Chapter 9. San Diego Regional Survey Macrobenthic Communities

Introduction

Macrobenthic invertebrates fulfill essential roles as nutrient recyclers and bioeroders in marine ecosystems throughout the world (Fauchald and Jones 1979, Thompson et al. 1993, Snelgrove et al. 1997). In the Southern California Bight (SCB), the structure of these communities is influenced by numerous natural factors (see Chapter 5), especially depth gradients and/or sediment grain size (Bergen et al. 2001). Because of their ability to serve as reliable indicators of pollution or other environmental stressors, benthic macrofauna have been sampled extensively for the past several decades in order to monitor potential changes around SCB ocean outfalls and other point sources at small spatial scales (Stull et al. 1986, 1996, Swartz et al. 1986, Ferraro et al. 1994, Zmarzly et al. 1994, Diener and Fuller 1995, Diener et al., 1995, Stull 1995). Examples of such local assessments include the regular ongoing surveys conducted each year around the ocean outfalls operated by the City of Los Angeles, the City of San Diego, the Los Angeles County Sanitation District, and the Orange County Sanitation District, the four largest wastewater dischargers in the region (City of Los Angeles 2007, 2008, City of San Diego 2011a, b, LACSD 2010, OCSD 2011). In order to place data from these localized surveys into a broader biogeographic context, larger-scale regional monitoring efforts have also become an important tool for evaluating benthic conditions and sediment quality in southern California (Bergen et al. 1998, 2000, Hyland et al. 2003, Ranasinghe et al. 2003, 2007, 2012, USEPA 2004).

The City of San Diego has conducted annual regional benthic surveys off the coast of San Diego since 1994 (see Chapter 1). The primary objectives of these summer surveys, which typically range from Del Mar to the USA/Mexico border, are to (1) describe the overall condition and quality of the diverse benthic habitats that occur off San Diego, (2) characterize the ecological health of the soft-bottom marine benthos in the region, and (3) gain a better understanding of regional variation in order to distinguish anthropogenically-driven changes from natural fluctuations. These surveys typically occur at an array of 40 stations selected each year using a probability-based, random stratified sampling design as described in Bergen (1996), Stevens (1997), and Stevens and Olsen (2004). During 1995–1997, 1999–2002 and 2005–2007, the surveys off San Diego were restricted to continental shelf depths (<200 m), while the area of coverage was expanded beginning in 2009 to also include deeper habitats along the upper slope (200–500 m). No survey of randomly selected sites was conducted in 2004 due to sampling for a special sediment mapping project (Stebbins et al. 2004), while surveys in 1994, 1998, 2003 and 2008 were conducted as part of larger, multi-agency surveys of the entire SCB (Bergen et al. 1998, 2001, Ranasinghe et al. 2003, 2007, 2010, 2012).

This chapter presents analyses and interpretations of the benthic macrofaunal data collected during the 2011 regional survey of the continental shelf and upper slope off San Diego. Included are descriptions and comparisons of the soft-bottom macrobenthic assemblages present, as well as the corresponding analyses of benthic community structure for the region. Additionally, a multivariate analysis of benthic macrofaunal data collected from the 2009–2011 regional surveys is presented. Although regional data exist prior to this time period, 2009 represents the first year where upper slope sites were included as a fourth depth stratum, allowing this region to be comparable to the three continental shelf strata. Results of benthic sediment quality analyses at the same sites are presented in Chapter 8.

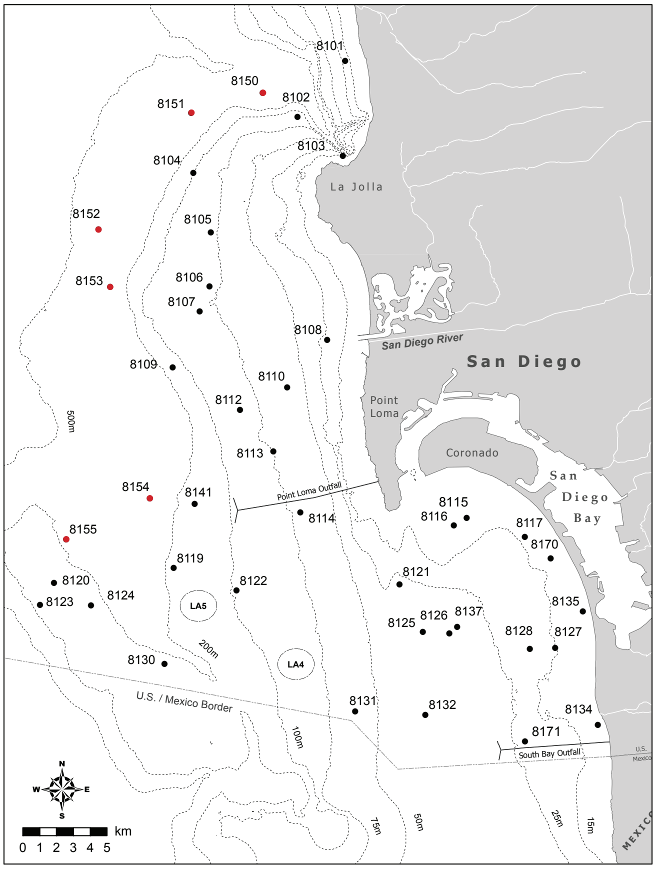


Figure 9.1
Regional benthic survey stations sampled during July 2011 as part of the City of San Diego's Ocean Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

Materials and Methods

Collection and Processing of Samples

The July 2011 regional survey covered an area ranging from off Del Mar in northern San Diego County south to the USA/Mexico border (Figure 9.1). Overall, this survey included 41 stations ranging in depth from 10 to 427 m and spanning four distinct depth strata characterized by the SCB regional monitoring programs (Ranasinghe et al. 2007) were sampled. These included 14 stations along the inner shelf (5–30 m), 14 stations along the mid-shelf (>30–120 m), 7 stations along the outer shelf (>120–200 m), and 6 stations on the upper slope (>200–500 m).

Samples for benthic community analysis were collected at each station using a double 0.1-m^2 Van Veen grab; one grab from each cast was used to sample macrofauna, while the adjacent grab was used to assess sediment quality (see Chapter 8). To ensure consistency of grab samples, protocols established by the United States Environmental Protection Agency (USEPA) were followed to standardize sample disturbance and depth of penetration (USEPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen, and organisms retained on the screen were collected and relaxed for 30 minutes in a magnesium sulfate solution before fixing 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 subcontracted laboratory and then identified to species (or the lowest taxon possible) following SCAMIT (2011) nomenclature and enumerated by City of San Diego marine biologists.

Data Analyses

For 2011 data, 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).

To explore spatial and temporal patterns in the regional benthic macrofaunal data collected from 2009−2011, multivariate analyses were conducted using PRIMER (Clarke and Warwick 2001, Clarke and Gorley 2006). Data were square-root transformed to lessen the influence of common species and increase the importance of rare species, and a Bray-Curtis similarity matrix created using year, depth category (i.e., inner shelf, mid-shelf, outer shelf, and upper slope), and sediment type (see Chapter 4) as factors. Three-way permutational multivariate analysis of variance (PERMANOVA, maximum number of permutations = 9999) was conducted to determine whether benthic communities varied by sediment type, depth or year across the region. To visually depict the relationship of individual grab samples to each other based on macrofaunal composition, a cluster dendrogram was created. Similarity profile (SIMPROF) analysis was used to confirm non-random structure of resultant clades in the dendrogram (Clarke et al. 2008), and major ecologically-relevant clusters supported by SIMPROF were retained at >22.43% similarly. Similarity percentages (SIMPER) analyses were used to determine which organisms were responsible for the greatest contribution to within-group similarities (i.e., characteristic species) and to identify which species accounted for differences among clades occurring in the dendrogram.

Results

Community Parameters

Species richness

A total of 713 macrobenthic taxa (mostly species) were identified during the summer 2011 regional survey. Of these, 271 (38%) represented taxa that occurred only once, and which may include rare species, unidentifiable juveniles of other documented species, or damaged specimens that cannot be identified. A total of six species not previously collected during the San Diego regional surveys were recorded: the anthozoan *Scolanthus triangulus*, the oweniid polychaete *Myriochele olgae*, the phyllodocid polychaete *Phyllodoce williamsi*, the polynoid polychaete *Malmgreniella liei*, the bivalve *Tivela stultorum*, and the sand dollar *Dendraster excentricus*. Species richness values from all four strata combined ranged from 20–118 species per station, with the range of values found within each stratum overlapping considerably (Table 9.1). However, average species richness values indicated that mid-shelf sites typically had more taxa than other strata, while the inner shelf and upper slope strata both contained sites with the lowest species richness (Figure 9.2A). In particular, inner shelf stations 8115 and 8116 and upper slope station 8150 had only 20 taxa/grab, while mid-shelf stations 8125 and 8131 each contained 118 taxa/grab. From 2009 to 2011, only slight differences in total species richness occurred within each stratum, with the greatest percent change (~25% increase) occurring at stations from the upper slope during 2009 and 2010.

Macrofaunal abundance

Macrofaunal abundance across all four strata ranged from 47–778 animals per site in 2011, with ranges within each stratum exhibiting some degree of overlap (Table 9.1). Abundance varied by depth with the inner shelf, mid-shelf, outer shelf and upper slope assemblages averaging ~191, 337, 181 and 115 animals/grab, respectively (Figure 9.2B). Although overall abundance was highest at mid-shelf depths, the greatest number of animals (778/grab) occurred at inner shelf station 8108 (Table 9.1). Only one other site, mid-shelf station 8131, had abundances >450 animals per grab. In contrast, upper slope station 8150 had the lowest abundance with 47 animals/grab (Table 9.1). Temporal differences from 2009 to 2011 varied within each stratum (Figure 9.2B), with the greatest change occurring on the inner shelf where a 40% reduction in mean abundance was observed over this 3-year period.

Diversity and evenness

During 2011, diversity (H') ranged from 2.2 to 4.3 across all strata (Table 9.1). Although diversity ranges overlapped among strata, average values indicate that sites along the upper slope had lower diversity than at shelf depths (Figure 9.2C). The five stations with the highest diversity (i.e., H'≥4.0) occurred along the mid- and outer shelf strata, while the lowest diversity occurred at inner shelf station 8116 located near the mouth of San Diego Bay. Evenness (J') compliments diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed and that an assemblage is not dominated by a few highly abundant species. J' values ranged between 0.73–0.95 during 2011 (Table 9.1), with evenness not varying much with depth (Figure 9.2D). Diversity and evenness values have remained relatively stable from 2009 to 2011, and exhibited little variability within each stratum.

Table 9.1

Macrofaunal community parameters calculated per 0.1-m^2 grab at regional stations sampled during 2011. SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index; *n* = 1.

	Station	Depth (m)	SR	Abun	H'	J'	Dom	BRI
Inner Shelf	8116	10	20	140	2.2	0.75	6	6
	8134	10	26	65	2.7	0.83	10	21
	8103	12	33	105	2.8	0.79	11	20
	8135	13	39	92	3.2	0.87	17	22
	8117	16	39	68	3.4	0.92	23	24
	8170	16	33	120	2.8	0.79	9	34
	8115	19	20	63	2.5	0.85	8	-2
	8101	20	64	170	3.7	0.88	26	16
	8127	20	57	105	3.8	0.95	31	22
	8128	20	38	76	3.4	0.92	20	20
	8108	24	73	778	3.3	0.76	13	22
	8171	25	43	91	3.4	0.91	21	19
	8121	29	114	443	3.9	0.82	33	27
	8137	29	110	358	3.8	0.82	35	27
Mid-shelf	8126	32	101	395	3.9	0.84	28	28
	8125	36	118	369	4.3	0.91	47	23
	8132	40	83	301	3.7	0.83	24	17
	8131	58	118	515	3.7	0.78	31	10
	8110	62	96	377	3.8	0.82	29	16
	8114	72	84	396	3.2	0.73	19	13
	8113	75	102	427	3.8	0.82	32	14
	8105	78	66	195	3.5	0.83	25	5
	8106	80	87	284	3.7	0.82	29	11
	8107	84	70	238	3.5	0.82	25	7
	8112	84	91	324	3.8	0.85	33	9
	8102	93	93	358	3.9	0.87	29	12
	8104	100	99	327	4.0	0.87	36	13
	8122	101	90	213	4.1	0.91	39	11
Outer Shelf	8109	122	98	318	4.0	0.86	34	15
	8124	139	67	213	3.5	0.83	24	8
	8130	139	94	277	4.0	0.87	37	9
	8120	148	42	97	3.4	0.90	18	1
	8123	161	51	130	3.6	0.91	24	-5
	8141	165	43	83	3.5	0.94	23	21
	8119	193	65	152	3.8	0.90	31	19
Upper Slope	8154	249	36	66	3.3	0.93	20	22
	8151	286	55	146	3.3	0.83	21	19
	8155	312	72	247	3.5	0.81	24	13
	8153	339	32	84	3.0	0.86	12	na
	8152	393	37	98	3.2	0.88	16	na
	8150	427	20	47	2.5	0.82	9	na

na = not applicable

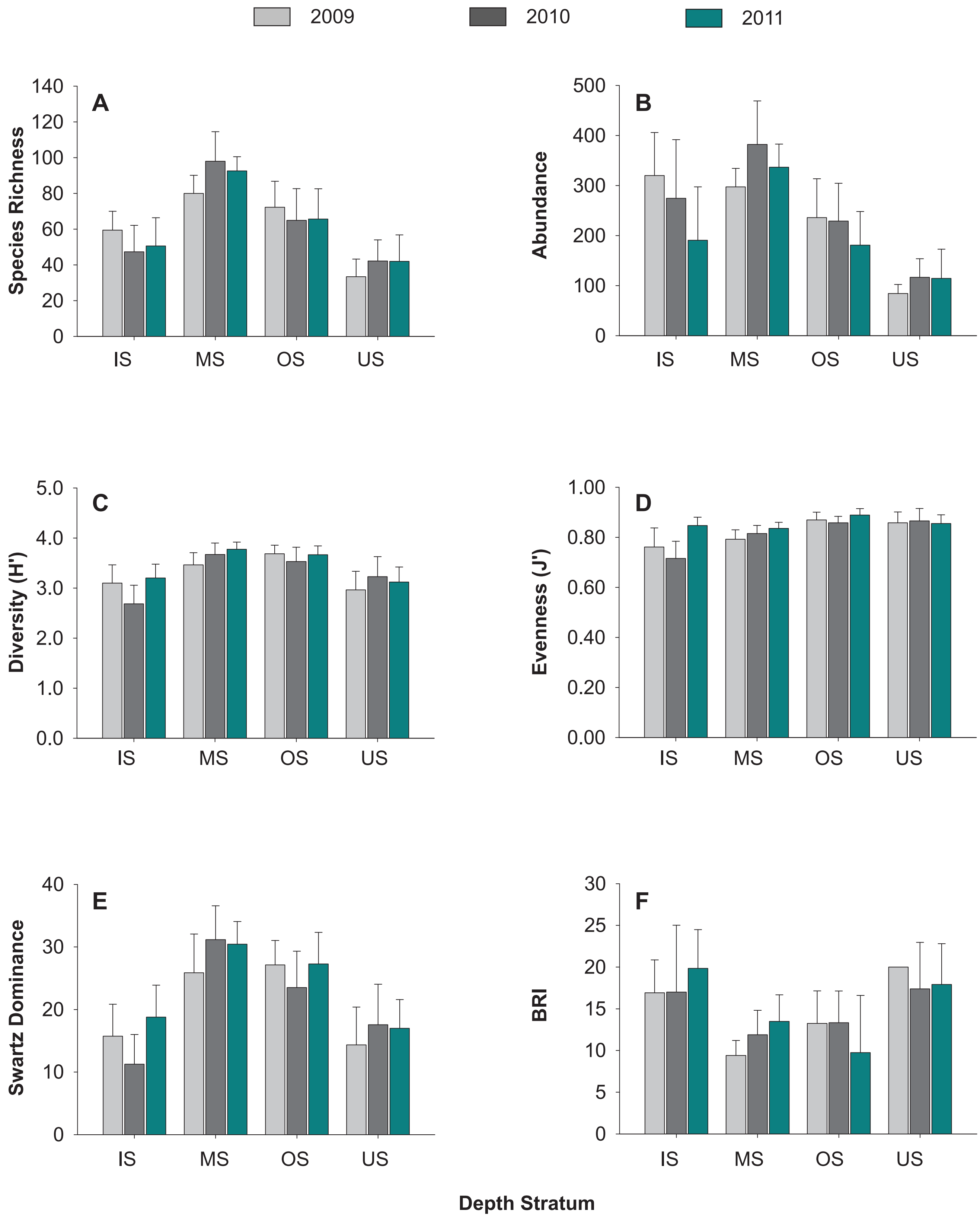


Figure 9.2

Comparison of macrofaunal community structure metrics for the four major depth strata sampled during regional surveys between 2009–2011. Data are expressed as means + 95% confidence interval (per 0.1 m^2). IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope.

Dominance

Swartz dominance values across all strata ranged between 6–47 taxa per station during 2011 (Table 9.1). Average dominance was notably higher (i.e., lower index values) at inner shelf and upper slope sites than at mid- and outer slope sites (Figure 9.2E). Typically, dominance values were inversely related to diversity. For example, sites 8125, 8122, and 8130 had the lowest dominance with index values ≥37, but exhibited high diversity values ≥4.0. Conversely, stations 8116, 8170, 8115, and 8150 possessed the highest dominance with index values <10, but had relatively low diversity values of 2.2 to 2.8 (Table 9.1). Within strata, temporal differences between 2009–2011 were variable, with the largest changes in dominance occurring along the inner shelf between 2010 and 2011 (Figure 9.2E).

Benthic response index (BRI)

The benthic response index (BRI) is an important tool for evaluating possible anthropogenic impacts to marine environments throughout the SCB. BRI values <25 are considered indicative of reference conditions, while values between 25–34 represent "a minor deviation from reference conditions" and should be corroborated with additional information. BRI values >34 represent different levels of degradation including losses in biodiversity or community function, and ultimately defaunation (Smith et al. 2001). During 2011, BRI values ranged from -5 to 34 at the regional stations (Table 9.1), and varied by depth stratum with the inner shelf, mid-shelf, outer shelf and upper slope sites having average BRI values of 20, 13, 10 and 18, respectively (Figure 9.2F). BRI values were not calculated for the three deepest upper slope stations >324 m because their depths are out of acceptable range for BRI calculations. Overall, 90% of the sites where the BRI was calculated had values indicative of reference conditions. However, stations 8121, 8137, 8126, and 8170 located north of the South Bay Ocean Outfall (SBOO) had BRI values between 27–34, which suggests a marginal deviation from reference conditions. BRI values varied from 2009 to 2011 depending on depth stratum. For example, mean BRI values at the inner and mid-shelf sites were higher in 2011 than those sampled in 2009, while outer shelf and upper slope values were lower (Figure 9.2F).

Table 9.2

The percent composition of species and abundance by major taxonomic group (phylum) for regional stations sampled during 2011. Data are expressed as means (range) for all stations combined; $n=41$.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	45 (30–78)	60 (15–83)
Arthropoda (Crustacea)	24 (2–45)	14 (1–65)
Mollusca	17 (4–36)	10 (1–68)
Echinodermata	5 (1–15)	11 (1–33)
Other Phyla	9 (2–22)	5 (1–14)

Dominant Taxa

As in previous years, annelid worms (mostly polychaetes) were the largest contributors to macrofaunal diversity in the San Diego region during 2011 (Table 9.2), and accounted for 45% of all species collected. Arthropods (mostly crustaceans, but also including pycnogonids) and molluscs were the next two most diverse phyla, accounting for 24% and 17% of species, respectively. Echinoderms accounted for 5% of all taxa, while all other phyla combined (e.g., Chordata, Cnidaria, Nematoda, Nemertea, Phoronida, Platyhelminthes, Sipuncula) accounted for the remaining 9%. Patterns apparent in the proportions of major taxa across shelf strata include: (1) the contribution of polychaetes to overall macroinvertebrate species richness increased from 46% along the inner shelf to 56% along the outer shelf, (2) the percentage of echinoderms increased slightly as depth increased, and (3) the proportions of crustaceans and the other phyla typically decreased with depth (Figure 9.3A). The greatest difference in invertebrate assemblages occurred between the continental shelf and upper slope where the percentage of molluscs increased sharply and the proportion of arthropods decreased.

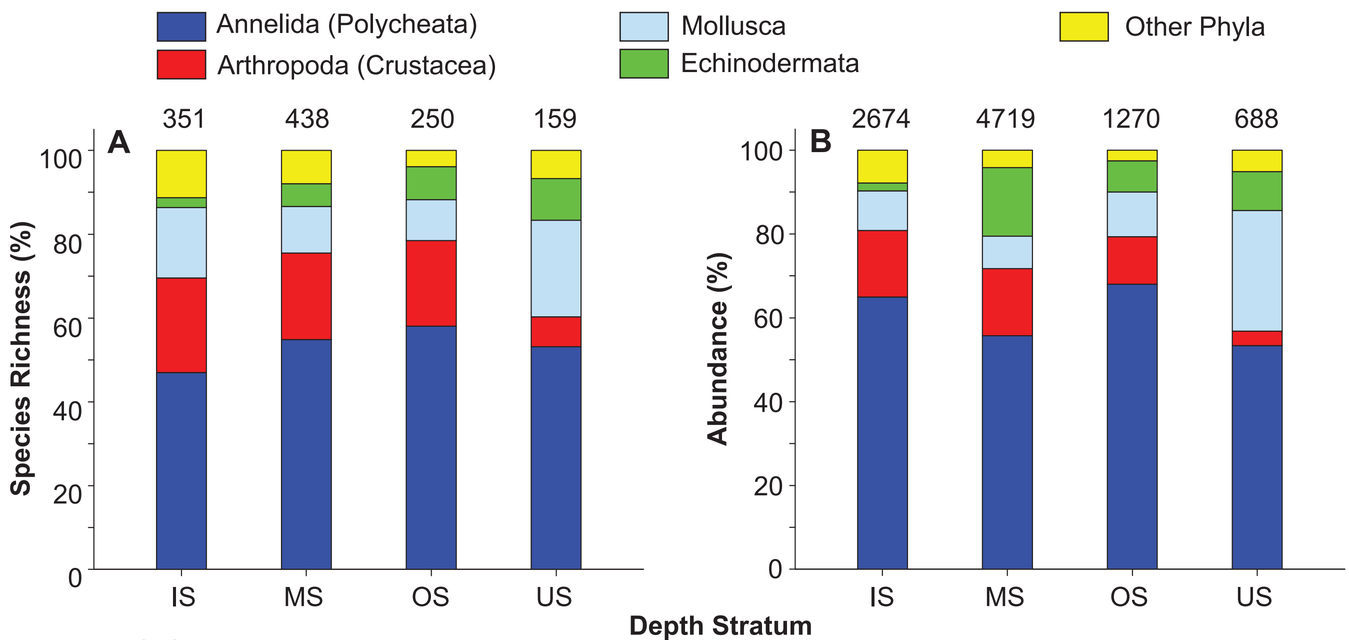


Figure 9.3
Comparison of percent composition of species and abundance by major phylum for each depth stratum sampled during 2011. IS = inner shelf (*n* = 14); MS = mid-shelf (*n* = 14); OS = outer shelf (*n* = 7); US = upper slope (*n* = 6). Numbers above bars represent total number of individual organisms enumerated for each stratum.

The proportion of echinoderms remained about the same between upper slope and outer shelf sites.

Polychaetes were also the most numerous invertebrates collected during 2011, accounting for 60% of the total abundance (Table 9.2). Crustaceans accounted for 14% of the animals, molluscs 10%, echinoderms 11%, and the remaining phyla 5%. Abundance patterns varied among strata (Figure 9.3B) with the proportion of polychaetes being lower at upper slope and mid-shelf stations (i.e., 53% and 56%, respectively) than along either the inner shelf or outer shelf (i.e., 65% and 68%, respectively). The lower proportional abundance of polychaetes along mid- shelf and upper slope sites corresponded to considerably higher numbers of echinoderms (i.e., 16%) and molluscs (i.e., 29%) at these depths, respectively.

The dominant species encountered in 2011 varied among strata (Table 9.3). Along the inner shelf, the 10 most abundant species were all polychaetes. Of these, the cirratulid *Monticellina siblina* was dominant averaging about 10 individuals per 0.1-m^2 grab. All other species averaged <8 animals/grab. The top 10 dominant species along the mid-shelf included three ophiuroids (brittle stars) and seven polychaetes. The brittle star *Amphiodia urtica* was the most common species, averaging about 40 animals per grab and occurring at 71% of the sites. The capitellid polychaete *Mediomastus* was the next most abundant taxon, averaging about 9 animals per grab. All other species averaged <9 animals/grab. On the outer shelf, the top 10 species included eight polychaetes and two bivalves. Individuals in the cirratulid polychaete *Aphelochaeta glandaria* Cmplx were most abundant, averaging 13 animals per grab, while none of the other dominant outer shelf species exceeded mean densities of 8 animals per grab. The 10 most abundant taxa along the upper slope included five polychaetes, two bivalves, a scaphopod, and one ophiuroid. The maldanid polychaete *Maldane sarsi* was the most abundant upper slope species with an average of 11 animals/grab, while the second most abundant species was the polychaete *Fauveliopsis glabra*, which averaged 10 animals/grab.

Regional Macrobenthic Assemblages (2009–2011)

Effect of depth, sediment type and year

PERMANOVA results revealed that benthic invertebrate communities across the San Diego

Table 9.3

The 10 most abundant macroinvertebrates per depth strata collected at regional benthic stations sampled during 2011. AS = abundance/survey; PO = percent occurrence (percent of total annual sites at which the species was collected); AO = abundance/occurrence. Abundance values are expressed as mean number of individuals per 0.1-m^2 grab sample.

Strata	Species	Taxonomic Classification	AS	PO	AO
Inner Shelf	*Monticellina siblina*	Polychaeta: Cirratulidae	10.0	43	23.3
	Pareurythoe californica	Polychaeta: Amphinomidae	7.9	7	110.0
	Polycirrus sp	Polychaeta: Terebellidae	6.6	7	92.0
	Mediomastus sp	Polychaeta: Capitellidae	6.1	71	8.6
	Spiophanes norrisi	Polychaeta: Spionidae	5.9	64	9.1
	Mooreonuphis nebulosa	Polychaeta: Onuphidae	5.7	14	40.0
	Lumbrineris latreilli	Polychaeta: Lumbrineridae	4.4	7	62.0
	Pisione sp	Polychaeta: Pisionidae	4.4	7	61.0
	Apoprionospio pygmaea	Polychaeta: Spionidae	3.5	29	12.2
	Scoletoma tetraura Cmplx	Polychaeta: Lumbrineridae	3.4	29	12.0
Mid-shelf	*Amphiodia urtica*	Echinodermata: Ophiuroidea	40.0	71	56.0
	Mediomastus sp	Polychaeta: Capitellidae	9.0	86	10.5
	Mooreonuphis sp	Polychaeta: Onuphidae	8.4	14	59.0
	Prionospio (*Prionospio*) *jubata*	Polychaeta: Spionidae	8.2	100	8.2
	Spiophanes norrisi	Polychaeta: Spionidae	7.9	57	13.9
	Mooreonuphis sp SD1	Polychaeta: Onuphidae	5.5	14	38.5
	Amphiodia sp	Echinodermata: Ophiuroidea	5.1	79	6.5
	Amphiuridae	Echinodermata: Ophiuroidea	4.8	79	6.1
	Monticellina siblina	Polychaeta: Cirratulidae	4.8	43	11.2
	Prionospio (*Prionospio*) *dubia*	Polychaeta: Spionidae	4.7	86	5.5
Outer Shelf	*Aphelochaeta glandaria* Cmplx	Polychaeta: Cirratulidae	12.7	71	17.8
	Chaetozone sp SD5	Polychaeta: Cirratulidae	8.1	43	19.0
	Spiophanes kimballi	Polychaeta: Spionidae	7.4	57	13.0
	Chloeia pinnata	Polychaeta: Amphinomidae	7.1	57	12.5
	Prionospio (*Prionospio*) *jubata*	Polychaeta: Spionidae	6.7	86	7.8
	Paraprionospio alata	Polychaeta: Spionidae	5.9	86	6.8
	Tellina carpenteri	Mollusca: Bivalvia	5.4	100	5.4
	Huxleyia munita	Mollusca: Bivalvia	4.0	57	7.0
	Lysippe sp A	Polychaeta: Ampharetidae	3.6	86	4.2
	Exogone lourei	Polychaeta: Syllidae	3.4	57	6.0
Upper Slope	*Maldane sarsi*	Polychaeta: Maldanidae	11.3	83	13.6
	Fauveliopsis glabra	Polychaeta: Fauveliopsidae	9.8	33	29.5
	Yoldiella nana	Mollusca: Bivalvia	5.5	33	16.5
	Amphiuridae	Echinodermata: Ophiuroidea	4.3	67	6.5
	Macoma carlottensis	Mollusca: Bivalvia	4.2	67	6.2
	Compressidens stearnsii	Mollusca: Scaphopoda	3.7	83	4.4
	Paraprionospio alata	Polychaeta: Spionidae	3.0	67	4.5
	Spiophanes kimballi	Polychaeta: Spionidae	2.8	50	5.7
	Mediomastus sp	Polychaeta: Capitellidae	2.7	67	4.0
	Ennucula tenuis	Mollusca: Bivalvia	2.5	50	5.0

region differed significantly by depth stratum, sediment type and year (Appendix H.1). These differences were due to minor variations in abundance of many species, with no single species accounting for more than 3% of the observed variation. Results also revealed select species as being representative of specific habitat types (Table 9.4). For instance, the oweniid polychaete *Owenia collaris* only occurred at inner shelf depths, polychaetes in the *Aphelochaeta glandaria* Cmplx appeared to occur and dominate only at outer shelf sites, and the bivalve *Macoma carlottensis* only inhabited the deepest upper slope sites. Other taxa exhibited broader habitat ranges, with species such as the spionid *Spiophanes kimballi* and the bivalve *Tellina carpenteri* occurring in more than one stratum. Limited sampling in environments characterized by fine sediments with a substantial coarse constituent (one mid-shelf site), sand mixed with both fine and coarse sediments (one inner shelf site), and coarse sediments mixed with sand (one inner shelf and one mid-shelf site) hindered a complete understanding of how sediment types may influence species distributions (see Table 9.4). Despite this constraint, it is suggestive that organisms such as the brittle star *Amphiodia urtica*, the bivalve *Axinopsida serricata*, and the spionid *Spiophanes berkeleyorum* dominated only mid-shelf habitats typically characterized by fine sediments mixed with sand; these species were less common or completely lacking in habitats with coarser sediments. Similarly, many species found in coarse sediments that were mixed with sand were restricted to this sediment type, and were not commonly found in finer sediments (e.g., *Spiophanes norrisi*).

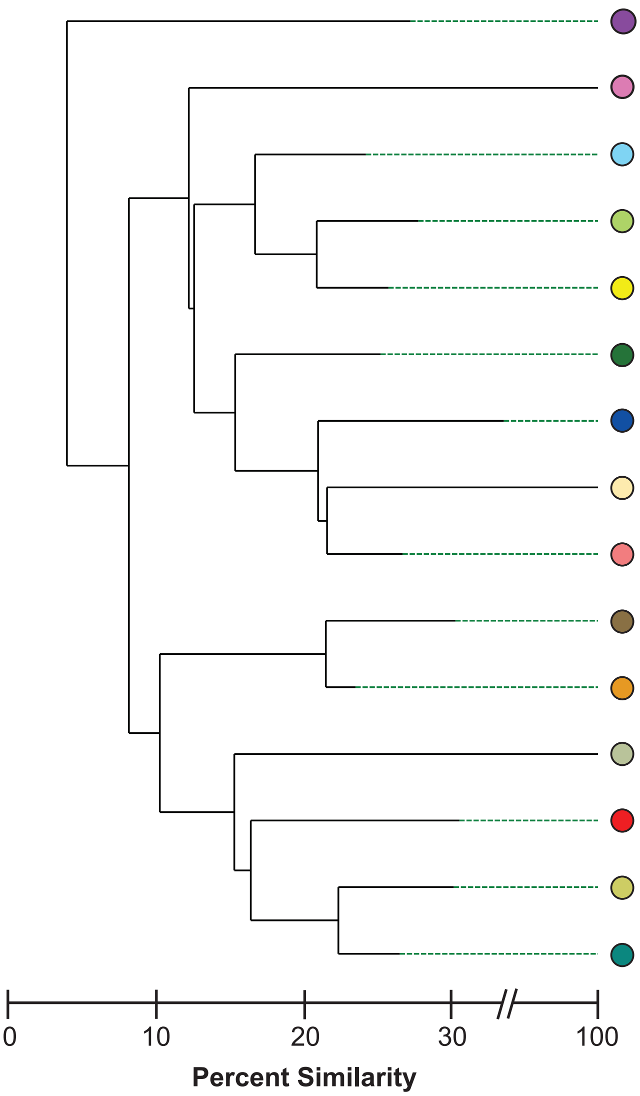
Discrimination of cluster groups

Classification (cluster) analysis discriminated 15 ecologically-relevant SIMPROF-supported groups (Figures 9.4, 9.5, Appendix H.2). These "assemblages," referred to herein as cluster groups A through O contained between 1–40 samples (sites) each. Species richness averaged 27–135 taxa per grab and abundances averaged 78–650 individuals per grab for the different groups (Table 9.5).

The 15 cluster groups formed three distinct main clusters defined primarily by depth (Figures 9.4, 9.5). These included: (1) Cluster group A, that represented a small cluster of inner shelf sites that shared about a 4% similarity with the other two main clusters; (2) Groups B–I represented a large "megacluster," that contained most sites located at inner to mid-shelf depths between 9–58 m; and (3) Groups J–O represented a second megacluster comprising primarily sites located at depths >50 m (Figures 9.4, 9.5). The two latter megaclusters shared only about an 8% similarity with each other. As indicated previously by the PERMANOVA and SIMPER results, depth and sediment type were the primary factors responsible for driving individual cluster group formation within the megaclusters (Figure 9.4, Table 9.5, Appendices H.1 and H.2). The ecological relevance of each of the cluster groups is described below in terms of whether they represent inner shelf, mid-shelf, outer shelf, upper slope or between-strata transitional assemblages.

<u>Inner shelf assemblages</u>

Cluster group A comprised two sites located along the 25-m isobath north of Point Loma that were distinct from the other 119 sites sampled (Figures 9.4, 9.5, Appendix H.2). In this cluster, a high fraction of coarse sediments containing substantial shell hash supported a faunal community characterized by large populations of nematodes, the polychaetes *Pareurythoe californica*, *Pisione* sp, *Polycirrus* sp, *Lumbrineris latreilli*, *Hesionura coineaui difficilis* and *Protodorvillea gracilis*, and the isopod *Eurydice caudata* (Table 9.5). The remaining inner shelf assemblages were represented by cluster groups B and F–I, which occurred at depths between 9–20 m. Within these groups, cluster group B comprised a single site (station 8103) with coarse sand sediments located at the head of the La Jolla Canyon. Group B was unique in possessing the only recorded individuals of the gastropod *Balcis oldroydae*, the bivalve *Tivela stultorum*, the polychaete *Paraonella platybranchia*, and the sea pen *Stylatula elongata* (Appendix H.3). Groups F and G together contained nine sandy, shallow water sites located close to the mouths of the San Diego River and San Diego Bay that lacked almost any fine sediments. The group F and G



Cluster Group	*n*	SR	Abun	Description
A	2	63	564	Inner shelf
B	1	33	105	Inner shelf
C	6	74	314	Inner to mid-shelf transition zone
D	14	90	356	Inner to mid-shelf transition zone
E	3	135	650	Inner to mid-shelf transition zone
F	5	28	147	Inner shelf
G	4	48	422	Inner shelf
H	1	39	92	Inner shelf
I	9	41	133	Inner shelf
J	6	35	97	Upper slope
K	6	27	78	Upper slope
L	1	72	247	Upper slope
M	11	66	220	Mid-shelf to outer shelf
N	40	86	306	Mid-shelf to outer shelf
O	13	55	144	Mid-shelf to outer shelf

Figure 9.4
Cluster analysis of macrofaunal assemblages at regional benthic stations sampled between 2009–2011. Data for species richness (SR) and infaunal abundance (Abund) are expressed as mean values per 0.1-m^2 over all stations in each group (*n*).

assemblages possessed 14 and 9 taxa, respectively, that were unique compared to any other cluster group (Appendix H.3) and that might include species tolerant of nearshore high energy environments. The group H and I assemblages occurred at a total of 10 inner shelf sites in the regular SBOO monitoring region that had sediments dominated by sand mixed with a substantial percentage of fines. Group H represented the assemblage from a single site (station 8135) that was the only location where the gastropod *Astyris gausapata*, the mysids *Exacanthomysis davisi* and *Mysidopsis intii*, and the polychaete *Cirriformia* sp B were recorded.

Inner to mid-shelf transition zone assemblages

Cluster groups C, D and E spanned inner to mid-shelf locations at 21–58 m depths. Group C was a sister group to the clade containing groups D and E (Figure 9.4). Although all three clusters occurred in the South Bay outfall region, sites in cluster group C tended to have coarser sediments and be located in deeper water than those in groups D and E

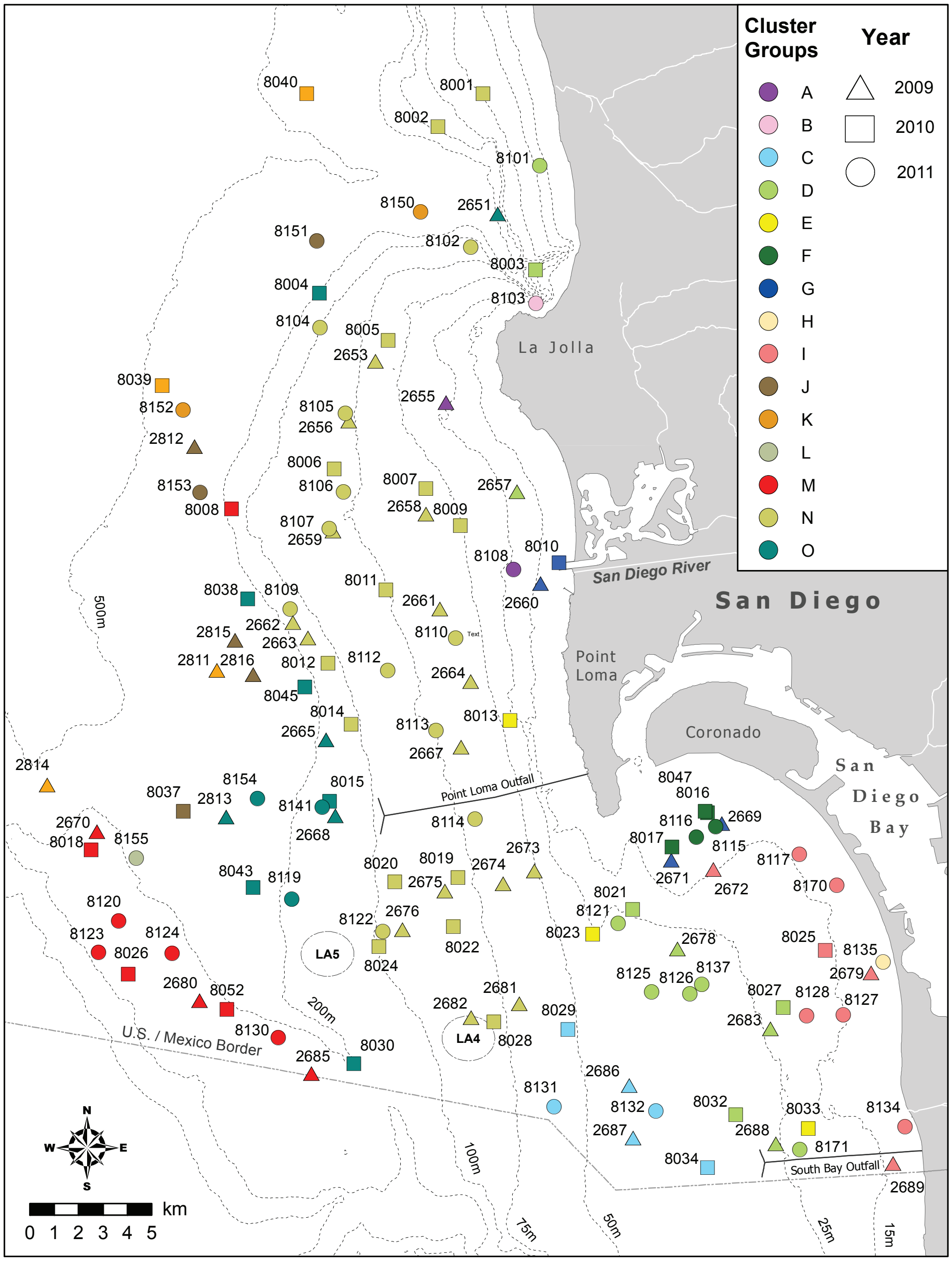


Figure 9.5

Spatial distribution of cluster groups in the San Diego region. Colors of each circle correspond to colors in Figure 9.4.

(Appendix H.3). Several taxa were unique to cluster group C, including the tunicate *Agnezia septentrionalis*, the amphipod *Laticorophium baconi*, and the polychaetes *Polycirrus* sp I, *Aphelochaeta* sp SD5, *Poecilochaetus* sp and *Aricidea* (*Allia*) sp SD1. The cluster groups D and E typically occurred at sites located on the broad, gently sloping inner to mid-shelf area mostly north to northwest of the SBOO. Eighteen taxa were restricted entirely to these two cluster groups, including the polychaetes *Paradoneis* sp SD1, *Streblosoma* sp SF1, the hydrozoan *Euphysa* sp A, and the bivalve *Rochefortia grippi*.

<u>Mid-shelf to outer shelf assemblages</u>

On the mid- to outer continental shelf, macrofaunal communities were most similar between cluster

Table 9.4

Most abundant taxa from each sediment type/depth stratum combination sampled between 2009–2011. Values correspond to average number of individuals of each taxon per 0.1-m^2 grab sample.

	Inner Shelf		Mid-shelf	
Fines with coarse	*n* = 0		*n* = 1	
			Spiophanes kimballi	22.0
			Paraprionospio alata	9.0
			Melinna heterodonta	8.0
			Glycera nana	7.0
			Pectinaria californiensis	5.0
Fines with sand	*n* = 0		*n* = 13	
			Amphiodia urtica	68.9
			Axinopsida serricata	9.8
			Proclea sp A	6.7
			Travisia brevis	5.5
			Amphiodia sp	5.2
			Spiophanes berkeleyorum	5.2
Sand with fines	*n* = 11		*n* = 25	
	Spiophanes norrisi	16.5	*Amphiodia urtica*	48.9
	Mooreonuphis nebulosa	13.8	*Axinopsida serricata*	14.0
	Owenia collaris	10.7	*Spiophanes norrisi*	11.5
	Monticellina siblina	9.3	*Mediomastus* sp	7.3
	Mediomastus sp	7.7	*Spiophanes berkeleyorum*	6.9
	Spiophanes duplex	5.9	*Amphiodia* sp	6.5
Sand with coarse and fines	*n* = 1		*n* = 0	
	Spiophanes norrisi	137.0		
	Apoprionospio pygmaea	129.0		
	Ampharete labrops	18.0		
	Mediomastus sp	17.0		
	Nematoda	16.0		
	Spiophanes duplex	15.0		
	Typosyllis hyperioni	15.0		
Sand	*n* = 18		*n* = 3	
	Owenia collaris	41.1	*Spiophanes norrisi*	29.7
	Spiophanes norrisi	25.1	*Spio maculata*	12.3
	Monticellina siblina	10.1	*Polycirrus* sp A	11.7
	Gibberosus myersi	8.3	*Amphiodia urtica*	11.3
	Zaolutus actius	7.3	*Eurydice caudata*	4.3
	Apoprionospio pygmaea	6.3	*Mediomastus* sp	3.7
Sand with coarse	*n* = 3		*n* = 5	
	Spiophanes norrisi	56.7	*Spiophanes norrisi*	83.4
	Apoprionospio pygmaea	43.3	*Mooreonuphis* sp	14.8
	Lumbrinerides platypygos	14.0	*Mooreonuphis* sp SD1	14.8
	Nematoda	13.0	*Lysippe* sp A	8.8
	Protodorvillea gracilis	7.0	Amphiuridae	8.2
	Ophelia pulchella	2.3	*Ophiuroconis bispinosa*	7.6
Coarse with sand	*n* = 1		*n* = 1	
	Pareurythoe californica	110.0	*Spiophanes norrisi*	68.0
	Polycirrus sp	92.0	*Chaetozone* sp SD5	50.0
	Lumbrineris latreilli	62.0	*Lumbrineris latreilli*	31.0
	Pisione sp	61.0	*Typosyllis heterochaeta*	29.0
	Polycirrus californicus	48.0	*Micropodarke dubia*	27.0
	Polycirrus sp SD3	42.0	*Lumbrineris ligulata*	24.0
	Rhabdocoela sp A	42.0		

Table 9.4 *continued*

	Outer Shelf		Upper Slope	
Fines with coarse	*n* = 0		*n* = 0	
Fines with sand	*n* = 5		*n* = 15	
	Axinopsida serricata	15.6	*Maldane sarsi*	9.2
	Spiophanes kimballi	10.0	*Yoldiella nana*	4.9
	Tellina carpenteri	7.4	*Macoma carlottensis*	4.9
	Mediomastus sp	6.0	*Nuculana conceptionis*	4.7
	Parvilucina tenuisculpta	4.6	*Spiophanes kimballi*	3.3
	Paradiopatra parva	4.6	*Eclysippe trilobata*	2.5
Sand with fines	*n* = 14		*n* = 2	
	Aphelochaeta glandaria Cmplx	18.9	*Fauveliopsis glabra*	29.0
	Chaetozone sp SD5	10.4	*Maldane sarsi*	9.5
	Monticellina siblina	8.1	*Tellina carpenteri*	5.0
	Tellina carpenteri	7.6	*Mediomastus* sp	4.0
	Amphiodia digitata	5.6	*Phyllochaetopterus limicolus*	2.5
	Micranellum crebricinctum	5.4	Lineidae	2.0
Sand with coarse and fines	*n* = 0		*n* = 0	
Sand	*n* = 0		*n* = 2	
			Macoma carlottensis	11.5
			Maldane sarsi	8.0
			Paraprionospio alata	4.0
			Mediomastus sp	3.5
			Compressidens stearnsii	3.0
			Lumbrineris cruzensis	3.0
Sand with coarse	*n* = 2		*n* = 0	
	Aphelochaeta glandaria Cmplx	19.0		
	Tellina carpenteri	15.5		
	Huxleyia munita	7.0		
	Exogone lourei	7.0		
	Chaetozone sp	6.5		
	Ampelisca careyi	6.0		
Coarse with sand	*n* = 0		*n* = 0	

Table 9.5

Mean abundance of the most common species found in cluster groups A−O (defined in Figure 9.4). Bold values indicate taxa that were considered among the most characteristic of that group according to SIMPER analysis.

	Cluster Group														
Taxa	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**
Pareurythoe californica	55.0														
Pisione sp	**49.5**		0.5		0.3										
Polycirrus sp	46.0		1.3	0.4	0.7						0.2	1.0	0.2	0.5	0.3
Lumbrineris latreilli	31.0		2.2		10.7									0.3	0.3
Spio maculata	30.5		12.0											0.1	
Spiophanes norrisi	2.5	31.0	**54.2**	**50.0**	**144.0**	**4.0**	**18.0**	1.0	8.8		0.3		0.2	0.4	
Dendraster excentricus		16.0				1.0									
Aphelochaeta glandaria Cmplx		7.0		0.2					0.1			3.0	**24.1**	1.9	2.5
Aphelochaeta sp SD13		4.0									0.2		0.5	0.1	
Chaetozone commonalis		4.0												0.1	1.2
Mooreonuphis sp	2.0		**27.3**										3.4	0.0	0.1
Mooreonuphis sp SD1	2.5		**24.2**										0.1		
Lanassa venusta venusta			12.0		0.3								0.4	0.2	0.6
Monticellina siblina		2.0	0.5	**26.6**	0.7	0.2			0.4	0.2			7.9	1.6	0.3
Mooreonuphis nebulosa				16.6	2.3									0.4	
Mediomastus sp	2.5		0.3	**12.4**	**14.0**	0.4	0.8	1.0	**6.7**	1.7	0.7	5.0	3.7	5.2	**5.2**
Spiophanes duplex			1.3	9.7	6.0		1.0		**7.2**	0.3			0.1	2.2	0.2
Apoprionospio pygmaea		1.0		1.8	43.3	**10.4**	9.3		0.8					0.1	
Chaetozone sp SD5			0.3	1.0	18.3		0.8		1.0				**13.9**	0.1	0.1
Apionsoma misakianum	10.0		0.3		16.0							1.0	0.1		
Gibberosus myersi			0.3	0.2	1.7	**20.8**	9.0	2.0	0.8						
Actiniaria	0.5			0.3	1.3	16.8	0.5				0.2			0.1	
Metharpinia jonesi						**14.8**	1.3								
Anchicolurus occidentalis						**11.6**	3.5								
Owenia collaris							**184.5**		13.3					0.1	
Zaolutus actius							**32.5**								

Table 9.5 *continued*

Taxa	Cluster Group														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Diastylopsis tenuis				0.2		1.8	15.0	2.0	3.1						
Rhepoxynius abronius				0.4		1.4	11.8		0.4						
Scoletoma tetraura Cmplx				0.2		0.4	9.3	18.0	4.2	0.5	0.3			0.9	1.9
Ampharete labrops			0.3	1.3	**9.0**			11.0	2.9					0.1	
Astyris gausapata								5.0							
Exacanthomysis davisi								4.0							
Rictaxis punctocaelatus								4.0							
Polydora cirrosa				0.1			1.0	1.0	7.7						
Macoma carlottensis										**13.5**	0.8			0.0	1.5
Maldane sarsi				0.2						**13.3**	9.3	13.0		1.8	3.2
Nuculana conceptionis										5.5	7.0				
Compressidens stearnsii										**4.5**	0.8	8.0	0.4	0.2	0.9
Maldanidae			1.3	1.6	0.7				0.1	4.5	0.2		0.2	1.5	0.6
Yoldiella nana											12.2				
Eclysippe trilobata											7.5		0.7	0.7	0.2
Myriochele gracilis											3.3		0.2	0.7	0.6
Fauveliopsis glabra										0.3	2.7	55.0		<0.5	
Amphiuridae		1.0	4.3	1.1	2.7		0.5	1.0	0.2	1.0	1.0	21.0	1.5	3.4	0.4
Adontorhina cyclia										0.7		10.0	0.6	2.9	2.8
Nephasoma diaphanes					0.3						0.4	10.0	0.1	0.4	
Tellina carpenteri										0.2	0.3	8.0	**8.7**	1.3	**6.8**
Micranellum crebricinctum	1.0		0.2		0.7								7.5		
Amphiodia urtica			0.2	1.1	0.7									**56.1**	1.1
Axinopsida serricata										0.2			1.5	**13.1**	7.2
Amphiodia sp			0.2	0.6	0.7	0.6		2.0	0.2				1.7	**6.0**	0.3
Spiophanes berkeleyorum			0.8	5.1	1.3				0.2	0.7			0.2	5.5	0.9
Spiophanes kimballi										2.8			1.0	1.9	**8.8**
Melinna heterodonta										0.7			0.2		**3.5**

groups N and O, which shared 22.4% similarity and 21 taxa not occurring in any other cluster groups (Figure 9.4, Appendix H.3). Together, these two groups encompassed about 44% of the samples collected between 2009−2011 and contained the vast majority of sites characterized by fine sediments mixed with sand (Figure 9.5). Cluster group N comprised primarily mid-shelf sites that correspond to the well-characterized "*Amphiodia urtica* zone" described previously by Thompson et al. (1993), whereas cluster group O consisted mostly of sites on the outer shelf. Cluster group M possessed all outer shelf sites located on the Coronado Bank plus one additional outer shelf site located north of sites contained in group O. Although all three of the mid- to outer shelf groups (M−O) possessed fine sediments mixed with sand, the percent fines in cluster group M was lower than in groups N and O. The group M assemblage also contained 34 unique taxa that were not encountered in any of the other cluster groups (Appendix H.3).

<u>Upper slope assemblages</u>

Although occurring on the upper slope, the cluster group L assemblage was more closely related to outer shelf groups M through O than to the other slope sites in cluster groups J and K. Group L represented the assemblage from a single site (station 8155) located off the northeast corner of the Coronado Bank at a depth of 312 m (Figure 9.5, Appendix H.2). This station was the only location recorded for several taxa, including the scaphopod *Cadulus californicus*, the pycnogonid *Anoplodactylus* sp, the sipunculid *Apionsoma* sp, and the cirratulid polychaete *Dodecaceria* sp (Appendix H.3). Macrofaunal communities from the six upper slope sites in each of cluster groups J and K supported populations of the bivalve *Nuculana conceptions*, an organism not present in any other cluster groups (Figure 9.4, Appendix H.3). Depths for cluster groups J and K ranged between 286−357 m and 393−433 m, respectively, with sediments for both groups containing the highest percent fines (71–72%) recorded during the 2009−2011 surveys.

Discussion

The SCB benthos has long been considered to be composed of "patchy" habitats, with the distribution of species and communities exhibiting considerable spatial variability. Results of regional surveys off San Diego support this characterization. Benthic assemblages surveyed between 2009–2011 varied between years and segregated by habitat characteristics such as depth and sediment grain size, and were similar to macrofaunal assemblages observed during regional surveys conducted between 1994−2003 (City of San Diego 2007). No unique infaunal assemblages occurred near either the Point Loma or South Bay Ocean Outfalls, suggesting that the presence of these outfalls has not affected invertebrate community population dynamics.

Many inner to mid-shelf (10–40 m depths) macrofaunal assemblages off San Diego were similar to those found in shallow, sandy habitats across the SCB (Barnard 1963, Jones 1969, Thompson et al. 1987, 1992, ES Engineering Science 1988, Mikel et al. 2007). These assemblages were characterized by sandy sediments that shared populations of polychaetes such as *Owenia collaris*, *Spiophanes norrisi*, and the bivalve *Tellina modesta* (e.g., cluster groups D, E, G, I). However, each cluster group had species that clearly differentiated it from other clusters, with organismal differences likely caused by either sediment or oceanographic characteristics.

The largest number of sites sampled off San Diego between 2009–2011 occurred in mid- to outer shelf areas (30–200 m depths), and were characterized by sandy sediments with a large percentage of fines. Macrofaunal assemblages in these areas were dominated by the brittle star *Amphiodia urtica.* For example, sites from cluster group N correspond to the *Amphiodia* "mega-community" described by Barnard and Ziesenhenne (1961), and are common in the Point Loma region off San Diego as well as other parts of the southern California mainland shelf (Jones 1969, Fauchald and Jones 1979, Thompson et al. 1987, 1993, Zmarzly et al. 1994, Diener and Fuller 1995, Bergen et al. 1998, 2000, 2001, Mikel et al. 2007, City of San Diego 2011a, b). Deeper outer shelf stations (e.g., the Coronado Bank) were typically devoid of *A. urtica,* and were instead dominated by polychaete worms such as the cirratulids *Aphelochaeta glandaria* Cmplx*, Monticellina siblina* and *Chaetozone* sp SD5 (i.e., cluster group M).

Similar to patterns described in past monitoring reports (City of San Diego 2011b, Ranasinghe et al. 2012), upper slope habitats off San Diego were characterized by a high percentage of fine sediments with associated macrofaunal assemblages that were distinct from most shelf stations surveyed. Macrofaunal assemblages from upper slope stations were often characterized by relatively high abundances of bivalves such as *Yoldiella nana*, *Nuculana conceptionis,* and *Tellina carpenteri*.

Although benthic communities off San Diego vary across depth and sediment gradients, there was no evidence of disturbance during the 2009−2011 regional surveys that could be attributed to wastewater discharges, disposal sites or other point sources. Benthic macrofauna appear to be in good condition throughout the region, with 90% of the sites surveyed from 2009−2011 being in reference condition based on assessments using the BRI. This is not unexpected as Ranasinghe et al. (2012) recently reported that 99.7% of the entire SCB was in good condition based on assessment data gathered during the 2008 bight-wide survey.

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