Lummi Intertidal Baseline Inventory

Appendix I:
Ecological Analysis

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Executive Summary

During the Intertidal Biota Survey (Appendix A) environmental data were collected in addition to benthic community samples. These data were analyzed using the results of a Detrended Correspondence Analysis (DCA) that distributed sites on a graph based on similarities and dissimilarities in the biota community that were present at those sites.

Biota that had a strong effect on the separation of sites during the DCA included purple varnish/mahogany clams, periwinkles, caprellid amphipods, eelgrass isopods, and chironomids.

Environmental variables that were found to have a significant effect on benthic community structure included tidal elevation, beach slope, salinity, substrate size, percentage of cover of barnacles (infraclass Cirripedia), percentage of cover of mussels (*Mytilus trossulus*), percentage of cover of Japanese eelgrass (*Zostera japonica*), percentage of cover of Pacific eelgrass (*Zostera marina*), and percentage of cover of red, brown, and green algae. Of these, the five variables that had the strongest relationship with community structure were tidal elevation, beach slope, salinity, substrate size, and percentage of cover of Pacific eelgrass. These findings are broadly consistent with the environmental gradients (vertical elevation, wave exposure, particle size, and salinity) that are known to determine biological patterns and ecological processes in intertidal zones worldwide (Raffaelli and Hawkins 1996).

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1.0 Introduction

Environmental factors such as elevation, salinity, substrate, exposure, vegetative cover, and structural complexity typically vary across tideland areas, and as a result, they form a series of environmental gradients. These gradients can potentially interact to determine the diversity and abundance of organisms found at any particular location (Raffaelli and Hawkins 1996). Accordingly, some sites that are located in different geographical areas may be more similar to each other than they are to other sites that happen to be within the same geographical area but that have a different set of environmental conditions.

An understanding of the relative importance of these environmental gradients and their relationships with the biota of the tidelands is necessary to develop predictive models that can potentially be used for resource management purposes such as planning resource enhancement, assessing impacts of environmental changes, or predicting the presence of biota that may be found in similar areas that have not been previously surveyed. It also allows the survey results to be aggregated based on the environmental variables present at each site instead of arbitrary geographical labels, and this allows estimates of abundance to be refined by stratifying the tidelands based on these environmental variables.

The LIBI Final Work Plan (LeMoine *et al*. 2009) identified the need to obtain data suitable for an ecological analysis of environmental variables and their influence on the diversity and abundance of the biota of the Lummi Reservation tidelands. To meet this objective, several environmental variables were derived from field data collected during the Light Detection and Ranging (LiDAR) survey (Appendix G) and the Intertidal Biota Survey (Appendix A), using Geographical Information System (GIS) analysis (Appendix H). These variables included beach elevation, beach slope, minimum salinity, wind fetch, and a Substrate Coarseness Index (SCI). Additionally, field observations of surface coverage of vegetation and habitat forming organisms (e.g., mussels, oysters) that provide structural complexity were collected during the Intertidal Biota Survey and were also included in the ecological analysis.

The objective of this ecological analysis is to:

- Determine the similarity of sites based on the biological communities present;
- Identify key species that best explain the separation of the sites;
- Determine which of the habitat variables that were measured best explain the observed patterns of benthic community structure on the Reservation tidelands;
- Describe the relationships between these habitat variables and the community structure observed at sites that were sampled in the LIBI.

2.0 Methods

The Vegan library in the R statistical computing platform (Hornik 2009; Oksanen *et al*. 2010) was used to conduct the ecological analysis. Since it was impossible to identify all of the organisms encountered in the Intertidal Biota Survey to species-level, the biological communities described here are restricted to the taxonomic resolution described in Appendix E.

Three ordination methods were tested to assess if sites were dissimilar based on the biotic community observed. These methods consisted of Principal Component Analysis (PCA); Correspondence Analysis (CA); and Detrended Correspondence Analysis (DCA).

These methods all separate sample locations based on the type and number of benthic organisms present at each site through the calculation of distances using eigenvalues. This is conceptually similar to defining specific sites on a map using geographical information, such as latitude and longitude, but in this instance, biological ‘coordinates’ are used instead of geographical ones. The result is a ‘map’ that shows the relation of the sites to each other in terms of biological similarities or dissimilarities, not in terms of spatial position. Once the sites have been ‘mapped’ using the characteristics of the biological communities, environmental measures at each site can then be assessed to determine whether one or more environmental gradients are influencing biological community structure across the Reservation tidelands.

Principal Component Analysis is a variance-based ordination that identifies “components” explaining the greatest amount of variance in all parameters. The PCA performs well over short gradients and with linear relationships. However, this method was not used because some of the environmental gradients measured in the LIBI appeared to have a non-linear relationship with the biota.

Correspondence Analysis and Detrended Correspondence Analysis methods both separate data using chi-squared values and are more robust than PCA with data that vary over long gradients and have nonlinear relationships. The DCA method also attempts to lessen the affect of extreme values commonly witnessed in biotic abundances where one taxon is dominant. Detrended Correspondence Analysis is commonly used in ecological analysis (e.g., McLachlan 1996) and has been described as a robust tool for investigating biological communities (Hill and Gauch 1980).

For the Intertidal Biota Survey data, DCA provided the best separation and was the best descriptor of the sites. Accordingly, DCA was used to separate the LIBI Intertidal Biota Survey sites based on the characteristics of their biological communities. All environmental measures were related to the ordination of sites resulting from the DCA using standard Spearman's correlation. For this correlation, p-values were assessed from the data set directly using a bootstrap method scripted within the Vegan library with 100,000 iterations. Statistically significant habitat parameters were reported. The gradients of the five habitat parameters that showed the strongest relationships with the

DCA of the taxonomic communities were then plotted across the DCA. The Vegan library in R offers this ability through the *efit* function.

3.0 Results

Separation of sites based on biological communities generally followed a continuum along both of the DCA axes (Figure M.1) and no distinctly different groupings of sites were observed. However, some sites showed localized clustering along DCA axis 1.

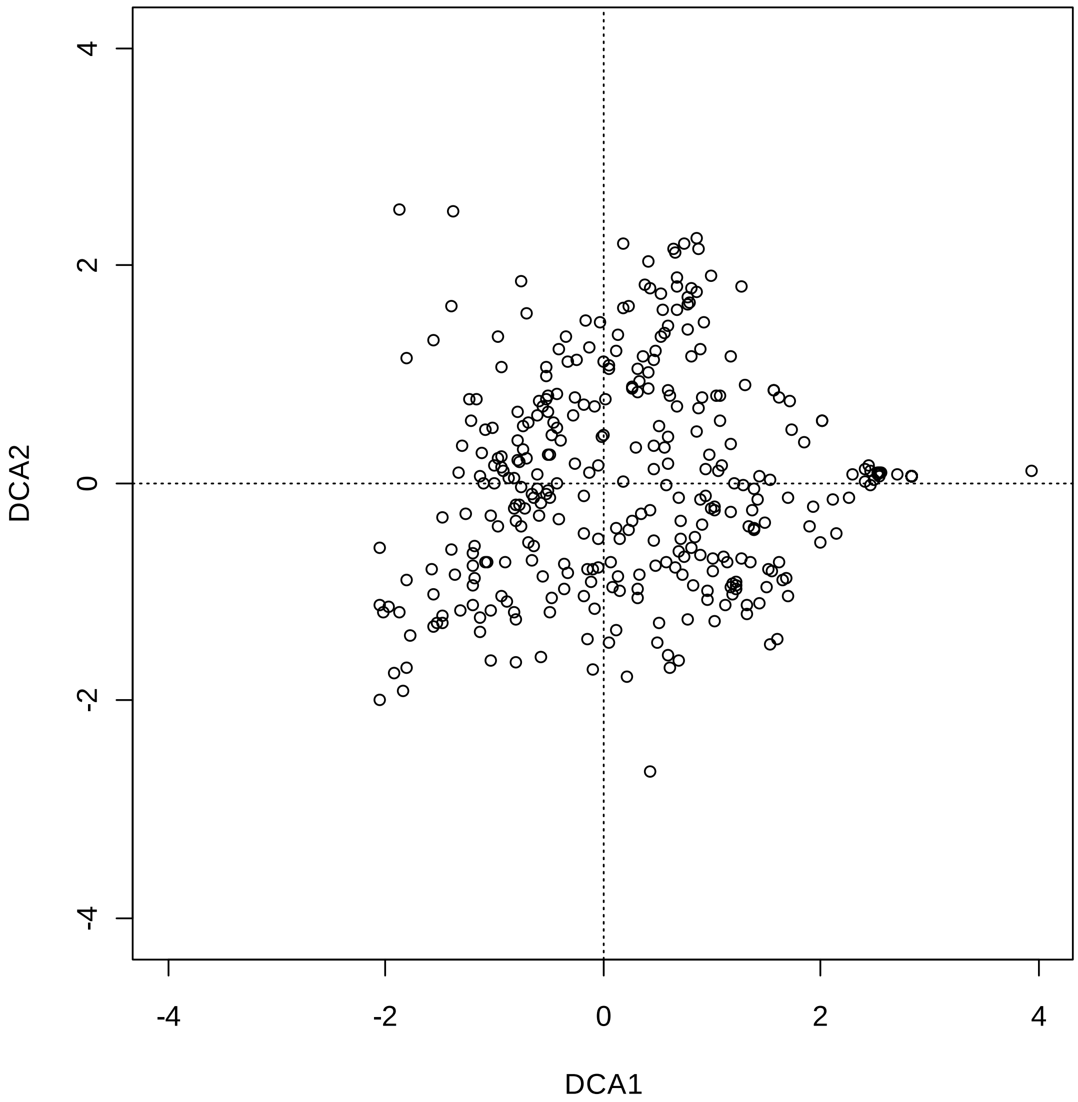

Figure M.1. Ordination of Intertidal Biota Survey Sites Using a Detrended Correspondence Analysis of Taxonomic Communities

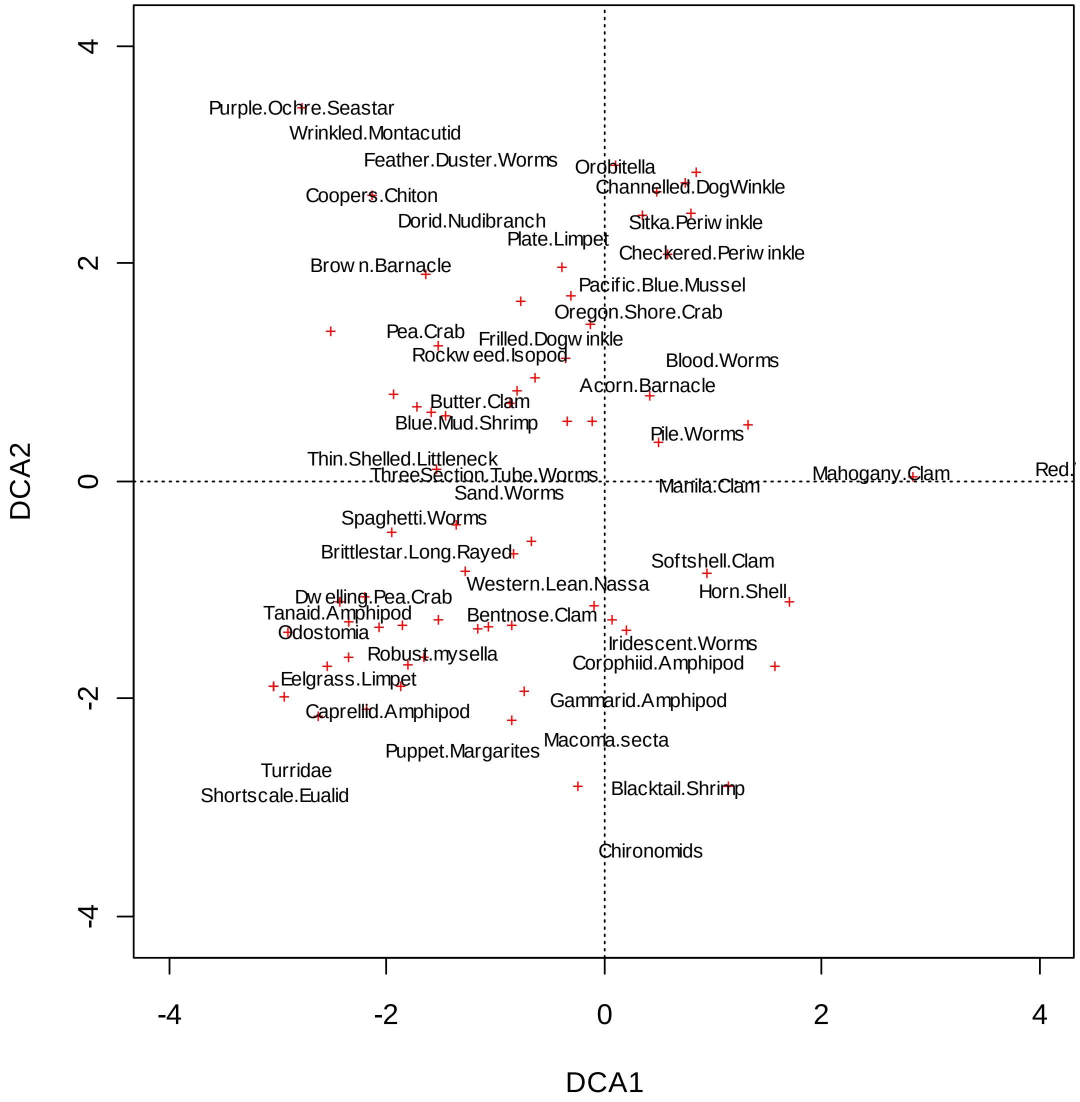

Figure M.2. Loadings of the DCA Ordination by Individual Taxa (not all taxa are labeled due to space limitations)

The taxonomic loadings on the DCA coordinates of sites generally exhibited ecologically meaningful trends (Figure M.2). For example, the presence of Caprellid amphipods (*Caprella* sp.) and eelgrass isopods (*Idotea resecata*) both had the effect of shifting the DCA coordinates of sites in a similar direction, which is to be expected because both taxa are highly associated with eelgrass meadows on soft sediments in the lower intertidal zone. However, the presence of periwinkle species (*Littorina* spp.) had the opposite influence on the DCA coordinates of sites, which is unsurprising given that periwinkles are usually associated with rocky substrates in the upper intertidal zone (Kozloff 2000).

Overall, purple varnish/mahogany clams (*Nuttalia obscurata*) and red velvet mites (*Neomolgus littoralis*) provided the strongest positive weighting along DCA axis 1. Tidal elevation, beach slope, salinity, percentage of cover of acorn barnacles (infraclass Cirripedia), percentage of cover of mussels (*Mytilus trossulus*), percentage of cover of Japanese eelgrass (*Zostera japonica*) and Pacific eelgrass (*Zostera marina*), percentage of cover of red, brown, and green algae, and the substrate coarseness index all had a significant relationship with the DCA of the taxonomic communities (Table M.1) indicating that these habitat variables have a significant impact on community structure.

Table M.1. *Habitat Measures and Spatial Information Relationship to the DCA of Taxonomic Communities.*

	VECTORS	**DCA1**	**DCA2**	**r^2**	**Prob.(>r)**	**Signif.**
	Tidal Height	0.9219	0.3874	0.492	0.00001	***
	Slope	0.4763	0.8793	0.366	0.00001	***
	Fetch	0.2285	**-0.9735**	0.001	0.81754	
	Salinity	**-0.4177**	-0.9086	0.066	0.00001	***
Percentage of Cover	**% Barnacles (Infraorder Cirripedia)**	**-0.0846**	0.9964	0.160	0.00001	***
	% Horn Snails (*Batillaria attramentaria*)	0.5661	**-0.8244**	0.007	0.33608	
	% Mussels (*Mytilus trossulus*)	**-0.0245**	0.9997	0.025	0.02017	*
	% Oysters (*Crassostrea gigas*)	0.3295	0.9442	0.005	0.47787	
	% *Jap. Eelgrass* (*Zostera japonica*)	**-0.1161**	**-0.9932**	0.044	0.00114	**
	% *Pac. Eelgrass* (*Zostera marina*)	-0.7179	-0.6961	0.325	0.00001	***
	% Saltmarsh Plants	0.9558	0.294	0.001	0.82127	
	% Brown Macroalgae	-0.7531	0.6579	0.048	0.00065	***
	% Green Macroalgae	-0.9446	0.3282	0.081	0.00002	***
	% Red Macroalgae	-0.4897	0.8719	0.032	0.00792	**
	SCI.Score	-0.0348	0.9994	0.352	0.00001	***
	Jap. Eeelgrass (shoots)	0.9965	0.0836	0.006	0.37123	
	Pac. Eelgrass (shoots)	-0.0733	0.9973	0.007	0.34601	
	Signif. Codes: '***' 0.001 '**' 0.01 '*' 0.05					

P. values based on 100,000 permutations.

Of these environmental gradients tidal elevation; beach slope; salinity; percentage of cover of Pacific eelgrass, and the substrate coarseness index have the strongest Spearman's correlation coefficients.

The influence of the remaining environmental gradients, such as the percentage of cover of macroalgae and habitat-forming organisms, was similar in effect to the ordination loadings for the organisms that are closely associated with those habitats (Figure M.3). For example, rockweed isopods (*Idotea wosnesenskii*) are most likely to be found at sites with brown macroalgae, and both rockweed isopods and percentage of cover of brown macroalgae have a similar loading on the separation of sites in the DCA.

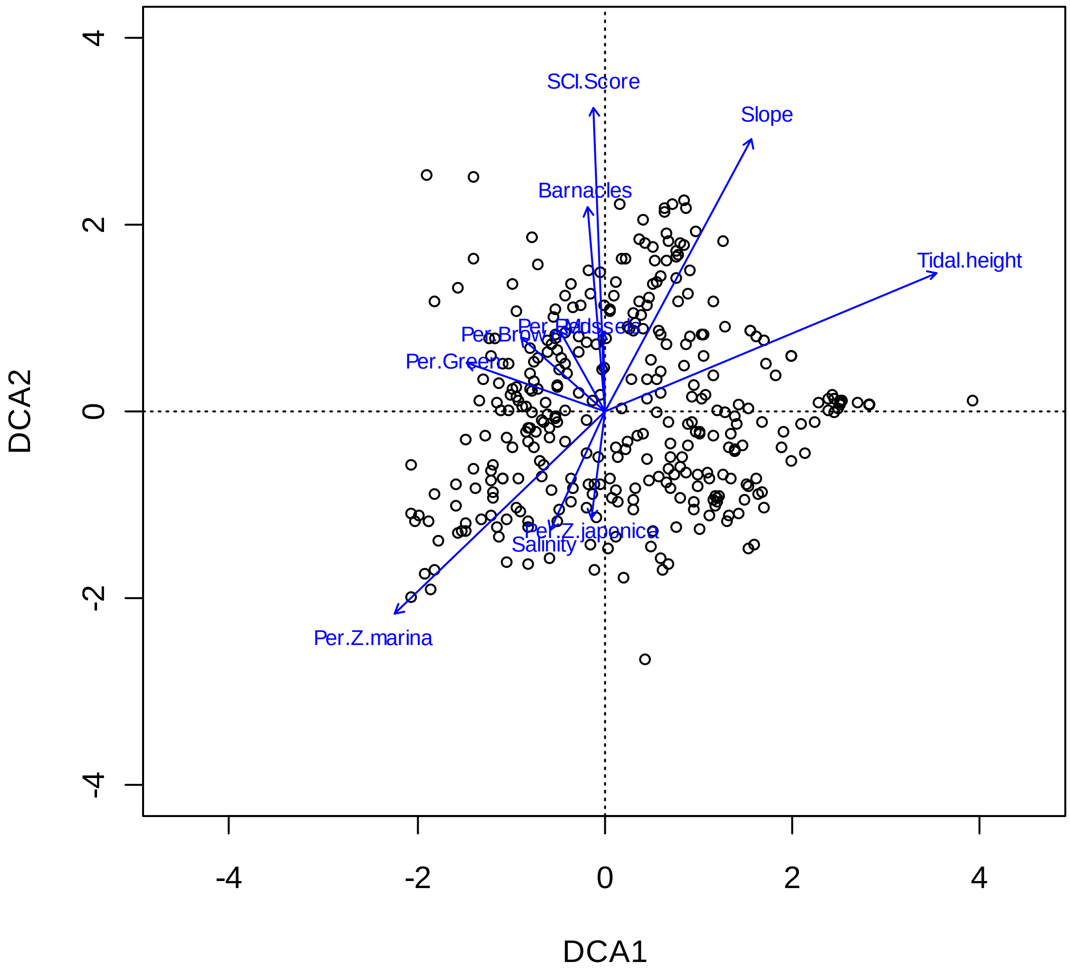

Figure M.3. Loadings of the DCA Ordination by Individual Environmental Gradients

The five most influential habitat parameters were selected to assess the role of these environmental gradients across the DCA of biological communities. This selection was based on the Spearman correlation coefficient within the DCA (r^2 in Table M.1). The gradient map of each of these parameters is shown in Figure M.4. Because the DCA is an adjusted correspondence analysis, the extreme sites have a reduced separation compared to other sites, and the actual relationships between the environmental gradient and the sites are limited by this adjustment.

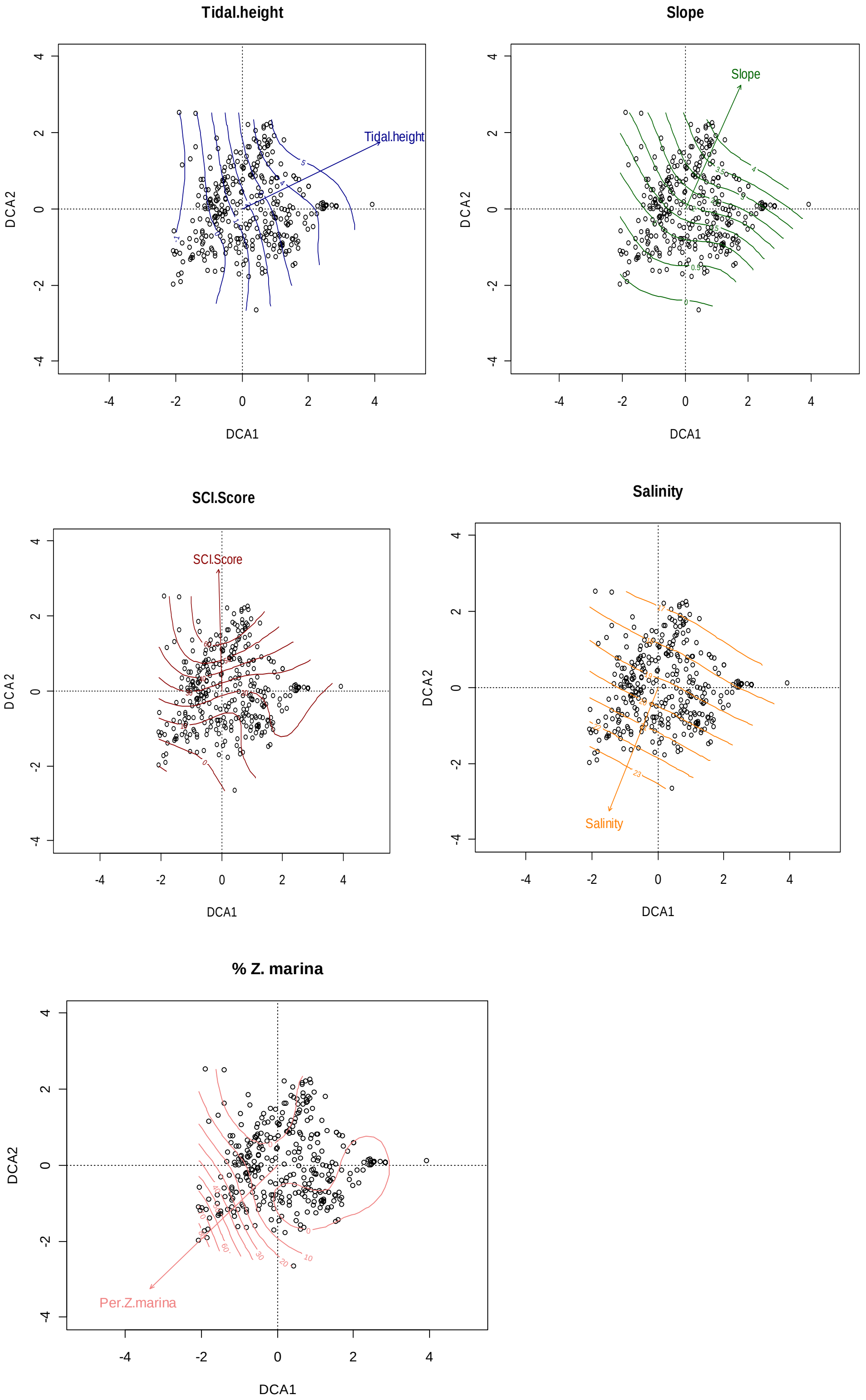

Figure M.4. Gradients of the Five Most Influential Habitat Parameters Overlaid on the DCA Map of Intertidal Biota Survey Sites

The tidal height gradient is relatively uniform across the range of beach elevations measured in the Intertidal Biota Survey, although there appears to be a slight decrease in the influence of this parameter at higher elevations.

The effect of beach slope on community structure appears to have a non-linear gradient that is relatively uniform for sites with high to moderate beach slopes but which has a reduced gradient for sites with comparatively flat slopes.

Salinity has a regular, linear gradient across the sites within the DCA plot.

The gradient of the substrate coarseness index (SCI) parameter is somewhat discontinuous when plotted over the DCA: there are plateaus at each end of the continuum that exhibit very little slope, separated by a comparatively steep gradient across the intermediate values.

Similarly, sites with 0% to 10% coverage of Pacific eelgrass tended to show no gradient, but a relatively strong, regular gradient was evident for sites that had greater than 20% Pacific eelgrass coverage.

4.0 Discussion

Similarity of Sites Based on Biological Communities

The DCA analysis showed that although there was some local-scale clustering of sites in the ordination, the sites were generally distributed along a continuum of biological community structures that result from multiple environmental gradients interacting together.

Key Species that Best Explain the Separation of the Sites

The species that had the most influence on the positioning of sites in the DCA tend to occupy distinctly different niches. For example, purple varnish (mahogany) clams tend to be distributed high on the shore, and in areas of reduced salinity. Species that occupy rocky substrates in medium to upper elevations, such as periwinkles, mussels, dogwinkles (*Nucella* sp.), plate limpets (*Tectura scutum*), and shore crabs (*Hemigrapsus* sp.), tended to group sites similarly to each other, but at the opposite end of the spectrum from species that tend to prefer soft substrates and associations with Pacific eelgrass, such as caprellid (*Caprella* sp.) and tanaid (Order Tanaidacea) amphipods, eelgrass limpets (*Lottia alveus paralella*), and eelgrass isopods. Chitons, seastars, nudibranchs, and rockweed ispods are more typically found near the subtidal fringe on heterogeneous substrates associated with red/brown macroalgae, rather than eelgrass, and these too tended to group sites similarly to each other. These observations suggest that the DCA method groups the sites in ways that make ecological sense for the communities of taxa present at those sites.

Habitat Variables that Best Explain Benthic Community Structure

The analysis of ecological parameters indicated that several of the environmental parameters examined helped to explain the observed patterns in biological community structure at sites (Table M.1). The five ecological parameters that appeared to have the most biological significance were tidal height (elevation), beach slope, substrate coarseness index values (particle size), surface cover by Pacific eelgrass, and salinity. These findings are generally consistent with the major environmental gradients (vertical elevation, wave exposure, particle size, and salinity) that are thought to determine biological patterns and ecological processes in intertidal zones worldwide (Raffaelli and Hawkins 1996)

Relationships Between Important Environmental Variables and Community Structure

Tidal elevation determines the amount of time that intertidal organisms are exposed when the tide is out and the duration of submergence when the tide is in. The results of this analysis showed this parameter has a strong influence on community structure and that the importance of this factor is relatively consistent across the vertical extent of the beach. For sites near the upper limit of the intertidal zone, the communities present are slightly less responsive to small changes in beach elevation.

Beach slope is related to wave energy, as high-energy waves can erode the shoreline and create steeper beach profiles. In turn, incoming wave energy is dissipated over different distances depending on beach slope, which exacerbates or mitigates the turbulence experienced by epibenthic organisms and modifies the substrate stability for burrowing infauna. The results of this analysis suggest that community structure is strongly affected by small changes in beach slope at sites with steep or moderately steep slopes, and less affected by small changes on relatively flat beaches.

The results of the analysis of salinity suggest that community structure varies similarly in response to small changes in salinity across the entire range of values observed.

Community structure at sites dominated by very fine or by very coarse sediments appears to be relatively unresponsive to small changes in the Substrate Composition Index. However, community structure at sites that have a mixture of intermediate-sized substrates is in comparison much more responsive to changes in substrate composition. This suggests that there are stable specially adapted communities that are found at sites with fine sediments only, and at sites with primarily rocky substrates, but that communities found on mixed/intermediate substrates vary depending on the specific proportions of fine and coarse sediments present at each site.

The results for Pacific eelgrass suggest that eelgrass coverage provides comparatively little influence on community structure when the surface coverage of Pacific eelgrass is sparse (<20%), but has a much stronger influence at moderate to high eelgrass shoot densities.

Each of these environmental variables influences individual taxa in different ways, which consequently helps explain the observed differences in community structure between sites. The correlations between each of these variables and some selected species are provided in Appendix A. However, the existence of a statistically significant correlation between two entities does not necessarily mean that one directly influences the other. It is also possible that both entities are related to a third entity, which provides the causal link for the observed relationship. Nonetheless, with additional work it would be possible to derive models from the data that may be able to predict the presence and abundance of these organisms given a particular set of ecological circumstances within the Reservation tidelands. Such a model would allow qualitative inferences to be made on how the biology will change if these habitat variables change over time, and may even enable a limited predictive capability for nearby beaches that exist off the Reservation.

5.0 References

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