CHAPTER 7. FISH AND MACROINVERTEBRATES

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I. INTRODUCTION

The soft bottom habitat of Los Angeles Harbor is currently a mixture of clay, silt, sand, and dredge spoils. In general, a gradient of sandy silt to sand exists from the inner portion of the Outer Harbor southward to the outer portions of the Outer Harbor (see CLA, EMD 1994a, 1995-2002). Additionally, the depth ranges from approximately 4 to 20 meters (some local areas have been recorded to near 30 meters after dredging activities associated with Pier 400 construction) from the inner to outer portions of the Outer Harbor. The combination of this depth and sediment gradient coupled with various point sources of potential contamination, e.g., the Dominguez Channel, various storm drains, and the filtered secondary effluent discharged from Terminal Island Treatment Plant's outfall, creates locally heterogeneous environments within the Harbor. Also, the San Pedro Breakwater, Middle Breakwater, and Pier 400, by adding topographic diversity to the environment and functioning as a substrate for the associated kelp beds, provide a complex combination of food, shelter, and a larger habitable area within the water column for fishes and invertebrates (see MEC Analytical Systems Inc. 1988 for review).

Quarterly monitoring of demersal fish (bottom living) and epibenthic macroinvertebrates (larger than 1.0 cm^2) was mandated in 1993 by the TITP NPDES Permit No CA0053856, Order No. 93-014. Modifications to the program were necessary in 1995 (Interim Monitoring Program) and 1996 (Post-Pier 400 Monitoring Program) due to Pier 400 construction activities and the final relocation of the TITP effluent discharge pipe, respectively. Sediment type or associated contaminants may exclude certain fish and epibenthic macroinvertebrates from an area either by precluding prey species (Cross et al. 1985), directly killing them, inhibiting settlement of their larvae, or driving certain species away, allowing more tolerant species to exploit these areas. Due to these factors, the composition of demersal fish and epibenthic macroinvertebrate populations varies between these ecologically distinct environments. The objective of the trawl program is to assess the demersal fish and epibenthic invertebrate assemblages in the vicinity of the Terminal Island Treatment Plant's wastewater outfall in order to partition out the relative anthropogenic and/or natural factors responsible for the biological patterns recognized in the Outer Los Angeles Harbor. To make this assessment, community indices were calculated and cladistic [= most parsimonious distribution of character data (species)] analyses were conducted in order to discern distributional patterns of trawl-caught organisms over space and time, and to determine community relationships among the trawl stations (communities) for the 2002 winter, spring, summer, and fall quarters.

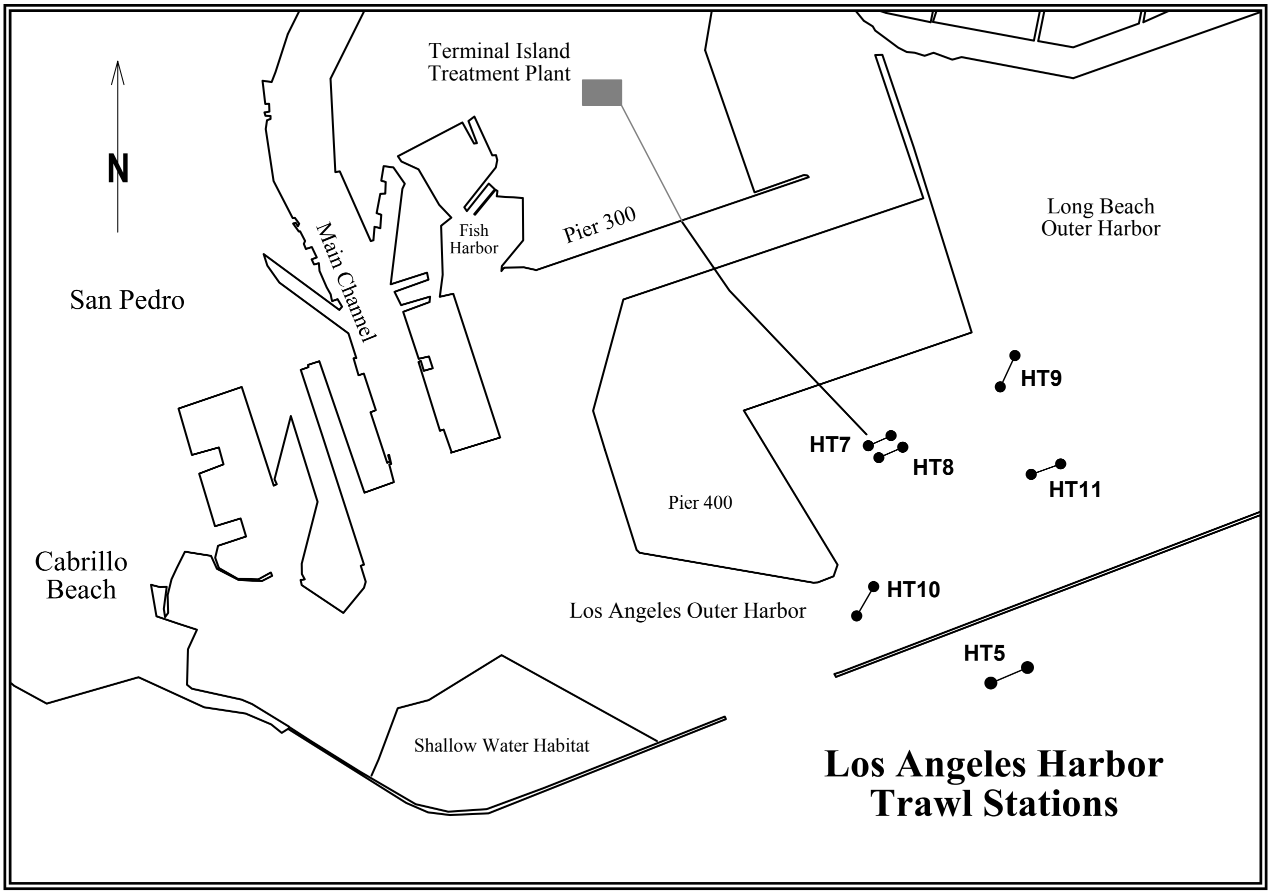

Figure 7-1. Trawl sampling stations in Los Angeles Harbor.

II. MATERIALS AND METHODS

A. FIELD SAMPLING

The NPDES-mandated trawls were conducted on March 7, 2002 (winter), May 1, 2002 (spring), August 26, 2002 (summer), and November 19, 2002 (fall), at six sites: HT5 (15-17 meters), HT7 (10-12 meters), HT8 (10-12 meters), HT9 (10-11 meters), HT10 (23-24 meters), and HT11 (11-13 meters); see Figure 7-1. Due to on-going construction within the Harbor, and a panoply of *Panulirus* (spiny lobster) traps outside the breakwater, only 19 of the 24 trawls were successfully completed over the 4 (quarterly) sampling periods.

Global Positioning Satellite (GPS) coordinates were recorded four times (net over, on bottom, end trawl, surface) during the course of each trawl to pinpoint the exact net location and direction. An otter trawl net having a headrope length of 7.6 m with a 1.27 cm cod end mesh was used. Trawls were towed at approximately two knots and due to the numerous navigational hazards within the trawl areas, the on-bottom time was restricted to five minutes. All fish and invertebrates captured were examined for abnormalities (e.g., fin erosion, tumors, lesions, parasites, and color abnormalities), identified, counted, and weighed. All individuals of a species were collectively weighed to the nearest 0.1 kg. Individuals weighing less than 0.1 kg, were weighed together resulting in a composite weight value. Standard length size-classes (rounded up to the nearest 1.0 cm) were obtained for all fish. After necessary measurements (length, weight) were taken for community analyses, the organisms were returned to the Harbor.

B. DATA ANALYSIS

Community parameters and indices were calculated for all stations. These concepts and calculations are presented in Magurran (1988). 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 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.

The most parsimonious cladograms, showing the relationships of the objects or stations (Q-analysis) under study were generated using the heuristic search Tree-Bisection and Reconnection and the Branch and Bound algorithm. Cladograms of species groups, showing the association or co-occurrence of these descriptors or species with one another (R-analysis) were also produced for all trawl-caught 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 4.0b10 (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). Robert Smith, formerly of Ecoanlysis, Inc., formatted the Nexus data files per Greg Deets' specifications.

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. FISH

1. Community Parameters

Demersal fishes collected in Los Angeles Harbor represent a moderately diverse, albeit uneven assemblage. During the four quarterly trawls, a total of 1,497 individuals, representing 27 species, were captured. No ambicoloration, epidermal tumors, or fin erosions were observed on fishes collected during this survey period.

Separate tables for fish and invertebrate community parameters [i.e., number of species, total abundance (number of individuals), biomass, Shannon-Wiener diversity index, evenness or relative diversity, and species richness] for the trawl sites over time are shown in Tables 7-1 and 7-2.

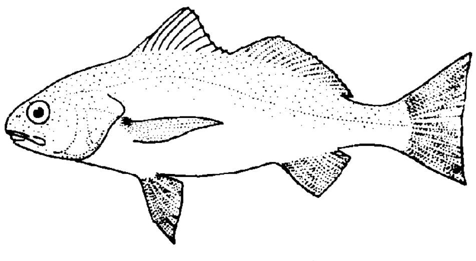

Figure 7-2. *Genyonemus lineatus.*

2. Community Composition

The white croaker *Genyonemus lineatus* [Figure 7-2, figure from Miller and Lea (1972)] (868 = 58%, relative to total fish trawled), speckled sanddab *Citharichthys stigmaeus* (301 = 20.1%), California tonguefish *Symphurus atricaudus* (95 = 6.3%), and queenfish *Seriphus politus* (72 = 4.8%) were the most abundant species collected (comprising 89.2% of the total fish abundance) during the sampling surveys. Other relatively abundant fish species, in descending order, are the California lizardfish *Synodus lucioceps* (40 = 2.7%), the California halibut *Paralichthys californicus* (38 = 2.5%), the specklefin midshipman *Porichthys myriaster* (16 = 1.1%), and the fantail sole *Xystreurys liolepis* (10 = 0.7%). All the remaining species of fish were collected with an abundance of only 9 individuals (0.6% of the total catch) or less.

The most widely occurring species was the speckled sanddab collected in 17 of the 19 sampling efforts (= trawling events). In descending order, both the white croaker and the California tonguefish were collected in 15 of the 19 trawls, the California halibut and specklefin midshipman 12, the queenfish 11, and finally the California lizardfish was collected 10 times. The remaining fish species were collected 6 times or less.

A perusal of the fish community parameters (Table 7-1) does not reveal any striking spatio-temporal trends. There is a slight unimodal trend of increasing species numbers peaking in the summer and fall; average number of species for the winter, spring, summer, and fall sampling quarters were 6.4, 7.2, 8.2, and 8.5 (nonsignificant), respectively. High total abundance values at specific stations were also evident during the spring and summer quarters, these were due to the extremely large numbers of white croaker captured during those trawling events. Relatively high biomass values recorded at stations with high abundance values were due to the collection of large numbers of white croaker. Other high biomass values were due to the collection of larger species such as California halibut, smoothhound sharks, and shovelnose guitarfish. As in last year's report, this year's data does not show many patterns or predilections for specific stations by a given fish species. There are some temporal patterns that appear seasonal, and some spatial patterns that suggest site-specificity, but these highly variable data make conclusive statements difficult.

B. INVERTEBRATES

1. Community Parameters

Epibenthic invertebrates collected at the trawl sites in Los Angeles Harbor represent an uneven, and less abundant assemblage relative to their piscine counterparts. During the four quarterly trawls, a total of 452 individuals, representing 30 taxa, were collected.

2. Community Composition

This year the recently introduced New Zealand cephalaspidean *Philine auriformis* (Figure 7-3) (168 = 37.2% relative to the total number of invertebrates trawled) was the most abundant invertebrate collected. In descending order, blackspotted bay shrimp *Crangon nigromaculata*

(133 = 29.4%), the tuberculate pear crab *Pyromaia tuberculata* (48 = 10.6%), and the ridgeback prawn *Sicyonia ingentis* (33 = 7.3%), were the most abundant species.

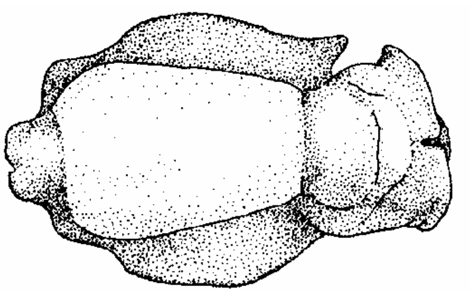

Figure 7-3. *Philine auriformis.*

Crangon nigromaculata, was the most widely occurring invertebrate species, collected in 15 out of the 19 trawl events. This was followed by *Philine auriformis* with 12 occurrences. All other invertebrates were collected eight times or less. Again, the species rank / relative abundance curve (Figure 7-4) exhibits the axiomatic zero-sum multinomial (Hubbell 2001) with a few highly abundant, widely occurring species, followed by a very long tail of exclusively distributed (hierarchically nested) taxa.

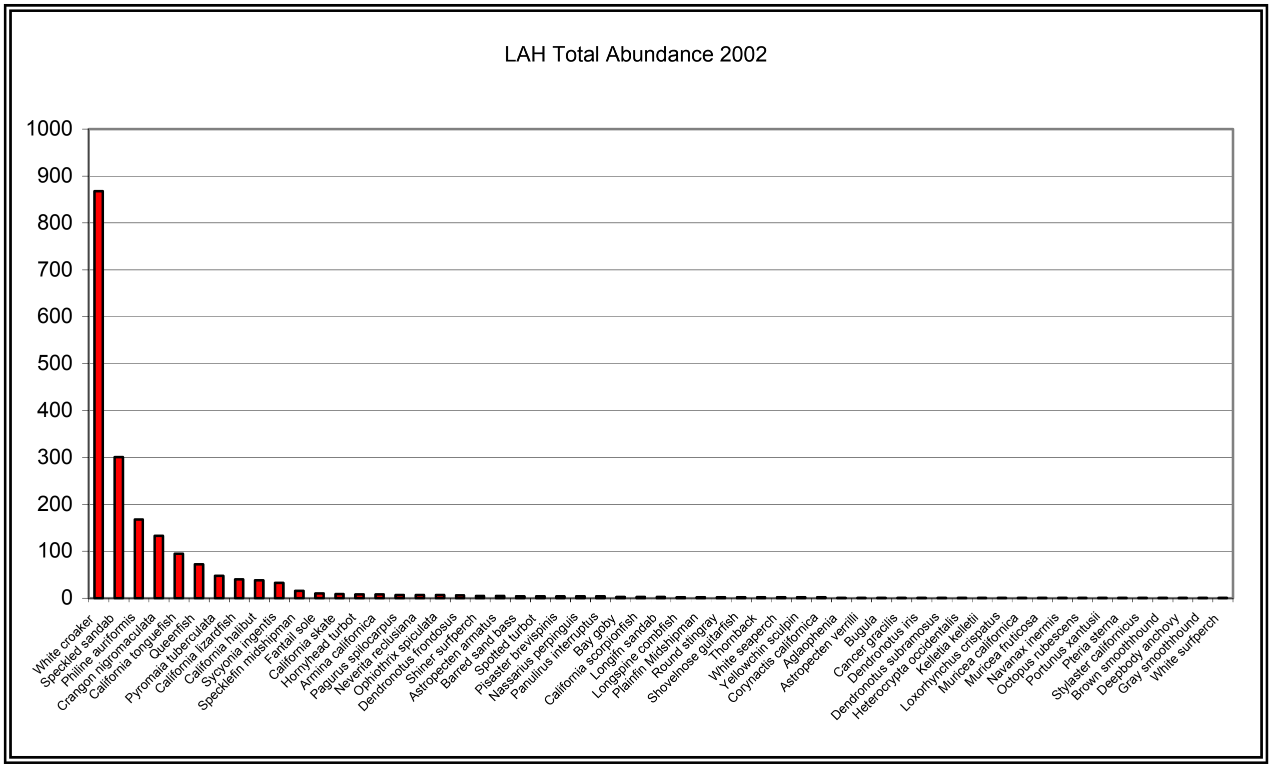

Figure 7-4. Trawl-caught 2002 species rank abundance curve.

Spatiotemporal trends are again difficult to discern with such variable data this year. The large biomass value observed at station HT11 during the winter is attributed to the collection of 2 spiny lobsters *Panulirus interruptis.* The relatively high biomass value at HT7 winter is due to the large numbers of *Philine auriformis* and another spiny lobster. The capture of a large ochre sea star *Pisaster brevipinis,* with 15 ridgeback prawn *Sicyonia ingentis,* were responsible for elevated biomass counts at HT10 spring. Both *Pisaster brevipinis* and the California golden gorgonian *Muricea californica* increased the biomass values at HT5 spring. The brown gorgonian *Muricea fruticosa* is the cause of the high biomass value reported at HT5 summer.

Relatively high abundance values from Table 7-2 are all a result of elevated numbers of *Philine auriformis* and / or *Crangon nigromaculata*.

C. GENERAL TRAWLED FISH AND INVERTEBRATE OBSERVATIONS

1. Trawled Fish

As witnessed over the last four years, relatively low numbers of species were found throughout the sampling period (Table 7-1), most likely a result from past and current construction activities within the Harbor.

Twenty-seven species of fish were collected this year compared to 29 last year. The total abundance of fish decreased from 1,833 last year to 1,497 this year (lower queenfish and white croaker abundance primarily responsible for this decrease). This represents an 18.3% decrease

Table 7-1. Fish community parameters for Los Angeles Harbor, 2002.

Station	No of Species	Total Abundance	Biomass (kg)	Shannon-Wiener Diversity	Evenness	Simpson's Dominance	Gleason's Richness
Winter							
HT7	7	31	0.7	0.84	0.43	0.35	1.75
HT8	6	17	2.0	1.49	0.83	0.77	1.76
HT9	7	45	2.8	1.31	0.67	0.62	1.58
HT10	9	97	5.5	1.63	0.74	0.76	1.75
HT11	3	23	0.4	0.67	0.61	0.38	0.64
Spring							
HT5	5	45	1.3	0.9	0.56	0.48	1.05
HT7	6	28	5	1.25	0.7	0.63	1.50
HT8	9	210	6.4	0.66	0.3	0.26	1.50
HT9	7	16	3.3	1.63	0.84	0.79	2.16
HT10	9	153	5.4	1.22	0.56	0.59	1.59
HT11	7	53	4.9	1.34	0.69	0.68	1.51
Summer							
HT5	7	49	4	1.3	0.67	0.62	1.54
HT7	10	38	4.2	1.83	0.79	0.82	2.47
HT8	7	31	1.2	1.71	0.88	0.82	1.75
HT9	7	369	7	0.42	0.22	0.16	1.02
HT10	11	74	2.4	1.62	0.68	0.72	2.32
HT11	7	113	4.7	0.86	0.44	0.38	1.27
Fall							
HT5	8	27	2.93	1.45	0.7	0.65	2.12
HT10	9	78	5.07	1.51	0.69	0.74	1.84

in abundance. *Genyonemus lineatus* remained the most abundant species, followed by *Citharichthys stigmaeus, Symphurus atricaudus* and *Seriphus politus*. Together, the two sciaenids (white croaker and queenfish) comprised 62.8% of the total abundance of the trawled-fish, the top 4 species comprised 89.2% of the total abundance of the trawled fish. As in previous years, the overwhelming majority of *Genyonemus lineatus* were juveniles known to feed on benthic organisms, particulates and plankton suspended in the water column (Ware 1979, Jahn et al. 1988, Love et al. 1984). The queenfish Se*riphus politus*, although the number of individuals is low for 2002, exhibit a more even distribution of immature and adult fish. Queenfish may be immature at sizes greater than 100 mm with some males mature at less than 100 mm and females mature at greater than 100 mm standard length (SL) (DeMartini et al. 1985).

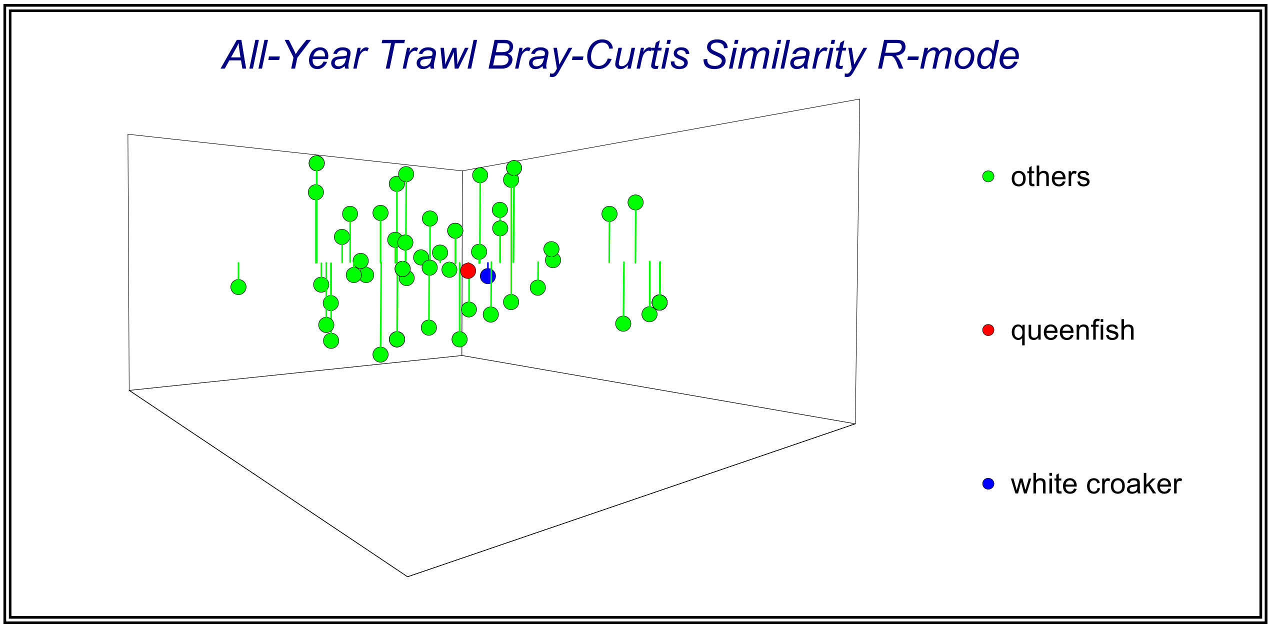

Figure 7-5. R-mode NMDS ordination of all trawl caught species for 2002 emphasizing sciaenid associations.

The two most abundant sciaenid species in the CalCOFI ichthyoplankton collections are *G. lineatus* and *S. politus*. Interestingly, these two species are known to associate intimately with one another contemporaneously, as well as in fossil records from the Pliocene (1.8 – 5.3 mya) and Pleistocene 1.8 mya – 11,000 ya) (Fitch 1969, Wake 1999). Fascinatingly, an R-mode multivariate non-metric multidimensional scaling ordination (using Bray-Curtis coefficients) group these two croakers in multivariate space (Figure 7-5) further underscoring their tight association and co-occurrence. Most sciaenids live on sand or mud bottoms in shallow coastal waters and bays feeding on small fishes, and bottom invertebrates, primarily crustaceans. In general, sciaenids become epibenthic early in the larval period (Moser, 1996). *G. lineatus* transforms (from the larval stage to the juvenile stage-with the loss of larval characters and the addition of adult characters) at approximately 17mm SL and may be epibenthic after preflexion ca. 9 mm notochord length (NL). Likewise, *S. politus* transforms at about 16 mm SL (Moser, 1996).

Genyonemus lineatus and *S. politus* are reported to approximately 410 mm and 300 mm total length (TL), respectively (Eschmeyer et al. 1983). The spawning season for *G. lineatus* is from December to April peaking in March. White croaker collected in the LAH 2002 survey ranged in size from 20 mm to 210 mm SL with a large number of juveniles, 41-90 mm SL, collected at station 8 (near the outfall) and station 9 (east of the outfall) during May and August. Realizing the limitations of the otter trawl for the collection of juvenile fish, the fact that relatively large abundances of juvenile white croaker collected is a positive indication that young-of-the-year are utilizing this portion of the harbor as part of their nursery area (Figure 7-6).

Citharichthys stigmaeus, are reported to 170 mm TL but are rarely over 130 mm SL. Speckled sanddabs occur from the nearshore to 366 m depth, but are usually caught in less than 91 meters. Speckled sanddabs transform (metamorhose) between 24-38 mm marking the end of the larval stage with the acquisition of juvenile characters. Ranking second in abundance, fish collected from the 2002 survey ranged from 31-100 mm SL with the highest numbers from 50-90 mm SL confirming the fact that the Los Angeles Harbor is an ecologically important area for the ontogeny of this species. Sanddabs are forage for fishes, mammals and sea birds (Eschmeyer, 1983), and are consequently, an essential component of the harbor community and a potential indicator of ecological risk assessment.

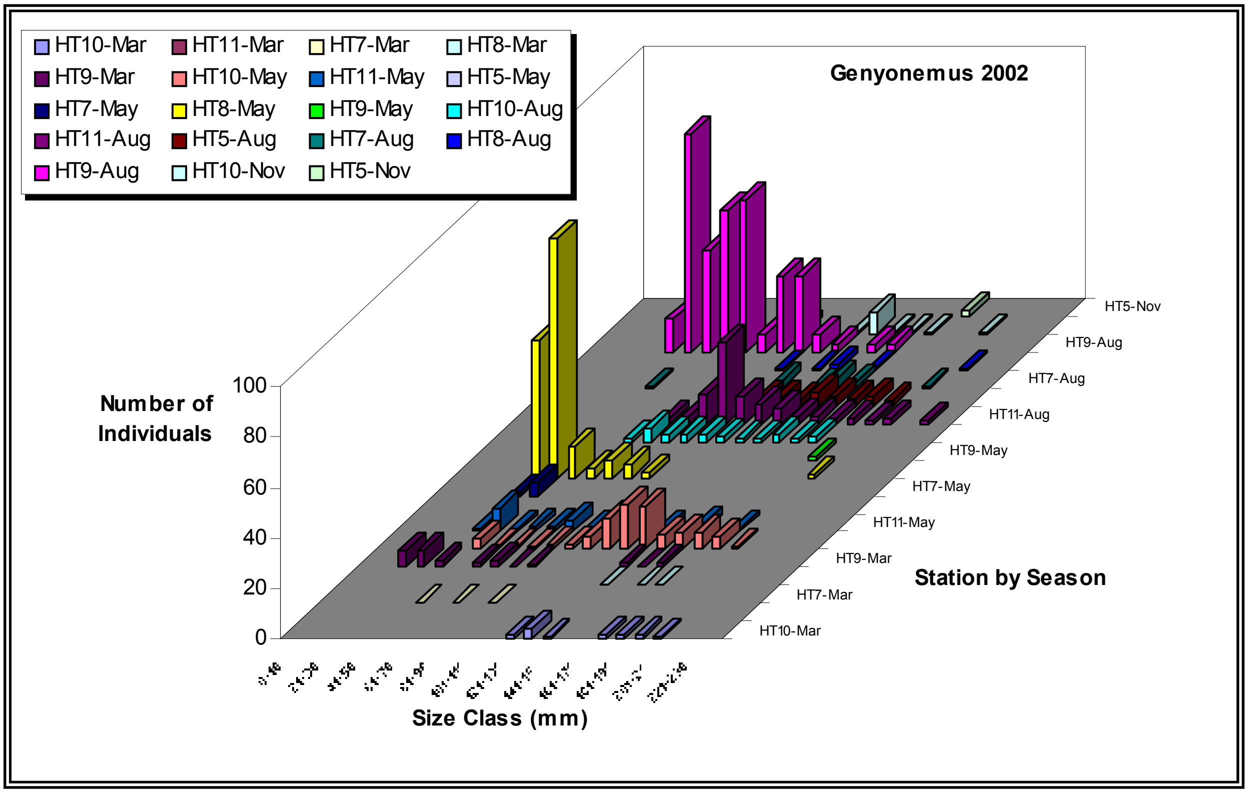

Figure 7-6. Bar graph depicting 2002 *Genyonemus lineatus* abundance and size class per station

2. Trawled Invertebrates

Relatively low numbers of species and abundance values continue from the previous reporting year, again this may be due to the excessive sedimentation and turbation as a result of the post Pier 400 construction activities affecting the entire area. Indeed, 8 of the 19 trawls captured only 4 or fewer species of invertebrates (see Table 7-2).

There is a 10% increase in the total number of trawled invertebrate species collected relative to last year. The total abundance of trawled invertebrates increased from 152 in 2000 to 408 in 2001, to 452 in 2002 .

3. Catch Per Unit Effort

Since unsuccessfully completed trawling events over different sampling periods may yield results difficult to assess, the catch per unit effort (CPUE) may be a better indicator or comparator over time. Thus, last year's CPUE for the fish was 1833/24 = 76, this year's CPUE was 1497 / 19 = 79. Likewise, the CPUE for the trawled invertebrate catch last year was 408/24 = 17, this year's CPUE is 452 / 19 = 24.

Table 7-2. Invertebrate community parameters for Los Angeles Harbor, 2002.

Station	No of Species	Total Abundance	Biomass (kg)	Shannon-Wiener Diversity	Evenness	Simpson's Dominance	Gleason's Richness
Winter							
HT7	8	42	0.7	1.21	0.58	0.47	1.87
HT8	6	70	<0.1	1	0.56	0.45	1.18
HT9	5	18	0.4	0.96	0.6	0.54	1.38
HT10	3	11	0.1	0.6	0.55	0.69	0.83
HT11	2	3	0.8	0.64	0.92	0.56	0.91
Spring							
HT5	10	16	1.2	2.08	0.90	0.16	3.25
HT7	5	37	<0.1	1.30	0.81	0.31	1.11
HT8	5	11	0.2	1.41	0.88	0.29	1.67
HT9	4	57	0.1	0.54	0.39	0.72	0.74
HT10	5	23	1.4	1.07	0.66	0.47	1.28
HT11	4	74	0.4	0.65	0.47	0.45	0.7
Summer							
HT5	10	15	5	2.18	0.95	0.13	3.32
HT7	2	6	<0.1	0.45	0.65	0.72	0.56
HT8	6	13	<0.1	1.67	0.93	0.21	1.95
HT9	2	7	<0.1	0.41	0.59	0.76	0.51
HT10	5	19	0.1	1.44	0.89	0.39	1.36
HT11	4	13	<0.1	1.12	0.81	0.37	1.17
Fall							
HT5	4	8	0.2	1.21	0.87	0.34	1.44
HT10	3	19	<0.1	0.84	0.76	0.52	0.68

4. Species Abundance Patterns

Rank abundance and occurrence values for fish and invertebrate species exhibit a characteristic species abundance pattern; only a few species are highly abundant. 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 curves for all trawl stations (Figure 7-4) seems to mimic the axiomatic zero-sum multinomial (Hubbell 2001) with a few highly abundant, widely occurring species, followed by a very long tail of exclusively distributed (hierarchically nested) taxa.

D. CLADISTIC ANALYSIS and NON-METRIC MULTIDIMENSIONAL SCALING

The generation of a pattern accurately representing the environmental conditions of a study area is ultimately the goal in any type of monitoring endeavor. Without a pattern, regardless of its apparent randomness or non-randomness, science has little if anything to explain. Furthermore, one would be equally unlikely to achieve any understanding of these ecological processes without an understanding of the patterns they generate (Lambshead 1986, Patterson 1980). Several theories and methods to generate patterns are currently in practice. The method now dominating systematics (classification) is cladistics. This methodology is employed herein as an ecomonitoring tool. The cladogram generated by the most parsimonious distribution of species over space and time for the Los Angeles Harbor trawl monitoring stations is presented in Figure 7-7.

1. Annual Analysis - Trawled Fish Plus Invertebrates

Since deleting rare species can damage the sensitivity of community-based methods to detect ecological changes (Cao et al. 1998 and 2001), all species (fish and invertebrates) were included in the analysis. The cladistic analysis resulted in three very similar equally parsimonious reconstructions of the data (cladogram). Tree number one was randomly chosen. The cladograms had a tree length of 132.26, a consistency index (CI) of 0.4918 (maximal value = 1.0), and a retention index (RI) of 0.4117 (maximal value = 1.0).

The resultant cladogram (Figure 7-7) appears to be composed of three major station groupings or clades. Closer inspection of the monitoring station relationships seems to reveal minimal spatiotemporal patterns that warrant mention. For example, the group rooting the tree (referred to as the outgroup) nearest the bottom of the page is composed of two of the three succesfully trawled HT5 stations, located outside of the harbor. The sample not included in this group is HT5 from the spring sampling quarter. Interactive mapping of species and their abundance attributes via MacClade 4.05 (Maddison and Maddison 2000) quickly explains the reason for this appararent station grouping anomaly. Specifically, HT5 spring sample shares the California Armina (a dorid nudibranch) *Armina californica*, the California tonguefish *Symphurus atricaudus*, the blackspotted bay shrimp *Crangon nigromaculata,* the spotwrist hermit *Pagurus spilocarpusI,* the tuberculate pear crab *Pyromaia tuberculata*, and the spotted turbot *Pleuronichthys ritteri*, with other Harbor station samples, thus grouping more intimately with those station samples, than with its cohorts outside the Harbor. The only species uniquely shared by the sample from station HT5 spring with any of the other two HT5 samples is the club-tipped or strawberry anenome *Corynactis californica* with the HT5 summer sample, thus making the community composition from spring HT5 much more akin to those stations found within the Harbor than with its natural cohorts (HT5) outside the Harbor. Optionally, reviewing the apomorphy list generated by PAUP* allows one to see where the data is mapped onto the branches after character optimization. This explicit and optimized distribution of the data or species is a concise method explaining why the stations in the cladogram are related in the way that they are. Indeed, the distributions of the species are the result (as they are response variables) of certain causal processes, which we must infer.

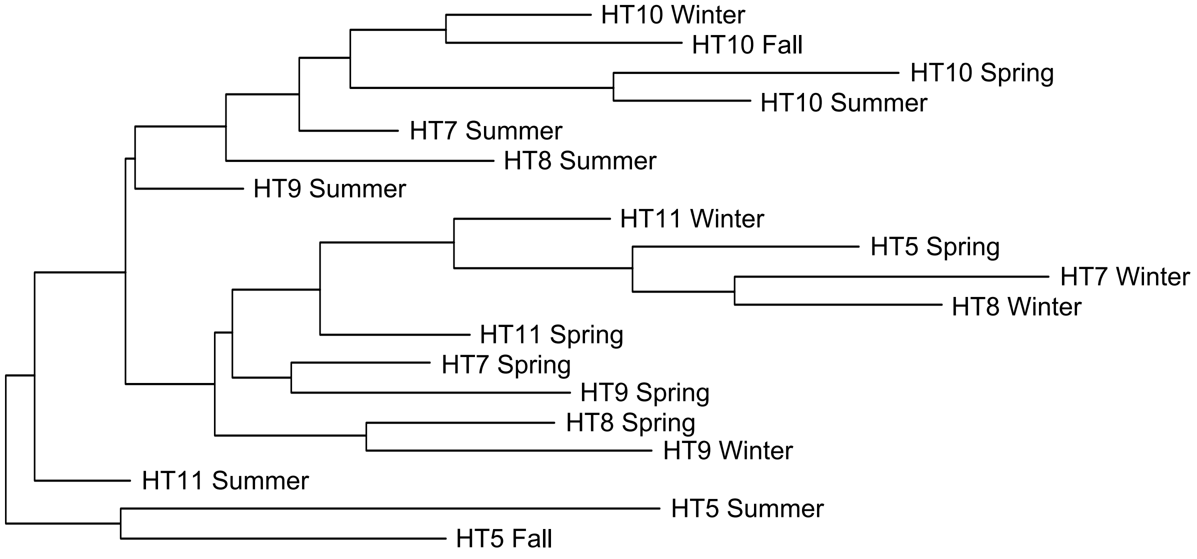

Figure 7-7. Cladogram of 2002 monitoring stations using trawl-caught species as descriptors.

The node separating the aforementioned outgroup with the remaining part of the cladogram is due to the derived presence of the California tonguefish and blackspotted bay shrimp, and abundance increases of the California halibut and California lizardfish in the ingroup. The four species have consistency indices (a measure of fit to the cladogram) of 0.333, 0.475, 0.265, and 0.449, respectively.

Although there is a hint of seasonality in the cladogram and a slight hint of spatial grouping of HT7 with HT8, the lack of spatial fidelity in the groupings, coupled with the variability of the data, does not suggest that the effluent from the Terminal Island Treatment Plant is creating an environmentally disturbed community.

Perhaps the most obvious spatial groupings observed are the two samples (summer and fall) from station HT5 located outside the Harbor, and the clade composed of all four samples from station HT10. The presence of the ridgeback prawn *Sicyonia ingentis* (RI = 0.750, RI of step-matrix = 0.943), longfin sanddab, longspine combfish, plainfin midshipman, and the yellowchin sculpin at all or at a subset of these four samples are responsible for this tight station grouping. HT10 is unique in that it's the deepest station trawled inside the Harbor, and located between two rocky kelp bearing areas, namely the middle breakwater and the southernmost extension of pier 400.

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

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 analyses. Stress values for the ordinations were 0.18 for the conventional phenetic approach using the Bray-Curtis coefficient and only 0.12 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. The 3-dimensional NMDS plot (Figure 7-8) from the patristic distances derived from the cladogram yielded a much more informative map than that resulting from the phenetic approach.

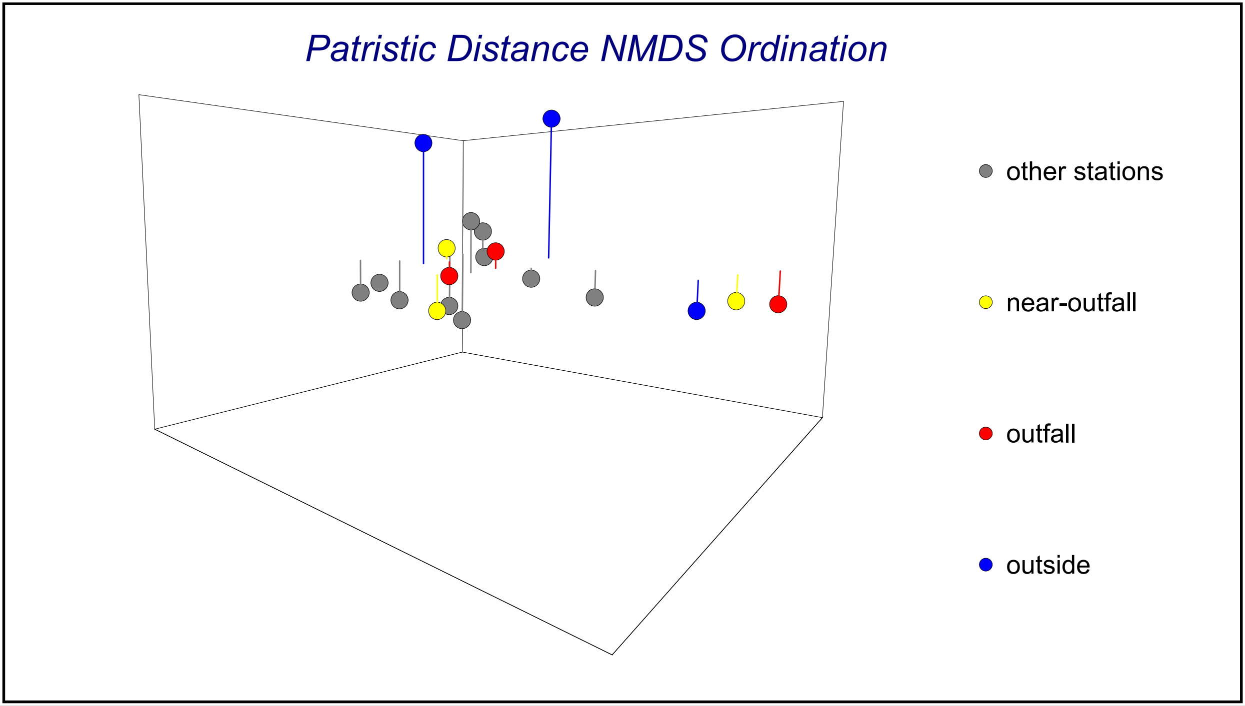

Figure 7-8. 3D Non-metric multi-dimensional scaling (NMDS) ordination of patristic distance derived from parsimony analysis of 2002 monitoring stations.

The 3-d map derived from the patristic distance matrix shows much more distinct groupings of station relationships than the Bray-Curtis approach (not shown herein), especially with regards to how removed the samples from HT5 summer and HT5 fall are from the rest of the samples. Interestingly, two of the three "outfall-station" samples group together and each "near-outfall" station sample does indeed group adjacent to that quarter's "outfall-station" indicating some relative close degree of site or spatial fidelity (grouping).

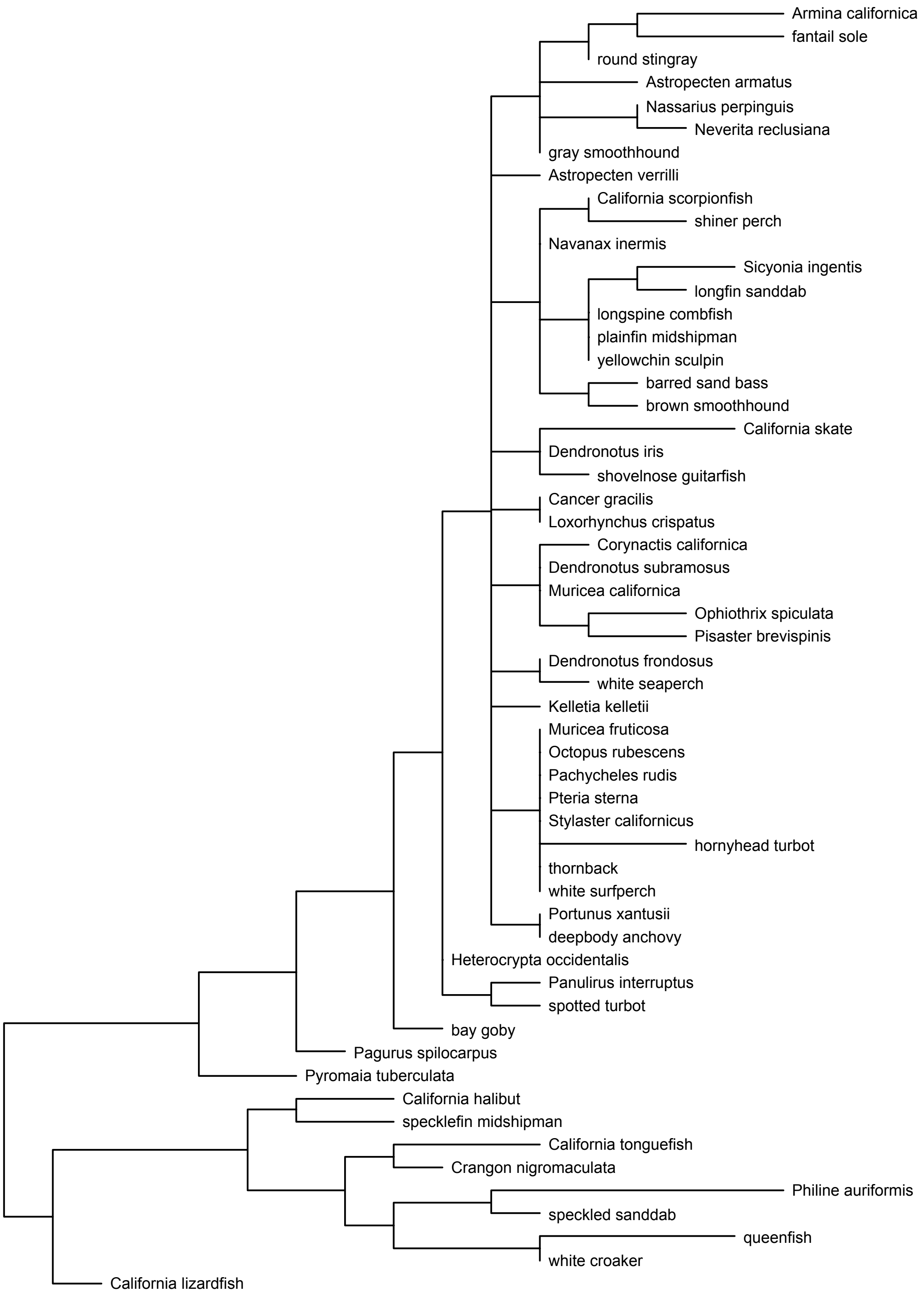

Figure 7-9. Parsimony analysis of co-occurring species (PACOS) cladogram of summer 2002 infauna.

An interesting duality exists between objects (monitoring stations in this case) and their descriptors (the species or response variables in this case). The previously discussed data and resultant cladogram and ordination were analyzed via Q-analysis, which measures the relationship between objects (stations) based on descriptors (taxa or species). The relationship between descriptors based on objects is commonly referred to as an R-analysis. Parsimony analysis was conducted on the transposed binary-matrix of fish taxa by stations. Again several very similar, equally parsimonious PACOS cladograms were generated. A single cladogram (Figure 7-9) was randomly chosen to present. The cladogram had a tree length of 101, a consistency index of 0.1818, and a relatively high retention index of 0.6168.

IV. DISCUSSION

A. REVIEW OF PREVIOUS STUDIES

Adult fish populations in Los Angeles Harbor have been studied in the past using otter trawls, gill nets, purse seines, and diver studies (MEC 1988). The sampling devices most frequently used were otter trawls of various sizes, and it has been shown that catch efficiency of otter trawls is highly variable (8-52%) depending on trawl size, fish size, and fish species (MEC 1988). Hence, it is difficult to assess how quantitatively comparable previous reports are with our results reported herein. The aforementioned variability reported from our community parameters over the last few years (Tables 7-1 and 7-2) continue to bear testimony to this concept (CLA, EMD 1994a - present chapter).

This year, with all 19 sampling efforts completed, the same small group of fish and invertebrate species that typically dominate year after year were recorded. The dominant fish species were *Genyonemus lineatus*, *Citharichthys stigmaeus*, *Symphurus atricaudus*, and *Seriphus politus.* This year, once again *Philine auriformis* dominated the catch with, *Crangon nigromaculata* the next closest in abundance and occurrence.

B. Conclusion

The lack of trend or pattern observed in the number of species and abundance values across the various sampling stations, in conjunction with only a slight hint of spatiotemporal groupings revealed by the cladistic analysis and NMDS, suggest community patterns are more a result from previous sediment fallout, or from the very active trawling programs occurring in the Harbor by various research vessels, than from some impact associated with the filtered secondary effluent discharged from the Terminal Island Treatment Plant. In fact, 14 out of the 19 trawls yielded relatively depauperate catches of five invertebrate species or less; however, only 1 of 19 trawls (HT11 winter) had catches of 3 fish species or less.

Additionally, it has been hypothesized that establishing monitoring programs in spatially open systems such as the open ocean using highly mobile organisms (e.g., fish) can impose formidable problems when trying to assess local effects and changes (Thomas 1993). However, in "spatially captive" systems, such as the Los Angeles Harbor, the mobility of fish may in effect increase information sensitivity. Fish have the immediate capability in both space and time to avoid or exploit these minimally impacting perturbations such as secondary-treated effluent in spatially captive environments. Antithetically, this type of data may yield finer pattern resolution than other biological data sets (i.e., infauna) in these unique (captive and relatively homogeneous) situations.

Although Pier 400 construction is complete, current activities including proximate dredging and filling of spoils remain. This combined with the previous construction, dredging, and fill activities appear to constitute a lasting effect upon the behavior and, therefore, the distribution of species often captured in our monitoring program. Additionally, the future main channel deepening project (refer to Chapter1 in this report) will possibly affect community structure. Hence, any message possibly obtained from the data analysis would most likely be garbled, altered, and not informative relative to the objective of the Los Angeles Harbor Monitoring Program: to investigate potential effects of the effluent discharged from the Terminal Island Treatment Plant's outfall on the biological communities (i.e., benthic infauna, trawled fish and invertebrates, and sportfish) in the L.A. Harbor. Hence, we must continue to recommend that the results from the trawling program be viewed with extreme caution until the Los Angeles Harbor environment becomes more stabilized.

V. LITERATURE CITED

Bellan, G., and D. Bellan-Santini. 1997. The use of parsimonious cladistic analyses in benthic synecology: case studies from a pollution zone. Italian Society of Ecology 18: 247-250.

Bellan-Santini, D., J.C. Dauvin, and G. Bellan. 1994a. Analyse de donnϑes en ϑcologique benthique: utilisation de la mϑthode de l'analyse de parcimonie. Oceanologica Acta 17 (3): 331-340.

Bellan-Santini, D., P.M. Arnaud, and G. Bellan. 1994b. Affinites entre peuplements mediterraneens benthiques avec et sans *Caulerpa taxifolia*. Second International Workshop on *Caulerpa taxifolia.* November 1994, Barcelona, Spain: 1-4 pp.

Berlocher S. H. and D. Swofford.1997. searching for phylogenetic trees under the frequency parsimony criterion: An approximation using generalized parsimony. Systematic Biology. 46(1): 211-215

Cao, Y., D.D. Williams, and N.E. Williams. 1998. How important are rare species in aquatic community ecology and bioassessment? American Society of Limnology and Oceanography, Inc. 43 (7): 1403-1409.

Cao, Y., D.P. Larsen, and R.St-J. Thorne. 2001. Rare species in multivariate analysis for bioassessment: some considerations. Journal of the North American Benthological Society. 20 (1): 144-153.

CLA, EMD. See City of Los Angeles, Environmental Monitoring Division.

Chamberlain, T.C., 1897. The method of multiple working hypotheses. Journal of Geology 5: 837-848.

City of Los Angeles, Environmental Monitoring Division. 1994a. Marine Monitoring in the Los Angeles Harbor: Annual Assessment Report for the Period March 1993 through December 1993. Report submitted to EPA and RWQCB (Los Angeles). Department of Public Works, Bureau of Sanitation, Terminal Island Treatment Plant, San Pedro, California, pp. 1-1 to 9-4 + appendices.

City of Los Angeles, Environmental Monitoring Division. 1994b. Marine Monitoring Santa Monica Bay: Annual Assessment Report for the Period July 1992 through June 1993. Report submitted to EPA and RWQCB (Los Angeles). Department of Public Works, Bureau of Sanitation Hyperion Treatment Plant, Playa del Rey, California, pp. 1-1 to 9-24 + appendices.

City of Los Angeles, Environmental Monitoring Division. 1995b. Marine Monitoring in the Los Angeles Harbor: Annual Assessment Report for the Period January 1994 through December 1994. Report submitted to EPA and RWQCB (Los Angeles). Department of Public Works, Bureau of Sanitation, Terminal Island Treatment Plant, San Pedro, California, pp. 1-1 to 9-8 + appendices.

City of Los Angeles, Environmental Monitoring Division. 1996. Marine Monitoring in the Los Angeles Harbor: Annual Assessment Report for the Period January 1995 through December 1995. Report submitted to EPA and RWQCB (Los Angeles). Department of Public Works, Bureau of Sanitation, Terminal Island Treatment Plant, San Pedro, California, pp. 1-1 to 9-12 + appendices.

City of Los Angeles, Environmental Monitoring Division. 1997. Marine Monitoring in the Los Angeles Harbor: Annual Assessment Report for the Period January 1996 through December 1996. Report submitted to EPA and RWQCB (Los Angeles). Department of Public Works, Bureau of Sanitation, Terminal Island Treatment Plant, San Pedro, California, pp. 1-1 to 8-32 + appendices.

City of Los Angeles, Environmental Monitoring Division. 1998. Marine Monitoring in the Los Angeles Harbor: Annual Assessment Report for the Period January 1997 through December 1997. Report submitted to EPA and RWQCB (Los Angeles). Department of Public Works, Bureau of Sanitation, Terminal Island Treatment Plant, San Pedro, California, pp. 1-1 to 8-12 + appendices.

City of Los Angeles, Environmental Monitoring Division. 1999. Marine Monitoring in the Los Angeles Harbor: Annual Assessment Report for the Period January 1998 through December 1998. Report submitted to EPA and RWQCB (Los Angeles). Department of Public Works, Bureau of Sanitation, Terminal Island Treatment Plant, San Pedro, California, pp. 1-1 to 7-20 + appendices.

City of Los Angeles, Environmental Monitoring Division. 2000. Marine Monitoring in the Los Angeles Harbor: Annual Assessment Report for the Period January 1999 through December 1999. Report submitted to EPA and RWQCB (Los Angeles). Department of Public Works, Bureau of Sanitation, Terminal Island Treatment Plant, San Pedro, California, pp. 1-1 to 8-12 + appendices.

City of Los Angeles, Environmental Monitoring Division. 2001. Marine Monitoring in the Los Angeles Harbor: Annual Assessment Report for the Period January 2000 through December 2000. Report submitted to EPA and RWQCB (Los Angeles). Department of Public Works, Bureau of Sanitation, Terminal Island Treatment Plant, San Pedro, California, pp. 1-1 to 8-12 + appendices.

City of Los Angeles, Environmental Monitoring Division. 2002. Marine Monitoring in the Los Angeles Harbor: Annual Assessment Report for the Period January 2001 through December 2001. Report submitted to EPA and RWQCB (Los Angeles). Department of Public Works, Bureau of Sanitation, Terminal Island Treatment Plant, San Pedro, California, pp. 1-1 to 8-12 + appendices.

Clarke, K.R. and R.N. Gorley. 2001. *PRIMER version 5.02: User Manual / Tutorial*. PRIMER-E: Plymouth, England, 91 pp.

Cracraft, J. 1994. Species diversity, biogeography, and the evolution of biotas. American Zoologist 34: 33-47.

Cross, J.N., J.D. Roney, and G.S. Kleppel. 1985. Fish food habits along a pollution gradient. California Fish and Game 71 (1): 28-39.

Deets, G.B. and E. Dyerson. (in press). Phylogenetic approaches to ecological problems. Journal of Biogeography. Blackwell Press. United Kingdom.

DeMartini, L. G. Allen, R.K. Fountain and D. Roberts. 1985. Diel and depth variations in the sex-specific abundance, size composition, and food habits of queenfish, (Sciaenidae), Fish. Bull. 83 (2) 171-185.

Enghoff, H. 2000. Reversals as branch support in biogeographical parsimony analysis. Vie et Milieu 50 (4): 255-260.

Eschmeyer, W.N., E.S. Herald, H. Hammann. 1983. A Field Guide to Pacific Coast Fishes from the Gulf of Alaska to Baja California. The Peterson Field Guide Series, 28. Houghton Mifflin Company, Boston, 336 pp.

Fitch, J.E. 1966. Additional fish remains, mostly otoliths from a Pleistocene deposit at Playa Del Rey, California. Contributions in Science. Los Angeles Museum of Natural History, Exposition Park, Los Angeles, California. 119: 1-16.

Goloboff, P. 1993. Estimating character weights during tree search. Cladistics 9: 83-91.

Goodsell P. J. and S. D. Connell 2002. Can habitat loss be treated independently of habitat configuration? Implications for rare and common taxa in fragmented landscapes. Marine Ecology Progress Series 239 : 37-44.

Harold, A.S. and R.D. Mooi. 1994. Areas of endemism: definition and recognition criteria. Systematic Biology 43 (2): 261-266.

Hillis, D.M. 1998. Phylogenetic analysis of frequency data in molecular ecological studies. Advances in Molecular Ecology. Pp. 25-38, *in* Proceedings of the NATO Advanced Study Institute on Molecular Ecology. G. R. Carvalho (Ed.). IOS Press, 313 pp.

Hooper, J. N. A., J. A. Kennedy, and R. J. Quinn. 2002. Biodiversity "hotspots", patterns of richness and endemism, and taxonomic affinities of tropical Australian sponges (Porifera). Biodiversity and Conservation. 11: 851-885.

Hubbell, S.P. 2001. The unified Neutral Theory of biodiversity and biogeography. Princeton University Press, Princeton, New Jersey, 375 pp.

Jahn, A.E., D.M. Gadomski and M.L. Sowby. 1988. On the role of food-seeking in the suprabenthic habitat of larval white croaker, *Genyonemus lineatus* (Pisces: Sciaenidae). Fish. Bull. 86(2) 251-262.

Kitching, I.J, P.L. Forey, C.J. Humphries, and D. M. Williams. 1998. Measures of character fit and character weighting Pp. 92-116, *in* Cladistics: the theory and practice of parsimony analysis. 2nd edition. Oxford University Press, New York, 228 pp.

Lambshead, P.J.D. 1986. Sub-catastrophic sewage and industrial waste contamination as revealed by marine nematode faunal analysis. Marine Ecology - Progress Series 29: 247-260.

Lambshead, P.J.D. and G.L.J. Paterson. 1986. Ecological cladistics-an investigation of numerical cladistics as a method for analysing ecological data. Journal of Natural History 20: 895-909.

Lambshead, P.J.D., B.J. Elce, D. Thistle, J.E. Eckman, and P.R.O. Barnett. 1994. A comparison of the biodiversity of deep-sea marine nematodes from three stations in the Rockall trough, Northeast Atlantic, and one station in the San Diego trough, Northeast Pacific. Biodiversity Letters 2: 95-107.

Legendre, P. 1986. Reconstructing biogeographic history using phylogenetic tree analysis of community structure. Systematic Zoology 35: 65-80.

Love, Milton S., G.E. McGowen, W. Westphal, R.J.Lavenberg, and L. Martin. 1984. Aspects of the life history and fishery of the white croaker, *Genyonemus lineatus* (Sciaenidae), off California. Fish. Bull.82 (1): 179-198.

Lyons-Weiler, J. and R.J. Tausch. 1997. The demarcation of historical from ecological variance in species diversity patterns. Pp. 209-221, *in* Conservation and management of native plants and fungi. A. Liston, R.M. Love, D.L. Luoma, R.J. Meinke, and M.V.Wilson, (eds), Native Plant Society of Oregon, Corvallis, Oregon, 296 pp.

Maddison, DR and W.P. Maddison. 2000. MacClade 4. Analysis of phylogeny and character evolution. Version 4.0. Sinauer Associates, Sunderland Massachusetts.

Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, New Jersey, 179 pp.

Masselot, G, A. Nel, A. Thomas, and J. Nel. 1997. Parcimonie de Wagner et biomonitoring de cours d'eau: Application au bassin de la Risle (Normandy, France). Annales de la Societe Entomologie . 33 (3): 237-258.

MEC Analytical Systems (MEC). 1988. Biological baseline and an ecological evaluation of existing habitats in Los Angeles Harbor and adjacent waters. Volume II. Prepared for the Port of Los Angeles, 447 pp.

Miller, D.J. and R.N. Lea. 1972. Guide to the coastal marine fishes of California. California Department of Fish and Game Bulletin. No. 157, 249 pp.

Morrone, J.J. 1994. On the identification of areas of endemism. Systematic Biology 43 (3): 438-441.

Morrone, J.J. and J.V. Crisci. 1995. Historical biogeography: Introduction to methods. Annual Review of Ecology and Systematics. 26: 373-401.

Moser, H.G. 1996. SCIAENIDAE: Croakers and drums. Pp. 1017-1019, *in* The early stages of fishes in the California Current region, H. G. Moser, (Ed). Calif. Coop. Oceanic Fish. Invest. Atlas 33, 1505 pp.

Nel, A., J. Nel, G. Masselot, and A. Thomas. 1998. An investigation into the application of the Wagner parsimony method in synecology. Biological Journal of the Linnean Society. 65: 165-189.

Patterson, C. 1980. Cladistics. Biologist 27: 234-240.

Perochon, E., G. Masselot, and Andre Nel. 2001. Freshwater macroinvertebrates sampling problems in synecological analyses and biomonitoring. A concrete example. Annales Societie de Entomologie Francais. (N.S.). 37 (3): 341-346.

Podani, J., P. Csontos, and J. Tamas. 2000. Additive trees in the analysis of community data. Community Ecology. 1 (1): 33-41.

Quicke, D.L.J. 1993. Principles and techniques of contemporary taxonomy. Blackie Academic and Professional, Glasgow, Scotland, 311 pp.

Rosen, B.R. 1988. From fossils to earth history: applied historical biogeography. Pp. 437-481, *in* A. A. Myers and P. S. Giller (eds.). Analytical biogeography: An integrated approach to the study of plant and animal distributions. Chapman and Hall, Glasgow, Scotland, 584 pp.

Rosen B.R. and B. Smith. 1988. tectonics from fossils? Analysis of reef-coral and sea-urchin distributions from from late Createaceous to recent, using a new method. Pp. 275-306, *in* M.G. Audeley-charles and A. hallam (Eds.). Gondwana and Tethys,. Geological Society Special publication 37. London, England, 317 pp.

Salen-Picard, C., G. Bellan, D. Bellan-Santini, D. Arlhac, and R. Marquet. 1996. Long-term changes in a benthic community of a Mediterranean gulf (Gulf of Fos). Oceanologica Acta, 20 (1): 299-310.

Sankoff, D. and R.J. Cedergren. 1983 Simultaneous comparison of three or more sequences related by a tree, Pp. 253-263*, in* D. Sankoff and J.B. Kruskal (eds.), Time warps, string edits, and macromolecules: The theory and practice of sequence comparison. Addison-Wesley, Reading, Massachusetts, 408 pp.

Sankoff, D. and P. Rousseau. 1975. Locating the vertices of a Steiner tree in arbitrary space. Mathematics Progress. 9: 240-246.

Seibert, D.J. 1992. Tree statistics; trees and "confidence"; consensus trees; alternatives to parsimony; character weighting; character conflict and its resolution. Pp. 39-76, *in* Cladistics: a practical course in systematics. P.L. Forey, C.J. Humphries, I.J. Kitching, R.W. Scotland, D.J. Seibert, and D.M. Williams, contributing authors. Oxford University Press, New York, 191 pp.

Smith, A. B. 1994. Systematics and the fossil record: documenting evolutionary patterns. Blackwell Scientific publications. Oxford, England, 223 pp.

Swofford, D. 2000. PAUP*. Phylogenetic analysis using parsimony version 4.0b10, National Museum of Natural History, Smithsonian Institution, Washington, D.C.

Swofford, D.L., G.L. Olsen, P.J. Waddel, and D.M. Hillis. 1996. Phylogeny reconstruction. Pp. 407-514, *in* Molecular systematics, 2nd ed., (D.M. Hillis, C. Moritz, and B.K. Mable, eds,). Sinauer Sunserland, Massachusetts, 655 pp.

Tamas, J., J. Podani, and P. Csontos. 2001. An extension of presence/absence coefficients to abundance data: a new look at absence. Journal of Vegetation Science. 12: 401-410.

Thomas, J.D. 1993. Biological monitoring and tropical biodiversity in marine environments: a critique with recommendations, and comments on the use of amphipods as bioindicators. Journal of Natural History 27: 795-806.

Trejo-Torres, J. C. and J.D. Ackerman. 2002. Composition patterns of Caribbean limestone forests: Are parsimony, classification, and ordination analyses congruent? Biotropica. 34(4): 502-515.

Wake, T. 1999. Temporal variation in vertebrate archaeofaunas from Camp Pendleton Marine Corps Base, San Diego County, California. Pacific Coast Archaeological Society quarterly. 35 (4): 46-64.

Ware, R.R. 1979. The food habits of the white croaker *Genyonemus lineatus* and an infaunal analysis near areas of waste discharge in outer Los Angeles Harbor. M.S. Thesis, Calif. State Univ., Long Beach, 164 pp.

Warwick, R.M. and K.R. Clarke. 1995. Multivariate measures of community stress and their application to marine pollution studies in the east Asian region. Phuket Marine Biological Center Research Bulletin. 60: 99-113.

Watanabe, K. 1998. Parsimony analysis of the distribution pattern of Japanese primary freshwater fishes, and its application to the distribution of the bagris catfishes. Ichthyological Research 45 (3): 259-270.