CHAPTER 6. MACROFAUNAL ASSEMBLAGES

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I. INTRODUCTION

Macrofauna constitute a myriad of small-bodied (>1.0 mm in any one dimension) invertebrate organisms living in or on the sediments. They are an important component of the marine ecosystem, playing an important role through their feeding and burrowing (bioturbation) activities, stabilization of sediments through tube-building, input of larvae into pelagic and soft-bottom ecosystems, and trophic dynamics as both prey and predator. The macrofauna, being less mobile than the larger invertebrates and fishes, more accurately reflect the changes in the physical and chemical conditions of the soft-bottom ecosystem than the more mobile organisms. Monitoring the macrofaunal community is important because these organisms live in direct contact with the sediments and often ingest sediments and suspended particulates, which may contain organic food and/or contaminants (Gray et al. 1992, Diener et al. 1995). Soft-bottom sediments provide a long-term record of changing environmental conditions reflecting the effects created by natural or man-made disturbances. Impacts of anthropogenic inputs, particularly those of sewage outfalls, will be manifested in the soft-bottom sediments by changes in macrofaunal community structure (e.g., abundance, diversity, and biomass). The soft-bottom macrofauna represent a community where the species assemblage can reflect a gradient of tolerances (enhancement to degradation) in relation to environmental (man-made or natural) stresses (Pearson and Rosenberg 1978, Thompson et al. 1987, Gray 1989, Weston 1990, Ferraro et al. 1991,Warwick and Clark 1993,1994, Diener et al. 1995, Sheppard 1995).

The macrofaunal assemblages of Los Angeles Harbor have been well documented by baseline studies since the mid-1970's (HEP 1976a, 1980, 1983; SCOSC 1979, 1982; MEC 1988). Environmental Impact Reports have utilized these baseline surveys in assessing the potential impacts associated with the Pier 300/400 Implementation Project (PIP) (ACE 1992), the TITP Outfall Modernization Project (ES 1994) and the Port of Los Angeles Channel Deepening Project (ACE 2000). Increment 2 of PIP, began in 1994 and completed in July of 1996, consisted of dredging existing navigation channels in Outer Los Angeles Harbor to a depth of 63 feet (ACE 1992). This project provided fill for 143 acres of Pier 400, the Access Corridor to Terminal Island, and the Shallow Water Habitat near Cabrillo Beach (ACE 1992). In conjunction with Increment 2 of PIP was the dredging for and placement of the new TITP outfall extension through the future Increment 3 fill for Pier 400 that extended into the Outer Los Angeles Harbor from the southeast face. With the new outfall in place, secondary effluent began discharging into the Outer Los Angeles Harbor from the southeast face of Pier 400 during the last week of July 1996. Any impacts created during the outfall construction activities and the initiation of effluent being discharged was expected to be minimal, when compared to the impacts associated with the PIP (ACE 1992). With no further dredge or fill disturbances following the completion of Increment 2 of PIP, normal recovery would have been expected to occur within 1-3 years through both adult and larval recruitment (Oliver et al. 1977, Rosenberg 1977).

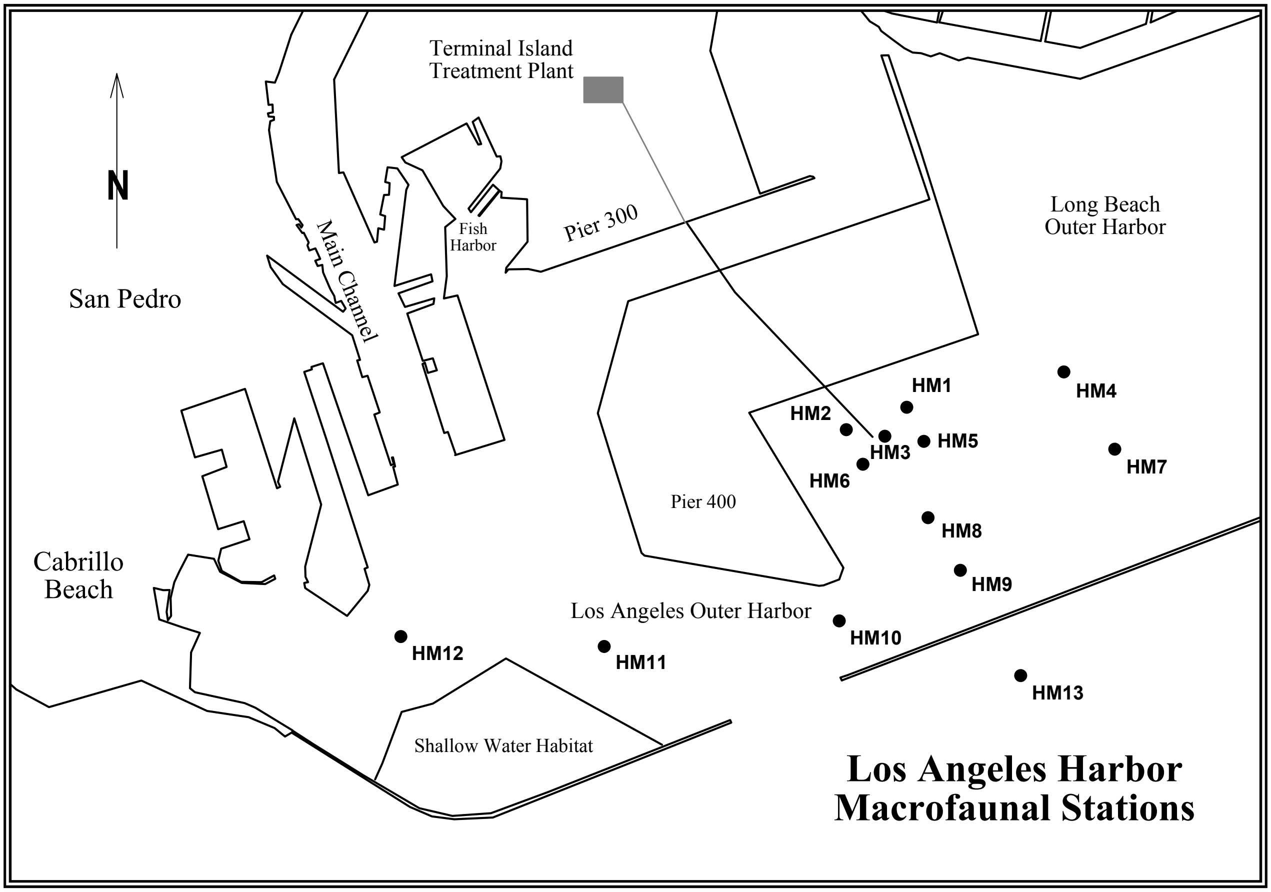

Figure 6-1. Macrofaunal sampling stations in Los Angeles Harbor.

With implementation of Increment 3 of PIP in August 1996, navigation channels originally dredged to 63 feet were further deepened to 81 feet. In addition, new channels and a turning basin were dredged around the southeast side of Pier 400 (see Figure 6-1) to 75 feet (ACE 1992). This dredge material provided fill for an additional 337 acres (north portion) of Pier 400 (ACE 1992). The newly redredged channels and turning basin again saw the total destruction of most of the soft-bottom macrofauna that had recently recolonized the area. Further short-term impacts on the surrounding soft-bottom community (see CLA, EMD 1998, Chapter 1) were expected due to the effect of turbidity plumes resulting from the associated fill operations. Recolonization of the impacted areas should be quite rapid, with recovery of the soft-bottom macrofaunal communities probably not being fully complete for 2-3 years. The composition of the reestablished species assemblages will likely show some variability from those found prior to the initiation of the PIP due to the biotic and abiotic conditions created by the new Outer Harbor shoreline configuration and water current circulation patterns.

The soft-bottom habitat affected by Increments 2 and 3 of PIP was greatly perturbed as a result of dredging and fill activities associated with the construction of Pier 400. With the completion of Increments 4 and 5 expected by the year 2010 (ACE 1992), Pier 400 will have caused the permanent loss of 25% of the original Outer Los Angeles Harbor habitat for soft-bottom macrofauna (ACE 1992).

As required by the Regional Water Quality Control Board (RWQCB), the macrofauna in the vicinity of the TITP outfall are to be monitored to determine impacts that may have occurred due to the discharge of secondary effluent. Due to dredge and fill activities associated with Increment 2 of the PIP, major disruptions occurred in the original 1993 NPDES-required permit sampling program. Following approval by the RWQCB in September 1995, an Interim Monitoring Program was initiated (see Chapter 1). With completion of the new TITP terminus and the initiation of effluent discharge into the new area of the Outer Harbor next to the southeast face of Pier 400 in July 1996, the TITP marine monitoring program was reevaluated to accurately assess any environmental impacts that may occur at this discharge point. With the approval of the RWQCB in July 1996, the Post-Pier 400 Monitoring Program was implemented in August 1996 (see Chapter 1).

Since the 1996 summer survey, with the exception of the 1998 summer survey, the Los Angeles Harbor Annual Assessment Reports (CLA, EMD 1997-2002 and this report) have been based on the Post-Pier-400 Monitoring Program.

II. MATERIALS AND METHODS

A. SAMPLE COLLECTION

Single macrofaunal grab samples were collected semiannually at 13 NPDES sites HM1 – HM13 from the Outer Los Angeles Harbor and outside the entrance (Figure 6-1). The semiannual collections occurred during the winter (February 21 and 26) and summer (August 15 and 22) 2002. All samples were successfully collected. All infauna and sediment samples were collected from the M/V *Marine Surveyor*. Station locations were positioned using global positioning satellite (GPS) coordinates. Station locations, coordinates, and depths were recorded in the station log by the vessel skipper, and the field data system (FDS) by a Water Biologist.

All samples of infauna and sediment were collected with a modified Van Veen grab sampler (Word 1976), which sampled an approximate surface area of 0.1 m^2. Although it is desireable to achieve a penetration depth of 10 cm, penetration was sometimes limited in sandier areas; therefore, acceptable samples were required to have minimal surface disturbance with no leakage, canting, or washing (SCBPP 1994, SCBRMP 1998). The Van Veen was placed onto a specially designed sample-washing table and assessed for sample acceptability. All pertinent information about the sample was recorded in a field-sampling (FDS) log. If the sample was accepted, the inside of the Van Veen was rinsed for adhering sediments. The sample was washed carefully with seawater from a hose fan-spray (to avoid animal fragmentation) through a 1.0-mm mesh screen. The material retained on the screen was placed into a 1-liter nalgene container; any animals adhering to the screen were carefully removed with forceps and added to the container. Containers were filled to no more than two-thirds volume with sample material to allow for proper fixation of animals. A 0.2% solution of propylene phenoxytol was initially added to each container to relax the animals in order to prevent fragmentation during preservation. After a minimum of 30 minutes, the sample was preserved in a 10% buffered seawater-formalin solution. All containers were labeled on both the inside and outside and transported to the laboratory in plastic crates.

B. LABORATORY ANALYSIS

Samples were rescreened and transferred to 70% ethanol for storage and sample processing after a minimum of 48 hours in formalin. Samples were sorted using stereoscopic dissection microscopes into six basic taxonomic groups: polychaetes, crustaceans, molluscs, echinoderms, ophiuroids, and miscellaneous (other invertebrate phyla). To increase sorting efficiency for samples having large clumps of ophiuroids, only the disks were sorted from the debris for identification and biomass measurement. Each sorted sample was checked to determine if a minimum of 95% of all organisms were removed. If less than 95% of the individuals had been removed, then the sample was completely resorted. All individuals were identified to species or lowest possible taxon. To ensure taxonomic consistency, the identifications of organisms collected were compared with the laboratory voucher collection. All questionable identifications or unknowns were sent to specialists for confirmation or identification. Specialists are recognized experts and usually are members of the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT). Additional QA/QC included standardization of identification with accepted taxonomic designations of SCAMIT to ensure consistency with other marine monitoring programs in southern California (SCAMIT 1994).

Total ophiuroid biomass was estimated using the following equation:

$$\text{Total weight} = 1.21 + (9.95)(\text{Dry disk weight})$$

The relationship between total and dry disk weight is significant ($p<0.0001$, $R = 0.916$) providing an estimate of brittlestar weight in the samples. Wet-weight biomass was determined for each of the five major taxonomic groups. The wet-weight biomass for ophiuroids and other echinoderms were combined. A total station wet-weight biomass was then determined.

C. COMMUNITY PARAMETERS

Simple community parameters, i.e., total number of species, total number of individuals, biomass, Shannon-Wiener index of diversity (H'), evenness (J'), infaunal trophic index (ITI), Simpson's dominance (D), and Gleason's species richness (d), were calculated for each individual station. These concepts and calculations are presented in Magurran (1988).

D. SPECIES ASSEMBLAGE ANALYSIS

Cladograms were generated using both the branch and bound algorithm for the smaller data sets (13 or fewer objects) and the heuristic search, Tree-Bisection and Reconnection (TBR) algorithm for the larger data sets (14 or more objects) from the computer program PAUP* [Phylogenetic Analysis Using Parsimony (*and other methods)] Version 4.0b10 (Swofford 2000). The species assemblages were analyzed via parsimony or cladistic analyses. Parsimony analysis of endemicity (PAE) uses a parsimony algorithm in order to obtain area or site cladograms based on the taxa (species) inhabitating the areas under scrutiny (monitoring stations).

Although richly cited and formalized in the systematic literature by Rosen (1988) and Rosen and

Smith (1988), the seminal work ignored in the systematic literature was in fact applied to marine infaunal data for eco-monitoring purposes from European waters two years earlier (Lambshead and Paterson 1986, Lambshead 1986).

Further justification for the use of PAE is the fact that communities and the species they contain are typically nested and cladistics is the dominant method in systematics for parsing out nested subsets of character distributions. Contemporary work by Trejo-Torres and Ackerman (2002), conclude that the methodological, theoretical, and interpretive advantages of PAE make it an attractive and complementary method for ecological studies of fine-scale species assemblage composition patterns. Comparing methodologies, Hooper et al. (2002) show congruent groupings of Australian sponge communities between phenetic Non-Metric Multidimensional Scaling (NMDS) ordinations and parsimony analyses, as did Lambshead et al. (1994) with deep sea nematode assemblages.

Recent literature has shown that deleting rare species can damage the sensitivity of community-based methods to detect ecological changes (Cao et al. 1998 and 2001), and that taxon autochthony may be more informative than their abundance, especially in parsimony analyses (Perochon et al. 2001). Additionally, recent work underscores that it is the rare species, not the common and abundant taxa, that respond or are affected to varying aspects of habitat change or modification (Goodsell and Connell 2002). Hence, all species (operational equivalent for character) were included in the analysis.

In addition to the cladograms showing the relationships of the objects or stations (Q-analysis), cladograms of species groups showing the association or co-occurrence of these descriptors or species with one another (R-analysis) (Legendre and Legendre 1998), were also produced for all infaunal organisms. This parsimony analysis of co-occuring species has been coined “PACOS” herein. All analyses were performed with the computer program PAUP* - Phylogenetic Analysis Using Parsimony (* and other methods) version 4.0b6 (Swofford 2000). Methods of calculations for measure of fit indices are presented in Kitching et al. (1998).

Specifically, the data was analyzed via a “generalized parsimony” or “step-matrix” approach (Sankoff and Rousseau 1975, Sankoff and Cedergen 1983, Swofford et al. 1996). Generalized parsimony is an efficient and highly adaptable approach for systematic analyses, as the parsimony criterion is easily applied to virtually any comparative (frequency, behavioral, ecological, etc) data set (Hillis 1998). This computationally intensive, “brute force” approach enumerates all possible combinations of character state assignments at every node, calculating partial costs (relative abundance of a given species) and converging on the most parsimonious tree. Species (characters) abundance values were standardized to relative abundance equally weighting each species (character). The approach herein is very similar to the step-matrix approach utilized in MANOB (Manhattan Distance, Observed Frequency Arrays) introduced by Berlocher and Swofford (1997), but utilizes a two-column reductive coding approach guaranteeing the logical independence of a species’ absence from its presence, and the associated abundance states represented by a given step-matrix. This approach accommodates continuous data without resorting to coding strategies with problematical coding justifications, reduces impact of sampling error (e.g., the failure to detect or utilize rarely occurring or less abundant species), and utilizes potentially useful frequency or relative abundance data not conventionally used in presence / absence coding (see Berlocher and Swofford 1997).

Non-metric multidimensional scaling (NMDS) is a highly recommended multivariate ordination method that works on any similarity or distance matrix (Warwick and Clarke 1995, Quicke 1993). Non-metric MDS was applied to patristic distance (branch-length) matrices derived from the cladistic analyses (the cladogram). Patristic distances were chosen as it has been shown that pairwise similarity or distance is underestimated by the conventionally used phenetic distance methods (e.g. Bray-Curtis). Pairwise comparisons using cladistic methods which include all changes (including homoplasy or lack-of-fit) along the branches is a better estimator or representation of the data (Smith 1994). The patristic distance matrices derived from the cladograms generated in PAUP*, were then imported into Primer v. 5.2.9 (Clarke and Gorley 2001) for the subsequent multivariate NMDS analyses and stress calculations.

III. RESULTS

A. COMMUNITY PARAMETERS

The community parameters, i.e., number of species, abundance, biomass, Shannon-Wiener diversity, evenness, Infaunal Trophic Index (ITI), Simpson's Dominance, and Gleason's species richness, are summarized for the 2002 winter and summer surveys in Table 6-1.

Three stations, namely HM6, HM7, and HM12 during the winter survey had species assemblages with relatively depressed numbers of species with stations HM7 and HM12 exhibiting low abundances. Station HM6 during the summer reporting period continued to have relatively low numbers of species and abundance values. A distinct trend of increased number of species, abundance, and biomass during the summer sampling period can be seen in Table 6-1, with average values of 45 species and 133 individuals per station in the winter survey compared to average values of 55 and 224 per station for the summer survey, respectively. Station HM13 (outside of the breakwater) had the highest number of species and second highest abundance value during the winter, and relatively high values of each in the summer survey. The outfall station HM3, does not seem to possess any measure strikingly higher or lower than the other Outer Harbor stations, albeit relatively high numbers of species and abundance values were seen during the summer sampling period.

The ITI is an index that provides a measure of the "health" of an infaunal community (Word 1978, 1980). ITI values calculated greater than 60 are considered representative of a "normal" infaunal community, numbers between 30 and 60 represent a "changed" community, and numbers below 30 represent a "degraded community (Word 1978, 1980). ITI values calculated for both the winter and summer surveys were between 73 and 87 (Table 6-1) indicating that all stations sampled were representative of a "normal" infaunal community.

Table 6-1. Community parameters for Los Angeles Harbor winter and summer infauna 2002.

Station	No of Species	Total Abundance	Biomass (g)	Shannon-Wiener Diversity	Evenness	ITI	Simpson's Dominance	Gleason's Richness
Winter								
HM1	52	184	5.45	3.06	0.77	77.30	0.05	9.78
HM2	36	105	3.48	3.10	0.87	73.36	0.05	7.52
HM3	58	152	3.07	3.31	0.82	73.64	0.05	11.35
HM4	41	151	5.17	2.95	0.79	83.35	0.09	7.97
HM5	39	119	5.56	3.15	0.86	79.65	0.06	7.95
HM6	23	153	8.33	2.22	0.71	76.21	0.16	4.37
HM7	31	61	2.80	3.00	0.87	82.07	0.07	7.30
HM8	60	171	15.46	3.54	0.86	81.50	0.04	11.47
HM9	52	145	14.52	3.36	0.85	74.69	0.05	10.25
HM10	54	157	8.19	3.52	0.88	80.97	0.03	10.48
HM11	46	104	2.49	3.28	0.86	84.07	0.07	9.69
HM12	26	55	13.59	2.94	0.90	81.84	0.07	6.24
HM13	66	167	2.79	3.42	0.82	82.85	0.03	12.70
Summer								
HM1	48	172	6.50	3.35	0.87	86.97	0.04	9.13
HM2	47	155	7.25	3.23	0.84	76.83	0.03	9.12
HM3	64	325	8.16	3.37	0.81	82.37	0.05	10.89
HM4	49	179	6.91	3.36	0.86	79.51	0.03	9.25
HM5	47	199	11.76	3.11	0.81	83.35	0.08	8.69
HM6	33	117	5.86	2.76	0.79	79.51	0.09	6.72
HM7	57	193	10.38	3.50	0.87	80.02	0.04	10.64
HM8	69	293	11.72	3.42	0.81	84.70	0.05	11.97
HM9	57	364	4.32	2.20	0.54	77.80	0.29	9.50
HM10	71	278	12.53	3.63	0.85	84.23	0.02	12.44
HM11	59	213	16.52	3.53	0.87	79.59	0.03	10.82
HM12	41	123	10.33	3.16	0.85	76.69	0.06	8.31
HM13	67	297	9.98	3.18	0.76	86.06	0.03	11.59

There were 226 (219 in previous year) taxa contributing to the total of 4,193 (4,207 previous year) individuals (both species and supraspecific taxa included) enumerated during the 2002 winter and summer surveys. The most 10 abundant species were: *Theora lubrica* (275 = 6.6%), *Amphideutopus oculatus* (233 = 5.6%), *Streblosoma* sp B (213 = 5.1%), *Nuculana taphria* (220 = 5.2%), *Spiophanes berkeleyorum* (162 = 3.9%), *Scleroplax granulata* (141 = 3.4%), *Terebellides californica* (137 = 3.3%), *Pista alata* (121 = 2.9%), *Spiophanes duplex* (101 = 2.4%), and *Monticellina siblina* (92 = 2.2%). All other species occurred at abundances less than 2.1% of the total. Additionally, 167 (138 in previous year) and 178 (199 in previous year) unique taxa were collected in the winter and summer sampling periods, respectively.

The 12 most widely occurring species (collected 19 times or more out of a possible total of 26) were: *Glycera americana* (24), *Theora lubrica* (23), *Terebellides californica* (23), *Spiophanes berkeleyorum* (22), *Rochefortia tumida* (22), *Streblosoma* sp B (21), *Scoletoma* sp A (21), *Cossura* sp A (21), *Listriella goleta* (20), *Paraprionospio pinnata* (20), *Amphideutopus oculatus* (19), and *Spiochaetopterus costarum* (19)*,* All other species were collected 18 times or less.

As in previous reports and most other community analyses, a characteristic species abundance pattern emerged; only a minor subset of species are highly abundant and/or widely occurring and, a few species possess moderate to high abundance and the majority of species are represented by very few or by single individuals. The shape of the curve for all infaunal monitoring stations (Figure 6-2) seems to mimic the axiomatic zero-sum multinomial (Hubbell 2001) with a few highly abundant, widely occurring species (represented by the large circles), followed by a very long tail of exclusively distributed (rare and hierarchically nested) taxa (the smaller and smaller circles).

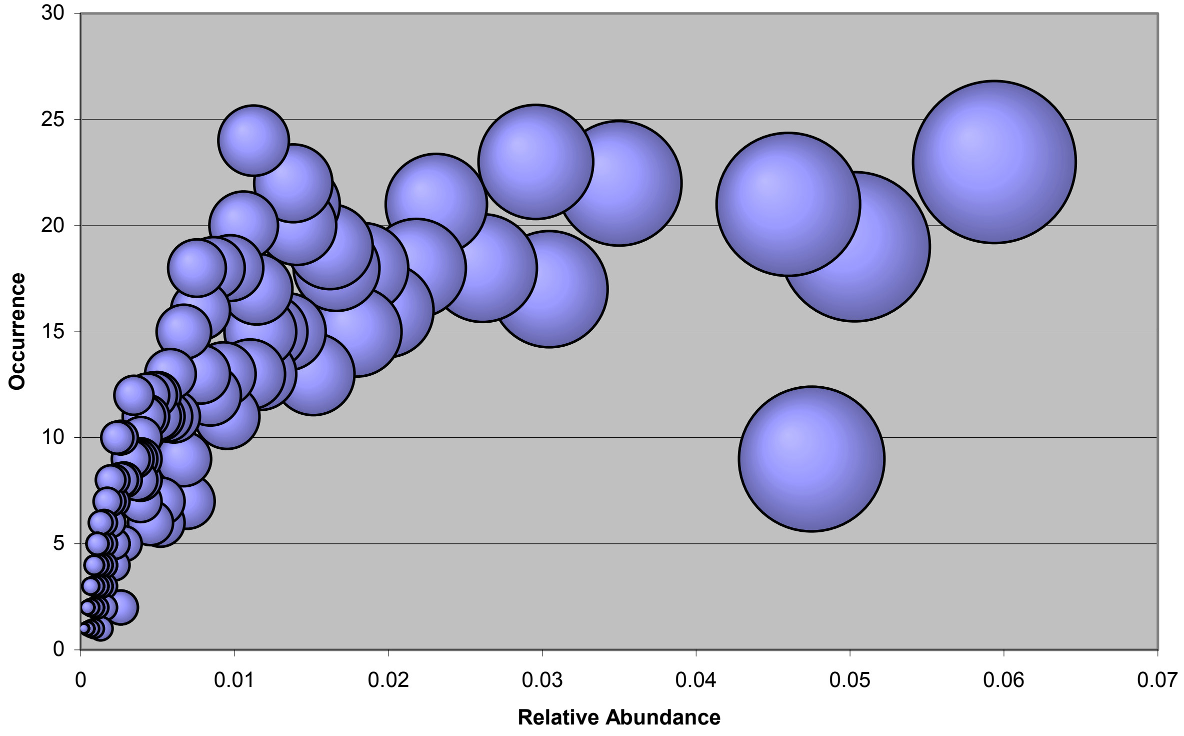

Figure 6-2. Bubble chart of all-year 2002 infauna relative abundance and occurrence. Ball size represents total abundance.

B. PARSIMONY ANALYSES and N0N-METRIC MULTIDIMENSIONAL SCALING

All available taxa and all sampled stations were used in the seasonal and annual cladistic analyses.

A single (most parsimonious) tree (Figure 6-3) resulted from the winter analysis. The tree possessed a tree length of 389.51, a consistency index of 0.4896 (maximal value = 1.00), and a retention index of 0.3098 (maximal value = 1.00). For the winter survey, the most conspicuous pattern in station grouping, revealed by the cladogram (Figure 6-3), was that the station outside the breakwater (HM13), used as the outgroup, remained well removed from the remaining stations found within the Harbor.

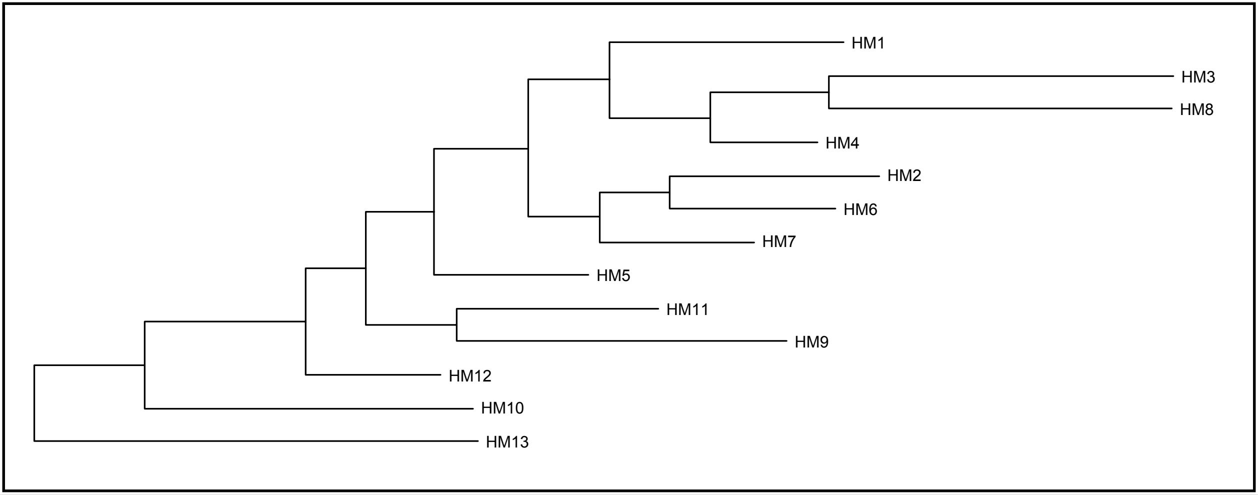

Figure 6-3. Cladogram of winter 2002 infauna stations.

This illustrates that the species assemblage collected outside the Harbor was quite different from those within the Harbor. The "outfall" station HM3 grouped with two of its "near-outfall" cohorts, stations HM1 and HM4, but was found most closely associated with station HM8 located somewhat removed from these three stations. The apomorphy list output (showing the changes or species distributions along the vertices between the nodes of the cladogram), generated by PAUP*, indicates that 13 of the 15 species responsible for the HM2-HM3 station grouping, or clade, show slight abundance increases. Additionally, a subset of these organisms are suspension feeders suggesting relatively clean conditions are present at this location. Both the spatial pattern and species signal still appear too equivocal to formulate any obvious statement or specific causal hypothesis for the species' distributions at that node.

For the summer survey, a single, most parsimonious tree resulted from the analysis (Figure 6-4). The tree possessed a tree length of 392.95, a consistency index of 0.5113 (maximal value = 1.00), and a retention index of 0.3306 (maximal value = 1.00).

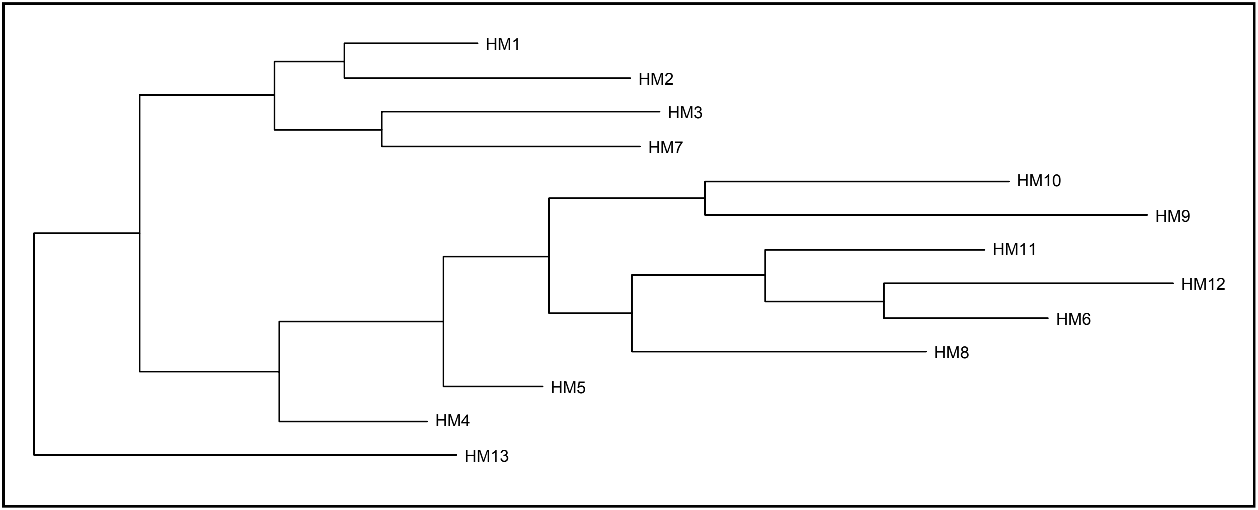

Figure 6-4. Cladogram of summer 2002 infauna stations.

Again, HM13 designated as the outgroup, remained distinct from the stations within the Harbor. The "outfall" station HM3 grouped with "near-outfall" stations HM1 and HM2, but was found most closely associated with station HM7 located somewhat removed from these more proximally located stations. Again, the distribution patterns of the species and their increasing or decreasing relative abundance responsible for this relationship at that node are not indicative of any signal that could be ascribed to an outfall-mediated pattern.

The combined winter and summer analysis produced a single most parsimonious cladogram (Figure 6-5) with a tree length of 732.14, a consistency index of 0.3486 (maximal value = 1.00), and a retention index of 0.3544 (maximal value = 1.00). As noted in previous surveys (CLA, EMD 1997 – 2002), both the winter and summer samples from station HM13, outside the Harbor, grouped away from all stations inside the Harbor. The "outfall" station HM3 did not group with itself over the two seasons, suggesting that processes associated with some other temporal or seasonal events may be responsible for the observed pattern than some localized spatial event such as the effluent from TITP's outfall. However, an interesting grouping of "outfall" and "near-outfall" stations exists. Specifically, "outfall" station HM3 summer groups with "near-outfall" stations HM1 summer and HM1 winter. Additionally, "outfall" station HM3 winter groups with "near-outfall" stations HM2 summer, HM2 winter, HM4 winter, HM6 winter, and HM6 summer. This probably represents nothing more than simple spatial auto-correlation (spatially proximal and therefore similar areas with similar organisms grouping together). The cladogram overlays other striking spatial groupings with like stations grouping together (note, stations HM10, HM9, HM12, HM8, HM6, and HM13) on top of the aforementioned specific sub-patterns, with a few summer and winter "clades" or groupings.

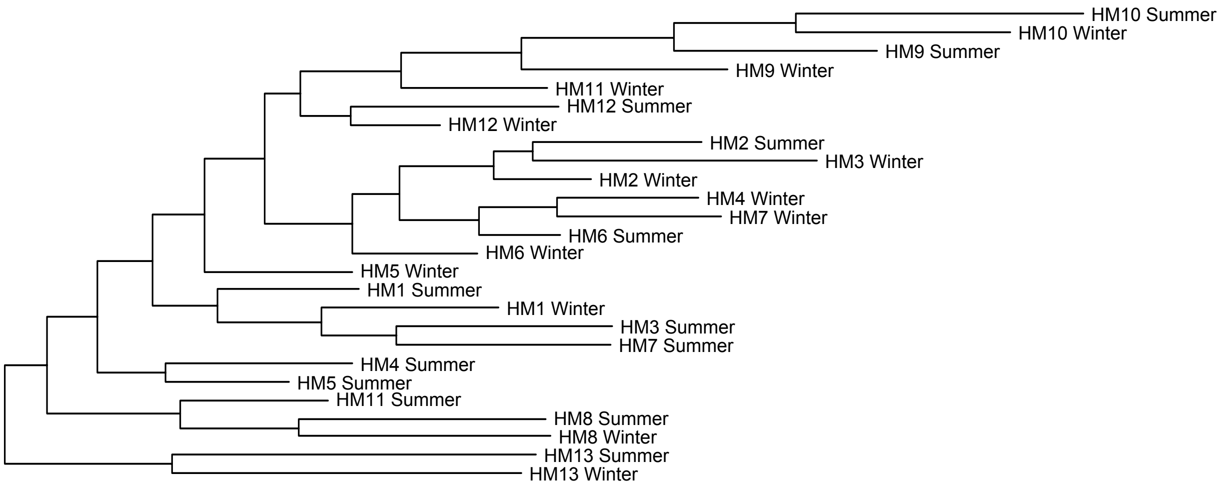

Figure 6-5. Cladogram depicting all-year 2002 infauna stations.

Patterns regarding the distribution of the other species are best examined with the mapped output, (CLA, EMD unpublished data; available upon request).

Of interest is the pattern that emerges when the number of species and the total abundance values (Table 6-1) are independently mapped onto the cladogram. The species assemblages distinguishing the most basal station HM13, outside the breakwater, possessed 66 and 67 species in the winter and summer, respectively. These are nearly the most species-rich and diverse samples from each sampling survey station. Station HM10 summer possessed the most species with 71, whilst HM8 summer and HM8 winter contained relatively high species richness with 68 and 60 species, respectively. The advantage of using additive trees (which cladograms derived from parsimony analyses are) in ecological studies is that branch lengths are directly proportional to the changes or observations derived from the cladistic analyses. Hence, a quick perusal of any cladogram herein allows one to quickly assess species richness or diversity by looking at the relative length of the branches.

The mapping of independent attributes or ecological characters on pre-existing cladograms is of great interest in analyses and assessments of this type. This procedure aids in the discovery of potential variables and/or processes responsible for the infaunal pattern or monitoring station relationships revealed from the parsimony analysis (cladogram). It has been shown in previous studies that depth and sediment are the variables primarily associated with or responsible for infaunal community composition (see CLA, EMD 1997 - 2001 and references therein). With depth a veritable constant in the Harbor (thus functionally factored out), we need only to map the differential sediment fractions namely, percent sand, silt, and clay that comprise the benthic substrata. Covariation of these independent attributes on the pre-existing cladogram is strong evidence for the processes responsible for the observed pattern. When the percent sand, silt, and clay fractions are mapped (not shown herein), a notable trend emerges (see Chapter 5 herein).

With reference to the cladogram for the summer samples (Figure 6-4), the sediment characteristics are very consistent with the topology of the cladogram. The station possessing the highest sand fraction is outgroup station HM13 with sand, silt, and clay fractions of 74, 20, and 6 %, respectively. The remainder of the cladogram generally possesses stations with lower sand, higher silt, and lower clay sediment fractions. Another interesting pattern emerges when one inspects the shape or modality from the actual spectrum of sediment size-classes derived from the Coulter particle size analyzer. Some stations have sediments with a relatively unimodal distribution, while some stations are distinctly bimodal. These sediment characteristics although not as strongly defined as in the previous report, do seem to co-vary with some of the groupings from the cladogram. All sediment samples are right-skewed and leptokurtotic (majority of values are centered around the mean). This suggests that not just general size-class fractions, but the actual modality (the fine scale topographic heterogeneity) may play an important and previously overlooked component in community assembly.

Arguably, one of the better ordination techniques is the method of non-metric multidimensional scaling (NMDS). NMDS was carried out on both Bray-Curtis coefficients and the patristic distance (branch-length) matrix derived from the cladistic analysis from the combined winter and summer data. Stress values for the ordinations were 0.18 for the conventional phenetic approach using the Bray-Curtis coefficient and only 0.13 from the parsimony analysis-derived patristic distance matrix. The lower the stress the better the correspondence between the NMDS map and the multi-dimensional relationships amongst the samples. Both the 2-dimensional (Figure 6-6) and the 3-dimensional NMDS plot (Figure 6-7) from the patristic distances derived from the cladogram yielded a much more distinctive map than that resulting from the phenetic approach. The 3-D map derived from the patristic distance matrix shows much more discrete spatial groupings of the stations than did the Bray-Curtis approach (not shown herein), especially with regards to how removed the samples from station HM13 (outside the Harbor) are from the rest of the samples, and how close the

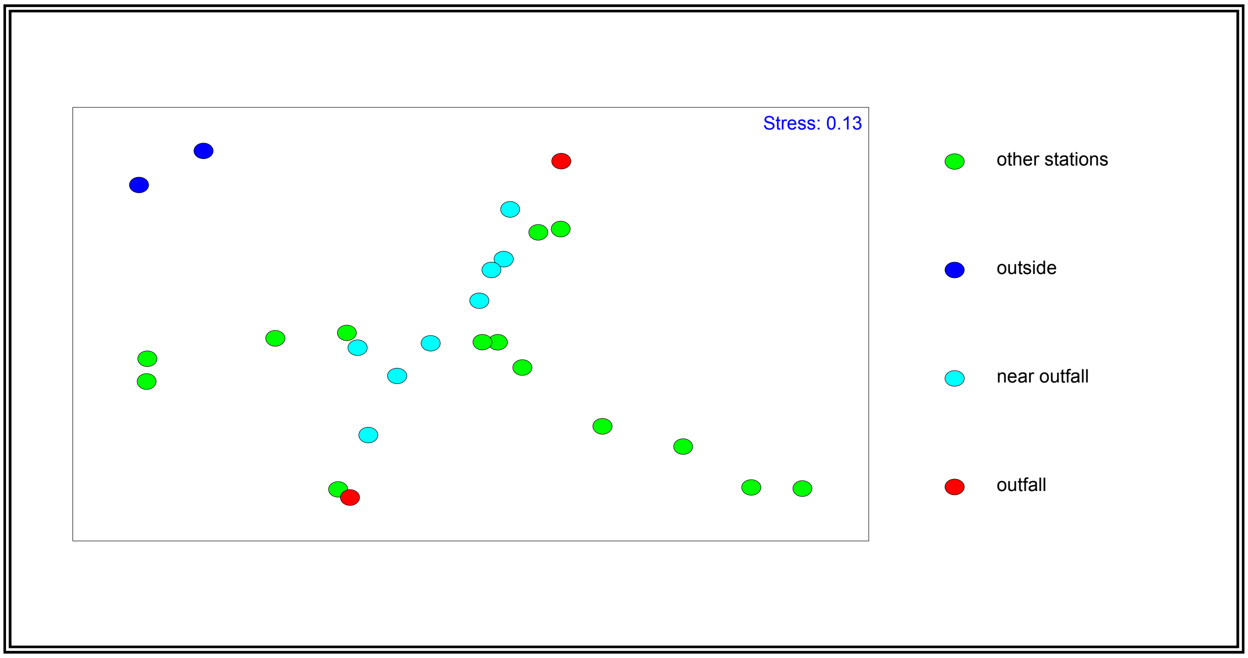

Figure 6-6. 2D Non-metric multi-dimentional scaling (NMDS) ordination for patristic distance derived from parsimony analysis of 2002 infauna monitoring stations.

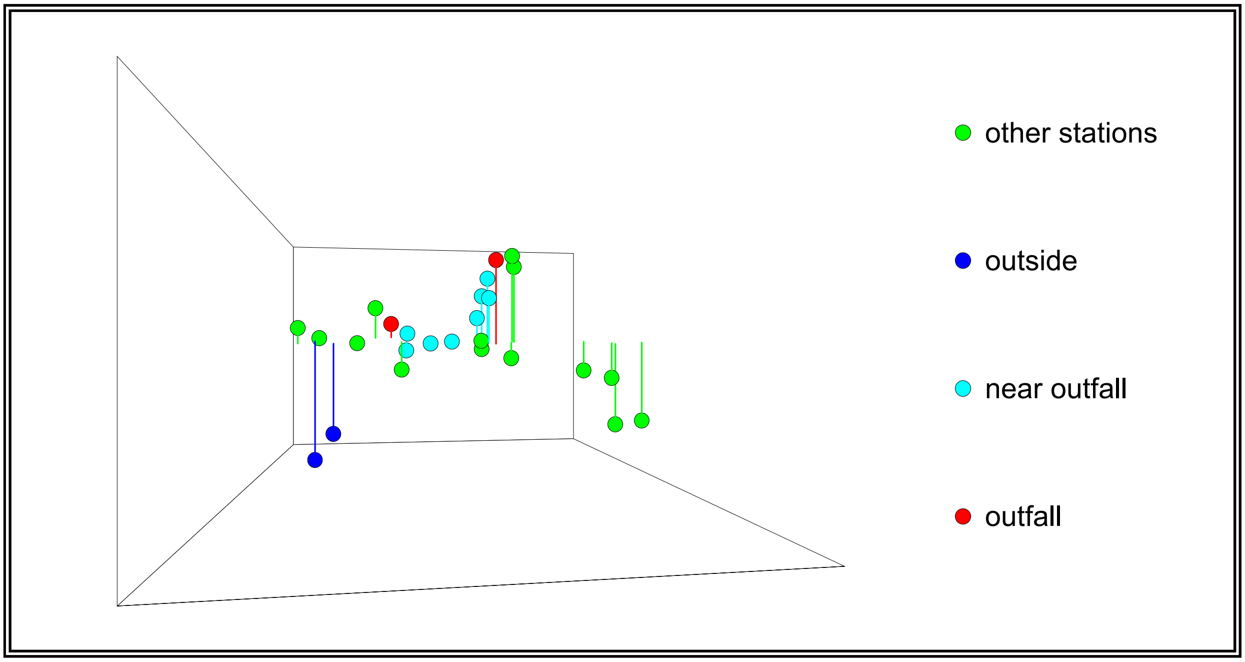

Figure 6-7. 3D Non-metric multi-dimentional scaling (NMDS) ordination for patristic distance derived from parsimony analysis of 2002 infauna monitoring stations.

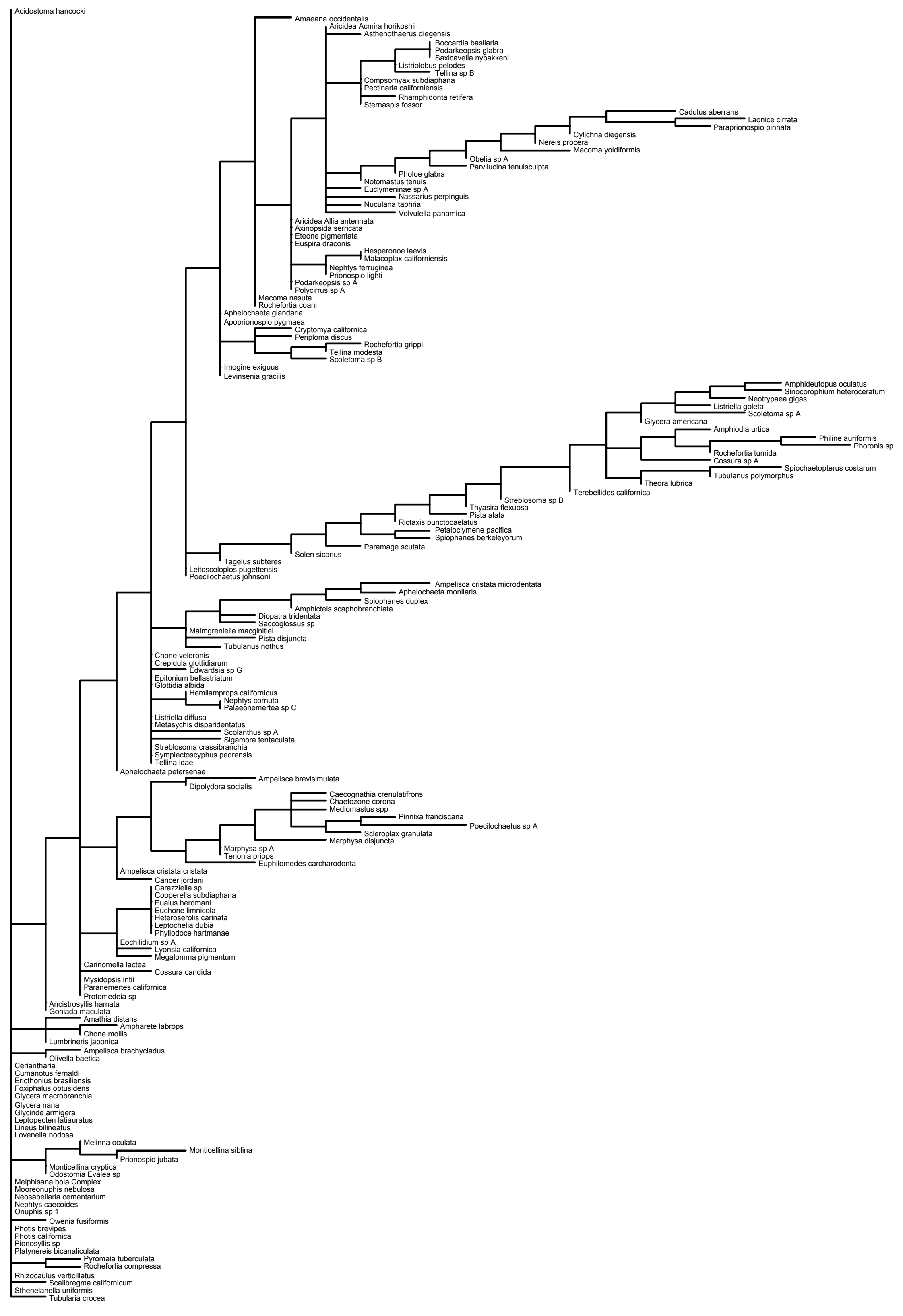

Figure 6-8. Parsimony analysis of co-occurring species (PACOS) cladogram of winter 2002 infauna.

Figure 6-9. Parsimony analysis of co-occurring species (PACOS) cladogram of summer 2002 infauna.

"near-outfall" stations group with the "outfall" station HM3, underscoring a fair degree of site or spatial fidelity (grouping).

An interesting duality exists between objects (monitoring stations in this case) and their descriptors (the species or response variables in this case). Parsimony analysis was conducted on the transposed binary-matrix of infauna taxa by stations.

For the winter data several very similar, equally-parsimonious PACOS cladograms were generated. A single cladogram (Figure 6-8) was randomly chosen to present. The cladogram had a tree length of 161, a consistency index of 0.0807, and an incredibly high retention index of 0.7139, indicating very reliable grouping of the major clades or groups of species.

The summer species data also resulted in many very similar equally parsimonious cladograms. A single tree was randomly chosen to present (Figure 6-9). The cladogram had a tree length of 161, a consistency index of 0.0800, and an even higher retention index than the result from the winter data of 0.7814.

This novel utilization of parsimony for an R-analysis proved very informative regarding the distributions and associations of the various species. Both the winter and summer PACOS cladograms (Figures 6-8 and 6-9) were rooted with the unique species found from the outgroup station HM13 outside the harbor. The large elongated basal clades seen in both cladograms, represents the group of species with the greatest number of stations occupied. This illustrates yet another example of the advantages of additive trees (which cladograms are) in ecomonitoring or community ecology, as the length of the branches in this case represent the number of stations or the number of occurrences that species co-occupy. The species on the cladogram lacking branches or having very short branches, represent species with highly exclusive (not as widely occurring or abundant) distributions, being found at very few or at just a single station within the Outer Harbor. This approach shows that even at this fine spatiotemporal scale, species can be classified hierarchically within a series of nested subsets of areas of occupancy, and parsimony is the best tool for this approach (see Myers and De Grave 2000).

V. DISCUSSION

The macrofaunal communities sampled in Outer Los Angeles Harbor in 2002 continued to show a progression of recovery since the major disturbance created by PIP in 1995-1996 (CLA, EMD 1996-1997). The total number of taxa collected in 2002 (226 taxa) was similar to 2001 (219) and 2000 (236 taxa) that showed the continuing increase seen since the depressed values found in 1995 - 1996. During this sampling period the extent of recovery was evident in the uniform distribution of number of species, abundance, and diversity values. The only variation from this pattern occurred at HM9 during the winter where depressed values for Shannon-Weiner Diversity (H') and Evenness (J) and an elevated value for Simpson's Dominance (D) occurred due to the large settlement of juveniles of the bivalve *Nuculana taphria*, which accounted for over 50% of the station's abundance.

Environmental impacts (whether natural or anthropogenic) have been defined as a change that creates a gradient of response by a species or a community. The features of macrofaunal communities have long been studied as an integral and necessary part of environmental impact prediction and assessment (Elliot 1994). Previous studies dealing with the effects of an environmental impact have focused on the analysis of the spatial distribution and abundance patterns of species (Pearson and Rosenberg 1978, Gray 1979, Dauer and Conner 1980, Gray and Pearson 1982, Poiner and Kennedy 1984, Swartz et al. 1986, Ferraro et al. 1991, Maurer et al. 1993, Zmarzly et al. 1994). Approaches now being utilized with greater frequency are the assessments of the changes in community parameters along environmental gradients, the identification of common response patterns (Rapport et al. 1985, Schindler 1987, Gray 1989, Sheppard 1995), and parsimony analyses of biotic data (see Lambshead and Paterson 1986, Lyons-Weiler and Tausch 1997, Masselot et al. 1997, Nel et al. 1998, Watanabe 1998, Myers and De Grave 2000).

Since late 1994, construction activities related to Increment 2 of PIP began to impact the macrofaunal community in the Outer Los Angeles Harbor (CLA, EMD 1995-1998). Historically, construction in the Outer Los Angeles Harbor has resulted in reduced number of species, individuals, biomass, and diversity from dredging and landfill operations (SCOSC 1982, HEP 1983, and MEC 1988). During Increment 2 of PIP, the dredging of existing shipping channels removed the upper 12 feet of sediment (ACE 1992). In areas around the proposed Pier 400, where there were no existing channels, a greater amount of sediment was removed for the creation of new channels and turning basins during Increment 3 (ACE 1992). Within those dredged areas, the surface and near-surface sediments were characterized by organic silt, silty sand, and sand (KLI 1991, ACE 1992, CLA, EMD 1994). The resultant turbidity plumes created by rock dike construction, dredging, and the pumping of this dredged material for Pier 400 fill was generated between 1994 and 1999. It was predicted that suspended material would eventually settle during in-harbor disposal and affect only areas within several hundred feet from the sites of disposal (ACE 1992). The majority of macrofaunal sampling stations, selected for the Post-Pier 400 NPDES Monitoring Program are within these aforementioned zones of potential impact (Figure 6-1).

When comparing the dominant species in the Harbor from historical records (Reish 1959, HEP 1980 and 1983, SCOSC 1982, MEC 1988), and from previous EMD surveys (CLA, EMD 1994-2002), it is apparent that the abundant species are composed of a core group of dominant organisms that vary in proportion from year to year. These species include the amphipod *Amphideutopus oculatus*, the bivalve *Theora lubrica*, and polychaetes *Chaetozone corona*, *Cossura spp.* (*C. candida* and *C.* sp. A SCAMIT), *Monticellina siblina*, *Mediomastus* spp., *Petaloclymene pacifica,* and *Paraprionospio pinnata*. Improvements in taxonomy that have occurred since samples were first collected and identified in 1954 have resulted in the identification of multiple species once considered as the same species. These include *Cossura* spp. (*Cossura candida* and *Cossura* sp. A SCAMIT), *Monticellina siblina* (*Tharyx parvus*, *Tharyx tessellata*, *Tharyx* sp., and *Monticellina tessellata*), *Mediomastus* spp. (*Capitita ambiseta, Mediomastus ambiseta, and Mediomastus californiensis*), *Petaloclymene pacifica* (Maldanidae sp. A, Maldanidae sp. 1, and *Euclymene* sp.), and *Scoletoma* sp. A (Harris) (*Lumbrineris* sp. A (Harris), *Lumbrineris* spp. and *Lumbrineris* Group III) and *Scoletoma* sp. B (Harris) (*Lumbrineris* sp. B (Harris), *Lumbrineris* spp. and *Lumbrineris* Group III).

The continued occurrence of these abundant species in Outer Los Angeles Harbor over the last 20 years is due to the fact that all of these species commonly occur in southern California nearshore coastal waters. *Theora lubrica,* an exotic transport from Asia, was first identified from local waters in the early 1970's. This bivalve has now become a common inhabitant in bays and harbors throughout the Southern California Bight. It has been the most abundant infaunal organism collected in Outer Los Angeles Harbor since 1997 (CLA,EMD 1998-2002 and this report). Hence, with some of these non-indigenous exceptions, the benthic infauna of Outer Los Angeles Harbor is similar in species composition to the open coast benthic infauna found outside the Harbor on the San Pedro Shelf (MEC 1988, ACE 1992) and Outer Long Beach Harbor (MBC 1984). Impacts created by the continuous dredging operations of PIP since 1994 on the abundance of these dominant species has been temporary, since many of these local species found in the Outer Harbor or nearby communities reproduce throughout the year or have extended reproductive periods (Reish 1982). With the completion of dredging operations for Pier 400 in April 2000 the successful settlement of larvae and migration of adults should have been uninterrupted (Maurer et al. 1981a, 1981b, 1982). However, with construction of the new pier 400 dredge disposal site and future deepening of the main channel, infaunal recolonization is likely to be disrupted.

Samples collected in 2002 reflected the continued effects created by Increment 3 of PIP. The dominant species identified in 2002 were similar to pre-PIP construction communities in Outer Los Angeles Harbor based on total abundance. This year, the most abundant species over both the winter survey and summer survey were *Theora lubrica*, followed by *Amphideutopus oculatus*, *Streblosoma* sp. B, *Nuculana taphria*, and *Spiophanes berkeleyorum*. Other high-ranking species from last year (CLA,EMD 2002) have become less dominant relative to the above species this year. These shifts, in conjunction with the aforementioned congruence between species distribution and sediment patterns, indicate the differential exclusion and tolerance of various species (indeed, the definition of a ***response variable***) to the continuing (albeit less this year) effect from the construction activities associated with Pier 400.

The dominant species reported for pre-PIP communities (CLA, EMD 1994 - 1996) maintained their presence in the infaunal community sampled in 2002, with most species in reduced numbers. The amphipod *Amphideutopus oculatus* is beginning to exhibit increased abundance and occurrences at the stations sampled. The decrease seen in the total number of species (CLA, EMD 1996-1998) is now reversed as seen with the continuing increase of species collected through this sampling period (CLA, EMD 1999-2002 and this report). The decrease in total species collected following the initiation of PIP reflected the important loss of “rare species” (species that typically occur in lower frequencies relative to the community). Gray and Pearson (1982) suggested that in response to a disturbance, rare species may decrease in abundance or may be totally eliminated, and that moderately common species increase in abundance. The effect that PIP had on the Outer Harbor infauna, in relation to the number of species and abundances since 1994 (CLA, EMD 1995-1998), support their hypothesis. With the dominant species maintaining a constant presence in the samples collected (CLA, EMD 1994-2002 and this report), the increase in species number now becoming evident is most likely due to the return of “rare species” within the community. The return of the filter-feeding species, *Amphiduetopus oculatus*, as a dominant species within the Outer Harbor, in addition to the increase in “rare species”, point to the continuing recovery from construction of Pier 400.

It has been noted that recolonization, following a disturbance to a macrobenthic community, may be relatively rapid, but time to recovery is variable and depends on the nature of the habitat, reproductive periodicity of the macrobenthos, and abiotic and biotic factors (e.g., food, and space resources) (Flemer et al. 1997). Following the destruction of a soft bottom habitat, the most generally observed feature of succession is the early dominance in the community of shallow-dwelling, tube building, surface-deposit feeders (Gallagher et al. 1983). In addition to the core group of dominant species mentioned earlier, several of these shallow, tube-building, surface-deposit feeders increased in abundance following the initiation of Increment 2 of PIP. These species include *Petaloclymene pacifica*, *Streblosoma* sp. B SCAMIT, *Marphysa* sp. A SCAMIT, *Pista alata,* and *Terebellides californica*. Since 1995, the fluctuations seen in these dominant species reflect the restructuring of the infaunal community following the initiation of Increment 2 of PIP.

Theora lubrica is another species that can be used to follow the dredging events and the settling out of fine silts and clays from the turbidity plume. *Theora lubrica* is a response variable that indicates a high silt/clay fraction and is a major component of infaunal communities found in the Inner Harbor (MBC 1993, 1994; MEC 1988, SCBRMP2003). As species that favor sediments with a high silt/clay ratio settle out, they will out-compete those opportunistic species found following a major perturbation. Indeed, as previously stated, this has been the most abundant infaunal species collected in our surveys since 1997 (CLA, EMD 1998-2002 and this report). With the noted improvements reported above in the composition of the infaunal community, the continued dominance of *Theora lubrica*, reflect the composition of sediments still being a high percentage of silt and clay.

A process pattern became discernible when evaluating the community parameters, grain size analyses, and the cladistic analysis. The macrofaunal community of Outer Los Angeles Harbor has been altered by heavy sediment loading due to construction activities of PIP (CLA, EMD 1995-2000). This has been identified through a continued reduction in the number of species, the total abundance of individuals, and a change in composition of the most abundant species now existing in the Los Angeles Harbor. Previous studies have identified reductions in diversity due to man-made environmental impacts (Pearson and Rosenberg 1978, Gray 1979, HEP 1983, Gray 1989, Weston 1990). When the key components of the diversity indices, i.e., the number of species and their abundance, become sharply reduced, they can be a precursor to changes in the dominance of these communities.

The key factors that influence marine communities have been identified as water depth, sediment grain size, and carbon content (organic matter). For the Outer Los Angeles Harbor the factors of water depth and carbon content (CLA, EMD 1994-2002 and this report) have been relatively stable. Sediment grain size, however, has shown a major change in areas sampled around PIP since 1993 (Chapter 5 in CLA, EMD 1994-2000). The importance of sediment grain size as a key parameter controlling macrofaunal community structure has been well documented (Nichols 1970, Gray 1974, and Rhoads and Germano 1982, 1986). Analytical techniques (correlation or regression analyses, covariation in cladistic analyses) that utilize physical and chemical parameters can be used to help infer which variables are important or associated with specific community structure or species assemblages. Once these patterns and inferred processes are identified, predicting specific community or organismal response and/or structure may be possible.

This amount of sediment grain size variability, underscores the instability of the local environment and the associated changes in the infaunal community structure reported by EMD (CLA, EMD 1994-2002 and this report) since the implementation of the monitoring requirements of the current NPDES permit.

The general composition of the present community is not represented by organisms identified as opportunistic and/or prevalent in areas recovering from major organic loading (Weston 1990). These results suggest that the adverse impacts on the macrofaunal organisms are not caused by organic loading (e.g., the TITP outfall), but by other factors, such as sediment removal and burial by siltation. With the completion of Increment 3 of PIP in April 2000, it is expected that the infaunal communities will continue to recover to original population levels within 1-3 years (Reish 1961, 1963; Oliver et al. 1977; SCOSC 1982; Currie and Parry 1996; Kenny and Rees 1996). The initial repopulation (CLA, EMD 2000, 2001), following the dredging of the shipping channels and turning basin for Increment 3, was rapid since many of the local species are found throughout Los Angeles Harbor, Long Beach Harbor, and the San Pedro Shelf. These local species reproduce throughout the year or have extended reproductive periods that allow for the continuous settlement of larvae upon the affected areas (Reish 1982).

Extensive resuspension and subsequent sedimentation has occurred in the Outer Los Angeles Harbor with similar past construction events (SCOSC 1982, HEP 1983). Even with the completion of dredging and fill activity in the Outer Los Angeles Harbor for Increment 3 of PIP, a continuing impact on the Post-Pier 400 Monitoring stations around the TITP outfall is still being noted. This impact upon the Outer Los Angeles Harbor continues to affect the distribution of species, their behavior, and composition of the macrofaunal community collected by the City of Los Angeles' Post-Pier 400 Monitoring Program. With recovery from the impacts caused by the construction activities related to PIP continuing to progress, the message or signal that has been obtained from the most recent data analysis continues to be garbled and altered, and thus not fully informative relative to the objective of the Post-Pier 400 Monitoring Program: to investigate the potential effects of the effluent discharged from the TITP on the surrounding infaunal communities in Outer Los Angeles Harbor.

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