

Chapter 5. Macrobenthic Communities

INTRODUCTION

The southern California coastal shelf contains a diverse community of macrofaunal invertebrates (Fauchald and Jones 1979, Thompson et al. 1992, Bergen et al. 2001). These animals are essential members of the marine ecosystem, serving vital functions in wide ranging capacities. For example, many species of benthic invertebrates are important for fish and other organisms, while others decompose organic material as a crucial step in nutrient cycling. The structure of marine macrofaunal communities is influenced by many factors including sediment conditions (e.g., particle size, sediment chemistry), water conditions (e.g., temperature, salinity, dissolved oxygen, current velocity), and biological factors (e.g., food availability, competition, predation). While human activities can affect these factors, natural processes largely control the structure of invertebrate communities in marine sediments. In order to determine whether changes in community structure are related to human impacts or natural processes, it is necessary to have documentation of background or reference conditions for an area. Such information is available for the region surrounding the Point Loma Ocean Outfall (PLOO) and the San Diego region in general (e.g., City of San Diego 1995, 1999, 2004).

Benthic macrofauna living in marine soft sediments can be sensitive indicators of environmental disturbance (Pearson and Rosenberg 1978). Because these animals have limited mobility, many are unable to avoid adverse conditions such as those brought about by natural stressors (e.g., El Niño/La Niña events) or human impacts (e.g., toxic contamination, organic enrichment). Consequently, assessment of benthic communities has been used to monitor the effects of municipal wastewater discharges on the ocean environment (see Zmarzly et al. 1994, Diener et al. 1995, Bergen et al. 2000). Analyses and interpretation of the macrofaunal data collected during 2005 at fixed stations surrounding the PLOO discharge site off San Diego, California

are presented in this chapter. Descriptions and comparisons of the different assemblages that inhabit soft bottom sediments in the area and analysis of benthic community structure are included.

MATERIALS AND METHODS

Collection and Processing of Samples

Benthic samples were collected at 22 stations that span 8 km south and 11 km north of the outfall terminus and located along the 88, 98, and 116 m depth contours (**Figure 5.1**). A total of 68 benthic grabs were taken during 2 surveys in 2005. All 22 benthic stations were sampled in July while, sampling in January was limited to the 12 primary core stations located along the 98-m contour

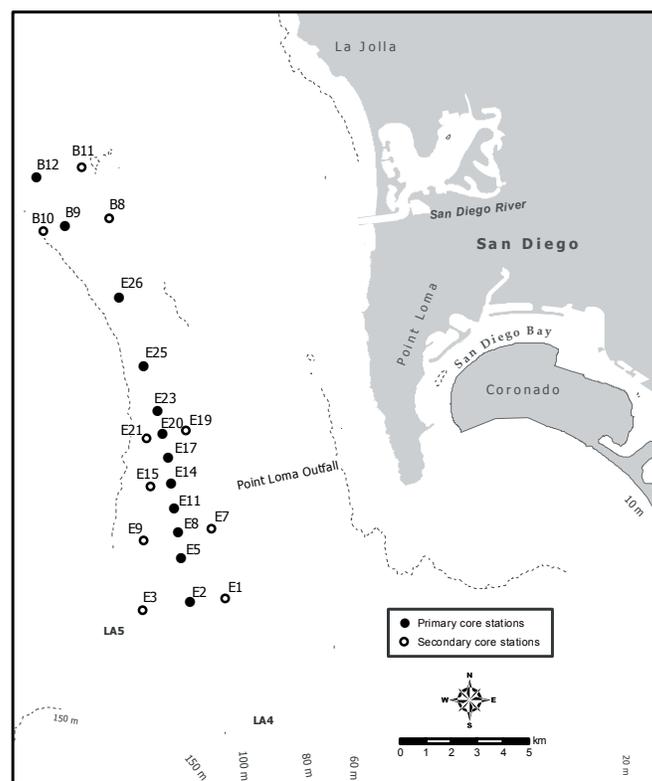


Figure 5.1

Benthic stations surrounding the City of San Diego's Point Loma Ocean Outfall. Primary core stations were sampled in January and July 2005. Secondary core stations were sampled July 2005.

due to participation in special strategic process studies as determined by the City in coordination with the Executive Officer of the RWQCB and the United States Environmental Protection Agency (USEPA) (see City of San Diego 2006). Detailed methods for locating the stations and conducting benthic sampling are described in the City of San Diego Quality Assurance Plan (City of San Diego in prep.).

Samples for benthic community analysis were collected from 2 replicate 0.1 m² van Veen grabs per station during each survey. The criteria established by the USEPA to ensure consistency of grab samples were followed with regard to sample disturbance and depth of penetration (USEPA 1987). All samples were sieved aboard ship through a 1.0 mm mesh screen. Organisms retained on the screen were relaxed for 30 minutes in a magnesium sulfate solution and then fixed in buffered formalin (see City of San Diego in prep.). After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All organisms were sorted from the debris into major taxonomic groups by a subcontractor then identified to species or the lowest taxon possible and enumerated by City of San Diego marine biologists.

Statistical Analyses

Multivariate analyses were performed using PRIMER v5 (Plymouth Routines in Multivariate Ecological Research) software to examine spatio-temporal patterns in the overall similarity of benthic assemblages in the region (see Clarke 1993, Warwick 1993). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group-average linking and ordination by non-metric multidimensional scaling (MDS). Prior to analysis, macrofaunal abundance data were square-root transformed and the Bray-Curtis measure of similarity was used as the basis for comparison in both classification and ordination. SIMPER (similarity percentage) analysis was used to identify individual species that typified each cluster group. Analyses were run on mean abundances of replicate

grabs per station/survey to identify distinct cluster groups from 68 samples among 22 stations.

Annual means for the following community parameters were calculated for each station and each cluster group: species richness (number of species); total number of species per site (i.e., cumulative of 2 replicate samples); abundance (number of individuals); biomass (grams, wet weight); Shannon diversity index (H'); Pielou's evenness index (J'); Swartz dominance index (minimum number of species accounting for 75% of the abundance; see Swartz 1978); Infaunal Trophic Index (ITI; see Word 1980) and Benthic Response Index (BRI; see Smith et al. 2001).

A BACIP (Before-After-Control-Impact-Paired) statistical model was used to test the null hypothesis that there were no changes in various community parameters due to operation of the Point Loma outfall (see Bernstein and Zalinski 1983, Stewart-Oaten et al. 1986, 1992, Osenberg et al. 1994). The BACIP model tests differences between control (reference) and impact sites at times before (i.e., July 1991–October 1993) and after (i.e., January 1994–July 2005) an Aimpact@ event (i.e., the onset of discharge). The analyses presented in this report are based on 2.5 years (10 quarterly surveys) of before impact data and 9 years (44 quarterly or semi-annual surveys) of after impact data. The E stations, located within 8 km of the outfall, are the most likely to be affected by the discharge. Station E14 was selected as the impact site for all analyses; this station is located nearest the Zone of Initial Dilution (ZID) and is probably the site most susceptible to impact. In contrast, the B stations are located farther from the outfall (>11 km) and are the obvious candidates for reference or control sites. However, benthic communities differed between the B and E stations prior to discharge (Smith and Riege 1994, City of San Diego 1995). Thus, 2 stations (E26 and B9) were selected to represent separate control sites in the BACIP tests. Station E26 is located 8 km from the outfall and is considered the E station least likely to be impacted. Previous analyses suggested that station B9 was one of the most appropriate B stations for comparison with the E stations (Smith and Riege 1994, City of San Diego 1995). Six

dependent variables were analyzed, including 3 community parameters (number of species, infaunal abundance, ITI) and abundances of 3 taxa that are considered sensitive to organic enrichment. These indicator taxa included ophiuroids in the genus *Amphiodia* (mostly *A. urtica*), and amphipods in the genera *Ampelisca* and *Rhepoxynius*. All BACIP analyses were interpreted using a Type I error rate of $\alpha=0.05$.

RESULTS AND DISCUSSION

Community Parameters

Number of species

A total of 584 macrofaunal taxa were identified during the 2005 PLOO surveys. Mean values of species richness ranged from 93 to 160 species per 0.1 m² (Table 5.1). As in previous years, the number of species was highest at stations generally characterized by coarser sediments (e.g., E3, E9, B10), as well as the northern reference stations B11 and B12 which historically have been high in species richness (City of San Diego 2005). The lowest species richness was found at stations E5, E8, E21, E23, and B8, all of which had fewer than 100 species.

Polychaetes were the most diverse taxa in the region, accounting for 54% of all species collected during 2005. Crustaceans accounted for 26% of the species, molluscs 9%, echinoderms 6%, and all remaining taxa combined for 5% of the species.

Macrofaunal abundance

Mean macrofaunal abundance averaged 343 to 1074 animals per 0.1 m² in 2005 (Table 5.1). The largest number of animals occurred at stations B9 and B8, which averaged 1074 and 606 animals per 0.1 m², respectively. The fewest animals (<350 per 0.1 m²) were collected at stations E14 and E21. The remaining sites had abundances ranging from 361 to 558 animals per 0.1 m².

Polychaetes were the most numerous animals, accounting for 62% of the total mean abundance.

Crustaceans accounted for 21%, echinoderms 10%, molluscs 5%, and all other phyla combined 2%. There was an apparent change in community structure at E14 compared to 2004. Polychaete numbers decreased from 70% to 65% of the total abundance, while echinoderms (mostly ophiuroids) increased from 4% to 7% (see City of San Diego 2005). The 2 most abundant species collected in 2005 were the polychaete worm, *Prionospio (Prionospio) jubata* (n=1516), and the ophiuroid *Amphiodia urtica* (n=1492, not including unidentified juveniles).

Species diversity and dominance

Species diversity (H') among sites ranged from 3.4 to 5.0 during the year (Table 5.1) which was similar to that observed prior to wastewater discharge (see City of San Diego 1995). The highest diversity occurred along the 98-m contour where every station had $H' >4.4$. Diversity was lowest at station B11 ($H'=3.4$).

Species dominance was expressed as the Swartz 75% dominance index, the minimum number of species comprising 75% of a community by abundance. Therefore, lower index values (i.e., fewer species) indicate higher dominance. Benthic assemblages in 2005 were characterized by relatively high numbers of evenly distributed species (Table 5.1). Dominance averaged 37 species per station, higher than the 30 species per station typical in 2004 (see City of San Diego 2005). The highest Swartz dominance values (≥ 50) occurred at stations E3 and E9, while the lowest values (≤ 31) were at stations B8, E8, and E23. Evenness (J') varied little in 2005, with mean values ranging from 0.7 to 1.1.

Environmental disturbance indices

Mean benthic response index (BRI) values ranged from 3 to 13 at the various stations in 2005. These values suggest that benthic communities in the region are relatively undisturbed, as BRI values below 25 (on a scale of 100) are considered indicative of reference conditions (Smith et al. 2001). The highest value was measured at E14 (13), located nearest the PLOO discharge site. The only other stations with values ≥ 10 also occurred at 2 sites within 1.8 km of the PLOO (i.e., E11, E21).

Table 5.1

Benthic community parameters at PLOO stations sampled during 2005. Data are expressed as annual means for: species richness, no. species/0.1 m² (SR); total cumulative no. species for the year (Tot Spp); abundance/0.1 m² (Abun); diversity (H'); evenness (J'); Swartz dominance, no. species comprising 75% of a community by abundance (Dom); benthic response index (BRI); infaunal trophic index (ITI); n = number of replicate grabs.

Station*	n	SR	Tot Spp	Abun	H'	J'	Dom	BRI	ITI
<i>88-m</i>									
B11	2	160	223	471	3.4	0.7	34	4	75
B8	2	97	131	606	3.8	0.8	29	4	80
E19	2	115	154	377	4.1	0.9	39	8	82
E7	2	111	157	431	4.0	0.9	37	5	85
E1	2	119	163	460	4.1	0.9	41	4	87
<i>98-m</i>									
B12	4	133	184	361	5.0	1.0	45	8	77
B9	4	101	139	1074	4.8	1.1	34	3	82
E26	4	101	136	558	4.7	1.0	35	3	83
E25	4	103	132	399	4.7	1.0	34	7	82
E23	4	93	130	395	4.6	1.0	31	7	83
E20	4	102	136	509	4.6	1.0	32	8	82
E17	4	107	146	457	4.7	1.0	33	10	82
E14	4	103	142	343	4.5	1.0	29	13	77
E11	4	103	138	432	4.7	1.1	36	11	80
E8	4	97	133	426	4.5	1.0	31	6	85
E5	4	99	134	425	4.7	1.1	35	3	84
E2	4	108	154	400	4.8	1.1	38	4	86
<i>116-m</i>									
B10	2	143	201	456	4.2	0.8	43	8	75
E21	2	95	133	346	4.0	0.9	35	10	79
E15	2	115	164	379	4.3	0.9	42	7	83
E9	2	150	200	373	4.4	0.9	50	7	78
E3	2	152	207	435	4.5	0.9	57	5	81
<i>All stations</i>	Mean	114	156	460	4.4	1.0	37	7	81
	Min	93	130	343	3.4	0.7	29	3	75
	Max	160	223	1074	5.0	1.1	57	13	87

* 98-m sites = primary core stations sampled during January and July 2005; 88- and 116-m sites = secondary core stations sampled only in July 2005.

Mean ITI values ranged from 75 to 87 per station in 2005 (Table 5.1), and were similar to those reported in previous years (see City of San Diego 2005). These values were indicative of undisturbed sediments or “normal” environmental conditions (see Bascom et al. 1979).

Dominant species

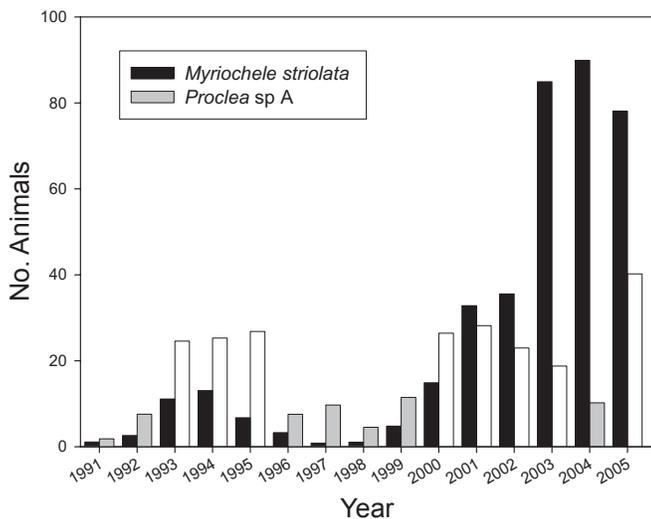
Most assemblages in the Point Loma region were dominated by polychaete worms (Table 5.2).

For example, 10 polychaetes species, 3 crustaceans, 2 echinoderms, and 1 mollusc were among the dominant macroinvertebrates. The 3 most abundant species were the spionid *Prionospio (P.) jubata*, the terebellid polychaete *Proclea* sp A, and the ophiuroid *Amphiodia urtica*, each averaging >20 individuals per 0.1 m². However, since juvenile ophiuroids are usually identified to only the generic or familial level (i.e., *Amphiodia* sp or Amphiuroidae), mean abundances per sample underestimate actual populations of *A. urtica*. The only other species

Table 5.2

Dominant macroinvertebrates at the PLOO benthic stations sampled during 2005. Included are the 10 most abundant species overall, the 10 most abundant per occurrence, and the 10 most frequently collected (or widely distributed) species. Abundance values are expressed as mean number of individuals per 0.1 m² grab sample.

Species	Higher taxa	Abundance per sample	Abundance per occurrence	Percent occurrence
<u>Most abundant</u>				
<i>Prionospio (P.) jubata</i>	Polychaeta: Spionidae	22.3	22.3	100
<i>Amphiodia urtica</i>	Echinodermata: Ophiuroidea	21.9	23.3	94
<i>Proclea</i> sp A	Polychaeta: Terebellidae	20.1	20.1	100
<i>Myriochele striolata</i>	Polychaeta: Oweniidae	17.2	39.1	44
<i>Euphilomedes carcharodonta</i>	Crustacea: Ostracoda	14.7	15.2	97
<i>Euphilomedes producta</i>	Crustacea: Ostracoda	13.4	13.4	100
<i>Spiophanes duplex</i>	Polychaeta: Spionidae	12.8	12.8	100
<i>Paraprionospio pinnata</i>	Polychaeta: Spionidae	10.7	10.7	100
<i>Amphiodia</i> sp	Echinodermata: Ophiuroidea	10.1	10.1	100
<i>Mediomastus</i> sp	Polychaeta: Capitellidae	9.3	9.3	100
<u>Most abundant per occurrence</u>				
<i>Myriochele striolata</i>	Polychaeta: Oweniidae	17.2	39.1	44
<i>Amphiodia urtica</i>	Echinodermata: Ophiuroidea	21.9	23.3	94
<i>Prionospio (P.) jubata</i>	Polychaeta: Spionidae	22.3	22.3	100
<i>Proclea</i> sp A	Polychaeta: Terebellidae	20.1	20.1	100
<i>Euphilomedes carcharodonta</i>	Crustacea: Ostracoda	14.7	15.2	97
<i>Caecum crebricinctum</i>	Mollusca: Gastropoda	1.3	15.2	9
<i>Euphilomedes producta</i>	Crustacea: Ostracoda	13.4	13.4	100
<i>Spiophanes duplex</i>	Polychaeta: Spionidae	12.8	12.8	100
<i>Hamatoscalpellum californicum</i>	Crustacea: Scalpellidae	0.3	11.5	3
<i>Pholoides asperus</i>	Polychaeta: Pholoidae	1.0	11.0	9
<u>Most frequently collected</u>				
<i>Prionospio (P.) jubata</i>	Polychaeta: Spionidae	22.3	22.3	100
<i>Proclea</i> sp A	Polychaeta: Terebellidae	20.1	20.1	100
<i>Euphilomedes producta</i>	Crustacea: Ostracoda	13.4	13.4	100
<i>Spiophanes duplex</i>	Polychaeta: Spionidae	12.8	12.8	100
<i>Paraprionospio pinnata</i>	Polychaeta: Spionidae	10.7	10.7	100
<i>Amphiodia</i> sp	Echinodermata: Ophiuroidea	10.1	10.1	100
<i>Mediomastus</i> sp	Polychaeta: Capitellidae	9.3	9.3	100
<i>Spiophanes kimballi</i>	Polychaeta: Spionidae	9.1	9.1	100
<i>Paradiopatra parva</i>	Polychaeta: Onuphidae	8.6	8.6	100
<i>Chaetozone hartmanae</i>	Polychaeta: Cirratulidae	8.5	8.5	100



of *Amphiodia* present off Point Loma in 2005 was *A. digitata*, which accounted for about 6% of ophiuroids in the genus *Amphiodia* that could be identified to species (i.e., *A. urtica* = 94%). If values for these taxa are adjusted accordingly, then the estimated population size for *A. urtica* becomes 29 animals per 0.1 m² off Point Loma.

Many of these abundant species were dominant prior to discharge and have remained dominant since the initiation of outfall operation in november 1993 (e.g., City of San Diego 1995, 1999, 2004). For example, *A. urtica* has been among the most abundant and most commonly occurring species along the outer shelf since sampling began. However, densities of some numerically dominant polychaetes have been more cyclical. For instance, while *Myriochele striolata* and *Proclea sp A* were among the most abundant polychaetes in 2005, their populations have varied considerably over time (Figure 5.2). Such variation can have significant effects on other descriptive statistics (e.g., dominance, diversity, and abundance) and environmental indices such as ITI and BRI that use the abundance of indicator species in their equations.

BACIP Analyses

Significant differences were found between the impact site (station E14) and the control sites

Table 5.3

Results of BACIP t-tests for number of species (SR), infaunal abundance, ITI, and the abundance of several representative taxa around the Point Loma Ocean Outfall (1991–2005). Impact site=near-ZID station E14; Control sites=far-field station E26 or reference station B9. Before impact period=July 1991 to October 1993 (n=10); After impact period=January 1994 to July 2005 (n=43). Critical t value=1.680 for $\alpha=0.05$ (one-tailed t-tests, df=51). ns=not significant .

	Control vs Impact	t	p
	E26 v E14	-3.152	0.001
	B9 v E14	-3.671	<0.001
	E26 v E14	-1.415	ns
	B9 v E14	-2.712	0.005
	E26 v E14	-3.775	<0.001
	B9 v E14	-2.239	0.015
spp	E26 v E14	-7.381	<0.001
	B9 v E14	-5.004	<0.001
spp	E26 v E14	-1.598	ns
	B9 v E14	-0.041	ns
<i>Rhepoxynius</i> spp	E26 v E14	-0.830	ns
	B9 v E14	-0.922	ns

(stations E26 and B9) in 7 out of 12 BACIP t-tests (Table 5.3). For example, there has been a net change in the mean difference between E14 and both control sites in species richness, ITI values and ophiuroid abundance (*Amphiodia* spp). The difference in species richness may be due to the increased variability and higher numbers of species at the impact site over time (Figure 5.3A). Some of the change in species richness between 1995 and 2005 also may be due to increased taxonomic resolution of certain taxa. For example, the polynoid polychaete recorded as *Malmgreniella* sp in 1995 was split into 4 recognizable species by 2005. Differences in *Amphiodia* populations mostly reflect a decrease in the number of these ophiuroids collected at E14 since discharge began (Figure 5.3e). However, 2005 saw an increase in *Amphiodia urtica* populations at E14 along with coincident decreases at the control sites. These changes in ophiuroid abundance in 2005 may be anomalous and future surveys will be needed to identify any lasting trend. Differences in ITI are generally due to lower index values at station E14

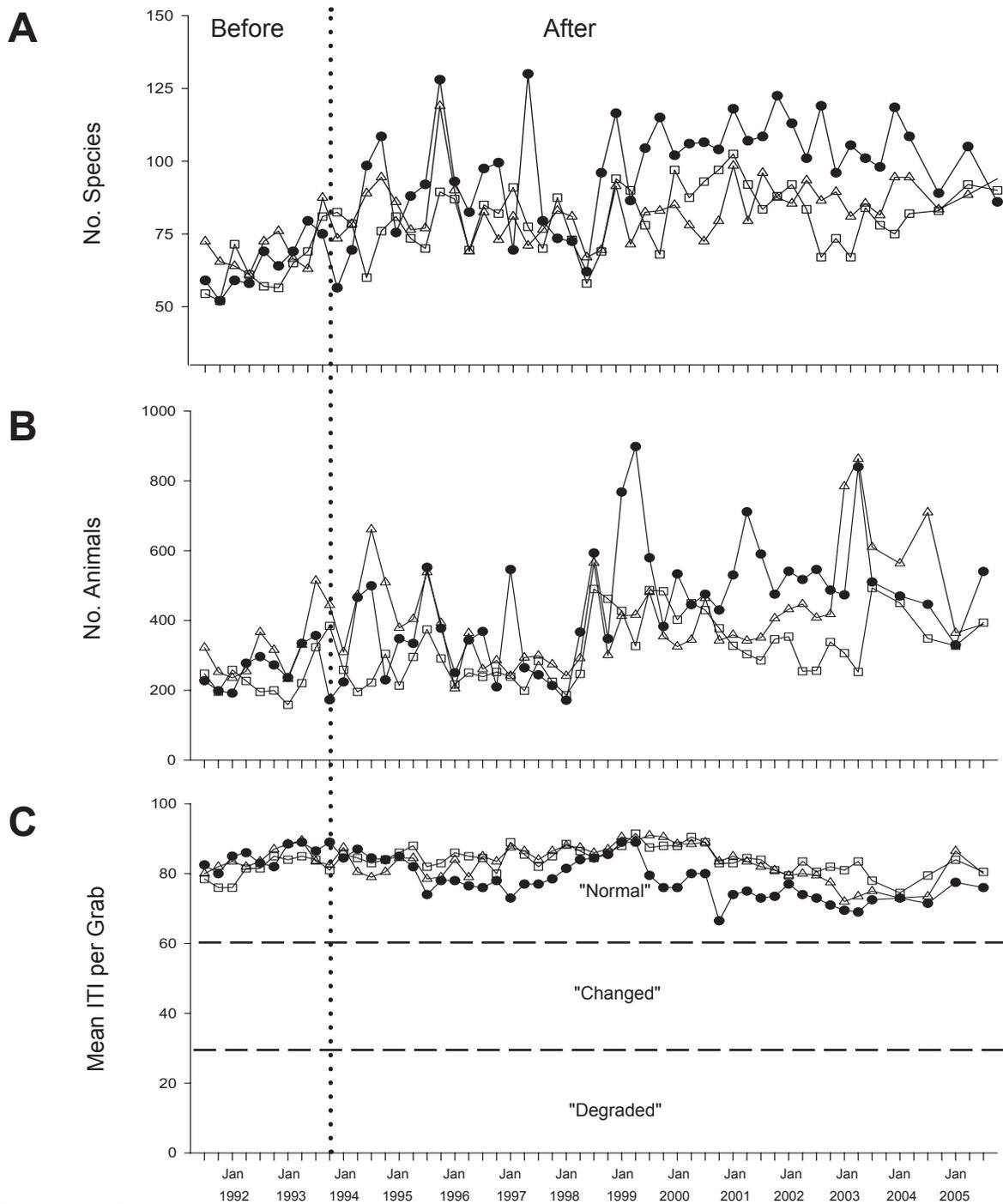


Figure 5.3

Comparison of several parameters at “impact” site (station E14) and “control” sites (stations E26, B9) used in BACIP analyses (see Table 5.3). Data for each station are expressed as means per 0.1 m² (n=2 per survey). (A) Number of infaunal species; (B) infaunal abundance; (C) infaunal trophic index (ITI); (D) abundance of *Ampelisca* spp (Amphipoda); (E) abundance of *Amphiodia* spp (Ophiuroidea).

over several prolonged periods (July 1995–July 1999 and October 1998–present, Figure 5.3C). These decreased ITI values may in part be explained by the historically lower numbers of *Amphiodia*. The results for total infaunal abundances were more

ambiguous (Figure 5.3B, Table 5.3). Although a significant change is indicated between the impact site and station B9, no such pattern has been found regarding the second control site (E26). Finally, there was no net change in the mean difference between

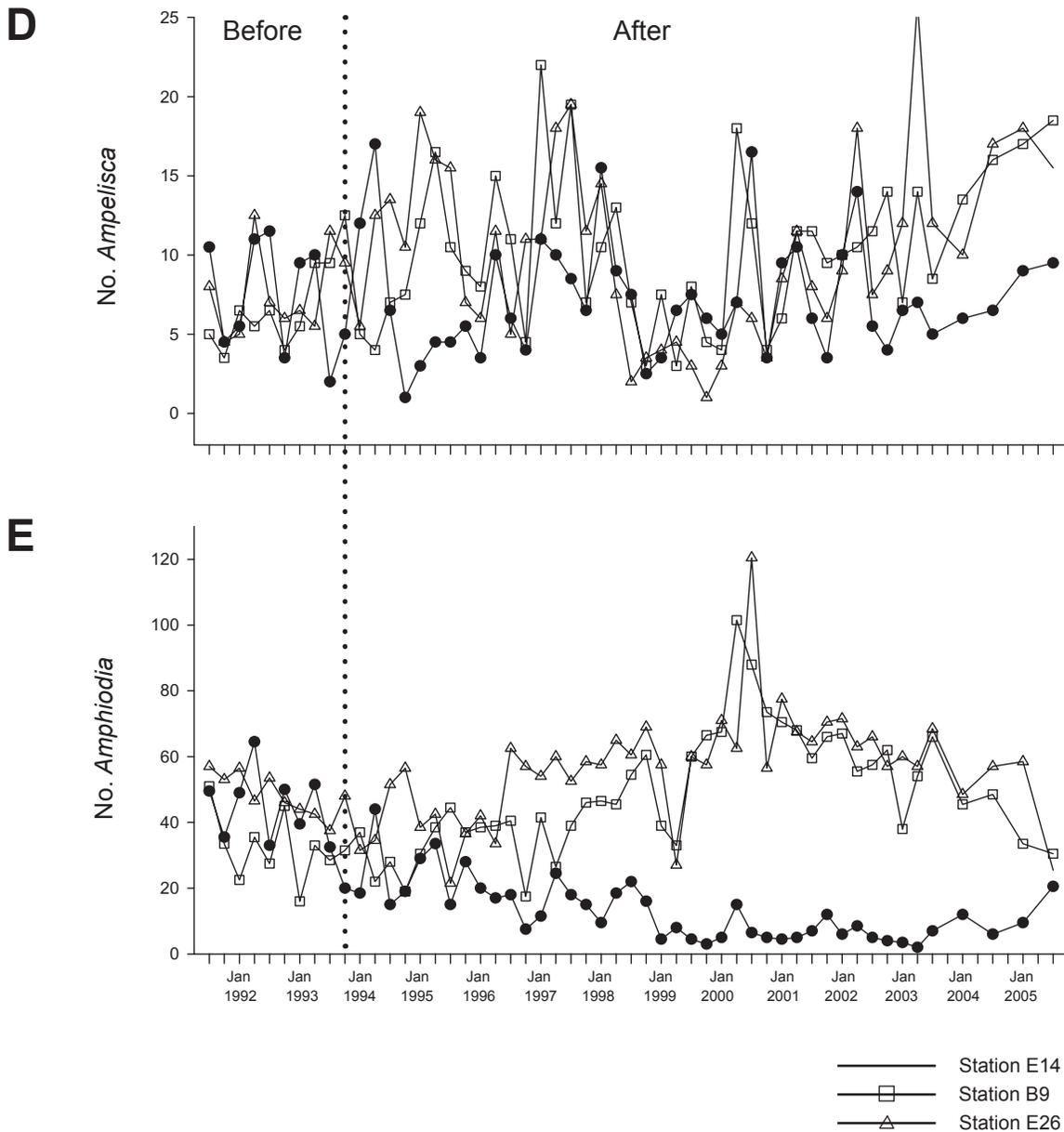


Figure 5.3 Continued

impact and control sites in numbers of ampeliscid or phoxocephalid amphipods.

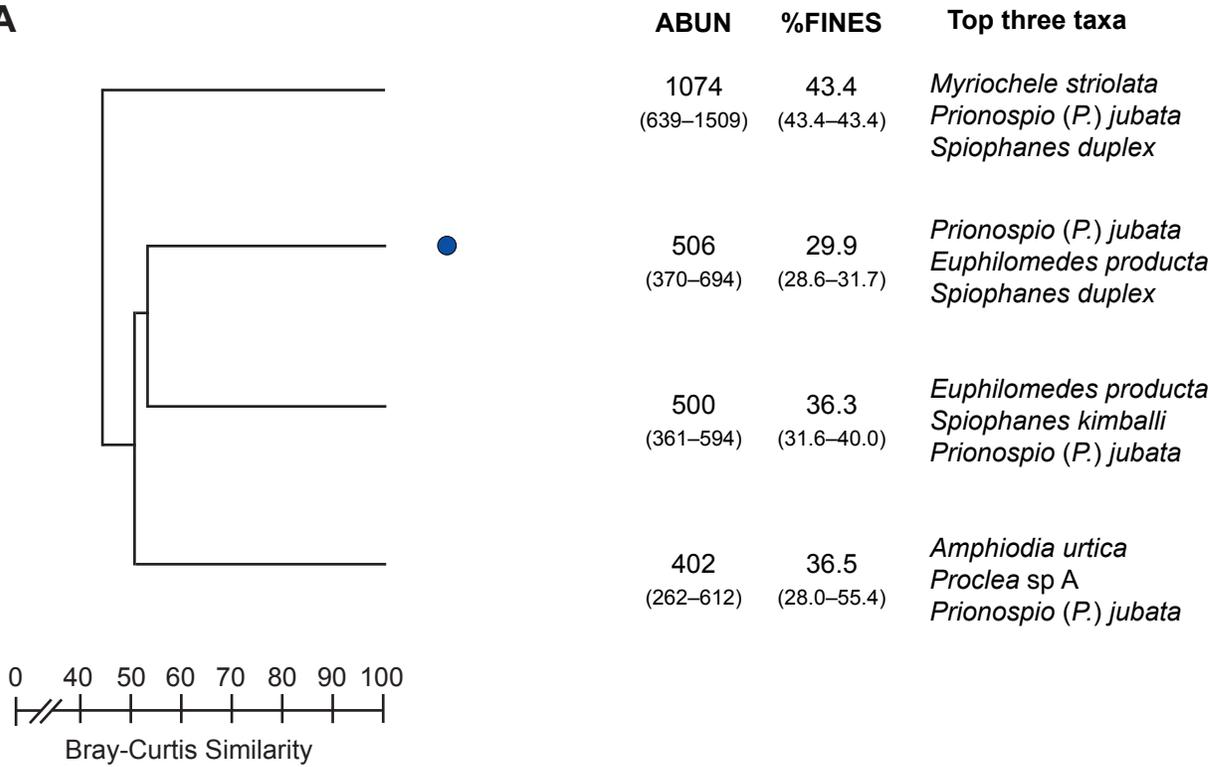
Classification of Benthic Assemblages

Classification analyses discriminated differences between 4 main benthic assemblages (cluster groups A–D) during 2005 (Figures 5.4, 5.5). These assemblages differed in terms of their species composition, including the specific taxa present and their relative abundances. The dominant species for each assemblage are listed in

Table 5.4. Additionally, a MDS ordination of the survey entities confirmed the validity of the major cluster groups (Figure 5.4).

Cluster group A comprised a single northern station located along the 88-m contour (B11). This station was sampled on during July in 2005. Sediments at this site were mixed with both a relatively high percentage of fine particles (~43%) and the most coarse particles among all cluster groups (~4.7%). This assemblage also had the highest average abundance (1074 per 0.1 m²) and species richness

A



B

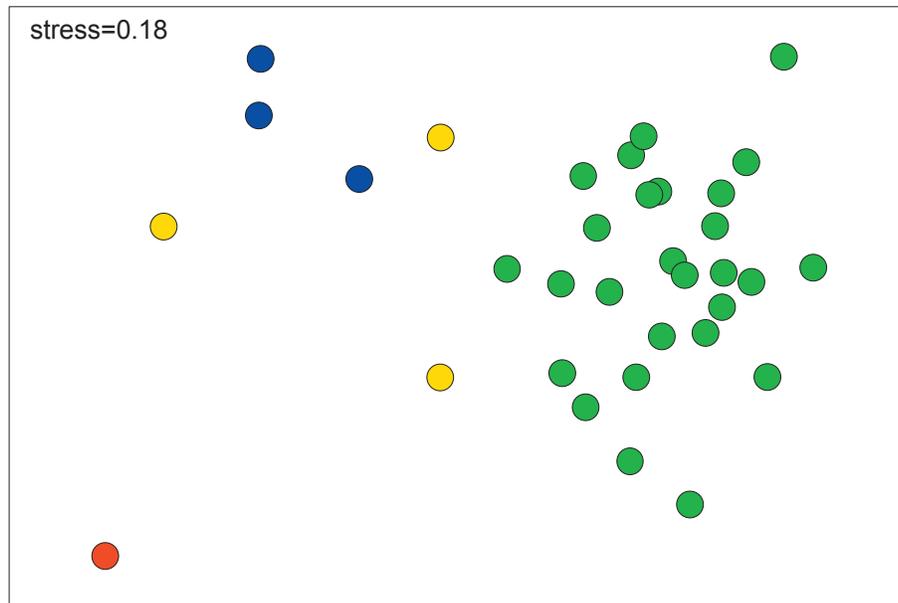


Figure 5.4

(A) Cluster are expressed species; ABUN=number of PLOO benthic data for each between major faunal assemblages.

(160 species per 0.1 m²) compared to the other cluster groups. The oweniid polychaete *Myriochele striolata* was the overwhelmingly dominant species characterizing this assemblage, averaging more than 460 animals per 0.1 m². In contrast, the next two most abundant species, *Prionospio (P.) jubata* and *Spiophanes duplex* each averaged fewer than 50 worms per sample. The ophiuroid *Amphiodia urtica* (adults and juveniles) averaged 27 individuals per sample.

Cluster group B included 1 site each along the 98 and 116-m contours. Sediments associated with cluster group B had relatively high amounts of sand and the lowest percentage of fine particles (30%) compared to the other groups. As is typical of these sites, species richness was relatively high (136 species per 0.1 m²). The spionid polychaete *Prionospio (Prionospio) jubata* was among the dominant animals in this assemblage. Other dominant species included the ostracod *Euphilomedes producta* and the spionid polychaete *Spiophanes duplex*.

Cluster group C represented samples from 3 southern stations, 2 along the 116-m contour (E3, E9), and the July sample from station E2 along the 98-m contour. Sediments at these stations were mixed, composed of silt and sand with some coarse materials and rock. This assemblage averaged 500 individuals and 142 species per 0.1 m². The dominant species in this group were the ophiuroid *Amphiodia urtica* (adults and juveniles), and the polychaetes *Spiophanes kimbali* and *Prionospio (P.) jubata*.

Cluster group D was the largest assemblage in 2005, representing 79% of the samples from 17 stations. The sediments of this cluster group were characterized by silty sand with ~37% fines. Infauna averaged 402 individuals and 102 species per 0.1 m², the lowest among all cluster groups. Dominant taxa included ophiuroids (i.e., *Amphiodia urtica*, *Amphiodia* sp, and Amphiuiridae) as well as the terebellid polychaete *Proclea* sp A and *Prionospio (Prionospio) jubata*. Station E14 located nearest to the PLOO discharge site was included in this group. Historically, this station has

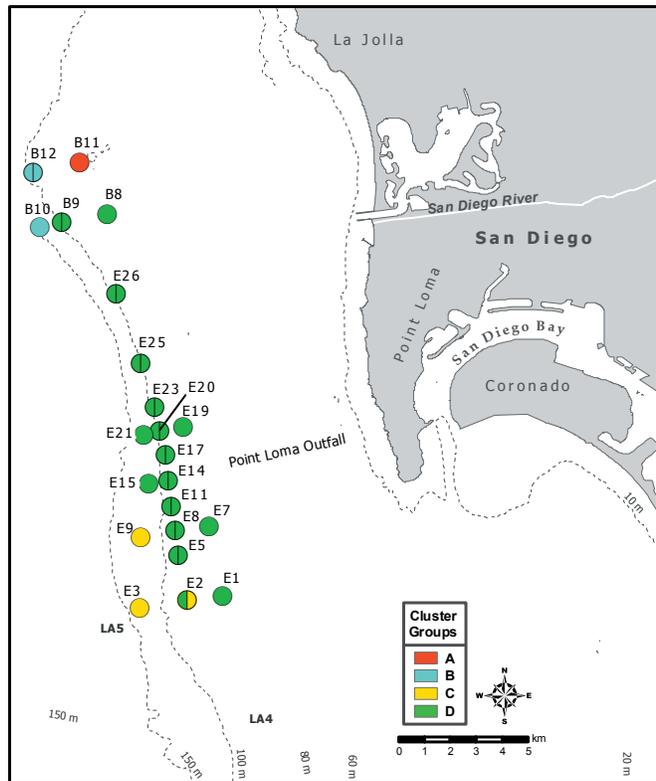


Figure 5.5 Results of ordination and classification analyses of macrofaunal abundance data during 2005. Cluster groups are color-coded on the map to reveal spatial patterns in the distribution of benthic assemblages.

not clustered with reference stations (City of San Diego 2004, 2005). However, an increase in the abundance of the ophiuroid *Amphiodia urtica* in 2005 altered the community structure at E14 making it statistically more similar to the other stations in this cluster group.

SUMMARY AND CONCLUSIONS

Benthic communities around the PLOO continue to be dominated by ophiuroid-polychaete based assemblages, with few major changes having occurred since monitoring began (see City of San Diego 1995, 2004). Polychaetes continue to be the most abundant and diverse infauna in the region. Although many of the 2005 assemblages were dominated by similar species, the relative abundance of these species varied between sites. In contrast to 2004, the oweniid polychaete *Myriochele striolata* dominated just a single assemblage (cluster

Table 5.4

Summary of the most abundant taxa composing cluster groups A–D from the PLOO benthic stations surveyed in 2005. Data are expressed as mean abundance per sample (no./0.1m²) and represent the 10 most abundant taxa in each group. Animals absent from a cluster group are indicated by a dash. The 3 most abundant taxa in each cluster group are bolded.

Species/Taxa	Higher taxa	Cluster group			
		A (n=1)	B (n=3)	C (n=3)	D (n=27)
<i>Amphiodia</i> sp	Echinodermata: Ophiuroide	6.0	2.2	8.8	11.3
<i>Amphiodia urtica</i>	Echinodermata: Ophiuroidea	17.5	1.5	14.3	25.2
Amphiuridae	Echinodermata: Ophiuroidea	3.5	2.7	5.5	9.3
<i>Caecum crebricinctum</i>	Mollusca: Gastropoda	—	14.3	0.8	—
<i>Chaetozone hartmanae</i>	Polychaeta: Cirratulidae	10.0	9.5	5.0	8.7
<i>Euphilomedes carcharodonta</i>	Crustacea: Ostracoda	7.0	8.0	6.0	16.7
<i>Euphilomedes producta</i>	Crustacea: Ostracoda	1.5	27.2	21.7	11.4
<i>Exogone lourei</i>	Polychaeta: Syllidae	3.0	0.8	9.5	0.2
<i>Leptochelia dubia</i>	Crustacea: Tanaidacea	14.0	7.8	3.0	2.5
<i>Mediomastus</i> sp	Polychaeta: Capitellidae	13.5	11.0	18.5	7.9
<i>Myriochele striolata</i>	Polychaeta: Oweniidae	466.0	0.7	—	4.4
<i>Paradiopatra parva</i>	Polychaeta: Onuphidae	3.5	19.3	10.5	7.4
<i>Paraprionospio pinnata</i>	Polychaeta: Spionidae	10.5	17.2	8.2	10.2
<i>Pherusa negligens</i>	Polychaeta: Flabelligeridae	11.5	0.3	—	0.0
<i>Phisidia sanctaemariae</i>	Polychaeta: Terebellidae	2.5	2.8	9.7	8.0
<i>Pholoides asperus</i>	Polychaeta: Pholoidae	24.5	—	2.8	—
<i>Photis californica</i>	Crustacea: Amphipoda	13.5	3.0	1.7	0.5
<i>Prionospio (Prionospio) jubata</i>	Polychaeta: Spionidae	28.5	32.5	19.2	21.3
<i>Proclea</i> sp A	Polychaeta: Terebellidae	3.0	1.7	15.8	23.3
<i>Spiophanes berkeleyorum</i>	Polychaeta: Spionidae	13.0	15.5	4.2	7.1
<i>Spiophanes duplex</i>	Polychaeta: Spionidae	45.5	22.8	15.3	10.2
<i>Spiophanes kimballi</i>	Polychaeta: Spionidae	8.5	12.0	20.2	7.6

group A). *Prionospio (P.) jubata* was the most widespread benthic invertebrate in the region, being dominant or co-dominant in all assemblages. Adult and presumed juvenile *Amphiodia urtica* combined were the most abundant taxon. Assemblages similar to those off Point Loma have been described for other areas in the Southern California Bight (SCB) by Barnard and Ziesenhenné (1961), Jones (1969), Fauchald and Jones (1979), Thompson et al. (1987, 1992, 1993), Zmarzly et al. (1994), Diener and Fuller (1995), and Bergen et al. (1998, 2000).

Although variable, benthic communities off Point Loma generally have remained similar between years in terms of the number of species, number

of individuals, and dominance (City of San Diego 1995, 2005). In addition, values for these parameters in 2005 were similar to those described for other sites throughout the SCB (e.g., Thompson et al. 1992, Bergen et al. 1998, 2001). In spite of this overall stability, there has been an increase in the number of species and macrofaunal abundance since discharge began (see City of San Diego 1995, 2004). However, the increase in species has been most pronounced nearest the outfall, suggesting that significant environmental degradation is not occurring in the area. In addition, the observed increases in abundance at most stations have been accompanied by decreases in dominance, a pattern inconsistent with predicted pollution effects.

Whatever the cause of such changes, benthic communities around the PLOO are not numerically dominated by a few pollution tolerant species. For example, the opportunistic polychaete *Capitella capitata*, which is associated with degraded soft bottom habitats, continues to be found in low numbers off Point Loma. Only 29 individuals were found among all stations in 2005, with 15 (52%) recorded at E14. In heavily polluted environments, *Capitella capitata* can reach densities of >500 individuals per 0.1 m² and constitute as much as 85% of the total abundance (Swartz et al. 1986).

Changes near the outfall suggest some effects are coincident with anthropogenic activities. Benthic response index (BRI) values are higher at stations nearest the outfall (E14, E11, E17, and E21) than at other sites in the region. In addition, a decrease in the infaunal trophic index (ITI) at station E14 after discharge began may be considered indicative of organic enrichment or some other type of disturbance (see City of San Diego 1995, 2004). However, both BRI and ITI values at this and all other sites remain characteristic of undisturbed areas. In addition, the increased variability in number of species and infaunal abundance at E14 since discharge began may be indicative of community destabilization (see Warwick and Clarke 1993, Zmarzly et al. 1994). The instability or patchiness of sediments near the PLOO and the corresponding shifts in assemblages suggest that changes in this area may be related to localized physical disturbance (e.g., shifting sediment types) associated with the structure of the outfall pipe as well as to organic enrichment associated with the discharge of effluent.

Populations of some indicator taxa revealed changes that correspond to organic enrichment near the outfall, while populations of others revealed no evidence of impact. For example, since 1997, there has been a significant change in the difference between ophiuroid (*Amphiodia* spp) populations that occur near the outfall (i.e., station E14) and those present at reference sites, though 2005 was an exception. This difference is due mostly to a historic decrease in numbers of ophiuroids near the outfall as compared to those at the control sites

during the post-discharge period. Although long term changes in *Amphiodia* populations at E14 are likely to be related to organic enrichment, predation pressure from fish, altered sediment composition or some other factor, abundances of *Amphiodia* off Point Loma are still within the range of those occurring naturally in the SCB. In addition, natural population fluctuations of these and other resident organisms (e.g. *Myriochele striolata* and *Proclea* sp A) are common off San Diego (Zmarzly et al. 1994, Deiner et al. 1995). Further complicating the picture, stable patterns in populations of pollution sensitive amphipods (i.e., *Rhepoxynius*, *Ampelisca*) and a limited presence of pollution tolerant species (e.g., *Capitella capitata*) do not offer strong evidence of outfall-related effects. In 2005, station E14 saw an increase in the abundance of the pollution sensitive ophiuroid, *Amphiodia urtica*, as well as a decrease in abundances of *Capitella capitata*. Continued sampling in future years will help to determine if this is a trend in the shift of community structure or a temporal anomaly.

While it is difficult to detect specific effects of the PLOO on the offshore benthos, it is possible to see some changes occurring nearest the discharge site (e.g., E14). Because of the minimal extent of these changes, it has not been possible to conclusively determine whether the observed effects are due solely to the physical structure of the outfall pipe or to organic enrichment in the area. Such impacts have spatial and temporal dimensions that vary depending on a range of biological and physical factors. In addition, abundances of soft bottom invertebrates exhibit substantial spatial and temporal variability that may mask the effects of any disturbance event (Morrissey et al. 1992a, 1992b, Otway 1995). The effects associated with the discharge of advanced primary treated and secondary treated sewage may be negligible or difficult to detect in areas subjected to strong currents that facilitate the dispersion of the wastewater plume (see Diener and Fuller 1995). Although some changes in benthic assemblages have appeared near the outfall, assemblages in the region are still similar to those observed prior to discharge and to natural indigenous communities characteristic of the southern California continental shelf.

LITERATURE CITED

- Barnard, J.L., and F.C. Ziesenhenn. (1961). Ophiuroidea communities of southern Californian coastal bottoms. *Pac. Nat.*, 2: 131–152.
- Bascom, W., A.J. Mearns, and J.Q. Word. (1979). Establishing boundaries between normal, changed, and degraded areas. In: Southern California Coastal Water Research Project Annual Report, 1978. Long Beach, CA. p. 81–95.
- Bergen, M., D.B. Cadien, A. Dalkey, D.E. Montagne, R.W. Smith, J.K. Stull, R.G. Velarde, and S.B. Weisberg. (2000). Assessment of benthic infaunal condition on the mainland shelf of southern California. *Env. Monit. Assmt.* 64:421–434.
- Bergen, M., S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, R.W. Smith, J.K. Stull, and R.G. Velarde. (1998). Southern California Bight 1994 Pilot Project: IV. Benthic Infauna. Southern California Coastal Water Research Project, Westminster, CA. 260 p.
- Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde, and J.A. Ranasinghe. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. *Mar. Biol.*, 138: 637–647.
- Bernstein, B.B., and J. Zalinski. (1983). An optimum sampling design and power tests for environmental biologists. *J. Environ. Manag.*, 16: 35–43.
- City of San Diego. (1995). Outfall Extension Pre-Construction Monitoring Report. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.
- City of San Diego. (1999). San Diego Regional Monitoring Report for 1994–1997. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.
- City of San Diego. (2004). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2003. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.
- City of San Diego. (2005). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2004. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.
- City of San Diego. (2006). EMTS Division Laboratory Quality Assurance Report, 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.
- City of San Diego. (in prep.). EMTS Division Laboratory Quality Assurance Project Plan. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.
- Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. *Aust. J. Ecol.*, 18: 117–143.
- Diener, D.R., and S.C. Fuller. (1995). Infaunal patterns in the vicinity of a small coastal wastewater outfall and the lack of infaunal community response to secondary treatment. *Bull. Southern Cal. Acad. Sci.*, 94: 5–20.
- Diener, D.R., S.C. Fuller, A. Lissner, C.I. Haydock, D. Maurer, G. Robertson, and R. Gerlinger.

- (1995). Spatial and temporal patterns of the infaunal community near a major ocean outfall in Southern California. *Mar. Poll. Bull.*, 30: 861–878.
- Fauchald, K., and G.F. Jones. (1979). Variation in community structures on shelf, slope, and basin macrofaunal communities of the Southern California Bight. In: Southern California outer continental shelf environmental baseline study, 1976/1977 (second year) benthic program. Vol. II, Principal Invest. Repts., Ser. 2, Rep. 19. Available from: NTIS, Springfield, Virginia; PB80 16601. Science Applications, Inc., La Jolla, CA.
- Jones, G.F. (1969). The benthic macrofauna of the mainland shelf of southern California. *Allan Hancock Monogr. Mar. Biol.*, 4: 1–219.
- Morrisey, D.J., L. Howitt, A.J. Underwood, and J.S. Stark. (1992a). Spatial variation in soft sediment benthos. *Mar. Ecol. Prog. Ser.*, 81: 197–204.
- Morrisey, D.J., A.J. Underwood, L. Howitt, and J.S. Stark. (1992b). Temporal variation in soft sediment benthos. *J. Exp. Mar. Biol. Ecol.*, 164: 233–245.
- Osenberg, C.W., R.J. Schmitt, S.J. Holbrook, K.E. Abu-Saba, and R. Flegel. (1994). Detection of environmental impacts: Natural variability, effect size, and power analysis. *Ecol. Appl.*, 4: 16–30.
- Otway, N.M. (1995). Assessing impacts of deepwater sewage disposal: a case study from New South Wales, Australia. *Mar. Poll. Bull.*, 31: 347–354.
- Pearson, T.H., and R. Rosenberg. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol. Ann. Rev.*, 16: 229–311.
- Smith, R.W., M. Bergen, S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, J.K. Stull, and R.G. Velarde. (2001). Benthic response index for assessing infaunal communities on the southern California mainland shelf. *Ecological Applications*, 11(4): 1073–1087.
- Smith, R.W., and L. Riege. (1994). Optimization and power analyses for the Point Loma monitoring design. Unpublished report to City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA
- Stewart-Oaten, A., W.W. Murdoch, and K.R. Parker. (1986). Environmental impact assessment: APseudoreplication@ in time? *Ecology*, 67: 929–940.
- Stewart-Oaten, A., J.R. Bence, and C.W. Osenberg. (1992). Assessing Effects of Unreplicated Perturbations: No Simple Solutions. *Ecology*, 73: 1396–1404.
- Swartz, R.C. (1978). Techniques for sampling and analyzing the marine macrobenthos. U.S. Environmental Protection Agency (EPA), Doc. EPA-600/3-78-030, EPA, Corvallis, Oregon. 27 p.
- Swartz, R.C., F.A. Cole, D.W. Schults, and W.A. Deben. (1986). Ecological changes in the Southern California Bight near a large sewage outfall: Benthic conditions in 1980 and 1983. *Mar Ecol Prog Ser* 31:1-13.
- Thompson, B., J. Dixon, S. Schroeter, and D.J. Reish. (1993). Chapter 8. Benthic invertebrates. In: Dailey, M.D., D.J. Reish, and J.W. Anderson (eds.). *Ecology of the Southern California Bight: A Synthesis and Interpretation*. University of California Press, Berkeley, pp. 369–458.
- Thompson, B.E., J.D. Laughlin, and D.T. Tsukada. (1987). 1985 reference site survey. Tech. Rep.

- No. 221, Southern California Coastal Water Research Project, Long Beach, CA.
- Thompson, B.E., D. Tsukada, and D. O'Donohue. (1992). 1990 reference survey. Tech. Rep. No. 355, Southern California Coastal Water Research Project, Long Beach, CA.
- [USEPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control (QA/QC) for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuarine Protection. 267 p.
- Warwick, R.M. (1993). Environmental impact studies on marine communities: pragmatical considerations. *Aust. J. Ecol.*, 18: 63–80.
- Warwick, R.M., and K.R. Clarke. (1993). Increased variability as a symptom of stress in marine communities. *J. Exp. Mar. Biol. Ecol.*, 172: 215–226.
- Word, J.Q. (1980). Classification of benthic invertebrates into infaunal trophic index feeding groups. In: Bascom, W. (ed.). Biennial Report for the Years 1979 1980, Southern California Coastal Water Research Project, Long Beach, CA. pp. 103–121.
- Zmarzly, D.L., T.D. Stebbins, D. Pasko, R.M. Duggan, and K.L. Barwick. (1994). Spatial patterns and temporal succession in soft bottom macroinvertebrate assemblages surrounding an ocean outfall on the southern San Diego shelf: Relation to anthropogenic and natural events. *Mar. Biol.*, 118: 293–307.

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