1997 Conclusions Summary

The conclusions of the 1997 Carr Inlet pilot project are summarized as follows:

1. Our work in Carr Inlet constitutes the first significant test of a model to quantify the relationship between geophysical features and biota, and to extrapolation with reasonable accuracy what organisms (and in what abundances) should be found in beaches in Carr Inlet that were not sampled.

2. Any attempt to scale up biotic data (whether from a beach to the inlet, or from the inlet to the Sound) will involve adding new sources of variation. At some point in this scaling process, the communities in 'similar' beaches are likely to become so different (e.g., as one moves into a different oceanic mixing regime or biogeographic province) that comparisons are not meaningful.

3. Future decisions about monitoring programs need to be question-driven, with the questions specifying the scale of resolution needed (and thus the scale of variation that must be accepted). Regions, habitat types, and species of particular concern need to be identified by the potential users of monitoring programs.

4. We recommend that an effort be made to obtain maps of the whole Sound generated by the Harper methodology, and that these be used as a basis for choosing regions and substrate types for further research.

5. Reference sites need to be chosen on a finer spatial scale, and should be matched geophysically, either with each other or with degraded sites under study. Concentrating research in the low intertidal zone may provide the most information per unit cost in terms of the biota at this level being diverse, productive, and vulnerable to stressors from land and sea. Sampling methodologies need to be consistent among sites, and must include large enough sample sizes to deal with the high natural spatial variability within a site.

6. In contrast with other, lower-resolution shoreline mapping methods, potential applications of the SCALE methodology and resulting maps include: 1) selecting matched sites for field research or applied monitoring programs; 2) denoting sensitive habitats, e.g. to oil spills; 3) predicting resource-rich habitats, or those where key resource species could exist; 4) assessing biotic damage following unnatural events; 5) choosing areas for conservation efforts; and 6) improving change detection by choosing sites where much of the environmental variation has been factored out.

7. More field work is needed to determine how much variability in biota is added at increasingly large spatial scales and over different temporal scales.

The strong nearshore cell gradients in Carr Inlet are caused by the rapid shallowing of the bathymetry, the discharge of fresh water from rivers, and the protection from wave energy by a highly convoluted shoreline. This resulted in no replicate cells within the bay and the relatively large observed differences in community structure among the nearshore cell biota even when the beaches were otherwise similar. Case Inlet (immediately adjacent to and west of Carr Inlet) appeared physically similar to Carr Inlet in configuration and orientation and was likely to contain similar nearshore cells and beach segments. Case Inlet had potential for testing how well community structure can be extrapolated among similar beaches in similar nearshore cells. We hypothesized that replicate beaches in nearshore cells with the same water properties are more similar than replicate beaches in nearshore cells with different water properties.

1998 SOUTH PUGET SOUND PILOT PROJECT

This project examined the spatial and temporal variability of shoreline biota in Southern Puget Sound using the SCALE model. The project objectives were:

1. To measure natural variation in biota over 2 years in Carr Inlet.

2. To examine spatial variability in shoreline biota in South Puget Sound through comparing results in Carr Inlet to areas in Case Inlet and Budd Inlet

3. To test how well the SCALE model predicts biotic community structure within small areas and over larger areas.

4. Project results will also be used to assess how the SCALE model fulfills needs to characterize habitat quality over space and time.

Methods

Identifying nearshore cells

The general methods described above pertaining to the quantification of nearshore cells in Carr Inlet were applied to Case and Budd Inlets in South Puget Sound. We determined which areas to sample by first identifying nearshore cells quantitatively and partitioning the alongshore into approximate salinity increments of 2 ppt and temperature increments of 2°C.

Beach selection

To test the annual variability of community structure on the same Carr Inlet beach segments one year later, we first assessed whether quantifiable differences in physical condition had occurred over the winter by applying the same physical assessment protocols as in 1997. To test the validity of our model predictions within a group of similar beaches, we randomly selected several new Carr Inlet beach segments of each shoretype from the respective cluster groups. To test how well we can spatially extrapolate the biota found in Carr Inlet to geophysically similar beaches in similar nearshore cells in a nearby basin, we selected new mud, sand, and pebble sample sites in Case Inlet and in Budd Inlet. To minimize costs we did not map the nearshore beaches of Case or Budd Inlets, opting instead to qualitatively survey these shorelines for specific beach types similar to those sampled in Carr Inlet. Once a similar beach was found we quantified the physical conditions to ensure physical similarity with those in Carr Inlet

Biological sampling

Epiflora and fauna, and infauna abundances were sampled during the spring low tides of May 25 - 29, June 8-13, and June 21-27, 1998. We followed the same sampling protocols used in 1997. Data were taken at the 3 sand, 3 mud and 3 pebble beach segments in Carr, Case, and Budd Inlets. The cobble beaches in Carr Inlet were also resampled.

The sampling design had three nested spatial scales for each shore type; samples within segments (10's of meters apart); segments within a cells (kilometers apart), and cells within South Puget Sound (10's of kilometers apart). The design was balanced so that the number of samples were the same for each of the segments (10), and the same number of segments for each of the cells (3), and the number of cells compared across the South Sound for each habitat type (3). If the biota in these habitats are tightly tied to the quantified geophysical features, we hypothesized that communities should be relatively similar within cells, communities should not be similar among cells with different water properties, and should be similar among cells with similar water properties.

Statistical analysis

Multivariate analyses were used to detect patterns in the distribution of communities of macrofauna and macroflora. The methods of Clark (1993) and PRIMER software (Primer, 1997), including the subroutines MDS, SIMPER, and ANOSIM were used. Prior to analysis, the very rare taxa (frequencies <5%) were removed to reduce the zero rich nature of the data matrix, thus improving the reliability of the results (McCune and Mefford, 1997). This caused a matrix reduction of 48% for mud, 37% for sand, 40% for pebble, and 47% for cobble beaches. The indicator value of Dufrene and Legendre (1997) was calculated for each taxon (based on ten replicates per beach segment). This summation to each beach still allows variation within bays and within nearshore cells to be estimated and used in comparison among each of these spatial scales. A fourth root transformation was applied to the indicator values so that analysis considered both high and low indicators, a matrix of Bray-Curtis similarities was generated, and the technique of non-metric multidimensional scaling (MDS) was used on the matrix. Similarity percentage analyses (SIMPER) were used to identify the taxa contributing most to average similarity within groups. Analyses of similarity (ANOSIM) tested the significance of any apparent differences among spatial scales.

Multivariate analyses were used to evaluate the variation of abundance at different spatial scales (segments within nearshore cells, and cells within bays) for each population in the low zone. The sampling design was spatially nested and the samples were considered random, therefore the abundance data for individual taxa were analyzed with nested ANOVA (Sokal and Rohlf, 1995). All abundances were fourth root transformed to improve assumptions of normality and homogeneity of variance. ANOVA assumptions of normality of residuals and equality of error terms were determined by visually examining plots of estimated values against residuals.

Results

Identifying nearshore cells

The observed salinity and sea surface temperature (SST) distributions in Carr Inlet at the end of April 1998 were similar to the distributions observed in 1997. This result is based on visual inspection of Figure 7a and 8a, and contours on Figure 9, for both parameters after smoothing of the raw data and a kriging interpolation procedure (Surfer, 1997). The inlet mean SST was 12.1°C, and the mean salinity was 28.5 ppt (Figure 10). During the tidal flood, relatively cold and saline water appears on the surface along the east side of the inlet, while warmer and less saline water was measured along the west shoreline. The salinity gradient in Carr Inlet is small, about 2 ppt along the axis of the inlet, and 1 ppt across the axis. The SST gradient is about 4°C along the axis and 3 degrees across the axis of the inlet. This is consistent with the nearshore cell partitioning done in 1997. The exact location of the west shore split between Cell 1 and 2 is subject to variation in the data. Last year the split was made near Minter Creek, but this year the split could be made closer to Glenn Cove.

The mean SST in Case Inlet was 11.7°C, and the mean salinity was 28.3 ppt. Although the mean temperature and salinity are slightly lower than in Carr Inlet, the ranges are greater and the along axis gradients were much steeper. The temperature range was 3.2 degrees along axis and 1 degree across axis, and the salinity range was 5 ppt along the axis and about 1 ppt across the axis (Figures 7b and 8b). Relative to Carr Inlet, there were lower lows and higher highs for salinity in Case Inlet (Figure 10). Visual inspection of the contour plots for SST and salinity show these strong gradients and a spatial distribution suggesting a minimum of 6 cells to partition Case Inlet shore segments, however only the two cells actually used for this project are shown on Figure 9.

The SST and salinity patterns in Budd Inlet are consistent with those observed in Case and Carr Inlets. Colder and more saline water appears along the west shore during the flooding tide, warmer and less saline water dominates the eastern shore. A strong gradient exists along the axis of the inlet and also across the axis Figures 7c and 8c). The average salinity is 26.0 ppt, with a range from 27.5 at the mouth of the inlet near Boston Harbor, to 22.5 at the head near Olympia. The average SST is 13.5°C, with a range from 15.0 near Olympia to 11.5 near Boston Harbor. There is a minimal gradient in both parameters from the mouth of the inlet to the vicinity of Priest Point, then a very sharp gradient from the vicinity of Priest Point to the head of the inlet. This blocks the inlet into north and south halves. There is a strong across-axis gradient from west to east north of Priest Point decreasing slightly near Boston Harbor. The across-axis gradient is minimal south of Priest Point. But the head of the inlet is split (East Bay and West Bay), creating four cells to partition this inlet although only three were used for this project as shown on Figure 9.

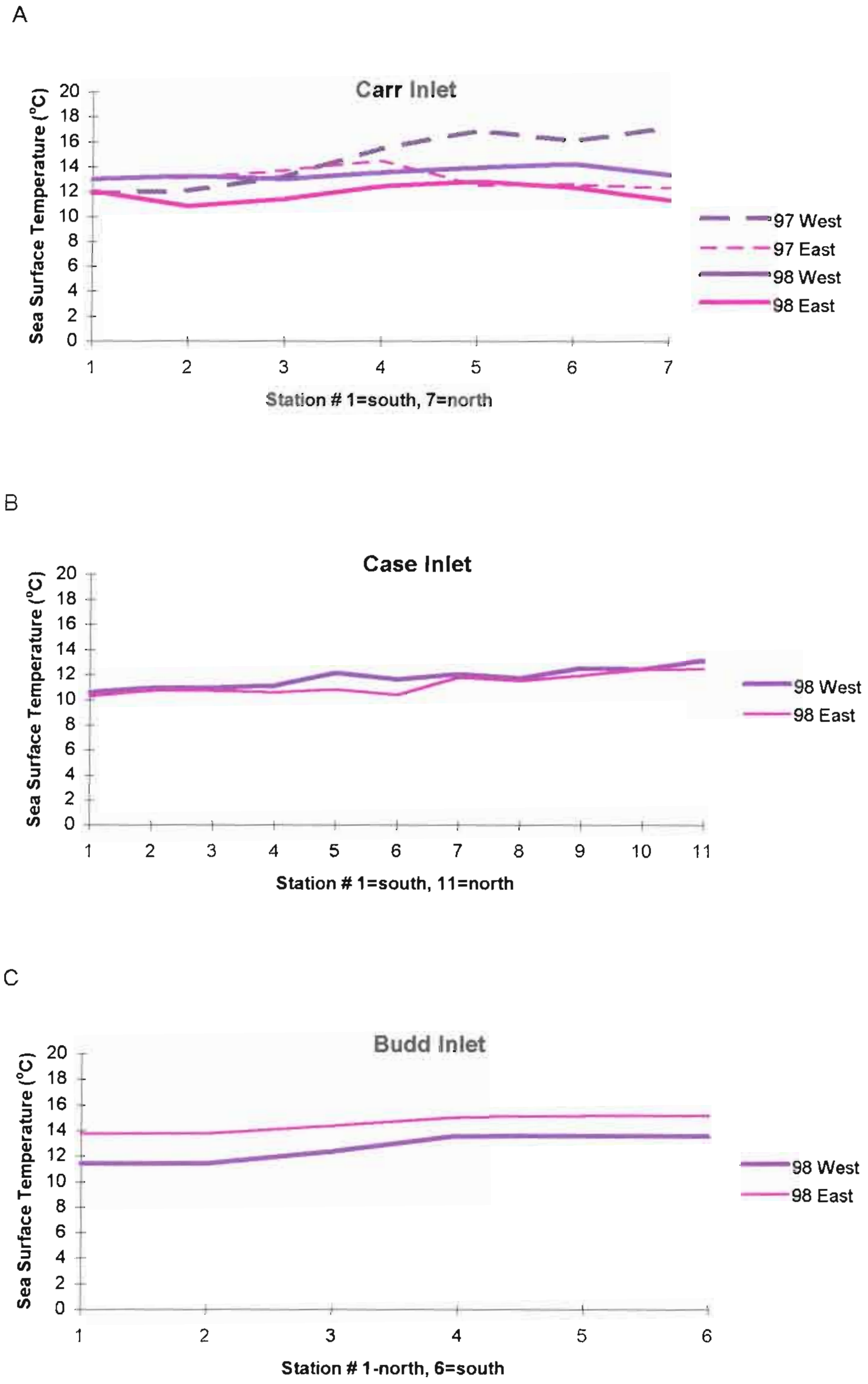


Figure 7. Sea surface temperature profiles for Carr, Case and Budd Inlets (at 1 meter depth).

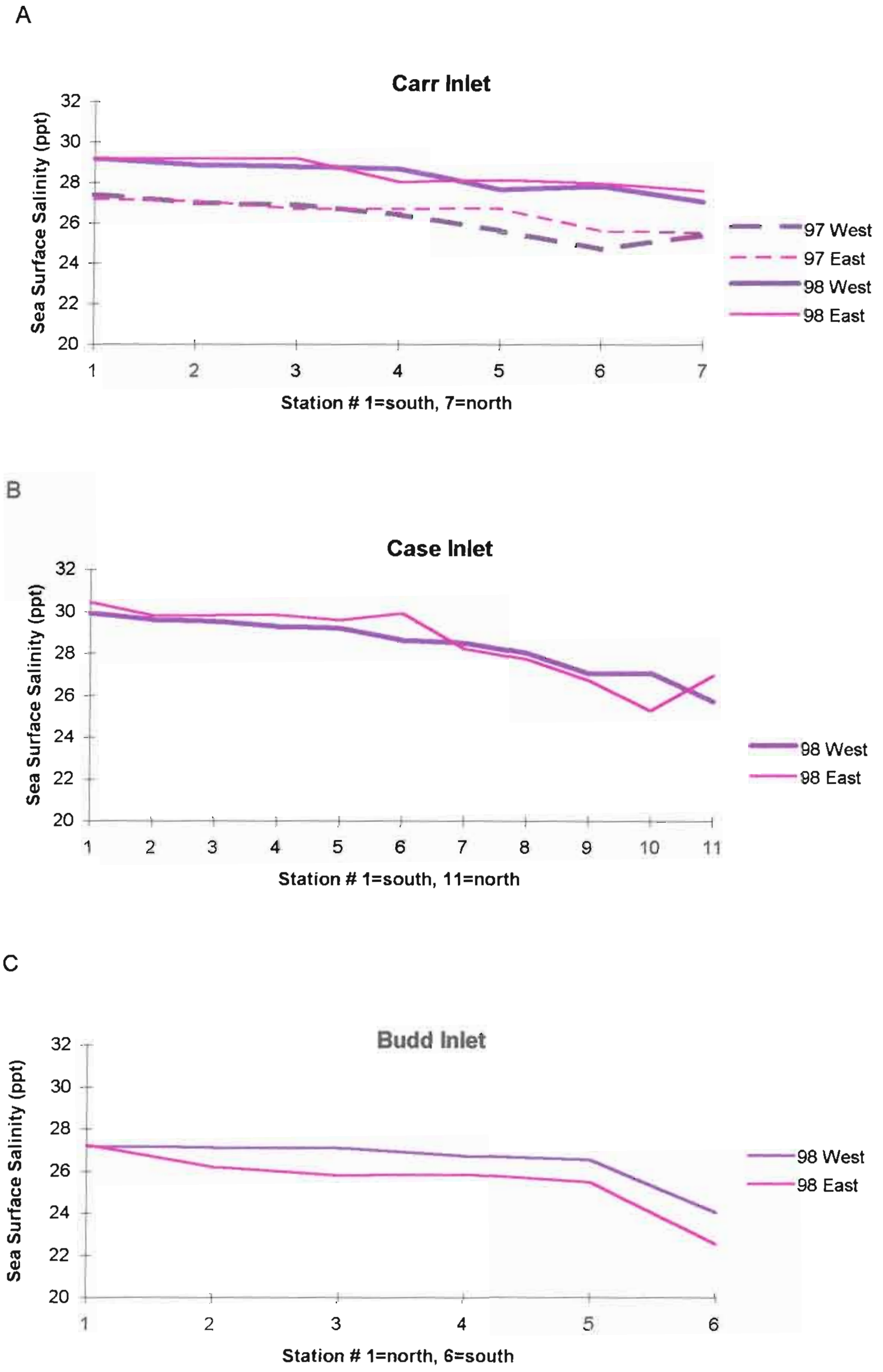


Figure 8. Sea surface salinity profiles (at 1 meter depth).

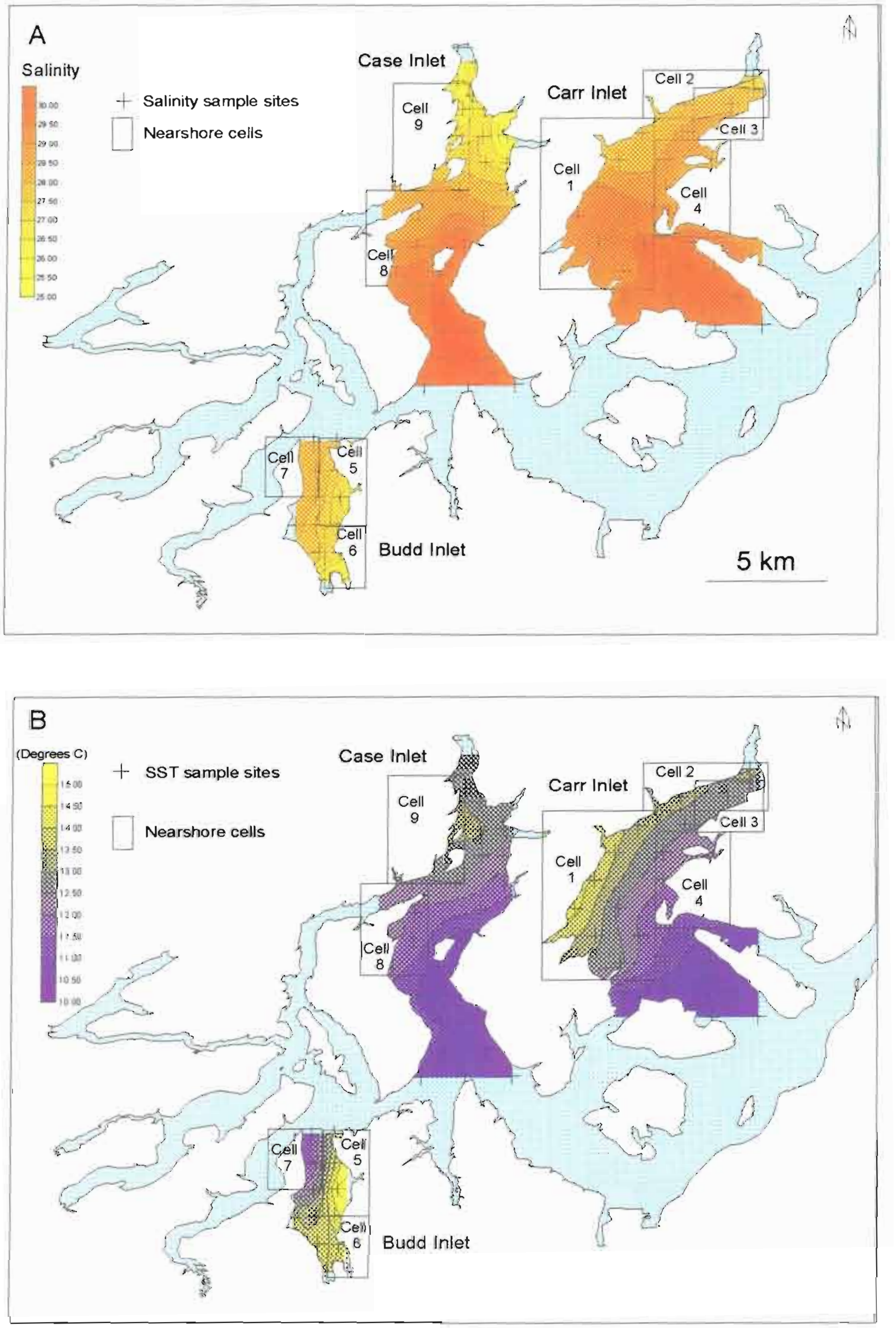
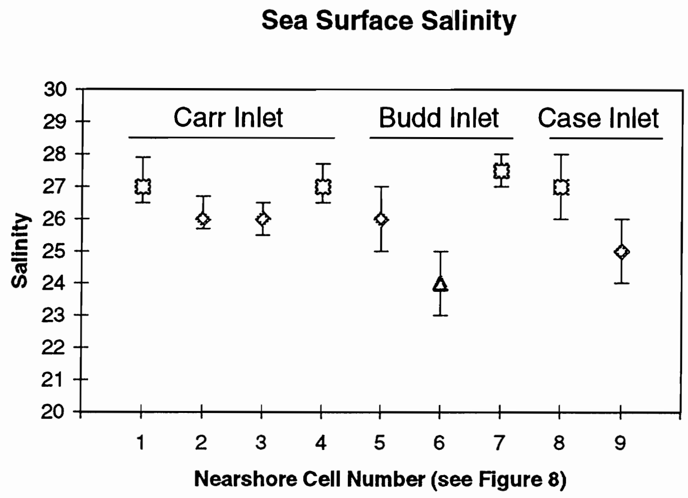


Figure 9. Sea surface salinity (A) and temperature (B) contour maps of Carr, Case and Budd Inlets in South Puget Sound. Salinity was calculated from conductivity measurements and temperature was measured directly with a thermistor. Measurements were taken at 1 m depth on a 1 km grid as shown. Nearshore cells were defined by areas having alongshore gradients not exceeding 2 units of salinity or temperature (pss and degrees C).



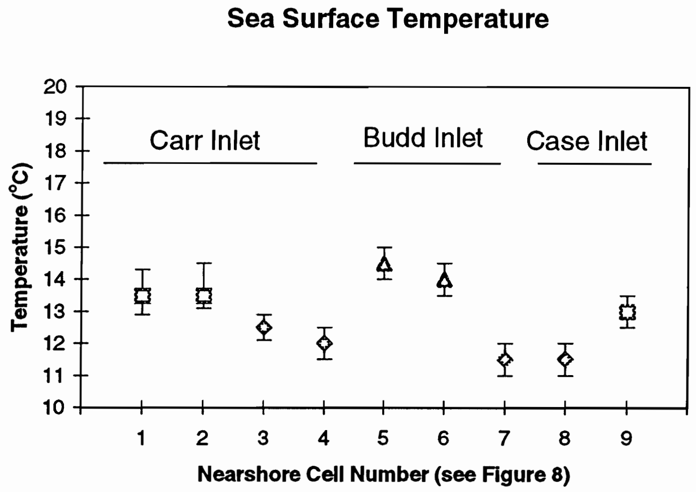


Figure 10. Comparison of nearshore cell sea surface salinity and temperature, with mean, maximum and minimum values shown for cells in Carr, Case, and Budd Inlets. The salinity in Cells 1, 4, 7, and 8 were similar (p=0.84, df 3 and 8), Cells 2, 3, 5, and 9 were similar (p=0.33, df 3 and 8), but those two groups and Cell 6 were very different (p<<0.0001, df 2 and 24). These comparisons showed that no two cells in any of the inlets were comparable, but that some cells among inlets were similar. Cells 1, 2, and 9 were similar in SST (p=0.43, df 2 and 6), and Cells 3, 4, 7, and 8 were similar (p=0.09, df 3 and 8), and Cell 5 and 6 were similar (p=0.29, df 1 and 4), but a comparison among the three groups of nearshore cells showed they were very different (p<<0.001, df 2 and 24).

Beach selection

In Carr Inlet, mud beaches 16, 34, and 74 from segment Group 8 in Cell 1 (as shown on Figure 11) were visited in May 1998 to determine if changes to any physical conditions had occurred over the winter. No geophysical changes were observed or measured on these segments so all were selected for measuring the annual variation in biotic communities. Segments 21, 84, and 92 were randomly selected for model validation of the Group 8 predicted biota. The selection of new mud segments resulted in a spatially skewed distribution with 2 segments in Glen Cove, and 1 segment in Mayo Cove. No new segments were selected from Von Geldern Cove since no other segments belonging to this habitat group occur here. Sand beaches from segment Group 3 in Cell 1 were also visited. Segments 56, 98, and 107, which were sampled in 1997, were also sampled in 1998 for determining the annual variation of sandy beach biota. New Segments 50, 63, and 103 were randomly selected for sampling this year and for validating the modeled predictions of sand beach biota.

A thorough survey of Case Inlet revealed a shoreline geomorphology and beach structure quite different from Carr Inlet. Mud, sand, and gravel segment representatives of Carr Inlet segment Groups 8 (mud), 3 (sand), and 11 (gravel) are either not present or infrequent in Case Inlet. Low zone sand flats (segment Group 3) occur but are lower in elevation than those in Carr Inlet. The shore is characterized by large pebbles and small cobbles (barnacle encrusted where wave energy is low), and interstitial sand. There is a strong particle size gradient with grain size decreasing towards the head of the inlet. This indicates that Case Inlet has less sand supply and nearshore sand transport than Carr Inlet where sand flats are ubiquitous. This is generally caused by the absence of a sand source, such as the relative lack of eroding bluffs along the west shore. Sand flats extending above MLLW are rare and generally isolated. We found a series of sand flats suitable for sampling along the west shore near the northern tip of Hartstene Island (see Figure 11 sites 1, 2, and 3 in Cell 8). Pebble beaches were selected at sites 27, 53, and 102.

Low zone mud beaches are also not common in Case Inlet except at the very head of the inlet north of Allyn where they dominate the intertidal. Based on the observed muddy shores, it appears that the mud in Case Inlet contains more sand than the sampled mud segments in Mayo, Von Geldern, and Glen Cove of Carr Inlet. Lower zone mud shores south of Allyn in Case Inlet are restricted to the small bays along the west shore north of Pickering Passage. With the exception of Vaughn Bay and Whiteman Cove, the eastern shore bays of Case Inlet are elevated, the mud occurs at elevations higher than MLLW. Vaughn Bay is an almost completely enclosed lagoon so the flow regime, and thus the SST and salinity conditions, are bound to differ considerable from the sampled bays in Carr Inlet. Whiteman Cove is too spatially removed for a meaningful comparison. The mud beaches in the small bays in Cell 9 (the northwest corner of the inlet) are the best choice for a meaningful comparison with the mud segments in Carr Inlet. However the mud shores within this small area show considerable variation with sandy mud towards the southern end of the cell (McLane Cove), pebbly mud in the middle near Reach Island, and silty mud towards the north near Allyn. Oyster aquaculture operations dominate the

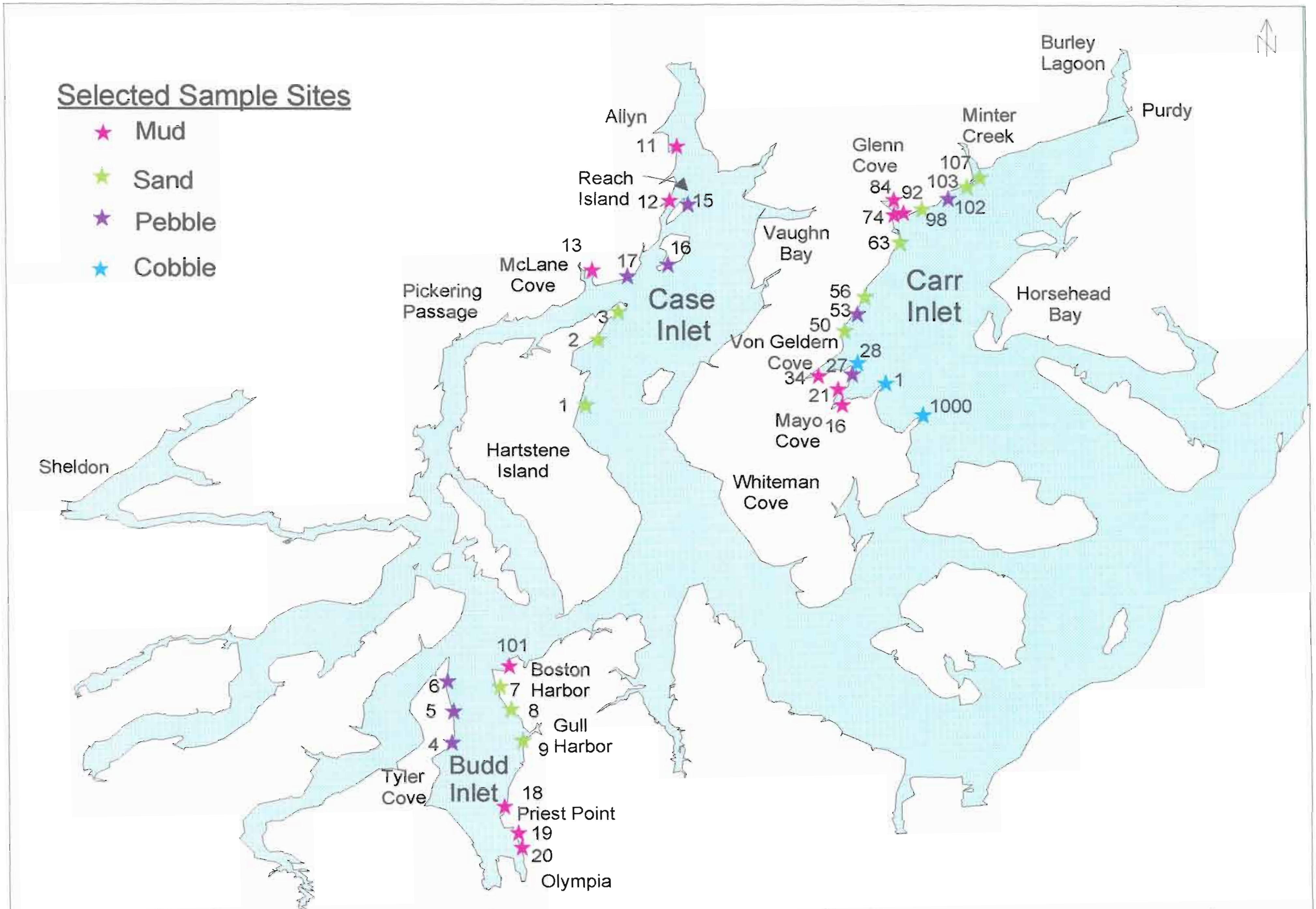


Figure 11. South Puget Sound sample sites chosen for intertidal biota comparisons.

bays north of Reach Island. Although the data will reflect this variation, we sampled sites in McLane Cove (Case 13), the bay west of Reach Island (Case 12), and the bay south of Allyn (Case 11). The selected beach at Case 12 is surrounded by oyster aquaculture and according to the land owner, the beach was tilled for clams about one year ago.

We found few cobble beaches in Case Inlet and none similar to those sampled in Carr Inlet. Therefore, no meaningful extrapolations of biota can be expected between the cobble beaches in Case Inlet and the cobble beaches sampled in Carr Inlet. Pebble beach sites 15, 16, and 17 were selected on the western shore of the inlet. In Budd Inlet, coarse grained beaches dominate the northern shores and fines characterize the south. In the north, gravel beaches (mostly pebble and cobble with interstitial sand) were found on the west shore and sandy pebble beaches occur on the eastern shore. Low tide sand flats were observed in isolated pockets but are not prevalent in the 2 northern cells. The frequency of sandy low zones increases towards the south. South of Gull Harbor on the east shore, and Tyler Cove on the west shore, sand and sandy mud flats dominate. Surprisingly, the mud beaches consist primarily of sand and organics rather than the expected silt size grains and organics, however several pockets of very soft mud were found near Priest Point in an area once possibly occupied by structures on piles (now gone). Silty mud prevails at the head of the bay near the marinas. Sand flats suitable for sampling were selected at sites 7, 8, and 9 in Cell 5. Mud beaches for sampling were selected at sites 18, 19, and 20 in Cell 6 with an additional comparison to made with the mud low zone at Boston Harbor (101, Cell 5). Pebble beach sites were chosen at 4, 5, and 6 as shown on Figure 10.

Measurement of the physical condition of each beach site allowed for quantitative comparisons within and among segment groups as illustrated in Figure 12. These figures are useful for assessing the actual physical similarity among beach segments. Note that for the most part the segments are evenly matched but there are exceptions particularly among the mud segments. For example, segment 74 in Figure 12A shows a larger primary particle size, and smaller secondary size than other members of the clustered group. This beach was misclassified last year but was nevertheless sampled. It supports a dense *Dendraster* population which do not typically flourish in mud environments, but this area in Glenn Cove, Carr Inlet received a large pulse of sand in the past few years which is slowly being covered up with a fine layer of mud. The layer is still thin enough to support the *Dendraster* but over time will become thicker and may eventually compromise the population density.

Biological sampling

A total of 390 samples, each consisting of a quadrat and core, were taken in 1998 from the low zone of mud, sand, pebble, and cobble beaches in Carr, Case, and Budd Inlets. The 177 taxa found were mostly identified to the species level (75%) and all were identified to family level. The mud beaches had 91 taxa, the sand had 59, the pebble had 81, and the cobble had 73. This is a big change from the 1997 samples where we found the highest richness in sand beaches and the lowest in mud. The 1998 gamma diversity (the average number of taxa per sample) by beach type was highest for the pebble (14.0)

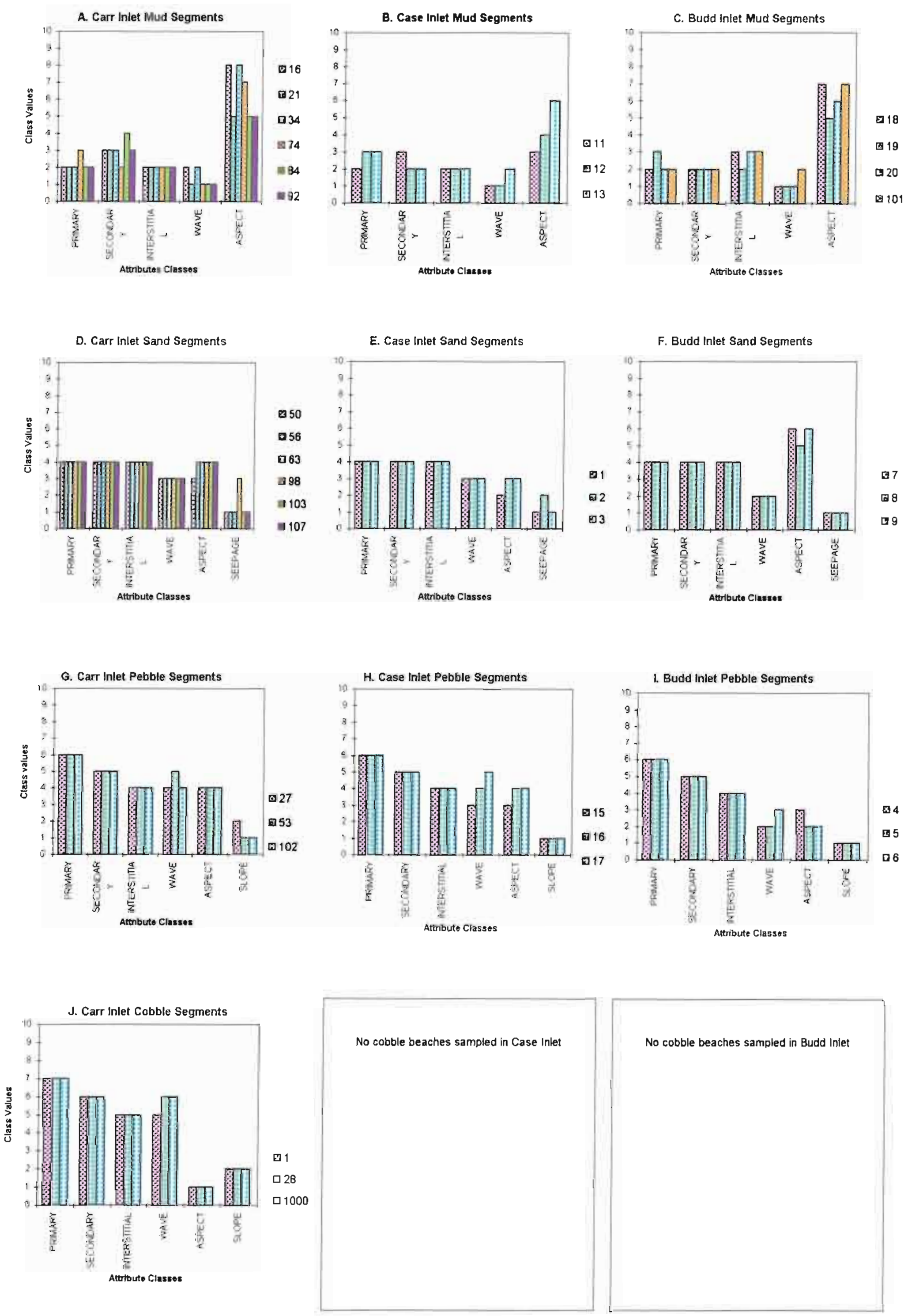


Figure 12. Segment attribute distributions for mud, sand, and pebble beaches in Carr, Case, and Budd Inlets, and cobble beaches in Carr Inlet. Class value and Attribute class refers to the attribute categories shown on Table 1.

and cobble (8.5) as expected for complex substrates, and lowest for sand (3.5) and mud (6.2).

Figure 13 shows the relationship between the number of taxa found and the cumulative area sampled over Carr, Case, and Budd Inlets. These diagrams are useful for evaluating how well a beach segment accounts for the representative community structure of each shore type. The ideal is for the curve to approach the asymptote within the number of samples collected. This would indicate that the sampled taxa account for most of community under investigation for each shore type. The slope of the line for the last ten points was calculated and is noted on each graph. The graphs represents the 90 quadrats and cores collected for each shore type (with the exception of cobble which was not sampled beyond Carr Inlet) with the first 30 samples in Carr, the second 30 in Case and the last 30 in Budd Inlet. The first 10 samples reflect the steepest portion of the curve and account for 40% of the mud, 38% of the sand, 53% of the pebble, and 53% of the cobble taxa. Most of the community structure was accounted for in the first 30 quadrats and cores (representing 3 separate beaches) for the mud (68%), sand (63%) , pebble 75%, and cobble (73%) beaches. Note that the remaining percentages are accounted for by infrequent organisms that slowly increase species richness as the sampled area increases. But the final slope angle noted on each graph indicates that new taxa were still appearing at relatively high frequencies on all but the sandy beaches. Note that the pebble curve flattens out slightly faster than the others in part because a higher percentage of species in pebble beaches are found in the quadrats, and area in the quads is accumulating faster. It is clear from these graphs that at least 2, and preferably 3, beach segments need to be sampled in order to capture the community structure of these habitats in South Puget Sound. Based on this information we can be certain to find differences in community structure within a beach segment and even between 2 beaches based on individual quadrat and core samples. The infrequent taxa, represented particularly by the rare worms, account for most of this accumulation and are probably not important to the long term community structure. These results also point to the multi-scale patchiness of nearshore biota, even on geophysically homogenous beaches (e.g. sand flats), and the difficulty in consistently capturing large scale community structure with small quadrats and cores. Therefore, this justifies pooling abundances of each taxa into one value to represent the beach segment. The disadvantage is the statistical cost of reducing the 10 quadrat and core replicates into one sample. To make up for this loss of power, more replicate beaches (within a nearshore cell) need to be sampled in order to make meaningful comparisons within and among nearshore cells (see discussion).

Statistical analysis

The illustrations accompanying each of the following analyses include: an ordination plot with georeferenced labels for each plotted point; a map of the project area showing the location of each sample referenced on the ordination plot; a table listing only the taxa contributing to within-group similarity; a graph showing the trophic distribution of the entire community for each group; and finally a graph summarizing the relative numbers of taxa sampled on the sediment (quadrats) vs. in the sediment (cores).

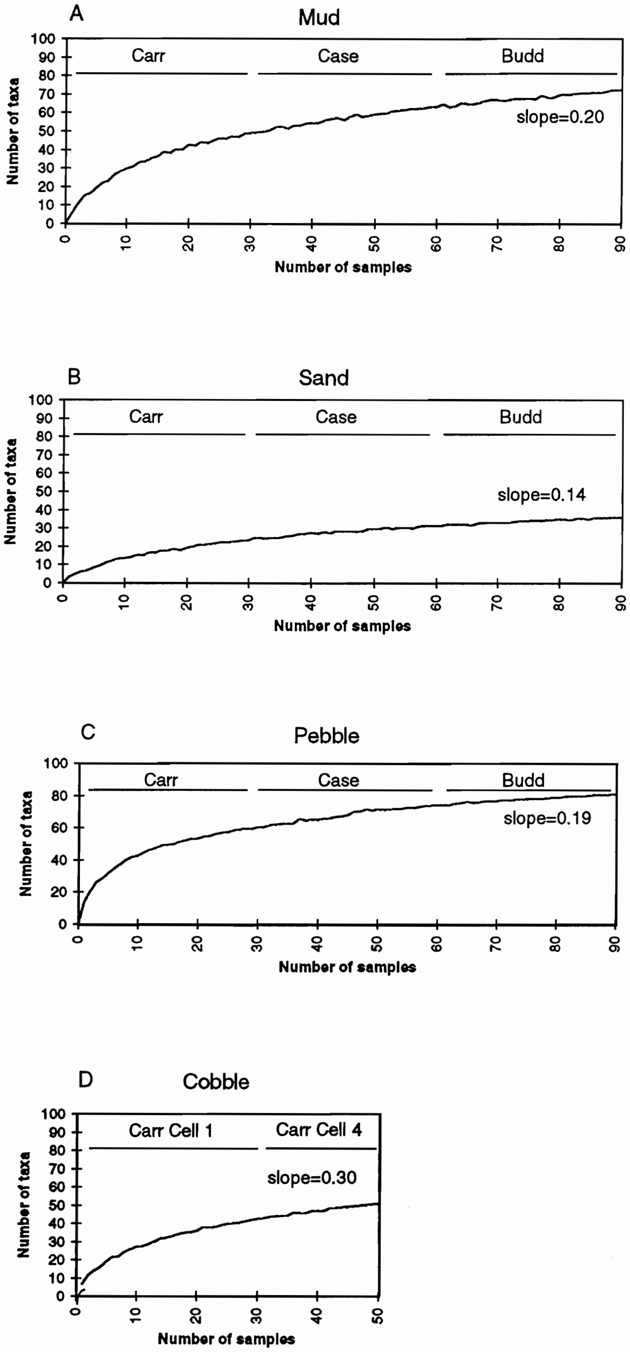


Figure 13. Species-area curves for selected habitats sampled in South Puget Sound (quadrats and cores). Samples are identified by the inlets in which they were collected. All samples were collected in 1998 except for the cobble beach data. Species-area curves for mud (A), sand (B), and pebble (C) beaches cover a larger area than the cobble (D) beaches which are limited to Carr Inlet as noted.

The MDS ordination plots show relationships among sampled communities. Note that the axes are arbitrary and do not correspond to numerical values. Rather, they represent a 2-dimensional view of samples in "species space", or the taxa composition of each sample (i.e. if two samples have exactly the same species and indicator values then the plotted points will be exactly superimposed). The stress value refers to the goodness-of-fit for the 3-dimensional solution. Stress values greater than approximately 0.2 indicate a poor fit, thus making interpretation of the solution difficult.

The ANOSIM analyses of similarity reports the global R-values, the number of permutations, and the significance level. The global R-value indicates average group homogeneity, a high R-value occurs when the difference among groups is greater than the difference within groups. Note that low R-values will generally have high significance levels. The permutation number refers to the number of random allocations of the data to compute the significance level. Comparing 2 groups of 3 samples each gives 10 possible permutations which is not as powerful as comparing 2 groups of 5 samples each giving 126 permutations. A low number of permutations will constrain the power of this test, so that a Type II error is likely when significance levels are low. The significance level is also the Type 1 error, or the probability of falsely rejecting the null hypothesis (H_o = the hypothesis of no difference). This is useful for our purposes because it allows more flexibility with interpreting the result. The significance level reported here should be read as the probability of making a Type 1 error if H_o is rejected. For example, with a significance level of 60%, if H_o is rejected then there is a 60% chance that it was incorrectly rejected. In other words, in this case it would be wise to not reject H_o. Use of the significance level is suggested to evaluate degrees of similarity in the following comparisons rather than absolute significance usually associated with p-values.

The tables list the taxa contributing to within group similarity (SIMPER), the percent contribution to similarity of each taxon, and the cumulative percentage. Similarity is based on the indicator value of the taxa. Note that the taxa are listed in ranked order, with the organism contributing the most to within group similarity listed first. The total number of taxa in each community (with rare species omitted) is also given. Note that within group similarity increases as the number of listed taxa approaches the total number of taxa in the community, although we rarely find that more than 50% of the taxa are actually similar among samples. This is because of the high number of infrequent and low abundance taxa present in the samples. The taxa contributing to within group similarity and that are also present in both groups are highlighted.

For each comparison, a figure shows the trophic distribution of the entire community for each sample group. We classified each taxon into trophic level categories and graphed the total number of each category present in each sample group. The trophic levels categorized are: suspension feeders, deposit feeders, carnivores, herbivores, primary producers, scavengers, commensal organisms, and omnivores. These figures allow a visual comparison of community structure for evaluating which trophic levels are best represented in each sample group.

The final figure given for each comparison shows the community structure by the number of epifauna and epiflora vs. infauna for each sample group. The combined number of taxa is indicated as well as the total number for each sample group and the number of taxa the sample groups have in common. These illustrations and values are useful for comparing the contribution of cores vs. quadrats, the difference in species richness among groups, and the similarity of the groups based on the presence/absence of taxa.

Annual variation

Monitoring programs are generally plagued by large temporal variability of community structure and population abundances. We hypothesize that community patterns will be consistent among similar beach segments (replicates), even though the entire community structure may change over time because of population level fluctuations. We examined the natural variability of community structure among replicate segments in Carr Inlet by comparing 1997 and 1998 samples from mud, sand, and cobble beaches.

The results of comparing 1997 and 1998 samples from mud segments 16, 34, and 74 are shown on Figures 14-16, and Table 2. The MDS plot shows a slight shift in the 1998 community structure away from the structure represented by the 1997 samples. Interestingly, this shift is in the same direction for all 1998 samples, meaning that the community structure changed in the same way for each segment between years. However, this change is not significant, and even with few permutations, the strength of the global R supports this result. SIMPER analysis showed that the alga *Gracilaria pacifica* dominated the community structure in 1997 (27% contribution), followed by ulvoids (20% for both *Enteromorpha sp.* and *Ulva sp.*), ghost shrimp (19%), the capitellid polychaete *Notomastus tenuis* (7%), while in 1998, juvenile clams, another capitellid *Mediomastus sp.*, ulvoids, and the alga *Punctaria lobata* dominated (16%, 15%, 15%, and 13% contribution, respectively). Segment 74 stands apart from the other segments reflecting the consistent effects of *Dendraster excentricus* (sand dollar) bioturbation in both years. Figure 15 shows that suspension feeders, deposit feeders, and carnivores dominate both years but that in 1998 the numbers increased although there was no relative change among trophic dominants. Figure 16 illustrates that infauna dominated both years as expected on a muddy shore. There were 16 taxa (out of 35) common to both years.

The sand beach comparison results for segments 56, 98, and 107 are shown on Figures 17-19, and Table 3. The MDS plot shows that segments 56 and 107 changed more than segment 98, but again the general change of the community structure was in the same direction. Segment 98 still has more groundwater seepage in the low zone and the community shift seen in the other 2 beaches may be dampened by this background effect. The temporal change is not significantly different and both sample groups show the same dominant taxa. *Dendraster excentricus* and ulvoids dominated in 1997 (45% and 40% contribution, respectively), and again in 1998 (24% and 24% contribution, respectively). *Polysiphonia sp.* (red alga) shows on the 1997 similarity list with 15% contribution but it was not similar among 1998 samples. Figure 18 shows that the counts were higher for each of the trophic dominants in 1998, but there was no relative change among trophic

Community analysis of annual variation on mud beaches in Carr Inlet, South Puget Sound

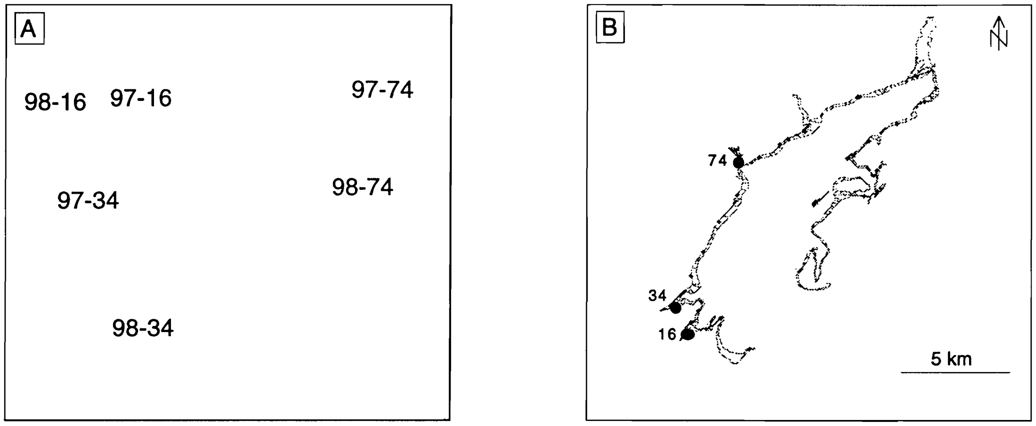


Figure 14. Temporal variation within mud beaches in Carr Inlet Cell 1. MDS ordination of community data for samples collected from Segment Group 2 (74, 34, and 16) in June of 1997 and 1998, (stress=0.01). One-way ANOSIM with 10 permutations, global R=0.00, sig. level=60%.

Table 2. Taxa contributing the most to within year similarity (ranked by percent contribution). Listed taxa are the best indicator organisms for the year. The 4 indicator taxa common to both years are highlighted in bold.

A. 1997 samples

Taxa (9 of 19)	%	Cum%
Gracilaria pacifica	26.65	26.65
Ulvoids	19.92	46.57
Neotrypaea californiensis	19.4	65.97
Notomastus tenuis	6.92	72.89
Unid. clam or shrimp holes	6.75	79.64
Juvenile macoma	5.68	85.32
Haminoea vesicula	5.33	90.65
Tellina sp.	5.33	95.98
Hemigrapsus oregonensis	4.02	100

B. 1998 samples

Taxa (11 of 32)	%	Cum%
Juvenile macoma	15.94	15.94
Mediomastus sp.	15.35	31.29
Ulvoids	15.21	46.49
Unid. clam or shrimp holes	14.98	61.47
Punctaria lobata	12.91	74.38
Leitoscoloplos pugettensis	5.35	79.73
Protothaca staminea	4.6	84.33
Spiochaetopterus costarum	4.34	88.68
Clinocardium nuttallii	4.34	93.02
Haminoea vesicula	3.79	96.81
Leptosynapta clarki	3.19	100

Annual variation of mud beach communities in Carr Inlet Cell 1

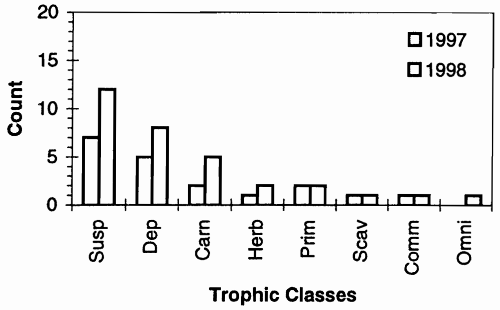


Figure 15. Community distribution by trophic class for 1997 and 1998 mud beach quadrat and core samples.

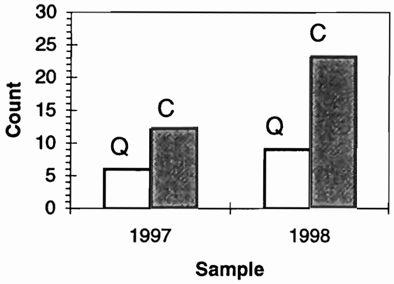


Figure 16. Comparison of organism counts by epifauna and epiflora (Q) and infauna (C). Total count=35 taxa, with 19 in 1997, 32 in 1998, and 16 taxa common to both years

Community analysis of annual variation on sand beaches in Carr Inlet, South Puget Sound

Figure 17. Temporal variation within sand beaches in Carr Inlet Cell 1. MDS ordination of community data for samples collected from Segment Group 20 (107, 98, and 56) in June of 1997 and 1998, (stress=0.11). One-way ANOSIM with 10 permutations, global R=0.19, sig. level=40%.

Table 3. Taxa contributing the most to within year similarity (ranked by percent contribution). Listed taxa are the best indicator organisms for the year. The 2 indicator taxa common to both years are highlighted in bold.

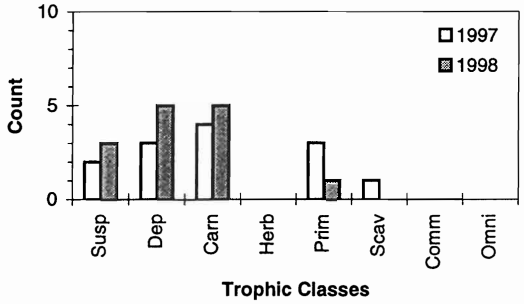
A. 1997 samples

Taxa (3 of 13)	%	Cum%
Dendraster excentricus	45.39	45.39
Ulvoids	39.84	85.23
Polysiphonia sp.	14.77	100

B. 1998 samples

Taxa (9 of 16)	%	Cum%
Dendraster excentricus	23.75	23.75
Ulvoids	23.75	47.51
Notomastus tenuis	9.04	56.54
Neotrypaea californiensis	8.84	65.38
Glycinde picta	8.23	73.61
Nephtys caeca	7.6	81.21
Polydora kempi japonica	6.29	87.5
Spiochaetopterus costarum	6.25	93.75
Unid. clam holes	6.25	100

Annual variation of sand beach communities in Carr Inlet Cell 1



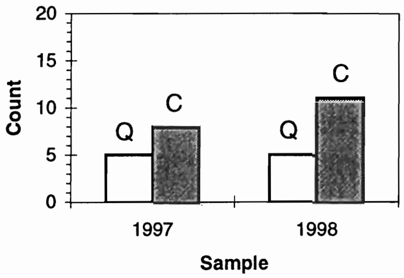


Figure 18. Community distribution by trophic class for 1997 and 1998 sand beach quadrat and core samples.

Figure 19. Comparison of organism counts by epifauna and epiflora (Q) and infauna (C). Total count=22 taxa, with 13 in 1997,16 in 1998, and 7 taxa common to both years.

classes. Infauna dominated the communities in both years, and although 22 taxa were identified in both groups, only 7 were found in both years.

Cobble beach results are shown on Figures 20-22, and Table 4 for segments 1, 28, and 1000. A simultaneous shift in community structure also occurred on the cobble beaches in Carr Inlet, but in this habitat the shift in community structure was large enough to cause difference. Although the ANOSIM test is not significantly different (p>0.05), the large global R-value suggests that the test statistic is more extreme than would be expected if the groups were similar. SIMPER analysis showed that in 1997 the dominant taxa were the polychaete *Notomastus tenuis*, the green ephemeral ulvoids, the barnacle *Balanus glandula*, and the polychaete *Ophiodromus pugettensis* (13%, 12%, 11%, and 10% contributions, respectively). In 1998, ulvoids were the most Figure 17 dominant (7%), but the percent contribution was much lower than in 1997. The difference between the years also can be seen by the range in percent contribution of the similar taxa. The range in 1997 (2%-13%) is almost double the 1998 range (1%-7%). Figure 21 shows that primary producers were higher in 1997 and suspension feeders were lower than in 1998. Figure 22 shows that in 1997 there were more taxa found in cores than in quadrats, but in 1998 there were more taxa found in quadrats. The number of taxa found were very similar in both years (25 in 1997, and 27 in 1998).

Model validation

We are interested in how well the community structure from a beach can be extrapolated to another similar beach within the same nearshore cell. We hypothesized that similar beach segments (replicates) within the same nearshore cell will have similar communities. We tested this by sampling a series of 3 segments from both the mud and sand beach groups. Then using these community patterns as predictors for the entire segment group, we validated the predictions by sampling a random selection of additional beaches from the same beach groups, and comparing the community patterns. We were also interested in assessing the statistical confidence (uncertainty) associated with SCALE predicted intertidal communities in Carr Inlet.

Results for the mud beach comparisons between segments 16, 34, 74 and 21, 84, 92 are shown on Figures 23-25, and on Table 5. The MDS plot illustrates the distribution of prediction and validation samples. The plotted points are labeled either with a "P" or a "V" to indicated group membership. The site map also show where these samples were taken and the spatial relationship among the samples. Note that although the map shows two spatially independent groups, one in Glenn Cove and the other in Von Geldern and Mayo Coves, this is not how the samples were grouped. The samples are appropriately labeled on the map to indicate which belong to the prediction group or the validation group. The ANOSIM test of similarity showed no difference between the sampled groups. SIMPER results on Table 5 show that of the 11 taxa that contribute the most to within group similarity, 8 are the same between the two groups (8 out of 13 for the validation group). Juvenile Macoma, the capitellid *Mediomastus sp.*, ulvoids, clam or ghost shrimp holes, and *Punctaria lobata* contribute the most to the prediction group similarity (74% combined), and *Punctaria lobata*, *Spiochaetopterus costarum*, clam or shrimp holes,

Community analysis of annual variation on cobble beaches in Carr Inlet, South Puget Sound

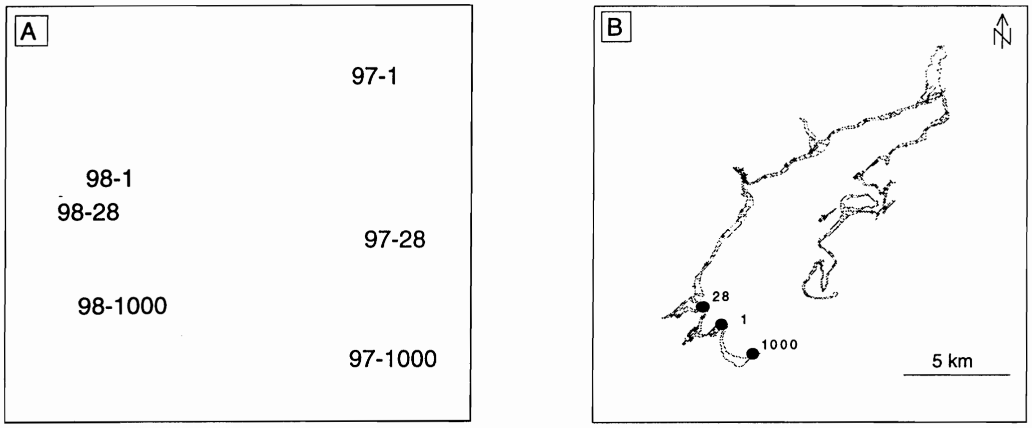


Figure 20. Temporal variation within cobble beaches from Carr Inlet Cell 1 (A). MDS ordination of community data for samples collected from Segment Group 56 (1000, 1, and 28) in June of 1997 and 1998 (B), (stress=0.01). One-way ANOSIM with 10 permutations, global R=0.89, sig. level=10%.

Table 4. Taxa contributing the most to within group similarity (ranked by percent contribution). Listed taxa are the best indicator organisms for the year. The 8 indicator taxa common to both years are highlighted in bold.

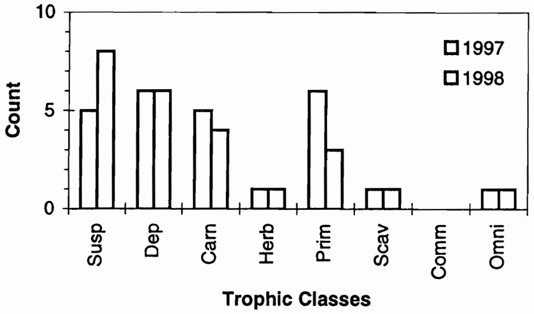
A. 1997 samples

Taxa (13 of 25)	%	Cum%
Notomastus tenuis	12.85	12.85
Ulvoids	12.41	25.26
Balanus glandula	11.39	36.66
Ophiodromus pugettensis	10.29	46.95
Hemipodus borealis	9.99	56.95
Crepidula dorsata	9.41	66.35
Micropodarki dubia	8.58	74.93
Glycinde picta	8.06	82.99
Cancer sp.	4.81	87.8
Acrosiphonia sp.	4.04	91.84
Unid. red crust	2.91	94.75
Unid. Nemertea	2.81	97.56
Nereis procera	2.44	100

B. 1998 samples

Taxa (22 of 27)	%	Cum%
Ulvoids	7.47	7.47
Balanus glandula	7.31	14.78
Hemigrapsus oregonensis	7.17	21.95
Crepidula dorsata	6.56	28.51
Unid. red crust	6.52	35.03
Spiochaetopterus costarum	6.06	41.09
Lophopanopeus bellus	5.9	46.99
Armandia brevis	5.57	52.57
Protothaca staminea	4.8	57.37
Lottia pelta	4.8	62.17
Mastocarpus papillatus	4.77	66.94
Unid. clam holes	4.72	71.66
Notomastus tenuis	4.65	76.31
Leitoscoloplos pugettensis	4.08	80.4
Unid. Nemertea	3.87	84.27
Glycinde picta	3.85	88.12
Hemipodus borealis	3.76	91.88
Ceramium sp.	1.82	93.7
Metridium sp.	1.73	95.42
Juvenile Macoma	1.68	97.11
Pholoe sp.	1.64	98.75
Terebellid sp.	1.25	100

Annual variation of cobble beach communities in Carr Inlet Cell 1



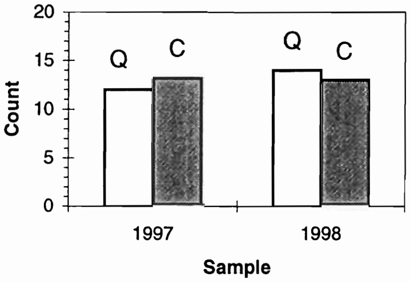


Figure 21. Community distribution by trophic class for 1997 and 1998 sand beach quadrat and core samples.

Figure 22. Comparison of organism counts by epifauna and epiflora (Q) and infauna (C). Total count=38 taxa with 25 in 1997, 27 in 1998, and 14 common to both years.

Community analysis for model validation of mud beaches in Carr Inlet, South Puget Sound

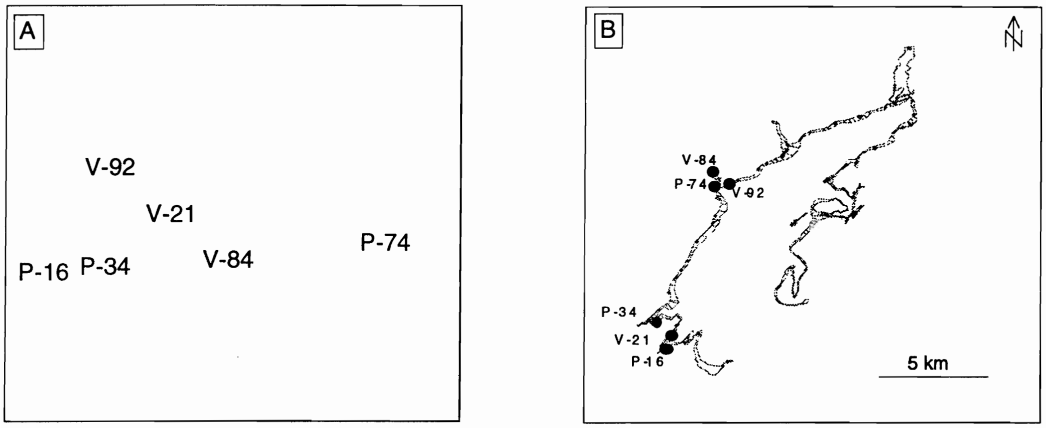


Figure 23. Analysis of mud beach biota within Carr Inlet Cell 1. MDS ordination of community data collected from Segment Group 2 to generate group predictions (P), and samples collected for model validation (V), (stress=0.00). One-way ANOSIM with 10 permutations, global R=0.00, sig. level=60%.

Table 5. Taxa contributing the most to within group similarity (ranked by percent contribution). Listed taxa are the best indicator organisms for the group. The 8 indicator taxa common to both sample sets are highlighted in bold.

A. Sampled from Group 2 for modeled predictions			B. Sampled from Group 2 for model validation		
Taxa (11 of 32)	%	Cum%	Taxa (13 of 26)	%	Cum%
Juvenile macoma	15.94	15.94	***Punctaria lobata***	15.05	15.05
Mediomastus sp.	15.35	31.29	***Spiochaetopterus costarum***	13.74	28.79
Ulvoids	15.21	46.49	**Unid. clam or shrimp holes**	12.2	40.99
Unid. clam or shrimp holes	14.98	61.47	**Ulvoids**	11.7	52.69
Punctaria lobata	12.91	74.38	*Nephtys caecoides*	9.06	61.75
Leitoscoloplos pugettensis	5.35	79.73	*Hemipodus borealis*	8.85	70.59
Protothaca staminea	4.6	84.33	**Juvenile macoma**	8.85	79.44
Spiochaetopterus costarum	4.34	88.68	***Mediomastus sp.***	4.02	83.46
Clinocardium nuttallii	4.34	93.02	*Notomastus tenuis*	4	87.46
Haminoea vesicula	3.79	96.81	***Clinocardium nuttallii***	3.38	90.84
Leptosynapta clarki	3.19	100	***Leptosynapta clarki***	3.06	93.9
			Macoma nasuta	3.06	96.96
			Notomastus lineatus	3.04	100

Predicted mud beach community structure in Carr Inlet Cell 1

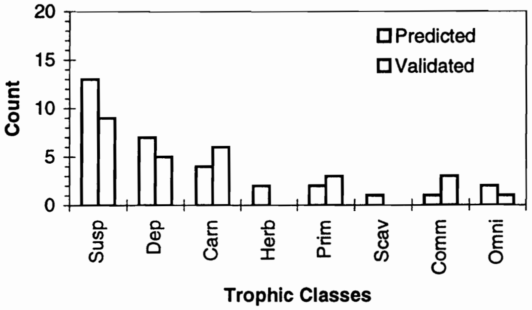


Figure 24. Community distribution by trophic class for sampled and validated groups of mud beach quadrat and core samples.

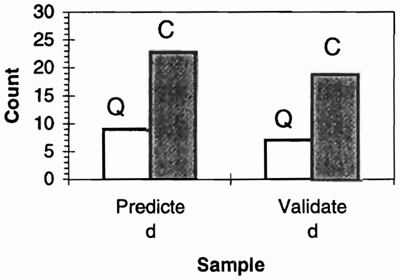


Figure 25. Comparison of organism counts by epifauna and epiflora (Q) and infauna (C). Total count=38 taxa, with 32 predicted, 26 validated, and 20 taxa common to both sample sets.

ulvoids, the carnivorous polychaetes *Nephtys caecoides* and *Hemipodus borealis*, and juvenile clams contribute the most to the validation group (79% combined). The trophic class distributions are also consistent but with slight differences in the number of carnivores relative to deposit feeders and suspension feeders between the groups. Of the 38 taxa found, 20 occurred in both groups. Note that the *Dendraster excentricus* dominated segment, P-74, is separated from the others. If this sample was excluded then the results would indicate even more similarity.

The analysis of sand beaches 50, 63, 103 and 56, 98, 107 had similar results as shown on Figures 26-28, and Table 6. The MDS plot on Figure 26 shows the community relationship among labeled samples. The spatial relationship among these samples is shown on the site map. No difference was found between the prediction group and the validation group (ANOSIM). SIMPER results show that, as expected, *Dendraster excentricus* and ulvoids dominated both groups (48% combined contribution in the prediction group, and 70% in the validation group). Clam holes and the polychaete *Glycinde picta* contributed smaller percentages (14% combined contribution in the prediction group, and 20% in the validation group). Interestingly, 6 out of 16 taxa in the prediction group were deposit feeders while no deposit feeders were sampled in the validation group. Only 3 deposit feeders showed up on the list of taxa contributing to the prediction group similarity, the capitellid *Notomastus tenuis*, the ghost shrimp *Neotrypaea californiensis*, and the polychaete *Polydora kempi japonica* (24% combined contribution). Of the 20 combined taxa identified in these groups, 8 were found in both groups.

Nearshore cells within a bay (1997)

This analysis re-examined data collected in 1997 to evaluate differences between nearshore cells for mud, sand, and cobble beaches in Carr Inlet. This was done to compare habitat community differences reflecting changes in nearshore cell conditions. These differences can be compared to the communities sampled from nearshore cells in other bays in South Puget Sound.

The results of tests comparing the mud beaches 16, 34, and 74 in Cell 1 to mud beaches 186, 198, and 222 in Cell 4 are shown on Figures 29-31, and Table 7. The MDS plot shows that Cell 1 points are grouped separately from the Cell 4 points as would be expected when comparing among beaches with large differences in nearshore cell conditions. Nearshore Cell 1 is generally exposed to higher wave energy, higher salinity, and less stratification of the water column than nearshore Cell 4. The ANOSIM tests however, show no significant differences ($p>0.05$), but the global R-value suggests a difference exists. SIMPER results show that *Gracilaria pacifica* and ulvoids are strongly dominant in Cell 1 (47% combined contribution), compared to *Neotrypaea californicus* and *Glycinde picta* being the most dominant in Cell 4 (31% combined contribution). As a further indication of the strong difference between these sample sets, the sample groups share only 3 taxa from the list of organisms that contribute to within group similarity. The trophic class distribution on Figure 30 shows differences in the number of carnivores and commensals. There are 3 carnivorous polychaetes on the Cell 4 similarity list and none on

Community analysis for model validation of sand beaches in Carr Inlet, South Puget Sound

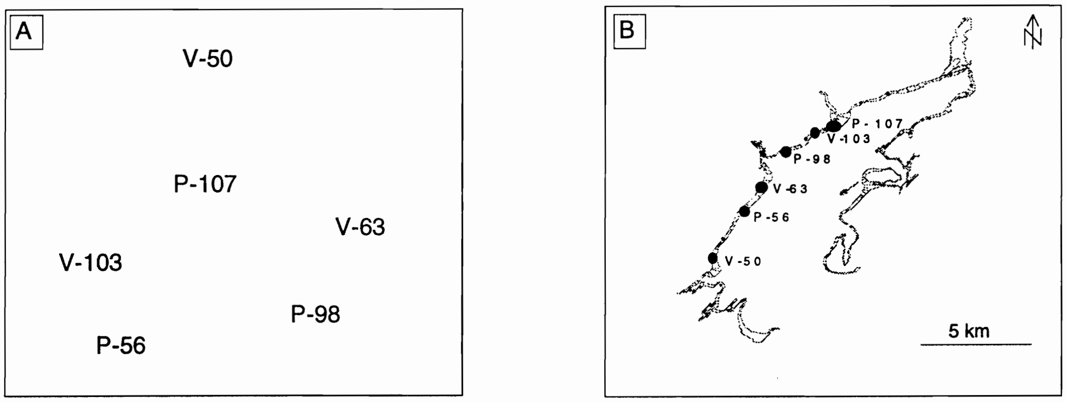


Figure 26. Analysis of sand beach biota within Carr Inlet Cell 1. MDS ordination of community data collected from Segment Group 20 to generate group predictions (P), and samples collected for model validation (V), (stress=0.05). One-way ANOSIM with 10 permutations, global R=0.10, sig. level=60%.

Table 6. Taxa contributing the most to within group similarity (ranked by percent contribution). Listed taxa are the best indicator organisms for the group. The 4 indicator taxa common to both sample groups are highlighted in bold.

A. Sampled from Group 20 for modeled predictions		
Taxa (9 of 16)	%	Cum%
Dendraster excentricus	23.75	23.75
Ulvoids	23.75	47.51
Notomastus tenuis	9.04	56.54
Neotrypaea californiensis	8.84	65.38
Glycinde picta	8.23	73.61
Nephtys caeca	7.6	81.21
Polydora kempi japonica	6.29	87.5
Spiochaetopterus costarum	6.25	93.75
Unid. clam holes	6.25	100

B. Sampled from Group 20 for model validation		
Taxa (5 of 12)	%	Cum%
Ulvoids	45.49	45.49
Dendraster excentricus	25.2	70.69
Unid. clam holes	13.35	84.04
Juvenile macoma	9.48	93.52
Glycinde picta	6.48	100

Predicted sand beach community structure in Carr Inlet Cell 1

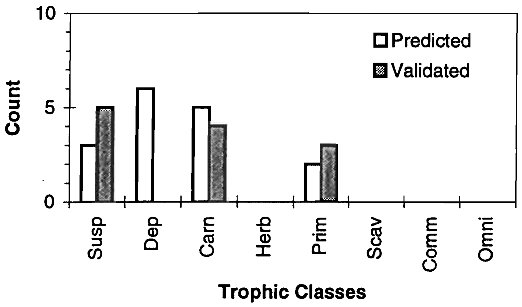


Figure 27. Community distribution by trophic class for sampled and validated groups of sand beach quadrat and core samples.

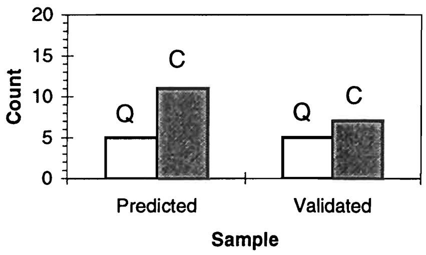


Figure 28: Comparison of organism counts by epifauna and epiflora (Q) and infauna (C). Total count=20 taxa, with 16 predicted,12 validated, and 8 taxa common to both sample sets.

Community analysis of within-bay variation for mud beaches in Carr Inlet, South Puget Sound

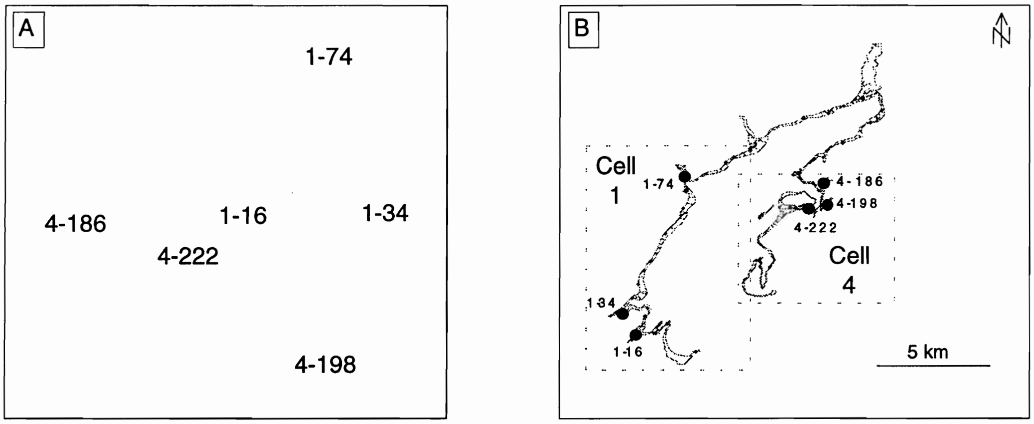


Figure 29. Analysis of mud beach biota within Carr Inlet. MDS ordination of community data collected from Segment Group 2 (74, 34, and 16) and Segment Group 4 (222, 198, and 186) to assess within-bay variation, (stress=0.02). One-way ANOSIM with 10 permutations, global R=0.44, sig. level=10%.

Table 7. Taxa contributing the most to within cell similarity (ranked by percent contribution). Listed taxa are the best indicator organisms for the cell group. The 3 indicator taxa common to both cells are highlighted in bold.

A. 1997 Cell 1 samples			B. 1997 Cell 4 samples		
Taxa (9 of 19)	%	Cum%	Taxa (13 of 22)	%	Cum%
Gracilaria pacifica	26.65	26.65	***Neotrypaea californiensis***	17.22	17.22
Ulvoids	19.92	46.57	*Glycinde picta*	14.23	31.45
Neotrypaea californiensis	19.4	65.97	***Notomastus tenuis***	8.58	40.03
Notomastus tenuis	6.92	72.89	*Pinnotherid sp.*	8.43	48.46
Unid. clam or shrimp holes	6.75	79.64	Unid. clam or shrimp holes	7.46	55.92
Juvenile macoma	5.68	85.32	Unid. Nemertea	6.95	62.87
Haminoea vesicula	5.33	90.65	*Hemipodus borealis*	6.36	69.23
Tellina sp.	5.33	95.98	*Scleroplax granulata*	5.97	75.19
Hemigrapsus oregonensis	4.02	100	*Cryptomya californica*	5.84	81.03
			Protothaca staminea	4.92	85.96
			Balanus glandula	4.75	90.71
			Pseudopythina rugifera	4.75	95.45
			Juvenile macoma	4.55	100

Within-bay mud beach community variation for Carr Inlet Cell 1 and Cell 4

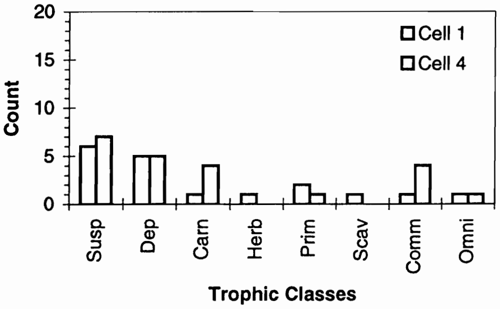


Figure 30. Community distribution by trophic class for Cell 1 and Cell 4 mud beach quadrat and core samples.

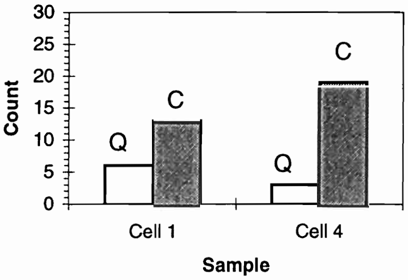


Figure 31. Comparison of organism counts by epifauna and epiflora (Q) and infauna (C). Total count=30 taxa, with 19 in Cell 1, 22 in Cell 4 and 11 taxa common to both Cells.