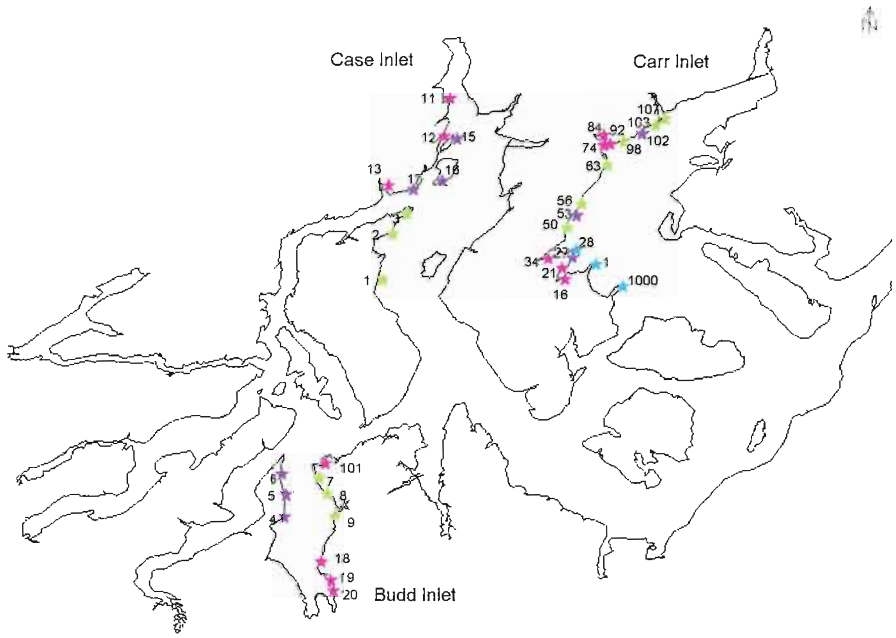
Spatial and Temporal Comparisons of Shoreline Biota in South Puget Sound (FY98-112 Task 1e Final)



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EXECUTIVE SUMMARY

Groups as diverse as natural resource agencies, local governments, private landowners, and shoreline developers have a stake in the marine habitats and natural resources of Puget Sound. Information needs about the Sound are similarly diverse, but all can benefit from a comprehensive and detailed map of shoreline and nearshore habitats, and from information on changes seen through time. At present, no such detailed map exists, and gathering this level of information for this large an area is daunting. The Department of Natural Resources Aquatic Resources group has been refining and testing a method for gathering such habitat information in a cost-effective yet detailed manner. This methodology is called SCALE (Shoreline Classification and Landscape Extrapolation). At its core is the fact that most marine organisms, including seaweeds, seagrass, invertebrates, and fishes are linked rather tightly to their physical environment, including such factors as salinity, wave or current regime, and substrate type (i.e. rock versus sand versus mud). Thus detailed mapping of the physical habitats in an area should provide us with information on the biota inhabiting (or potentially inhabiting) that area. If the physical habitats in an area are mapped and then a random subset of each habitat type is studied in detail, describing its flora and fauna, then the data on those organisms can be inferred to other habitats of that same type in that region.

This model has now been tested on rocky shores of San Juan Island, on the Olympic coast of Washington, and most extensively in the soft sediments of Carr Inlet in south Puget Sound. Physical data in a region is gathered in a hierarchical fashion. First, data on oceanographic conditions (salinity, temperature, wave regime, etc.) are gathered for a coarse-scale division of a region into nearshore "cells" that differ in these key parameters (thus Carr Inlet, for example, was divided into 4 sections or cells). Then for regions where detailed mapping is desired, the shoreline of each cell is divided into linear units (segments), each of which is physically homogenous (i.e., similar substrate size, slope, wave energy, etc.). Carr Inlet was divided into 310 segments. This information is gathered by walking the shoreline of concern. A statistical clustering methodology is then applied to the data, to show which beach segments (within a cell) are the same according to these physical parameters. According to the model, these similar segments should also contain similar organisms, but should be different from segments in the same cell with finer substrate, and different from segments in another cell even if the substrate is the same.

Testing of this model in Carr Inlet in 1997 showed that, as predicted, organisms in the intertidal zone are tightly linked to physical features of the beach. Despite the rather high normal level of patchiness or variability of marine organisms seen at numerous scales, the plants and animals in similar segments within a cell tended to be very similar, but quite different from those in different segments and in different cells. Our initial study, however, did not allow us to answer 3 subsequent, critical questions: 1) Does the model really allow extrapolation about the character of the organisms in beaches that were not sampled as part of the original test? 2) How consistent are the biota in a given beach from year to year? If there was a human-caused change, would we be able to distinguish it from natural variation? 3) How well can we extrapolate the character of the biota from Carr

Inlet to elsewhere in Puget Sound, e.g. to nearby Case Inlet and a more distant one such as Budd Inlet\)? Our 1998 research addressed these questions.

To test the ability of the model to extrapolate to unsampled beaches in Carr Inlet, we randomly chose 3 new muddy beaches and 3 new sandy beaches that were physically similar to those sampled in 1997, including being in the same oceanographic cell. In each case, the biota of the new beaches were very similar (statistically indistinguishable) to those from the beaches already sampled, despite the fact that some of them are at considerable distance from each other. Thus the predictive value of SCALE, at the within-cell level, has been demonstrated. A potential practical application of this result is that if there were some localized event, such as an oil spill, that impacted just a few beaches in an inlet, the effects of that spill could be assessed via detailed sampling of physically matched but unimpacted beaches within the same oceanographic cell; these data would illustrate (with high statistical confidence) the biota that should have been there before the spill.

Temporal (annual) variability within beaches was assessed by resampling the biota of 3 mud, 3 sand, and 3 cobble beaches in Carr Inlet. None of these showed changes in measured physical characteristics over the intervening year. The biotic data showed that for each habitat type there were some changes in flora and fauna between the two years; this change was statistically significant for the cobble habitats, and less pronounced in the other two. In most cases, all the beaches shifted in the same "direction", i.e. there were shifts in the dominance of one species over another that were reflected in all three replicates for that habitat type. These data suggest that the organisms were responding to an environmental shift occurring at scales large enough to encompass all the segments sampled. Such shifts might comprise a major recruitment throughout the bay of a key species, or a series of storms that affected many organisms, or an effect of the El Nino that was impacting the Sound in 1997 but not in 1998.

There are several practical implications of this result; first, since temporal variation (on the scales of days, seasons, or years) is likely to occur at any given beach, sampling only one site will not allow us to distinguish real long-term change from random variation (unless the change is catastrophic). But if replicate sites are monitored through time and if similar changes are seen in all beaches, then this constitutes a strong signal that change is occurring (e.g., in response to increased armoring of the shore, or global warming). Second, in the case of a localized oil spill as described above, it would be misleading to rely on data gathered at that site in a previous year to assess what was expected to be there in the spill year. Only comparing replicate sites within that same year will allow unambiguous interpretation of differences seen at the spill site.

A potential avenue for future research is to extend the SCALE concepts and link the abundance of higher taxa to shoreline productivity. The first step would be to consider the effect of broader marine and terrestrial physical environments and prey resources on the behavior and diets of high priority fish and wildlife.

INTRODUCTION

Ecologists have been challenged to understand the factors that determine structure in both natural and managed communities. This understanding will lead to predictions of ecological responses caused by environmental changes. Detecting a response in community structure is an inherent part of small scale ecological research and applied monitoring programs. Many scientists and resource agencies have attempted to monitor localized intertidal and subtidal transects in hopes of finding a short term experimental response or a long term indicator of ecosystem health. Long term monitoring presumably will provide a statistical baseline from which a change can be detected. However, the dynamic nature of the marine environment causes high spatial and temporal variation in organism abundance and community structure. Two common problems include: 1) many monitoring and impact detection programs have confounded spatial and temporal variation by assuming that change has occurred at an impacted site because it is different from a control site, when really the sites were not adequately matched (Schmitt and Osenberg, 1996); and 2) results often need to be generalized from specific sites to a larger area.

Organisms within marine ecosystems are sensitive to environmental changes and may serve as indicators of environmental health. Because the nearshore lies between the marine and terrestrial environments, organisms living there are affected by a complex array of stressors. If we are to utilize the nearshore community as an indicator of ecosystem health then the problem arises of how to determine causal effects of multiple stressors over different scales of space and time. This problem can be separated into the following distinct components:

1. Spatial heterogeneity of the environment causes variability in community structure.

2. Variability over time of the environment and communities is normal.

3. Only a properly designed sampling program will detect a signal if one were to appear.

4. Results of the sampling program need to be to extrapolated to larger spatial scales.

5. If a signal is detected, we may not know why the change occurs since in many ecosystems there are multiple stressors with few known mechanistic links to biological indicators.

An approach we are testing in Puget Sound, the outer Olympic Peninsula coast and in Alaska is the Shoreline Classification and Landscape Extrapolation model (SCALE). This model increases biological homogeneity by partitioning a shoreline into a spatially nested series of geophysically uniform segments. By then statistically aggregating similar but spatially separated units, we can scale up localized biological data to larger regions. This has important implications for resolving many scientific and resource management issues.

Stresses on marine ecosystems due to changing global climate and the encroachment of anthropogenic development are manifested in the Pacific Northwest by loss of nearshore habitat and the reduction or extinction of many important organisms. Studying the ecological functions of marine habitats and measuring the extent and rate of habitat loss are important for determining the 'health' of developing basins like Puget Sound.

The Nearshore Habitat component of the Puget Sound Ambient Monitoring Program (PSAMP) has the dual goals of inventorying nearshore habitat and monitoring trends in health. For the purpose of the monitoring program, nearshore habitat includes the physical and biotic components of intertidal and shallow subtidal areas. Monitoring habitat is a challenge due to the size and complexity of the study area, which includes approximately 3,862 miles of shoreline east of Cape Flattery, and encompasses a wide range of habitats, from vertical rocky shores to wide, protected mudflats.

Nearshore habitat degradation and loss are recognized to be major threats to the health of Puget Sound (ESRI, 1996). Inventory data are needed to characterize the quantity, location, and quality of habitats, and to guide land use planning. Information on trends in habitat health is needed to identify the habitat features and functions that are most at risk, and to relate these changes to the state of the Puget Sound ecosystem (Berry et al., 1998).

The PSAMP Management Committee has outlined basic requirements for its monitoring programs. Monitoring must measure valued ecosystem components in a cost-effective manner, be meaningful to the public, and link to management activities. The conceptual model of Puget Sound identifies broad questions about habitat to be addressed (Redman, 1996):

1. How is the condition of Puget Sound biota correlated with environmental or food web stresses? Biotic habitats of special concern include marine vegetation such as kelp and eelgrass beds, and biotic communities that support valued or protected species.

2. How is the quality and spatial extent of the ambient physical environment correlated with Puget Sound's biological communities and functions? Priority issues include the effect of shoreline alteration and changes in water quality on habitats and the species they support.

PROJECT OBJECTIVES

The general objective of this study was to test for a deterministic organization of communities among replicate soft-sediment beach segments in South Puget Sound. We hypothesized that benthic communities of macroalgae and invertebrates are similar within groups of replicate segments in estuarine environments. This project builds on the results of tests conducted in Carr Inlet in 1997 (summarized below) using the SCALE model to address the PSAMP issues. For this analysis the specific objectives were:

1. to measure the natural variation in biota over multiple years in Carr Inlet by continuing research completed in 1997 under Interagency Agreement FY97-078;

2. to examine spatial variability in shoreline biota in South 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, over multiple years, and over larger areas.

This report presents a summary of work completed in 1997 and background information pertaining to the SCALE model and the analyses performed. We conclude that nearshore biota of South Puget Sound are tightly linked to the condition of the marine environment and responds to terrestrial and oceanic stresses imposed at multiple scales of space and time. Given this linkage, we make recommendations on developing a nearshore habitat monitoring strategy to evaluate the effects of shoreline alteration and changes in water quality on habitats and taxa supported by those habitats.

BACKGROUND

1997 Carr Inlet Pilot Project

The Washington Department of Natural Resources Nearshore Program, funded a pilot project in 1997 to examine the usefulness of the SCALE model for addressing the monitoring objectives identified by the PSAMP in the marine nearshore of Puget Sound.

The information generated provided a high resolution shoreline inventory by quantifying how many habitat types occur in Carr Inlet and determined the similarity of the biotic elements within and among the habitats. Ultimately this will help define reference sites for further PSAMP monitoring efforts.

Specifically, the objective of the pilot project was to test how well the SCALE model predicts community structure and organism abundances at various spatial scales on a range of soft sediment beach types. The questions driving the research were:

1. Are the biota of the nearshore linked to their physical habitat types, i.e. a particular combination of substrate, salinity, wave energy, etc.?

2. If so, then how similar do physical habitats have to be before one can expect to see parallel communities in them?

3. To what extent can we extrapolate the character of biotic communities from one beach to another?

1997 Methods summary

The site selected for the 1997 study was Carr Inlet, the first major embayment south of the Tacoma Narrows in the Puget Sound estuary as shown on Figure 1. The long axis of Carr Inlet is oriented roughly southeast-northwest and is about 17 km long before the orientation abruptly curves into Henderson Bay which is oriented roughly southwest-northeast and is about 15 km long. The width at the inlet mouth is about 3.3 km and at the head of the bay about 1.3 km.

Field mapping using the SCALE approach consists of the following general steps:

1. Identify nearshore cells based on regions of oceanic homogeneity, especially in salinity, and sea surface temperature at scales greater than 1 km (grid).

2. Select and prioritize habitats of interest for high resolution SCALE modeling.

3. Field map the shoreline (on the ground) to partition and quantify the habitats identified and selected in Step 1-2 into geophysically homogeneous segments (10-100 m linear), quantifying the geophysical attributes known to force biological community structure in the nearshore.

4. Sample selected reference shore segments (from geophysically similar segment clusters) for macroalgae and macroinvertebrates, or other organisms of interest (see below).

5. Statistically scale-up these community or population data by extrapolating biota among segments within geophysically similar clusters within an oceanic cell. These communities can also be scaled up among cells but with a loss of resolution to detect ecological change.

<u>1997 Identifying nearshore cells</u>

The ecological linkages between the nearshore ocean and the benthos are poorly understood. For example, production in some intertidal communities may be regulated by the delivery of nutrients from the ocean or by drainage from nearby rivers and estuaries, larval recruitment may be regulated by coastal current patterns, and wave energy may structure communities by direct forces on organisms or through sediment transport processes. However, it is clear that there is strong physical and biological coupling between the nearshore and the intertidal. Such "edge" communities at the transition between one regime and another may provide a rare opportunity to study linkages and how changes in the environment can affect those linkages.

Menge et al. (1997)demonstrated a correlation between nearshore concentrations of chlorophyll-a and growth rates of rocky-shore organisms at 2 sites 10's of km apart within an upwelling region. They suggest that oceanic processes (e.g., local water-exchange rates

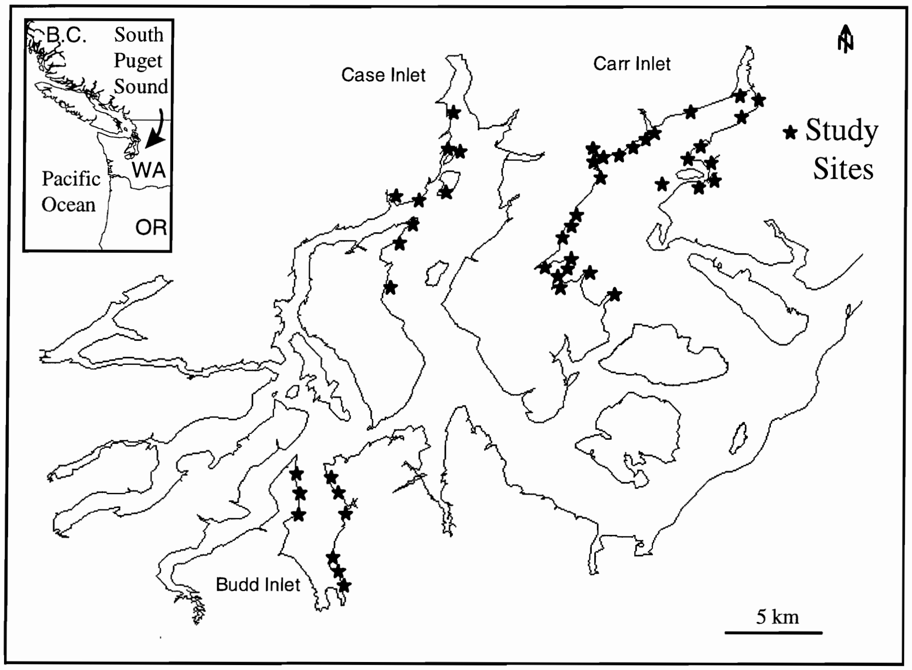

Figure 1. South Puget Sound study sites in Carr, Case, and Budd Inlets. In 1997, the 65 km shoreline of Carr Inlet was partitioned into 310 homogeneous segments. These were aggregated into 51 groups of beach replicates for hypothesis testing of community similarity in mud, sand, and cobble habitats. In 1998, these beaches were sampled again to test for temporal variability. In 1998, beaches were selected in Case and Budd Inlets to compare to the beach segments sampled in Carr Inlet to test for spatial variability among replicate beach habitats within South Puget Sound.

alongshore or inshore-offshore) may be driving these site differences. Inshore nutrient levels can directly affect productivity of nearshore algae (Bustamente et al., 1985; Ormond and Banaimoon, 1994) and the feeding and growth rates of a variety of suspension-feeding organisms are generally enhanced in higher flow conditions (e.g. Frechette and Bourget, 1985; Eckman et al., 1989; Lesser et al., 1994; Sanford et al., 1994).

Differences in salinity and water temperature are often reflected in the composition of intertidal and nearshore flora and fauna communities. It is difficult to quantify boundaries of salinity or water temperature due to the large temporal and spatial changes caused by precipitation, surface runoff, groundwater flow, and evaporation. But most nearshore regions have characteristic patterns that can be quantified. Many intertidal organisms are extremely sensitive to the salinity range of the water. Some can survive by adaptation of osmotic mechanisms that protect them against damage from salinity changes. Since some organisms are better adapted to lower salinity than others, the entire community structure of one beach may differ from that of another beach having similar morphology but different salinity. Typically the open ocean has a mean salinity of 35 ppt, but in estuaries large salinity gradients can occur at the scale of individual organisms due to the effects of river plumes and groundwater seeps.

The nutrient regime and chlorophyll-a distributions were not determined for Carr Inlet but future modeling work should consider these attributes. The Washington State Department of Ecology has conducted marine water quality monitoring at a number of stations in Puget Sound since 1973. Figure 2 shows the seven stations monitored in South Puget Sound on a rotating schedule from 1990-1995. Parameters monitored include temperature, light transmission, Secchi disk depth, salinity, density, pH, dissolved oxygen, ammonium-N, nitrate-nitrite-N, orthophosphate-P, chlorophyll a, phaeopigment, and fecal coliform bacteria. Depth of sampling includes: 0.5, 10, and 30 meters (fecal coliform bacteria data are from 0.1 meter). Samples are collected on a monthly basis but not all stations are visited annually. Therefore, large data gaps occur which precluded use for this study (but see Figure 3 for annual variation of salinity and water temperature in Budd Inlet).

Eutrophication, the external addition of nutrients to a system, can lead to environmental problems such as low dissolved oxygen, noxious algal blooms, and fish kills. Areas in South Puget Sound at risk to eutrophication are those permanently stratified or that show evidence of natural or anthropogenic contributions (high fecal coliform or ammonium concentrations). Figure 2 also shows a summary classification based on five water quality indicators: degree of density stratification; high fecal coliform bacteria concentration; high ammonium concentration; consecutive months of below limit nitrate; and low dissolved oxygen (DO). Low DO is used as an end-point measurement of where eutrophication may have occurred. The MWM stations in Puget Sound that have low DO are shown by red (<3 mg/L = near-hypoxia) and yellow (<5 mg/L = biological stress) dots. Locations that indicate susceptibility to eutrophication due to water column stratification are shown in blue (Newton, 1995).

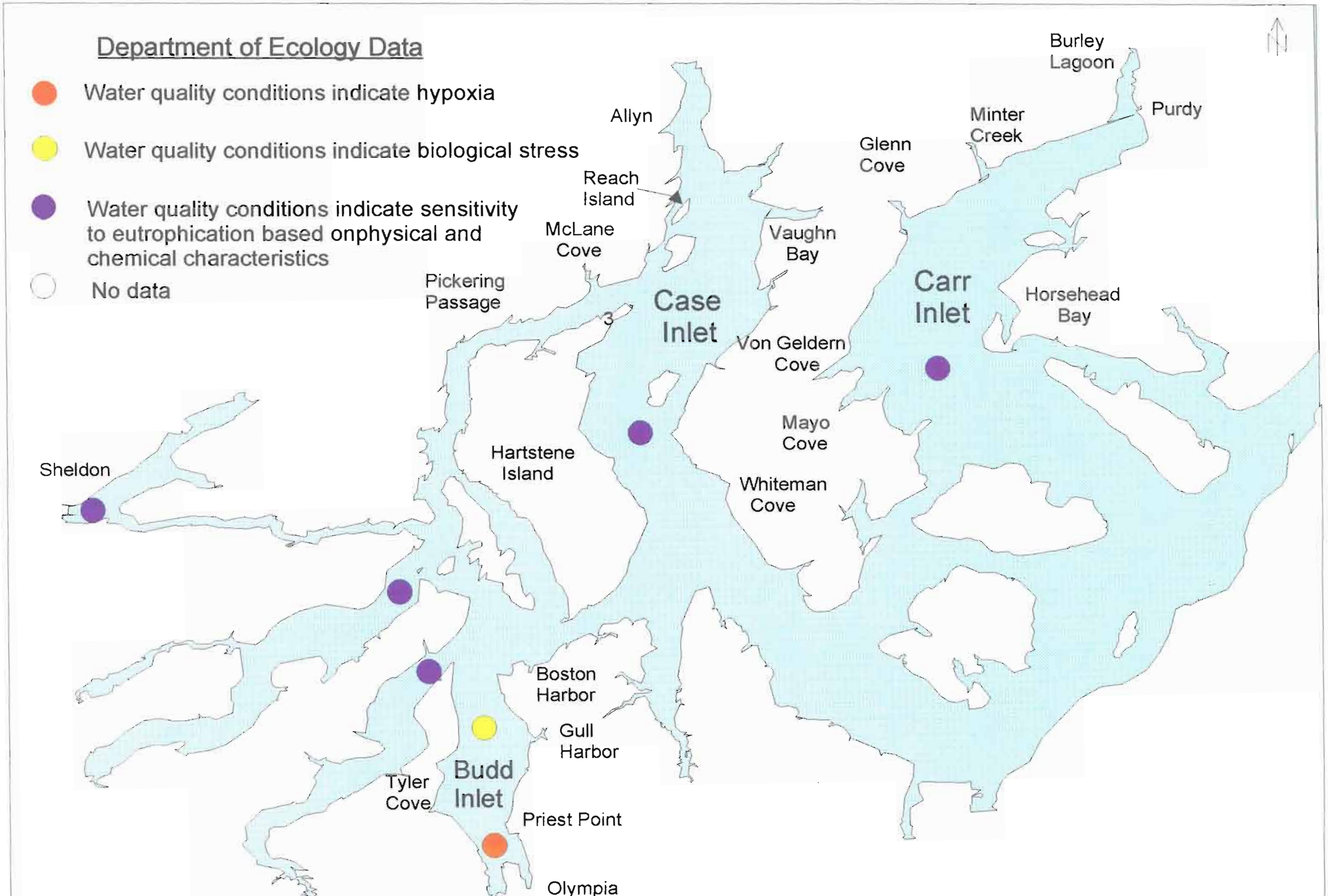

Figure 2. Department of Ecology water quality stations in South Puget Sound.

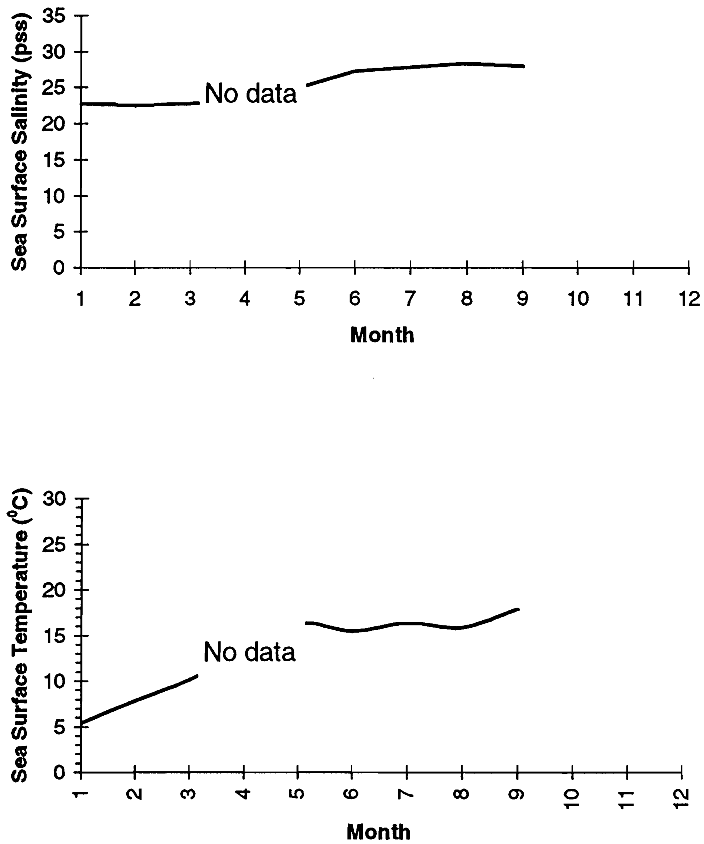

Figure 3. Salinity (A), and water temperature (B) seasonal trends in Budd Inlet. The temporal gradients particularly evident in water temperature suggest that the timing of macroalgal and invertebrate sampling in the nearshore should consider the effects of increased salinity and water temperature during the summer months when the water column is likely to become stratified.

Partitioning of Carr Inlet began at alongshore scales of 1-10 km based on gradients of salinity and water temperature. Night time imagery from the Advanced Very High Resolution Radiometer (AVHRR) satellite sensor (band 4, 1 km resolution obtained from the National Environmental Satellite Data and Information Service) provided a large scale temporal data series of sea surface temperature (SST). These data showed a consistent (over a 3 year annual interval) temperature gradient from the cold deeper water in outer Carr Inlet to the warmer shallow water of inner Henderson Bay.

Field measurements of SST and salinity were made over a two day period with a hand held instrument at 14 sites, at a water depth of 1 meter, with stations spaced approximately 5 km apart and about 100 m from shore. The field data confirmed the remotely sensed salinity and water temperature gradient along the axis of the bay. The field data also showed a gradient across the axis, particularly in Henderson Bay, thus defining four nearshore cells each constraining the alongshore salinity gradient to no more than 2 ppt and the water temperature to 2°C as shown on Figure 4. A final criterion for defining the spatial extent of each nearshore cell was the general configuration of the shoreline with respect to the prevailing winter wind direction which influences nearshore sediment transport processes such as net shore drift.

1997 Beach selection

The following section summarizes the methods and results of the physical assessment of Carr Inlet. For a more detailed description see Schoch et al., 1999.

The objective of the comprehensive physical assessment was to identify and map physical gradients. We used this information to resolve issues of biological variability and scaling in the marine realm by systematically quantifying and eliminating geophysical gradients among biological sample sites. Minimizing gradients in the physical environment can enhance our ability to detect an actual change in the biota from natural variation, because at least in some systems, sampled communities show significant fidelity to their physical habitat types (Schoch and Dethier, 1996). Application of the SCALE model increases biological homogeneity by partitioning a shoreline into a spatially nested series of geophysically uniform segments.

At all spatial scales in Carr Inlet, the primary environmental determinants of nearshore community structure are substrate size (e.g., bedrock vs. gravel vs. sand etc.) and immersion time (or elevation above low water). Substrate size determines the stability (movement potential) and dynamism (movement frequency), both are factors in community disturbance. Solid surfaces generally preclude infauna, while dynamic mobile substrates preclude most sessile organisms. Many mobile but low dynamism substrates (e.g., mud) are extremely rich in biota, especially infauna. Sediment size and dynamism also affect moisture retention, O_2 content, and organic content. The position or elevation within the intertidal zone leads to differences in tidal immersion periods which result in distinctive community zonation patterns.

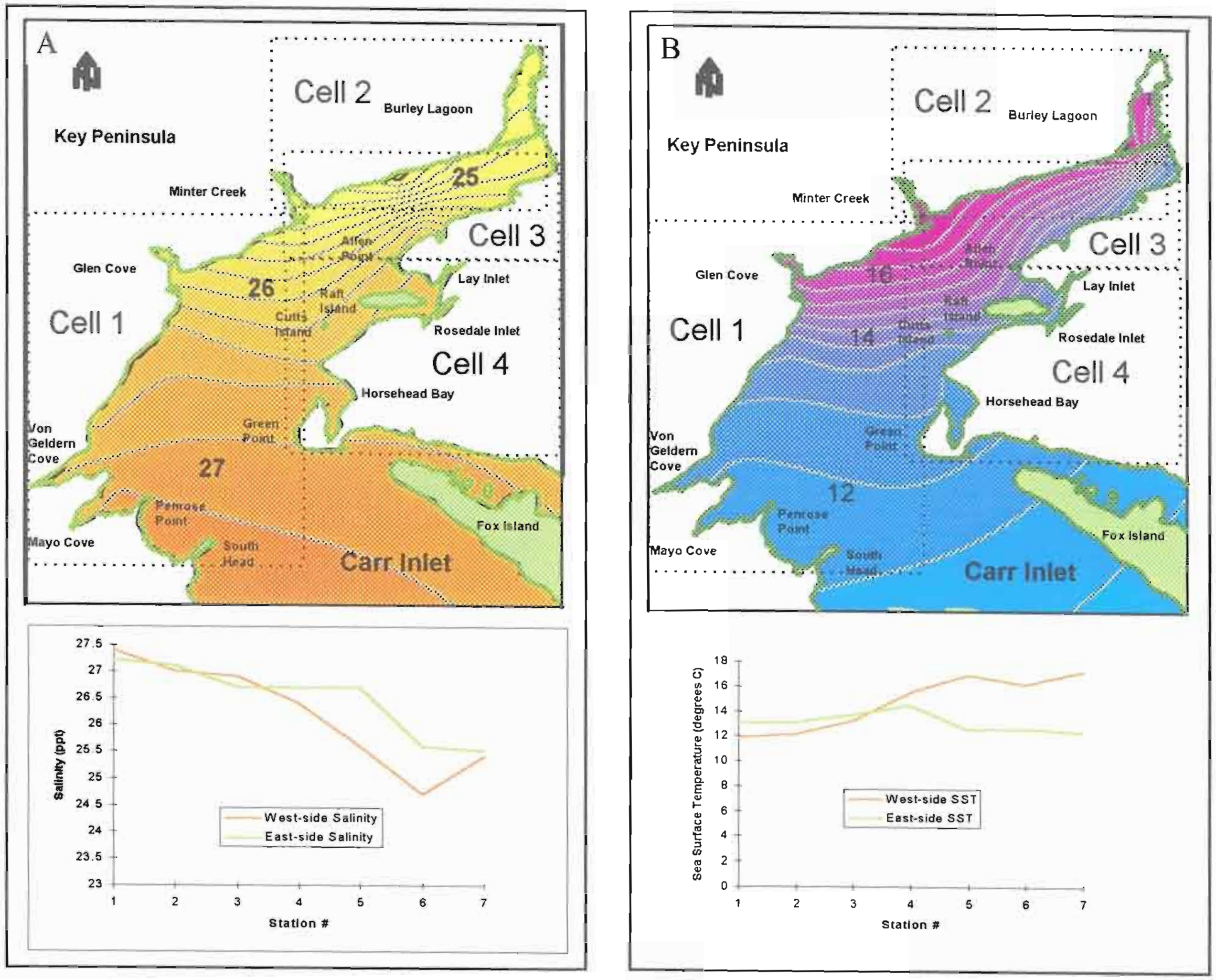

Figure 4. The sea surface salinity distribution (A) and the sea surface temperature (SST) distribution (B) for late April, 1997. The salinity is higher (orange) in southern Carr Inlet and lower (yellow) in the north. SST is colder (blue) in the south and warmer (purple) in the north.

A key physical feature of the marine nearshore is wave energy which affects community structure both directly through episodic disturbance events and indirectly by controlling substrate dynamics over short and long temporal periods. The magnitude of wave runup or swash can also affect community structure by elevating zonation levels, delivering nutrients and preventing desiccation. In relatively protected areas such as Carr Inlet, wave runup is practically non-existent and large waves are infrequent, such that wave energy does little to directly structure the intertidal community. However, indirect effects include current propagation and substrate movement over long temporal scales. In Carr Inlet, the processes of sediment suspension and transport can be expected to occur primarily during the winter when strong southerly winds blow along the axis of the bay.

Ground surveys partitioned the intertidal beaches of Carr Inlet, in both the alongshore and across-shore, according to beach slope and substrate size (primary, secondary, and interstitial). Table 1 lists the various physical attributes measured on each beach segment. The geophysically homogeneous alongshore segments (10-100 meters in length) identified in the field were delineated on orthophoto basemaps during the spring low tides from April 8 -11, 1997. Each alongshore segment was vertically separated into four across-shore polygons centered at specific elevations that correspond to immersion times during the daily tidal cycle, based on the mean tidal statistics for Carr Inlet. Substrate size was measured according to the Wentworth particle size classification for the following percent cover categories (Pettijohn, 1949): primary (for particles comprising more than 60% of the substrate), secondary (for particles less than 40% of the substrate), and interstitial. Beach slope was measured with a hand held digital inclinometer. Substrate permeability and ground water salinity were measured in the lower intertidal zone by digging a hole to 0.3 m and inserting a perforated bucket. Permeability was quantified by the time required to fill the bucket with ground water, and salinity was measured *in situ*. Substrate roughness was qualitatively categorized based on the degree of armoring. Ground water seepage was estimated as a percentage of the polygon length exhibiting seepage from the beach prism based on photogrammetric interpretation of CIR aerial photos. Dynamism is the relative bed stability calculated using predicted wave velocities.

The effect of waves on beaches is best represented by surf characteristics such as the Iribarren number which requires calculations based on wave statistics. There are few published wave statistics for this area of Puget Sound, so for each segment the required parameters were calculated from measurements of maximum fetch, or the longest over water distance unimpeded by a landmass (obtained from a GIS coverage of the South Sound). We classified each distance measurement and estimated the wave statistics for each fetch class. The Iribarren number (a measure of wave dissipation) was calculated for each across-shore polygon since slope angles vary considerably across most segments: an upper intertidal seawall is generally highly reflective and a lower intertidal sand flat is highly dissipative.

The ground surveys delineated 310 alongshore segments, composed of 1227 across-shore polygons (309 upper, 304 upper-middle, 313 lower-middle, 301 lower: 'missing' polygons occurred, for example, in the shallow inlets where there was no low zone). SCALE

Table 1. The SCALE Nearshore Segmentation and Classification Model

Physical Units (see Howes et al., 1994)													
Alongshore Segments 10-100 m			Across-shore Zones 10-100 m										
Orientation	Wave Power (watts/m^2)	Drift Exposure	Zone	Area (m2)	Size	Iribarren	Mean Vertical Runup	Seepage	Slope	Dynamism	Permeability	Roughness	
1 = N	1 = 50	1 = same direction	1 = Backshore (uplands)	1 = 100-1,000	1 = clay	1 = <.5	1 = < 0.5m	present	1 = 1 - 2°	1 = < 1.0	1 = > 10 min	1 = very smooth (sand)	
2 = NE	2 = 250	2 = 135 degrees	2 = Supratidal (spray zone)	2 = 1,000 - 10,000	2 = mud	2 = .5 - 1.0	2 = 0.5 - 1.0m	absent	2 = 2 - 4°	2 = 1.0 - 2.0	2 = 5 - 10 min	2 = smooth (small pebbles)	
3 = E	3 = 1,000	3 = 90 degrees	3 = Upper Intertidal (MHHW)	3 = 10,00 - 100,000	3 = silt	3 = 1.0 - 2.0	3 = 1.0 - 2.0m		3 = 4 - 7°	3 = 2.0 - 5.0	3 = 2 - 5 min	3 = gnarled (cobbles)	
4 = SE	4 = 5,000	4 = 45 degrees	3 = Upper Middle Intertidal (MSL-MHW)	4 = 100,000 - 1,000,000	4 = sand	4 = 2.0 - 3.0	4 = 2.0 - 3.0m		4 = 7 - 10°	4 = 5.0 - 10.0	4 = 1 - 2 min	4 = rough (boulders)	
5 = S	5 = 10,000	5 = opposite direction	4 = Lower Middle Intertidal (MLW-MSL)	5 = > 1,000,000	5 = granules	5 = >3.0	5 = > 3.0m		5 = 10 - 15°	5 = > 10	5 = < 1 min	5 = crevices (blocks)	
6 = SW	6 = 25,000		5 = Lower Intertidal (MLLW)		6 = pebbles				6 = 15 - 20°				
7 = W	7 = 50,000		6 = Upper Subtidal (< 10 m)		7 = cobbles				7 = 25 - 35°				
8 = NW	8 = 100,000		7 = Lower Subtidal (>10 m)		8 = boulders				8 = 35 - 45°				
	9 = 200,000				9 = blocks				9 = 45 - 65°				
	10 = 400,000				10 = basement				10 = > 65°				
	11 = 600,000												
	12 = 1,000,000												

models biological community structure based on the premise that populations coexist in spatially predictable patterns. If the physical forces controlling ecological responses can be quantified for every beach over an area of interest, then similar beaches can be statistically grouped and the biota compared among group members. Beach members within a group should have more similar communities than members among groups. If biota are sampled from randomly selected group members, then the data can be inferred to all the remaining group members. Therefore the method used to group beach segments becomes critical when using this statistical extrapolation technique. When the beaches are exactly the same, the probability of finding the same biota are greatly improved. But very few (if any) beaches are exactly the same. Slight changes in any of the attributes described above can effect a change in community structure. Linked to these biophysical interactions are changes caused by interactions among taxa, compounding observed differences.

We chose to form groups based on intertidal elevation, three dominant substrate sizes, and oceanic attributes represented here by the nearshore cells and wave energy. Area was also a grouping criterion to account for beach size, since we know that small habitats are confounded by edge effects and small populations are generally more at risk to perturbations. Figure 5 shows the distribution of low zone segment clusters in terms of the number of segments per cluster, and the shoreline length and shore area represented by each cluster. Spatially dominant habitats in the lower zone are semi-protected sand, protected sand, protected silt and mud, protected pebbles, and sheltered mud. These represent 58% of the total shore length. The biological sampling design was centered around these analysis groups.

1997 Biological sampling

Schoch et al. (1999, and summarized above) describe the SCALE model for partitioning and classifying shorelines such that geophysical homogeneity within a beach segment is maximized. Here we summarize to what extent this process leads to biotic homogeneity. See Schoch and Dethier (1998) for a complete description of methods and results.

Spatial and temporal variation of macrofauna and macroflora on sand, mud, and cobble beaches were examined simultaneously over three nested scales in Carr Inlet during springtime low tides in May, 1997. Data were taken at 3 sand, 3 mud and 3 gravel beach segments in each of 3 zones (at 0, 1.5, and 3 m above MLLW), and additional data were taken at 6 sand, 3 mud and 2 gravel segments in the lower zone only. Sampled segments were selected randomly from the spatially dominant geophysical groups described above. At each sampled level, a 50 m horizontal transect was positioned near the center of the segment to eliminate edge effects. A total of 10 random samples were collected along each transect (as shown on Figure 6). Each sample consisted of quantifying epiflora and fauna in a 0.25 m^2 quadrat, and infauna in a 10-cm diameter core dug to 15 cm depth. Core samples were sieved on 2 mm mesh. Several samples from each substrate type were also sieved to 1 mm, but few additional organisms were retained. All organisms not identifiable in the field were placed in formalin and later identified in the lab, when possible to the species level.

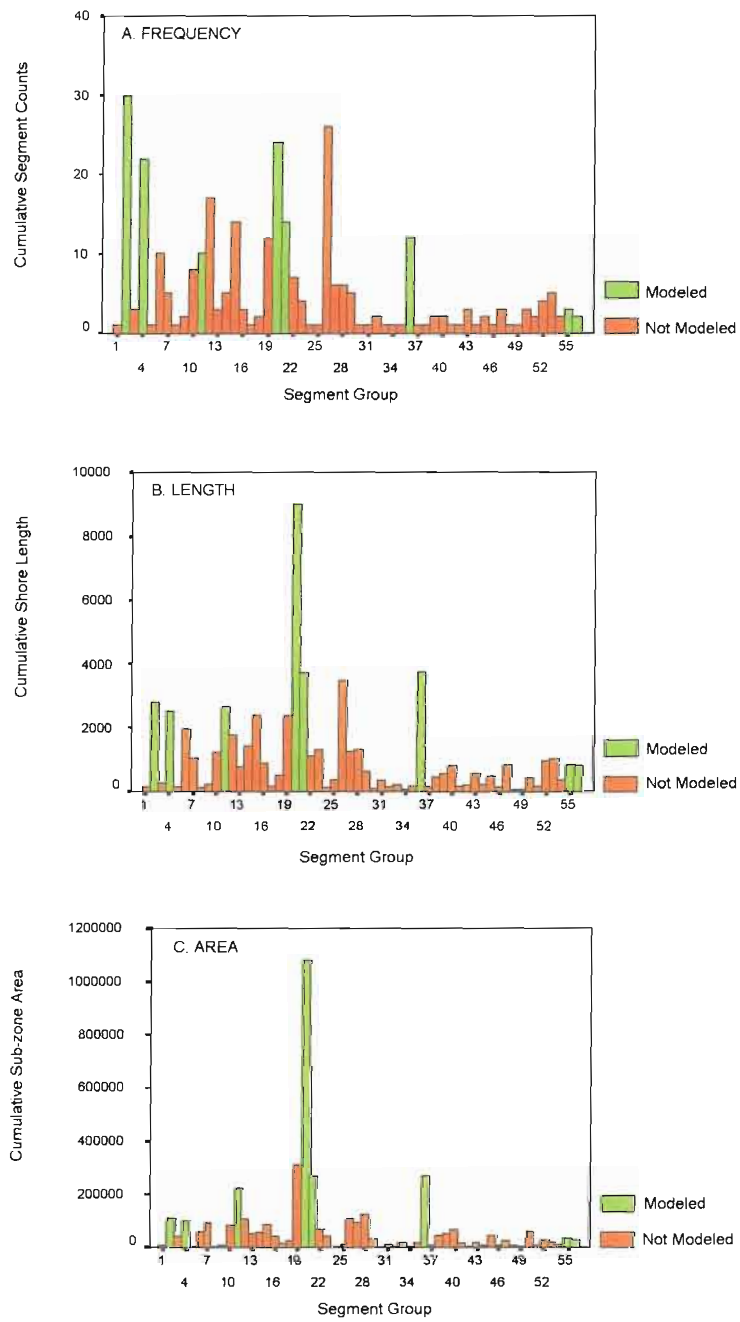

Figure 5. Lower sub-zone segment group distribution by A) frequency, B) cumulative shore length, and C) the cumulative polygon area. Also, shown in green are the groups sampled/modeled vs. the red which have no data other than the physical attributes. Note that low numbered groups represent smaller substrate sizes. In terms of area and shore length, the sand flats of group 20 are the most extensive, and the pebble group 36 are also large in area and shorelength. Mud segments of group 2 and 4 are the most frequent but do not contribute much to the shore length or area. Cobble segments of group 55 and 56 are low in number, shore length and area.

The three nested spatial scales for each shore type were: sample blocks within a segment (tens of meters), segments within a nearshore cell (kilometers apart), and nearshore cells within the Inlet (tens of kilometers apart). Our predictions, based on the SCALE model, were:

1. Within a beach segment (i.e. among the 5 sections of the transect line) there should be high biotic uniformity – since beach segments were defined by being geophysically homogeneous, the biota were predicted to be homogeneous, too.

2. Among beach segments that clustered together within a cell, i.e. were all fairly similar geophysically, the biota should again be similar.

3. Among beach segments in different cells, i.e. varying more in wave energy and salinity but still very similar in substrate type, we expected more biotic variability.

4. Among segments that did not cluster together, i.e. different substrate types, we expected very high biotic variability.

<u>1997 Statistical analysis</u>
Multivariate techniques were used to detect patterns in the communities across spatial scales. The data sets were transformed (to improve normality) and ordinated using non-metric multidimensional scaling to evaluate how each performed in describing the differences in community structure among the groups of sample units. Graphical plots of ordination results for the two axes explaining the greatest proportion of the variance were examined together with overlays of the various grouping variables (the different spatial units). Formal significance tests for differences among groups, either in species abundances or species presence/absence, were computed using a non-parametric multi-response permutation procedure.

For each species at each spatial scale we also calculated an 'indicator value' (Dufrene and Legendre, 1997)which integrates the 'reliability' or fidelity of each species to its habitat. This value combines information on the evenness of species abundances in a particular group of samples and the fidelity or faithfulness of occurrence (frequency) of a species in that group.

We used fully nested ANOVA to show how population variability was distributed over different spatial scales, thus determining the species whose abundances could be extrapolated from segment-level spatial scales to larger areas with a minimum of increased variability.

1997 Results Summary

A total of 840 quadrats and cores were collected, containing a total richness of 114 taxa. We found 86% of these taxa in the lower zone, 43% in the middle, and 18% in the upper.

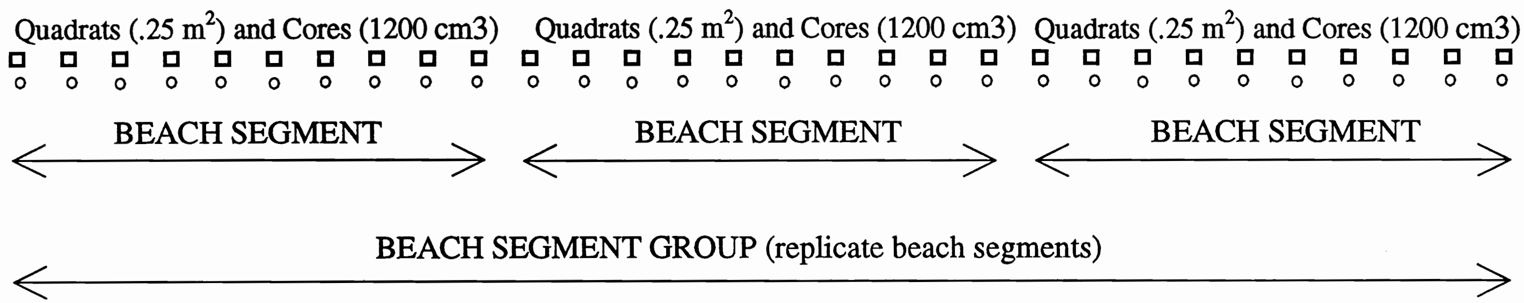

Figure 6. Nested sampling design to test hypotheses of lower zone (0 m, MLLW) biotic similarity among replicate beach segments. Quadrats (.25 m^2) are used to estimate the percent cover of sessile algae and invertebrates, and counts of mobile invertebrates. Sediment cores (1200 cm^3) were sieved (2mm mesh) for counts of infauna. Segment group is the highest level of the hierarchy, with 3 replicate beach segments representing the habitat in one nearshore cell.

The sand habitats had 113 taxa, while the gravel had 94 and the mud had 58. Biota among substrate types differed especially clearly in the low zone. Low zone sand segments were either dominated by the sand dollar *Dendraster* (reaching densities of >1000/m^2) and had few other infauna, or had no *Dendraster* and a diverse infauna of burrowing sea cucumbers, anemones, and tube-building and mobile polychaetes. Low gravel segments were characterized by barnacles and ephemeral green algae on the surface, and extremely numerous capitellid polychaetes in the sediment, often with a variety of predatory worms such as nemerteans, glycerids, goniadids, and hesionids. Low mud segments were dominated by ghost shrimp and associated commensal fauna such as small clams and crabs that inhabit shrimp burrows, and by capitellid and predatory polychaetes. Ephemeral green algae, opisthobranch molluscs, and shore crabs were found on the surface in many segments.

The ordination plots and analyses of similarity showed consistent within-segment homogeneity relative to among-segment heterogeneity, suggesting that the partitioning model was successful in reducing geophysical gradients that cause ecological heterogeneity at the scale of interest. However, some plots also show there is still a moderate amount of variability in biota among beaches that clustered together. Thus a key conclusion is that looking at broad-scale patterns in biota of shorelines will always entail accepting much inherent variability, because the biota shifts in character with fairly subtle changes in physical characteristics.

The calculated indicator values allowed an assessment of species that could be considered characteristic of a particular set of geophysical conditions, i.e. ones that tended to be found with high fidelity in a group of samples. Ordinations of all the low-zone taxa showed that the gravel groups had their patterns driven especially by the epifaunal *Balanus glandula* and *Enteromorpha*, and the infaunal polychaetes *Micropodarke* and *Notomastus tenuis*. One gravel group (in a slightly higher-energy area) was distinct from another by having *Acrosiphonia, Crepidula, Ophiodromus*, and Piddock clams. Two of the mud groups separated from the rest by having abundant populations of *Neotrypaea (=Callianassa), Glycinde*, and *Tellina*. All three sand groups shared nemerteans (not common, but present in all groups), *Punctaria, Spiochaetopterus*, and ulvoids, but only sand segments in Cells 1 and 3 had significant populations of *Dendraster* and *Scoloplos*, and only Cell 2 (warmer, lower salinity) had *Edwardsia, Haminoea* eggs, and *Notomastus lineatus*.

Results of the community extrapolation for the lower sub-zone showed that 31 segments out of 305 (10%) were sampled, representing 7 of 56 segment groups. These sampled segments allowed for 117 segments (35%) to be modeled or extrapolated in terms of the biota that should be present. The 117 segments are representative of a cumulative shore length of 26,264 meters or 44% of the project shoreline length (52% of the project area).