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Indigenous Sea Gardens have been Adapting to Sea Level Change for at least Four Millennia

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Article

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Indigenous Sea Gardens have been Adapting to Sea Level Change for at least Four Millennia

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Main Message:

By tending clam beaches and repositioning rock-walled terraces through time, Indigenous peoples have maintained resilient mariculture systems over millennia despite changing sea levels.

ABSTRACT

Indigenous peoples along the northwest coast of North America have maintained sea gardens (clam gardens), an ancestral form of mariculture, for at least four thousand years. While their occurrence is being increasingly reported, the degree to which Holocene sea level change has obscured existing ancestral structures along parts of the coast was unknown. We used intertidal and subtidal archaeological excavations, ground-penetrating radar, and radiocarbon dating to assess sea garden wall structure, thickness, and site formation processes at two coastal sites in southern British Columbia, Canada. By comparing sea garden wall depth to the local relative sea level history, we found that sea gardens have been continuously modified and maintained for at least four millennia, and that the morphology of sea gardens is different in areas of transgressing versus regressing shorelines. Moreover, we found that different local sea level histories will influence the visibility of these monumental features today. These observations, woven with Indigenous knowledge, demonstrate that not only is sea gardening an enduring, adaptive cultural practice that has been resilient to changes in sea level position for millennia, but also offers a strategy for climate change adaptation today.

KEYWORDS: archaeology, clam garden, Indigenous knowledge, mariculture, sea level rise, underwater archaeology

MAIN PAPER

Introduction

Globally, there is growing recognition of the persistent role Indigenous peoples play, and have played, in shaping, maintaining, and managing terrestrial [1-4] and marine environments [5,6]. Along the Northwest Coast of North America, Indigenous traditional practices have diversified and enhanced forest and plant communities [7-11], shaped shoreline topography [12-14] and left visible clues of rock wall alignments, intentional

terracing, and cleared beaches within the intertidal [15-17]. The many different types of intertidal modifications exist on a continuum and are diverse and varied, as are the cultures and ecosystems they have supported. Here we focus on clam gardens, or sea gardens as is the preferred term in our study area; rock-walled terraces found at the lowest tidal position along semi-protected bays, inlets, and island beaches of southeast Alaska [18], British Columbia [19-21] and Washington State [22] and which have been enduring features of eco-cultural seascapes for thousands of years [21,23,24].

While long known to Indigenous communities by various terms in local languages, western scientists and the general public have only recently become aware of how these purposely constructed rock-walled terraces expand, enhance, and often create intertidal and rocky reef habitat for a diversity of culturally important species including clams [21,23,25-30]. In addition to providing food, these locations support intergenerational knowledge transfer and socio-cultural and ceremonial practices within Indigenous communities [31-33]. While colonialism and population decline interrupted the widespread use of sea gardens [34], Indigenous communities today are working to restore and rebuild their traditional clamming beaches [32,33,35-37]. With this has come the realization that variable localized sea level histories affect the visibility of these mariculture features on regional scales, and that sea garden identification and restoration are particularly urgent in areas of rapidly rising sea levels. Amidst these restoration efforts, questions are emerging about the degree to which past sea level rise has obscured unrestored ancestral sea garden structures in areas of transgressing sea levels, and the challenges current climate warming and rising oceans pose to restored gardens and bivalve populations.

Since 2014, the Hul'q'umi'num' and W̲SÁNEĆ First Nations have been working with Parks Canada to restore two sea gardens in the southern Gulf Islands, British Columbia, Canada (Figure 1) [32,33,38]. Unlike other parts of the northwest coast where tectonic rebound and uplift may be outpacing or matching sea level rise resulting in sea level regression or stasis since the last glaciation, the southern Gulf Islands are experiencing incremental, annual sea level rise [39,40]; a phenomenon that has persisted in the area for the last 11,000 years [41,42] and is predicted to accelerate in years to come with climate

change [43]. To reveal insights into sea garden antiquity, continuity of use, detectability, and the relationship between sea garden morphology, wall depth, and changing sea level over the millennia, we conducted intertidal and subtidal archaeological investigations at two sea gardens sites in British Columbia, Canada's southern Gulf Islands. By contrasting these observations with archaeological data from an area experiencing sea level regression in British Columbia's northern Gulf Islands (Quadra Island), we identify differences in sea garden morphology and visibility between the two regions and consider how relative sea level histories can be used to establish age estimates for initial sea garden construction.

The results suggest that people have been maintaining sea gardens amidst sea level change for at least four millennia. In addition to the archaeological findings, the community restoration project in the southern Gulf Islands afforded project scientists opportunities to learn from Indigenous knowledge holders about cultural sea garden practices including wall and terrace construction and maintenance. These practices have affected formation processes and morphological characteristics of sea gardens locally, and allow for their continuous use and resiliency through time amidst sea level change. Here, we examine how this resiliency relates to many factors including peoples' longstanding relationship with place, and cultural practices that recognize the interconnected and reciprocal relationships between people and all elements of the environment. These relationships guide beach management practices. With every visit to dig clams, there are opportunities to reposition the rock walls and terraces to productive tidal heights and to tend the beach gardens. This results in a flexible technology that has been adaptable to changing environmental circumstances, such as shifting shoreline position, for millennia. We therefore suggest that sea gardens hold promise as a resilient mariculture technology into the future, particularly if Indigenous communities today are supported in restoring and reclaiming their longstanding cultural practices and ancestral food systems.

Background and Methods Summary

Study area, sea level history, human history in the area

This project focused on two sea garden study sites located in the southern Gulf Islands, British Columbia, Canada (Figure 1), in the traditional territories of the Coast Salish peoples. While a human presence in the broader region predates 13,800 years [44,45], documented late-Pleistocene to early-Holocene sites associated with ancient shorelines are lacking in the study area given their likely positions well inland or submerged offshore [46,47]. Studies of the relative sea level history for the area demonstrate that shorelines fell rapidly from an upper limit of +75 m above modern following the end of the last glaciation to a position of -30 m below modern sea level by 11,200 cal B.P., before gradually rising to present day levels [41,42], thereby inundating ancient shorelines and associated sites [42,47-49]. Intact archaeological deposits associated with lower sea levels have been recorded in the intertidal zone at several locations throughout the southern Gulf Islands and San Juan Islands [42,50-52], allowing for a refined sea level curve for the mid through late Holocene [42].

Restoration initiative

The archaeological investigations took place at two sea garden sites in the southern Gulf Islands as part of a much larger initiative led by Hul'q'umi'num' and W̱SÁNEĆ First Nations and Parks Canada to restore the sea gardens to a workable height above chart datum and to reconnect communities with traditional clamming beaches and cultural practices. The direction of the restoration program is guided by Hul'q'umi'num' and W̱SÁNEĆ working groups including knowledge holders, Elders, community leaders and shellfish harvesters. Since 2014, Indigenous working group members have guided the eco-cultural restoration and worked with Parks Canada to document ecological and environmental data[32,33,38]. This research included intertidal archaeological survey and excavation at one of the sites in 2016 and underwater archaeology at both sites in 2017 [53,54] (see Methods 1A and Supplemental Table 1 for summary of previous work and radiocarbon dates).

Intertidal and subtidal methods

To better understand the relationship between sea garden morphology and changing sea levels over time, we first defined the spatial extent of the sea garden features. Maps and profiles were produced using a combination of high precision handheld GPS unit (Mobile Mapper), total station, self-levelling laser level, fibreglass tape baselines, excavation unit datums, and hand drawn plans and profiles with methods adapted to intertidal and subtidal contexts (see Methods 1B). As this project represented the first underwater excavation of sea garden walls, our methodology was refined as fieldwork progressed. To determine wall thickness, structure, stratigraphy and maximum depth we used ground-penetrating radar in the intertidal (Methods 1C) and archaeological excavations on intertidal and subtidal sections of the wall (Methods 1D). Radiocarbon analyses of barnacle scars (on the underside of rocks) as well as clams, whelks and limpets below the rock walls were the target samples to establish clam garden age, and their sampling followed established protocols [23](STable1). The archaeological fieldwork was conducted with cultural workers from the Hul'q'umi'num' and WSÁNEĆ First Nations who ensured that field methods adhered to cultural protocols for work at ancestral sites. Fieldwork was conducted under federal and provincial heritage permits (Methods 1E).

Comparison of wall heights above and below chart datum with relative sea level history

Once depths and stratigraphy of the cobblestone walls were established, we compared the tidal heights of the sea garden wall bases to the relative sea level history [42,48] to estimate timing for when the walls were likely first established. This comparison assumes that a sea garden wall would have been constructed within 1 m of the lowest position of a tidal range (Methods 1F). We then compared profiles of sea gardens and their positions relative to present day chart datum in the southern Gulf Islands with two gardens in the northern Gulf Islands (Quadra Island) to consider regional variability and differences in sea garden detectability between the two locations.

Observations and Results

Morphology, structure, depth of the walls

The two sea gardens in the southern Gulf Islands differ in size and configuration (Figure 2, Supplemental Figure 1), but both show evidence that the walls were augmented with rock to match sea level rise over time. The larger sea garden located in Fulford Harbour on Salt Spring Island (DeRu-192) spans 824 m of continuous shoreline. The other sea garden site on Russell Island (DeRu-203) consists of two smaller walled beaches separated and bounded by bedrock outcrops measuring a combined length of 103 m. The top of the original unrestored wall at DeRu-192 was visible at a +0.7 m tide or lower, while the Russell Island garden was only discernible at a +0.4 m tide or lower. Ground penetrating radar in the intertidal at DeRu-192 indicated that the wall's stratigraphic thickness does not exceed 60 cm (Supplemental Figure 2). Archaeological investigations similarly revealed that both walls are stratigraphically shallow (up to 40 cm) but also very wide with the DeRu-192 wall measuring 20.5 m and the DeRu-203 wall measuring 14.2 m wide at our excavation locations. At both sites, most of each wall was underwater at a low-low tide (0 m), leaving a smaller portion of the wall exposed in the intertidal (~ 9 m wide at DeRu-192; ~ 4 m wide at DeRu-203). Parks Canada's Underwater Archaeology Team (UAT) located the maximum seaward extent of both walls at depths of -1.4 m (DeRu-192) and -2.14 m (DeRu-203) demonstrating that both walls span a vertical tidal range of over 2 m from top to bottom.

Radiocarbon dates and using relative to sea level history to establish sea garden age in the southern Gulf Islands

Radiocarbon dates at Fulford Harbour's DeRu-192 demonstrate the intertidal portion of the wall has been in use for the last 1700 years and into the modern era, with more recent ages associated with shallower and more landward positions from the low tide (Supplemental Table 1). These comparatively recent age estimates concur with ethnographic accounts from Salt Spring Island of Indigenous families digging clams and

moving rocks onto the rock wall into the 1920s [55]. Combined, these age estimates demonstrate that the Fulford Harbour wall (DeRu-192) built up incrementally through time with sea level rise. While we have been unable to locate ethnographic accounts of rocks being added specifically to the Russell Island sea garden walls into the historic period, communities and local families have recognized the site as a good place to harvest butter clams throughout the historic and recent periods. While further data are needed to assess the upper limits of the walls, the lower tidal height of the Russell Island wall may indicate that rocks ceased being added to the wall in the historic period. Previous excavation and radiocarbon dating at Russell Island indicate that this sea garden was established and in use between 700 and 325 cal B.P.[21].

We were unable to find barnacle scars on the underside of rocks in the subtidal excavations at Fulford Harbour (DeRu-192), while radiocarbon dates of barnacle scars from multiple sides of rocks at the base of the Russell Island (DeRu-203) wall returned mostly modern ages. Combined with observations of crabs and octopus moving boulders in the lower wall, the dates at Russell Island suggest the wall was subjected to some degree of movement and is no longer in its primary depositional position. The Hul'q'umi'num' Elders have also talked about geoduck and horseclam gardens that may benefit from this dispersed configuration suggesting the spread-out nature of rocks may be anthropogenic. In contrast, the DeRu-192 wall was robust, measuring up to 40 cm thick stratigraphically and consisting of up to three stacked boulders with no evidence of mobility or substantial bioturbation at the wall base. We were therefore confident to compare the position of the DeRu-192 wall to the local sea level curve, which indicates the lowest part of the wall would have been within 1 m of low tide position around 4000 years ago (Figure 2).

Establishing more specific chronologies proved difficult given potential dating uncertainties. Within the relative sea level curve, we assume that the sea level data points reflect elevations equivalent to the ancient high tide. It is possible, however, that sample points may represent locations which were elevated and farther inland [42]. If this is the case, then the bases of the sea garden walls would be positioned lower on the relative sea

level curve, increasing the age estimate. Similarly, information on cultural practices for wall building and maintenance shared by Elders on our team are instructive. They have shared that boulders were at times floated by canoe at high tide and lowered to the bases of walls in order to firmly anchor them. In this scenario our age estimate could be more recent as the boulders may not mark the low tide position but rather a slightly lower depth. As we also learned through restoration activities, boulders could be moved upslope from lower parts of a wall with rising sea level, meaning that the original wall base may have been lower and hence older. Given the potential sources of uncertainty for the tidal range on either side of the relative sea level curve (likely a vertical range of ± 0.5 m), we assess the initial age of construction of the sea garden walls as being 4000 ± 750 years. This estimate intersects with a sharp incline in the sea level curve and incorporates uncertainty in the age of marine reservoir effect to adjust to calibrated years before present.

Comparison of sea garden wall morphology between southern Gulf Islands and Quadra Island

With sea garden wall profiles displayed in relation to the relative sea level history for the southern Gulf Islands, it is informative to compare them to sea gardens in the northern Gulf Islands where these mariculture features have been studied more intensively and where there is a different relative sea level curve. Figure 2 illustrates two clam garden profiles from Quadra Island radiocarbon dated to circa 3200 and 1600 years cal B.P. positioned in relation to the relative sea level curve for the area. In this region of falling relative sea level, older clam garden features are positioned higher in the intertidal [23,24]. Notably, we observe that sea garden walls exhibit stark morphological and tidal height differences depending on the local sea level history. Along the regressing shorelines of Quadra Island we observe taller, narrower and more coherent walls in comparison to the wider and more horizontally diffused walls in the southern Gulf Islands where transgressing shorelines have submerged older components of the features well below the present day low tide mark. Averaged measurements indicate that the walls in the southern Gulf Islands are both thinner and up to four times wider than on Quadra.

Discussion

The position of sea garden walls in the southern Gulf Island suggests that these two mariculture sites were established and in use for the better part of four millennia (Figure 2). Former sea level positions are used increasingly to estimate chronologies for archaeological features in terrestrial [56], intertidal [24,57] and underwater [58] contexts, particularly for inorganic structures like stone fish traps. In comparison to fish traps, sea gardens with abundant butter clams and littlenecks are restricted to the lowest intertidal and generally fall within 1 m of chart datum which includes the upper habitat range of these clam species. This tight intertidal range allows for age determinations nearing millennial increments particularly where the relative sea level history is steadily rising or falling through time. Given the persistent sea level rise observed across the southern Gulf Islands of 0.4 - 0.6 mm per year [42,59], ancestral peoples would have had to build up the walls incrementally through time to match the sea level rise and maintain maximum access to productive clam habitat. With this study there is now evidence from two parts of the northwest coast indicating that sea gardens have been in use for at least 3000 to 4000 years and into the present day, and that they have been resilient to relative sea level change, both rising and falling.

Our observations and chronologies indicate that the morphology and visibility of sea garden rock wall features differ substantially between the northern and southern Gulf Islands. On Quadra Island in the north, archaeological dates on clam gardens indicate peoples would iteratively reposition rocks seaward and downslope when sea levels were falling, resulting in tall, narrow walls with the bases of the most recent features closely corresponding to present day low tide (0 m LLWLT) [23,24]. In contrast, similar features in the Southern Gulf Islands at Fulford Harbour and Russell Island the walls will be stratigraphically thinner, wider, and extend underwater well below present day chart datum. On average, and assuming consistent sea level rise through time, the wall at Fulford Harbour gained 5 m in width and 50 cm in tidal elevation per millennium (Figure 3). With additional research into sea garden wall profiles and slopes in areas of transgressing shorelines, it is possible that periods of gradual, rapid or punctuated sea

level rise will become detectable. We would expect sections of steeper wall slope in times of more rapid or punctuated sea level rise, and more gradual wall slopes in periods of consistent sea level rise, although local topography, bathymetry, and cultural practices will also be influential factors in the evolution of wall morphology.

Wall morphology will also affect the kinds of samples suitable for radiocarbon dating. Taller narrower walls in areas of falling sea level offer more radiocarbon sample choices including clams, which can burrow into the walls, or be trapped in growth position under the wall during initial construction. In the southern Gulf Islands, wider and thinner walls might not extend beyond the burrowing depth of butter clams, making the depositional environment more vulnerable to bioturbation from bivalves burrowing through the wall and settling at its base any time throughout the garden's existence. Indeed, one member of the Hul'q'umi'num' working group noted how the subtidal portion of a sea garden wall is desirable habitat for butter clams today who preferentially live amidst the warmth of the boulders.

While stark regional differences are apparent, our sample size of sea gardens and radiocarbon dates in the southern Gulf Islands remains limited. Ongoing surveys and data sharing are needed to better characterize the variability and commonalities of sea garden morphology and distribution in the region, but survey and monitoring are hampered by sea level rise. While clam gardens elsewhere may be visible at a +1 m tide, those in the southern Gulf Islands will still be underwater and the temporal window for recording much shorter. We therefore must be careful with coast-wide interpretations of cultural similarities and differences based on apparent sea garden density and broaden survey efforts in the intertidal and underwater areas where shorelines have been transgressing. The urgency for intertidal survey in the southern Gulf Islands and adjacent American San Juan Islands cannot be understated: climate change induced sea level rise projections of up to 50 cm by 2050 and 1+ m by 2100 threaten to eclipse many sea gardens from intertidal view into the foreseeable future. Without the present restoration efforts, the Russell Island sea garden would most certainly have slipped below the waves and become inaccessible by 2050.

Fortunately, as demonstrated by our results, underwater investigations of sea gardens are feasible. This study adds to an emerging body of work on submerged Indigenous cultural heritage sites along the northwest coast [42,47,49,60-63] and offers a promising way forward for establishing chronologies of submerged archaeological features. With the benefit of well-documented intertidal and terrestrial analogues for comparison, and considering the preliminary steps taken during our study, underwater archaeological methods can broaden knowledge about sea gardens and submerged cultural landscapes. Methods such as side-scan sonar, nearshore multibeam echosounder bathymetry and targeted scientific diving searches could be used to map and identify: partially or wholly submerged sea gardens; and add to the growing research on ancestral intertidal octopus houses [35,64], subtidal reef nets [60,61], and other nearshore mariculture practices that also required strategic placement of rocks and boulders to target other subtidal species such as rock scallop and geoduck [33]. The deployment of scientific diving teams during the winter months with better underwater visibility will yield more direct information on the form and age of the submerged elements of sea gardens. Underwater excavations including trenches bisecting subtidal walls will yield a better understanding of the formation and maintenance of sea garden walls. The preliminary evidence from our study suggests that datable organic sample material, such as barnacles, might survive better underwater and present a rich source for radiocarbon dating. Notwithstanding the above potential, the resources required to mount such in-water efforts are substantial, underscoring the urgent need for more low-tide intertidal surveying, ideally over the next decade.

At the same time there is an urgency for increased survey and documentation of sea gardens, there is urgency to create opportunities for knowledge exchange both intergenerationally among Indigenous community members, and between researchers and communities. An unexpected emergent result of our work was how the interplay of contemporary restoration efforts and the archaeological research led to reciprocal learning opportunities and knowledge generation. During wall restoration researchers witnessed and discussed with community members the restoration practices that affected the morphology of the wall, such as the movement of rocks from underwater into the

intertidal, floating anchor boulders to the base of the wall, and maintaining spaces in the wall for canoes to come ashore and corridors for crabs to reach deeper water. Such practices may elude scientists unless local knowledge holders share teachings and guidance. Additionally, the writing and reviewing of paper drafts provided opportunities to consider aspects of worldviews that lead to a resilient, sustainable and flexible mariculture technology such as reciprocity, interconnectedness and equality of people with all other components of the environment.

The scope of the restoration project thus far has also allowed for intergenerational knowledge exchange among community members. Each year the younger generations learn new teachings, protocols, and social-ecological insights from the Elders as experiences and contexts within the restoration project expand and diversify. Digging for clams and turning over sediments during midnight winter tides, for example, elicits different teachings and memories than during summer daylight tides. Varied experiences trigger new lessons and learning opportunities and take time to cultivate. This gradual and reciprocal learning with community members can be difficult to replicate in scientific studies with short timespans but should nonetheless be attempted before lessons about tangible and intangible heritage are lost to rising shorelines.

Conclusion

The recent restoration initiatives in British Columbia's southern Gulf Islands, at Fulford Harbour and Russell Island, will ensure these sea gardens will remain accessible to communities for food, social and ceremonial purposes into the future. In the years to come, community members and scientists will monitor both the ecosystem effects and resilience of sea gardens to present-day environmental and socio-political disturbances. Colonization interrupted Indigenous communities' traditional connections to their clamming beaches [34] and Elders have seen the health of beaches decline over their lifetimes. Studies show that clams grew faster when Indigenous ancestors actively managed and harvested clam gardens [26]. While the ecological benefits of their efforts

can still be detected today [25,28,29], sustained beach health requires consistent care. Indeed, this message is strongly communicated by the Hul'q'umi'num' and WSÁNEĆ Nations who emphasize that when people recognize and honour the reciprocal relationships between people and environment, and care for beaches in the same way one would care for a family member, there is a better ability to adapt to environmental changes year to year, season to season, and tide to tide [32,33]. That ongoing care is evident locally in the walls carefully and gradually built through time at Fulford Harbour and Russell Island.

Globally cultural heritage is severely threatened by sea level rise. While many tangible cultural heritage sites and features are static and present heritage managers with decisions to protect, relocate or salvage what they can, sea gardens are inherently flexible and can be adaptable to shifting shorelines when located on, and constrained by, gently sloping landforms. With purposeful visits to maintain or restructure the wall, as well as during clam-digging visits, people have an opportunity to maintain and restructure a wall, tend the terrace, and continue the cultural practices that have shaped beaches and ecosystems over millennia. Restoring ecosystems often means restoring peoples' connections to the land and sea and their functional roles in maintaining the productivity, biodiversity and resilience of these ecosystems [30,36,65]. This means, enabling those who have looked after the environment for so long, to continue to do so. While rapidly changing oceans today present new challenges to ocean ecosystems, lessons from the past like those from sea gardens can inform resilient and sustainable ocean stewardship today and into the future.

"It is a sacred law given to us by the creator to look after the islands, we address the islands as our relatives, we are to look after them like our relatives, and in turn they will look after our people. This is the law of the people" John Elliott in Olsen 2019:4

Methods

Methods Section 1A – Summary of Archaeological Work at Sea Garden Sites

The restoration project began in 2014 with its initial years devoted to collecting baseline ecological and environmental data [32,33] including intertidal archaeology at one of the sites in 2016 and underwater archaeology at both sites in 2017 [53,54]. Prior to the restoration project, one of the sea gardens (Russell Island) had been subject to small intertidal excavations in 2013 as part of a larger coast wide study examining the feasibility of dating clam garden features [21]. Radiocarbon dates of 325 and 700 cal B.P. (Supplemental Table 1), were interpreted as reflecting relatively recent construction or maintenance of its upper wall, possibly associated with landward expansion of the wall with rising sea level [21].

Methods Section 1B - Mapping

Maps and profiles were produced using a combination of high precision handheld GPS unit (Mobile Mapper), total station, self-levelling laser level, fiberglass tape baselines, excavation unit datums, fiberglass tape measures affixed to floats, submersible electronic depth gauges, and hand drawn plans and profiles, with methods adapted to intertidal and subtidal contexts as appropriate. At each underwater study location the Underwater Archaeology Team installed a tape baseline across the wall and cleared subtidal vegetation along a 4-m wide transect to locate the wall base. The exposed walls were photographed and videoed, and scale plans and profiles were surveyed using standard archaeological methods, with particular care taken to record elevations along each wall transect relative to chart datum. At Fulford Harbour tidal station #7330 the tidal range between Highest Astronomical Tide (HAT) and Lowest Astronomical Tide (LAT) is 3.991 m. Lower Low Water Large Tide (LLWLT) is -0.055m relative to chart datum. Distance from chart datum to CGVD28 is 2.213 m. Elevations provided by Canadian Hydrographic Service, March 6, 2017.

Methods Section 1C - Ground Penetrating Radar

Ground Penetrating Radar (GPR) data were collected with a GSSI 400 MHz Sir 3000 system attached to a wheeled cart. A series of transects were run along the first 5 m of wall adjacent to the intertidal excavation location within the Fulford Harbour wall, as well as along the sea garden terrace. After collection, the radar data were uploaded to a personal computer, verified for accuracy and consistency, and analyzed using radar mapping software. The data were manipulated using a host of statistical methods to enhance and smooth the raw data[66]. The wall thickness as observed during excavation was compared to GPR data and a 20 cm discrepancy observed between the two methods. This may indicate that saltwater affected the GPR projection of the wall, although further testing and data collection are needed to confirm this.

Methods Section 1D- Intertidal and Subtidal Excavation

The intertidal and subtidal excavations consisted of 1 m wide trenches running perpendicular to the length of the wall. The intertidal excavation at Fulford Harbour spanned the 9-m width of the wall as exposed at low tide. The subtidal excavation began at the subtidal (offshore) limit of the wall and progressed upslope for 2.7 m at Fulford Harbour and 2 m at Russell Island. An additional 1.15 m x 0.6 m unit was excavated 4.5 m upslope from the base of the wall at Russell Island. Excavation proceeded by hand trowel in the intertidal and by water induction dredge (powered from a surface vessel) and hand trowel in the subtidal, with wall stones moved by hand in both scenarios. At each wall the stratigraphic sequence was intact allowing wall rocks to be discerned from non-wall sediments, most notably at Fulford Harbour. Excavation entailed careful dismantling of wall stones (which were set aside) to allow for a view of the wall stratigraphy and underlying sediment. Throughout the excavation, barnacle scars (particularly on the underside of rocks), trapped clams and other organic materials that could be used for radiocarbon dating were collected after being recorded in situ. In the intertidal, smaller rocks and sediments were examined by hand while subtidally they were both examined in situ and suctioned through the dredge intake into a collection bag which was later screened on shore. The excavation extents and observed wall stratigraphic thicknesses were recorded and surveyed as described above. We submitted

radiocarbon samples of barnacle scars and butter clams to the Keck Carbon Cycle AMS Laboratory at the University of California, Irvine.

Methods 1E - Protocols and Permits

The archaeological work was conducted with cultural workers from the Hul'q'umi'num' and W̲SÁNEĆ First Nations who ensured that field methods adhered to cultural protocols for working at ancestral sites. Each year the archaeological work overlapped with science and culture camps, which recognize sea gardens as places of learning. This collaborative setting provided opportunities for youth to learn from Elders and knowledge keepers, research team members, and Parks Canada staff – and indeed for all to learn from one another. After fieldwork, follow-up meetings with Hul'q'umi'num' and W̲SÁNEĆ working groups were held to discuss the findings and results of the archaeological investigations as well as interpretations shared within this paper. This project required two archaeological permits as the sea gardens overlapped with federal and provincial lands and waters. The Fulford Harbour sea garden site falls entirely within the jurisdiction of the Province of British Columbia, while the intertidal component of the Russell Island sea garden is managed federally by Parks Canada and the subtidal portion of the wall by the Province of British Columbia. The work was therefore conducted under federal Parks Canada Research and Collection Permit GINP-2017-25737 and a British Columbia Heritage Investigation Permit 2016-0138.

Methods 1F - Comparison of wall depth to sea level history

Based on ecological observations for the study area and data elsewhere [25,28], we assume that sea gardens constructed for intertidal clam harvest in the southern Gulf Islands will function best within +1 m of low tide (chart datum) to coincide with the upper ranges of butter clam (+1.25 m) and littleneck habitat (+1.3 m). To establish the age of the Fulford wall we compared the basal depth of the wall at -1.4 m below chart datum, to the established relative sea level curve for the area based on data points from nine excavated sites within the southern Gulf Islands [42] which demonstrate that sea levels were 1.5 m lower than present around 4200 calendar years ago. This curve is consistent with additional local paleoenvironmental and archaeological data points in the study area

which indicate sea level was about 1.74 m lower than present 4,700 years ago (note 1.74 m measurement has been adjusted to chart datum from the high tide benchmark used in the publication) [48]. As a sea garden wall built for the purposes of clam harvesting can be up to 1 m above chart datum, we would therefore expect a 4200 year old segment of sea garden wall to fall within the range of -1.5 m to -0.5 m relative to modern chart datum, and a 3,000 Cal B.P. (3250 calendar years) segment to fall within -1.0 m and 0 m. While the sea level curve flattens over the last 2,000 years making millennial distinctions less pronounced, we would nonetheless expect a 2,000 cal B.P. wall segment to fall within -0.6 m and +0.4 m, a 1,000 year old segment to be within -0.4 to 0.6 m and a historic or modern segment of clam garden wall to fall within 0 m to +1.0 m.

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Author contributions (names must be given as initials)

NFS, SA, JM led and conducted the fieldwork under the guidance of infield cultural workers HJ, CJ, and SJ and the Hul'q'umi'num and W̱SÁNEĆ working groups including LAC, AS, NS, KJ, NN, RS, TS, KT and JE, MS, SS, AS, CO, EP, TS, RS. NFS and JM compiled archaeological observations, results and preliminary reports. LAC, AS, NS, KJ, NN, RS, TS, KT and JE, MS, SS, AS, CO, EP, TS, RS provided traditional knowledge used in the paper. NFS prepared Figures 1, 2, supplemental information and annotated Figure 3 illustrated by CP. NFS, SA, JM, AS conceived of the initial paper. NFS, SA, JM, AS, KJ wrote the paper. All authors reviewed and provided comments and edits to the paper.

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Data availability statement

All relevant data generated by this study are provided in the article and supplemental documents.

Competing Interests

NFS was hired as an Independent Contractor by Gulf Islands National Park Reserve and Parks Canada to lead the archaeological investigations of the two southern Gulf Islands sea gardens which included fieldwork, analysis, report writing and the preliminary drafts of this paper between 2016 and mid-2022. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Figure Legends

Figure 1 – Study area in British Columbia, Canada's northern and southern Gulf Islands: photos of Quadra Island sea gardens showing base of wall at EbSh-13 (a) and aerial view of EbSh-36 (b), contrasted with wider southern Gulf Island walls extending underwater at DeRu-192 in Fulford Harbour (c) and DeRu-203 at Russell Island (d). Photos by Nicole Smith (a,c,d) and Keith Holmes (b).

Figure 2 – Comparison of sea garden wall morphology in areas of sea level regression (Quadra Island in red) and sea level transgression (southern Gulf Islands in blue), and inferring age based on wall position relative to chart datum. a. Relative sea level position over last four millennia for Quadra Island (based on Crowell 2017 as depicted in Smith et al. 2019) and southern Gulf Islands (based on Fedje et al. 2009). b. Comparison of sea garden wall width, thickness, and tidal height position relative to chart datum for two sea gardens on Quadra Island - EbSh-36 (Fedje et al. 2018; Smith et al. 2019), EbSh-13 (Smith et al. 2019) and two in the southern Gulf Islands -DeRu-192 (this paper), DeRu-203 (Lepofsky et al. 2015; this paper). Lower position of undisturbed wall at DeRu-192 indicates age of up to 3500 years Cal. B.P. equivalent to ~4000 calendar years.

Figure 3 – Artistic illustration of sea garden development over 4000 years at DeRu-192, Fulford Harbour, Saltspring Island. Recent wall in intertidal spans present to ~1700 years ago, and is mixed modern, historic, and ancestral use and maintenance - based on peoples' memories and radiocarbon dates. Ancestral wall underwater is around 1700 to ~ 4000 years old and includes some recent use for subtidal foods, and ancient construction, maintenance and use - based on traditional knowledge and sea level history (Illustration by Carol Pillar, Parks Canada, annotation by Nicole Smith). Note: Around 4200 years ago sea level was about 1.5 m lower than today.

Figure1

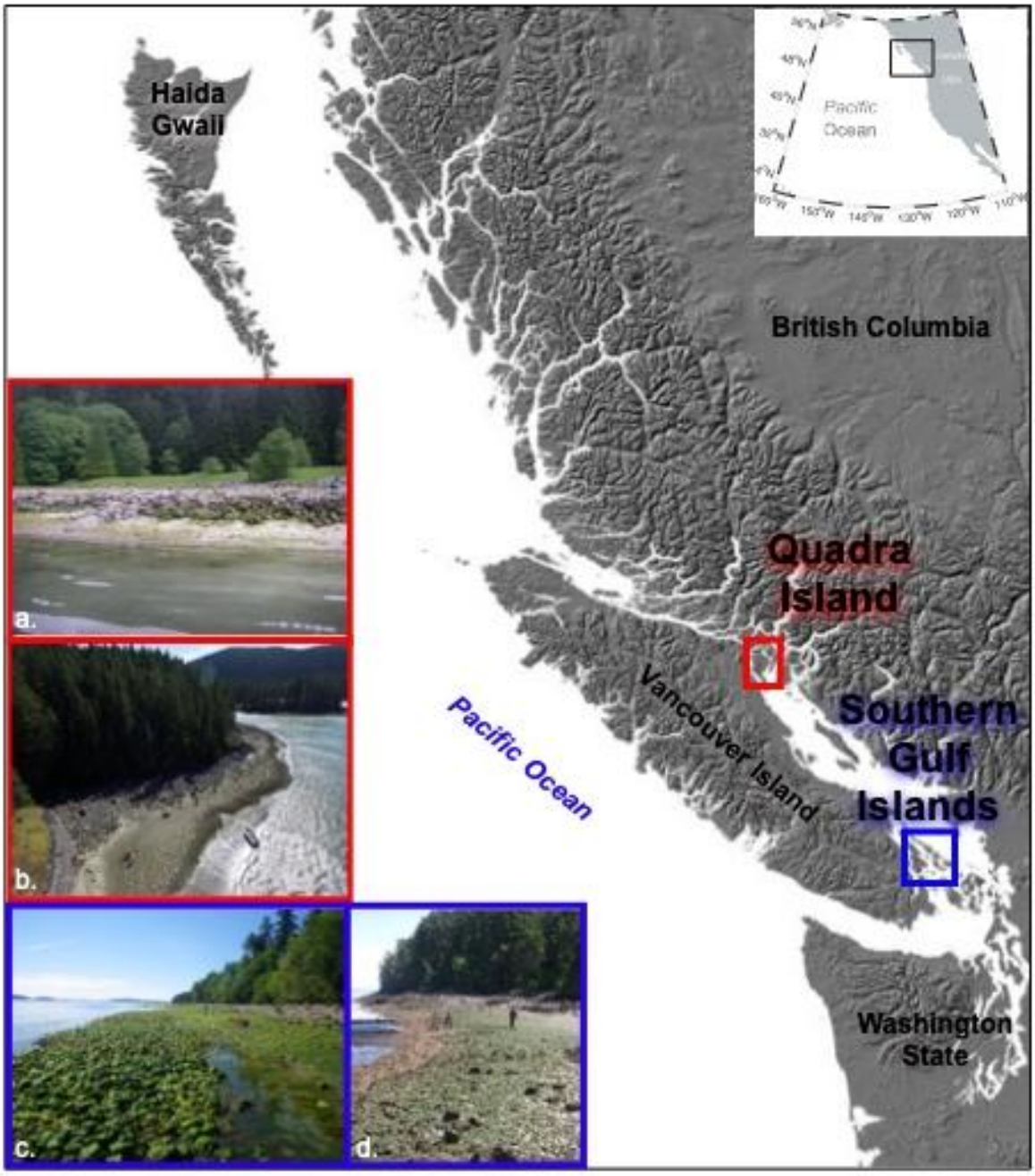

Haida Gwaii
British Columbia
Pacific Ocean
Quadra Island
Vancouver Island
Southern Gulf Islands
Pacific Ocean
Washington State
a.
b.
c.
d.

Figure 2

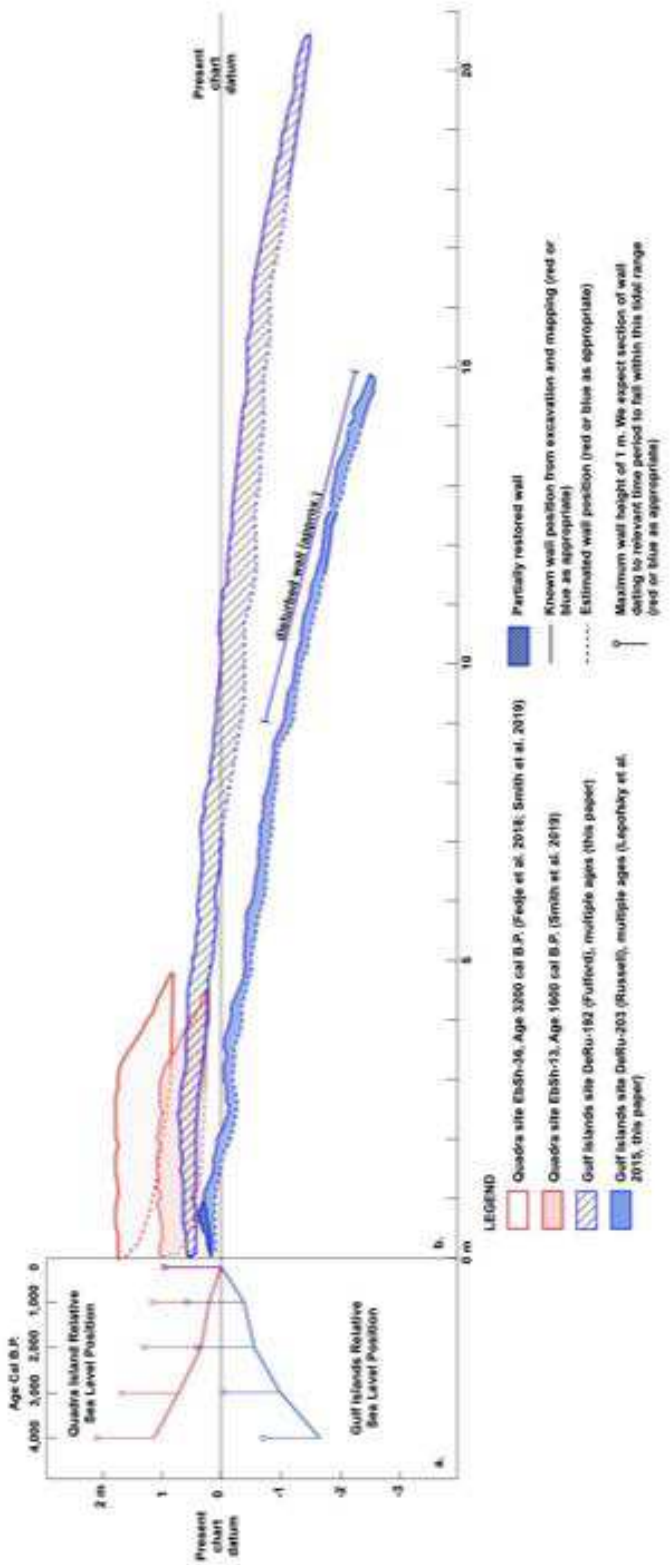
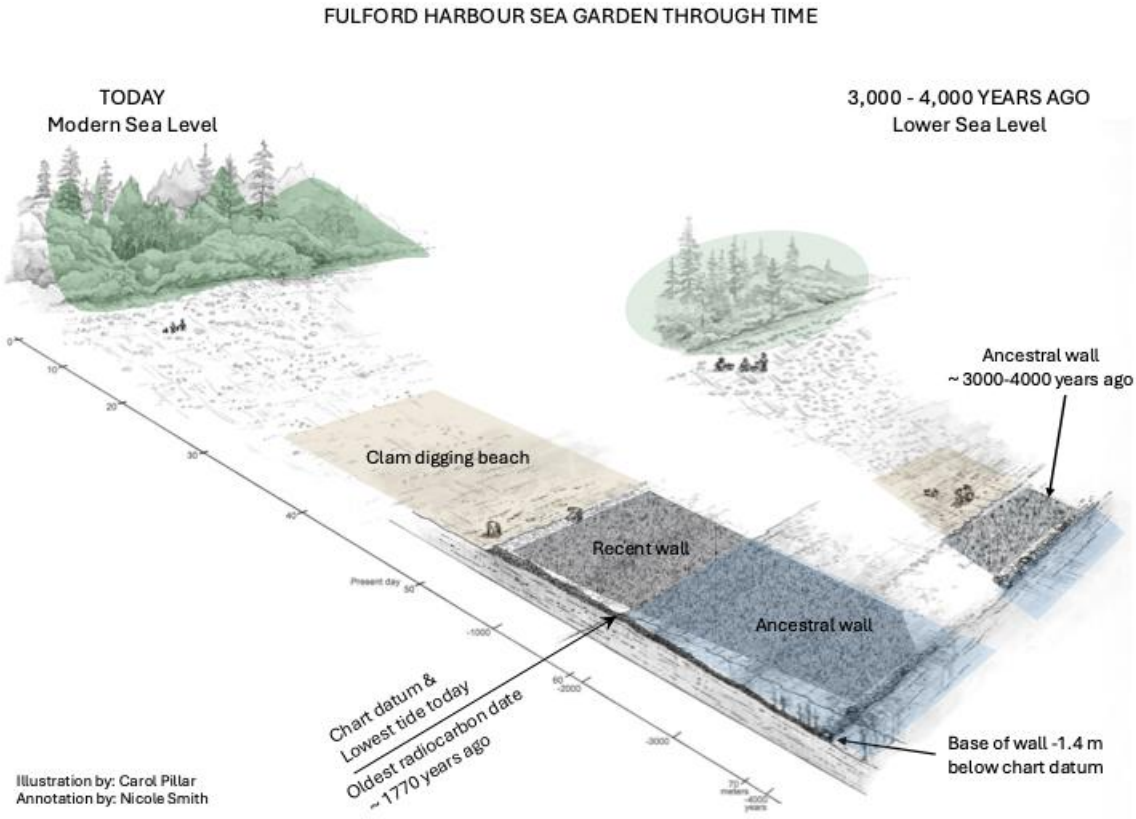

Present chart datum
Disturbed wall (schematic)
0 m
a.
b.
Age Cal B.P.
4,000 3,000 2,000 1,000 0
Quadra Island Relative Sea Level Position
Gulf Islands Relative Sea Level Position
2 m
1
0
-1
-2
-3
Present chart datum
LEGEND
Quadra site EbSh-36, Age 3200 cal B.P. (Fedje et al. 2018; Smith et al. 2019)
Quadra site EbSh-13, Age 1600 cal B.P. (Smith et al. 2019)
Gulf islands site DeRu-182 (Fulford), multiple ages (this paper)
Gulf islands site DeRu-203 (Russell), multiple ages (Lopofsky et al. 2015, this paper)
Partially restored wall
Known wall position from excavation and mapping (red or blue as appropriate)
Estimated wall position (red or blue as appropriate)
Maximum wall height of 1 m. We expect section of wall dating to relevant time period to fall within this tidal range (red or blue as appropriate)

Figure 3


FULFORD HARBOUR SEA GARDEN THROUGH TIME
TODAY
Modern Sea Level
3,000 - 4,000 YEARS AGO
Lower Sea Level
Ancestral wall
~ 3000-4000 years ago
Clam digging beach
Recent wall
Ancestral wall
Chart datum &
Lowest tide today
Oldest radiocarbon date
~ 1770 years ago
Base of wall -1.4 m
below chart datum
Illustration by: Carol Pillar
Annotation by: Nicole Smith

Supplemental Table and Figures Legends (separate file)

SFigure 1 – Site maps and shoreline profiles with radiocarbon date locations for Fulford Harbour (a, c) and Russell Island (b, d).

SFigure 2 – Ground penetrating radar imagery of transition from sea garden terrace to sea garden wall in the intertidal at Fulford Harbour (Perry 2017).

STable 1 – Radiocarbon results from Fulford Harbour DeRu-192 and Russell Island DeRu-203

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- IndigenousSeaGardensSupplementalTableXFigures.pdf