

DECADAL CHANGES IN SHORELINE BIOTA IN WESTCOTT AND GARRISON BAYS, SAN JUAN COUNTY

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SUMMARY

The Washington State Department of Natural Resources and the University of Washington participate in a long-term collaborative project to monitor intertidal biotic communities as indicators as ecosystem condition. In June 2007, we sampled beaches in Westcott and Garrison Bays, San Juan County in order to compare current biota with communities sampled in the 1990s. In the area sampled, virtually all of the eelgrass (*Zostera marina*) disappeared between 2001 and 2003. The cause of this decline is not understood. The purpose of this study was to determine whether there has been a similar radical change in intertidal biotic communities over this time period. The presence or absence of change in these communities, which are largely ecologically independent of eelgrass communities, could provide a key piece of data on the causes of the eelgrass decline.

We censused intertidal biotic communities at multiple tidal heights using quadrat and core sampling techniques, and compared current data to historical records ranging from 1974-1998. Virtually all of the species found in the 1990s were also found in 2007. While species richness varied among years, this difference was primarily attributed to differences among sampling techniques, most notably the number of samples collected. Data collected on clams, some of the longest lived organisms in the study, show high similarity in species, densities and size distributions among sample years and sites. Additionally, we documented extensive eelgrass losses throughout the area between 1998 and 2007. The proportion of linear shoreline with eelgrass present decreased from 86% in 1998 to 11% in 2007.

The intertidal biotic community data collected in 2007 suggest that eelgrass loss in the early part of this decade was not indicative of a broader ecosystem-wide change in Westcott and Garrison Bays. It appears that some factor differentially impacted the eelgrass and not other nearshore communities. Our study helps rule out some potential causes of eelgrass decline, including a substantial change in sediment type, temperature, or salinity.

INTRODUCTION

The Washington State Department of Natural Resources (DNR) and the University of Washington (UW) have a long-term collaborative project to monitor intertidal biotic communities as indicators as ecosystem condition. In June-August 2007, the collaborative team undertook three separate sampling efforts as part of its long-term monitoring program of shoreline communities in the greater Puget Sound area. Two of these efforts followed our normal sampling/monitoring protocol and worked in mixed sand-pebble beaches, and are reported elsewhere (Dethier and Berry 2008). The third effort, described in this report, involved sampling mud-cobble beaches in San Juan County, in the northern Puget Lowlands, to compare current biota with communities sampled in the 1990s.

Objective: Between 2001 and 2003, virtually all of the eelgrass (*Zostera marina*) disappeared from the intertidal and shallow subtidal areas of Westcott and Garrison Bays, on northern San Juan Island. The causes of this decline are not understood, and are under separate investigation (Dowty 2007). Our objective was to determine whether there has been a similar radical change in other intertidal communities over this time period; the presence or absence of change in these communities, which are largely ecologically independent of eelgrass communities, could provide a key piece of data on the causes of the eelgrass decline. This analysis is possible because of sampling done (for various

purposes) on the shores of Westcott and Garrison Bays in 1974-6 (Nyblade 1977), 1993 (Dethier 1993), and 1998 (Dethier and Ferguson 1998). In June-July of 2007 we re-sampled some of these sites and analyzed differences in overall intertidal communities and of clam populations.

METHODS

Eelgrass Sampling

In August 2005, DNR personnel repeated an eelgrass sampling effort done in 1998 (Dethier and Ferguson 1998). The survey had two parts. First, on a day with good visibility and a low tide (at least -1' MLLW), DNR personnel drove all the way around the margins of Westcott and Garrison Bays in a small boat, noting presence or absence of eelgrass. Second, at 24 points (ca. every 500 m along the shoreline), they ran a boat-based transect from very shallow water out to depth, noting: a) the distance of the shallow and deep margins of the eelgrass bed from the low water line; b) the depth of shallowest eelgrass, c) the depth of the deepest visible eelgrass, d) the Secchi depth (i.e., how far could they see into the water at deep edge of the bed where eelgrass was present or at a comparable depth where eelgrass was absent), and e) the general characteristics of the eelgrass bed (continuous versus patchy). These data were compared to the 1998 data.

Intertidal Biota Sampling

During the very low tides of late June-early July 2007, a team of researchers from UW and the DNR sampled 4 intertidal sites for which earlier surveys existed. Three of the sites were chosen because of their proximity to shallow-water sites used at the same time by DNR researchers studying possible eelgrass stressors. These covered a gradient from the innermost to the outermost part of Westcott Bay (Figure 1). Two of these sites were also within several hundred meters of sites sampled numerous times in the 1970s by Nyblade (1977): his "Webb Camp" (south of our Stern site), and "Westcott Bay" (east of our Judd site). Nyblade's sampling included variable numbers (1-5) of samples per tidal level per date and many dates (12-14) over the course of two years, and thus included seasonal as well as interannual variation. The tidal levels in Nyblade (1977) were not directly comparable with those sampled in any of the other years (Table 1).

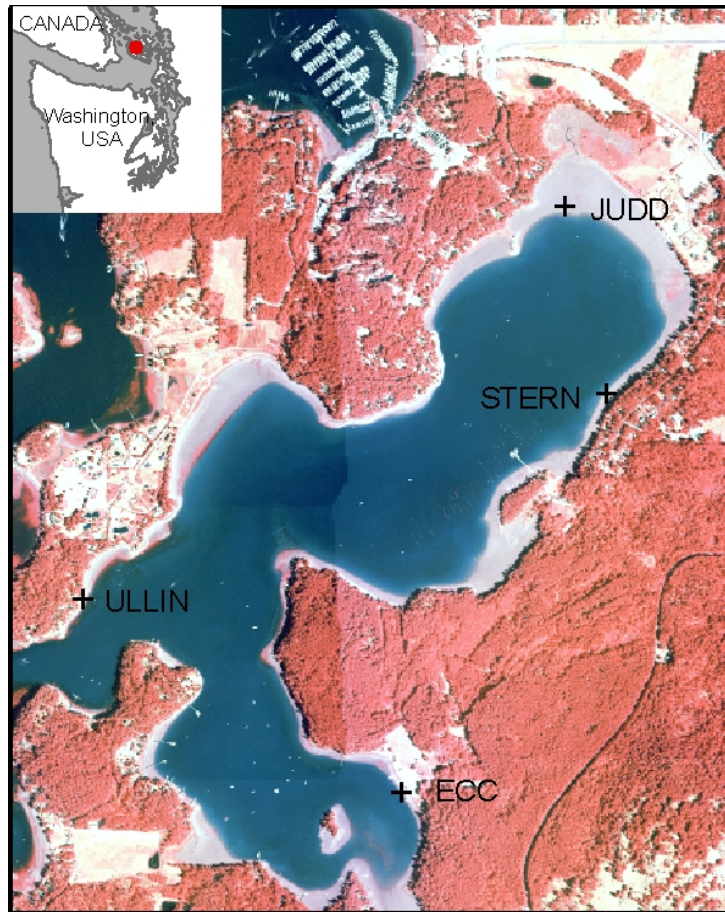


Figure 1. Sites sampled for intertidal biota in 2007.

The fourth site is in English Camp in Garrison Bay, near the old Blockhouse. Detailed sampling in this area occurred in 1980 as part of a Master's thesis (Rawson 1980), and in 1993 as part of a broad survey of marine communities on the shorelines of San Juan Island National Historical Park (Dethier and Ferguson 1993). This location has been closed to recreational clamming since 1974, and thus lacks one of the stressors that occur in most other locations.

At each site in 2007 we sampled the biota at 4 intertidal levels, trying to match the levels used in some of the older surveys. We used standard DNR intertidal biotic community monitoring methodology (ie., Dethier and Schoch 2005), with one exception: we sieved samples to 1 mm (instead of the usual 2 mm) to be more consistent with the older surveys (Table 1). At 0 ft relative to Mean Lower Low Water (MLLW) and +3' MLLW, we sampled all the biota in 10 quadrats and cores placed randomly along a 50m horizontal transect line (Fig. 2). Quadrats were 0.5m x 0.5m, used for counting surface flora and fauna and the types of surface sediment (cobbles, mud, etc). Cores were approx. 10 cm diameter by 15 cm deep, and were sieved on 1 mm mesh; all worms and tiny clams were retained and preserved for later identification. The +3' level was not cored at the Ullin site because there was insufficient space at this level in the small pocket beach sampled (more area was available at MLLW, below some bedrock outcrops).

Year	Source	Comparable Sites	Components	Heights (ft)	Sizes (m ²) Core/Box	N per Zone	Mesh (mm)
1974	Nyblade	Near Judd, Stern	Surface, infauna, clams	-1, +2, +6	0.05 0.25	2-4 Many dates	1, 4
1980	Rawson	Near ECC	Clams only	0, +2.5	0.25	64	5
1993	Dethier	ECC	Surface, infauna, clams	0, +2.6, +4.3, +6.8	0.01 core (10 cm dia) 0.10 box	4 4	1, 10
1998	Dethier & Ferguson	Judd, Stern, Ullin	Surface, infauna, clams	0, +1.5, +3, +6	0.01 core 0.10 box & surface	4 4	1, 10
2007	Dethier & Berry	Judd, Stern, Ullin, ECC	Surface, infauna, clams	0, +1.5, +3, +6	0.01 core 0.25 surf. 0.10 box	10, 10, 4	1, 10

Table 1. Variation in sampling sites and survey methods among the data that were compared.

We also added additional sampling effort for 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). At MLLW and +3’ and also at +1.5’ and +6’ we dug out box cores (0.3 m per side) and sieved this sediment on 1 cm mesh sieves. These box cores do a more effective job sampling clams than the small cores, especially because of their greater depth. Clams from these cores were identified, measured, and replaced in the sediment.

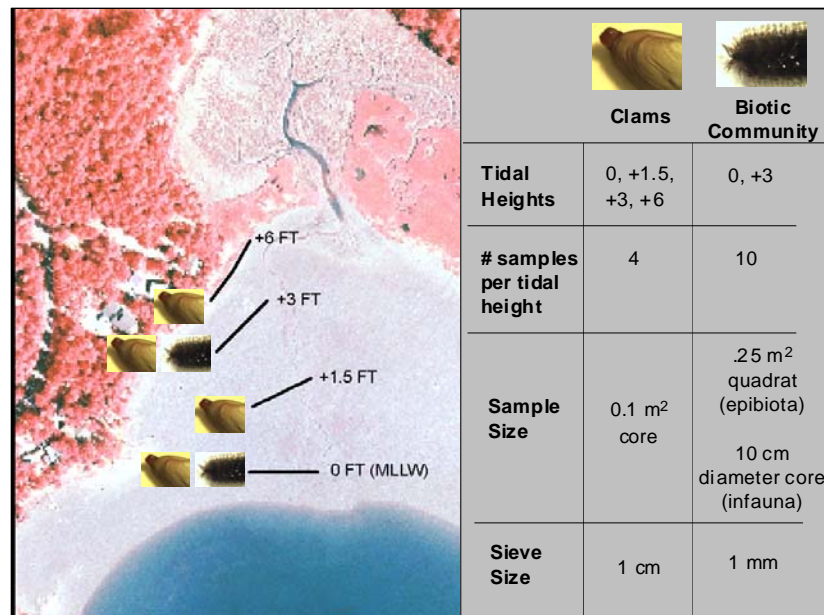


Figure 2. Sampling heights and biota sampled at each tidal height, represented at the Judd site.

RESULTS AND DISCUSSION

Eelgrass sampling

As found in other surveys (e.g. Dowty et al. 2005), the eelgrass in Westcott and Garrison Bays has undergone radical declines in abundance since we surveyed it in 1998. The overall distribution of eelgrass changed from a virtually continuous ring around the two bays in 1998 to very small and scattered populations in 2007 (Figure 3). The proportion of linear shoreline with eelgrass present decreased from 86% in 1998 to 11% in 2007.

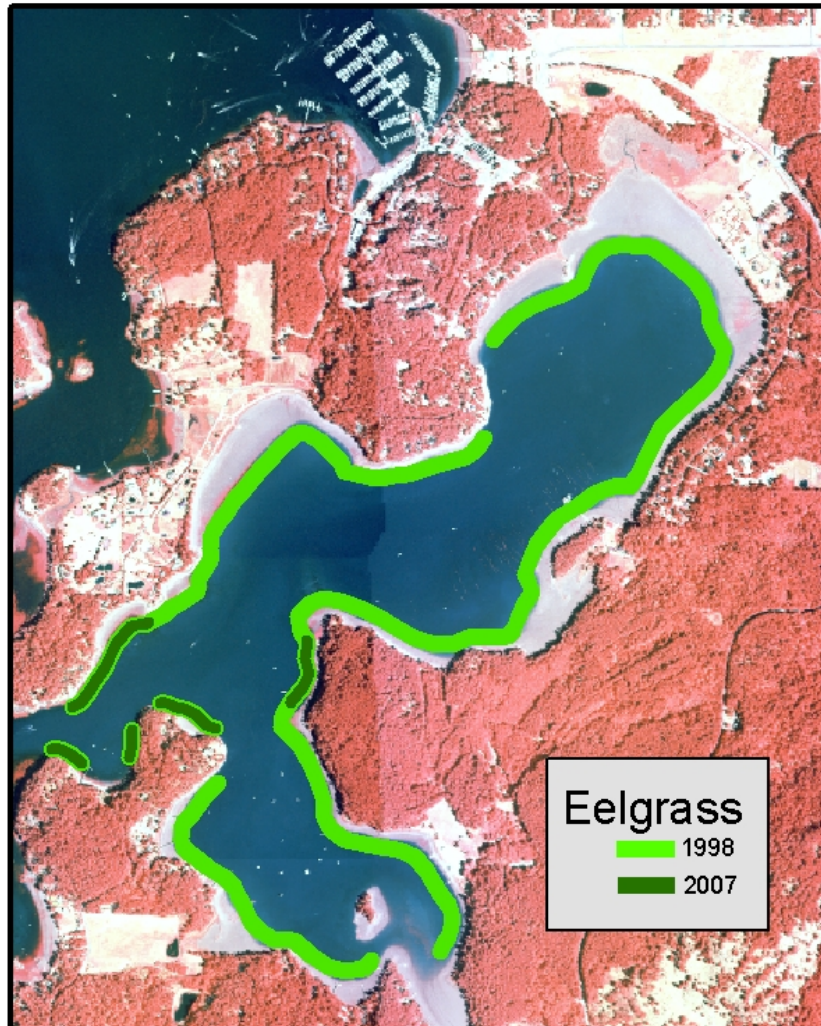


Figure 3. Mapping results showing eelgrass presence in 1998 and 2007.

Figure 4 shows the shore-perpendicular transects where eelgrass was found in the two years, and Appendix 1 provides data on depths where eelgrass was present in 2007. Only 2 of the original 24 transects, both near the mouth of the bay, had any eelgrass remaining; in 1998, 20 transects had eelgrass. At #19, the bed had shrunk from 17 to 8 m wide. At #21, an apparent increase in bed width over time from 10 to 20 m probably is due to slightly different transect placement in an area with highly variable habitat characteristics.

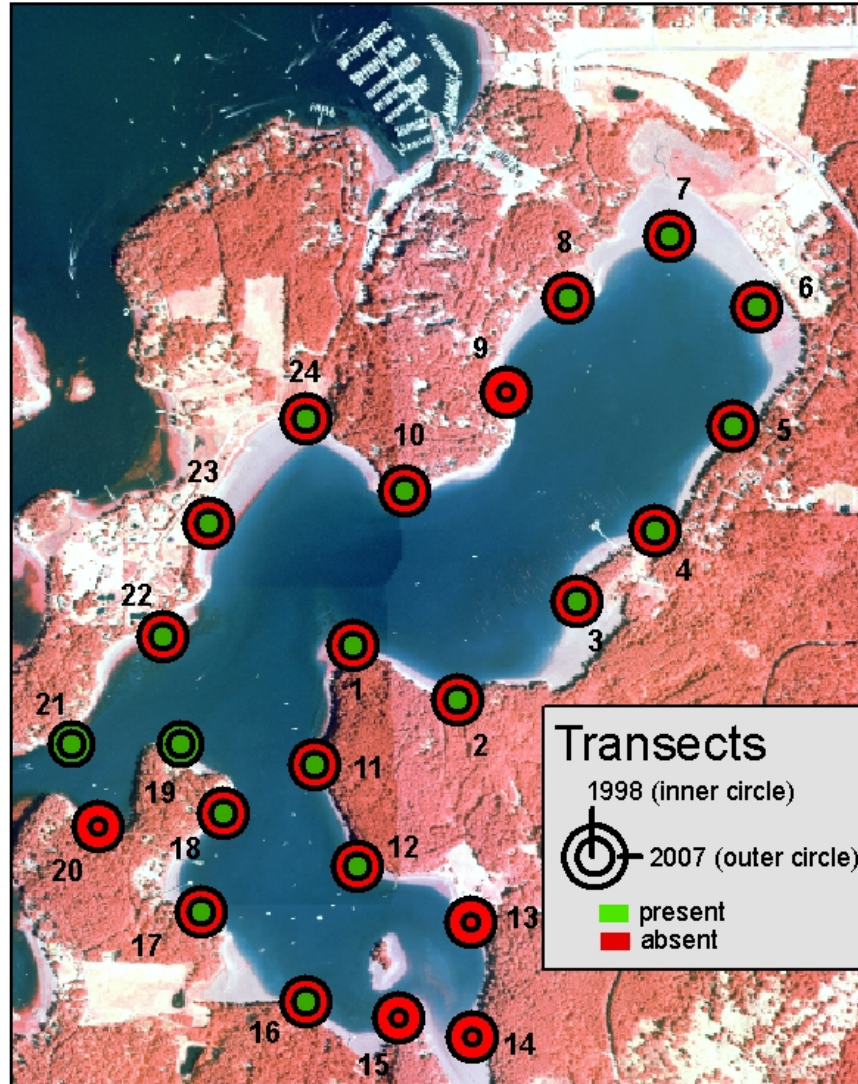


Figure 4. Transect results showing eelgrass presence in 1998 and 2007.

Intertidal Biota

All the sites sampled in Westcott and Garrison Bays have diverse soft-sediment communities. Appendix 2 lists species found at each of the sites. Most sites have muddy-sand on the low shore, mixed with pebbles and cobbles higher on the shore. The ECC site has an unusual amount of cobble in the low zone, which was probably placed on the shore when this site was an English garrison. Low and mid-shore communities at all sites are dominated by ulvoids, diatoms, shorecrabs, amphipods, and littorine snails on the surface, and a variety of clams and polychaete worms in the sediment. Clam species varied among sites (see below), with more bentnose clams in the muddier sites (e.g. Judd) and more littleneck clams in the more pebbly sites. Dominant polychaetes included capitellids and other deposit feeders, dorvilleids, hesionids, and other omnivores, and goniadids and other carnivores. The upper shore sampled at the Ullin site was a rocky promontory, with typical protected-shore flora and fauna (rockweed, barnacles, limpets, and littorine snails, plus oysters).

It is difficult to make direct, quantitative comparisons with the older surveys because of the variation in exact sites, tidal heights, core sizes, and numbers of samples per level (Table 1). The 1974 data included a total of approximately 40 samples per tidal level taken over 14 dates over 2 years (Webb Camp) and 24 samples over 12 dates (Westcott Bay). In 1993 and 1998 there were 4 samples (cores and quadrats) taken per level, and in 2007 there were 10. It was impossible to compare all these data quantitatively, but species lists were tallied. Appendix 3 lists the species found uniquely in the various years.

Figure 5 shows the results of a Multidimensional Scaling (MDS) analysis of just the 2007 data for all transects where both surface biota and infauna were sampled. The biota at the English Camp Mid zone was so different from the other Mid sites that it had to be excluded from this analysis to make it possible to see the relationships of the other points; this difference is almost certainly due to the large amount of surface cobble. The biota at the other two mid-zone sites (Judd and Stern) were so similar that the data points overlap in the MDS plot. The low-zone points show something of an exposure gradient, with the most-protected site, Judd, at the extreme left and the site nearest the mouth, Ullin, at the extreme right. English Camp and Stern are intermediate and lie virtually on top of each other.

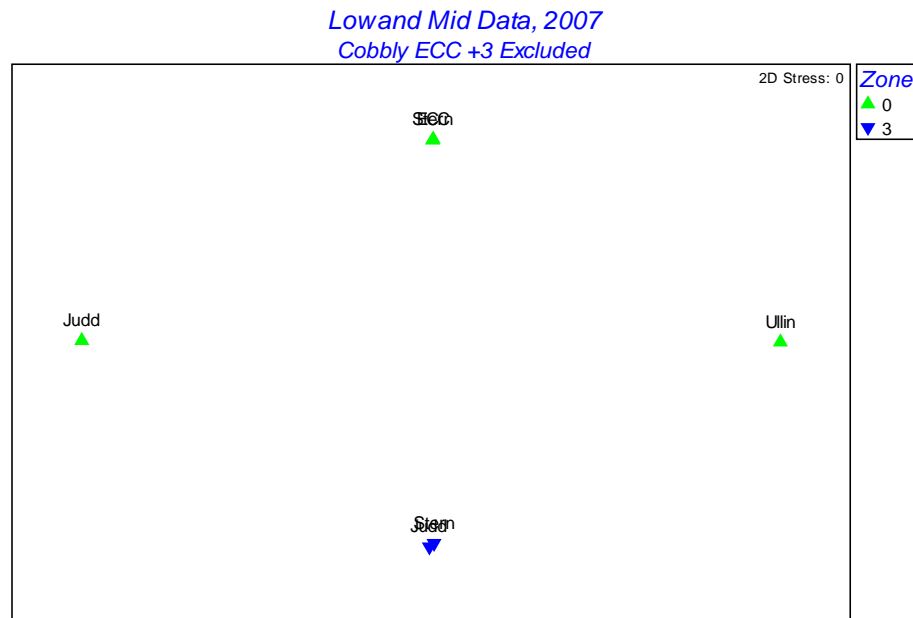


Figure 5. MDS plot of 2007 data from the two zones where infauna and epibiota were fully sampled.

Figure 6 includes the 2007 data but adds comparable data from other sample periods when infauna were quantified. This analysis uses simply presence/absence data, because comparing abundances between 2007 and historic samples, which used different core sizes and sample numbers, was impossible. The figure suggests a substantial separation in community composition among years; the years appear as more dissimilar (points farther apart) than the sites or tidal levels (given as numbers after each site name). Figure 7 similarly suggests that species richness (all infauna and epibiota) increased at all sites and heights from the 1990s to 2007. However, these apparent differences among years are probably a sample size artifact, as discussed below.

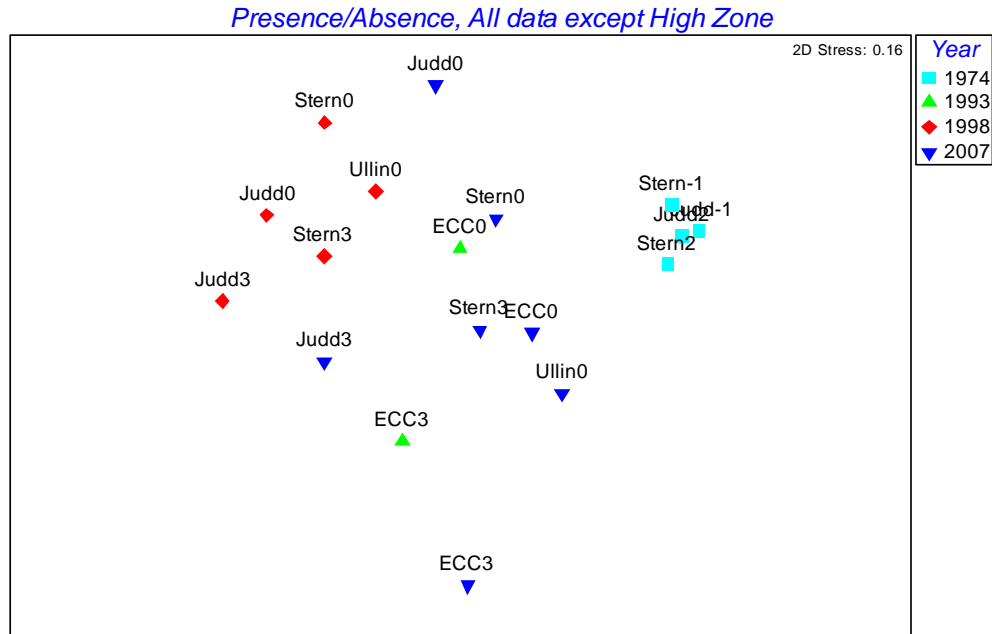


Figure 6. MDS of all ‘comparable’ datasets from all years (ie., excluding Rawson data and tidal heights without infaunal data)

Appendix 3, as well as Fig. 7, suggest that there were more species found in 1974 and 2007 than in 1993 or 1998. Because numbers of species tend to increase with numbers of samples, we analyzed ‘species accumulation curves’ for the 2007 data, which examine the numbers of species found per sample and extrapolate curves of cumulative species richness based on many permutations of these real data (analyses done in Primer 6). Figure 8 shows examples from two transects (one with greater diversity than the other); they show that an N = 4 samples (as in the 1993 and 1998 datasets) will contain only a subset of the species found in 10 samples; the smaller sample sizes are less likely to encounter many of the uncommon polychaete worm species that make up most of the species richness in these habitats. In the 2007 data, 4 samples captured only 68-86% of the species richness of 10 samples at these sites.

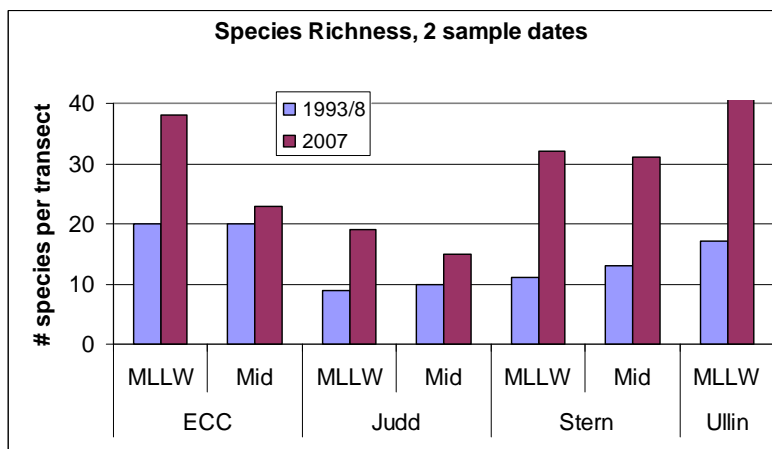


Figure 7. Number of species (infauna and epibiota) found per transect at each of two tidal levels on two sampling dates.

Likewise, it is not surprising that the N = 24-40 samples in the 1974 database contained more species than were found on other dates, especially because those samples included many months of the year not surveyed on the later dates. Of the 19 species found only in 1974 (Appendix 3), six were small spionid polychaetes (which tend to be present in small numbers and are hard to identify) and six were amphipods, which are probably undersampled in the SCALE sampling because of their high mobility. In short, it is unlikely that there has been a real decline in richness since the 1974 samples, rather the differences seen are sampling artifacts.

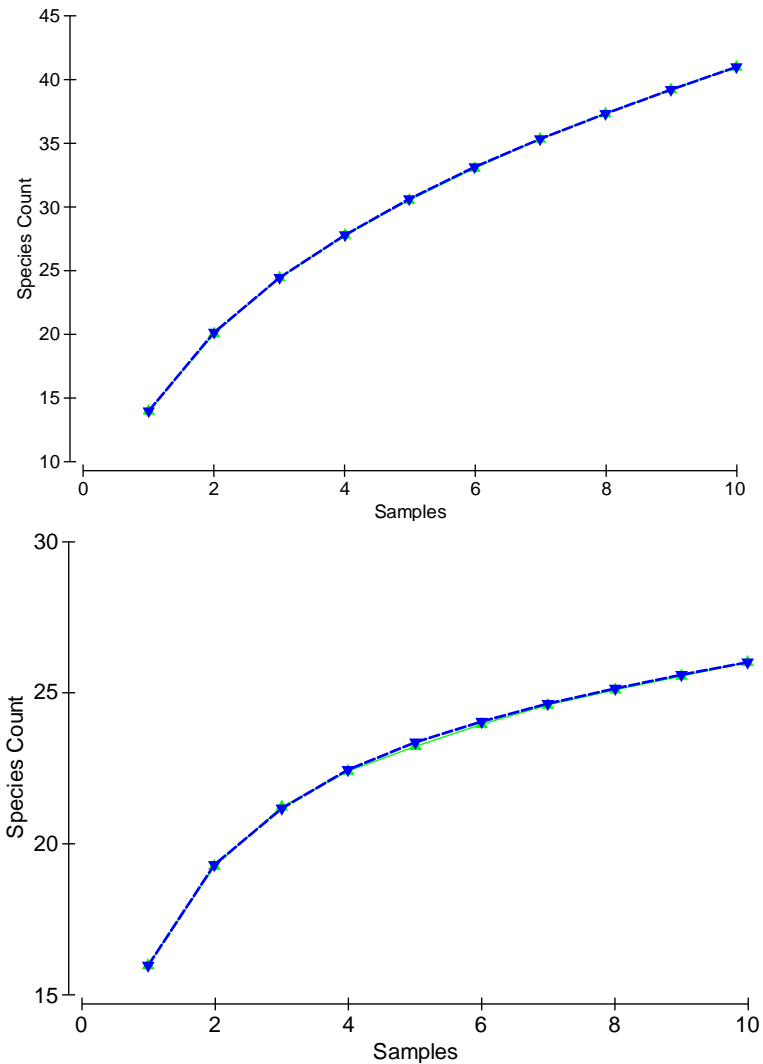


Figure 8. Species-accumulation curves at ECC Low (upper panel) and the less-diverse ECC Mid (lower panel).

Appendix 3 shows that virtually all the species found in the 1990s were also found in 2007; this alone suggests that there has not been a major change in the intertidal communities over the same time period as the loss in eelgrass. Appendix 4 shows the species that were found in samples

both before and after the eelgrass die-off (i.e. in 2007 and either 1993 or 1998 or both). The length and diversity of this list suggests a broad level of community similarity before and after the eelgrass die-off. It includes primary producers and all kinds of consumers, mobile and sessile species, and surface and infaunal species. If shoreline communities were affected by whatever physical or biological process caused the loss of eelgrass, we would have expected either a clear loss in species since the 1990s, or perhaps a dramatic change in the types of species present; neither of these changes was observed.

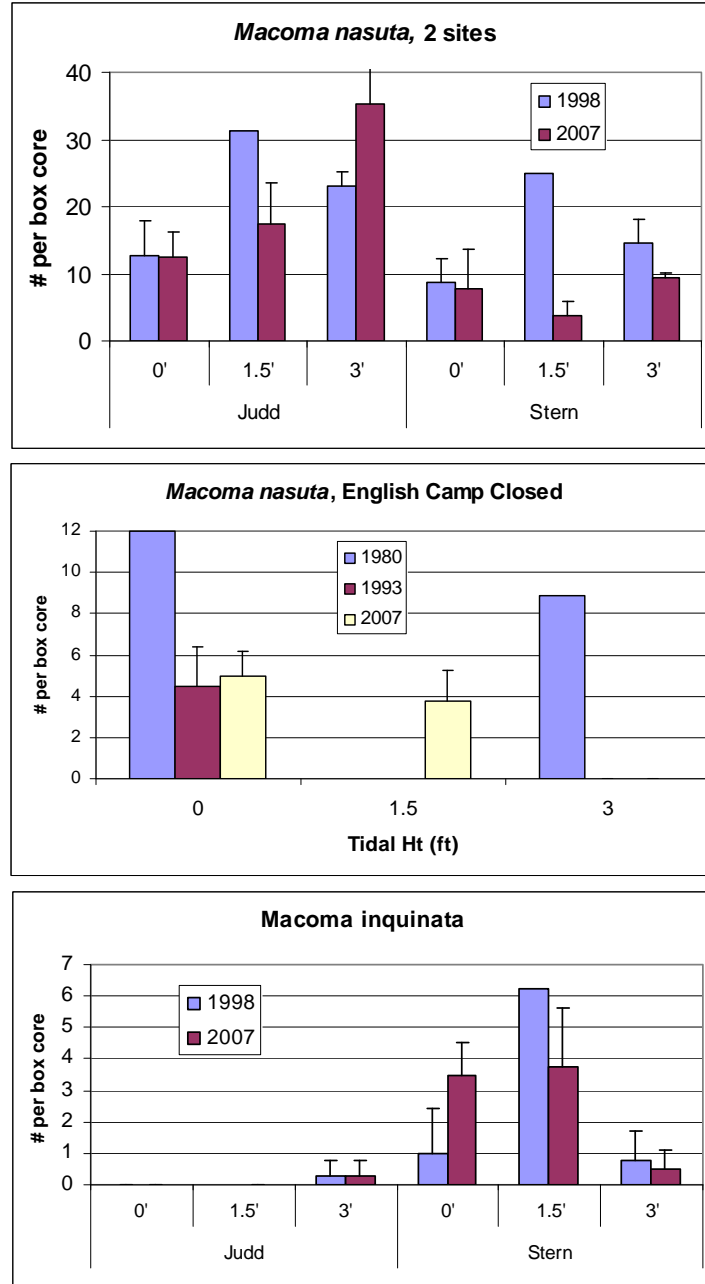


Figure 9. Densities (per box core) of two *Macoma* species at the sites where they were common.

The data collected over time on abundance and size distributions of clams do not suffer from many of the sampling artifacts seen with the other infauna, since sample sizes and volumes have remained similar since the 1990s. Our detailed clam data at the four sites sampled in 2007 show virtually no changes from the 1990s. At most sites and tidal levels, clam species, densities and size distributions (i.e. proportions in different size classes) are very similar to the older data. Data are shown by species, site, and tidal height. For some species we show data from 3 tidal heights (MLLW, +1.5', 3'); for comparing with previous years, however, the data from +1.5' height only comprise 2 box cores for 1998, so no error bars can be shown.

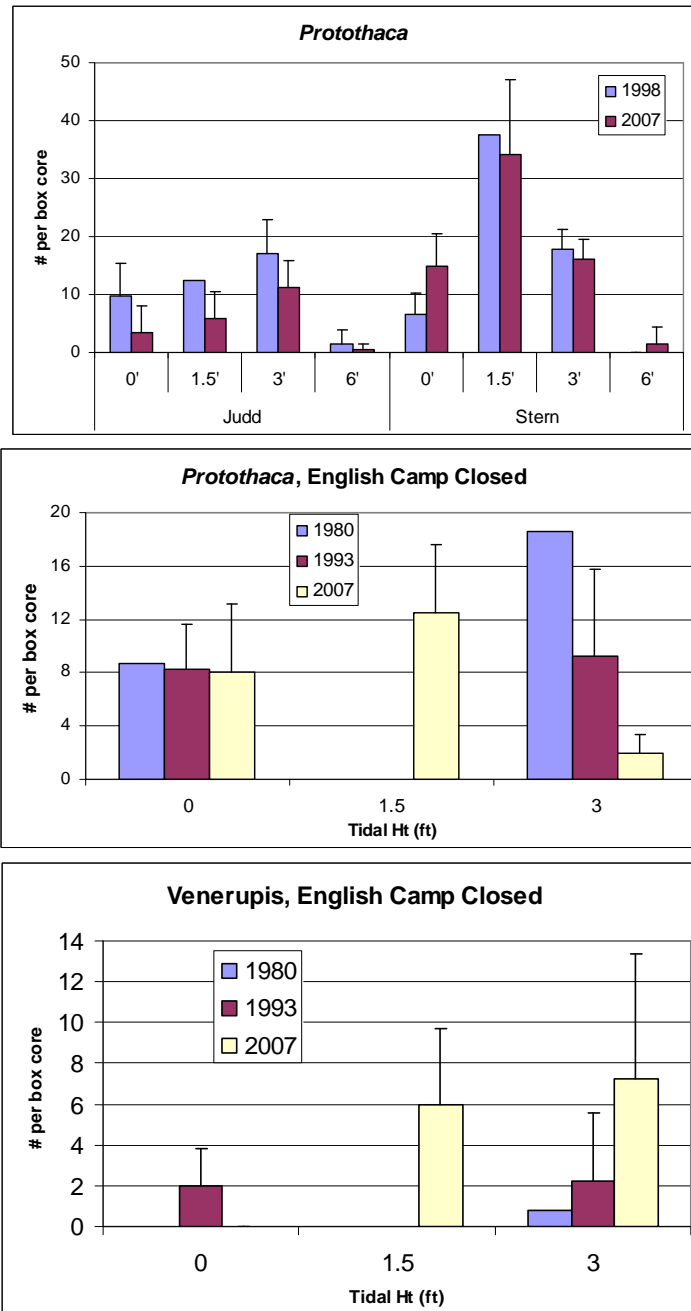


Figure 10. Numbers of native and Japanese littleneck clams at three sites over time.

Bentnose clams, *Macoma nasuta*, were especially abundant at the muddier sites in inner Westcott Bay. The data for the Judd and Stern sites show large numbers of clams, with densities quite consistent between 1998 and 2007 (Fig. 9). This species is less abundant at English Camp (Fig. 9); for this site, we also show data from Rawson (1980). His samples were from slightly different sites and heights, however, and thus may not be directly comparable. Densities of *Macoma inquinata* (Fig. 9) are much lower and somewhat more variable with time, but clearly have not suffered major declines.

Densities of the native littleneck clam, *Protothaca staminea*, were also very consistent among years, both in terms of the sites and tidal heights as well as absolute densities. The only data that suggest a change was the apparent decline from 1993 to 2007 in *Protothaca* at +3' at English Camp (Fig. 10). There is a corresponding increase over that period in that location of the Japanese littleneck, *Venerupis* (Fig. 10). This could be an actual switch among these competing species, or could be a result of misidentifications in one or the other year, because these two taxa are very hard to differentiate (without destructive sampling).

Densities of other clams (the butter clam *Saxidomus*, the cockle *Clinocardium*, and the softshell clam *Mya*) were always low but showed no clear change over time. *Mya* densities are shown in Figure 11; it is one of only two species (the other is *Nuttallia*) that is more common higher on the shore. The introduced varnish clam *Nuttallia* was found in small numbers in the higher zones at the Ullin site, where it had not been noted previously.

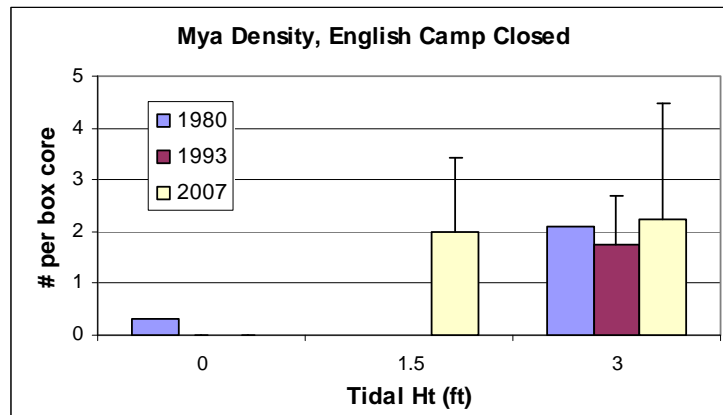


Figure 11. Densities of softshell clams, *Mya arenaria* at ECC, from three years.

The relative consistency of clam densities among years can also be seen in Figure 12, which shows the mean of the total (summed) densities of clams for each box core through time for both the Low and Mid zones. While there is certainly variation among years, in no case is there a dramatic increase or decrease between the pre-eelgrass-decline years (1980-1998) and the post-decline 2007 sampling.

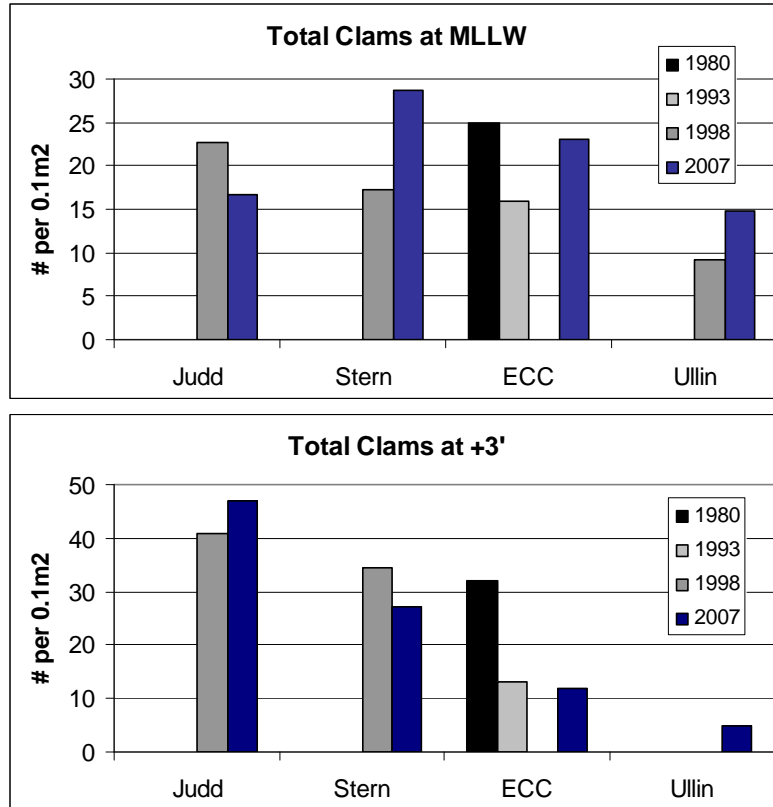


Figure 12. Summed clam densities at all sites and all years with available data.

Clam sizes also generally consistent among sample years and sites, with a broad range of sizes present for most species (Figs. 13-18). Broad size ranges are a sign of a regularly recruiting population, and the presence of larger individuals is probably indicative that they have been in the beach since before the eelgrass die-off, although we do not have direct data on growth rates of these species locally. For English Camp, the almost identical size distributions of two species (*Protothaca*, Fig. 13 and *Macoma nasuta*, Fig. 18) since Rawson (1980) is strong evidence of stability.

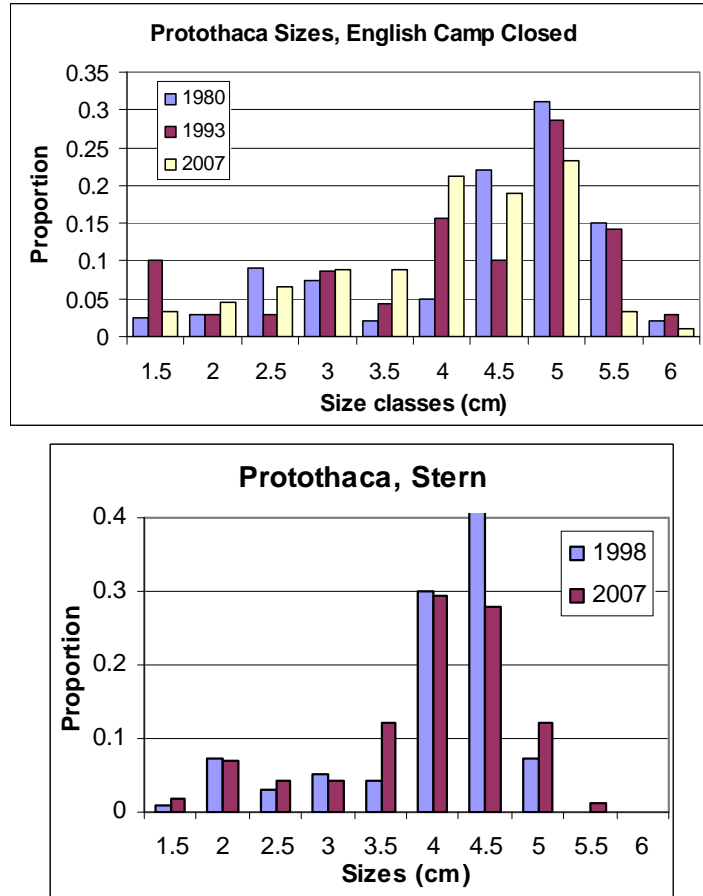


Figure 13. Sizes of littleneck clams at two-three sites in 2-3 years.

The only exception to the consistent size distribution among years was an intriguing pattern of sizes of *Protothaca* at Judd (most protected site), where no small individuals were found in the box cores in 2007 (Fig. 14). Sample sizes were large for each year ($N > 80$ both years), so this is unlikely to be a sampling artifact.

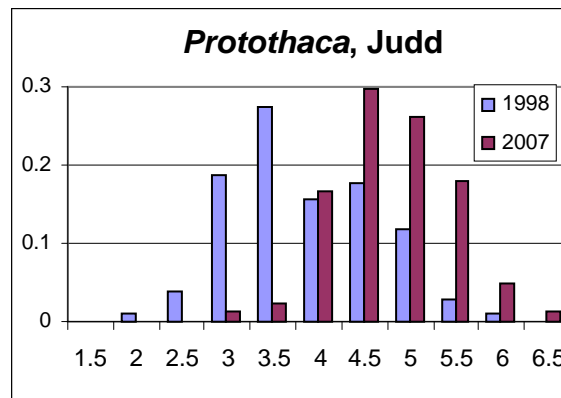


Figure 14. Sizes of littleneck clams at Judd, the most protected site.

Juvenile (<1 cm) *Protothaca* were found in 2007 at the other sites (Figure 15), illustrating the striking absence of small littleneck clams at Judd. These data suggest a recruitment failure for this species at this site in 2007 (and probably 2006, given the absence of clams <3 cm) but not in other sites or years.

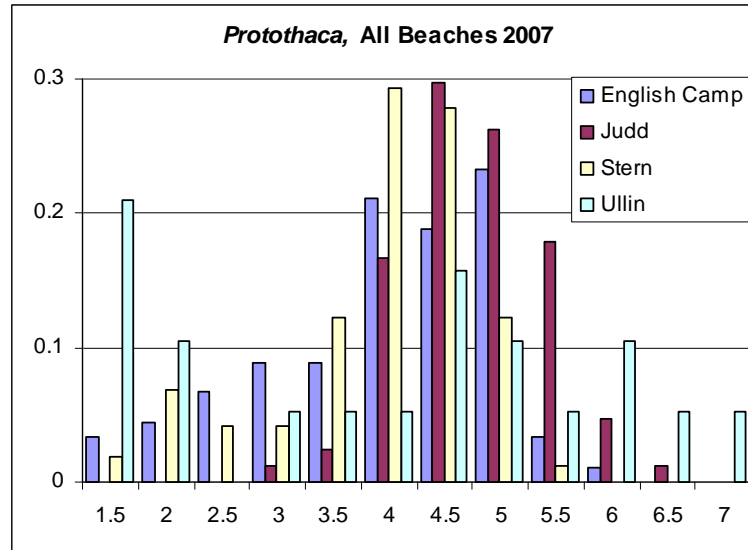


Figure 15. Sizes of littleneck clams at all four sites sampled in 2007.

Judd is the most protected of the four sites sampled in 2007, and the muddiest. Juvenile *Protothaca* prefer and/or survive better when there is gravel or cobble on the sediment surface, probably because it is harder for predators to get them. Judd has no such surface gravel (Fig. 16), but there is no indication that this factor has changed thru time; the field notes from 1998, when there was good recruitment, similarly indicated the substrate was just sand/mud and shell. Collectively these data suggest that 2006/7 may simply have been a poor year for recruitment for this species at this site. Such a localized issue does not suggest any connection to the broad eelgrass loss.

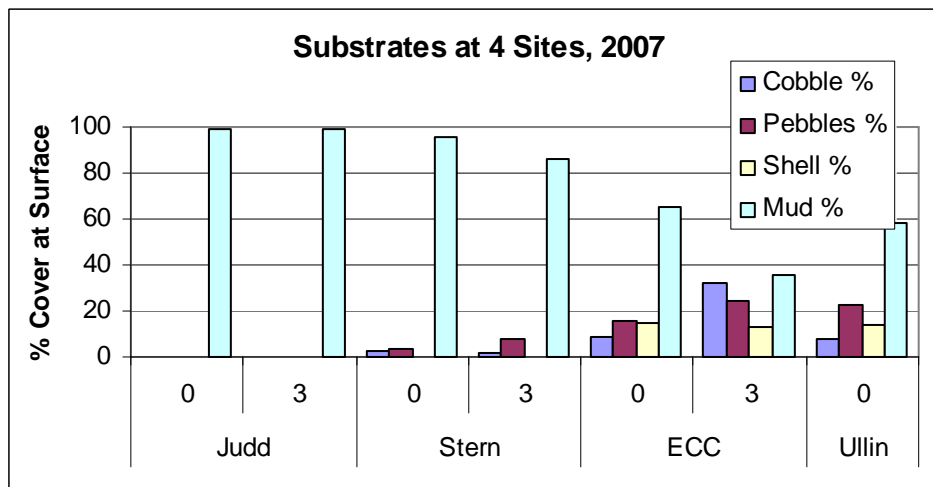


Figure 16. Amount of different substrate types seen in surface quadrats at 2 tidal levels (0 and +3 feet, MLLW) in 2007.

The only other anomalous patterns to appear in the clam size data were odd size distributions in 2007 of *Macoma inquinata* at the three sites where it is present. The Ullin site had a large number of small clams, while the Stern site had mostly large clams (Fig. 17). The Ullin site also had large numbers of small *Protothaca*; it may be that this site, near the mouth of the bay, receives many larvae and is appropriate for settlement and early survival of clams. English Camp has few large *M. inquinata*; this muddy site may be less appropriate for survival of this species.

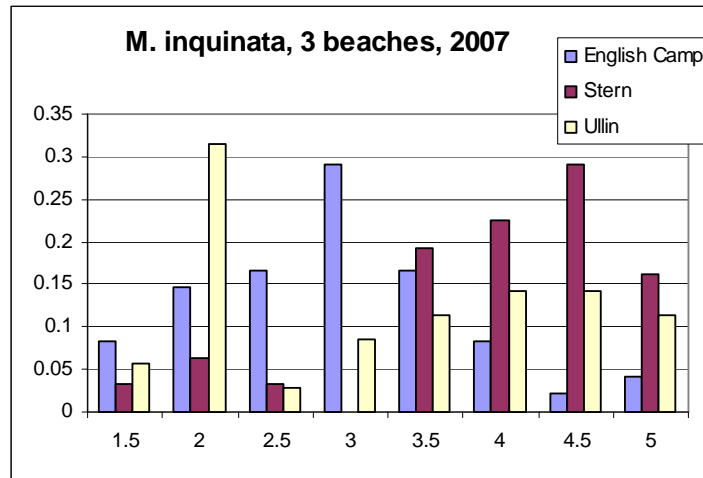


Figure 17. Sizes of *Macoma inquinata* in 2007 at the 3 sites where it was common. N for each site >30.

Bentnose clam size distributions were very consistent among years (including with 1980) at the three sites where it was common (this species prefers finer muds and was uncommon at the coarser Ullin site) (Fig. 18).

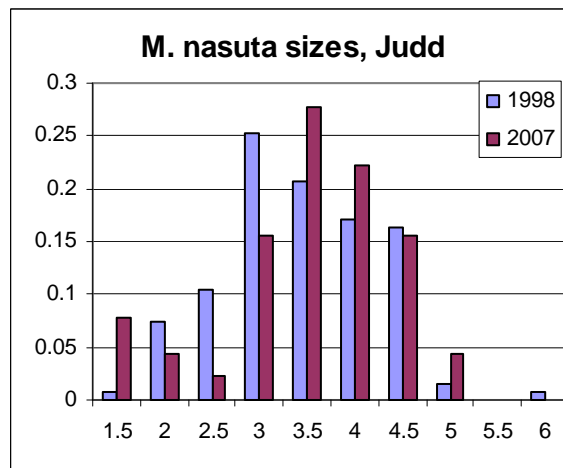
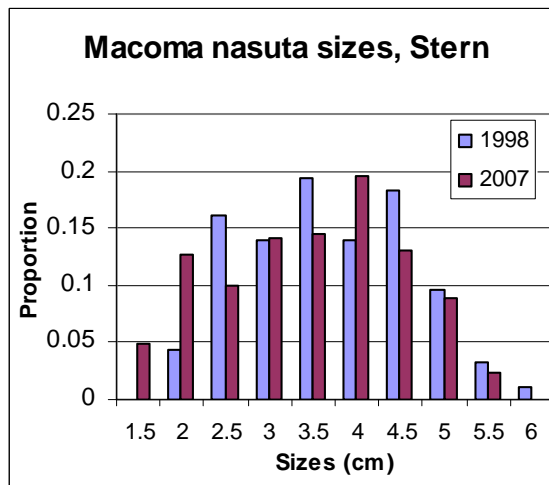
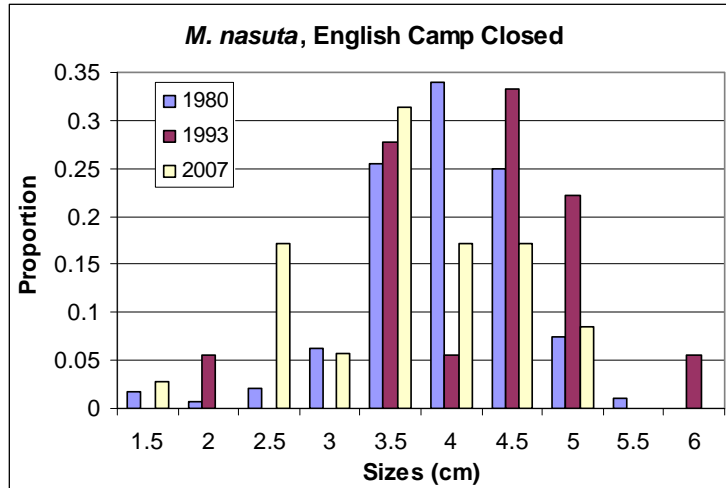


Figure 18. Sizes of *Macoma nasuta* at three sites over 2-3 years.

CONCLUSION

The data collected in 2007 suggest that the eelgrass loss in the early part of this decade was not indicative of a broader change in Westcott and Garrison Bays. It appears that some factor differentially impacted the eelgrass and not other nearshore communities. While this question is still under investigation, our study helps rule out some potential causes of eelgrass decline. For example, a significant change in type of sediment (e.g. a large influx of fine muds) into the bays should have caused a change in the biota in the beaches we studied (in both clams and other infauna, all of which have distinct sediment-preferences; Dethier and Schoch 2005). A large-scale change in temperature or salinity should similarly have affected the beach communities, although it is possible that they could have survived a short-term extreme event (because of the buffering effects of living in the mud) that eelgrass could not. It may be more likely that the eelgrass was affected by processes that would be especially stressful to a lower intertidal and subtidal plant, such as reduction of water clarity or change in water column nutrients, or an interaction of stressors such as increased water temperature and turbidity.

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APPENDIX 1. Data from 2007 Resurvey of 1998 Eelgrass Transects in Westcott Bay. All locations were surveyed on August 9, 2007.

Time (PDT)	Seg #	Eelgrass present (y/n)	Pred. tidal height (ft)	Bed Location (m)				Secchi Depth (m)		Density			Patchy	Substrate Description
				beg dist (m)	end dist (m)	bed width (m)	max depth (m)	visibility at deep edge of eelgrass bed	visibility at sites without eelgrass	near	mid	off		
6:28	9	n	-0.3						1.7					anoxic, fine silty mud. Coats rake.
6:47	8	n	-0.6						1.6					anoxic, fine silty mud. Coats rake.
6:56	7	n	-0.7						1.6					anoxic, fine silty mud. Coats rake.
7:01	6	n	-0.8						1.7					anoxic, fine silty mud. Coats rake.
7:10	5	n	-1						1.6					anoxic, fine silty mud. Coats rake. Less silty - not as smooth.
7:19	4	n	-1.1						1.7					anoxic, fine silty mud. Coats rake.
7:29	3	n	-1.2						1.8					anoxic, fine silty mud. More sand patches. Sill coats rake.
7:38	2	n	-1.3						1.9					anoxic, fine silty mud. More sand patches. Sill coats rake.
7:43	1	n	-1.3						1.8					sandy mud. Not anoxic.
8:02	11	n	-1.3						1.85					sandy mud. Not anoxic.
8:17	12	n	-1.4						2					anoxic, fine silty mud.
8:28	13	n	-1.4						0.54					anoxic, fine silty mud.
8:32	14	n	-1.4						0.54					anoxic, fine silty mud.
8:40	15	n	-1.4						0.84					anoxic, fine silty mud.
8:42	16	n	-1.4						0.95					anoxic, fine silty mud.
8:48	17	n	-1.3						2					anoxic, fine silty mud.
9:06	18	n	-1.3						2.5					muddy sand. Not anoxic.
9:20	19	y	-1.1	15	23.2	8.2	1.36	1.36		sparse	sparse	sparse	n	sandy mud - not anoxic.
9:41	20	n	-0.8						1.85					medium coarse sandy mud
10:04	21	y	-0.5	5	25	20	4.6	4.6		dense	moderate	sparse	y	coarse sand with pebbles and cobbles
10:16	22	n	-0.2						1.7					sandy mud, slight anoxia smell.
10:26	23	n	-0.1						1.7					sandy mud. Not anoxic.
10:29	24	n	0						1.8					sandy mud. Anoxic.
10:42	10	n	0.2						1.5					sandy mud. Slightly anoxic.

APPENDIX 2. Species found in 2007 (mean per zone of either percent cover or count).

Site Zone (ft MLLW)	ECC		Judd			Stern			Ullin		Ullin Rocky
	0	3	0	3	6	0	3	6	0	3	6
Abarenicola sp.	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Acrosiphonia spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0
Americorophium salmonis	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphicteis mucronata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Amphipholis squamata	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Aphelochaeta multifilis	0.2	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Armandia brevis	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Axiothella rubrocincta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0
Bittium eschrichtii	1.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Capitella capitata	0.1	0.0	0.7	0.2	0.0	0.3	0.1	0.0	0.3	0.0	0.0
Clinocardium nuttallii	0.3	0.0	0.4	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.0
Cobble percentage	9.0	32.0	0.0	0.0	0.0	2.5	1.5	9.0	7.5	0.0	0.0
Crassostrea gigas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	2.5	8.8
Dead barnacles (Class Cirripedia)	0.4	2.2	0.0	0.0	1.8	0.0	1.1	1.0	0.9	12.5	10.0
Diatoms, chain-forming	4.6	4.0	0.8	22.0	99.0	0.0	22.0	0.0	4.6	0.0	0.0
Dorvillea annulata	10.4	0.0	0.0	0.0	0.0	9.1	2.4	0.0	0.4	0.0	0.0
Endocladia muricata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	0.0	0.8	1.5
Eogammarus confervicolus	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eteone californica	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Eteone tuberculata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Eulalia spp.	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Fleshy crust	0.0	0.5	0.0	0.0	0.2	0.0	0.0	1.8	0.4	25.0	12.5
Fucus gardneri	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.2	0.7	27.5	41.3
Fucus spiralis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	2.5
Gammarid amphipods	2.0	4.7	0.0	0.0	7.6	0.0	0.0	13.0	0.7	0.0	0.0
Glycinde picta	0.6	0.1	1.6	1.9	0.0	2.7	0.2	0.0	0.5	0.0	0.0
Haliplanella lineata	0.0	0.7	0.0	0.0	0.2	0.2	0.1	0.6	0.0	0.0	0.0
Haminoea vesicula	0.1	0.0	0.1	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Harmothoe imbricata	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemigrapsus oregonensis	0.1	3.8	0.0	0.1	0.2	0.0	0.0	0.0	1.1	0.0	0.0
Hesionid sp. (unident.)	5.7	0.0	0.5	0.0	0.0	7.9	1.4	0.0	6.4	0.0	0.0
Idotea sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
Lacuna vincta	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Leitoscoloplos pugettensis	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.1	0.0	0.0
Lepidochitona dentiens	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Lirularia sp.	0.1	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.2	0.0	0.0
Littorina sp.	0.0	67.5	0.0	0.0	3.0	0.0	0.0	142.0	0.0	4.0	55.0
Live barnacles (Class Cirripedia)	0.4	10.0	0.0	0.1	2.6	0.1	0.3	9.0	0.3	50.0	35.0
Lottid limpets	0.8	53.8	0.0	0.0	0.4	0.0	0.8	0.6	0.1	125.0	61.3
Lumbrineris zonata	1.2	0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.2	0.0	0.0
Macoma inquinata	0.4	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.3	0.0	0.0
Macoma inquinata juveniles	0.2	0.1	0.0	0.0	0.0	0.1	0.0	0.0	1.3	0.0	0.0
Macoma nasuta	0.1	0.0	1.1	3.3	0.0	0.5	1.1	0.0	0.0	0.0	0.0
Macoma nasuta juv.	0.5	0.0	2.5	3.2	0.0	2.1	1.9	0.0	1.0	0.0	0.0
Macoma secta	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malacoceros glutaeus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0
Mastocarpus sp.	0.0	0.1	0.0	0.0	0.0	0.0	0.0	4.2	0.6	3.0	4.0
Mediomastus californiensis	0.7	0.0	2.0	21.2	0.0	5.8	31.6	0.0	68.2	0.0	0.0
Melanochlamys diomedea	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0

APPENDIX 2 (Continued).

Site	ECC		Judd			Stern			Ullin		Ullin Rocky
	0	3	0	3	6	0	3	6	0	3	6
Monocorophium spp.	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Mud Percentage	0.0	0.0	99.0	99.0	0.0	95.4	91.4	15.0	0.0	0.0	0.0
Mya arenaria	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Mya arenaria juveniles	0.0	0.8	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Mysella tumida	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Mytilus trossulus	0.0	1.3	0.0	0.0	0.0	0.0	0.1	1.6	0.0	0.8	0.5
Nemertean (unident.)	0.0	0.0	0.1	0.0	0.0	0.2	0.2	0.4	0.0	0.0	0.0
Nereis brandti	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.0
Nereis vexillosa	0.0	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.0
Notomastus tenuis	0.1	0.0	0.0	0.4	0.0	0.1	0.3	0.0	3.9	0.0	0.0
Nucella lamellosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Pagurus spp.	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0
Pebble percentage	16.0	24.0	0.0	0.0	24.0	3.3	7.6	85.0	23.0	0.0	0.0
Pectinaria granulata	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Petalonia fascia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Pinnotherid sp. (unident.)	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0
Platynereis bicanaliculata	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0
Podarke pugettensis	0.2	0.0	0.0	0.0	0.0	1.7	0.2	0.0	0.3	0.0	0.0
Podarkeopsis glabrus	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polydora cardalia	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polysiphonia sp. (unident.)	0.1	0.0	0.1	0.0	0.0	0.7	0.0	0.0	0.0	0.3	0.0
Porphyra sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	4.0
Prionospio multibranchiata	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Protothaca staminea	0.7	0.0	0.1	0.9	0.0	1.2	1.8	0.0	0.1	0.0	0.0
Protothaca staminea juv.	0.0	0.3	0.0	0.0	0.0	0.3	0.2	0.0	0.2	0.0	0.0
Pseudopolydora kempji japonica	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Salicornia virginica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
Sand percentage	65.0	36.0	0.0	0.0	74.0	0.0	0.0	0.0	58.5	0.0	0.0
Shell percentage	15.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0	0.0	0.0
Stichaeidae	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Syllids (unident.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Tellina modesta	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thelepus crispus	0.5	0.2	0.0	0.0	0.0	0.4	0.2	0.0	0.0	0.0	0.0
Transennella tantilla	0.0	0.3	0.7	0.9	0.0	1.4	2.6	0.0	1.5	0.0	0.0
Tresus capax	0.0	0.0	0.3	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Tubifex spp.	0.1	12.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ulvoids (unident.)	23.9	1.9	1.3	0.5	6.6	5.5	2.2	0.0	23.5	28.8	18.8
Venerupis philippinarum	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 3. Species found in limited sampling dates in Westcott Bay.

Seen in 1993 only

Gnorimosphaeroma oregonense
Naineris dendritica
Phyllodoce maculata

Seen in 1998 only

Euclymene spp.
Lumbrineris inflata
Scoloplos armiger

Species seen in 98 and 07 only

Americorophium salmonis
Crassostrea gigas
Harmothoe imbricata
Lirularia sp.
Macoma inquinata
Macoma sp. (unident.)
Mediomastus californiensis
Nereis brandti
Polysiphonia sp. (unident.)
Pseudopolydora kempii japonica

Seen in 2007 only

Infauna

Acrosiphonia spp.
Amphicteis mucronata
Amphipholis squamata
Axiothella rubrocincta
Capitella capitata
Endocladia muricata
Eogammarus oclairi
Eteone tuberculata
Eulalia spp.
Idotea sp.

Leitoscoloplos pugettensis
Malacoceros glutaeus
Macoma secta
Monocorophium sp.
Mysella tumida
Nereis vexillosa
Pectinaria granulata
Platynereis bicanaliculata
Podarkeopsis glabrus
Prionospio multibranchiata
Syllids (unident.)
Tellina modesta
Tresus capax

Species seen in 93 and one or both other years

Infauna

Aphelochaeta multifilis
Armandia brevis
Bittium
Clinocardium nuttallii
Dorvillea annulata
Eteone californica
Gammarid amphipods
Glycinde picta
Haliplanella lineata
Hesionid sp. (unident.)
Live barnacles (Class Cirripedia)
Lottid limpets
Lumbrineris zonata

Surface Organisms

Fleshy crust
Fucus gardneri
Haminoea vesicula
Hemigrapsus oregonensis
Lacuna spp.
Lepidochitona dentiens
Littorina sp.
Mastocarpus sp.
Melanochlamys diomedea
Nucella lamellosa
Petalonia fascia
Porphyra sp.
Stichaeidae (gunnels and pricklebacks)

APPENDIX 3. Continued

Species seen in 93 and one or both other years

Infauna (con't)

Macoma nasuta
 Mya arenaria
 Mytilus trossulus
 Nemertean (unident.)
 Notomastus tenuis
 Pagurus spp.
 Podarke pugettensis
 Polydora cardalia
 Protothaca staminea
 Thelepus crispus
 Transennella tantilla
 Ulvoids (unident.)
 Venerupis philippinarum

Surface Organisms (con't)

"Additions" that simply weren't recorded in earlier years:

Dead barnacles (Class Cirripedi)
 Diatoms, chain-forming
 Macoma inquinata juveniles
 Macoma nasuta juv.
 Mud Percentage
 Mya arenaria juveniles
 Pebble percentage
 Pinnotherid sp. (unident.)
 Protothaca staminea juv.
 Shell percentage
 tubificid oligochaetes

Species found in samples from 1974 only (Nyblade study)

Out of 19 species, 6 are amphipods, 6 are small spionids, 7 are other polychaetes

Aoroides ?columbiae	amphipods	
Calliopius spp.	amphipods	
Eobrolgus chumashi	amphipods	
Orchestia georgiana	amphipods	
Allorchestes angusta	amphipods	
Anisogammarus pugettensis	amphipods	
Pilargis berkeleyae	polychaetes	few
Pista brevibranchiata	polychaetes	some, very low shore
Polydora proboscidea	polychaetes	few
Polydora quadrilobata	polychaetes	some
Polydora socialis	polychaetes	some
Pygospio elegans	polychaetes	some
Spio filicornis	polychaetes	very few
Boccardiella hamata	polychaetes	very few
Cirratulus multioculatus	polychaetes	few
Goniada annulata	polychaetes	very few
Nereis procera	polychaetes	few
Owenia fusiformis	polychaetes	some
Pholoe minuta	polychaetes	very few

Appendix 4. Species seen both before and after the eelgrass die-off

Group	Taxa
Algae	Ulvoids Polysiphonia sp.
Amphipods	Gammarid amphipods (various spp)
Anemone	Haliplanella lineata
Barnacles	Live barnacles (Class Cirripedia)
Clams	Clinocardium nuttallii Macoma nasuta Mya arenaria Protothaca staminea Transennella tantilla Venerupis philippinarum Macoma inquinata
Mussel	Mytilus trossulus
Snails	Bittium Lirularia sp.
Limpets	Lottid limpets
Hermits	Pagurus spp.
Polychaetes	Aphelochaeta multifilis Armandia brevis Dorvillea annulata Eteone californica Glycinde picta Harmothoe imbricata Hesionid sp. (unident.) Lumbrineris zonata Mediomastus californiensis Nereis brandti Notomastus tenuis Podarke pugettensis