Chapter 5. Macrobenthic Communities

Introduction

Benthic macroinvertebrates along the coastal shelf of southern California represent a diverse faunal community that is important to the marine ecosystem (Fauchald and Jones 1979, Thompson et al. 1993a, Bergen et al. 2001). These animals serve vital ecological functions in wide ranging capacities (Snelgrove et al. 1997). For example, some species decompose organic material as a crucial step in nutrient cycling; other species filter suspended particles from the water column, thus affecting water clarity. Many species of benthic macrofauna also are essential prey for fish and other organisms.

Human activities that impact the benthos can sometimes result in toxic contamination, oxygen depletion, nutrient loading, or other forms of environmental degradation. Certain macrofaunal species are sensitive to such changes and rarely occur in impacted areas, while others are opportunistic and can persist under altered conditions (Gray 1979). Because various species respond differently to environmental stress, monitoring macrobenthic assemblages can help to identify anthropogenic impact (Pearson and Rosenberg 1978, Bilyard 1987, Warwick and Clarke 1993, Smith et al. 2001). Also, since many animals in these assemblages are relatively stationary and long-lived, they can integrate the effects of local environmental stressors (e.g., pollution or disturbance) over time (Hartley 1982, Bilyard 1987). Consequently, the assessment of benthic community structure is a major component of many marine monitoring programs, which are often designed to document both existing conditions and trends over time.

Overall, the structure of benthic communities may be influenced by many factors including depth, sediment composition and quality (e.g., grain size distribution, contaminant concentrations), oceanographic conditions (e.g., temperature, salinity, dissolved oxygen, ocean currents), and biological factors (e.g., food availability, competition, predation). For example, benthic assemblages on the coastal shelf of southern California typically vary along sediment particle size and/or depth gradients (Bergen et al. 2001). Therefore, in order to determine whether changes in community structure are related to human impacts, it is necessary to have an understanding of background or reference conditions for an area. Such information is available for the monitoring area surrounding the Point Loma Ocean Outfall (PLOO) and the San Diego region in general (e.g., see City of San Diego 1999, 2010, Ranasinghe et al. 2003, 2007).

This chapter presents analyses and interpretations of the macrofaunal data collected in 2010 at fixed stations surrounding the PLOO, including comparisons of the different soft-bottom macrofaunal assemblages in the region and descriptions of benthic community structure. The primary goals are to: (1) identify possible effects of wastewater discharge on local macrofaunal communities, (2) determine the presence or absence of biological impacts near the discharge site, and (3) identify any spatial or temporal trends in benthic community structure in the region.

Materials and Methods

Collection and Processing of Samples

Benthic samples were collected at 22 benthic stations in the PLOO region located along the 88, 98, or 116-m depth contours (Figure 5.1). These sites included 17 “E” stations located from approximately 5 km south to 8 km north of the outfall, and five “B” stations located at least 10 km north of the outfall. Four of these stations are considered to represent “nearfield” conditions (i.e., E11, E14, E15, E17) and are located within 1000 m of the outfall wye or diffuser legs.

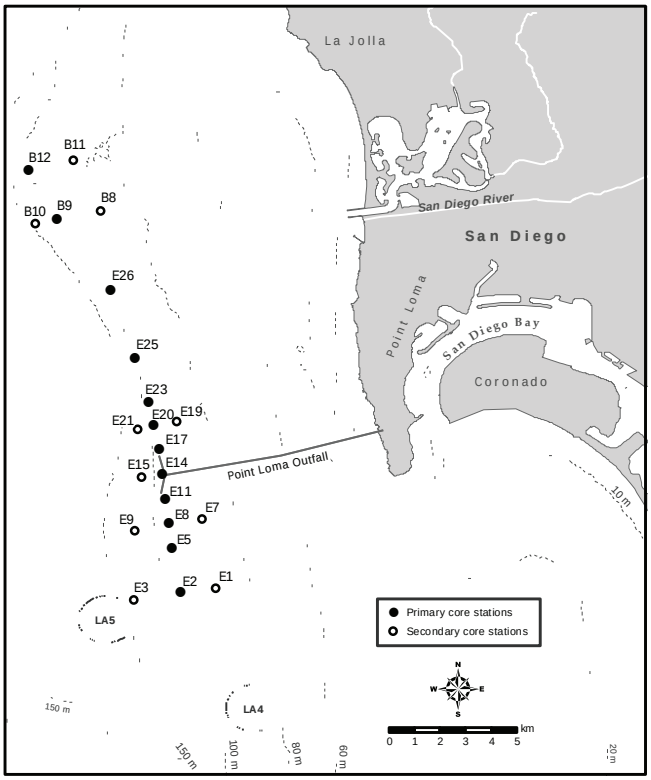

Figure 5.1
Benthic station locations sampled for the Point Loma Ocean Outfall Monitoring Program.

Two replicate samples for benthic community analyses were collected per station during each survey using a double 0.1-m^2 Van Veen grab. One of the two grabs from the first cast was used for analysis of macrofauna, while the adjacent grab was used for sediment quality analysis (see Chapter 4); a second grab for macrofauna was then collected from a subsequent cast. 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 collected and relaxed for 30 minutes in a magnesium sulfate solution and then fixed in buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All animals were sorted from the debris into major taxonomic groups by a subcontractor, and then identified to species (or the lowest taxon possible) and enumerated by City of San Diego marine biologists.

Data Analyses

The following community structure parameters were calculated for each station per 0.1-m^2 grab: species richness (number of species), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (see Swartz et al. 1986, Ferraro et al. 1994), and benthic response index (BRI; see Smith et al. 2001). Additionally, the total or cumulative number of species over all grabs was calculated for each station.

In order to examine spatial and temporal patterns among benthic macroinvertebrate communities in the PLOO region, multivariate analyses were conducted using PRIMER (Clarke and Warwick 2001, Clarke and Gorley 2006). Data from each Van Veen grab were considered individual replicates, and a square-root transformation was performed on the resultant abundance data matrix to lessen the influence of prevalent species and increase the weight of rare species. A Bray-Curtis similarity matrix was created from transformed data, with site provided as a factor. One-way analysis of similarity (ANOSIM, maximum number of permutations = 9999) was conducted to determine whether benthic macroinvertebrate communities varied spatially across the PLOO region. To visually depict the relationship of all individual grab samples to each other based on benthic invertebrate composition, a cluster dendrogram was created, and similarity profile (SIMPROF) analysis was used to confirm non-random structure of the resultant clades (Clarke et al. 2008). Similarity percentages (SIMPER) analysis was used to identify which species accounted for differences between clades occurring in the dendrogram.

A BACIP (Before-After-Control-Impact-Paired) statistical model was used to test the null hypothesis that there have been no changes in select community parameters due to operation of the PLOO (Bernstein and Zalinski 1983, Stewart-Oaten et al. 1986, 1992, Osenberg et al. 1994). The BACIP model compares differences between control (reference) and impact sites at times before

(July 1991–October 1993) and after (January 1994–July 2010) an impact 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 17 years (53 quarterly or semi-annual surveys) of after impact data. The E stations, located between ~0.1 and 8 km of the outfall, are considered most likely to be affected by wastewater discharge (Smith and Riege 1994). Station E14 was selected as the impact site for all analyses; this station is located near the boundary of the Zone of Initial Dilution (ZID) and probably is the site most susceptible to impact. The B stations are located farther from the outfall (>10 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, two stations (E26 and B9) were selected to represent separate control sites in the BACIP tests. Station E26 is located 8 km north of 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 three community parameters (number of species, infaunal abundance, BRI) and abundances of three taxa that are considered sensitive to organic enrichment. These indicator taxa include ophiuroids in the genus *Amphiodia* (mostly *A. urtica*), and amphipods in the genera *Ampelisca* and *Rhepoxynius*. All BACIP analyses were interpreted using one-tailed paired t-tests with a type I error rate of $\alpha = 0.05$.

Results

Community Parameters

Species richness

A total of 564 taxa were identified during the 2010 PLOO surveys. Of these, 445 taxa were identified to the species level, 63 to genus, 33 to family, 11 to order, 10 to class, and 2 individuals to phylum. The majority of taxa were found throughout the region, while about 26% ($n = 146$) represented taxa that were recorded only once. Annual mean values of species richness ranged from a low of 71 taxa per 0.1 m^2 at station E1 to a high of 120 taxa per 0.1 m^2 at station E14 (Table 5.1). Overall, the average species richness among the 12 primary core stations increased ~3% since 2009. This comparison between years is limited to the 12 primary core stations because of a reduction in sampling during January 2009 to accommodate the Bight'08 regional project (City of San Diego 2010).

Macrofaunal abundance

A total of 27,684 macrofaunal individuals were counted in 2010, with mean abundance values ranging from 245 to 491 animals per 0.1 m^2 (Table 5.1). The greatest number of animals occurred at nearfield station E14, which averaged 491 individuals per sample. In contrast, the fewest animals occurred at station E3 (245/0.1 m^2) located near the LA-5 disposal site. Overall, there was a ~3% increase in macrofaunal abundance collected at the 12 primary core stations between 2009 and 2010, with the largest increase occurring at station E14 (City of San Diego 2010).

Species diversity, evenness, and dominance

Diversity index values (H') averaged from 3.1 to 4.2 at PLOO stations during 2010 (Table 5.1), and were similar to values for previous years (e.g., City of San Diego 1995, 2010). The lowest diversity (H' = 3.1) occurred at station E1, while the remaining stations had mean H' values ≥3.4. There were no apparent patterns in diversity relative to distance from the discharge site (Table 5.1). Evenness (J') compliments diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed and the assemblage is not dominated by a few highly abundant species. During 2010, J' values averaged between 0.72 and 0.92 per station, with spatial patterns similar to those for diversity. Benthic assemblages in 2010 were characterized by relatively high numbers of evenly distributed species during the year. Swartz dominance values averaged from 21 to 45 species per station with the highest value occurring at

Table 5.1

Summary of macrofaunal community parameters for PLOO benthic stations sampled during 2010. Tot Spp = cumulative number of species for the year; SR = species richness (no. species/0.1 m^2); Abun = abundance (no. individuals/0.1 m^2); H' = Shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index; * = nearfield stations. Data are expressed as annual means (n = 4) except Tot Spp (n = 1).

	Station	Tot Spp	SR	Abun	H'	J'	Dom	BRI
88-m Depth Contour	B11	252	118	331	4.2	0.88	45	9
	B8	156	76	263	3.4	0.79	23	3
	E19	174	92	328	3.9	0.86	32	8
	E7	164	90	321	3.8	0.85	32	6
	E1	152	71	251	3.1	0.72	21	4
98-m Depth Contour	B12	202	102	321	4.1	0.88	36	10
	B9	157	81	274	3.9	0.89	31	7
	E26	157	84	314	3.8	0.87	30	10
	E25	164	90	375	3.9	0.86	29	8
	E23	170	89	289	4.0	0.89	33	10
	E20	169	88	326	3.9	0.87	30	10
	E17*	162	86	334	3.9	0.87	29	14
	E14*	259	120	491	4.1	0.86	37	20
	E11*	155	81	303	3.8	0.86	27	15
	E8	171	90	283	4.0	0.89	34	10
	E5	183	97	311	4.1	0.90	38	9
	E2	168	86	281	3.8	0.86	32	7
116-m Depth Contour	B10	197	101	353	4.0	0.87	36	13
	E21	166	83	248	4.0	0.90	32	10
	E15*	195	100	380	4.1	0.89	37	9
	E9	193	97	300	4.1	0.89	40	7
	E3	195	100	245	4.2	0.92	43	7
All Grabs	Mean	180	92	315	3.9	0.87	33	9
	Std Error	6	2	7	0.1	0.01	1	0.4
	Min	152	56	140	3.0	0.70	19	2
	Max	259	129	570	4.4	0.94	50	26

station B11, one of the northern reference stations (Table 5.1). The lowest dominance value occurred at station E1 located inshore of the LA-5 disposal site. Overall, the results for 2010 were similar to historical values for the PLOO region (see City of San Diego 2007).

Benthic response index

The benthic response index (BRI) is a useful tool for evaluating environmental conditions in soft-bottom benthic habitats off southern California at depths between 10–324 m (Smith et al. 2001). BRI values < 25 are considered indicative of reference conditions, while values between 25–34 represent a minor or marginal deviation from reference conditions. Higher BRI values > 34 represent progressive levels of impact from losses in biodiversity, community function, and ultimately defaunation. About 99% of the benthic samples collected off Point Loma in 2010 had BRI values < 25 and were therefore indicative of reference conditions. Overall, BRI values averaged from 3 to 20 at the different stations, while individual grab sample values ranged from 2 to 26 (Table 5.1).

The single sample with the relatively high BRI of 26 occurred at near-ZID station E14, which also had the highest annual mean BRI of 20. The three next highest mean BRI values of 13–15 occurred at nearfield stations E11 and E17 and northern reference station B10. BRI values at all other stations averaged ≤10 during the year, with the lowest BRI value of 3 occurring at reference station B8.

Dominant Species

In 2010, macrofaunal diversity in the PLOO region was dominated by polychaete worms, which accounted for 55% of all species collected (Table 5.2). Crustaceans accounted for 24% of species reported, while molluscs, echinoderms, and all other taxa combined accounted for the remaining 11%, 5%, and 5%, respectively. Polychaetes were also the most numerous animals, accounting for 57% of the total abundance. Crustaceans accounted for 20% of the animals collected, molluscs 10%, echinoderms 11%, and the remaining phyla 2%. Overall, the percentage of taxa that fell within each major taxonomic grouping and their relative abundances were similar to those observed in 2009 (City of San Diego 2010).

The 10 most abundant macroinvertebrates sampled during the year included six polychaetes, two crustaceans, one echinoderm and one mollusc (Table 5.3). The numerically dominant polychaetes were the terebellid *Polycirrus* sp A, the paraonid *Aricidea* (*Acmira*) *catherinae*, the cirratulids *Chaetozone hartmanae* and *Aphelochaeta glandaria* complex, the capitellid *Mediomastus* sp, and the ampharetid *Lysippe* sp A. The two dominant crustaceans were the ostracods *Euphilomedes producta* and *E. carcharodonta*. The dominant echinoderm and mollusc were the ophiuroid *Amphiodia urtica* and the bivalve *Axinopsida*

Table 5.2

Percent composition of species and abundance by major taxonomic group (phylum) for PLOO stations sampled during 2010. Data are expressed as annual means (range) for all stations combined; *n* = 22.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	55 (46–61)	57 (32–73)
Arthropoda (Crustacea)	24 (18–29)	20 (9–29)
Mollusca	11 (7–15)	10 (3–25)
Echinodermata	5 (3–8)	11 (2–42)
Other Phyla	5 (2–8)	2 (1–4)

Table 5.3

The 10 most abundant macroinvertebrates collected at the PLOO benthic stations sampled during 2010. Abundance values are expressed as mean number of individuals per 0.1-m^2 grab sample. Percent occurrence = percent of total annual samples where the species was collected.

Species	Higher Taxa	Abundance per Sample	Percent Occurrence
Amphiodia urtica	Echinodermata: Ophiuroidea	25.5	98
Axinopsida serricata	Mollusca: Bivalvia	10.8	89
Euphilomedes producta	Arthropoda: Ostracoda	9.9	91
Polycirrus sp A	Polychaeta: Terebellidae	9.6	95
Aricidea (*Acmira*) *catherinae*	Polychaeta: Paraonidae	8.1	95
Chaetozone hartmanae	Polychaeta: Cirratulidae	7.2	98
Mediomastus sp	Polychaeta: Capitellidae	6.6	95
Aphelochaeta glandaria Cmplx	Polychaeta: Cirratulidae	6.3	93
Euphilomedes carcharodonta	Arthropoda: Ostracoda	5.7	86
Lysippe sp A	Polychaeta: Ampharetidae	5.1	100

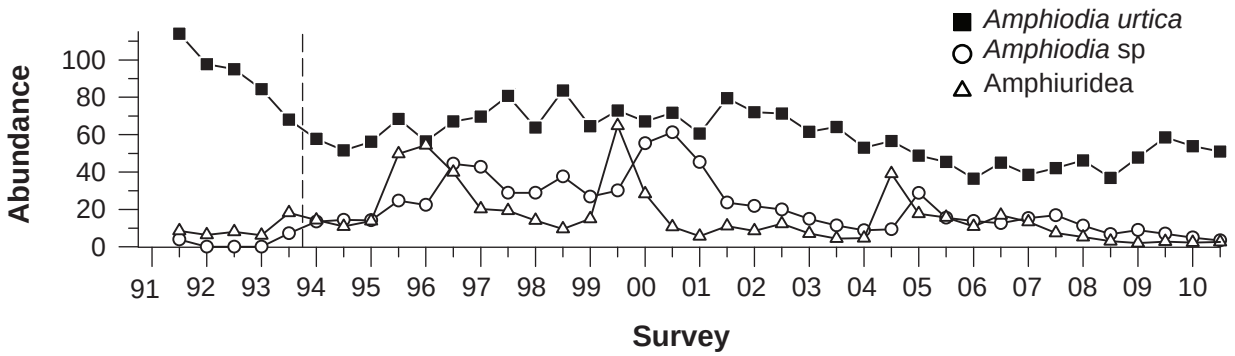

Figure 5.2

Abundance per survey for adult *Amphiodia urtica* and unidentifiable juveniles (*Amphiodia* sp and Amphiuridea) from PLOO benthic stations sampled between 1991 and 2010. Data are expressed as mean values of biannual (i.e., first and third quarters) samples during each survey ($n = 22$); sampling was limited to primary core stations ($n = 12$) during the quarters 03-3, 04-3, 05-1, 08-3, and 09-1 due to regulatory relief to accommodate special projects. Dashed line indicates onset of discharge from the PLOO.

serricata, respectively. The most abundant species collected overall was the ophiuroid *Amphiodia urtica*, which occurred at 98% of stations surveyed and averaged ~26 individuals per sample. While *A. urtica* was nearly ubiquitous in the PLOO region, abundances at individual stations varied (range 7–383 individuals/site). Overall, *A. urtica* accounted for ~8% of the macrobenthic fauna sampled during 2010 and has been among the most abundant species collected since monitoring began in 1991 (Figure 5.2).

Many of the dominant species collected in 2010 figured prominently in past years as well. For example, five of the most abundant species collected in 2010 (i.e., *Amphiodia urtica*, *Euphilomedes producta*, *E. carcharodonta*, *Chaetozone hartmanae*, *Mediomastus* sp) were among the 10 most abundant taxa collected historically (Appendix D.1). In contrast, some species were found in relatively high abundances at a limited number of stations. For example, the gastropod mollusc *Micranellum crebricinctum* was collected at only two stations (B12 and E3), but with mean abundances of 8.5 animals per 0.1 m^2 grab.

BACIP Analyses

BACIP t-tests indicate that there has been a net change in the mean difference of species richness, BRI values, and *Amphiodia* spp abundance between impact site E14 and both control sites since the onset of wastewater discharge from the PLOO (Table 5.4). There also has been a net change in infaunal abundance between E14 and control site B9, and a net change in *Ampelisca* spp abundance between E14 and E26. The change in species richness is likely driven by increased variability and higher numbers of species at E14 between 1997 and 2007 (Figure 5.3A). Differences in *Amphiodia* populations reflect both a decrease in the number of ophiuroids collected at E14 and a general increase at the control stations until about 2006 (Figure 5.3E). *Amphiodia urtica* densities at station E14 in 2010 are in range of the low densities that have been reported since about 1999. While populations of this brittle star have declined in recent years at both control sites, their densities at these sites are more similar to pre-discharge values than near the outfall. Changes in BRI differences generally have occurred due to increased index values at station E14 since 1994 (Figure 5.3C). The BACIP results for total infaunal abundances were more ambiguous (Figure 5.3B, Table 5.4). While the difference in mean abundances between stations B9 and E14 has changed since discharge began, no significant change is apparent regarding the second control site (station E26). No significant changes in the difference in mean abundances of phoxocephalid amphipods (i.e., *Rhepoxynius*) at the impact and control sites have occurred over time (Table 5.4). However, there has been a significant change in the difference in mean abundance of ampeliscid

Table 5.4

Results of BACIP t-tests for species richness (SR), infaunal abundance, BRI, and abundance of several representative taxa around the PLOO (1991–2010). Critical t-value = 1.680 for $\alpha = 0.05$ (one-tailed t-tests, df = 61); ns = not significant.

Variable	Control vs. Impact	t	*p*
SR	E26 vs E14	-3.17	0.001
	B9 vs E14	-3.52	< 0.001
Abundance	E26 vs E14	-1.46	ns
	B9 vs E14	-2.78	0.004
BRI	E26 vs E14	-15.53	< 0.001
	B9 vs E14	-10.72	< 0.001
Ampelisca spp	E26 vs E14	-1.95	0.028
	B9 vs E14	-1.31	ns
Amphiodia spp	E26 vs E14	-6.50	< 0.001
	B9 vs E14	-4.51	< 0.001
Rhepoxynius spp	E26 vs E14	-0.61	ns
	B9 vs E14	-0.53	ns

amphipods (i.e., *Ampelisca*) between E14 and E26 (Figure 5.3D, Table 5.4).

Classification of Macrobenthic Assemblages

ANOSIM results revealed that benthic invertebrate communities differed significantly between most sites (Global R = 0.705, $p = 0.0001$), although several pairwise comparisons between individual sites immediately north and south of the PLOO were non-significant (i.e., E20, E21, E23, E25 and E5, E8, E11). Station E14, located nearest the PLOO, as well as all 88-m sites, all 116-m sites, and the extreme northern and southern 98-m sites (Figure 5.1) contained invertebrate communities that were significantly different from every other site.

Cluster analysis examined the relationship of invertebrate communities from each individual Van Veen grab (two grabs over each sampling period). In accordance with some of the statistical similarities revealed through ANOSIM, the cluster analysis revealed a large clade comprising 47 samples that shared greater than 50% similarity (Figure 5.4). These 47 samples were collected from along all three depth contours and included all four grabs from 11 geographically-close sites (i.e., E5, E7, E8, E11, E15, E17, E19, E20, E23, E25, E26) and three grabs from a twelfth site (i.e., E21). The only site surveyed located within this geographically-defined group whose invertebrate community differed substantially was E14, a nearfield site located <150 m west of the outfall wye. Three of the grabs from E14 shared only ~30% similarity with any other site, and clustered together as an outgroup to the rest of the sites sampled (Figure 5.4). The fourth grab, collected from E14 in January, possessed invertebrate communities similar to the large main clade (clade 1 in Figure 5.4) described above. A sediment sample corresponding to this one January grab was not collected (see Materials and Methods); however, the presence of organisms associated with finer sediments in this grab (e.g., the ophiuroid *Amphiodia urtica*) suggests that benthic substrates where this sample occurred were more similar to the sediments found in clade 1 than in the other three E14 grabs. In general, sediment conditions at station E14 tend to be highly variable and patchy, possibly due to coarse material deposited in the area at the time of outfall construction, and/or unique hydrodynamic activities and scouring of sediments around the physical structure of the pipe.

Cluster analysis revealed the five northern-most sites sampled (B8, B9, B10, B11, B12) to possess benthic communities distinct from each other and all other sites surveyed (Figure 5.4). Except for B10, the four grabs from each site shared a high degree of similarity, allowing each of these northern sites to form its own distinct clade in the dendrogram. Inter-seasonal grabs from site B10 were distinct, each falling into a different clade. Four southern sites (E1, E2, E3, E9) also formed clades unique from all other sites surveyed. Benthic invertebrate communities at E1 and E2 were distinct, with the four grabs from each site sharing a high degree of intra-site similarity. Invertebrate communities from E3 and E9, both occurring along the 116-m contour, shared similarities, and grabs from both sites commingled in the dendrogram.

Although ANOSIM revealed invertebrate communities among many PLOO sites to be

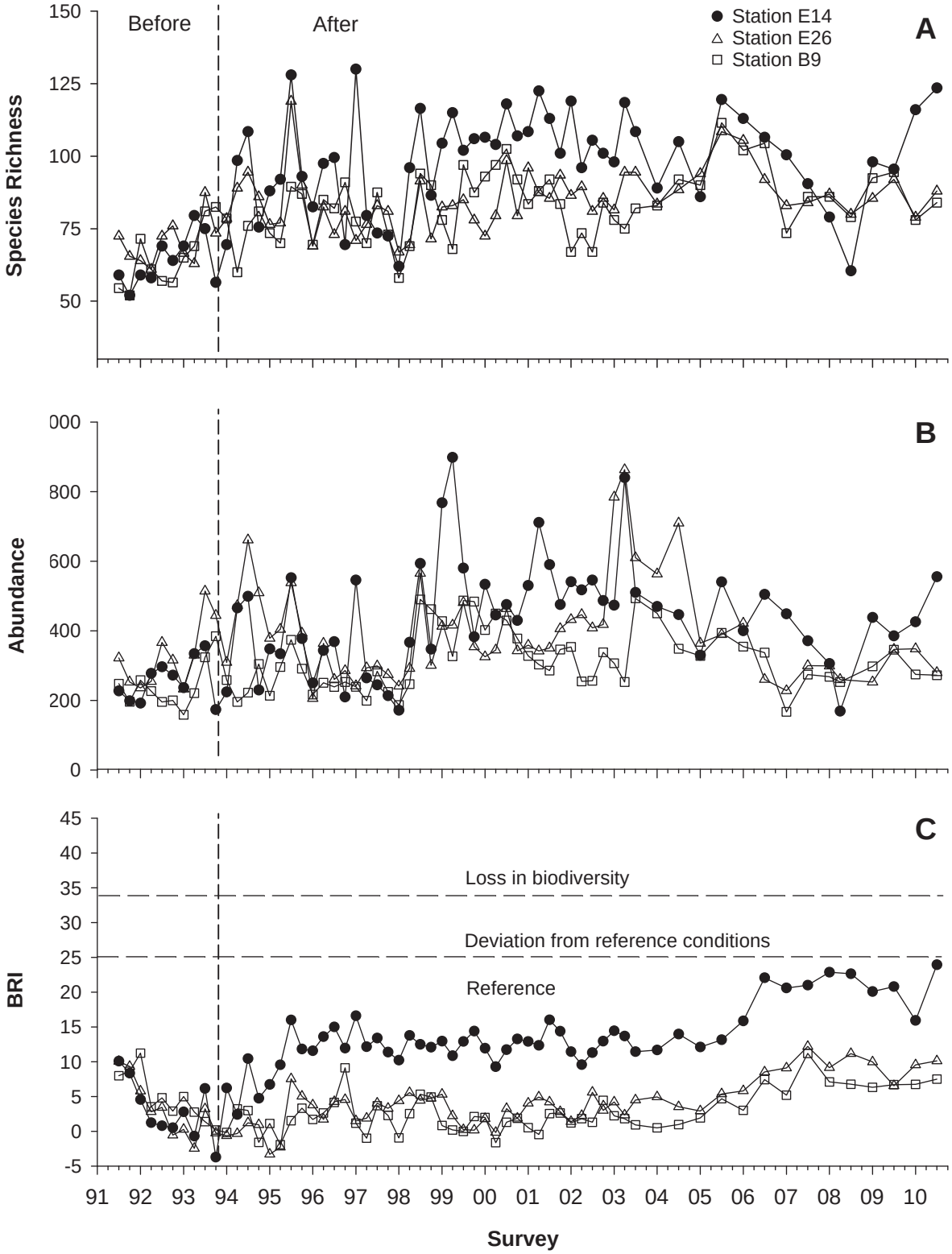

Figure 5.3

Comparison of several parameters at "impact" site (station E14) and "control" sites (stations E26, B9) used in BACIP analyses (see Table 5.4). Parameters include: (A) species richness; (B) infaunal abundance; (C) benthic response index (BRI); (D) abundance of *Ampelisca* spp; (E) abundance of *Amphiodia* spp. Data for each station are expressed as means per 0.1 m^2 ($n = 2$ per survey).

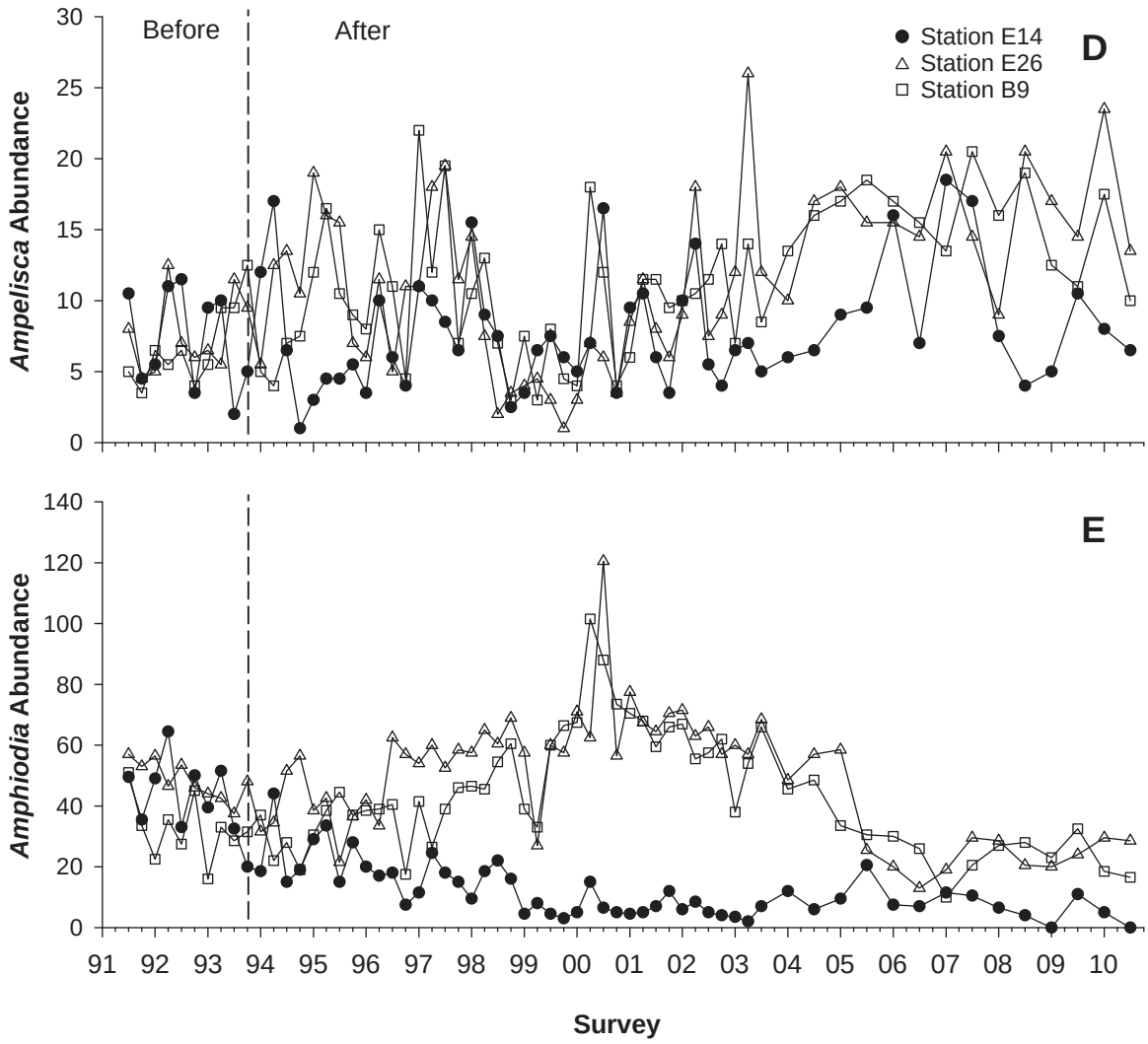

Figure 5.3 *continued*

statistically distinct, a site-level SIMPER indicated that the mix of species occurring at many stations was similar. Thus, it was often not invertebrate diversity that differed significantly among sites, but differences in species abundance. As an example, Appendix D.2 shows that although the presence of many species was ubiquitous across all PLOO sites sampled, the number of individuals recorded from each site differed substantially. In fact, with few exceptions (see below), there were so many minor differences in species abundances among sites that no one or two species could clearly explain why sites differed from each other. Instead, the vast majority of species identified at each site accounted for <1% of differences between sites, and abundances of well over 200 species were required to describe 90% of the variation observed between sites.

As stated above, a few distinct differences among species diversity or abundance did occur that partially explained the statistically-supported clades found in Figure 5.4. For example, one January grab from site E21 was depauperate in species that occurred ubiquitously in all other grabs from both seasons sampled, but the low diversity in this one grab could have occurred by chance. However, station E14 (located next to the PLOO) consistently contained high abundances of the polychaetes *Capitella teleta*, *Notomastus* sp A, and species of *Polycirrus*, and relatively low abundances of the arthropods *Ampelisca pacifica* and *Eyakia robusta* and the echinoderms *Amphiodia digitata* and *A. urtica* when compared to other sites surveyed (Appendix D.2). These differences, especially the presence of *C. teleta*, are likely due to outfall discharge (Reish 1957, Pearson and

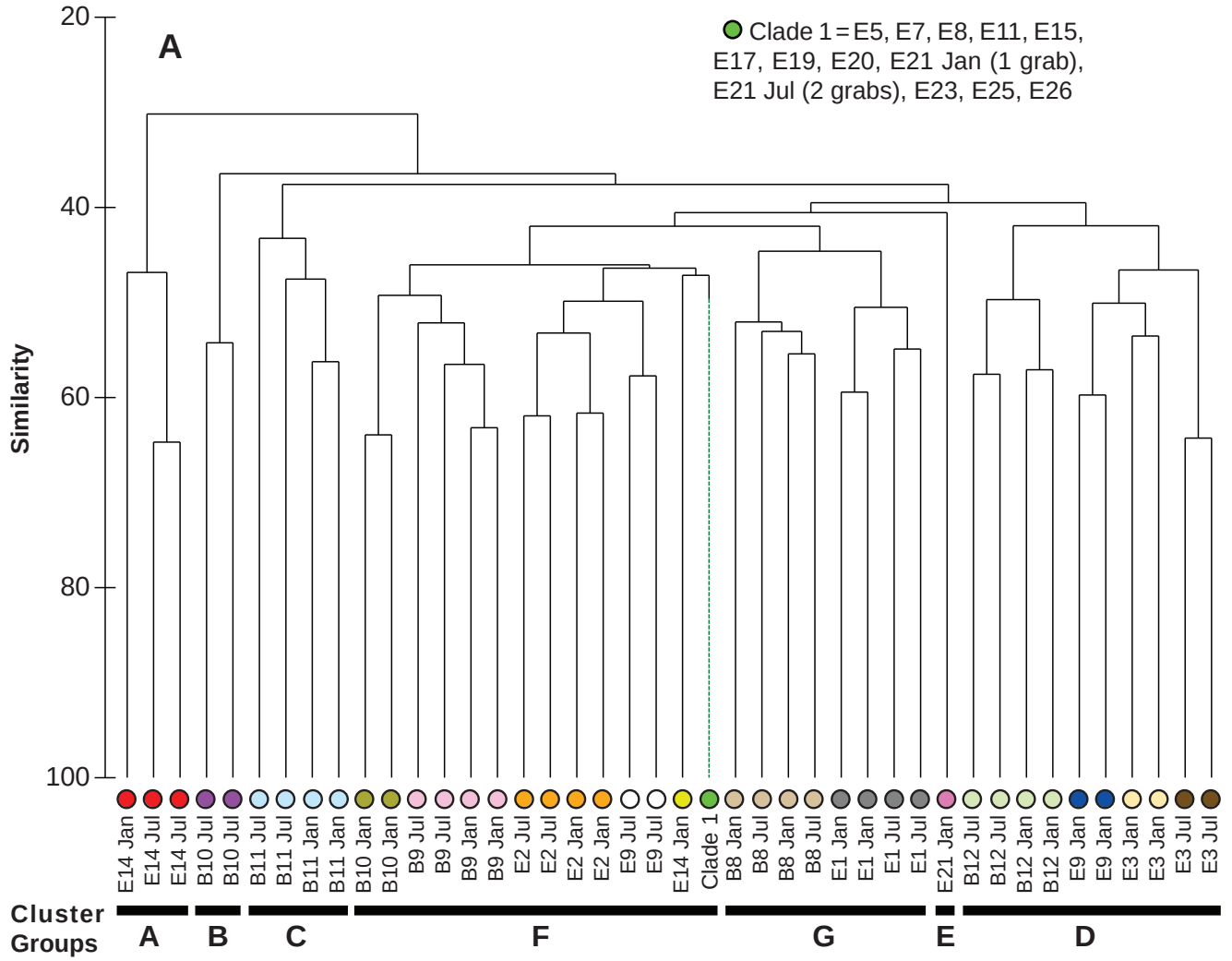

Figure 5.4

Results of multivariate analyses of macrofaunal assemblages at PLOO stations in 2010. (A) Cluster dendrogram depicting relationship of sites. Four grabs (two grabs in both January and July 2010) were collected from each of the 22 surveyed sites. Horizontal bold lines indicate cluster groups retained within 41% similarity. (B) Spatial distribution of macrobenthic assemblages delineated by cluster analysis. Each quarter circle represents a single grab. Colors within each quarter circle correspond to colors in dendrogram.

Rosenberg 1978). Two of the southern 116-m sites (i.e., E3, E9) and one northern 98-m site (i.e., B12) that formed a supported clade in the dendrogram (Figure 5.4) shared the only recorded populations of the gastropod *Micranellum crebricinctum*, and contained among the highest abundances of the ophiuroid *A. digitata* (Appendix D.2), likely due to the presence of coarse sediments.

Even though many sites possessed macroinvertebrate communities that differed significantly, cluster analysis revealed which sites shared the greatest similarity to each other. In order to assess broad-scale invertebrate community attributes and explore physical environmental factors that potentially influence community relatedness, clades in the cluster dendrogram were compressed at the 41% similarity level, resulting in six retained cluster groups (cluster groups A–G; Figure 5.4A). Average invertebrate abundance by taxon was determined for each cluster, and a SIMPER analysis conducted by cluster group to identify the characteristic species found within each assemblage (the most characteristic species are not always the most abundant). For single sample cluster groups (i.e., cluster group E), the most abundant taxa were used to characterize the assemblages. A

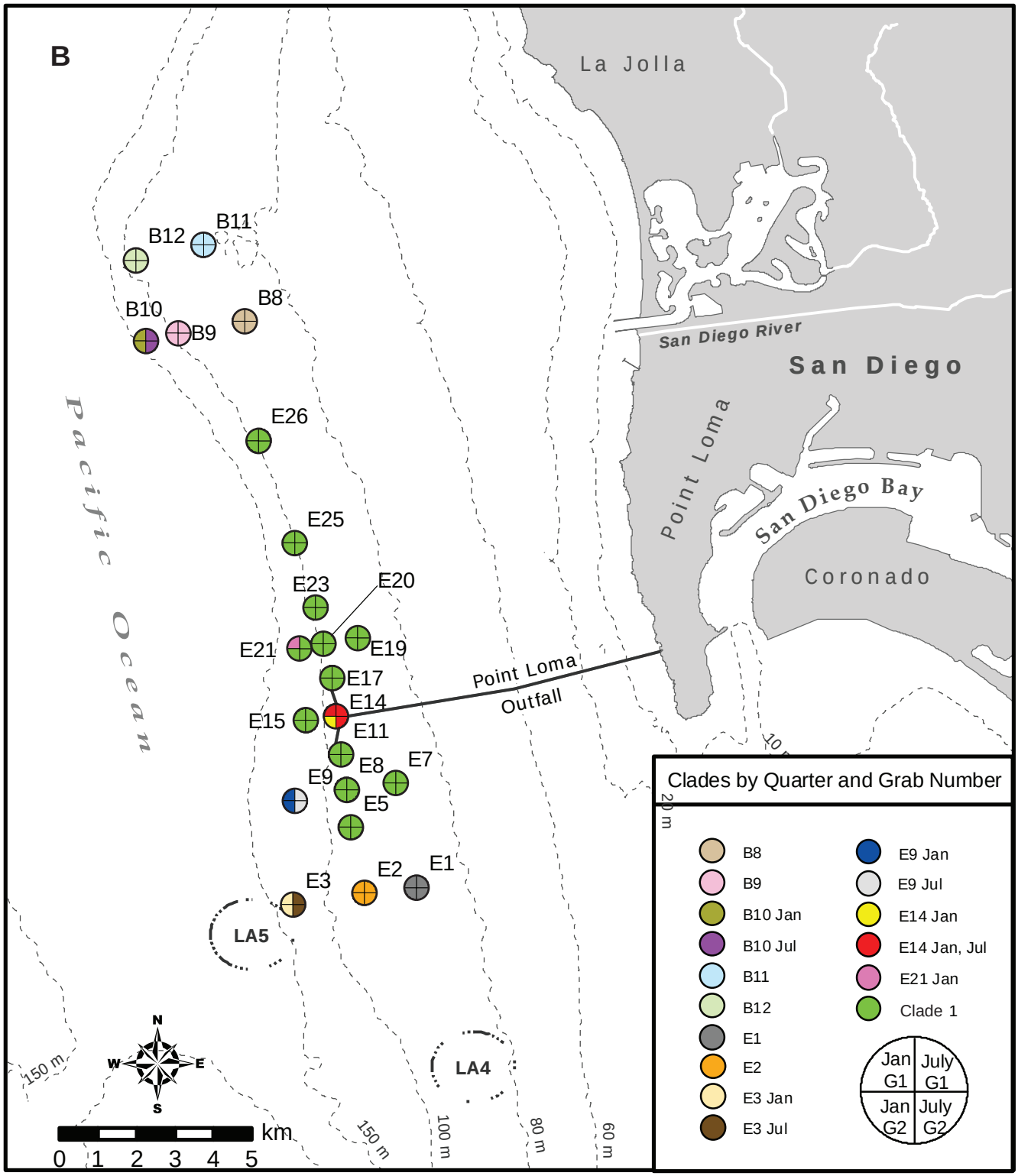

Figure 5.4 *continued*

matrix composed of the five most abundant species for each cluster group as defined above are presented in Table 5.5. A list of species identified by SIMPER as discriminating between individual cluster groups can be found in Appendix D.3. Overall, clusters were similar and no single species strongly discriminated between groups.

Cluster group A was composed of three grabs from station E14, located within a few hundred

Table 5.5

Description of cluster groups A–G defined in Figure 5.4. Data for species richness and infaunal abundance are expressed as mean values per 0.1-m^2 over all stations in each group. The five most abundant species in each cluster are represented. Bold values indicate taxa that were considered among the most characteristic of that group according to SIMPER analysis (i.e., greatest percentage contribution to within-group similarity).

	Group A	Group B	Group C	Group D	Group E	Group F	Group G
Number of Grabs	3	2	4	10	1	60	8
Species Richness	124	104	118	102	56	90	74
Abundance	510	326	331	280	140	320	257
Taxa	**Mean Abundance**						
Polycirrus sp	40.3	9.0	4.8	2.4		3.7	0.6
Notomastus sp A	**27.3**	1.5	1.0	1.0		0.3	0.1
Decamastus gracilis	**26.3**	8.0	1.0	3.9	1.0	2.1	0.1
Chloeia pinnata	25.3	**8.5**	2.0	7.0		3.0	0.1
Aphelochaeta glandaria Cmplx	18.3	**28.5**	1.8	4.8	3.0	6.2	1.0
Axinopsida serricata	6.7	**15.5**	**31.5**	4.5		10.3	14.9
Aphelochaeta monilaris	1.0	**11.5**	2.3	1.2		3.4	1.1
Aricidea (*Acmira*) *rubra*	5.0	**11.0**				1.0	
Adontorhina cyclia	0.3	2.0	**22.8**	1.0		4.0	11.3
Chaetozone hartmanae	13.0	5.5	**14.3**	1.8	4.0	**8.2**	1.0
Aphelochaeta sp LA1	2.0	6.0	**8.5**	4.8	1.0	2.8	1.5
Dipolydora socialis	1.0		7.3	0.2		0.3	
Monticellina siblina	5.3	7.0	2.8	**12.0**	1.0	1.5	0.6
Amphiodia digitata		3.0	0.3	**11.3**		0.8	0.3
Lysippe sp A	2.7	0.5	3.3	**8.3**	7.0	5.2	2.3
Polycirrus sp A	6.0		4.3	**8.0**	8.0	**11.6**	3.8
Aricidea (*Acmira*) *lopezi*			0.3	7.4		4.1	1.3
Amphiodia urtica		1.5	4.8	3.6	14.0	**26.2**	**76.0**
Mediomastus sp	5.0	6.0	4.3	5.0	12.0	7.6	1.3
Lumbrineris sp Group I	2.0	1.0	0.3	1.3	7.0	6.1	2.3
Euphilomedes producta		3.5	0.3	**6.6**	6.0	**13.1**	0.4
Aricidea (*Acmira*) *catherinae*	3.0	2.5	1.8	5.0	1.0	**10.3**	1.1
Ennucula tenuis	0.3	1.5	**6.0**	1.8		3.5	**7.8**
Travisia brevis			2.3	1.5		2.4	6.0

meters of the PLOO along the 98-m depth contour (Figure 5.4B). Average species richness and mean abundance were 124 taxa and 510 individuals/grab, respectively. July sediments for this cluster consisted of 52.9% coarse, 30.2% sand, and only 16.8% fines. The most abundant species encountered were the polychaetes *Polycirrus* sp A, *Notomastus* sp A, *Decamastus gracilis* and *Chloeia pinnata* (Table 5.5). SIMPER revealed the polychaetes *Notomastus* sp A, *Decamastus gracilis*, *Capitella teleta* and Euclymeninae, and the bivalve *Parvilucina tenuisculpta* to be the five most characteristic species that defined the cluster group.

Cluster group B consisted of two grabs collected from station B10 in July along the 116-m depth contour (Figure 5.4B). Average species richness and mean abundance were 104 taxa and 326 individuals/grab, respectively. Sediments consisted of 31.5% fines. The most abundant species encountered included polychaetes from the *Aphelochaeta glandaria* complex, *Aphelochaeta monilaris*, and *Aricidea* (*Acmira*) *rubra*, and the bivalve *Axinopsida serricata* (Table 5.5). SIMPER revealed that the four most abundant taxa listed above and *Chloeia pinnata* were the five most characteristic species that defined these assemblages.

Cluster group C consisted of all four grabs collected throughout the year from station B11, situated along the 88-m depth contour (Figure 5.4B). Average species richness and mean abundance were 118 taxa and 331 individuals/grab, respectively. Sediments from two separate grabs ranged from 1.7%−28.5% coarse (mean = 15.1%), 29.3%−46.5% sand (mean = 37.9%) and 42.2%−51.8% fines (mean = 47.0%). The most abundant species included the molluscs *Axinopsida serricata* and *Adontorhina cyclia* (Table 5.5). The five most characteristic invertebrates found in these assemblages included the polychaetes *Chaetozone hartmanae* and *Aphelochaeta* sp LA1, and the molluscs *A. serricata*, *A. cyclia* and *Ennucula tenuis*.

Cluster group D contained assemblages from ten samples located along the 98 and 116-m depth contours. Average species richness and mean abundance were 102 taxa and 280 individuals/grab, respectively. Sediments ranged from 0−13.9% coarse (mean = 2.8%), 56.1%−70.2% sand (mean = 64.5%) and 15.9%−43.9% fines (mean = 32.7%). The polychaete *Monticellina siblina* and the echinoderm *Amphiodia digitata* were the most abundant species encountered (Table 5.5). In addition to the two most abundant species listed above, the arthropod *Euphilomedes producta* and the polychaetes *Lysippe* sp A and *Polycirrus* sp A were the most characteristic taxa for the cluster group.

Group E comprised a single grab from station E21 collected in January along the 116-m depth contour (Figure 5.4B). Species richness and abundance were 56 taxa and 140 individuals, respectively. No sediments were collected along with this grab. The most abundant taxa found in the grab included the echinoderm *Amphiodia urtica*, and the polychaetes *Mediomastus* sp, *Polycirrus* sp A, *Lysippe* sp A, and *Lumbrineris* sp Group 1 (Table 5.5). As discussed in the detailed description of cluster analysis (above), this group was characterized by the absence of common species (e.g. *Aphelochaeta monilaris*, *Axinopsida serricata*) rather than abundance of organisms present.

Cluster group F was the main assemblage and consisted of 68% of grabs collected during 2010 and encompassed sites from all depth contours (Figure 5.4B). Average species richness and mean abundance were 90 taxa and 320 individuals/grab, respectively. Coarse sediments ranged from 0−1.3% (mean = 0.1%), sand ranged from 52.6%−70.5% (mean = 62.1%), and fines ranged from 29.5%−47.4% (mean = 37.8%). The most abundant organism that defined these sites was the ophiuroid *Amphiodia urtica* (Table 5.5). PRIMER revealed the five most characteristic species for the clade to be *A. urtica*, the arthropod *Euphilomedes producta*, and the polychaetes *Polycirrus* sp A, *Aricidea* (*Acmira*) *catherinae*, and *Chaetozone hartmanae*.

Cluster group G comprised all grabs from stations E1 and B8 located along the 88-m depth contour. Average species richness and mean abundance were 74 taxa and 257 individuals/grab, respectively. Sediment composition ranged from 0−1.1% coarse (mean = 0.3%), 41.7%−58.7% sand (mean = 50.0%), and 40.2%−58.3% fines (mean = 50.0%). As with cluster group F, the most abundant species collected was *Amphiodia urtica* (Table 5.5). The five most characteristic taxa for this group included *A. urtica*, the mollusc *Ennucula tenuis*, the polychaetes *Clymenura gracilis* and *Proclea* sp A, and the amphipod *Rhepoxynius bicuspidatus*.

Discussion

As in previous sampling years, benthic communities surrounding the PLOO in 2010 continued to be dominated by ophiuroid-polychaete based assemblages, with few major changes having occurred since monitoring began (City of San Diego 1995, 1999, 2010). The brittle star *Amphiodia urtica* was the most abundant and widespread species, while the bivalve *Axinopsida serricata* was the second most widespread benthic invertebrate. Many sites surveyed off Point Loma during the year were found to possess species assemblages similar to those described for other areas in the Southern California Bight (SCB) by Barnard and Ziesenhenne (1961), Jones (1969), Fauchald and Jones (1979), Thompson et al. (1987, 1993a), Zmarzly et al. (1994), Diener and

Fuller (1995), Bergen et al. (1998, 2000, 2001), and others. However, even though overall diversity was similar among sites, the relative abundance of specific species often varied depending mostly on sediment type or proximity to the discharge site, which led to many of the significant differences documented via multivariate analysis.

Abundance and dominance of select species (e.g., *Amphiodia urtica*) in benthic macroinvertebrate communities off Point Loma have generally remained static at most sites since monitoring began in 1991 (e.g., City of San Diego 1995, 1999, 2007). Additionally, values for these parameters in 2010 were within the range of those described for other sites throughout the SCB (Thompson et al. 1993b, Bergen et al. 1998, 2000, 2001, Ranasinghe et al. 2003, 2007). In spite of this overall stability, an increase in the abundance of a few species documented at stations located adjacent to the PLOO during the post-discharge period may be indicative of organic enrichment or other types of disturbance that have destabilized the benthic community (Warwick and Clarke 1993, Zmarzly et al. 1994). For example, BRI values have increased at near-ZID station E14 since discharge began as well as at two other nearfield stations (E11 and E17), likely because of limited organic enrichment to the area. However, despite these increases, overall BRI values in the PLOO region remain indicative of relatively undisturbed areas (Smith et al. 2001, Ranasinghe et al. 2010). Additionally, there have been changes in sediment composition at station E14 possibly related to construction of the PLOO (see Chapter 4 herein, City of San Diego 2007) that likely influenced invertebrate community structure near the outfall due to localized physical disturbances.

Specific changes to indicator taxa that may correspond to organic enrichment near the outfall include a decrease in brittle star, *Amphiodia urtica*, populations at station E14 since discharge began, while concomitant increases in abundances of this brittle star occurred at reference sites from 1997 to 2006. Although long term changes in *Amphiodia* populations at E14 may be related to organic enrichment, factors such as altered sediment composition and increased predation pressure near the outfall may also be important. Regardless of the cause of these changes, abundances of *Amphiodia* off Point Loma still remain within the range of natural variation in the SCB.

Recent increases in populations of the opportunistic polychaete *Capitella teleta* may also be indicative of changing benthic conditions nearest the discharge site. For example, a total of 92 individuals of *C. teleta* were reported across the entire PLOO region in 2010 of which 95% occurred at the four nearfield stations located within 750 m of the discharge site. At these locations, *C. teleta* averaged 6.2 individuals per site, with the greatest concentration occurring at station E14 adjacent to the outfall (72 individuals, averaging 18 individuals per grab). Although these abundances represented a noticeable change, they are still much lower than the high densities (e.g., $>500/0.1\ m^2$) associated with polluted sediments reported elsewhere in the SCB (Swartz et al. 1986). Natural population fluctuations of other resident polychaetes commonly occur off San Diego (Zmarzly et al. 1994, Diener et al. 1995) and are not likely an effect of wastewater discharge. Further complicating the picture, relatively stable populations of pollution-sensitive amphipods in the genus *Rhepoxynius* at station E14 suggest the outfall has little to no effect on these indicator species.

In conclusion, while it is difficult to detect specific effects of wastewater discharge via the PLOO on the marine benthos off San Diego, it is possible to see some changes occurring nearest the discharge site. Because of the minimal extent of these changes, it has not been possible to determine whether observed effects are due to habitat alteration related to organic enrichment, the physical structure of the outfall pipe, or a combination of factors. In addition, abundances of soft bottom invertebrates naturally exhibit substantial spatial and temporal variability that may mask the effects of any disturbance event (Morrisey et al. 1992a, 1992b, Otway 1995). The effects associated with the discharge of advanced primary treated sewage may be difficult to detect in areas subjected to strong currents that facilitate the dispersion of the wastewater plume (Diener

and Fuller 1995). Although some changes in macrobenthic assemblages have appeared near the outfall, most assemblages in the Point Loma region remain similar to those observed prior to discharge and to the natural indigenous communities characteristic of the southern California continental shelf. Overall, benthic macrofauna appear to be in good condition off Point Loma, with all of the sites surveyed in 2010 being classified in reference condition based on assessments using the benthic response index. This is not unexpected as Ranasinghe et al. (2010) recently reported that 98% of the entire SCB remains in good condition based on data gathered during the 1994, 1998, and 2003 bight-wide surveys.

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