NATURAL RESOURCES

Shoreline Changes over 40 Years in the Seahurst Region, Central Puget Sound

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UNIVERSITY OF WASHINGTON

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Peter Goldmark - Commissioner of Public Lands

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The Nearshore Habitat Program is part of the Washington State Department of Natural Resources' (DNR) Aquatic Resources Division, the steward for state-owned aquatic lands. Program funding is provided through the Aquatic Lands Enhancement Act. The Nearshore Habitat Program monitors and evaluates the status and trends of intertidal biotic communities as part of DNR's environmental stewardship activities as well as to conserve and restore Puget Sound through the Puget Sound Partnership.

Much of the work in this report is based on previous studies by other scientists, including – but not limited to – Alan Kohn, Ron Thom, Coastal Geologic Services, and Jason Toft.

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EXECUTIVE SUMMARY

The Washington State Department of Natural Resources (DNR) is steward of 2.6 million acres of state-owned aquatic land. As part of its stewardship responsibilities, DNR monitors the condition of nearshore habitats. Monitoring results are used to guide land management decisions for the benefit of current and future citizens of Washington State. This work also supports the Puget Sound Partnership's effort to protect and restore Puget Sound.

Intertidal habitats are an important constituent of the nearshore ecosystem, and they are vulnerable to both terrestrial and aquatic stressors. One indicator of intertidal habitat health is its biotic community – the complex of flora and fauna living in and on the beach. DNR and the University of Washington (UW) have collaboratively monitored intertidal biotic communities since 1997.

Our 2009 research effort sought to quantify decadal-scale changes on beaches in south-central Puget Sound by undertaking a historical comparison between 1971 and current conditions at Seahurst Park. This area provides an opportunity to measure changes associated with both development and restoration. The park shoreline was extensively armored following beach surveys in 1971. In winter 2004-2005, the armoring in the south part of the park was removed and the beach was nourished as Phase I of a larger shoreline restoration effort. Phase II, removal of much of the remaining armoring in the park, will occur in the fall of 2011.

In the study, intensive biotic surveys at Seahurst Park in 2009 were compared with historic surveys completed by Kohn in 1971 and by Thom between 1982 and 1984. Additionally, more recent changes in the region were assessed using monitoring data collected by DNR and UW between 1999 and 2009.

We found substantial changes in both beach morphology and biota at all sites surveyed within Seahurst Park in 2009, as compared to the 1971 and 1983 surveys. Key findings:

- The mid-upper shore is now narrower, steeper, and coarser in most locations, and the lower shore is narrower at most locations, especially those north of the main stream delta.
- The intertidal biota overall is much more depauperate than in 1971, especially in the area north of the main stream.
- Low shore infaunal communities, even in the same substrate type, are very different from those found in 1982. Species richness is generally a function of numbers of individuals, and these numbers were an order of magnitude lower in 2009 in both the sand and cobble transects sampled.
- Adult clams of several species were large and abundant in both 1971 and 1982. In contrast, in 2009, densities of clams were extremely low, and most of the

individuals were very small. Changes in densities of clams could have resulted indirectly from geomorphologic changes, or directly from overharvesting by humans.

- Juvenile clam densities in 2009 were also low, although we do not have comparable data for small clams from 1971 or 1982.
- The majority of the changes seem to have occurred between 1983 and 1999 (not 1971-1983 or 1999-present):
    - At a cobble site, clam densities in 1982 surveyed by Thom were the same order of magnitude as those found in 1971 by Kohn. In contrast, 2009 densities were an order of magnitude lower.
    - SCALE monitoring data since 1999 suggest no substantive changes in the last decade, either positive or negative.

- The changes we observed could result from a variety of causes, or combinations thereof. We consider the most likely causes to be:
- Construction of seawalls both before and after the 1971 survey, and recent nourishment of the beach.
- Changes in land use in the local watershed, potentially altering sediment loads and water quality of the streams that impact the park beaches.
- Intense human use of the park, including turning over rocks, digging, and collecting organisms.

The planned Phase II seawall removal and nourishment activities at Seahurst Park will provide an opportunity to observe the biological community’s response to restoration of beach geomorphology. However, if intensive human use at the park or changes in land use caused the current low diversity, restoration of the upper beach by removal of seawalls will not lead to an increase in diversity to previous levels. Monitoring of changes following Phase II should help determine whether the seawall is only affecting high-shore communities (for example by covering the drift line and amphipods that use it), or whether impacts to these beaches include a broader zone.

1 Introduction

1.1 Program Background

The overall goal of the Intertidal Biotic Community Monitoring Project is to assess the condition of intertidal biota in greater Puget Sound. This work supports the mandate of the Washington State Department of Natural Resources (DNR) to ensure environmental protection of the 2.6 million acres of state-owned aquatic lands that it stewards (RCW 79.105.030). Additionally, this work supports the Puget Sound Partnership's effort to protect and restore Puget Sound through tasks that are defined in the Puget Sound Action Agenda (Puget Sound Partnership 2009), and in the monitoring plans by its predecessor, the Puget Sound Action Team (Puget Sound Action Team 2007).

Intertidal and shallow subtidal habitats are an important constituent of the nearshore ecosystem. They are highly diverse and productive, harboring extensive populations of algae and seagrasses that contribute to food webs (both nearshore and in deeper water) and provide habitat for many other organisms (e.g., Duggins et al. 1989). Invertebrates that live in intertidal habitats are important in recycling of detritus (e.g., Urban-Malinga et al. 2008) and reduction of water turbidity (e.g., Peterson and Heck 1999), as well as providing food for shorebirds, nearshore fishes, commercially important invertebrates such as crabs, and humans. Intertidal and nearshore communities also serve as useful 'indicators' of ecosystem health. Because most organisms in these habitats are relatively sessile and thus unable to move away from stressors, they are vulnerable to both natural and anthropogenic stressors from terrestrial and aquatic sources. Demonstrated examples include sensitivity to changes in rainfall (Ford et al. 2007), ocean temperatures (Schiel et al. 2006), local pollution (Hewitt et al. 2005), and larger-scale factors such as the North Atlantic Oscillation index (Labrune et al. 2007).

DNR and the University of Washington (UW) have jointly monitored biotic communities since 1997. The intertidal biotic community sampling design and statistical analyses have been described in peer-reviewed publications (Schoch and Dethier 1995, Dethier and Schoch 2005, Dethier and Schoch 2006) and multiple technical reports (available through DNR at http://www.dnr.wa.gov/ResearchScience/Topics/AquaticHabitats/Pages/aqr_nrsh_publications.aspx).

This report summarizes 2009 research activities , when a combination of historical data and longstanding monitoring methods were used to explore long-term changes in intertidal communities in Central Puget Sound.

1.2 2009 Research

Intensive, relatively recent monitoring programs in Puget Sound are able to quantify changes in parameters such as eelgrass abundance or shoreline biota on the time scales of years (Gaeckle et al. 2009, Dethier and Berry 2009). However, quantifying long-term changes – for example, over the 100+ years of development along Puget Sound's shorelines – is not possible, except on a very coarse scale, because of the absence of data. Comparisons of general shoreline morphology between the 1800s and the present have recently been accomplished by PSNERP (Puget Sound Nearshore Ecosystem Restoration Program 2010). This was possible because early survey efforts contained sufficient detail on gross shoreline morphology (the presence of bluffs, lagoons, etc.) to allow assessment of change through time. These comparisons have demonstrated substantial change even in these large-scale features, such as losses of wetlands and small embayments, addition of many kilometers of artificial (e.g., armored) shoreline, and overall straightening and shortening of the shore. Unfortunately, the resolution of the historic data is not good enough to assess other parameters known to be critical to nearshore ecosystem function, such as beach slope or width, or sediment type.

Human impacts to shorelines come in many forms, only a few of which cause changes visible at the coarse scale of the PSNERP Change Analysis. Water pollution, for example, is believed to be an issue in Puget Sound but is not visible in shoreform analyses, nor are more subtle effects such as overharvesting of biotic resources. The data can suggest some processes that must have been altered (e.g., rates of sediment supply to the shore that have been reduced by armoring eroding bluffs), but they cannot quantify these changes or assess their impacts on nearshore ecosystems. Moving beyond these coarse assessments of change thus requires either demonstration of processes affected by large-scale shoreline changes or quantitative demonstration of the effects of changes we know have occurred. Because the shoreline continues to be impacted by humans, it is possible to use data gathered in recent decades to assess recent changes. This report discusses an effort to quantify shoreline changes on this decadal scale, using qualitative and quantitative data collected in the 1970s and 1980s.

In Puget Sound, one of the human activities hypothesized to be significantly detrimental to the health of the marine ecosystem is armoring of the shorelines. Armoring is listed as a significant "threat" in the Action Agenda (Puget Sound Partnership 2009), and as a key feature in need of restoration and adaptive management in the Biennial Science Work Plan (Puget Sound Partnership Science Panel 2008). It appears as a factor disrupting natural processes in the conceptual models of the Puget Sound Nearshore Ecosystem Restoration Project (Simenstad et al. 2006). Numerous projects involving armor-removal are underway or are being considered. Yet there are surprisingly few data documenting actual negative impacts of armoring on physical or biological features of nearshore ecosystems, especially for gravel beaches of the sort that dominate Puget Sound (Sobocinski et al 2010). In addition, armor-removal projects usually incorporate beach nourishment as part of the management plan in an attempt to rebuild a "natural" beach, but few data exist on the biological effects of beach nourishment. Currently, it is estimated that roughly 30% of Puget Sound's shorelines are armored (PSP Action Agenda; PSNERP Change Analysis dataset). The proportion for south-central Puget Sound is much higher, around 64%, and the demand for shoreline protection structures is almost certain to increase with heightened concerns about erosion caused by sea-level rise.

Shoreline armoring is thought to affect the nearshore environment by as many as five different mechanisms: 1) Encroachment over the upper shore, directly burying habitat (“placement loss”); 2) Disconnection of terrestrial and marine ecosystems, e.g., via loss of riparian vegetation and associated insects and lack of recruitment of wrack and drift logs to the shore; 3) Sediment impoundment, preventing sediment eroding from banks from reaching the shore; 4) Active erosion, from reflection of waves off bulkheads (especially those built lower on the shore); and 5) Prevention of passive erosion, i.e., stopping the natural bank retreat that is occurring on many U. S. coastlines. Both active and passive erosion, in some circumstances, cause removal of fine sediments from the beach, thus steepening and coarsening the beach profile below armored portions (seen to some extent in Thurston County: Herrera 2005). These changes may make the beach less suitable for the many infaunal organisms that require finer sediments. A difficulty in assessing the impacts of armoring is that while some mechanisms (e.g., Encroachment) act immediately, others (e.g., Passive Erosion) may take decades to be visible. The objective of the work described in this report was to seek both short-term and decades-scale changes to a section of shoreline in south-central Puget Sound that might be related to armoring.

Our 2009 research effort sought to quantify decadal-scale changes on beaches in south-central Puget Sound by undertaking a historical comparison between 1971, 1982-1983, and recent conditions (1999-2009) at Seahurst Park. The park is subject to changes occurring broadly through Puget Sound (such as in water quality and other effects of upland development) as well as to more localized effects, such as intense human use and armoring of the shoreline. The park shoreline was extensively armored following beach surveys in 1971. In winter 2004-2005, the armoring in the south part of the park was removed and the beach was nourished as Phase I of a larger shoreline restoration effort. Phase II, removal of much of the remaining armoring in the park, will occur in the fall of 2011. Intensive biotic surveys at Seahurst Park in 2009, following the methods used in the older surveys, thus provide a dataset that can be compared with both historic surveys (1971 and 1983). More recent changes in the region are analyzed using our own monitoring results from 1999 to the present and serve as a baseline prior to Phase II restoration.

1 Methods

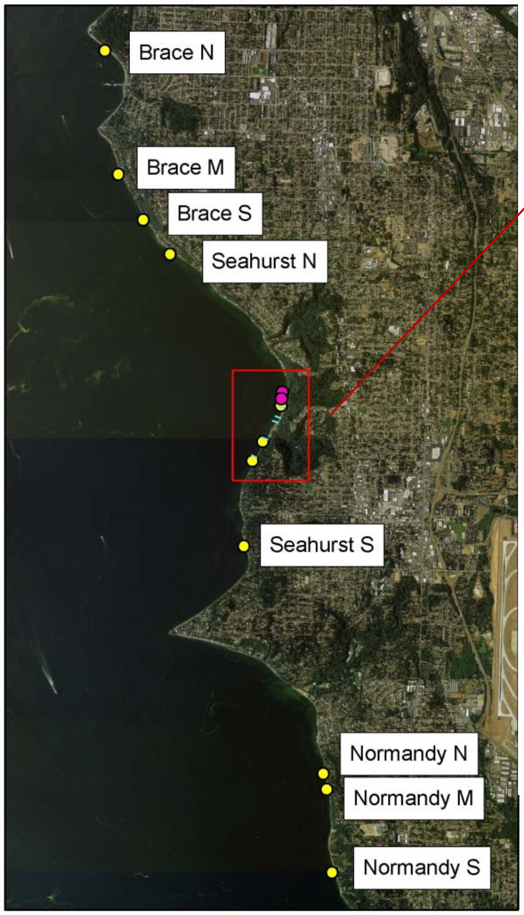
We used three sets of methods and data sources to compare shoreline conditions in 2009 with those from several previous years, beginning in 1971. Due to differences among methods, each study is described separately below. Figure 1 shows the location of all sites where data was collected.

1.1 Across-shore transects and clam pits surveyed by Kohn et al. (1971)

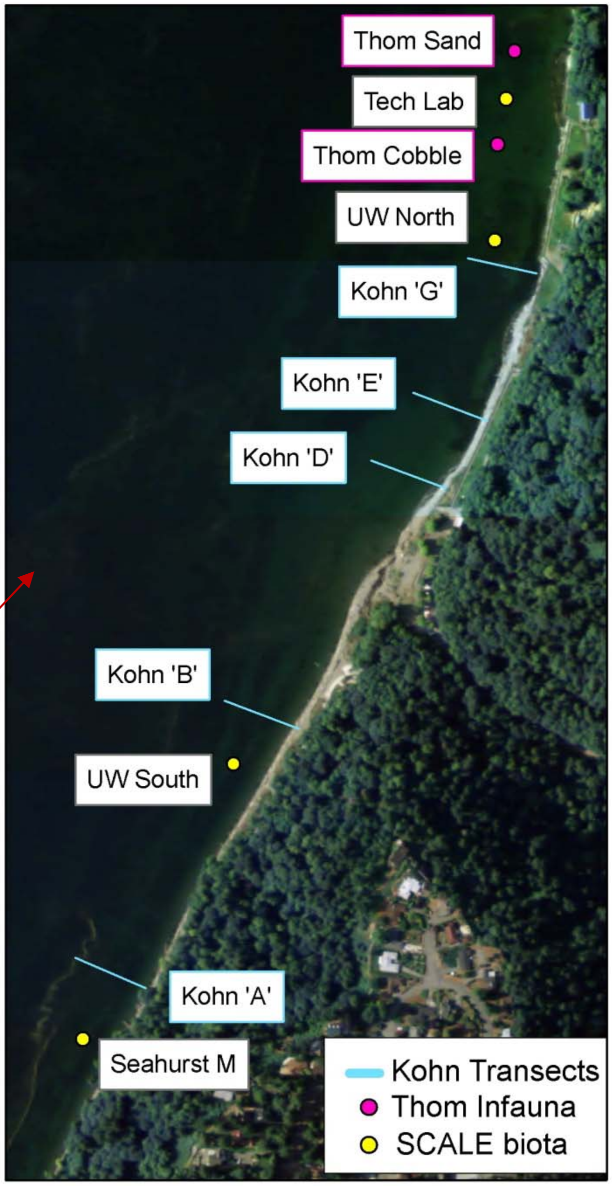
Kohn et al. (1971) (hereafter "Kohn") ran a series of seven transects perpendicular to the shoreline, spaced approximately equally from the south to the north ends of Seahurst Park. Transects ran from the "toe of slope" to the water line on a low tide. Some were surveyed in January, others in April and May. The survey was primarily qualitative. At each transect, Kohn recorded the approximate start and end (in terms of vertical elevation and distance from bluff) of the dominant species visible from the surface: barnacles, tubes, siphons, *Zostera*. No infauna were quantified except for clams, for which an irregular number (0-12) of $0.1m^2$ pits were dug at haphazard intervals along most transects. Sizes of *Macoma* spp. were measured, but there were few size data for other clam species. In addition, at several transects quantitative data were gathered on densities of chaetopterid polychaete tubes, phoronid tubes, and *Tresus* (horse clam) siphons, all of which are visible on the surface.

We duplicated Kohn's methods (including clam pits) at the five transects for which we could find the most complete data (including data archived with King County Archives). For four of these transects, the "toe of slope" is no longer visible because the bank has a seawall and riprap (northern three areas) or has been restored after construction (southern area). Thus for our vertical reference we used the lower end of the transects, i.e., the lower tidal elevation to which Kohn surveyed in 1971. We measured up from this elevation until either a seawall or terrestrial vegetation was encountered. We compared the substrates and surface flora and fauna at the distances along the transect used by Kohn. Comparisons between these 1971 and 2009 datasets are by necessity qualitative.

A. Washington State



B. Three Tree Point Area



C. Seahurst Park

Figure 1. Maps of Sites Sampled. Multiple scale maps show: A. location of study within Washington State; B. area map showing SCALE long-term monitoring sites used for comparison; C. sites sampled at Seahurst Park by Kohn et al (1971), Thom et al (1984), and UW/DNR in 2009 as part of this research.

1.2 Infaunal Samples collected by Thom et al. (1984)

Thom et al. (1984) (hereafter "Thom") completed extensive quantitative surveys of a series of beaches in Puget Sound between 1982 and 1984. Seahurst Park was chosen as one of the "long-term study sites," with repeated observations in 1982 and 1983. Biotic sampling of "small infauna" and large bivalves was conducted at two locations at ca. MLLW within the park, a "low cobble site" near the northern end and an "intertidal sand site" at the very north end of the park (Fig. 1C). At each of these, small infauna were sampled 3 times in the summer in 12 cores (24 cm^2 x 10 cm deep, sieved to 1 mm) (no information given on placement of cores, and surface flora and fauna were not sampled). Bivalves were sampled in 10-15 box cores of 625 cm^2 x 30 cm deep, sieved on 12.5 mm mesh; abundances and sizes were reported for the 3 most common species. We cored (for both small infauna and clams) in the same two habitat types, but these had shifted locations; there was a sandy site at MLLW *south* of a cobble site at MLLW, the reverse of 1983.

1.3 Quadrat and Core Sampling using SCALE

In previous years, DNR and UW have monitored biota at MLLW at the south end of Seahurst Park (at the Seahurst Mid site), as well as at sites to the north and the south of the park (named Seahurst South and Seahurst North). Those transects were repeated this year at the same locations and elevation. We added three new transects within the park:

- UW South, in the restored area near Seahurst Mid, where high-shore sampling has been done by another UW team (Toft et al. 2008).
- UW North, near Kohn transect G, in the armored section of the park.
- Tech Lab, in front of the Marine Technology Lab.

At each of these six sites, we conducted standard SCALE sampling at MLLW (described below) for comparison to other SCALE long term monitoring data, and added an additional transect at MLW (+2.8') for surface biota and infauna. These data can be compared with our transect data from previous years, and the infauna in these transects compared with that found by Thom in both low-sand and low-cobble cores.

In addition, we dug four clam pits (at MLLW only) to estimate adult clam populations; these larger and longer-lived organisms can constitute better "integrators" of long-term conditions than most of the other, shorter-lived infauna (e.g., worms). Additional 0.1 m^3 (0.3 m per side and 0.3 m deep) box core samples were collected and sieved using 1 cm mesh to characterize adult clam abundance and size distribution. These larger core samples are targeted to adequately sample large clams, but they are prohibitively large for sampling smaller infauna.

We compared data at these sites over time, as well as with data from other nearby SCALE sites over time, to the north (named Brace S, M, and N) and to the south (named Normandy S, M, and N) (Fig. 1).

1.3.1 SCALE Monitoring Methods

SCALE intertidal biotic community sampling design and statistical analyses have been described in previous peer-reviewed publications (Schoch and Dethier 1995, Dethier and Schoch 2005, Dethier and Schoch 2006) and technical reports (available through DNR at http://www.dnr.wa.gov/ResearchScience/Topics/AquaticHabitats/Pages/aqr_nrsh_publications.aspx). General methods are summarized here.

We used a nested sampling design to quantitatively assess patterns in benthic nearshore populations and communities at spatial scales ranging from meters to tens of kilometers within the Puget Sound region. At the smallest scale, we selected and sampled shore segments that were physically similar in terms of substrate size, slope angle, and field cues of wave energy, such as exposure to long wave fetch and local presence of fine sediments.

Biological sampling was conducted during spring tides in late June and early July. A surveying level and stadia rod were used to locate the appropriate transect elevation relative to the predicted tide at the time of the measurement. This approach has been compared to the actual tide within this region. Locations were typically within ± 0.15 m of the target elevation (Dethier and Schoch 2005).

Biotic community samples consisted of mean species abundances for epibiota and infauna from 10 randomly spaced sample units along a 50 m horizontal transect. Each sample unit consisted of a 0.25 m^2 quadrat to quantify abundance of surface macroflora and fauna, plus a 10 cm diameter x 15 cm deep core for macroinfauna. Percent cover was estimated for all sessile taxa in the quadrats, and all motile epifauna (organisms > ca. 3 mm) were counted. Fresh core samples were washed through 2 mm mesh sieves, thereby excluding meiofauna, juveniles of some worms, and adults of smaller crustaceans, such as cumaceans and harpacticoids. The finest taxonomic resolution used in field sampling and laboratory identification was species level, although some difficult taxa were only identifiable to genus or higher levels (e.g., *Pagurus* spp., Phylum Nemertea). Taxonomic references were Kozloff (1996) for invertebrates and Gabrielson et al. (2000) for macroalgae.

The multivariate analysis methods of Clarke and Warwick (1994) and PRIMER software (Clarke and Gorley 2001) were used to detect patterns in the spatial and temporal distributions of communities. The data matrix of taxon abundances was square-root transformed to reduce the contribution of highly abundant species in relation to less abundant ones in the calculation of similarity measures. We used the ordination technique of non-metric multidimensional scaling (MDS) to group communities based on the Bray-Curtis similarity metric. Graphic plots of ordination results for the two axes explaining the greatest proportion of the variance were examined for obvious sample groupings. Analysis of similarity (ANOSIM) tested the significance of hypothesized differences among sample groups. Similarity percentage (SIMPER) analyses identified the variables (species) that contributed the most to different groupings seen in the MDS plots.

2 Results

2.1 Comparison with 1971 Kohn Transects

Table 1 provides a summary of physical differences between Kohn’s 1971 transects and our 2009 transects in the same locations. Biological differences are discussed for each transect below.

Transect A: Located in the Reference area (neither altered nor restored) at the south end of the park. The transect overall was shorter in 2009, indicating that the beach is less wide than it was in 1971, but only by about 15 m. This difference appeared to comprise entirely the lower-shore area (i.e., the sandier area below the common slope-break), which was 55 m wide in 1971 but only ca. 40 m now. The transect length we found (from the bank to the predicted low-water elevation) was very similar to those calculated in beach profiles for this area by Coastal Geologic Services (2008) and by Toft et al. (2008), validating our measurement technique. Comparing Kohn’s notes with the current situation, the upper shore now is steeper and more depauperate; he recorded barnacles and mussels on the upper shore, but none is present now. The lower shore surface biota appear to be fairly similar among time periods, with both having patches of *Zostera* in the sand among boulders. Coastal Geologic Services (2008) compared beach topography in this area with data from surveys in 1973. They found that in this unarmored stretch of shore, the high shore (+8’ MLLW) has accreted by about 2 vertical feet, and the low shore (+1’ MLLW) by about 1 vertical foot. Beach nourishment in 2005 caused a slight additional accretion (less than 0.5’) on this transect, because most of the sediment movement from the nourishment site (which was to the north of this transect) was further north.

Transect B: Located in the restored area, south of the stream delta. The transects in 1971 and 2009 were about the same length overall, with the current low shore area approximately 5 m narrower. The current upper shore, which presumably consists of sediments placed there during beach nourishment, appears to be less stable and more depauperate than in 1971, as in Transect A. Kohn recorded barnacles and mussels on the upper shore, now lacking. Coastal Geologic Services (2008) compared modern beach profiles (pre-and post-restoration) in this area with a profile done in 1973. This comparison suggests that the beach is now steeper and narrower than in 1973, even after the sediment nourishment done at this location. Prior to nourishment, the high shore (+8’ MLLW) had lost 3-4 vertical feet since 1973, and the low shore (+1’) 1.5 to 2.5 vertical feet. The Coastal Geologic Services data also suggest that the low tide terrace is about

Table 1. Comparisons of transect data between 1971 and 2009. Transect lengths in 2009 are referenced to the same tide level as Kohn et al. (1971).

Trans.	Location	Ref Point	Transect length (m)		Supra-tidal		Upper Shore		Dist to Slope Break (m) 1971/2009	Low Shore	
			1971	2009	1971	2009	1971	2009		1971	2009
A	End of new park path	-1.7' contour	79	65	Natural	Natural	Sloping sand, pebble, gravel	Steep, unstable pebble and gravel	NA/40	Boulders, sand	Boulders, sand
B	Toft S (picnic shelter)	-0.7' contour	58	Similar	Natural	Restored	Cobble-pebble slope, some sand	Cobble-pebble slope, some sand	~30/~25	Sand, patchy *Zostera marina*	Sand, patchy *Z. marina* + *Z. japonica*
D	Just N of stream, below restroom	-1.5' contour	131	<100	Natural	Seawall	40m wide; Sloped sand, stream bed, some pebbles and cobbles	26m wide; steep sand, riprap band, coarse sand and pebbles. Stream lower	~40/~68	Sand, pebbles, mussels and barnacles. Sand bar at 78-90m	Fine sand, scattered small boulders. Sand bar at 84-97m
E	~midway on armored section	-1.2' contour	84	53	Natural (probably)	Seawall	Cobbles and boulders	Steep pebble-sand	~20/~37	Very fine stable sand, anaerobic, some *Zost*. 62m wide	Muddy sand, some pebbles, *Zost*. sparse; 9m wide
G	Just S of Toft North transect	-1.2' contour	91	65	Old seawall + riprap	New seawall + riprap	Rocks, pebbles, cobbles, 16m wide	Sand, a few pebbles, moderately steep, 12m wide	No slope break	Sand, sparse boulders, 66m wide	Sand then cobbles, sparse boulders, 33m wide

15 m narrower than it was in 1973. In the low shore, patches of *Zostera* were present in both time periods, although *Z. japonica* now accompanies the *Z. marina*. The biggest differences in this area are in the clams. Kohn reported many *Tresus* siphons visible, and many clams in sample pits. We found zero *Tresus*, and the clams in our sample pits were sparse (Table 2). Kohn recorded fairly high densities of both *Macoma* (referred to as *M. nasuta*, but probably really *M. inquinata*) and *Saxidomus*, both typical cobble-sediment species. In contrast, there are very few of either of these species now – the density differences are approximately one order of magnitude. Surface tubes of *Spiochaetopterus* were obvious in both eras. Kohn recorded an average of 200/m^2; we found an average of 66/m^2.

Transect D: Located north of the stream, below the modern restroom. These transects were extremely different through time, due in part to variation in the stream behavior. In 1971, the stream crossed the transect at the upper beach and may have formed a small lagoon (seen in some drawings); whereas, now it crosses about halfway down the beach slope and there is no lagoon. The supratidal at this site is now truncated by a seawall, although there is a healthy community of dune grass and drift logs below this. In both periods, the low shore was recorded as having a sand bar running through it, and chaetopterid tubes were in the lower sand (57/m^2 in 1971, and 48/m^2 in 2009). Kohn also recorded surface clumps of phoronid tubes, but none were visible in our sampling. Higher on the shore, Kohn et al. recorded "*Mytilus edulis* [mussels] holding stones in clumps with byssus"; none were seen in 2009. Overall, it was hard to compare these transects because of the differences inherent in the stream.

Transect E: Located in the middle of the armored section of shore. Although this transect now has a seawall (it is not clear if it was armored in 1971), this wall is emplaced very high on the shore so that there are logs and dune grasses below it. However, the substrate on the upper shore seems to be unnatural, unstable, and completely depauperate; it is composed of loose, small pebbles. We saw no surface biota in this area, whereas Kohn noted barnacles, isopods, amphipods, and many small littorinid snails. In addition, the low shore is completely different than in 1971. What was once a broad (62 m wide) muddy sand flat is now a very narrow (9 m) one. *Zostera* was recorded as sparse and patchy in 1971, and now is only present as individual shoots. In both periods, the clams present were the mud-loving *Macoma nasuta* rather than the sand-loving *M. secta* or the cobble-loving *M. inquinata*. The muddier substrate seems to be a result of the protection from southerly wave fetch by the stream delta. Clams were much less dense than in the past; however, again by an order of magnitude (Table 2). Chaetopterids were also much less dense than in the past. Kohn recorded an average of 62/m^2, we found 6/m^2.

Transect G: Located south of UW North transect. This area appears to be affected by the presence of large old boulders (part of an old dock system) in the low zone. The seawall at the top of this transect extends less far into the intertidal zone than at adjacent areas. This was the only transect where there was not a clear break between a steep, coarse high-shore and a flatter, finer low-shore. There did appear to be differences between times, however. The upper shore is sandier now than in 1971. Kohn described it as a pebble and cobble beach with barnacles, mussels, littorinids, and even the rockweed *Fucus*, whereas now it is sandy with a few pebbles. In contrast, the low shore in 1971 was broad (ca. 66 m) and sand-dominated, and now it is much narrower (ca. 33 m) and is characterized by surface cobbles covered with ulvoids. *Zostera* was present as a band in 1971, but is now absent from the intertidal at this location. *Spiochaetopterus* were abundant at both times, but were in a 50 m-wide zone before compared to about 30 m now. *Anthopleura* anemones were common at both times. Perhaps most strikingly, in 1971 the horse clam *Tresus*, readily visible as large siphons at the sediment surface, were abundant in a swath alongshore from this transect to the north end of the park. An extensive search in 2009 yielded only one adult individual. The *Tresus* found in various clam pits (Table 2) were all juveniles. This transect also had substantial populations of butter (*Saxidomus*) and littleneck (*Protothaca*) clams in 1971, but almost none in 2009 (Table 2).

2.2 Comparisons of Clam Populations

Additional data on changes through time in clam populations can be gleaned from both Kohn's notes and more quantitative information gathered by Thom. Kohn noted, from the region of transect G northward, the presence of many pits where recreational clam diggers had been harvesting recently. We saw no such pits, although Beach Naturalists (from the Seattle Aquarium) report observing people digging throughout the park.

Table 2. Clam densities (#/m^2) and sizes at Seahurst Park; comparisons between data from Kohn (1971) and UW/DNR in 2009. "Park Overall" densities from 2009 include data from all clam pits dug in the region, including SCALE sites Seahurst N and S.

		Densities on 3 Transects			Density Park	Avg. Size
Species	Year	B	E	G	Overall	Overall (mm)
Macoma spp.	1971	15.3	45	48	21	53
	2009	1.7	7.5	6.0	4.7	24
Saxidomus	1971	9.0	0	30	ND	69
	2009	0	0	2.0	9.7	37
Tresus	1971				2.3	>100
	2009				1.6	24
Protothaca	1971	2.0	0	10	3.6	31
	2009	0	0	0	2.8	19
Clinocardium	1971	1	2	2	ND	61 (N=2)
	2009	0.8	0	2	5.5	33

The low cobble area in this region sampled by Thom in 1982-83 had very high densities of recreationally valuable clams (Fig. 2). They did not report *Clinocardium* densities, but these were less abundant than the other three species, which reached tens of individuals per square meter. Thom's clam samples were dug in the optimal habitat type for these clams (a cobble-sand mix), so it is not surprising that the densities recorded were generally higher than the more scattered pits dug by Kohn (Table 2). In this same habitat type in 2009, however (in an area slightly to the north of the samples of Thom, because the cobble shifted), we found a total of only 6 clams in 10 pits (Fig. 2). Only one clam, a *Clinocardium*, was larger than 2 cm.

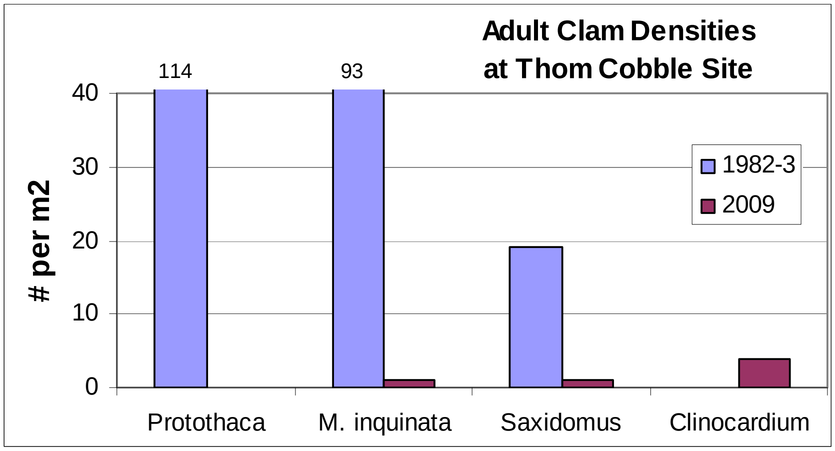


Figure 2. Densities of adult clams found by Thom (data averaged over holes dug in summers 1982 and 1983) and in 2009 in a low cobble habitat near Thom's site.

Figure 3 puts these clam densities into a larger regional perspective. Clams were not sampled at other sites in 2009, but general SCALE sampling in the region just south (Normandy) and north (Brace) of Seahurst was done in recent years (2004 and 2003, respectively). Our SCALE infaunal cores do not sample adult clams effectively because they only go to 15 cm depth, while our clam pits (as in the Seahurst data) extend to 30 cm depth. Density estimates for the non-Seahurst data are thus approximate and are probably underestimates. All these sites had some surface cobble. Figure 3 shows that the 1982 Thom site had substantially more clams than any sites in recent years, including both edible and non-harvested species. The whole Seahurst region is currently rather depauperate in clams compared with sites to the south (left) and north (right). Normandy S is a site impacted by occasional sand waves and had only *Clinocardium*, while other sites had more diverse species. Seahurst M (in the park) and N and S (outside the park) all had generally similar (relatively low) clam abundances, suggesting that this may be a regional rather than a park-effect.

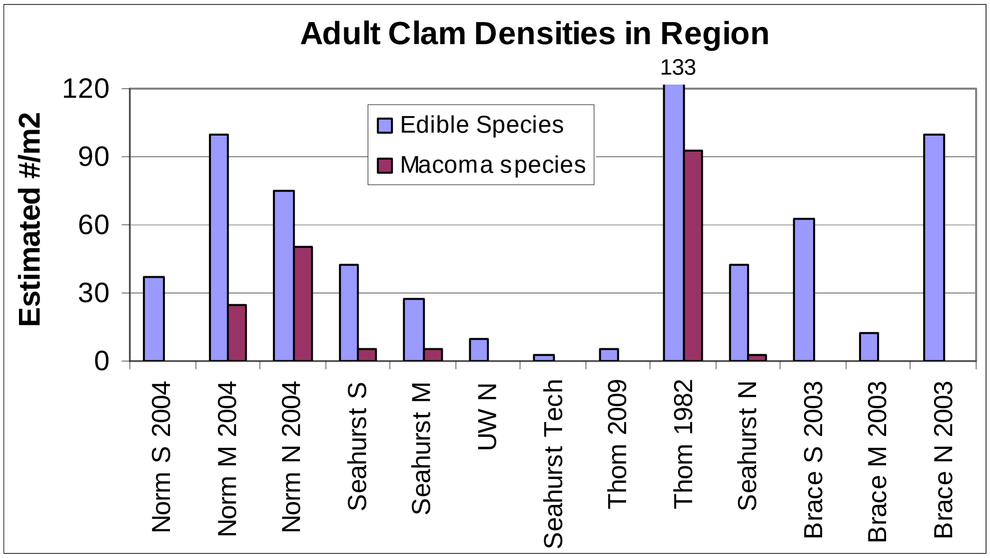
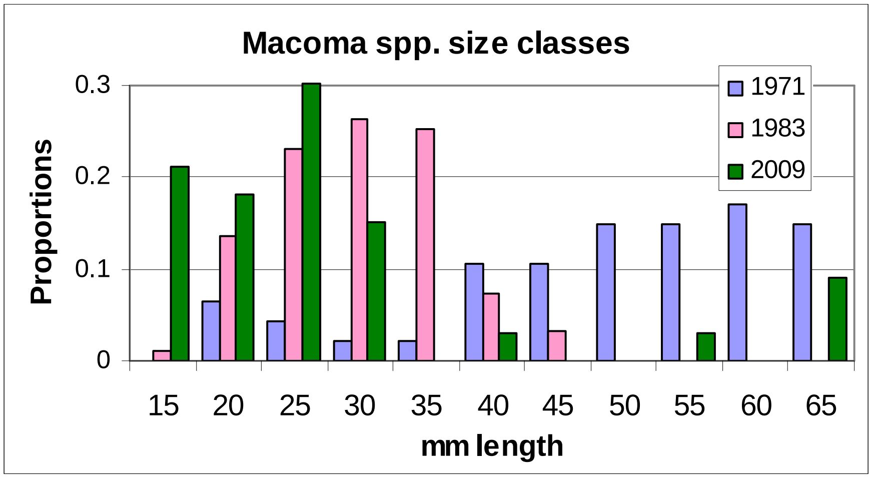


Figure 3. Comparison of densities of adult clams in 3 monitoring regions in south-central Puget Sound. Sites are arranged from south to north. Data are from 2009 except where otherwise noted. "Edible species" are *Clinocardium, Protothaca, Saxidomus,* and *Tresus; Macoma* species include *M. inquinata, M. secta*, and *M. nasuta*.

Another striking difference between historic and current results is the consistently small sizes of clams currently found within the park. We found a total of only 3 edible clams of legal size in the 46 pits dug north of the stream delta. Clam size data, where available, are summarized in Table 2. Kohn reported clam sizes sometimes as averages for the whole park, sometimes as individuals per transect, and no size data were reported for some species. Figure 4 illustrates Kohn's size distribution data for the most common clam taxa (sizes for all *Macoma* spp. are lumped because Kohn did not consistently distinguish the species) as well as data from Thom from the low cobble site within the park, and our 2009 data from all clams found in the region. Sample sizes in one or more years are too small to allow statistical analyses, but for both taxa, the 2009 data illustrate a striking and consistent pattern—almost all clams in the area are small individuals. For *Macoma* spp., the data suggest that by 1983 there was already a dearth of large clams relative to 1971, and this pattern became even more striking by 2009. The large *Macoma* found in 2009 were three *M.secta* in sandy areas within the park. For *Protothaca*, in both 1971 and 1983, there were relatively more large individuals than in 2009. The average size data shown in Table 2 also dramatically illustrate how small the clams are now in this area.



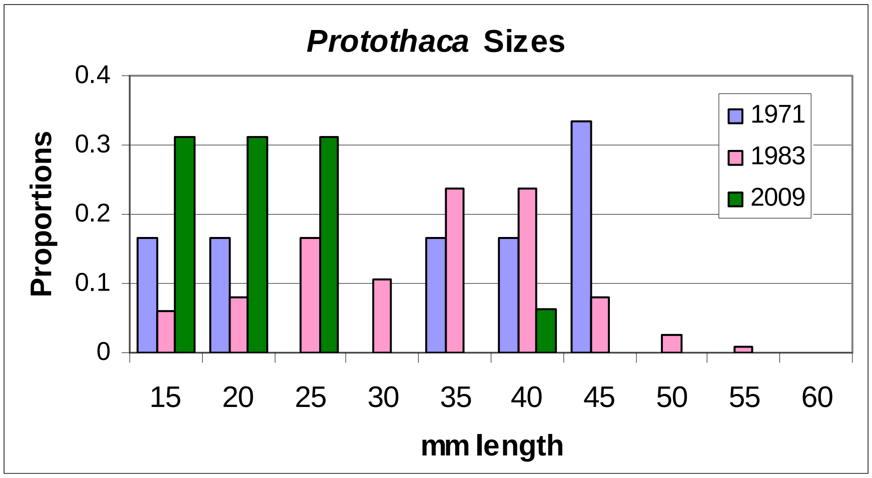


Figure 4. Sizes of clams for the two species where there were size data available in the historic surveys. 2009 data are from all clam pits dug in the Seahurst area, inside and outside the park.

Figure 5 shows size data from 2009 for three clam species for which no size data were available in the historic surveys. With few exceptions, large clams were rare. Sizes of *Saxidomus* were not recorded in 1971 or 1983 except for a park mean in 1971 (Table 2), which was almost twice as large as the current mean size. A very small number of large *Saxidomus* were found in 2009, mostly from SCALE transects outside the park (Seahurst S and N).

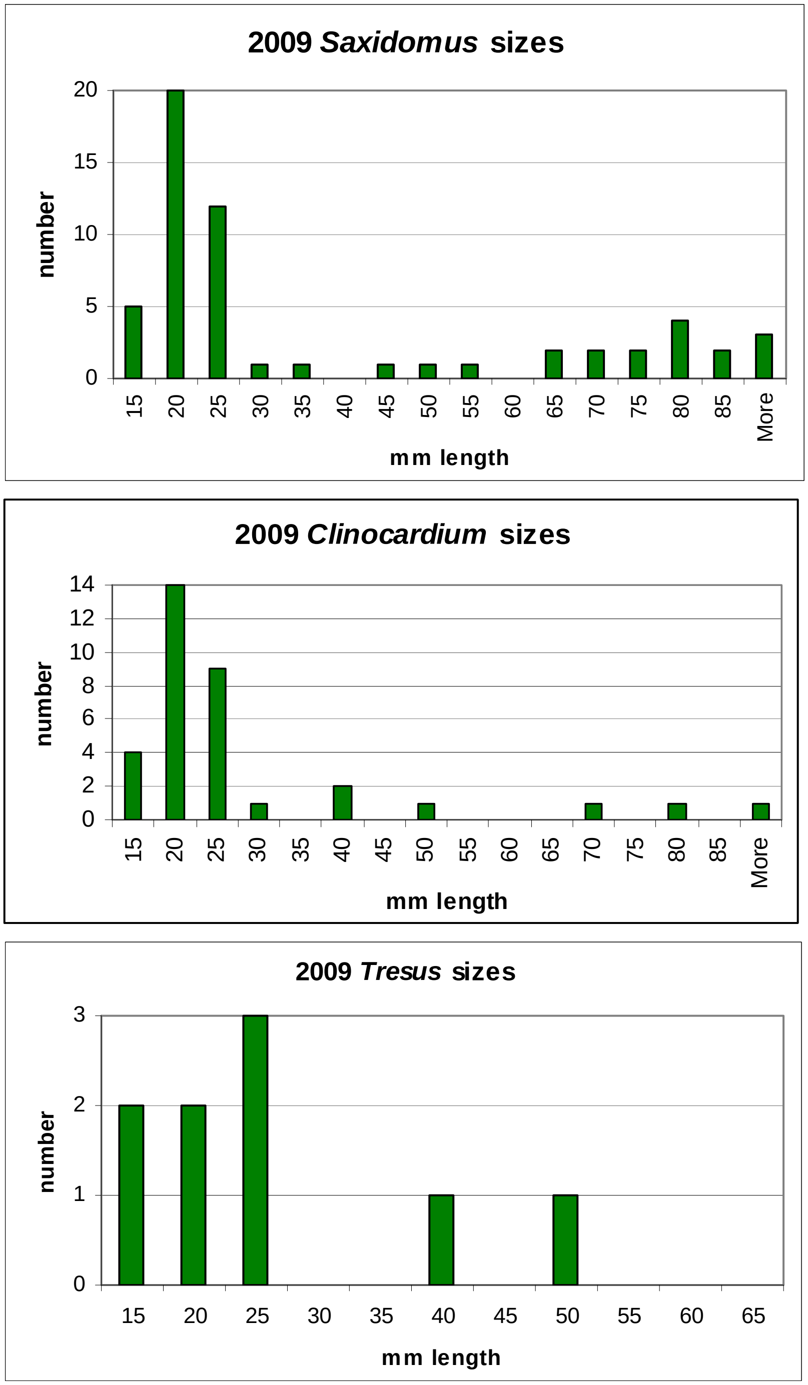


Figure 5. Sizes of clams for which no size data were available in the historic surveys. Size data are from all clam pits dug in the Seahurst area, inside and outside the park.

Small clams (<1.5 cm length) were found more commonly than large clams in the 2009 transects, although we do not have historic data to compare with these densities. Figure 6 shows densities of small clams in infaunal cores at all the sites where such cores were dug, including three previous years of SCALE sampling. "Thom sand" had no small clams and is thus omitted. Data in Figure 6 are categorized into juvenile individuals of larger clams (the species in Figures 4 and 5), versus "small species" that never get larger than 1.5 cm and thus are not recreationally dug; these include *Tellina* spp., *Mysella tumida*, *Transenella tantilla*, and *Lucina* spp. There were moderate numbers of these non-edible species within the park (Seahurst M, Tech Lab, UW North, and Thom Cobble); juveniles of edible species were much patchier in space and time.

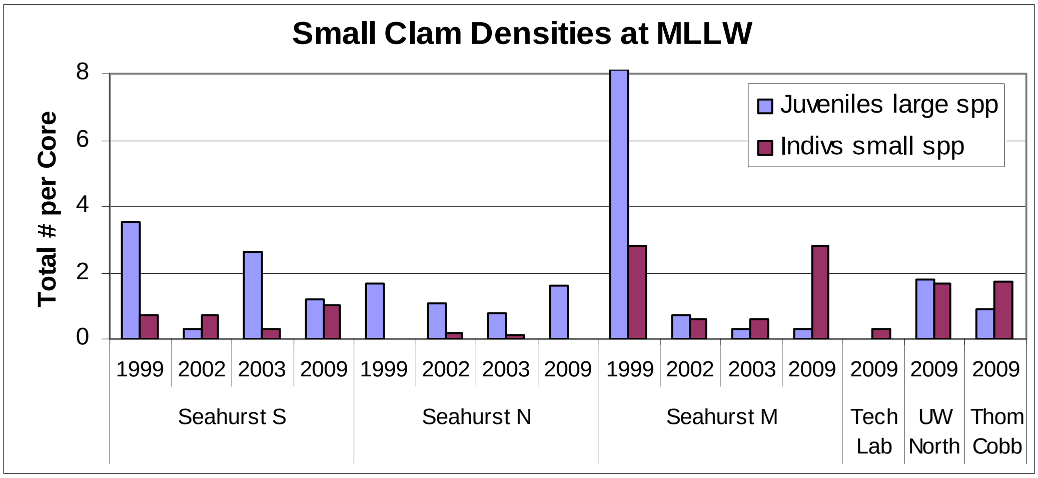


Figure 6. Densities of all small clams (<1.5 cm) from all transects with infaunal cores.

Figure 7 shows data from these same transects, with only the juvenile clams shown, and with individual species' data. Most of the large peaks in abundance of juvenile clams seen in Figure 6 are due to good recruitment years and sites for *Tresus*, and to a lesser extent *Saxidomus*. The Tech Lab site, which was very sandy, had no juveniles; other patterns are difficult to discern, but it may be notable that Seahurst M, at the south end of the park and next to the restored area, has had extremely low recruitment of clams in the last decade.

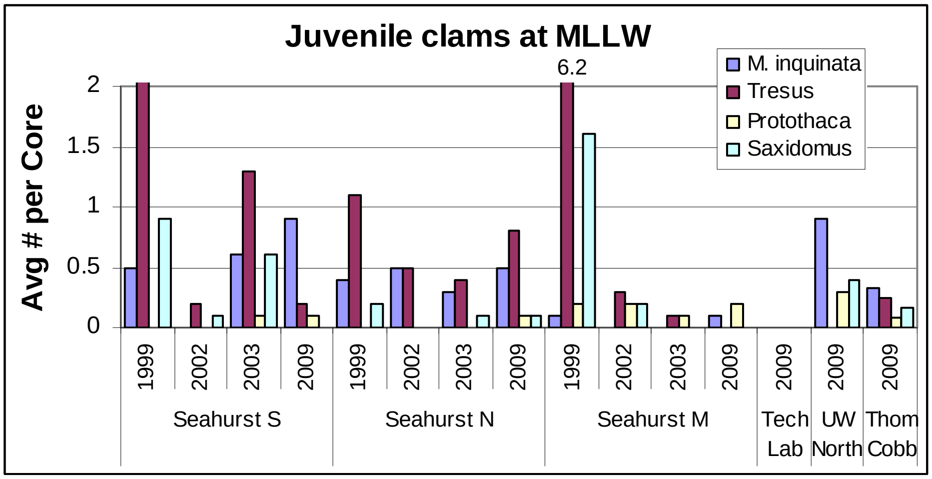


Figure 7. Densities of juvenile clams in cores at MLLW, broken down by species. UW South had no juvenile clams and is omitted.

Transects at MLW (+2.8') had even lower densities of juvenile clams (Fig. 8), although some species were found exclusively at this level, i.e., the invasive varnish clam *Nuttallia obscurata* and the manila clam *Venerupis philippinarum*. Substrate data for this mid-shore level suggest that sediment type plays an important role here. The UW South (restoration) site, which had no clams, had substrate that was almost entirely unstable pebbles (Figure 9; also see Kohn transect B, above). The substrate at Seahurst S and M was also dominated by pebbles and had no juvenile clams.

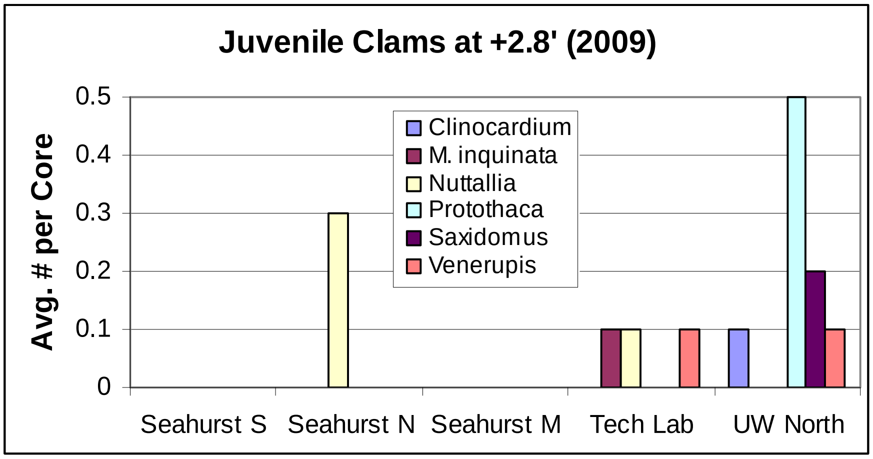


Figure 8. Densities of juvenile clams in cores at +2.8', by species. UW South had no juvenile clams and is omitted. This mid-shore level was not sampled at the Thom sites.

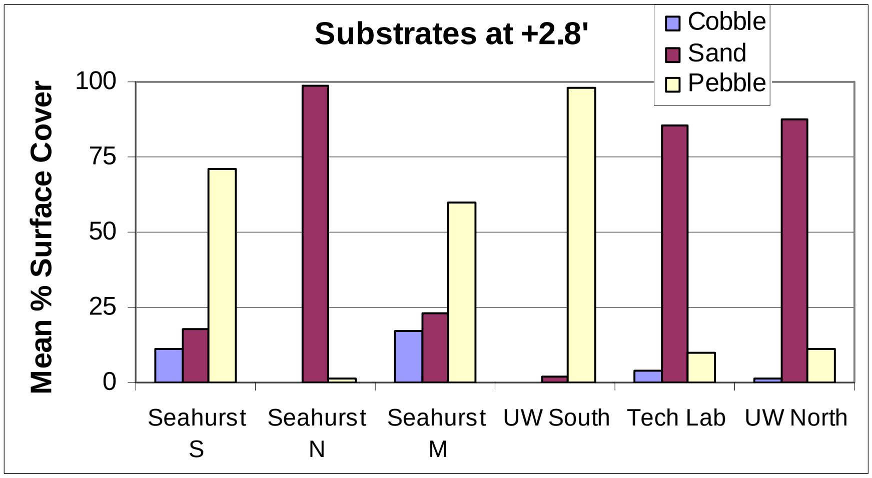


Figure 9. Percentages of surface sediment in each of 3 size categories at +2.8'. Pebble percentages were not quantified in the field, but are estimated by subtraction. Values for cobble and sand are means from 10 quadrats.

The potential effects of substrate type on juvenile clams can be seen even more clearly in the data from MLLW. Figure 10 shows the surface substrates recorded at 6 transects; substrates were not noted for Thom Cobble. Most of the transects had a mix of cobble and sand at this elevation, with the proportion of sand varying quite widely. The UW

South transect was pure sand, whereas Seahurst North had a large amount of cobble. Pebble percentages were not quantified but are generally low at this tidal elevation.

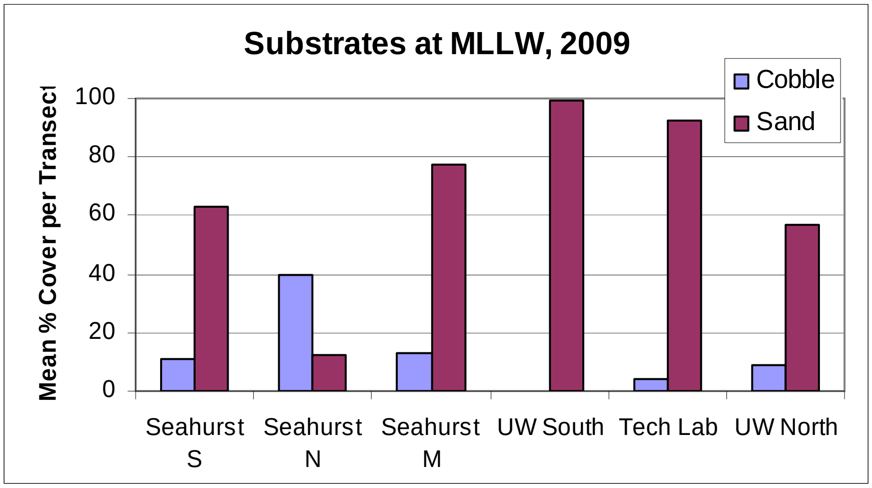


Figure 10. Percentages of surface sediment that was either cobble or sand in the transects at MLLW in the Seahurst region. Values for cobble and sand are means from 10 quadrats.

Figure 11A shows a negative correlation between the 2009 sand abundance and the densities of small clams in each transect. Figure 11B presents similar data but also includes the sites with multiple years' of data (the SCALE Seahurst sites), and shows a similar negative effect of sand on small clams. In 11B, the three points on the left are the 3 years' of data from Seahurst N, which has always had less sand than the other sites in the region. Even within that site, however, the data suggest that juvenile clams settle or survive poorly in years when there is a higher proportion of sand. The other points in Figure 11B are Seahurst S and M and the UW sites, all of which have more sand, and the same negative correlation is seen there.

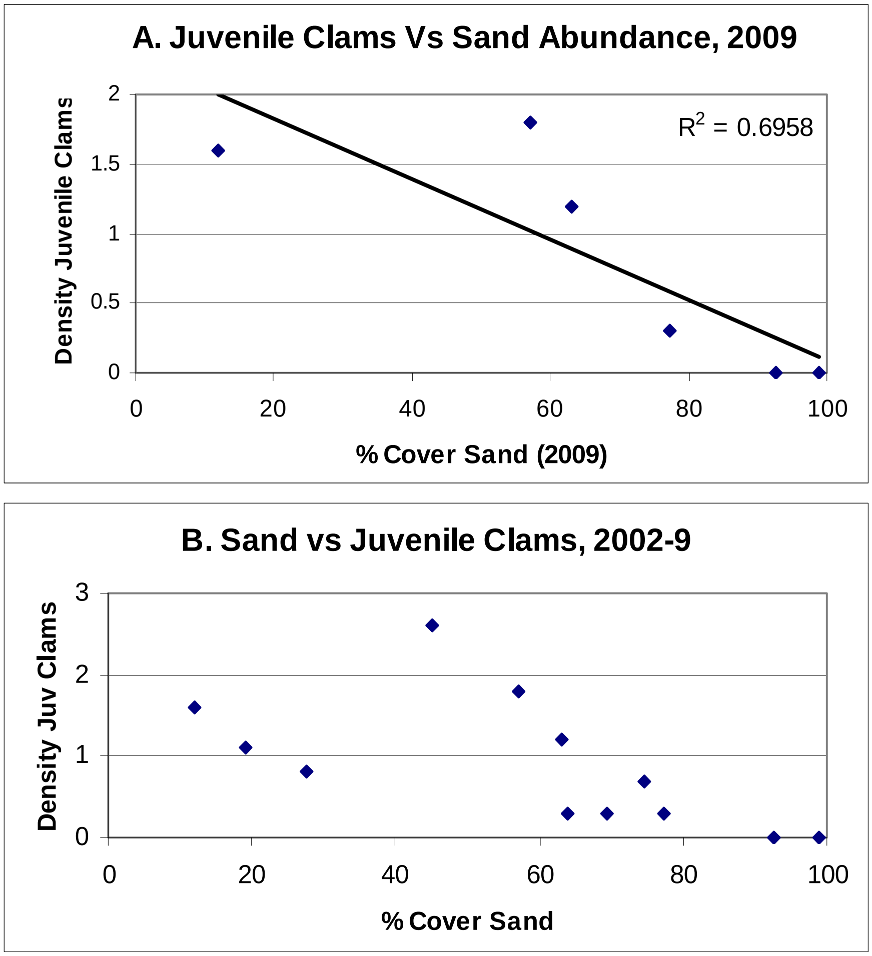


Figure 11. Correlations between surface sand abundance and densities of juvenile clams. A. Data from all MLLW transects in 2009. B. All MLLW data from 2002, 2003, and 2009, including all three SCALE sites plus the Seahurst UW sites.

2.3 Community Analyses

Kohn did not quantitatively sample infauna except for clams, or surface flora and fauna, and thus it is not possible to compare community-level data at Seahurst in 1971 with current biota. However, Thom took core samples of “small infauna” in both a cobble and a sandy area on repeated dates in 1982-83. We had to shift the locations of our 2009 samples from these historic sites because of a major shift in substrates — the area that was cobble-dominated in the 1980s is now pure sand, forming a delta in front of the small stream near the Tech Center. Thom’s “sand” site, slightly further to the north, now is cobble-dominated. Data are thus compared via substrate type rather than by exact location.

Figure 12 shows the species richness at all MLLW transects sampled in 2009, with the data broken down by total richness (blue bars) or core-only richness (red and yellow bars). Thom did not sample surface biota, so the comparable 1983 data are core-only richness figures. Sampling surface biota leads to richness that is 1.5 to 2 times higher than the core-only data. In both time periods the sand transects (Thom Sand and UW South) had much lower species richness than the transects with cobble, as expected for this generally depauperate habitat type. In the two transects with comparable 1983 and 2009 data, species richness in 2009 was substantially lower than in 1983 — 27% lower in the cobble habitat, 41% in the sand.

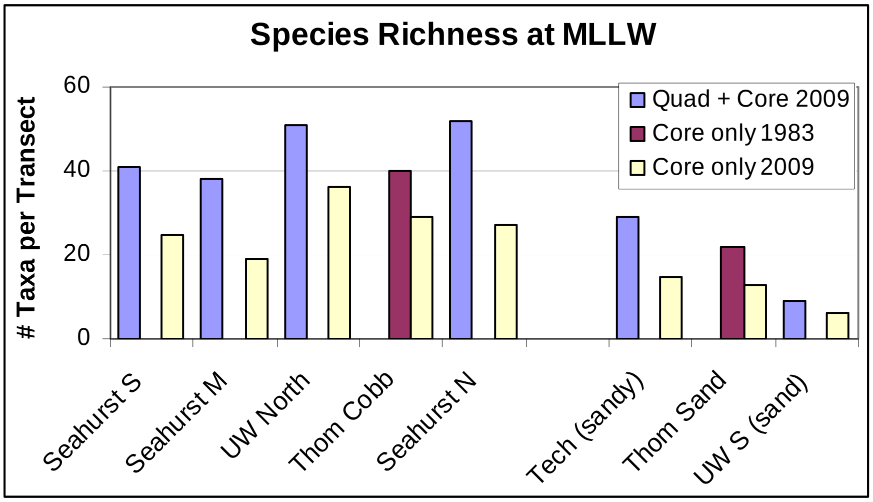


Figure 12. Species richness in all transects sampled in 2009, with comparable data for the 2 transects sampled in 1983. Transects with cobble are on the left, mostly-sand transects are on the right.

Figure 13 shows the core-only data for all the cobble sites for all the sampled years. It shows temporally stable richness at some sites (e.g., Seahurst M) and rather variable for others (Seahurst S and N). The 1983 Thom cobble richness was the highest recorded in this dataset, although we cannot ascertain how he distinguished taxa; for instance, for identification purposes, he may have split some species that we lump.

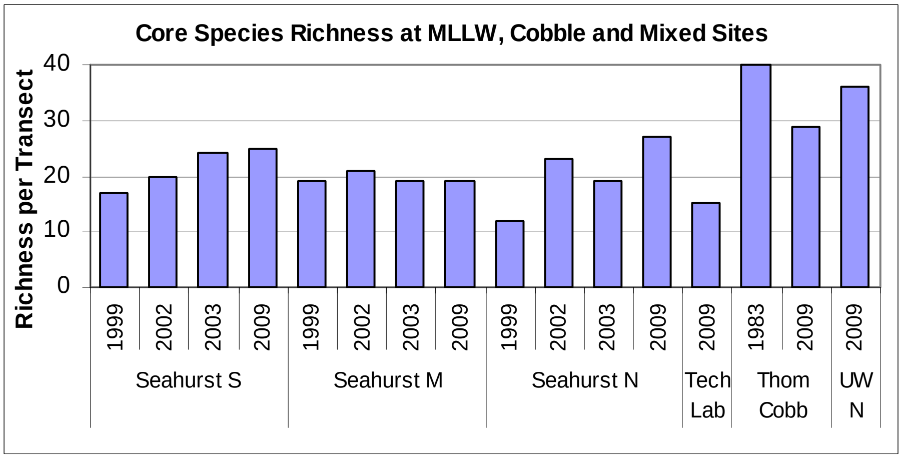


Figure 13. Species richness in all non-sandy transects for all years sampled.

Figure 14 plots this core richness for all the cobble sites and years for which we have data on the amount of sand (percent cover in surface quadrats). As in Figure 11, there appear to be two groups of points: the 3 points on the left are all Seahurst N, while the 8 points on the right are at Seahurst S and M, plus Tech Lab and UW N within the park. As with the abundance of juvenile clams (Fig. 11), there is a negative relationship between the amount of surface sand and the species richness of infauna in the cores.

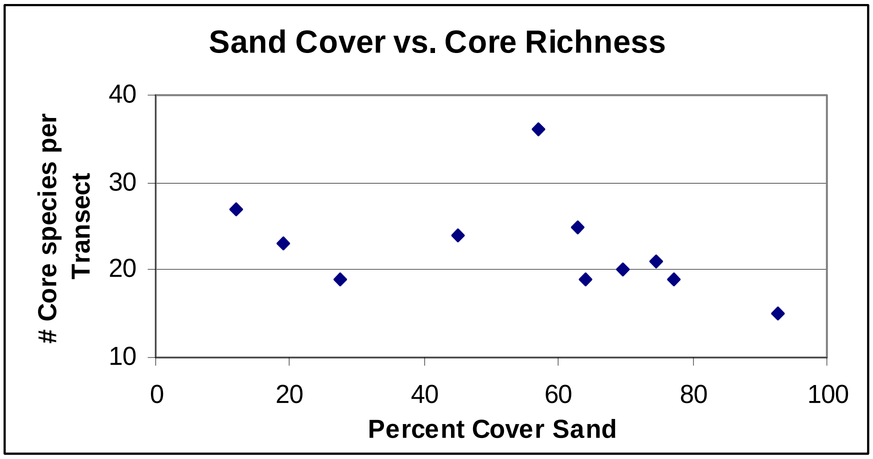


Figure 14. Species richness versus surface sand cover in all non-sandy transects for 2002-09.

While Thom does not provide full species lists for their transect data, they do list the "numerically dominant infauna" and their average abundances. We present these data in Table 3 along with our data from the same areas. The table shows radical shifts in fauna in both the cobble and sand sites between 1983 and 2009. In the cobble area, several species were found in common in the two periods, but the 2009 abundances are up to two orders of magnitude lower than the 1983 abundances. The most abundant organisms in 2009 were juvenile sand dollars, various polychaetes, and a small clam species, none of which were on Thom's "numerically dominant" list. In 1983, the average total number of individuals (of these dominant species, excluding nematodes) per core in the cobble habitat was 503; the average number of individuals of all species in our cobble cores (scaled up to the larger area of Thom's cores) was 37. Similar, striking changes are seen in the sand transect, with relatively low species overlap and order-of-magnitude lower abundances in 2009 (Table 3). The average number of individuals in a sand core was 57 in 1983, as compared to 7.5 in 2009. Given the striking drops in total numbers of individuals among time periods, it is not surprising that the species richness in 2009 was much lower than that of 1983 (Fig. 12), because species richness usually increases with numbers of individuals collected (Gotelli and Colwell 2001).

Table 3. Numerically dominant infauna at Seahurst sites in Thom et al. (1984) (mean values from 3 summer sample dates) and in 2009. Abundance data for both years are converted to the core size used by Thom et al. (number per 285 cm^2). “n.d.” indicates that these taxa were not listed among the ‘numerically dominant’ species in Thom’s report.

	Species	1983 Abundance	2009 Abundance
COBBLE site	*Mediomastus* and *Barantola*	304	0.6
	Nematoda	112	(not sampled)
	Nemertea	11	0.9
	Notomastus tenuis	75	1.2
	Armandia brevis	30	0
	Platynereis bicanaliculata	82	0.9
	Owenia fusiformis	rare	0.6
	Dendraster (juvenile)	n.d.	7.5
	Glycinde picta	n.d.	5.1
	Amphipods (pooled species)	n.d.	2.7
	Tellina modesta	n.d.	4.8
	Nereis procera	n.d.	3.0
	Spio filicornis	n.d.	1.8
SAND site	*Scoloplos* spp.	6	0
	Transenella tantilla	6	0.3
	Glycinde picta	2	0.6
	Nephtys spp.	1	0
	Platynereis bicanaliculata	15	0
	Aorides spp.	5	0
	Macoma spp. juvenile	4	0
	Tellina modesta	6	0
	Micropodarke dubia	5	0
	Pontogeneia spp.	3	0
	Dendraster (juvenile)	n.d.	0.9
	Hemipodus borealis	n.d.	2.4
	Edwardsia sipunculoides	n.d.	0.9

Multivariate analyses comparing Thom’s 1983 data with ours from 2009 are not possible because we have access to only a portion of the community-level data (the most common species) from those transects. Figure 15 shows all the MLLW core data from 2009, including that from the Thom-location transects, along with the core data from the three SCALE Seahurst sites from all years’ samples. While the plot suggests some separation of core infaunal communities by year, the ANOSIM test for year was not significant (R = 0, p = 0.57), probably because there is so much variation among the 2009 samples (which include the sand transects as well as the cobble).

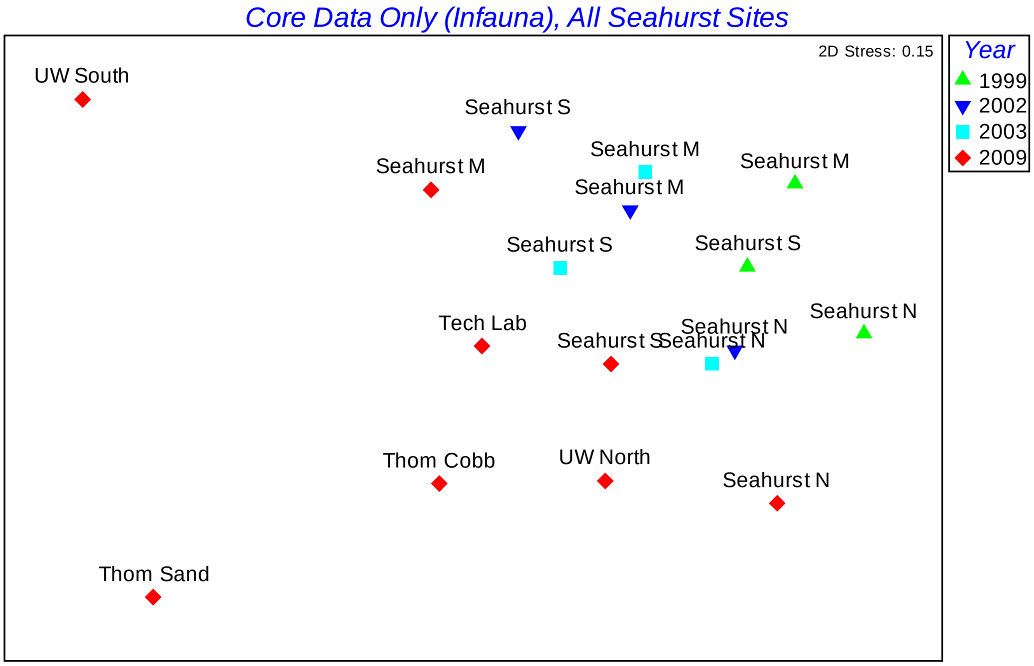


Figure 15. Non-metric multidimensional scaling plot of all the core-infaunal data at MLLW from all 4 sampled years for the SCALE Seahurst sites, plus the 2009 data from the other MLLW transects within Seahurst Park. Each point represents average values from the 10-12 cores per transect.

Figure 16 shows these same data with the points (transects) coded by their substrate type: pure-sand (2 transects), cobble (<25% sand), and mixed (with some cobble, and 10-75% sand). This substrate factor was significant (R = 0.51, p = 0.001), i.e., the transect biota were different depending on the substrate type. Sand transects are clearly the most different, but the mixed and cobble transects were also significantly different from each other.

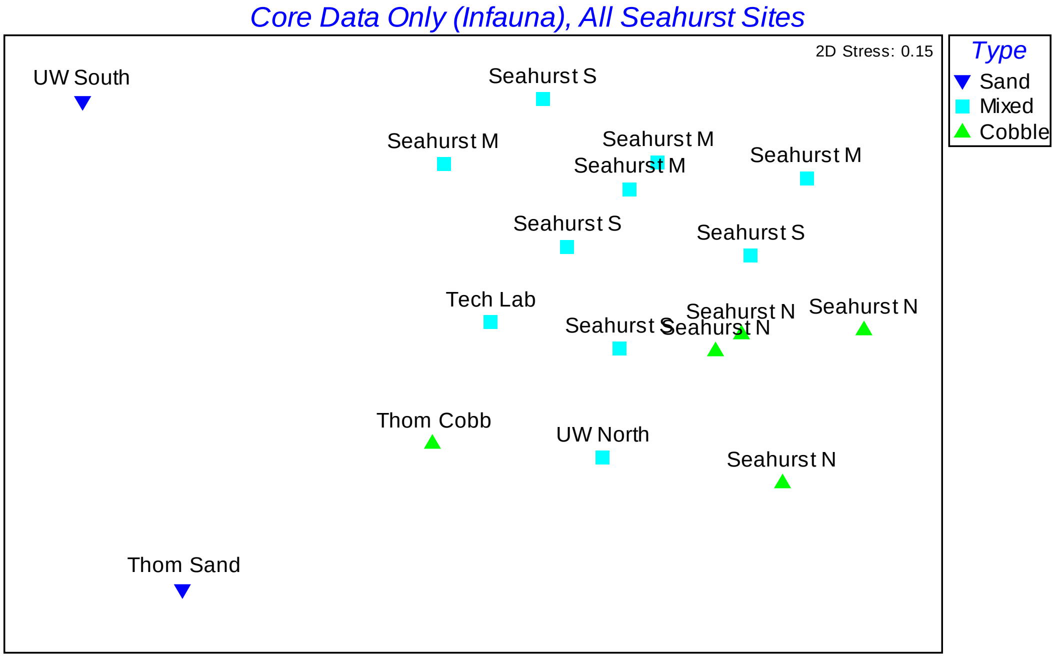


Figure 16. Non-metric multidimensional scaling plot of all the MLLW core-infaunal data from all 4 sampled years for the SCALE Seahurst sites, plus the 2009 data from the other MLLW transects within Seahurst Park.

Additional community-level analyses were done on infauna and surface biota data, not including the Thom transects for which no surface biota data were gathered. Figure 17 illustrates the different communities found at MLW (+2.8') vs. MLLW (0') at all the sampled transects. Communities at these tidal elevations were significantly different (R = 0.58, p = 0.001). This relationship would be even stronger if the very-sandy and low-diversity transect (Figs. 10, 12) at UW South was omitted. Species richness at MLW was only 13-73% of richness at MLLW, except at the sandy sites (Tech Lab and UW South) where the values were very similar at the two levels. Species found in greater abundances at 2.8' were gammarid amphipods and the predatory polychaete *Hemipodus*; most other species were most abundant at MLLW, although there was considerable overlap in the species lists.

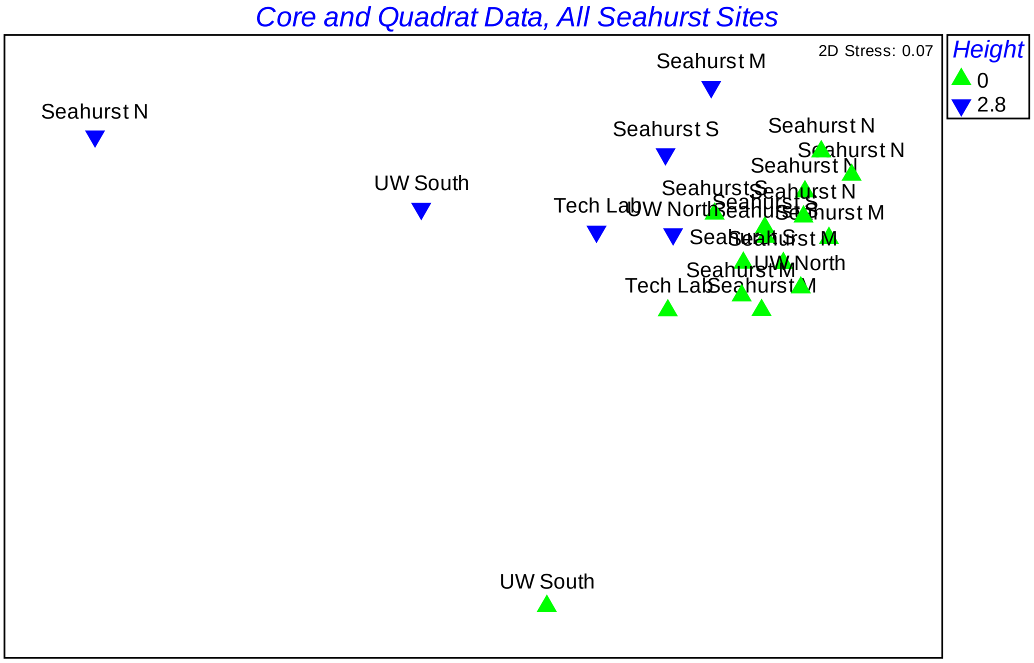


Figure 17. Non-metric multidimensional scaling plot of all the sample data from all 4 sampled years for the SCALE Seahurst sites, plus the 2009 data from the other MLLW transects within Seahurst Park.

When the MLLW data are plotted without the mid-shore data, and the UW South outlier is removed, it is easy to see how the different years (=points) for each of the Seahurst sites group together (Fig. 18), i.e., the communities at each site tend to be consistent from year to year (Site R = 0.61, p = 0.001). Note that the Seahurst M sites are more similar to the other sites nearby within the park (Tech Lab and UW North) than are the more-distant Seahurst S or N. If the sites outside the park (Seahurst S and N) are contrasted with those inside (Seahurst M, Tech, and UW N), these regions have significantly different biota (p = 0.015), although the difference is not large (R = 0.257). Transects outside the park had more live barnacles, *Lacuna*, limpets, and gammarid amphipods, while inside the park there was more *Zostera*, capitellids, and *Spiochaetopterus* tubes.

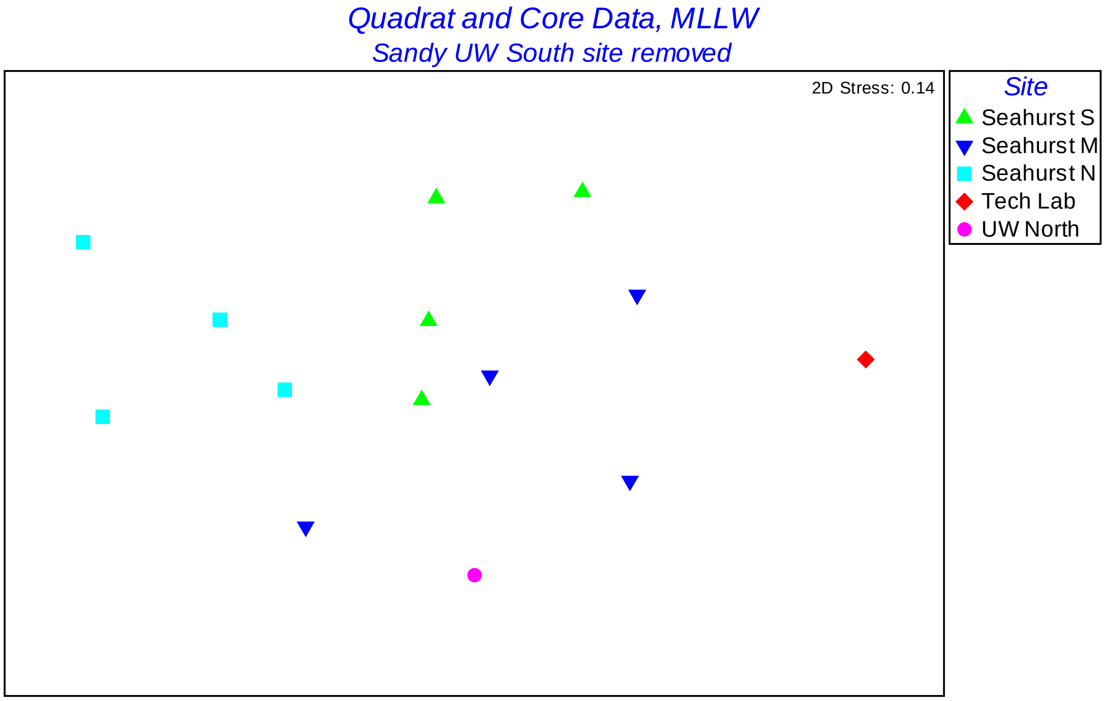


Figure 18. Non-metric multidimensional scaling plot of all the sample data from all 4 sampled years for the SCALE Seahurst sites, plus the 2009 data from the other MLLW transects within Seahurst Park. The outlier (sandy) UW South point was removed.

Figure 19 plots just the 4 years' worth of data for each of the three SCALE Seahurst sites to examine year-to-year and site-to-site similarities. ANOSIM analyses of these data show that Sites are significantly different (R = .51, p = 0.004), although of the pairwise site comparisons, Seahurst S and M are not different (both are different from Seahurst N). Note that Seahurst N has much more cobble and much less sand than Seahurst M or S, which have similar substrates (Fig. 10). Species (from SIMPER analyses) that characterized the North site more than Mid or South were barnacles, limpets, *Lacuna*, flatworms, and other cobble-associated species. The transects do not show significant grouping by Year (R = 0.20, p = 0.10), although all the 2009 transects are at the bottom of the plot;t; this lack of difference probably stems from the points in the other 3 years being intermixed. SIMPER analyses show that 2009 differed from all other years in having few flatworms, *Onchidoris*, and *Nucella* (all barnacle predators), few juvenile *Tresus* (as seen in Fig. 7), and more nemertean worms, juvenile sand dollars, and the capitellid *Notomastus*. Barnacle abundances (dead or alive) were not different among years.

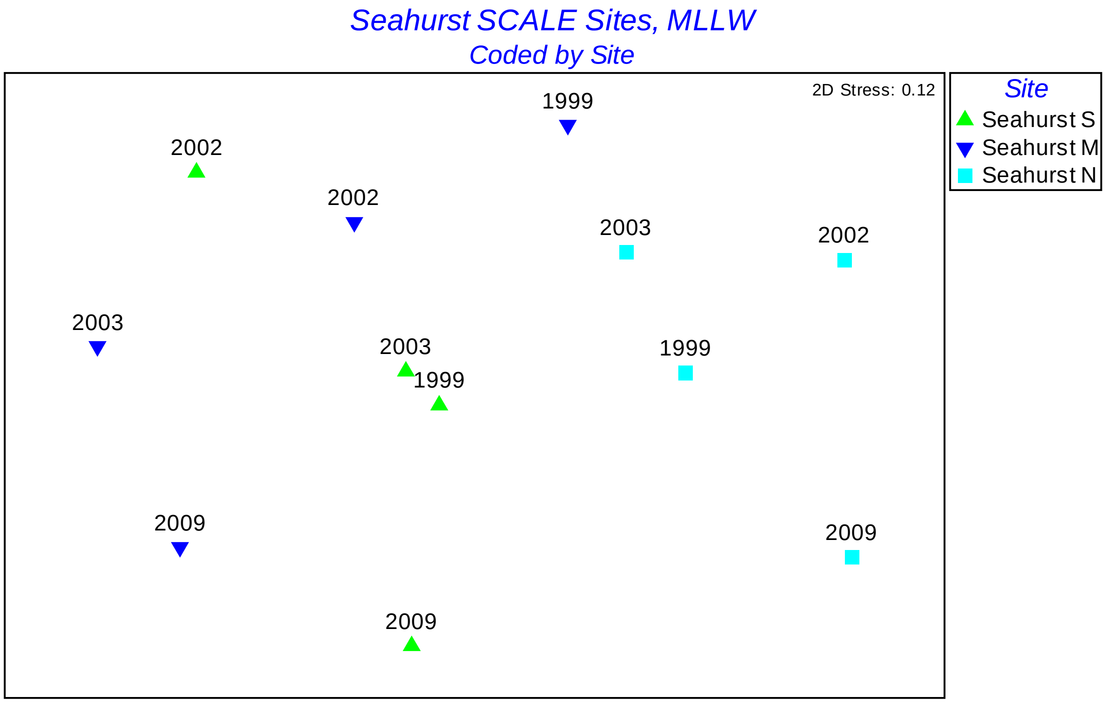


Figure 19. Non-metric multidimensional scaling plot of all the sample data from all 4 sampled years for the SCALE Seahurst sites, plus the 2009 data from the other MLLW transects within Seahurst Park.

3 Discussion and Conclusions

3.1 Discussion

Our comparison with Kohn's 1971 and Thom's 1983 surveys found large changes in both beach morphology and biota at all sites surveyed within Seahurst Park. The mid-upper shore is different from the way it was in 1971 at most of the transect areas; in general, the beach is now narrower, steeper, and coarser. The lower shore (below the slope break, which was evident at most areas in the park) is also different at most of the transect locations, especially those north of the main stream delta, where the sandy low-tide platform is much narrower than it used to be. The low zone substrates along the park shoreline still consist of a mix of sandy areas and cobble-dominated areas, but these areas have shifted locations over the years. The intertidal biota overall is much more depauperate than in 1971, especially in the area north of the stream. Upper-shore areas have much less surface flora and fauna than those recorded in Kohn's notes, perhaps because of the lack of stable cobbles and boulders. In the lower areas, *Zostera* is still present in most of the areas where it was recorded by Kohn, although it is impossible to make a quantitative comparison based on his notes. The tube-building polychaete *Spiochaetopterus* was present at both time periods, although densities are now lower, and there is less habitat area for this species because of the narrowing of the sandy low-tide terrace where it lives.

Low shore infaunal communities, even in the same substrate type, are very different from those found by Thom. Species richness in 2009 in both cobble and sand transects are somewhat lower than those in 1982-83, although this may not mean that species have actually disappeared from the area -- species richness is generally a function of numbers of individuals, and these numbers are an order of magnitude lower in 2009 than in 1982 in both the sand and cobble transects sampled. A variety of worms, amphipods, and clams are all much less abundant in 2009, and there has been a shift to a different suite of organisms. The cobble area in 1982 was numerically dominated by deposit feeders, whereas now it has much lower diversity (and probably biomass) and the species are a mix of suspension feeders, scavengers, and carnivores. Interestingly, while Kohn did not consistently identify the species of *Macoma* found in his clam pits, he recorded a predominance of *M. nasuta* and only a few *M. inquinata* (plus many recorded as "*Macoma*"), whereas we found a total of 25 *M. inquinata* in the park and only 4 *M. nasuta* (plus 3 *M. secta*). Most (3) of the *M. nasuta* we found were at transect E, in the lee of the stream delta where the substrate is muddier, as is consistent with the normal habitat type for this species; the *M. inquinata* were in the cobble and sand areas, and the *M. secta* in the clean sand. If this difference in species dominant in 1971 and 2009 is real, it suggests a shift to sandier substrate over time, especially north of the stream delta, consistent with the shift away from deposit feeders in Thom's cobble transects.

The strongest quantitative data comparing the three time periods are clam abundances and sizes. In 1971, Kohn (p. 2) wrote: "In this zone, regions of the beach characterized by a complex, mixed substrate of cobbles, gravel and sand support dense populations of clams which were the subject of a rather intensive sport fishery during the period of observation" – even though some of his observations were on rainy wintertime night tides. Densities were still high in 1982-83, although Thom did not sample at the precise locations sampled by Kohn. At Thom's cobble site (optimal for many species of clams), densities were in the same order of magnitude as those found by Kohn. In contrast, in 2009, densities are consistently an order of magnitude lower than those found by either Kohn or Thom, and most of the individuals are very small. There are virtually no clams large enough to be worth harvesting. The horse clam *Tresus* was very abundant in the low intertidal zone in the park in 1971, but only one was found in an intensive search in 2009. Clam size data also show drastic changes. Kohn's limited size data from 1971 showed an abundance of large individuals of all species, and large average sizes. Thom's 1982 data (for only two species) showed many large littleneck clams, but an unexpected shift to smaller individuals for *Macoma* spp. (which are not harvested for food). However, Kohn did not distinguish the different species of *Macoma*, so these data may not be directly comparable. By 2009, the only clams > 5 cm in our samples within the park were 3 *Macoma secta* north of the stream (found in the sand; this species is generally not considered edible) and 1*Macoma inquinata* plus 5 *Saxidomus* at UW South, at the southern edge of the park. A few other large individuals were found in areas sampled outside the park. Juvenile clam densities in 2009 were also low, although we do not have comparable data for small clams from 1971 or 1982.

These changes could result from a variety of causes, or combinations thereof. First, some could result directly from the construction of seawalls both before and after the Kohn survey. The companion geological survey to Kohn's biological one (Sternberg and Scott 1971) noted: "As an increasing length of coastline is stabilized by bulkheads and revetments, the potential for erosion in the unprotected areas and the existing beach face increases. The beaches in the area have been losing sand for at least 15 years. The rate of erosion was further increased around 1967 presumably as a result of the additional stabilization of the shoreline within the park boundary." (p. 5). One of the hypothesized effects of seawall construction is increased wave reflection, leading to erosion of fines from the upper shore and causing the beach to become steeper and coarser, as the data suggest for some locations at Seahurst. However, at most places in the park, the seawalls are high enough on the shore that this effect would not be expected, and this kind of morphological change is one of the least well-documented effects of seawalls (Coyle and Dethier 2010).

Nourishment of the beaches in the park, for example, following restoration of the area south of the stream delta, likely have altered the shape and grain sizes of the beach, especially the upper and mid-shore areas (Coastal Geologic Services 2008). If this nourishment caused the mid-upper shore to be characterized by coarse pebble sediment, it could contribute to recent biotic changes.

The physical and biological changes we have documented could also be unrelated or only indirectly related to the seawall and beach nourishment within the park. Beach morphology and biological communities can both be impacted by the supply of sediment into the drift cell. While, in Puget Sound as a whole, erosion of bluffs is estimated to supply 90% of the sediment to beaches (Johannessen and MacLennan 2007), and seawalls that prevent erosion can thus disrupt that key process, the streams that flow into Seahurst Park appear to be important local sources of sediment. Changes over several decades in the flow rate and loads of sediment and organic matter of the streams are totally undocumented but could be substantial, given development within the watershed (City of Burien). Either increases (from disturbance to vegetation and from construction) or decreases (from deliberate reduction in erosion of stream banks) in sediment load could have affected the local beach substrates, especially to the north of the main stream , which is down-drift from the stream mouth. Reduced sediment load in the large stream, for example, could have reduced sediment supply to the whole area to its north and contributed to the narrowing of the low tide terrace. Our data suggest (Table 1, Transect D) that the large-stream delta is at least 30 m less wide than it used to be, which could have resulted in less protection from wave energy for the section of beach to the north. This, in turn, could have contributed to the apparent reduction in deposit-feeding organisms (worms and *Macoma* clams). In addition, changes to the two smaller streams to the north (closer to the Marine Technology Lab) could have altered the beach morphology. None of the notes or maps from 1971 describe the distinct sandy delta that now exists in front of the Lab. Thom (1984) described this area as having cobble in the low shore, but it is now sand-dominated. These observations suggest that the sediment load in the small north stream may have increased, for example, due to upland development increasing runoff. Our data from 2009 and from previous research suggest a negative effect of sand on infaunal richness and on the abundance of juvenile and adult clams. Thus it is possible that changes in the streams could have been a cause of changes to the low-shore biota. *Zostera* is still present in much of the park, although it appears to be less abundant north of the stream than it was in 1971. It could readily be affected by changes in sediment load from the stream.

Finally, the intense human use of the park may have altered the biota. The current virtual absence of clams could result indirectly from the geomorphologic changes described above, or directly from overharvesting by humans. The presence of juvenile clams in some areas implicates the latter; clams are recruiting to this site, but not surviving to adulthood. Conversely, the reduction (even between 1971 and 1983) of numbers and sizes of *Macoma* spp., which are not harvested by humans, implicates at least some involvement of other causes. In addition, many of the organisms noted as in low abundance or missing in 2009, such as many species of small worms, are not of direct interest (e.g., for harvest) by the public. However, the sheer volume of human use of the beaches could indirectly impact the whole biotic community, e.g., by trampling, turning over rocks, and haphazard digging. Visitation of the park and use of the beaches is enormous, both by the general public and by numerous school groups. It is clear that movable rocks in the park are turned over frequently, resulting in death of organisms on both sides. If human use is a proximate cause of the current low diversity, restoration of the upper beach by removal of seawalls will not remedy the situation.

Larger-scale changes in Puget Sound, i.e., those occurring beyond the boundaries of Seahurst Park, could also have contributed to the changes over these four decades, although this seems less likely than local causes. For example, toxins in the water could have affected the biota in terms of either abundance or species richness. However, only a substantial toxic event (such as an oil spill) or a chronic and rather severe stress could have affected the biota to the extent seen, and no such factor has been noted for the area. Toxins also would not have affected the beach morphology. Our SCALE monitoring data since 1999 suggest no substantive biotic changes in the last decade, either positive or negative. Increases or decreases in sediment supplies outside of the study area (either to the north or south) should not have affected the park, because all the transect locations are near the up-drift end of the drift cell. Thus it seems likely that the changes in both the beach morphology and the local biota have causes that are relatively local, i.e. from changes within the park itself and/or areas in its watershed.

3.2 Conclusions

We draw the following primary conclusions from this work:

- Comparison with Kohn's 1971 surveys and Thom's 1983 surveys found large changes in both beach morphology and biota at all sites surveyed within Seahurst Park. The mid-upper shore is now narrower, steeper, and coarser in most locations, and the lower shore is narrower at most locations, especially those north of the main stream delta.
- The intertidal biota overall is much more depauperate than in 1971, especially in the area north of the main stream.
- Low shore infaunal communities, even in the same substrate type, are very different from those found in 1982. Species richness is generally a function of numbers of individuals, and these numbers were an order of magnitude lower in 2009 in both the sand and the cobble transects sampled.
- At Thom's cobble site (optimal for many species of clams), densities in 1982 were at the same order of magnitude as those found in 1971. In contrast, in 2009, densities were consistently an order of magnitude lower than those found on the earlier dates, and most of the individuals were very small. There were virtually no clams large enough to harvest in 2009. The current virtual absence of clams could have resulted indirectly from geomorphologic changes

(e.g., affecting recruitment or survival or juvenile clams), or directly from overharvesting by humans.

- Juvenile clam densities in 2009 were also low, although we do not have comparable data for small clams from 1971 or 1982.

These changes could result from a variety of causes, or combinations thereof: construction of seawalls both before and after the Kohn survey, and recent nourishment of the beach in some areas; changes in land use in the local watershed, potentially altering sediment loads and water quality of the streams that impact the park beaches; and intense human use of the park, including turning over rocks, digging, and collecting organisms.

The planned Phase II seawall removal and nourishment activities at Seahurst Park will provide an opportunity to observe the biological community's response to restoration of beach geomorphology.

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