for the Powell River region on the southern coast of British Columbia in the traditional territory of the Tla'amin First Nation. This thesis also tested the feasibility of using oxygen isotope sclerochronology of a second bivalve species, *L. staminea*, as a proxy for cultural practices and past climate conditions.

Chapter 2, "*Leukoma staminea* (Conrad 1857) as a new proxy for evaluating shellfish harvest intensity on the Pacific Northwest Coast: A Case Study from Powell River British Columbia," looked at seven shell midden sites from the Powell River region on the south coast of British Columbia to identify the relative harvest intensity exhibited at these sites. Chapter 2 used both *Saxidomus gigantea* (Deshayes 1839) and *L. staminea* shells to interpret relative harvest intensity and to see if there is a difference in harvest intensity between species. The results showed that at defensive sites and campsites, both *S. gigantea* and *L. staminea* showed a higher relative harvest intensity. *S. gigantea* showed higher relative harvest intensity at village sites, and *L. staminea* showed lower relative harvest intensity. Archaeological and ethnographic evidence states that the Tla'amin were heavily reliant on marine resources for subsistence (Angelbeck 2009; Caldwell 2015; Jackley 2013; Johnson 2010; Springer et al. 2013; 2020). These records also state that there was a long-standing practice of resource management through the manipulation of the landscape, such as clam gardens, to further augment the production of resources. (Augustine and Dearden 2014; Caldwell 2015; Deur et al. 2015; Groesbeck 2014; Lepofsky and Caldwell 2013; Smith et al. 2019; Springer et al. 2013; Toniello et al. 2019). It is also important to note that shell growth on the south coast is faster than the central or northern coasts, and therefore affects the results of the growth stage analysis on the southern coast. Furthermore, there was only one larger settlement or village site examined and only one campsite examined, which limits the ability to form any definitive conclusions about harvest intensity for this region.

Chapter 3, "A Dual Proxy Bivalve Approach for Interpreting Past Sea Surface Temperatures and Seasonality from Shell Midden Sites" tested the feasibility of using the bivalve species *L. staminea* as a new proxy for the season of shellfish capture and past sea surface temperature. For this analysis, live-collected *L. staminea* shells were used from the Swik'als site in Sechelt, British Columbia in the traditional territory of the Shíshálh First Nation. The data collected from both the shells and the site were used to calibrate the archaeological shell data. The Böhm et al. (2000) palaeotemperature equation was used and resulted in a temperature range of 6.1 to 32.0 °C. The results are an overestimation of past sea surface temperature due to the variation in salinity and freshwater influxes that affected the $\delta^{18}O_{shell}$ values of the archaeological shells. The seasonality interpretation of the archaeological shells showed that all of the *S. gigantea* shells tested indicated spring as the season of capture. There was more variation in the *L. staminea* results showing two shells captured in the spring, one in late spring to early summer, one in the summer, and one in the autumn or winter. The archaeological shell midden site examined also had a larger number of herringbones which would indicate a spring or autumn season of occupation (Springer et al. 2013), and a paleoethnobotany analysis at a proximal site (DlSd-6 and 7) showed an occupation of early to late summer (Jackley 2013). When all of these pieces of evidence were joined, it became evident that the defensive lookout site DlSd-1 was occupied during the spring and likely throughout other seasons. The use of multiple proxies and sources of information allow for a better understanding of settlement patterns and can change our interpretations on seasonal rounds of occupation.

4.2. MULTIPROXY APPROACHES IN ZOOARCHAEOLOGY

If a multi-species approach is employed, it could potentially change the way shellfish harvesting has been interpreted. The use of a different proxy for the interpretation of relative harvest intensity shows how interpretation changes depending upon the collected data. If this study had only looked at *S. gigantea* shells for growth stage analysis, the results would follow to the same conclusion that other studies have found for the shell midden sites on the southern coast of British Columbia, that all sites show a higher harvest intensity and that there appears to be no change in harvest intensity between different settlement types (campsites versus villages). The use of a second proxy species, in this case, the *L. staminea*, showed results presenting a different story, that there is a clear difference in the relative harvest intensity between settlement types, where campsites exhibit higher harvest intensity whereas villages show a lower harvest intensity.

The results indicate that with more data, a different interpretation can emerge with possible repercussions for our understanding of the past. More robust sample size or change in sample type has consequences for how we view the past and understand cultures and societies. The results showing that differing harvest intensities for different species can have varying effects. One possibility could be selective harvesting, that instead of simply gathering all types of shellfish at once, that the inhabitants of these settlements would selectively collect one species over another. These results could also exhibit ecological concerns, that a particular location was a better habitat for a select species. In the sites where there was higher harvest intensity for both species of clams, this could suggest that shellfish was a primary food source and as such was over-harvested as a staple food. There are also temporal considerations for considering relative harvest intensity, meaning that a particular species could be more heavily harvested at one particular point in time and another at another point in time. Some of these possibilities can be answered through an increase in sample size for both *S. gigantea* and *L. staminea* from the sites that were examined in this study. Another possible avenue of exploration is the re-examination of other shell middens throughout coastal British Columbia to examine the relative harvest intensity of *L. staminea* from other sites to see if they coincide or differ from the previously collected results from growth stage analysis of *S. gigantea*. The results from this study simply shows that a multiproxy approach to analysis can change the interpretation of the data.

4.3. REGIONAL PERSPECTIVES ON SUBSISTENCE AND SHELLFISH HARVESTING IN BRITISH COLUMBIA

Shells grow faster on the south coast (Hallmann et al. 2009), where senile growth occurs in *S. gigantea* at 5-6 years of age and 4-5 years of age for *L. staminea*, meaning that this pattern of harvest cannot be directly compared to the data from the north and central coasts without considering the influence of latitude on shell growth rates (see Jones and Quitmyer 1996) (Burchell et al. 2013a; Gillespie and Bourne 1997). A faster growth rate should result in senility at an earlier age indicating potentially more intensive harvest at southern coast shell midden sites than the higher proportion of mature shells would suggest (Burchell 2013).

Previous shellfish harvest intensity research conducted on the southern coast of British Columbia was completed at Deep Bay on Vancouver Island in the traditional territory of the Central Coast Salish and Sechelt in the traditional territory of the Shíshálh First Nation (Leclerc 2018, Sparrow 2016) (Fig. 4.1.). Deep Bay is identified as a village site and exhibited lower relative harvest intensity with 20% mature growth stage *S. gigantea* shells and 70% senile growth stage *S. gigantea* shells (Sparrow 2016). In Sechelt, the *S. gigantea* shells tested at two village sites (DjRw-3 and DkRw-26) showed higher harvest intensity and the two campsites (DjRw-18 and DkRw-22) also showed higher relative harvest intensity (Leclerc 2018). The village site DeRt-1 and DeRt-2 at Pender Island also showed higher relative harvest intensity with 63% mature growth stage *S. gigantea* shells and 25% senile growth stage *S. gigantea* shells (Burchell 2013). The *S. gigantea* shells examined from the village site of this study (DlSd-11) follow the results found by Leclerc (2018) at the two village sites in Sechelt and Burchell (2013) at Pender Island differ from those of Sparrow (2016) at Deep Bay. The *L. staminea* shells examined from the village site DlSd-11 follow the lower harvest intensity found by Sparrow (2016) and contradict those of Leclerc (2018) and Burchell (2013).

The lower relative harvest intensity of *L. staminea* and higher relative harvest intensity of *S. gigantea* from the same site could indicate preferential species selection for diet or for preservation. These results could also suggest a difference in the availability of *L. staminea* versus *S. gigantea*. As the results of harvest intensity at the village site DlSd-11 are different between the species, further analyses could look at other village sites to see if there is a difference in relative harvest intensity dependent on species at other village sites. Both campsites examined by Leclerc (2018) indicate higher harvest intensity. The campsite of this study (DlSf-6) also shows higher harvest intensity for both species tested. The higher harvest intensity at campsites could indicate that these sites were resource procurement places for shellfish harvesting.

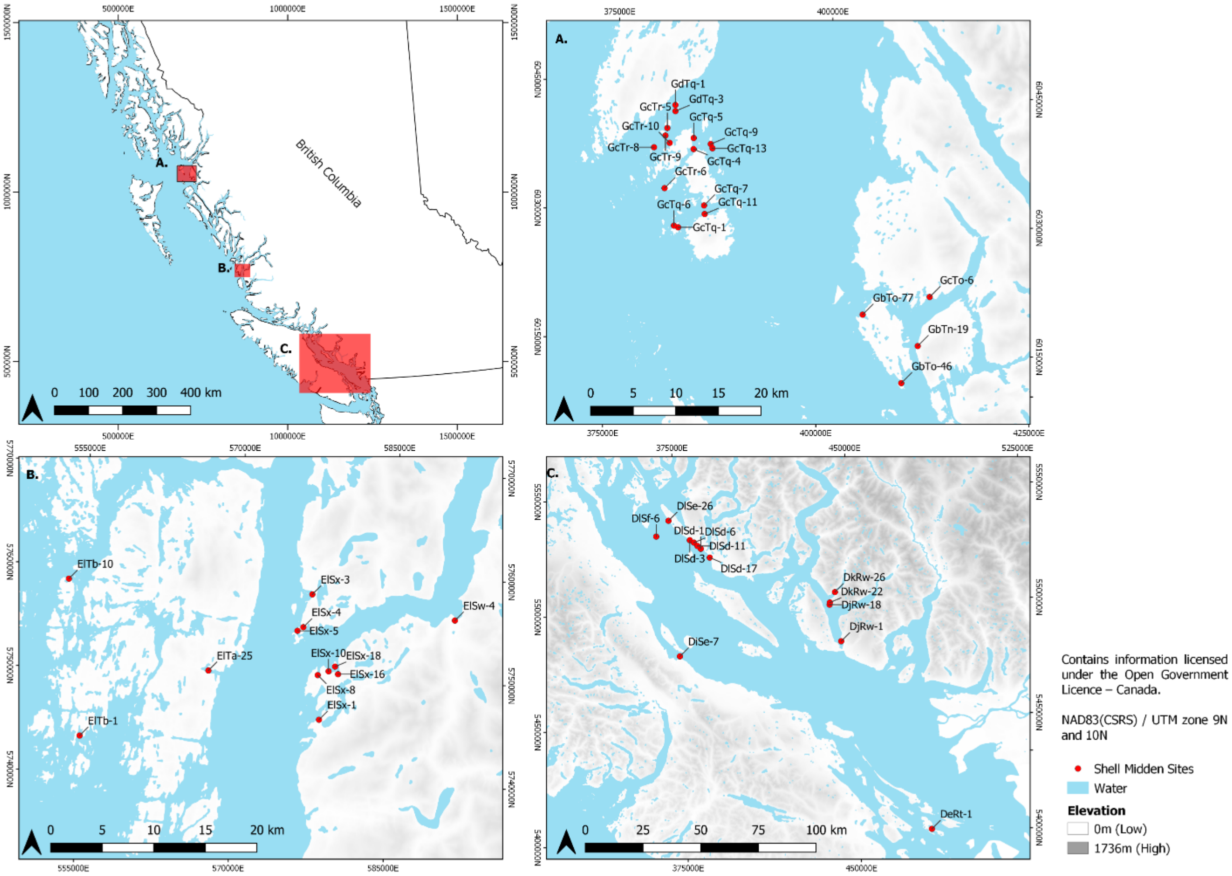

Figure 4.1 Map of shell midden sites on the north, central, and southern coasts of British Columbia to interpret shellfish harvesting pressure, seasonality and estimate PSST. A. Shell midden sites in the Dundas Islands Group and Prince Rupert Harbour, (Burchell et al. 2013a; Hallmann et al. 2009; 2013). B. Shell midden sites examined on the central coast of British Columbia (Burchell et al. 2013b, c; Cannon and Burchell 2009, 2016). C. Shell midden sites examined on the southern coast of British Columbia (Burchell 2013; Hallmann et al. 2009; Leclerc 2018; Sparrow 2016).

Unfortunately, we are limited in understanding any true patterns between different types of sites. The results do show diversity between both the overall harvest level intensity and the species intensity between villages and camps.

4.3.2. Shellfish Harvest Intensity on the Northern and Central Coast

Previous research in other coastal regions of British Columbia has also used the clam species *S. gigantea* to interpret relative harvest intensity. Cannon and Burchell (2009) examined shell midden sites on the central coast of British Columbia in the traditional territory of the Heiltsuk First Nation and found that there was lower harvest intensity at village sites and higher harvest intensity at campsites (Fig 4.2). Burchell et al. (2013a) examined shell midden sites at the Dundas Islands Group and Prince Rupert Harbour on the northern coast of British Columbia in the traditional territory of the Tsimshian First Nation found that there was lower harvest intensity at campsites and higher harvest intensity at village sites. The growth stage analysis results of the *L. staminea* shells from this study show agreement of those found on the central coast of British Columbia. In contrast, the growth stage analysis results of the *S. gigantea* shells of this study more closely resemble those of the southern coast where Leclerc (2018) found that both village and campsites show a higher relative harvest intensity.

The central coast showed a different relationship, where the shell midden sites with higher harvest intensity were the campsites and the sites with a lower harvest intensity were village sites (Cannon and Burchell 2009). The southern coast was different again by showing that all sites examined, including villages and campsites, all showed higher harvest intensity (Leclerc 2018; Sparrow 2016).

The results of the growth stage analysis of *S. gigantea* shells of this study showed that they coincided with those of the other studies of the southern coast, that both campsites and villages showed high harvest intensity. The difference arrived when this study performed a growth stage analysis on the second species of clams, the littleneck clam or *L. staminea*. The results of the analysis performed on the *L. staminea* showed that there is a clear difference in harvest intensity between village sites and campsites, where the village site (DlSd-11) showed a lower harvest intensity as it had a higher proportion of senile growth stage shells, whereas the campsite (DlSf-6) had a higher harvest intensity as it had a larger percentage of mature growth stage clamshells. The results showed no agreement between *S. gigantea* and *L. staminea* for the harvest intensity for the village or the campsite. As presented in the discussion, the change in relative harvest intensity between species for the same site can have different and varying reasons. Possible solutions to this would be to examine more shells from the seven sites analyzed in this study so that more data is available for interpretation. Another avenue of future research could be to look at the *L. staminea* shells from other shell midden sites throughout coastal British Columbia to see if they show the same harvest intensity as *S. gigantea* from those sites or if they also differ.

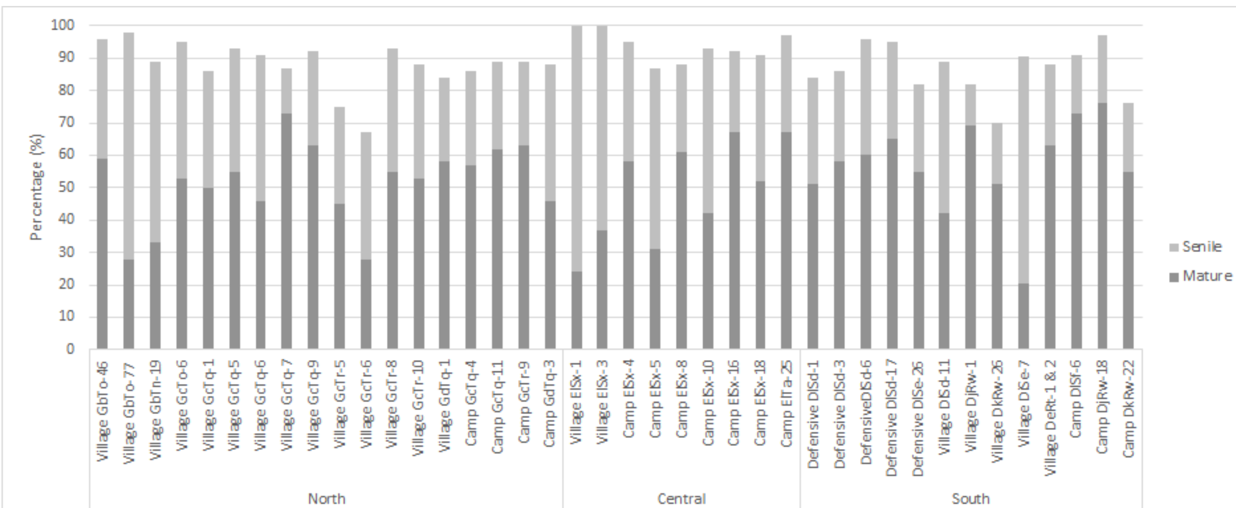

Figure 4.1 Relative shellfish harvest intensity for archaeological shell midden sites on the north (Burchell et al. 2013a), central (Cannon and Burchell 2009, 2016), and south (Burchell 2013; Leclerc 2018; Sparrow 2016) coasts of British Columbia.

4.4. REGIONAL PERSPECTIVE ON PALAEOTEMPERATURE ESTIMATES IN BRITISH COLUMBIA

Multiproxy analyses of past sea surface temperatures allow the opportunity to test the results to either confirm data or the ability to identify the strengths and weaknesses of the proxies involved (Lotter 2003; Mann 2002). The multiproxy analysis of past sea surface temperatures for the archaeological shell midden site DlSd-1 in the Powell River region of southern British Columbia in the traditional territory of the Tla'amin First Nation showed a temperature range calculated for archaeological shells from Powell River was 6.1 to 32.1°C. Observed SST data from the Departure Bay Lighthouse recorded a temperature range from 5.7 to 20.4°C. The archaeological temperature values are warmer and have a greater range. The results confirm that the region is highly affected by seasonal and sub-seasonal salinity changes and freshwater influxes that result in an overestimation of past sea surface temperatures.

The Powell River results coincide with those found by Hallmann et al. (2009) which looked at sea surface temperature proxy *S. gigantea* at Pender Island. Hallmann et al. (2009) found an overestimation of ~6°C for the southern coast of British Columbia. Hallmann et al. (2009) also analyzed *S. gigantea* shells from Alaska which had an over-estimated sea surface temperature of ~8°C. Burchell et al. (2013b) also used *S. gigantea* as a palaeotemperature proxy and found a past sea surface temperature range of ~21°C, whereas the measured temperature range was ~7°C. The over-estimation for the northern, central, and southern coasts of British Columbia shows that changes in salinity and freshwater influxes greatly affect the reliability of the palaeotemperature reconstructions for the region. Future research could refine palaeotemperature estimation using minor element (Mg/Ca, Sr/Ca) analysis, which would aid in reducing the possible overestimation of past sea surface temperature due to changes in salinity (Gillikin et al. 2006; Gillikin et al. 2019; Klein et al. 1997; Schöne and Gillikin 2013).

4.5. REGIONAL PERSPECTIVE ON SEASONALITY OF SHELLFISH HARVESTING AND SETTLEMENT IN BRITISH COLUMBIA

The interpretation of the season of shellfish harvesting has been completed on the north, central and southern coasts of British Columbia. On the north coast, Burchell et al. (2013a) looked at nine shell midden sites from the Dundas Islands Group and Prince Rupert Harbour in the traditional territory of the Coast Tsimshian First Nation. The sites on the northern coast show a more even distribution for the season of shellfish harvesting, with spring, autumn, and winter having more shells collected than in the summer (Burchell et al. 2013a). When separating the site types into villages and camps, the season of shell collection at village sites shows a higher level of shellfish collection during the spring and autumn and campsites showing the highest season of the collection during the winter (Burchell et al. 2013a).

Stable oxygen analysis of *S. gigantea* shells from nine sites on the central coast of British Columbia in the traditional territory of the Heiltsuk First Nation shows a different seasonal distribution (Burchell et al. 2013c; Cannon and Burchell 2016). The results showed that overall, the season of shellfish collection of the central coast was spring, followed by autumn, then winter, and with the fewest shells collected in the summer (Burchell et al. 2013c; Cannon and Burchell 2016). When the sites are split between villages and camps, the results remain the same for the villages, where spring has the highest number of shells collected, followed by winter, then autumn, with the fewest shells collected in the summer (Burchell et al. 2013c; Cannon and Burchell 2016). The campsites show that autumn was the season where the most shellfish were collected, followed by spring and with fewer shells collected in the winter and fewer still collected in the summer (Burchell et al. 2013c; Cannon and Burchell 2016).

The season of capture analysis for the southern coast of British Columbia shows different results. The data comes from four sites from the Sechelt region, in the traditional territory of the Shíshálh First Nation, one site in the Powell River region, in the traditional territory of the Tla'amin First Nation, and one site from Pender Island in the traditional territory of the Tsawout and Tseycum First Nations (Leclerc 2018; Burchell 2013). Overall, the season of shellfish harvesting on the southern coast of British Columbia is often the spring, with fewer shells collected in the summer, followed by the autumn, and with the least amount of shellfish harvesting occurring in the winter (Leclerc 2018; Burchell 2013). When the season of shellfish harvesting is broken down into site types, the village sites show the most shellfish harvesting in the spring followed by the summer, then an equal amount of shellfish harvesting in the winter and autumn (Leclerc 2018; Burchell 2013). For the campsites, the season of shellfish harvesting is the spring with less collection in the winter and less in the autumn, and with no shellfish harvesting in the summer (Leclerc 2018). The defensive site shows the highest level of shellfish harvesting in the spring, with some collection in the summer and autumn/winter.

The overall image of shellfish harvesting for coastal British Columbia is that shellfish collection occurred year-round, with the highest shellfish harvesting occurring during the spring (Burchell et al. 2013a, c; Burchell 2013; Cannon and Burchell 2016; Leclerc 2018). The heavier use of shellfish as a subsistence resource in the spring could be attributed to the depletion of other food sources over the winter and that shellfish are widely available year-round. Different cultural groups have different subsistence and settlement patterns based on the resources available. However, as shellfish occur throughout coastal British Columbia and are available throughout the year, it would be plausible to suggest that shellfish played an important role in the diet of coastal populations of the Pacific Northwest.

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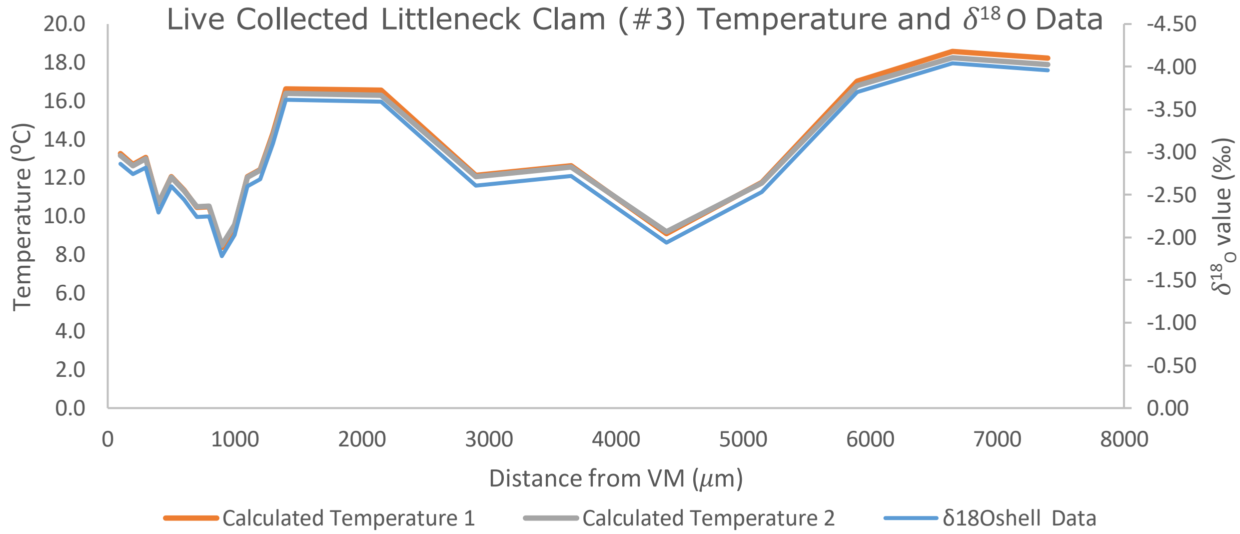
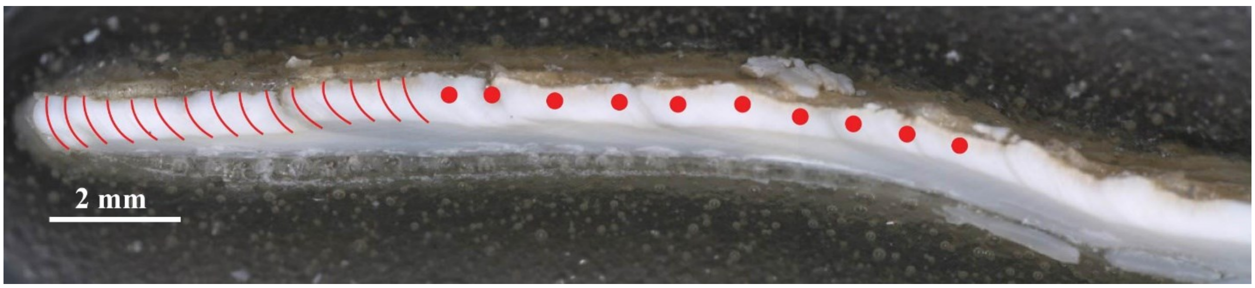
APPENDIX A: STABLE OXYGEN ISOTOPE PROFILES, SEASONALITY DETERMINATIONS, AND PALAEOTEMPERATURE CALCULATIONS

<u>Swik'als</u>

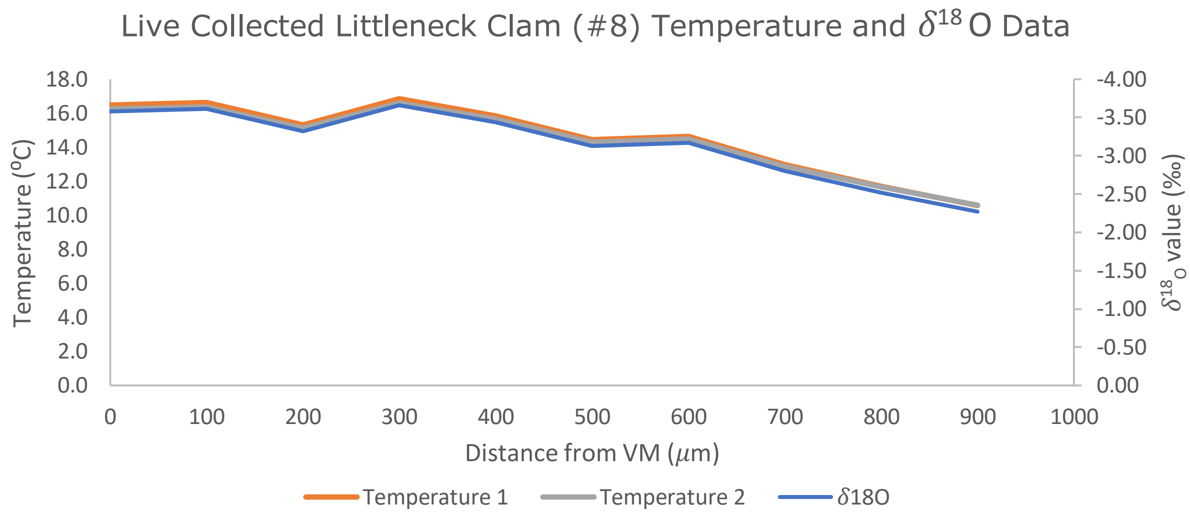
Figure 1: Live-Collected *Leukoma staminea* #3





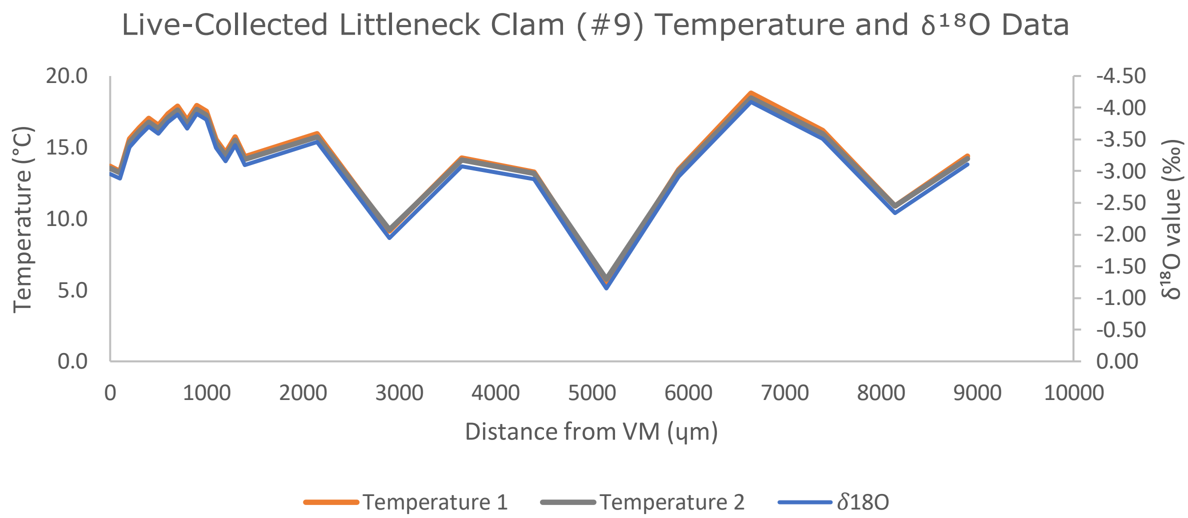
Live-collected *Leukoma staminea* shell #3 displays a mature growth stage and had 15 micro-milled and 10 micro-drilled shell carbonate samples analyzed. Ventral margin δ¹⁸O value (-2.86‰) trends towards more negative values without reaching the typical summer values. Three years of growth was sampled. The maximum δ¹⁸O value was -1.78‰ the minimum was -4.04‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 18.6°C and a minimum of 8.0°C.

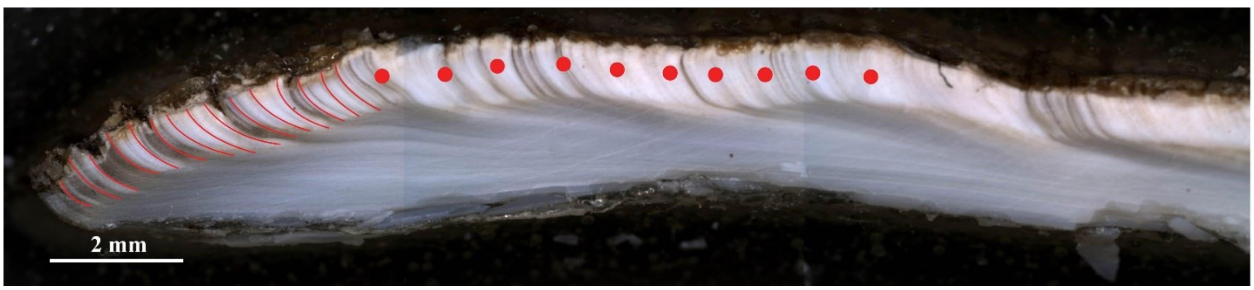
Figure 2: Live-Collected *Leukoma staminea* #8



Live-collected *Leukoma staminea* shell #8 displays a mature growth stage and had 10 micro-milled shell carbonate samples analyzed. Ventral margin δ^{18}O value (-3.58‰) trends towards more negative values without reaching the typical summer values. Less than one year of growth was sampled. The maximum δ^{18}O value was -2.27‰ the minimum was -3.66‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 17.0°C and a minimum of 10.2°C.

Figure 3: Live-Collected *Leukoma staminea* #9

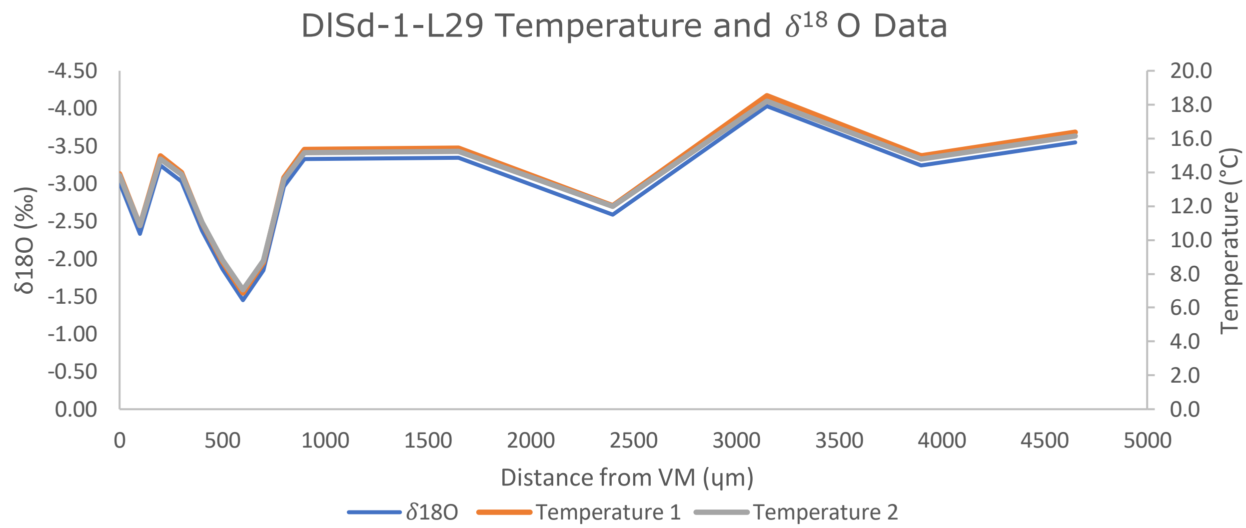


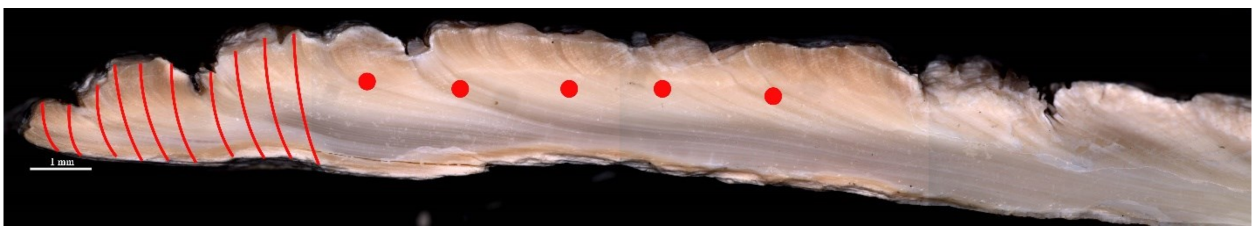


Live-collected *Leukoma staminea* shell #9 displays a senile growth stage and had 15 micro-milled and 10 micro-drilled shell carbonate samples analyzed. Ventral margin $\delta^{18}O$ value (-2.95‰) trends towards more positive values. Seven years of growth was sampled. The maximum $\delta^{18}O$ value was -2.88‰ the minimum was -3.9‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 18.9°C and a minimum of 5.1°C.

<u>DlSd-1 *Leukoma staminea*</u>

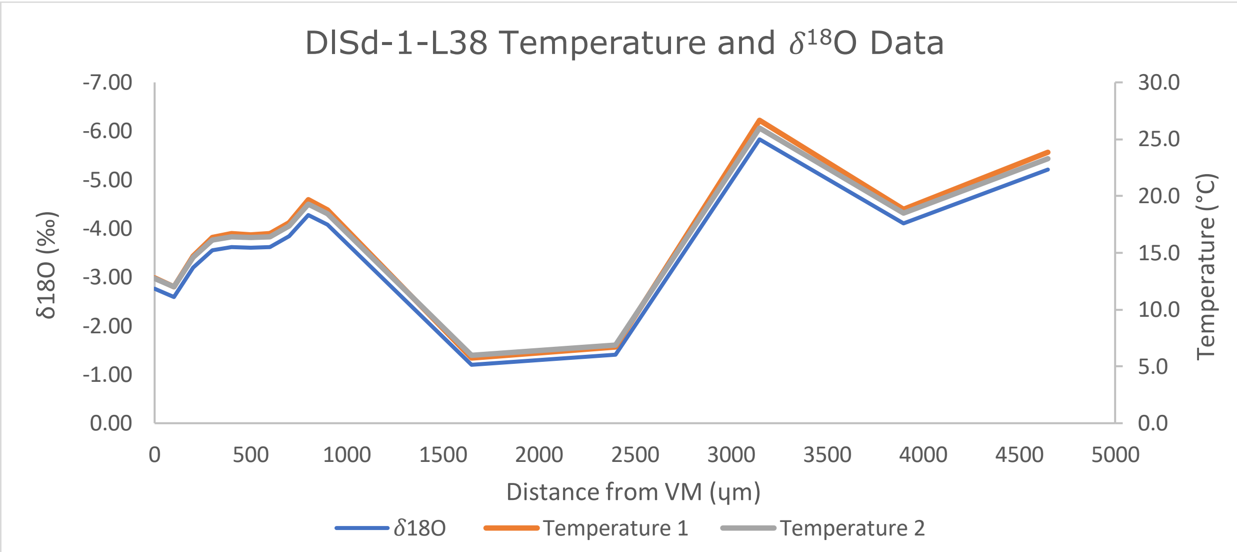
Figure 4: DlSd-1-L29 **Season: Spring/Summer**





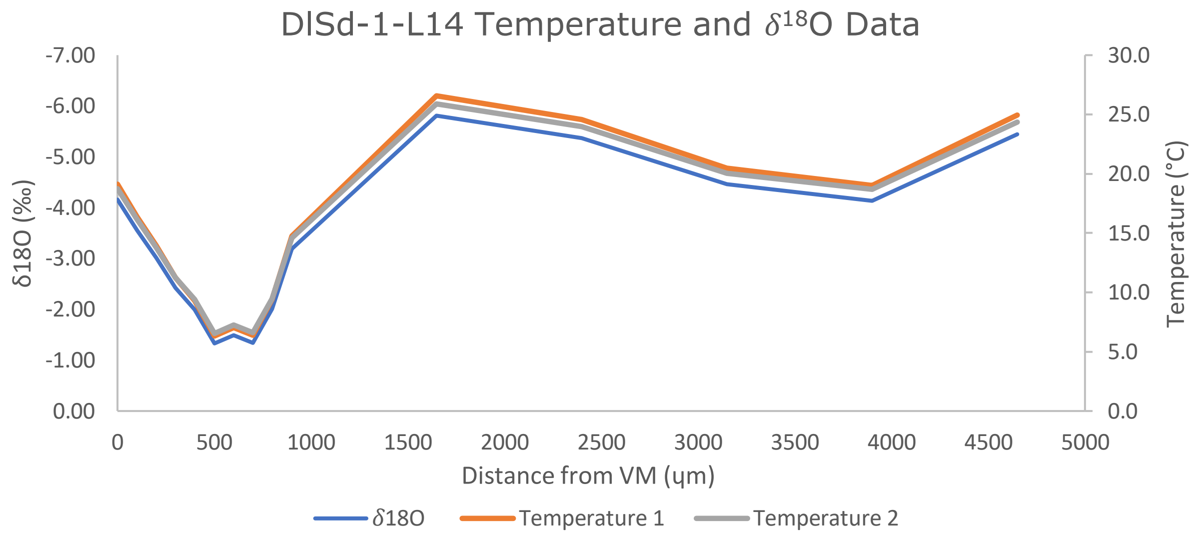
Archaeological *Leukoma staminea* shell L29 from DlSd-1 displays a mature growth stage and had 10 micro-milled and 5 micro-drilled shell carbonate samples analyzed. Ventral margin $\delta^{18}O$ value (-3.01‰) trends towards more negative values, reaching the typical late spring to early summer values. Four years of growth was sampled. The maximum $\delta^{18}O$ value was -1.45‰ the minimum was -4.03‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 18.6°C and a minimum of 6.5°C.

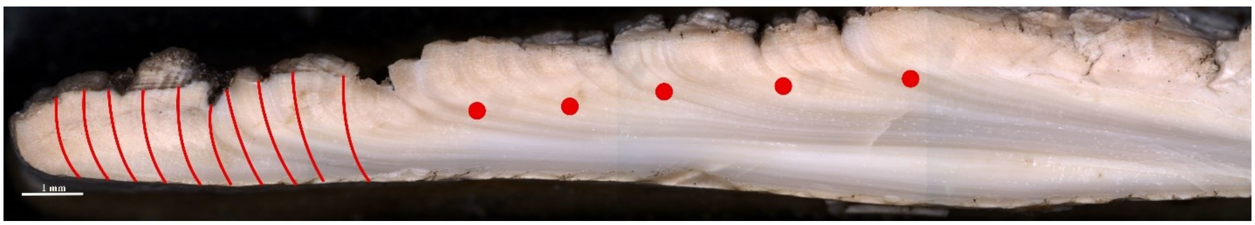
Figure 5: DlSd-1-L38 **Season: Spring**



Archaeological *Leukoma staminea* shell L38 from DlSd-1 displays a mature growth stage and had 10 micro-milled and 5 micro-drilled shell carbonate samples analyzed. Ventral margin $\delta^{18}O$ value (-2.76‰) trends towards more negative values without reaching the typical summer values. More than two years of growth was sampled. The maximum $\delta^{18}O$ value was -1.20‰ the minimum was -5.83‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 26.7°C and a minimum of 5.3°C.

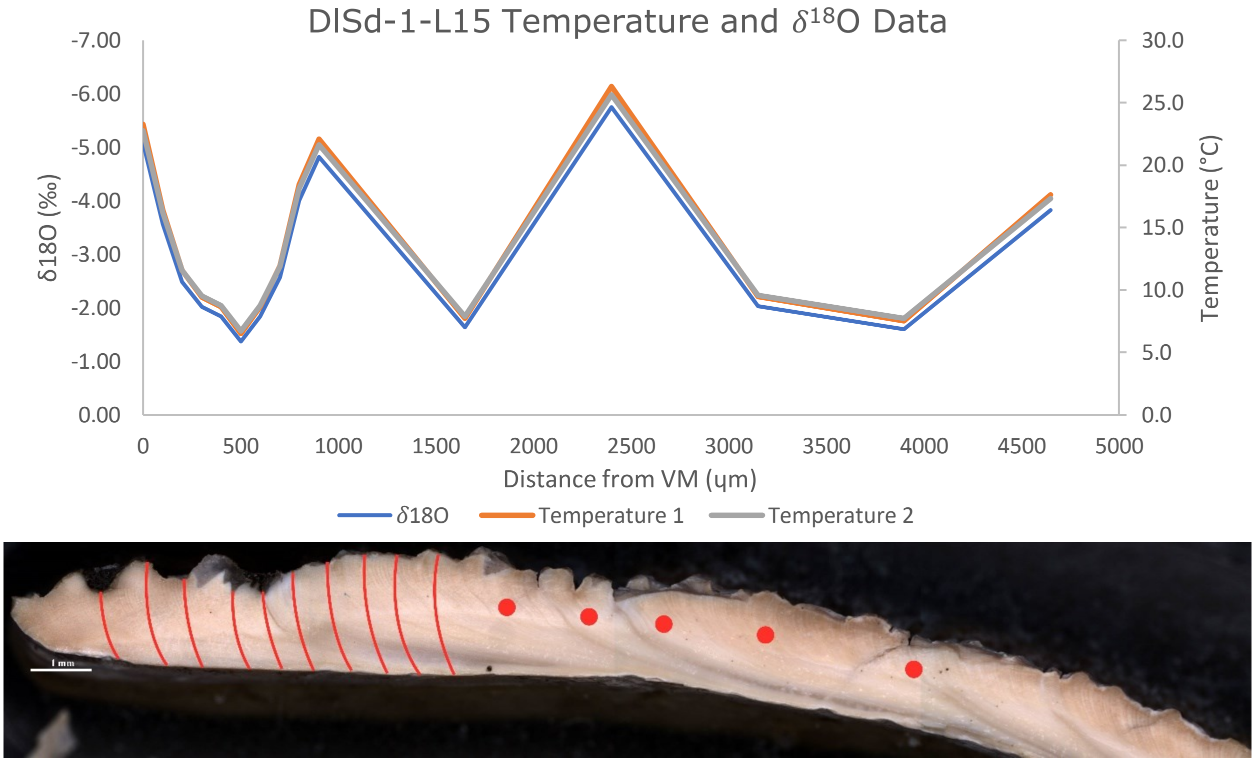
Figure 6: DlSd-1-L14 **Season: Spring**





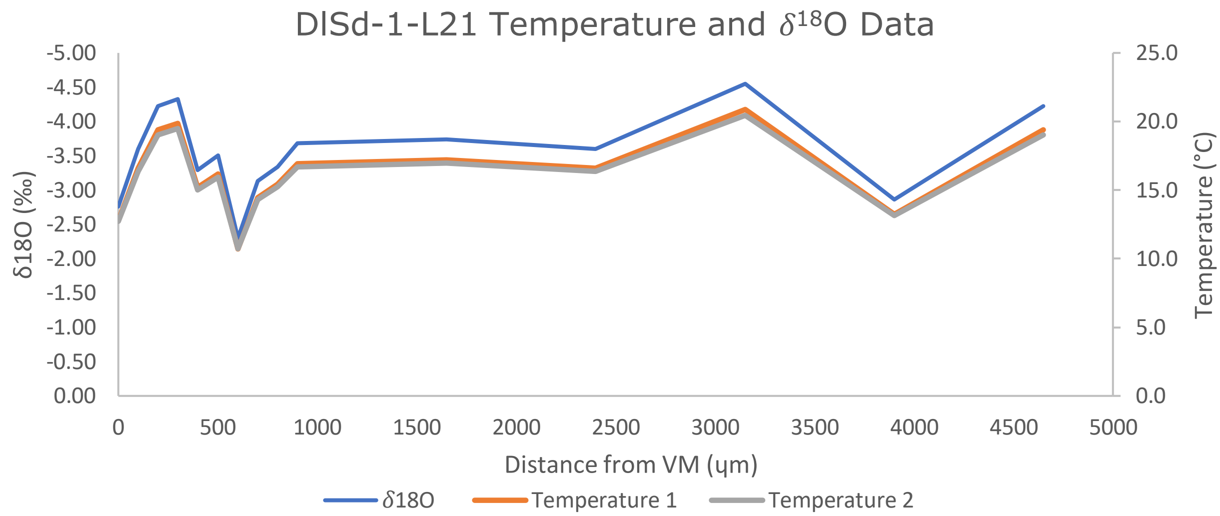
Archaeological *Leukoma staminea* shell L14 from DlSd-1 displays a mature growth stage and had 10 micro-milled and 5 micro-drilled shell carbonate samples analyzed. Ventral margin $\delta^{18}O$ value (-4.16‰) trends towards more negative values without reaching the typical summer values. More than four years of growth was sampled. The maximum $\delta^{18}O$ value was -1.33‰ the minimum was -5.81‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 26.6°C and a minimum of 5.9°C.

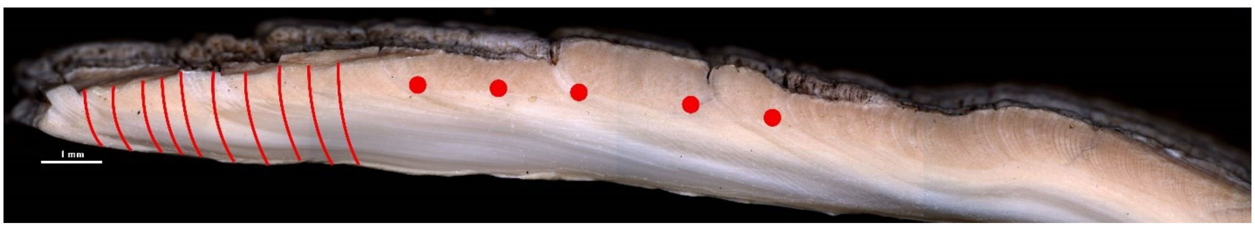
Figure 7: DlSd-1-L15 **Season: Summer**



Archaeological *Leukoma staminea* shell L15 from DlSd-1 displays a mature growth stage and had 10 micro-milled and 5 micro-drilled shell carbonate samples analyzed. Ventral margin δ^{18}O value (-5.08‰) trends towards more negative values, reaching the typical summer values. Three years of growth was sampled. The maximum δ^{18}O value was -1.37‰ the minimum was -5.75‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 26.3°C and a minimum of 6.1°C.

Figure 8: DlSd-1-L21 **Season: Autumn/Winter**

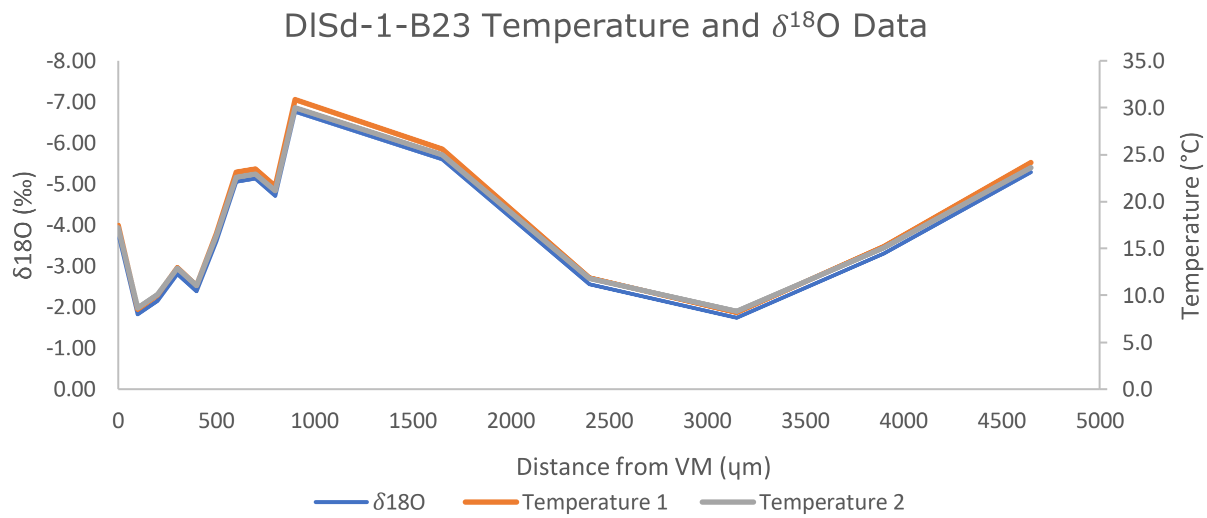


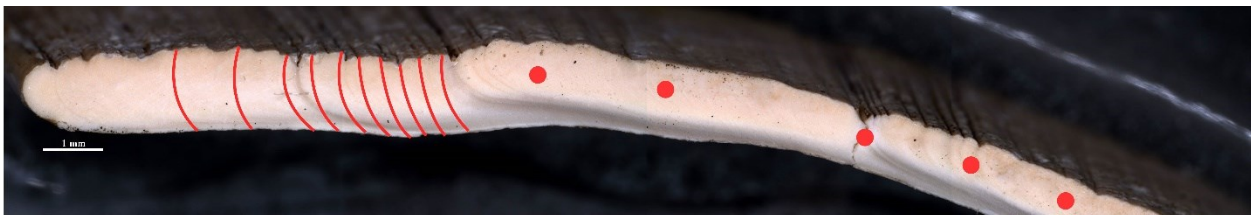


Archaeological *Leukoma staminea* shell L21 from DlSd-1 displays a mature growth stage and had 10 micro-milled and 5 micro-drilled shell carbonate samples analyzed. Ventral margin δ^{18}O value (-2.76‰) trends towards more positive values, reaching the typical late fall to early winter values. More than four years of growth was sampled. The maximum δ^{18}O value was -2.30‰ the minimum was -4.55‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 20.9°C and a minimum of 10.3°C.

DlSd-1 *Saxidomus gigantea*

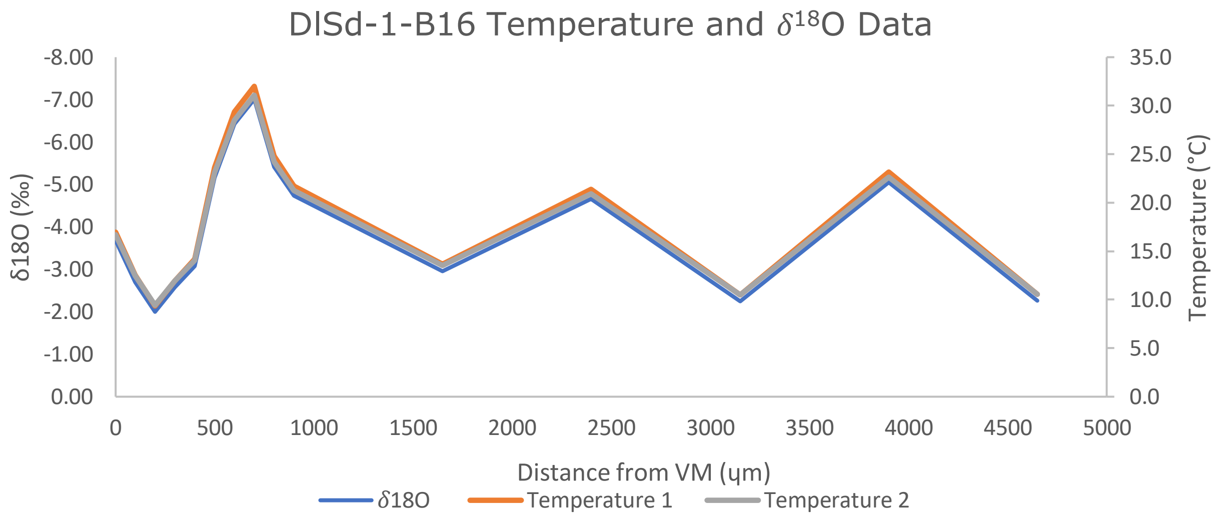
Figure 9: DlSd-1-B23 **Season: Spring**

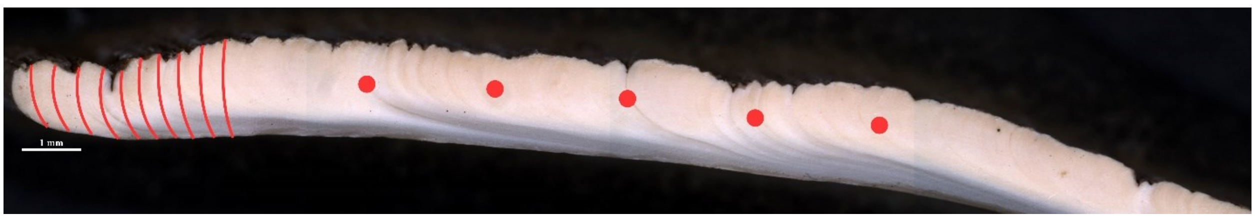




Archaeological *Saxidomus gigantea* shell B23 from DlSd-1 displays a mature growth stage and had 10 micro-milled and 5 micro-drilled shell carbonate samples analyzed. Ventral margin $\delta^{18}O$ value (-3.76‰) trends towards more negative values, reaching the typical spring values. More than three years of growth was sampled. The maximum $\delta^{18}O$ value was -1.74‰ the minimum was -6.76‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 30.9°C and a minimum of 7.8°C.

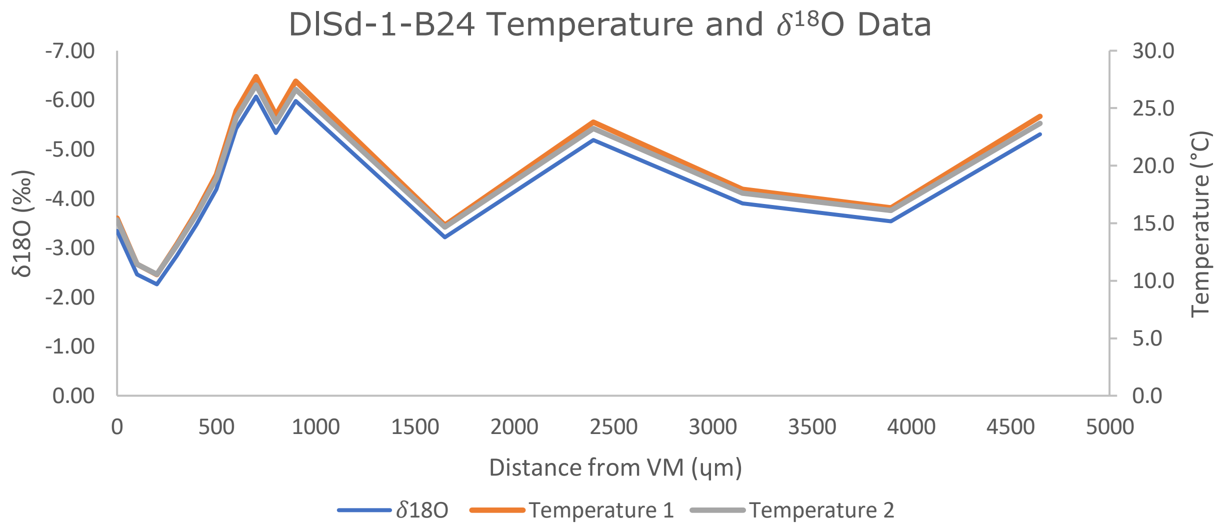
Figure 10: DlSd-1-B16 **Season: Spring**

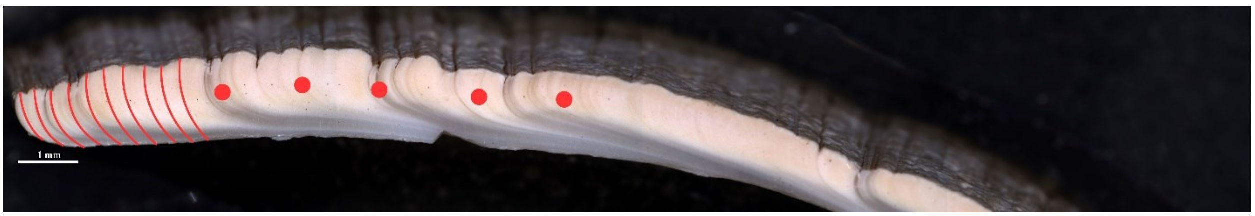




Archaeological *Saxidomus gigantea* shell B16 from DlSd-1 displays a mature growth stage and had 10 micro-milled and 5 micro-drilled shell carbonate samples analyzed. Ventral margin $\delta^{18}O$ value (-3.68‰) trends towards more negative values, reaching the typical spring values. More than three years of growth was sampled. The maximum $\delta^{18}O$ value was -2.00‰ the minimum was -7.01‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 32.0°C and a minimum of 9.0°C.

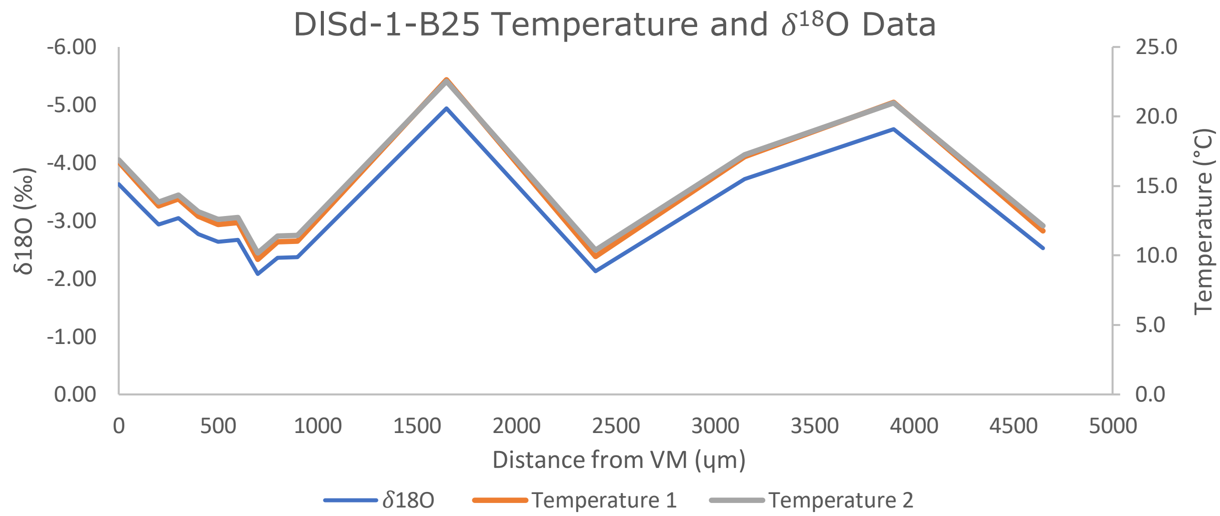
Figure 11: DlSd-1-B24 **Season: Spring**





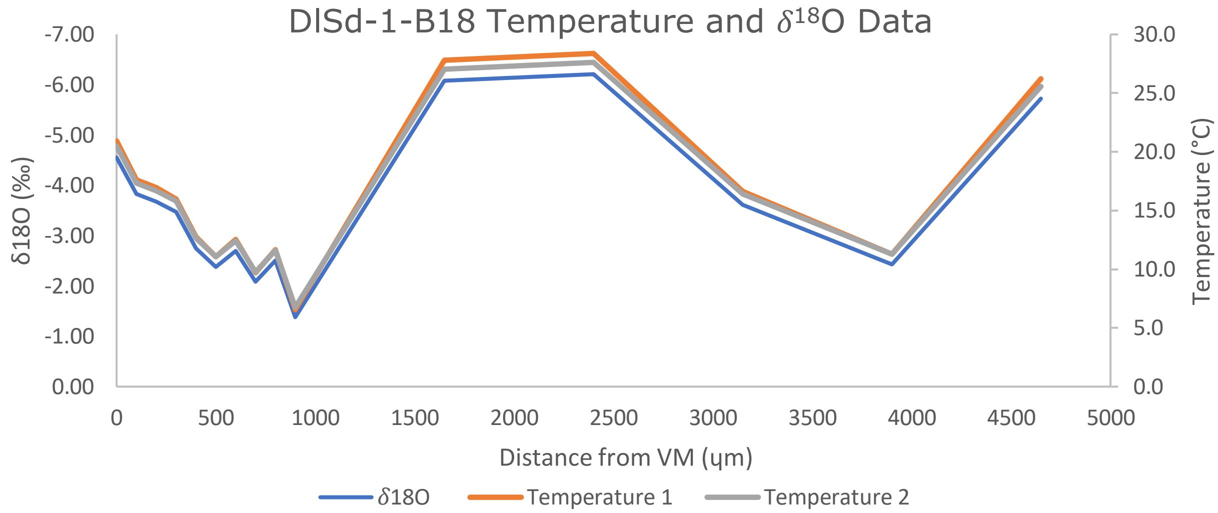
Archaeological *Saxidomus gigantea* shell B24 from DlSd-1 displays a mature growth stage and had 10 micro-milled and 5 micro-drilled shell carbonate samples analyzed. Ventral margin $\delta^{18}O$ value (-3.35‰) trends towards more negative values, reaching the typical spring values. More than four years of growth was sampled. The maximum $\delta^{18}O$ value was -2.26‰ the minimum was -6.07‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 27.7°C and a minimum of 10.1°C.

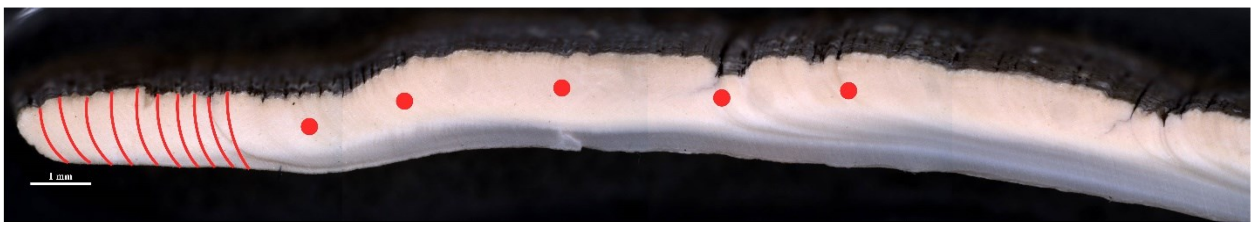
Figure 12: DlSd-1-B25 **Season: Spring**



Archaeological *Saxidomus gigantea* shell B25 from DlSd-1 displays a mature growth stage and had 10 micro-milled and 5 micro-drilled shell carbonate samples analyzed. Ventral margin $\delta^{18}O$ value (-3.63‰) trends towards more negative values, reaching the typical spring values. More than two years of growth was sampled. The maximum $\delta^{18}O$ value was -2.08‰ the minimum was -4.94‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 22.6°C and a minimum of 9.3°C.

Figure 13: DlSd-1-B18 **Season: Spring**





Archaeological *Saxidomus gigantea* shell B18 from DlSd-1 displays a mature growth stage and had 10 micro-milled and 5 micro-drilled shell carbonate samples analyzed. Ventral margin δ^{18}O value (-4.56‰) trends towards more negative values, reaching the typical spring values. More than two years of growth was sampled. The maximum δ^{18}O value was -1.38‰ the minimum was -6.21‰. The temperature reconstruction resulted in a calculated sea surface temperature (SST) maximum of 28.4°C and a minimum of 6.1°C.