SHELLFISH HARVEST ON THE COAST OF BRITISH COLUMBIA: THE ARCHAEOLOGY OF SETTLEMENT AND SUBSISTENCE THROUGH HIGH-RESOLUTION STABLE ISOTOPE ANALYSIS AND SCLEROCHRONOLOGY

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THROUGH HIGH-RESOLUTION STABLE ISOTOPE ANALYSIS
AND SCLEROCHRONOLOGY

By:

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ABSTRACT

In many interpretations of hunter-gatherer settlement systems, archaeologists have assumed implicitly or explicitly that a pattern of mobility based on seasonally-scheduled movements between different site locations was practiced. This pattern of mobility is often characterized as a seasonal round, where different locations are used during specific times of the year for different purposes. An implication of this pattern of mobility is that short-term occupation sites are visited annually, approximately at the same time each year and longer-term residential sites can span multiple seasons. To interpret seasonality, indirect indicators are often used but the high-resolution methods presented in this study provide direct evidence of seasonal site occupation. The Pacific Northwest Coast provides an ideal landscape to examine seasonality since many of the staple resources, particularly salmon, were available on a seasonal basis. Contrary to longstanding assumptions of regular seasonal movement between sites, the analysis of shell samples from multiple archaeological sites from distinct regions in British Columbia show complex patterns of multi-seasonal occupation at smaller campsites and specific seasonal or multi-seasonal emphasis in occupation and/or shellfish harvest at longer-term residential sites.

To identify patterns of shellfish harvest, stable oxygen isotope analysis and high-resolution sclerochronology were applied to the bivalve *Saxidomus gigantea* (butter clam). Combined with shell growth increment analysis to examine relative levels of harvest pressure, local rates of shellfish collecting are also interpreted. To examine regional variability in seasonality and resource use in British Columbia, three environmentally and historically distinct areas were selected spanning approximately 6000 years of history. These regions include the central coast in the tradition territory of the Heiltsuk, and two areas on the northern coast, specifically the Dundas Islands Group and Prince Rupert Harbour in the traditional territory of the Tsimshian. The results of the analysis show site-specific trends in shellfish harvesting on the central coast; a pattern which is not as clear on the northern coast. Sites on the Dundas Islands show multi-seasonal collection and a stronger emphasis on winter shellfish harvesting. The results also show that shellfish were harvested more intensively in the Dundas Islands area relative to the central coast. The pattern of seasonal shellfish harvesting on the mainland coast at village sites in Prince Rupert Harbour is similar to the pattern found at long-term residential sites on the central coast. With respect to the dietary importance of clams, another longstanding issue in Northwest Coast archaeology, the results show a mix of patterns including casual resource use at most campsites, intensive multi-season harvest in some regions and strategic multi-season harvest and spring consumption at some residential sites.

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For Andrew Burchell

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CHAPTER 1

Well I think the last one that I know, what we do for our food for the year round, that's the clams. The clams last just about all through the winter. We had to go out and pick it anytime through the winter, but sometimes we smoked it and dried it, because it's a different taste when it's smoked and dried. That is all we do with it. That's our food right through the winter. We live on that all through the winter. Even if we run out of different kinds of food, we just go down the beach and dig some clams and we eat it anytime we want it in the winter time. I think that's all about that I know.

-'Food Gathering' by Eli Wallace. *Bella Bella Stories* (1973:112)

1. INTRODUCTION

The Pacific Northwest Coast provides an ideal landscape to examine the question of archaeological seasonality since the majority of local economies relied on foods that were seasonally available, specifically anadromous fish, such as salmon. There is documented inter-site variability in the subsistence strategies for the acquisition of both fish and shellfish remains on the coast of British Columbia, which may also suggest there was variability in seasonal patterns of resource acquisition. The analysis of salmon remains from sites on the central coast have yielded evidence pointing to food storage dating back 7000 years, suggesting that seasonal harvests of salmon supported long-term occupation at village sites. (Cannon and Yang, 2006). Different patterns in shellfish harvesting strategies have also been identified at different types of sites, such as long-term occupation or short-term camp-sites. For example, growth increment analysis of butter clams on the central coast of British Columbia demonstrated different shellfish harvesting intensity between sites within the region, based on the premise that less intensive harvest would result in greater numbers of senile-aged clams (Cannon and Burchell, 2009). Long-term occupational sites, such as villages had a higher proportion of shells in a senile stage of growth. In contrast, short-term camps have a higher proportion of shells in a mature stage of growth. However, the antiquity of the seasonal patterns of food acquisition is unknown, not only for the central coast, but for the whole of the Pacific Northwest coastline.

This thesis applies three analytical methods to understand regional and temporal variability in the season and intensity of shellfish collection using: 1) high-resolution stable oxygen isotope analysis; 3) sclerochronology; and 2) macro-growth increment analysis. These analytical techniques are applied in a multi-scalar analysis of multiple archaeological shell midden sites from the central and northern coasts of British Columbia. A multi-region approach is crucial for understanding the range of variability in settlement and subsistence since the cultural variation in resource use is directly related to variation in local environments (Richardson 1981). This dissertation also challenges low-resolution seasonality methods and over-reliance on the ethnographic record. More significantly, this dissertation provides a new method for the precise analysis of seasonality from archaeological shellfish recovered from estuarine and freshwater influenced marine environments and offers insight into hunter-fisher-gatherer settlement and subsistence on the coast of British Columbia.

1.2 RESEARCH OBJECTIVES AND STUDY AREA

The species studied, *Saxidomus gigantea* (butter clam) is ideal for conducting seasonality and harvesting studies since it is one of the most commonly recovered bivalve species on the coasts of British Columbia, Alaska and Washington (Cannon et al., 2008; Fitzhugh, 1995; Moss, 1993, 2012; Moss and Erlandson, 2010; Wessen, 1988). In this study, eight sites on the central coast in the traditional territory of the Heiltsuk are analyzed along with 15 sites from the Dundas Islands Group and four sites in Prince Rupert Harbour in the traditional territory of the Coast Tsimshian.

The shellfish data (stable oxygen isotopes, sclerochronology and macro-growth increments) are integrated with information about local resource variability and are interpreted within specific environmental, cultural and historical contexts. These multiple lines of evidence provide the data necessary to begin to develop historical narratives that examine the specific contingencies that shaped seasonal settlement systems.

The objectives of this dissertation are as follows: 1) to critically evaluate the seasonality methods for marine bivalves applied on the coast of British Columbia and to improve the accuracy and precision of seasonality estimates obtained from shellfish; 2) to analyze live-collected shellfish specimens from the central coast of British Columbia and apply these data to interpret the results obtained from archaeological shells from multiple sites within the immediate vicinity of the Namu village site (ElSx-1); and 3) to extend the methodology of growth increment analysis to the northern coast of British Columbia and the use of high-resolution stable isotope sclerochronology to examine harvest pressure and the seasonality of clam harvest on the Dundas Islands and in Prince Rupert Harbour. The results have provided new insights into regional patterns of settlement and subsistence on the central and northern coasts of British Columbia.

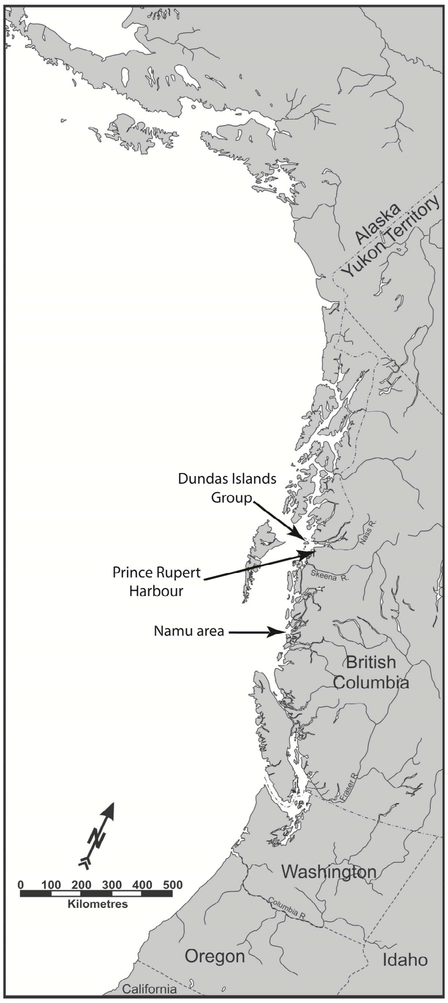

Figure 1.1 – Map showing locations of seasonality and growth increment studies on the central coast in the Namu vicinity, the Dundas Islands, Prince Rupert Harbor

Table 1.1 – Sites examined for growth increment analysis and seasonality*

				# of Shells Analyzed	
Region	**Borden**	**Site**	**Site Type**	**Stable Isotopes**	**Growth Increments**
Central Coast**	ElSx-1	Namu	Village	22	197
	ElSx-3	Kisameet	Village	12	67
	ElSx-4		Small camp	7	36
	ElSx-5		Large residential site	7	52
	ElSx-10		Large residential site	14	102
	ElTa-25	Kiltik Cove	Camp	12	240
	ElTb-1	Hurricane Island	Village	10	42
	ElTb-10	McNaughton	Village	6	30
North Coast					
Dundas Islands	GcTq-1		Village		140
	GcTq-11		Camp		73
	GcTq-13		Camp	5	32
	GcTq-4		Camp		180
	GcTq-5		Village	7	590
	GcTq-6		Camp	6	315
	GcTq-7		Village		314
	GcTq-9		Village	5	171
	GcTr-10		Village		127
	GcTr-5		Village		194
	GcTr-6		Camp	5	18
	GcTr-8		Village		580
	GcTr-9		Camp		78
	GdTq-1		Village	5	38
	GdTq-3		Camp	8	153
Prince Rupert	GbTn-19	Ridley Island	Village	5	208
Harbour	GbTo-46	Tremayne Bay	Village		153
	GbTo-77		Village		163
	GcTo-6	McNichol Creek	Village	5	166

*Site types from the central coast are based on Cannon (2012); Dundas Islands (Brewster and Martindale, 2011); Ridley Island (May, 1979); McNichol Creek (Coupland et al., 1993); Digby Island (Patton, 2011) and Tremayne Bay (Archer, 2001).
**All central coast shell growth data except ElTb-10 is from Cannon and Burchell 2009.

1.3 SEASONALITY AND ARCHAEOLOGY

Seasonality plays a critical role in hunter-fisher-gatherer societies since it influences the availability of food resources and structures the organization of activities and the timing of events. It is therefore an important component for understanding long-term patterns of settlement and subsistence. It can also be extended to explore broader understandings of belief systems (Cannon 2002) and the nature of mobility and the development of sedentism (Milner, 2005). The ability to acquire food in temperate locations is associated with seasonal cycles, therefore environmental changes are integrated into all economic and settlement activities. Seasonal subsistence practices are scheduled in such a way that they optimize the acquisition of resources that may vary in quantity, availability and abundance. The importance of seasonality also varies by location and it becomes more important in areas where there is a 'hungry season' resulting in the storage of food resources to ensure a supply throughout the year (Harrison 1988:27). In response to seasonal changes hunter-gatherers can practice resource management including the ability to repeatedly alter the means of subsistence by re-shaping the landscape and controlling access to resources through territorial rights or season-specific harvesting (Smith and Wishnie, 2000). It should also be noted that hunter-gatherers can also over-use resources and diminish their availability through repeated harvesting in a localized area (Braje et al., 2007).

The question of seasonality is often cited as central in understanding subsistence strategies in prehistoric economies (Andrus and Crowe, 2000; Coutts and Higham, 1971; Harrison, 1988; Kennett and Voorhies, 1996; Killingley, 1981). Seasonality studies are used most frequently to determine the season of resource acquisition and by proxy the season of site occupation, which is essential for examining patterns of mobility and sedentism. When the availability of both floral and faunal resources is considered, more specific models of yearly resource cycles can be constructed (Milner, 2005). However, many archaeological contexts do not preserve sufficient quantities of faunal and especially floral remains to construct an annual cycle of subsistence activities. If the relationship between seasonality and settlement is to be answered, "[a]ny attempt to reconstruct the economy of a site is likely to be at best, partially successful, unless the settlement system in which the site was embedded is taken into account" (Rowley-Conwy, 1993: 179)

People may aggregate to process seasonally abundant resources and during lean seasons they may disperse to obtain resources that may be available in other areas. The aggregation and dispersion of people is a common result of seasonal fluctuations in resource availability (Monks, 1981:179), and logistical positioning in regards to settlement will be the greatest in regions with extreme seasonal variability (Binford, 1980:15). By identifying the season of resource procurement it is possible to identify what percentage of the year a group may have spent in a specific area, and to interpret the annual cycle of mobility (Sanger, 1988), or group coalescence (Cannon, 2002). Ethnographic observations on the Northwest Coast showed shifts in settlement size and structure according to different seasons (Mitchell, 1983), and these periodic group movements have been viewed as necessary to harvest the abundance of seasonally available resources (Suttles, 1960:527-529 in Ham and Irving, 1975).

The methods for estimating seasonality based on zooarchaeological data generally rely on the presence or absence of seasonally available species, migratory patterns of animals, and the presence of juvenile or neo-natal individuals. Physiological events in an animal's life such as antler formation, tooth development and the formation of medullary bone deposits are also used to link a biological process to a specific time of the year (Monks, 1981). The analysis of growth structures in teeth, otoliths, fish scales, and mollusk shells are used to identify the season of death based on the timing of the formation of increments, or 'growth lines' (Monks, 1981). However, the use of 'growth lines' to interpret season of death in shellfish cannot be considered reliable without geochemical alignment and a modern comparative study (Andrus, 2011).

1.4 SEASONALITY AND SHELLFISH STUDIES ON THE NORTHWEST COAST

Archaeological shell midden sites on the central and northern coasts represent a diverse range of site types, and the nature of the sites and reasons for their occupation may have changed through time. Although the size, shape, form and function of sites vary locally and regionally, one common characteristic is a similar variety of taxa represented in the middens, including butter clam, horse clam, littleneck clam, cockles, barnacles, mussels, whelks and urchin (Cameron et al., 2008; Cannon et al., 2008; Coupland et al., 1993; May, 1979). The availability of shells and their potential use as seasonality indicators has resulted in their common use for this purpose on the Northwest Coast (e.g., Ham and Irving, 1975; Keen, 1979; Clarke and Clarke, 1980; Crockford and Wigen, 1991; Coupland et al., 1993; Stevenson 1977).

Although commonly represented in archaeological sites, shellfish have been considered a less significant resource, especially when compared to other foods such as marine fish or terrestrial mammals (Erlandson, 2001:294). In many archaeological studies, the presence of shellfish is acknowledged, but their importance is overlooked (Fitzhugh, 1995:130). The use of intertidal resources has been ubiquitous on the coast of British Columbia for over 5000 years (Fladmark, 1975), and was in place as long ago as ~10,000 years on Haida Gwaii (Fedje et al. 2001). Shellfish are one of the most abundant classes of archaeological remains at coastal sites, and, whatever their absolute dietary contribution might have been, they were a source of nutrition that had been universally integrated into hunter-gatherer subsistence strategies throughout the Holocene (Fitzhugh, 1995).

There is limited ethnographic and archaeological information regarding the role and significance of shellfish along the entire Pacific Coast (Cannon et al., 2008), and much of the ethnographic information on shellfish gathering is limited to select cultural groups. The lack of ethnographic information on shellfish harvesting may be attributable to the uneven distribution of attention that was paid to male-dominated and more dramatic subsistence activities such as fishing and sea mammal hunting (Moss, 1993). Based on the ethnographic record, the Northern Coast Salish dug for clams during the winter when the tides were low at night (Kennedy and Bouchard, 1990:445). Similarly, the Tsimshian in Prince Rupert Harbour harvested shellfish during the winter (Halpin and Seguin, 1990:271). Shellfish were gathered year-round by the Haida, and, if there was a poor salmon harvest, shellfish became more important in the winter and spring when other foods were scarce (Blackman, 1990:24). The Nuu-chah-nulth on Vancouver Island gathered shellfish in the spring because of the scarcity of other foods (Arima and Dewhirst, 1990:394). Regardless, the observations of seasonal resource procurement made during the ethnographic period are not necessarily representative of the archaeological past, nor do they take into account the potential for change over time (Conneller, 2005; Ford, 1989; Jochim, 1991).

The majority of seasonality studies from the Northwest Coast have focused on the presence of an assumed 'seasonal round' (Ames, 1981:798), which was based on the need to procure and process food in the late summer and autumn to sustain village populations throughout the winter months. This pattern of residential mobility has been heavily generalized for most of the North Pacific Coast and is influenced by observations from the early European contact era

(Ford, 1989). After European contact, during the ethnohistoric era, residential mobility was frequently noted (Barnett, 1938; Mitchell, 1983; Mitchell and Donald, 1988), and this model of the 'seasonal round' has permeated archaeological interpretations (Ford, 1989). One of the primary reasons for archaeological interest in the analysis of shellfish is not only to gain insight into subsistence practices, but also to determine, by proxy, the season of site occupation. However, even high-resolution analysis of shellfish will not identify when a site *was not* occupied.

Low-resolution seasonality indicators, such as presence/absence studies of migrating faunas have been applied to understand seasonal patterns of site occupation on the northern coast (Stewart, 1975; Stewart and Stewart, 1996). However, presence/absence indicators such as migrating species can overlap (Monks, 1981) and do not provide a precise estimate for the time of capture or the season of site occupation. Other approaches, such as ancient DNA analysis have been proven successful in refining patterns of site occupation based on the specific species identification of migrating fish (Cannon and Yang, 2006; Ewonus et al., 2011), but seasonal ranges for specific species can still be broad.

As an alternative, bivalve analysis has been widely used to determine seasonality on the Pacific Northwest Coast. Growth line analysis has been the most commonly used technique (e.g., Clarke and Clarke, 1980; Coupland et al., 1993; Crockford and Wiggen, 1991; Ham and Irvine, 1975; Keen, 1979; Maxwell, 2003; May, 1979; Stevenson, 1977). This approach to determining the season of shellfish harvesting is based on the assumption that mollusks deposit calcium carbonate when they are submerged during high-tide, and grow more rapidly in the summer and either slow or stop growing in the winter to form an annual line (Rhoads and Pannella, 1970). For this method the season of shellfish collection is determined by comparing growth increments (the periods of rapid growth) to growth lines (periods of slow or no growth) and then by dividing the width of the pre-death increment by the width of the last complete increment (Monks and Johnston, 1993). The distance between the last years of growth is compared to the previous year's growth, and based on the distance between the lines a season of death is inferred.

An alternative approach focuses on seasonal variability in shell stable isotope values. Coarse-resolution stable oxygen isotope analysis, for example, was conducted at the Yuak site in Alaska, showing an emphasis on autumn and winter harvesting (Fitzhugh, 1995). Recent advances in stable isotope sclerochronology have shed light on a variety of factors rendering the method of 'growth line' analysis unreliable for determining seasonality (Andrus 2011; Hallmann et al., 2009). Shell growth rates are variable across time and space, which can make 'winter growth' lines indistinguishable from lines deposited by stress, changes in temperature, salinity or food (Hallmann et al., 2009). Furthermore, 'winter growth' line analysis, or shell growth colouration methods do not consider regional variability in shell growth rates or the decrease in shell growth rates through ontogeny (Schöne, 2008). Additionally, in some butter clams multiple 'winter growth lines' are observed in a single year (Gillikin et al., 2005), and these cannot be identified as 'winter' breaks without both geochemical and sclerochronological analysis.

1.5 MATERIALS AND METHODS

The butter clam, *Saxidomus gigantea* precipitates an aragonitic shell (Gillikin et al. 2005). It is a temperate marine species that burrows to a depth of approximately 30 cm below the sediment surface in the intertidal zone (Nickerson, 1977; Paul et al., 1976). Although it lives in both marine and estuarine, and freshwater-influenced marine settings on the Northwest Coast, almost all clam beds associated with shell middens in the area are subject to freshwater fluxes from river outflow or precipitation. Therefore this factor must be considered when interpreting stable oxygen isotope data.

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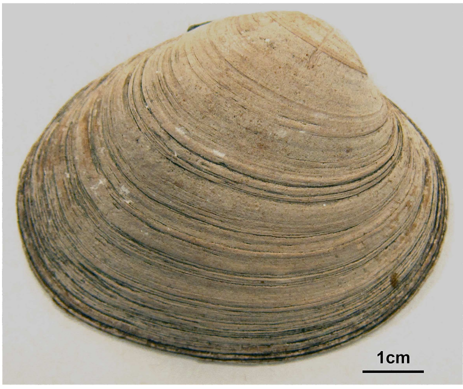

Figure 1.2 – Butter clam, *Saxidomus gigantea.*

The shell samples used in this study were collected in the field, and from museum and university archives. Samples from the Namu region on the central coast were obtained from samples collected with a 7 cm bucket auger (Cannon, 2000). Additional whole *S. gigantea* valves from Namu were obtained from level bag samples from the 1977–78 archaeological field school excavations conducted by Simon Fraser University. Live-collected shells along with water samples were collected from the beach in front of Namu (ElSx-1) and from the intertidal zones in front of nearby archaeological sites ElSx-4 and ElTa-25 in August 2009. An additional live-collected specimen from Kakushdish Harbour, located to the north of Fitz Hugh Sound, was collected in June 2008 by the Department of Fisheries and Oceans Canada during intertidal surveys of clam beds.

On the northern coast, butter clam shells from the Dundas Islands were also obtained from bucket-auger sampling (Brewster and Martindale, 2011), following the methods used by Cannon (2000). Shells from the Prince Rupert Harbour village site of McNichol Creek (GcTo-6) and shell midden sites at Tremayne Bay (GbTo-46) and GbTo-77 were obtained from excavations conducted by the University of Toronto. Shells from the Ridley Island site (GbTn-19), which are curated at the Canadian Museum of Civilization, were recovered in May's 1979 excavations at the site.

1.5.1 Growth increment analysis to determine relative levels of harvest pressure

Using butter clam shell fragments >2 cm in width, measured from the ventral margin, it is possible to identify a shell's growth stage as either 'senile' or 'mature'. Shells in a younger stage of growth have evenly spaced growth increments, whereas older shells have growth lines and increments that are tightly packed as a result of irregular and slowed growth (Claassen, 1988) (Figure 1.3).

Figure 1.3 – Shells showing senile (left) and mature (right) stages of growth.

Shell midden sites with intensive harvest pressure should have more shells in a mature stage of growth than sites with less intensive harvest pressure, which will have a higher proportion of shells in a senile stage of growth. Cannon and Burchell (2009), found that sites on the central coast of British Columbia identified as villages had a higher proportion of senile-stage shells, suggesting conservation of intertidal resources in the immediate site vicinity. Specialized campsites, such as those used for the processing of shellfish were dominated by shells in a mature stage of growth.

Application of the same methodology to sites in the Dundas Islands and Prince Rupert Harbour was undertaken to assess the overall intensity of shellfish harvest in the region and to look for potential variability between sites and regions. Variability in the distribution of natural resources and the occupational histories of the Dundas Islands compared with sites on the mainland coast in Prince Rupert Harbour presented an ideal case in which to test for regional variability in shellfish harvesting intensity and seasonality. Analysis of auger samples from the Dundas Islands revealed an extremely low density of vertebrate faunal remains when compared to sites in Prince Rupert Harbour and the central coast (Brewster and Martindale, 2011). This implies that fish resources were less abundant within the immediate vicinity of the Dundas Islands, suggesting the possibility that people may have been more likely to harvest clams as a staple food source. Growth increment analysis was applied to 3003 individual shells from 15 sites on the Dundas Islands and 690 individual shells from four sites in Prince Rupert Harbour to compare regional variability in the intensity of butter clam collection. These data were further compared to the published data from the central coast (Cannon and Burchell, 2009) along with preliminary seasonality results (Chapter 4).

1.5.2 Stable oxygen isotope analysis to determine season of butter clam collection

The application of stable isotope geochemistry to resolve archaeological questions of seasonality was first proposed by Shackleton (1973), who applied Urey's (1947) principle that the isotopic composition of calcium carbonate in fossils could be analyzed to interpret palaeotemperature. The isotopic composition of calcium carbonate fossils could not be applied to understand palaeotemperature until calibration studies using modern specimens were conducted and the palaeotemperature scale was developed (Epstein et al., 1953; Grossman and Ku, 1986; McCrea 1950). Böhm et al. (2000) improved upon this equation by reducing the error of the calculated temperature by combining data from synthetic aragonite (Tarutani et al., 1969), molluscs and foraminifera (Grossman and Ku, 1986), gastropods (Rahimpour-Bonab et al., 1997) and coralline sponges (Böhm et al., 2000). This technique has been widely applied in archaeology (i.e., Deith, 1986; Kennett and Voorhies, 1996; Killingley, 1981; Mannino et al., 2003, 2007; Rick et al., 2006; Shackleton, 1973; Stephens et al., 2008), however, these studies have not applied high-resolution micro-milling to extract shell carbonate, nor have they integrated analysis of micro-growth formation to establish a more precise seasonal estimate.

In aquatic mollusks, shells grow when they are submerged in surrounding water and when submerged they record local environmental information into their shell matrix. When the ratios of stable oxygen isotopes are analyzed sequentially throughout the duration of shell growth it is possible to produce an environmental record of the animal's life based on the interpretation of geochemical data. The samples obtained from the last phase of growth indicate season of death, and can therefore be used to interpret seasonal patterns of shellfish collection.

To prepare shells for oxygen isotope analysis ($\delta^{18}O_{shell}$) shell aragonite powder was obtained by hand micro-milling at the ventral margin, followed by micro-drilling. Micro-milling allows for an uninterrupted record to be obtained from the shell's growth history and minimizes the effects of time-averaging, which is the mixing of different time intervals/seasons of shell growth (Goodwin et al., 2004). Micro-milling began at the ventral margin and moved in ~100 μm consecutive steps that contoured the micro-growth lines using a 1 mm diamond coated cylindrical drill bit. The faster growing portions of the shell were micro-drilled using a 300 μm conical drill bit.

Isotope samples were processed in a Thermo Finnigan MAT 253 continuous flow – isotope ratio mass spectrometer coupled to a GasBench II at the Johannes Guttenberg University in Mainz, Germany. The $\delta^{18}O$ values were calibrated against NBS-19 ($\delta^{18}O$ = -2.20‰) with a 1σ external reproducibility (= 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 given as per mil (‰). Stable carbon isotope values ($\delta^{13}C$) were also recorded but are not discussed in this dissertation. A total of 1563 discrete isotope samples were obtained from 90 archaeological shells from eight shell midden sites in the vicinity of Namu to establish seasonal patterns of harvest. Forty-one butter clam shells with 1837 discrete isotope samples from seven shell midden sites were obtained from the Dundas Islands, and 10 shells with 100 discrete isotope samples were obtained from Prince Rupert Harbour.

1.5.3 High-resolution sclerochronology

Sclerochronology is analogous to dendrochronology, where numbers of micro-growth lines in hard tissues are counted and measured, permitting an evaluation of the life-history traits, specifically the length and duration of the growing season. The term *sclerochronology* was first applied to a radiographic study on corals by Buddemier et al. (1974:196), but is now widely applied to studies of aquatic and terrestrial mollusks, including bivalves, univalves and gastropods[1]. The alignment of stable oxygen isotope data to sclerochronological measurements is necessary in freshwater-influenced marine environments because of the opposing effects of salinity and temperature on $\delta^{18}O_{shell}$ values, which can make interpreting the isotope profiles of shellfish problematic, resulting in an inaccurate season of death estimate. Stable oxygen isotope ratios, of $^{18}O/^{16}O$ in marine carbonates are influenced by the isotopic variation in source water and this variation in carbonate values are influenced by temperature and salinity (Andrus and Crowe, 2000:39). Salinity may correlate with oxygen isotope variation since evaporation will preferentially enrich the water in ^{18}O, as well as create a more saline environment. Precipitation will deplete the source water with respect to ^{18}O and lower the salinity, and therefore lower both carbon and oxygen isotope ratios (Andrus and Crowe 2000:39; Mozley and Burns, 1993). Less saline water is therefore isotopically lighter (Deith, 1986). Using regular variation in oxygen isotopes seasonal patterns in salinity can be observed in areas with distinct wet and dry seasons (Andrus and Crowe, 2000:39), but this method is more 'easily' applied in non-freshwater influenced environments (Andrus and Whatley Rich, 2008:1), where temperature is the dominant factor.

The archaeological application of high-resolution stable isotope sclerochronology for *S. gigantea* has benefited from foundational research by Gillikin (2005) and Hallmann et al. (2009). Hallmann et al. (2009) conducted alignment studies that calibrated lunar daily growth increments (LDGI) and stable

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[1] See *GeoMarine Letters* (vol. 28, 2008) and *Palaeogeography, Palaeoclimatology and Paleoecology* (vol. 373, 2013) for special issues on sclerochronology.

oxygen isotopes ($\delta^{18}O_{shell}$) from live-collected shells from Pender Island in southern British Columbia, the Dundas Islands in northern British Columbia and Alaska. The results of the alignment study were then applied to shells from the Dundas Islands Group and Alaska (Hallmann et al. 2011, 2012) to interpret palaeoenvironmental changes over a 6000-year period. The alignment of $\delta^{18}O_{shell}$ values to LDGI permitted an understanding of variations in growth rates due to latitude and local environmental conditions, specifically the influence of freshwater influxes on $\delta^{18}O_{shell}$.

Sclerochronological measurements of *S. gigantea* are based on micro-growth lines formed by tidal action, known as lunar daily growth increments (LDGI) (Figure 1.4). The growth cycles of *S. gigantea* can be recognized by counting and aligning the LDGI to shell stable isotope data. This identifies excursions in the stable oxygen isotope values from seasonal freshwater influxes. To count and measure LDGI, polished shell cross-sections were immersed in Mutvei's solution following the methods presented in Schöne et al. (2005). The three main components of Mutvei's solution are alcian blue, glutaraldehyde, and dilute acetic acid, which simultaneously etch the shell carbonate while preserving and staining parts of the organic matrix of the biomineral dark blue (Schöne et al., 2005). The organic-rich lines are clearly visible since they are etch-resistant and appear as dark blue ridges, whereas the growth increments (the space between consecutive growth lines) are more strongly etched and appear as a lighter shade of blue.

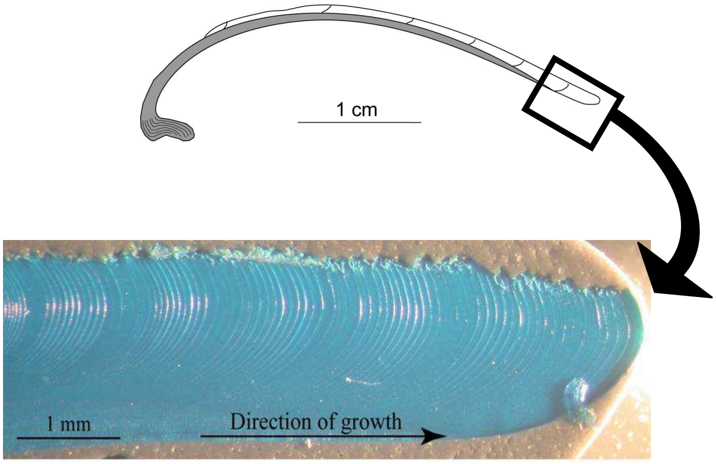

Figure 1.4 – Image of the ventral margin of a shell stained with Mutvei's solution showing LDGI.

This technique, when applied to butter clams, distinguishes between lines formed in the winter and lines formed as a result of a growth cessation from freshwater influxes in the spring. In addition to identifying growth cessation/slowing in the winter, it is also possible to identify disturbance lines that can be caused by spawning, predation or rapid environmental change. Lunar daily growth increment widths abruptly decrease then slowly increase after a disturbance occurs, but slowly decrease and then slowly increase around the annual growth cessation (Clark, 1974). In addition, fortnightly cycles of tidal bundles of neap and spring tides can be identified.

1.6 Thesis Format

This thesis follows a 'sandwich format', with three papers, as well as the introduction and concluding chapter. The references appear at the end of each chapter, and follow the specific guidelines for each journal to which the paper was submitted. The references for the introductory and concluding chapters follow the reference style for the *Journal of Archaeological Science*. The reader will note that there is repetition in the papers, specifically the description of the methodology applied in chapters 2, 3 and 4. A summary of each paper, the contributions of each author and where they are published follows:

Paper 1

Refining estimates for the season of shellfish collection on the Pacific Northwest Coast: Applying high-resolution oxygen isotope analysis and sclerochronology

Meghan Burchell, Aubrey Cannon, Nadine Hallmann, Henry P. Schwarcz, and Bernd R. Schöne

This paper presents the methodology used in determining precise seasonality estimates from archaeological shells, specifically the estuarine bivalve, *S. gigantea*, from the village site of Namu (ElSx-1) on the central coast of British Columbia. This paper is published in the journal, *Archaeometry* (2013, 55: 258-276) and is co-authored by M. Burchell along with A. Cannon, N. Hallmann, H.P. Schwarcz and B.R. Schöne. M. Burchell wrote all original drafts, and collected and analyzed all of the data. A. Cannon provided shell materials and funding, and assisted with editing. M. Burchell and N. Hallmann worked together on the analysis on the micro-growth data to ensure consistency between this study and Hallmann et.al.'s (2009) alignment study. H.P. Schwarcz provided geochemical insight into the behaviour of oxygen isotopes and manuscript editing. B.R. Schöne provided lab facilities and assisted with editing.

This paper is original since it identifies the region-specific patterns that influence the biological controls and the distribution of stable oxygen isotope data for this species. Understanding the seasonal variability in freshwater influences has a significant impact on how these data are interpreted for archaeological seasonality. It is of interest to researchers in both archaeology and the geosciences since it has implications for interpreting past human subsistence and settlement patterns, but also addresses the limits of this technique for palaeoclimate and palaeoenvironmental reconstructions from archaeological shells in fresh-water influenced marine environments. Furthermore, this paper set the foundational research to expand the analysis to examine regional variability in seasonality on the central coast of British Columbia.

Paper 2

Inter-site variability in the season of shellfish collection on the central coast of British Columbia

Meghan Burchell, Aubrey Cannon, Nadine Hallmann, Henry P. Schwarcz, and Bernd R. Schöne.

This paper is co-authored and is published in the *Journal of Archaeological Science* (2013, 40:626-636). M. Burchell wrote all original drafts, and collected and analyzed all of the data. A. Cannon provided shell material and funding, and assisted with editing. N. Hallmann and M. Burchell worked together on the analysis on the micro-growth data to ensure consistency with LDGI analysis. H.P. Schwarcz contributed insight into the geochemistry and assisted with manuscript editing. B.R. Schöne provided lab facilities and assisted with editing.

This is the first systematic, multi-site investigation of archaeological seasonality using a high-resolution sampling strategy that uses both stable oxygen isotopes and sclerochronology. Based on the results from Burchell et al. (2013b), the alignment of sclerochronological data with $\delta^{18}O_{shell}$ was used to expand the analysis beyond the village site of Namu to examine other residential and non-residential sites in the immediate vicinity. The results showed site-specific patterns of seasonal shellfish procurement at different types of sites, specifically long-term occupations, such as villages and short-term sites, such as shellfish procurement camps. These results are significant because they demonstrate that generalized models of seasonality are inadequate to address pattern and variability in subsistence-settlement practices. The results found on the central coast are likely to be found in other regions of the coast as well.

Paper 3

Seasonal Patterns and Intensity of Shellfish Harvesting on the Northern Coast of British Columbia

Meghan Burchell, Nadine Hallmann, Andrew Martindale, Aubrey Cannon and Bernd R. Schöne

This manuscript has been accepted for publication in the *Journal of Island and Coastal Archaeology* (December 2012). It incorporates stable oxygen isotope data from previously analyzed archaeological bivalves from the Dundas Islands from Hallmann et al. (2012) along with new stable oxygen isotope data from the Dundas Islands and Prince Rupert Harbour. Results from growth increment analysis from shells recovered from the Dundas Islands are compared to sites on the mainland coast to evaluate variability in harvest pressure between different sites within and between the two localities. The purpose is to interpret regional variation in seasonality and subsistence patterns. M. Burchell wrote all original drafts, and collected and analyzed the data for the manuscript [with the exception of the data from 27 shells from Hallmann et al. (2012), which was done in association with N. Hallmann]. The manuscript was then reviewed and edited by all co-authors. The fieldwork to collect the archaeological shells was facilitated by A. Martindale and auger samples were collected by N. Brewster. B.R. Schöne provided lab facilities for LDGI and stable oxygen isotope analysis. A. Cannon provided the lab facilities to prepare and analyze the growth increments of ventral margin fragments of butter clam shells. This is the first analysis of shellfish harvesting strategies on the Dundas Islands and the first application of growth increment analysis in Prince Rupert Harbour.

In addition to providing new information on seasonality and shellfish harvesting patterns on the northern coast, the paper critically examines ethnographic analogy in interpreting shellfish harvest patterns and challenges lower resolution studies of seasonality based on growth lines (i.e. Coupland 1993, May 1979). The results show variation in the overall intensity of shellfish harvesting between the Dundas Islands and Prince Rupert as well as differences in seasonal collection patterns. The results are then further compared to previous studies of shellfish harvesting (Cannon and Burchell, 2009) and seasonality on the central coast (Burchell et al., 2013a, b). The sample size from Prince Rupert is relatively small, yet it is effective in showing that previous interpretations of shellfish seasonality in the region are likely inaccurate. This paper is significant because it addresses both temporal and regional variation in the factors that influence seasonal subsistence practices and settlement patterns on the northern coast of British Columbia.

CHAPTER 2

REFINING ESTIMATES FOR THE SEASON OF SHELLFISH COLLECTION ON THE PACIFIC NORTHWEST COAST: APPLYING HIGH-RESOLUTION STABLE OXYGEN ISOTOPEANALYSIS AND SCLEROCHRONOLOGY

M. BURCHELL, A. CANNON, N. HALLMANN, H. P. SCHWARCZ & B. R. SCHÖNE

2013 *Archaeometry.* 55:258-276

ABSTRACT

Stable oxygen isotopes from estuarine bivalve carbonate from *Saxidomus gigantea* were analysed combined with high-resolution sclerochronology from modern and archaeological shells from British Columbia, Canada, to determine the seasonality of shellfish collection from the archaeological site of Namu. The combination of high-resolution sclerochronology and a micro-milled sampling strategy for $\delta^{18}O$ analysis permits a precise estimate of archaeological seasonality, because seasonal freshwater influxes and changes in temperature have dual effects on the $\delta^{18}O$ value of the shell. Sclerochronological analysis identifies the timing and duration of growth that is temporally aligned to stable oxygen isotope results, since $\delta^{18}O$ shell appears to be strongly influenced by seasonal inputs of very low $\delta^{18}O$ snowmelt-water from adjacent coastal mountain ranges. The results show that shellfish were collected year-round at this site over a 4000-year period, and these data combined with other zooarchaeological lines of evidence support the interpretation of year-round occupation.

Keywords: Seasonality, British Columbia, stable oxygen isotope analysis, sclerochronology, *Saxidomus gigantea*, Holocene

INTRODUCTION

Identifying the seasonality of shellfish collection using growth patterns and stable isotopes in freshwater and marine molluscs has been a component for understanding patterns of shellfish harvest at archaeological sites for over 30 years. Growth lines and increments that form seasonally and/or annually have been used to attain a lower-resolution seasonal identification in some species, mainly distinguishing between warm and cold periods for the timing of shellfish collection (i.e., Coutts 1970; Claassen 1983; Milner 2001). Shell stable oxygen isotope values (i.e., Shackleton 1973; Killingley 1981; Deith 1986; Kennett and Voorhies 1996; Mannino *et al*. 2003; Rick *et al*. 2006; Mannino *et al*. 2007; Stephens *et al*. 2008) can provide more precise seasonality estimates, but require sufficient sampling resolution and knowledge of local environmental factors that control oxygen isotope values.

Recent advances in sclerochronology have shed light on a variety of factors that influence seasonal and annual shell growth, and subsequently how these growth structures are interpreted in archaeological contexts (Andrus 2011). More recent sclerochronological and stable isotope studies from the north and south coasts of British Columbia (BC) and Alaska have demonstrated that growth line analysis alone cannot distinguish winter lines from disturbance lines (Clark 1974) caused by stress, predation, spawning or freshwater influxes (Hallmann *et al*. 2009). These studies have also demonstrated a distinct regional variability in shell growth rates (Hallmann *et al*. 2009, 2011, 2012). Therefore, prior to determining the season of shellfish collection, the region-specific growth rates of the species in question for both modern and archaeological specimens must be determined. Studies from other regions, such as those conducted on hard clams (*Mercenaria* spp.) on the east coast of North America have demonstrated regional variability in the periodicity of growth line and increment formation, which can vary according to latitude (Jones and Quitmyer 1996). Also, the timing of the formation of growth structures for this species may vary within the same location (Henry and Cerrato 2007). Near estuaries or freshwater influenced environments, where many shell middens are located, the interpretations of stable oxygen isotope values ($\delta^{18}O$) can be problematic because of the dual effects of temperature and salinity ($\delta^{18}O$ of seawater) on $\delta^{18}O_{shell}$ ratios (Schöne 2008; Culleton *et al*. 2009; Andrus 2011). Studies that combine stable oxygen isotopes with shell growth patterns have greater success in achieving a more precise season of collection, since the $\delta^{18}O$ values can be placed within the growth phases of the shell (i.e., Jones and Quitmyer 1996; Quitmyer *et al*. 1997; Andrus and Crowe 2000). Until recently, there have been few archaeological studies that combine sclerochronology (shell growth pattern analysis) and geochemistry to understand the seasonal growth cycles and the local variability in $\delta^{18}O$ values of modern shells, which can then be applied as an analogue to determine the season of shellfish collection in archaeological contexts (Andrus 2011).

There are three objectives to this study. The first is to understand the region-specific life-history traits of bivalve *Saxidomus gigantea*, the most commonly recovered bivalve from shell midden sites on the central coast of BC (Cannon *et al*. 2008). This was accomplished through the application of high-resolution sclerochronology to live-collected specimens from the intertidal zones in front of the archaeological site of Namu (ElSx-1) and two other shell midden sites in the immediate vicinity. By counting and measuring the micro-increment formation, the stable oxygen isotope data were aligned to specific growth periods. These data were used as an analogue to interpret the stable oxygen isotopes of the archaeological shells. The second objective was to evaluate the implications of using different isotope sampling strategies and demonstrate how different sampling methods can affect seasonality results and interpretations. The final objective was to use the results of the modern sclerochronology and $\delta^{18}O$ shell alignment to interpret the seasonality of archaeological shells from the site of Namu (ElSx-1) on the basis of stable oxygen isotope analysis.

THE SEASONALITY OF SHELLFISH HARVESTING ON THE NORTHWEST COAST

Seasonality has been examined on the Pacific Northwest Coast for the purpose of identifying the ‘seasonal round’ that was observed ethnographically, where people engaged in a pattern of residential mobility that closely followed seasonally available food sources (Ford 1989). For example, Tlingit communities in south-eastern Alaska were observed collecting shellfish during the spring months, when people were living closer to the coast (Oberg 1973). During the period after European contact, residential mobility was frequently noted, where communities would move according to the availability of local resources (Barnett 1938; Mitchell 1983; Mitchell and Donald 1988). However, questions still remain concerning whether this pattern of seasonal mobility was in place in the archaeological past (Ford 1989), and whether comparable patterns of seasonal mobility and shellfish harvest are applicable to the different cultural and environmental regions of the Pacific Northwest Coast.

Lower-resolution shellfish seasonality studies on the coast of BC have examined growth lines (structures that form during recurring shell growth reduction) and increments (the space between growth lines) to determine the season of shellfish collection, and by proxy the season of site occupation (e.g., Ham and Irvine 1975; Keen 1979; May 1979; Clarke and Clarke 1980; Maxwell 1989; Crockford and Wigen 1991; Coupland *et al*. 1993). This approach to determining the season of shellfish harvesting is based on the assumptions that molluscs deposit $CaCO_3$ when they are submerged in water during high tide, grow more rapidly in the summer, slow down and eventually stop growing in the winter, to form an annual line (e.g., Rhoads and Lutz 1980). Typically, in this region, the season of shellfish collection is derived by comparing growth increments (the periods of rapid growth) to growth lines (periods of slow or no growth) and then by dividing the width of the pre-death increment by the width of the last complete increment (Monks and Johnston 1993). However, this method is unreliable (Hallmann *et al*. 2009), and little success has been achieved using the variation observed in the coloration of different growth periods and growth line formation even in association with a careful analysis of monthly collected specimens (Maxwell 2003). Furthermore, this method does not take into account regional variability in shell growth rates or the decrease in shell growth rates through ontogeny (Schöne 2008).

STUDY AREA AND CRITERIA FOR THE ANLAYSIS OF *S. GIGANTEA*

The archaeological site of Namu (ElSx-1) is on the central coast of BC in the traditional territory of the Heiltsuk First Nation, and has been identified as one of the longest continuously occupied sites in North America (Carlson 1979, 1996; Cannon 2000, 726) (Fig. 2.1). Archaeological clamshells used for this analysis were collected with a 7 cm bucket auger, a sampling strategy that was originally intended to collect samples to assess variability in the salmon and herring fisheries (Cannon 2000). This method also allowed for the collection of shell fragments, many with preservation of the intact ventral margin necessary for seasonality analysis, since the ventral margin contains the environmental record formed immediately prior to the death of the animal. Additional whole *S. gigantea* valves from Namu were obtained from the level bag samples from the 1977–78 archaeological field school excavations conducted by Simon Fraser University.

Live-collected shells for $\delta^{18}O$ and sclerochronological analysis were collected from the beach in front of Namu and from the intertidal zones in front of nearby archaeological sites ElSx-4 and ElTa-25 in August 2009. An additional live-collected specimen from Kakushdish Harbour, located in an area just to the north of Fitz Hugh Sound, was collected on 2 June 2008 by the Department of Fisheries and Oceans Canada during intertidal surveys of clam beds.

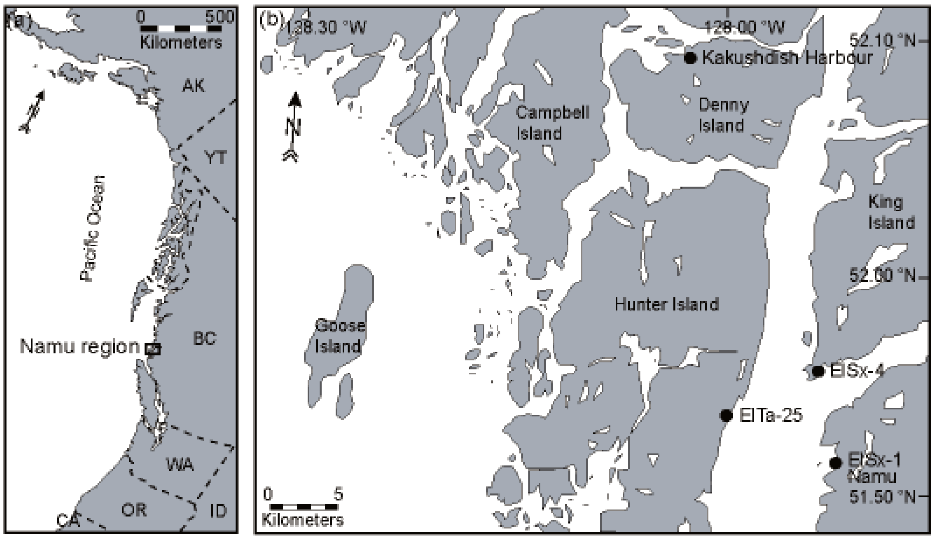

Figure 2.1 - Area maps of the coast of BC showing locations of studies. (a) Map showing location of the Namu region. (b) Central coast of BC showing the archaeological site of Namu, ElSx-1 and locations of live-collected shells at archaeological sites ElSx-4, ElTa-25 and Kakushdish Harbour.

Saxidomus gigantea, commonly known as the butter clam, precipitates an aragonitic shell and is a temperate marine species that burrows to a depth of approximately 30 cm below the sediment surface in the intertidal zone (Paul *et al*. 1976; Nickerson 1977). On the basis of ‘winter line’ counts from the exterior of the shell, *S. gigantea* can live for approximately 20 years or more (Quayle and Bourne 1972). This species lives in marine and estuarine settings on the Northwest Coast, and almost all clam beds associated with shell middens in the area are subject to freshwater fluxes from river outflow or precipitation. This species has a limited tolerance for low salinity and may not grow during periods of increased freshwater influx (Gillikin *et al*. 2005).

In shallow-water environments of coastal settings, the oxygen isotope values of the shell carbonate are more sensitive to local seasonal fluctuations in temperature and salinity (Andrus 2011). On the central coast of BC, seasonal fluctuations in temperature and salinity are predominantly caused by rain-fed stream run-off and snowmelt-water. The effect of these two processes on the $\delta^{18}O$ of seawater ($\delta^{18}O_{sw}$) varies along the coastline depending on proximity to a stream and the average flow of the nearest stream. The $\delta^{18}O$ of rainwater is also known to vary seasonally (Dansgaard 1964). During the fall and winter and into the early spring, snow accumulates in the mountain ranges, where it is stored until late spring. The average isotopic signature of this snow is substantially more negative than that of coastal, low-elevation rains due to its greater elevation and lower temperature, which further shifts the $\delta^{18}O$ values of local waters towards more negative values (Yurtsever and Gat 1981). During the late spring and summer, this snow melts and the melt-water makes up a large part of the stream flow entering the Pacific Ocean. Temperature and salinity, along with the factors discussed above, are the main forces that influence the seasonal variability observed in $\delta^{18}O$ shell from the Pacific Northwest Coast (Hallmann *et al*. 2009). To some extent, these differences are averaged out as a result of coastal marine currents that sweep water generally southward along the coast. In this environmental setting the $\delta^{18}O_{sw}$ value becomes more negative with freshwater influxes and more positive with evaporation (Craig and Gordon 1965).

In environments where the ocean experiences seasonally varying inputs of freshwater, a high isotope sampling resolution should be applied in association with the alignment of tide-controlled microgrowth patterns; namely, lunar daily growth increments (LDGI) and fortnight bundles of LDGI. This permits a more precise seasonality estimate because the growth patterns can be used to help place freshwater-based excursions in oxygen isotope values into a temporal context relative to the presence of an annual winter growth line. In addition to a high sampling resolution and the analysis of LDGI and fortnightly bundles of LDGI, geochemical studies of live-collected shells are required to build more confidence in the seasonality interpretations.

As suggested by Mannino *et al*. (2007), the shell sample selection for isotope analysis was done carefully to ensure that the shells had not been subject to recrystallization. *Saxidomus gigantea* shells for $\delta^{18}O$ analysis were selected on the basis of the following criteria: (1) preservation of an intact ventral margin; (2) preservation of an intact upper shell layer; (3) the absence of exposure to fire, which would potentially cause a polymorphic inversion of the shell's $CaCO_3$ composition from aragonite to calcite; and (4) the size of the shell fragment, which had to be large enough to adequately sample multiple years of growth to observe the seasonal amplitude. Prior to $\delta^{18}O$ analysis, shells were also subject to X-ray diffraction (XRD) to ensure that the specimens were not affected by diagenesis and had adequate aragonite preservation, with no secondary calcite deposits (Kingston 2007). While many stable oxygen isotope studies of shell use the axis of maximum growth (e.g., Klein *et al*. 1996; Gillikin *et al*. 2005; Schöne *et al*. 2005b; Surge and Walker 2006), it is not necessary to do so with *S.*

gigantea, because if only a portion of the ventral margin is preserved, it will still produce the same seasonality results if sampled perpendicular to the growth lines (Kingston *et al*. 2008).

SCLEROCHRONOLOGICAL AND STABLE OXYGEN ISOTOPE ANALYSIS

For both microgrowth pattern and stable oxygen isotope analysis, methods followed those of Schöne *et al*. (2005a,b) and Hallmann *et al*. (2009, 2011, 2012). One valve of each specimen was mounted on a Plexiglas cube with plastic welder (Multipower, GlueTec) and coated with metal epoxy resin (WIKO) to prevent the shell from breaking while being cross-sectioned. Two 3 mm thick portions of the cross-section of each shell were cut perpendicular to the growth lines, using a low-speed precision saw (Buehler IsoMet 1000) and a 0.4 mm thick diamond-coated saw blade. The cut shell slices were mounted with metal epoxy resin on glass slides, ground on glass plates with 1000 and 800 SiC grit powder, and finally polished with 1 μm Al_2O_3 colloidal solution. After each grinding and polishing step, the shells were cleaned via an ultrasonic bath to remove any adhering media. All samples were cleaned with deionized water and air-dried.

To determine the length of the growing season of *S. gigantea* in the Namu region, the LDGI were counted from live-collected shells from intertidal zones in front of the archaeological sites Namu (ElSx-1) and ElTa-25. By examining multiple localities, we were able to confirm if there was interregional variability in growth rates that should be considered when interpreting both microgrowth patterns and $\delta^{18}O$ results. The live-collected specimens were cross-sectioned, one half was polished and immersed in Mutvei's solution for 20 minutes under constant stirring at 37–40°C. The other half of the unstained shell was retained for $\delta^{18}O$ analysis. The three main components of Mutvei's solution are alcian blue, glutaraldehyde and dilute acetic acid, which simultaneously etch the shell carbonate while preserving and staining the organic matrix of the biomineral dark blue (Schöne *et al*. 2005a). The organic-rich lines are clearly visible, since they are etch-resistant and appear as dark blue ridges, whereas the growth increments (the space between consecutive growth lines) are more strongly etched and appear as a lighter shade of blue. After staining, the shell portions were gently rinsed in deionized water and then air-dried. To analyse shell growth patterns, digital images of polished and stained shells were taken from each specimen, using a Nikon Coolpix 995 camera attached to a binocular microscope (Wild Heerbrugg M3Z). Lunar daily growth increment widths from shells with a known date of death were measured in the direction of growth to the nearest 2 µm from four live-collected specimens from ElSx-1 and ElTa-25, using the image processing software Panopea (© Peinl and Schöne).

A total of 20 archaeological shells from Namu with 457 discrete isotope samples were analysed for seasonality. Four live-collected specimens of *S. gigantea* from the intertidal zones in front of sites Namu (ElSx-1), ElTa-25, ElSx-4 and Kakushdish Harbour were also analysed. To determine the $\delta^{18}O$ of archaeological and modern specimens, shell aragonite powder was obtained by hand micro-milling at the ventral margin, followed by micro-drilling in the faster growing portions from the outer shell layer of polished cross-sections (Fig. 2.2). Micro-milling, using a 1 mm diamond-coated cylindrical drill bit (Komet/Gebr. Brasseler GmbH & Co. KG, model no. 835 104 010), began directly at the ventral margin and moved in ~100 µm consecutive steps that contoured the microgrowth lines. The faster-growing portions in younger parts of the shell, further away from the ventral margin, were micro-drilled using a 300 µm conical drill bit (model no. H52 104 003). The centre-to-centre distance between drill points varied between 400 and 600 µm with the fine-sampling technique. Since shell sample sizes and ontogenetic age varied, each polished shell fragment was evaluated using 40X magnification to observe microgrowth structures, and to determine a specific sampling strategy combining micro-milling and micro-drilling to attain the most appropriate seasonality resolution.

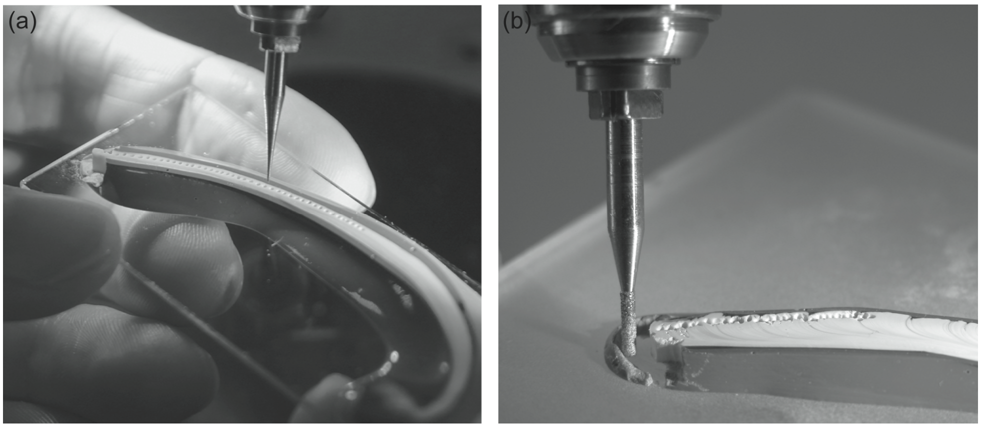

Figure 2.2 - Sampling methods, showing the different sampling techniques. (a) Carbonate powder was obtained by micro-drilling in the periods of faster growth (diameter of the drill bit at the tip = 300 µm). (b) Samples were micro-milled in 100 µm consecutive steps in the slower-growing shell portions at the ventral margin (diameter of this cylindrical bit = 1 mm).

Ontogenetically older shells had more samples milled at the ventral margin than younger shells, since the rate of growth slows considerably with age and therefore more time is represented within each shell portion. Larger archaeological shell fragments and the live-collected specimens were more extensively sampled so that multiple years of seasonal amplitudes could be observed. To test the effects of different sampling resolutions, the specimen from Kakushdish Harbour was analysed following the above sampling methods, but also analysed with a coarse-sampling resolution. For the coarse-sampling test, the cross-section of the shell was hand-drilled with a 1 mm carbide drill bit, with samples spaced ~0.5–1.0 mm apart.

All isotope samples were processed in a Thermo Finnigan MAT 253 continuous flow – isotope ratio mass spectrometer coupled to a Gas Bench II. Isotope data were calibrated against NBS-19 ($\delta^{18}O$ = –1.95‰) with a 1-sigma external reproducibility (= accuracy) of 0.07‰ for oxygen, 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 given as per mil (‰). When the live-collected shells were gathered, water measurements were also obtained using an Omega© conductivity meter to determine the salinity in PSU (practical salinity units) and the temperature of the water. Three separate water measurements were taken at the same locations where the shells were collected at Namu (ElSx-1), ElSx-4 and ElTa-25, and the average values of water temperature and salinity were calculated.

The palaeothermometry equation by Böhm *et al*. (2000) was applied to calculate the oxygen isotope values of the seawater ($\delta^{18}O_{sw}$) from measured seawater temperatures and the $\delta^{18}O_{shell}$ values of *S. gigantea* in this region, assuming that it is secreting in isotopic equilibrium with ambient seawater:

1) $T_{\delta^{18}O}(°C) = (20 \pm 0.2) - (4.42 \pm 0.1) \cdot (\delta^{18}O_{shell}(VPDB) - \delta^{18}O_{sw}(VSMOW))$

where *T* is the temperature of the seawater in which the mollusc was growing. We used this equation instead of the one by Grossman and Ku (1986), since it reduces the error of the calculated temperature by combining data from synthetic aragonite (Tarutani *et al*. 1969), molluscs and foraminifera (Grossman and Ku 1986), gastropods (Rahimpour-Bonab *et al*.1997) and coralline sponges (Böhm *et al*. 2000). With the Böhm *et al*. (2000) equation, the precision error on the mass spectrometer results in an average reconstructed temperature error of 0.06°C (1-sigma).

RADIOMETRIC DATING

Accelerator mass spectrometry (AMS) dates were obtained from seven shells that were sampled for seasonality. Several years of growth were sampled in each shell to average seasonal fluctuations in the local marine ^{14}C reservoir ages (Culleton *et al*. 2006). The periostracum and the outermost 100 mm of shell carbonate were physically removed, and then between 70 and 180 mg of shell carbonate was submitted for AMS dating. Radiometric age analysis was performed at the Poznan´ Radiocarbon Laboratory (Poland) and at Beta Analytic Inc. (USA). Conventional radiocarbon ages were converted to calibrated ^{14}C

AMS ages by the program Calib 6.0 (Stuiver and Reimer 1993), using the Marine09 calibration data set (Reimer *et al*. 2009). The average local ^{14}C marine reservoir effect (ΔR) for the study region is 390 ± 50 years (Cannon *et al*. 1999). All dates in years BP were calibrated to 2-sigma, and converted to years BC (see Table 2.3).

RESULTS

The isotope profiles from modern shells produce clear seasonal cycles with a sinusoidal curve and consistently have more positive $\delta^{18}O_{shell}$ associated with colder temperatures, and more negative values associated with warmer temperatures. However, negative $\delta^{18}O_{shell}$ values are also associated with seasonal freshwater influxes and/or snowmelt-water run-off, which occur mainly during the spring (Fig. 2.3). There is an increase in precipitation during the autumn, with maximum precipitation during the winter (Environment Canada, 2006). Therefore, the observed $\delta^{18}O_{shell}$ values reflect changes in both local sea-surface temperature (SST) and salinity.

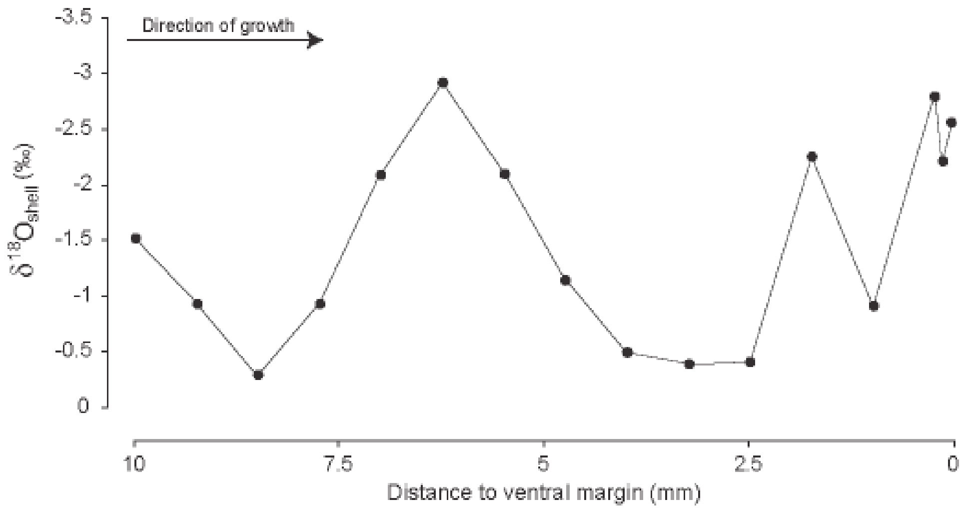

Figure 2.3 - The stable oxygen isotope profile of live-collected S. gigantea, collected at the intertidal zone in front of ElSx-4 on 12 August 2009. The ventral margin $\delta^{18}O_{shell}$ value (–2.56‰) is consistent with more negative values associated with warmer water temperatures. Note the peak towards the ventral margin with the most negative value (–2.78‰), which could be associated with spring precipitation, an increase in river water run-off and/or an increase in glacial melt-water. The y-axis has been reversed to reflect water temperature cycles, since the most positive $\delta^{18}O_{shell}$ values are associated with colder temperatures.

Table 1 presents the analyses of local water and the shells that were actively growing in the areas at Namu (ElSx-1) and nearby archaeological sites ElSx-4 and ElTa-25. These data are based on instrumental temperature and salinity (*S*) measurements at the time of collection, measured $\delta^{18}O_{shell}$ and the inferred $\delta^{18}O_{sw}$ assuming the Böhm *et al*. (2000) equation (1).

Table 2.1 – Results of live-collected *S. gigantea* specimens and water samples

Site	Date of Collection 2009	T (°C) of water measured in the field	Measured Salinity (PSU)	Average $\delta^{18}O_{shell}$ ‰ VPDB	Ventral margin $\delta^{18}O_{shell}$ ‰ VPDB	$\delta^{18}O_{seawater}$ ‰ VSMO reconstructed	$\delta^{18}O$river $_{water}$ ‰ SMOW reconstructed	# $\delta^{18}O$ samples
ElSx-1	10 August	13.5	21.7	-3.03	-4.64	-6.01	-16.2	44
ElSx-4	11 August	14	22.3	-1.49	-2.56	-3.81	-10.8	16
ElTa-25	10 August	17.9	20	-3.23	-3.43	-3.78	-9	4

In column 7, assuming that the seawater is a two-component mixture of normal seawater ($\delta^{18}O$ = 0‰) and a single river input with isotopic composition $\delta^{18}O_{rw}$, we use the previous data (*S*, $\delta^{18}O_{sw}$) to calculate values for $\delta^{18}O_{rw}$. The results in Table 2.1 show variation in temperature and salinity between the locations ElSx-1, ElSx-4 and ElTa-25, and that the salinity values were significantly lower than that of normal seawater. Using the observed growth temperatures and $\delta^{18}O_{shell}$ values for the ventral margins, $\delta^{18}O_{sw}$ was reconstructed from where the shells lived, all of which are much lower than that of normal seawater. If it is assumed that these waters are two-component mixtures of nearby stream-water, then the $\delta^{18}O$ value of the streams whose waters were admixed to generate these estuarine conditions can be estimated. It is also assumed that the water in which the clams lived was a two-component mixture consisting of pure seawater (sw) with $\delta^{18}O$ = 0‰ (VSMOW) having a salinity of 35 (PSU) plus river (r) water with $\delta^{18}O = \delta^{18}O_r$ and with a salinity of 0 PSU. The isotopic composition of the mixture is as follows:

$$(2)\ \delta^{18}O_{sw} = X_{sw}\ \delta^{18}O\ (\text{pure sea water}) + (1 - X_{sw})\ \delta^{18}O_{rw} = (1 - X_{sw})\ \delta^{18}O_{r}$$

Note that S (salinity) = 35 X, from which we derive that:

$$(3)\ \delta^{18}O_{sw} = (1 - 0.029\ S)\ \delta^{18}O_{rw}$$

These estimates are given in columns 7 and 8 of Table 2.1. Two of the waters could be accounted for by local rain alone ($\delta^{18}O > 10‰$), while that for ElSx-1 is so low that it probably includes a component from snowmelt-water.

Although there is variation in $\delta^{18}O_{sw}$ that directly affects the $\delta^{18}O_{shell}$, it is possible to align the microgrowth structures with the isotope data to establish the seasonal cycles in shell growth. The LDGI from the live-collected specimens were counted from the known date of collection, and on the basis of the number and widths of increments, the maximum growth rate occurred in July. On the basis of LDGI counts from live-collected shells in the vicinities of ElSx-1 and ElTa-25, *S. gigantea* experiences a slowing of growth from October to April, with a cessation of growth for 2–6 months from November/December until February/March/April (Fig. 2.4). Disturbance lines are observed in the spring (May/June) and again in the fall, probably due to freshwater influxes. In some samples, a distinct line was observed in the middle of the growing season (July), which may be associated with spawning. The number of LDGI per year in shells from the central coast is, on average, 226 ± 40. In some years, a maximum growth cessation of up to 6 months, from November to April, was observed. Shells from the central coast can stop growing for approximately four months, between October and April; therefore the observation of an isotopic record of the lowering of $\delta^{18}O_{sw}$ by winter rains is not expected in these shells.

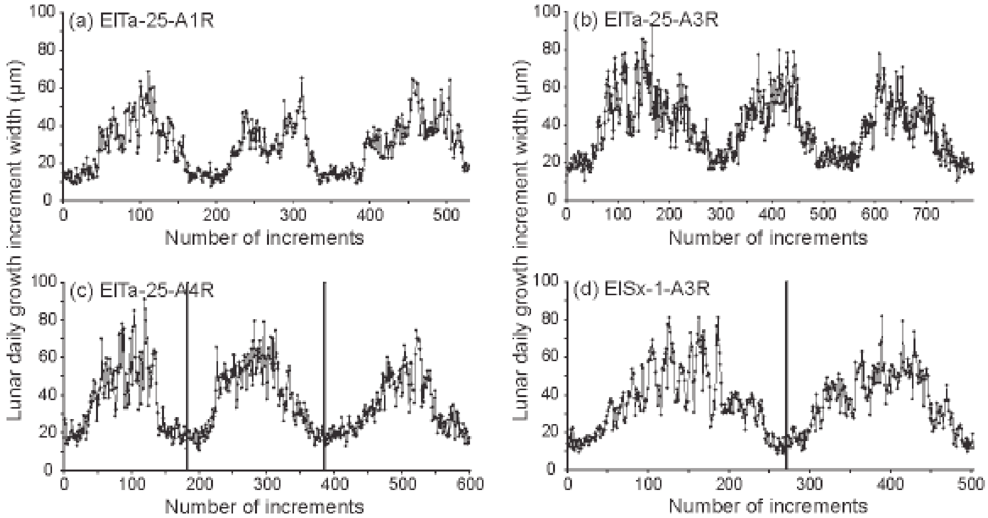

Figure 2.4 - Lunar daily growth increments (LDGI) from four live-collected shells from sites ElSx-1 and ElSx-4, in the direction of growth from left to right: (a) EITa-25-A1R; (b) EITa-25-A3R; (c) EITa-25-A4R; (d) EISx-1-A3R. The number of increments ranges between 172 and 293 per year. *Saxidomus gigantea* ceases its growth for 3–6 months per year depending on the seasonal variation of temperature and salinity. The vertical black bars are winter growth lines that could be clearly observed in the shell, which were further confirmed by isotope analysis, since these are associated with the most positive $\delta^{18}O$ values.

The analysis of microgrowth increments of modern shells clearly shows tidal patterns and bundles of neap and spring tidal cycles, with the most positive isotope values associated with the presence of a winter line (Fig. 2.5). However, it should be noted that some specimens, both modern and archaeological, do not show clear winter growth lines. In some specimens, prominent disturbance lines were observed that could be misinterpreted as a 'winter line', but the nature of these lines can only be determined by confirming their oxygen isotope composition.

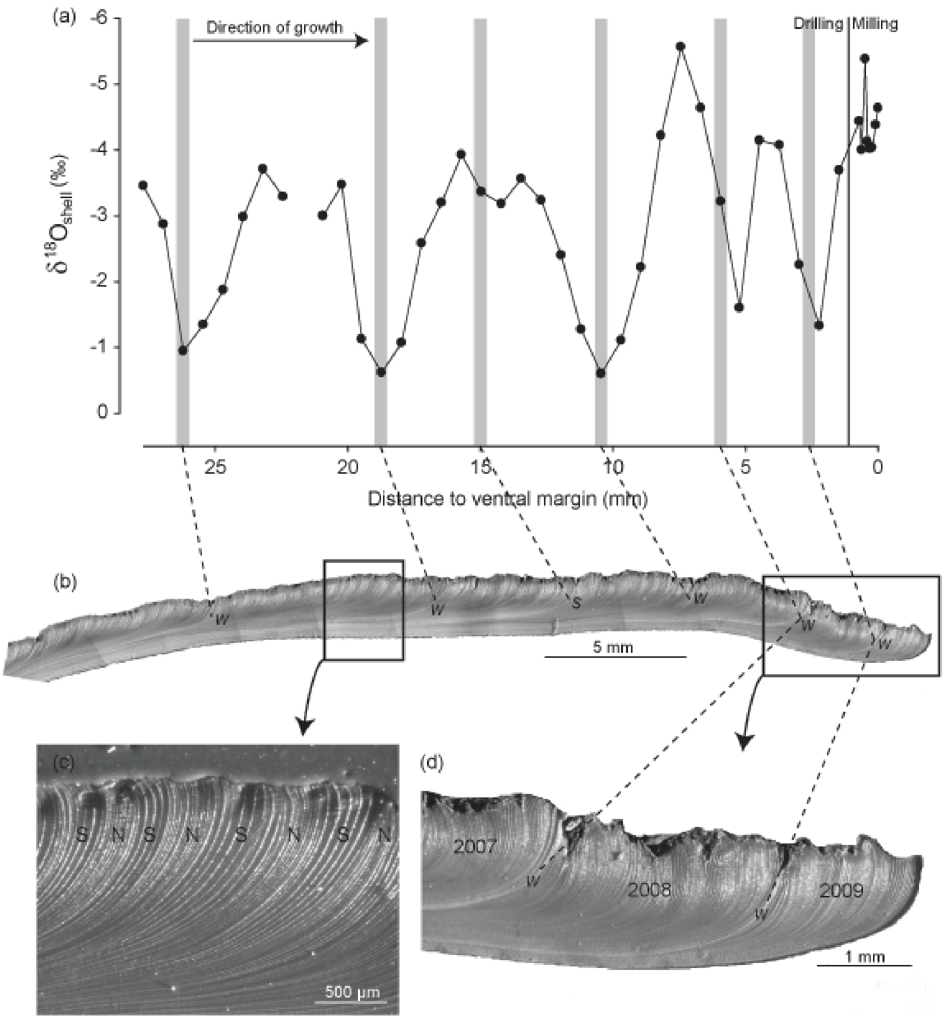

Figure 2.5 - A live-collected specimen from ElSx-1 (sample ID ElSx-1A2R) stained with Mutvei's solution and aligned with δ^{18}O shell, showing the season of collection in the summer (a,b). Winter lines (w) are visible in this specimen and correspond to the most positive δ^{18}O shell values. (b) A disturbance line formed in the summer (s) 15 mm away from the ventral margin. (c) On the basis of LDGI counts, bundles of neap (N) and spring (S) tidal cycles are clearly visible.

To demonstrate the effects of a coarse-sampling resolution compared to a fine-sampling resolution, a more conventional sampling strategy was applied using a hand-held drill versus micro-milling directly at the ventral margin from a shell that was live-collected on 2 June 2008 from Kakushdish Harbour, BC (Fig. 2.6). For the coarse sampling, the 1 mm drill bit was not placed directly at the ventral margin, but instead 0.48 mm from the ventral margin, providing an end $\delta^{18}O_{shell}$ value of –0.52‰. The sample that was micro-milled was obtained directly from the ventral margin and provided an end value of –4.64‰. The seasonal amplitude varied (using the data from the drilled specimen) between –2.80‰ and 0.15‰, with an average value of –1.05‰. In contrast, the milled specimen showed a range between –5.09‰ and –0.17‰, with an average value of –2.19‰. The milled shell showed greater amplitude than the drilled shell. If the range of the high-resolution milling (4.92‰) is attributed to temperature changes alone, this would correspond to an annual temperature range of 21.8°C. Modern sea-surface temperature data recorded from local lighthouses in the region show an annual temperature range for this region of approximately 7°C [7–14°C] (Environment Canada 2006). This further demonstrates that most of the variations in $\delta^{18}O$ shell are related to seasonal freshwater discharges and not to temperature change; a phenomenon that is more clearly observed in the sample that was subject to the higher sampling resolution.

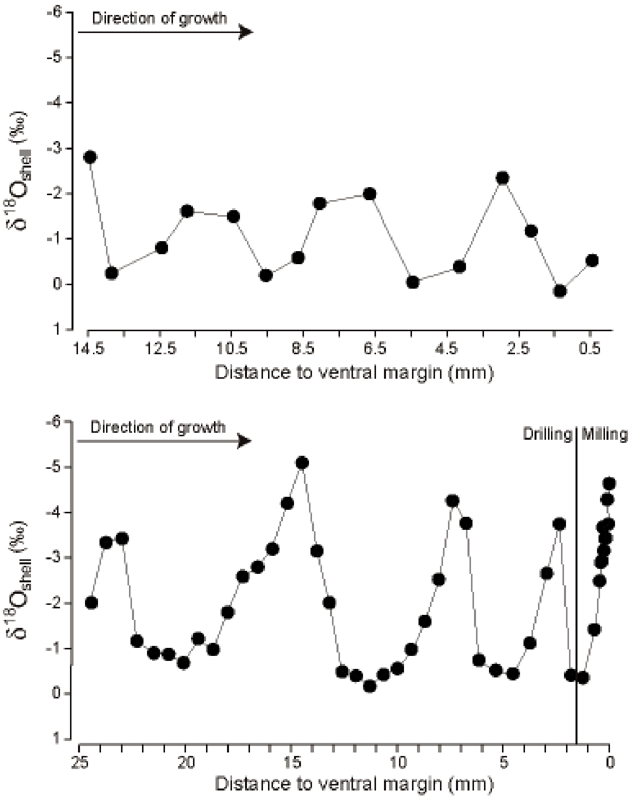

Figure 2.6 - $\delta^{18}O_{shell}$ profiles derived from different sampling resolution on a live-collected shell (2 June 2008) from Kakushdish Harbour, BC. (a) The coarse sampling resolution using a 0.5 mm drill bit, with samples spaced ~1 mm apart. The distance from the ventral margin to the first sample is 0.48 mm. (b) The results of micro-milling in 100 mm consecutive steps, beginning directly at the ventral margin of the shell followed by drilling in the faster-growing portions of the shell.

Figure 2.7 shows examples of four $\delta^{18}O_{shell}$ profiles, showing the different seasons of collection (winter, spring, summer and autumn), and illustrating how the plotted curves can be interpreted with respect to the season of shellfish collection. The most negative values observed in both modern and archaeological specimens are associated with freshwater discharges, which occurred in the spring. The most positive $\delta^{18}O_{shell}$ values are observed during the coldest times of the year (winter). In archaeological specimens, we sampled between six and 57 discrete isotope samples, with an average of 23 samples per shell. This allowed us to match the shape and values of the isotope curve to specific growth rates and $\delta^{18}O_{shell}$ values from live-collected and whole archaeological specimens.

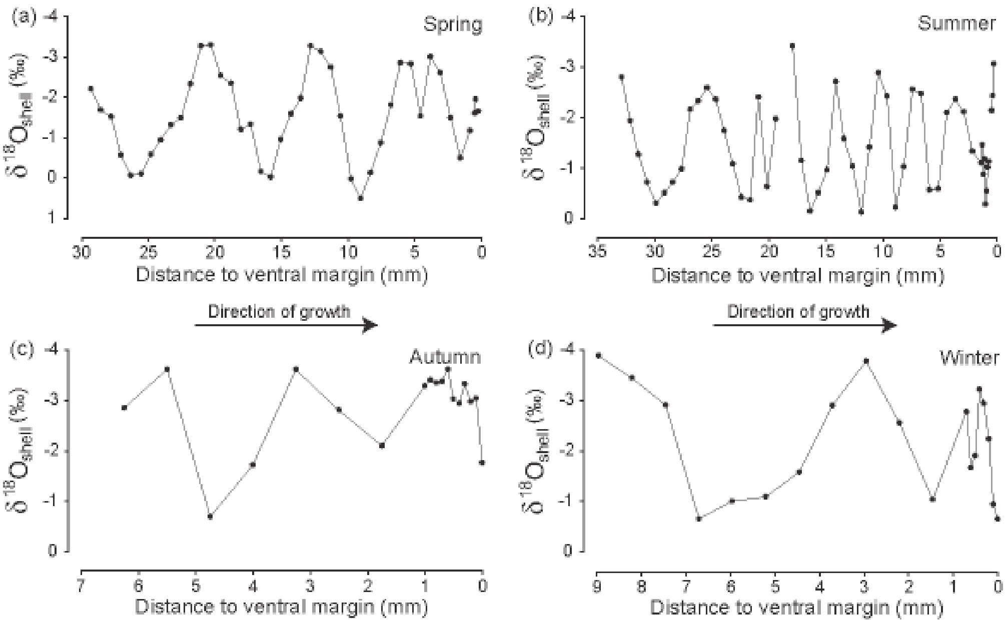

Figure 2.7 - $\delta^{18}O$ profiles of four archaeological specimens from the site ElSx-1, showing different seasons of collection. The season of collection is determined by examining the shape of the curve and the micro-growth structures at the ventral margin, as well as the $\delta^{18}O$ value at the ventral margin of the shell.

The results of the stable oxygen isotope analysis of archaeological specimens demonstrated a pattern of multiple seasons of shellfish collection, with an emphasis on spring and autumn collection (Table 2.2). Thirty-five per cent of the shells analysed for seasonality were collected in the spring, and 35% were collected in the autumn. Three shells (15%) were collected in the winter, the remaining 15% were collected in the summer. On the basis of the radiocarbon dates, this emphasis on spring and autumn collection persisted at Namu over a period of at least 2000 years (Table 2.3).

Table 2.2 Summary list of shell analysed from each of the seven sites for $\delta^{18}O$ seasonality and sampling technique used.

Sample	Milled	Drilled	# δ18O samples	Ventral margin δ18O‰	Season
ElSx-1-1	15	42	57	-3.05	Summer
ElSx-1-2	14	10	24	-4.04	Autumn
ElSx-1-3	4	10	14	-2.15	Spring
ElSx-1-4	8	38	46	-1.65	Spring
ElSx-1-5	15	29	44	-2.75	Autumn
ElSx-1-6	10	7	17	-1.18	Spring
ElSx-1-7	16	5	21	-3.54	Autumn
ElSx-1-8	8	11	19	-0.64	Winter
ElSx-1-9	10	5	15	-1.58	Autumn
ElSx-1-10	5	15	20	-2.25	Spring
ElSx-1-11	10	13	23	-1.06	Spring
ElSx-1-12	15	8	23	-2.07	Spring
ElSx-1-13	9	41	50	-2.41	Summer
ElSx-1-14	11	6	17	-1.76	Autumn
ElSx-1-15	6	6	12	-1.66	Autumn
ElSx-1-16	13	0	13	-3.07	Spring
ElSx-1-17	12	0	12	-0.73	Autumn
ElSx-1-18	10	0	10	-0.25	Winter
ElSx-1-19	10	0	10	-0.53	Winter
ElSx-1-20	10	0	10	-2.72	Summer

Table 2.3 – Seasonality and dates for seven $^{14}C_{AMS}$-dated shells at ElSx-1

Site	Season	Conventional 14C age	Lab ID	Calibrated date (2-sigma)
ElSx-1	Summer	2410 ± 35 BP	Poz-30565	cal AD 210-540
ElSx-1	Autumn	2425 ± 35 BP	Poz-33565	cal AD 180-510
ElSx-1	Autumn	3260 ± 30 BP	Beta-297419	cal 790-520 BC
ElSx-1	Spring	3695 ± 35 BP	Poz-30564	cal 1370-1020 BC
ElSx-1	Autumn	3750 ± 30 BP	Beta-297421	cal 1420-1110 BC
ElSx-1	Summer	3860 ± 40 BP	Poz-33587	cal 1570-1240 BC
ElSx-1	Autumn	4630 ± 40 BP	Beta-297420	cal 2560-2200 BC

DISCUSSION

Temperature and the oxygen isotope signature of the water in which the shells grew determine the $\delta^{18}O$ composition of mollusc shells, and both temperature and $\delta^{18}O_{sw}$ are expected to change through the course of a year. Temperature tracks changes in atmospheric temperature and insolation, with the result that temperature is at a minimum in the winter and a maximum in midsummer. As previously discussed, $\delta^{18}O_{sw}$ is controlled by the influx of freshwater from streams, either fed by rainfall (which reaches a maximum in midwinter) or by melt-water from snow-packs in the adjacent coastal mountain ranges. These effects are large enough that even seawater some distance from the mouth of streams will undergo a seasonal cycle.

In an environment in which $\delta^{18}O_{sw}$ was equal to that of normal seawater (~ 0‰) throughout different seasons, temperature would be the dominant control of $\delta^{18}O_{shell}$, leading to maximum values in midwinter and a minimum in midsummer. Where streams are fed only by rain with $\delta^{18}O$ ~ –10‰ (typical of winter rain on

Vancouver Island; Environment Canada 2011), $\delta^{18}O_{sw}$ could acquire values as low as –1‰ to –2‰, depending on the salinity values, equivalent to an apparent increase in temperature of 4–8°C. In contrast, late-spring to summer snowmelt water, at comparable salinity values, would substantially lower $\delta^{18}O_{sw}$. In fact, $\delta^{18}O$ shell values measured during the summer (as estimated from sampling position relative to winter lines and LDGI) are much lower than would be expected for a mollusc growing at typical midsummer temperatures, clearly indicating that the water in which they were growing contained a significant admixture of freshwater with a low $\delta^{18}O$ value. Through the course of the year, a shell at a given coastal site will record an isotopic cycle from winter-like (more positive) values to summer-like (more negative) values, although the numerical values cannot be interpreted directly as either temperature or $\delta^{18}O_{sw}$. In spite of the consequent uncertainties in their quantitative interpretation, these records of $\delta^{18}O_{shell}$ still provide an additional means of identifying the timing of shellfish collection. A ventral margin value that yields a $\delta^{18}O_{shell}$ close to the maximum value must have been collected in midwinter. However, the absolute $\delta^{18}O_{shell}$ recorded for a particular season of collection will vary from place to place, and from year to year, depending on the local level of mixing of fresh- and seawater as well as the 'background' $\delta^{18}O$ of the seawater, which is regionally influenced by more distal sources of freshwater. Therefore, determination of the season of shellfish collection depends critically on being able to measure, with the appropriate resolution, enough shell growth (ideally one full year) to assign with confidence a position in the local seasonal cycle. Live-collected shells should have multiple years sampled to observe the full spectrum of seasonal amplitudes.

Even though the coast of BC is subject to seasonal freshwater influxes, previous studies have argued that growth rates of this species are controlled more by temperature than by freshwater (Hallmann *et al*. 2009, 2011), and the changes in $\delta^{18}O_{shell}$ are strongly controlled by seasonal influxes of freshwater. This analysis demonstrates that it is irrelevant to discuss changes in $\delta^{18}O$ in terms of *palaeotemperature* in this region, since the effect of temperature on $\delta^{18}O$ of shells is comparatively lower. The influence of winter rains is moderated by the comparatively slow (to zero) growth rates during this season. The extremely low $\delta^{18}O$ shell values of spring and summer are due to the combined effects of injection of snowmelt-water and higher temperatures.

The seasonal interpretations of seasonality of $\delta^{18}O$ presented here are uniquely conditioned by the geographical setting, with a coastal waterway with partly restricted access to open ocean seawater, heavier winter rains and a nearby mountain range that accumulates a thick snow-pack that rapidly melts in the spring to produce run-off in local streams. This combination of circumstances may occur in other regions that are being studied for their *palaeoclimate* records, and our model could be used as a possible means of interpreting isotope values. The effects of coarse versus fine-resolution sampling were also demonstrated, and this may prove to be useful in other studies of shell seasonality in estuarine environments.

The interregional variability observed in the annual growth cycles of the modern shells may be the product of local variation in salinity changes that could affect the growing season. Gillikin *et al*. (2005) analysed *S. gigantea* from Puget Sound, Washington and observed up to three growth lines per year, and the growth lines observed in his study did not correspond with expected isotope values for a cold season. This variability in growth rates and growth structures can be problematic when attempting to identify a season of death using low-resolution methods that rely on the identification of a 'winter line'. The results of the studies by Gillikin *et al*. (2005) and Hallmann *et al*. (2009, 2011, 2012), as well as the present study, provide a strong foundation to examine the variability observed in region-specific growth rates, the influence of seasonal freshwater influxes and seasonality in the Namu region. Regardless of the variability observed in growth rates, all specimens from the Pacific Northwest Coast show the most positive $\delta^{18}O_{shell}$ values during the coldest times of the year (winter) and overall more negative values during the warmest temperatures (summer). The most negative peaks in the isotope curves were observed during the short-term seasonal periods of freshwater influxes in the autumn and spring. The results of the regional study of growth rates reinforces the necessity for local calibration studies to be performed prior to attempting to determine the season of shellfish collection in an archaeological context.

The variability in LDGI numbers implies that shells from the central coast do not continue to deposit lines on a daily basis according to tidal action, and this may be due to the increased amounts of freshwater that cause the shell to stop growing (Gillikin *et al*. 2005). Both 'winter growth lines' and disturbance lines formed at other times of the year can be detected microscopically, but their identity can only be resolved by locating the most negative isotope values that occur in the spring because of snowmelt water.

Applying a high sampling resolution for stable oxygen isotope analysis permits the determination of an accurate season of death in shell fragments from different ontogenetic ages, and without the problems associated with using growth lines to determine seasonality. For example, Figure 2.8 demonstrates an example of senescent growth in *S. gigantea* compared to a younger specimen in a mature phase of growth. Growth increment widths decrease with ontogeny, so the amount of carbonate precipitated between winter-growth breaks will also decrease over the lifetime of the clam. However, sampling in 100 μm steps is sufficient to identify a precise season of collection, even in shell fragments recovered from auger-collected samples that are ~2 cm in length. When using micro- or macroscopic examination of growth lines to determine seasonality of shellfish collection in estuarine settings (i.e., Monks and Johnston 1993), there is a larger margin of error in the estimated season of shellfish death. Equally dividing the increment between 'winter growth lines' into three seasons (spring, summer and autumn) will probably result in an inaccurate season of death estimate, since there are variable rates of growth in the growing season, and the growing season(s) cannot be equally divided into three parts. There is more rapid growth in the peak of the growing season; therefore that portion of shell growth will be larger in comparison to the periods of growth prior to, and after, the period of maximum growth. This knowledge of seasonal shell growth variability renders the more traditional method of 'winter growth line' analysis obsolete.

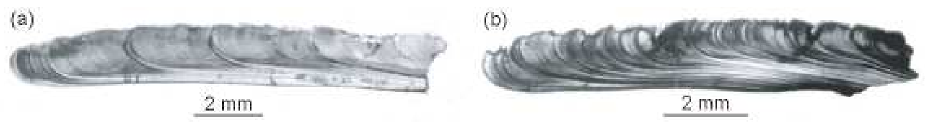

Figure 2.8 - Mature (a) and senile (b) shell growth from ElSx-1. The mature shell reveals clear and evenly spaced growth lines; the growth lines in the senile shell are more compact.

CONCLUSIONS

The application of high-resolution stable oxygen isotope analysis combined with sclerochronology has provided the first conclusive evidence to show that shellfish were collected year-round at the site of Namu. An isotope sampling strategy that uses micro-milling in 100 μm steps allows for a more precise seasonality estimate than low-resolution sampling, since micro-milling at the ventral margin allows for an uninterrupted environmental record to be obtained and minimizes the effects of time-averaging. Essentially, low isotope sampling resolution and/or an inadequate number of samples that do not observe at least one full year of growth will result in a mixing of seasons, and therefore an inaccurate seasonality result.

The analysis of shell samples from the site of Namu (ElSx-1) indicates multiple seasons of shellfish collection, consistent with an interpretation of year-round habitation at this site. Other seasonal proxies for this site include large numbers of herring, which are available in abundance in late winter/early spring, the presence of neonatal harbour seal, available in late spring, and a consistent emphasis on fishing a variety of salmon species, which spawn from late summer through autumn (Cannon and Yang 2006). The most significant finding of the current study is the clear emphasis on spring and autumn shellfish gathering at Namu. The consistency of this pattern is confirmed by the results for shells that were analysed for both radiometric dating and stable oxygen isotope analysis. An emphasis on shellfish harvesting in the spring probably compensated for the depletion of winter food stores. People could have relied on shellfish as a readily available protein source until other foods such as herring and salmon became available. In autumn, people probably harvested shellfish for the purpose of drying and storing the meat for the winter, since winter is a time of relative food scarcity.

These results indicate a much more complex pattern of seasonal site usage than is implied in the traditional, ethnographically derived model of the ‘seasonal round’. The results of this technique have enabled new insights into settlement, seasonality and resource procurement patterns at the site of Namu on the Pacific Northwest Coast. These and the results of further studies will provide a basis for region-wide understanding of the nature of seasonal settlement and subsistence practices.

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CHAPTER 3

INTER-SITE VARIABILITY IN THE SEASON OF SHELLFISH COLLECTION ON THE CENTRAL COAST OF BRITISH COLUMBIA

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ABSTRACT

High-resolution stable oxygen isotope analysis of the bivalve *Saxidomus gigantea* from shell midden sites was applied to identify seasonal patterns of resource procurement on the central coast of British Columbia, Canada. A total of 90 archaeological shells were examined from eight distinct sites spanning a 4,500-year period. Combining micro-growth pattern analysis with high-resolution stable oxygen isotope sampling allows for a precise season of collection to be determined in estuarine bivalves recovered from archaeological sites. The results of the stable oxygen isotope analysis provide insights into seasonally structured harvest of *S. gigantea* (butter clam), which is associated with different types of sites. The results show a variety of patterns, including multi-seasonal collection, intensive seasonal harvesting and casual, supplemental use of butter clams at different locations.

Keywords: Seasonality; Pacific Northwest Coast; stable oxygen isotopes; shellfish harvesting; sclerochronology; shell middens

INTRODUCTION

The investigation of seasonality has been the subject of research on the Pacific Northwest Coast for over thirty years. A major goal has been to examine the timing of site occupation and to place sites within a framework of a larger seasonal-settlement system. Another aim has been to find evidence for multi-seasonal, permanent village settlements, or sedentism. Most seasonality studies have focused on the presence of an assumed ‘seasonal round’ (Ames, 1981), which was based on the need to procure and process food in the late summer and autumn to sustain village populations through the winter months.

This pattern of residential mobility has been heavily generalized for most of the North Pacific Coast and is influenced by observations from the early European contact era (Ford, 1989). After European contact, during the ethnohistoric era, residential mobility was frequently noted (Barnett, 1938; Mitchell, 1983; Mitchell and Donald, 1988), and this model of the ‘seasonal round’ has permeated archaeological interpretations (Ford, 1989). Using ethnography to understand long-term behavioural patterns, such as settlement or shellfish gathering, does not account for change over time, nor does it permit consideration of year-to-year variation on a seasonal scale (Jochim, 1991). For example, Pomeroy (1980) coined the term ‘Central-Based Seasonally Mobile’ with regards to Bella Bella (Heiltsuk) settlement patterns (1978:210) without the analysis of any precise seasonality indicators. Although a model of seasonal movement between site locations is widely assumed for the Northwest Coast, no archaeological studies have been of sufficient scale to document any particular model of seasonal movement in any region of the coast.

Bivalves are ideal for seasonality studies since they are sensitive geo-cultural archives that record the changes in sea surface temperature and salinity in their shells, and stable oxygen isotope analysis ($\delta^{18}O_{shell}$) provides a means to interpret these seasonal changes. The application of shell oxygen isotope studies has permitted the seasonal identification of shellfish collection, and by proxy the season of site occupation in a variety of geographic contexts (i.e., Andrus and Crowe, 2000; Deith, 1986; Kennett and Voorhies, 1996; Mannino et al., 2003, Mannino et al., 2007; Rick et al., 2006; Shackleton 1973; Stephens et al., 2008). Shell seasonality studies that employ high-resolution isotope sampling, as well as calibration with modern specimens are also likely to produce more accurate seasonality results than studies that use growth line analysis alone (Andrus, 2011). This study incorporates data from a high-resolution oxygen isotope and sclerochronological alignment study of live-collected and archaeological shells from the site of Namu (ElSx-1) from Burchell et al. (2012), and incorporates new data from seven additional shell midden sites to examine regional patterns of butter clam collection over a period of more than 4500 years.

Previous seasonality studies assumed that variations in $\delta^{18}O_{shell}$ are principally driven by seasonal changes in the temperature of seawater because of the effect of isotopic fractionation between aragonite and water (Epstein et al., 1953). A paper by Burchell et al. (2012), which examined shells from the site of Namu on the central coast of British Columbia, showed that most of the variation in $\delta^{18}O_{shell}$ is due to seasonal changes in $\delta^{18}O$ of seawater ($\delta^{18}O_{sw}$), while temperature has a negligible effect on $\delta^{18}O_{shell}$, especially during seasonal periods of freshwater influxes. This was demonstrated through the sclerochronological (shell growth patterns) results of lunar daily growth increment (LDGI) alignment combined with $\delta^{18}O_{shell}$ data of live-collected specimens in which the annual variation in $\delta^{18}O_{shell}$ was at least four times larger than could be accounted for based on observed seawater temperatures. These shifts in $\delta^{18}O_{sw}$ are related to influxes of stream-water from the melting snow in the adjacent coast mountain ranges and seasonal increases in precipitation. These influxes, which have more negative oxygen isotope values than the water in which the shell lived, occur typically in the late spring and early summer, and also coincide with the seasons of higher seawater temperatures. This lack of sole dependence of $\delta^{18}O_{shell}$ on temperature is further emphasized by the fact that shell growth in most locations stops, or slows significantly during the coldest time of the year (Hallmann et al., 2011). In this paper, variation in $\delta^{18}O_{shell}$ is used to reconstruct the season of collection of shells while recognizing that the sinusoidal seasonal variation in $\delta^{18}O_{shell}$ within shells was strongly influenced by variation in $\delta^{18}O_{sw}$.

Shellfish and seasonality on the Northwest Coast

Cannon (1991, 1998) has argued that the site of Namu was occupied year-round by some residents of the local population, and that the economy was dependent on the mass harvest and storage of salmon, a pattern that remained unchanged from the time of the earliest preserved faunal remains around 7000 years cal. BP (Cannon and Yang, 2006:126). Faunal remains from this site include neonatal harbour seal, which indicate presence around the peak of the pupping season in mid-June, and herring, which are available in late winter/early spring, and a range of salmon species, which spawn from summer through late autumn. These indicators combined with the initial high-resolution study of clam shells from the Namu site support the interpretation of year-round presence at this settlement. However, the same range of seasonal indicators is not available from the more limited site investigations that have been done at other locations in the region.

The importance of shellfish as a resource on the Northwest Coast in both the archaeological and historic time periods is a subject of debate (Cannon et al., 2008; Moss, 1993), and inferences concerning the seasonal patterns of their procurement have relied heavily on the historic period documentation. Based on the ethnographic record, the Northern Coast Salish dug for clams during the winter when the tides were low at night (Kennedy and Bouchard 1990:445). Similarly, the Tsimshian in Prince Rupert Harbour harvested shellfish during the winter (Halpin and Seguin, 1990:271). In contrast, the Nuu-chah-nulth on Vancouver Island gathered shellfish in the spring because of the scarcity of other foods (Arima and Dewhirst, 1990:394). Shellfish were gathered throughout the year by the Haida, especially winter (Blackman, 1990:24). For the Haida, if there was a poor salmon harvest, shellfish became more important in the winter and spring when other foods were scarce (Blackman, 1990). However, it should be noted that the observations of seasonal resource procurement made during the ethnographic period are not necessarily representative of the archaeological past, nor do they take into account the potential for change over time (Conneller, 2005; Ford, 1989). A seasonality study at the Little Qualicum River Wet Site on the east coast of Vancouver Island (Bernick and Wigen, 1990), which relied on the presence and absence of migrating faunas suggested that the site was more continuously occupied than the reported patterns of ethnographic mobility suggest. This may be the case for many other sites on the Pacific Northwest Coast, and can be further investigated using high-resolution isotope sampling of archaeological shells recovered from shell middens.

STUDY AREA

Sites used in study

The archaeological sites examined include the village site of Namu (ElSx-1) and seven additional small to large shell midden sites located on the central coast of British Columbia within the traditional territory of the Heiltsuk First Nation (Fig. 3.1). This region has been the focus of archaeological investigation for over 40 years, and researchers have applied a range of excavation techniques including traditional excavation (Carlson, 1979, 1996; Hester and Nelson, 1978) and a coring and augering program (Cannon 2000a, b). The results of these investigations have shown continuous occupation at the site of Namu over a period of 11,000 years (Carlson 1991, 1996). Cannon’s research program has provided additional insights into regional variability in subsistence and settlement (Table 3.1), but there has been no systematic study of the seasonality of occupation at sites other than Namu.

Table 3.1 – Classification of sites, radiocarbon dates and number of shells sampled for seasonality.

Site Type	Site	Earliest Date of Shell Midden Deposits	Seasonality Samples	
		Years cal. BP	# shells	# oxygen isotope samples
Village	ElSx-1, Namu	6690-6400	22	509
	ElSx-3, Kisameet	2890-2720	12	204
	ElTb-1, Hurricane Island	2755-2360	10	150
	ElTb-10, McNaughton Island	2760-2355	6	63
Large residential site	ElSx-5	6730-6460	7	97
	ElSx-10	6265-5910	14	180
Small camp site	ElSx-4	2845-2620	7	134
	ElTa-25, Hunter Island	4370-3975	12	199
TOTAL			**90**	**1536**

Figure 3.1 – Map of central British Columbia showing sites used in analysis.

Shellfish research on the central coast of British Columbia

Although Namu was occupied for close to 11,000 years, shellfish remains are only available for the last 7000 years (Cannon et al., 2008). Absence of shell in the earliest deposits could be due to a lesser reliance on this resource and/or to preservation. Stein (1992) argued that preservation is a major factor in interpreting trends in shellfish harvest, with low shell density in early deposits attributable to the effects of groundwater leaching.

The quantification and identification of shell recovered from other sites in the area has shown that a wide diversity of taxa were harvested, including butter clams, horse clams, cockles, whelks, urchins and barnacles. Additionally, there are site-specific patterns in the abundance of different species, suggesting a pattern of local resource procurement (Cannon et al., 2008). A study that compared butter clams in mature phases of growth (younger) to those in a senile stage of growth (older) demonstrated a pattern of less intensive harvest at longer-term residential sites and a more intensive harvest at shorter-term encampments (Cannon and Burchell, 2009). This documented inter-site variability in butter clam collection strategies suggests that seasonal harvest patterns might also vary between site locations.

MATERIALS AND METHODS

Saxidomus gigantea

S. gigantea (butter clam) precipitates an aragonitic shell, and is a temperate marine species that burrows to a depth of ~30 cm below the intertidal surface (Nickerson, 1977; Paul et al., 1976). This species is ideal for high-resolution seasonality studies since it is one of the most commonly recovered bivalves in shell middens from the coast of British Columbia and Alaska. To determine seasonal patterns of butter clam collection a total of 90 individual clamshells were sampled, including 20 shells from Burchell et al. (2012), two additional shells from Namu, and 68 shells from seven other shell middens in the immediate vicinity.

Analysis of lunar daily growth increments (LDGI) to facilitate seasonality analysis

Growth cycles can be recognized in *S.gigantea* by counting LDGI, which identifies the duration of the growing season, and the seasonal rate of shell growth. To count and measure LDGI, polished shell cross-sections were immersed in Mutvei's solution following the methods presented in Schöne et al., (2005). The three main components of Mutvei's solution are alcian blue, glutaraldehyde, and dilute acetic acid, which simultaneously etch the shell carbonate while preserving and staining parts of the organic matrix of the biomineral dark blue (Schöne et al., 2005). The organic-rich lines are clearly visible since they are etch-resistant and appear as dark blue ridges, whereas the growth increments (the space between consecutive growth lines) are more strongly etched and appear as a lighter shade of blue. This technique distinguishes between lines that were formed in the winter, and/or lines that had been formed as a result of a growth cessation from freshwater influxes in the spring, as well as disturbance lines that can be caused by spawning, predation or rapid environmental change. Lunar daily growth increment widths abruptly decrease then slowly increase after a disturbance occurs, but slowly decrease and then slowly increase around the annual growth cessation (Clark, 1974). Calibration studies using LDGI and $\delta^{18}O_{shell}$ have been performed on live-collected specimens of *S.gigantea* from Pender Island in southern British Columbia, the Dundas Islands in northern British Columbia and Alaska (Hallmann et al., 2009; 2011; 2012), as well as the central coast (Burchell et al., 2012). These studies are used to align the $\delta^{18}O_{shell}$ values to specific seasons and to understand the influence of seasonal freshwater influxes on $\delta^{18}O_{shell}$ to refine seasonality estimates from estuarine bivalves.

High-resolution stable isotope sampling

A total of 1,563 discrete isotope samples, including 850 high-precision micro-milled samples and 686 micro-drilled samples were obtained from cross-sections of the 90 selected shells beginning at each shell's ventral margin then moving towards the umbo. Samples were taken from the outer shell layer. To prepare shells for oxygen isotope analysis, a 3-mm thick cross-section of each specimen was cut perpendicular along the axis of maximum growth from the umbo to the ventral margin using a low-speed precision saw (Buehler IsoMet 1000) with a 0.4 mm thick diamond-coated wafering blade. The cut shell slices were mounted with metal epoxy resin on glass slides, ground on glass plates with 800 and 1000 μm SiC grit powder and polished with 1 μm Al_2O_3 colloidal solution. After each grinding and polishing step, the shells were cleaned via ultrasonic bath and air-dried.

Shell aragonite powder was obtained by hand micro-milling at the ventral margin, followed by micro-drilling. Micro-milling allows for an uninterrupted record to be obtained from the shell's growth history and minimizes the effects of time-averaging, which is the mixing of different time intervals/seasons of shell growth (Goodwin et al., 2004). Micro-milling began at the ventral margin and moved in ~100 μm consecutive steps that contoured the micro-growth lines using a 1 mm diamond coated cylindrical drill bit (Komet/Gebr. Brasseler GmbH & Co. KG model no. 835 104 010). The faster growing portions of the shell were micro-drilled using a 300 μm conical drill bit (model no. H52 104 003) (Fig. 3.2).

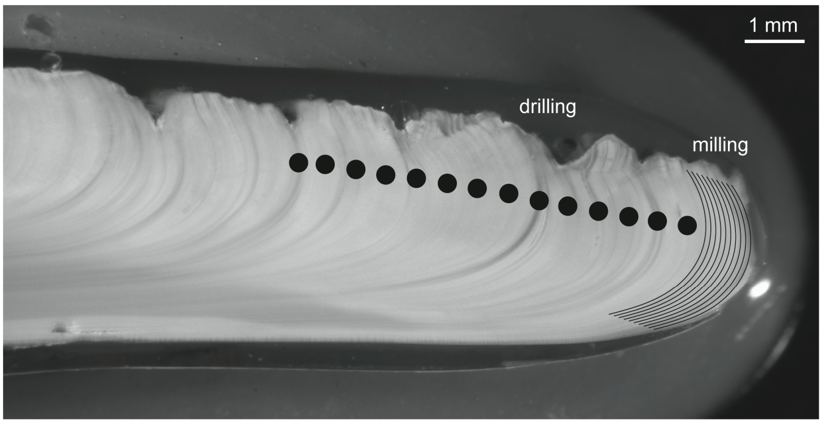


Figure 3.2 – Sampling techniques to obtain carbonate powder for stable oxygen isotope analysis. Samples were micro-milled directly at the ventral margin and moved in ~100 μm steps that contoured the micro-growth lines. After the ventral margin was milled, the faster growing portions of the shell were micro-drilled using a 300 μm conical drill. The centre-to-centre distance between drill points varied between 400 and 600 μm.

The centre-to-centre distance between drill points varied between 400 and 600 μm. Since shell samples varied in both the size of the fragment as well as ontogenetic age, each polished shell was evaluated under 40 X magnification to observe micro-growth structures, and a specific sampling strategy combining micro-milling and micro-drilling was selected to attain the highest possible seasonality resolution. In each shell fragment analysed, micro-drilling, micro-milling or a combination of both techniques was extended to attempt to gain one year or more of shell growth history.

The majority of shells analysed were in a mature stage of growth, but the ontogenetically older shells had more samples milled at the ventral margin than younger shells. This strategy was put in place since the rate of shell growth slows considerably with age and therefore more time is represented within each shell portion. Using high-resolution milling, it is possible to obtain a reliable measure of seasonality from senile shells, even though their growth lines are more tightly spaced and, consequently, the growth increments are narrower than in ontogenetically younger specimens. Since shells in younger stages of growth were preferred, they constitute the majority of the samples (n = 75/90). However, at some sites, it was necessary to sample senile shells in order to cover the temporal span of the midden (ElSx-1 n = 7/22; ElSx-3 n = 1/12; ElSx-5 = 1/7; ElSx-10 n = 5/14).

Isotope samples were processed in a Thermo Finnigan MAT 253 continuous flow – isotope ratio mass spectrometer coupled to a GasBench II. The

$\delta^{18}O$ values were calibrated against NBS-19 ($\delta^{18}O$ = -2.20‰) with a 1σ external reproducibility (= 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 given as per mil (‰). Stable carbon isotope values ($\delta^{13}C$) were also recorded but will not be discussed in this paper.

Sample selection

To obtain a representative temporal and spatial sample, shells were strategically selected from different depths, locations and time periods from each shell midden site. Figure 3.3 shows a map of ElTb-1 as an example of how shells were selected spatially and temporally based on the depth and horizontal distribution of the auger samples. The majority of shells (n = 55) used for $\delta^{18}O$ analysis were collected with a 7 cm diameter bucket auger, a sampling strategy that was originally intended to collect samples to assess variability in the salmon and herring fisheries (Cannon, 2000a). This method also allowed for the collection of shell fragments with preservation of an intact ventral margin. Additional whole butter clam valves (n = 15) from ElSx-1 were obtained from the level bag samples from the 1977-1978 field school excavations conducted by Simon Fraser University (SFU) (Carlson, 1991). Other complete valves (n = 13) were obtained from eroded sections of the middens at sites ElTa-25 and ElSx-10. Shells (n = 6) from the village site of ElTb-10 were obtained from the SFU archived collections from the 1970 excavations at the site (Pomeroy, 1980).

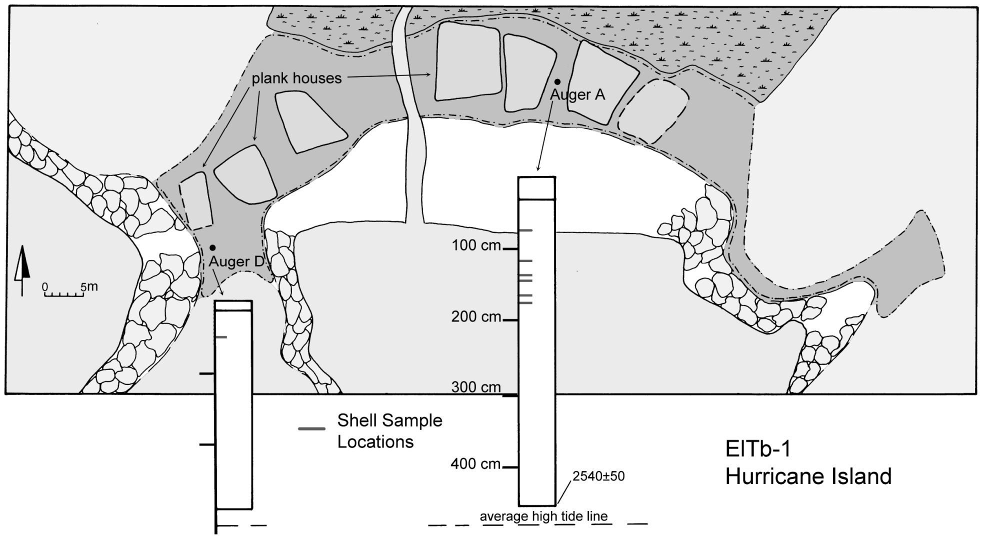


Figure 3.3 – Map of ElTb-1 showing locations of shells sampled for seasonality relative to its position in the site and auger.

Shells analysed for $\delta^{18}O$ were selected based on the following criteria: the preservation of an intact ventral margin and an intact upper shell layer; absence of exposure to fire, which can cause a polymorphic transition of shell $CaCO_3$ from aragonite to calcite; and the size of the shell/shell fragment, which had to be large enough to observe the seasonal amplitude. The mineralogy of the shells that were submitted for radiocarbon dating was tested by X-ray diffraction (XRD) and the results confirmed that no diagenetic changes had occurred (Kingston, 2007).

Radiometric dating

Accelerator Mass Spectrometry (AMS) dates were obtained from 11 shells that were sampled for seasonality. For each specimen, the periostracum and the outermost 100 μm of shell carbonate was physically removed, and between 70 and 180 mg of shell carbonate per shell were submitted for AMS dating.

Radiometric age analysis was performed at Beta Analytic Inc. (United States) and the Poznań Radiocarbon Laboratory (Poland). Conventional radiocarbon ages were converted to calibrated $^{14}C_{AMS}$ ages by the program Calib 6.0 (Stuiver and Reimer, 1993) using the Marine09 calibration dataset (Reimer et al., 2009). The average local ^{14}C marine reservoir effect (ΔR) for the study region is 390 ±50 years (Cannon et al., 1999). All dates presented in this paper were calibrated to 2-sigma and are presented in years BP.

Interpreting shell seasonality using $\delta^{18}O_{shell}$ *and micro-growth lines*

The $\delta^{18}O_{shell}$ data were plotted against the distance to the ventral margin in millimeters (mm), with $\delta^{18}O_{shell}$ on the y-axis, and the data were inverted to put the more negative isotope values, typically associated with warmer seasons, at the top of the curve. Where the sequence of data was sufficiently long, a sinusoidal pattern was observed that showed multiple seasons over a period of years in several cases. The average amplitude between the maximum and minimum value of $\delta^{18}O_{shell}$ is approximately 4‰. If this were entirely due to seasonal changes in water temperature of constant isotopic composition, it would correspond to a winter to summer difference in seawater temperature of more than 17ºC using any of the common palaeotemperature equations such as those by Grossman and Ku (1986), or Böhm et al. (2000). However, the actual difference in seawater temperature is approximately 7ºC (Environment Canada, 2006), which confirms that most of the variation in $\delta^{18}O_{shell}$ on the central coast of British Columbia is due to variation in $\delta^{18}O$ of seawater caused by an admixture of snow melt-water and precipitation (Burchell et al., 2012).

The cyclical variation in $\delta^{18}O_{shell}$ can be used to determine the season of collection, since the time of maximum fresh-water influence occurs seasonally during the late spring. The time of deposition of shell material with the most negative $\delta^{18}O_{shell}$ values is interpreted as "summer" while the time of most positive $\delta^{18}O_{shell}$ values is interpreted as "winter". The flanks of the sinusoidal pattern where the curve is either decreasing or increasing most steeply as a function of distance from the ventral margin represent autumn and spring, respectively. However, the absolute minimum is observed during the spring, but only during the temporary periods of melt-water influxes, and this is confirmed by aligning the $\delta^{18}O_{shell}$ to the LDGI. This model of the sinusoidal curve is used to establish seasonality, depending on how $\delta^{18}O_{shell}$ varies with distance from the ventral margin, and with this, four possible cases are observed: (1). If there is a complete sinusoidal curve, the season is established based on position of the ventral margin with respect to the curve. (2). If there is little or no variation in $\delta^{18}O_{shell}$ the season of collection is assigned based on the absolute magnitude of $\delta^{18}O_{shell}$. For winter collection, $\delta^{18}O_{shell}$ is close to the maximum value of the sine curve for the site (typically ~ 0‰). For summer collection, $\delta^{18}O_{shell}$ is near the minimum value for the site (average = -4‰). When little or no variation was observed it was likely an effect of too few samples taken, sampling a young shell with rapid growth, or a combination of the two factors. (3). If the $\delta^{18}O_{shell}$

becomes more positive with distance from the ventral margin it indicates autumn collection. (4). If the $\delta^{18}O_{shell}$ decreases with distance from the ventral margin, this indicates spring collection. In addition, we encountered some anomalous samples (n = 16) for which contradictory data were observed, specifically when values were more negative than observed for summer. In these samples, the LDGI were used to identify the duration of the growth period and, together with the $\delta^{18}O_{shell}$ data, to assign a season of collection.

RESULTS

Modern and archaeological shells

The results from the live-collected shells shows sinusoidal curve with the most positive isotope values in the winter and the most negative associated with spring freshwater influxes and summer temperatures (Burchell et al., 2012). The results of the live-collected shells are used as a model to interpret the sinusoidal curves of the archaeological shells (Fig. 3.4). The 11 shells selected for radiocarbon dating also had between one and five years of growth sampled, with the exception of one shell that had eight years sampled. There were 39 archaeological shells that had less than one year of growth analysed, and the remainder of archaeological shells had between one full year to 4.5 years analysed. Since 79% of the archaeological shells analysed recorded one or more complete years of growth, it is possible to observe the amplitude of variation at each site, and therefore accurately identify the position of the ventral margin in this sequence using the criteria discussed above. The maximum amplitude of variation in $\delta^{18}O_{shell}$ varies slightly between each site, depending on the maximum amount of snow-melt-derived freshwater that was mixing with seawater at that site. The live-collected shell had a $\delta^{18}O_{shell}$ range from -0.60‰ to -5.56‰, with a ventral margin value of -4.63‰ and amplitude of 4.96‰.

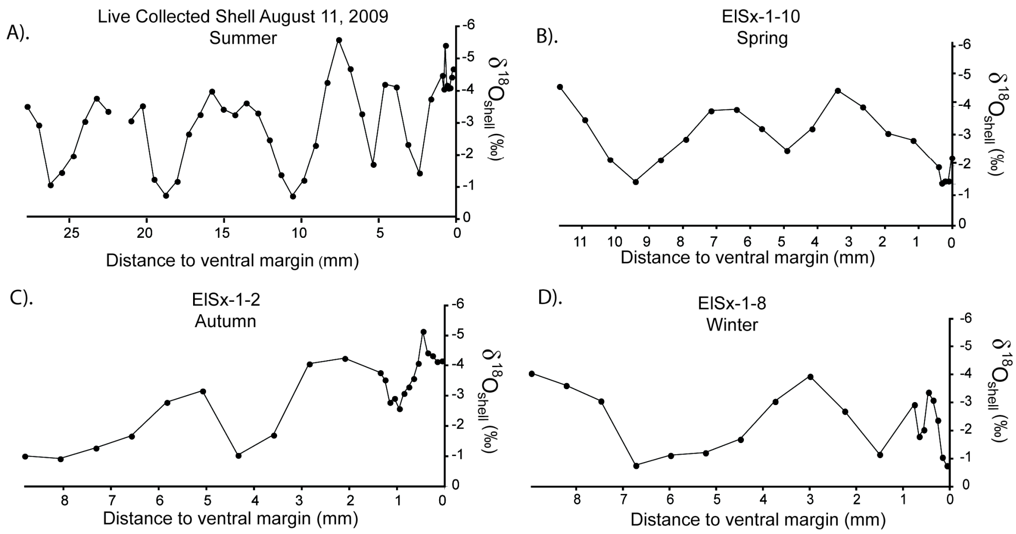


Figure 3.4 – Isotope profiles showing shellfish collection in four different seasons. A). The live- collected shell (August 11/09 from Burchell et al. 2012) is used as an analogue to interpret the profiles of the archaeological data. Archaeological shells show different seasons of collection B). spring, C). autumn, and D). winter.

The most negative $\delta^{18}O_{shell}$ value (-5.56‰) is associated with a spring freshwater influx to the site of the live-collected specimen, which indicates that this shell had grown in seawater containing a significant component of snow melt-water. The maximum amplitude for each site ranges from 2.0 to 4.3‰ (Table 3.2), excluding one sample from the site ElSx-5, (amplitude = 5.2‰). The site with the lowest amplitude (2‰) and therefore with smallest impact of snow melt-water, is ElTb-10 located on an island farthest from the mainland coast of all sites used in this study.

Table 3.2 - Maximum amplitudes (‰) and maximum $\delta^{18}O_{shell}$ for sites

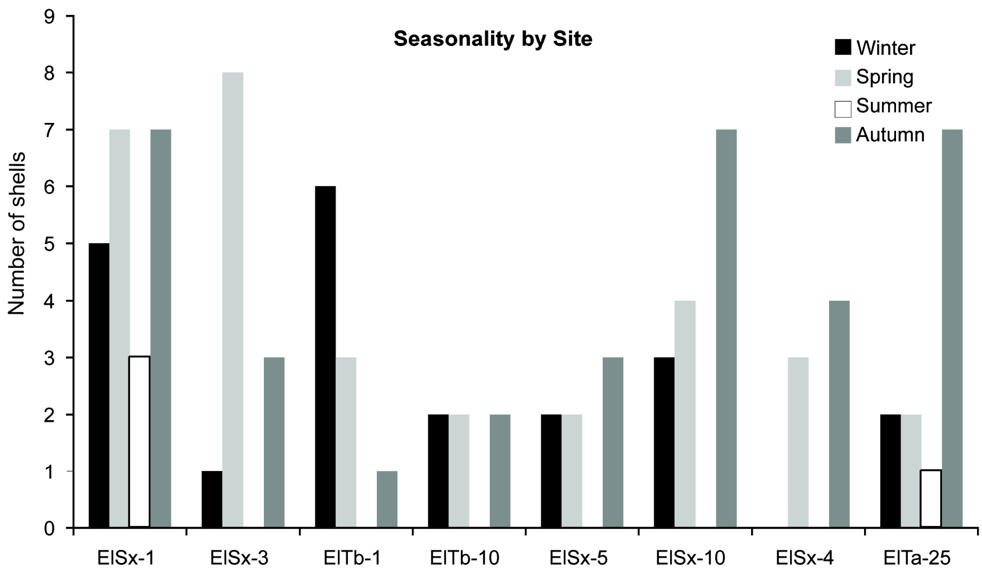
Site	Maximum Amplitude	Max δ^{18}O	Average Max
ElSx-1	4.3	0.5	-0.56 ± 0.83
ElSx-10	3.4	-0.06	-0.52 ± 0.45
ElSx-3	3.6	-0.27	-0.93 ± 0.53
ElSx-4	3.5	0.04	-1.45 ± 1.14
ElSx-5	3.09	-0.14	-0.48 ± 0.35
ElTa-25	3.8	-0.2	-1.16 ± 0.49
ElTb-1	3.4	0.03	-0.35 ± 0.66
ElTb-10	2	0.42	-0.39 ± 0.49
*Average max of island sites			0.08 ± 0.25
Average max of mainland sites			-0.09 ± 0.33

The maximum $\delta^{18}O_{shell}$ values for each site, representing winter-deposited shell material, range from -0.61‰ to 0.50‰. The effect of temperature on $\delta^{18}O_{shell}$ is greater during the winter since there would have been relatively less variation attributable to mixing of glacial or snow melt-water during that season. This is further confirmed by the lack of a significant difference in maximum values of $\delta^{18}O_{shell}$ between the mainland coast sites (-0.09 ± 0.33‰) and the island sites (0.08 ± 0.25‰).

Seasons of butter clam harvesting

Based on the interpretation of the $\delta^{18}O_{shell}$ data, there is a regional emphasis on butter clam collection in the autumn and spring. The results show 38% of shells were collected in the autumn, 34% in the spring, and 23% in winter (Fig. 3.5). It does not appear that butter clam harvesting was as important in the summer months, since only 4% of shells were collected in this season and are only observed at two sites, ElSx-1 and ElTa-25.

Figure 3.5 – Seasonality of shellfish collection by site.



The dates of shells analysed for seasonality at Namu range from 4630-4330 cal. yr. BP to 1740-1410 cal. yr. BP. The shells from ElTa-25 are closer in age range, 1300-1060 cal. yr. BP to 950-670 cal. yr. BP (Tables 3.3 and 3.4).

Although only 11 of the 90 shells were directly radiocarbon dated, of the shells that were dated, all four seasons are represented, with a strong focus on spring and autumn harvest, further emphasizing the long-term importance of butter clam harvesting during those seasons within this region.

Table 3.3 – Shell samples and seasonality results by site

Site	ID	Milled	Drilled	# $\delta^{18}O$ samples	Ventral margin $\delta^{18}O$‰	Season	# of years sampled (approx.)
ElSx-1	ElSx-1-1	15	42	57	-3.05	Summer	8
	ElSx-1-2	14	10	24	-4.04	Autumn	>1
	ElSx-1-3	4	10	14	-2.15	Spring	>1
	ElSx-1-4	8	38	46	-1.65	Spring	4
	ElSx-1-5	15	29	44	-2.75	Autumn	5
	ElSx-1-6	10	7	17	-1.18	Spring	>1
	ElSx-1-7	16	5	21	-3.54	Autumn	>1
	ElSx-1-8	8	11	19	-0.64	Winter	3
	ElSx-1-9	10	5	15	-1.58	Autumn	>1
	ElSx-1-10	5	15	20	-2.25	Spring	3.5
	ElSx-1-11	10	13	23	-1.06	Spring	2.5
	ElSx-1-12	15	8	23	-2.07	Spring	1
	ElSx-1-13	9	41	50	-2.41	Summer	5.5
	ElSx-1-14	11	7	18	-1.76	Autumn	2.5
	ElSx-1-15	6	6	12	-1.66	Autumn	2.5
	ElSx-1-16	13	0	13	-3.07	Spring	>1
	ElSx-1-17	12	0	12	-0.73	Autumn	>1
	ElSx-1-18	10	0	10	-0.25	Winter	>1
	ElSx-1-19	10	0	10	-0.53	Winter	>1
	ElSx-1-20	10	0	10	-2.72	Summer	>1
	ElSx-1-21	12	17	29	-0.26	Winter	2
	ElSx-1-22	10	12	22	-0.43	Winter	3
ElSx-3	ElSx3-1	11	4	15	-3.09	Spring	>1
	ElSx3-2	12	8	20	-2.54	Spring	3
	ElSx3-3	10	5	15	-2.49	Spring	>1
	ElSx3-4	17	15	32	-1.04	Autumn	3
	ElSx3-5	11	4	15	-3.76	Spring	1.5
	ElSx3-6	10	5	15	-2.08	Spring	>1
	ElSx3-7	19	3	22	-2.13	Autumn	1
	ElSx3-8	11	4	15	-0.95	Winter	>1
	ElSx3-9	5	5	10	-2.91	Spring	1.5
	ElSx3-10	10	5	15	-1.66	Spring	1.5
	ElSx3-11	10	5	15	-3.06	Autumn	>1
	ElSx3-12	10	5	15	-2.57	Spring	3
ElSx-4	ElSx-4-1	7	8	15	-1.48	Autumn	2
	ElSx-4-2	10	10	20	-2.18	Autumn	2.5
	ElSx-4-3	14	6	20	-2.3	Autumn	2
	ElSx-4-4	15	9	24	-3.22	Spring	>1
	ElSx-4-5	8	13	21	-2.04	Spring	3
	ElSx-4-6	9	10	19	-0.44	Spring	3
	ElS-4-7	11	4	15	-1.56	Autumn	1.5
ElSx-5	ElSx-5-1	10	10	20	-0.52	Winter	2
	ElSx-5-2	12	4	16	-0.62	Winter	>1
	ElSx-5-3	6	6	12	-3.1	Spring	1.5
	ElSx-5-4	7	5	12	-2.53	Autumn	1.5
	ElSx-5-5	8	7	15	-2.74	Spring	1.5
	ElSx-5-6	7	8	15	-1.22	Autumn	>1
	ElSx-5-7	6	1	7	-1.76	Autumn	>1
ElSx-10	ElSx-10-1	8	0	8	-1.98	Autumn	>1
	ElSx-10-2	7	8	15	-1.15	Spring	1
	ElSx-10-3	7	4	11	-1.55	Autumn	1.5
	ElSx-10-4	5	6	11	-0.06	Winter	2
	ElSx-10-5	11	4	15	-2.03	Spring	>1
	ElSx-10-6	5	5	10	-1.64	Autumn	1
	ElSx-10-7	6	9	15	-2.05	Autumn	1.5
	ElSx-10-8	3	7	10	-0.12	Winter	1
	ElSx-10-9	10	3	13	-1.91	Autumn	2
	ElSx-10-10	7	5	12	-2.72	Spring	>1
	ElSx-10-11	15	0	15	-1.79	Autumn	1.5
	ElSx-10-12	10	9	19	-1.76	Spring	4
	ElSx-10-13	7	4	11	-2.02	Autumn	>1
	ElSx-10-14	11	4	15	-1.23	Winter	3
ElTa-25	ElTa-25-1	0	9	9	-3.22	Spring	>1
	ElTa-25-2	13	2	15	-1.91	Autumn	>1
	ElTa-25-3	9	4	13	-3.17	Summer	1
	ElTa-25-4	5	10	15	-3.49	Autumn	3.5
	ElTa-25-5	9	6	15	-2.98	Autumn	1.5
	ElTa-25-6	12	4	16	-1.96	Spring	>1
	ElTa-25-7	10	0	10	-0.2	Winter	>1
	ElTa-25-8	9	21	30	-2.62	Autumn	4.5
	ElTa-25-9	8	34	42	-4.35	Autumn	4.5
	ElTa-21-10	6	0	6	-1.41	Autumn	>1
	ElTa-25-11	10	8	18	-0.82	Winter	2
	ElTa-21-12	10	0	10	-1.45	Autumn	>1
ElTb-1	ElTb-1-1	5	13	18	-0.44	Winter	1.5
	ElTb-1-2	7	5	12	-0.56	Winter	>1
	ElTb-1-3	6	7	13	-0.62	Winter	2
	ElTb-1-4	10	7	17	-0.91	Winter	2
	ElTb-1-5	5	15	20	-1.62	Spring	3
	ElTb-1-6	12	8	20	-0.63	Winter	2
	ElTb-1-7	10	10	20	-0.2	Spring	1.5
	ElTb-1-8	16	4	20	-0.33	Winter	>1
	ElTb-1-9	4	6	10	-1.65	Spring	>1
ElTb-10	ElTb-10-1	10	0	10	-1.86	Autumn	>1
	ElTb-10-2	12	0	12	-1.87	Autumn	>1
	ElTb-10-3	11	0	11	-1.18	Spring	>1
	ElTb-10-4	10	0	10	-0.07	Winter	>1
	ElTb-10-5	10	0	10	0.36	Winter	>1
	ElTb-10-6	10	0	10	-2.22	Spring	>1

Table 3.4 – Radiocarbon dates for shells analysed for seasonality

Site	Sample	Season	Conventional 14C age	Lab ID	Calibrated date (2-sigma)
ElSx-1	ElSx-1-13	Summer	2410 ± 35 BP	Poz-30565	cal AD 210-540
ElSx-1	ElSx-1-2	Autumn	2425 ± 35 BP	Poz-33565	cal AD 180-510
ElSx-1	ElSx-1-15	Autumn	3260 ± 30 BP	Beta-297419	cal 790-520 BC
ElSx-1	ElSx-1-4	Spring	3695 ± 35 BP	Poz-30564	cal 1370-1020 BC
ElSx-1	ElSx-1-7	Autumn	3750 ± 30 BP	Beta-297421	cal 1420-1110 BC
ElSx-1	ElSx-1-1	Summer	3860 ± 40 BP	Poz-33578	cal 810-480 BC
ElSx-1	ElSx-1-9	Autumn	4630 ± 40 BP	Beta-297420	cal 2560-2200 BC
ElSx-1	ElSx-1-22	Winter	4730 ± 30 BP	Beta-317860	cal 2680-2380 BC
ElTa-25	ElTa-25-7	Autumn	1670 ± 50 BP	Poz-30567	cal AD 1000-1270
ElTa-25	ElTa-25-8	Autumn	1760 ± 30 BP	Poz-30566	cal AD 900-1180
ElTa-25	ElTa-25-7	Spring	2030 ± 30 BP	Beta-297422	cal AD 650-890

Growth lines and stable oxygen isotopes

Growth structures that appear as darker lines in the shell, commonly referred to as ‘winter lines’, do not exclusively form during that particular season (Gillikin et al., 2005; Hallmann et al., 2009). The analysis of modern shells from Namu (ElSx-1) showed that butter clams also deposit lines in the spring as a result of growth cessation due to freshwater influx, and this is observed at other sites on the mainland coast. Figure 3.6 depicts an archaeological shell from site ElSx-3 with the shell’s micro-growth structure aligned with $\delta^{18}O_{shell}$ values. The most negative $\delta^{18}O_{shell}$ value (-4.56‰) is during a period of spring freshwater influx and not the summer in this particular specimen. Only by reference to the timing defined by the micro-growth structures can the period of lowest $\delta^{18}O_{shell}$ be aligned to the spring and not to the summer. As noted earlier, the higher seawater temperatures experienced in the summer would have only a slight moderating effect on the overall isotopic profile, which is always dominated by the seasonally varying inputs of low $\delta^{18}O_{freshwater}$ to the coastal seawater.

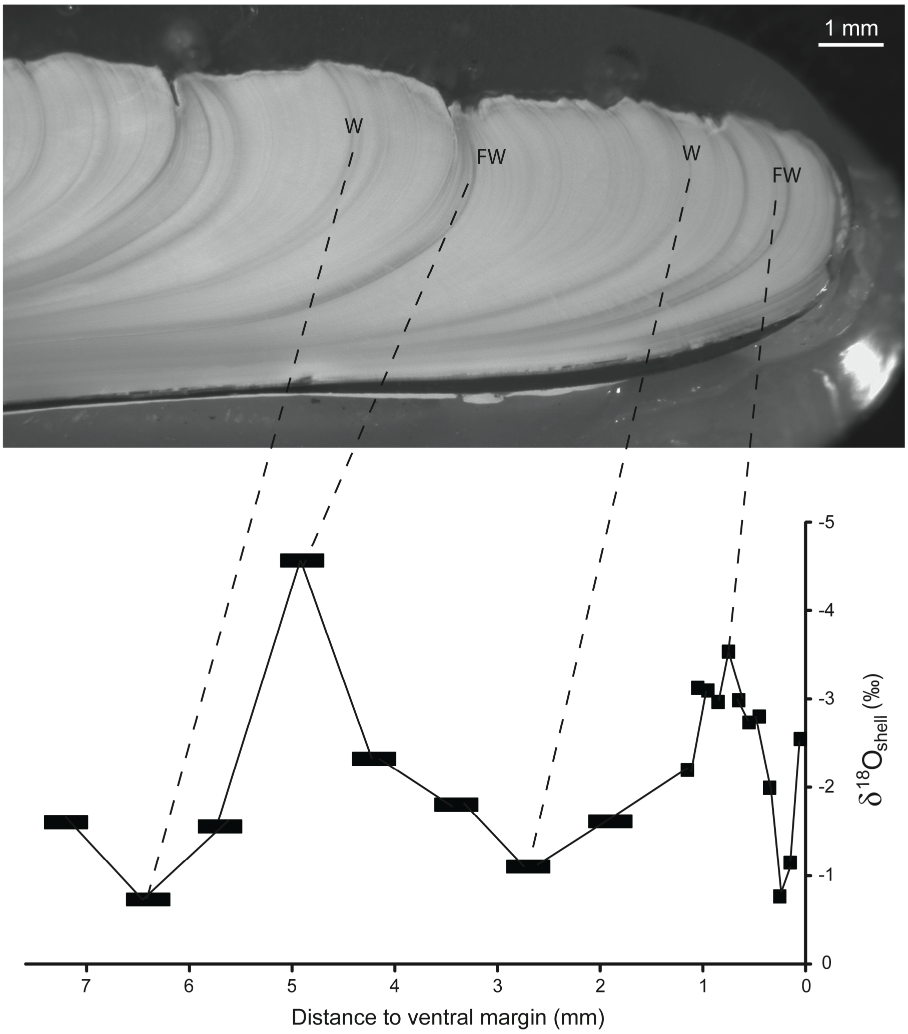


Figure 3.6 – Alignment of growth lines and stable oxygen isotope data for sample ElSx-3-2. The squares represent milled samples, and drilled samples are rectangles. Lines in the shell correspond to both the most positive and negative stable oxygen isotope values. This is because there is a cessation of growth in the winter and again in the spring during periods of freshwater influxes.

DISCUSSION

Site-specific seasonality patterns

The results of the high-resolution seasonality analysis based on stable oxygen isotope data indicate year-round collection of butter clams on the central coast, with season-specific patterns of collection at some sites. At the village site of Namu (ElSx-1), the analysis indicates multi-season collection throughout the past 4500 years, consistent with year-round occupation. There is a clear emphasis on spring and autumn gathering at Namu. More intensive harvest in the autumn may have been for the purpose of drying for storage and use through the winter. Butter clams may have been harvested in the spring to supplement depleted stocks of stored foods, and to serve as a source of fresh food when other sources were in shorter supply. People could have relied on shellfish as a readily available protein source until other foods, such as herring, became available.

The village site of Kisameet (ElSx-3) has a pattern of seasonal collection similar to Namu. Butter clams were collected during multiple seasons with an emphasis on spring and autumn. Like Namu, Kisameet shows an areal extent and a density and diversity of fish remains consistent with its use as a winter village site (Cannon, 2002), and the shell seasonality data are consistent with this interpretation. The McNaughton Island site (ElTb-10), has a seasonality profile similar to the village sites at Namu and Kisameet, but the smaller sample size in this case (n = 6) does not provide a basis for inferring any particular seasonal emphasis. The village site on Hurricane Island, ElTb-1, has previously been described as a spring/summer village with the emphasis on spring based on the presence of very high densities of herring (Cannon, 2002). The results show that butter clams were exclusively collected in the winter and the spring, confirming its likely seasonal occupation. The evidence for an emphasis on winter/spring harvest at this location is consistent across the site and at multiple depths of deposits (see Fig. 3.2).

ElSx-10 is another major residential site, with multi-seasonal collection of butter clams, but the pattern of seasonality differs slightly from that of Namu and Kisameet. At ElSx-10, there is an emphasis on both autumn and spring collection but also evidence for winter collection, and no collection during the summer. Again, this seasonal distribution implies occupation of the site through the winter. This pattern of seasonality and the density and diversity of fish remains at ElSx-10 is similar to those of the residential site of ElSx-5. Based on the evidence, ElSx-10 and ElSx-5 demonstrate multi-seasonal harvest, and a moderately high level of consumption and deposition of salmon and herring. These patterns are broadly comparable to those observed at the multi-seasonal villages at Namu and Kisameet, but the density of fish remains is much lower at ElSx-5 and ElSx-10, which suggest less intensive or more intermittent occupation. It is possible these sites were occupied year-round, almost year-round, or on a periodic basis as the result of historically contingent circumstances that are not yet clear.

The campsite at ElSx-4 also demonstrates a different seasonal pattern of butter clam collection. This is a small site, especially compared to other sites in the region, and it has a low density of fish remains, which is an indicator of short-term, more ephemeral occupations. There is a clear emphasis on spring and autumn harvest, but there is no evidence for any particular or consistent pattern of site use, only that on some occasions it was the location of butter clam harvest in the spring and in the autumn. It is possible that this location was occasionally a place for supplemental food gathering by residents from the nearby and more substantial residential site of ElSx-5.

The shell midden on Hunter Island, ElTa-25 has been identified as a non-residential site based on its small size, and its extremely low density of fish remains compared to other sites in the area (Cannon, 2002). It has been proposed that this was a site specifically used for intensive shellfish gathering, at least during some period of its occupation, since there is a large intertidal zone that surrounds the midden. The shells harvested from this site are younger in ontogenetic age when compared to shells collected from village sites, which implies a pattern of more intensive collection at this location (Cannon and Burchell, 2009). Based on its location, the density of shells in the midden deposits, and the lack of fish or other faunal remains, ElTa-25 was characterized as a site for the seasonally intensive harvest of clams, but the seasonality results show its use through multiple seasons. It seems unlikely that this is evidence of continuous, multi-seasonal occupation, but it also does not indicate a pattern of prescribed seasonal use. The site was in use for more than 4000 years, but dates from shells suggest that intensive clam harvest may have been restricted to a relatively short period of time of no more than 600 years, beginning around 1300 cal. BP. Although there is evidence for year-round collection here, there is a stronger emphasis on autumn collection, which suggests people may have mainly used the site to harvest clams for drying, storage and consumption in the winter months at residential village sites.

Precision and error of seasonality estimates from estuarine bivalves

Several studies have used bivalves to determine seasonality on the Pacific Northwest Coast using growth lines and increments in shellfish (e.g., Clarke and Clarke, 1980; Coupland et al. 1993; Crockford and Wiggen, 1991; Ham and Irvine, 1975; Keen, 1979; Maxwell, 2003; May, 1979; Stevenson, 1977). This approach to determining the season of shellfish harvesting is based on the assumptions that mollusks deposit $CaCO_3$ when they are submerged in water during high-tide, grow more rapidly in the summer, slow down, and eventually stop growing in the winter to form an annual line (e.g., Rhoads and Pannella, 1970). In most specimens from the Pacific Northwest Coast, major growth lines form in the winter. However, shell growth rates are variable across time and space, which can make 'winter growth' lines indistinguishable from lines deposited by stress, changes in temperature, salinity or food (Hallmann et al., 2009). Relying on 'winter growth' line analysis to determine seasonality does not consider regional variability in shell growth rates or the decrease in shell growth rates through ontogeny (Schöne, 2008), and in some specimens multiple 'winter growth lines' are observed in a single year (Gillikin et al., 2005).

A study of shell seasonally visualizing the formation of ‘winter lines’ on shells from Namu by Stevenson (1977) showed that clams were collected year round. However, the results were ambiguous, using designations that spanned two seasons, such as spring/summer. Other seasonality studies of shellfish on the Pacific Northwest Coast have also produced ambiguous results (e.g., Maxwell 2003). With high-resolution isotope sampling combined with growth line analysis, it is possible to refine the analysis to a specific season with a higher degree of confidence.

When sampling shells for archaeological seasonality using $\delta^{18}O$, the number of shell samples, and the number of samples taken per shell should be considered prior to analysis. A balance between robust numbers of shells but also sufficient isotope data is ideal. Mannino et al. (2003) proposed taking three samples at the ventral margin. However, an isolated analysis of the most recent growth in a shell is inadequate as a proxy for seasonal temperature variation (Andrus and Crowe, 2000), and it does not account for variation in local environments over time (Bailey et al., 1983). The number of samples required to precisely determine seasonality is contingent on the ontogenetic age of the bivalve. It is difficult to predict or standardize the number of discrete samples from archaeological shells in a multi-site study since the growth history of each shell is unique to its age, locality, and time. Ontogenetically older shells require higher sampling resolution (milling), since more time is represented in each discrete sample because of the slowing of shell growth as it ages. Younger shells can have fewer samples milled directly at the ventral margin, followed by microdrilling.

CONCLUSIONS

The combination sclerochronology and high-resolution stable oxygen isotope records of the ventral margin of shell fragments has permitted the determination of the season of butter clam collection, and by proxy, the season of occupation over a 4,500 year period on the central coast of British Columbia. The majority of the shells display a sinusoidal isotopic signal, which is influenced by both temperature and salinity, which is largely the result of seasonal influxes of low δ^{18}O melt-water from the adjacent coastal mountain range. The results show that it is possible to establish seasonality using comparatively small shell fragments recovered from auger samples, greatly expanding the applicability of these methods.

The archaeological implications show a multi-seasonal pattern of butter clam harvest, with an emphasis on spring and autumn. Spring would be the time when stored food was running out, and autumn was the time of clam harvest for storage and winter consumption. Less intensive harvest of shellfish would be expected in the summer months because of the greater threat of paralytic shellfish poisoning (Quayle and Bourne, 1972); but summer harvest is evident at some sites, though absent at others. There is also a consistent pattern of clam harvest in the winter suggesting this was a food source harvested throughout the year. The smaller sites do not show patterns expected from a formalized seasonal round. It is more likely that they were periodically used by small groups of people on a less frequent basis than the larger residential sites.

These results indicate a much more complex pattern of seasonal site usage than is implied in the traditional, ethnographically derived model of the 'seasonal round'. A model of a 'seasonal round' assumes that the environment, resources, and historical circumstances were stable throughout history. It does not take into account any variability due to factors such as environmental stability, fluctuations in resource availability, and human agency (c.f., Jochim, 1991). Additionally, site-specific patterns of butter clam collection further refine our understanding of local strategies for food procurement of shellfish resources. It also supports interpretations of early sedentary village occupation in this part of the coast (Cannon and Yang, 2006).

This study has demonstrated that a relatively small sample size and a highly precise technique can produce meaningful results to interpret seasonal patterns. The results of this technique have contributed new insights into settlement, seasonality and resource procurement on the Pacific Northwest Coast. Patterns of seasonal activities across the millennia are beginning to emerge, but those patterns are more complex and more specific to particular times and places than has been assumed based on a simpler generalized model of sedentary winter villages and a seasonal round of a task group movements between remote resource procurement locations. Based on the results of the seasonality analysis similar patterns of variability are likely to be found in other regions of the Northwest Coast.

ACKNOWLEDGEMENTS

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CHAPTER 4

SEASONALITY AND INTENSTIY OF SHELLFISH HARVESTING ON THE NORTH COAST OF BRITISH COLUMBIA

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ABSTRACT

Biochemical and growth increment analyses show contrasting seasonal patterns of butter clam collection and rates of harvest intensity between archaeological shell midden sites from the Dundas Islands archipelago and the mainland coast in Prince Rupert Harbour, in northern British Columbia. Growth increment analysis shows more intensive clam harvest in the Dundas Islands in comparison to the residential sites in Prince Rupert Harbour. Stable oxygen isotope analysis shows multi-seasonal collection of clams in the Dundas Islands and a more seasonally specific emphasis in Prince Rupert Harbour. Comparison of these results to those of similar studies in the Namu region on the central coast of British Columbia provides a basis for broader regional understanding of variation in shellfish harvesting intensity and seasonality on the Pacific Northwest Coast.

Keywords: Seasonality, subsistence, settlement, stable isotope analysis, Pacific Northwest Coast, multi-site/multi-regional analysis

1. INTRODUCTION

Interpreting seasonal settlement patterns and subsistence in the northern Northwest Coast region has remained a challenge for archaeologists. There has been some recent emphasis on variation in regional fishing economies (Brewster and Martindale 2011; Coupland et al. 2010), but less consideration has been given to the influence of environmental and historical circumstances that shaped local variation in shellfish use between locations and settlement types. Shellfish provide a valuable geo-cultural archive to examine patterns of harvest pressure as well as the season of collection, and by proxy, the season of site occupation. By employing shell growth increment analysis to determine relative rates of harvest pressure (Cannon and Burchell 2009), and stable oxygen isotope analysis ($\delta^{18}O_{shell}$) to interpret a precise season of collection (Burchell et al. 2012, 2013) it is possible to develop a more comprehensive and fine grained understanding of how shellfish were integrated into local subsistence practices than would be possible through previous approaches. This study compares seasonality and butter clam harvesting from a wide range of sites, from different environmental settings, specifically comparing sites from the Dundas Islands to the mainland coast in Prince Rupert Harbor in northern British Columbia, Canada (Fig.4.1). This comparison allows for the identification of regional patterns of shellfish use from two different environmental settings, which likely influenced how and why shellfish were gathered. Further comparison of the results from the northern coast to studies from the central coast allows for a broader understanding of regional settlement and subsistence, with a specific focus on the role of shellfish.

While the north coast of British Columbia has been the subject of archaeological investigation for several decades, mainly through single-site excavations (i.e., Ames 2005; Coupland et al. 2000, 2003; MacDonald and Inglis 1981), only in recent years has the explicit focus of research shifted to regional,

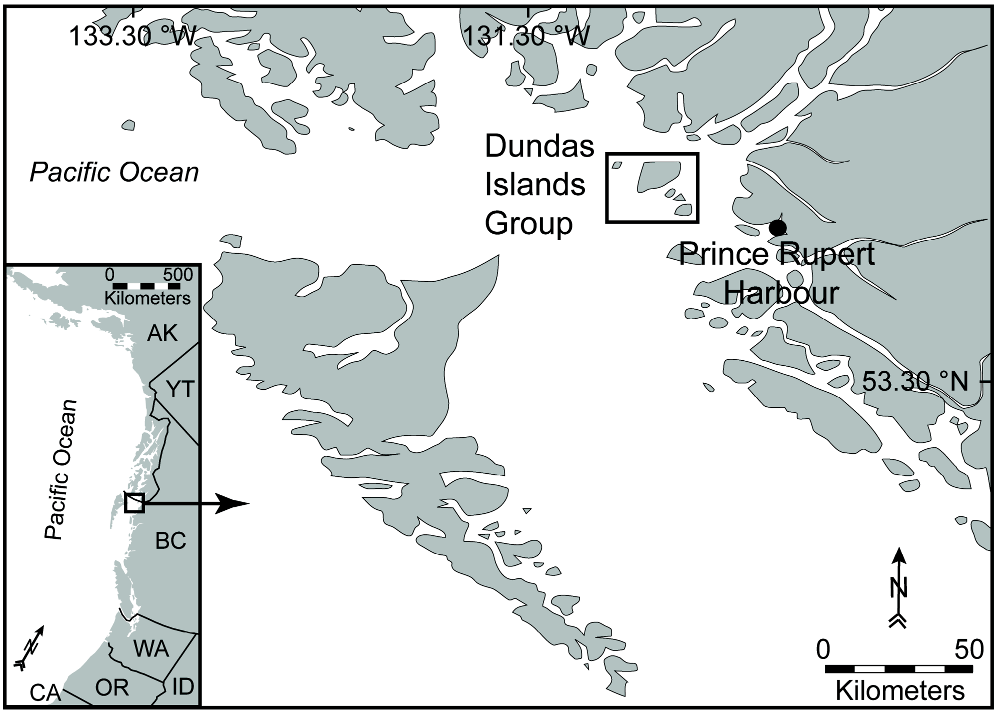

Figure 4.1 – Regional map of the north coast of British Columbia showing the locations of the Dundas Islands Group and Prince Rupert Harbour.

multi-site investigations (Brewster and Martindale 2011; Coupland 2010; Martindale et al. 2009; McLaren et al. 2011). These research programs have provided critical insight on variability in regional fishing economies, but variation in shellfish harvesting has been less well documented. General descriptions suggest northern Northwest Coast subsistence was particularly focused on fisheries (Ames and Maschner 1999; Matson 1992). As Moss has pointed out there is a lack of attention to shellfish consumption and harvesting patterns in general descriptions of Northwest Coast subsistence (Moss 1993; Moss and Erlandson 2010).

1.1 Study area and subsistence practices

Located in the traditional territory of the Coast Tsimshian, the Dundas Islands Group and Prince Rupert Harbour provide a unique landscape to assess variability in resource procurement and seasonality. The Dundas Islands are located 14 km west of Prince Rupert Harbour and are composed of five main islands and multiple smaller islets (Martindale et al. 2009). In some parts of the island archipelago it is possible during low tide to walk through the intertidal zones to shell midden sites located on the different islets. Occupation at the Dundas Islands dates back as far as 10,000 years (Martindale 2010; McLaren et al. 2011). It has been described as a marginal resource area (Ames 1998) because it is relatively isolated from the mainland coast where the major rivers that supported regional fishing economies are located. Shell middens from the Dundas Islands used in this study exhibit variability in shape, size and depth with a temporal span from 6900 to 1800 years cal. BP (Hallmann et al. 2012). In contrast to sites in Prince Rupert Harbor, sites in the Dundas Islands Group are characterized by a low density of fish, particularly salmon (Brewster and Martindale 2011).

The Prince Rupert Harbour sites examined in this study include the shell midden sites of McNichol Creek (GcTo-6), Tremayne Bay (GbTo-46), GbTo-77 and Ridley Island (GbTn-19), which date from approximately 3380 to 1890 years cal. BP (Patton 2010). The full range of shell midden site types on the northern coast remains untested, however, with the exception of Ridley Island all the

Prince Rupert Harbour sites examined in this study have been identified as villages (Archer 2001).

Based on the ethnographic record, fishing was identified as the most important resource procurement activity for the Tsimshian, and the seasonal availability of fish influenced the movement of settlements and the organization of labor (Halpin and Seguin 1990; Stewart 1975). In the late spring, herring would move to near shore waters to spawn, where they would be intensively fished and then dried or rendered for oil (Garfield 1951). The ethnographic records of the Tlingit in Alaska also describe people fishing for herring in the summer and fall (Moss et al. 2011). Eulachon, an oil-rich smelt, was identified as an important resource since it was the first fish available in the springtime when stores of dried foods were running low (Garfield 1951; Miller 1997). Other economically important fish resources used by the Tsimshian include halibut and cod, which were available between November and January and were important during times of low food productivity (Garfield 1951; Stewart 1975).

There is limited ethnographic and archaeological information regarding the role and significance of shellfish not only within the territory of the Tsimshian, but also along the entire Pacific coast (Cannon et al. 2008). Historically, the Tsimshian gathered shellfish during the lowest tides in the winter months (Arima and Dewhirst 1990:34; Moss 1993). However, the lack of ethnographic information on shellfish harvesting may be attributed to the uneven distribution of attention that was paid to male-dominated and more dramatic subsistence activities such as fishing and sea mammal hunting (Moss 1993). This has likely influenced how shellfish remains have been treated in archaeological interpretation, specifically regarding pan-coastal ideas that shellfish are a low-priority resource. As further noted by Martindale (2006:175), the major ethnographic accounts of Tsimshian pre-contact settlement and subsistence practices (Boas 1916; Garfield 1939, 1951) appear to conflate multiple time frames, further emphasizing the questionability of the ethnographic record.

1.2 Seasonality and shellfish on the north coast

The proposed seasonal round of the Coast Tsimshian has been discussed in ethnographic accounts, but not in great detail (Coupland et al. 2010) [see Boas 1916:399; Drucker 1965; Garfield 1939; Halpin and Seguin 1990; Miller 1997:21-24]. A generalized 'seasonal round' indicates that people moved between resource procurement locations through the spring and summer, and, by late autumn, groups of people returned to winter villages with dried salmon and other preserved foods (Coupland et. al 2010). Although the antiquity of this annual round is unknown, it likely pre-dates the arrival of the first Europeans (Martindale 1999:190). The lack of detailed ethnographic information on Coast Tsimshian 'seasonal rounds' may indicate there was more variability in seasonal-settlement patterns than could be adequately observed and described. Furthermore, there is little reason to assume this pattern of seasonal mobility can be applied uniformly to the archaeological past. Using ethnography to understand long-term archaeological histories is not always reliable since it does not take into account change over time in environmental and/or cultural conditions (Conneller, 2005; Ford, 1989; Jochim, 1991), and, as discussed in detail by Moss (1993), there are inherent problems with the nature of ethnographic data on this point. Ethnography can still contribute valuable information to understanding the past (see Grier 2007; Martindale 2006; Moss 2011), however, these data should be used with caution when integrated into archaeological narratives of long-term history.

In the Prince Rupert Harbour area, low-resolution analysis of clamshells based on the formation of ‘winter growth lines’ has been conducted to determine the season of site occupation at McNichol Creek and Ridley Island (Coupland et al. 1993; May 1979). The initial seasonality investigations indicated that shellfish gathering at Ridley Island was a year-round activity, with an emphasis on winter and spring collection (May 1979:82). For the initial 1979 study, a total of 97 butter clams (*Saxidomus gigantea*) and horse clams (*Tresus capax*) from bulk samples were selected for seasonality analysis and shell growth patterns were ‘read’ by two independent observers. Of the shells analyzed, there was an agreement by both observers on the season of death in only 24 specimens (24%). Coupland et al.’s (1993) seasonality analysis of shellfish from McNichol Creek incorporated butter clams, littleneck clams and cockles, beginning with a total sample of 1128 specimens, which was reduced to 127 (11% of the original sample) by removing older shells, and shells that were damaged during preparation. Using Monk’s (1987) method of analysis, season of death was determined by the position of the last winter growth cessation line or ‘biocheck’ in relation to the previous four years of growth. The study concluded that shellfishing occurred throughout the year but with an emphasis during the spring and early summer (Coupland et al. 1993:79). This analysis relied on a control sample of live-collected shellfish from the Fraser Delta region from the southern coast that was the basis of Ham’s (1982) seasonality study. In contrast to these seasonal patterns, Fitzhugh’s (1995) study using stable isotopes found an emphasis on autumn and winter shellfish collection for the Uyak site on Kodiak Island, Alaska. Although this is a different cultural and environmental region, it provides an interesting foundation from which to re-examine seasonality methods using bivalves.

Recent advances in identifying the season of shellfish collection have shed light on a variety of factors that make using ‘winter growth lines’ an unreliable method (Andrus 2011; Burchell et al. 2013; Hallmann et al. 2009). For example, a control sample of bivalves from the Fraser Delta in southern British Columbia cannot be applied to the northern coast since there is a significant difference in shell growth between the two regions. Based on the sclerochronology of live-collected shells from Pender Island on the south coast (closer to the Fraser Delta) and Alaska (closer to Prince Rupert Harbor), there is approximately a four to six month difference between the growing seasons. Shells from southern British Columbia can grow nearly throughout the year, whereas shells from more northern latitudes can stop growing for six to seven months (Hallmann et al.

2009). Additionally, different bivalve species produce different forms and shapes of growth lines during different periods of the year. For example, the growth patterns of butter clams and horse clams are strikingly different (Fig. 4.2).

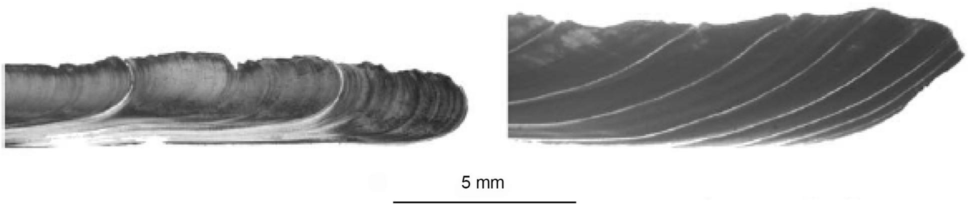

Figure 4.2 – Thin sections of *S. gigantea* (left) and *T. capax* (right) under transmitted light (adapted from Cannon and Burchell 2009). The white lines in both specimens represent growth interruptions representing either a slowed growth during the winter or an increase in freshwater.

The present study uses whole butter clam shells and shell fragments with a preserved ventral margin from 15 sites on the Dundas Islands (Fig. 4.3) and four sites in Prince Rupert Harbour (Fig. 4.4). Butter clams are an ideal species to examine seasonality and subsistence since they are found in abundance in archaeological sites on the coasts of Washington, British Columbia and Alaska (Cannon et al. 2008; Fitzhugh 1995; Moss 1993, 2012; Moss and Erlandson 2010; Wessen 1988). A preliminary study of relative species abundances from four sites in the Dundas Islands (GcTq1, GcTq-5, GcTq-7, GcTr-8) showed butter clams and horse clams represent between 60-80% of the shellfish assemblage based on both counts and weights of non-repetitive elements (Cameron et al. 2008). Archaeological shells from McNichol Creek (GcTo-6), GbTo-77, Tremayne Bay (GcTo-46), and Ridley Island (GbTn-19) in Prince Rupert Harbour were obtained from column samples archived at the University of Toronto and the Canadian Museum of Civilization[2].

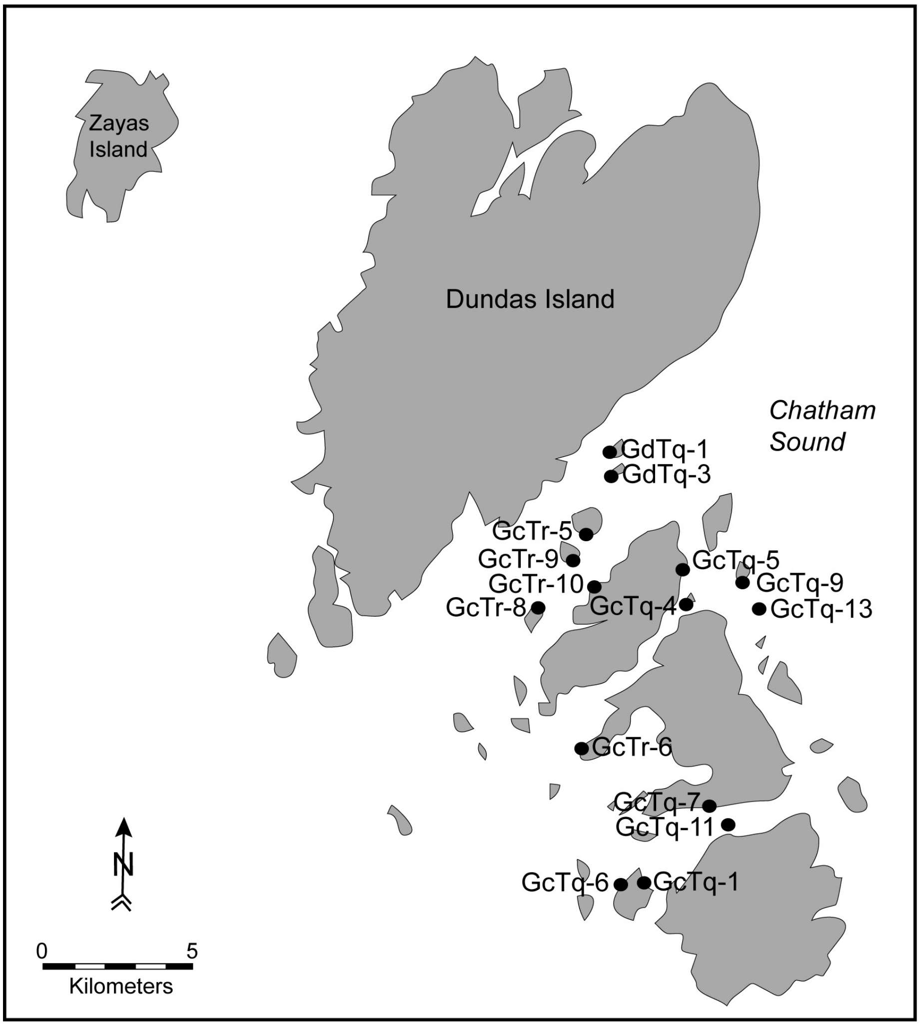

Figure 4.3 – Map of the Dundas Islands showing the location of sites analyzed in the study.

[2] Additional shell growth increment data from four sites from the Dundas Islands (GcTq-1, GcTq-5, GcTq-7, GcTr-8) were incorporated from Brunton and Burchell (2008).

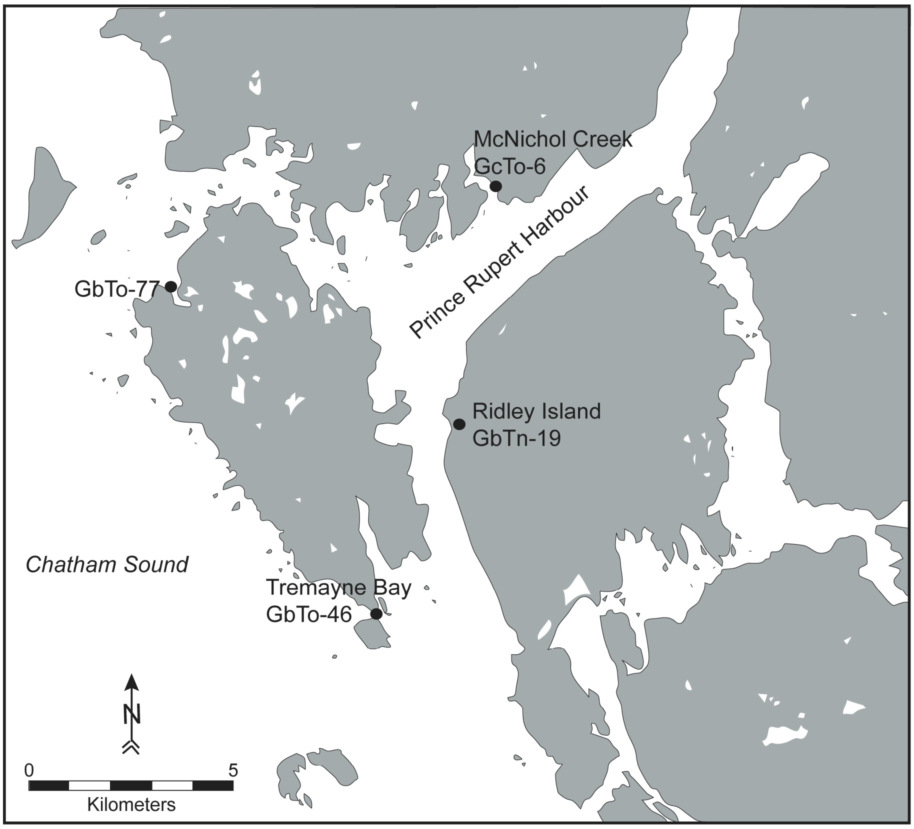

Figure 4.4 – Map of Prince Rupert Harbor showing the location of sites analyzed in the study.

2. GROWTH INCREMENT ANALYSIS

Following the methods developed by Cannon and Burchell (2009) for interpreting the relative intensity of shellfish harvest, 3003 butter clam shell fragments > 1cm with an intact ventral margin were analyzed from the Dundas Islands. To prepare shells for growth increment analysis, specimens were cut along the axis of maximum growth perpendicular to the growth lines using a low-speed precision saw (Buehler IsoMet 1000) with a 0.4 mm thick diamond-coated saw blade. Shell portions were ground with distilled water on 320 and 240 μm

SiC grit paper then polished with 1 μm Al_2O_3 colloidal solution on a billiard cloth using a high-speed polisher (Buehler Ecomet 3). After each grinding and polishing step the shells were cleaned via ultrasonic bath to remove any adhering powder and allowed to dry. Polished shell fragments were examined with a Nikon SMZ800 digital zoom microscope under 40 X magnification to examine the pattern of growth lines and determine if the shell was in a mature or senile stage of growth. A record was kept of the growth patterns, and matched between shell fragments to avoid analyzing the same specimen twice.

Age categories of mature and senile growth can easily be distinguished by examining the distribution of growth bands at the ventral margin of the shell. Older shells have a distinct growth pattern where darker lines are tightly clustered at the ventral margin due to slowing rates of shell carbonate deposition. In contrast, shells in a mature stage of growth have even and broadly spaced growth lines because of the higher growth rates (Claassen 1998). Any shell that could not be readily identified as either 'mature' or 'senile' was classified as 'unknown' (Fig. 4.5). Sites with a higher proportion of shells in a mature stage of growth imply a more intensive harvesting rate than those with higher proportions of senile shells, since shellfish are being harvested before they reach the stage of senile growth. To compare the results of the Dundas Islands to those from the mainland coast, a total of 690 butter clam fragments were analyzed from the four sites in Prince Rupert Harbour (Table 4.1).

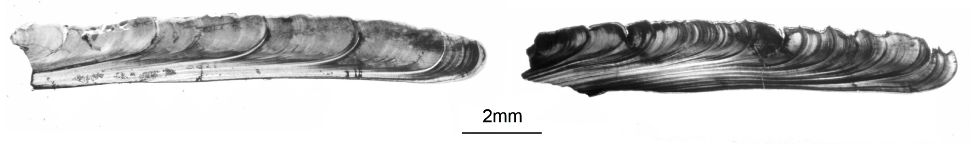

Figure 4.5 – Examples of mature (left) and senile (right) growth in *S. gigantea.*

Growth patterns in butter clams from the northern coast of British Columbia can be compared to shells from the central coast since they have similar growth rates; shells from both regions can stop growing for up to six months (Burchell et al. 2012; Hallmann et al. 2009). Shells from the southern coast grow faster, reaching senile growth between five to six years, whereas shells from the central and northern coasts reach senility between eight to ten years (Gillespie and Bourne 2005a,b; Gillespie et al. 2004). Intertidal zones where shellfish are not harvested on a regular basis are generally dominated by shells in a senile stage of growth. All live-specimens collected from the Dundas Islands that were used as a proxy to interpret the stable oxygen isotope values were older than eight ontogenetic years, and had clearly developed a senile growth pattern. Table 5 in Cannon and Burchell (2009) shows the distribution of a sample of live-collected shells in areas monitored by Fisheries and Oceans Canada on the central coast of British Columbia.

Table 4.1 -Total number of shells used and their associated age categories from the Dundas Islands and Prince Rupert Harbour

Dundas Islands	**Senile**	**Mature**	**Uncertain**	**Site total**
GdTq-1	10	22	6	38
GcTr-5	58	88	48	194
GcTq-5	211	324	55	590
GcTq-7	44	229	41	314
GcTr-10	45	67	15	127
GcTq-13	10	20	2	32
GcTr-8	223	319	38	580
GcTr-9	20	49	9	78
GcTq-1	51	70	19	140
GcTq-6	143	144	28	315
GcTq-9	50	107	14	171
GcTq-4	52	102	26	180
GcTr-6	7	5	6	18
GdTq-3	65	70	18	153
GcTq-11	20	45	8	73
Regional Total	**1009**	**1661**	**333**	**3003**

Prince Rupert Harbour	**Senile**	**Mature**	**Uncertain**	**Site total**
McNichol Creek, GcTo-6	70	88	8	166
Tremayne Bay, GbTo-46	57	91	5	153
Dodge Cove, GbTo-77	114	45	4	163
Ridley Island, GbTn-19	116	69	23	208
Regional Total	**357**	**293**	**40**	**690**

The Dundas Islands growth increment analysis reveals that butter clams were collected intensively since there are a greater proportion of shells in a mature stage of growth at 14 of the 15 sites (Fig. 4.6). When the results from all the sites are combined, 55% of the shells were in a mature stage of growth, and 34% were in a senile stage of growth. A total of 11% of the shells were classified as ‘unknown’, however, it is important to note that this classification was more often than not the result of annual growth lines not being clearly visible under reflected light and magnification.

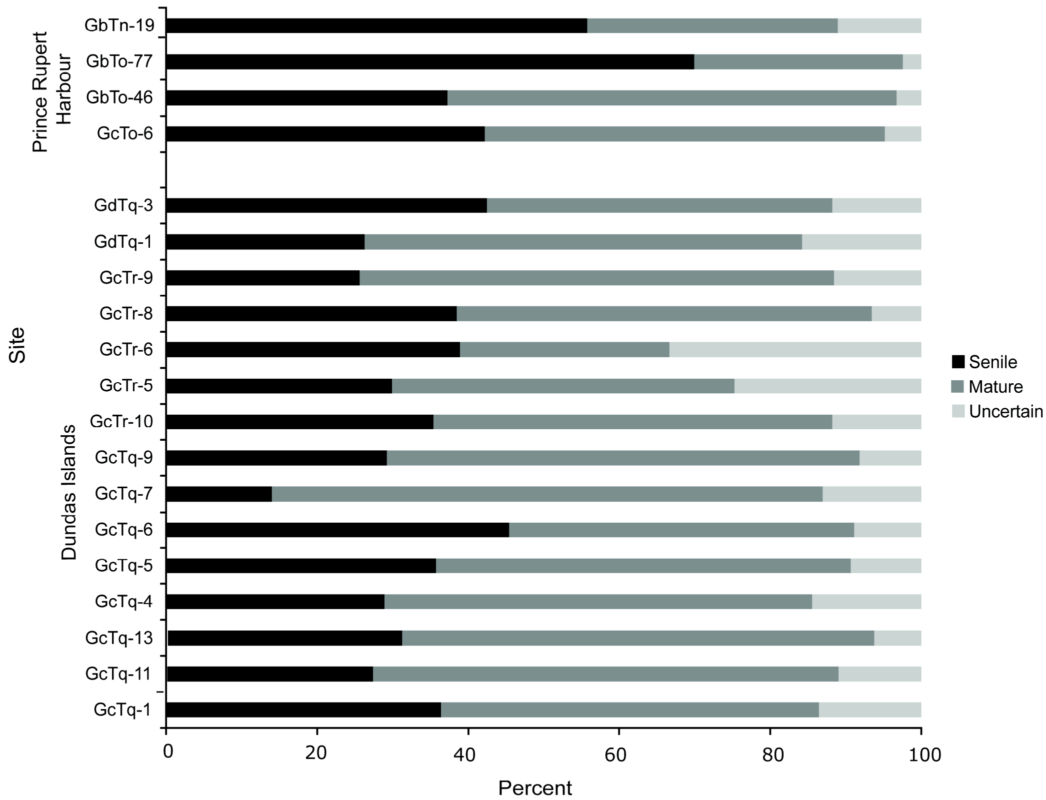

Figure 4.6 – Percent of butter clam shell age categories determined by growth increment analysis from four sites in Prince Rupert Harbour and 15 sites in the Dundas Islands.

The pattern of harvesting observed at the Dundas Islands differs from the overall pattern of butter clam collection at Prince Rupert Harbour, which shows less intensive collection (Fig. 4.6). Overall, 51% of the butter clams in Prince Rupert Harbor were in the senile stage of growth, and 42% were in a mature stage of growth. Only 7% of the shell samples from Prince Rupert were classified as 'unknown'. Although the overall pattern of harvest is less intensive on the mainland coast, there was variability observed between sites. Butter clams from McNichol Creek and Tremayne Bay have higher proportions of shells in mature stages of growth (53% and 59% mature, respectively), and GbTo-77 and Ridley Island have higher proportions of shells in a senile stage of growth (70% and 65% senile, respectively).

3. STABLE OXYGEN ISOTOPE ANALYSIS

Butter clam shells from five sites from the Dundas Islands (GcTq-5, GcTq-6, GcTr-6, GdTq-1 and GdTq-3) were previously selected for radiocarbon dating and stable isotope analysis to examine trends in paleoclimate and to develop a preliminary assessment of the season of butter clam collection (Hallmann et al. 2012). Shells from two additional Dundas Islands sites (GcTq-9 and GcTq-13) were added to expand the analysis of seasonal butter clam harvest. Both additional sites exhibited higher densities of herring and eulachon suggesting a possible spring occupation (Brewster and Martindale 2011). Since both species of fish could be stored, it is difficult to assess seasonal occupation based on their presence alone. Incorporating the seasonality of butter clam collection makes it possible to refine this interpretation. A total of 1333 discrete isotope samples from 42 individual shell samples from the Dundas Islands were analyzed to determine the season of shellfish collection. Ten butter clam shells with 100 discrete isotope samples from McNichol Creek (n = 5) and Ridley Island (n = 5) were also analyzed for seasonality. While the number of shell samples from Prince Rupert Harbour is small, it provides a basis from which to re-examine the previous seasonality interpretations that relied on lower-resolution methods. The results are sufficient to suggest a new understanding of patterns of shellfish harvesting and site occupation.

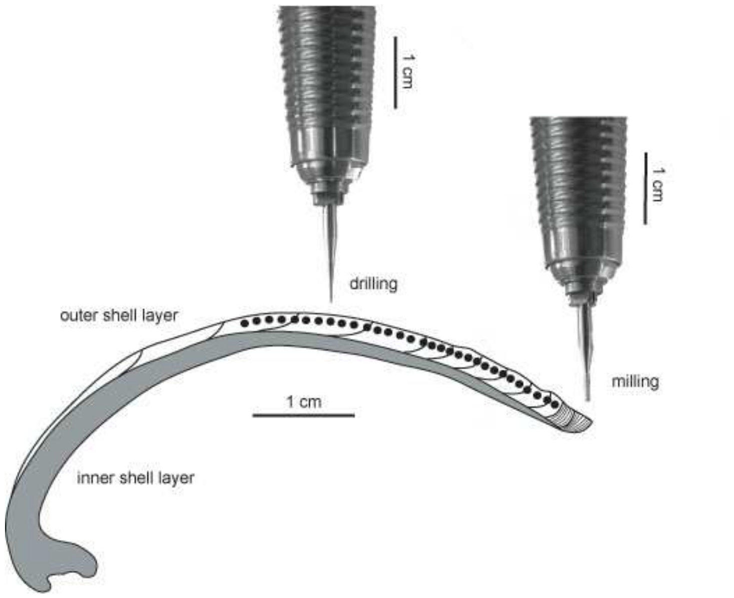

Figure 4.7 – Sampling strategy for micromilling at the ventral margin and microdrilling shell carbonate to identify the season of shellfish collection.

To determine $\delta^{18}O_{shell}$, carbonate powder was obtained by hand micromilling at the ventral margin followed by microdrilling in the faster growing portions from the outer shell layer of polished cross sections. Micromilling was applied to attain a higher resolution for determining seasonality by moving in ~100 μm consecutive steps beginning at the ventral margin, contouring the growth lines using a 1 mm diamond coated cylindrical drill bit (Komet/Gebr. Brasseler GmbH & Co. KG model no. 835 104 010) (Fig. 4.7). Micromilling allows for an uninterrupted record to be obtained, and minimizes the effects of time-averaging, which is the mixing of different time periods of shell growth (Goodwin et al. 2004). After the ventral margin was milled, the faster growing portions of the shell were micro-drilled using a 300 μm conical drill bit (Komet/Gebr. Brasseler GmbH & Co. KG model no. H52 104 003). The distance between the center-to-center of the drill samples varied between 400 and 600 μm. Since shell samples varied in both the size of the fragment as well as ontogenetic age, each polished shell was examined under 40X magnification to observe the microgrowth structures, and a specific sampling strategy combining micromilling and microdrilling was selected to attain the highest seasonality resolution possible by selecting the appropriate spacing of sample points to capture the last few months of shell growth.

Isotope samples were analyzed by reaction with phosphoric acid in a Gas Bench II coupled to a Thermo Finnigan MAT 253 continuous flow – isotope ratio mass spectrometer. Isotope data were calibrated against NBS-19 ($\delta^{18}O$ = -1.95‰). The $\delta^{18}O_{shell}$ values are expressed relative to the international VPDB (Vienna Pee Dee Belemnite) standard and are given as per mil (‰).

Stable oxygen isotope studies of butter clam demonstrated that this species secretes its shell in close isotopic equilibrium with ambient seawater (Burchell et al. 2012, Gillikin et al. 2005; Hallmann et al. 2009, 2011, 2012). When the sequence of isotope data is sufficiently long to cover one or more years of shell growth, a sinusoidal curve is produced when the data are plotted, reflecting seasonal changes in both the water temperature and salinity (Fig. 4.8). Stable oxygen isotope ratios from the ventral margin of the shell with more negative oxygen isotope ratios are interpreted as 'summer', and the more positive are interpreted as 'winter'. The flanks of the sinusoidal curve where it is either decreasing or increasing as a function of distance from the ventral margin represent autumn and spring respectively when the data are plotted inversely (Burchell et al. 2012).

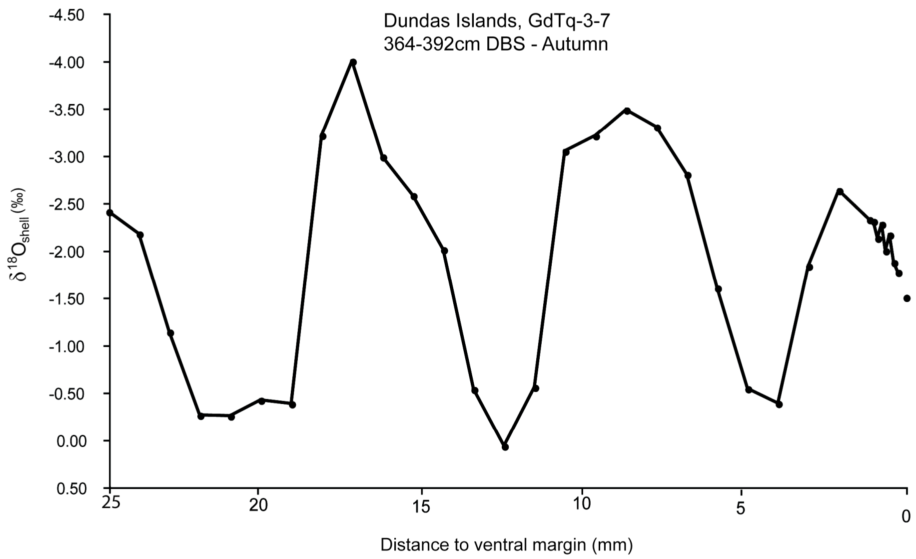

Figure 4.8 – Stable oxygen isotope profile of an autumn collected shell from site GdTq-3, Dundas Islands. The $\delta^{18}O$ values are plotted inversely, with the most positive values associated with winter at the bottom of the Y-axis and the more negative values associated with warmer temperatures at the top of the Y-axis. The greater numbers of data near the ventral margin results from higher sampling resolution (milling vs. drilling).

It should be noted that seasonal freshwater discharges have more negative $\delta^{18}O_{water}$ value, and increase the overall $\delta^{18}O_{shell}$ amplitude, therefore, the overall amplitude of the isotope data is also considered in association with microgrowth line formation and the direction of the slope of the curve (see Fig. 6 in Burchell et al. 2013). The $\delta^{18}O_{shell}$ ventral margin values from the Dundas Islands ranged from to 0.29‰ to -4.36‰, and from -1.11‰ to -4.46‰ in Prince Rupert Harbour. The amplitude of $\delta^{18}O_{shell}$ ventral margin values in Prince Rupert is 5.57‰ and 4.65‰ for the Dundas Islands. Prince Rupert Harbour is located between the mouths of two major rivers, the Skeena and the Nass, therefore it is likely that shells from this area are more prone to freshwater influxes, specifically the increase in freshwater from snow melting during the spring and early summer. This is observed in several specimens where shells identified as 'spring collected' have the most negative $\delta^{18}O_{shell}$ at the ventral margin, for example samples GcTq-9-5 (-4.23‰), GcTo-6-1 (-3.02‰), and GbTn-19-5 (-3.30‰). Since a 1‰ shift in $\delta^{18}O$ equates to approximately a 4.42°C change in ambient seawater using the Böhm et al. (2000) paleothermometry equation, an amplitude of 3.35‰ equates to a temperature range of almost 24°C, exceeding the observed sea surface temperatures for the region of 2.5 °C to 17°C by approximately 10°C (Hallmann et al. 2012). However, when the microgrowth lines are examined in relation to the most negative isotope values, they correspond to shell collection in the early spring as determined by the number of daily growth increments counted from the last growth cessation from the winter.

At the Dundas Islands the overall seasonality results show that butter clam collection occurred throughout the year at almost all of the sites investigated, but with a stronger emphasis on harvesting during the winter (Table 4.2; Fig. 4.9). Four of the seven sites investigated were dominated by winter harvesting. The site GcTq-6 was the only site investigated that had a stronger emphasis on spring collection. Autumn and summer are represented at all the sites, but to a slightly lesser extent. The sites (GcTq-9, GcTq-13) had the highest density of herring and eulachon, which suggests a pattern consistent with what could be described as winter village occupation or multi-seasonal residential occupation. These sites show shellfish collection occurred predominantly in the winter, but also in the spring and autumn.

On the mainland coast in Prince Rupert Harbor, butter clam collection was identified during the autumn and spring months at Ridley Island and McNichol Creek (Table 4.3). Although the sample sizes for the sites are small (n = 5 per site) in comparison to the original seasonality studies (i.e., Coupland et al. 1993; May 1979), the increase in precision has presented a new interpretation for the seasons of butter clam harvesting. At McNichol Creek, three shells were collected in the autumn and two were collected in the spring. This differs from Coupland et al.'s (1993) results, which showed an emphasis on spring and early summer. Similarly, the Ridley Island results showed four shells collected in the spring and one collected in the autumn, contrasting with May's (1979) conclusion that winter and spring were the preferred seasons of collection. Since the sample size for Prince Rupert Harbour is small, results of the current study are not sufficient to demonstrate conclusively any particular seasonal emphasis, but they clearly contrast with the Dundas Islands pattern, and suggest a possible emphasis on spring and autumn collection in Prince Rupert Harbour. The implication would be that shellfish was collected in the spring when stored winter food became depleted and in the fall when people were preparing shellfish meat to be dried and stored for the winter.

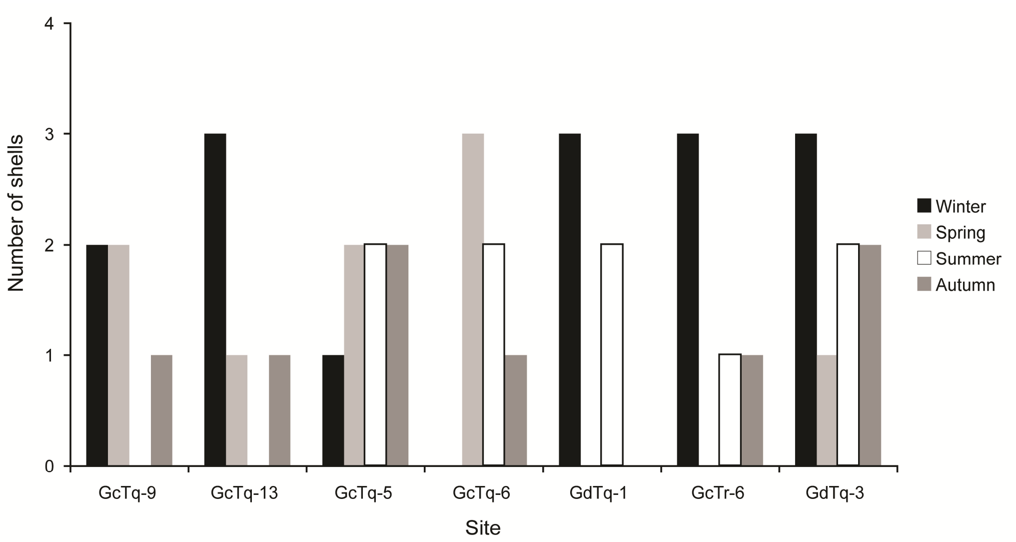

Figure 4.9 – Results of seasonality analysis from seven sites in the Dundas Islands based on shell oxygen isotopes and micro-increment analysis.

Table 4.2 – Seasonality and radiocarbon dates from butter clams from the Dundas Islands. Martindale et al. (2009) present comprehensive details on all radiometric dates from the Dundas Islands.

Site	Sample ID	Auger Depth (cm) DBS	$\delta^{18}O$ (‰) at ventral margin	Season	Years Cal. BP 2-sigma
GcTq-9	GcTq-9-1	80-100	0.08	Winter	
	GcTq-9-2	80-100	-2.73	Spring	
	GcTq-9-3	120-140	-1.40	Autumn	
	GcTq-9-4	120-150	-0.17	Winter	
	GcTq-9-5	140-169	-4.23	Spring	
GcTq-13	GcTq-13-1	80-100	-0.07	Winter	
	GcTq-13-2	80-100	-2.07	Autumn	
	GcTq-13-3	100-120	-0.24	Winter	
	GcTq-13-4	120-140	-0.81	Winter	
	GcTq-13-5	120-140	-3.55	Spring	
GcTq-5	GcTq-5-1	60-80	0.21	Winter	1852-2346
	GcTq-5-2	60-80	-1.10	Spring	
	GcTq-5-3	220-240	-1.45	Spring	2315-2797
	GcTq-5-4	240-260	-3.30	Summer	2340-2855
	GcTq-5-5	260-280	-4.36	Summer	2369-2929
	GcTq-5-6	440-460	-1.41	Autumn	2745-3529
	GcTq-5-7	440-460	-2.35	Autumn	
GcTq-6	GcTq-6-1	60-80	-0.62	Autumn	1337-1824
	GcTq-6-2	60-80	-0.99	Spring	
	GcTq-6-3	100-120	-2.94	Summer	1391-1182
	GcTq-6-4	200-220	-1.14	Spring	1438-1952
	GcTq-6-5	240-260	-1.58	Spring	
	GcTq-6-6	240-260	-2.18	Summer	1379-1868
GdTq-1	GdTq-1-1	84-112	-2.81	Summer	
	GdTq-1-2	143-168	-0.04	Winter	
	GdTq-1-3	143-160	-0.03	Winter	1513-2025
	GdTq-1-4	168-196	-3.72	Summer	1921-2479
	GdTq-1-5	224-245	0.29	Winter	1596-2125
GcTr-6	GcTr-6-1	110-115	0.14	Winter	6489-7361
	GcTr-6-2	112-140	0.18	Winter	
	GcTr-6-3	140-168	0.06	Winter	
	GcTr-6-4	170-175	-1.39	Autumn	6968-7438
	GcTr-6-5	196-224	-0.83	Spring	
GdTq-3	GdTq-3-1	140-168	-2.33	Spring	5382-5862
	GdTq-3-2	140-168	-0.71	Winter	
GdTq-3	GdTq-3-3	252-280	-0.55	Winter	5657-6167
	GdTq-3-4	252-280	-0.29	Winter	
	GdTq-3-5	282-308	-2.61	Summer	6315-6813
	GdTq-3-6	336-364	0.00	Autumn	6428-6949
	GdTq-3-7	364-392	-1.50	Autumn	
	GdTq-3-8	364-392	-2.12	Summer	6497-7047

Table 4.3 – Seasonality of butter clam shells from McNichol Creek (GcTo-6) and Ridley Island (GbTn-19), Prince Rupert Harbour.

Sample ID	Unit	Location/Depth (cm DBS)	$\delta^{18}O$ (‰) at ventral margin	Season
McNichol Creek				
GcTo-6-1	21N, 10W	Layer C, Level 2	-3.02	Autumn
GcTo-6-2	21N, 10W	Layer C, Level 9	-2.44	Autumn
GcTo-6-3	21N, 10W	Layer C, Level 16	-3.72	Spring
GcTo-6-4	21N, 10W	Layer C, Level 19	-1.89	Autumn
GcTo-6-5	21N, 10W	Layer C, Level 14	-1.54	Spring
Ridley Island				
GbTn-19-1	1-2S, 10-11E	140-150	-2.37	Spring
GbTn-19-2	1-2S, 10-11E	160-170	-1.11	Autumn
GbTn-19-3	5-7S, 0-1W	80-90	-4.46	Spring
GbTn-19-4	5-7S, 0-1W	110-120	-2.36	Spring
GbTn-19-5	6-7S, 11-12W	180-190	-3.30	Spring

4. REGIONAL VARIABILITY IN SHELLFISH HARVESTING

The intensity of shellfish harvesting at the Dundas Islands can be interpreted by examining historical and environmental contexts of the region. There is a Northwest Coast precedent for the transportation of large volumes of dried fish up to 100 km from where they were captured (Ames 1994), and Oberg (1973:66) notes that shellfish meat was processed on the islands and traded to locations in the mainland. Therefore it is plausible that shellfish was harvested at the Dundas Islands and transported back to Prince Rupert Harbour. The intertidal zones at the Dundas Islands provide ample zones of shellfish productivity, however, the potential transportation of shellfish meat is almost impossible to evaluate. It is likely the inhabitants of the Dundas Islands were more reliant on shellfish as a staple food source, and that people living on the mainland coast did not need to harvest shellfish as intensively since there were other locally abundant resources from which to choose. Shellfish in both areas may have provided crucial nutrition in the spring and winter months prior to the spawning of eulachon and herring.

Shellfish are a poor source of calories when compared to plant and terrestrial and/or other marine animal foods (Erlandson 1988), and it has been argued that the investment required to obtain shellfish is not worth the economic return (Osborn 1977). However, shellfish can be gathered in abundance fairly quickly, and provide enough daily protein to sustain an individual (Erlandson 1988:105). The evidence suggests shellfish were collected in the Dundas Islands at an intensive rate throughout the year, indicating they were important and necessary components of the diet.

In contrast to the pattern of year-round shellfish harvesting in the Dundas Islands, the albeit limited seasonality data from Prince Rupert Harbor suggests an emphasis on clam collection during the autumn and spring months, a pattern which is consistent with the seasonal pattern observed at long-term residential sites on the central coast (Burchell et al. 2013). If the sample size was increased, we expect that the results would show that butter clams were collected to supplement the diet throughout the year, but the emphasis was on harvest in autumn and spring.

Long-term residential sites on the central coast, such as Namu (ElSx-1) and Kisameet (ElSx-3), show a clear emphasis on spring and autumn harvesting (Burchell et al. 2013) and a less intensive rate of collection when compared with specialized resource camps in the vicinity (Cannon and Burchell 2009). Locations identified as places for the specific purpose of shellfish gathering show an emphasis on summer, autumn and winter, whereas smaller sites show year-round collection. The intensity of butter clam harvesting on the central coast is comparable to Prince Rupert Harbour, but it is different than the more intensive harvesting observed in the Dundas Islands. The growth increment analysis of 772 shells from nine sites on the central coast by Cannon and Burchell (2009) revealed that overall 51% (390/772) of shells were collected in a mature stage of growth and 45% (351/772) in a senile stage of growth, with the remaining shells classified as unknown (4%) Specific patterns of shellfish harvesting are observed between longer-term residential sites and short-term occupation sites, especially those with a specific emphasis on gathering shellfish. For example, only 38% (70/185) of the shells from the village site of Namu were in the mature stage of growth and 62% (115/185) were senile. In contrast, the shell midden site at Kiltik Cove, ElTa-25, which was identified as a small camp occasionally used specifically for harvesting shellfish showed 67% (174/261) mature-growth shells and 30% (79/261) senile-growth shells, with eight shells classified as ‘unknown’. In general, on the central coast, the intensity of shellfish collection is lower at long-term residential sites than at smaller sites representing more ephemeral occupations (Cannon and Burchell 2009).

The Prince Rupert Harbour results show there is variation in the intensity of harvest, even at village sites. The lower harvest intensity at GbTo-77 and the Ridley Island site is similar to the pattern observed at long-term residential sites and villages on the central coast (Cannon and Burchell 2009). In contrast, the more intensive harvest at the larger village sites of McNichol Creek and Tremayne Bay is similar to the patterns observed at smaller campsites or specialized resource procurement camps. It is possible that shellfish were integrated differently into the subsistence economies of the Prince Rupert Harbour sites based on currently unknown historical or environmental contingencies. Much more information on shellfish harvest at a wider range of sites, more detailed understanding of site occupations, and estimates of the sizes of resident populations are needed to thoroughly assess and evaluate the nature and role of shellfish collection in Prince Rupert Harbour.

5. CONCLUSIONS

The results of the growth increment and stable oxygen isotope analyses have shown variability in the season of butter clam collection not only between regions, but also between sites within a region. This variability is likely attributable to the environmental and historical circumstances that structure the need (or desire) to harvest butter clams. On the Dundas Islands, the seasonality pattern and the rates of harvest intensity suggest that shellfish were a crucial resource. Shellfish were intensively collected year round over a 5000-year period. In Prince Rupert Harbour, shellfish were harvested at variable rates between sites, but overall were less intensively harvested than in the Dundas Islands. This is likely attributable to access to a greater abundance of salmon (Coupland et al. 2010).

By comparing the results of the north coast to the central coast, differences in regional shellfish harvesting practices have begun to emerge. Although the sample size of shells analyzed for seasonality from Prince Rupert Harbor is small, it has provided a more precise estimate of shellfish harvesting patterns, and one that stands in contrast to earlier, lower-resolution studies. The combination of studies from the north and central coasts demonstrates that seasonal shellfishing strategies are contingent on multiple factors, including environment and variable patterns of site use over time. At this point, it is not possible to find a simple correlation between the seasons of collection and harvest intensity since the factors that influence subsistence and settlement are likely numerous and potentially changed over time.

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CHAPTER 5

CONCLUSION

5.1 SUMMARY AND SIGNIFICANCE OF RESULTS

The results of this dissertation have provided new insights into regional variation in patterns of seasonality, settlement and shellfish harvesting on the coast of British Columbia. They have also shown the interpretive limits and the potential of high-resolution stable oxygen isotope analysis ($\delta^{18}O$) and sclerochronology to resolve the season of shellfish collection in freshwater-influenced marine settings. Most significantly, the data presented break down conventional interpretations of seasonality on the Pacific Northwest Coast both theoretically and methodologically.

Methodologically, this research demonstrates the problems associated with traditional methods of seasonality analysis as applied in archaeology, specifically the use of growth increments to identify the season of capture (Clarke and Clarke, 1980; Coupland et al., 1993; Crockford and Wiggen, 1991; Ham and Irvine, 1975; Keen, 1979; Maxwell, 2003; May, 1979; Stevenson, 1977). It provides evidence to support the necessity for high-resolution isotope sampling to determine seasonality, and demonstrates the need to align geochemical data to micro-growth patterns in shells from freshwater-influenced marine settings. These findings have implications for how archaeologists have used shell growth patterns and stable oxygen isotopes in their research to resolve seasonality questions. These findings also have implications for palaeoclimate reconstructions that rely on stable isotope ratios of shell carbonate that employ a lower sampling resolution (1mm) (i.e. Bar-Yosef Mayer et al., 2012). A low sampling resolution does not show the full amplitude of isotope values, and therefore provides a more limited glimpse into past environments.

The multi-scalar analysis of different sites from different regions showed a range of variation in shellfish procurement on the coast. It confirmed that no general pattern of shellfish harvest applies coast-wide. The acquisition and use of shellfish on the coast of British Columbia is contingent on historical and environmental circumstances, some of which are not yet known. Combined, the three manuscripts that comprise this dissertation provide the methodological foundations on which to improve the precision and accuracy of seasonality estimates from bivalves. They also provide evidence that calls into question previous assumptions of seasonal mobility and resource procurement on the Northwest Coast.

5.1.1 Refining estimates for the season of shellfish collection on the Pacific Northwest Coast: Applying high-resolution stable oxygen isotope analysis and sclerochronology

This paper documents the methodology specifically designed to improve the precision of seasonality estimates from freshwater-influenced marine bivalves recovered from archaeological sites. A combination of high-resolution sclerochronology and stable oxygen isotope analysis ($\delta^{18}O$) allowed for an understanding of the life-history traits of *Saxidomus gigantea* (butter clam), specifically the duration and length of the growing season. This information derived from live-collected specimens was then applied to understand $\delta^{18}O_{shell}$ and interpret seasonality at the site of Namu (ElSx-1) on the central coast of British Columbia.

From the analysis of live-collected butter clam shells and water data from different localities in the vicinity of the Namu site, local variability in salinity and $\delta^{18}O_{water}$ was observed. Obtaining modern environmental data (live-collected shells and water) was essential to understand the behavior of $\delta^{18}O_{shell}$ isotopes in relation to the number of micro-increments (LDGI) since the water on the central coast of British Columbia is subject to seasonal increases in freshwater discharge from isotopically more negative melting snow packs. By aligning the micro-milled isotope samples to the LDGI it was possible to account for negative excursions in $\delta^{18}O_{shell,}$ where the most negative values correlate with growth cessations due to temporary decreases in salinity. More negative isotope values are typically associated with warmer water temperatures, however, these negative excursions in the oxygen isotope data do not correspond to temperature, but rather are associated with decreases in salinity since freshwater influxes and changes in temperature have dual and opposing effects on $\delta^{18}O_{shell.}$ In addition to improving the methods applied to determine seasonality using $\delta^{18}O_{shell}$ this analysis also demonstrated the variation in $\delta^{18}O_{shell}$ that occurs when a low-resolution sampling strategy is applied. Low-sampling resolution results in time-averaging (Goodwin et al., 2004) of the shell carbonate, and ultimately a ‘blending’ of seasons, and an inaccurate seasonal estimate.

5.1.2 Significance of results

With regards to paleoclimate reconstructions the data clearly show that using $\delta^{18}O$ from freshwater-influenced marine shells is not a reliable method for determining precise sea-surface palaeotemperature estimates, since the effects of temperature and salinity cannot be separated. However, the results do show that it is possible to establish seasonality when $\delta^{18}O_{shell}$ is aligned with micro-growth increments. This method provides a reliable means to interpret seasonality based on the geochemistry of shellfish in areas with seasonal freshwater discharge(s). With regards to archaeological interpretations, this paper provided two significant conclusions. The first pertains to the use of low-resolution isotope sampling to determine seasonality, which is more commonly employed in archaeology than precision micro-milling (i.e. Culleton et al., 2009; Godfrey, 1988; Jones et al., 2008; Kennet and Voorhies, 1996; Killingly 1981; Mannino et al., 2003, 2007; Rick et al., 2006). By directly comparing conventional drilling to precision micro-milling it showed that low-resolution sampling is likely to provide a less accurate season of death estimate.

This paper also provided seasonality data spanning 4000 years of occupation at the site of Namu based on the analysis of 20 archaeological shells, seven of which had associated radiocarbon dates. These results were significant for interpreting archaeological patterns of subsistence and occupation at Namu since the data showed shellfish were collected year-round, which is consistent with year-round habitation at the site (Cannon and Yang, 2006). This contradicts ethnographic observations of season-specific patterns of shellfish collection (i.e. Arima and Dewhirst, 1990; Blackman, 1990; Halpin and Seguin, 1990; Kennedy and Bourchard, 1990). The emphasis on spring and autumn harvesting as revealed through the $\delta^{18}O_{shell}$ analysis and sclerochronological alignment suggests that people harvested shellfish in the spring when winter food stocks had become depleted, and collected more intensively in the autumn to dry shellfish meat, which was stored and consumed through the winter. This pattern is further reinforced by the fact that all shells with radiocarbon dates were collected in the spring or autumn. This paper revealed new insights into seasonal subsistence strategies and settlement patterns, and using both the modern and archaeological data a foundation for the analysis was established to examine regional variability in seasonality and shellfish harvesting on the central coast of British Columbia.

5.2.1 Inter-site variability in the season of shellfish collection on the central coast of British Columbia

This paper uses the methodology and the original data from Burchell et al. (2013b) and expands the seasonality analysis at the village site of Namu by increasing the number of shells analyzed for $\delta^{18}O$ (n = 22) and expanding the number of radiocarbon dated shells (n = 8 from ElSx-1, n = 3 from ElTa-25). More importantly, the analysis was expanded to seven other shell midden sites in the immediate area to examine variability in seasons of shellfish harvesting. Previous studies of growth increments of butter clams revealed different patterns of collection intensity at different sites, specifically between long-term residential villages and short-term camps, especially those used specifically for shellfish procurement (Cannon and Burchell 2009). A total of 90 individual shell samples spanning 4,500 years were examined from residential village sites, large residential sites and small campsites to interpret region-wide patterns in the seasons of butter clam harvesting.

5.2.2 Significance of results

The results of this paper are significant because they clearly show regional variability in the seasons of butter clam collection, and by proxy, seasons of site occupation. Overall, the results show a more complex pattern of seasonal resource procurement and settlement than previously discussed in ethnography and archaeology. The results show multi-seasonal clam harvest, with an emphasis on the spring and autumn. At all sites, summer was the season least likely to be represented and this could be due to the increased risk of paralytic shellfish poisoning (Quayle and Bourne, 1972), or the fact that people did not want or need to harvest shellfish during the summer. This paper presents data from the largest number of samples, both individual shells and discrete isotope samples, published to date for a seasonality study using stable isotopes. It is also one of the only examples of a high-resolution study of seasonality from multiple sites within a specific, localized region.

5.3.1 Seasonal patterns and shellfish harvest on the north coast of British Columbia

In this paper the variability in butter clam harvesting between sites on the northern coast of British Columbia is shown through the biochemical analysis of shells from 15 shell midden sites on the Dundas Islands and four sites on the mainland coast in Prince Rupert Harbour. Using Hallmann et al.'s (2012) initial isotope data from 27 archaeological shells from the Dundas Islands, the sample was increased to 42 shells specifically to assess seasonality for the island archipelago, and for comparison to the results from 10 shells from two sites in Prince Rupert Harbour. On the Dundas Islands two sites were tested for seasonal patterns of shellfish harvest (GcTq-3 and GcTq-9) and, by proxy, seasonal occupation since the results of the faunal analysis suggested occupation during the spring from the high density of herring found at these sites when compared to other sites in the area (Brewster and Martindale, 2011). The results of the seasonality analysis of shellfish from these two sites indicate collection in the winter, spring and autumn, supporting the interpretation from the fisheries data that these sites were occupied during the spring.

The comparison of shellfish data from the Dundas Islands and Prince Rupert Harbour is an ideal basis from which to examine variability in resource procurement strategies, since the Dundas Islands are considered to be a marginal resource area (Ames, 1994), whereas sites in the Prince Rupert have access to fish from the Skeena and Nass rivers. These data are further compared to the results of growth increment analysis and seasonality data from the central coast (Burchell et al., 2013a,b; Cannon and Burchell, 2009) to observe the range of variability between and within the north and central coast regions.

5.3.2 Significance of results

A significant finding was the extent of variability in shellfish harvest intensity and seasonality not only between regions but also within regions. This is especially interesting because the Dundas Islands are a relatively short distance from Prince Rupert Harbour (14 km), yet their shell midden sites are drastically different with regards to both the low abundance of vertebrate faunal remains (Brewster and Martindale, 2011) and their indications of shellfishing patterns. The intensity of shellfish harvesting appears to be largely contingent on environmental factors. Areas with marginal resources exhibit more intensive shellfish harvest than do places where there is access to abundant fish resources. It is likely that shellfish was a crucial resource for people living on the Dundas Islands, and this interpretation is supported by the consistent pattern of intensive harvest observed at all sites over a 5000-year period. In contrast, shellfish in Prince Rupert Harbour were harvested at variable rates at different sites. While three of the sites from Prince Rupert Harbour were identified as 'villages', the pattern of shellfish harvesting is not consistent with the pattern of harvesting observed at village sites on the central coast. Shellfish harvesting appears to be more intensive on the northern coast than on the central coast since there is a higher proportion of clam shells in a mature stage of growth. On the central coast, long-term residential sites and villages have a higher proportion of clams in a senile stage of growth (Cannon and Burchell, 2009). In Prince Rupert Harbour, a contrasting pattern is observed in the intensity of shellfish gathering between village sites. For example, the village site McNichol Creek has a higher proportion of shells in a mature stage of growth, whereas the village site on Ridley Island has a higher proportion of shells in a senile stage of growth. The pattern of shellfish harvest at Ridley Island is more consistent with the pattern of shellfish harvesting observed at villages and long-term residential sites on the central coast (Burchell et al., 2013c). These results imply that shellfish resources were acquired at different rates between sites in Prince Rupert, and further imply that shellfish were integrated into local economies based on specific circumstances, which are not yet known.

Overall, these findings are significant because they provide critical insight into intra- and inter-site variability within and between regions, and provide a basis for understanding variation in shellfish harvesting intensity and seasonality on the Pacific Northwest Coast more generally. They also show that a relatively small sample of shells (specifically from Prince Rupert Harbour) is sufficient to re-examine previous seasonality interpretations and observations from the ethnographic record. The seasonality results from the Dundas Islands revealed year-round collection at all sites, but in Prince Rupert Harbour, the focus is on harvest in the spring and autumn. While the data from this paper are robust, since they combine stable isotopes and growth increments from the north and central coasts, more research is needed. An increase in the number of shells analyzed for seasonality, especially from Prince Rupert Harbour, would be useful, and more precise temporal information would make it possible to assess whether there is any correlation between seasonality and the intensity of shellfish collection.

5.3 Limits and potential of high-resolution stable isotope sclerochronology in archaeological contexts

Stable isotope data from freshwater-influenced marine mollusks have been used in a variety of contexts to reconstruct past environmental conditions from deep geological time (i.e. Colonese et al., 2011; Dettmann et al., 2004; Kirby et al., 1998; Loren and Muehlenbachs, 2001; Schöne et al., 2004). However, as demonstrated through the research on the central coast, a reconstruction of past sea surface temperature from freshwater-influenced marine bivalves can lead to an over-estimation of past temperatures. Regardless of the precision used to attain the isotope samples, the nature of oxygen isotope data (being strongly influenced by the opposing effects of both freshwater and temperature) limits the ability to accurately reconstruct sea surface palaeotemperature (Burchell et al. 2013b). The use of a growth-temperature model based on the numbers and widths of LDGI (i.e. Hallmann et al., 2011) may help resolve issues surrounding the influence of freshwater on $\delta^{18}O_{shell}$ from freshwater-influenced marine settings. However, in some shell specimens LDGI widths may not be visible or yield any form of pattern that can be used to aid in the reconstruction of past sea surface temperatures.

One of the most significant limitations to this type of analysis is the cost and expertise required for stable isotope analysis, especially when aligned with the micro-increment structure of the shell. The high-cost of analysis prohibits the analysis of a 'large' sample of shells for seasonality partly because each shell is sampled at a higher resolution (i.e. 100 μm instead of 1mm), however, the improved accuracy compensates for the small sample size, and, as demonstrated in this thesis, a small sample of shells will provide meaningful insights into seasonal patterns of shellfish harvest and, by proxy, site occupation.

Reducing the sample size to improve the accuracy of the season-at-death estimate can still provide meaningful results, though a limited sample size should be used with caution and not be taken to represent the full range of seasonal activities at the site. At present, the sample sizes for shellfish seasonality in Prince Rupert Harbour (n = 10 shells) are small compared to the central coast (n = 90), and it would be prudent to expand the number of shells analyzed from Prince Rupert Harbour to ensure that the pattern of spring/autumn harvest remains consistent. This raises an important question regarding the number of individual shell samples required to identify a seasonal pattern. The answer to this is contingent on several factors including the occupational history of the site and the preservation of the shellfish remains. When approaching seasonality questions, the number of shell samples analyzed should be considered within the temporal and spatial context of the site. Larger sites with longer periods of occupation require more samples than smaller, more ephemeral sites. However, there is no specific number of samples required to identify seasonal patterns of shellfish collection. It should also be noted that identifying patterns of sedentism and mobility, a goal frequently linked to seasonality studies, would require not only a greater number of samples than presented in this dissertation, but also multiple seasonal proxies.

5.4 Future research

There are several ways in which the research presented in this dissertation can be expanded and the new knowledge of regional variability in shell growth rates integrated into archaeological research programs. An increase in the number of shells and sites examined is crucial to better understand seasonal shellfish gathering. Expanding the sample to look at more shells from McNichol Creek and Ridley Island in Prince Rupert Harbour would be prudent to ensure whether the pattern of spring and autumn harvesting remains consistent throughout their occupational history. Expanding the seasonality analysis to include Treymane Bay, Dodge Cove and other sites in the area would also provide a better understanding of site-specific seasonality patterns. The expansion of both the seasonality and harvest pressure analyses to other areas of the Northwest Coast would permit a broader perspective of the range of variability in subsistence practices.

Preliminary analysis of shellfish harvesting strategies has been conducted on shells from Pender Island (DeRt-1 and DeRt-2)[3] in the Gulf of Georgia on the south coast of British Columbia, which has an occupational history spanning more than two millennia (Fedje et al. 2009). The combined 'site' area is comparable to

[3] The shell midden 'sites' on Pender Island have been assigned two different Borden numbers. It is more likely that it is a single site disrupted by the construction of a modern canal, and not two separate shell middens as the Borden numbers would suggest.

Namu, and has been identified as a 'village', however, the temporal occupation of the site is significantly shorter. Growth increment analysis of 398 ventral margin fragments revealed that shells were collected at a relatively intensive rate, (63% mature, 25% senile, 12% unknown). Shells grow faster in the south coast (Hallmann et al., 2009), and this pattern of harvest cannot be directly compared to the data from the north and central coasts without considering the influence of latitude on shell growth rates (see Jones and Quitmyer, 1996). A faster growth rate should result in senility at an earlier age indicating potentially more intensive harvest at Pender Island than even the high proportion of mature shells would suggest.

To improve the accuracy of growth increment analysis and extend it to further regions of the Northwest Coast, a new approach using whole shells and the application of a von Bertalanffy growth equation could provide more specific details of shellfish harvest pressure by assigning shells to age categories more specific than 'mature' or 'senile'. If whole shells are used, precise age estimates could be determined by counting the annual growth lines. However, because it is virtually impossible to distinguish annual bands in butter clam shells over 15 years (i.e. Fig. 1.1), there would still be limits to the ability to establish a precise demographic profile of the harvested shellfish population. In addition, there is no relationship between the size and age of a shell after senile growth is reached (Cannon and Burchell, 2009), which is problematic for the von Bertalanffy growth equation. Otherwise, the von Bertalanffy growth equation may be particularly useful for clams recovered from shell midden sites, since this equation is most effective for populations that cover an extended period of time (James, 1991).

Using the same methods of high-resolution stable isotope sampling and sclerochronological alignment, preliminary seasonality data for *S. gigantea* have been obtained for two additional areas on the coast of British Columbia, Pender Island, on the south coast, and Moresby Island, on Haida Gwaii. The initial seasonality results from Pender Island revealed multi-seasonal collection (winter, spring, summer). While the sample size is small (n = 5), the initial results do not imply any particular emphasis on a single season. A recent study of the life-history traits, LDGI, and stable isotopes of *S. gigantea* shells from occupations dating approximately 500 years ago on Moresby Island, Haida Gwaii by Brombacher (2012), showed evidence for year-round collection, with a slight emphasis on spring and autumn collection. Again, the sample size is small (n = 10), but even with this sample the results directly contradict the 'winter' patterns of shellfish harvesting observed ethnographically in the area (i.e., Blackman, 1990). These results, especially when considered in the larger regional framework of the British Columbia coast further demonstrate the potential variability in the seasonality of clam harvest and site occupation patterns. They also highlight discrepancies with the subsistence practices observed ethnographically.

In addition to expanding the methodology applied to *S.gigantea* to other areas from the Pacific Northwest Coast, these methods may be beneficial in other geographic regions, and with other species. Preliminary stable oxygen isotope results from the calcite bivalve *Mytilus edulis* (blue mussel), from a historic era Métis sod house in Labrador has shown promise as a reliable seasonality indicator when high-resolution sampling is applied. However, macro-growth lines and LDGI are not visible in this species even when stained with Mutvei's solution, therefore, it is not possible to use this species for geochemical alignment, nor for estimating patterns of past mussel harvesting pressure.

In addition to using different bivalve species, fish otoliths may also provide reliable seasonality estimates using stable isotopes and/or growth lines (i.e., Gao et al. 2001; Jamieson et al. 2004; Schwarcz et al. 1998; Van Neer et al. 1993). As well as studying different organisms, other geochemical methods could be applied to refine seasonality estimates, and provide insight into past climates. Clumped isotopes (i.e., Eiler, 2007; Huntington et al, 2010; Tripati et al., 2010) and trace element analyses (i.e., Sessa et al., 2012; Schöne et al., 2011; Toyofuku et al., 2011) are other possible approaches to resolving seasonality in freshwater-influenced marine environments. The ratios of Mr/Ca and Sr/Ca are not influenced by salinity however techniques to fully understand the relationship between trace elements and/or clumped oxygen isotopes and shell growth history are still under development (Andrus, 2011). If a reliable palaeothermometer is found, the calculation of past sea water temperatures could be possible, which would allow further insight into changes in salinity and precipitation (Andrus, 2011). It would likely also improve the precision of seasonality estimates from archaeological shells, not only at freshwater-influenced marine sites, but also in species that are not candidates for sclerochronological alignment.

5.5. Conclusions

The analysis of butter clams from the central and northern coasts of British Columbia clearly demonstrated the range of variability in resource procurement practices between the central British Columbia coast, Prince Rupert Harbour and the Dundas Islands. While the full spectrum of shellfish use is not fully understood, new insights have revealed the year-round use of butter clams, and their varying roles in local economies. It also showed the importance of shellfish as a resource on the Northwest Coast, whether it is one that is harvested seasonally to supplement food during times of shortage, or one that is used in marginal resource areas throughout the year.

A question that remains unanswered pertains to sample size. Using high-resolution sampling and sclerochronological alignment, it is possible to establish the number of discrete data points needed to establish seasonality from an individual shell. It is not yet resolved how many shells are needed to establish seasonality at a particular site or over time. A smaller sample size, such as those from the Prince Rupert Harbour region, is sufficient to determine the minimum number of seasons represented, however sites, such as Namu, with long occupation histories require analysis of a larger number of shells. The number of shells required to determine seasonal patterns is contingent not only on site size and the length of occupation, but also the goal of the study.

This dissertation provided improved methods for seasonality estimates from archaeological shells, tested the methods to understand regional patterns in settlement and subsistence on the central coast, and then expanded their regional application to examine variability in seasonality and harvest intensity on the north coast. Methodologically, the results showed that growth increment and growth colouration analysis to determine the season of shellfish collection is unreliable. It also demonstrated the need for high-resolution isotope sampling and sclerochronological alignment to determine seasonality in freshwater influenced environments. Overall, there is no evidence to support the previous suppositions of ‘seasonally mobile’ populations, which imply specific seasonal movements to particular locations, since there is no indication that most sites were occupied on a single-season basis. The results also indicate there is no single seasonal pattern of shellfish procurement on the Northwest Coast. More significantly, this dissertation has demonstrated the variability between and within regions and the diversity in subsistence and settlement practices on the coast of British Columbia, a subject that is worth further enquiry and investigation.

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APPENDIX A: STABLE OXYGEN ISOTOPE DATA

I. CENTRAL COAST

NAMU, ElSx-1

ElSx1-1	
Provenience 68-70S. 6-8W, 270-280cm DBS	
# samples	57
Max $\delta^{18}O$‰	-0.12
Min $\delta^{18}O$‰	-3.41
Ø $\delta^{18}O$‰	-1.46
Season	Autumn

ElSx-1-2	
Provenience 26-28S. 2-4E, 70-80cm DBS	
# samples	24
Max $\delta^{18}O$‰	-0.74
Min $\delta^{18}O$‰	-5.04
Ø $\delta^{18}O$‰	-2.92
Season	Spring

ElSx-1-3	
Provenience 28-30S. 2-4E, 180-190cm DBS	
Max $\delta^{18}O$‰	14
Min $\delta^{18}O$‰	-0.07
Ø $\delta^{18}O$‰	-2.60
Ø $\delta^{18}O$‰	-1.38
Season	Spring

ElSx-1-4	
Provenience 32-34S. 2-4W, 50-60cm DBS	
# samples	46
Max $\delta^{18}O$‰	0.50
Min $\delta^{18}O$‰	-3.29
Ø $\delta^{18}O$‰	-1.56
Season	Spring

ElSx-1-5	
Provenience 28-30S. 2-4E, 180-190cm DBS	
# samples	37
Max $\delta^{18}O$‰	-0.08
Min $\delta^{18}O$‰	-3.89
Ø $\delta^{18}O$‰	-2.69
Season	Autumn

ElSx-1-6	
Provenience 32-34S. 2-4W, 90-100cm DBS	
# samples	17
Max $\delta^{18}O$‰	-0.57
Min $\delta^{18}O$‰	-2.79
Ø $\delta^{18}O$‰	-1.57
Season	Autumn

ElSx-1-7	
Provenience 32-34S. 2-4W, 130-140cm DBS	
# samples	21
Max $\delta^{18}O$‰	-2.84
Min $\delta^{18}O$‰	-4.90
Ø $\delta^{18}O$‰	-3.55
Season	Autumn

ElSx-1-8	
Provenience 32-34S. 6-8W, 90-100cm DBS	
# samples	19
Max $\delta^{18}O$‰	-0.64
Min $\delta^{18}O$‰	-3.87
Ø $\delta^{18}O$‰	-2.15
Season	Winter

ElSx-1-9	
Provenience 66-68S. 4-6W, 300-310cm DBS	
# samples	15
Max $\delta^{18}O$‰	0.01
Min $\delta^{18}O$‰	-2.10
Ø $\delta^{18}O$‰	-1.40
Season	Autumn

ElSx-1-10	
Provenience 68-70S. 4-6W, 150-160cm DBS	
# samples	20
Max $\delta^{18}O$‰	-1.41
Min $\delta^{18}O$‰	-4.65
Ø $\delta^{18}O$‰	-2.83
Season	Winter

ElSx-1-11	
Provenience 68-70S. 6-8W, 90-100cm DBS	
# samples	23
Max $\delta^{18}O$‰	-0.69
Min $\delta^{18}O$‰	-4.28
Ø $\delta^{18}O$‰	-1.87
Season	Spring

ElSx-1-12	
Provenience 68-70S. 6-8W, 260-270cm DBS	
# samples	23
Max $\delta^{18}O$‰	-0.30
Min $\delta^{18}O$‰	-4.42
Ø $\delta^{18}O$‰	-1.69
Season	Spring

ElSx-1-13	
Provenience 68-70S. 8-10W, 0-50cm DBS	
# samples	50
Max δ^{18}O‰	0.25
Min δ^{18}O‰	-3.11
Ø δ^{18}O‰	-1.37
Season	Summer

ElSx-1-14	
Provenience 66-68S. 8-10W, 340-350cm DBS	
# samples	18
Max δ^{18}O‰	-0.69
Min δ^{18}O‰	-3.61
Ø δ^{18}O‰	-2.86
Season	Autumn

ElSx-1-15	
Provenience Auger J1 Shell C	
# samples	12
Max δ^{18}O‰	-0.60
Min δ^{18}O‰	-3.70
Ø δ^{18}O‰	-2.21
Season	Autumn

ElSx-1-16	
Provenience Column Sample 1, STR 6.	
# samples	13
Max δ^{18}O‰	-0.80
Min δ^{18}O‰	-3.07
Ø δ^{18}O‰	-2.32
Season	Spring

ElSx-1-17	
Provenience Column Sample 1, STR 6.	
# samples	12
Max δ^{18}O‰	-0.42
Min δ^{18}O‰	-1.11
Ø δ^{18}O‰	-0.82
Season	Autumn

ElSx-1-18	
Provenience Column Sample 1, STR 6.	
# samples	10
Max δ^{18}O‰	0.07
Min δ^{18}O‰	-0.25
Ø δ^{18}O‰	-0.11
Season	Winter

ElSx-1-19	
Provenience Column Sample 1, STR 6.	
# samples	10
Max δ^{18}O‰	-0.44
Min δ^{18}O‰	-0.89
Ø δ^{18}O‰	-0.60
Season	Winter

ElSx-1-20	
Provenience Column Sample 1, STR 6.	
# samples	10
Max δ^{18}O‰	-2.73
Min δ^{18}O‰	-3.44
Ø δ^{18}O‰	-3.08
Season	Summer

ElSx-1-21	
Provenience Column Sample 1, STR 6.	
# samples	29
Max δ^{18}O‰	0.00
Min δ^{18}O‰	-4.45
Ø δ^{18}O‰	-1.71
Season	Winter

ElSx-1-22	
Provenience 32-34S. 2-4W, 150-160cm DBS	
# samples	22
Max δ^{18}O‰	-0.12
Min δ^{18}O‰	-3.19
Ø δ^{18}O‰	-1.28
Season	Winter

KISAMEET, ElSx-3

ElSx-3-1	
Provenience Auger C3 39-63cm DBS	
# samples	15
Max $\delta^{18}O$‰	-1.26
Min $\delta^{18}O$‰	-3.94
Ø $\delta^{18}O$‰	-2.88
Season	Spring

ElSx-3-2	
Provenience Auger C3 39-63cm DBS	
# samples	20
Max $\delta^{18}O$‰	-0.73
Min $\delta^{18}O$‰	-4.56
Ø $\delta^{18}O$‰	-2.26
Season	Spring

ElSx-3-3	
Provenience Auger C17	
# samples	32
Max $\delta^{18}O$‰	-0.55
Min $\delta^{18}O$‰	-4.11
Ø $\delta^{18}O$‰	-2.21
Season	Spring

ElSx-3-4	
Provenience Auger D13	
# samples	15
Max $\delta^{18}O$‰	-1.30
Min $\delta^{18}O$‰	-3.31
Ø $\delta^{18}O$‰	-2.38
Season	Autumn

ElSx-3-5	
Provenience Auger D17	
# samples	15
Max $\delta^{18}O$‰	-1.27
Min $\delta^{18}O$‰	-3.76
Ø $\delta^{18}O$‰	-2.60
Season	Spring

ElSx-3-6	
Provenience Auger D17	
# samples	15
Max $\delta^{18}O$‰	-0.27
Min $\delta^{18}O$‰	-3.62
Ø $\delta^{18}O$‰	-1.56
Season	Spring

ElSx-7	
Provenience Auger D24	
# samples	21
Max $\delta^{18}O$‰	-0.61
Min $\delta^{18}O$‰	-3.03
Ø $\delta^{18}O$‰	-2.01
Season	Autumn

ElSx-3-8	
Provenience Auger C3	
# samples	15
Max $\delta^{18}O$‰	-0.92
Min $\delta^{18}O$‰	-3.55
Ø $\delta^{18}O$‰	-1.73
Season	Winter

ElSx-3-9	
Provenience Auger C11	
# samples	10
Max $\delta^{18}O$‰	-0.57
Min $\delta^{18}O$‰	-2.96
Ø $\delta^{18}O$‰	-1.90
Season	Spring

ElSx-3-10	
Provenience Auger F19	
# samples	15
Max $\delta^{18}O$‰	-0.37
Min $\delta^{18}O$‰	-2.98
Ø $\delta^{18}O$‰	-1.38
Season	Spring

ElSx-3-11	
Provenience Auger D20	
# samples	15
Max $\delta^{18}O$‰	-2.09
Min $\delta^{18}O$‰	-5.19
Ø $\delta^{18}O$‰	-3.70
Season	Spring

ElSx-3-12	
Provenience Auger C19	
# samples	16
Max $\delta^{18}O$‰	-0.96
Min $\delta^{18}O$‰	-3.54
Ø $\delta^{18}O$‰	-2.25
Season	Spring

ElSx-5

ElSx-5-1	
Provenience Auger B3	
# samples	20
Max $\delta^{18}O$‰	-0.17
Min $\delta^{18}O$‰	-5.37
Ø $\delta^{18}O$‰	-2.23
Season	Winter

ElSx-5-2	
Provenience B17	
# samples	16
Max $\delta^{18}O$‰	-0.31
Min $\delta^{18}O$‰	-2.86
Ø $\delta^{18}O$‰	-1.18
Season	Winter

ElSx-5-3	
Provenience Auger B19-A	
# samples	12
Max $\delta^{18}O$‰	-0.49
Min $\delta^{18}O$‰	-3.21
Ø $\delta^{18}O$‰	-1.99
Season	Spring

ElSx-5-4	
Provenience Auger B19-B	
# samples	12
Max $\delta^{18}O$‰	-0.37
Min $\delta^{18}O$‰	-3.46
Ø $\delta^{18}O$‰	-2.01
Season	Autumn

ElSx-5-5	
Provenience Auger B23-A	
# samples	15
Max $\delta^{18}O$‰	-0.95
Min $\delta^{18}O$‰	-2.93
Ø $\delta^{18}O$‰	-2.08
Season	Spring

ElSx-5-6	
Provenience High terrace	
# samples	15
Max $\delta^{18}O$‰	-0.14
Min $\delta^{18}O$‰	-2.83
Ø $\delta^{18}O$‰	-1.59
Season	Autumn

ElSx-5-7	
Provenience High terrace	
# samples	7
Max $\delta^{18}O$‰	-0.97
Min $\delta^{18}O$‰	-2.00
Ø $\delta^{18}O$‰	-1.72
Season	Autumn

ElSx-10

ElSx10-1	
Provenience Auger A5-B, 105-107 cm	
# samples	8
Max $\delta^{18}O$‰	-1.01
Min $\delta^{18}O$‰	-2.90
Ø $\delta^{18}O$‰	-2.35
Season	Autumn

ElSx10-2	
Provenience Auger A6-B, 107-116 cm	
# samples	15
Max $\delta^{18}O$‰	-0.89
Min $\delta^{18}O$‰	-3.37
Ø $\delta^{18}O$‰	-2.30
Season	Spring

ElSx10-3	
Provenience Auger A7, 116-126cm	
# samples	11
Max $\delta^{18}O$‰	-0.60
Min $\delta^{18}O$‰	-3.22
Ø $\delta^{18}O$‰	-2.23
Season	Autumn

ElSx10-4	
Provenience Auger A10 157-170cm	
# samples	11
Max $\delta^{18}O$‰	-0.06
Min $\delta^{18}O$‰	-3.04
Ø $\delta^{18}O$‰	-1.33
Season	Winter

ElSx10-5	
Provenience Auger A11-A 170-190cm	
# samples	15
Max $\delta^{18}O$‰	-0.25
Min $\delta^{18}O$‰	-2.98
Ø $\delta^{18}O$‰	-1.31
Season	Spring

ElSx10-6	
Provenience Auger F6 128-148cm	
# samples	15
Max $\delta^{18}O$‰	-0.22
Min $\delta^{18}O$‰	-3.49
Ø $\delta^{18}O$‰	-2.25
Season	Autumn

ElSx10-7	
Provenience Auger F6 128-148cm	
# samples	10
Max $\delta^{18}O$‰	-0.07
Min $\delta^{18}O$‰	-3.46
Ø $\delta^{18}O$‰	-1.62
Season	Autumn

ElSx10-8	
Provenience Auger A13-C 202-207cm	
# samples	10
Max $\delta^{18}O$‰	-0.81
Min $\delta^{18}O$‰	-3.88
Ø $\delta^{18}O$‰	-2.21
Season	Winter

ElSx10-9	
Provenience Upper erosional surf.	
# samples	12
Max $\delta^{18}O$‰	-1.63
Min $\delta^{18}O$‰	-3.91
Ø $\delta^{18}O$‰	-2.79
Season	Autumn

ElSx10-10	
Provenience Lower erosional surf.	
# samples	12
Max $\delta^{18}O$‰	-0.71
Min $\delta^{18}O$‰	-2.98
Ø $\delta^{18}O$‰	-1.77
Season	Spring

ElSx10-11	
Provenience Auger A6, 107-116cm	
# samples	15
Max $\delta^{18}O$‰	-0.31
Min $\delta^{18}O$‰	-3.11
Ø $\delta^{18}O$‰	-1.74
Season	Autumn

ElSx10-12	
Provenience Auger A8, 126-135cm	
# samples	19
Max $\delta^{18}O$‰	-0.15
Min $\delta^{18}O$‰	-3.22
Ø $\delta^{18}O$‰	-1.50
Season	Spring

ElSx10-13	
Provenience Auger A16, 230-246cm	
# samples	10
Max $\delta^{18}O$‰	-0.46
Min $\delta^{18}O$‰	-3.09
Ø $\delta^{18}O$‰	-2.09
Season	Autumn

ElSx10-14	
Provenience Auger F2	
# samples	15
Max $\delta^{18}O$‰	-0.14
Min $\delta^{18}O$‰	-2.77
Ø $\delta^{18}O$‰	-1.79
Season	Winter

HUNTER ISLAND, ElTa-25

ElTa-25-1	
Provenience Auger C6	
# samples	9
Max δ^{18}O‰	-0.98
Min δ^{18}O‰	-3.22
Ø δ^{18}O‰	-2.06
Season	Autumn

ElTa-25-2	
Provenience Auger A3, 94-113cm	
# samples	14
Max δ^{18}O‰	-1.43
Min δ^{18}O‰	-3.79
Ø δ^{18}O‰	-2.92
Season	Winter

ElTa-25-3	
Provenience Auger10, 191-201cm	
# samples	13
Max δ^{18}O‰	-2.04
Min δ^{18}O‰	-3.76
Ø δ^{18}O‰	-2.93
Season	Autumn

ElTa-25-4	
Provenience Auger A15, 234-240 191cm	
# samples	15
Max δ^{18}O‰	-1.79
Min δ^{18}O‰	-4.38
Ø δ^{18}O‰	-3.20
Season	Summer

ElTa-25-5	
Provenience Auger A27, 280-296cm	
# samples	15
Max δ^{18}O‰	-0.85
Min δ^{18}O‰	-3.71
Ø δ^{18}O‰	-2.95
Season	Autumn

ElTa-25-6	
Provenience Auger A30, 303-305cm	
# samples	16
Max δ^{18}O‰	-0.82
Min δ^{18}O‰	-4.51
Ø δ^{18}O‰	-2.73
Season	Autumn

ElTa-25-7	
Provenience Auger A15, 234-240cm	
# samples	10
Max δ^{18}O‰	-0.20
Min δ^{18}O‰	-2.37
Ø δ^{18}O‰	-1.31
Season	Spring

ElTa-25-8	
Provenience Auger C3, 51-63cm	
# samples	30
Max δ^{18}O‰	-1.05
Min δ^{18}O‰	-3.93
Ø δ^{18}O‰	-2.97
Season	Autumn

ElTa-25-9	
Provenience Auger C18, 171-181cm	
# samples	42
Max δ^{18}O‰	-1.17
Min δ^{18}O‰	-5.00
Ø δ^{18}O‰	-3.25
Season	Autumn

ElTa-25-10	
Provenience Exposure	
# samples	6
Max δ^{18}O‰	-1.41
Min δ^{18}O‰	-3.06
Ø δ^{18}O‰	-2.39
Season	Autumn

ElTa-25-11	
Provenience Exposure	
# samples	18
Max δ^{18}O‰	-0.82
Min δ^{18}O‰	-3.37
Ø δ^{18}O‰	-2.38
Season	Winter

ElTa-25-12	
Provenience Exposure	
# samples	10
Max δ^{18}O‰	-1.40
Min δ^{18}O‰	-2.95
Ø δ^{18}O‰	-2.16
Season	Autumn

ElTb-1

ElTb-1-1	
Provenience Auger A4-A	
# samples	18
Max $\delta^{18}O$‰	0.44
Min $\delta^{18}O$‰	-2.93
Ø $\delta^{18}O$‰	-0.99
Season	Winter

ElTb-1-2	
Provenience Auger A4-C	
# samples	12
Max $\delta^{18}O$‰	-0.56
Min $\delta^{18}O$‰	-2.37
Ø $\delta^{18}O$‰	-1.87
Season	Winter

ElTb-1-3	
Provenience Auger A6-B	
# samples	13
Max $\delta^{18}O$‰	-0.62
Min $\delta^{18}O$‰	-1.98
Ø $\delta^{18}O$‰	-1.39
Season	Winter

ElTb-1-4	
Provenience Auger A8	
# samples	17
# samples	-0.04
Max $\delta^{18}O$‰	-2.32
Min $\delta^{18}O$‰	-1.17
Ø $\delta^{18}O$‰	Winter

ElTb-1-5	
Provenience Auger A9	
# samples	20
Max $\delta^{18}O$‰	-1.62
Min $\delta^{18}O$‰	-1.49
Ø $\delta^{18}O$‰	-1.46
Season	Spring

ElTb-1-6	
Provenience Auger A10	
# samples	20
Max $\delta^{18}O$‰	-0.63
Min $\delta^{18}O$‰	-2.11
Ø $\delta^{18}O$‰	-1.49
Season	Winter

ElTb-1-7	
Provenience Auger A12-E	
# samples	20
Max $\delta^{18}O$‰	0.03
Min $\delta^{18}O$‰	-2.98
Ø $\delta^{18}O$‰	-0.94
Season	Spring

ElTb-1-8	
Provenience Auger A12-H	
# samples	20
Max $\delta^{18}O$‰	0.22
Min $\delta^{18}O$‰	-2.30
Ø $\delta^{18}O$‰	-1.09
Season	Winter

ElTb-1-9	
Provenience Auger D3	
# samples	10
Max $\delta^{18}O$‰	-0.95
Min $\delta^{18}O$‰	-2.34
Ø $\delta^{18}O$‰	-1.43
Season	Spring

ElTb-10

ElTb-10-1	
Provenience	3B
# samples	10
Max $\delta^{18}O$‰	-0.82
Min $\delta^{18}O$‰	-2.57
Ø $\delta^{18}O$‰	-1.72
Season	Autumn

ElTb-10-2	
Provenience	3C1
# samples	11
Max $\delta^{18}O$‰	-0.24
Min $\delta^{18}O$‰	-2.27
Ø $\delta^{18}O$‰	-1.72
Season	Autumn

ElTb-10-3	
Provenience	3C2
# samples	11
Max $\delta^{18}O$‰	-0.30
Min $\delta^{18}O$‰	-1.78
Ø $\delta^{18}O$‰	-0.78
Season	Spring

ElTb-10-4	
Provenience	3B
# samples	10
Max $\delta^{18}O$‰	-0.07
Min $\delta^{18}O$‰	-1.38
Ø $\delta^{18}O$‰	-0.60
Season	Winter

ElTb-10-5	
Provenience	3H-2
# samples	10
Max $\delta^{18}O$‰	0.42
Min $\delta^{18}O$‰	-1.47
Ø $\delta^{18}O$‰	-0.39
Season	Winter

ElTb-10-6	
Provenience	C3
# samples	10
Max $\delta^{18}O$‰	-0.79
Min $\delta^{18}O$‰	-2.22
Ø $\delta^{18}O$‰	-1.23
Season	Spring

II. DUNDAS ISLANDS

GcTq-9

GcTq-9 A	
Provenience 60-80 cm DBS	
# samples	10
Max $\delta^{18}O$‰	0.03
Min $\delta^{18}O$‰	-4.48
Ø $\delta^{18}O$‰	-1.93
Season	Winter

GcTq-9 B	
Provenience 80-100 cm DBS	
# samples	15
Max $\delta^{18}O$‰	-0.57
Min $\delta^{18}O$‰	-3.71
Ø $\delta^{18}O$‰	-2.06
Season	Spring

GcTq-9 C	
Provenience 120-140 cm DBS	
# samples	10
Max $\delta^{18}O$‰	-0.75
Min $\delta^{18}O$‰	-3.79
Ø $\delta^{18}O$‰	-1.85
Season	Winter

GcTq-9 D	
Provenience 120-150 cm DBS	
# samples	10
Max $\delta^{18}O$‰	-0.17
Min $\delta^{18}O$‰	-4.64
Ø $\delta^{18}O$‰	-2.67
Season	Autumn

GcTq-9 E	
Provenience 140-160 cm DBS	
# samples	10
Max $\delta^{18}O$‰	-0.90
Min $\delta^{18}O$‰	-4.24
Ø $\delta^{18}O$‰	-2.76
Season	Spring

GcTq-5

12-3 DA	
Provenience 60-80 cm DBS	
# samples	37
Max $\delta^{18}O$‰	0.40
Min $\delta^{18}O$‰	-3.44
Ø $\delta^{18}O$‰	-1.58
Season	Winter

12-3 DB	
Provenience 60-80 cm DBS	
# samples	87
Max $\delta^{18}O$‰	0.81
Min $\delta^{18}O$‰	-3.88
Ø $\delta^{18}O$‰	-1.42
Season	Spring

12-3 DE	
Provenience 220-240 cm DBS	
# samples	49
Max $\delta^{18}O$‰	0.57
Min $\delta^{18}O$‰	-5.89
Ø $\delta^{18}O$‰	-2.08
Season	Spring

12-3 D4	
Provenience 220-240 cm DBS	
# samples	28
Max $\delta^{18}O$‰	0.42
Min $\delta^{18}O$‰	-3.30
Ø $\delta^{18}O$‰	-1.41
Season	Summer

12-3 DA	
Provenience 220-240 cm DBS	
# samples	49
Max $\delta^{18}O$‰	0.31
Min $\delta^{18}O$‰	-5.13
Ø $\delta^{18}O$‰	-1.93
Season	Summer

12-3 D1	
Provenience 440-460 cm DBS	
# samples	53
Max $\delta^{18}O$‰	0.29
Min $\delta^{18}O$‰	-4.08
Ø $\delta^{18}O$‰	-1.71
Season	Autumn

12-3 D2	
Provenience 440-460 cm DBS	
# samples	66
Max $\delta^{18}O$‰	0.33
Min $\delta^{18}O$‰	-6.23
Ø $\delta^{18}O$‰	-2.43
Season	Autumn

GcTq-6

6-10-2 DB	
Provenience 60-80 cm DBS	
# samples	44
Max $\delta^{18}O$‰	0.20
Min $\delta^{18}O$‰	-3.09
Ø $\delta^{18}O$‰	-1.21
Season	Autumn

6-10-2 DC	
Provenience 60-80 cm DBS	
# samples	106
Max $\delta^{18}O$‰	0.57
Min $\delta^{18}O$‰	-3.31
Ø $\delta^{18}O$‰	-1.01
Season	Spring

60-10-2-DL	
Provenience 100-120 cm DBS	
# samples	40
Max $\delta^{18}O$‰	0.81
Min $\delta^{18}O$‰	-3.75
Ø $\delta^{18}O$‰	-1.76
Season	Summer

6-10-2 D	
Provenience 240-260 cm DBS	
# samples	64
Max $\delta^{18}O$‰	1.00
Min $\delta^{18}O$‰	-3.20
Ø $\delta^{18}O$‰	-0.86
Season	Spring

6-10-2 DB	
Provenience 240-260 cm DBS	
# samples	46
Max $\delta^{18}O$‰	0.59
Min $\delta^{18}O$‰	-3.67
Ø $\delta^{18}O$‰	-1.45
Season	Summer

GcTq-13

GcTq-13 A	
Provenience 80-100 cm DBS	
# samples	12
Max δ^{18}O‰	-0.07
Min δ^{18}O‰	-2.94
Ø δ^{18}O‰	-1.32
Season	Winter

GcTq-13-B	
Provenience 80-100 cm DBS	
# samples	11
Max δ^{18}O‰	-0.68
Min δ^{18}O‰	-3.98
Ø δ^{18}O‰	-2.97
Season	Autumn

GcTq-13 C	
Provenience 100-120 cm DBS	
# samples	14
Max δ^{18}O‰	-0.24
Min δ^{18}O‰	-4.12
Ø δ^{18}O‰	-2.19
Season	Winter

GcTq-13 D	
Provenience 120-140 cm DBS	
# samples	10
Max δ^{18}O‰	-0.81
Min δ^{18}O‰	-4.62
Ø δ^{18}O‰	-2.75
Season	Winter

GcTq-13 E	
Provenience 120-140 cm DBS	
# samples	11
Max δ^{18}O‰	-0.96
Min δ^{18}O‰	-4.63
Ø δ^{18}O‰	-3.26
Season	Spring

GdTq-1

GdTq-1 224-245	
Provenience 224-245 cm DBS	
# samples	30
Max δ^{18}O‰	0.29
Min δ^{18}O‰	-4.18
Ø δ^{18}O‰	-1.45
Season	Winter

GdTq-1 143-168	
Provenience 143-168 cm DBS	
# samples	37
Max δ^{18}O‰	0.26
Min δ^{18}O‰	-4.36
Ø δ^{18}O‰	-1.70
Season	Winter

GdTa-1 168-196 DA	
Provenience 168-196 cm DBS	
# samples	41
Max δ^{18}O‰	0.40
Min δ^{18}O‰	-5.02
Ø δ^{18}O‰	-2.59
Season	Summer

GdTq-1 A	
Provenience 84-112 cm DBS	
# samples	10
Max δ^{18}O‰	-2.37
Min δ^{18}O‰	-2.82
Ø δ^{18}O‰	-2.51
Season	Summer

GdTq-1 143-168 DC	
Provenience 143-168 cm DBS	
# samples	37
Max δ^{18}O‰	0.26
Min δ^{18}O‰	-4.36
Ø δ^{18}O‰	-1.70
Season	Winter

GdTq-3

22-1 DA	
Provenience 140-168 cm DBS	
# samples	63
Max $\delta^{18}O$‰	0.27
Min $\delta^{18}O$‰	-5.55
Ø $\delta^{18}O$‰	-2.19
Season	Winter

22-1 D	
Provenience 140-168 cm DBS	
# samples	29
Max $\delta^{18}O$‰	0.35
Min $\delta^{18}O$‰	-5.12
Ø $\delta^{18}O$‰	-1.86
Season	Spring

22-1 DC	
Provenience 252-280 cm DBS	
# samples	35
Max $\delta^{18}O$‰	0.41
Min $\delta^{18}O$‰	-4.50
Ø $\delta^{18}O$‰	-1.44
Season	Winter

22-1 DF	
Provenience 252-280 cm DBS	
# samples	23
Max $\delta^{18}O$‰	0.27
Min $\delta^{18}O$‰	-3.68
Ø $\delta^{18}O$‰	-1.26
Season	Winter

22-1 DB	
Provenience 280-308 cm DBS	
# samples	28
Max $\delta^{18}O$‰	0.40
Min $\delta^{18}O$‰	-4.66
Ø $\delta^{18}O$‰	-1.93
Season	Summer

22-1 DF	
Provenience 336-364 cm DBS	
# samples	32
Max $\delta^{18}O$‰	0.76
Min $\delta^{18}O$‰	-3.41
Ø $\delta^{18}O$‰	-1.25
Season	Autumn

22-1 DA	
Provenience 364-392 cm DBS	
# samples	50
Max $\delta^{18}O$‰	0.07
Min $\delta^{18}O$‰	-4.00
Ø $\delta^{18}O$‰	-1.91
Season	Autumn

22-1 DD	
Provenience 364-392 cm DBS	
# samples	35
Max $\delta^{18}O$‰	0.57
Min $\delta^{18}O$‰	-4.53
Ø $\delta^{18}O$‰	-1.54
Season	Summer

GcTr-6

GcTr-6 D1R	
Provenience 110-115 cm DBS	
# samples	40
Max $\delta^{18}O$‰	0.55
Min $\delta^{18}O$‰	-3.46
Ø $\delta^{18}O$‰	-1.11
Season	Winter

GcTr-6 D1L	
Provenience 170-175 DBS	
# samples	54
Max $\delta^{18}O$‰	0.61
Min $\delta^{18}O$‰	-4.80
Ø $\delta^{18}O$‰	-1.54
Season	Autumn

GcTr-6 A	
Provenience 112-140 cm DBS	
# samples	10
Max $\delta^{18}O$‰	0.30
Min $\delta^{18}O$‰	-2.31
Ø $\delta^{18}O$‰	-0.83
Season	Winter

GcTr-6 B	
Provenience 140-168 cm DBS	
# samples	10
Max $\delta^{18}O$‰	0.06
Min $\delta^{18}O$‰	-2.78
Ø $\delta^{18}O$‰	-1.42
Season	Winter

GcTr-6 C	
Provenience 196-224 cm DBS	
# samples	10
Max $\delta^{18}O$‰	-0.61
Min $\delta^{18}O$‰	-2.38
Ø $\delta^{18}O$‰	-1.38
Season	Spring

III. PRINCE RUPERT HARBOUR

RIDLEY ISLAND, GbTn-19

GbTn-19-1	
Provenience 1-2S; 10-11E, 140-150cm DBS	
# samples	15
Max $\delta^{18}O$‰	-0.94
Min $\delta^{18}O$‰	-2.95
Ø $\delta^{18}O$‰	-2.01
Season	Spring

GbTn-19-2	
Provenience 1-2S; 10-11E, 160-170cm DBS	
# samples	15
Max $\delta^{18}O$‰	-0.96
Min $\delta^{18}O$‰	-3.08
Ø $\delta^{18}O$‰	-2.34
Season	Autumn

GbTn-19-3	
Provenience 5-7S; 0-1W, 80-90cm DBS	
# samples	10
Max $\delta^{18}O$‰	-0.25
Min $\delta^{18}O$‰	-4.46
Ø $\delta^{18}O$‰	-1.32
Season	Spring

GbTn-19-4	
Provenience 5-7S; 0-1W, 110-120cm DBS	
# samples	10
Max $\delta^{18}O$‰	-1.67
Min $\delta^{18}O$‰	-3.30
Ø $\delta^{18}O$‰	-2.51
Season	Spring

GbTn-19-5	
Provenience 6-7S; 11-12W, 180-190cm DBS	
# samples	10
Max $\delta^{18}O$‰	-1.64
Min $\delta^{18}O$‰	-3.11
Ø $\delta^{18}O$‰	-2.23
Season	Spring

McNICHOL CREEK, GcTo-46

GcTo-6-1	
Provenience N21; W10 Layer C, Level 2	
# samples	14
Max $\delta^{18}O$‰	-1.08
Min $\delta^{18}O$‰	-3.72
Ø $\delta^{18}O$‰	-2.92
Season	Autumn

GcTo-6-2	
Provenience N21; W10 Layer C, Level 9	
# samples	15
Max $\delta^{18}O$‰	-0.83
Min $\delta^{18}O$‰	-5.29
Ø $\delta^{18}O$‰	-2.56
Season	Autumn

GcTo-6-3	
Provenience N21; W10 Layer C, Level 16	
# samples	10
Max $\delta^{18}O$‰	-2.27
Min $\delta^{18}O$‰	-3.96
Ø $\delta^{18}O$‰	-3.17
Season	Spring

GcTo-6-4	
Provenience N21; W10. Layer C, Level 19	
# samples	10
Max $\delta^{18}O$‰	-1.67
Min $\delta^{18}O$‰	-3.30
Ø $\delta^{18}O$‰	-2.51
Season	Spring

GcTo-6-5	
Provenience N21; W10 Layer C, Level 14	
# samples	10
Max $\delta^{18}O$‰	-1.64
Min $\delta^{18}O$‰	-3.11
Ø $\delta^{18}O$‰	-2.23
Season	Spring

APPENDIX B: GROWTH INCREMENT DATA

I. DUNDAS ISLANDS

GcTq-1

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A		1		2006-70	40-60
B		1		2006-70	40-60
C		1		2006-70	40-60
A			1	2006-70	60-80
B			1	2006-70	60-80
C		1		2006-70	60-80
D		1		2006-70	60-80
E		1		2006-70	60-80
F		1		2006-70	60-80
G	1			2006-70	60-80
H	1			2006-70	60-80
I		1		2006-70	60-80
J			1	2006-70	60-80
K	1			2006-70	60-80
L	1			2006-70	60-80
A	1			2006-70	80-100
B		1		2006-70	80-100
C	1			2006-70	80-100
D	1			2006-70	80-100
E		1		2006-70	80-100
F	1			2006-70	80-100
G	1			2006-70	80-100
H	1			2006-70	80-100
I	1			2006-70	80-100
J	1			2006-70	80-100
K	1			2006-70	80-100
L			1	2006-70	80-100
M		1		2006-70	80-100
N	1			2006-70	80-100
O			1	2006-70	80-100
P			1	2006-70	80-100
Q	1			2006-70	80-100
R		1		2006-70	80-100
S			1	2006-70	80-100
T			1	2006-70	80-100
U	1			2006-70	80-100
V	1			2006-70	80-100
W		1		2006-70	80-100

GcTq-1, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
X	1			2006-70	80-100
A		1		2006-70	100-120
B	1			2006-70	100-120
C		1		2006-70	100-120
D		1		2006-70	100-120
E			1	2006-70	100-120
F	1			2006-70	100-120
G	1			2006-70	100-120
H	1			2006-70	100-120
I	1			2006-70	100-120
J	1			2006-70	100-120
K		1		2006-70	100-120
L		1		2006-70	100-120
M	1			2006-70	100-120
N	1			2006-70	100-120
O	1			2006-70	100-120
P	1			2006-70	100-120
A	1			2006-70	120-140
B		1		2006-70	120-140
C		1		2006-70	120-140
D	1			2006-70	120-140
E			1	2006-70	120-140
F	1			2006-70	120-140
G		1		2006-70	120-140
H	1			2006-70	120-140
I		1		2006-70	120-140
J		1		2006-70	120-140
K		1		2006-70	120-140
L	1			2006-70	120-140
M	1			2006-70	120-140
N	1			2006-70	120-140
O		1		2006-70	120-140
P		1		2006-70	120-140

GcTq-1, continued (b)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A		1		2006-70	140-160
B		1		2006-70	140-160
C			1	2006-70	140-160
D	1			2006-70	140-160
E	1			2006-70	140-160
F		1		2006-70	140-160
G		1		2006-70	140-160
H			1	2006-70	140-160
I	1			2006-70	140-160
J			1	2006-70	140-160
A	1			2006-70	160-180
B	1			2006-70	160-180
C	1			2006-70	160-180
D	1			2006-70	160-180
E	1			2006-70	160-180
F	1			2006-70	160-180
A		1		2006-70	180-200
B			1	2006-70	180-200
C		1		2006-70	180-200
D	1			2006-70	180-200
A	1			2006-70	200-220
B	1			2006-70	200-220
C		1		2006-70	200-220
D		1		2006-70	200-220
E			1	2006-70	200-220
F		1		2006-70	200-220
G		1		2006-70	200-220
H		1		2006-70	200-220
I		1		2006-70	200-220
J		1		2006-70	200-220
K		1		2006-70	200-220
L			1	2006-70	200-220
M		1		2006-70	200-220
N			1	2006-70	200-220
O		1		2006-70	200-220
P	1			2006-70	200-220
Q	1			2006-70	200-220
R			1	2006-70	200-220
S	1			2006-70	200-220
T		1		2006-70	200-220
U	1			2006-70	200-220
V	1			2006-70	200-220
W	1			2006-70	200-220
X		1		2006-70	200-220
A		1		2006-70	220-240
B		1		2006-70	220-240
C	1			2006-70	220-240

GcTq-1, continued (c)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
D			1	2006-70	220-240
E	1			2006-70	220-240
F		1		2006-70	220-240
G	1			2006-70	220-240
H	1			2006-70	220-240
I		1		2006-70	220-240
J	1			2006-70	220-240
K	1			2006-70	220-240
L	1			2006-70	220-240
M	1			2006-70	220-240
N		1		2006-70	220-240
O	1			2006-70	220-240
P	1			2006-70	220-240
Q	1			2006-70	220-240
R	1			2006-70	220-240
A	1			2006-70	240-260
B		1		2006-70	240-260
C	1			2006-70	240-260
D	1			2006-70	240-260
E	1			2006-70	240-260
F		1		2006-70	240-260
G	1			2006-70	240-260

GcTq-4

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A	1			2006-47	40-60
B	1			2006-47	40-60
C			1	2006-47	40-60
D	1			2006-47	40-60
E	1			2006-47	40-60
F	1			2006-47	40-60
G	1			2006-47	40-60
H	1			2006-47	40-60
I	1			2006-47	40-60
J			1	2006-47	40-60
K		1		2006-47	40-60
L	1			2006-47	40-60
A	1			2006-47	100-120
B	1			2006-47	100-120
C	1			2006-47	100-120
D	1			2006-47	100-120
A		1		2006-47	120-140
B		1		2006-47	120-140
C	1			2006-47	120-140
D	1			2006-47	120-140
E	1			2006-47	120-140
F	1			2006-47	120-140
G			1	2006-47	120-140
H		1		2006-47	120-140
I	1			2006-47	120-140
J	1			2006-47	120-140
K		1		2006-47	120-140
L	1			2006-47	120-140
M		1		2006-47	120-140
N	1			2006-47	120-140
O		1		2006-47	120-140
P		1		2006-47	120-140
Q	1			2006-47	120-140
R	1			2006-47	120-140
S		1		2006-47	120-140
T	1			2006-47	120-140
U	1			2006-47	120-140
V			1	2006-47	120-140
W	1			2006-47	120-140
X	1			2006-47	120-140
Y		1		2006-47	120-140
Z			1	2006-47	120-140
A	1			2006-47	120-140
B	1			2006-47	120-140
C			1	2006-47	120-140
D	1			2006-47	120-140

GcTq-4, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A		1		2006-47	140-160
B		1		2006-47	140-160
C	1			2006-47	140-160
D	1			2006-47	140-160
E		1		2006-47	140-160
F		1		2006-47	140-160
G	1			2006-47	140-160
H			1	2006-47	140-160
I	1			2006-47	140-160
J	1			2006-47	140-160
K			1	2006-47	140-160
L	1			2006-47	140-160
M			1	2006-47	140-160
N			1	2006-47	140-160
O			1	2006-47	140-160
P	1			2006-47	140-160
Q	1			2006-47	140-160
R	1			2006-47	140-160
S	1			2006-47	140-160
T	1			2006-47	140-160
U			1	2006-47	140-160
V	1			2006-47	140-160
W	1			2006-47	140-160
X	1			2006-47	140-160
Y	1			2006-47	140-160
Z	1			2006-47	140-160
A	1			2006-47	140-160
B			1	2006-47	140-160
A	1			2006-47	160-180
B		1		2006-47	160-180
C	1			2006-47	160-180
D	1			2006-47	160-180
E		1		2006-47	160-180
F	1	1		2006-47	160-180
G	1			2006-47	160-180
H		1		2006-47	160-180
I	1			2006-47	160-180
J		1		2006-47	160-180
K	1			2006-47	160-180
L	1			2006-47	160-180
A	1			2006-47	180-200
B	1			2006-47	160-180
C	1			2006-47	180-200
D		1		2006-47	160-180
E	1			2006-47	180-200
F	1			2006-47	160-180

GcTq-4, continued (b)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
G	1			2006-47	180-200
H	1			2006-47	160-180
A	1			2006-47	200-220
B	1			2006-47	200-220
C	1			2006-47	200-220
D	1			2006-47	200-220
E	1			2006-47	200-220
F	1			2006-47	200-220
G	1			2006-47	200-220
H			1	2006-47	200-220
I			1	2006-47	200-220
J		1		2006-47	200-220
A		1		2006-47	220-240
B			1	2006-47	220-240
C	1			2006-47	220-240
D			1	2006-47	220-240
E		1		2006-47	220-240
F	1			2006-47	220-240
G			1	2006-47	220-240
H	1			2006-47	220-240
I	1			2006-47	220-240
J	1			2006-47	220-240
A	1			2006-47	240-260
B		1		2006-47	240-260
C			1	2006-47	240-260
D	1			2006-47	240-260
E		1		2006-47	240-260
A	1			2006-47	260-280
B		1		2006-47	260-280
C	1			2006-47	260-280
D	1			2006-47	260-280
E		1		2006-47	260-280
F		1		2006-47	260-280
G	1			2006-47	260-280
H		1		2006-47	260-280
I			1	2006-47	260-280
J	1			2006-47	260-280
K	1			2006-47	260-280
L	1			2006-47	260-280
M	1			2006-47	260-280
N		1		2006-47	260-280
O	1			2006-47	260-280
P	1			2006-47	260-280
A		1		2006-47	280-300
B	1			2006-47	280-300
C		1		2006-47	280-300
D		1		2006-47	280-300

GcTq-4, continued (c)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
E	1			2006-47	280-300
F			1	2006-47	280-300
G		1		2006-47	280-300
H		1		2006-47	280-300
I		1		2006-47	280-300
J	1			2006-47	280-300
K		1		2006-47	280-300
L		1		2006-47	280-300
A		1		2006-47	300-320
B	1			2006-47	280-300
C			1	2006-47	300-320
D	1			2006-47	280-300
E		1		2006-47	300-320
F			1	2006-47	280-300
G		1		2006-47	300-320
H	1			2006-47	280-300
I	1			2006-47	300-320
J		1		2006-47	280-300
K		1		2006-47	300-320
L	1			2006-47	280-300
M		1		2006-47	300-320
N	1			2006-47	280-300
A		1		2006-67	320-340
B	1			2006-67	320-340
C	1			2006-67	320-340
D		1		2006-67	320-340
E	1			2006-67	320-340
F	1			2006-67	320-340
G		1		2006-67	320-340
H		1		2006-67	320-340
I		1		2006-67	320-340
J	1			2006-67	320-340
A		1		2006-67	340-360
B		1		2006-67	340-360
C		1		2006-67	340-360
D	1			2006-67	340-360
E	1			2006-67	340-360
A			1	2006-67	360-380
B			1	2006-67	360-380
C			1	2006-67	360-380

GcTq-5

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A		1		2006-43	60-80
B	1			2006-43	60-80
C	1			2006-43	60-80
A	1			2006-43	80-100
B	1			2006-43	80-100
C	1			2006-43	80-100
D	1			2006-43	80-100
A	1			2006-43	100-120
B	1			2006-43	100-120
C		1		2006-43	100-120
D		1		2006-43	100-120
E	1			2006-43	100-120
A	1			2006-43	120-140
B	1			2006-43	120-140
C	1			2006-43	120-140
A	1			2006-43	160-180
B	1			2006-43	160-180
C		1		2006-43	160-180
D		1		2006-43	160-180
A	1			2006-43	140-160
B	1			2006-43	140-160
C	1			2006-43	140-160
A		1		2006-43	180-200
B	1			2006-43	180-200
C		1		2006-43	180-200
D		1		2006-43	180-200
E	1			2006-43	180-200
F	1			2006-43	180-200
G	1			2006-43	180-200
A	1			2006-43	240-260
B	1			2006-43	240-260
C	1			2006-43	240-260
D	1			2006-43	240-260
A	1			2006-43	220-240
B	1			2006-43	220-240
C	1			2006-43	220-240
D		1		2006-43	220-240
A		1		2006-43	260-280
B		1		2006-43	260-280
C	1			2006-43	260-280
A	1			2006-43	240-260
B	1			2006-43	240-260
C	1			2006-43	240-260
A	1			2006-43	280-300
B	1			2006-43	280-300
C		1		2006-43	280-300

GcTq-5, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
D	1			2006-43	280-300
A	1			2006-43	300-320
B	1			2006-43	300-320
C	1			2006-43	300-320
D	1			2006-43	300-320
E	1			2006-43	300-320
A	1			2006-43	320-340
B	1			2006-43	320-340
C	1			2006-43	320-340
D	1			2006-43	320-340
E	1			2006-43	320-340
F	1			2006-43	320-340
G	1			2006-43	320-340
H	1			2006-43	320-340
I	1			2006-43	320-340
A	1			2006-43	340-360
B		1		2006-43	340-360
C		1		2006-43	340-360
D	1			2006-43	340-360
E	1			2006-43	340-360
A	1			2006-43	360-380
B	1			2006-43	360-380
C	1			2006-43	360-380
D		1		2006-43	360-380
A	1			2006-43	380-400
B		1		2006-43	380-400
C	1			2006-43	380-400
A		1		2006-43	380-400
B	1			2006-43	380-400
C	1			2006-43	380-400
D	1			2006-43	380-400
A	1			2006-43	400-420
B		1		2006-43	400-420
C		1		2006-43	400-420
A		1		2006-43	420-400
B	1			2006-43	420-400
C	1			2006-43	420-400
A		1		2006-43	440-460
B	1			2006-43	440-460
C	1			2006-43	440-460
A	1			2006-43	460-480
B	1			2006-43	460-480
C	1			2006-43	460-480
A	1			2006-43	480-300
B		1		2006-43	480-300
C	1			2006-43	480-300

GcTq-5, continued (b)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
D	1			2006-43	480-300
E	1			2006-43	480-300
AA	1			2006-45	80-100
B	1			2006-45	80-100
I	1			2006-45	80-100
DD	1			2006-45	80-100
Z	1			2006-45	80-100
G	1			2006-45	60-80
L	1			2006-45	60-80
J	1			2006-45	60-80
A	1			2006-45	100-120
B	1			2006-45	100-120
G	1			2006-45	100-120
F		1		2006-45	120-140
K				2006-45	120-140
M				2006-45	120-140
B	1			2006-45	140-160
Q		1		2006-45	140-160
H	1			2006-45	140-160
E	1			2006-45	160-180
F	1			2006-45	160-180
G	1			2006-45	160-180
R	1			2006-45	160-180
B				2006-45	180-200
E				2006-45	180-200
K				2006-45	180-200
O		1		2006-45	180-200
P		1		2006-45	180-200
BB		1		2006-45	180-200
A	1			2006-45	200-220
D	1			2006-45	200-220
H	1			2006-45	200-220
I	1			2006-45	200-220
Z	1			2006-45	200-220
BB	1			2006-45	200-220
GG		1		2006-45	200-220
D		1		2006-45	240-260
H	1			2006-45	240-260
N	1			2006-45	240-260
U		1		2006-45	240-260
HH	1			2006-45	240-260
MM	1			2006-45	240-260
D	1			2006-45	260-280
L	1			2006-45	260-280
V		1		2006-45	260-280
BB	1			2006-45	260-280
FF	1			2006-45	260-280

GcTq-5, continued (c)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
B	1			2006-45	340-460
C	1			2006-45	340-460
J				2006-45	340-460
P	1			2006-45	340-460
V	1			2006-45	340-460
B	1			2006-45	360-340
L	1			2006-45	360-340
U			1	2006-45	360-340
Y	1			2006-45	360-340
AA	1			2006-45	360-340
Q	1			2006-45	360-380
F	1			2006-45	360-380
U		1		2006-45	360-380
B	1			2006-45	380-400
M	1			2006-45	380-400
C	1			2006-45	320-340
F		1		2006-45	320-340
J	1			2006-45	320-340
D		1		2006-45	320-340
T	1			2006-45	320-340
Y		1		2006-45	320-340
T	1			2006-45	320-340
C	1			2006-45	400-420
J	1			2006-45	400-420
E			1	2006-45	420-440
H	1			2006-45	420-440

GcTq-6

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A		1		2006-67	40-60
B	1			2006-67	40-60
C		1		2006-67	40-60
D	1			2006-67	40-60
E	1			2006-67	40-60
F	1			2006-67	40-60
G	1			2006-67	40-60
H			1	2006-67	40-60
I		1		2006-67	40-60
J		1		2006-67	40-60
K		1		2006-67	40-60
L	1			2006-67	40-60
M	1			2006-67	40-60
A		1		2006-67	60-80
B		1		2006-67	60-80
C		1		2006-67	60-80
D		1		2006-67	60-80
E	1			2006-67	60-80
F		1		2006-67	60-80
G	1			2006-67	60-80
H	1			2006-67	60-80
I		1		2006-67	60-80
J		1		2006-67	60-80
K		1		2006-67	60-80
L	1			2006-67	60-80
M			1	2006-67	60-80
N		1		2006-67	60-80
O		1		2006-67	60-80
P	1			2006-67	60-80
Q		1		2006-67	60-80
R	1			2006-67	60-80
S		1		2006-67	60-80
T		1		2006-67	60-80
U		1		2006-67	60-80
V	1			2006-67	60-80
W			1	2006-67	60-80
A	1			2006-67	80-100
B			1	2006-67	80-100
C		1		2006-67	80-100
D		1		2006-67	80-100
E		1		2006-67	80-100
F	1			2006-67	80-100
G		1		2006-67	80-100
H			1	2006-67	80-100
I		1		2006-67	80-100
J		1		2006-67	80-100
K			1	2006-67	80-100

GcTq-6, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
L		1		2006-67	80-100
M		1		2006-67	80-100
N		1		2006-67	80-100
O	1			2006-67	80-100
P		1		2006-67	80-100
Q			1	2006-67	80-100
R			1	2006-67	80-100
S		1		2006-67	80-100
T	1			2006-67	80-100
U		1		2006-67	80-100
V	1			2006-67	80-100
W	1			2006-67	80-100
X	1			2006-67	80-100
Y	1			2006-67	80-100
Z		1		2006-67	80-100
A		1		2006-67	100-120
B		1		2006-67	100-120
C	1			2006-67	100-120
D		1		2006-67	100-120
E	1			2006-67	100-120
F		1		2006-67	100-120
G		1		2006-67	100-120
H		1		2006-67	100-120
I	1			2006-67	100-120
J	1			2006-67	100-120
K		1		2006-67	100-120
L		1		2006-67	100-120
M		1		2006-67	100-120
N		1		2006-67	100-120
O		1		2006-67	100-120
P		1		2006-67	100-120
Q	1			2006-67	100-120
R		1		2006-67	100-120
S	1			2006-67	100-120
T		1		2006-67	100-120
U		1		2006-67	100-120
V		1		2006-67	100-120
W		1		2006-67	100-120
X	1			2006-67	100-120
Y			1	2006-67	100-120
Z	1			2006-67	100-120
A		1		2006-67	100-120
B		1		2006-67	100-120
C		1		2006-67	100-120
D		1		2006-67	100-120
E			1	2006-67	100-120
F		1		2006-67	100-120

GcTq-6, continued (b)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
G	1			2006-67	100-120
H	1			2006-67	100-120
I			1	2006-67	100-120
J		1		2006-67	100-120
K		1		2006-67	100-120
L			1	2006-67	100-120
M		1		2006-67	100-120
N	1			2006-67	100-120
O		1		2006-67	100-120
P	1			2006-67	100-120
Q		1		2006-67	100-120
R		1		2006-67	100-120
S	1			2006-67	100-120
T		1		2006-67	100-120
U	1			2006-67	100-120
V	1			2006-67	100-120
W		1		2006-67	100-120
X		1		2006-67	100-120
Y	1			2006-67	100-120
A		1		2006-67	120-140
B	1			2006-67	120-140
C	1			2006-67	120-140
D	1			2006-67	120-140
E	1			2006-67	120-140
F		1		2006-67	120-140
G		1		2006-67	120-140
H		1		2006-67	120-140
I		1		2006-67	120-140
J		1		2006-67	120-140
K		1		2006-67	120-140
L		1		2006-67	120-140
M		1		2006-67	120-140
N		1		2006-67	120-140
O		1		2006-67	120-140
P		1		2006-67	120-140
Q		1		2006-67	120-140
R	1			2006-67	120-140
S			1	2006-67	120-140
T	1			2006-67	120-140
U	1			2006-67	120-140
V			1	2006-67	120-140
W	1			2006-67	120-140
X			1	2006-67	120-140
Y	1			2006-67	120-140
Z		1		2006-67	120-140
A	1			2006-67	120-140
B	1			2006-67	120-140
C		1		2006-67	120-140

GcTq-6, continued (c)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
D		1		2006-67	120-140
E	1			2006-67	120-140
F	1			2006-67	120-140
G			1	2006-67	120-140
H	1			2006-67	120-140
A		1		2006-67	140-160
B		1		2006-67	140-160
C			1	2006-67	140-160
D	1			2006-67	140-160
E		1		2006-67	140-160
F	1			2006-67	140-160
G		1		2006-67	140-160
H		1		2006-67	140-160
I	1			2006-67	140-160
J	1			2006-67	140-160
K	1			2006-67	140-160
L				2006-67	140-160
M	1			2006-67	140-160
N		1		2006-67	140-160
O			1	2006-67	140-160
P	1			2006-67	140-160
Q	1			2006-67	140-160
R	1			2006-67	140-160
S	1			2006-67	140-160
T	1			2006-67	140-160
U	1			2006-67	140-160
V	1			2006-67	140-160
W	1			2006-67	140-160
X	1			2006-67	140-160
Y	1			2006-67	140-160
Z	1			2006-67	140-160
A	1			2006-67	140-160
B		1		2006-67	140-160
C	1			2006-67	140-160
D	1			2006-67	140-160
A		1		2006-67	160-180
B		1		2006-67	160-180
C				2006-67	160-180
D		1		2006-67	160-180
E	1			2006-67	160-180
F		1		2006-67	160-180
G		1		2006-67	160-180
H		1		2006-67	160-180
I		1		2006-67	160-180
J	1			2006-67	160-180
K	1			2006-67	160-180
L	1			2006-67	160-180
M			1	2006-67	160-180

GcTq-6, continued (d)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
N	1			2006-67	160-180
O		1		2006-67	160-180
P	1			2006-67	160-180
Q			1	2006-67	160-180
R		1		2006-67	160-180
S	1			2006-67	160-180
T	1			2006-67	160-180
A	1			2006-67	180-200
B	1			2006-67	180-200
C		1		2006-67	180-200
D	1			2006-67	180-200
E		1		2006-67	180-200
F		1		2006-67	180-200
G	1			2006-67	180-200
H		1		2006-67	180-200
I	1			2006-67	180-200
J		1		2006-67	180-200
K		1		2006-67	180-200
L			1	2006-67	180-200
M	1			2006-67	180-200
N			1	2006-67	180-200
O		1		2006-67	180-200
P		1		2006-67	180-200
Q	1			2006-67	180-200
R		1		2006-67	180-200
S		1		2006-67	180-200
T		1		2006-67	180-200
U	1			2006-67	180-200
V		1		2006-67	180-200
W	1			2006-67	180-200
X			1	2006-67	180-200
Y		1		2006-67	180-200
Z	1			2006-67	180-200
A		1		2006-67	180-200
A		1		2006-67	200-220
B	1			2006-67	200-220
C		1		2006-67	200-220
D		1		2006-67	200-220
E		1		2006-67	200-220
F		1		2006-67	200-220
G	1			2006-67	200-220
H	1			2006-67	200-220
I	1			2006-67	200-220
J		1		2006-67	200-220
K	1			2006-67	200-220
L	1			2006-67	200-220
M		1		2006-67	200-220
N		1		2006-67	200-220

GcTq-6, continued (e)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
O	1			2006-67	200-220
P			1	2006-67	200-220
Q	1			2006-67	200-220
R	1			2006-67	200-220
S	1			2006-67	200-220
T	1			2006-67	200-220
U	1			2006-67	200-220
V	1			2006-67	200-220
W		1		2006-67	200-220
X	1			2006-67	200-220
Y		1		2006-67	200-220
Z		1		2006-67	200-220
A		1		2006-67	200-220
B		1		2006-67	200-220
C	1			2006-67	200-220
D	1			2006-67	200-220
E		1		2006-67	200-220
F	1			2006-67	200-220
G	1			2006-67	200-220
H	1			2006-67	200-220
I	1			2006-67	200-220
J	1			2006-67	200-220
K	1			2006-67	200-220
L		1		2006-67	200-220
M	1			2006-67	200-220
N		1		2006-67	200-220
O		1		2006-67	200-220
P	1			2006-67	200-220
Q	1			2006-67	200-220
R	1			2006-67	200-220
A	1			2006-67	220-240
B	1			2006-67	220-240
C	1			2006-67	220-240
D		1		2006-67	220-240
E		1		2006-67	220-240
F	1			2006-67	220-240
G		1		2006-67	220-240
H	1			2006-67	220-240
I			1	2006-67	220-240
J	1			2006-67	220-240
K	1			2006-67	220-240
L	1			2006-67	220-240
M	1			2006-67	220-240
N	1			2006-67	220-240
O	1			2006-67	220-240
P	1			2006-67	220-240
Q	1			2006-67	220-240
R		1		2006-67	220-240

GcTq-6, continued (f)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
S	1			2006-67	220-240
T			1	2006-67	220-240
U	1			2006-67	220-240
V		1		2006-67	220-240
W	1			2006-67	220-240
X	1			2006-67	220-240
Y		1		2006-67	220-240
Z	1			2006-67	220-240
A	1			2006-67	240-260
B	1			2006-67	240-260
C		1		2006-67	240-260
D			1	2006-67	240-260
E	1			2006-67	240-260
F		1		2006-67	240-260
G	1			2006-67	240-260
H		1		2006-67	240-260

GcTq-6, continued (g)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
I		1		2006-67	240-260
J		1		2006-67	240-260
K	1			2006-67	240-260
L	1			2006-67	240-260
M			1	2006-67	240-260
N				2006-67	240-260
O		1		2006-67	240-260
P		1		2006-67	240-260
Q	1			2006-67	240-260
R		1		2006-67	240-260
S		1		2006-67	240-260
T	1			2006-67	240-260
U	1			2006-67	240-260
V	1			2006-67	240-260
W		1		2006-67	240-260
X		1		2006-67	240-260

<u>GcTq-7</u>

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A		1		2006-64	60-80
B	1			2006-64	60-80
C	1			2006-64	60-80
D	1			2006-64	60-80
E	1			2006-64	60-80
F	1			2006-64	60-80
G	1			2006-64	60-80
H	1			2006-64	60-80
I	1			2006-64	60-80
J	1			2006-64	60-80
K	1			2006-64	60-80
A	1			2006-64	60-80
B	1			2006-64	60-80
C	1			2006-64	60-80
D	1			2006-64	60-80
E	1			2006-64	60-80
F	1			2006-64	60-80
G	1			2006-64	60-80
H	1			2006-64	60-80
I	1			2006-64	60-80
J	1			2006-64	60-80

GcTq-7, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
K	1			2006-64	60-80
A	1			2006-64	80-100
B	1			2006-64	80-100
C	1			2006-64	80-100
D	1			2006-64	80-100
E	1			2006-64	80-100
F	1			2006-64	80-100
G	1			2006-64	80-100
H	1			2006-64	80-100
I	1			2006-64	80-100
J	1			2006-64	80-100
K		1		2006-64	80-100
L	1			2006-64	80-100
M	1			2006-64	80-100
N	1			2006-64	80-100
A		1		2006-64	100-120
B		1		2006-64	100-120
C	1			2006-64	100-120
D	1			2006-64	100-120
E			1	2006-64	100-120
F	1			2006-64	100-120

GcTq-7, continued (b)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
G	1			2006-64	100-120
H	1			2006-64	100-120
I			1	2006-64	100-120
J	1			2006-64	100-120
K			1	2006-64	100-120
L			1	2006-64	100-120
M			1	2006-64	100-120
N	1			2006-64	100-120
O	1			2006-64	100-120
P			1	2006-64	100-120
Q	1			2006-64	100-120
A	1			2006-64	120-140
B			1	2006-64	120-140
C	1			2006-64	120-140
D	1			2006-64	120-140
E	1			2006-64	120-140
F	1			2006-64	120-140
G	1			2006-64	120-140
H		1		2006-64	120-140
I	1			2006-64	120-140
J			1	2006-64	120-140
K	1			2006-64	120-140
L	1			2006-64	120-140
A		1		2006-64	140-180
B		1		2006-64	140-180
C	1			2006-64	140-180
D	1			2006-64	140-180
E		1		2006-64	140-180
F	1			2006-64	140-180
G		1		2006-64	140-180
H			1	2006-64	140-180
I	1			2006-64	140-180
J	1			2006-64	140-180
K	1			2006-64	140-180
L	1			2006-64	140-180
M	1			2006-64	140-180
N	1			2006-64	140-180
O	1			2006-64	140-180
P		1		2006-64	140-180
Q	1			2006-64	140-180
R	1			2006-64	140-180
S	1			2006-64	140-180
T	1			2006-64	140-180
U		1		2006-64	140-180
V		1		2006-64	140-180
W			1	2006-64	140-180
A			1	2006-64	160-180
B	1			2006-64	160-180

GcTq-7, continued (c)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
C	1			2006-64	160-180
D		1		2006-64	160-180
E	1			2006-64	160-180
F		1		2006-64	160-180
G		1		2006-64	160-180
H	1			2006-64	160-180
I	1			2006-64	160-180
J	1			2006-64	160-180
K	1			2006-64	160-180
L		1		2006-64	160-180
M	1			2006-64	160-180
N		1		2006-64	160-180
O	1			2006-64	160-180
P			1	2006-64	160-180
Q	1			2006-64	160-180
R			1	2006-64	160-180
S	1			2006-64	160-180
T	1			2006-64	160-180
U	1			2006-64	160-180
V		1		2006-64	160-180
W	1			2006-64	160-180
X	1			2006-64	160-180
Y	1			2006-64	160-180
Z	1			2006-64	160-180
AA	1			2006-64	160-180
BB		1		2006-64	160-180
CC	1			2006-64	160-180
DD	1			2006-64	160-180
EE	1			2006-64	160-180
FF		1		2006-64	160-180
GG	1			2006-64	160-180
HH		1		2006-64	160-180
II		1		2006-64	160-180
JJ	1			2006-64	160-180
KK	1			2006-64	160-180
A	1			2006-64	180-200
B	1			2006-64	180-200
C		1		2006-64	180-200
D	1			2006-64	180-200
E		1		2006-64	180-200
F	1			2006-64	180-200
G	1			2006-64	180-200
H	1			2006-64	180-200
I	1			2006-64	180-200
A	1			2006-64	200-220
B	1			2006-64	200-220
C	1			2006-64	200-220
D	1			2006-64	200-220

GcTq-7, continued (d)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
E	1			2006-64	200-220
F	1			2006-64	200-220
A	1			2006-64	240-260
B	1			2006-64	240-260
C	1			2006-64	240-260
D		1		2006-64	240-260
E	1			2006-64	240-260
A	1			2006-64	240-260
B	1			2006-64	240-260
C	1		1	2006-64	240-260

GcTq-7, continued (e)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
D	1			2006-64	240-260
A			1	2006-64	260-280
B			1	2006-64	260-280
C			1	2006-64	260-280
D	1			2006-64	260-280
A	1			2006-64	280-290
B		1		2006-64	280-290
C	1			2006-64	280-290
D	1			2006-64	280-290

<u>**GcTq-9**</u>

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A		1		2006-50	60-80
B		1		2006-50	60-80
A	1			2006-50	80-100
B		1		2006-50	80-100
C	1			2006-50	80-100
D	1			2006-50	80-100
E		1		2006-50	80-100
F		1		2006-50	80-100
G		1		2006-50	80-100
H	1			2006-50	80-100
A	1			2006-50	100-120
B		1		2006-50	100-120
C	1			2006-50	100-120
D	1			2006-50	100-120
E	1			2006-50	100-120
F	1			2006-50	100-120
G	1			2006-50	100-120
H	1			2006-50	100-120
I	1			2006-50	100-120
J	1			2006-50	100-120
K	1			2006-50	100-120
L	1			2006-50	100-120
A	1			2006-50	120-140
B	1			2006-50	120-140
C		1		2006-50	120-140
D	1			2006-50	120-140
E	1			2006-50	120-140
F	1			2006-50	120-140

GcTq-9, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
G	1			2006-50	120-140
H	1			2006-50	120-140
I	1			2006-50	120-140
J		1		2006-50	120-140
K			1	2006-50	120-140
L	1			2006-50	120-140
M	1			2006-50	120-140
N	1			2006-50	120-140
O		1		2006-50	120-140
P	1			2006-50	120-140
Q	1			2006-50	120-140
R	1			2006-50	120-140
S	1			2006-50	120-140
T			1	2006-50	120-140
U	1			2006-50	120-140
V	1			2006-50	120-140
A	1			2006-50	120-140
B	1			2006-50	120-140
C	1			2006-50	120-140
D	1			2006-50	120-140
E	1			2006-50	120-140
F	1			2006-50	120-140
G	1			2006-50	120-140
H		1		2006-50	120-140
I		1		2006-50	120-140
J		1		2006-50	120-140
K	1			2006-50	120-140
L		1		2006-50	120-140

GcTq-9, continued (b)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
M		1		2006-50	120-140
N		1		2006-50	120-140
O	1			2006-50	120-140
P	1			2006-50	120-140
Q		1		2006-50	120-140
R		1		2006-50	120-140
S			1	2006-50	120-140
A		1		2006-50	120-140
B	1			2006-50	120-140
C	1			2006-50	120-140
D		1		2006-50	120-140
E	1			2006-50	120-140
F	1			2006-50	120-140
G	1			2006-50	120-140
H		1		2006-50	120-140
I	1			2006-50	120-140
J	1			2006-50	120-140
K	1			2006-50	120-140
L		1		2006-50	120-140
M		1		2006-50	120-140
N		1		2006-50	120-140
O		1		2006-50	120-140
P		1		2006-50	120-140
Q		1		2006-50	120-140
R		1		2006-50	120-140
S			1	2006-50	120-140
T	1			2006-50	120-140
A	1			2006-50	120-140
B	1			2006-50	120-140
C	1			2006-50	120-140
D	1			2006-50	120-140
E			1	2006-50	120-140
F	1			2006-50	120-140
G			1	2006-50	120-140
H		1		2006-50	120-140
I		1		2006-50	120-140
J	1			2006-50	120-140
K			1	2006-50	120-140
L		1		2006-50	120-140
M	1			2006-50	120-140
N			1	2006-50	120-140
O		1		2006-50	120-140
P	1			2006-50	120-140
Q	1			2006-50	120-140
R	1			2006-50	120-140
S		1		2006-50	120-140
T		1		2006-50	120-140
U	1			2006-50	120-140

GcTq-9, continued (c)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
V		1		2006-50	120-140
W	1			2006-50	120-140
X		1		2006-50	120-140
Y			1	2006-50	120-140
Z		1		2006-50	120-140
AA	1			2006-50	120-140
A	1			2006-50	120-140
B	1			2006-50	120-140
C	1			2006-50	120-140
D		1		2006-50	120-140
E	1			2006-50	120-140
F		1		2006-50	120-140
G	1			2006-50	120-140
H	1			2006-50	120-140
I	1			2006-50	120-140
J	1			2006-50	120-140
K	1			2006-50	120-140
L			1	2006-50	120-140
M	1			2006-50	120-140
N	1			2006-50	120-140
O	1			2006-50	120-140
P	1			2006-50	120-140
Q		1		2006-50	120-140
R	1			2006-50	120-140
S	1			2006-50	120-140
T		1		2006-50	120-140
U	1			2006-50	120-140
A	1			2006-50	120-140
B		1		2006-50	120-140
C	1			2006-50	120-140
D	1			2006-50	120-140
E		1		2006-50	120-140
F	1			2006-50	120-140
G			1	2006-50	120-140
H		1		2006-50	120-140
I				2006-50	120-140
J	1			2006-50	120-140
K	1			2006-50	120-140
L	1			2006-50	120-140
M	1			2006-50	120-140
N			1	2006-50	120-140
O	1			2006-50	120-140
P				2006-50	120-140
Q	1			2006-50	120-140
R	1			2006-50	120-140
S	1			2006-50	120-140
T		1		2006-50	120-140
U	1			2006-50	120-140

GcTq-9, continued (d)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
V	1			2006-50	120-140
W	1			2006-50	120-140
X	1			2006-50	120-140
Y	1			2006-50	120-140
Z		1		2006-50	120-140
AA	1			2006-50	120-140
A		1		2006-50	120-150
B	1			2006-50	120-150
C	1			2006-50	120-150
D	1			2006-50	120-150
E	1			2006-50	120-150

GcTq-9, continued (e)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
F	1			2006-50	120-150
G		1		2006-50	120-150
H		1		2006-50	120-150
I	1			2006-50	120-150
J	1			2006-50	120-150
K			1	2006-50	120-150
L		1		2006-50	120-150
M	1			2006-50	120-150
N	1			2006-50	120-150
O			1	2006-50	120-150

GcTq-13

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A	1			2006-51	60-80
B	1			2006-51	60-80
C	1			2006-51	60-80
D	1			2006-51	60-80
A		1		2006-51	80-100
B	1			2006-51	80-100
C	1			2006-51	80-100
D	1			2006-51	80-100
E	1			2006-51	80-100
F	1			2006-51	80-100
G	1			2006-51	80-100
H	1			2006-51	80-100
A		1		2006-51	100-120
B		1		2006-51	100-120
C	1			2006-51	100-120
D		1		2006-51	100-120
E	1			2006-51	100-120
F	1			2006-51	100-120
G	1			2006-51	100-120
H		1		2006-51	100-120
I		1		2006-51	100-120
J	1			2006-51	100-120
K		1		2006-51	100-120
L			1	2006-51	100-120
M	1			2006-51	100-120
N	1			2006-51	100-120
O	1			2006-51	100-120

GcTq-13, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
P			1	2006-51	100-120
A	1			2006-51	120-140
B		1		2006-51	120-140
C		1		2006-51	120-140
D		1		2006-51	120-140

GcTq-11

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A	1			2006-59	80-100
A		1		2006-59	100-120
B	1			2006-59	100-120
C	1			2006-59	100-120
D			1	2006-59	100-120
E	1			2006-59	100-120
A	1			2006-59	120-140
B	1			2006-59	120-140
C	1			2006-59	120-140
D		1		2006-59	120-140
E				2006-59	120-140
F	1			2006-59	120-140
G	1			2006-59	120-140
H		1		2006-59	120-140
A	1			2006-59	140-160
B	1			2006-59	140-160
C		1		2006-59	140-160
D		1		2006-59	140-160
E		1		2006-59	140-160
F		1		2006-59	140-160
G	1			2006-59	140-160
A			1	2006-59	160-180
B	1			2006-59	160-180
C		1		2006-59	160-180
D	1			2006-59	160-180
E	1			2006-59	160-180
F	1			2006-59	160-180
G		1		2006-59	160-180
H		1		2006-59	160-180
I	1			2006-59	160-180
J	1			2006-59	160-180
A	1			2006-59	180-200
B		1		2006-59	180-200
C	1			2006-59	180-200
D		1		2006-59	180-200
E	1			2006-59	180-200
F	1			2006-59	180-200
G		1		2006-59	180-200
H	1			2006-59	180-200
I		1		2006-59	180-200
J	1			2006-59	180-200
K	1			2006-59	180-200
L	1			2006-59	180-200
M		1		2006-59	180-200
N	1			2006-59	180-200
O	1			2006-59	180-200
P			1	2006-59	180-200

GcTq-11, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
Q			1	2006-59	180-200
R	1			2006-59	180-200
S			1	2006-59	180-200
T	1			2006-59	180-200
U	1			2006-59	180-200
V		1		2006-59	180-200
A		1		2006-59	200-220
B		1		2006-59	200-220
C	1			2006-59	200-220
D	1			2006-59	200-220
E	1			2006-59	200-220
F	1			2006-59	200-220
G			1	2006-59	200-220
H		1		2006-59	200-220
I			1	2006-59	200-220
J	1			2006-59	200-220
K	1			2006-59	200-220
L	1			2006-59	200-220
M	1			2006-59	200-220
A		1		2006-59	200-220
B	1			2006-59	200-220
C	1			2006-59	200-220
D	1			2006-59	200-220
E	1			2006-59	200-220
F	1			2006-59	200-220
G			1	2006-59	200-220
H	1			2006-59	200-220

GcTr-5

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A	1			05-12	308-336
B	1			05-12	308-336
C	1			05-12	308-336
D	1			05-12	308-336
E	1			05-12	308-336
F	1			05-12	308-336
A		1		05-13	28-56
B		1		05-13	28-56
C		1		05-13	28-56
D			1	05-13	28-56
E		1		05-13	28-56
F			1	05-13	28-56
G		1		05-13	28-56
H		1		05-13	28-56
I			1	05-13	28-56
J		1		05-13	28-56
K		1		05-13	28-56
L			1	05-13	28-56
M		1		05-13	28-56
N		1		05-13	28-56
O	1			05-13	28-56
P	1			05-13	28-56
Q	1			05-13	28-56
A	1			05-13	112-140
B	1			05-13	112-140
C		1		05-13	112-140
D		1		05-13	112-140
E	1			05-13	112-140
F			1	05-13	112-140
G	1			05-13	112-140
H			1	05-13	112-140
I	1			05-13	112-140
J	1			05-13	112-140
K		1		05-13	112-140
L		1		05-13	112-140
				05-13	168-196
A		1		05-13	196-224
B	1			05-13	196-224
C			1	05-13	196-224
D	1			05-13	196-224
A				05-13	224-252
B		1		05-13	224-252
C	1			05-13	224-252
D	1			05-13	224-252
A	1			05-13	252-280
B	1			05-13	252-280
C		1		05-13	252-280

GcTr-5, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
D		1		05-13	252-280
E			1	05-13	252-280
F			1	05-13	252-280
G			1	05-13	252-280
H		1		05-13	252-280
A	1			05-13	280-308
B			1	05-13	280-308
C	1			05-13	280-308
D			1	05-13	280-308
E				05-13	280-308
F				05-13	280-308
G				05-13	280-308
H			1	05-13	280-308
I	1			05-13	280-308
J		1		05-13	280-308
K	1			05-13	280-308
L	1			05-13	280-308
				05-13	280-308
A	1			05-13	308-336
B	1			05-13	308-336
C	1			05-13	308-336
D	1			05-13	308-336
E	1			05-13	308-336
F	1			05-13	308-336
G	1			05-13	308-336
H	1			05-13	308-336
				05-13	336-343
A			1	05-14	56-84
B	1			05-14	56-84
C			1	05-14	56-84
D	1			05-14	56-84
E	1			05-14	56-84
F	1			05-14	56-84
A		1		05-14	84-112
B	1			05-14	84-112
C			1	05-14	84-112
D	1			05-14	84-112
E		1		05-14	84-112
F	1			05-14	84-112
G			1	05-14	84-112
H			1	05-14	84-112
I	1			05-14	84-112
J		1		05-14	84-112
K		1		05-14	84-112
L	1			05-14	84-112
M	1			05-14	84-112
N		1		05-14	84-112

GcTr-5, continued (b)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
O	1			05-14	84-112
P		1		05-14	84-112
Q		1		05-14	84-112
R			1	05-14	84-112
S	1			05-14	84-112
T			1	05-14	84-112
U			1	05-14	84-112
V	1			05-14	84-112
W			1	05-14	84-112
X		1		05-14	84-112
Y	1			05-14	84-112
Z		1		05-14	84-112
AA		1		05-14	84-112
BB		1		05-14	84-112
A		1		05-14	140-168
B			1	05-14	140-168
C		1		05-14	140-168
D			1	05-14	140-168
E			1	05-14	140-168
F		1		05-14	140-168
G	1			05-14	140-168
H			1	05-14	140-168
I	1			05-14	140-168
J	1			05-14	140-168
K		1		05-14	140-168
L		1		05-14	140-168
M	1			05-14	140-168
N			1	05-14	140-168
A	1			05-14	168-196
B	1			05-14	168-196
C		1		05-14	168-196
D	1			05-14	168-196
E	1			05-14	168-196
A		1		05-14	224-252
B			1	05-14	224-252
C			1	05-14	224-252
D			1	05-14	224-252
E	1			05-14	224-252
F	1			05-14	224-252
A	1			05-14	252-280
B	1			05-14	252-280
C		1		05-14	252-280
D		1		05-14	252-280
E			1	05-14	252-280
				05-14	280-308
A			1	05-14	308-346
B	1			05-14	308-346
C		1		05-14	308-346

GcTr-5, continued (c)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
D			1	05-14	308-346
E			1	05-14	308-346
F	1			05-14	308-346
G	1			05-14	308-346
H			1	05-14	308-346
I	1			05-14	308-346
J		1		05-14	308-346
K	1			05-14	308-346
L	1			05-14	308-346
A			1	05-14	346-374
B		1		05-14	346-374
C		1		05-14	346-374
D		1		05-14	346-374
E			1	05-14	346-374
F		1		05-14	374-402
A	1			05-15	168-196
B	1			05-15	168-196
C		1		05-15	168-196
D		1		05-15	168-196
E			1	05-15	168-196
F			1	05-15	168-196
G	1			05-15	168-196
H	1			05-15	168-196
I	1			05-15	168-196
J	1			05-15	168-196
A	1			05-15	196-224
B		1		05-15	196-224
C	1			05-15	196-224
D		1		05-15	196-224
A	1			05-15	224-252
B		1		05-15	224-252
C	1			05-15	224-252
D	1			05-15	224-252
E	1			05-15	224-252
F	1			05-15	224-252
G			1	05-15	224-252
H	1			05-15	224-252
I		1		05-15	224-252
J	1			05-15	224-252
K			1	05-15	224-252
A			1	05-15	252-280
B			1	05-15	252-280
C	1			05-15	252-280
D	1			05-15	252-280
E	1			05-15	252-280
A	1			05-15	280-308
B	1			05-15	280-308
C			1	05-15	280-308

GcTr-5, continued (c)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
D		1		05-15	280-308
E			1	05-15	280-308
F	1			05-15	280-308
				05-15	28-56
A		1		05-15	308-336
B		1		05-15	308-336
C			1	05-15	308-336
D			1	05-15	308-336
E			1	05-15	308-336
F	1			05-15	308-336
G		1		05-15	308-336
A		1		05-15	336-364
B		1		05-15	336-364

GcTr-6

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A		1		05-35	140-168
B		1		05-35	140-168
A			1	05-35	168-196
B				05-35	168-196
C	1			05-35	168-196
D			1	05-35	168-196
E			1	05-35	168-196
F	1			05-35	168-196
G			1	05-35	168-196
H		1		05-35	168-196
I		1		05-35	168-196
A			1	05-35	224-252
B		1		05-35	224-252
C		1		05-35	224-252
D	1			05-35	224-252
E			1	05-35	224-252
A		1		05-35	252-269
B	1			05-35	252-269
C	1			05-35	252-269

GcTr-8

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A	1			2006-62	60-80
B	1			2006-62	60-80
C	1			2006-62	60-80
A	1			2006-62	100-120
B	1			2006-62	100-120
C	1			2006-62	100-120
D	1			2006-62	100-120
A	1			2006-62	100-120
B	1			2006-62	100-120
C	1			2006-62	100-120
D	1			2006-62	100-120
E	1			2006-62	100-120
F	1			2006-62	100-120
G	1			2006-62	100-120
H	1			2006-62	100-120
I	1			2006-62	100-120
A	1			2006-62	120-140
B	1			2006-62	120-140
C		1		2006-62	120-140
D		1		2006-62	120-140
E		1		2006-62	120-140
F		1		2006-62	120-140
G		1		2006-62	120-140
H	1			2006-62	120-140
I		1		2006-62	120-140
J	1			2006-62	120-140
K	1			2006-62	120-140
L	1			2006-62	120-140
M		1		2006-62	120-140
N	1			2006-62	120-140
O	1			2006-62	120-140
A		1		2006-62	140-160
B		1		2006-62	140-160
C	1			2006-62	140-160
D		1		2006-62	140-160
E		1		2006-62	140-160
F	1			2006-62	140-160
G	1			2006-62	140-160
H	1			2006-62	140-160
I		1		2006-62	140-160
J	1			2006-62	140-160
K		1		2006-62	140-160
L	1			2006-62	140-160
M		1		2006-62	140-160
N	1			2006-62	140-160
O	1			2006-62	140-160
P	1			2006-62	140-160

GcTr-8, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
Q	1			2006-62	140-160
R	1			2006-62	140-160
S	1			2006-62	140-160
T	1			2006-62	140-160
U	1			2006-62	140-160
V	1			2006-62	140-160
W	1			2006-62	140-160
X	1			2006-62	140-160
Y	1			2006-62	140-160
Z			1	2006-62	120-140
A	1			2006-62	120-140
B	1			2006-62	120-140
C	1			2006-62	120-140
D	1			2006-62	120-140
E	1			2006-62	120-140
F	1			2006-62	120-140
G	1			2006-62	120-140
H	1			2006-62	120-140
I			1	2006-62	120-140
J	1			2006-62	120-140
K		1		2006-62	120-140
L		1		2006-62	120-140
M	1			2006-62	120-140
N	1			2006-62	120-140
O	1			2006-62	120-140
P			1	2006-62	120-140
A	1			2006-62	160-180
B	1			2006-62	160-180
C	1			2006-62	160-180
D		1		2006-62	160-180
E	1			2006-62	160-180
F	1			2006-62	160-180
G		1		2006-62	160-180
H		1		2006-62	160-180
I	1			2006-62	160-180
J		1		2006-62	160-180
K		1		2006-62	160-180
L	1			2006-62	160-180
M	1			2006-62	160-180
N	1			2006-62	160-180
O	1			2006-62	160-180
P		1		2006-62	160-180
Q	1			2006-62	160-180
R	1			2006-62	160-180
S	1			2006-62	160-180
T		1		2006-62	160-180
U	1			2006-62	160-180

GcTr-8, continued (b)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
V	1			2006-62	160-180
W	1			2006-62	160-180
X		1		2006-62	160-180
Y	1			2006-62	160-180
Z	1			2006-62	160-180
A		1		2006-62	160-180
B	1			2006-62	160-180
C	1			2006-62	160-180
D		1		2006-62	160-180
E	1			2006-62	160-180
F			1	2006-62	160-180
A		1		2006-62	180-200
B		1		2006-62	180-200
C	1	1		2006-62	180-200
D	1			2006-62	180-200
E	1			2006-62	180-200
F			1	2006-62	180-200
G	1			2006-62	180-200
H		1		2006-62	180-200
I		1		2006-62	180-200
J	1			2006-62	180-200
K	1			2006-62	180-200
L		1		2006-62	180-200
M	1			2006-62	180-200
N		1		2006-62	180-200
O	1			2006-62	180-200
P	1			2006-62	180-200
Q		1		2006-62	180-200
R		1		2006-62	180-200
S		1		2006-62	180-200
T			1	2006-62	180-200
U	1			2006-62	180-200
V	1			2006-62	180-200
W	1			2006-62	180-200
X	1			2006-62	180-200
Y	1			2006-62	180-200
Z	1			2006-62	180-200
A	1			2006-62	180-200
B	1			2006-62	180-200
C	1			2006-62	180-200
D		1		2006-62	180-200
A		1		2006-62	200-220
B	1			2006-62	200-220
C	1			2006-62	200-220
D	1			2006-62	200-220
E		1		2006-62	200-220
F	1			2006-62	200-220
G	1			2006-62	200-220

GcTr-8, continued (c)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
H	1			2006-62	200-220
I		1		2006-62	200-220
J		1		2006-62	200-220
K		1		2006-62	200-220
L	1			2006-62	200-220
M		1		2006-62	200-220
N			1	2006-62	200-220
O		1		2006-62	200-220
P	1			2006-62	200-220
Q	1			2006-62	200-220
R	1			2006-62	200-220
S	1			2006-62	200-220
T		1		2006-62	200-220
U	1			2006-62	200-220
V		1		2006-62	200-220
W	1			2006-62	200-220
X	1			2006-62	200-220
Y	1			2006-62	200-220
Z	1			2006-62	200-220
A		1		2006-62	220-240
B		1		2006-62	220-240
C		1		2006-62	220-240
D		1		2006-62	220-240
E		1		2006-62	220-240
F	1			2006-62	220-240
G		1		2006-62	220-240
H	1			2006-62	220-240
I	1			2006-62	220-240
J		1		2006-62	220-240
K		1		2006-62	220-240
L	1			2006-62	220-240
M		1		2006-62	220-240
N	1			2006-62	220-240
O	1			2006-62	220-240
P		1		2006-62	220-240
Q	1			2006-62	220-240
R		1		2006-62	220-240
S			1	2006-62	220-240
T	1			2006-62	220-240
U			1	2006-62	220-240
V		1		2006-62	220-240
W	1			2006-62	220-240
X		1		2006-62	220-240
Y	1			2006-62	220-240
Z		1		2006-62	220-240
A		1		2006-62	240-260
B	1			2006-62	240-260
C	1			2006-62	240-260

GcTr-8, continued (d)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
D	1			2006-62	240-260
E		1		2006-62	240-260
F		1		2006-62	240-260
G	1			2006-62	240-260
H		1		2006-62	240-260
I	1			2006-62	240-260
J		1		2006-62	240-260
K		1		2006-62	240-260
L		1		2006-62	240-260
M	1			2006-62	240-260
N	1			2006-62	240-260
O		1		2006-62	240-260
P		1		2006-62	240-260
Q	1			2006-62	240-260
R		1		2006-62	240-260
S	1			2006-62	240-260
T	1			2006-62	240-260
U	1			2006-62	240-260
V		1		2006-62	240-260
W			1	2006-62	240-260
X		1		2006-62	240-260
Y			1	2006-62	240-260
Z	1			2006-62	240-260
A	1			2006-62	260-280
B		1		2006-62	260-280
C		1		2006-62	260-280
D	1			2006-62	260-280
E	1			2006-62	260-280
F		1		2006-62	260-280
G	1			2006-62	260-280
H	1			2006-62	260-280
I		1		2006-62	260-280
J	1			2006-62	260-280
K			1	2006-62	260-280
L	1			2006-62	260-280
M		1		2006-62	260-280
N	1			2006-62	260-280
O		1		2006-62	260-280
P		1		2006-62	260-280
Q		1		2006-62	260-280
R	1			2006-62	260-280
S	1			2006-62	260-280
T			1	2006-62	260-280
U	1			2006-62	260-280
V				2006-62	260-280
W	1			2006-62	260-280
X		1		2006-62	260-280
Y		1		2006-62	260-280

GcTr-8, continued (e)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A		1		2006-62	268-280
B	1			2006-62	268-280
C		1		2006-62	268-280
D	1			2006-62	268-280
E		1		2006-62	268-280
F	1			2006-62	268-280
G	1			2006-62	268-280
H		1		2006-62	268-280
I		1		2006-62	268-280
J	1			2006-62	268-280
K		1		2006-62	268-280
L	1			2006-62	268-280
M			1	2006-62	268-280
N	1			2006-62	268-280
O	1			2006-62	268-280
P	1			2006-62	268-280
Q	1			2006-62	268-280
R	1			2006-62	268-280
S	1			2006-62	268-280
T		1		2006-62	268-280
U	1			2006-62	268-280
V		1		2006-62	268-280
W			1	2006-62	268-280
X			1	2006-62	268-280
Y	1			2006-62	268-280
Z			1	2006-62	268-280
A	1			2006-62	280-300
B	1			2006-62	280-300
C		1		2006-62	280-300
D	1			2006-62	280-300
E	1			2006-62	280-300
F	1			2006-62	280-300
G		1		2006-62	280-300
H		1		2006-62	280-300
I		1		2006-62	280-300
J	1			2006-62	280-300
K	1			2006-62	280-300
L		1		2006-62	280-300
M	1			2006-62	280-300
N		1		2006-62	280-300
O	1			2006-62	280-300
P		1		2006-62	280-300
Q		1		2006-62	280-300
R	1			2006-62	280-300
S		1		2006-62	280-300
T	1			2006-62	280-300
U	1			2006-62	280-300
V		1		2006-62	280-300

GcTr-8, continued (f)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
W		1		2006-62	280-300
X		1		2006-62	280-300
Y		1		2006-62	280-300
Z		1		2006-62	280-300
A	1			2006-62	280-300
B		1		2006-62	280-300
C		1		2006-62	280-300
D		1		2006-62	280-300

GcTr-9

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A	1			2005-34	56-84
B	1			2005-34	56-84
C	1			2005-34	56-84
A	1			2005-34	84-112
B		1		2005-34	84-112
C		1		2005-34	84-112
Q		1		2005-34	112-140
R	1			2005-34	112-140
S	1			2005-34	112-140
T		1		2005-34	112-140
P	1			2005-34	112-140
A		1		2005-34	112-140
B	1			2005-34	112-140
C		1		2005-34	112-140
D		1		2005-34	112-140
E	1			2005-34	112-140
F			1	2005-34	112-140
G		1		2005-34	112-140
H		1		2005-34	112-140
I		1		2005-34	112-140
J	1			2005-34	112-140
K	1			2005-34	112-140
L	1			2005-34	112-140
M	1			2005-34	112-140
N	1			2005-34	112-140
A	1			2005-34	140-168
B	1			2005-34	140-168
C	1			2005-34	140-168
D	1			2005-34	140-168
E	1			2005-34	140-168

GcTr-9, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
F		1		2005-34	140-168
G	1			2005-34	140-168
H	1			2005-34	140-168
I	1			2005-34	140-168
J	1			2005-34	140-168
K			1	2005-34	140-168
L	1			2005-34	140-168
M	1			2005-34	140-168
N			1	2005-34	140-168
O	1			2005-34	140-168
A		1		2005-34	168-196
B	1			2005-34	168-196
C	1			2005-34	168-196
D			1	2005-34	168-196
E	1			2005-34	168-196
F	1			2005-34	168-196
G		1		2005-34	168-196
H	1			2005-34	168-196
I		1		2005-34	168-196
J		1		2005-34	168-196
A	1			2005-34	196-224
B	1			2005-34	196-224
C		1		2005-34	196-224
D	1			2005-34	196-224
E			1	2005-34	196-224
F	1			2005-34	196-224
G	1			2005-34	196-224
H	1			2005-34	196-224
I	1			2005-34	196-224
J			1	2005-34	196-224

GcTr-9, continued (b)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
K	1			2005-34	196-224
L	1			2005-34	196-224
M	1			2005-34	196-224
N	1			2005-34	196-224
O			1	2005-34	196-224
P		1		2005-34	196-224
Q	1			2005-34	196-224
R	1		1	2005-34	196-224
S	1			2005-34	196-224

GcTr-9, continued (c)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
T	1			2005-34	196-224
U	1			2005-34	196-224
A	1			2005-34	224-252
B	1			2005-34	224-252
C		1		2005-34	224-252
D			1	2005-34	224-252
E		1		2005-34	224-252
F		1		2005-34	224-252

GcTr-10

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A	1			2006-57	60-80
B	1			2006-57	60-80
C		1		2006-57	60-80
D		1		2006-57	60-80
E		1		2006-57	60-80
F	1			2006-57	60-80
G	1			2006-57	60-80
H		1		2006-57	60-80
I		1		2006-57	60-80
J	1			2006-57	60-80
A		1		2006-57	80-100
B			1	2006-57	80-100
C			1	2006-57	80-100
D	1			2006-57	80-100
E		1		2006-57	80-100
F		1		2006-57	80-100
G	1			2006-57	80-100
H	1			2006-57	80-100
I			1	2006-57	80-100
J	1			2006-57	80-100
K	1			2006-57	80-100
L	1			2006-57	80-100
A				2006-57	100-120
B	1			2006-57	100-120
C		1		2006-57	100-120
D	1			2006-57	100-120
E	1			2006-57	100-120
F	1			2006-57	100-120

GcTr-10, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
G	1			2006-57	100-120
A		1		2006-57	120-140
B	1			2006-57	120-140
C		1		2006-57	120-140
D			1	2006-57	120-140
E	1			2006-57	120-140
F				2006-57	120-140
G	1			2006-57	120-140
H		1		2006-57	120-140
I	1			2006-57	120-140
J	1			2006-57	120-140
K	1			2006-57	120-140
L	1			2006-57	120-140
M	1			2006-57	120-140
N		1		2006-57	120-140
O		1		2006-57	120-140
P	1			2006-57	120-140
Q			1	2006-57	120-140
R	1			2006-57	120-140
S	1			2006-57	120-140
A		1		2006-57	160-180
B	1			2006-57	160-180
C	1			2006-57	160-180
D	1			2006-57	160-180
E			1	2006-57	160-180
F	1			2006-57	160-180
G			1	2006-57	160-180
H	1			2006-57	160-180

GcTr-10, continued (b)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
I	1			2006-57	160-180
J	1			2006-57	160-180
K	1			2006-57	160-180
L	1			2006-57	160-180
M		1		2006-57	160-180
N	1			2006-57	160-180
O	1			2006-57	160-180
P		1		2006-57	160-180
Q		1		2006-57	160-180
R	1			2006-57	160-180
S	1			2006-57	160-180
T	1			2006-57	160-180
U		1		2006-57	160-180
V		1		2006-57	160-180
W	1			2006-57	160-180
X		1		2006-57	160-180
A		1		2006-57	180-200
B	1			2006-57	180-200
C		1		2006-57	180-200
D		1		2006-57	180-200
E	1			2006-57	180-200
F			1	2006-57	180-200
G	1			2006-57	180-200
H			1	2006-57	180-200
A	1			2006-57	200-220
B	1			2006-57	200-220
C	1			2006-57	200-220
D	1			2006-57	200-220
E		1		2006-57	200-220
F		1		2006-57	200-220
G	1			2006-57	200-220
H			1	2006-57	200-220
I		1		2006-57	200-220
J	1			2006-57	200-220
K	1			2006-57	200-220
L		1		2006-57	200-220
M	1			2006-57	200-220
N	1			2006-57	200-220
O	1			2006-57	200-220
P		1		2006-57	200-220
Q	1			2006-57	200-220
A	1			2006-57	220-240
B		1		2006-57	220-240
C		1		2006-57	220-240
D	1			2006-57	220-240
E	1			2006-57	220-240
F		1		2006-57	220-240

GcTr-10, continued (c)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
G	1			2006-57	220-240
H	1			2006-57	220-240
I			1	2006-57	220-240
J	1			2006-57	220-240
A	1			2006-57	240-260
B		1		2006-57	240-260
C		1		2006-57	240-260
D			1	2006-57	240-260
E		1		2006-57	240-260
F		1		2006-57	240-260
G	1			2006-57	240-260
H	1			2006-57	240-260
I		1		2006-57	240-260
J		1		2006-57	240-260
K			1	2006-57	240-260
L			1	2006-57	240-260
A		1		2006-57	260-280
B		1		2006-57	260-280
C		1		2006-57	260-280
D			1	2006-57	260-280
E		1		2006-57	260-280
F		1		2006-57	260-280
G		1		2006-57	260-280
H		1		2006-57	260-280
I	1			2006-57	260-280
J	1			2006-57	260-280

GdTq-1

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A	1			05-04	84-112
B		1		05-04	84-112
C	1			05-04	84-112
A	1			05-04	112-140
B	1			05-04	112-140
C			1	05-04	112-140
A	1			05-04	168-196
B		1		05-04	168-196
C		1		05-04	168-196
D		1		05-04	168-196
E		1		05-04	168-196
F			1	05-04	168-196
A	1			05-04	196-224
B	1			05-04	196-224
C		1		05-04	196-224
A			1	05-07	112-140
B	1			05-07	112-140
C	1			05-07	112-140
A	1			05-07	143-168

GdTq-1, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
B	1			05-07	143-168
C	1			05-07	143-168
D		1		05-07	143-168
E		1		05-07	143-168
F		1		05-07	143-168
A	1			05-08	112-140
B	1			05-08	112-140
C	1			05-08	112-140
D	1			05-08	112-140
A		1		05-08	140-168
B	1			05-08	140-168
C		1		05-08	140-168
A		1		05-08	168-196
B		1		05-08	168-196
C		1		05-08	168-196
A		1		05-08	196-224
A	1			05-08	224-245
B	1			05-08	224-245
C	1			05-08	224-245

GdTq-3

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A	1			05-35	196-224
B		1		05-35	196-224
A		1		05-38	140-168
B			1	05-38	140-168
C		1		05-38	140-168
D			1	05-38	140-168
E		1		05-38	140-168
F	1			05-38	140-168
G	1			05-38	140-168
H	1			05-38	140-168
I	1			05-38	140-168
J		1		05-38	140-168
K		1		05-38	140-168
L	1			05-38	140-168
M		1		05-38	140-168
N	1			05-38	140-168

GdTq-3, continued (a)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
A		1		05-38	168-196
B		1		05-38	168-196
C		1		05-38	168-196
A		1		05-38	196-224
B		1		05-38	196-224
C	1			05-38	196-224
D	1			05-38	196-224
F	1			05-38	196-224
G		1		05-38	196-224
A		1		05-38	224-252
B	1			05-38	224-252
C	1			05-38	224-252
D		1		05-38	224-252
E		1		05-38	224-252
A		1		05-38	252-280
B			1	05-38	252-280

GdTq-3, continued (b)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
C	1			05-38	252-280
D	1			05-38	252-280
E	1			05-38	252-280
F		1		05-38	252-280
G	1			05-38	252-280
H		1		05-38	252-280
I	1			05-38	252-280
J	1			05-38	252-280
A		1		05-38	280-308
B		1		05-38	280-308
C		1		05-38	280-308
D		1		05-38	280-308
A	1			05-38	308-336
B		1		05-38	308-336
C	1			05-38	308-336
D		1		05-38	308-336
E	1			05-38	308-336
F		1		05-38	308-336
G			1	05-38	308-336
A		1		05-38	336-364
B		1		05-38	336-364
C	1			05-38	336-364
A		1		05-38	364-392
B		1		05-38	364-392
C			1	05-38	364-392
D		1		05-38	364-392
E			1	05-38	364-392
F	1			05-38	364-392
G		1		05-38	364-392
H		1		05-38	364-392
I	1	1		05-38	364-392
J		1		05-38	364-392
K	1			05-38	364-392
A	1			05-39	112-140
B		1		05-39	112-140
A	1			05-39	140-168
B	1			05-39	140-168
C	1			05-39	140-168
D	1			05-39	140-168
E		1		05-39	140-168
F			1	05-39	140-168
G			1	05-39	140-168
H		1		05-39	140-168
I	1			05-39	140-168
J			1	05-39	140-168
K	1			05-39	140-168
A		1		05-39	168-196

GdTq-3, continued (c)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
B			1	05-39	168-196
C			1	05-39	168-196
D	1			05-39	168-196
E	1			05-39	168-196
F		1		05-39	168-196
G	1			05-39	168-196
H	1			05-39	168-196
I	1			05-39	168-196
J	1			05-39	168-196
K	1			05-39	168-196
L	1			05-39	168-196
A	1			05-39	196-224
B	1			05-39	196-224
C		1		05-39	196-224
D	1			05-39	196-224
E		1		05-39	196-224
F			1	05-39	196-224
G		1		05-39	196-224
H			1	05-39	196-224
I	1			05-39	196-224
J		1		05-39	196-224
A		1		05-39	224-252
B	1			05-39	224-252
C			1	05-39	224-252
D	1			05-39	224-252
E	1			05-39	224-252
A		1		05-39	252-280
B		1		05-39	252-280
C		1		05-39	252-280
D	1			05-39	252-280
A		1		05-39	280-308
B	1			05-39	280-308
C			1	05-39	280-308
D	1			05-39	280-308
E	1			05-39	280-308
F		1		05-39	280-308
G	1			05-39	280-308
H	1			05-39	280-308
I			1	05-39	280-308
A	1			05-39	308-336
B		1		05-39	308-336
A		1		05-39	336-364
B		1		05-39	336-364
C		1		05-39	336-364
D		1		05-39	336-364
E		1		05-39	336-364
F	1			05-39	336-364

GdTq-3, continued (d)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
G	1			05-39	336-364
H	1			05-39	336-364
I	1			05-39	336-364
J	1			05-39	336-364
K	1			05-39	336-364
L	1			05-39	336-364
A		1		05-39	364-392
B	1			05-39	364-392
C	1			05-39	364-392
D	1			05-39	364-392
E	1			05-39	364-392
F		1		05-39	364-392
G		1		05-39	364-392

GdTq-3, continued (e)

SAMPLE	MATURE	SENILE	UNKNOWN	AUGER	DBS [cm]
H			1	05-39	364-392
I		1		05-39	364-392
J	1			05-39	364-392
K			1	05-39	364-392
L		1		05-39	364-392
M		1		05-39	364-392
N		1		05-39	364-392
O	1			05-39	364-392
P	1			05-39	364-392
Q	1			05-39	364-392
R	1			05-39	364-392
S		1		05-39	364-392
T		1		05-39	364-392

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