Chapter 8. San Diego Regional Survey Sediment Conditions

Introduction

Ocean sediments are the primary habitat for macrobenthic invertebrate and demersal fish communities on the coastal shelf and slope. The physical and chemical conditions of these sediments can therefore influence the ecological health of marine communities by affecting the distribution and presence of various species (Gray 1981, Cross and Allen 1993, Snelgrove and Butman 1994). For this reason, sediments have been sampled extensively near Southern California Bight (SCB) ocean outfalls in order to monitor benthic conditions around these and other point sources over the past several decades (Swartz et al. 1986, Anderson and Gossett 1987, Finney and Huh 1989, Stull 1995, Bay and Schiff 1997). 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 (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009).

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 (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009).

This chapter presents analyses and interpretations of the sediment grain size and chemistry data collected during the 2011 regional survey of the continental shelf and upper slope off San Diego. Included are descriptions of the region's sediment conditions during the year, and comparisons of sediment characteristics and quality across the major depth strata defined by the SCB regional programs. Additionally, a multivariate analysis of sediment chemistry 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 macrofaunal community analyses for these same sites are presented in Chapter 9.

Materials and Methods

Field Sampling

The July 2011 regional survey covered an area ranging from Del Mar in northern San Diego County

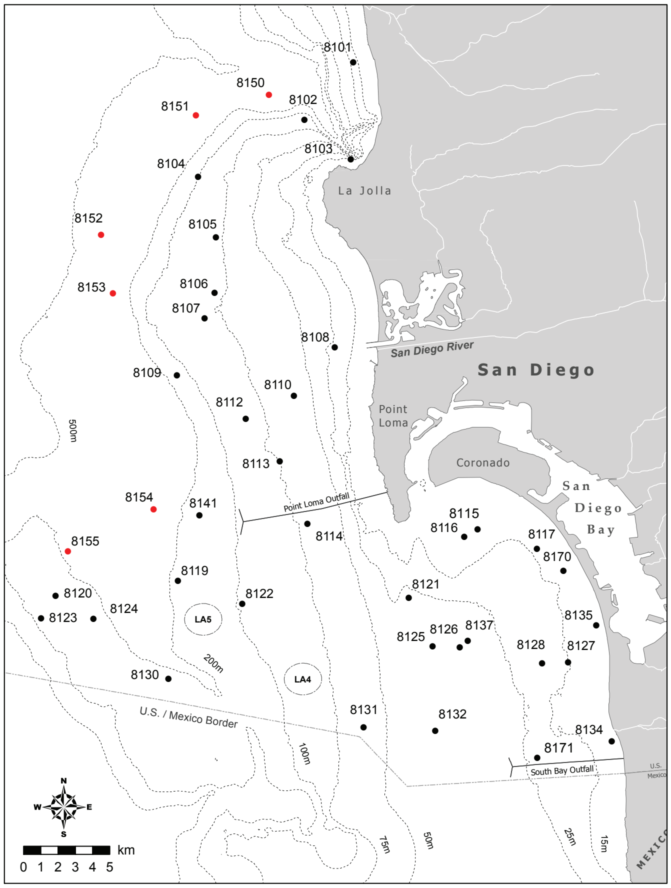

Figure 8.1
Regional benthic survey stations sampled during July 2011 as part of the City of San Diego's Outfall Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

south to the USA/Mexico border (Figure 8.1). Overall, this survey included 41 stations ranging in depth from 10 to 427 m and spanning 4 distinct depth strata as characterized by the SCB regional monitoring programs (Schiff et al. 2006). 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).

Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-m^2 surface area; the other grab sample from the cast was used for macrofaunal community analysis (see Chapter 9) and visual observations of sediment composition. Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to standard guidelines available in USEPA (1987).

Laboratory Analyses

All sediment chemistry and grain size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Grain size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of nested sieves. The Horiba measures particles ranging in size from about 0.5 to 2000 µm. Coarser sediments were removed and quantified prior to laser analysis by screening samples through a 2000 µm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%. When a sample contained substantial amounts of coarse sand, gravel, or shell hash that could damage the Horiba analyzer and/or where the general distribution of sediments would be poorly represented by laser analysis, a set of sieves with mesh sizes of 2000 µm, 1000 µm, 500 µm, 250 µm, 125 µm, and 63 µm was used to divide the samples into seven fractions. Sieve results and output from the Horiba were converted into grain size fractions (e.g., percent sand, silt, clay) based on the Wentworth scale (Appendix C.1). The proportion of fine particles (percent fines) was calculated as the sum of silt and clay fractions for each sample, and each sample was then categorized as a "sediment type" based on relative proportions of percent fines, sand, and coarser particles (Appendix C.2). The distribution of grain sizes within each sample was also summarized as mean particle size in microns, and the median, mean, and standard deviations of phi sizes. The latter values were calculated by converting raw data measured in microns into phi sizes, fitting appropriate distribution curves (e.g., normal probability curve for most Horiba samples), and then determining the descriptive statistics mentioned above.

Each sediment sample was also analyzed to determine concentrations of total organic carbon, total nitrogen, total sulfides, total volatile solids, trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis. Data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix G.1). However, concentrations below MDLs were included as estimated values if presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols is provided by the Wastewater Chemical Services Laboratory (City of San Diego 2012).

Data Analyses

Data summaries for the various sediment parameters measured included detection rates, means of detected values for all stations combined, and minimum, median, and maximum values. In addition, means of detected vales were calculated for each depth stratum. Total DDT (tDDT), PCB (tPCB), and PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix G.2 for individual constituent values). Spearman rank correlation was used to identify any association of percent fines with depth and each chemical parameter. This non-parametric analysis accounts for non-detects in the data (i.e., analyte concentrations <MDL) without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in ranked-based analyses may intensify with increased censoring (Conover 1980). Therefore, a criterion of <50% non-detects was used to screen eligible constituents for this analysis.

Sediment contaminant concentrations were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available. The ERLs represent chemical concentrations below which adverse biological effects are rarely observed, while values above the ERL but below the ERM represent levels at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998).

In order to examine spatial and temporal patterns in overall sediment condition in the San Diego region, a cluster analysis was performed using a 3-year data matrix comprised of the main chemical parameters analyzed for each site (i.e., trace metals, indicators of organic loading, pesticides, total PCBs, total PAHs). This analysis was conducted for all data collected between 2009 and 2011 using PRIMER software (see Clarke and Warwick 2001, Clarke and Gorley 2006). Any non-detects (see above) were first converted to "0" values to avoid data deletion issues with the clustering program, after which the data were normalized and a Euclidean distance matrix was created. Similarity profile (SIMPROF) analyses were used to confirm the non-random structure of the resultant dendrogram (Clarke et al. 2008), and major ecologically-relevant clusters supported by SIMPROF were retained at 5.78% dissimilarity. Similarity percentages (SIMPER) analysis was subsequently used to identify which parameters primarily accounted for observed differences among cluster groups, as well as to identify the parameters typical of each group.

Results

Sediment Grain Size Composition

Ocean sediments were diverse at the benthic stations sampled during the summer 2011 regional survey (Table 8.1). The fine, sand, and coarse sediment fractions ranged between 0–79%, 21–96%, and 0–49%, respectively. Additionally, observations recorded for benthic infauna samples revealed the presence of coarse red relict sands, coarse black sands, gravel, rock, shell hash and/or organic debris at different stations (see Appendix G.3). Overall, sediment composition varied as expected by region and depth stratum (Figure 8.2, Appendices G.3, G.4). For example, sediments from regional sites collected along the inner and middle shelf in the SBOO region tended to be predominantly sand (~84%), whereas those collected along the middle and outer shelf in the PLOO region generally had much finer sediments (~55% fines). Correlation analysis confirmed that percent fines generally increased with depth (Table 8.2, Figure 8.3A), a pattern that has been consistent over the past three years (Figure 8.4A). Notable

Table 8.1

Summary of sediment grain sizes and sediment chemistry concentrations in sediments from regional benthic stations sampled during 2011. Data include detected values averaged by depth stratum, as well as the detection rate (DR), minimum, median, maximum, and mean values for the entire survey area; *n* = number of stations; SD = standard deviation.

	Depth Strata				2011 Survey Area [a]				
	Inner Shelf	**Mid-shelf**	**Outer Shelf**	**Upper Slope**					
	n = 14	*n* = 14	*n* = 7	*n* = 6	**DR (%)**	**Min**	**Median**	**Max**	**Mean**
Sediment Grain Size									
Mean (*μm*)	226	107	176	54	—	38	106	848	151
Mean (*phi*)	2.8	4.2	3.5	5.1	—	0.6	3.8	5.6	3.7
SD (*phi*)	1.0	1.5	1.6	1.7	—	0.9	1.5	2.1	1.4
Coarse (%)	4.4	0.4	2.6	0.0	—	0.0	0.0	48.5	2.1
Sand (%)	84.4	57.3	65.8	32.4	—	20.7	66.2	96.2	64.4
Fines (%)	11.2	42.3	31.6	67.6	—	0.0	30.7	79.3	33.5
Organic Indicators									
Sulfides (*ppm*)	10.7	6.9	9.2	88.0	98	nd	7.7	444.0	20.7
TN (*% weight*)	0.031	0.094	0.086	0.163	100	0.011	0.048	0.268	0.081
TOC (*% weight*)	0.28	0.53	1.66	1.85	100	0.03	0.63	4.71	0.83
TVS (*% weight*)	0.85	2.35	3.36	5.87	100	0.44	2.43	7.15	2.53
Trace Metals (*ppm*)									
Aluminum	3472	7645	5011	13,775	100	791	5430	17,000	6668
Antimony	0.42	0.63	0.48	0.68	63	nd	0.46	0.86	0.58
Arsenic	2.45	4.62	5.51	6.00	100	1.28	4.57	10.50	4.23
Barium	26.8	44.6	33.7	75.4	100	2.4	39.4	97.6	41.1
Beryllium	0.066	0.157	0.189	0.244	100	0.021	0.143	0.308	0.144
Cadmium	0.178	0.171	0.161	0.377	73	nd	0.145	0.610	0.211
Chromium	7.8	16.3	17.4	26.1	100	2.8	13.9	30.4	15.0
Copper	2.88	7.60	8.45	15.20	100	0.21	5.78	20.40	7.25
Iron	5025	11,235	10,573	17,035	100	2070	9310	23,200	9850
Lead	2.51	6.62	5.88	9.36	100	1.09	5.39	12.50	5.49
Manganese	46.9	91.5	62.3	137.2	100	10.4	70.0	201.0	78.0
Mercury	0.015	0.038	0.038	0.061	83	nd	0.021	0.124	0.036
Nickel	2.84	8.23	7.60	14.81	93	nd	5.04	20.40	7.31
Selenium	nd	nd	nd	0.372	12	nd	nd	0.600	0.372
Silver	nd	0.083	nd	0.051	5	nd	nd	0.083	0.067
Thallium	nd	nd	nd	nd	0	—	—	—	—
Tin	0.563	1.426	0.869	1.443	90	nd	0.780	2.020	1.044
Zinc	13.3	28.4	26.5	48.1	100	5.0	25.1	64.0	25.8
Pesticides (*ppt*)									
Total DDT	635	538	572	970	56	nd	380	1500	626
Total PCB (ppt)	nd	3460	4530	nd	5	nd	nd	4530	3995
Total PAH (ppb)	21.2	49.1	473.7	28.6	29	nd	nd	473.7	80.4

nd = not detected

[a] Minimum, median, and maximum values were calculated based on all samples (*n* = 41), whereas means were calculated on detected values only (*n* ≤ 41).

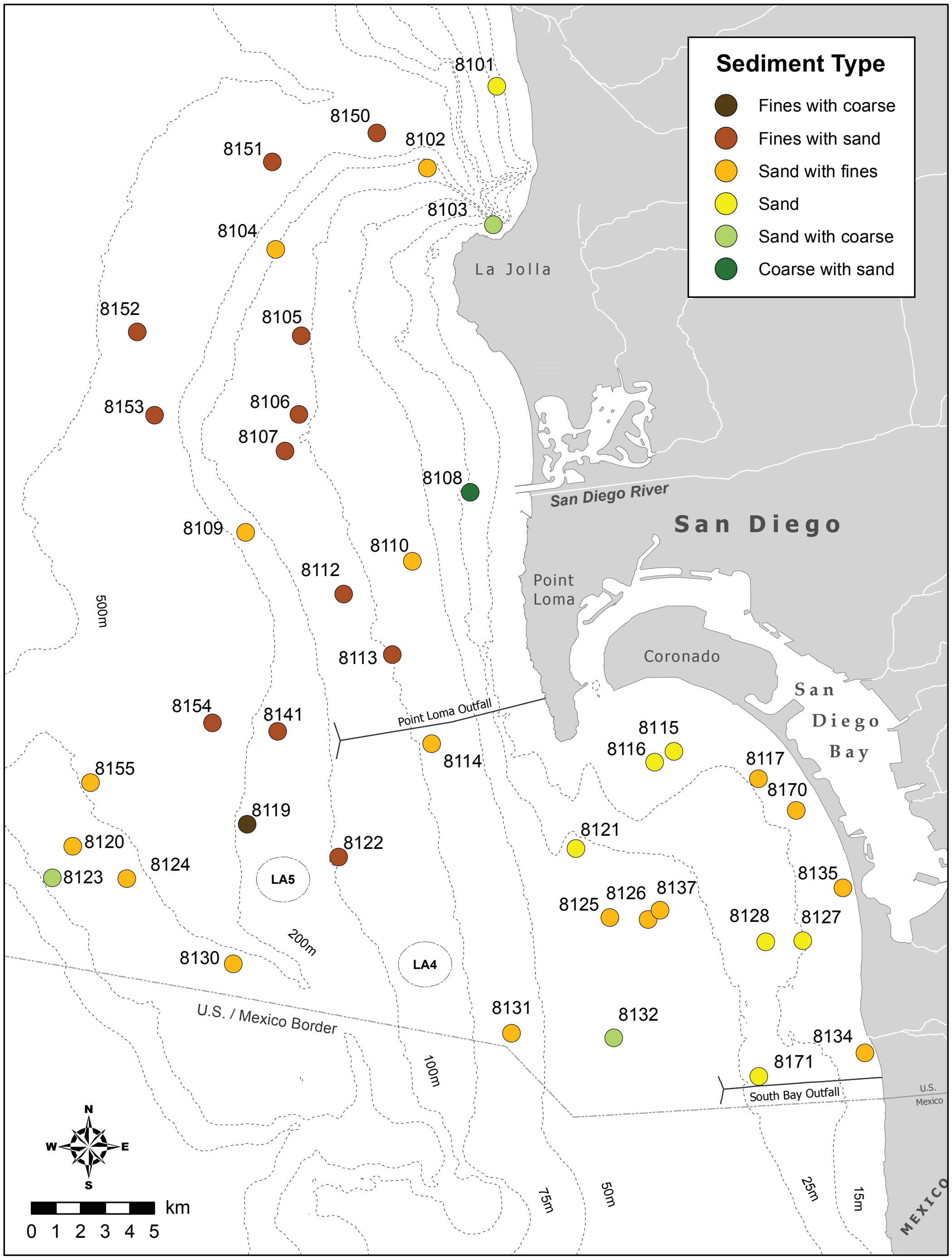

Figure 8.2
Distribution of sediment types at regional benthic stations sampled during July 2011.

exceptions to this pattern included samples from inner shelf station 8170 (located off Coronado beach), which had relatively high percent fines compared to nearby stations (46% versus ≤18.6%), and samples from outer shelf/upper slope stations located on the Coronado Bank (8120, 8123 8124, 8130, 8155), each of which had lower percent fines (≤46%) than other stations at similar depths (Figure 8.2, Appendicies G.3, G.4).

The sorting coefficient is calculated as the standard deviation (SD) in phi size units for each sample,

Table 8.2

Results of Spearman rank correlation analyses of percent fines versus depth and various sediment chemistry parameters from regional benthic samples collected in 2011. Shown are analytes that had correlation coefficients $r_s \geq 0.70$. For all analyses $p < 0.0001$; n = the number of detected values. The strongest correlations with organic indicators and trace metals are illustrated graphically in Figure 8.3.

Analyte	*n*	r_s
Depth	41	0.71
Organic Indicators (% weight)		
Total Nitrogen	41	0.78
Total Volatile Solids	41	0.90
Trace Metals (ppm)		
Aluminum	41	0.93
Antimony	26	0.83
Barium	41	0.87
Beryllium	41	0.87
Chromium	41	0.88
Copper	41	0.94
Iron	41	0.92
Lead	41	0.92
Manganese	41	0.86
Mercury	34	0.87
Nickel	38	0.94
Tin	37	0.85
Zinc	41	0.94

therefore reflecting the range of sediment grain sizes present, and is considered indicative of the level of disturbance (e.g., fluctuating or variable currents and sediment deposition) in an area. Regionally, sediments ranged from moderately to very poorly sorted during 2011, with sorting coefficients ranging from 0.9 to 2.1 phi (Table 8.1, Appendix G.3). The most well sorted sediments (i.e., SD < 1.0 phi) were collected from seven inner shelf stations located throughout the region (8101, 8103, 8115, 8116, 8127, 8128, 8171). The sediments most likely exposed to higher levels of disturbance (i.e., SD ≥ 2.0 phi) occurred at two mid-shelf and one upper slope station (8131, 8122, 8155). These sites were located offshore of the SBOO, inshore of the LA5 dredge spoils dumpsite, and on the Coronado Bank, respectively.

Indicators of Organic Loading

Sulfides were detected in 98% of the 2011 regional sediment samples at concentrations between 0.78–444 ppm with no discernible spatial or depth patterns (Table 8.1, Appendix G.5). Unusually high sulfide values occurred at the upper slope station 8150, located within La Jolla canyon, upper slope station 8153, located offshore of Mission Beach, and inner shelf station 8134, located near the mouth of the Tijuana River. These values (444, 52, 85 ppm, respectively) were at least seven times higher than all other sulfide concentrations reported off San Diego over the past three years (Figure 8.4B), as well as those reported for SBOO or PLOO fixed grid stations in 2011 (see Chapter 4, City of San Diego 2011a).

Total nitrogen (TN), total organic carbon (TOC) and total volatile solids (TVS) were detected in all regional samples and concentrations of these parameters increased across depth strata (Table 8.1). For example, TN averaged 0.031% wt at the inner shelf stations versus 0.163% wt at upper slope stations, while TOC averaged 0.28% wt versus 1.85% wt and TVS averaged 0.85% wt versus 5.87% wt. Additionally, TN and TVS were positively correlated with the percent fines in each sample (Table 8.2, Figure 8.3B) and mirrored changes in percent fines from 2009 to 2011 (Figure 8.4A). In contrast, TOC has been more variable over this 3-year period (Figure 8.4C).

Trace Metals

Ten trace metals were found in all sediment samples collected during the 2011 regional survey, including aluminum, arsenic, barium, beryllium, chromium, copper, iron, lead, manganese, and zinc (Table 8.1). Antimony, cadmium, mercury, nickel, and tin were also detected frequently at rates between 63–93%, while selenium and silver occurred in ≤ 12% of the samples. Thallium was not detected during this survey. Almost all metals were found at low levels below both ERL and ERM thresholds. The only exception

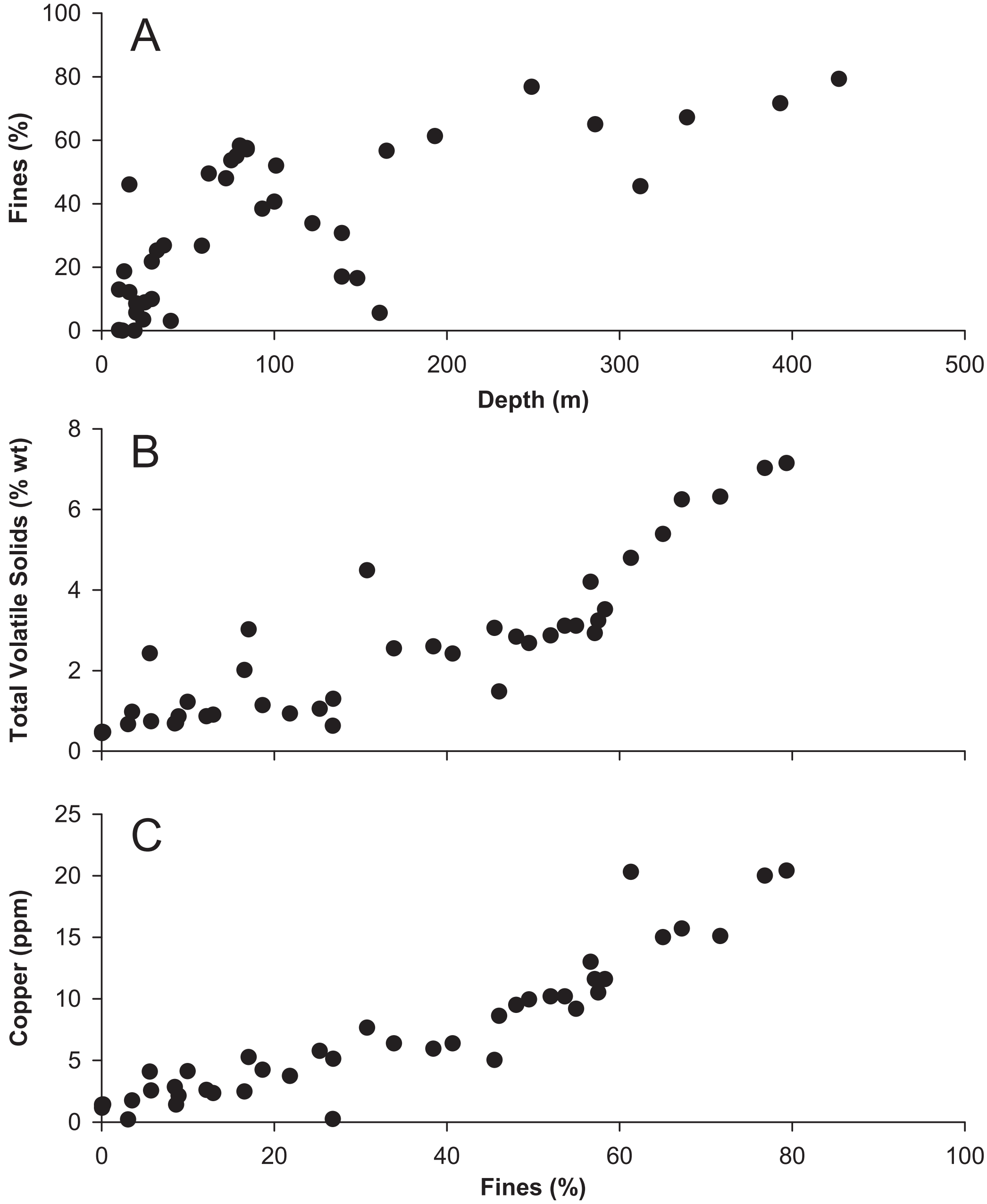

Figure 8.3

Scatterplot of percent fines versus (A) depth, (B) total volatile solids, and (C) copper in sediments from regional benthic stations sampled during 2011.

was arsenic, which exceeded its ERL (but not ERM) at stations 8130 and 8150 (Appendix G.5). Concentrations of aluminum, antimony, barium, beryllium, chromium, copper, iron, lead, manganese, mercury, nickel, tin, zinc were positively correlated with percent fines (Table 8.2, Figure 8.3). Therefore the highest concentrations of these metals tended to occur at the upper slope stations where the greatest proportions of fine material were found (e.g., stations 8150, 8153, 8154; Appendix G.5). These results were somewhat consistent with those reported during 2009 and 2010 (e.g., Figure 8.4A, D, E). Although arsenic and cadmium were not correlated as strongly with percent fines (i.e., $r_s < 0.70$), their concentrations also tended to increase across depth strata (i.e., inner shelf versus upper slope) during 2009, 2010, and 2011 (Table 8.1, Figure 8.4F, G).

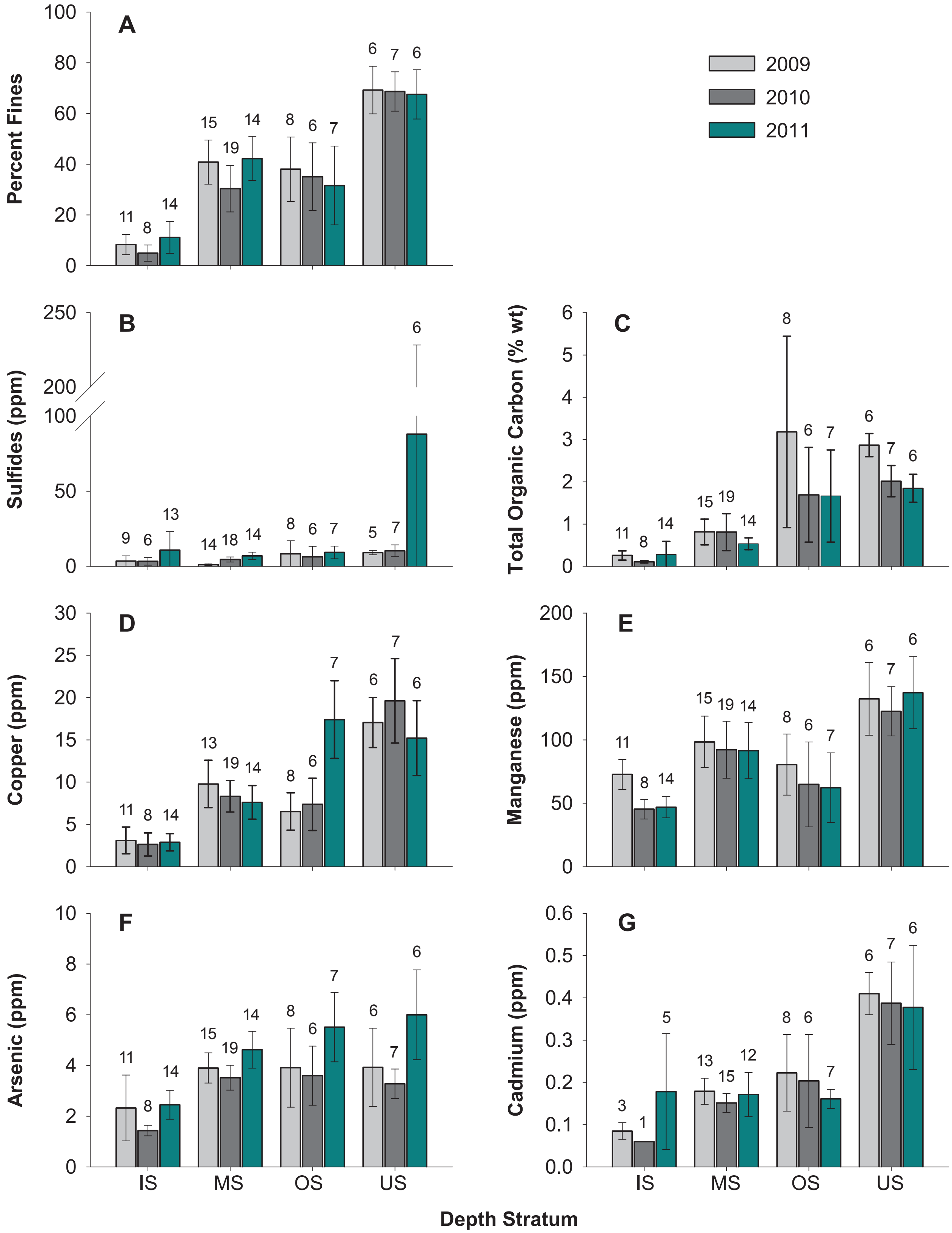

Figure 8.4

Comparison of representative sediment grain size and chemistry parameters in sediments from the four major depth strata sampled during regional surveys between 2009–2011. Data are expressed as means ±95% confidence intervals calculated on detected values only; IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope. Numbers above bars represent number of detected values.

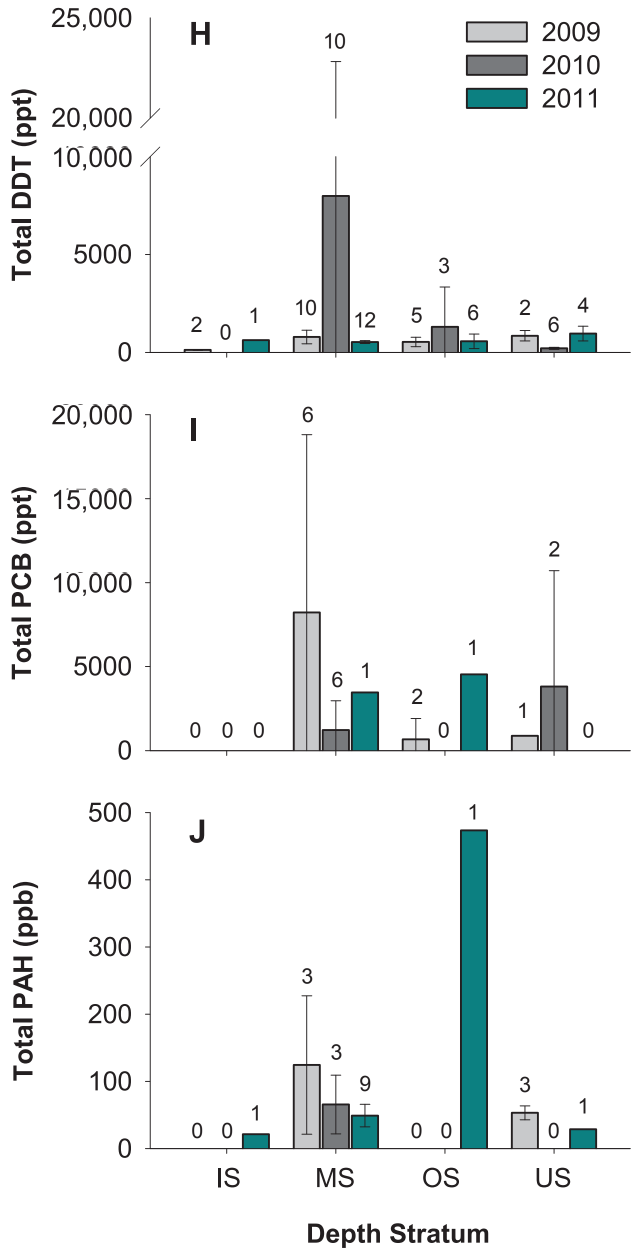

Figure 8.4 *continued*

Pesticides

Total DDT, consisting solely of p,p-DDE, was the only pesticide detected during the 2011 regional survey. It was detected at a rate of 56% at concentrations below threshold values (i.e., <1580 ppt; Table 8.1, Appendix G.5). This pesticide was found at 86% of the middle and outer shelf stations, 67% of the upper slope stations, but only 7% of the inner shelf stations. Concentrations ≥1000 ppt occurred at outer shelf station 8141 and upper slope stations 8151 and 8153. In contrast, tDDT was below 770 ppt at all inner and mid-shelf stations. From 2009 to 2011, DDT levels were variable, with no discernible spatial patterns except low detection rates at inner shelf stations (Figure 8.4H).

PCBs and PAHs

PCBs were detected in sediments from just two regional stations (8126, 8119), at concentrations of 3460 and 4530 ppt, respectively (Table 8.1, Appendix G.5). Total PCB from these samples primarily consisted of congeners PCB 101, PCB 110, PCB 138, and PCB 149 (Appendix G.2). As with tDDT, tPCB levels have been variable over the past three years, with no detected values found in sediments from the inner shelf (Figure 8.4I).

PAHs were detected at 29% of the regional stations at concentrations well below threshold values (i.e., <4022 ppb; Table 8.1, Appendix G.5). PAHs occurred primarily at middle shelf stations, at a rate of 64%. In contrast, PAHs were found in only one sample from the inner shelf (8101), outer shelf (8119) and upper slope (8150). Sediments from station 8119 had the highest concentration of tPAH at about 474 ppb. The compounds dibenzo (A,H) anthracene, 2,6-dimethylnaphthalene, benzo [G,H,I] perylene, and indeno (1,2,3-CD) pyrene had detection rates between 7 and 17%, whereas fluoranthene, pyrene, anthracene, benzo [A] anthracene, benzo [e] pyrene, benzo [A] pyrene, and chrysene were each reported only once (Appendix G.2). As with tDDT and tPCB, the occurrence and concentrations of tPAH have been variable over the past three years (Figure 8.4J).

Classification of Sediment Conditions

Results of cluster analyses performed on all sediment chemistry data collected between 2009 and 2011 discriminated 15 groups of sediment samples (Figures 8.5, 8.6). These groups (cluster groups A–O) differed in relative

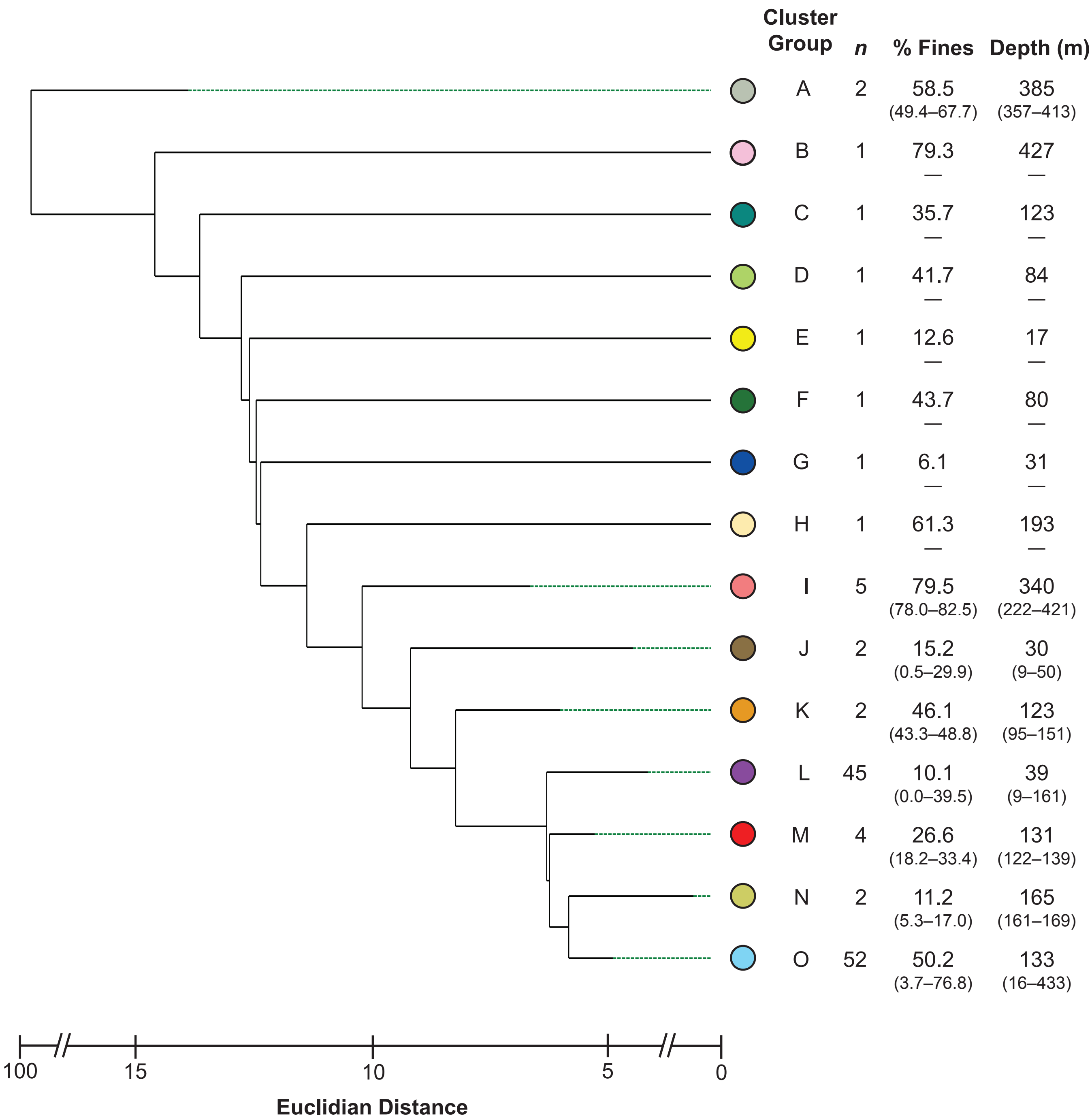

Figure 8.5

Cluster analyses of sediment chemistry data from regional benthic stations sampled between 2009−2011. Data for depth and percent fines include the mean (range) of values calculated over all stations within each group (*n*).

concentrations of metals, pesticides, total PCB and total PAH in each sample (Appendices G.6, G.7). Contaminant levels present in 2011 were generally similar to previous years. They varied along a general depth gradient, as well as by region. The two main groups (cluster groups L and O) contained 80% of the 121 samples. Group L comprised 45 sites primarily located either within the South Bay monitoring region, or at depths <25 m from Del Mar to Point Loma, and were characterized by relatively coarse/sandy sediments (e.g., ~10% fines). This group corresponds to cluster group F described in Chapter 4. Group O comprised 52 mid-depth sites with finer sandy

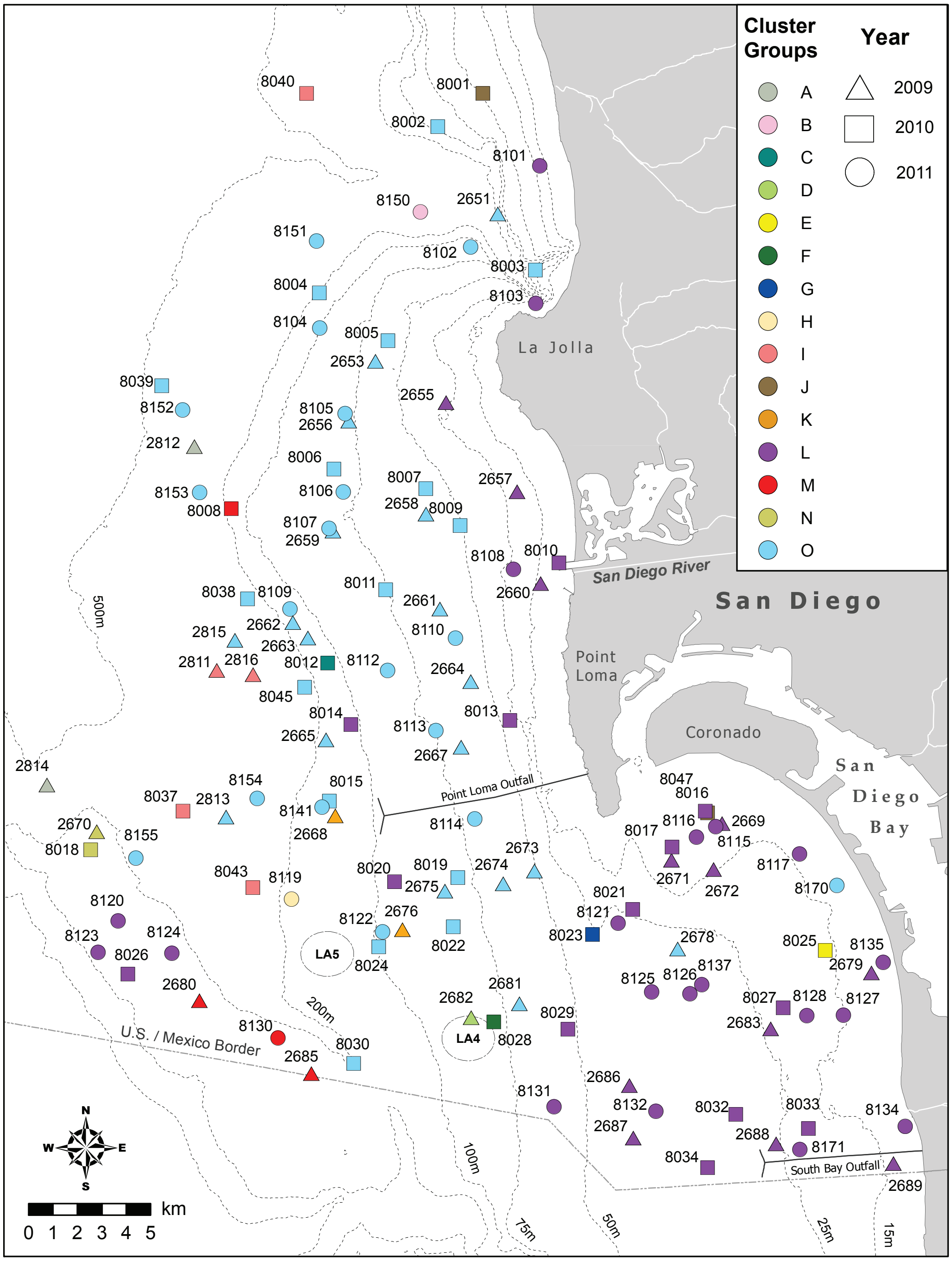

Figure 8.6

Spatial distribution of cluster groups in the San Diego region. Colors of each circle correspond to colors in Figure 8.5 dendrogram.

sediments (e.g., ~50% fines) located in the "mud belt" of the PLOO region (see Chapter 5, Chapter 9, and Thompson et al. 1993). With one exception, contaminant levels were below accepted thresholds in both cluster group L and O. The exception was arsenic, which exceeded the ERL for this parameter. Together, these two groups represent typical background conditions for the San Diego region.

The thirteen remaining cluster groups each comprised 1–5 outlier samples, which differed from groups L and O primarily by having higher values of a few select contaminants (Figure 8.5, Appendices G.6, G.7). For example, 42% of these samples contained at least one contaminant that exceeded its ERL or ERM. Eight outliers (groups A, B, I) were found along the upper slope at depths between 222–427 m and were characterized by the highest proportions of fine material (49–82%) and the highest concentrations of aluminum, antimony, arsenic, chromium, iron, nickel, selenium, and tin. Additionally, sediments from stations 2812 and 2814 (group A) were the only to contain chlordane and the gamma isomer of HCH. Another five outliers from groups M and N (sites 2670, 2680, 2685, 8018, 8130) were collected on the Coronado Bank at depths between 122–169 m. Sediments from these sites had low percent fines (≤33%) compared to other sites at similar depths (see discussion in Chapter 4), and were characterized by relatively high concentrations of TOC, arsenic, barium, chromium or iron. The two outliers represented by groups D and F (sites 2682 and 8028, respectively) were collected at the LA4 dredge spoils dumpsite at about 80 m. These had the highest concentrations of tPCBs and tDDTs found during 2009−2011 surveys. At station 2682, tDDT exceeded its ERL, while tDDT exceeded its ERM at station 8028. Four outliers represented by groups C, H, and K occurred throughout the PLOO monitoring region and three outliers represented by groups E, G and J occurred throughout the SBOO monitoring region. These samples were characterized by concentrations of chemistry parameters that were intermediate to those characteristic of groups L and O versus those described above.

Discussion

Sediment grain size composition at the regional benthic stations sampled in 2011 were typical for the continental shelf and upper slope off the coast of southern California (Emery 1960), and consistent with results from previous surveys (e.g., City of San Diego 2008–2011b). Overall, sediments varied as expected by region and depth stratum. For example, regional stations sampled along the inner and middle shelf within the vicinity of SBOO fixed-grid stations (see Chapter 4) tended to be predominantly sand (~84%), whereas regional stations sampled along the middle and outer shelf within the vicinity of PLOO fixed-grid stations (see City of San Diego 2011a) tended have much finer sediments (~55% fines). However, exceptions to this overall pattern occurred throughout the region, particularly along the Coronado Bank, a southern rocky ridge located southwest of Point Loma at depths of 150–170 m. Sediment composition at stations from this area tend to be coarser than stations at similar depths located off of Point Loma and further to the north. Much of the variability in sediment grain size composition throughout the region may be due to the complexities of seafloor topography and current patterns, both of which affect sediment transport and deposition (Emery 1960, Patsch and Griggs 2007). Additionally, several other stations lie within accretion zones of coastal littoral cells and receive more frequent deposition of sands and fine sediments. The diverse sediment transport and deposition patterns are further illustrated by the range of sorting coefficients measured in regional sediments in 2011. The most well sorted sediments (i.e., with the lowest sorting coefficients) were collected from inner shelf stations and are indicative of areas subject to consistent, moderate currents. In contrast, the sediments most likely exposed to higher levels of disturbance (i.e., with the highest sorting coefficients) occurred at deeper stations of the middle shelf and upper slope located near the LA5 dredge spoils dumpsite and along the Coronado Bank. This level of sorting is typical of areas with fluctuating weak to violent currents or rapid deposition (e.g., resulting from storm surge or dredge material dumping) that often result in highly variable or patchy sediment grain size distributions (Folk 1980).

As with sediment grain size composition, regional patterns of sediment contamination in 2011 were similar to patterns seen in previous years. There was no evidence of degraded sediment quality in the general San Diego region. While various indicators of organic loading, trace metals, chlorinated pesticides, PCBs and PAHs were detected at variable concentrations in sediment samples collected throughout the region, almost all contaminants occurred at levels below both ERL and ERM thresholds, as they have in previous years (City of San Diego 2008–2011b). The only exception during 2011 was arsenic, which exceeded the ERL threshold at two stations. Further, there was no evidence of disturbance during the 2009−2011 regional surveys that could be attributed to local wastewater discharges. Instead, concentrations of total nitrogen, total volatile solids and several trace metals were found to increase with increasing amounts of fine sediments (percent fines). As percent fines also increased with depth in the region, many contaminants were detected at higher concentrations in deeper strata compared to the shallow and mid-shelf regions. For example, the highest concentrations of most contaminants occurred in sediments along the upper slope, where some of the finest sediments were measured. This association is expected due to the known correlation between sediment size and concentration of organics and trace metals (Eganhouse and Venkatesan 1993). Finally, concentrations of these contaminants remained relatively low compared to many other coastal areas located off southern California (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, City of San Diego 2007, Maruya and Schiff 2009).

Literature Cited

Anderson, J. and R. Gossett. (1987). Polynuclear aromatic hydrocarbon contamination in sediments from coastal waters of southern California. Southern California Coastal Water Research Project, Technical Report No. 199. Long Beach, CA.

Bay, S. and K. Schiff. (1997). Impacts of stormwater discharges on the nearshore environment of Santa Monica Bay. In: S. Weisberg, C. Francisco, and D. Hallock (eds.). Southern California Coastal Water Research Project, Annual Report 1995–1996. Westminster, CA. p 105–118.

Bergen, M. (1996). The Southern California Bight Pilot Project: Sampling Design, In: M.J. Allen, C. Francisco, D. Hallock. (eds.). Southern California Coastal Water Research Project: Annual Report 1994–1995. Southern California Coastal Water Research Project, Westminster, CA.

City of Los Angeles. (2007). Santa Monica Bay Biennial Assessment Report 2005–2006. Department of Public Works, Bureau of Sanitation, Environmental Monitoring Division, Los Angeles, CA.

City of Los Angeles. (2008). Los Angeles Harbor Biennial Assessment Report 2006–2007. Department of Public Works, Bureau of Sanitation, Environmental Monitoring Division, Los Angeles, CA.

City of San Diego. (2007). Appendix E. Benthic Sediments and Organisms. In: Application for renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements, Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011a). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012). 2011 Annual Reports and Summary for the South Bay Water Reclamation Plant and Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. and R.N. Gorley. (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R. and R.M. Warwick. (2001). Change in marine communities: an approach to statistical analysis and interpretation. 2nd edition. PRIMER-E, Plymouth.

Clarke, K.R., P.J. Somerfield, and R.N. Gorley. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. Journal of Experimental Marine Biology and Ecology, 366: 56–69.

Conover, W.J. (1980). Practical Nonparametric Statistics, 2ed. John Wiley & Sons, Inc., New York, NY.

Cross, J.N. and L.G. Allen. (1993). Fishes. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 459–540.

Eganhouse, R.P. and M.I. Venkatesan. (1993). Chemical Oceanography and Geochemistry. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 71–189.

Emery, K. O. (1960). The Sea Off Southern California. John Wiley, New York, NY.

Finney, B. and C. Huh. (1989). High resolution sedimentary records of heavy metals from the Santa Monica and San Pedro Basins, California. Marine Pollution Bulletin, 20(4): 181–187.

Folk, R. L. (1980). Petrology of Sedimentary Rocks. Hemphill, Austin, TX.

Gray, J.S. (1981). The Ecology of Marine Sediments: An Introduction to the Structure and Function of Benthic Communities. Cambridge University Press, Cambridge, England.

Helsel, D.R. (2005). Nondetects and Data Analysis: Statistics for Censored Environmental Data. John Wiley & Sons, Inc., Hoboken, NJ.

[LACSD] Los Angeles County Sanitation Districts. (2010). Joint Water Pollution Control Plant Biennial Receiving Water Monitoring Report 2008–2009. Whittier, CA.

Long, E.R., D.L. MacDonald, S.L. Smith, and F.D. Calder. (1995). Incidence of adverse biological effects within ranges of chemical concentration in marine and estuarine sediments. Environmental Management, 19(1): 81–97.

Maruya, K.A. and K. Schiff. (2009). The extent and magnitude of sediment contamination in the Southern California Bight. Geological Society of America Special Paper, 454: 399–412.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2002). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

[OCSD] Orange County Sanitation District.(2011). Annual Report, July 2009–June 2010. Marine Monitoring, Fountain Valley, CA.

Patsch, K. and G. Griggs. (2007). Development of Sand Budgets for California's Major Littoral Cells. Institute of Marine Sciences, University of California, Santa Cruz, CA.

Schiff, K.C. and R.W. Gossett. (1998). Southern California Bight 1994 Pilot Project: Volume III. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

Schiff, K., R. Gossett, K. Ritter, L. Tiefenthaler, N. Dodder, W. Lao, and K. Maruya, (2011). Southern California Bight 2008 Regional Monitoring Program: III. Sediment Chemistry. Southern California Coastal Water Research Project, Costa Mesa, CA.

Snelgrove, P.V.R. and C.A. Butman. (1994). Animal-sediment relationships revisited: cause versus effect. Oceanography and Marine Biology Annual Review, 32: 111–177.

Stebbins, T.D., K.C. Schiff, and K. Ritter. (2004). San Diego Sediment Mapping Study: Workplan for Generating Scientifically Defensible Maps of Sediment Conditions in the San Diego Region. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, and Southern California Coastal Water Research Project, Westminster, CA.

Stevens Jr., D.L. (1997). Variable density grid-based sampling designs for continuous spatial populations. Environmetrics, 8: 167–195.

Stevens Jr., D.L. and A.R. Olsen (2004). Spatially-balanced sampling of natural resources in the presence of frame imperfections. Journal of the American Statistical Association, 99: 262–278.

Stull, J.K. (1995). Two decades of marine biological monitoring, Palos Verdes, California, 1972 to 1992. Bulletin of the Southern California Academy of Sciences, 94(1): 21–45.

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. Marine Ecology Progress Series, 31: 1–13.

Thompson, B.E., J. Dixon, S. Schroeter, and D.J. Reish. (1993). Chapter 8. Benthic invertebrates. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 369–458.

[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, Washington, DC.

This page intentionally left blank