# Refining Local Sea-Levels through Settlement Change in Kanish and Waiatt Bays, Quadra Island

**by**

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**Title:** **Refining Local Sea-Levels through Settlement Change in Kanish and Waiatt Bays, Quadra Island**

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## Abstract

Post-glacial sea-level histories along the Pacific Northwest Coast are complex and heterogeneous, varying significantly temporally and spatially. Even well-refined regional sea-level curves do not allow us to understand and appreciate the effect this dynamism had on lived lives, particularly in cases where sea-level changed up to several meters in an instant. This thesis details how human settlement histories, intimately connected to sea-level, may be used to provide well-refined relative sea-level curves on a local scale. Archaeological reconstructions of settlement histories in Kanish and Waiatt Bays, Quadra Island reveal extremely localized sea-level variations, including at least one tectonic event affecting deposits in Waiatt Bay. Overall agreement of our sea-level estimates with that of broader regional models indicates that intensive coring of settlement sites is an accurate and efficient means of accumulating powerful datasets, which can provide important insights into past environmental and cultural histories.

**Keywords**: Relative sea-level change; Quadra Island; settlement histories; tectonics; Pacific Northwest Coast; archaeology.

# Dedication

This thesis is dedicated to my parents, Steve and Karen, who deserve more recognition than I can give, so having their names in a library will have to do. Please stop replacing photos of me with photos of the grandchild.

# Acknowledgements

This thesis exists through the collaboration of a multitude of individuals and organizations. First, I had the exceptional fortune and privilege to work with my supervisor Dana Lepofsky and my committee member Daryl Fedje. This project was dreamed up in a conversation between Daryl and Dana, and I am grateful they afforded me the opportunity to carry it out. Second, none of this work would have been possible without the funding and logistical support of the Hakai Institute, Simon Fraser University, and SSHRC. Finally, our research was conducted in the traditional territories claimed by the We Wai Kai, We Wai Kum, Komoks and Homalco First Nations and we are grateful for their permission to work on their ancestral lands.

A special thank-you is owed to Chris Roberts and Louie Wilson, for their patience, humour and hard-work while in the field. Chris and Louie's insights, usually over lunch, were instrumental in framing and interpreting the data. Team Bingo Wings, our resourceful and energetic group of volunteers (Bryn Letham, Colton Vogelaar, Richard Chia, Emily Purcell) were not only able-workers, but were also an awesome group of people to hang out with. This includes honorary member Peter Locher, the "Q" to our MI6.

Ginevra Toniello, Nicole Smith, Ian Hutchinson and the Happy Clam Lab Group provided valuable data and interpretation throughout this project. Neil Molloy and Shannon Wood prepared numerous figures both for this thesis and for public presentations. Andrew Martindale generously allowed the use of his coring equipment, mapping programs, and shared his experience coring settlements on the Central Coast. The Koropecki family allowed us to core on their property and supplied us with beer for our efforts. Thomas Royle provided needed insights and edits, and helped me navigate my Masters. A special mention to the late Sid Lively, who told me the right stories when I needed to hear them. Business as usual Sid. I must also thank the many grad students, secretaries, professors, friends, family, and my amazing cohort whose support sustained me throughout the past two-years. My partner and future wife, Katherine Ryan, also deserves mention for her limitless patience, her encouragement and her grace. Lastly, my deep appreciation to CKTZ 89.5 fm, Cortes Community Radio, who keep the "freak" in frequency.

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# Chapter 1. Introduction

More than half of the world's current population lives within sixty kilometers of the ocean and depend on coastal resources in their daily lives (Burke et al. 2001). This intimate relationship between people and the sea has existed throughout human history (Erlandson 2001:305-306), and is likely true of many of the earliest Indigenous peoples of North America's Pacific Northwest Coast (NWC). In areas where detailed long-term settlement histories exist, there is evidence that people have been following the shore with their settlements from the early Holocene onwards (Letham et al. 2015:74; McLaren et al. 2011:104; Fedje et al. 2005:185; Cannon 2000:70). However, the almost 26,000 kilometers of coastline we know today in British Columbia is not the same coastline people knew in the past. The dynamic interplay of geological and post-glacial processes has resulted in shifting shorelines throughout the Holocene that varies both regionally and locally (Clague et al. 1982; Shugar et al. 2014). These changes in relative sea-level (RSL), whether sudden or gradual, have profound implications for archaeological sampling and reconstructions of past coastal lives.

On the Pacific Northwest Coast, researchers have constructed some of the most refined regional sea-level histories in the world, identifying the dramatically different RSL curves of inner and outer locales (Clague 1982; Fedje et al. 2005; Fedje et al. 2009; McLaren 2014; Letham et al. 2016). However, even these sea-level curves, built on a multitude of data points, reflect some amount of temporal and spatial interpolation (Shugar et al. 2014:189). A closer examination of sea-level change reveals that they are complex histories of highly localized events, including tectonic events, which can shift sea-levels by several meters in an instant (Atwater 1987:942; Mathewes and Clague 1994; Leonard 2010:2081).

Settlement histories are closely linked to changes in relative sea-level. This is evidenced in places on the coast where sea-level has dropped throughout the Holocene and the oldest parts of the settlement are located towards the back edge of the site (McMillan 1998:11). In some cases, we know that people followed receding shores so closely that they created living surfaces on the upper tidal zone (Springer et al. 2013:226). Today, evidence of this close and ancient relationship between the leading edge of sites and the high tide line are the eroding midden faces in places with rising sea-levels (e.g., Pomeroy 1980:93). These patterns suggest settlement histories of coastal populations can be a tool for tracking sea-level change at a finer-scale and capture geographically and temporally specific events (e.g., tectonic events). Numerous researchers on the Northwest Coast have used archaeological settlement data to help constrain sea-level, however there has yet to be a systematic approach to tracking localized sea-level change exclusively through settlement patterns (Fedje et al. 2005:23; Fedje et al. 2009:240; Grier et al. 2009:255). While archaeological limiting points are not as precise as index points for sea-level, which can identify specific moments of sea-level change, they can provide a multitude of data points in a specific geographical area, for time periods that may otherwise be relatively unconstrained.

Archaeological evidence in northern Quadra Island suggests a complex history of sea-level change that is not reflected in regional sea level histories (Toniello et al. 2017). This suggests a need for further refinement of the RSL curve to account for spatial and temporal variation. Prior regional archaeological and paleo ecological investigations for the north Salish Sea and Quadra Island detail a rapid drop in sea-level in the early post-glacial period followed by a smooth decline of 2.0-3.0 meters over the past 10,000 years to modern levels (James et al. 2005; Hutchinson et al. 2004). However, the discovery of terrestrially deposited soils in the intertidal zone and old artifacts in younger soils suggest more local changes in relative sea-level that are not visible in these broader sea-level models (Fedje et al. 2016). This is supported by evidence from intertidal clam garden features which front settlement sites. Clam garden walls, by definition built to the lowest tidal limit to maximize the amount of ideal clam habitat created (Deur et al. 2015:203; Groesbeck et al. 2014:2; Lepofsky et al. 2015: 242), are found stranded either above or below their ideal intertidal position, or with lower wall heights where they are not bedrock constrained (Toniello et al. 2017). These anomalies represent local changes in relative sea-level which would have had severe effects on peoples' lives, and influence how we study and interpret the archaeological record.

In this thesis, we detail how human settlement histories, intimately connected to sea-level, provide a window into the effect that sea-level change has on a finer scale than models for larger geographic areas. Our research builds on the refined RSL curve developed for Quadra Island by Fedje et al. (2017). Using an intensive coring and dating program, we collect limiting points for sea-level from the basal components of coastal, shell-bearing archaeological sites. To make our inferences more robust, we combine the settlement data with dates from the base of clam garden walls and relative clam garden wall heights (Toniello et al. 2017; Smith et al. 2017). To control for the effects of tectonic-induced subsidence, we sample from sites resting on a variety of substrates. Together, our sample represents 9,000 years of human-coastline interactions, and details the way in which human settlement patterns responded to shifting shorelines. From this sample, we construct an age-altitude plot estimating sea-level change throughout the Holocene in Kanish and Waiatt Bays. Comparison of samples between bays and those resting on differential substrates allow us to hypothesize a possible localized tectonic event in the Late Holocene. We also consider the effects of compaction-induced subsidence of archaeological deposits, such as autocompaction (e.g., Massey et al. 2006:226), and how post-depositional processes affect our interpretations of relative sea-level.

# Chapter 2. Study Area

Our research was conducted in Kanish and Waiatt Bays, Quadra Island (Figure 1). Quadra Island, located in the northern Salish Sea, sits at the confluence of three major marine influences (Strait of Georgia, Johnson Strait, and Bute Inlet). Geologically, the island is near the northern limit of the Cascadia subduction zone, a tectonically active region where the Juan de Fuca plate subducts beneath the North American plate (James et al. 2005:114). As recent as 1946, a 7.2 magnitude earthquake struck 25km south of the island, causing widespread soil failure (e.g. landslides, liquefaction, and slumping) on Quadra Island, Campbell River, and nearby Read Island (Rogers 1980:125).

Archaeological evidence from Waiatt and Kanish Bays suggest that subsidence events may have occurred well into the past, and understanding the effects of tectonic activity in the Late Holocene is one of the objectives of this research.

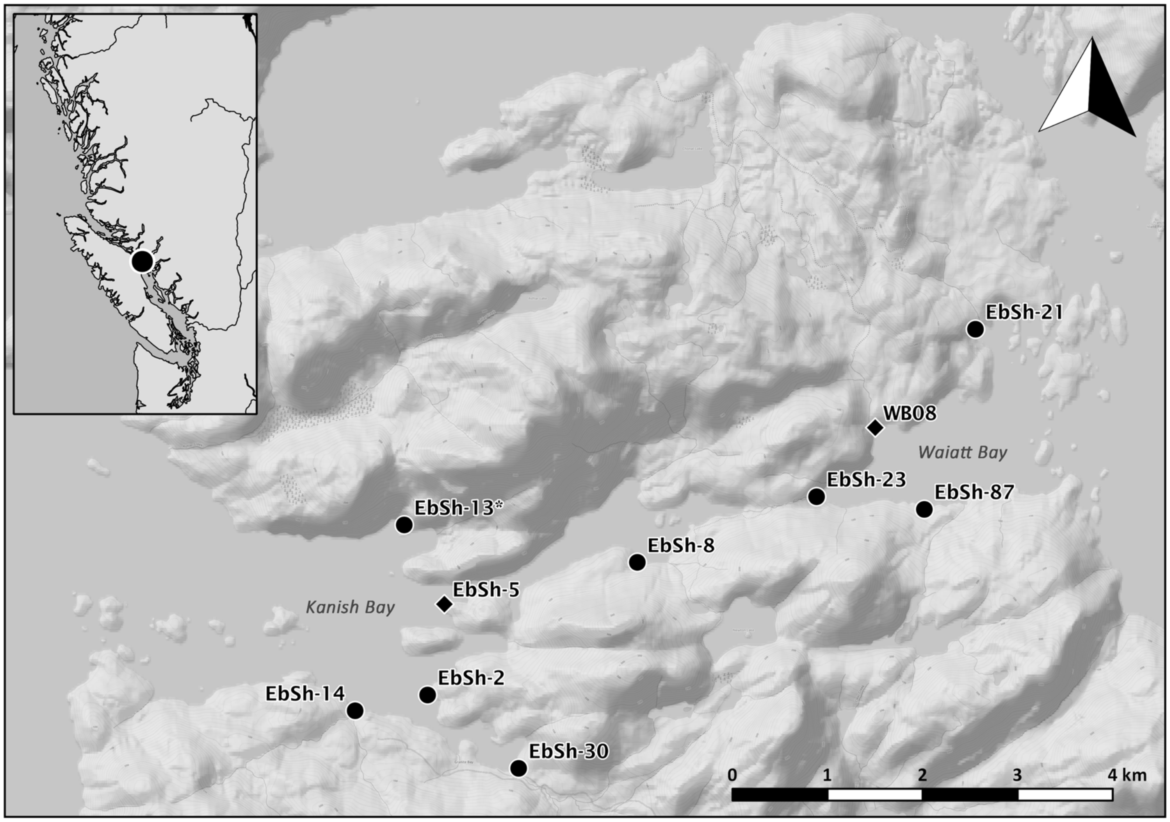

Figure 1: Sites sampled in Kanish and Waiatt Bays. Black circles represent terrestrial shell-bearing sites, while black diamonds represent clam gardens.

Kanish and Waiatt Bays can be considered a single eco-cultural unit throughout time due to spatial proximity. The narrow Okisollo Channel to the northeast and Surge Narrows to the east, infamous for their powerful currents, encircle and connect Kanish and Waiatt Bays by sea. Terrestrially, the bays are separated by only a short portage route. Today, as in the past, this trail facilitates travel between the bays. Archaeological research was limited within Kanish and Waiatt Bays until ten years ago, with the beginning of research by SFU's Dr. Dana Lepofsky and the initiation of two projects funded by the Hakai Institute: the Discovery Island Ancient Landscapes project (DILA) and the Clam Garden Network. These projects focus on the history of human-environmental interactions from deglaciation to today, and detail the prolonged period of occupation on northern Quadra Island.

Generations of human settlement have left an archaeological legacy of stunning scope within the study area. Indigenous populations lived in Kanish and

Waiatt Bays throughout the Holocene, investing their labour and experiences in the land for millennia (Toniello et al. 2017; Fedje et al. 2016). Past occupation of the bays is represented today by lithic scatters, place names, rock art, clam gardens, and shell-bearing sites. The larger of these shell-bearing sites have been terraformed to create expansive terraces, some of which rise to heights of 5 meters. These terraces, which served as the foundation for generations of households, are the focus of sampling efforts in this research. Previous archaeological surveys have recorded clam gardens and settlements that were constructed directly on top of bedrock shelves, as well as on substrates composed mostly of soft sediments (Puckett et al. 2014; Toniello 2017). This difference in substrate likely resulted in different responses to local changes in relative sea-level.

Indigenous occupation of Kanish and Waiatt Bays lasted into the colonial period, until massive depopulation caused by epidemics (Harris 1994:609) and settler encroachment (Taylor 2009:39) forced the abandonment of permanent settlements. First Nations presence in the bays after the 19th century was likely restricted to temporary visits for clam harvesting, herring fishing, and berry-picking (Williams 2004:59; Assu 1989:30). Today, Kanish and Waiatt Bays are within the traditional territories of the Laich-Kwil-Tach and northern Coast Salish people, including both the Island and Mainland Comox (Williams 2004:54). Clam gardens, the engineering feat of their ancestors, continue to provide for local peoples. Recent and historic logging has left an indelible mark on former village sites. However, disturbance to the archaeological record is largely limited to the surface, leaving the deepest, and thus older, deposits intact.

# Chapter 3. Methodology

## 3.1. Site Selection

To determine the relationship between the age of shell-bearing sites and relative sea-level, we used three criteria to select which archaeological sites would be sampled with an JMC Environmentalist's Sub-Soil Probe percussion corer (ESP; Cannon 2000:69). First, we sought sites that were large enough to extract a series of cores along a transect from landward to seaward. In general, this meant sites that were at least 50m long parallel to shore and 15m wide. Second, we sought sites with deep deposits, reasoning that these sites would tend to represent a lengthy time sequence of occupation. Finally, when possible, we chose sites that were directly associated with clam gardens (n=4).

To test the hypothesis that the effect of tectonics on relative sea-level is localized and influenced by site substrate, we selected sites within both bays that are resting on either hard substrate (i.e., bedrock or fractured bedrock) or soft substrate (i.e., sands and gravels). Our assumption, based off geological site response studies (Cassidy and Molnar 2009) is that bedrock substrate mitigates the consequences of tectonic activity, such as subsidence or uplift. Conversely, we expect those sites on soft sediment to experience more extreme effects of these geological processes due to increased ground-motion amplification (Clague 2002:20). We hypothesize that fractured bedrock, which is weathered near-surface or has a high density of fracturing from natural processes (e.g., previous tectonic events), may still be adversely affected by tectonics, but not to the degree of sites on soft substrate (Moore et al. 2011:3115; Steidl 1996:1748). Whenever possible, we selected sites that had both hard and soft substrates in different areas of the sites. Our sampling method allowed us to develop sea-level histories both within and between bays.

## 3.2. Georeferencing Sampling Locations

Spatial data for core, column and clam garden samples were obtained using a combination of high precision GPS, laser rangefinder, and handheld GPS survey points (Holmes 2015). Mapping data from the field was converted into georeferenced points using the LOA Bearing-Distance Calculator for Archaeological Survey (Martindale 2016). These points were then uploaded into a LiDAR digital terrain model (DTM) of the study area (Hakai Institute 2014).

Elevations in this paper are measured relative to geodetic mean sea level per the Canadian Geodetic Vertical Datum of 1928 (CGVD28) benchmarks at Owen Bay and Brown Bay, which are 2.47m and 2.57m above Chart Datum respectively (Canadian Hydrographic Survey, personal communication, 2016). Owen and Brown Bay tidal stations are closest to our study area, and best represent tidal activity at Waiatt (Owen Bay) and Kanish (Brown Bay). These benchmarks are treated as equivalent to mean sea level as the “z=0” for elevation.

Elevations for ESP core samples and column samples were derived from the LiDAR DTM or from a site datum. All core samples achieved an elevation accuracy of >±0.25m. Core-shortening (or compression) of material within cores was determined by a simple compression ratio for all components excluding sand (Total Depth/Material Collected=Compression Ratio). A unique ratio was derived for each core. Elevations for clam garden wall heights and samples in Kanish Bay were measured in reference to tidal heights at specific times of day. Elevation to chart datum was determined by using the WWW Tide/Current Predictor (http://tbone.biol.sc.edu/tide/index.html), which models relative tidal height to the minute. In Waiatt Bay, elevations of clam garden samples were determined using Digital Surface Models (DSM) of intertidal areas conducted by drone flight (Hakai Institute 2016). For consistency, all elevations presented here are referenced to mean sea-level.

## 3.3. Site Sampling

To collect datable samples from the basal components of settlement sites, we extracted core samples using ESP percussion corer. Samples from the base of these sites provide an upper limiting point for sea-level, as settlement is assumed to have been constrained by the upper tidal limit (HHWLT). Cores were collected in transects running perpendicular to the shoreline, from the back to the front (seaward) of the site. Transect locations were placed in areas of the site judged to be the oldest, based upon prior dating (Fedje et al. 2016) and field survey conducted prior to testing. Core locations were tied into RTK datum points using a TruPulse 200X Laser Rangefinder to provide precise horizontal and vertical coordinates.

To understand local sea level changes, we augmented the ESP data with data from column samples and from clam garden excavations. Column sample excavations, from the front-facing portion of shell-bearing sites, provided additional basal dates. Samples from column excavations included those collected as part of our study, as well as samples collected by previous researchers (Fedje et al. 2016). In addition, we included dates on shells extracted from the base of clam garden walls (Smith et al. 2017). These specimens were trapped by the building of the clam garden wall and thus provide a maximum age on the time of wall construction. Given that clam gardens were likely built at the lowest tidal limit (LLWLT), these samples provide additional limiting points for sea-level at the time of wall construction.

## 3.4. Sample Selection and Age Measurements

To extract basal radiocarbon dates from the ESP cores, we sought organic materials from the lower-most cultural deposits (i.e., those bearing charcoal and shell). Ideally, basal, sterile deposits were captured below these layers in the cores. In cases where no sterile sediments were collected in the core, and it was suspected we reached bedrock, we sampled from the deepest part of the core. In the first round of dating, we selected cores from the front (shoreward) and back of sites to test whether sites were indeed older at the back and younger at the front. Cores from the middle of transects were sampled to trace site expansion over time. In accordance with other sea-level studies, only samples with known location, age, and elevation relative to mean sea-level were used to collate sea-level histories (Shennan et al. 2006:587; Table 1).

Radiocarbon samples from terrestrial and intertidal archaeological sites were processed by the W.M. Keck AMS Laboratory in Irvine, California (UCIAMS). Dates were calibrated using Calib 7.1.0 and are reported here as 2 sigma ranges (Stuvier et al. 2017; Table 1). Terrestrial samples were calibrated using the IntCal13 dataset, while marine samples use the Marine13 dataset. Calibration of marine carbonate ages (e.g., shell) used a marine reservoir correction of 320 +/- 90 BP, determined by Hutchinson et al. (2004) for the Salish Sea area. All dates presented here are in calendar years before present (cal BP).

# Chapter 4. Results

We obtained 42 $^{14}C$ dates that were used to construct a revised sea-level history for Waiatt (n=21) and Kanish (n=21) Bays. This includes 37 samples from archaeological habitation sites and 5 samples from the base of clam garden walls. Ten samples from archaeological sites and the clam garden dates are from previous studies (Table 1; Smith et al. 2017). Collectively, our dataset allows us to trace the growth and expansion of settlement sites in Kanish and Waiatt Bays, to explore the effects of site substrate on subsidence and post-depositional lowering, and to interpret Holocene sea-level change based upon the archaeological record. A full compliment of dates will be reported elsewhere.

Table 1: Radiocarbon dates for limiting points used to constrain Kanish and Waiatt Bay RSL curve and detail settlement patterns.

| *Lab #* | *Sample Unit* | *14C Age BP* | *±* | *Cal BP (2 sigma)* | *Easting* | *Northing* | *Elevation msl (m)* | *Material* | *Substrate* |
|---|---|---|---|---|---|---|---|---|---|
| ***Kanish Bay*** | | | | | | | | | |
| **EbSh-2** | | | | | | | | | |
| 178090 | ESP1-2016 | 580 | 15 | 541-636 | 0334786 | 5568372 | +2.38 ± 0.25 | Charcoal | HS |
| **EbSh-5** | | | | | | | | | |
| 175684 | 28-4[1] | 1960 | 15 | 980 - 1362 | 0335008 | 5569113 | -2.26 ± 0.25 | Shell (butterclam) | SS |
| **EbSh-8** | | | | | | | | | |
| 178102 | ESP3-2016 | 4265 | 15 | 3684 - 4200 | 0337011 | 5569708 | +4.24 ± 0.25 | Shell | HS |
| 178104 | ESP5-2016 | 1050 | 15 | 146-520 | 0337020 | 5569710 | +2.99 ± 0.25 | Shell (cockle) | HS |
| 182772 | ESP4-2016 | 2555 | 15 | 2624-2747 | 0337015 | 5569710 | +3.41 ± 0.25 | Charcoal | HS |
| **EbSh-13** | | | | | | | | | |
| 182774 | ESP3-2016 | 2155 | 15 | 2069-3000 | 0334595 | 5570146 | +2.6 ± 0.25 | Charcoal | HS |
| 182776 | ESP7-2016 | 4520 | 15 | 5054-5301 | 0334595 | 5570146 | +3.89 ± 0.25 | Charcoal | HS |
| 145732 | PC10b[2] | 2950 | 25 | 3004-3179 | 0334574 | 5570153 | +3.27 ± 0.25 | Charcoal | HS |
| 182777 | ESP16-2016 | 5750 | 20 | 6490-6633 | 0334589 | 5570163 | +4.3 ± 0.25 | Charcoal | HS |
| 182778 | ESP22-2016 | 6695 | 20 | 7512-7606 | 0334605 | 5570170 | +4.3 ± 0.25 | Charcoal | HS |
| 141798 | PC11[2] | 8005 | 20 | 8777-8999 | 0334605 | 5570178 | +4.71 ± 0.35 | Charcoal | HS |
| 175664 | ESP23-2016 | 1715 | 15 | 1563-1693 | 0334561 | 5570210 | +2.28 ± 0.25 | Charcoal | SS |
| 182779 | ESP26-2016 | 1955 | 15 | 1872-1942 | 0334573 | 5570218 | +4.13 ± 0.25 | Charcoal | SS |
| 182891 | Column2-2016 | 2700 | 15 | 1809-2275 | 0334487 | 557025 | +5.55 ± 0.25 | Shell | HS |
| 171659 | Tgt09S3[1] | 2375 | 15 | 1404-1844 | 0334449 | 5570168 | -2.22 ± 0.25 | Shell (whelk) | SS |
| 175690 | STGT09-S2[1] | 2425 | 15 | 1472-1910 | 0334449 | 5570168 | -2.17 ± 0.25 | Shell (macoma) | SS |
| **EbSh-14** | | | | | | | | | |
| 175660 | ESP16-2016 | 295 | 15 | 301-429 | 0334091 | 5568220 | +2.92 ± 0.25 | Charcoal | SS |
| **EbSh-30** | | | | | | | | | |
| 182887 | CT2016-005 | 3225 | 15 | 2381-2859 | 0335728 | 5567634 | +3.78 ± 0.10 | Shell | HS |
| 182781 | CT2016-013 | 2075 | 15 | 1994-2112 | 0335717 | 5567585 | +1.98 ± 0.10 | Charcoal | SS |
| 175659 | CT2016-02(b) | 2435 | 15 | 2361-2681 | 0335733 | 5567639 | +11.05 ± 0.10 | Charcoal | HS |
| 182890 | CT2016-003 | 3120 | 15 | 2324-2734 | 0335739 | 5567640 | +8.34 ± 0.10 | Shell | HS |

| *S #* | *Sample Unit* | *14C Age BP* | *±* | *Cal BP (2 sigma)* | *Easting* | *Northing* | *Elevation msl (m)* | *Material* | *Substrate* |
|---|---|---|---|---|---|---|---|---|---|
| ***Waiatt Bay*** | | | | | | | | | |
| **EbSh-21** | | | | | | | | | |
| 175661 | ESP1-2016 | 4510 | 15 | 5053-5251 | 0340646 | 5572018 | +4.99 ± 0.25 | Charcoal | HS |
| 182780 | ESP4-2016 | 3720 | 15 | 3987-4145 | 0340661 | 557191 | +2.35 ± 0.25 | Charcoal | SS |
| 175662 | ESP6-2016 | 2495 | 15 | 2492-2718 | 0340656 | 5572014 | +2.05 ± 0.25 | Charcoal | SS |
| 182773 | ESP7-2016 | 3720 | 15 | 3987-4145 | 0337015 | 5569710 | +2.37 ± 0.25 | Charcoal | SS |
| 178095 | ESP9-2016a | 2185 | 15 | 2134-2306 | 0340665 | 5571915 | +2.11 ± 0.25 | Charcoal | SS |
| 145726 | MCol6-29[1] | 2450 | 25 | 2361-2701 | 0340668 | 5572010 | +2.10 ± 0.25 | Charcoal | SS |
| **WB08** | | | | | | | | | |
| 171663 | ST1S2[1] | 2895 | 15 | 1988 - 2492 | 0339844 | 5570993 | -2.15 ± 0.25 | Shell (butter) | HS |
| 175687 | WB08-NS6-M38[1] | 2920 | 15 | 2025 - 2563 | 0339880 | 5570978 | -2.03 ± 0.25 | Shell (macoma) | HS |
| **EbSh-23** | | | | | | | | | |
| 145727 | PC2[2] | 5365 | 30 | 6008-6176 | 0338899 | 5570334 | +6.57 ± 0.25 | Charcoal | SS |
| 143279 | sec1-135[3] | 2035 | 15 | 1933-2040 | 0338929 | 5570330 | +2.27 ± 0.25 | Conifer charcoal | SS |
| 143280 | LT2-35[3] | 5390 | 20 | 6130-6278 | 0338946 | 5570281 | +7.87 (3) ± 0.25 | Decid. Charcoal | SS |
| **EbSh-87** | | | | | | | | | |
| 145730 | PC1c[2] | 3750 | 25 | 3990-4226 | 0340045 | 5570153 | +3.04 ± 0.25 | Charcoal | FS |
| 145729 | PC4b[2] | 2525 | 25 | 2495-2742 | 0340045 | 5570153 | +0.99 ± 0.25 | Charcoal | SS |
| 182771 | ESP5 | 3665 | 15 | 3926-4082 | 0340038 | 5570160 | +1.94 ± 0.25 | Charcoal | FS |
| 186381 | ESP6 | 2105 | 15 | 2005-2132 | 340044 | 5570167 | +1.08 ± 0.25 | Charcoal | SS |
| 178103 | ESP16 | 4685 | 15 | 4180-4791 | 0340060 | 5570149 | +3.44 ± 0.25 | Shell (butter) | FS |
| 178092 | ESP18 | 3645 | 15 | 3900-4066 | 0340051 | 5570153 | +4.17 ± 0.25 | Charcoal | HS |
| 178095 | ESP22 | 3405 | 20 | 2615-3117 | 0340087 | 5570150 | +4.49 ± 0.25 | Shell | HS |
| 178094 | ESP23 | 1190 | 15 | 1067-1175 | 0340027 | 5570185 | +3.63 ± 0.25 | Charcoal | HS |
| 143275 | WBT1[3] | 1440 | 15 | 1302-1356 | 0340054 | 5570170 | +1.97 ± 0.25 | Conifer Charcoal | SS |
| 166922 | C1S8[2] | 3755 | 20 | 3999-4224 | 0340018 | 5570147 | +3.14 ± 0.25 | Charcoal | FS |

[1] Clam garden dates from Smith et al. 2017

[2] Dates from Toniello et al. 2017

[3] Dates from Fedje et al. 2016

[4] SS=soft substrate; HS=hard substrate; FS=fractured bedrock.

[5] Calibration using Calib 7.1 (Reimer et al. 2013) with a marine Delta R of 320±90 for post-10,000 $^{14}$C BP samples (Hutchinson et al. 2004).

## 4.1. Settlement Expansion and Sea-Level Histories

Eleven transects were completed at six sites, two in Waiatt Bay (EbSh-21, EbSh-87), and four in Kanish Bay (EbSh-8, EbSh-13, EbSh-14, and EbSh-30), to trace site expansion and sea-level change over time (Figure 1). All radiocarbon samples come from the basal components of archaeological sites (n=35) or date the construction of clam garden walls (n=5). Due to the poor preservation, or absence, of marine carbonate (i.e., shell) in the charcoal-rich basal components of some settlement sites, single-source charcoal was more frequently dated (Table 1). Our earliest basal dates from shell-bearing archeological sites place people on the landscape as early as 9,000 cal BP (Table 1). On-going research by Fedje et al. (2017) indicates that people were in the bays much earlier.

Sea-level played a determinant role in settlement patterning, limiting the expansion of sites to subaerially exposed land. Our basal dates indicate two different patterns of settlement expansion through time that appear to be influenced by whether the natural topography is expansive (Figure 2) or restricted (Figure 3). At settlements built on expansive landforms (EbSh-8, EbSh-13, EbSh-21, EbSh-87), we see the construction of linear habitations which hug the shoreline. The centers of these sites are often older than site peripheries. Over time, these sites grew shoreward and laterally, expanding parallel to the shore. Basal dates gathered along transects detail expansion towards modern shorelines, with occupation dates getting younger in age and lower in elevation as we move from the back to the shore-proximal edge of the site (Figure 4). This pattern is evident in the majority of sites sampled, and we interpret this pattern to represent populations expanding settlement sites to follow regressing sea-levels.

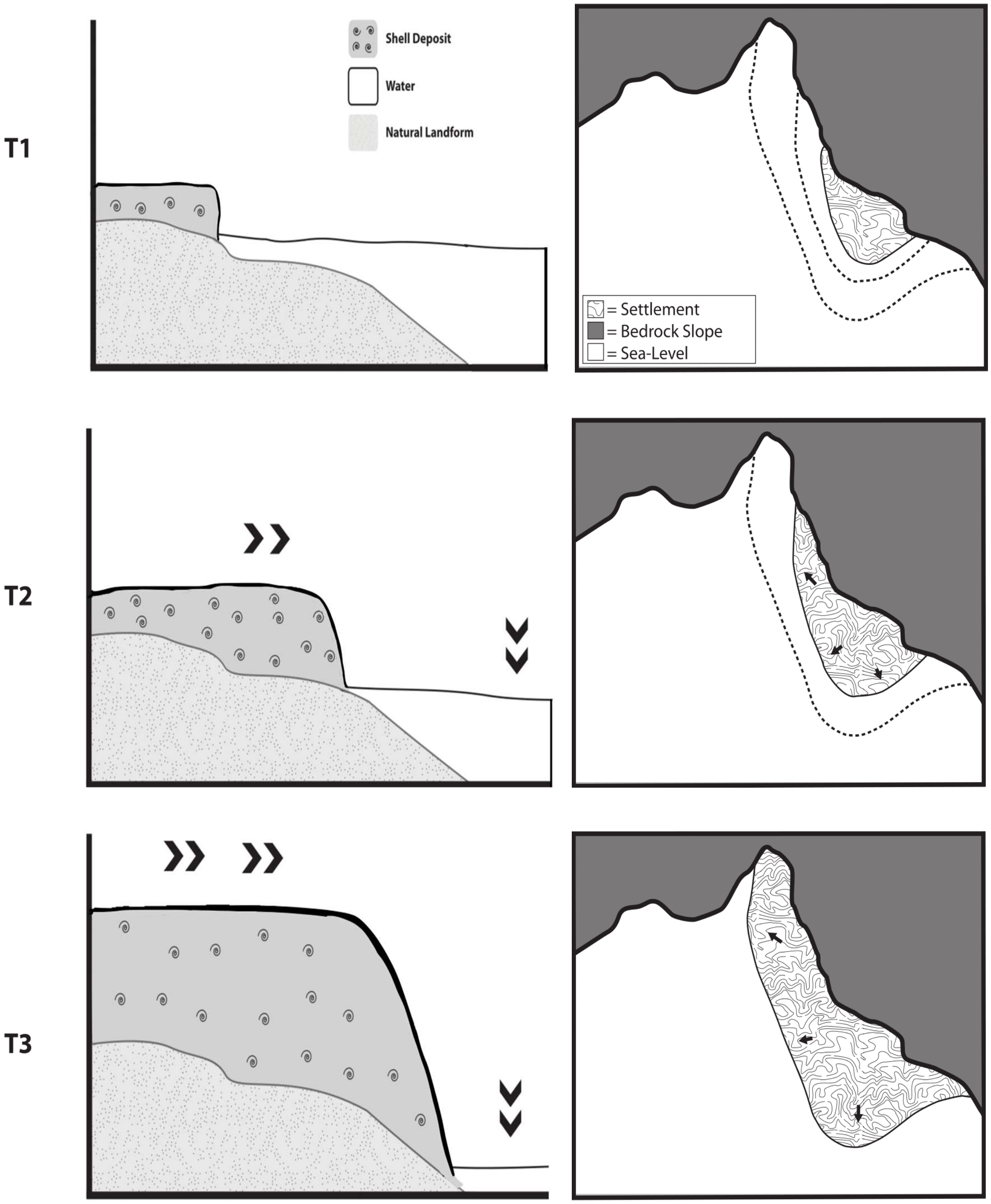

Figure 2: Cross section (first panel) and plan view (second panel) of settlement change time series for expansive landforms based on observed settlement history of EbSh-13. As sea-levels decline, settlement expands forward and laterally onto recently subaerially exposed landforms. Settlements in these contexts tend to have older basal deposits at the back, with more recent deposits at the front, at lower elevations. The dashed lines represent submerged landforms.

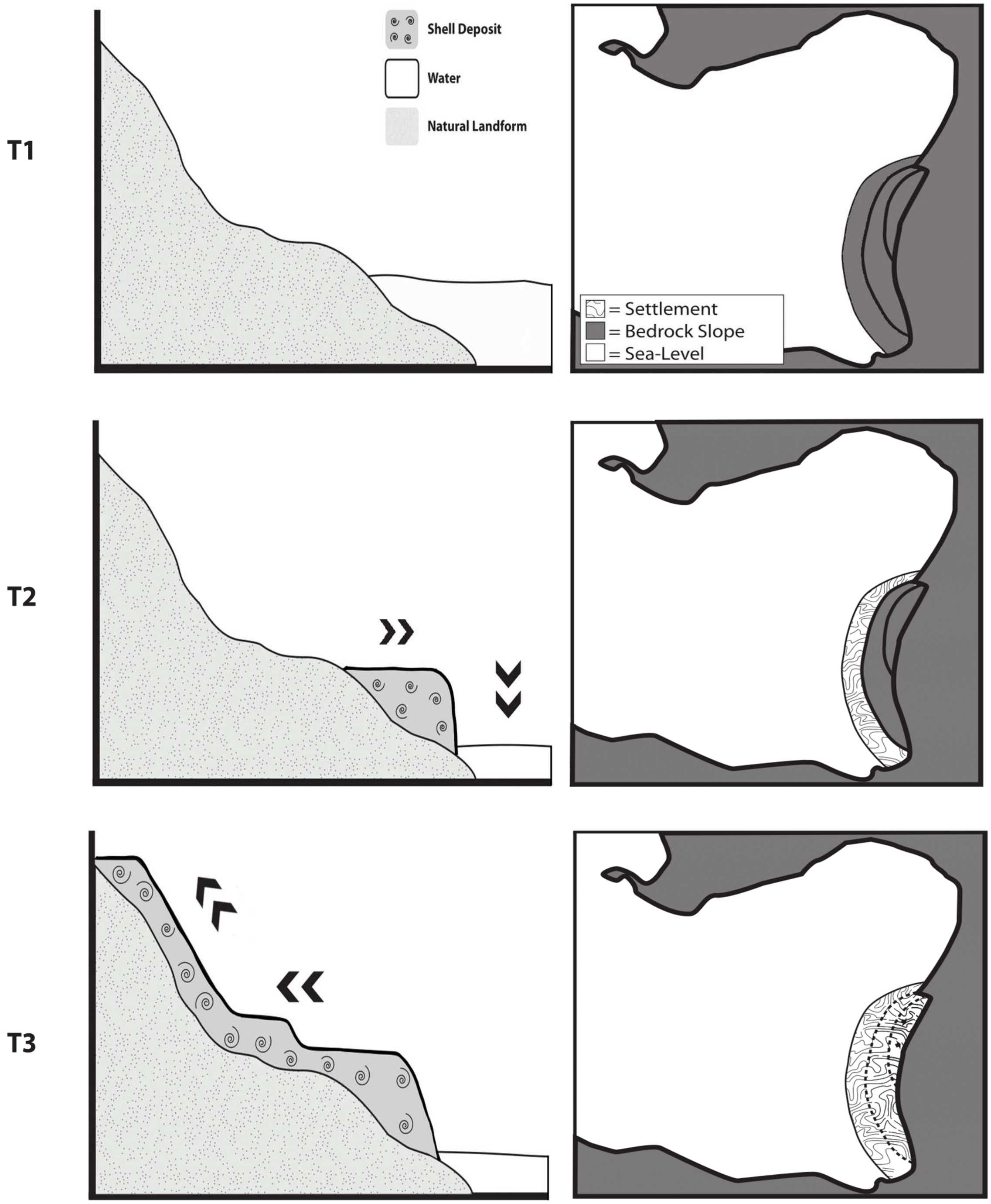

Figure 3: Time series of observed settlement change on restricted landforms. These sites are characterized by limited foreshore area due to steep, bedrock slopes. Unable to "follow" lowering seas, or expand laterally, people expanded settlements up slope, using shell to create level terraces on steep ground.

Settlements on more restricted landforms, (e.g., with steep bedrock slopes) were initiated at lower elevations, but limited space close to shore forced expansion upward to higher elevations (Figure 3). This results in more recent deposits located at the back of these sites, at higher elevations, rather than at the front. Thus, while settlement expansion on sites built on restricted landforms may be a correlate of relative sea-level, expansion may also be unrelated and not an accurate indication of sea-level change.

The intimate relationship between settlement and sea-level histories is clear when we consider that people rarely lived far from the shore in Kanish and Waiatt Bays. All settlements investigated, regardless of age, were within 50m linear distance of modern shorelines, and most were within 30m (Figure 4). The elevation of most samples (n=26) are within 2.0m and 5.5m above msl, with few exceeding 8.0m. Samples under 5.5m above msl span the entire 9000 years of the temporal sequence. While a close relationship between settlements and the sea is evident in our samples, numerous sites on Quadra Island exist at higher elevations as well. For example, numerous non-shell-bearing sites have been found on terraces higher than 7m above msl at the time of their occupation (Fedje et al. 2017).

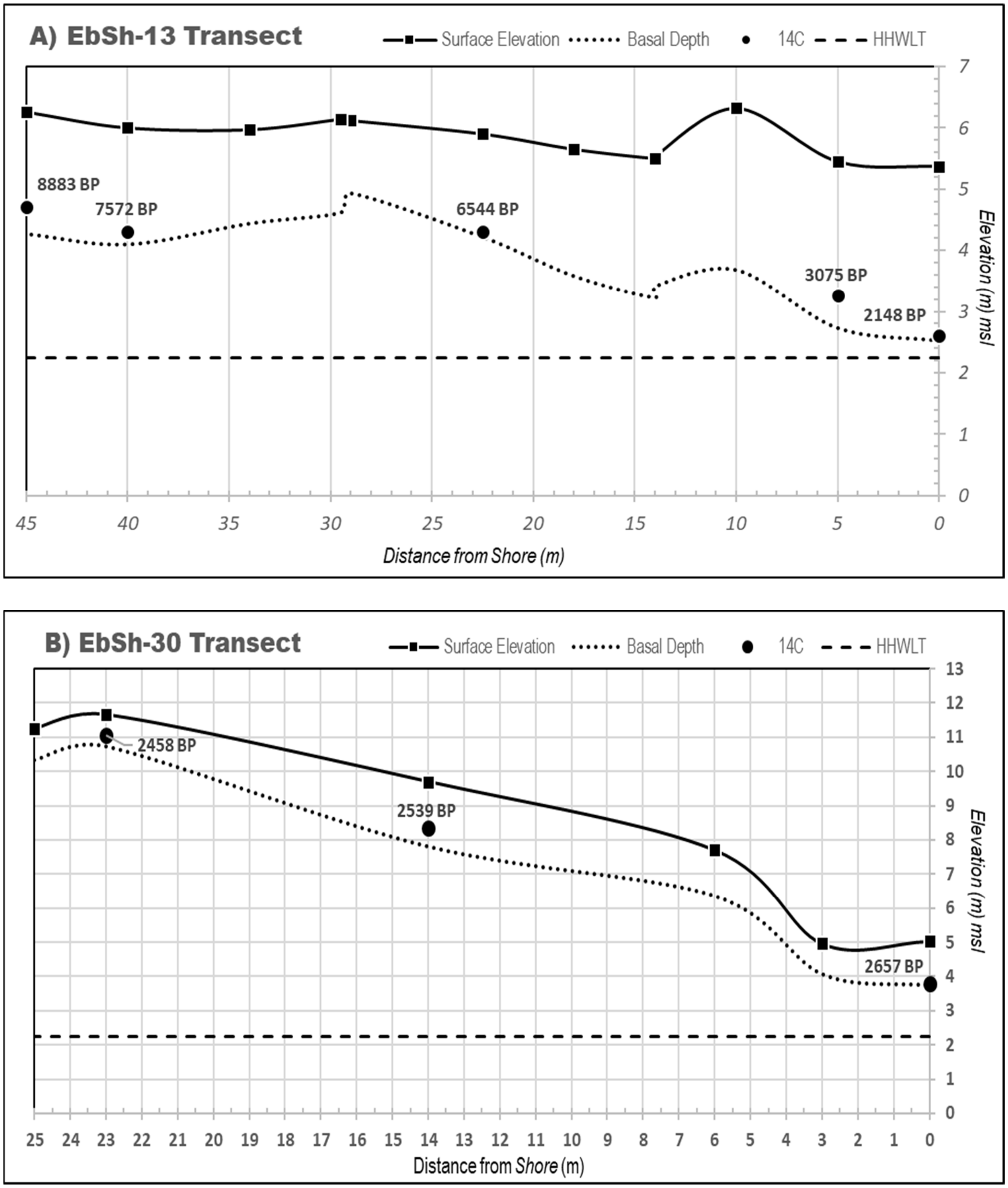

Figure 4: Transect lines from A) expansive site (EbSh-13) and B) restrictive site (EbSh-30) demonstrating proximity of settlements to modern shorelines. The dashed line represents the inferred natural topography based upon basal depth of the cores. Black squares represent the surface location of the ESP sample. Black circles represent the location of radiocarbon dates taken from basal cultural deposits. Note that the Y axis of graph (A) is amplified so the slope would be more gradual than represented here.

## 4.2. Tectonics, Substrate, and Subsidence in Kanish and Waiatt Bays

Our analysis of basal depths of terrestrial archaeological deposits and clam garden wall heights (Toniello et al. 2017) demonstrates that substrate influences post-depositional stability of archaeological deposits. Along the length of clam garden walls in Kanish and Waiatt Bays, there is a notable difference in wall height that we interpret to be the result of differential compaction on soft versus hard substrate. Generally, portions of walls which are constructed on soft substrate are approximately 0.6m lower than portions of walls which rest on hard substrate. We interpret these relatively lower wall heights to be the result of compaction of underlying water-saturated sediments by the weight of the wall. This difference in the surface elevation of clam garden walls on hard vs. soft substrate allow us to make a coarse estimate of the potential magnitude of compaction found in Kanish and Waiatt Bays. While we cannot measure the extent to which terrestrial archaeological deposits compact overtime due to the weight of overburden or shell dissolution (Stein 1992:138), we expect that compaction in basal components of shell-bearing sites will not exceed the 0.6m observed along clam garden walls.

In several instances, terrestrial deposits in Waiatt Bay exhibit a drop in elevation that considerably exceeds our 0.6m threshold; we attribute these relatively lower elevations to tectonic-induced subsidence. At two sites (EbSh-87 and EbSh-21), four radiocarbon samples on fractured bedrock or soft substrate are ~1.5m lower than similarly aged deposits on solid bedrock (S#182773,182771,145729,186381; Table 1). These samples date between 4,000 and 2,000 years old. That these samples are outliers in terms of elevations at a given age is especially obvious when they are compared to the projected relative sea level curve from those times (see below). It is possible that samples within our 0.6m compaction threshold have also lowered due to tectonic activity (e.g., S#145726, 175662, 178095), however we are not at present able to distinguish the causal mechanisms resulting in minor subsidence.

Evidence for a subsidence event in the terrestrial shell-bearing site at EbSh-87 is also reflected in the relative heights of the clam garden wall located directly in front of the site. Here, the portion of the wall sitting on soft sediments is approximately 1.0m lower than the adjacent portions sitting on bedrock. This is the only wall in the study area where the difference in wall height appears too great to attribute to compaction or to modern disturbance. Clam gardens within the study area date no later than 2,200 cal BP (Smith et al. 2017). If the clam garden at EbSh-87 was constructed at a similar time, then the subsidence event may post-date 2,200 cal BP.

Our dating of deposits from settlement sites with evidence of subsidence within the last two millennia (i.e., >0.6m drops) allows us to narrow down the timing of a hypothesized subsidence event to sometime between 2,100-1,900 cal BP. The effects of this event are, at minimum, visible in the archaeological record of Waiatt Bay. In particular, evidence comes from a lower constraining age from a terrestrial date found in the upper intertidal at site EbSh-87 (S#186381); the upper constraining age at that is provided by settlement data (EbSh-23, S#143279) on soft substrate that does not appear to have experienced tectonic-induced subsidence.

In Kanish Bay, we have no dated samples from soft sediment substrates older than 2,000 years, and thus we can not evaluate whether the inhabitants of Kanish Bay also experienced a major geological event. Additional dates from soft sediment sites in Kanish Bay (S#175664) and Waiatt Bay (S#143275), dating ~1,600 and ~1,300 cal BP, are found at similar elevations to bedrock-constrained samples of comparable ages, and supports an absence of tectonic-induced subsidence post-1,900.

## 4.3. Holocene Sea-Level Change in Kanish and Waiatt Bays

Our reconstruction of settlement histories allows us to estimate sea-level change over the last 9,000 years in Kanish and Waiatt Bays. A total of 40 upper limiting points, 35 samples from terrestrial shell-bearing settlement sites and 5 samples from intertidal clam garden features, were collated into an age-altitude plot (Figure 5). From this sample, we generated a RSL curve for Kanish and Waiatt Bays using select data points. Data from EbSh-13 were used to give skeletal structure to our curve. We chose these data points because of the longevity of occupation of the site. Additionally, these samples rest on solid bedrock, which are less subject to post-depositional changes in elevation. Next, we only included samples from deposits that did not significantly subside (i.e., those with a drop >0.6m). In addition, we only retained samples no more than 1.0m elevation above similarly-aged EbSh-13 data points. Finally, if multiple samples from the same site overlap in age and elevation, only the sample with the tightest dated standard deviation was used to estimate sea-level position. A polynomial trendline was fitted to our selected data to approximate our curve.

Assembling these data results in an estimate of sea-level change which smooths out noise in our data from instrument error and sediment compaction. While our RSL curve depicts a general decline over the Holocene, it is possible that sea-level changes were more uneven and abrupt than what we present. For example, if we were attempt to fit all data in our RSL curve in a way that ensured all points fall at, or slightly above the projected highest tidal position (HHWLT), this would estimate fluctuating sea-levels over time, with sea-levels reaching modern by ~2,500 cal BP. However, due to the complications of subsidence and compaction of underlying sediments, estimating RSL change in this way could lead to over-estimating of the timing and severity of RSL change (Brain et al. 2016:78).

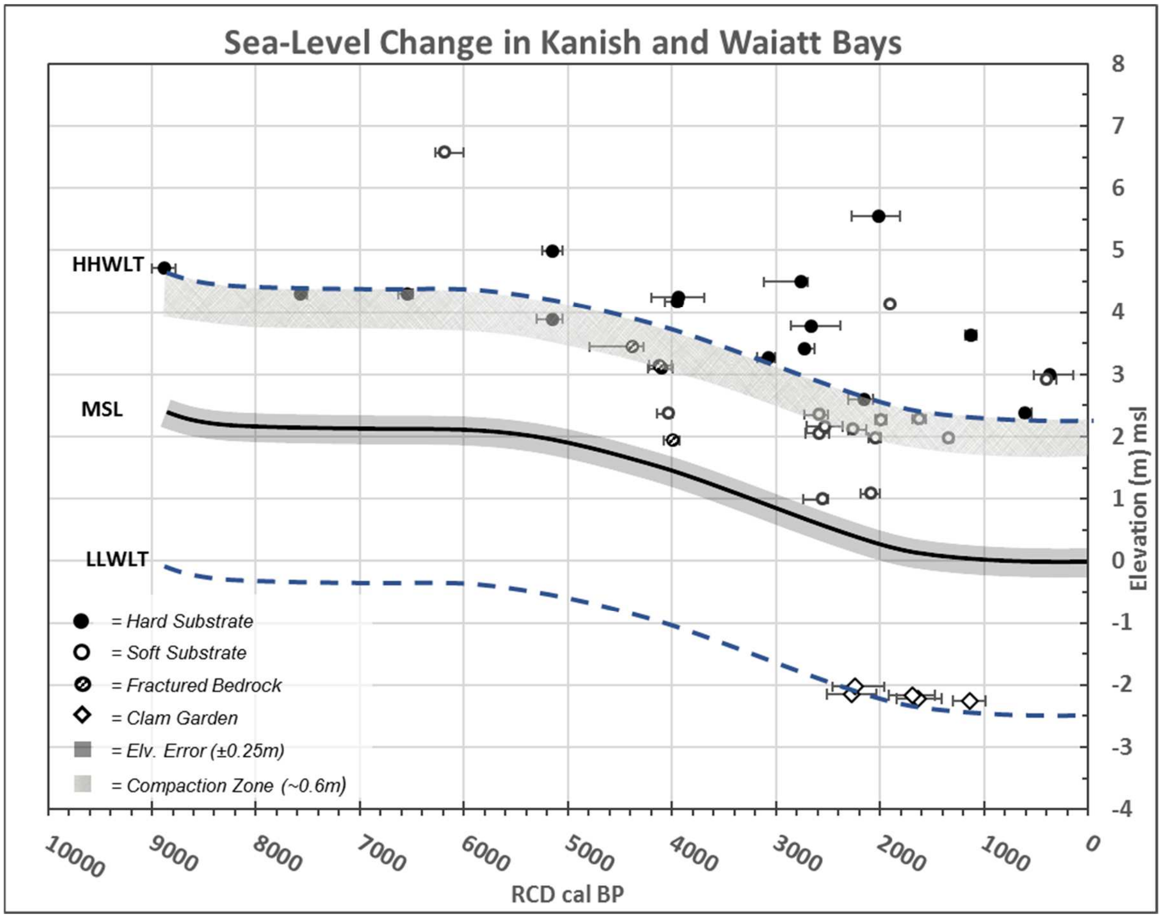

Figure 5: An estimation of RSL decline in Waiatt and Kanish Bays over the last 9,000 years. The statistical range of calibrated radiocarbon ages is included (Sigma2 95.4%). Based on a mix of Kanish and Waiatt limiting points, the solid black line is our best estimate of sea-level change over time. The grey zone surrounding this line represents elevation error (+/-0.25m). Paleo-tidal ranges (HHWLT/LLWLT) are projected based upon modern tidal heights. The zone beneath the projected tidal high-tide represents our 0.6m compaction threshold.

Our data show a general trend of sea-level regression throughout the Holocene in Kanish and Waiatt Bays (Figure 5). Six data points from three sites (EbSh-13; 21; 23) place sea-levels no higher than approximately 3.0m above modern between 9,000 and 5,000 years ago. Basal dates from EbSh-13 suggest a slow decline during this period, with younger deposits found at slightly lower elevations than older deposits (Figure 5). Isostatic uplift in the immediate post-glacial period produced dramatic relative sea-level change on Quadra Island with sea-level falling rapidly from ~+175m to +7.0m between 14,500 and 12,500 cal BP. By ~12,000 cal BP this vertical movement had significantly slowed (James et al. 2000:1526; Fedje et al. 2017). The relative stability in Early Holocene sea-level seen in Kanish and Waiatt Bays likely represents a slowing of isostatic uplift relative to global eustatic sea-level rise, similar to that experienced in other areas of the Northwest Coast (Peltier and Fairbanks 2006:3334; Clague et al. 2002:78).

Most of our data points for constraining sea-level are for the Late Holocene (post-5,000 cal BP); these illustrate the complexity of sea-level change during this period. Generally, RSL in Kanish and Waiatt Bays continued to decline through the Late Holocene, but at a quicker rate than during the Early Holocene. This may reflect a shift to regional plate tectonic uplift with eustatic mediation no longer present (Riddihough 1982:329; Clague et al. 1982:615). Sea-levels dropped ~2.0m over three millennia, reaching modern levels by ~1,500 years ago. Multiple data points from both clam gardens (S#175684, 171659, 175690) and terrestrial archaeological sites (S#5143275, 175664) place sea-levels at or around modern by1500 BP (Figure 5). Additional points place sea-levels no higher than modern at ~1200 cal BP (EbSh-5; S#175684) and ~600 cal BP (EbSh-2; S#178090). However, due to the paucity of data points for the last ~1,500 years, we can not know for certain whether sea level was stable during this period of the Holocene.

Our results demonstrate how sea-level histories vary substantially even over short distances. Comparing our terrestrial archaeological results by bay, and by substrate, shows a marked difference in the age-elevation of samples in Waiatt Bay compared to Kanish Bay (Figure 6). Samples in Waiatt Bay show a greater vertical spread between points, with samples on soft substrate and fractured bedrock found at lower elevations than similarly-aged samples on solid bedrock. As previously discussed, lower samples in Waiatt Bay are likely the result of subsidence and/or the compaction of underlying substrate. Kanish Bay samples, by contrast, reflect a general sea-level decline in the Late Holocene, with little vertical fluctuation between samples. The majority of samples from Kanish Bay come from bedrock-constrained sites, which is likely why we see such consistency in the age-elevation of samples. The few soft substrate samples from Kanish Bay (S#175664,182779,175660,182781) exhibit little to no evidence of either compaction or subsidence, and all post-date our hypothesized tectonic event between ~2,100 and 1,900 BP. Consequently, while we have identified a tectonic event in Waiatt Bay, we possess too few soft substrate samples in Kanish Bay to infer whether tectonic activity affected sites in this bay as well.

Neoglacial fluctuations in the Coast Mountains, common throughout the Holocene (Mood and Smith 2015:23), may also have caused sea-levels to change in fits and starts, with regression interrupted or reversed by isostatic uplift. For example, relative sea-levels on Quadra are currently declining (slowly) as modern isostatic or tectonic uplift (>4mm/year; Clague et al. 1982:613) outpaces global eustatic sea-level rise (http://www.geodesy.cwu.edu/data/bysite/; Peltier and Fairbanks 2006:3334). The uplift on Quadra Island may be a product of glacial retreat and advance in the Coast Mountains following the Little Ice Age, analogous to the Neoglacial-induced uplift documented in southeast Alaska (T. James, personal communication, 2017; Larsen et al. 2005:558). Detecting these subtle sea-level changes associated with past neoglacials is difficult given the large uncertainties of radiocarbon dates, particularly those obtained from marine carbonate samples.

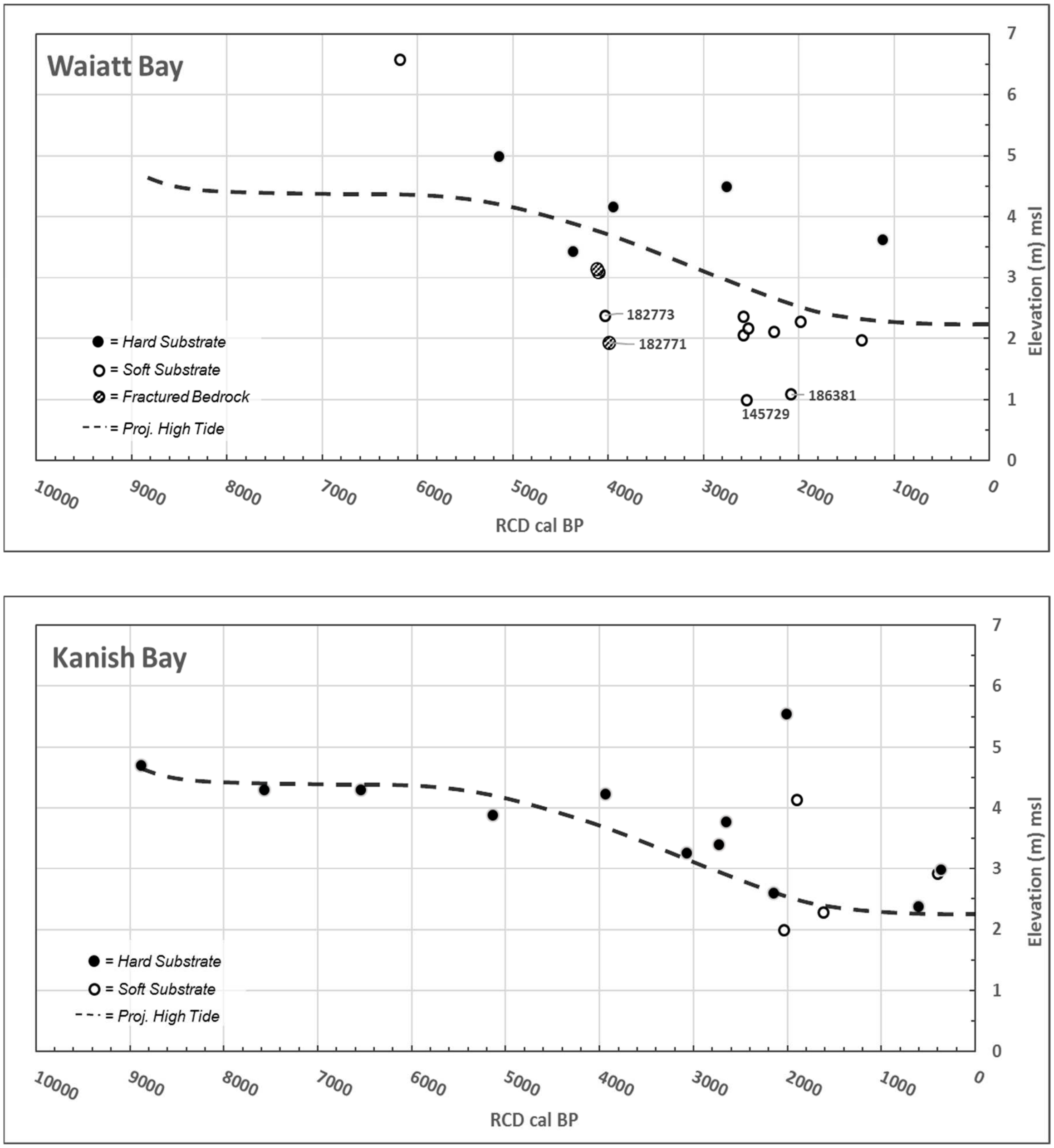

Figure 6: Age-altitude plots of terrestrial archaeological samples relative to msl. The dashed black line is projected paleo-high tide based on our RSL curve for both bays, and helps emphasize the variability of samples from Waiatt Bay compared to Kanish Bay. Deposits from Waiatt Bay that we believe subsided are shown with sample numbers.

# Chapter 5. Discussion

Our detailed temporal and spatial data from settlements and clam gardens in Kanish and Waiatt Bays allows for the reconstruction of local relative sea-level during the Holocene. Our results have demonstrated that ESP coring along transects is an accurate and efficient means of collecting these data, though we found that the general pattern of settlements following declining seas is not true of all sites. We also found that sites sitting on soft substrate are more likely to experience post-depositional lowering from a number of factors, including compaction and tectonic-induced subsidence, compared to sites on hard, consolidated substrates. Our understanding of these processes allowed us to identify a Late Holocene tectonic event with extremely localized consequences within our study area. Taken together, our data show a general sea-level regression throughout much of the Holocene (Figure 5).

Settlement histories can be used to estimate sea-level change on a fine spatial-scale with accuracy and efficiency. Our data supports that of previous researchers who identify a general trend of populations building settlements close to shorelines, and following shifting sea-levels over time (Carlson 1996:87; McLaren et al. 2011; Letham et al. 2015:54). Developing a site-appropriate sampling strategy is critical to investigating localized sea-level change, as researchers must consider the natural topography prior to human modification, underlying substrate, and possible deviations from general settlement patterns of local populations. For instance, sites on restricted landforms (e.g., EbSh-30), sites developed upslope over time due to limited foreshore area, contradicting our RSL prediction (Figure 4). Thus, settlement sites built on expansive, bedrock-constrained landforms are more suitable for acquiring accurate sea-level data. Our methodology also further demonstrates the adaptability of ESP coring to answer a variety of questions, and to provide powerful data for both cultural and environmental reconstructions (Cannon 2000:68; Martindale et al. 2009:1566).

Consistent with observations made by other researchers (Clague 2002:20; Horton et al. 2009:1086; Brain 2016), our results suggest that substrate plays a major role in the post-depositional stability of archaeological samples, and therefore must be considered when interpreting sea-level change and its effect on people's lives. For instance, compaction of soft substrate in sea-level regressive scenarios can lead to an over-estimation of the rate and magnitude of change (Brain 2016:78), whereas tectonic activity causing uplift or subsidence of the archaeological record can complicate constraining sea-level data (Hutchinson 2015:925). In Kanish and Waiatt Bays, we identified three types of substrate which respond differently to tectonic or compaction-induced subsidence. Soft substrate sites (e.g., EbSh-21) are severely affected by both compaction and tectonics, sites on fractured bedrock (e.g., EbSh-87) are susceptible to tectonic activity but not compaction, while sites on solid bedrock (e.g., EbSh-13) show little effect of either compaction or tectonic subsidence (Figure 4). Therefore, researchers should be cautious when assigning a causal mechanism to post-depositional lowering of deposits, and when possible, control for the influence of substrate.

Our data allow us to highlight the mosaic of regional and local seismic events which make up the tectonic history of the Northwest Coast. Evidence of significant subsidence in sites resting on either fractured bedrock or soft substrate points to at least one life-changing tectonic event in Waiatt Bay approximately 2,000 years ago. This event closely matches the timing of Mathewes and Clague's (1994:691) hypothesized "Event 2", a major plate-boundary earthquake which caused subsidence on southern Vancouver Island and in northern Washington (691). Should subsidence in Waiatt Bay be connected to this event, it would suggest that other significant, regional seismic events other the last 9,000 years may have resulted in substantial localized change in RSL (Clague 1997:442; Enkin et al. 2013:756; Leonard et al. 2010:2081).

Conversely, subsidence in Waiatt Bay does not appear to be related to more recent, local tectonic activity, such as the magnitude 7.2 earthquake which struck just 25km south of Quadra Island in 1946. This recent event caused severe terrestrial and marine down drops, liquefaction, and the disappearance of whole beaches in nearby locales (Rogers 1980:123), yet we cannot confirm related evidence of subsidence in either Kanish or Waiatt Bay. The limited wave erosion (e.g., undercutting) of shore-proximal archaeological sites, aside from EbSh-87, implies they have not recently subsided. It is possible that the dips observed in clam garden walls may be related to more recent tectonic activity, however more precise elevation and aging data is required to explore this line of evidence.

Our dataset for Kanish and Waiatt Bays is part of a larger, coast-wide effort to produce increasingly local reconstructions of sea-level and environmental change. For instance, a decade ago, sea-level studies in the Salish Sea focused on the early post-glacial period (James et al. 2005:121; Hutchinson et al. 2004:191), and for the Late Holocene relied on few data points to estimate millennia of change (cf: Fedje et al. 2009). Recent research centered on Quadra Island by Fedje et al. (2017) refined these earlier regional reconstructions, identifying subtle, but important differences in sea-level. This included finding no evidence of an Early Holocene low-stand below modern sea-level.

Our data for Kanish and Waiatt Bays looks even closer at sea-level change than previous studies, identifying changes specific to northern Quadra Island. While our findings largely agree with previous estimates, our results show that the rate of declining seas was not uniform throughout the Holocene and that regressing sea-level was punctuated by at least one major tectonic event. The subtle changes we see, at even a site-specific level, are not always represented in broader reconstructions of sea-level. Identification of local tectonic and geological effects are important when interpreting the lived lives of coastal populations, and may even serve as temporal touchstones or “anchors”

(Gauvreau and McLaren 2016:312) when comparing archaeological reconstructions of the past to Indigenous oral histories and traditions (McMillan and Hutchinson 2002:46-53; Martindale 2006:171; Ludwin et al. 2005:141; Kii7iljuus and Harris 2005:131).

For people who rely on the ocean, changes in sea-level can have a profound effect on daily lives, connections to place, and identity. For archaeologists, sea-level histories are a useful tool for locating ancient sites, and understanding settlement histories. Refining sea-level histories to identify local, even site-specific, changes in relative sea-levels is crucial to understanding complex human-environmental dynamics. Local, life-changing geomorphological processes almost certainly occurred throughout the coastal regions at varying times in the past, meaning that populations along the Northwest Coast and elsewhere have had to contend with a changing, and sometimes volatile environment (Mackie et al. 2014:138). Identifying the timing and effect of sea-level change at increasingly local scales enhances our understanding of past people's connection to place and recognizes the challenges created by a changing environment and shifting shorelines.

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