LONG-TERM HISTORIES OF CLAM HARVESTING AND SEASONAL SETTLEMENT STRATEGIES ON SHÍSHÁLH LANDS, BRITISH COLUMBIA

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B.A. University of Toronto, 2015

A Thesis

submitted to the School of Graduate Studies

in partial fulfillment of the requirements for the degree of

Master of Arts in Archaeology

Memorial University of Newfoundland

May 2018

St. John's, Newfoundland and Labrador

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ABSTRACT

This thesis investigated seasonality and intensity of shíshálh shellfish harvesting practices, and, by proxy, seasonal site occupation in the Sechelt Inlet system (SIS), located on the inner coast of the Sunshine Coast, southern British Columbia. Three different site types were examined: a large village, an inlet village and two formal camps. This represents the first systematic study of shellfish harvesting and seasonality in the region that applied high-resolution stable oxygen isotope analysis ($\delta^{18}O_{shell}$) coupled with macro- and micro-growth line analyses of archaeological and live-collected butter clam (*Saxidomus gigantea*) shells. The $\delta^{18}O_{shell}$ results showed that shellfish harvesting in the SIS occurred year-round, though seasonal preferences differed by site type. The large village showed a preference for winter/early spring harvesting, the smaller inlet village showed a preference for spring and summer collection, and the formal camps showed a preference for spring harvesting. Seasonal preference generally followed the seasons when the sites would have been occupied by the most people. Few autumn-collected shells were found suggesting that butter clams were harvested and dried in the summer instead of the autumn to be prepared for winter consumption or were not harvested for the intension of winter consumption. The results demonstrated that, from 930 to 0 cal. BP, the shíshálh “seasonal round” generally followed the SIS’s ethnographically present seasonal occupation but was also flexible to environmental contingencies. In addition, the $\delta^{18}O_{shell}$ data support a seasonal shift between the Tzoonie Narrows inlet village and the Porpoise Bay year-round village, which had not been recorded ethnographically. The results continue to showcase the value in challenging the ethnographic record.

The macro-growth line analysis results demonstrated a pattern of high harvesting intensity at all sites regardless of their site type. This differed from results previously obtained from other investigations on the British Columbian coast, specifically sites in eastern Vancouver Island, the Namu region on the central coast, and the Dundas Islands and Prince Rupert Harbour on the northern coast, thereby highlighting the uniqueness of shellfish-related practices on shíshálh lands and the variability along the Pacific Northwest Coast. Results also suggested that proximity to mixed substrate beaches, the preferred medium for butter clams, may have been a factor in clam harvesting intensity in addition to the density of occupation.

Macro-growth line alignment with $\delta^{18}O_{shell}$ results suggested that low salinity coupled with frequent freshwater incursions led to the deposition of macro-growth lines in the autumn and the spring, as well as winter and summer. Micro-growth line analysis, which involves measuring lunar daily growth increments (LDGI), was not able to account for a full year of growth, while previous work on butter clam shells from the outer coast was able to do so. This demonstrated that LDGI measurements could not be used in the SIS to clarify salinity effects on $\delta^{18}O_{shell}$.

ACKNOWLEDGEMENTS

Thank you to Dr. Meghan Burchell for her supervision, advice, and early emails with project ideas. Thank you also for introducing me to the world of sclerochronology and for exemplifying true academic integrity.

Thank you to the shíshálh Nation for their permission to work on their lands and their continued interest in my research. In particular, special thanks to Chief and Council, Jasmine Paul and the staff of the Rights and Title Department.

Thank you to Dr. Gary Coupland and Dr. Terence Clark for their mentorship and love of British Columbian archaeology that they have passed on to me. Special thanks to the shíshálh Archaeological Research Project and Bryn Letham for the provision of research materials and for digging for butter clams with Aiden Douglas and me. Thank you to Jerry Campbell for arranging travel to collect live butter clams. Thank you to Anna Sparrow and Margaret Way for their help in training my eyes to discern shell growth patterns and their company in the lab. Thank you to Dr. David Grant for training me to use a scanning electron microscope and Jochen Körner for his provision of maps.

Thank you to Dr. Michael Deal for his helpful comments throughout the completion of this thesis, from the proposal to the final edits. Thank you also to the Department of Archaeology at Memorial University of Newfoundland and the Memorial Archaeological Sciences Laboratory without which I would not have been able to conduct this research.

Thank you to Prof. Dr. Bernd Schöne and Michael Maus for training me in preparation and geochemical analysis methods at JGU. Thank you also to the INCREMENTS Working Group for their support and friendship while in Mainz, Germany.

Thank you to my brilliant cohort who inspired me to work hard, and karaoke hard. Thank you to Dustin Riley, Caitlynn Beckett, and Marshal Rodriguez for keeping my spirits up and harboring me during brain fog and stormy Newfoundland weather.

Thank you to the Social Sciences and Humanities Research Council, Canadian Museum of History, Scotiabank Bursary for International Study, and MUN’s Quick Start Fund for Public Engagement who funded my research at MUN and Johannes Guttenberg University of Mainz (JGU), and engagement with the shíshálh Nation.

Lastly, thank you to all other family and friends, my partner in crime, and the almighty powers of the universe, for their encouragement, love, and for pushing me to be the best version of myself.

#CLAMDA

CHAPTER 1

INTRODUCTION OF SEASONALITY, SETTLEMENT PATTERNS AND BRITISH COLUMBIAN SHELL MIDDENS

The Pacific Northwest Coast of Canada has been occupied by Indigenous peoples for over 12,700 years (Fedje et al. 2011) with long-term occupation dating back to over 7,000 years ago on the central coast of British Columbia (Cannon and Yang 2006)[1]. This far-reaching history of occupation has resulted in shell midden deposits percolating the British Columbian landscape. Shell middens are accumulations of shellfish material and other food remains which preserve well in the acidic coastal British Columbian soil due to the chemical makeup of shells ($CaCO_3$) that can lower the acidity of archaeological deposits, insuring their preservation (Cannon 2000b:726; Ham 1982:155). Shell middens preserve fish remains, notably salmon and herring, in addition to bird, terrestrial and sea mammal remains. They also contain artifacts and features such as burials, posts and hearths.

Shell middens have often been at the heart of food economy and settlement research along the Pacific Northwest Coast due to their richness in faunal remains and artifacts, which enabled archaeologists to study the relationships between people, places, technology, economy, and culture (e.g., Cannon 2000a,b; 2013; Mackie 2003; Maschner and Stein 1995). Archaeological studies that have focussed on food economies on the Pacific Northwest Coast prior to European contact have been closely related to studies on mobility and settlement patterns, since key food resources are not available year-round

[1] A presentation at the 50th Annual Meeting of the Canadian Archaeological Association in 2017 by Alisha Gauvreau and Duncan McLaren suggested that a village site (EkTb-9) on Triquet Island, BC, dates back to at least 14,000 BP.

(Ford 1989). The seasonal nature of food resources on the British Columbia (BC) coast required flexible mobility and seasonal migration (Binford 1980; Coupland 1998:41). Accordingly, groups living in coastal BC were mobile fisher-hunter-gatherers and some moved seasonally in their lands. The generalized ethnographic 'seasonal round' suggested that they collected and stored fish, shellfish, and berries from the spring to autumn in smaller encampments, and consumed these stored foods later during winter aggregations in large villages. The mobilization of some coastal Indigenous groups to obtain seasonal foods led early ethnographers to describe settlement patterns as static seasonal migrations used to take advantage of specific, seasonally available foods (Mitchell 1983; Ford 1989; e.g., Barnett 1955). However, this assumption downplayed the great geographic, cultural, and temporal variability of seasonal mobility and food-related practices in coastal BC *(for a critique of the ethnographic record, see section 2.1.5.)*.

Archaeologists have continued to be influenced by the ethnographic record, often using the presence of vertebrate faunal remains in archaeological sites, some of which were seasonally abundant such as salmon and herring, as evidence of seasonal occupation. While shell middens have been an important source of information for archaeologists studying food economies and settlement patterns, the overwhelming interest in archaeological fish remains, also known as "salmonopea" (Monks 1987), has led to the downgrading of shellfish remains to a food of lesser importance. The lack of focus on shellfish has also limited the way archaeologists understand shellfish-related practices and variability in shell deposits. However, shellfish remains in shell deposits are cultural and environmental recorders, and the physical and chemical investigation of their incremental growth can provide information on harvesting practices and seasonality.

1.1. Research Objectives

This thesis examines shellfish remains from archaeological sites in the Sechelt Inlet system (SIS), on shíshálh lands, in southern BC (Figure 1.1.). Its first aim was to determine the season(s) when *Saxidomus gigantea* (butter clams) were collected and, by proxy, when pre-contact archaeological sites were occupied. Its second aim was to determine relative butter clam harvesting pressure rates for each site to understand the local importance of shellfish to the food economy. Seasonality and intensity of butter clam harvesting was investigated with high-resolution stable oxygen isotope ratio ($\delta^{18}O_{shell}$) analysis coupled with micro-growth analysis, and macro-growth line analysis, respectively (*for detailed descriptions of $\delta^{18}O_{shell}$, micro-growth line and macro-growth line analyses, see Chapter 4).*

The SIS reported a lower salinity percentage than those reported in previous $\delta^{18}O_{shell}$ calibration studies on the Pacific Northwest Coast (Hallmann et al. 2009; 2011; 2013). The less saline seawater of the SIS was of particular interest and concern in this thesis since freshwater influxes have strong controls on $\delta^{18}O_{shell}$ integration (Gillikin et al. 2005a). Therefore, modern live-collected SIS butter clams were analyzed for $\delta^{18}O_{shell}$. $\delta^{18}O_{shell}$ results were reviewed in conjunction with known modern temperature and precipitation records to understand how the SIS environment would affect $\delta^{18}O_{shell}$ values. $\delta^{18}O_{shell}$ results were also aligned with lunar daily growth increment analysis to clarify salinity effects on $\delta^{18}O_{shell}$ integration in the SIS. This thesis is the first high-resolution $\delta^{18}O_{shell}$ and shell macro-growth line study in the SIS, and the inner coast of British Columbia, which has a distinctly fresher seawater regime than the outer coast.

Figure 1.1. *Map of British Columbia indicating locations where shellfish seasonality and/or shell growth increment studies have been conducted: Dundas Island Group and Prince Rupert Harbour (Burchell et al. 2013a); the Namu Region (Burchell et al. 2013b; Cannon et al. 2008; Cannon and Burchell 2009); Pender Island, Clamity, Ladysmith, and Montague Harbour (Burchell n.d.; Leclerc et al. 2016); Deep Bay (Sparrow 2016). The southernmost boxed region indicates the location of the Sechelt Inlet system.*

1.2. Study area

The sites investigated in this thesis were located on the inner coast of the Sunshine Coast in southern BC. The analyzed materials come from previously excavated shell middens and shell-bearing sites in shíshálh lands: inlet village DkRw-26, formal camps DjRw-18 and DkRw-22, and the larger village site DjRw-1 (Figure 1.2.). The inlet village and formal camps were located on the southern side of Narrows Inlet near the narrows (a.k.a. Tzoonie Narrows) and on the west and east side of Storm Bay, which protrudes out of Narrows Inlet, respectively. These three sites are found northeast of the larger village site, DjRw-1, which is situated along one of the largest sand flats in shíshálh lands, Porpoise Bay, near the isthmus that separates the SIS from the outer coast. Many freshwater streams flow into the SIS making it an ideal region to fish for salmon returning to their natal streams to spawn in the autumn, as well as herring, which are known to spawn in Porpoise Bay in late winter/early spring (Coupland et al. 2012). Salmon and herring have been used to infer seasonality of archaeological sites and develop understandings of regional settlement patterns on the Pacific Northwest Coast (e.g., Cannon 2000a;b; Coupland et al. 1993). This is also the case for settlement pattern research and seasonality determinations of sites in shíshálh lands (Bilton 2014; Coupland et al. 2012; Letham 2011;2014). Letham's (2014) archaeological study of settlement patterns in Narrows Inlet and Salmon Inlet utilized faunal analysis, principally reliant on salmon and herring remains, and ethnographic information to argue that pre-European contact settlement patterns were similar to those described ethnographically by Barnett (1955), who described the shíshálh people living in a large village in Pender Harbour near the outer coast in the winter, and moving to their smaller village at the mouth of Narrows

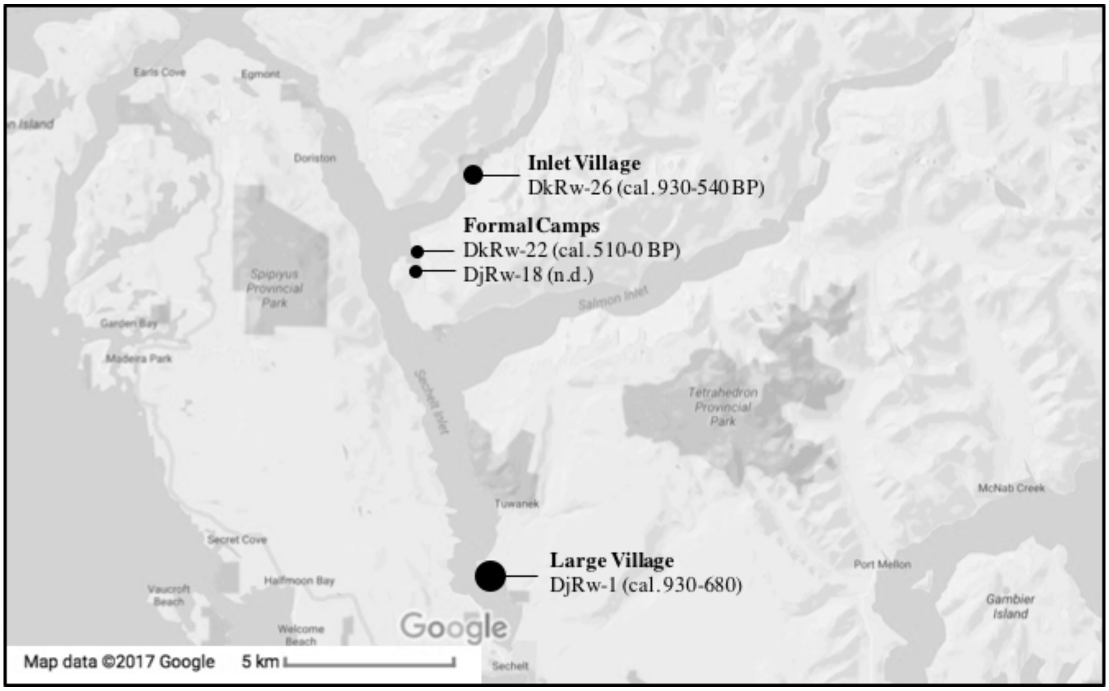

Figure 1.2. Sites examined in the Sechelt Inlet system. Size of circles indicate the relative size of sites

Inlet in the spring until the autumn (Figure 2.1.). Further, Coupland et al. (2012) suggested that the large village in Porpoise Bay located near the outer coast was a winter village with a component of the site being used as a specialized herring fishing and processing camp in the late winter to spring, suggesting a main occupation during the winter and spring. However, Barnett never specifically discussed the seasonal occupation of the sites investigated in this thesis. In addition, Letham, Coupland, and colleagues used low-resolution seasonal indicators (i.e., salmon and herring remains) as well as ethnographic evidence to infer seasonality and mostly discussed shellfish in terms of diversity and density of shell remains. Letham (2011) observed the variability between and within shell deposits in the SIS and was the first to discuss how this variability suggested variable shíshálh shellfish harvesting practices.

1.3. Intra- and inter-midden variability

Shell midden archaeology has been criticised for de-emphasising intramidden and intermidden variability and often treated them as homogenous deposits (Claassen 1991b:249). Since this thesis discusses variability of shellfish harvesting patterns between and within shell deposits, careful consideration of the types of shell deposits discussed in this thesis is warranted. Shell-bearing and shell midden definitions here are based on Widmer (1989)'s typology. Shell-bearing deposits are comprised of secondarily deposited shell and other materials as a result of consumption or other activities, while shell midden deposits are comprised of secondarily deposited shell and other food remains resulting solely from consumption. Archaeological shellfish remains found in shell-bearing deposits therefore may not only be a product of consumption. Onat (1985) explained that shellfish material found in Northwest Coast middens may also have been used in the construction of house floors, hearth, and house insulation. In addition, archaeological shells may also represent the usage of shellfish meat for fish bait, which was well documented in many regions around the world including Vancouver Island (Claassen 1991b:253; Arrima and Dewhirst 1990:397).

Special consideration needs to be taken when working with shell-bearing and midden deposits since the character of shells complicates interpretations of temporal change. For instance, Muckle (1985), who conducted multiple experiments to understand shell midden formation processes, found that trampling over shells resting on a loam substrate 1000 times caused 96% of the shells to be found 2 cm below the surface, 3% to be found 2-4 cm deep, and 1% found 4-6 cm deep. This vertical migration of shellfish remains in shell deposits can therefore disrupt stratigraphic integrity. Shell matrices may also leave open spaces for shells and other smaller material to migrate into lower layers (Waselkov 1987:147), however the rapid accumulation of shellfish material may also enhance the stratigraphic integrity of shell deposits (Waselkov 1987:143).

Their active status during site occupation and their preserving quality make shell middens and shell-bearing deposits intriguing contexts to investigate shellfish-related practices and seasonal occupation. As previously stated, seasonality of sites has often been discussed in the context of what seasonal faunal remains were found in shell deposits. However, as the next section will show, these are low-resolution seasonal indicators and seasonal determinations of sites can be improved with the integration of high-resolution $\delta^{18}O_{shell}$ analysis of shellfish remains.

1.4. Seasonality indicators

1.4.1. Fish remains

The presence of anadromous fish remains can indicate seasonality because their spawning behaviour is seasonal; often herring return to the coast to spawn in late winter/early spring and salmon return to their natal streams in the interior to spawn in the summer and autumn months depending on the species (Cannon 2002; Haegele and Schweigert 1985). During spawning time, these fish species become locally abundant and can be fished *en masse*. However, the seasonal timing of herring and salmon have not been stable when looking at long-term histories (Groot and Margolis 1991; Hay and

McCarter 2006). Furthermore, without species-specific identification of salmon remains, some seasons cannot be eliminated, or accounted for (Ford 1989:141; see also Butler 1987). Therefore, the seasonal abundance of these fish may not have been fixed in the pre-European contact past, and cannot always single out specific season(s) of occupation. In addition, the identification of other seasonal fauna may only provide wide seasonal ranges unable to pinpoint seasonality at a higher resolution (Cannon and Yang 2006:126). Accordingly, they should not be the sole determinant of archaeological seasonality (Ford 1989). Furthermore, the storage-based economy of Indigenous cultures in BC prior to European contact made it so that salmon fished in the autumn were kept and consumed throughout the winter and into the spring. Therefore, the presence of seasonally available salmon remains, while representative of the season of collection may not account for all seasons during which the site was occupied.

1.4.2. Shellfish growth line and $\delta^{18}O_{shell}$ analysis

'Annual growth rings' have also been used to interpret seasonally in bivalves recovered from shell midden sites. Until fairly recently (see Hallmann et al. 2009), it was assumed that growth lines or rings, especially in butter clams were deposited annually in the winter when growth slowed (e.g., Coupland et al. 1993; Monks 1977; Wessen 1988*; for more information of butter clam growth line deposition, see section 3.1.3.).* Hallmann et al.'s (2009) studies using lunar daily growth increment (LDGI) analysis found that butter clam 'growth rings' on the southern, central, and northern coasts of BC as well as the Alaskan coast were actually tightly bundled micro-growth lines which are deposited daily (Hallmann et al. 2009; 2011; 2013; *for more information on LDGI see section 1.4.3.*). The deposition of these 'growth rings', or more accurately called macro-growth lines, occurred during times of temperature stress in the winter, and were also deposited during storm events, ice melt, freshwater incursions, and spawning events. These studies highlighted how problematic it was to use macro-growth line analysis to infer seasonality on the Pacific Northwest Coast since macro-growth lines were shown to be influenced by factors beyond seasonality (Burchell et al. 2013c).

Burchell et al. (2013a,b) demonstrated that macro-growth line analysis to determine seasonal occupation of sites in the Prince Rupert Harbour area, and other locations in coastal BC was an un-reliable method to determine season of shellfish collection. Coupland et al's (1993) study investigated seasonality at the McNichol Creek site, near Prince Rupert Harbour, BC, by using shell macro-growth line analysis of butter clams, littleneck clams and cockles (n=127), and faunal analysis, which provided evidence of winter salmon storage and absence of eulachon and sea mammal remains. The results suggested that shellfish harvesting occurred year-round but mainly in mid-summer. They therefore concluded that the site was occupied mainly from winter to mid-summer. On the other hand, Burchell et al.'s (2013a) high-resolution $\delta^{18}O_{shell}$ analysis suggested that shellfish harvesting at the McNichol Creek site occurred mainly during the spring and autumn, and that the site was occupied from spring to autumn (n=5). Though Burchell et al.'s (2013a) sample size was small in comparison to Coupland et al's (1993), a regional seasonal emphasis on spring and autumn collection was found through the investigation of two other sites in the Prince Rupert Harbour area, suggesting that the use of macro-growth line analysis for the purpose of determining seasonal harvest produced un-reliable data in the Coupland et al. (1993) study.

A similar but different approach was taken by Maxwell (1989) who attempted to use the differential colouration of macro-growth lines in shell cross-sections as proxy for seasonality. Using a method modelled from Quitmyer's et al.'s (1985) and Claassen's (1982) studies, Maxwell observed ratios of opaque (white) and translucent (grey) shell in thick sections of six shellfish species, under the assumption that translucent shell was produced during slow growth (winter) and opaque shell was produced during fast growth (warmer seasons). This assumption is similar to those found in macro-growth line analyses for the purpose of determining seasonality; it does not take into consideration variation in growth rates as a result of different regional environments or ontogeny (*for critique of macro-growth line methods, see* Burchell 2013).

High-resolution $\delta^{18}O_{shell}$ analysis is currently the best method to robustly determine the seasonality of shellfish harvesting (Burchell et al. 2013a,b; *for detailed description of this method, see sections 4.6. and 4.7.).*

1.4.3. Lunar daily growth increments (LDGI): Clarifying estuarine $\delta^{18}O_{shell}$ results

Previous $\delta^{18}O_{shell}$ calibration studies were conducted in BC by comparing local $\delta^{18}O$ integration to known seawater temperature, salinity, and tidal conditions (Hallmann et al. 2009; 2011; 2013). The results showed that salinity effects influenced $\delta^{18}O_{shell}$ in addition to seawater temperature, thereby disabling the use of $\delta^{18}O_{shell}$ alone to determine paleo-temperatures. Accordingly, these same studies developed a growth-temperature model which involved measuring LDGI, daily deposited growth increments (Hallmann et al. 2009; 2011; 2013). Generally, increments are widest during the summer when conditions are favorable for growth and are narrowest during the winter when growth slows. Accordingly, LDGI have been used to clarify $\delta^{18}O_{shell}$ results from estuary-borne shells that were heavily affected by freshwater effects, and to increase the resolution of $\delta^{18}O_{shell}$ seasonality interpretation (Burchell et al. 2013c; Goodwin et al. 2001).

1.5. Shellfish harvesting pressure indicators

Qualitative macro-growth line analysis, while not accurate methodology to determine seasonality, has been used to investigate relative rates of shellfish harvesting pressure (Burchell et al. 2013a; Cannon et al. 2008; Cannon and Burchell 2009). In the past quantitative methods were used to determine shellfish harvesting pressure including: counting external growth rings to determine age of mollusk shells (Jones et al. 1978), quantifying densities of preferred shellfish species (Botkin 1980), measuring the sizes of shells (Coupland et al. 2003; Wessen 1988); or shell weights (Lasiak 1992). These methods however, have been criticized because of the strong environmental controls on external shell growth ring deposition, shell size and consequently, weight (Claassen 1998:45), making it difficult to make any inferences about human shellfish harvesting practices. Furthermore, shell middens are accumulations of shell material which makes it difficult to distinguish separate shell deposition events to determine stratigraphic changes in harvest pressure without radiocarbon dating each shell analysed (Bailey 2007:204).

Macro-growth line and increment (i.e., shell material between growth lines) analysis of butter clam shells can be used to classify archaeological shells into growth stages (senile, mature, and juvenile) and determine relative frequencies of each growth stage to interpret relative shellfish harvesting rates between sites. Shells in a younger stage of growth will have evenly spaced macro-growth lines while shells in a senile stage of growth will have unevenly distributed and tightly packed macro-growth lines near the ventral margin (i.e., the growing edge) as growth rate slows with ontogeny (Claassen 1998). Accordingly, shells recovered from middens with a higher proportion of younger shells than senile shells have been hypothesized to represent more intensive shellfish harvesting (Cannon et al. 2008). The reasoning behind this hypothesis was that if higher intensity shellfish harvesting was occurring in the past, fewer butter clams would have been permitted to reach senility. In contrast, sites with a higher proportion of senile shells were hypothesized to represent less intensive harvesting (Figure 1.3.).

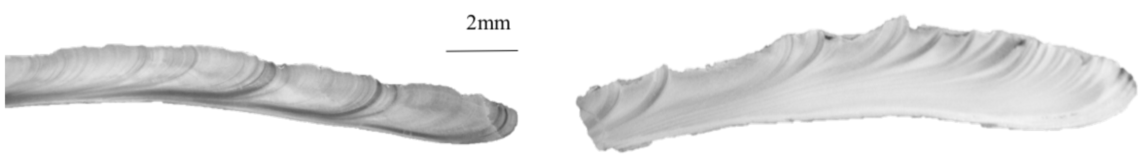

Figure 1.3. *Left to right: Mature and senile Saxidomus gigantea shell fragments.*

Macro-growth increment results from the Namu region, on the central BC coast, showed a pattern of higher shellfish harvesting intensity at camps and lower shellfish harvesting at village sites (Cannon and Burchell 2009). The significance of these results was contextualized through resource conservation theory (Smith and Wishnie 2000). This theory suggested that resource management was possible if access to resources was controlled. Accordingly, clam bed management has been reported in many places on the Pacific Northwest Coast (e.g., clam bed ownership, clam gardens) (Groesbeck et al. 2014; Moss 1993; Wessen 1988; Williams 2006). This led Cannon and Burchell (2009) to suggest that Heiltsuk peoples on the central coast purposefully limited shellfish harvesting in front of villages as a long-term strategy to protect shellfish beds. Macro-growth increment data can inform coastal archaeologists on the relationship between people and places. Further, they can inform us on the geographic variability of shell growth rates, which should be factored-in in investigations using macro-growth line and $\delta^{18}O_{shell}$ analyses (*for information on geographic variability of growth rates,* *see pp. 103*).

Macro-growth increment analysis in conjunction with $\delta^{18}O_{shell}$ analysis has been applied to settlement pattern and seasonal shellfish harvesting research on the central and northern coasts of BC, and represent the first systematic regional studies of seasonality and intensity of shellfish harvesting practices utilizing the most current cutting-edge methodology (Burchell et al. 2013a;b;c; Cannon et al. 2008; Cannon and Burchell 2009). This thesis builds on this foundational research by expanding research in southern British Columbia, specifically in shíshálh lands (Figure 1.1.).

CHAPTER 2

ETHNOGRAPHIC &ARCHAEOLOGICAL APPROACHES TO SEASONALITY & SHELLFISH HARVESTING PRACTICES

2.1. Ethnography

2.1.1. The shíshálh

The shíshálh are the largest cultural group associated to the Northern Coast Salish linguistic group (Kennedy and Bouchard 1990:441) and closely tied to the Comox language group (Barnett 1938:141). They have been ethnographically described as fisher-hunter-gatherers (Barnett 1955), and have been shown to have settled in the Sechelt Inlet system (SIS) as early as cal. 6500-6350 BP (Coupland et al. 2012)[2]. There are discrepancies between how different ethnographers identified the shíshálh subgroups but there is a general consensus that the shíshálh were divided into four main subgroups (Kennedy and Bouchard 1990:443; Hill-Tout 1978 [1904]:21; Barnett 1955:30) (Table 2.1). Of specific interest in this thesis are the tuwanek people who are the only people to have ethnographically inhabited the SIS. Of the shíshálh, the tuwanek are known ethnographically to have been the largest faction (Barnett 1955), and the sites under investigation in this thesis are within their ethnographically described lands. It is however impossible to confirm the antiquity of the 'tuwanek' name for the people who occupied the investigated sites solely off of how they were recognized ethnographically. For this reason, I will refer to the people that habited the SIS generally as 'ancestral shíshálh' instead of the 'tuwanek' designation.

[2] The earliest date for occupation of shíshálh lands was found at DkSb-30 in Saltery Bay, near the mouth of Jervis Inlet, 7670-7570 cal. BP (2-sigma) (Golder Associates 2007).

2.1.2. The shíshálh 'seasonal round'

Ethnographically, their main village was situated at the head of Narrows Inlet (Kennedy and Bouchard 1990) which was occupied during the summer. During this time, they occupied shed-style plank houses (Barnett 1955:35), or simple one-night setups (1955:39). When winter arrived, all shíshálh subgroups mobilized to collectively settle at the large village in Pender Harbour, *Kalpilin*, (Barnett 1955:30; Figure 2.1.). This was a special time for the shíshálh, when there would have been traditional dances and feasts in gable-style houses (1955:51). During this time, limited food resource collection would have occurred as the Coast Salish were known to have had a storage-based food economy which allowed them to collect surplus food in the warmer months for winter consumption (Barnett 1955:59).

Table 2.1. Principle occupation locations of the four main subgroups identified in three different ethnographic records.

	Sechelt Inlet System	Near the Source of Jervis Inlet	Near the Mouth of Jervis Inlet	Near Pender Harbour
Hill-Tout (1978[1904]:21)	**Tūwănekq** Head of Narrow's Arm	**Tsŏnai** Deserted Bay, the junction of Queen's Reach and Princess Royal Reach	**Qúnētcin** Head of Queen's Reach	**Sqaiaqōs** Many settlements but no fixed abode
Barnett (1955:30)	**Tuwankw, kLiLwim** River mouths of Narrows Arm, Salmon Arm and Sechelt Inlet	**Klalamklatc, tsonai, skwakwiɛm** Deserted Bay and Vancouver Bay	**Xexoats, hane:tcan, tatkwotetan** Thunder Bay, Hotlam Sound, and Stillwater Bay	**Siceltmot, tskwana** Pender Harbour and opening of Sakinaw Lake
Kennedy & Bouchard (1990:443)	**Tuwanek** Head of Narrows Inlet	**Tsoonai** Deserted Bay	**Hunechen** Head of Jervis Inlet	**Skaiakos** Garden Bay, Pender Harbour Area

2.1.3. The shíshálh food economy

Their dietary profile was extensive and included: fish (salmon, herring, lingcod, greenling, steelhead, flounder, sole, rockfish); sea mammals (sea lion, harbor seal, and harbor porpoise); land mammals (mostly deer, but also bears, porcupine, beaver, marten, mink, raccoon, and mountain goat); birds (waterfowl, grouse, pigeon eggs, and gulls); plants (berries, seeds, green vegetables, and underground plant parts) and; intertidal resources (chiton, sea urchin, sea cucumber, mussels, cockles and clams) (Kennedy and Bouchard 1990:444-45; Hill-Tout 1978 [1904]:29-30). However, they mainly subsisted on dried foods, principally salmon, clams, and fish eggs (Barnett 1955:60). In addition, the shíshálh may have traded foods or animal products, such as large mussel shells used as knifes, during the winter when shíshálh subgroups coming from the source of Jervis Inlet or all the way from the SIS could trade their respective locally available resources (Barnett 1955:63). Barnett also suggests that among the Coast Salish, specialized mainlander sea and land mammal hunters may have traded their meats for clams and other foods which were more abundant in island settings. He elaborates by stating that "[r]eliance upon seals, sea lions, clams and mussels reveal a more complete salt-water adaptation for the islanders than for the mainlanders who relied more upon sturgeon and other river products" (Barnett 1955:93).

2.1.4. Shellfish in the ethnographic record: An underappreciated resource

Barnett and other ethnographers limited their discussions about shellfish-related practices to food preparation methods and shell material uses, and rarely discussed shellfish harvesting methods (Table 2.2.). This lack of emphasis, and interest, on shellfish harvesting has also been noted in other regions of the Pacific Northwest Coast (Moss 1993). Some have argued that this resulted from the lack of emphasis on female economic practices, or a "de-gendering" of shellfish-related activities, since women, children, and slaves were often the principal shellfish collectors (Claassen 1991a:276; Lasiak 1991; Moss 1993; Waselkov 1987:97). The absence of ethnographic information on who would have collected shellfish in the shíshálh's lands, supports Claassen's and Moss' statements. The closest inference of gendered shellfish harvesting comes from Kennedy and Bouchard (1990:446), who described Northern Coast Salish women making baskets to carry items such as clams. This leads one to infer that that women were likely the primary shellfish collectors in the SIS. Further, while shellfish is incorporated in Coast Salish women's ceremonies and rituals surrounding childbirth, they are also linked to taboos for boys entering puberty (Barnett 1955:152; also see Moss 1993; see Table 2.2.). This suggests that shellfish were more closely associated to Coast Salish women than to men. However, there may have been acceptable circumstances for men to collect shellfish when practicality overrode "a man's ideal behaviour" (Moss 1993:641). The fact that shellfish refuse percolates the shíshálh landscape, often representing the bulk of archaeological faunal material, with shell-bearing sites being the most common site-type in shíshálh lands (Letham 2011), further indicates the importance of shellfish resources during pre-contact times. The high density and long-term histories of shell-bearing sites in the SIS also suggests that ancestral shíshálh developed methods to identify or circumvent the effects of paralytic shellfish poisoning (PSP) (*for detailed descriptions of PSP and methods to bypass its effects, see section 6.6.1.*), which has been argued to have possibly deterred people from consuming shellfish in the past (Moss 1993). Others have suggested that shellfish were supplementary or complimentary resources as they were perceived as low-caloric food (Osborn 1977; Waselkov 1987:110). However, there exists a great amount of caloric variability between shellfish species, with some that overlap published caloric values of turkey, quail, drum fish, and catfish (Claassen 1991b:271-75), thereby elevating their dietary value. Further, since clams were ethnographically described as being a major component of the regular Coast Salish diet and readily available all year, shellfish likely played crucial part in ancestral shíshálh diets and present interesting material culture to study seasonality and their contribution to the local economy.

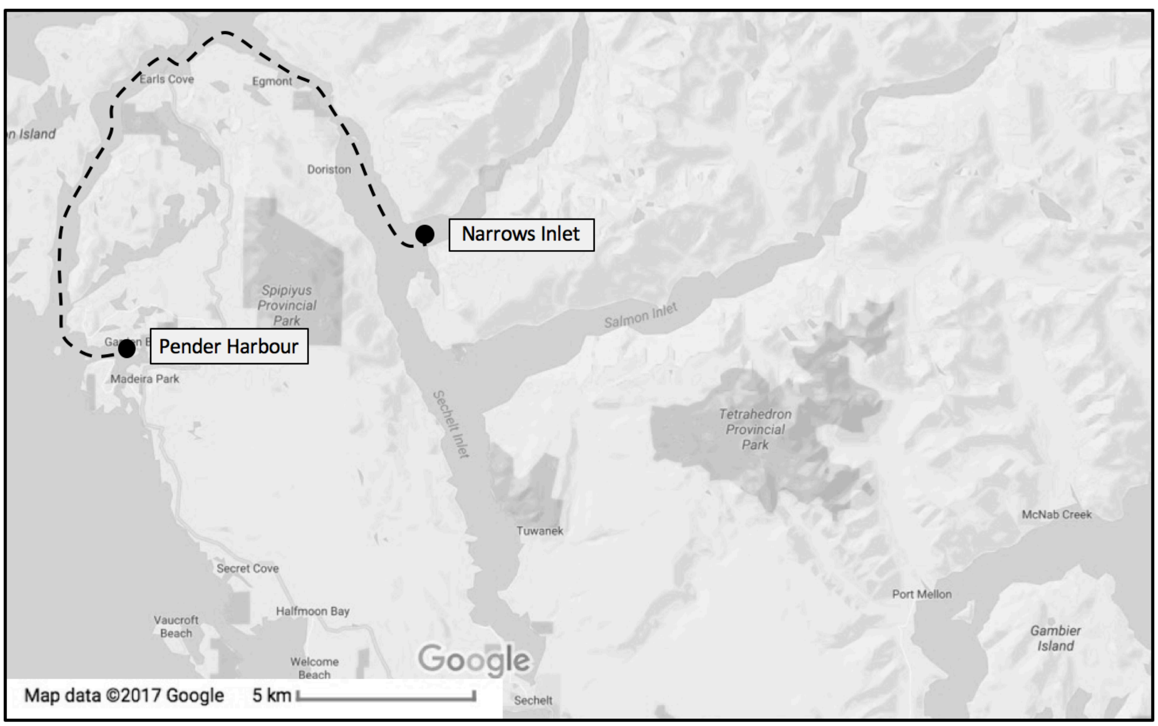

Figure 2.1. *The shíshálh 'seasonal round' as described by Barnett (1955).*

2.1.5. The reliability of the ethnographic record

Ethnographic records on hunter-fisher-gatherers that rely on personal observations and informants' testimonies are historically specific and may only relay information from a couple of preceding generations. This means that we need to be cautious when using the ethnographic record to interpret pre-contact behavior. Grier (2003) stated that archaeologists often used the ethnographic record to support their archaeological findings instead of the other way around, and therefore if we do not have solid support for the antiquity of ethnographically-described practices it becomes problematic to use the ethnographic record as a singular evidentiary resource. While some archaeologists continue to be heavily influenced by notions borne by the ethnographic record, recent studies have sought to test its reliability for pre-contact times and have shown how there was much more variability in seasonal settlement and food procurement patterns on the Pacific Northwest Coast (e.g., Burchell et al. 2013a,b; Cannon et al. 2008; Cannon and Burchell 2009; Mitchell and Donald 1988; Tobiasz 2015).

I do not argue that ethnographic records were wrong. I recognize on the other hand, that the majority were written by European men who documented their interpretations of what they saw and heard from their informants. Their unique view was first influenced by their culture and their othering of their 'subjects'. Furthermore, the amount of time ethnographers spent with their 'subjects' varied but were generally short and this further limited the scope of their records. Indigenous informants were record keepers in their own right as information was passed down to them in the form of storytelling and would have had continuities with the far-reaching past, but it was also "socially situated and contextually contingent" (Martindale 2006:158-159). This layering of biases inevitably made their way into the ethnographic record skewing it towards the present. As G.N. Bailey (1983:170) once wrote: "Literary documents and archaeological artifacts may refer to past events, but they are objects of the present". Accordingly, multiple studies have shown that seasonal settlement patterns and/or food procurement patterns were affected by European contact on the Pacific Northwest Coast as well as other colonized places (e.g., Bolt 1992; Fisher 1977; Ford 1989; Moss 1993; Wessen 1988). For instance, Washington Coast Salish were seasonally employed as hop pickers in the autumn and also moved to preferential trading posts where they could sell goods to Americans (photographs taken by Ashael Curtis and Arthur Warner, in Suttles 1990). Similarly, the tuwanek moved their village back to Porpoise Bay in order to be closer to the mission in Trail Bay (Kennedy and Bouchard 1999:440; Beaumont 1985:xvii; Barnett 1955:30-31; Hill-Tout 1978 [1904]:21). Therefore, the seasonality information in the ethnographic record may be misleading when applying it to pre-contact archaeological sites.

Further, we cannot assume that pre-contact settlement patterns were stable and unchanging. It has been shown that settlement patterns changed in other places on the Pacific Northwest Coast due to conflict with other Indigenous groups. Maschner (1996; 1997) who studied the site in Tebenkof Bay, Alaska, found evidence of political conflict around 1650-1450 BP, arguing that this caused people to seek out defensible locations to establish their villages. In addition, Harris (1997:6) argued through the use of oral records that the effects of smallpox epidemics resulted in depopulation, disruption of mobility patterns, only a few years before the arrival of Europeans. It was further argued that this, in turn caused social and political disruptions that increased inter-regional conflict among Coast Salish cultures in the Salish Sea. This is corroborated by Angelbeck and Grier (2012) who argued that epidemics and the arrival of Europeans caused a new wave of disruption and chaos in the Salish Sea between [160 and 80 BP]. Hill-Tout (1978 [1904]) and Barnett (1955) also stated that kwakwaka'wakw raids occurred along the Salish Sea in the past. This further casts doubt on the antiquity and stability of ethnographically-described settlement pattern in shíshálh lands.

In addition, Karpiak (2003) inputted multiple variables into GIS software to predict where pre-contact sites would most likely have been situated, and developed two models: one that was a direct translation of the ethnographic record and the other predicted where sites would be found based on ethnographic data. Consequently, Karpiak did not find many ancestral Nuu-chah-nuuth shell midden sites on western Vancouver Island conforming with either models' predictions. This further highlights issues concerning the application of the ethnographic record to archaeological interpretations of pre-contact settlement patterns in BC.

However, it would be wasteful and limiting to completely disregard ethnographic accounts as they contain rich information representative of continuities that stretch far back prior to contact however contextual they may be. Indigenous peoples did not meet Europeans on their shores, blink, and then completely and utterly adopt European practices. It is certain that continuities between pre-contact events and post-contact ethnographic events exist, therefore it must be used critically and cautiously (Moss

2011:23; Grier 2003). This is why I have chosen to use my data to challenge the ethnographic record while also cautiously drawing upon it along with other lines of evidence to inform my results.

2.2. Archaeology

Archaeology in shíshálh lands can be traced back to Charles Hill-Tout (1978 [1904]:34) who conducted informal excavations of a shell midden mound at an unspecified location that yielded artifacts including arrows, spear heads, and a pestle hammer. Later, Barnett (1955:56) states that a house was excavated, but does not specify where, and whether he excavated it or if it had previously been excavated. The first systematic archaeological survey on shíshálh lands was conducted by Acheson and Riley (1977) who focussed on sites in Jervis Inlet further north than the SIS. Since 2001, the Sechelt Indian Band (SIB) has continued to support contract archaeology in the SIS and other shíshálh lands (e.g., Merchant 2001ab, 2002, 2008; Jessome 2007; 2014; 2015; 2016; 2017). However, the sites under investigation in this thesis (DjRw-1, DkRw-22, DjRw-18, DkRw-26) were not investigated until the 2008 survey conducted by the *shíshálh Archaeological Research Project* (sARP), a collaborative project with the SIB, the University of Toronto, the Canadian Museum of History, and recently the University of Saskatchewan. This survey was a part of a large-scale project targeted at identifying sites and conducting preliminary excavations including test pits, auger tests, and excavations at selected sites. Excavations focussed on village sites and small scale excavations at camps (*for site type characteristic see* Table 2.4.).

Table 2.2. Summary of ethnographically described Coast Salish shellfish-related practices.

Shellfish Resource	**Practice**	**Sources**
Shellfish	Not used as bait	Coast Salish: Barnett (1955:86)
	Often used in ceremonies specific to women and childbirth	Coast Salish: Barnett (1955: 128,130,131,138)
	Women wove baskets to carry fish, clams, berries, and firewood	Northern Coast Salish: Kennedy and Bouchard (1990:446), Barnett (1955:123)
Clams	Gathered during winter low tides by the light of pitchwood torches	Northern Coast Salish: Kennedy and Bouchard (1990:445)
	Food preparation: Boiled, steamed, or "barbecued" on wooden sticks Smoked dried or sundried	Northern Coast Salish: Kennedy and Bouchard (1990:445); Barnett (1955:63)
	Were often steamed, roasted, and trampled whilst placed between two mats to be made tender. They were then strung up, and may have been worn around necks	Washington Coast Salish: Menzies (1792 *in Barnett 1955:61*) observed the clam necklaces in Puget Sound
	Traded for sea and land mammal Pubescent boys could not eat them until a ceremony released the taboos	Coast Salish: Barnett (1955:93) Sanetch, Coast Salish: Barnett (1955:152)
	Shellfish harvesting in late spring and early summer	Northern Washington Coast Salish: Wessen (1988)
	Shells used as containers for oil, coal, cooking fat	Coast Salish: Barnett (1955:63)
	Calcified shells were used as paints to paint canoes with edges sometime inlayed with shells	Coast Salish: Barnett (1955:112)
Abalone	Shells worn as pendants	Coast Salish: Barnett (1955:76)
Mussels	Large shells used as fish-knifes	Coast Salish: Barnett (1955:63)

2.2.1. Shell middens and shell-bearing deposits in the Sechelt Inlet system

As previously stated in the introduction, shell-bearing deposits and shell midden deposits are two different types of shell deposits, and both are examined in the sites under investigation in this thesis. Shell-bearing deposits resulting from secondary deposition of shells and other food refuse may include features, and shell layers may be delineated by soil layers above and below it. Previous evidence elsewhere on the Pacific Northwest Coast suggested that shellfish remains in shell-bearing deposits may be a result of shellfish being used as fish bait (Arrima and Dewhirst 1990:397). However, according to Barnett (1955:86) shellfish were not used as bait by the Coast Salish. In addition, Onat (1985) suggested that shell midden material could be re-used as building material for house floors and walls; this would inevitable disrupt the stratigraphic integrity and disable interpretations of temporal change in these shell-bearing deposits. Accordingly, DkRw-22 was the only site of the four sites discussed in this thesis that proposed evidence of structural floors and it did not appear to have used shell as construction material. It appears that the overwhelming majority of shellfish remains examined in this thesis are solely resulting from consumption.

Shell midden deposits are comprised of secondarily deposited shell from food consumption with no other evident activities. According to Letham (2011) shell middens in the SIS were placed either at the front or the back of sites away from living areas. Shell material from different types of shell deposits have been specified in section 2.2.1.

2.2.2. Excavation methods

Bryn Letham led the survey of Narrows Inlet and Salmon Inlet in the SIS in 2010 and conducted a series of auger tests (ATs) at recorded sites. Subsequently, Letham analysed bulk auger samples, which were separated into arbitrary levels during testing (2011;2014). Using nested 8mm, 4mm, 2mm and 1mm screens, Letham measured relative ratios of shell fragmentation by weighing and measuring the volumes of shell for each screen size fraction and comparing it to the weight and volume of whole samples. This was used to determine relative rates of trampling according to Muckle's (1985)'s recommendations. Shell material greater than 4mm was sorted into species to discuss diversity and density of shellfish species and temporal change of shellfish harvesting practices. Bone fragments were picked out of the 2mm fraction, identified to species when possible, counted and weighed to determine seasonality and site types. In 2012, sARP returned to Storm Bay and Tzoonie Narrows to conduct small-scale excavations of DkRw-22 and DkRw-26. They excavated contents in layers and later sorted column samples with nested 8mm, 4mm, 2mm and 1mm screens, counted number of identified specimens (NISP) in each screen size fraction, except 1mm fraction, and measured weights and volumes in comparison to the volume of whole samples.

Gary Coupland and colleagues led excavations at the Porpoise Bay site. They excavated the western part of the site near an area that indicated that a house may once have stood there. The shell material from DjRw-1 used in this thesis comes both from in situ excavations and sorted column samples.

2.2.3. Site information and background

2.2.3.1. Porpoise Bay (DjRw-1 – *sihatl, tsúlích*[3])

DjRw-1 is situated in Porpoise Bay on the east shore of Sechelt Inlet on one of the most extensive mixed-sediment beaches in the SIS making it an ideal site for butter clam collection. It was first surveyed in 2008, and excavated the following summer in 2009 (Coupland et al. 2012). The site itself covers approximately 15,000m^2 and 300m of beach shore and extends 65m inland[4]. DjRw-1 has been described as a large multi-component village site with an initial occupation date of 4150 cal. BP (2-sigma; Coupland et al. 2012). Land on the eastern side of the site, now covered by local housing, would have held multiple house structures. The western part of the site, where excavations took place, may have been used for housing and to perform small tasks (Coupland et al. 2012). The large amounts of herring remains found and a lack of faunal diversity suggests that the excavated portion of the site may have been utilized temporally to process spawning herring in the late winter and early spring (Coupland et al. 2012).

The shell material used in this thesis was dated to a time period prior to the 19th C. re-settlement of the site (Beaumont 1985:xvii; Hill-Tout 1978 [1904]:21; Kennedy and Bouchard:443) and comes from two different excavation trenches: N78-80 E68 excavated in 2009, and N80 E85-86 excavated in 2012 (*for a summary of excavation layer contents see* Table 2.3.). Radiocarbon dates from unit N80 E68 suggest that the layers of interest

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[3] *Sihalt* and *tsúlích* are two different traditional shíshálh site names for the Porpoise Bay village site according to Coupland et al. (2012:5) and Merchant (2008:6).

[4] The area currently lies in *shíshálh* Band Lands 5. All of the archaeological sites excavated by sARP are located on *shíshálh* band lands and have been excavated with the permission and collaboration of the SIB.

in this thesis were deposited between 930 and 680 cal. BP (2-sigma range).

Both excavated trenches were described as having clearly delineated layers, comprising of alternating soil and shell layers suggesting that they are composed of shell-bearing deposits (Terence Clark, personal communication 2017). Therefore, minimal mixing may have occurred between layers.

Table 2.3. Summary of DjRw-1 excavation layer's shellfish contents [5]**.**

N78-80 E68	N80 E85-86
Zone 1 Crushed shell (clam, cockle and mostly mussel)	**Layer B** Heavy fauna content, especially herring
Zone 2 Dense "burned" clam and ash, likely refuse moved from original preparation and cooking feature	**Layer C** Intermittent layers of herring with significant amount of shell
Zone 3 A few large clam shell fragments and a great volume of "burned" mussel shell	**Layer D** Less shell, containing large mammal bones with some fish
Zone 4 Whole pieces of "burned" clam shell and absence of mussel shell	**Layer E** Mostly mussel with other shell species mixed in, the most amount of salmon than any other level

2.2.3.2. Storm Bay (DkRw-22 and DjRw-18)

Both, DkRw-22 and DjRw-18 have been interpreted as large formal camps in Storm Bay, an isolated bay situated near the mouth of Narrows Inlet. The pebble beach adjacent to DkRw-22 is not very productive for butter clam harvesting (Letham 2011:166-167). Conversely, the beach adjacent to DjRw-18, on the other side of the bay, is a mixed substrate beach (preferred substrate for clams). It has been suggested that the

[5] The 2009 excavations blocked stratigraphic layers into discreet deposition zones and the 2013 excavation abandoned the use of zones and only used discreet layers.

Storm Bay area may have functioned as a 'community' where the same people utilized its multiple highly productive beaches at the same time (Letham 2014) [6]. The location of DkRw-22 would have been ideal to surveil productive beaches on the other side of the bay, as well as salmon streams feeding into the bay, and control people coming through as Letham (2014) suggested about further up Narrows Inlet near Tzoonie Narrows. DjRw-18, on the other hand, was located near another large mud tidal flat, that may have been a productive clam bed in the past, and the mouth of a small creek, which may have hosted a modest Coho salmon run in autumn (Coupland et al. 2012:101; Letham 2011:38). This location might have therefore been chosen for its proximity to resource diversity. Letham (2011) noted that most sites with signs of house features in Narrows Inlet and Salmon Inlet were connected to beaches adjacent to pebble beaches, which would not have been suitable for butter clam harvesting, and that their occupants may have travelled by boat to nearby productive beaches to obtain clams. It is therefore possible that people living at DkRw-22 travelled by boat to neighbouring beaches in Storm Bay to collect and process shellfish in addition to more accessible fish resources. This is one of the benefits of having boat technology in a limiting landscape such as the SIS, which had relatively little flat land conducive to settlement (Ames 2002; Letham 2011). Since these sites were likely used at the same time by the same people, they are both examined in this thesis, with more emphasis on DjRw-18 because of the higher amount of butter clam shells fitting the study's criteria for analysis (*see section 4.2.*).

[6] Clark (2011) argued that Northwest Coast archaeology should use 'communities' as a better site classification unit than separating nearby sites that would have likely made-up areas used during the same period into individual 'villages' and nearby 'camps'.

Unfortunately, DjRw-18 has not yet been dated. There are however dates attributed to DkRw-22 with an initial date of cal. 510-330 BP (2-sigma) and terminal date of cal. 280-0 BP (2-sigma). These dates cannot directly be linked to the activities at DjRw-18, and dating this site will be helpful in the future to confirm or discuss the possibility of sites in the Storm Bay acting as a 'community'.

DkRw-22, located near the mouth of the bay, was first interpreted as a single- or several-family base camp with surface evidence of 3-4 house depressions during auger test surveying (Letham et al. 2015). However, later excavations on a corner of a possible house structure casted doubts on there actually having been house structures at DkRw-22 (Letham et al. 2015). Levels of shell fragmentation in the excavated portion of the site suggested that it was subjected to increased trampling resulting from intensive occupation (Letham 2011).

Letham (2014) who used fish remain densities from auger tests to classify sites similarly to Cannon (2000a), saw that DkRw-22 had relatively low fish yields for a formal camp site, with no herring remains identified during excavations, only a few during auger test analysis, and a relatively even split between mammal and salmon remains found during excavation based on NISP (Letham 2011; Letham et al. 2015; *see Table 2.5.*). The lack of herring remains suggested that late winter to early spring was not the main season of occupation, when herring was most abundant. When discussing the local availability of salmon, a current communication with a Storm Bay resident mentioned that, a small Coho salmon run passes through the Bay every October. If this salmon run was active 500 years ago, this might point to a possible occupation in the autumn.

The location of excavations and auger tests at DkRw-22, while being within the shell boundary of the site, was not in shell midden but an area of the site that contained shellfish remains (*for details on content of excavated layers, see Table 2.6.*). For this reason, relatively fewer shell remains were found in these deposits when compared to other sites discussed in this thesis where auger tests were taken in shell midden deposits (i.e., AT 2010-002 at DkRw-26). Furthermore, DkRw-22 provided even fewer butter clam remains that fit the criteria for seasonality and harvesting intensity analyses because of the high rates of shell fragmentation. Excavation at DkRw-22 occurred in 2012 and consisted of six clustered units near the auger test performed at the site in 2010. Since the excavations took place on the corner of a perceived house depression identified during the surveying of the site, the excavations also did not yield many shells useful for this study due to the high degree of fragmentation.

DjRw-18, which was also classified as a large formal camp, did not have apparent structures, but had a large shell midden which led Letham to identify it more specifically as a specialized shellfish harvesting and processing site (Letham 2011; *see* Table 2.4.). Only auger tests were taken at DjRw-18 and therefore it is difficult to assess whether the portions of the site investigated should be considered shell midden or shell-bearing deposit. However, auger tests at DjRw-18 contained the highest densities of cockle compared to all the surveyed sites in the SIS, and clams dominated the faunal assemblage further suggesting a shellfish processing purpose. There was also much less shell fragmentation than DkRw-22 suggesting that they may be better described as shell midden deposits. DjRw-18 also had high concentrations of salmon with the third highest frequency of salmon remains of all auger tests conducted in the SIS by Letham in 2009-

2010 (*for contents of auger test levels, see Table 2.5.*). Accordingly, this suggested that the area was occupation during the autumn. There are also few remains of herring which suggested a spring occupation as well though maybe not as intensive. While there are some indicators of summer, spring and autumn occupations of these two sites, Letham's (2014) faunal analyses did not suggest a mid-winter occupation.

2.2.3.3. Tzoonie Narrows (DkRw-26)

Though Kennedy and Bouchard and earlier ethnographers stated that the main tuwanek village was situated at the mouth of Narrows Inlet (Merchant 2001a:7), this site has never been archaeologically recorded or found (Letham 2011:191). Instead, Letham's Narrows Inlet survey in 2009 and 2010 suggested that village sites may have preferentially been placed on the northern shore and near the narrowing of Narrows Inlet to surveil productive beaches further down on the opposite side of the inlet. Such is the case for the seasonal inlet village, DkRw-26. It is the largest site in Narrows Inlet with an approximate size of 1500 m^2 hosting seven possible house platforms and large shell middens dated from 930 to 540 cal. BP (2-sigma). Along with DkRw-22, it was first surveyed in 2010 and excavated on a small scale in 2012 by sARP. During surveying, the team also took three auger tests, AT 2010-001, AT 2010-002 and AT 2010-003 (Figure 2.2.; Letham 2014)[7].

AT 2010-001 was situated near the front of the site on-top of a possible house

[7] AT 2010-003 was never analysed by Letham and was therefore not used in this study.

Table 2.4. Descriptions of site types based on Letham's (2014) criteria for sites in the SIS.

Site Type	Classifying Characteristics
Village	Very large size
	Multiple house platforms/depressions
	Differential purpose areas
	Higher shell fragmentation rate
	Higher faunal remain density
	Associated modified beach features (e.g. canoe skids, fish traps)
Seasonal Inlet Village	Large size (if not wide along the coast, extends up the slope)
	Multiple house platforms/depressions
	Differential purpose areas
	Shell midden extends at the back of site
	Higher shell fragmentation rate
	Higher faunal remain density
	Associated modified beach features (e.g. canoe skids, fish traps)
Large Formal Camp	Large-medium size (located on wider and flatter benches, landform is Located on wide and flat landform (can accommodate at least 1 house)
	Associated modified beach features
	Dense shell midden at the front of the site
	Fairly high levels of shell fragmentation from trampling
	Fairly high density of faunal remains
Large Formal Camp with specialized shellfish and fish processing purpose	Large-medium size
	Located on wide and flat landform (can accommodate at least 1 house)
	Often with associated modified beach features
	Dense shell midden at the front of the site
	Low fragmentation rates
	High shell density
	High fish remain density

Table 2.5. Summary of DkRw-22 and DjRw-18 auger test (AT) contents

DkRw-22 Auger Test 2010-017	DjRw-18 Auger Test 2010-014	Auger Test 2010-016
On top of a possible house terrace, maybe cleared of refuse	Whole clam shells eroding from bank in front of site which was likely a refuse area	Top of high beach at South end of site
Shell is only 20% of weight, excluding rocks	Low area at North end of site	Shallow positive auger test (53cm)
High fragmentation, 86% of shells <4mm	Fragmentation decreases with depth	40% shell component from top 21cm
Top layer had high density of sand-dwelling mollusks	Above 73cm, 30% of shells are >4mm	Decreases to 5% over subsequent 30cm
38% faunal bones are mammal	Below 73cm, 60% of shells are >4mm	Almost all shells are butter clam or horse clam
Faunal remains are mostly fish	25% of >4mm shells are cockle	Trace amount of cockle
No salmon remains	Trace amount of littleneck	Trace amount of littleneck
Low herring density	Lowest density of vertebrate remains	Moderate density of herring
>121cm Sterile soil	No herring or salmon	3rd highest density of salmon remains of all 2010 ATs

platform, and is therefore interpreted as a shell-bearing site since shell middens are often found outside houses or at the front or rear of settlements. The contents of the test were pre-dominantly shell (approximately 72% of total weight without rocks). This level of density was maintained all the way down suggesting no change in shellfish deposition or harvesting through time (Letham 2011:117), however fragmentation increased with depth. On the other hand, the density of mussels also increased with depth along with the higher shell fragmentation. Mussels, which are known to be more friable than other

Table 2.6. Stratigraphic summary of unit D at DkRw-22. Layers are a mix of shell-bearing and shell midden deposits, and are well delineated. Layers alternate between different levels of fragmentation and species.

Layers	Descriptions
Layer A	Humic layer
Layer B	Mixing of humic to cultural layer, FCR, flecks of shell, and few vertebrate remains
Layer C	Sterile soil
Layer D	Barnacle and mussel fragments, some whole clam shell fragments
Layer E	Small shellfish fragments
Layer F	Crushed mussel shells
Layer G	Lots of whole and large fragments of clam shells
Layer H	Burnt crushed mussel shells
Layer J	Typical shell midden content, whole to crushed clam shells
Layer K	Whole and crushed shell
Layer L	Crushed shell
Layer M	Crushed burnt mussel shell
Layer N and P	Sterile soil
Layer O	No shell and a few pieces of faunal bone

bivalve species (Muckle 1994), may be responsible for the higher degree of fragmentation in the lower layers which suggests that mussels may have been the preferred species earlier in the occupation of the site. Furthermore, the ratio of littlenecks to general clams (which included horse and butter clams, but mostly butter clams) shifted from 1:1 to 1:4 in the last 35 cm of the test (Letham 2011:117), maybe as a result of change in ecology, harvesting preference, or species switching as a resource conservation method. This auger test had the second highest densities of herring and salmon remains, which further implied that this was indeed a village site. The high yields of herring and salmon suggested that the site had been occupied in the spring since herring would have been most available during this time and salmon may indicate autumn occupation with salmon being caught coming up or down through Tzoonie Narrows or brought in from other locations in the inlet (Letham 2011:118). Salmon densities were however not high enough to be identified as a winter village, where consumption and deposition of dried salmon would have been heightened (Letham 2014).

AT 2010-002 is situated at the back of the site in a shell midden. The test was also pre-dominantly shell with a higher density (60-80%) than AT 2010-001 between 21-60 cm below the surface. The overlaying and foundational layers of the test had densities of around 20% shell, suggesting that the middle of the deposit was deposited when the site was maybe more populated or that this portion of the site was preferentially used as a shellfish midden during the time of deposition. Further, the fragmentation level of this auger test was the 2nd lowest of all tests analyzed by Letham, with 68% of the shell weight being from shells larger than 4mm, predominantly of horse and butter clams, further implying its purpose as a shell midden. This context was very useful for this study since >90% of the auger test material that was larger than 4mm was classified as butter clam.

The contrast between the two auger tests at DkRw-26 show how site-bearing deposits and shell midden deposits should not be treated normatively (Letham 2011; Claassen 1991a), and warns that butter clam remains from both contexts may reflect different activities and deposition processes.

Excavations at DkRw-26 were done on a small scale with only one 1m x 1m unit for this relatively large site very near to AT 2010-001. The shells analyzed in this thesis come from layers B, C, D, and E (*for summary of contents, see Table 2.7.*).

Preliminary seasonality interpretations from the vertebrate faunal data of the site suggested predominant spring occupation with possible occupation going through to the autumn.

2.3. Summary of previous seasonality and shellfish harvesting interpretations

The seasonality interpretations for the three occupation communities (i.e., Porpoise Bay, Storm Bay, and Tzoonie Narrows) were supported by faunal and anecdotal evidence. They all uphold the ethnographically recorded 'seasonal round' settlement strategy where ancestral shíshálh would have lived in the SIS from the spring to the autumn and returned up the inlet to Pender Harbour village site, traditionally known as *Kalpilin*, for the winter months (Figure 2.1.). These seasonality interpretations however, have not been able to eliminate or account for a winter occupation of Storm Bay or Tzoonie Narrows, and instead rely on the ethnographic record to support that herring found at these sites would have been collected in the spring and not so much in the late-winter. Furthermore, no robust indicators for summer occupation were ever discussed in previous archaeological work, and therefore cannot be eliminated or accounted for at any of the sites. Furthermore, since butter clams are not limited as seasonal resources, their presence was not able to show the seasonality of their harvest, since they are available year-round. As for the information on the intensity of shellfish harvesting, there is currently evidence of changing shellfish harvesting strategies but no clear indication of how intense butter clam harvesting would have been in the past.

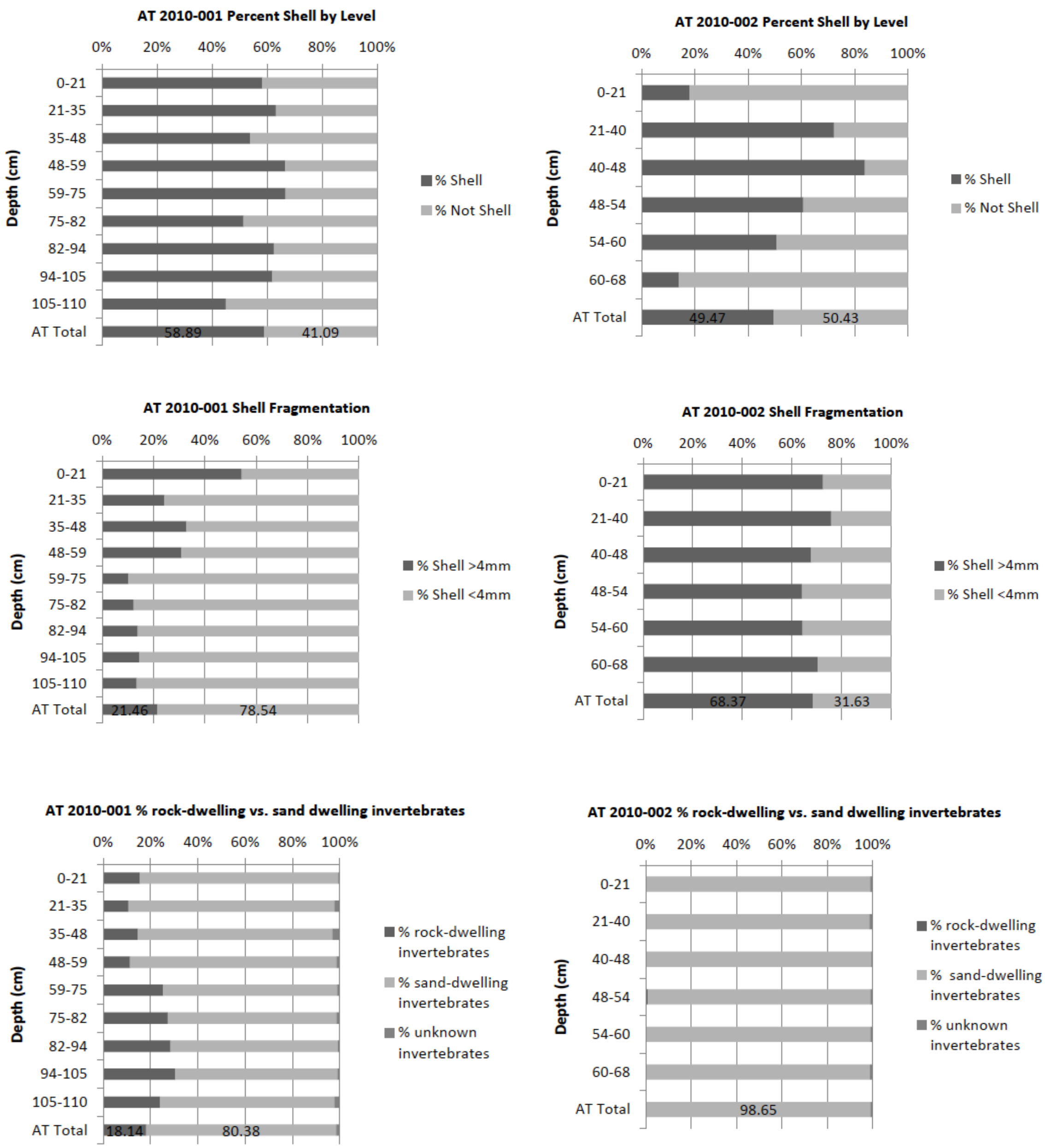


Figure 2.2. *DkRw-26 auger test level constituents from Letham (2011).*

Table 2.7. Description of DkRw-26 excavated layers. Layers here can be described as shell-bearing deposits, since they contain a roasting feature (layers B-C), and different densities of fish and shellfish species. Layer D shows increasing shell density with depth, suggesting different shellfish deposition and/or consumption patterns. Layers E and F contain fewer faunal remains suggesting less intense use of this area during early occupation of the site.

Layers	Descriptions
Layer A	Humic layer, 2-3 cm thick
Layer B	30-40 cm thick; fragmented littleneck, horse/butter clams; abundant fish remains (notably herring); ashy circular feature was found between layer B and C, with crushed and burnt mussel shell, likely a roasting feature
Layer C	25-35 cm thick; large and finely crushed shell material; fish density increased half way through the layer and decreased towards the bottom of the layer
Layer D	28-45 cm thick, compact layer with less shell than C; shell content increases with depth, and included whole butter clam shells; dense in littleneck, horse/butter clams and whelk; not as many vertebrate faunal remains as layer C but augments near bottom of layer
Layer E	Some shell, but less than Layer D; fewer vertebrate faunal remains were found and were dominated by mammal remains
Layer F	Sterile soil

CHAPTER 3

CLAMMING TASKSCAPES IN FLUID LANDSCAPES: THEORETICAL APPROACHES TO UNDERSTANDING SHELLFISH HARVESTING

3.1. Theoretical framework and considerations

Interpretations of seasonal settlement and butter clam harvesting in this thesis were informed through a combination of landscape/taskscape (Anschuetz et al. 1999; Ingold 2000), resource conservation (Smith and Wishnie 2000), and historical ecology theories (Crumley 1994). Previously, food procurement-settlement studies on the Pacific Northwest Coast principally examined the relationship between the geographic distribution of sites and accessibility to food resources, such as spawning locations of anadromous fish (Acheson 1998; Beattie 1995; Cranny 1975; Hobbler 1983; Maschner 1997; Maschner and Stein 1995; McLay 1999; Thompson 1978). Other studies have recognized that several other factors influence settlement choice and sought to study settlement patterns with the perspective that multiple variables would be involved in the choice to set up camp or settle in certain locations (e.g., Letham 2014; Tobiazs 2015). The studies seeking to understand how and why site types were distributed in a certain way often treated the landscape as a principal factor dictating people's settlement choices. On the other hand, the decision to settle in a place may have been affected by other factors. For instance, Brewster and Martindale (2011) investigated sites on the Dundas Islands in northern BC, and asked how and why the Tsimshian maintained island villages given that resources ethnographically important to them were only marginally accessible in this island context. The relatively low densities of fish remains in comparison to densities found on the mainland suggested that Dundas Island populations may have relied more heavily on shellfish and sea mammals. They further argued that shellfish resources could not have supported long-term dense occupations because of their susceptibility to overharvest. Accordingly, the type and fragmentation of fish bones found in shell middens suggested instead that fish remains were likely archaeologically underrepresented since fish could have been processed near the Skeena River near the mainland and brought to the Dundas Islands for consumption. They concluded that it was not strictly resources that brought the Tsimshian to the Dundas Islands, but simply population expansion from the mainland.

Similarly, Mackie (2003) examined whether the size of 238 midden zones on western Vancouver Island were connected to the distances between sites. The data did not support a clear relationship between midden sizes and distance between large midden sites, suggesting that their locations were perhaps a result of behavior resembling Bourdieu's *habitus*, where people's decision to establish larger sites at a given location might have been more a function of which location felt right rather than a function of relative closeness to other sites (2003:280). My approach to looking at the landscape was inspired by these works which presented the landscape as less of an imposing factor and more of a consideration which people assessed actively while living in a region.

3.2. Clamming taskscapes

Landscape theory considers how individuals physically modified and conceptually thought about their landscape (Anschuetz et al. 1999; Ingold 2000). It explores lived experiences within a place and how people would have thought about their space not only how they would have physically transformed it. By using this theoretical framework, the landscape then becomes an active and interactive space where certain activities occurred in some places and not others. In a coastal setting such as the SIS, the landscape should also incorporate the seascape, and should conceptually become more fluid as more of it becomes increasingly accessible by boat travel (Ames 2002). For example, boat travel may conceptually mold villages and camp sites into one active space. In this way, contemporaneous nearby sites occupied by the same people may be more aptly described as communities. However, this should not be confused with the homogenization of a landscape, since different activities would have occurred in different locations. For instance, ethnographic shíshálh villages were described as having held large multi-lineage feasting activities in the winter, and camps and inlet villages in the SIS, where fish traps were found, would have been active fishing areas during their occupation. Ingold (2000) tackled this idea with his concept of the taskscape, which he explained as “a pattern of activities collapsed into an array of features” (2000:198). If we consider a shellfish harvesting taskscape, shell middens become the archaeological remnants of this task, though they can also be remnants of other tasks such as resource management, transportation to processing area, shelling, drying, roasting, consumption, shell-reuse and deposition. This string of tasks performed in a landscape forms a network of taskscapes, which can be investigated through the study of shell midden and shell-bearing deposits. Furthermore, by taking up the concept of taskscapes within a community, different site types and deposits can be compared in order to examine whether different butter clam-related tasks or practices were preferentially conducted in different places and, if so, interpret why.

Furthermore, shellfish-related tasks will preferentially occur at different places in a landscape because some beaches are naturally more successful at producing certain species of shellfish. That is, mixed sediment beaches such as sand and gravel flats are more conducive for clam species, while rocky beaches are not although they can produce large populations of mussel species (Figure 3.1.). Therefore, shell middens containing clams are remnants of harvesting activities that occurred at mixed sediment beaches. We can then take a landscape approach to strive to understand whether people were transporting and processing shellfish further away from the site of deposition or from beaches adjacent to the site.

Figure 3.1. *Mixed sediment beach with a large clam population at the mouth of Narrows Inlet in the SIS, with large boulders that also accommodated small mussel populations.*

In addition, food procurement taskscapes may have a seasonal nature, whether they be natural such as areas near mouths of rivers or inlets that would be very active during the autumn when salmon runs would flow up these bodies of water to spawn, or cultural such as large middens associated with feasting events at large multi-lineage villages in the winter. However, taskscapes may have been and likely were multi-seasonal. When discussing the seasonality of sites, many archaeologists have chosen to take a simplistic approach, where large villages are occupied in the winter, and camps are occupied during the other seasons. For example, I frequently see BC archaeologists referring to large multi-seasonal or year-round villages as 'winter villages' (e.g., Brewster and Martindale 2011; Caldwell 2015; Coupland et al. 1993; 2010; 2012; Letham 2014; McLay 1999). The notion of the 'winter village' comes from the ethnographically described Pacific Northwest Coast generalized 'seasonal round' where peoples were described as occupying large multi-lineage villages in the winter and dispersing into smaller camps in the spring (Fladmark 1975). The seasonal attribution given to these villages (i.e., winter) is reinforced by finding large quantities of salmon remains which are linked to winter consumption of stored foods (Cannon 2000b). However, the winter designation is misleading since people may not have occupied these sites only in the winter, and it may neither indicate principal season of occupation without robust high-resolution seasonal indicators. Accordingly, this approach does not take into consideration the agency people have in their interactions with the landscape and how they would have chosen or altered how they collected their food resources seasonally or otherwise (Smith & Wishnie 2000).

This study challenges the strict nature of the 'seasonal round' with an approach that incorporates individual and group agency and supposes that people may have applied flexible settlement and food procurement strategies.

3.3. Fluid landscapes

Framing the SIS landscape in a way where movement inside it was permitted to be fluid allowed me to interpret how people may have chosen to inhabit it and utilize its resources according to environmental, social, cultural and historical contingencies. This hence freed landforms from being automatically slotted into seasonal boxes, and allowed me to become open to any interpretations that could be supported by the data presented in this thesis. I also recognized that this fluidity was historically, socially and environmentally contingent. For example, according to Letham (2014), Narrows Inlet has occasionally frozen over in recent memory, and this may be a factor in why Narrows Inlet may not have been occupied during the winter. I therefore integrated this information in the interpretation of my results, while also considering that the current environment of Narrows Inlet is likely different than the environment of 930 cal. BP. Consequently, while freeze-over events in Narrows Inlet may have occurred in the past, seasonality results had the potential to highlight environmental variability and human flexibility in settlement patterns. In addition, a historical condition that was considered in my interpretations was that warfare was present in the Salish Sea area between 1600 and 500 cal. BP, and more recently between 160 and 80 BP (ca. AD 1790-1870) (Angelbeck 2007; Angelbeck and Grier 2012), two eras relevant to the occupations of the sites examined in this thesis. Therefore, interpretations were also framed to consider whether or not harvesting and settlement strategies reflected warfare-stress on the shíshálh community during this time.

Pursuing a flexible community type of landscape approach was facilitated by the incorporation of multiple sites spread out in the SIS. This enabled me to examine the sites together to understand regional patterns (e.g., Cannon 2013:21). By looking at contemporary sites, these data can inform our understanding of the variability of settlement patterns and of regional occupation within a set timeframe. Further, by looking at seasonal shellfish harvesting in combination with vertebrate faunal analysis at contemporary sites, we can start forming an understanding of how resources were managed within a community in addition to how variable people's movements and use of sites were in the past.

This multi-site analysis also allowed me to examine temporal changes in settlement and food procurement strategies by specifically investigating whether there were stratigraphic changes in seasonal occupation or butter clam harvesting practices within shell middens and shell-bearing deposits. The porosity and mounded nature of shell middens can create time-averaging (Claassen 1998:86, Bailey 2007:204). Shell middens often represent multiple deposition events, and can create palimpsests of consumption over the duration of a site's occupation. Further, financial budgets often do not allow for both the dating and stable oxygen isotope analyses of every shell analyzed; it is impossible to complete these analyses for every shell in a midden to determine each depositional event. However, examining stratigraphic trends and variability between shell deposits may provide support for variable shellfish-related practices. By analyzing shells from multiple layers and contexts within a site we can get a sense of seasonal patterns and shellfish harvesting strategies, as well as get insights on how parts of a site may have been used differently. For instance, we can examine whether certain parts of a site were frequented more, or less, to harvest shellfish, or maybe more accurately to process it, because where people deposit shellfish remains is most often related to the where the shellfish were shelled.

Faunal remains are critical for this study to obtain a more encompassing understanding of consumption practices and differential economic importance of foods between sites, or changing importance within sites.

3.4. Shellfish resource management and ecological feedbacks

Historical ecology theory is also linked to landscape theory as it speaks to the reciprocal relationships between humans and the environment manifested within a landscape (Crumley 1994). It opens up discussion about how the environment (e.g., seasonal changes, distribution of premium shellfish harvesting beaches) were factors in the landscape management process while also affirming that the people making these decisions may have had cultural or social motivations for their shellfish harvesting decisions (e.g., feeding large groups of people, harvesting for long-term storage, clam bed ownership). Therefore, seasonality may indicate a pattern of preference influenced by natural and cultural factors but may also reflect flexibility.

Historical ecology is also directly applicable to the sclerochronological study of shellfish since $\delta^{18}O_{shell}$ and shell growth are significantly influenced by environmental factors, which in turn may affect shíshálh decisions to harvest shellfish (e.g., employ resource management strategies). Historical ecology is therefore another way to conceptualize how the environment and human activities create feedbacks, which allow archaeologists to interpret the relationship between them through the examination of butter clam remains in shíshálh shell-bearing and shell midden deposits.

The flexible community approach to landscape, which also elevates the relationship between peoples and their environments, enabled me to discuss the possibility of patch switching, beach cycling, or species switching activities negotiated between different shellfish beaches (Smith and Wishnie 2000:512). This involves conscious management choices in response to the environment, its parameters, and social circumstances (e.g., clam bed ownership). This approach also recognizes the knowledge people had about their ecological relationships with their food resources. Smith and Wishnie (2000) argued that resource conservation among hunter-gatherers was rare but possible in situations where access to resources was controlled. Accordingly, clam beds have been shown to have been owned hereditarily by certain groups on the Pacific Northwest Coast (Moss 1993). Therefore, resource conservation may have been an integrated practice in the shíshálh food economy as a measure taken to protect and capitalize on shellfish resources.

In terms of shellfish harvesting, there are archaeological and ethnographic examples of people purposefully modifying their landscape and incorporating strategies in order to maintain shellfish beds, such as clam gardens (Groesbeck et al. 2014; Williams 2006)[8]. There are also examples of people either harvesting and processing

[8] There is limited ethnographic evidence of “clam gardens” and their antiquity is still poorly defined. As such, more research in this area is required to better understand these features in the context of resource management.

shellfish on the bank adjacent to the harvesting beach as well as residential sites. For example, Bird and Bliege Bird (1997) discussed contemporary shellfish harvesting practices among the Meriam of the Torres Islands in Australia, and demonstrated how large clams were often processed near procurement sites instead of residential places because of the higher energy it would take to transport them back to central places, but also showed that sometimes a mix of processed and unprocessed shell material were brought back to sites. Similarly, Burchell et al. (2013b) suggested that butter clams on the central coast were collected and processed at a higher intensity at camp sites than village sites as a way to conserve shellfish resources near villages. On the other hand, according to central foraging models, processing shellfish remains at a residential site instead of a procurement site is more likely where mobility is high (Bettinger et al. 1997:897). Following this logic, shellfish resources in shíshálh lands, where mobility is facilitated by boat travel, may have been more frequently processed at residential sites. In fact, many butter clam remains are found in residential sites which are not adjacent to butter clam-suitable beaches (Letham 2014). This further strengthens the possibility of multiple shellfishing beaches being used, akin to a network of shellfish procurement sites. Accordingly, through shell growth stage analysis we can further our understanding of site use by examining differential butter clam harvesting rates at different sites. Further, by learning about shellfish harvesting strategies, such as the intensity of harvest, we can examine if resource management occurred, and start to ask how these processes were negotiated in accordance to social, cultural and historical circumstances. With the integration of faunal (terrestrial, marine and shellfish) analysis, we then can start to understand, whether management strategies were utilized because of the importance of that resource or historically-specific situations.

Butter clam shells from shell deposits are the ideal archaeological material to examine the relationship between the shíshálh people and their landscape because of their ability to record cultural practices and environmental conditions.

3.5. Butter clams, *Saxidomus gigantea*: Ecology

According to Thompson (1913:38), the butter clam is one of the "most delicious" of the inland species but is surpassed by species that live on the outer coast. The butter clam, *Saxidomous gigantea*, is one of the two dominating clam species in BC (Thompson 1913:38), and can be found from the Aleutian Islands in Alaska to northern California (Quayle and Bourne 1972:27). Its success as a species is in great part related to its ability to thrive in a variety of environments from cold temperatures (temperature range of -1 to +26 °C; Bernard 1983) to low salinity waters (salinity range of 18 to 32 PSU; Gillikin et al. 2005b). Its shell is easily identifiable by its concentric ridges and absence of radial ridges such as those found on the common littleneck clam (Figure 3.2.). This relatively large clam inhabits the middle (Thompson 1913:38) to lower parts of the intertidal zone in gravel, sand, mud, and mixed substrate beaches, and can burrow up to 30.5 cm below the beach surface (Quayle and Bourne 1972:27). While their geographic occurrence is wide-spread, some beaches have a productive advantage, specifically those where gravel bars occur at the mouth of rivers (e.g., the beach adjacent to DjRw-18) (Quayle and Bourne 1972). However, productivity is also dependent on the size of clam beds, where smaller areas are more susceptible to be dug out while larger ones are less so (Quayle and

Bourne 1972:35). Very rocky ground will further hinder the productivity of clam beds (Quayle and Bourne 1972:35), as well as high anthropomorphic disturbances, irregular food availability, and greater fluctuations in salinity (Goong and Chew 2001). Its growth reduces with age, which can reach 20 years or more (Quayle and Bourne 1972:8).

Figure 3.2. *Butter clam shell, Saxidomus gigantea.*

3.5.1. *Saxidomus gigantea* growth

Butter clam, and other aquatic accretionary creatures, grow by accreting calcium carbonate ($CaCO_3$). Their shells grow by depositing aragonite (a crystal form of $CaCO_3$) at the ventral margin, when they are submerged under water, where the temperature and salinity signals of local seawater are recorded in their shell structure (Gillikin et al. 2005a). Growth is rapid in the spring and summer when there is an abundant food supply and temperatures are preferable, and decreases in the cold season forming annual 'checks' on the surface of the shell (Quayle and Bourne 1972). However, checks are also produced in the summer, therefore external shell checks are not annually, sub-annually or seasonally distinguishable.

Furthermore, butter clam shells form internal periodic growth features (i.e., growth bands/lines and growth increments) that can sometimes be seen with the naked eye (macro-growth lines) and/or microscopically (micro-growth lines) (Jones 1983). The study of these periodic growth features is called sclerochronology.

3.6. Sclerochronology history

Similar to dendrochronology, which involves counting growth rings in tree, sclerochronology is the study of physical and chemical variations in accretionary hard tissues (Gröcke and Gilikin 2008). The term was first coined by Buddemeire et al. (1974) who applied radiographic methods to investigate whether the physical examination of growth variation in corals could be used as an environmental proxy. Physical sclerochronological methods in archaeology, however, precede the coining of the term.

3.6.1. Physical sclerochronological methods in archaeology

The uses of physical growth features in molluscan shells for the purpose of determining archaeological seasonality can be traced back to studies coming out of New Zealand (Shawcross 1967; Saxon and Higham 1969) and California (Weide 1969) in the late 1960's. In the 1970's British Columbian archaeologists introduced similar methods to also determine seasonality by looking at internal and external growth features (Ham and Irvine 1975; Keen 1979; Monks 1977). While these early studies recognized the relationship between growth and the environment, they failed to consider the many factors that influence molluscan growth beyond seasonal variability. For example, Keen (1979) and Monks (1977) measured percentage of growth from the last deposited macro-growth line closest to the ventral margin in butter clam shells. Spring-collected shells were determined by having deposited 0 to 25% growth since the last macro-growth line, 25 to 50% for summer-collected shells, 50 to 75% for autumn-collected shells, and 75 to 100% for winter-collected shells. However, molluscan growth is controlled by a web of factors, notably ontogeny, food supply, stress events such as storms, tides, and seawater temperature and salinity (Clark 1974). As previously discussed in the introduction, macro-growth lines are not deposited equidistantly as they start to cluster when growth rate slows with ontogeny. In addition, Deith (1983) examined tidal lines and increments in the edible cockle species, *Cerastoderma edule L.* Specifically, Deith looked at the timing of the growth onset and cessation, and variation between different years in modern live-collected specimens. By comparing two studies that used different species he concluded that the two species varied a lot in the consistency of how they laid down growth lines as well as in the sharpness and clarity of lines. Therefore, an understanding of shellfish growth for the specific shellfish species of interest needs to be considered and integrated in physical sclerochronological studies.

3.6.1.1. Periodicity of growth: Considerations for *Saxidomus gigantea* sclerochronology

While growth lines have been shown to be an inadequate method from which to determine seasonality (*see section 1.4.2.*), they can be used to classify butter clam shells into different growth stages. This method does not aim to calculate the exact age of specimens from growth line deposition similar to dendrochronology because, as previously stated, macro-growth lines are not deposited with the robust periodicity required to comply with this aim. Rather, the distribution of growth lines observable in cross-sections of shells can provide us with a relative age (i.e., older or younger specimens). Since, butter clams' growth rates slow with ontogeny, the deposition of growth lines will start to bunch up near the ventral margin in older specimens.

Cannon and Burchell (2009) developed a method examining macro-growth line distributions in butter clam shells where they classified butter clams into senile, mature, and juvenile growth stages. The ratio of senile to mature archaeological shells from shell midden sites in central BC allowed them to determine relative intensity of shellfish harvesting between different site types.

To determine relative harvest intensity, shells are cut along the axis of growth to expose internal growth features, resulting shell sections are ground and polished to observe macro-growth lines, and are classified into growth stages (*for detailed methodological steps, see section 4.5.*). If shell growth lines were evenly distributed and did not cluster at the ventral margin, the specimen would be classified into a younger phase of growth at time of death (i.e., mature or juvenile), and if the lines were tightly packed, especially at the ventral margin, the specimen was classified into an older phase of growth (i.e., senile) (Cannon et al. 2008:17; Cannon and Burchell 2009; Claassen 1998:25-26). It is important to look at internal macro-growth lines rather than external growth lines on the surface of shells otherwise the age of younger clams will be overestimated and the age of older clams will be underestimated (Jones et al. 1978), ultimately resulting in an inaccurate profile of the growth patterns.

As previously stated, internal macro-growth lines are not always deposited with a robust periodicity, however Claassen (1993) and Clark (1974) found that some growth-lines in *Mercenaria mercenaria* from North Atlantic regions have some periodicity such as spring and winter lines, therefore evenly spaced growth line clusters could be used to determine if a shell fragment was in a mature stage growth. Similarly, butter clams from the SIS, deposited macro-growth lines multiple times during the year, but were observed to be periodically spaced out in young specimens (Leclerc et al. 2017). Therefore, butter clam shells from the SIS were able to be classified into senile, mature, and juvenile stages of growth. However, it is crucial that only fragments with preserved ventral margins are used in these analyses as increasing clustering of macro-growth lines near the ventral margin, a diagnostic feature in senile butter clams, is required to determine whether the fragment is from a senile, mature, or juvenile specimen. Therefore, by looking at the overall pattern of growth (Claassen 1993), some shell species, including butter clams can be placed into different growth stage categories and aid in the interpretation of the intensity of shellfish harvesting (Figure 3.3.; *for details on the relationship between growth stages and harvesting rates, see section 1.5.*). In addition, chemical sclerochronological studies should also incorporate growth understandings.

Figure 3.3. *Left to right: Mature and senile Saxidomus gigantea shell fragments from the Namu region on the central BC coast (Cannon and Burchell 2009).*

3.6.2. Stable oxygen isotope analysis ($\delta^{18}O_{shell}$) to determine archaeological seasonality

The chemical study of molluscs started with Urey (1947), who first hypothesized that there was a relationship between past sea surface temperature (PSST) and the isotopic composition of $CaCO_3$ mollusc fossils. From this hypothesis, Epstein et al. (1953) found a strong relationship between $\delta^{18}O_{shell}$ and $\delta^{18}O_{seawater}$. These early chemical studies showed that shells, as they grew, integrated various ratios of oxygen-18 to oxygen-16 into their structure. During $\delta^{18}O_{shell}$ analysis this ratio is expressed in relation to Vienna Pee Dee Belemnite (VPDB), the international carbonate standard, and is presented in per mille values (‰) using the formula:

$$\delta^{18}O_{shell} = \left[\frac{^{18}O/^{16}O_{sample}}{^{18}O/^{16}O_{standard}} - 1\right] x\ 1000$$

The $\delta^{18}O$ ratio in mollusk shells has been shown to be controlled in great part by surrounding seawater temperature and salinity (Epstein et al. 1953), and latitude (Hallmann et al. 2009). The relationship between shell growth and the integration of oxygen isotopes from surrounding seawater is well established and continues to be refined especially in the field of paleoclimatology.

Shackleton (1969) was the first to discuss the archaeological potential of shellfish isotopic chemistry to determine seasonality of sites. However, his criteria for $\delta^{18}O_{shell}$ analysis did not take into consideration variability in shell growth rate during the year and life of mollusk specimens. Further, Shackleton placed principal emphasis on the relationship between $\delta^{18}O_{shell}$ and temperature and little emphasis on salinity and latitudinal effects.

3.6.2.1. Salinity, temperature and latitude effects on $\delta^{18}O_{shell}$ and *Saxidomus gigantea* growth on the Pacific Northwest Coast

Seawater temperature and salinity have an inverse relationship: an increase in temperature causes $\delta^{18}O_{shell}$ ratios to become more negative while an increase in salinity causes them to become more positive. This is why in the spring and summer we see $\delta^{18}O_{shell}$ values becoming more negative for two different reasons. In the spring, freshwater feeds into the water system due to ice and snow melt which makes the water less saline and thus more isotopically depleted (i.e., negative). This compounds with an increase in water temperatures which also makes the values more negative. On the other hand, in the summer water is not receiving as much freshwater but is getting warmer and thus $\delta^{18}O_{shell}$ values also become more negative. Therefore, careful considerations of salinity effects are important to distinguish spring from summer $\delta^{18}O$ signals (Figure 3.4.).

In addition, the most positive $\delta^{18}O_{shell}$ values vary with latitude: $\delta^{18}O$ values from Alaska are more positive than values from southern BC (Hallmann et al. 2009). Calibration studies that aimed to improve $\delta^{18}O_{shell}$-based paleo-temperature models with lunar daily growth increments in the same regions also found that growth increments were narrowest during cold temperatures and widest during warm temperatures. They also found longer growth cessation periods in northern latitudes than in southern regions. LDGI results from Pender Island, off the coast of eastern Vancouver Island, showed that almost a full year of growth was accounted for with much shorter growth cessation periods. Accordingly, for the archaeological purpose of determining seasonality, a high spatial-resolution understanding of the relationships between salinity/temperature/latitude

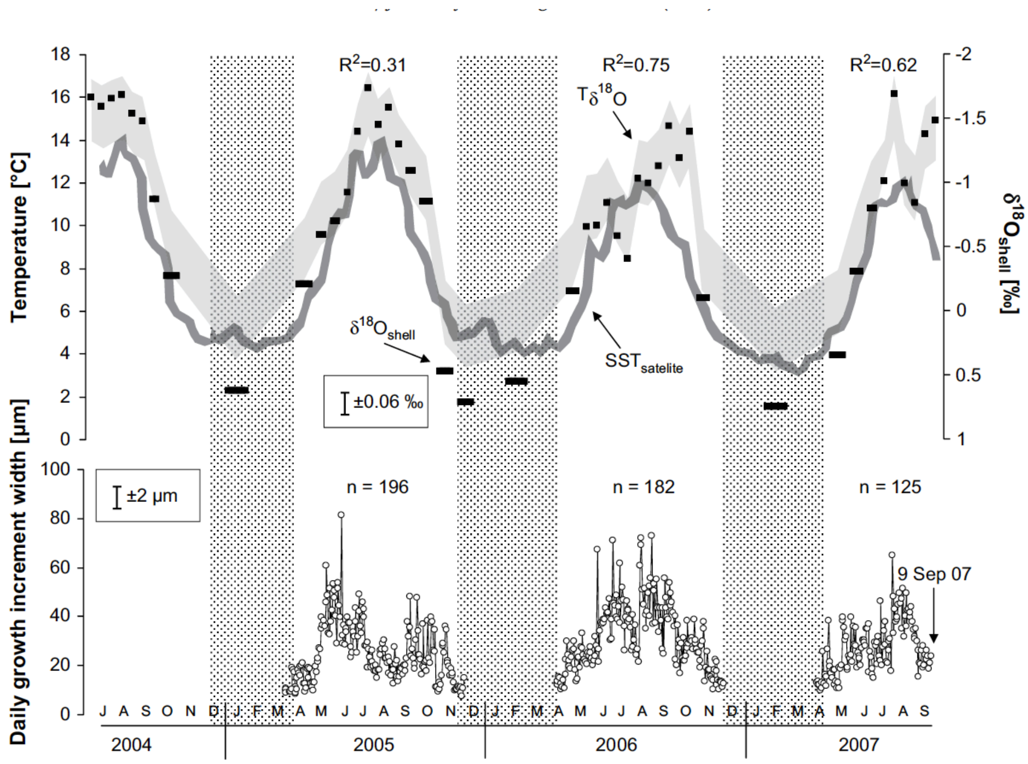


Figure 3.4. *Figure reproduced from Hallmann et al. (2009:2358): Oxygen isotope and sclerochronological data are shown for the S. gigantea specimen GI1-LTI0907-A2L from 2004 to 2007 which was collected alive on 9 September 2007 from Little Takli Island, Alaska. Upper panel: Shell oxygen isotope record ($\delta^{18}O_{shell}$, black bars, inverted scale) with an error bar of 0.06‰ which refers to the precision error of the mass spectrometer. Reconstructed temperatures ($T_{\delta 18O}$, light grey curve) include the error of the Böhm et al. (2000) paleotemperature equation and the variability in the oxygen isotopy of the water. Weekly sea surface temperature data ($SST_{satellite}$, dark grey curve) were used from www.cdc.noaa.gov. R2 represents the variation of the daily growth increment width explained by the sea surface temperature data. Lower panel: Daily growth increment width time series with a measurement error of approximately 2 mm. n=number of increments per year. The annual winter growth lines are confirmed by the oxygen isotope data. The most positive oxygen isotope values were measured at the growth lines, i.e., shell portions that formed during winter. The most negative oxygen isotope values were measured between two consecutive growth lines which correspond to highest temperatures during summer. Shaded bars represent annual winter growth lines. In 2006, a well-defined $\delta^{18}O_{shell}$ peak was produced in the spring and the summer.*

and $\delta^{18}O_{shell}$ played an important role in choosing a sampling procedure, especially in the SIS where differentiating $\delta^{18}O_{shell}$ signals from spring freshwater and warm summer was critical.

3.6.2.2. Coarse and high-resolution $\delta^{18}O_{shell}$ analyses in archaeology

While $\delta^{18}O$ analysis of shellfish remains has become increasingly enticing to archaeologists who want to investigate seasonality, the associated expense has made the high-resolution methods required for precise seasonality determinations unattractive for many (Fitzhugh 1995:139). This high cost has resulted in many archaeological $\delta^{18}O$ shellfish studies using coarse sampling methods and analysing fewer samples (e.g., Mannino et al. 2003). This sampling strategy reduces the confidence we can give to the interpretations because low-resolution methods do not allow for the researcher to see the full amplitude of $\delta^{18}O$ values encapsulated in the analysed shell structure, which is required so that influx of freshwater in the spring is not confused with high temperature of summer (Burchell et al. 2013c; *see above section 3.2.2.1.*).

An example of a coarse sampling method is Jones et al. (2008) who sampled the ventral margin and compared the $\delta^{18}O$ value to samples taken in 2mm increments along the axis of growth. They also drilled the exterior shell surface, which if not done at the proper angle following internal growth increments could lead to greater time averaging. It is important to note that the equal spacing of 2 mm between samples is not representative of equal amounts of time since shellfish do not grow at the same rate throughout the year or throughout their lives. Therefore, there is no guarantee that the full amplitude of

$\delta^{18}O_{shell}$ values will be observed. Similarly, Eerkens et al. (2014) determined seasonality of calcitic *Macoma nasuta* clams from the San Francisco Bay area using a 500µm drill bit to sample in 1mm increments along the exterior concentric shell ridges.

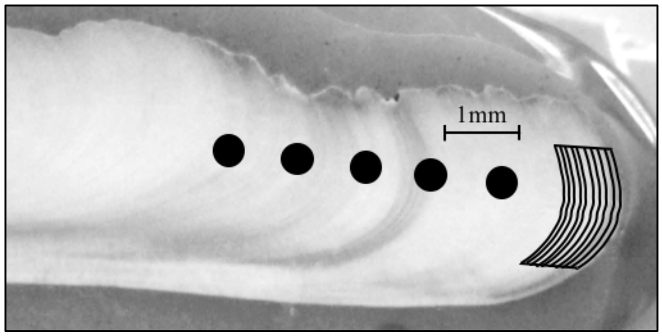


Figure 3.5. *Drilling (black circles) and milling (lines) sampling procedures along a cross section view of a butter clam sample.*

Drilled shell samples can produce lower resolution results than milled samples. A 500µm drill bit will sample shell material representing 500µm of growth. In addition, a drilled sample will have un-sampled space between it and the following sample. When the drilled material is mixed and analysed together, the $\delta^{18}O$ value obtained from that sample will be an average of the incorporated $\delta^{18}O$ during that period of growth (Goodwin et al. 2004). On the other hand, the milling technique can sample shell material at a higher resolution, representing smaller amounts of time, and does so without any gaps between samples (Figure 3.5.). Hence, since space is time in sclerochronology, a 500µm drilled sample will average more time than a 100µm milled sample, also known as time-averaging. For example, if we were to sample a summer-collected butter clam shell for seasonality, a drilled sample near the ventral margin might produce a $\delta^{18}O_{shell}$ value that was more positive than a milled sample since its $\delta^{18}O_{shell}$ values would be an

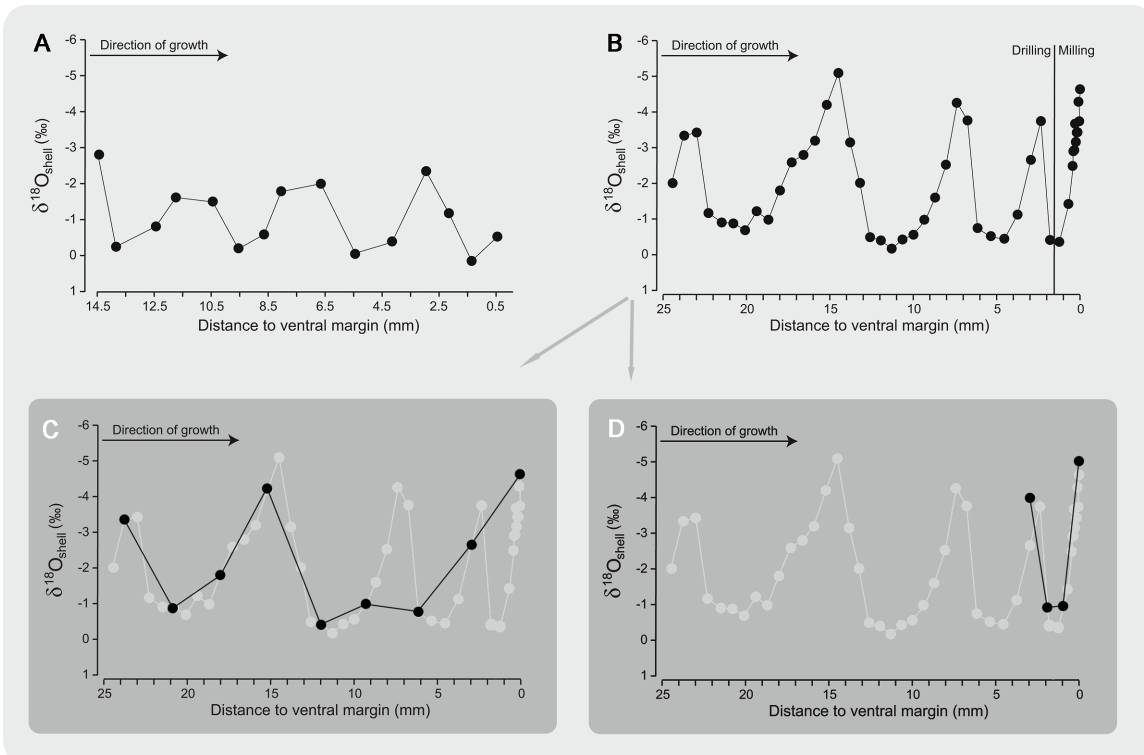


Figure 3.6. *Figure reproduced from West et al. (in press): Collected and modeled $\delta^{18}O$ data from a live-collected S. gigantea from Kakushdish Harbour, British Columbia showing the effects of sampling resolution and implications for interpreting data; A) illustrates sampling using 1 mm spatial increments, most commonly applied in archaeological studies of shell seasonality; B) shows a combination of micro-milling at the ventral margin in 100-micron continuous steps followed by micro-drilling a 0.5 mm increments; C) represents modeled sampling resolution using samples spaced 3mm apart; and D) shows another sampling resolution with samples spaced 1 mm apart (original and modeled data from Burchell et al. Archaeometry 2013 and modeled data based on sampling strategies from Mannino et al. 2007; Jew et al. 2013 (c) and Eerkens et al. 2012 (d))*

average of shell material deposited in the summer, spring, and possibly winter. Accordingly, it could be mistakenly interpreted as a spring-collected shell (Burchell et al. 2013c; see Figure 3.6.).

Furthermore, as butter clams age their growth rate slows whereby they accrete less and less shell material per year. This is in fact what causes the bunching up of macro-growth lines near the ventral margin. Accordingly, the same amount of shell material drilled from a senile shell (e.g., 500 μm), averages more time than a drilled sample from a mature shell. When conducting high-resolution $\delta^{18}O_{shell}$ analysis, younger specimens are typically selected over senile specimens because of their faster growth rate.

It is therefore important to use micro-milling, especially near the ventral margin, which has the most time represented in the case of older individuals and where seasonal fluctuations leading to the time of collection are most useful to determine the season of collection. On the other hand, coarse sampling methods may be useful and efficient for studies attempting to get a lower-resolution seasonal indicators, such as identifying wet versus dry seasons (Kennett and Voorhies 1996).

3.6.3. Previous high-resolution sclerochronological analyses in coastal British Columbia

High-resolution $\delta^{18}O_{shell}$ and growth increment analyses on archaeological butter clams have been conducted in the Dundas Islands and Haida Gwaii, on the northern BC coast, the Namu region on the central coast, and on the southern coast, BC (Burchell et al. 2013a,b; Cannon et al. 2008; Cannon and Burchell 2009; Hallmann et al. 2009; 2011; Schöne et al. 2013)These studies have highlighted the variability in seasonal occupation patterns and butter clam harvesting rates in pre-contact archaeological sites. Results from the Namu region on the central coast suggested that butter clams were collected most often in autumn and spring, though all seasons were represented at most sites (Burchell et al. 2013b). On the northern coast two broad patterns were observed (Burchell et al. 2013a). In the Dundas Islands, clam harvesting occurred year-round, while on the mainland side in the Prince Rupert Harbour area clam harvesting tended to occur in autumn and spring. It was suggested that preferential autumn and spring collection occurred to prepare for winter consumption in the spring and compensate for the depletion of winter-stored foods in the autumn.

As for the intensity of harvest, long-term village sites on the central coast tended to practice less intensive clam harvesting while small camps showed the opposite trend (Cannon et al. 2008; Cannon and Burchell 2009). This suggested that certain resource management precautions may have been taken at village sites. On the northern coast, the mainland sites in the Prince Rupert Harbour area had a very similar pattern as the central coast sites, while all the Dundas Islands sites exhibited intensive clam harvesting practices (Burchell et al. 2013b). It was suggested that this and the year-round collection of butter clams on the Dundas Island could be attributed to less accessibility to salmon on the islands compared to the mainland sites, which would have led to increased reliance on shellfish resources (Brewster and Martindale 2011).

The studies discussed in this section have all followed the same methodological steps. This consistency in methods is rare but important to compare results from different regions and to draw meaningful interpretations from them. Accordingly, the methods and materials used in the analyses presented in this thesis have followed these previously established protocols.

CHAPTER 4

MATERIALS AND METHODS

The shell midden materials and archaeological shells used in this research come from four of the 92 previously archaeologically recorded sites within the SIS. Research materials were gathered from multiple types of archaeological collections: column samples, *in situ* faunal collection, and sorted auger samples. This agglomeration of archaeological materials was utilized to maximize the sample sizes at each site and to account for spatial variability within sites.

For growth increment analysis to interpret harvest pressure, all available criteria-fitting shell fragments recovered from each excavation context from each of the four sites were used. To interpret the stable oxygen isotope data from archaeological shells, live-collected butter clam shells from three locations in the Sechelt Inlet system were collected and analyzed to act as a local baseline to interpret the $\delta^{18}O$ from the thirty archaeological shells analysed in this thesis.

4.1. Live-collection of *Saxidomus gigantea* samples

Live-collected specimens were collected in July 2015 from three locations in the SIS to access the location variability in regional $\delta^{18}O_{shell}$ values: Highland Point, Storm Bay and Salmon Inlet (Figure 4.1.). Butter clams were collected at low tide where *in situ* temperature and salinity measurements were obtained with an ©Omega CDH45 Salinity Meter able to calculate 0-10% salinity (Figure 4.2.). Temperature and salinity was measured in clear water at a depth of ~ 70 cm below surface. Measurements are reported in degrees Celsius (°C) and practical salinity unit (PSU). Butter clam specimens were randomly collected at each location for approximately 20 minutes and were killed within 12 hours of collection. Clam tissue was cut away from the mantle and removed from shells by inserting a knife between the valves. Emptied shells were then rinsed and let to sun dry before they were bagged and shipped to Memorial University of Newfoundland for processing. One live-collected specimen from each collection site was analyzed for $\delta^{18}O_{shell}$ analysis (n=3), to determine whether the butter clams from the SIS undergo similar environmental forcing on $\delta^{18}O$ values as other places previously investigated on the outer coast.

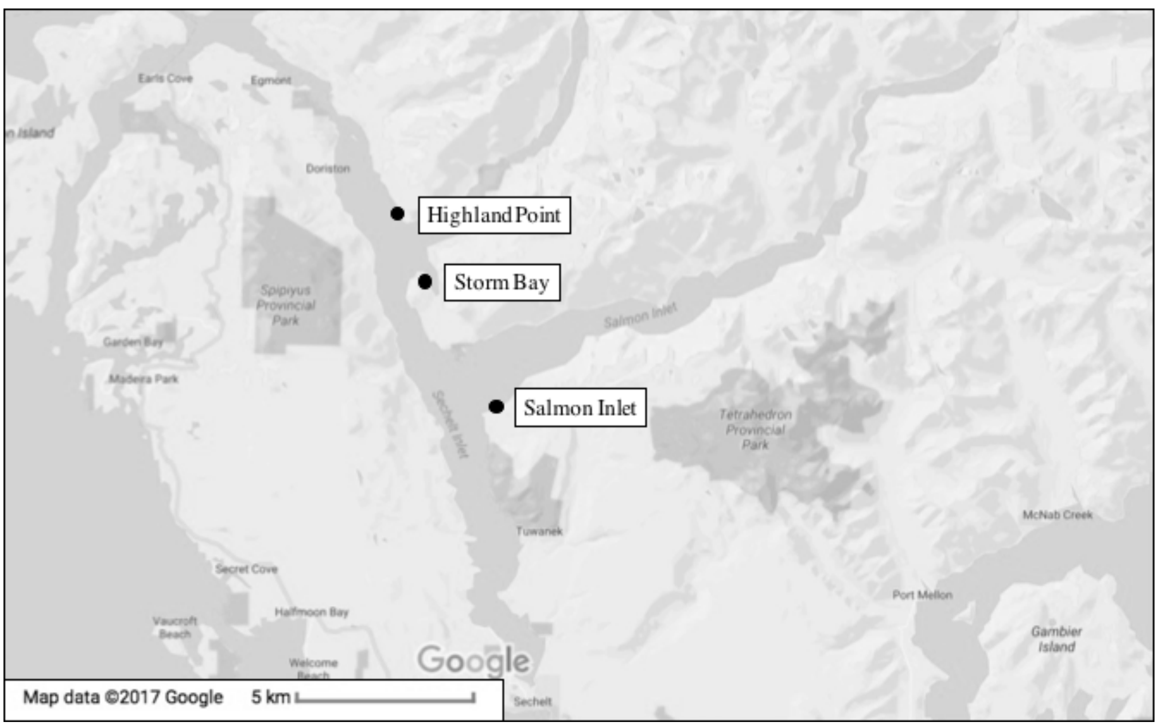


Figure 4.1. *Locations of butter clam collection and, temperature and salinity measurements in the Sechelt Inlet system.*

Figure 4.2. *Live-collection of butter clams at low tide in Storm Bay.*

4.2. Archaeological shell selection and preparation for $\delta^{18}O_{shell}$ & macro-growth line analysis

Shells were selected based on established criteria (Andrus 2011, Burchell et al. 2013c; Mannino et al. 2007; Twaddle et al. 2015): 1) preservation of ventral margin; 2) preservation of intact upper shell layer; 3) absence of exposure to fire and diagenetic effects ; and 4) size of shell fragments must have been larger than 1 cm in length. Once selected, they were lightly scrubbed with a soft bristle brush, and set aside to dry.

For identification purposes, each shell was given an ID number and labelled on the interior surface with pencil and sealed with clear nail polish. All viable shell fragments were cut in half with a Dremmel rotary tool with a diamond cut-off wheel. Each shell-section was then polished using a Buehler Metaserv 250 grinder-polisher, distilled water and a 320 grit SiC grinding disk. They then underwent another round of polishing with micropolish cloth and 0.3µm colloidal AlO_2 solution (Figure 4.3.). Shells were cleaned in an ultrasonic bath between each grinding and polishing step to remove adhering media.

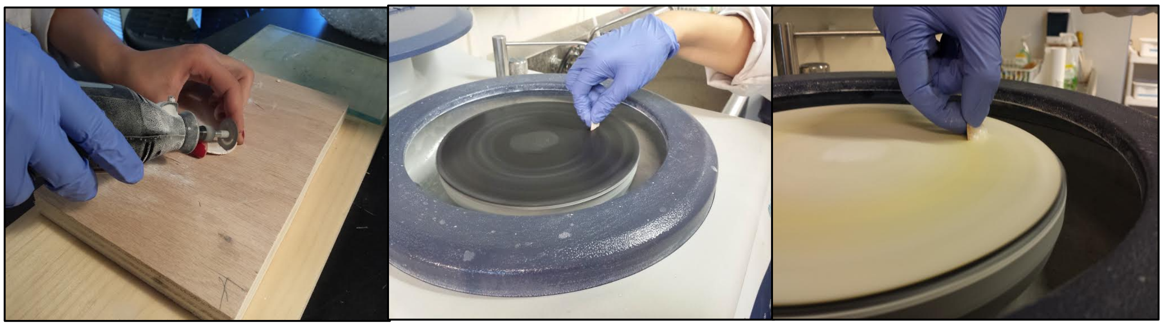


Figure 4.3. *Left to right: Cutting shell fragments with a Dremmel rotary tool;, grinding the shell fragment on the Buehler Metaserv 250 with a 320 grit SiC grinding disk; the final polish to reveal growth lines on the same Buehler Metaserv 250 with a micropolish cloth and 0.3μm colloidal AlO_2 solution.*

4.3. Processing of column samples for macro-growth line & $\delta^{18}O_{shell}$ analyses

Column samples from DjRw-1, DkRw-22 and DkRw-26 were obtained from the University of Toronto's Northwest Coast lab directed by Dr. Gary Coupland who has led sARP excavations with Dr. Terence Clark in the SIS since 2008. Shell fragments were selected from the whole column sample instead of taking a subsample from the whole to maximize the sample sizes for each site. The column samples had a higher proportion of small crushed shell fragments with fewer fragments that fit criteria for selection, likely as a result of preferential excavations near high activity zones (i.e., house platforms) prone to trampling or of other cultural (e.g., midden formation processes, inclusion of destructive materials), natural (e.g., weathering, degradation, acidity of soil), and /or excavation-related (e.g., troweling, bagging, transportation) processes.

4.4. *In situ*, and sorted shell materials for macro-growth line & $\delta^{18}O_{shell}$ analyses

During the 2009 excavation of site DjRw-1, archaeologists randomly extracted whole butter clam shells from a 3 x 1 m trench (N78-80 E68). All of these shells (n=147) were used for growth stage analysis.

During sARP's systematic survey in 2010, auger samples were taken from DjRw-18, DkRw-22, and DkRw-26. Previously sorted butter clam shells from the > 8mm fractions of these auger samples were also analyzed for the examination of these sites. Additional shell material from DkRw-22 and DkRw-26 was obtained from the 2012 excavation's column samples, which were sorted into different sized fractions in 2015. Only shells from Layer J (24-33 cm) at DkRw-22 were used for analyses since shells from other excavated layers did not yield shells fitting criteria for macro-growth line or $\delta^{18}O_{shell}$ analysis (n=28). In the case of DjRw-18, no excavations took place, therefore, only auger sample materials were used from this site.

4.5. Macro-growth line analysis for shellfish harvesting intensity

Polished butter clam cross-sections were classified into juvenile, mature, or senile growth stages depending on the overall pattern found in butter clam cross-sections. Classification was conducted after $\delta^{18}O_{shell}$ analysis since $\delta^{18}O_{shell}$ results aligned with growth features informed macro-growth line analysis. According to previous macro-growth line classification descriptions, shells that produced clustered growth lines near the ventral margin should be classified as senile (Cannon and Burchell 2009). However, $\delta^{18}O_{shell}$ results from the SIS showed clustering of macro-growth lines occurring in multiple locations along the axis of growth (Leclerc et al. 2017). Therefore, it was important to look at the overall distribution of macro-growth line clusters in each fragment. Shell fragments that showed equally distributed clusters of macro-growth lines were classified as mature. Shells with clustering of macro-growth line at the ventral margin that were un-equally distributed along the axis of growth were classified as senile (Figure 1.3.). In addition, thin shell fragments that had less than three macro-growth lines or clusters were classified as juvenile specimens.

4.5.1. Statistical analysis for temporal change of shellfish harvesting patterns

Two-tailed Fisher's exact tests were conducted to determine whether there were any statistically significant differences in growth stage ratios between sites. The ratio between summed mature and juvenile numbers, and senile numbers of butter clam shells were compared between sites. Further, stratigraphic layers and auger test depths were also compared to test whether statistically significant temporal change in shellfish harvesting practices could be observed.

4.6. Preparation for $\delta^{18}O$ analysis

To keep methods consistent, $\delta^{18}O_{shell}$ preparation steps follow those outlined in previous butter clam $\delta^{18}O$ studies on the northern and central coasts of BC (Hallmann et al. 2009; 2013; Burchell et al. 2013b,c). Only shells classified as mature were used to reduce time-averaging during the milling process near the ventral margin. In addition, it was paramount that samples affected by diagenesis and polymorphic conversion to calcite (a different crystal form of $CaCO_3$ than aragonite) as a result of burning or other diagenetic effects be excluded from analysis (*for exclusion of fire-affected shell criteria for selection, see section 4.2.*). To ensure shells were not subject to diagenesis or fire, a selection of shells was analyzed through Fourier Transform Infrared spectrometry (FTIR) using a Nicolet™ iS™5 FT-IR Spectrometry facilitated through a collaboration with Dr. Francesco Berna at Simon Fraser University. To test the effects of heating and burning on butter clams and the implications for $\delta^{18}O_{shell}$ analysis, a butter clam shell was roasted at 400 °C and another was boiled. The results of live-collected boiled and non-boiled shells, and a seemingly badly preserved archaeological shell fragment revealed that all these shells maintained their aragonitic structure and were therefore still viable to use. Further, the results also showed that the burnt live-collected shell at 400 °C underwent a polymorphic conversion to calcite in parts of the shell. Furthermore, scanning electron microscopy revealed that roasted shell at such a temperature caused fragmentation of shell material to such a degree that parts of shell were flaked off from the surface and would have created gaps in the time sequence of $\delta^{18}O_{shell}$ (Leclerc 2017; Figure 4.4.). Consequently, all shells with signs of burning were excluded for $\delta^{18}O$ analysis. These were identified by a greying and fracturing of the interior structure of shellfish (Figure 4.4.). One of the more popular sample preparation methods includes the roasting of shell material prior to the chemical analysis process to remove organic components (e.g., Kennett and Voorhies 1996; Mannino et al. 2003). However, this has been shown to change the structure chemistry of the material at temperatures higher than 300 °C (Milano et al. 2016). Since this step is not needed for butter clams that have a low organic content, sampled materials were not roasted.

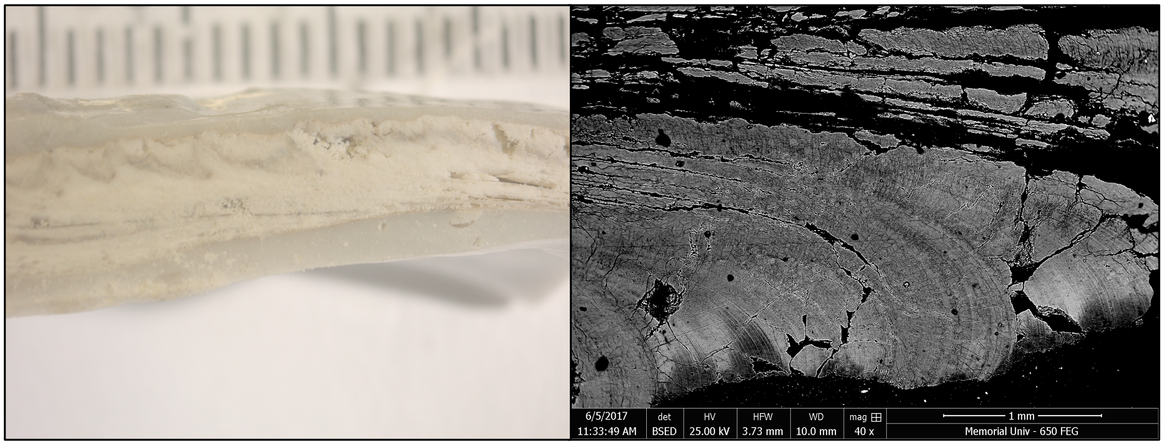


Figure 4.4. *Reproduced figure from Leclerc 2017. Left to right: Magnified image of butter clam shell that has been roasted at 400°C demonstrating greying of shell material, and backscatter electron image taken with a scanning electron microscope demonstrating the extreme heat-related fracturing.*

Ten archaeological shells per site were selected for seasonality interpretations through $\delta^{18}O$ analysis. While this sample size may be perceived as being too small to represent the innumerous shellfish harvesting events found in shell-bearing deposits, Cannon and Burchell (2016) have shown that increasing sample sizes to more than ten does not change seasonality patterns on the Pacific Northwest Coast, and that seasonality determinations of sites based on 10 analyzed shells can be treated with confidence. Due to the paucity of useable shells from DkRw-22, only two shells were selected from DkRw-22 excavations, and eight shells from neighboring site DjRw-18. Since both sites have been interpreted as being occupied at the same time and part of a 'community'

(Letham 2014), they have been grouped together to give a seasonal occupation of Storm Bay.

Figure 4.5. *Left to right: Coating butter clam shells with metal epoxy and polished cross-section mounted on labelled glass slide.*

Selected shells were coated with LePage metal epoxy and cut along the axis of maximum growth to create two mirrored shell slices approximately 3mm thick (Figure 4.5.). Each slice was ground and polished following the same sample preparation method detailed in section 4.2. (Schöne et al. 2005), and glued onto slides with LePage metal epoxy so that one could be sampled and the other could be stained to count lunar daily growth increments (LDGI). The exposed interior shell surface was ground and polished to produce a smooth surface to reveal macro- and micro-growth structures (*for detailed information on grinding and polishing steps, see section 4.2.*). Slides were also labelled with pencil and sealed with clear nail polish, and photographed under 40x magnification using a Zeiss sterozoom 2000 microscope with ERC 5 camera.

4.7. $\delta^{18}O$ Sampling procedure

Mounted shell slides were brought to the Johannes Gutenberg University of Mainz, Germany, where shells were sampled for $\delta^{18}O$ analysis (Figure 4.6.). Samples were hand-milled and –drilled in the Department of Applied and Analytical Paleontology where the samples were subsequently analyzed. First, epoxy was removed with the hand-drill from the ventral margin portion of the selected shells to prevent metal epoxy to be included in the shell samples since it affects the $\delta^{18}O$ values (Figure 4.7.). The lower shell layer was also milled off because this part of the shell re-mineralizes during the animal's life and would thereby produce unreliable results. Therefore, only the upper shell layer was sampled following the Burchell et al. (2013a,b,c) and Hallmann et al. (2011;2013) protocol. In addition, the friction created during drilling and milling has been shown to alter the chemical composition of samples (Waite and Swart 2015). Therefore, drilling and milling steps were conducted with one finger underneath the sample to feel if shells were warming up. Breaks from drilling and milling were taken when the glass slide and/or sample changed to a warmer temperature.

Detailed notes were taken for every shell and every sample, which included slight modifications to sampling procedure when it was needed and sketches detailing where macro-growth lines were distributed in relation to sampling locations. This permitted an alignment of each discrete $\delta^{18}O$ value to the growth features of the shell. Starting at the ventral margin of the archaeological shells, 10 hand-milled samples were taken in a

Figure 4.6. *Drilling and milling shells in the Department of Applied and Analytical Paleontology laboratory at Johannes Gutenberg University, Mainz, Germany.*

crescent-like motion, as to contour growth lines, with a 1mm diamond-coated cylindrical drill-bit in ~100µm increments to cover ~1mm of growth. This step was followed by the hand-drilling of five samples with a 300µm conical drill bit in ~750µm increments to cover ~3.75 mm of growth (Figure 4.7.). The live-collected shells were sampled differently with ~20 milled samples and ~10 drilled samples. Additional samples were taken in order to get a broad understanding of how shells from SIS, a lower salinity

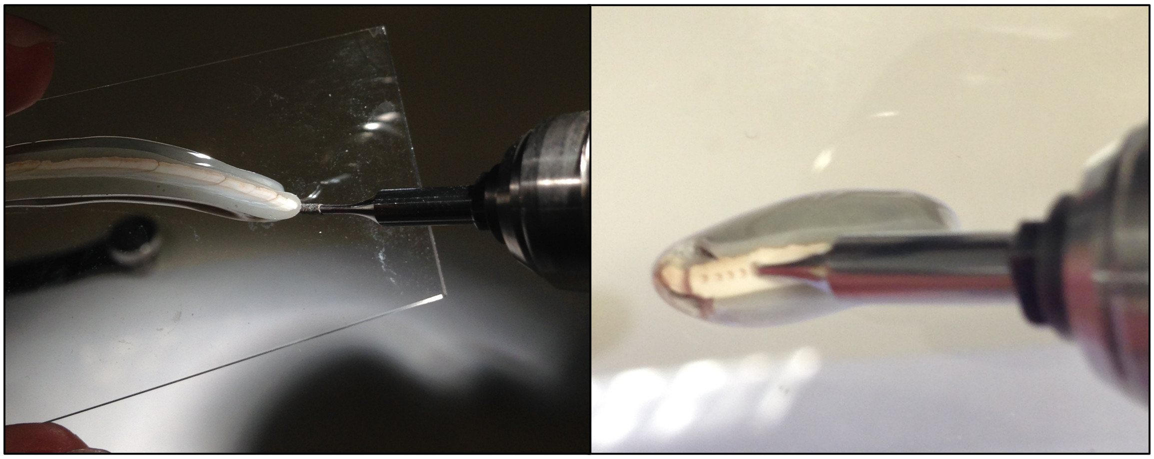


Figure 4.7. *Left to right: Taking metal epoxy off from around the ventral margin, and drilling a fifth drilled sample following the section of the shell that has already been milled.*

region than previous studies of *Saxidomus gigantea*, grow and integrate $\delta^{18}O$ according to known seawater conditions at time of collection during the last year of growth. Further, live-collected shells selected were younger than the archaeological mature shells sampled as was evident when viewing the $\delta^{18}O$ data. This meant that fewer samples were required to account for a full year of growth in the archaeological shells in comparison to the live-collected shells. The powdered samples were placed into brass crucibles for transport and later weighed out to 30-100μg portions with a micro-precision balance (Figure 4.8.). Weighed portions were placed and sealed into labelled borosilicate glass exetainers. Samples were then placed into the collector of a Thermo Finnigan MAT 253 continuous flow – isotope ratio mass spectrometer coupled to a Gas Bench II for $\delta^{18}O$ analysis in 60 sample batches (Figure 4.8.). Each batch also included 2 NBS-19 standards and 12 IVA Carrara standards of known weights (~ 40μg, ~ 60μg, ~ 90μg, ~ 120μg). The $\delta^{18}O$ values were calibrated against NBS-19 ($\delta^{18}O$ = -2.20‰) with a 1σ external reproducibility (i.e., accuracy) of ±0.07‰, and an internal precision of 0.07‰. The $\delta^{18}O_{shell}$ values are expressed relative to the international VPDB (Vienna Pee Dee Belemnite) standard and are presented in per mille values (‰).

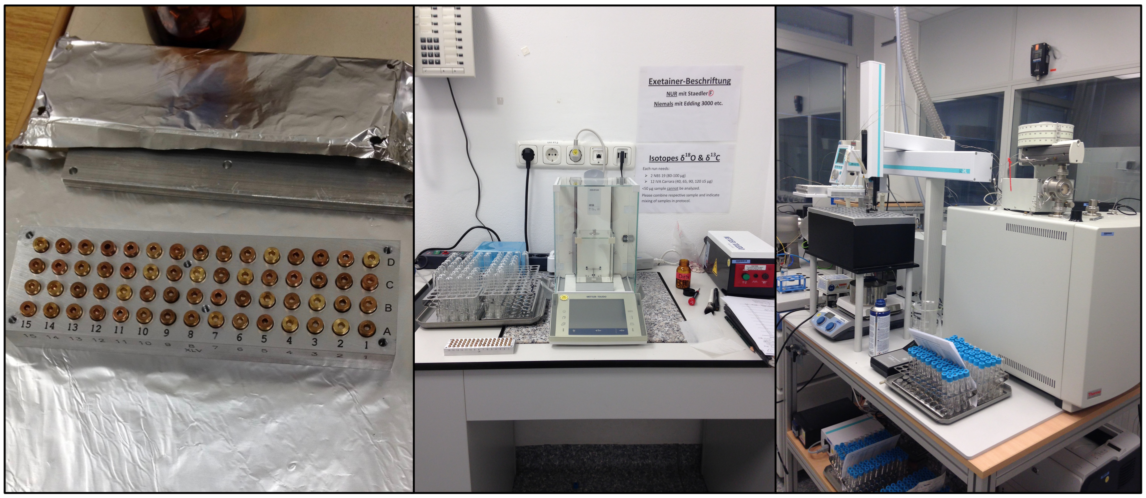


Figure 4.8. *Left to right: Brass crucibles with weighed powder, micro-precision balance; and Thermo Finnigan MAT 253 continuous flow isotope ratio mass spectrometer coupled to a Gas Bench II with glass vials ready for analysis.*

4.8. Lunar daily growth increment (LDGI) analysis

The cut shell fragments not used for $\delta^{18}O$ analysis were analyzed following the protocol by Schöne et al. (2005) for Mutvei staining. This facilitated the identification of LDGI. The Mutvei solution has three main components: alcian bleu, glutaraldehyde, and acetic acid. It stains, etches and fixates organic compounds in etch-resistant ridges (i.e. growth lines), and etched depressions (i.e. growth increments) simultaneously. This produces a dark blue staining of growth lines and a light blue staining of growth increments which enabled the distinction of periods of fast and slow growth. Shell slides were submerged in the Mutvei solution for one hour while being constantly stirred and maintained at a 37-40°C temperature on a hot plate with magnetic stirrer. They were then magnified and photographed, before being stitched together and spatially analyzed with © Panopea software which measures LDGI widths (Figure 4.9.). Width measurements were then temporally aligned with $\delta^{18}O$ analysis results to determine if shorter increments correspond to possible freshwater peaks or warmer temperatures (*for more details, see section 1.4.3.*).

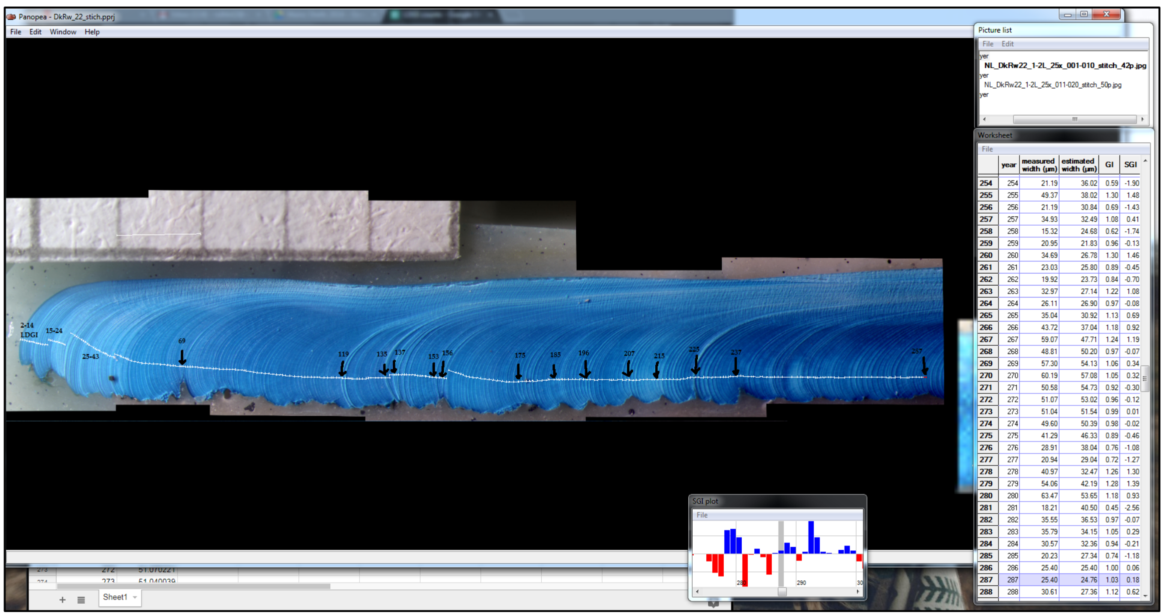


Figure 4.9. *Lunar daily growth increments counted and measured with © Panopea.*

CHAPTER 5

MACRO-GROWTH LINE, $\delta^{18}O_{shell}$ & LDGI RESULTS

5.1. Shell macro-growth line analysis

All four sites in the SIS show a higher proportion of mature and juvenile shells in comparison to senile shells (Figure 5.1.). A total of 662 individual shell fragments were analyzed and classified into growth stages with 29% (n =192/662) of the shells from DjRw-1, 11% from DjRw-18 (n=70/662), 5% from DkRw-22 (n=35/662), and 55% from DkRw-26 (n=365/662) (Table 5.1.). DjRw-18, DkRw-22 and DkRw-26, which were all connected to Narrows Inlet had higher proportions of senile shells (14-21%) compared to DjRw-1 (12%).

The site with the highest proportion of mature and juvenile shells (85%) was DjRw-1, with a split of 69% mature to 16% juvenile shells. All sites showed low proportions of shells with unknown growth stages (Table 5.2.) and therefore, these shells would not have significantly changed results had it been possible to identify their growth stages. Overall, the inter-site variation of younger (sum of mature and juvenile proportions) and senile shell proportions is small (10%), and the overarching pattern is constant, emphasizing collection of younger shells, and therefore higher shellfish harvesting intensity (Figure 5.2.).

Clusters of two to three macro-growth lines were observed in most shell fragments (Figure 5.3.). While many shells showed evidence of macro-growth line clustering at the ventral margin, the overall pattern of macro-growth line distribution in each cross-section was examined in order to determine whether clustering was evenly distributed along shell cross-sections. If shells exhibited evenly distributed macro-growth

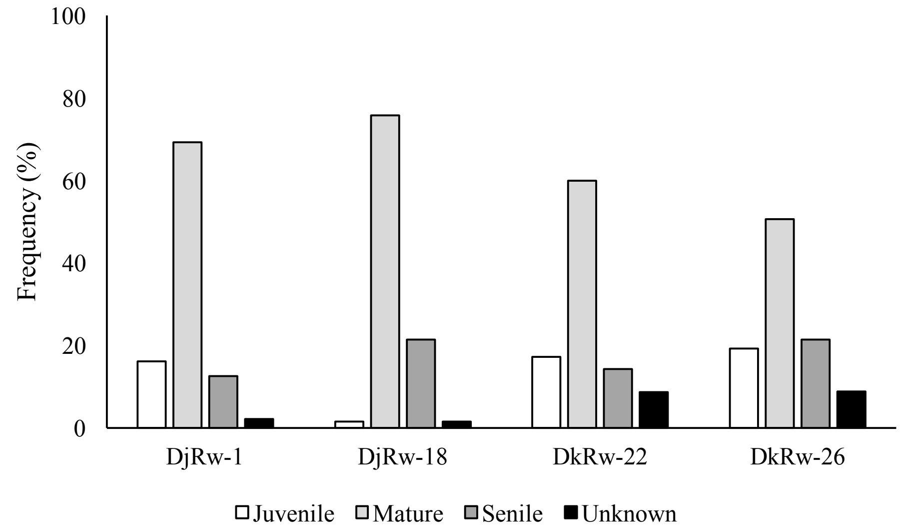


Figure 5.1. *Growth stage proportions for the four sites investigated in the Sechelt Inlet System based on macro-growth line analysis. While DjRw-18 had the highest proportion of mature butter clams, DjRw-1 had a higher proportion of young specimens (summed juvenile and mature proportions) and lower senile proportion, thereby indicating a higher shellfish harvesting intensity pattern.*

Table 5.1. ***Growth stage determinations and sample sizes for the four Sechelt Inlet System sites.***

Sites	Juvenile		Mature		Senile		Unknown		Site Total	
	N	%	N	%	N	%	N	%	N	%
DjRw-1	31	**16**	133	**69**	24	**13**	4	**2**	192	**28**
DjRw-18	1	**1**	53	**76**	15	**21**	1	**1**	70	**10**
DkRw-22	6	**16**	21	**55**	5	**21**	3	**8**	35	**6**
DkRw-26	78	**21**	185	**51**	70	**19**	32	**9**	365	**55**
Total	116	**17**	392	**58**	117	**17**	40	**6**	662	**100**

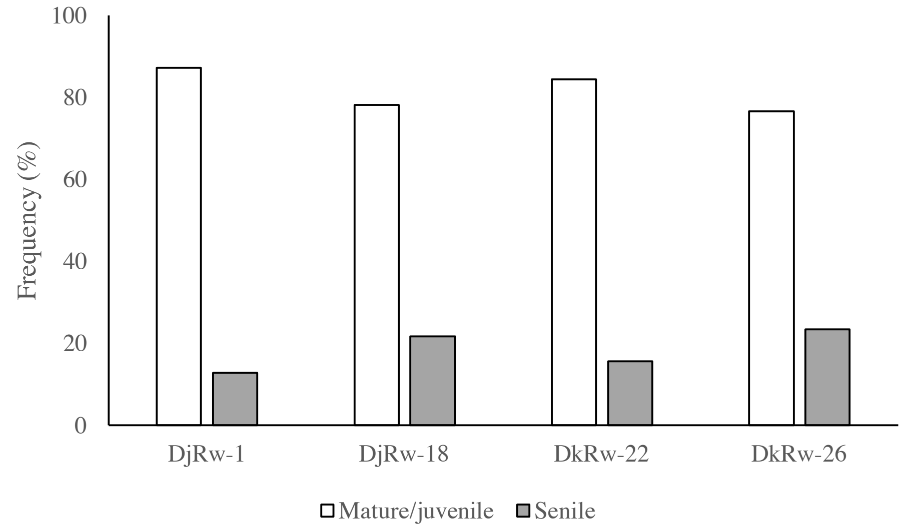


Figure 5.2. *Growth stage proportions for the four sites investigated in the Sechelt Inlet System based on macro-growth line analysis. Mature and juvenile growth stages have been grouped to show the contrast between young and older butter clam specimens. Shells of unknown growth stages are included in the summarizing tables for each site.*

line clusters, they were identified as mature. Therefore, shells were examined for clustering of macro-growth lines at the ventral margin and general distribution of macro-growth lines along the axis of growth before growth stage determinations. This method therefore considered variability within growth stages.

Growth stage proportions were examined by layer/level to determine whether there were meaningful differences between layers suggestive of shifts in shellfish harvesting practices.

5.1.1. DjRw-1

All excavated layers had a higher or equal proportion of younger shells to senile

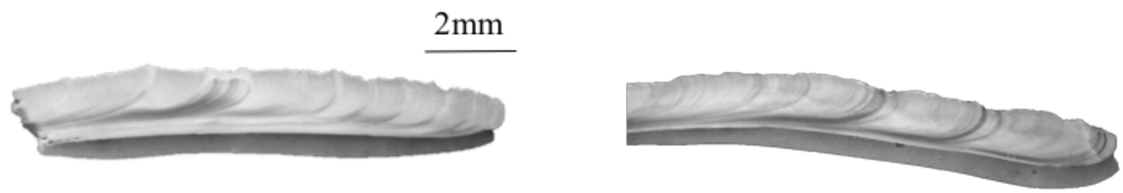


Figure 5.3. *Two mature shell fragments with different macro-growth line deposition patterns. Note the macro-growth line clusters. Left shell fragment demonstrates a cluster of three macro-growth lines and the right shell fragment demonstrates evenly distributed clusters of two to three macro-growth lines nearing the ventral margin.*

shells, with the exception on layer I of unit N80 E85-86 (n=1). Unit N80 E85-86 showed a clear increase of younger shells in layer D which also had the highest proportion of shells in the unit (Figure 5.4.). Sample sizes of layers above and beneath layer D, nearing the surface and the bottom of the unit, diminish accompanied with an increase in senile shells.

This pattern is also seen in unit N78-80 E68 where all layers show a higher proportion of younger shells, though there is still inter-layer variability. From layer Kc to G the proportion of mature shells decreases with an increase on the juvenile proportion. Following layer G, there is a decrease in the concentration of shells in layer C and an increase in the sample size in layer B and A coinciding with an increase in younger shells (Figure 5.5.). Layers B stand out as with higher proportion of senile specimens (31%)

5.1.2. DjRw-18

With the exception of one level, 62-73 cm, each layer of auger test 2010-014 had a higher proportion of mature shells than other growth stages (Table 5.3.). In both auger tests, more mature shells are found in deeper layers, followed by a decrease in mature

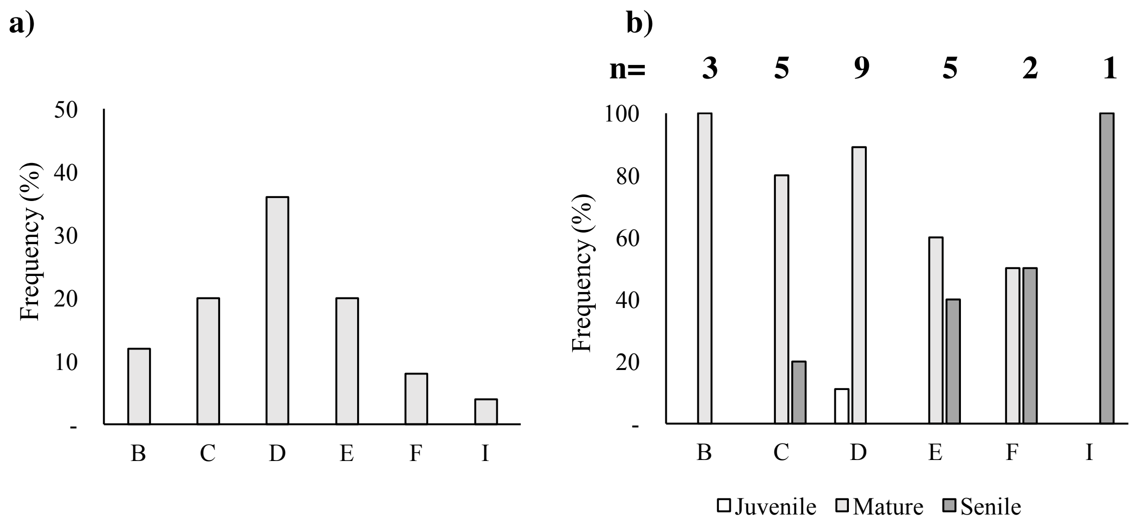


Figure 5.4. *DjRw-1 growth stage determinations by layer (a) and distribution of shells by layer (b) for Unit N80 E85-86.*

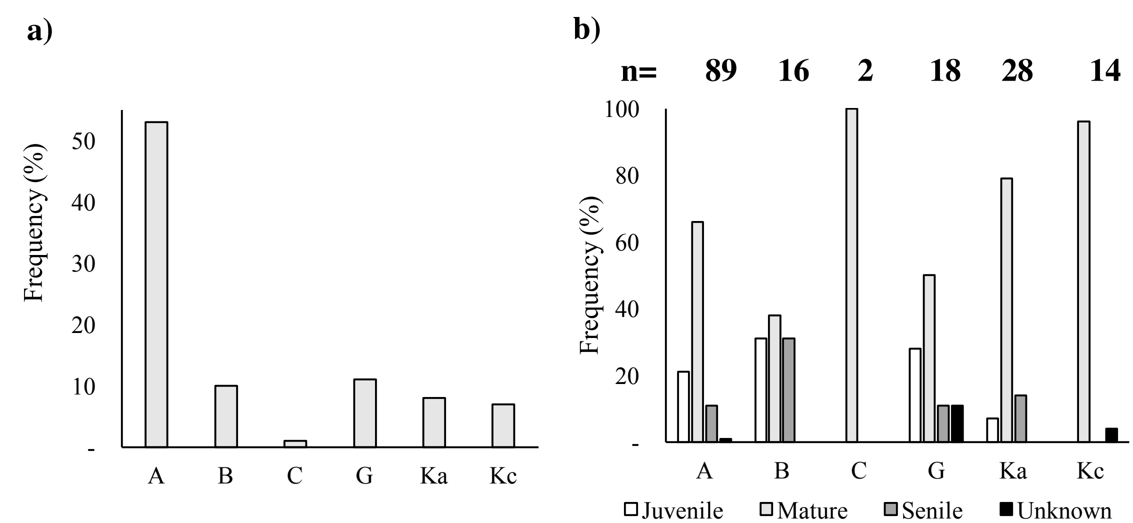


Figure 5.5. *DjRw-1 growth stage determinations by layer (a) and distribution of shells by layer (b) for Unit N78-80 E68.*

Table 5.2. DjRw-1 growth stage determinations by layer.

Unit	Layer	Juvenile		Mature		Senile		Unknown		Total	
		N	%	N	%	N	%	N	%	N	%
N80 E85-86	Layer B	0	**0**	3	**100**	0	**0**	0	**0**	3	**2**
	Layer C	0	**0**	4	**80**	1	**20**	0	**0**	5	**3**
	Layer D	1	**10**	8	**90**	0	**0**	0	**0**	9	**5**
	Layer E	0	**0**	3	**60**	2	**40**	0	**0**	5	**3**
	Layer F	0	**0**	1	**50**	1	**50**	0	**0**	2	**1**
	Layer I	0	**0**	0	**0**	1	**100**	0	**0**	1	**<1**
	Total	1	**4**	19	**76**	5	**20**	0	**0**	25	**13**
N78-80 E68	Layer A	19	**21**	59	**66**	10	**11**	1	**1**	89	**46**
	Layer B	5	**>31**	6	**37**	5	**>31**	0	**0**	16	**8**
	Layer C	0	**0**	2	**100**	0	**0**	0	**0**	2	**2**
	Layer G	5	**28**	9	**50**	2	**14**	2	**14**	18	**9**
	Layer Kc	0	**0**	27	**96**	0	**0**	1	**4**	28	**15**
	Layer Ka	1	**7**	11	**79**	2	**14**	0	**0**	14	**7**
	Total	30	**18**	114	**68**	19	**11**	4	**2**	167	**87**
TOTAL		31	**16**	133	**69**	24	**13**	4	**2**	192	**100**

shells, then another increase of mature shells (Figure 5.6.). This pattern is similar to unit N78-80 E68 at DjRw-1. The deepest level, 73-80cm DBS, contained more shells than the following layer, 62-73 cm DBS, followed by an increase in layer 21-62cm DBS. This pattern was mirrored in growth stage proportions. The highest proportions of mature shells are found in the topmost (n=4/6) and bottommost layers (n=6/8), while the middle layer, 62-73cm DBS, is the only layer with a higher proportion of senile shells (n=1/4). A similar pattern is found in auger test 2010-016 (Figure 5.7.). In the deepest level (46-53 cm DBS), mature shells are dominant (67%, n= 4/6) and senile shells are present but at a lower proportion (33%, n=2/6). The proportions of all analyzed shells and younger shells increase at 37-46 cm DBS (91%, n=10/11), followed by a sharp increase in senile shells at 21-37 cm DBS (42%, n=5/12), and a reinstatement of a high proportion of mature shells in the topmost layer 1-21 cm DBS, where the majority of the samples cluster and the only level we find juvenile shells (4%, n=1/23).

Table 5.3. DjRw-18 growth stage determinations by layer for auger tests 2010-016 and 2010-014.

Unit	Layer/ Auger depth	Juvenile		Mature		Senile		Unknown		TOTAL	
		N	%	N	%	N	%	N	%	N	%
AT 2010-016	1-21 cm	1	**4**	21	**91**	1	**4**	0	**0**	23	**31**
	21-37 cm	0	**0**	7	**58**	5	**42**	0	**0**	12	**17**
	37-46 cm	0	**0**	10	**91**	0	**0**	1	**9**	11	**16**
	46-53 cm	0	**0**	4	**67**	2	**33**	0	**0**	6	**9**
	Total	1	**2**	42	**81**	8	**15**	1	**2**	52	**74**
AT 2010-014	21-62 cm	0	**0**	4	**67**	2	**33**	0	**0**	6	**8**
	62-73 cm	0	**0**	1	**25**	3	**75**	0	**0**	4	**6**
	73-80 cm	0	**0**	6	**75**	2	**25**	0	**0**	8	**11**
	Total	0	**0**	11	**61**	7	**39**	0	**0**	18	**26**
TOTAL		1	**1**	53	**76**	15	**21**	1	**2**	70	**100**

5.1.3. DkRw-22

The results from DkRw-22 suggested that during at least one period of occupation, mature shells were more abundant than senile shells (Figure 5.8.). Layer J was the only layer from the Unit D excavation that produced criteria-fitting shells and also the only layer including those from AT 2010-017, that produced a decent sample size to interpret patterns of shellfish harvesting intensity (n=35) (Figure 5.9.). Layer J had

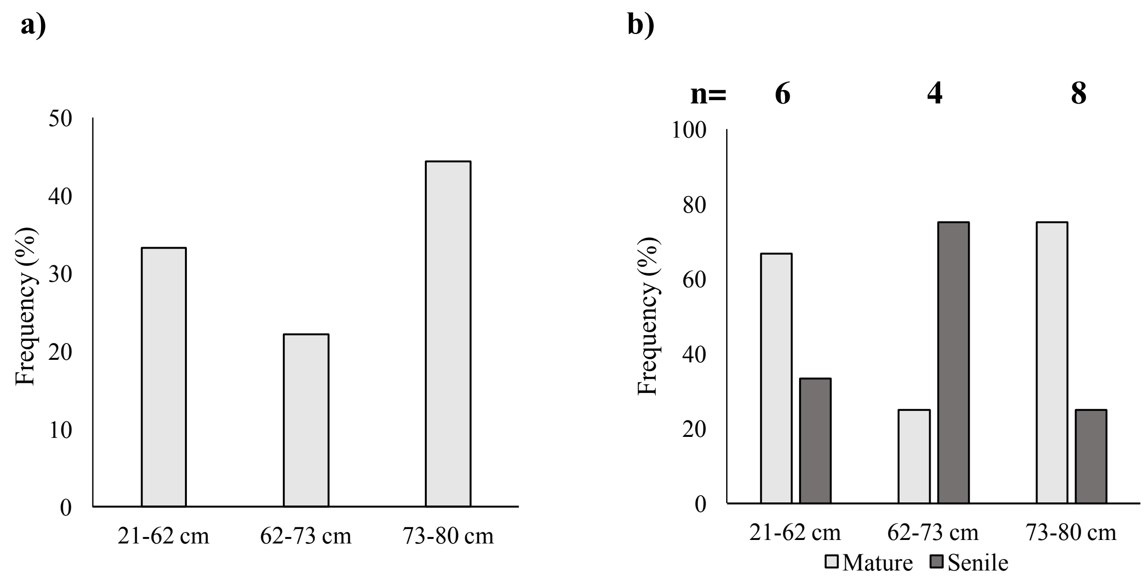


Figure 5.6. *DjRw-18 macro-growth line analysis results for AT 2010-014*
a) Distribution of samples by layer; b) frequency of growth stages by layer with occupying population sizes. No juvenile or unknown shells were identified.

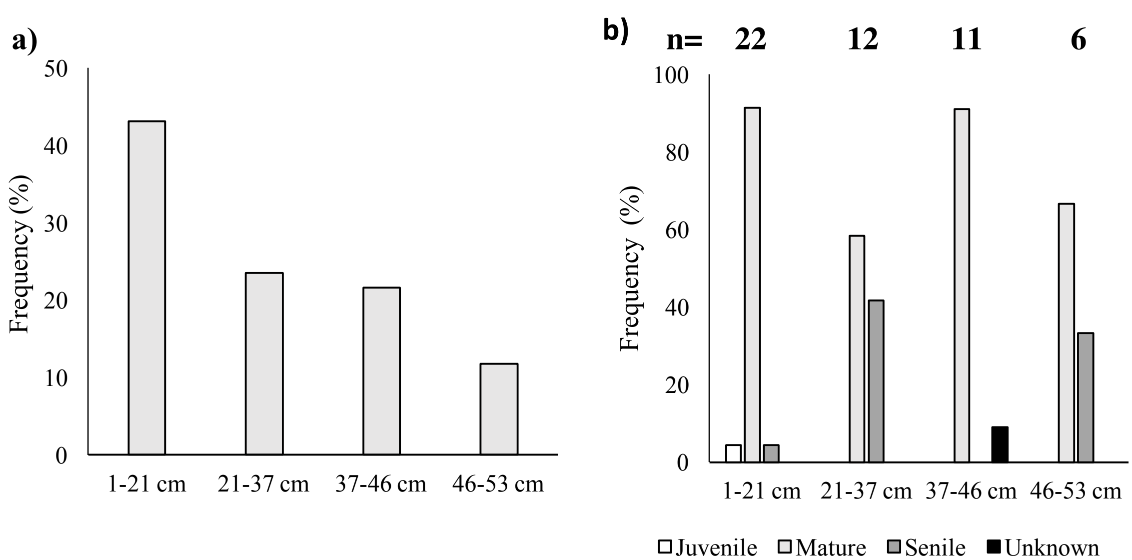


Figure 5.7. *DjRw-18 macro-growth line analysis results for AT 2010-016*
a) Distribution of samples by layer; b) frequency of growth stages by layer with occupying population sizes.

60% of the fragments classified as mature and 17% as juvenile (Table 5.4.). All the shells found in AT 2010-017 were all classified as senile (n=3).

Table 5.4. ***DkRw-22 Growth stage determinations by layer.***

Unit	Layer/ Auger depth	Juvenile		Mature		Senile		Unknown		Total	
		N	%	N	%	N	%	N	%	N	%
AT 2010-017	41-56 cm	0	**0**	0	**0**	1	**100**	0	**0**	1	**3**
	81-101 cm	0	**0**	0	**0**	2	**100**	0	**0**	2	**5**
	Total	0	**0**	0	**0**	3	**100**	0	**0**	3	**8**
Unit D	Layer J	6	**17**	21	**60**	2	**14**	3	**9**	32	**92**
TOTAL		6	**16**	21	**55**	5	**21**	3	**8**	35	**100**

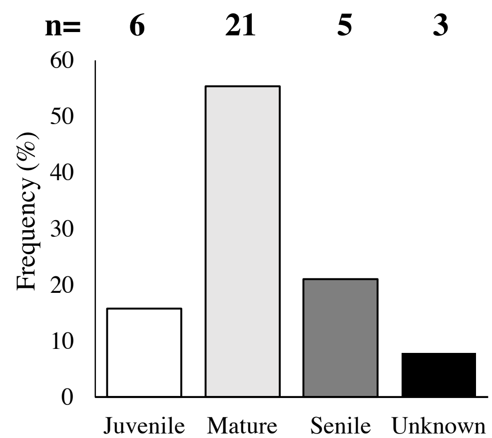


Figure 5.8. *DkRw-22 frequency of growth stages for layer J of Unit D.*

5.1.4. DkRw-26

Combined growth stage proportions from auger levels and excavated layers show

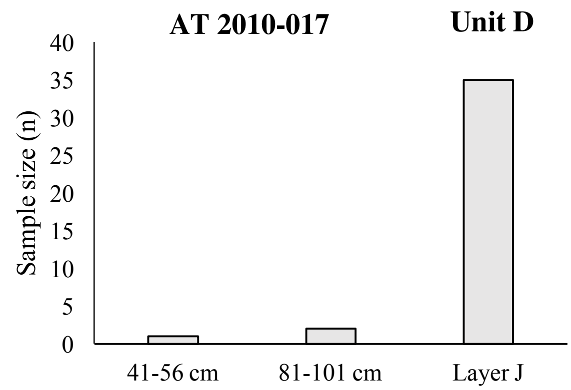


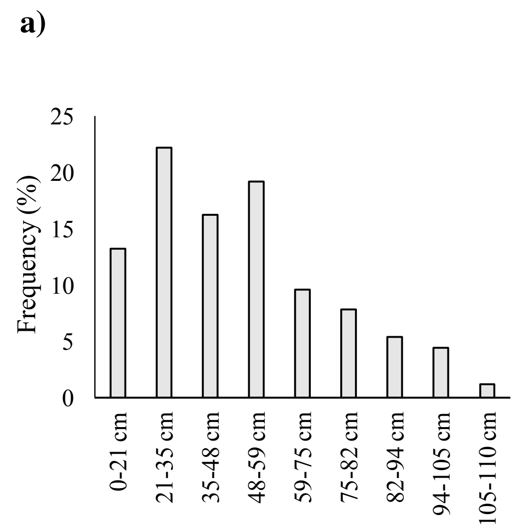
Figure 5.9. *DkRw-22 distribution of samples by layer for AT 2010-017 and Unit D.*

that 51% of shell were classified as mature, 21% as senile, 19% as juvenile, and 9% as unknown (Table 5.5.). In AT 2010-001, mature shells dominate the assemblage (50%, n=83/167) compared to the senile shell proportion (17%, n=28/167). From 94 cm to 0 cm DBS, senile proportions decreased (44-14%), as did mature proportions (44-32%). During this time, juvenile proportions increased and superseded mature proportions (11-45%) (Figure 5.10.). This is also reflected in the increase of sample size over time. Conversely to auger test 2010-001, auger test 2010-002 showed a different pattern with an increase in senile shells and a decrease in mature shells from lower to upper depths (Figure 5.11.). From layer 60-68cm DBS to layer 0-21cm DBS, senile shells increase from 0% to 71% and mature shells decrease from 87% to 14%. In addition, from 54cm to 21cm there is an increase in juvenile shells and a decrease in mature shells. When mature and juvenile specimens are grouped into one category, relatively unchanging proportions of younger and senile shells were observed from 54cm to 21cm DBS (Figure 5.12.). A closer look at the juvenile proportions between 54 cm to 21 cm DBS, showed an increase which coincides with an increase in the sample size per level. The topmost level, 0-21cm DBS, was the only layer where the senile shell proportion was higher than the mature proportion, and also had the lowest sample size.

From layer D to layer C of excavated Unit A, juvenile shells appear and the senile shell proportion decreases (Figure 5.13.). In addition, the absence of juveniles and higher proportion of senile shells in layer D may be related to its reduced sample size as a result from lower shellfish harvesting intensity. Next, layer B had a higher proportion of shells classified as unknown. These shells were classified as unknown because the upper shell layer was affected by diagenesis thereby making macro-growth lines difficult to read, not because they were they were in a transitionary phase of growth between senile and mature. Therefore, the growth stage proportions of layer B and layer D need to be cautiously interpreted since their sample sizes are so small/and or affected by diagenesis.

Table 5.5. DkRw-26 growth stage determinations by layer.

Unit	Layer/ auger depth	Juvenile		Mature		Senile		Unknown		Total	
		N	%	N	%	N	%	N	%	N	%
AT 2010-001	0-21 cm	10	**45**	7	**32**	3	**14**	2	**9**	22	**6**
	21-35 cm	16	**43**	12	**32**	4	**11**	5	**14**	37	**10**
	35-48 cm	6	**41**	15	**56**	3	**11**	3	**11**	27	**7**
	48-59 cm	3	**9**	18	**56**	8	**25**	3	**9**	32	**9**
	59-75 cm	0	**0**	10	**63**	5	**31**	1	**6**	16	**4**
	75-82 cm	4	**31**	7	**54**	1	**8**	1	**8**	13	**3**
	82-94 cm	1	**>11**	4	**>44**	4	**>44**	0	**0**	9	**2**
	94-105 cm	0	**0**	9	**100**	0	**0**	0	**0**	9	**2**
	105-110 cm	1	**50**	1	**50**	0	**0**	0	**0**	2	**<1**
	Total	41	**25**	83	**50**	28	**17**	15	**9**	167	**46**
AT 2010-002	0-21 cm	0	**0**	1	**14**	5	**71**	1	**14**	7	**2**
	21-40 cm	11	**23**	17	**36**	16	**34**	3	**6**	47	**13**
	40-48 cm	4	**12**	16	**48**	13	**40**	0	**0**	33	**9**
	48-54 cm	2	**4**	11	**48**	7	**30**	3	**13**	23	**6**
	54-60 cm	4	**12**	23	**68**	6	**18**	1	**2**	34	**9**
	60-68 cm	1	**13**	7	**87**	0	**0**	0	**0**	8	**2**
	Total	22	**14**	75	**49**	47	**31**	8	**5**	152	**42**
Unit A	Layer B	1	**11**	2	**22**	2	**22**	4	**45**	9	**2**
	Layer C	6	**18**	22	**67**	0	**0**	5	**15**	33	**9**
	Layer D	0	**0**	3	**75**	1	**25**	0	**0**	4	**1**
	Total	7	**15**	27	**59**	3	**7**	9	**20**	46	**12**
TOTAL		70	**19**	185	**51**	78	**21**	32	**9**	365	**100**



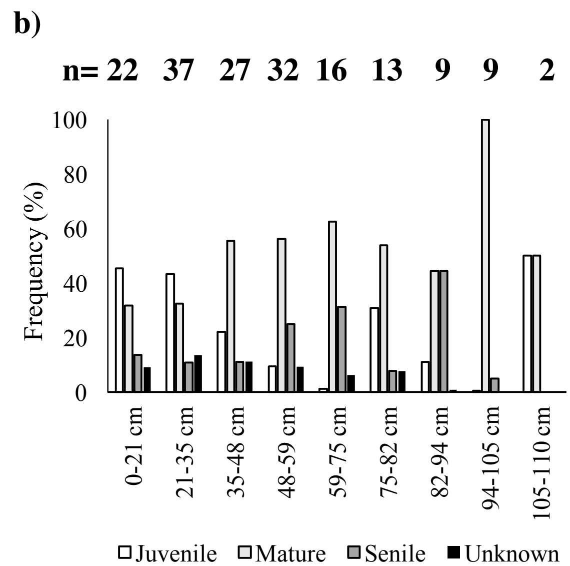
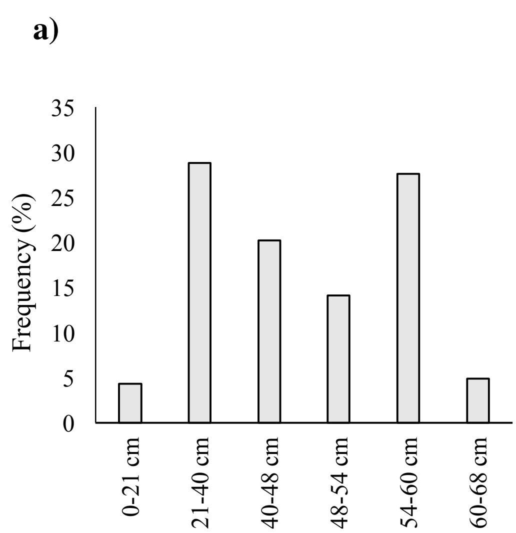


Figure 5.10. *DkRw-26 frequency of growth stages for AT 2010-001.*



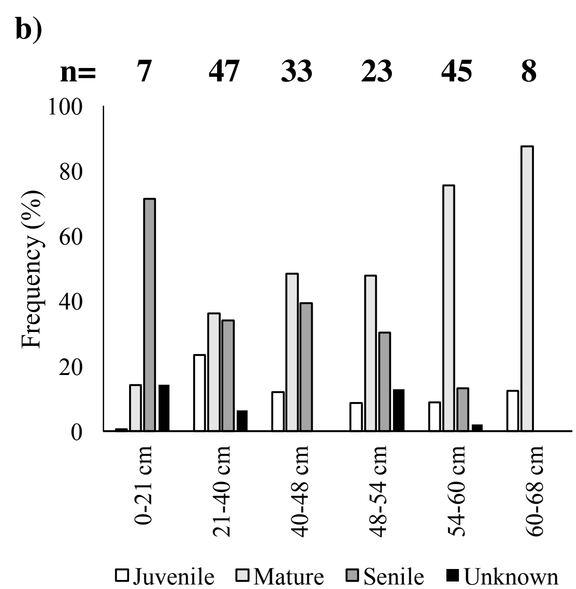


Figure 5.11. *DkRw-26 frequency of growth stages for AT 2010-002.*

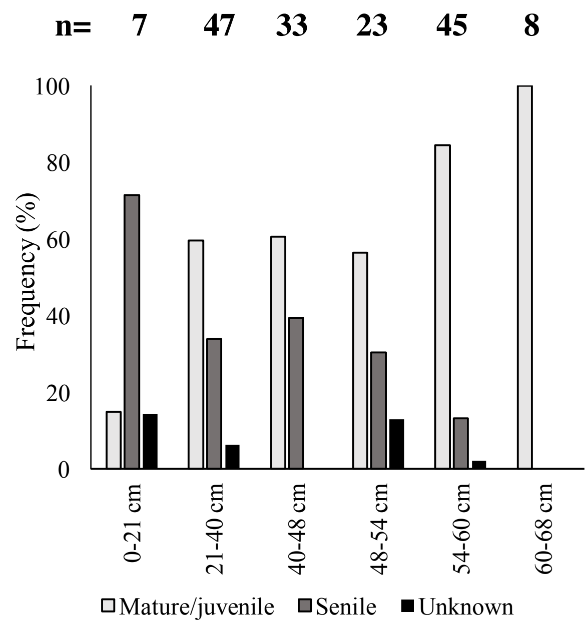


Figure 5.12. *DkRw-26 frequency of growth stages for AT 2010-002 with mature and juvenile classes grouped together.*

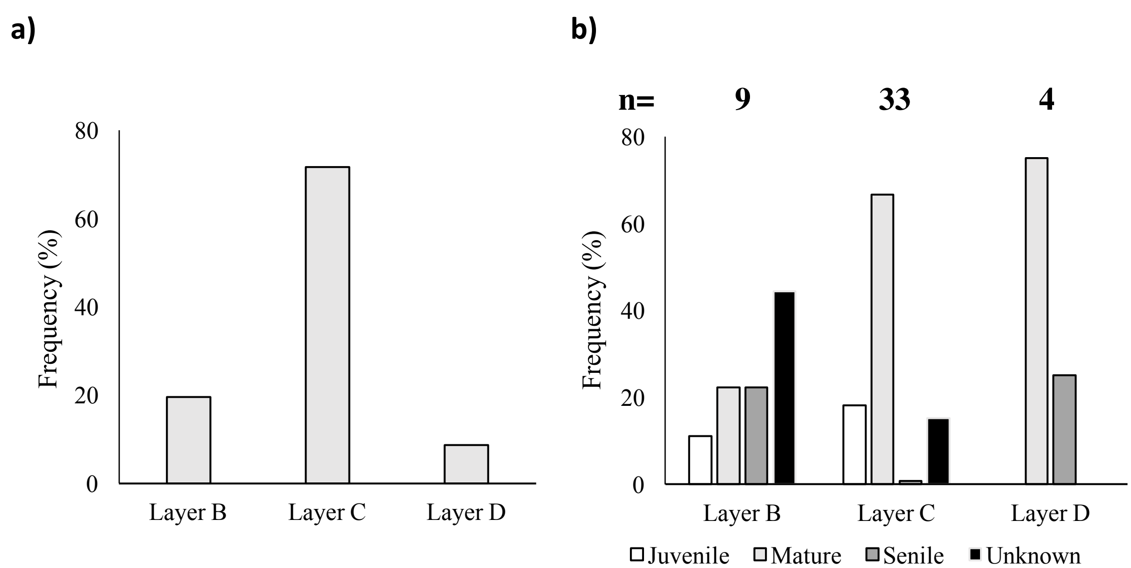


Figure 5.13. *DkRw-26 frequency of growth stages for Unit A.*

5.2. $\delta^{18}O$ and Lunar daily growth increment (LDGI) results

Previous research on the oxygen isotope composition and micro-growth line deposition of butter clam shells from British Columbia's outer coast demonstrated that this bivalve secretes calcium carbonate in close isotopic equilibrium with ambient seawater (Burchell et al. 2013d; Gillikin et al. 2005a; Hallmann et al. 2009). A specific study comparing specimens from Alaska and Pender Island, situated off the coast of southern Vancouver Island, (Hallmann et al. 2009), also showed that latitudinal and local freshwater input variability had strong controls on $\delta^{18}O_{shell}$ incorporation and incremental structures. In addition, the Pender Island specimens showed that LDGI widths were largest in the summer and the lowest in the winter and that $\delta^{18}O_{shell}$ values were most negative during summer growth and most positive during winter growth, thereby supporting the strong relationship with sea surface temperature (SST). Aligned data from 2004 to 2007 showed that $\delta^{18}O_{shell}$ and LDGI generally followed SST curves but fluctuations in $\delta^{18}O_{shell}$ suggested freshwater controls on $\delta^{18}O_{shell}$ integration and therefore the authors conclude that $\delta^{18}O_{shell}$ could not solely be used to reconstruct SST (Figure 3.4.).

The Sechelt Inlet system is situated on the southern coast, same as Pender Island. However, the SIS is situated on the inner coast with multiple freshwater feeding streams, while Pender Island is located on the outer coast where the salinity content of seawater is higher. To test the variability, and reliability of seasonality estimates derived from $\delta^{18}O_{shell}$ and sclerochronological measurements from the SIS, live-collected shells from three locations were analyzed and compared to previous research on *Saxidomus gigantea* and measured environmental data. This was essential to evaluate the variability in shell

$\delta^{18}O_{shell}$, potential growth variation, and to observe how butter clam shells records local ambient water conditions in an inlet system that is prone to greater fluxes of freshwater than previous studies on the outer coast.

5.2.1. Live-collected samples

According to SST and precipitation data for the study region obtained from Ocean Networks Canada (2017) and Environment Canada (2016) in the year leading up to collection (July 2014-July 2015), precipitation spiked in October (160.6 mm) and February (122 mm) with the highest SST in September (9.9 °C) and the lowest in March (8.9 °C)[9] (Figure 5.14. D). This year seems to have been warmer than the previous year which was 1.4 °C colder with the coldest SST observed in February (7.5°C). Furthermore, in 2013 precipitation increased in March (150.2 mm) compared to February in 2014 suggesting a later onset of spring weather compared to the following year. Since SST has a strong control on $\delta^{18}O$ integration, the 1.4 °C SST change from 2014 to 2015 was expected to manifest itself in $\delta^{18}O_{shell}$. In SST reconstructions, a 1‰ change in $\delta^{18}O_{shell}$ is approximately equivalent to a 4.48°C SST change (Burchell et al. 2013a). Therefore, if the SIS specimens secreted in perfect isotopic equilibrium, a ~0.35‰ change would be observed between 2014 and 2015. However, since salinity also has a strong relationship with $\delta^{18}O_{shell}$ integration, an exact ~0.31‰ change was not expected. Further, due to higher precipitation occurring in the autumn, and spring snow and ice

[9] SST data comes from the nearest monitoring station in the Gulf of Georgia which monitors SST at a deeper depth and is therefore not representative of the true SST of the Sechelt Inlet System at the time but should reflect regional temperature variability.

melt, more negative $\delta^{18}O_{shell}$ peaks were expected to manifest between the most positive (winter) and most negative (summer) $\delta^{18}O_{shell}$ values.

Accordingly, $\delta^{18}O_{shell}$ results from the live-collected butter clam shells reflected these expectations (Figure 5.14. A-C). The most negative $\delta^{18}O_{shell}$ values were found at the ventral margin approaching a value of -5.98‰ in the Storm Bay shell and ~ -6.45‰ in the Highland Point and Salmon Inlet shells. The sample shown as closest to the ventral margin of the Storm Bay-collected shell is in actuality the second, as the first sample nearest the ventral margin was contaminated by LePage metal epoxy which gave it a very negative $\delta^{18}O_{shell}$ value. Had the sample not been contaminated, it would have maybe reached a $\delta^{18}O_{shell}$ value similar to the Highland Point and Salmon Inlet shells. The second milled sample from the ventral margin should still provide a summer value reached slightly prior to collection. Since ventral margin $\delta^{18}O_{shell}$ values represent growth soon before death, a $\delta^{18}O_{shell}$ value of ~ -6.45‰ should reflect seawater condition near timing of collection (Table 5.6.).

Table 5.6. Summarized seawater information for live-collected samples

Location	Salinity (PSU)	Temperature (°C)
Salmon Inlet	12-13	21.8
Highland Point	15-16	19.7
Storm Bay	16-17	19.8

The Salmon Inlet and Highland Point shells produced winter $\delta^{18}O_{shell}$ values for 2015 (~ -3.5‰) that were less positive than those representing winter 2014 (~ -2.6‰).

This (~0.9‰) difference is higher than the predicted difference of ~0.35‰, and demonstrates the strong salinity effects on $\delta^{18}O_{shell}$ in the SIS. This pattern is not observed in the Storm Bay-collected shell, most likely because this sample was younger (i.e., faster growth in younger specimens makes the same space sampled represent less time than in an older specimen) and had fewer discrete $\delta^{18}O_{shell}$ samples compared to the other live-collected shells. This reduced the temporal range sampled to one year of growth and therefore did not provide data for winter 2014 (Table 5.7.). More negative peaks in the $\delta^{18}O_{shell}$ profiles were found leading up to summer during the spring with $\delta^{18}O_{shell}$ values ranging from -4.5‰ to -5.6‰ The negative peaks likely resulting from autumn precipitation are less obvious in the live-collected shells but are well demonstrated in the Highland Point sample, providing a $\delta^{18}O_{shell}$ value of -4.2‰ (Figure 5.14. B). The closeness of $\delta^{18}O_{shell}$ values between both spring and autumn negative peaks demonstrates the importance of the trending values leading to the ventral margin recorded through high-resolution sampling and incremental structure alignment to determine seasonality.

Table 5.7. Number of $\delta^{18}O$ samples taken from live-collected Saxidomus gigantea using milling and drilling methods and, summarized maximum, minimum and ventral margin $\delta^{18}O_{shell}$ values (‰).

Location	Max.	Min.	Ventral margin	# milled	# drilled
Highland Point	-2.63	-5.98	-5.98	23	10
Storm Bay	-3.07	-6.44	-6.44	15	8
Salmon Inlet	-2.60	-6.45	-6.45	20	10

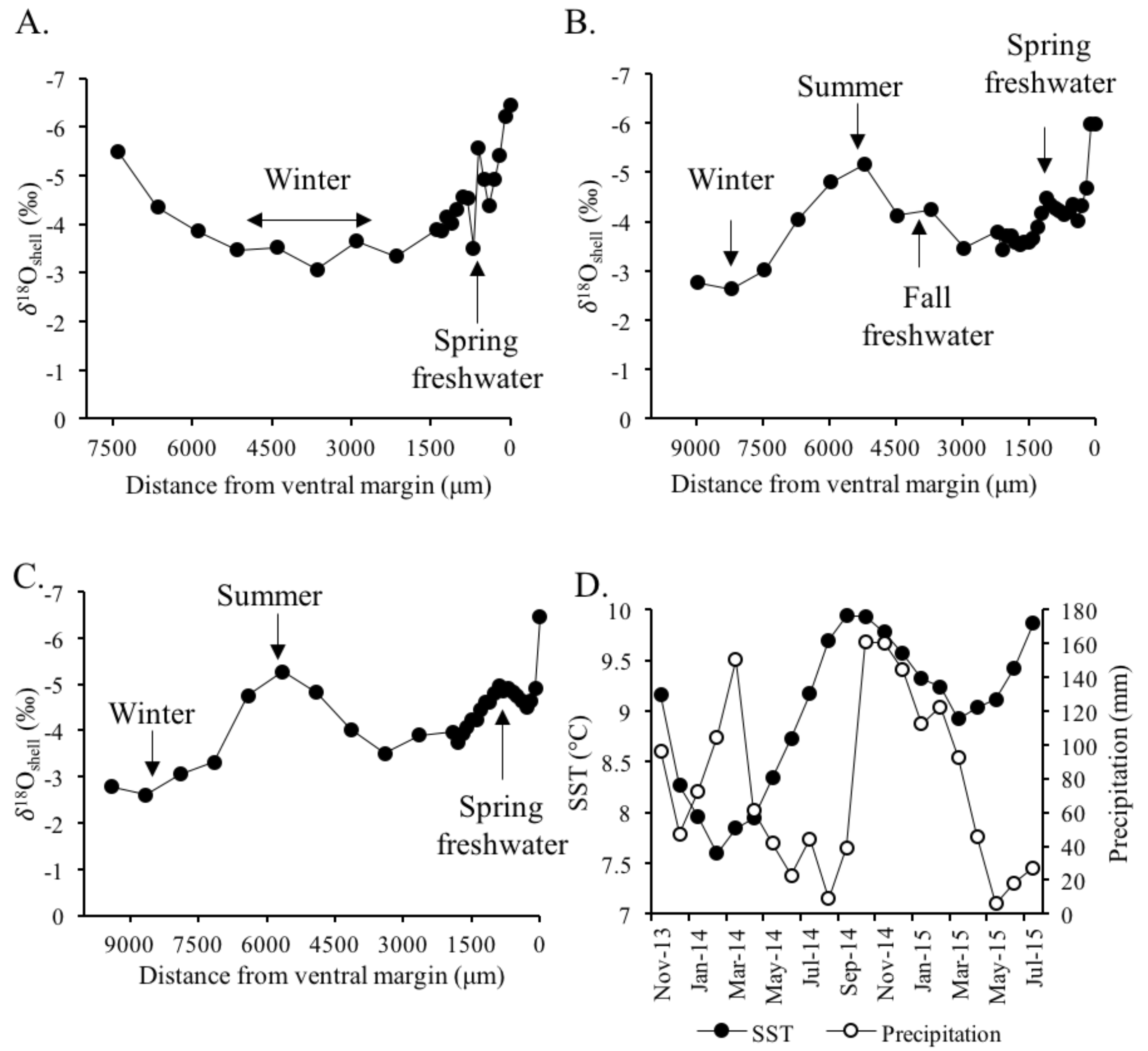


Figure 5.14. *A-C) $\delta^{18}O$ results from live-collected butter clams. A) Storm Bay; B) Highland Point; C) Salmon Inlet. D) Regional environmental data from November 2013 to July 2015. White circles indicate monthly precipitation provided by Environment Canada (2016). Black circles indicate average monthly SST provided by Ocean Networks Canada Data Archives (2017). The y-axis has been inverted to correspond with water temperature cycles with the most positive $\delta^{18}O$ values reflecting colder winter temperatures.*

All Mutvei-stained and non-stained live-collected shell cross-sections produced the most prominent macro-growth lines in the summer. While these shells were collected in the summer, they did not produce a strong macro-growth line at the ventral margin as the highest annual temperatures have not yet been reached. Based on this observation, it appears that butter clams in this region produce clear macro-growth lines during the winter and summer. In the past, macro-growth lines have been used as indicators of winter growth from which to infer seasonality (*see section 1.4.2.*). This evidence further shows how macro-growth line analysis for the purpose of determining seasonality would be problematic when working with butter clam shells from the SIS.

The Mutvei-stained thick sections show loosely packed LDGI near the ventral margin as a result from warmer temperatures, favorable conditions for fast shell growth (Figure 5.15.). Organic-rich micro-growth lines appear dark blue while increments appear light blue (Schöne 2005). At a 1000μm distance from the ventral margin, narrower LDGI were observed coinciding with a light blue colour in the Mutvei-stained shell (packed increments) and a dark translucent macro-growth line in the un-stained shell. This tighter bundle of LDGI were aligned with a smaller negative $\delta^{18}O$ peak (-4.45‰ - -5.57‰) than summer peaks (-5.98‰ - -6.0‰) likely demonstrating an increase in freshwater input and temperature in the spring since growth lines have been aligned to freshwater influx in the spring (Burchell 2013:21). This suggests that in some cases macro-growth lines and tighter LDGI are deposited when increased freshwater disrupted growth. Notably, this tightening of LDGI was also observed at the height of summer and winter, and were therefore not able to singularly clarify differences between freshwater input and summer $\delta^{18}O$ values in the SIS (Figure 5.16.). In the modern Storm Bay-collected shell, 251 LDGI were counted from summer 2015 to summer 2014. Time was anchored by summer growth lines paired with $\delta^{18}O$ summer values, suggesting around 4 months of growth shutdown.

Shellfish surveys in BC suggested that butter clams from the southern coast grew at a faster rate than those found in northern regions; butter clams from the Salish Sea reached a senile stage of growth after four to five years in comparison to the central and northern coasts where they reached senility after six to ten years (Gillespie and Bourne 2005a:25, b; Quayle and Bourne 1972:30). However, these surveyors from the Department of Fisheries and Oceans Canada determined senility based on shell size. More recent studies utilizing LDGI, which are better recorders of time than size measurements, also demonstrated coastal shell growth variability in BC (Burchell et al. 2013c; Hallmann et al. 2009). Butter clams from the Alaskan coast were shown to stop growing for multiple months per year, only depositing 170 ± 18 LDGI /year, less growth cessation months were observed in butter clams from the central coast, depositing 226 ± 40 LDGI/year, while butter clams from Pender Island on the southern coast were shown to grow year-round, depositing on average 321 ± 22 LDGI/year (Hallmann et al. 2009:2359; Burchell et al. 2013c:266). This data demonstrated that butter clam shells from the southern coast grew faster than those from the northern coast. However, only approximately 251 LDGI were counted for one year of growth in Storm Bay, numbers more similar to those produced on the central coast, than those produced on Pender Island. Further, LDGI widths showed a high degree of variability during the year prior to collection and were unable to demonstrate annual cycles (Figure 5.17.).

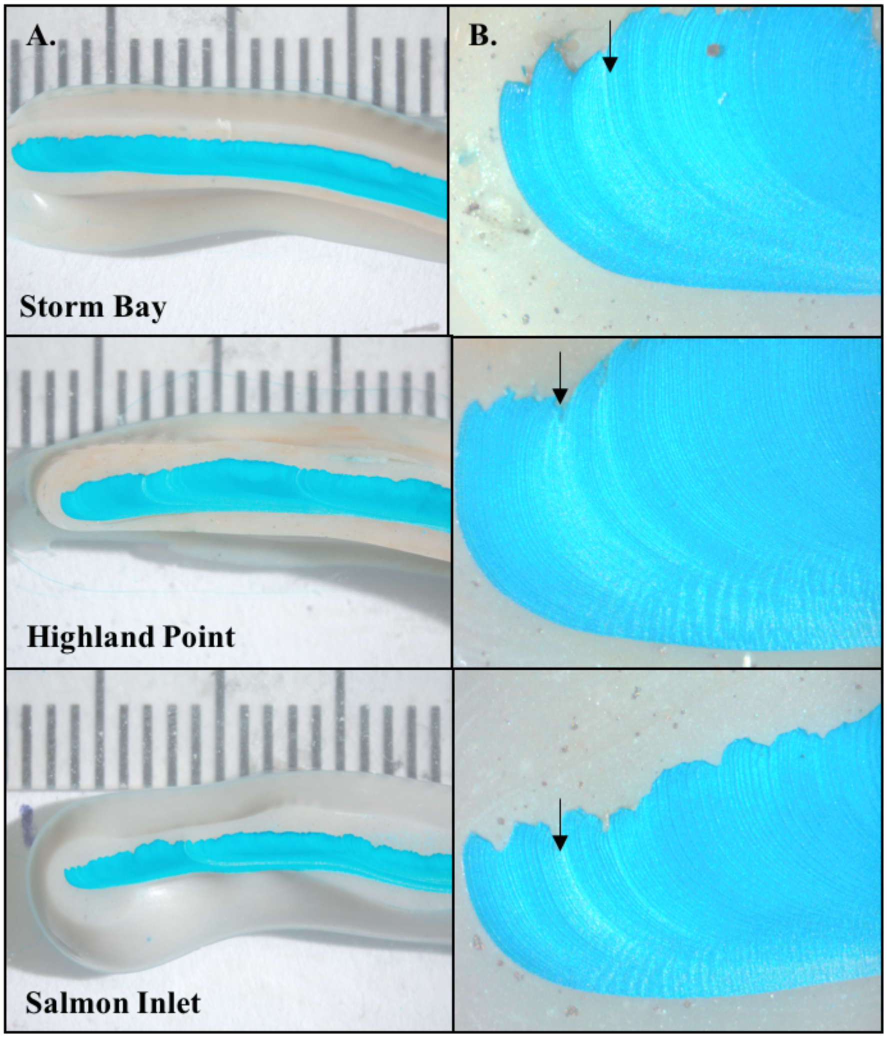


Figure 5.15. *A) Live-collected shells with Mutvei staining; B) magnified ventral margin (5X) with arrows indicating slow growth period in the spring.*

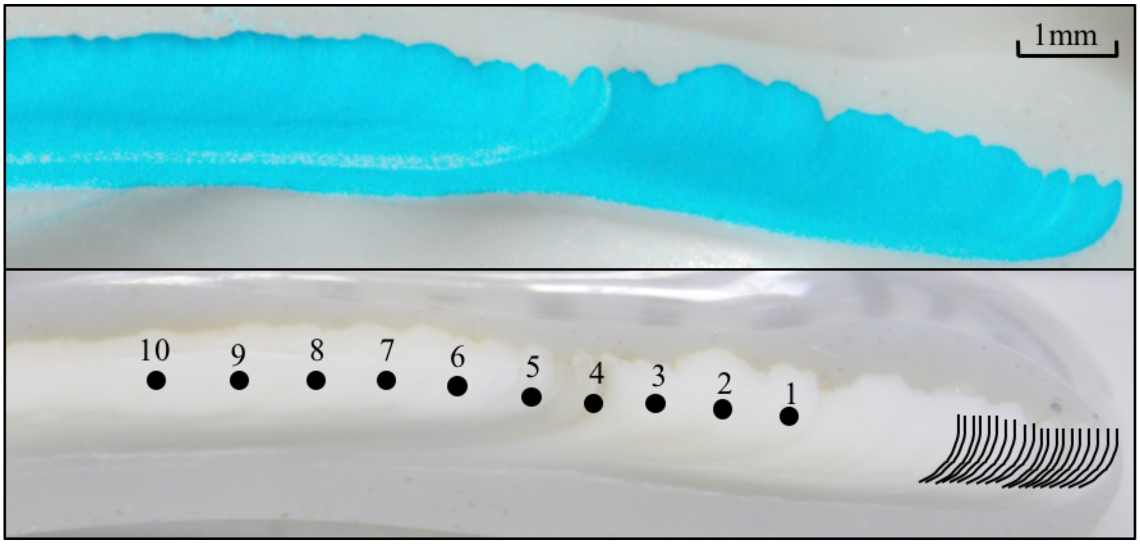


Figure 5.16. *Mutvei stained (top) and unstained (bottom) live-collected butter clam from Salmon Inlet with sampling procedure. The curved lines represent milled samples and circles represent drilled samples. The fourth drilled sample in the opposite direction of growth is taken on a macro-growth line which gave a value of -5.3 ‰, which was interpreted as an averaged value for the summer prior to collection.*

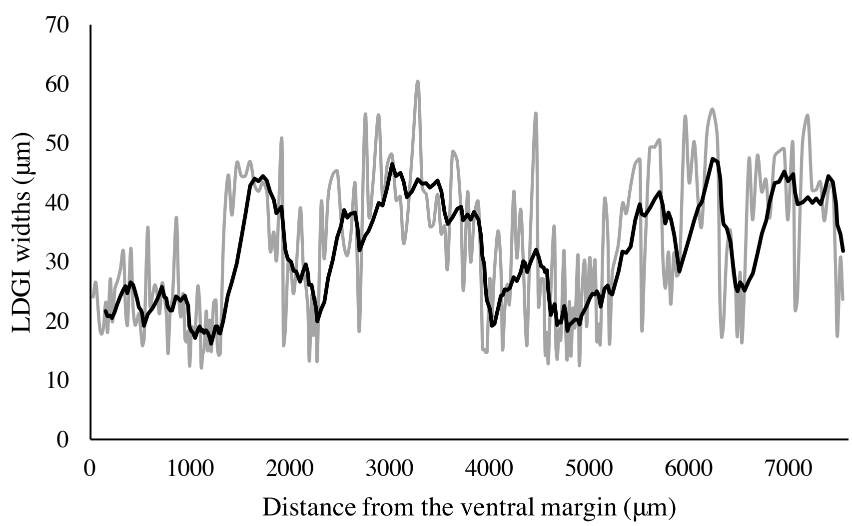


Figure 5.17. *Lunar daily growth increment (LDGI) measurements accounting for one year in the Storm Bay-collected shell.*

The comparable minimum, maximum, and ventral margin $\delta^{18}O_{shell}$ values in the three live-collected shells demonstrate low inter-specimen variability for $\delta^{18}O$ integration for shells from different parts of the SIS. Therefore, shells that have historically been harvested from different beaches in shíshálh lands should report similar seasonal trends, but also show variability based on their location of collection. The live-collected shells further support the methodological approach of using a combination of LDGI, macro-growth lines and $\delta^{18}O$ analysis to determine the season of death of the archaeological shells.

The seasonal $\delta^{18}O_{shell}$ trends in the live-collected shells were used to frame seasonality determinations from the archaeological shells. Shells with ventral margin $\delta^{18}O_{shell}$ values trending towards more positive $\delta^{18}O_{shell}$ values with evidence of recent freshwater influx based on observations of small peaks driving $\delta^{18}O_{shell}$ values negatively without reaching summer values and ventral margin $\delta^{18}O_{shell}$ values nearing -2.5‰ were interpreted as winter-collected. Shells that reach more negative $\delta^{18}O_{shell}$ values nearing -6.0‰ and have evidence of preceding freshwater peaks perceived to be the result of spring conditions were interpreted as summer-collected shells. Shells with evidence of more positive (i.e., winter) $\delta^{18}O_{shell}$ values followed by the beginning of a negative peak leading towards the ventral margin were interpreted as early spring-collected shells. Shells that surpass this initial peak (< -3.5‰) and have ventral margin $\delta^{18}O_{shell}$ values nearing -4.0‰ are interpreted as spring-collected shells. Shells that have $\delta^{18}O_{shell}$ values declining from the mid-spring peak towards the ventral margin without reaching summer values were interpreted as late spring-collected shells. Lastly, shells which have ventral margin $\delta^{18}O$ values trending positively following a summer peak were interpreted as autumn-collected shells. Early autumn-collected shells were identified through the observation of positively trending $\delta^{18}O_{shell}$ values towards the ventral margin following negative summer values and the absence of negative $\delta^{18}O_{shell}$ peaks as a result of autumn rains.

5.2.2. Archaeological samples

Seasonal fluctuations identified in modern shells were also exhibited in archaeological shells, such as strong spring $\delta^{18}O_{shell}$ negative peaks and weaker autumn $\delta^{18}O_{shell}$ peaks (Figure 5.18.). Furthermore, the range (amplitude = Δ) of $\delta^{18}O_{shell}$ values covered by all analyzed archaeological shells (Δ=5.45‰) was slightly larger than the range covered by live-collected shells (Δ=3.85‰) with $\delta^{18}O$ values ranging between -1.45‰ and -6.9‰. In addition, the amplitude of $\delta^{18}O_{shell}$ within each site was also different with an amplitude of 5.36‰ at Porpoise Bay (-2.08‰ to -6.81‰), 4.83‰ at Storm Bay (-1.45‰ to -6.28‰), and 5.13‰ at Tzoonie Narrows (-1.77‰ to -6.9‰). The observed differences in $\delta^{18}O_{shell}$ amplitude within the archaeological communities and between archaeological and live-collected samples likely results from multiple factors that influence the isotopic composition of bivalves. Specifically: a) the temporal range represented; b) slightly different seawater and food supply conditions differentially affecting $\delta^{18}O_{shell}$ incorporation. Similar to the modern live-collected shells, strong macro-growth lines in the archaeological shells were often observed in tandem with the most positive and negative values likely as a result of colder (winter) or warmer (summer) seawater temperatures. In addition, lighter disruption lines co-occur with less intense negative peaks likely as a result of higher freshwater input in the spring and autumn. In the archaeological shells, 8 to 15 discrete isotope samples were taken with an average of 9 milled and 5 drilled samples per shell, which accounted for at least one year of growth in most shells. Since 10 shells from each site were analyzed, interpretations of spatial and temporal seasonal differences within the site must be treated with caution since these sites hold un-quantifiable individual shell fragments (e.g., > 1 million) and 10 shells from a restricted space within a large site will highlight variability and season emphasis, but not be sufficient evidence to confidently discuss changing seasonal practices and occupation (Cannon and Burchell 2016).

The archaeological specimens from all four sites show a pattern of multiple seasons of collection, but each site showed emphasis on a specific season (Figure 5.19., Table 5.8.). Spring was the dominant season in Porpoise Bay and Storm Bay, and spring/summer were the dominant seasons at the Tzoonie Narrow's site. Fifty-seven per cent of archaeological specimens were interpreted as spring-collected shells (n=17) and 17% were collected in the summer (n=5). The autumn- (n=4) and winter-collected shells (n=4) were the least represented, each comprising 13% of all analyzed archaeological shells, with autumn-collected shells often (3/4 autumn-collected shells) found in the deepest layers of midden (*for all* $\delta^{18}O_{shell}$ *profiles and determinations, see Appendix 2*).

5.2.2.1. Porpoise Bay

All four seasons were identified at DjRw-1 (Table 5.9.). There was a higher frequency of shells collected in the spring (n=6) with half specified to an early spring collection (n=3), followed by a secondary emphasis on winter (n=2). Summer- (n=1) and autumn-collected shells (n=1) were the least represented. Seasonality profiles from shells

Table 5.8. Summary of archaeological $\delta^{18}O$ samples and season of death determinations.

Site	Shell ID	Unit	Layer/ Auger Depth	# milled	# drilled	Season of death
Porpoise Bay						
DjRw-1	1D	N78 E68	A	10	5	Spring
	3D	N78 E68	B	10	5	Summer
	4D	N78 E68	C	10	4	Winter
	6D	N78 E68	G	10	5	Winter
	19D	N79 E68	Ka	8	5	Autumn
	7D	N80 E68	Kc	10	5	Spring
	10D	N80 E85-86	B	10	5	Early Spring
	11D	N80 E85-86	C	10	5	Early Spring
	12D	N80 E85-86	D	10	5	Early Spring
	14D	N80 E85-86	E	9	5	Early Spring
Storm Bay						
DkRw-22	5D	D	J	9	5	Spring
	8D	D	J	9	7	Late Spring
DjRw-18	18D	AT 2010-016	1-21 cm	10	5	Winter
	9D	AT 2010-016	21-37 cm	10	5	Winter
	1D	AT 2010-016	21-37 cm	1	7	Spring
	2D	AT 2010-016	37-46 cm	10	5	Spring
	3D	AT 2010-016	37-46 cm	10	5	Spring
	12D	AT 2010-016	46-53 cm	10	5	Spring
	13D	AT 2010-016	46-53 cm	10	5	Spring
	15D	AT 2010-014	73-80 cm	6	5	Autumn
Tzoonie Narrows						
DkRw-26	3D	A	C	10	5	Late Spring
	19D	2010-001	0-21 cm	3	7	Spring
	20D	2010-001	21-35 cm	10	5	Summer
	5D	2010-001	35-48 cm	10	5	Summer
	6D	2010-001	48-59 cm	10	5	Early Summer
	8D	2010-001	94-105 cm	10	5	Early Autumn
	11D	2010-002	21-40 cm	10	5	Early Autumn
	12D	2010-002	40-48 cm	7	6	Spring
	15D	2010-002	54-60 cm	9	6	Spring
	18D	2010-002	60-68 cm	9	5	Summer

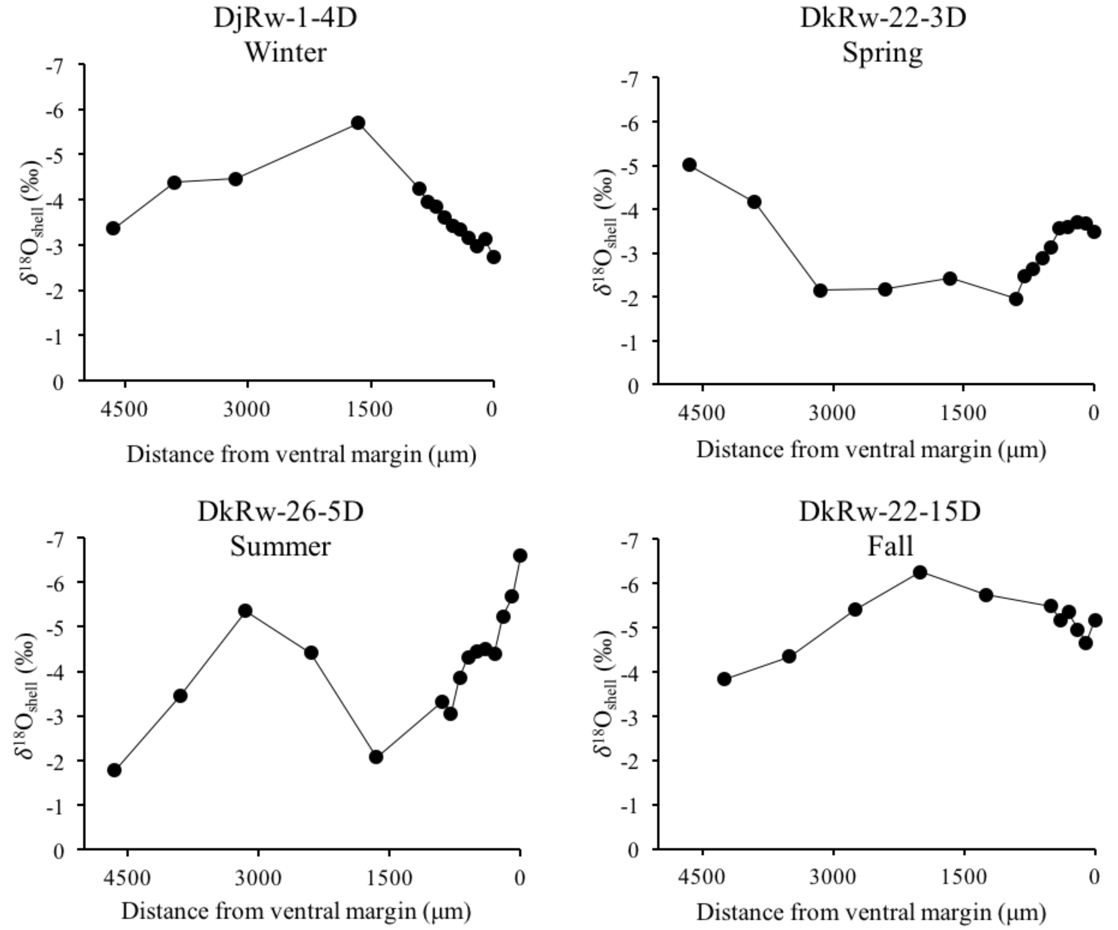


Figure 5.18. *Four seasons represented through isotope profiles from archaeological shells.*

recovered from the N78-80 E68 trench are more variable than the N80 E-85-86. In trench N78 80 E68 all four seasons are represented with an equal emphasis on winter- and spring collected shells. Included were two winter-collected shells which produced their most negative values (-2.74‰ and -2.39‰) at the ventral margin indicating early or peak winter conditions (Figure 5.20.), and an autumn-collected shell found in layer K, the deepest layer (170-180 cm DBS). Spring is the only season represented in trench N80 E-85-86, with three out of the four shells interpreted as early spring-collected.

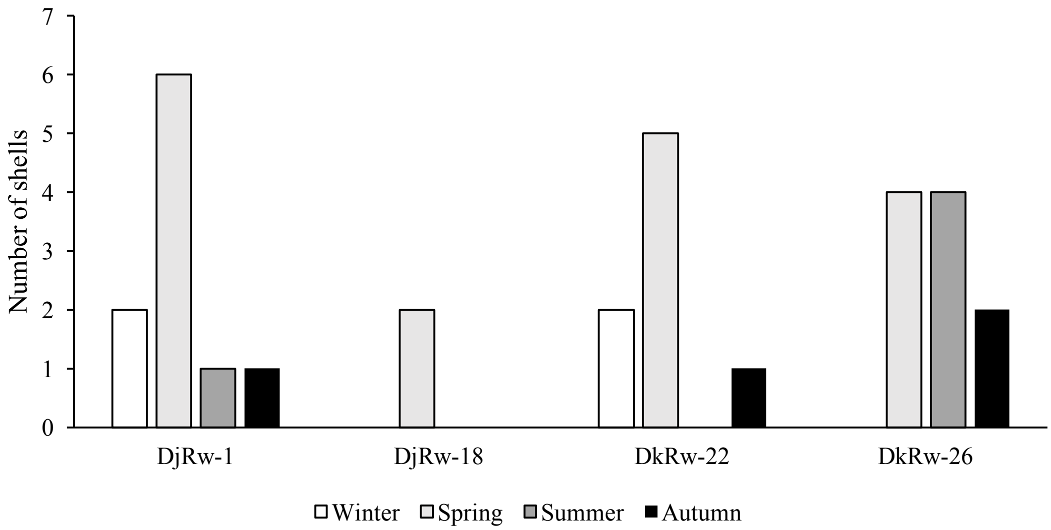


Figure 5.19. *Season of death determinations by site based on $\delta^{18}O$ analysis. For sub-seasonal determinations see tables 5.9., 5.10., and 5.11.*

Table 5.9. ***Summary of DjRw-1 butter clam $\delta^{18}O$ samples and values (‰).***

Shell ID	Max.	Min.	Ventral Margin	Season of death
1D	-3.04	-6.81	-4.34	Spring
3D	-2.68	-6.66	-6.66	Summer
4D	-2.74	-5.68	-2.74	Winter
6D	-2.39	-4.46	-2.39	Winter
19D	-3.36	-5.71	-3.36	Autumn
7D	-2.25	-5.57	-3.47	Early Spring
10D	-2.16	-6.23	-3.13	Early Spring
11D	-2.21	-4.84	-3.07	Early Spring
12D	-3.00	-5.54	-4.03	Early Spring
14D	-2.08	-4.66	-2.92	Early Spring

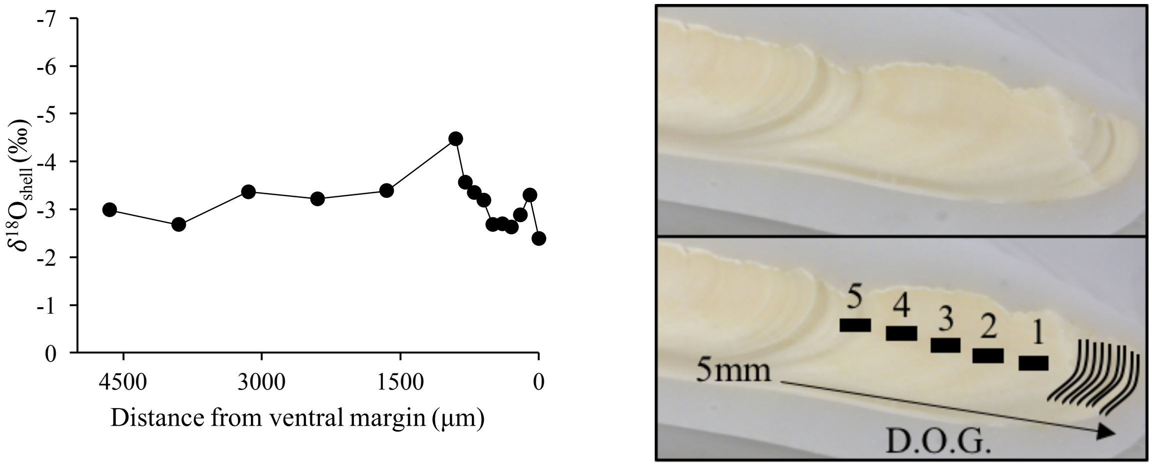


Figure 5.20. *The $\delta^{18}O$ value at the ventral margin (-2.39‰) nears the maximum value reached in the live-collected shells (~ -2.6‰), which was achieved during winter growth. A preceding more negative peak was likely caused by increased precipitation in the late autumn or early winter leading up to winter collection. This was a young specimen with less than a year sampled. D.O.G. = direction of growth.*

5.2.2.2. Storm Bay

Spring is the dominating season at both formal camp sites, DjRw-18 and DkRw-22. In total, seven were determined to be spring-collected, two were winter-collected, and one was autumn-collected (Table 5.10.). Only two shells from DkRw-22 were analyzed and they were both from the same layer since other layers did not yield criteria-fitting shells. Both were determined to be spring-collected shells. DjRw-18, which had more shells and contexts analyzed, provided more variable seasonality profiles. While DjRw-1 showed year-round collection, together DjRw-18 and DkRw-22 demonstrated sub-annual collection. However, although 10 shells were analyzed from Storm Bay, the results cannot confirm that shells were never harvested here in the summer. Following my theoretical framework, people living at the Tzoonie Narrows site may have brought butter clams from Storm Bay to their site for processing during the summer.

Table 5.10. Summary of DkRw-22 and DjRw-18 butter clam $\delta^{18}O$ samples and values (‰).

Shell ID	Max.		Ventral Margin	Season of death
DkRw-22				
5D	-2.77	-4.58	-4.00	Spring
8D	-2.42	-6.28	-4.71	Late Spring
DjRw-18				
18D	-1.45	-5.12	-1.96	Winter
9D	-1.56	-4.43	-2.28	Winter
1D	-2.04	-5.07	-4.43	Spring
2D	-2.07	-4.46	-3.64	Spring
3D	-1.96	-5.01	-3.50	Spring
12D	-2.36	-5.07	-3.22	Spring
13D	-1.90	-4.15	-4.15	Spring
15D	-3.82	-6.25	-5.17	Autumn

In AT 2010-016, winter was the dominating season in the upper layers, shifting towards exclusively spring in the lower layers from 21-37 cm to sterile soil. The only shell identified as autumn-collected was recovered from the deepest layer in AT 2010-014 (73-80cm). In addition, shell 18D provides evidence of a mid-winter-collected shell with the most negative $\delta^{18}O_{shell}$ value corresponding to the second sample closest to the ventral margin (-1.45‰) (Figure 5.21.).

5.2.2.3. Tzoonie Narrows

The 10 analyzed shells from DkRw-26 differ in their results from the other sites because of the higher frequency of summer-collected shells or shells collected during warmer seasons such as samples 3D, which was interpreted as a late-spring collected

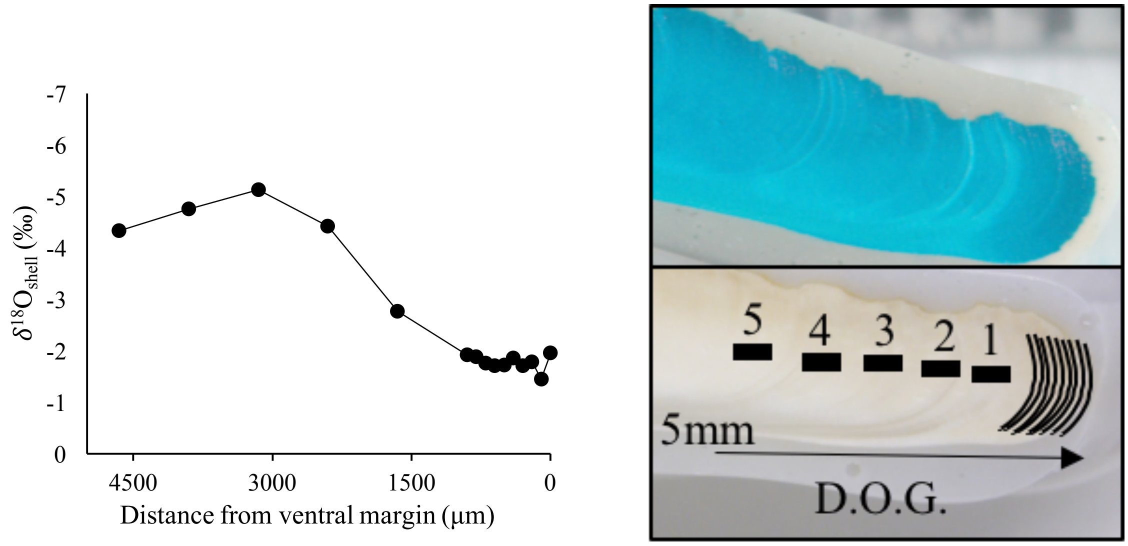


Figure 5.21. *Sample 18D from DjRw-18 was interpreted as a winter-collected shell because the $\delta^{18}O$ values at the ventral margin were positive from the cold seawater in the winter and trend towards more positive $\delta^{18}O$ values from the most negative value which was taken on a macro-growth line. D.O.G. = direction of growth.*

shell and, 8D and 11D which were interpreted as early autumn-collected shells (Figure 5.22., Table 5.11.). In total, three shells were spring-collected, one late spring-collected, one early summer-collected, three summer-collected, and two early autumn-collected. In addition, unlike the three other archaeological communities investigated, no shells were interpreted as being winter-collected.

The $\delta^{18}O_{shell}$ data alone does not suggest seasonal differences between the two auger tests (1 spring-collected shell, 2 summer-collected, 1 early summer-collected, and 1 early autumn-collected shell in AT 2010-001 and, 2 spring-collected, 1 summer-collected, 1 early autumn-collected shell in AT 2010-002) or between auger tests and excavation Unit A (1 late-spring collected shell) (Table 5.8.).

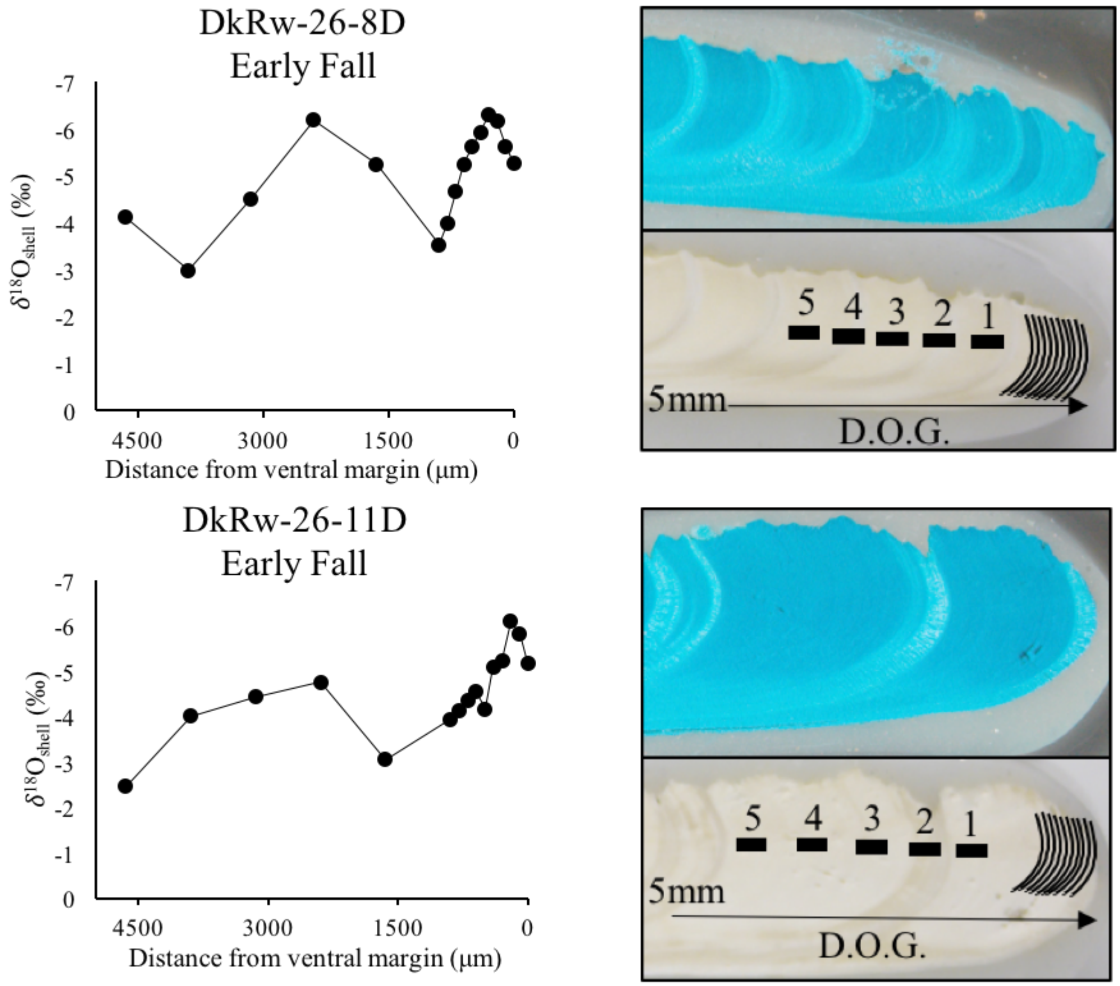


Figure 5.22. *Samples 8D and 11D from DkRw-26 were interpreted as an early autumn-collected shells because $\delta^{18}O$ values trend towards positive $\delta^{18}O$ values after a peak at the fourth and third milled samples with ventral margin values of -5.26‰ and -5.18‰, respectively. D.O.G. = direction of growth.*

Table 5.11. Summary of DkRw-26 butter clam $\delta^{18}O$ samples and values (‰).

Shell ID	Max.	Min.	Ventral Margin	Season of death
3D	-1.99	-4.97	-4.32	Late Spring
19D	-2.10	-4.97	-4.72	Spring
20D	-2.09	-4.88	-4.49	Summer
5D	-1.77	-5.39	-5.39	Summer
6D	-2.01	-5.71	-5.71	Early Summer
8D	-2.99	-6.30	-5.26	Early Autumn
11D	-2.46	-6.09	-5.18	Early Autumn
12D	-2.48	-6.30	-4.42	Spring
15D	-2.43	-4.72	-4.63	Spring
18D	-3.13	-6.90	-6.90	Summer

CHAPTER 6

FLEXIBLE SHELLFISH HARVESTING AND SEASONALITY

The butter clams from shell middens and shell-bearing deposits in the SIS investigated in this thesis have showed an intensive shellfish harvesting pattern and a year-round occupation of shíshálh lands. Intra- and inter- midden variability suggested heterogeneous shellfish harvesting patterns that may be indicative of certain resource conservation methods. $\delta^{18}O_{shell}$ evidence from DjRw-1 in Porpoise Bay has provided supporting evidence for the continuous occupation of large villages in the SIS. Formal camps and inlet village in Tzoonie Narrows further north in the SIS demonstrated- seasonal occupation. While, these patterns are similar to previous seasonality interpretations (Coupland et al. 2012; Letham 2014), seasonality results suggest a seasonal move between Tzoonie Narrows and the Porpoise Bay sites and a mid-winter presence in Storm Bay, two previously non-recorded seasonal patterns, suggesting that settlement patterns in the SIS may have been flexible.

Within a fluid landscape facilitated by boat travel, shellfish remains found in shell middens and shell-bearing deposits in the SIS were thought of as having the potential of coming from any of the nearby beaches, while acknowledging the landscape's ecological constraints on butter clam-suitable beach distribution within shíshálh lands. This is contrary to the general assumption made in other studies that investigated shellfish diversity, that shell middens are the product of harvesting beaches directly adjacent to sites (e.g., McLay 1999; Mackie and Sumpter 2005). By viewing the landscape as fluid and not partitioning certain areas into seasonal boxes, the landscape was conceptually viewed as a "community" with possible societal or cultural partitioning in the form of hereditary rights to access specific clam beds (Moss 1993).

6.1. Contribution to the food economy

According to Barnett (1955), clams were one of four principal resources important to Coast Salish peoples, however his ethnographic records were noticeably lacking information on the shellfish harvesting process (*see section 2.1.4.*). For the shíshálh, butter clams seem to have been a particularly important resource since macro-growth line analysis suggested an intense pattern of shellfish harvesting irrespective of site type, three of which were investigated here: large village (DjRw-1), inlet village (DkRw-26), and formal camps (DjRw-18 and DkRw-22). The difference between the younger shell proportion (sum of mature and juvenile proportions) and the senile shell proportions at each site is substantial with younger shell proportions ranging between 87% and 77% and senile proportions ranging between 23% and 13%. This evidence is disproportionate to what was recorded ethnographically about shellfish resources among the Coast Salish peoples. Accordingly, this supports Moss' (1993) and Claassen's (1991a) arguments on the depreciation of shellfish resources in the ethnographic record perpetuated in archaeology which deemed shellfish as low value resources (Claassen 1991a; Moss 1993; Osborn 1977).

6.1.1. Variability in the Sechelt Inlet System and beyond

These results are unique when compared to previous results from the central and northern coasts, where village sites showed a pattern of lower shellfish harvesting intensity than camp sites, or mainland sites showed a pattern of lower shellfish harvesting than island sites, respectively (Burchell et al. 2013a;b; Cannon and Burchell 2009). On the central coast, higher intensity of shellfish harvesting occurred at camp sites, especially the identified specialized shellfish harvesting camp (ElTa-25), whereas lower shellfish harvesting intensity occurred at village sites (Cannon and Burchell 2009). Conversely, none of shíshálh sites investigated in this thesis showed evidence of low shellfish harvesting intensity, however inter-site variability was found. DkRw-22 and DjRw-18 had low sample sizes and therefore no statistical differences were found between them. However, a Fisher's Exact two-tailed test showed that there was a statistically significant ($p < 0.05$) difference between senile and younger growth stage proportions at the large village site DjRw-1 and the inlet village DkRw-26 ($p=0.0238$), which had similar proportions to DkRw-22 and DjRw-18. Cannon and Burchell (2009:1059) argued that low shellfish harvesting intensity at large residential sites or village sites on the central coast suggested possible "active conservation efforts". The situation in shíshálh lands seems to be different from that of the central coast firstly, because all the sites showed evidence of intensive shellfish harvesting irrespectively to the site type in question and secondly, because the large village site had a statistically higher younger clam growth stage proportion than the smaller inlet village.

6.1.2. Juvenile proportions: Interpretation and considerations

Juvenile specimens were found at all sites. This supports the interpretation that intense shellfish harvesting was performed on shíshálh lands, because juvenile specimens would have provided less meat than mature or senile specimens, and would therefore have been less desirable to collect as a first choice. Small butter clams have the ability to re-burrow in the sand after being dug up and survive until their next harvest (Quayle and Bourne 1972:27). Therefore, if juvenile clams were collected by ancestral shíshálh, they could have been placed back on the beach to re-burrow until they were mature or older as a way to manage these resources. The presence of juveniles could be a result of ancestral shíshálh choosing to collect clams whether they were juvenile or not, or choosing to continue collecting shellfish while the population dynamics were becoming younger due to intense harvesting since juveniles would become increasingly common in shellfish beds.

Additionally, their presence could be attributed to children collecting and/or accidental collecting. Children from other coastal cultural groups have been observed accompanying their mothers to collect shellfish (Bird and Bliege Bird 1997). Furthermore, younger butter clams have been observed to burrow at shallower depth than older butter clam specimens (Quayle and Bourne 1972), and would have been easier for children to retrieve. If ancestral shíshálh children accompanied their parent(s) during this activity, children may also be responsible for the presence of some juvenile specimens in shell deposits. Currently, this question remains unresolved. However, in the following section, an increase in juvenile proportions was shown to correlate with other indicators of increasing intensity such as density, suggesting that an increase in juvenile proportions can in some cases suggest increasing harvesting intensity (*see section 6.2.1.2.*).

6.2. Resource management

It is important to note that evidence suggestive of intensive shellfish harvesting at the shíshálh sites does not necessarily indicate that ancestral shíshálh did not manage or protect their resources through the incorporation of different strategies. Smith and Wishnie (2000) argued that purposeful resource management was strictly possible in circumstances where there is exclusive ownership of resources. Accordingly, hereditary ownership of productive clam beds on the Pacific Northwest Coast, which has been discussed by Wessen (1982) and others (Moss 1993:635; also see Jenness n.d. in Matson et al. 1999:34) might have been an incentive not only to produce a high amount of butter clams but also to practice resource management. Clam gardens have been proposed as one method of clam bed management elsewhere on the coast (Groesbeck 2014; Williams 2006), and have been reportedly found in the SIS and interpreted as one method of butter clam management (Letham 2014). In addition, Raquel Joe, Curator of the tems swiya Museum in Sechelt, BC, explained that beach cycling was practiced on shíshálh lands in the past where shíshálh would cycle between different beaches to collect clams (personal communication 2017). Yesner (1987:293) also suggested that clam beds could be left fallow to allow the clam population to regenerate. Accordingly, DjRw-1, DjRw-18, and DkRw-26 all showed evidence of deposits that yielded less shells which also had higher proportions of senile specimens. This may be evidence for the fallowing of clam beds. However, it might also be evidence of switching to a different shellfish bed or choosing to deposit shellfish in a different location. Unfortunately, it is difficult to see beach cycling as a resource conservation method archaeologically in shell deposits because of their palimpsest nature which makes it difficult to distinguish specific shellfish deposition events without radiocarbon dating every shell (*for more details on shell-bearing and shell midden deposition, see section 1.3.*). However, following resource conservation theory discussed by Smith and Wishnie (2000), shellfish remains in shell middens would still have been sensitive to resource management strategies had they been utilized. Therefore, stratigraphic differences seen in shell midden deposits have the potential to archaeologically support shíshálh beach cycling.

Two particular types of beach cycling will be discussed in this section. The first, beach-switching, akin to patch-switching**,** is described as the practice of rotating harvesting locations to increase productivity or as a strategy to continue high harvesting intensity and not allow resources to become depleted. In this case, the species of interest for the harvesters may not change between different harvesting locations. This is not unique to the Pacific Northwest Coast and has been seen in many other cultures. For instance, the Three Sisters agricultural system was used by the Seneca and other North American cultures, which involved strategic field switching, as a means to spread out yields (Lewandowski 1987). The second, species cycling, is described as the practice of switching harvesting energy to a different species, which might have involved sticking to the same general location but to a different patch with a different resource. For instance, stratigraphic evidence from Ozette, the large Coast Salish village in northern Washington, showed gradual decrease of mussel density in middens with simultaneous increase in littleneck clam densities (Wessen 1988:199). However, in this case, the change was interpreted as a response to changing economics during historical times, not resource conservation methods.

6.2.1. Statistical analyses

While excavations of the two base camp sites (DjRw-18 and DkRw-22) provided relatively small amounts of butter clam fragments for macro-growth line analysis (n=70 and n=35, respectively), the large village site DjRw-1 and the inlet village DkRw-26 provided larger sample sizes to conduct Fisher's Exact two-tailed tests ($p < 0.05$) to provide some information on variability in senile to mature and juvenile proportions which could begin to shed light on butter clam resource management strategies.

6.2.1.1. DjRw-1, large village site

DjRw-1's excavation unit N78-80 E68 (n=167) contained mostly mature shells in its deepest layer, Kc (n=27/28) (*for proportions and figure, see section 5.1.*). In the following layers Ka and G, juveniles appeared and increased from 7% to 28% (n=1/14 to n=5/18) and mature proportion decreased from 79% to 50% (n=11/14 to n=9/18). This appeared to be the product of increasing shellfish harvesting activities. No statistically significant differences were found between mature and juvenile proportion in layer Ka and Kc, while there was a statistical difference ($p < 0.05$) found between layers Kc and G (p=0.0027) (Table 6.1.), suggesting intensifying shellfish harvesting.

The subsequently deposited layers did not yield any analyzable shell fragments and layer C also did not contain many shells (n=2), possibly as a result of letting the shellfish beds fallow for a period of time to recover their senile populations. This is strengthened by a statistically significant ($p < 0.05$) increase in the senile proportion in relation to the younger shell proportion in layer B from layer Kc (p=0.0045). In layer B (n=16), the mature, juvenile, and senile proportions are relatively close (38%, 31% and 31%, respectively), suggesting that shellfish harvesting had de-intensified since the first layers had been deposited (i.e., Kc). This was followed by an increasing mature

Table 6.1. Probabilities for two-tailed Fisher's exact tests conducted on the distribution of clams between mature and juvenile shells in pairwise comparisons between excavated layer in unit N78-80 E65 at DjRw-1 (probabilities < 0.05 in bold).

	Later					Earlier
	Layer A n = 78	Layer B n = 11	Layer C n = 2	Layer G n = 14	Layer Ka n = 12	Layer Kc n = 27
Layer A		0.1585	1.0000	0.5085	0.2871	**0.0028**
Layer B			1.0000	0.6968	0.0686	**0.0009**
Layer C				1.0000	1.0000	1.0000
Layer G					0.1696	0.**0027**
Layer Ka						0.3077
Layer Kc						

proportion in layer A (66% mature), which was statistically significant ($p < 0.05$) when comparing mature to senile proportions (p=0.0281).

Table 6.2. Probabilities for two-tailed Fisher's exact tests conducted on the distribution of clams between younger and senile shells in pairwise comparisons between excavated layer in unit N78-80 E65 at DjRw-1 (probabilities < 0.05 in bold).

	Later					Earlier
	Layer A n = 88	Layer B n = 16	Layer C n = 2	Layer G n = 16	Layer Ka n = 14	Layer Kc n = 27
Layer A		0.0526	1.0000	1.0000	0.6683	0.1137
Layer B			1.0000	0.3944	0.3992	**0.0045**
Layer C				1.0000	1.0000	1.0000
Layer G					1.0000	0.1329
Layer Ka						0.1110
Layer Kc						

6.2.1.2. DkRw-26, inlet village site

At DkRw-26, the two auger tests showed opposing trends, one of intensifying (AT 2010-001, n=167) and the other of de-intensifying (AT 2010-002, n=163) shellfish harvesting activities (*for figures and tables, see section 5.1.4.*). Auger test levels depths were arbitrarily separated during surveying and were not comparable to excavated layers, therefore only auger test data will be discussed in this section since they provided larger sample sizes for statistical analysis. Furthermore, while auger test levels are arbitrarily separated into different depth sections the two opposing trends observed in the auger test samples were observed from the bottom to the top of the auger test, and should therefore be considered.

6.2.2. Increasing harvesting intensity and species switching

In AT 2010-001, a statistically significant ($p < 0.05$) increase in senile proportions compared to younger shell proportions was found between 94-105 cm and 82-94 cm suggesting either a preceding period of de-intensified shellfish harvesting or switching to a different beach ($p=0.0412$; Table 6.3.). The trend of increasing harvesting intensity was observed in the subsequently deposited layers when comparing mature and juvenile proportions.

Juvenile proportions significantly increased and mature proportions significantly decreased when comparing material deposited 0-35 cm DBS and layers previously deposited below suggesting increasing harvesting intensity. There were statistically significant differences ($p < 0.05$) between proportion in 0-21 cm and 48-59 cm ($p=0.0062$), 59-75 cm ($p=0.0031$), and 94-105 cm ($p=0.0039$), as well as between 21-35 cm and 48-59 cm ($p=0.0031$), 59-75 cm ($p=0.0019$), and 94-105 cm ($p=0.0046$) (Table 6.4.). This increasing intensity of butter clam harvesting followed a similar pattern to previously discussed shellfish analyses conducted on AT 2010-001 that examined

Table 6.3. Probabilities for two-tailed Fisher's exact tests conducted on the distribution of clams between younger and senile shell proportions in pairwise comparisons between auger test depths (cm) in AT 2010-001 (probabilities < 0.05 in bold).

	Later					Earlier			
Depths (cm)	0-21 n = 20	21-35 n = 32	35-48 n = 24	48-59 n = 29	59-75 n = 15	75-82 n = 12	82-94 n = 9	94-105 n = 9	105-110 n = 2
0-21		1.0000	1.0000	0.4800	0.2400	1.0000	0.1581	0.5320	1.0000
21-35			1.0000	0.1996	0.1205	1.0000	0.0544	0.5592	1.0000
35-48				0.3078	0.2202	1.0000	0.0683	0.5447	1.0000
48-59					0.7367	0.2399	0.4230	0.1591	1.0000
59-75						0.1819	0.6785	0.1181	1.0000
75-82							0.1194	1.0000	1.0000
82-94								**0.0412**	1.0000
94-105									1.0000
105-110									

Table 6.4. Probabilities for two-tailed Fisher's exact tests conducted on the distribution of clams between mature and juvenile shell proportions in pairwise comparisons between auger test depths (cm) in AT 2010-001 (probabilities < 0.05 in bold).

	Later								Earlier
	0-21 n = 17	21-35 n = 28	35-48 n = 21	48-59 n = 21	59-75 n = 10	75-82 n = 11	82-94 n = 5	94-105 n = 9	105-110 n = 2
0-21		1.0000	0.0990	**0.0062**	**0.0031**	0.4401	0.3108	**0.0039**	1.0000
21-35			0.0808	**0.0031**	**0.0019**	0.3008	0.1748	**0.0046**	1.0000
35-48				0.4537	0.1411	0.7026	1.0000	0.1405	0.5257
48-59					0.5328	0.1967	1.0000	0.5345	0.3241
59-75						0.0902	0.3333	1.0000	0.1667
75-82							1.0000	0.0941	1.0000
82-94								0.3571	1.0000
94-105									0.1818
105-110									

shellfish diversity (Letham 2014:308). These results showed decreasing densities of rock-dwelling invertebrates (e.g., mussels) and increasing densities of sand-dwelling invertebrates (e.g., butter clams) from 94-105 cm DBS to 21-35 cm DBS (*see sections*

2.2.3. and 5.1.4.). This suggests that mussel harvesting decreased and butter clam harvesting increased, or in other words, that ancestral shíshálh switched between different shellfish species as a way to manage resources as was also suggested by Yesner (1983). In addition, previous analyses on shellfish diversity showed evidence of littlenecks becoming more common than butter clams in the upper layers of AT 2010-001 above 35 cm (Letham 2011:117). While butter clams and littlenecks are found together it is possible that either butter clams became less common due to overharvesting or that ancestral shíshálh were switching species. Meehan (1982)'s ethnoarchaeological work showed that Anborra women in Australia often only collected one shellfish species while dozens of other species that they also consumed by them grew in the same beds. Therefore, it is possible that ancestral shíshálh selectively harvested specific species as a resource management strategy.

6.2.3. Beach switching

In AT 2010-002, differences between layers were best seen between the younger and senile shell proportions and suggested decreasing harvesting intensity since relatively few juveniles were found (14%, n=22/152). Senile proportions significantly ($p < 0.05$) increased from 54-60 cm (n=6/44) to 21-40 cm DBS (n=16/44) (p=0.0254) and 40-48 cm DBS (n=7/33) (p=0.0153) and from 60-68 cm (n=0/8) to 21-40 cm (n=16/44) (p=0.0475) and 40-48 cm DBS (n=7/33) (p=0.0398, Table 6.5.)

In addition, while we see an increase in the senile proportion, an increase in the juvenile proportion from 54-60 cm (n=4/38) to 21-40 cm DBS (n=11/28) was also observed, with a statistical difference ($p < 0.05$) between mature and juvenile proportion

Table 6.5. Probabilities for two-tailed Fisher's exact tests conducted on the distribution of clams between younger and senile shells in pairwise comparisons between auger test depths (cm) in AT 2010-002 (probabilities < 0.05 in bold).

	Later					Earlier
	0-21 cm n = 6	21-40 cm n = 44	40-48 cm n = 33	48-54 cm n = 20	54-60 cm n = 44	60-68 cm n = 8
0-21 cm		0.6498	0.3906	0.6279	1.000	0.4286
21-40 cm			0.8159	1.000	**0.0254**	**0.0475**
40-48 cm				0.7791	**0.0153**	**0.0398**
48-54 cm					0.0901	0.0749
54-60 cm						0.5732
60-68 cm						

Table 6.6. Probabilities for two-tailed Fisher's exact tests conducted on the distribution of clams between mature and juvenile shell proportions in pairwise comparisons between auger test depths (cm) in AT 2010-002 (probabilities < 0.05 in bold).

	Later					Earlier
	0-21 cm n = 1	21-40 cm n = 28	40-48 cm n = 20	48-54 cm n = 13	54-60 cm n = 38	60-68 cm n = 8
0-21 cm		1.0000	1.0000	1.0000	1.0000	1.0000
21-40 cm			0.2122	0.1644	**0.0080**	0.2236
40-48 cm				1.0000	0.4278	1.0000
48-54 cm					0.6377	1.0000
54-60 cm						1.0000
60-68 cm						

found between these auger levels (p=0.0080) (Table 6.6.). The increase in senile and juvenile proportions would not occur if there was decreasing harvesting intensity occurring at one beach. This may therefore be evidence of two or more beaches being harvested at the same time, one where there is decreasing intensity and the other where there is increasing intensity.

This is corroborated by previous work done on material from AT 2010-002 that examined clam densities, which showed increasing clam density from 60-68 cm to 21-40 cm DBS (Letham 2014:309). Compared to AT 2010-001, meagre amounts of mussel remains were found at AT 2010-002, suggesting simultaneous decreasing and increasing intensity trends to be occurring at two or more butter clam-suitable beaches.

It is likely that ancestral shíshálh brought shellfish from different beaches to residential sites for processing, that intensive shellfish collection was found at all sites, and that shellfish beds may have been owned through hereditary rights. It is therefore possible that multiple productive shellfish beds in the three areas examined in this thesis, Porpoise Bay, Storm Bay and Tzoonie Narrows, were under hereditary control and being managed as a community. In other words, shellfish bed owners in the community may have managed clam resources together through beach cycling or letting shellfish beds fallow for a period of time as to not deplete clam populations. If sites were maintained as a community, this would dispel the notion that some sites are only villages, or processing camps, or specialized shellfish harvesting camps etc., because village sites could be used to process shellfish, and camp sites could be used cyclically to harvest and process shellfish.

The variability in the shellfish intensity trends at DjRw-1 and DkRw-26 support the idea that shellfish harvesting was not always intensifying suggesting that resource management methods may have been used on shíshálh lands in the past such as relaxing of shellfish harvesting, switching species, or beach cycling.

6.3. *Saxidomus gigantea* harvesting within the shíshálh landscape

Cannon and Burchell's (2009) interpretations were based on the premise that people were only harvesting from nearby beaches and other settlement pattern studies (McLay 1999; Acheson 1998; Machie and Sumpter 2005) have suggested that shellfish species found in shell deposits also tend to correlate with available species found nearby. Interestingly, the large village site DjRw-1 was adjacent to a mixed-substrate beach while DkRw-26 was adjacent to a pebble beach. The nearness to butter clam-suitable beaches therefore might be factor in why DjRw-1 shell deposits reflected higher harvesting intensities. Furthermore, one of the reasons why Letham (2014) suggested that the larger village sites clustered near the outer coast was because of the high density of large productive shellfish beds in these areas. DjRw-1, being near the outer coast, was itself adjacent to the Porpoise Bay beach, one of the largest beaches in the area. Larger shellfish beds have been shown to be less susceptible to overharvest than smaller ones (Quayle and Bourne 1972); the reduced susceptibility to shellfish resource depletion near DjRw-1 may have factored into ancestral shíshálh decision to settle in Porpoise Bay. Furthermore, because butter clams were found at sites that were not directly adjacent to butter clam-suitable beaches (i.e., DkRw-22 and DkRw-26); it be can assumed that ancestral shíshálh also brought butter clams to residential sites from nearby beaches. DkRw-26 was near DkRw-16 which was adjacent to the longest beach in Narrows Inlet and contained a clam garden (Letham 2014:294), and may have been a key location to harvest butter clams. High anthropomorphic disturbances can hinder productivity of shellfish beds (Goong and Chew 2001), and therefore ancestral shíshálh may have also chosen to settle adjacent to less productive shellfish beds in order not to disturb nearby productive clam beds or gardens.

Across the inlet from Porpoise Bay is the Snake Bay site also known as Oalthkyim in shashíshálhem, which also boarders off of a large productive mixed substrate beach. Steve Feschuk, Protector of shíshálh Culture, suggested that the Oalthkyim site may have been a mistranslation of 'Clam Bay' since the words for 'snake' and 'clam' in shashíshálhem are very similar, further pointing to the long-term cultural importance of this beach for clam resources (personal communication 2017), and the possibility that Porpoise Bay residents used Oalthkyim to harvest clams.

Seasonality results suggested that clams were harvested and brought to the site year-round. DjRw-1 was also one of the larger sites recorded in the SIS and would have likely accommodated large amount of people, and maybe more intensely during the winter if population agglomeration occurred during this time as they did ethnographically. Therefore, the year-round harvest of butter clams in the vicinity of DjRw-1 and the larger population size it would have had to feed may have been significant factors in why a higher frequency of younger shells were found at the large village site. Since both sites were near butter clam suitable beaches, the difference in harvesting intensity might be more significantly influenced by the seasonal occupation of DkRw-26 in comparison to the year-round occupation of DjRw-1 with its larger village population that it would have had to accommodate.

6.3.1. Historical contingencies: Regional warfare

The sites of interest in this thesis were occupied from 930 cal. BP to 0 cal. BP.

This period coincides with two periods of increased warfare in the Gulf of Georgia, 1600-500 cal. BP and 160-80 cal. BP (Angelbeck 2007; Angelbeck and Grier 2012). Accordingly, these periods have been shown to have brought instability to the region. The increased warfare during these times may have influenced the shíshálh's food economy as well as their settlement patterns. Therefore, social instability may have been a factor in the high shellfish harvesting intensity observed in the SIS as well as the observed variability in shellfish harvesting patterns. Since shellfish can easily be obtained year-round, and near residential sites, they may have been a very important food resource if ancestral shíshálh were under threat from neighboring groups. In addition, the seasonal settlement pattern of being near the outer coast during the colder months or year-round, and moving to Narrows Inlet during the warmer months seems to be stable throughout these periods. Nevertheless, there may have been some variability that could have been related to increased warfare since the two shells from Storm Bay suggested a winter occupation, a different pattern from the ethnographically described seasonal round. Increasing the temporal range may shed light on whether increased warfare in the region altered shíshálh settlement patterns and their food economy.

6.4. Sechelt Inlet system vs. eastern Vancouver Island

Since the SIS is not the first region on the southern coast where archaeological butter clams have been classified into growth stages, the local interpretation of cultural-specific food-procurement and settlement patterns can be compared and contrasted to similar studies conducted in the northern and central regions of the coast, in the ancestral lands of the Coast Tsimshian and Heiltsuk, respectively, in addition to other emerging research in the Salish Sea.

Macro-growth line analysis suggests that not all Coast Salish peoples or all areas in Coast Salish lands had the same shellfish harvesting practices. Data from ongoing research on Coast Salish sites on eastern Vancouver Island including DfRw-13, DkSf-20 (Leclerc et al. 2016), DiSe-7 (Sparrow 2016), and DfRu-13 (Leclerc et al. 2016) produced higher proportions of senile butter clams than mature butter clams. This suggests that sites on the western side of the Salish Sea on east-central Vancouver Island practiced less intensive butter clam harvesting than ancestral shíshálh (Figure 6.1.). These sites were classified into different site types, same as the shíshálh sites, yet they all produced a higher proportion of senile shells. In addition, two other sites, one on Pender Island (DeRt-1/DeRt-2) and one in Comox (DkSf-19), had higher proportions of mature butter clams than senile butter clams showcasing the variability in shellfish harvesting practices on eastern Vancouver Island (Burchell 2017).

6.5. Southern coast vs. northern coast

The opposing mainland and island harvesting intensity patterns are similar to what was found on the northern coast in the vicinity of the Dundas Islands and Prince Rupert Harbour (Burchell et al. 2013a). Dundas Islands sites all showed evidence of intensive collection while the general pattern found at the Prince Rupert Harbour sites on the mainland was of lower shellfish harvesting intensity. On the southern coast, the island and mainland patterns are inverted; lower shellfish harvesting intensity was found on eastern Vancouver Island and higher shellfish harvesting intensity was found in the SIS on the mainland. This puts into question what Barnett suggested in his ethnography of Coast Salish peoples that islanders relied more on clams than mainlanders (Barnett 1955:93). While the only mainland sites investigated have been in the SIS, the results of this thesis cast doubt on the antiquity of Barnett's blanket statement.

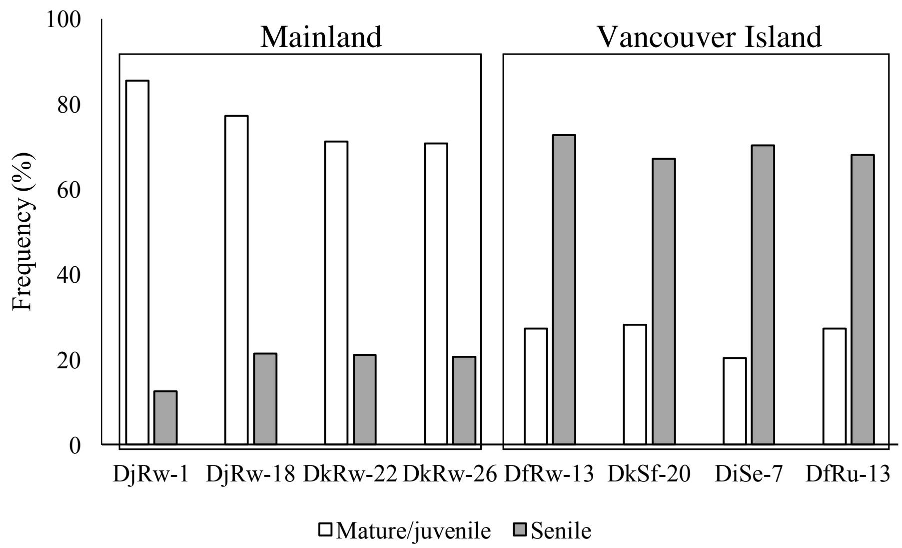


Figure 6.1. *Growth stage proportions from macro-growth line analysis of the shíshálh sites on the mainland (left) and the Vancouver Island sites (right).*

6.6. Seasonal occupation and mobility on shíshálh lands

Barnett (1955) first recorded the shíshálh seasonal round, and had described the shíshálh village in Pender Harbour as being occupied year-round with the tuwanek subgroup leaving in the spring to move to Narrows Inlet where they occupied their smaller summer village during the warmer months. This ethnographic description did not consider other large shíshálh villages such as the Porpoise Bay site (DjRw-1), neither did it acknowledge the seasonal occupation of Storm Bay where DkRw-22 and DjRw-18 were located. Furthermore, while Barnett spoke about a Narrows Inlet village, its location was supposedly near the mouth of the inlet and not at Tzoonie Narrows where DkRw-26 is located. Therefore, ethnographic records had not considered many areas in the SIS that had been occupied in the past.

In addition, previous ethnographic records about Coast Salish shellfish harvesting practices, suggested Northern Washington Coast Salish people harvested shellfish in the early summer and late spring (Wessen 1988), and Northern Coast Salish harvested clams during winter low tides (Kennedy and Bouchard 1990:445). The sparse information on the seasonal timing of shellfish collection for different cultural groups has only allowed for analogical interpretations of the seasonality of shíshálh butter clam harvesting. Letham (2014) suggested that the lack of large villages in Narrows Inlet and Salmon Inlet supported Barnett's description of the shíshálh people moving from large 'winter' villages on the outer coast to smaller villages and camps in the SIS during the warmer months. Furthermore, the high density of herring found at DjRw-1; given that herring are seasonally abundant in the area in the late winter/early spring; suggested that at least a component of the site was used intensively during winter and early spring (Coupland et al. 2012).

The $\delta^{18}O_{shell}$ analysis results supported Letham's (2014) conclusions by showing a stronger summer, spring, and autumn presence in Narrows Inlet and Storm Bay, and a year-round presence at the large village site DjRw-1, which was located near the outer coast[10]. Furthermore, the emphasis on early spring and winter collection of butter clams at DjRw-1 supported Coupland et al. (2012)'s interpretation of the function and main season of use for the herring fishing and processing camp component of the multi-component site. The $\delta^{18}O_{shell}$ data from DkRw-26 and DjRw-1 suggests that ancestral shíshálh may have moved seasonally between Porpoise Bay (winter) and Narrows Inlet (spring-autumn) since their periods of occupation overlapped. This further adds nuance and variability to Barnett's original statements. $\delta^{18}O_{shell}$ data have also shown that seasons of butter clam collection in the SIS were variable and have showcased how movement in the SIS and use of sites did not always fit narrow descriptions detailed in ethnography supported by seasonally abundant faunal analyses at archaeological sites.

6.6.1. Paralytic shellfish poisoning: Seasonal consumption deterrent

Paralytic shellfish poisoning (PSP) results from dinoflagellate blooms, specifically the *Gonyaulax catenella* and *Gonyaulax acatenella* species in BC, and is a modern-day issue with respect to food safety related to shellfish. These dinoflagellate blooms, which are a type of phytoplankton bloom, are also known to cause red tide events since they have the ability to colour the body of water that hosts them red (Department of Fisheries and Oceans 1990). It is said that it affects shellfish at the onset of spring until late summer which coincides with time of blooms (Haigh et al. 1992). Accordingly, some have suggested that Indigenous peoples in the past may have avoided shellfish, especially clams during this seasonal period (De Laguna 1990:212; Moss 1993).

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[10] $\delta^{18}O_{shell}$ results also support the year-round occupation of DjRw-1 recalled by shíshálh elders (Merchant 2008:6-7).

While there is evidence that red tides are an ancient phenomenon in Mediterranean regions, phytoplankton bloom records do not extend far into the past and have been shown to have been consistently and exponentially increasing in geography and occurrence since the first records (Department of Fisheries and Oceans 1994; Haigh et al. 1992). Furthermore, many reports in Europe, the Philippines, India and Australia documented their first cases of PSP in the 1970s and 80s (Claassen 1998:33). Therefore, PSP may not have significantly affected Indigenous peoples residing in coastal BC prior to European contact.

Butter clams can retain toxicity in their siphon for up to two years after exposure (Quayle and Bourne 1972:15), although very few deaths have been linked to it in BC (Quayle and Bourne 1972:9). If PSP was an issue in the past, the higher harvesting intensity and year-round collection of butter clams suggests that ancestral shíshálh utilized strategies to mitigate the effects of PSP. Ways to prevent resulting illnesses include: cutting off the siphon and gills as it can reduce toxicity up to 80% (Quayle and Bourne 1972); observing bioluminescence at night to inform people on phytoplankton blooms, as was observed by Carson (1951); putting shellfish to lips and waiting to see if they would go numb as the Tlingit have been observed to do (Fitzhugh 1995), or observing other animals that prey on shellfish (Fitzhugh 1995). Therefore, PSP resulting from dinoflagellate blooms could have had minimal effects on seasonality of shellfish harvesting in the past.

6.7. Archaeological and ethnographic disagreement

At DkRw-22 and DjRw-18, relatively few herring bones were recovered, while salmon bone were more abundant at DjRw-18; according to a resident of Storm Bay a small Coho salmon run was known to flow into the bay every October (Letham 2011:38). This led Letham to suggest that Storm Bay was mostly occupied in the autumn. $\delta^{18}O_{shell}$ results from Storm Bay suggested that butter clams were mostly collected in the spring at DkRw-22 and DjRw-18, with only 1/10 Storm Bay shells collected in the autumn, thereby adding a strong spring presence in the bay. In addition, sample 18D from Storm Bay was collected mid-winter, suggesting the area near the mouth of Narrows Inlet was also at least occasionally occupied in the mid-winter and likely during herring fishing activities in the late winter. Since ethnographic sources had never suggested that the inlet sites would have been occupied in the winter (Barnett 1955) and possibly disabled due to occasional freeze over (Letham 2014:317), this new evidence suggests variability in seasonal settlement strategy and ancestral shíshálh's seasonal flexibility to use different areas of their lands based on historical and environmental contingencies.

However, none of the analysed butter clam shells from DkRw-26 were interpreted as winter-collected shells, thereby suggesting that the area near the narrowing of Narrows Inlet was not occupied in the winter and only in the warmer months. This was also suggested by Letham who first interpreted the seasonality of the site based on the densities of herring and salmon remains. According to Letham, not enough salmon remains were found to correspond to the amount of salmon remains that would have been deposited from winter consumption of dried salmon collected during the autumn if the site had been occupied in the winter (Letham 2014:301; also see Cannon 2002).

Interestingly, most butter clam shells were collected during the summer and surrounding seasons (i.e., late spring, summer, and early autumn).

6.8. Coastal variability of *Saxidomus gigantea* harvesting seasonality

These data are unlike previous seasonal butter clam harvesting interpretations from the northern and central coasts where clam harvesting occurred most often either in the autumn in order to store for winter consumption or in the spring to compensate for the depletion of winter stored foods (Burchell 2013; Burchell et al. 2013a,b). The pattern found at DkRw-26 supports an alternate reason for shellfish collection, suggesting that clam collection was mostly not done for the purpose of preparing for winter storage. Instead, the $\delta^{18}O_{shell}$ evidence from DkRw-26 suggests that butter clams were collected and brought to the site, and then consumed at the site during its occupation and not stored for winter consumption, or dried for winter storage earlier than the autumn.

The large multi-component village site DjRw-1 was occupied year-round according to $\delta^{18}O_{shell}$ results with an emphasis on winter and spring collection, possibly because this would have been the time when the site would have been occupied by the most amount of people. As previously stated, a high amount of salmon remains were found at the site with an even higher abundance of herring remains, which had suggested that the component of the site where our clams originated was mostly used in the late winter/early spring as a specialized herring fishing camp. Based on $\delta^{18}O_{shell}$ data, butter clam collection rarely occurred in the autumn at DjRw-1 and the other sites investigated in this thesis. This supports an interpretation where clams may not have been collected for winter storage but harvested during the winter if needed, and/or during other seasons depending on need; occurring most often in the spring to make up for winter food depletion as suggested by Burchell et al. (2013a,b). Richard G. Newton (in Moss 1993:641) once said:

… no food is low status… Shellfish is there to be eaten, when you're hungry, you can eat it… say you just moved to camp and didn't have time to hunt, then it's okay to eat it.

Accordingly, shellfish harvesting at DkRw-26, as well as DjRw-18 and DkRw-22, may have occurred at the time when people were arriving to the sites, which was most often in the spring.

DjRw-1's year-round seasonality results coincide with previous $\delta^{18}O_{shell}$ seasonality analyses of village sites on the northern and central BC coasts, suggesting a certain level of coastal continuity of large multi-lineage villages being occupied year-round. However, different from other regions, shellfish harvesting in the SIS occurred mostly during seasons of intense occupation and coincided with timing of other resources' abundance such as spring for herring fishing, and summer for berry picking and other hunting activities.

6.9. Division of labour

Since we find shells that were collected during the same seasons that other resources were collected like salmon in the autumn, herring in the spring/late winter and berries in the summer this may suggest a certain level of division of labour, where the occupants might have split into subgroups to hunt or collect different resources[11]. However, since the temporal resolution of the $\delta^{18}O_{shell}$ data cannot be compared to the same temporal resolution enabled by other food resources found archaeologically, this is currently only a hypothesis. Furthermore, the spatial resolution of where the examined butter clams originated is relatively small compared to the extent of some of these larger sites. Therefore, sampling in more areas of these sites may yield different seasonal emphases. Accordingly, the seasonality differences in the two excavated trenches at DjRw-1, already suggest that different parts of sites were more intensively used during different seasons.

The lack of autumn-collected shells should not be assumed to be the result of other important activities taking priority at this time, such as salmon fishing, because we should not assume that all group members would have participated in the same activities (Claassen 1991b:271). In addition, since women are ethnographically the principal shellfish gatherers, we should neither assume that spring-collected shells meant that all men were busy fishing for herring and all women and children were bound to the intertidal zone to collect shellfish during this time. Ethnographic evidence from the Anbarra suggest that some women did not enjoy shellfish harvesting and therefore shellfish were not often consumed in their households (Meehan 1982). It is difficult to

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[11] $\delta^{18}O$ evidence from DkRw-26 suggested that butter clams were collected from spring to early autumn. Subtle seasonal collection variations of butter clams such as early summer, mid-summer, and late summer may be related to scheduling of other resources. Accordingly, ethnographic evidence tells us that the shíshálh collected high-bush cranberries in the late summer to early autumn, and collected coastal black gooseberries still green in the early summer (Turner 1995:69-100). Therefore, butter clam harvesting seasonality may have fluctuated by a few weeks depending on the availability of different berry species and may not have necessarily been related to division of labour.

discuss this in the context of the shíshálh because of the limited spatial range of archaeological materials discussed here. Therefore, interpretations of division of labour are purposefully vague but support the complexity of the food economy.

6.10. Stable oxygen isotope and *Saxidomus gigantea* growth within the Sechelt Inlet system

The range of $\delta^{18}O_{shell}$ values in the SIS was more negative than those produced in shells found on the outer southern coast, where seawater has a higher salinity percentage. For instance, shells from the SIS have produced $\delta^{18}O$ values ranging from -1.45‰ to -6.9‰, while the temporary camp site DfRw-13 in Ladysmith, BC, produced a minimum value of -5.48‰, live-collected butter clams from Kye Bay near Comox, BC, produced a minimum value of -3.14‰, and the Pender Island site DeRt-1/DeRt-2 produced a minimum value of -3.38‰ (Burchell 2017; Leclerc et al. 2016). To date, the SIS shells have produced the most negative $\delta^{18}O_{shell}$ values on the coast of BC, likely due to its lower salinity with frequent freshwater incursions coupled with warmer seawater temperatures throughout the year compared to northerly coastal regions. In addition, the occasional ice cover of Narrows Inlet and Salmon Inlet likely played a role in the Tzoonie Narrows and Storm Bay $\delta^{18}O_{shell}$ values being more positive than $\delta^{18}O_{shell}$ values from Porpoise Bay.

6.10.1. Estuary effects on macro- and micro-growth line deposition

Furthermore, frequent freshwater disturbances coupled with cold seawater in the winter and warm water or spawning events in the summer appear to have caused disturbance lines to be deposited during summer, winter, spring, and autumn which often times created clusters of macro-growth lines (Figure 5.3). This was only determined through $\delta^{18}O_{shell}$ alignment with macro-growth lines, and therefore $\delta^{18}O$ analysis is strongly recommended as a pre-requisite for macro-growth line analysis of estuary-borne shells. In addition, freshwater and other growth stressors prone to the SIS environment may have also played a role in the inability to discern a full year of growth increments through LDGI analysis. These growth stressors may have halted or disturbed growth multiple times in the year thereby not allowing for a full or close to a full year of growth increments to be accounted for in comparison to Pender Island shells on the outer southern coast which were able to record close to a year of micro-growth increments (Hallmann et al. 2009).

CHAPTER 7

CONCLUSIONS

Shell midden sclerochronology, settlement patterns and food-related research on the Pacific Northwest Coast have continued to show that seasonal occupation, migration and food procurement strategies were culturally and historically variable, dispelling the myth of the generalized ethnographically described seasonal round (e.g., Burchell et al. 2013a;b; Cannon 2002; Cannon and Burchell 2009; Maschner and Stein 1995; Maschner 1996;1997; Mitchell 1983; Mitchell and Donald 1988). However, this variability is best observed in long-term large-scale sub-regional multi-site analyses that incorporate multiple evidentiary sources similar to Cannon and colleagues work on the central BC coast. Through this research strategy, archaeological data can be contextualized and theoretically framed with landscape/taskscape, historic ecology, and resource management theories that acknowledge the network of variables that were considered in past decision-making.

7.1. Summary

The results from this thesis have demonstrated that: 1) shellfish harvesting was intensive in the SIS in comparison to other places on the southern BC coast; 2) an intensive shellfish harvesting pattern was found at all sites irrespective to the site type in question; 3) harvesting intensity at the smaller inlet village was statistically less intense than the larger village site; 4) seasonality of butter clam harvesting generally fit previous interpretations on the seasonality of occupation based on vertebrate faunal analysis but also suggested some flexibility and seasonal emphasis, and; 5) butter clam harvesting occurred mostly during the winter and spring at the large village site, and during the warmer seasons at the contemporary inlet village suggesting a possible seasonal shift between both sites.

Results also showcased the intimate relationship between seasonality and food procurement practices on the Pacific Northwest Coast. For example, the large village site in Porpoise Bay, DjRw-1, produced the highest shellfish harvesting intensity pattern and was the only site occupied year-round of all the sites investigated. This suggested that harvesting butter clams year-round may have produced a pattern of higher shellfish harvesting intensity than seasonal harvesting which occurred at the inlet village and the formal camps. Following landscape theory, the higher resource availability near the Porpoise Bay site, enabled by the density and size of nearby productive intertidal zones, may have been a strong factor in the decision to reside at the Porpoise Bay site year-round. Landscape theory further supported that boat travel would have facilitated community management of the multiple nearby shellfish beds.

Smith and Wishnie's (2000) resource management theory supported that shellfish resource conservation was possible in shíshálh lands. Accordingly, I proposed that intra- and inter-shell deposit variability was indicative of different shellfish resource conservation methods, such as species switching or beach switching. The different patterns found within and between shell deposits further supported Claassen's (1991b) assertion that shell midden deposits should not be treated normatively.

Historical ecology was integral to the study of butter clams since it supported the use of environmental proxies in archaeological settings to study human-environmental dynamics. Specific to this thesis, butter clams were used as environmental and cultural recorders of seasonality and intensity of shellfish harvest. The $\delta^{18}O_{shell}$ data presented here suggested that a shíshálh subgroup living at the Porpoise Bay site, DjRw-1, during the colder months, migrated southbound to the inlet village site near the narrowing of Narrows Inlet, DkRw-26, for the summer months. Since DjRw-1 was the only site occupied year-round, another subgroup must have stayed at the large village during the summer. However, the data also suggests that ancestral shíshálh were flexible in their seasonal moves since evidence showed that ancestral shíshálh occupied Storm Bay, near the mouth of Narrows Inlet as early as mid-winter. In addition, the presence of summer-collected shells suggested that paralytic shellfish poisoning, rampant in the summer months today, was not a significant consumption deterrent in the SIS.

Extending outside of the SIS, previous studies had shown that eastern Vancouver Island (Burchell 2017) produced a pattern of lower shellfish harvesting intensity than the one found in the SIS. This further challenged Barnett's (1955) ethnographic hypothesis that mainland Coast Salish groups had a more riverine adaptation than islander Coast Salish groups, which made them less reliant on clams.

In addition, micro- and macro-growth line deposition variation was observed between the inner and outer coast. Butter clam shells from the SIS deposited fewer LDGI than shells from Pender Island on the outer southern coast, and could not account for a full year of growth. Lunar daily growth increment widths within a year were also too variable to clarify seasonal freshwater effects on $\delta^{18}O_{shell}$ results. While seasonal $\delta^{18}O_{shell}$ trends were observed, and used to differentiate seasons of harvest, the $\delta^{18}O_{shell}$ results showed that year-to-year $\delta^{18}O_{shell}$ variability in the live-collected shells did not coincide with sea surface temperature variability, thereby warning against using $\delta^{18}O_{shell}$ results to reconstruct paleo-temperatures in the SIS and other inner coastal regions. This also has implications for future $\delta^{18}O_{shell}$ and LDGI work on the inner coasts of British Columbia, as shells from the same species had different growing patterns depending on location of growth. Furthermore, multiple macro-growth lines were deposited within a year, often appearing as macro-growth line clusters. Therefore, macro-growth line analysis for the purpose of determining seasonality of shellfish harvesting is not appropriate for butter clams from the SIS. Further, these observations demonstrated that macro-growth line clusters near the ventral margin should not be the only criteria for senility, and that uneven periodicity of growth line clusters should also be included as a criteria. Accordingly, the distribution or periodicity of macro-growth line clusters along the axis of growth were examined as well to make confident growth stage determinations, thereby stressing the importance of understanding local growth and $\delta^{18}O$ integration of butter clam shells before undertaking physical and chemical sclerochronological methods.

7.2. Future directions

As previously stated, there are 92 recorded sites in the SIS, and four of them were investigated in this thesis. These four sites represent a relatively short time period when compared to the 6000 years that the SIS has been occupied. Increasing the number of sites investigated in the SIS may be able to clarify whether the higher butter clam harvesting intensity pattern remains consistent or whether there exists temporal or spatial variability, similar to what recent studies on the western side of the Salish Sea have started to unveil (Burchell 2017). Increasing the number of sites should also aim to investigate sites that precede 1600 cal. BP, when warfare was initiated in the region. This would be able to clarify whether higher shellfish harvesting intensity in the SIS from 930 to 0 BP was related to this period of increased regional warfare. Furthermore, Terence Clark, director of sARP, has suggested that the Snake Bay site, just across the inlet from DjRw-1, may have been a defensible site due to its higher elevation (personal communication, 2017). Additional shell macro-growth line analysis at the Snake Bay site and earlier sites, would be required to determine whether or not regional warfare disrupted the shíshálh food economy. High-resolution $\delta^{18}O_{shell}$ analysis of more sites in shíshálh lands may also increase our understanding of seasonal mobility in the SIS.

The number of shells analyzed per site to determine seasonality has been shown elsewhere to be appropriate (Cannon and Burchell 2016). On the other hand, the DjRw-1 large village site had multiple components, only one of which was investigated in this thesis. Investigating seasonality in other components may reveal different seasonal emphases. In addition, more shell macro-growth line analysis at other sites in the SIS and within sites may further clarify whether the differences in the growth stage proportions are a result of the implementation of multiple clam bed management practices.

7.3. Understanding Pan-Regional Variability in Shellfish harvesting on the Pacific NWC

This thesis is the first systematic study on the inner coast of its kind, and the first $\delta^{18}O_{shell}$ study for seasonality on the Pacific Northwest Coast from a distinctly different environmental regime. Results highlighted the geographic variability in $\delta^{18}O$ integration and butter clam growth. The observed impacts of freshwater on growth and $\delta^{18}O_{shell}$

integration also cautioned against using $\delta^{18}O_{shell}$ and LDGI results from regions heavily influenced by freshwater incursions to reconstruct past sea surface temperatures.

The complexity of shellfish harvesting practices, which were generally disregarded ethnographically, are discoverable through the study of shellfish harvesting patterns in shell deposits, whether they concern resource conservation methods, warfare consumption adaptations, or seasonal harvesting practices. Broadening the temporal, geographic, and cultural scope of $\delta^{18}O_{shell}$ and mollusk shell growth increment analyses on the Pacific Northwest Coast will further our understanding of shellfish harvesting intensity and seasonality, and provide supporting evidence for broader implications.

Through this thesis, our understanding of pre-contact settlement and food-procurement strategies in the SIS has been revealed to be an ongoing endeavor. As increasing lines of evidence are brought to the forefront, such as $\delta^{18}O_{shell}$ and shell macro-growth line analysis, we have seen how complex and unique settlement and food procurement strategies in the SIS were in the past. This work continues to contribute to a growing body of knowledge on human-environmental interactions in coastal landscapes, in addition to cultural, temporal, and regional variability on the inner and outer coasts of British Columbia.

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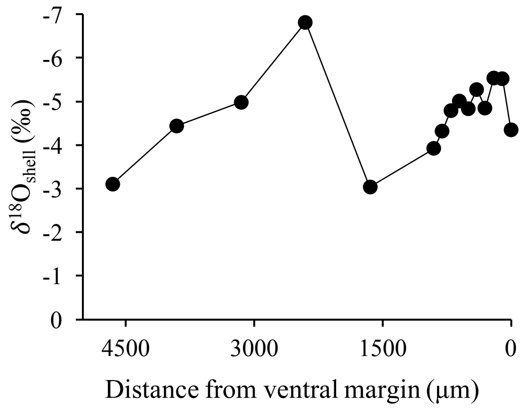
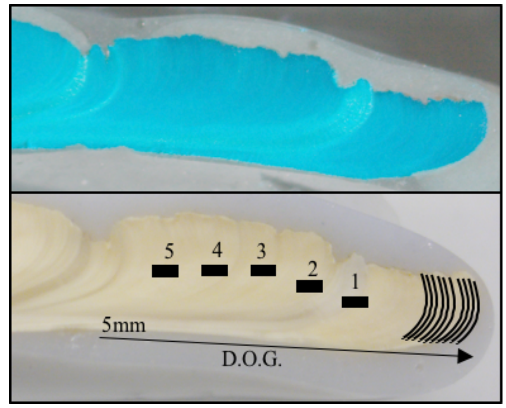
Appendix 1: Profiles and Seasonality Determinations

DjRw-1

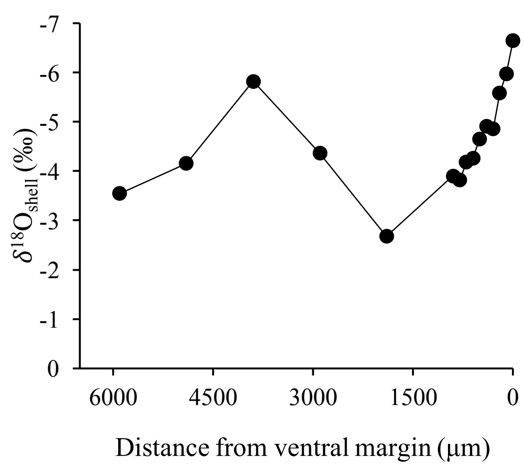
Figure 1: Sample 1D **Season: Spring**

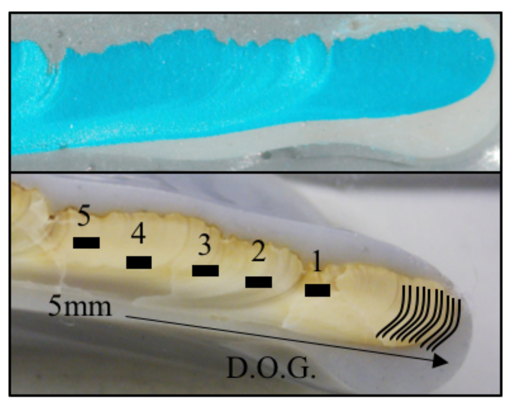




The ventral margin $\delta^{18}O$ value is trending towards more positive values (-4.34 ‰). The $\delta^{18}O$ values leading to the ventral margin are likely from warming and freshwater input in the spring. One year of growth was sampled.

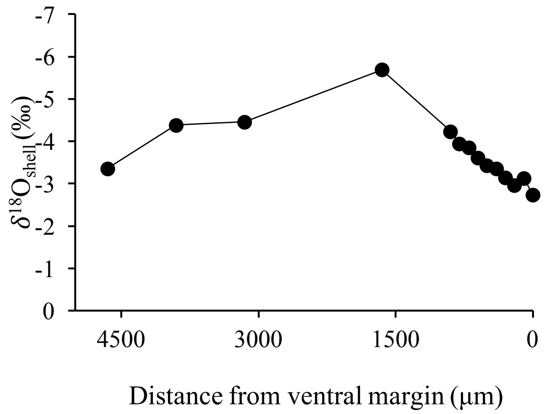
Figure 2: Sample 3D **Season: Summer**

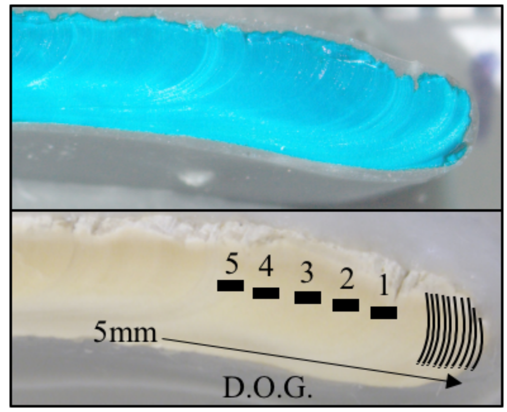




The ventral margin $\delta^{18}O$ value reaches the most negative values (-6.66 ‰) from extreme warm summer temperatures. Slightly over a year of growth was sampled.

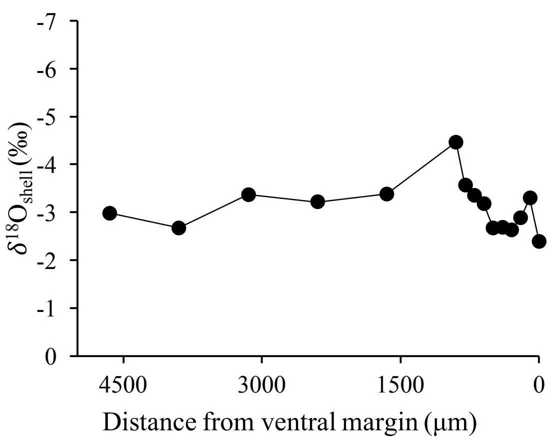
Figure 3: Sample 4D **Season: Winter**

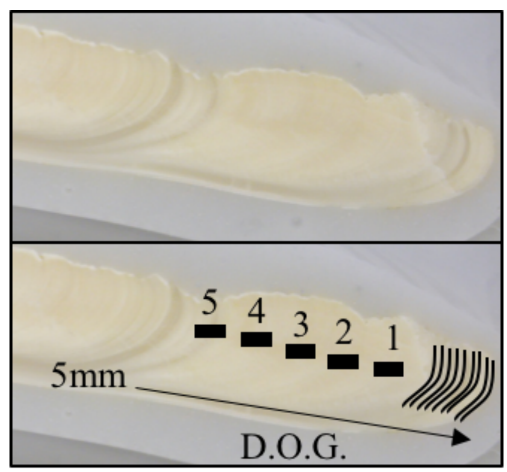




The ventral margin $\delta^{18}O$ value (-2.74‰) trends towards more positive $\delta^{18}O$ values and the sample was taken after a 'winter check' both caused by slowed growth in colder winter conditions. Slightly under a year of growth was sampled.

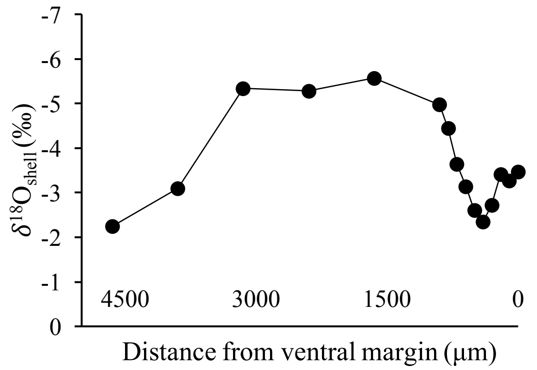
Figure 4: Sample 6D **Season: Winter**

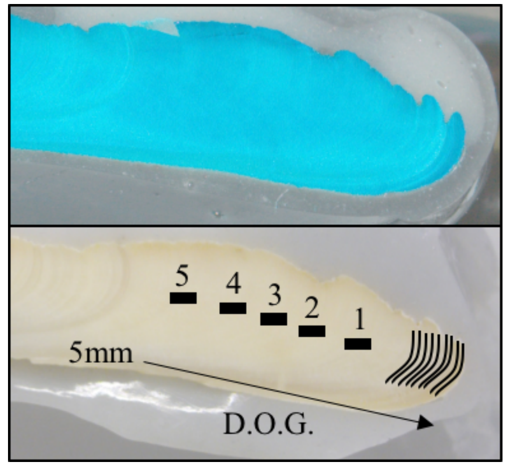




The $\delta^{18}O$ value at the ventral margin (-2.39‰) nears the maximum value reached in the live-collected shells (~ -2.6‰), which was achieved during winter growth. A preceding more negative peak was likely caused by increased precipitation in the late autumn or early winter leading up to winter collection. This was a young specimen with less than a year sampled.

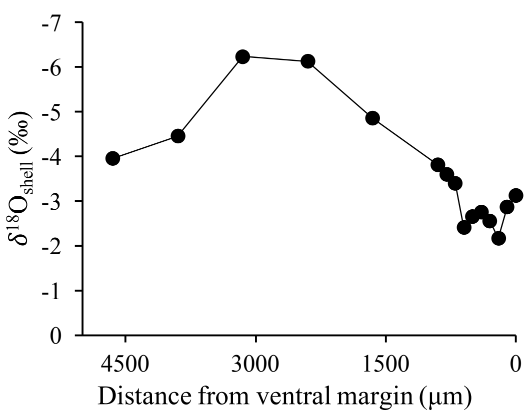
Figure 5: Sample 7D **Season: Spring**

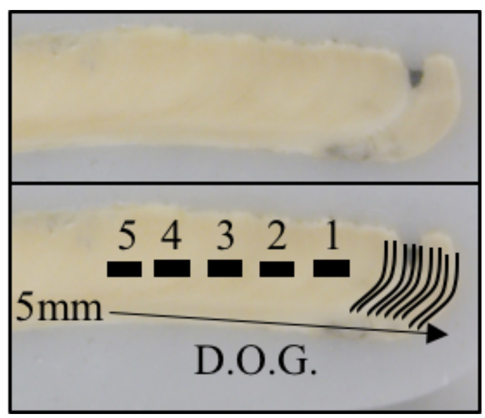




The ventral margin δ^{18}O values trend towards more negative values (-3.47‰ at the ventral margin) and come after a winter growth line and check which produced a positive winter value (-2.35 ‰). Over a year of growth was sampled.

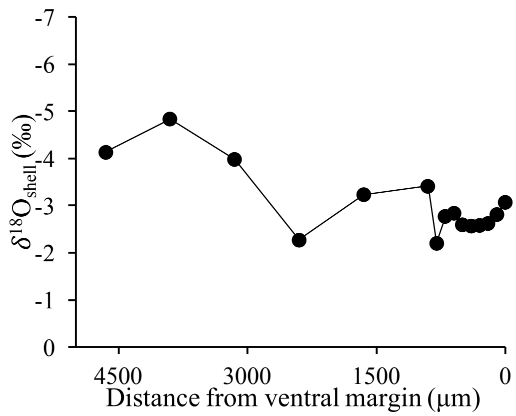
Figure 6: Sample 10D **Season: Early Spring**

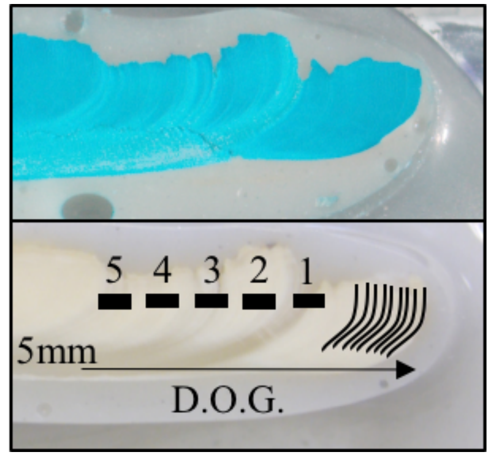




The ventral margin δ^{18}O values trend towards more negative values, producing a more positive value ventral margin value (-3.13 ‰) than sample 7D. Further, the ventral margin value of this sample comes after a positive winter δ^{18}O value (-2.56 ‰) that was sampled on a winter growth line and check. Slightly under a year of growth was sampled.

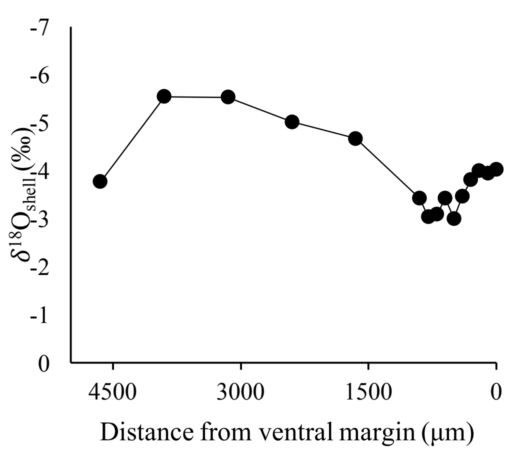
Figure 7: Sample 11D **Season: Early Spring**

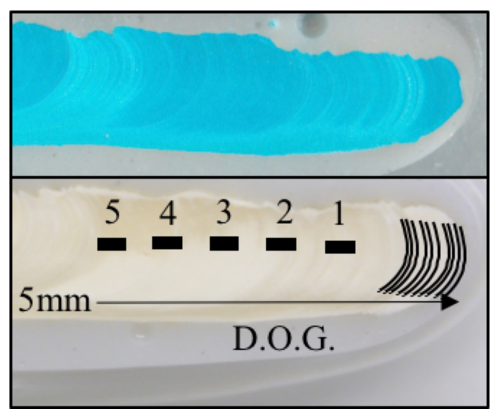




The spring season leading up to the ventral margin shows fluctuations in temperature and freshwater input causing 'noise' in the oxygen profile. The $\delta^{18}O$ values curve towards more negative values near the ventral margin further supporting a spring collection. The ventral margin $\delta^{18}O$ value (-3.07‰) is more positive than spring-collected sample 7D strengthening an early spring interpretation. Slightly under a year of growth was sampled.

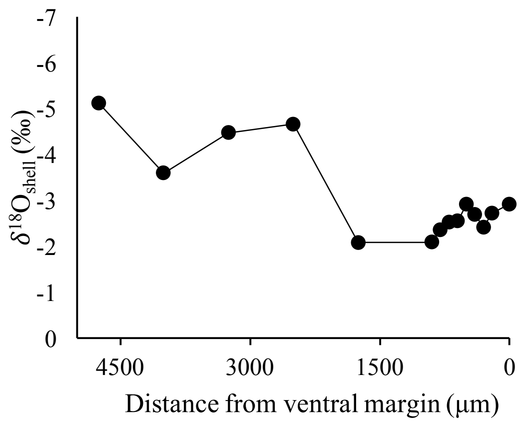
Figure 8: Sample 12D **Season: Spring**

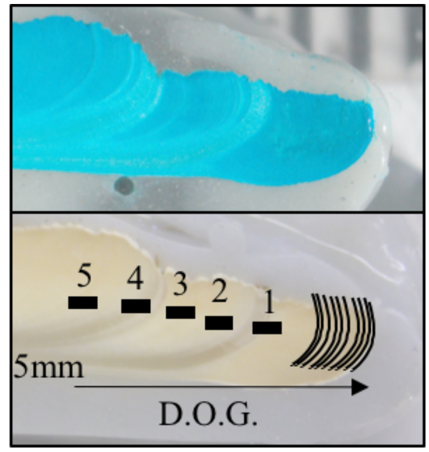




$\delta^{18}O$ values trend negatively towards the ventral margin value (-4.03‰) as a result of spring warming and increased freshwater input, and come after a winter growth line resulting from slowed growth in colder winter temperatures. One year of growth was sampled.

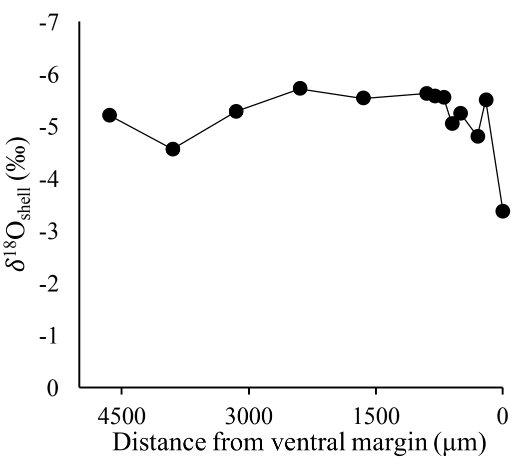
Figure 9: Sample 14D **Season: Early Spring**

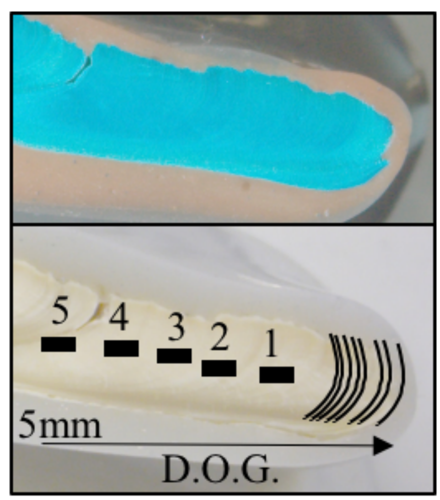




The $\delta^{18}O$ values trend negatively towards the ventral margin value (-2.92‰) and are preceded by a freshwater peak around 500µm from spring or winter freshwater input, and before that a positive winter value sampled on a winter growth line (drilled sample #1). This is a young specimen, and therefore sampling captured less than a year of growth.

Figure 10: Sample 19D **Season: Autumn**

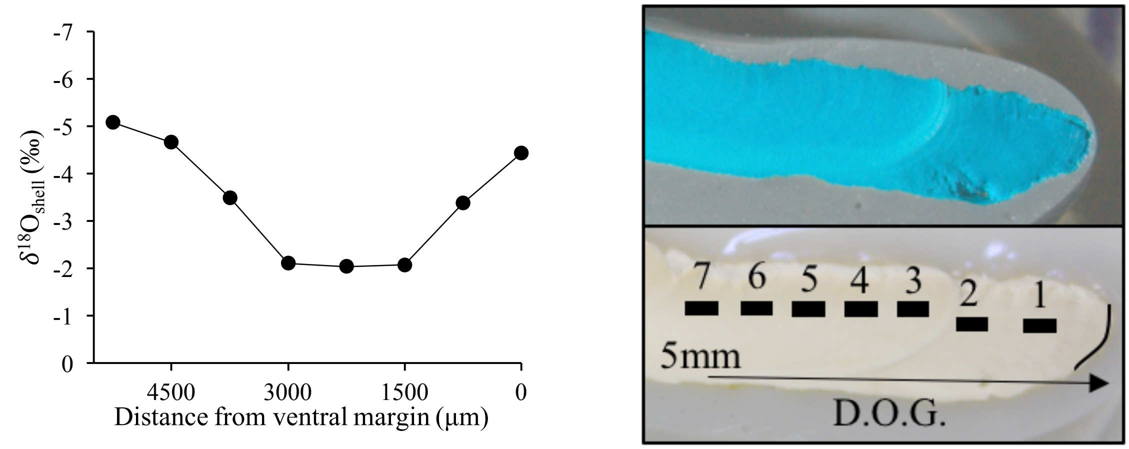




The ventral margin $\delta^{18}O$ values are positively trending towards the ventral margin value (-3.36 ‰) and come after a more negative values representative of summer growth. Less than a year of growth was sampled. The exact amount of time sampled is unclear due to the high amount of freshwater input driving values negatively.

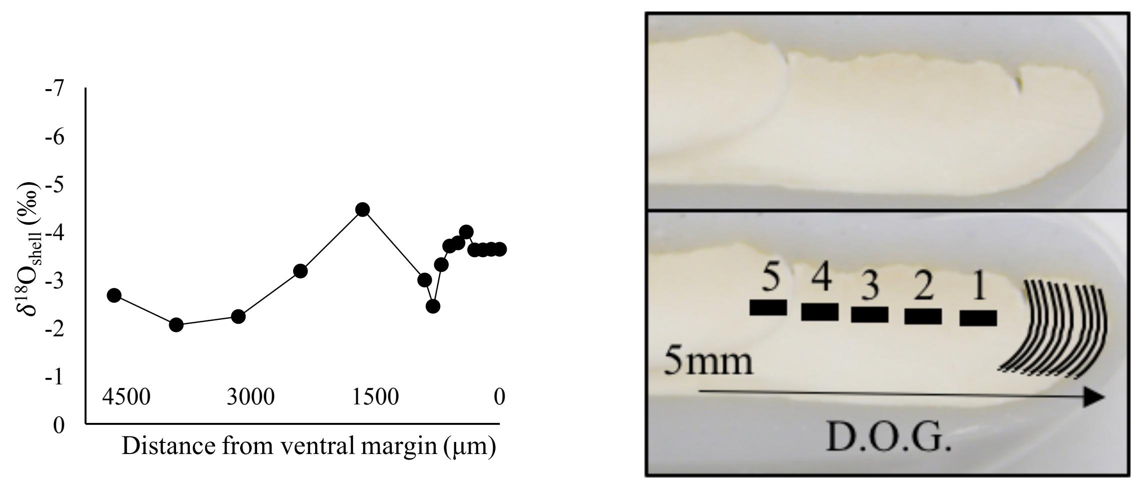
DjRw-18

Figure 11: Sample 1D **Season: Spring**



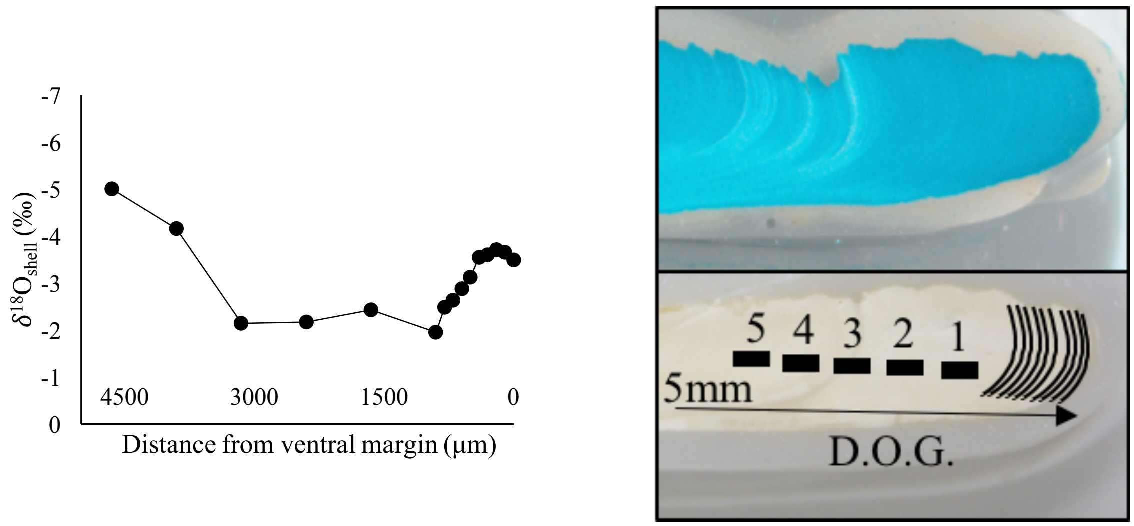
The ventral margin $\delta^{18}O$ value (-4.43 ‰) trends towards more negative values but does not reach summer $\delta^{18}O$ values (~ -6.0‰). A little bit under a year of growth was sampled in this fast-growing young specimen.

Figure 12: Sample 2D **Season: Spring**



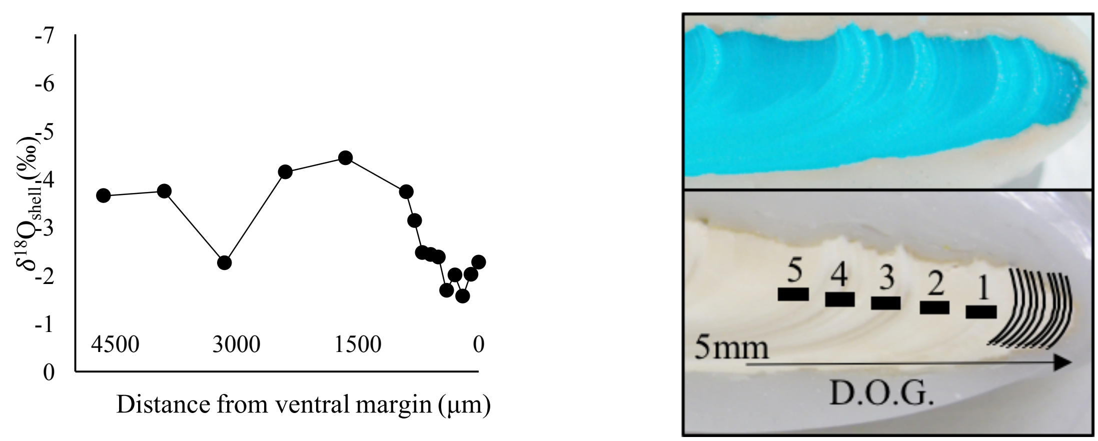
The ventral margin $\delta^{18}O$ value (-3.64‰) trends towards more negative values and is likely the result of spring freshwater input and warming. Milled sample taken near the winter check before the ventral margin has a more positive winter (-2.4 ‰). Over one year of growth was sampled.

Figure 13: Sample 3D **Season: Spring**



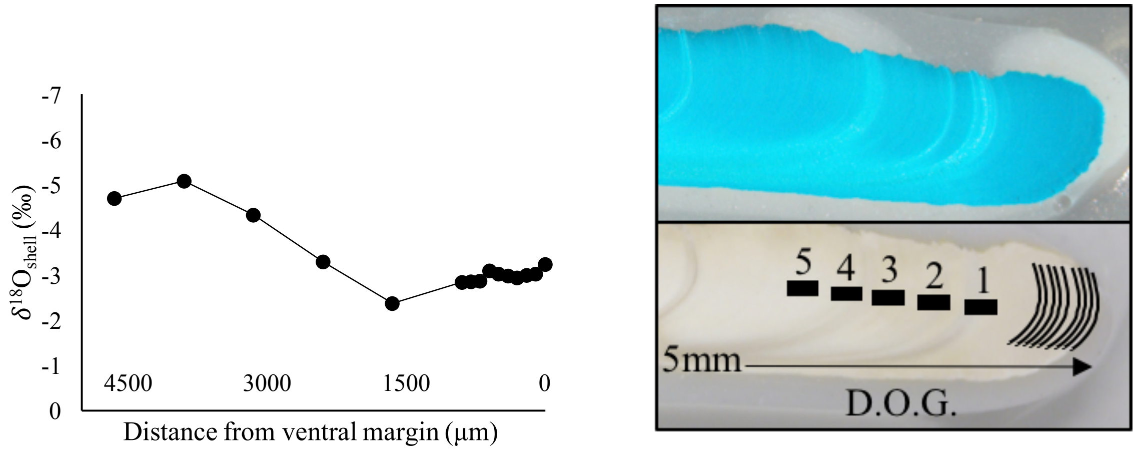
The ventral margin $\delta^{18}O$ value (-3.5‰) trends towards more negative $\delta^{18}O$ values with a slight decline towards more positive values in the last few milled samples (n=3, $\Delta\ \delta^{18}O$ = 0.2‰), which is typical before the warm summer signal masks the spring $\delta^{18}O$ values. Less than a year of growth was sampled.

Figure 14: Sample 9D **Season: Winter**



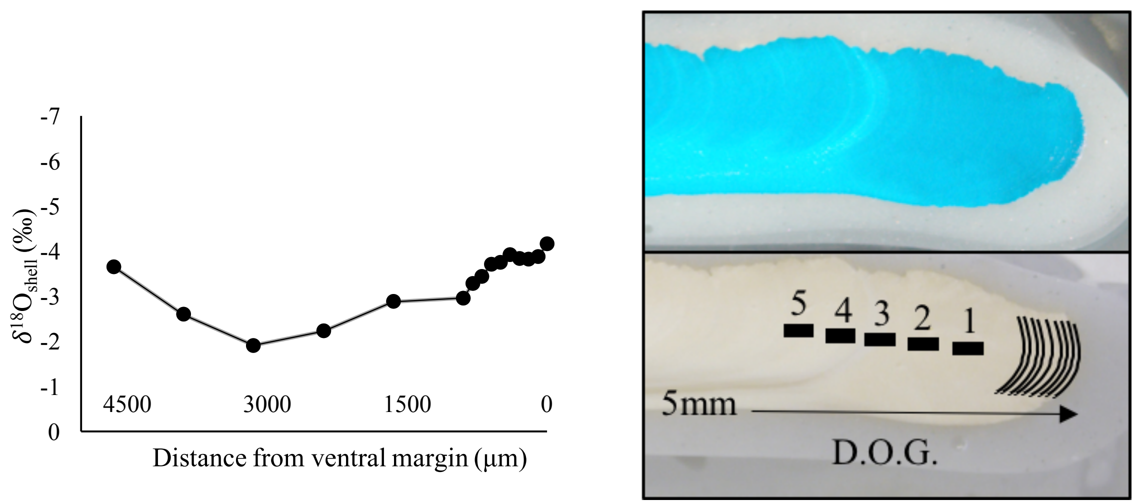
The ventral margin $\delta^{18}O$ value is very positive (-2.28‰) and is more positive than the average winter value from the live-collected shells (-2.6‰). Over a year of growth was sampled.

Figure 15: Sample 12D **Season: Early Spring**



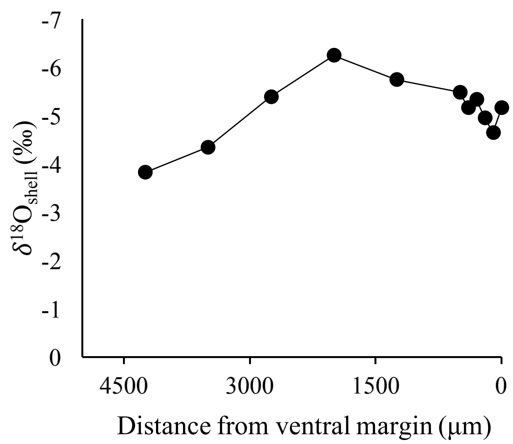
The ventral margin $\delta^{18}O$ value (-3.22 ‰) trends towards more positive values without reaching summer values and comes after a very positive value (drilled sample #1) which was taken on a winter growth line. Less than a year of growth was sampled.

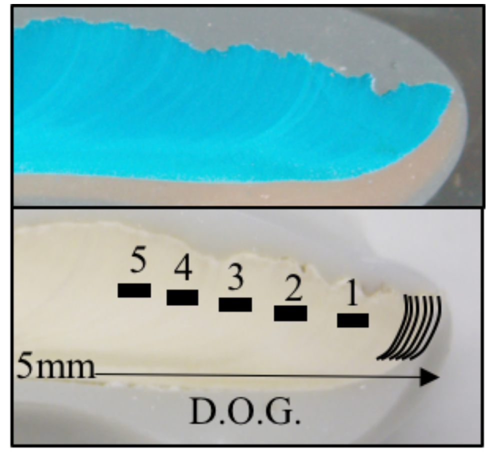
Figure 16: Sample 13D **Season: Spring**



The ventral margin $\delta^{18}O$ value (-4.15‰) trends more negatively and exhibit a more negative peak at 400µm nearing the ventral margin typical of spring freshwater input and warming. Only three seasons were sampled: autumn to spring.

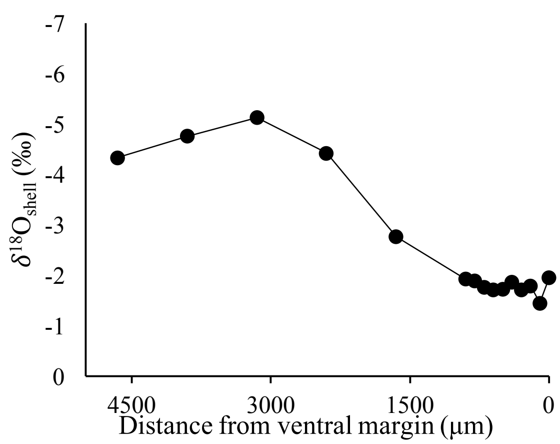
Figure 17: Sample 15D **Season: Autumn**

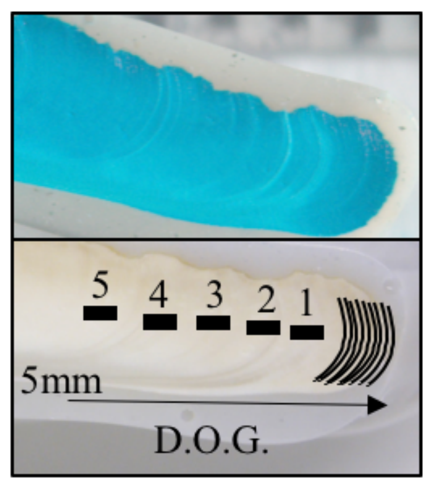




The $\delta^{18}O$ values for the eight samples leading to the ventral margin trend towards more positive $\delta^{18}O$ values ($\Delta\ \delta^{18}O = -1.1‰$). The ventral margin $\delta^{18}O$ value (-5.15‰) is more negative than the preceding sample resulting from higher precipitation in the autumn. Less than one season of growth was sampled.

Figure 18: Sample 18D **Season: Winter**

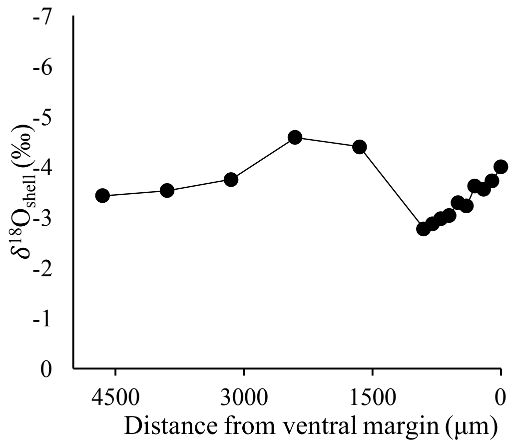




The ventral margin $\delta^{18}O$ value (-1.96‰) is very positive resulting from the cold winter seawater but is more negative than the preceding milled sample from winter precipitation. Slightly less than one year of growth was sampled.

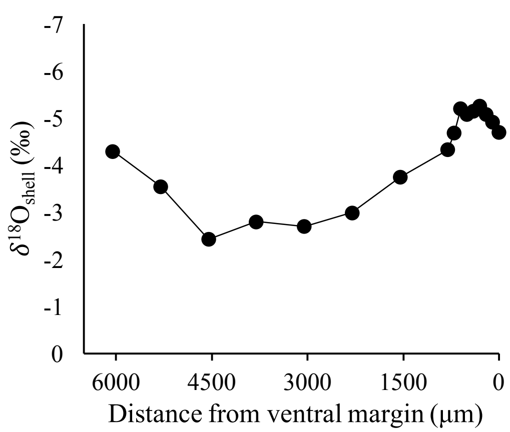
DkRw-22

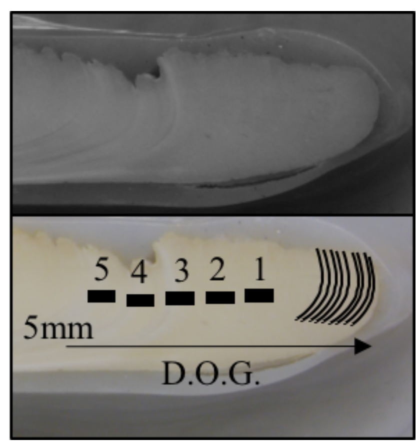
Figure 19: Sample 5D **Season: Spring**



The ventral margin $\delta^{18}O$ value (-4.00‰) trends towards increasingly negatively following a winter growth line, without reaching the summer values (~ -6.0‰). Over one year of growth was sampled.

Figure 20: Sample 8D **Season: Late Spring**

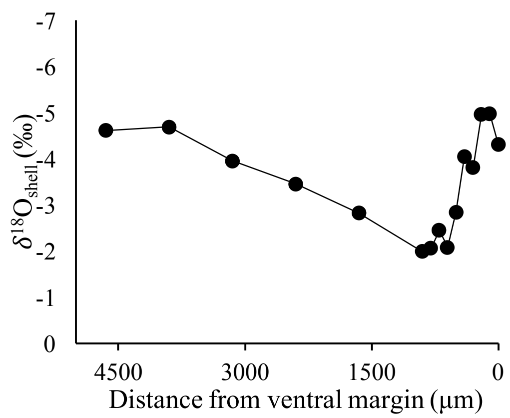


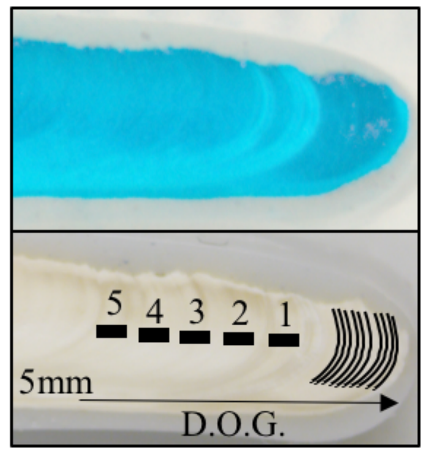


This specimen encountered higher freshwater input prior to collection, but has not yet registered a summer signal that nears values closer to -6.0. $\delta^{18}O$ values decline towards more positive values in the last few milled samples (n=4, $\Delta\ \delta^{18}O$ = 0.4‰), which is typical before the warm summer signal masks the spring $\delta^{18}O$ values. Only autumn to late spring growth was sampled.

DkRw-26

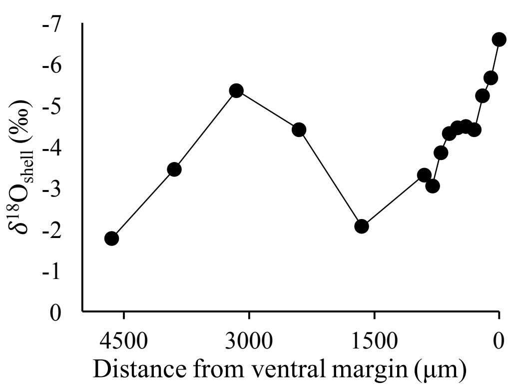
Figure 21: Sample 3D **Season: Late Spring**





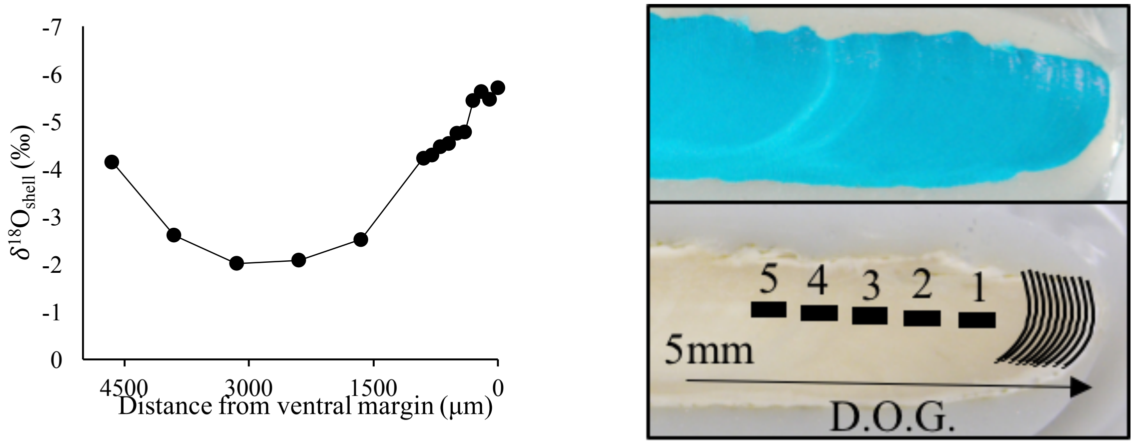
Milled samples trend towards more negative $\delta^{18}O$ values nearing the ventral margin (-4.32‰) and several freshwater peaks typical of spring melt, precipitation, and warming, without reaching the highly negative values of the summer (~ -6.0‰). Slightly under a year of growth was sampled.

Figure 22: Sample 5D **Season: Summer**



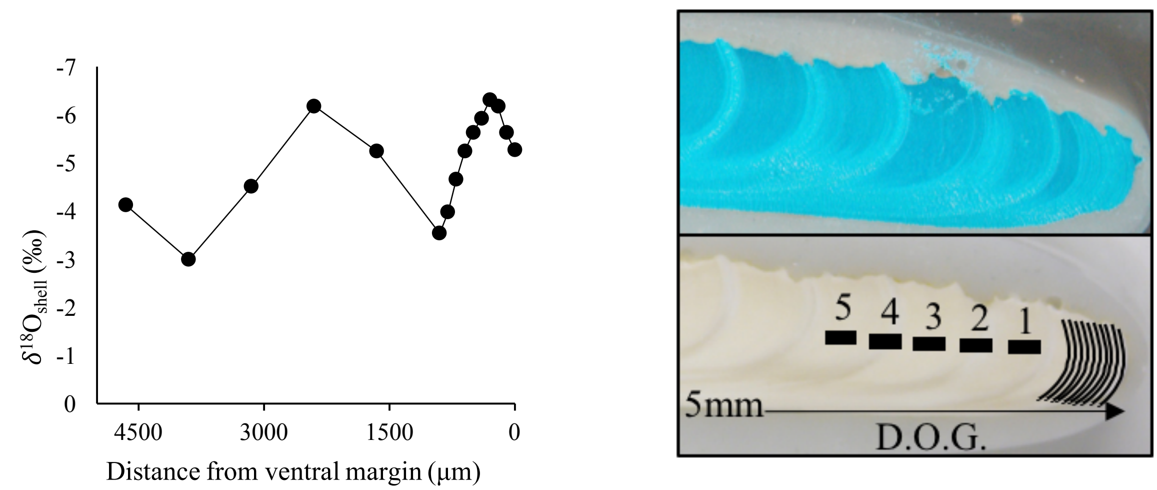
The ventral margin $\delta^{18}O$ value (-6.59‰) is more negative than the ventral margin $\delta^{18}O$ values of the summer live-collected shells (~ -6.0‰). Slightly over one year of growth was sampled.

Figure 23: Sample 6D **Season: Early Summer**



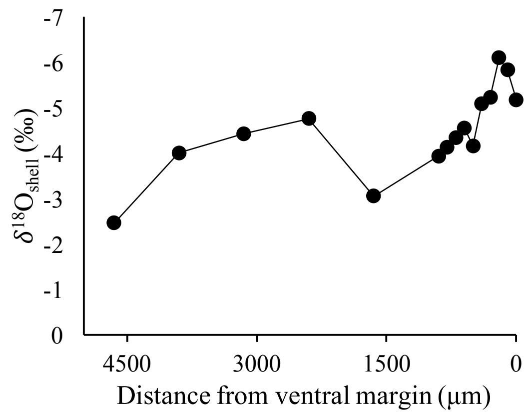
The $\delta^{18}O$ values of the milled samples trend towards more negative $\delta^{18}O$ values. The ventral margin $\delta^{18}O$ value (-5.71‰) appears to have surpassed negative spring peaks, and approaching summer $\delta^{18}O$ values (~ -6.0‰). Slightly less than one year of growth was sampled.

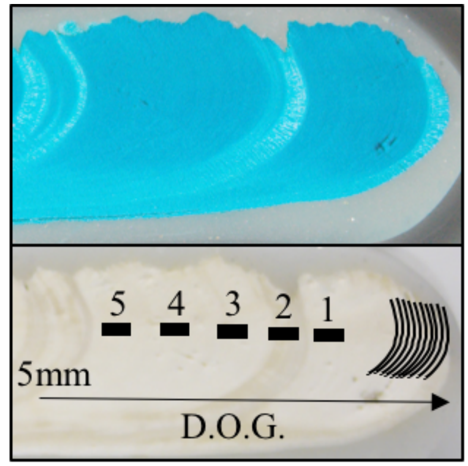
Figure 24: Sample 8D **Season: Early Autumn**



The ventral margin $\delta^{18}O$ value (-5.26‰) trends towards more positive values after 300µm which produced a summer value (-6.3‰). No freshwater peaks are observed after the summer peak suggesting an early autumn collection. Close to two years of growth were sampled.

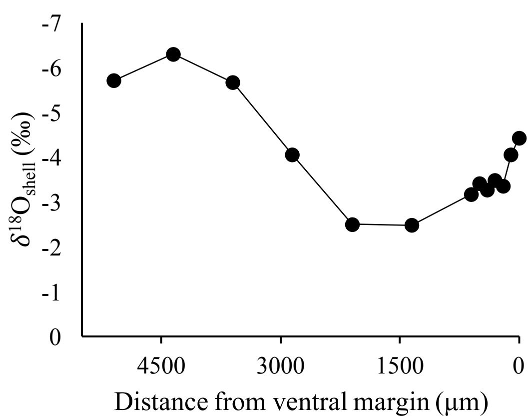
Figure 25: Sample 11D **Season: Early Autumn**





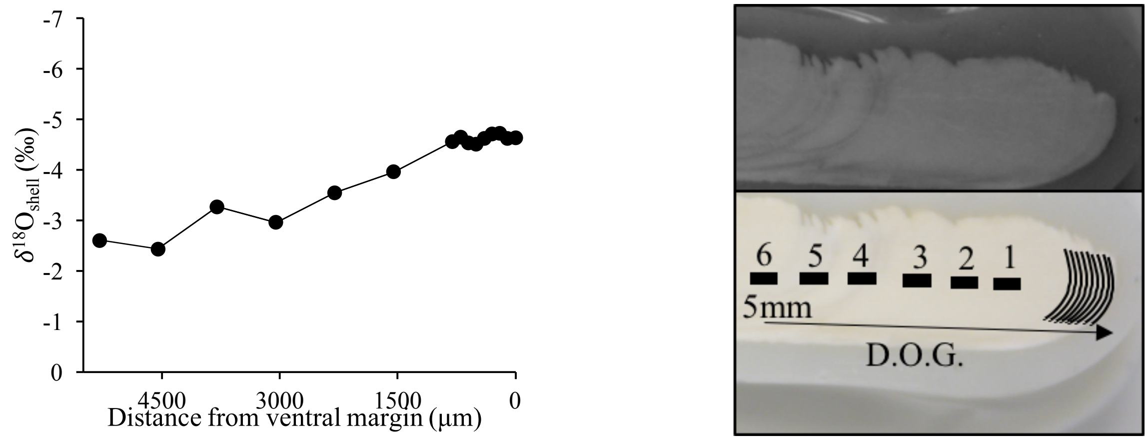
$\delta^{18}O$ values trends towards more positive values nearing the ventral margin (-5.18 ‰) following a summer peak at 200μm (-6.09‰), and follow a similar pattern to sample 8D. The ventral margin sample was also taken after the beginning of a growth band likely deposited in the summer. Over one year of growth was sampled.

Figure 26: Sample 12D **Season: Spring**



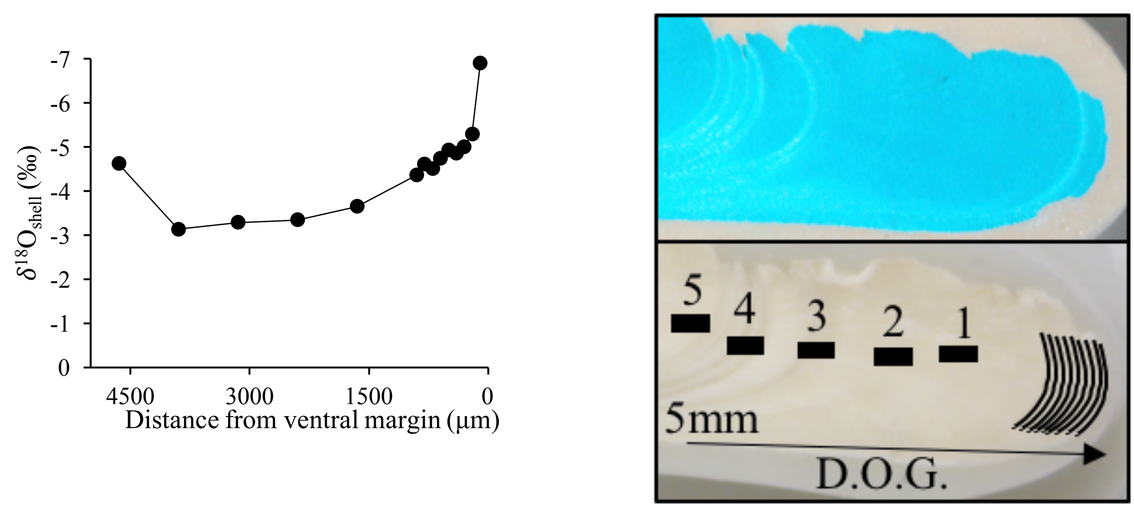
The ventral margin $\delta^{18}O$ value (-4.42‰) trends towards more negative values without reaching a summer value and exhibits freshwater fluctuations from 200 to 600μm. Slightly under one year of growth was sampled.

Figure 27: Sample 15D **Season: Spring**



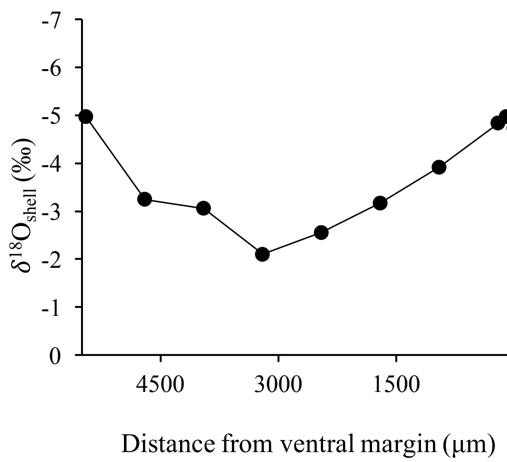
This young specimen appears to be growing fast and therefore a shorted period of time was sampled (only winter and spring). The ventral margin $\delta^{18}O$ value (-4.63‰) trends towards increasingly negative values without reaching the typical summer values and exhibits an early spring freshwater at drilled sample #4 taken on a disturbance line.

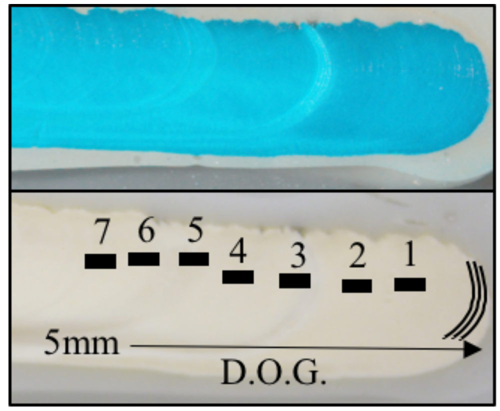
Figure 28: Sample 18D **Season: Summer**



The ventral margin $\delta^{18}O$ value (-6.90‰) trends towards more negative values and reach a more negative value than the summer live-collected shells. Only autumn to summer growth was sampled.

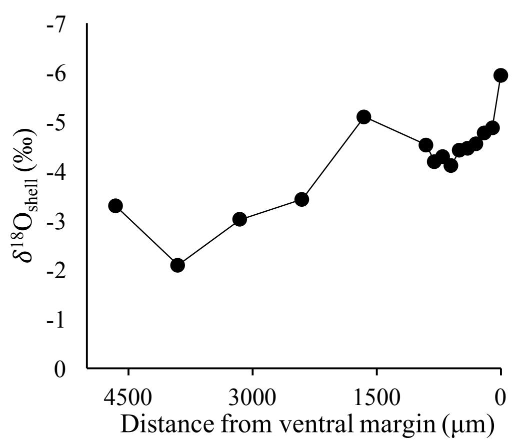
Figure 29: Sample 19D **Season: Spring**

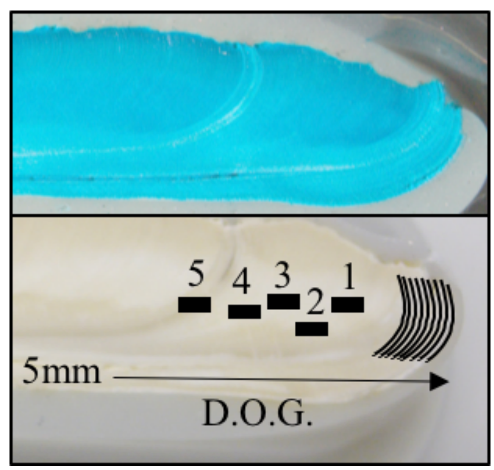




The ventral margin $\delta^{18}O$ value (-4.72‰) is between expected winter and summer values and trend towards more negative values after the fourth drilled sample. Slightly under one year of growth was sampled.

Figure 30: Sample 20D **Season: Summer**





The ventral margin $\delta^{18}O$ value (-5.93‰) trends towards more positive values and comes after a less negative peak at the 1st drilled sample caused by increased freshwater input in the spring leading up to the summer collection. Slightly under one year of growth was sampled.

Appendix 2: Growth Stage Determinations

DjRw-1 *In situ* Collection

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	UNIT	LAYER
35			1		N78 E68	A
36		1			N78 E68	A
37		1			N78 E68	A
38			1		N78 E68	A
39	1				N78 E68	A
40	1				N78 E68	A
41			1		N78 E68	A
42		1			N78 E68	A
43	1				N78 E68	A
44		1			N78 E68	A
45			1		N78 E68	A
46				1	N78 E68	A
47	1				N78 E68	A
48		1			N78 E68	A
49		1			N78 E68	A
50		1			N78 E68	A
51		1			N78 E68	A
52		1			N78 E68	A
53	1				N78 E68	A
54		1			N78 E68	A
55		1			N78 E68	A
56		1			N78 E68	A
57		1			N78 E68	A
58					N78 E68	A
59		1			N78 E68	A
60		1			N78 E68	A
61		1			N78 E68	A
62		1			N78 E68	A
63	1				N78 E68	A
64		1			N78 E68	A
65			1		N78 E68	A
66			1		N78 E68	A
67		1			N78 E68	A
68	1				N78 E68	A
69		1			N78 E68	A
70	1				N78 E68	A

In situ Collection, continued (a)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	UNIT	LAYER
71	1				N78 E68	A
72	1				N78 E68	A
73		1			N78 E68	A
74			1		N78 E68	A
75		1			N78 E68	A
76		1			N78 E68	A
77		1			N78 E68	A
78		1			N78 E68	A
79		1			N78 E68	A
80		1			N78 E68	A
81			1		N78 E68	A
82		1			N78 E68	A
83		1			N78 E68	A
84		1			N78 E68	A
85		1			N78 E68	A
86		1			N78 E68	A
87	1				N78 E68	A
88		1			N78 E68	A
89		1			N78 E68	A
90		1			N78 E68	A
91		1			N78 E68	A
92	1				N78 E68	A
93		1			N78 E68	A
94		1			N78 E68	A
95		1			N78 E68	A
96		1			N78 E68	A
97		1			N78 E68	A
98		1			N78 E68	A
99		1			N78 E68	A
100			1		N78 E68	A
101		1			N78 E68	A
102		1			N78 E68	A
103	1				N78 E68	A
105					N78 E68	A
106		1			N78 E68	A
107					N78 E68	A

In situ Collection, continued (b)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	UNIT	LAYER
108		1			N78 E68	A
109			1		N78 E68	A
110		1			N78 E68	A
111	1				N78 E68	A
112		1			N78 E68	A
113	1				N78 E68	A
114	1				N78 E68	A
115		1			N78 E68	A
116		1			N78 E68	A
117		1			N78 E68	A
118	1				N78 E68	A
119	1				N78 E68	A
120		1			N78 E68	A
121		1			N78 E68	A
122		1			N78 E68	A
123		1			N78 E68	A
124		1			N78 E68	A
125		1			N78 E68	A
126	1				N78 E68	A
416		1			N78 E68	A
104	1				N78 E68	B
3		1			N78 E68	B
4		1			N78 E68	B
5			1		N78 E68	B
6	1				N78 E68	B
7			1		N78 E68	B
8			1		N78 E68	B
9			1		N78 E68	B
10			1		N78 E68	B
11		1			N78 E68	B
12		1			N78 E68	B
13	1				N78 E68	B
14		1			N78 E68	B
15	1				N78 E68	B
16		1			N78 E68	B
17	1				N78 E68	B

In situ Collection, continued (c)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	UNIT	LAYER
1		1			N78 E68	C
2		1			N78 E68	C
18		1			N78 E68	G
19		1			N78 E68	G
20		1			N78 E68	G
21		1			N78 E68	G
22	1				N78 E68	G
23		1			N78 E68	G
24		1			N78 E68	G
25				1	N78 E68	G
26				1	N78 E68	G
27	1		1		N78 E68	G
28	1				N78 E68	G
29		1			N78 E68	G
30		1			N78 E68	G
31	1				N78 E68	G
32	1				N78 E68	G
33		1			N78 E68	G
34			1		N78 E68	G
154		1			N79 E68	Ka
155					N79 E68	Ka
156		1			N79 E68	Ka
157		1			N79 E68	Ka
158			1		N79 E68	Ka
159		1			N79 E68	Ka
160		1			N79 E68	Ka
161	1				N79 E68	Ka
162		1			N79 E68	Ka
163		1			N79 E68	Ka
164		1			N79 E68	Ka
165		1			N79 E68	Ka
166					N79 E68	Ka
167		1			N79 E68	Ka
168			1		N79 E68	Ka
169		1			N79 E68	Ka
127		1			N80 E68	Kc

In situ Collection, continued (d)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	UNIT	LAYER
128		1			N80 E68	Kc
129		1			N80 E68	Kc
130					N80 E68	Kc
131		1			N80 E68	Kc
132		1			N80 E68	Kc
133		1			N80 E68	Kc
134		1			N80 E68	Kc
135		1			N80 E68	Kc
136		1			N80 E68	Kc
137				1	N80 E68	Kc
138					N80 E68	Kc
139		1			N80 E68	Kc
140		1			N80 E68	Kc
141		1			N80 E68	Kc
142		1			N80 E68	Kc
143		1			N80 E68	Kc
144		1			N80 E68	Kc
145		1			N80 E68	Kc
146		1			N80 E68	Kc
147		1			N80 E68	Kc
148		1			N80 E68	Kc
149		1			N80 E68	Kc
150		1			N80 E68	Kc
151		1			N80 E68	Kc
152		1			N80 E68	Kc
153		1			N80 E68	Kc
648		1			N80 E68	Kc
650		1			N80 E68	Kc
651		1			N80 E68	Kc

Column Samples

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	UNIT	LAYER
766		1			N80 E85-86	B
768		1			N80 E85-86	B
10		1			N80 E85-86	B
775		1			N80 E85-86	C
776			1		N80 E85-86	C
777		1			N80 E85-86	C
778		1			N80 E85-86	C
11		1			N80 E85-86	C
1		1			N80 E85-86	D
2		1			N80 E85-86	D
3		1			N80 E85-86	D
4		1			N80 E85-86	D
5		1			N80 E85-86	D
6		1			N80 E85-86	D
7					N80 E85-86	D
8		1			N80 E85-86	D
9	1				N80 E85-86	D
10		1			N80 E85-86	D
1		1			N80 E85-86	E
2		1			N80 E85-86	E
3			1		N80 E85-86	E
7		1			N80 E85-86	E
8			1		N80 E85-86	E
773			1		N80 E85-86	F
774		1			N80 E85-86	F
772			1		N80 E85-86	I

<u>DkRw-22</u> Auger Test 2010-017

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
557			1		41-56
558			1		81-101
559			1		81-101

Column Sample

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	UNIT	Layer
648	1				D	J
649				1	D	J
650	1				D	J
651		1			D	J
652	1				D	J
653		1			D	J
654		1			D	J
655		1			D	J
658		1			D	J
661		1			D	J
665			1		D	J
668		1			D	J
669		1			D	J
670		1			D	J
671		1			D	J
672				1	D	J
673		1			D	J
674			1		D	J
675		1			D	J
676		1			D	J
677		1			D	J
678		1			D	J
679		1			D	J
681		1			D	J
682	1				D	J
684		1			D	J
685	1				D	J
686		1			D	J
689	1				D	J
690		1			D	J
692				1	D	J
693		1			D	J

DjRw-18, Auger Test 2010-016

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
477		1			1-21
478		1			1-21
479		1			1-21
480		1			1-21
481		1			1-21
482			1		1-21
483		1			1-21
484		1			1-21
485		1			1-21
486		1			1-21
487		1			1-21
488		1			1-21
489		1			1-21
490		1			1-21
491		1			1-21
492		1			1-21
494		1			1-21
495		1			1-21
496	1				1-21
497		1			1-21
498		1			1-21
499		1			1-21
500		1			1-21
502		1			21-37
503		1			21-37
504		1			21-37
505			1		21-37
506		1			21-37
507					21-37
508			1		21-37
509		1			21-37
510			1		21-37
511			1		21-37
512		1			21-37
513		1			21-37
514			1		21-37

AT 2010-016, cont. (a)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
515		1			37-46
516		1			37-46
517		1			37-46
518		1			37-46
519				1	37-46
520		1			37-46
521		1			37-46
522		1			37-46
523		1			37-46
524		1			37-46
525		1			37-46
526		1			46-53
528		1			46-53
529		1			46-53
530			1		46-53
531		1			46-53
533			1		46-53

Auger Test 2010-014

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
536		1			21-62
537			1		21-62
539		1			21-62
540		1			21-62
541		1			21-62
543			1		21-62
544			1		62-73
545			1		62-73
546			1		62-73
547		1			62-73
548			1		73-80
549		1			73-80
550		1			73-80
552		1			73-80
553		1			73-80
554		1			73-80
555			1		73-80
556		1			73-80

<u>DkRw-26</u> Auger Test 2010-001

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
281			1		0-21
282		1			0-21
283			1		0-21
284		1			0-21
285	1				0-21
286			1		0-21
287	1				0-21
288		1			0-21
289	1				0-21
290	1				0-21
291		1			0-21
292	1				0-21
394		1			0-21
395	1				0-21
396				1	0-21
397	1				0-21
398		1			0-21
399				1	0-21
400	1				0-21
401		1			0-21
402	1				0-21
403	1				0-21
293		1			21-35
294	1				21-35
295		1			21-35
296		1			21-35
297		1			21-35
298			1		21-35
299		1			21-35
300				1	21-35
301		1			21-35

AT 2010-001, cont. (a)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
302		1			21-35
303		1			21-35
404				1	21-35
405		1		1	21-35
406	1				21-35
407		1			21-35
408		1			21-35
409	1				21-35
410	1				21-35
411		1			21-35
305			1		35-48
306		1			35-48
307				1	35-48
308	1				35-48
309		1			35-48
310	1				35-48
311	1				35-48
312		1			35-48
313			1		35-48
314		1			35-48
315		1			35-48
316		1			35-48
317	1				35-48
412					35-48
413					35-48
414		1			35-48
415		1			35-48
416	1				35-48
417	1				35-48
418		1			35-48
419		1			35-48

AT 2010-001, cont. (b)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
420		1			35-48
421		1			35-48
422		1			35-48
423		1			35-48
424			1		35-48
425		1			35-48
318			1		48-59
319		1			48-59
320		1			48-59
321		1			48-59
322			1		48-59
323			1		48-59
324		1			48-59
325		1			48-59
326	1				48-59
327			1		48-59
328		1			48-59
329		1			48-59
330		1			48-59
331		1			48-59
332		1			48-59
333		1			48-59
334			1		48-59
335		1			48-59
426			1		48-59
427				1	48-59
428				1	48-59
429				1	48-59
430		1			48-59
431					48-59
432		1			48-59

AT 2010-001, cont. (c)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
433			1		48-59
434		1			48-59
435	1				48-59
436		1			48-59
437			1		48-59
438	1				48-59
439		1			48-59
440		1			48-59
336				1	59-75
337			1		59-75
338			1		59-75
339		1			59-75
340		1			59-75
341		1			59-75
342		1			59-75
343			1		59-75
344		1			59-75
345			1		59-75
346		1			59-75
347		1			59-75
348		1			59-75
349			1		59-75
350		1			59-75
351		1			59-75
441		1			75-82
442			1		75-82
443	1				75-82
444		1			75-82
445		1			75-82
446					75-82
447		1			75-82

AT 2010-001, cont. (d)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
448		1			75-82
449		1			75-82
450	1				75-82
451		1			75-82
452	1				75-82
453	1				75-82
453		1			82-94
454			1		82-94
455			1		82-94
456			1		82-94
457		1			82-94
458		1			82-94
459	1				82-94
460				1	82-94
461		1			82-94
462			1		82-94
463		1			94-105
464				1	94-105
465		1			94-105
466		1			94-105
467		1			94-105
468		1			94-105
469		1			94-105
470		1			94-105
471		1			94-105
472		1			94-105
473				1	94-105
474		1			105-110
475	1				105-110
476				1	105-110

Auger Test 2010-002

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
170			1		0-21
171			1		0-21
173					0-21
174			1		0-21
175			1		0-21
176		1			0-21
177			1		0-21
178			1		21-40
179		1			21-40
180			1		21-40
181			1		21-40
182			1		21-40
183			1		21-40
184			1		21-40
185		1			21-40
186		1			21-40
187			1		21-40
188			1		21-40
189		1			21-40
190	1				21-40
191	1				21-40
192		1			21-40
193			1		21-40
194		1			21-40
195		1			21-40
196	1				21-40
197		1			21-40
198			1		21-40
199			1		21-40
200	1				21-40
352		1			21-40

AT 2010-002, cont. (a)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
353		1			21-40
354	1	1			21-40
356			1		21-40
357	1				21-40
358			1		21-40
359					21-40
360	1				21-40
361		1			21-40
362		1			21-40
363		1			21-40
364	1				21-40
365		1			21-40
366			1		21-40
367	1				21-40
368	1				21-40
369			1		21-40
370	1				21-40
371					21-40
372		1			21-40
373			1		21-40
374		1			21-40
375					21-40
201			1		40-48
202		1			40-48
203			1		40-48
204		1			40-48
205			1		40-48
206			1		40-48
207			1		40-48
208			1		40-48
209		1			40-48

AT 2010-002, cont. (b)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
210	1				40-48
211			1		40-48
212		1			40-48
213		1			40-48
214	1				40-48
215		1			40-48
216			1		40-48
217			1		40-48
218		1			40-48
219	1				40-48
220		1			40-48
221			1		40-48
222		1			40-48
223			1		40-48
224			1		40-48
225a		1			40-48
225b	1				40-48
226			1		40-48
227		1			40-48
228		1			40-48
229		1			40-48
230		1			40-48
231		1			40-48
232		1			40-48
233			1		48-54
234			1		48-54
235			1		48-54
236			1		48-54
237			1		48-54
238		1			48-54
239		1			48-54

AT 2010-002, cont. (c)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
240		1			48-54
241		1			48-54
242		1			48-54
243		1			48-54
244		1			48-54
245			1		48-54
246		1			48-54
247		1			48-54
248				1	48-54
376	1				48-54
377				1	48-54
378		1			48-54
379		1			48-54
380				1	48-54
381	1				48-54
382			1		48-54
257		1			54-60
258			1		54-60
259		1			54-60
260		1			54-60
261			1		54-60
262		1			54-60
263			1		54-60
264		1			54-60
265		1			54-60
266	1				54-60
267		1			54-60
268		1			54-60
269			1		54-60
270		1			54-60
271		1			54-60

2010-002, cont. (d)

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	DBS (cm)
272		1			54-60
273		1			54-60
274		1			54-60
275		1			54-60
276			1		54-60
277		1			54-60
278a		1			54-60
278b		1			54-60
279	1				54-60
280		1			54-60
383	1	1			54-60
384	1				54-60
389			1		54-60
390				1	54-60
391				1	54-60
392		1			54-60
393		1			54-60
249a					54-60
249b					54-60
249		1			60-68
250		1			60-68
251		1			60-68
252		1			60-68
253		1			60-68
254		1			60-68
255	1				60-68
256		1			60-68

Column Samples

SAMPLE ID	JUVENILE	MATURE	SENILE	UNKNOWN	UNIT	LAYER
564				1	A	B
567		1			A	B
568			1		A	B
569		1			A	B
570				1	A	B
571				1	A	B
573	1				A	B
579			1		A	B
580				1	A	B
583		1			A	C
584				1	A	C
585		1			A	C
586				1	A	C
587		1			A	C
588		1			A	C
589	1				A	C
590		1			A	C
591	1				A	C
592		1			A	C
593		1			A	C
594	1				A	C
595		1			A	C
596		1			A	C
597		1			A	C
598		1			A	C
599	1				A	C
600		1			A	C
610				1	A	C
611		1			A	C
612				1	A	C
613		1			A	C