Chapter 4. Sediment Conditions

Introduction

Ocean sediment samples are analyzed as part of the City of San Diego's Ocean Monitoring Program to examine potential effects of wastewater discharge on the marine benthos from both the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively). Analyses of various contaminants are conducted because anthropogenic inputs to the marine ecosystem, including municipal wastewater outfalls, can lead to increased concentrations of pollutants within the local environment. Sediment grain sizes (e.g., relative percentages of sand, silt, clay) are also determined, because concentrations of some compounds are known to be directly linked to sediment composition (Emery 1960, Eganhouse and Venkatesan 1993) and because they can provide useful information about current velocity, wave action, and overall habitat stability (e.g., Folk 1980). Finally, physical and chemical sediment characteristics are monitored because they define the primary microhabitats for benthic invertebrates that live within or on the seafloor, and subsequently influence the distribution and presence of various species. For example, differences in sediment composition and associated levels of organic loading affect the burrowing, tube building, and feeding abilities of infaunal invertebrates, thus affecting benthic community structure (Gray 1981, Snelgrove and Butman 1994). Also, many demersal fish species are associated with specific sediment types that reflect the habitats of their preferred invertebrate prey (Cross and Allen 1993). Overall, understanding the differences in sediment conditions and quality over time and space is crucial to assessing coincident changes in benthic invertebrate and demersal fish populations (see Chapters 5 and 6, respectively).

Both natural and anthropogenic factors affect the composition, distribution, and stability of seafloor sediments on the continental shelf. Natural factors that affect sediment conditions include geologic history, strength and direction of bottom currents, exposure to wave action, seafloor topography, inputs from rivers and bays, beach erosion, runoff, bioturbation by fish and benthic invertebrates, and decomposition of calcareous organisms (Emery 1960). These processes affect the size and distribution of sediment types, and also sediment chemical composition. For example, erosion from coastal cliffs and shores, and flushing of terrestrial sediment and debris from bays, rivers, and streams augment the overall organic content and grain size of coastal sediments. These inputs can also contribute to the deposition and accumulation of trace metals or other contaminants to the sea floor. In addition, primary productivity by marine phytoplankton and decomposition of marine and terrestrial organisms are major sources of organic loading to coastal shelf sediments (Mann 1982, Parsons et al. 1990).

Municipal wastewater outfalls are one of many anthropogenic factors that can directly influence sediment characteristics through the discharge of treated effluent and the subsequent deposition of a wide variety of organic and inorganic compounds. Some of the most commonly detected contaminants discharged via ocean outfalls are trace metals, pesticides, and various indicators of organic loading such as organic carbon, nitrogen, and sulfides (Anderson et al. 1993). In particular, organic enrichment by wastewater outfalls is of concern because it may impair habitat quality for benthic marine organisms and thus disrupt ecological processes (Gray 1981). Lastly, the physical presence of a large outfall pipe and associated ballast materials (e.g., rock, sand) may alter the hydrodynamic regime in surrounding areas, thus affecting sediment movement and transport, and the resident biological communities.

This chapter presents analyses and interpretations of sediment grain size and chemistry data collected

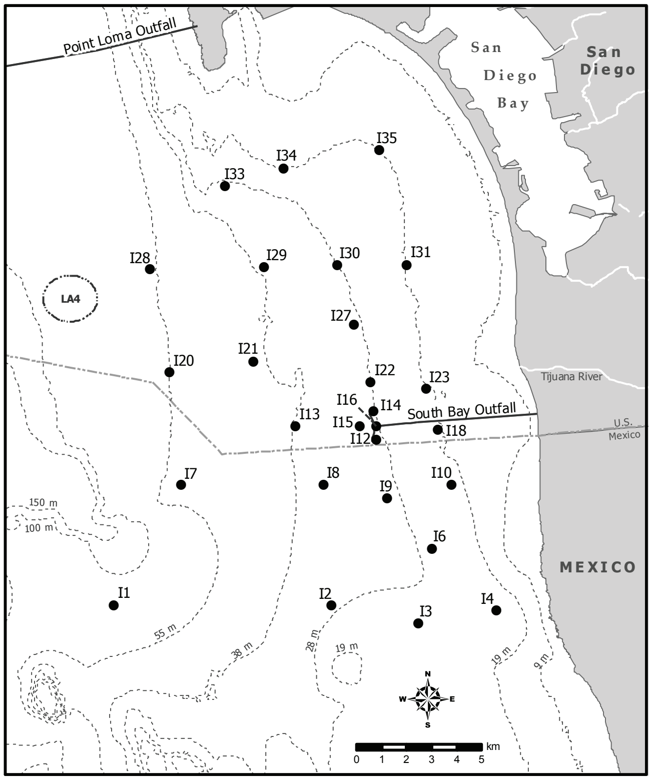

Figure 4.1
Benthic station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

in 2011 at fixed benthic monitoring stations surrounding the SBOO. The primary goals are to: (1) document sediment conditions during the year, (2) identify possible effects of wastewater discharge on sediment conditions in the region, and (3) identify other potential natural and anthropogenic sources of sediment contaminants to the local marine ecosystem.

Materials and Methods

Field Sampling

Sediment samples were collected at 27 benthic stations in the SBOO region during January and July 2011 (Figure 4.1). These stations range in depth from 18 to 60 m and are distributed along or adjacent to four main depth contours. The four stations considered to represent "nearfield" conditions (i.e., I12, I14, I15, I16) are located within 1000 m of the outfall wye. 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 5) 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 C.3). 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 Chemistry Services Laboratory (City of San Diego 2012).

Data Analyses

Data summaries for the various sediment parameters measured included detection rates, annual means of detected values for all stations combined (areal mean), and minimum, median, and maximum values. Total DDT (tDDT), PCB (tPCB), and PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix C.4 for individual constituent values). Spearman rank correlation was used to identify any association of percent fines with 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 SBOO region, a cluster analysis was performed using a 5-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 2007 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). Major ecologically-relevant clusters supported by SIMPROF were retained at >15.99% 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 Distribution

Ocean sediments were diverse at the benthic stations sampled around the SBOO in 2011. Sands made up the largest proportion of sediments at all stations, ranging from 61% to about 98% of each sample. In contrast, the fine and coarse sediment fractions ranged between 0–34% and 0–38%, respectively (Table 4.1). Additionally, observations recorded for benthic infauna samples revealed the presence of coarse red relict sands, coarse black sands, gravel, and/or shell hash at different

Table 4.1

Summary of sediment grain sizes and sediment chemistry concentrations in sediments from SBOO benthic stations sampled during 2011. Data include the detection rate (DR), areal mean of detected values, and minimum, median, and maximum values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1995–1998) is also presented. ERL = Effects Range Low threshold; ERM = Effects Range Median threshold; SD = standard deviation.

	2011 Summary [a]					Pre-discharge		
Parameter	**DR (%)**	**Areal Mean**	**Min**	**Median**	**Max**	**Max**	**ERL [b]**	**ERM [b]**
Sediment Grain Size								
Mean (*µm*)	—	279	2	177	754	na	na	na
Mean (*phi*)	—	2.5	0.9	2.8	3.9	na	na	na
SD (*phi*)	—	1.1	0.7	1.1	1.8	na	na	na
Coarse (%)	—	3.8	0.0	0.0	38.5	52.5	na	na
Sand (%)	—	86.9	61.0	90.5	98.2	100.0	na	na
Fines (%)	—	9.2	0.0	8.4	33.7	47.2	na	na
Organic Indicators								
Sulfides (*ppm*)	89	2.14	nd	1.27	9.09	222.00	na	na
TN (*% weight*)	100	0.021	0.011	0.018	0.051	0.077	na	na
TOC (*% weight*)	100	0.17	0.03	0.11	1.92	0.638	na	na
TVS (*% weight*)	100	0.80	0.41	0.72	1.89	9.20	na	na
Trace Metals (ppm)								
Aluminum	100	3848	503	2980	20,900	15,800	na	na
Antimony	35	0.54	nd	nd	0.85	5.60	na	na
Arsenic	98	2.3	nd	1.6	9.5	10.90	8.2	70
Barium	100	20.1	1.7	16.7	77.4	54.30	na	na
Beryllium	81	0.053	nd	0.033	0.222	2.14	na	na
Cadmium	41	0.21	nd	nd	0.47	0.41	1.2	9.6
Chromium	100	9.3	2.5	8.7	38.2	33.8	81	370
Copper	98	2.8	nd	2.4	15.8	11.10	34	270
Iron	100	5548	1080	4750	28,700	17,100	na	na
Lead	94	2.67	nd	2.06	10.40	6.80	46.7	218
Manganese	100	44.0	5.3	32.9	246.0	162.00	na	na
Mercury	48	0.009	nd	nd	0.024	0.078	0.15	0.71
Nickel	70	2.85	nd	1.46	10.10	13.60	20.9	51.6
Selenium	2	0.30	nd	nd	0.30	0.620	na	na
Silver	0	—	—	—	—	nd	1.0	3.7
Thallium	17	1.63	nd	nd	3.26	17.00	na	na
Tin	61	0.83	nd	0.36	2.23	nd	na	na
Zinc	100	12.9	2.3	9.6	66.4	46.90	150	410
Pesticides (ppt)								
Total DDT	15	1004	nd	nd	5270	23,380	1580	46,100
HCB	4	1595	nd	nd	2700	nd	na	na
Total PCB (ppt)	2	1220	nd	nd	1220	na	na	na
Total PAH (ppb)	0	—	—	—	—	636.5	4022	44,792

na = not available; nd = not detected

[a] Minimum, median, and maximum values were calculated based on all samples ($n = 54$), whereas means were calculated on detected values only ($n \leq 54$).

[b] From Long et al. 1995.

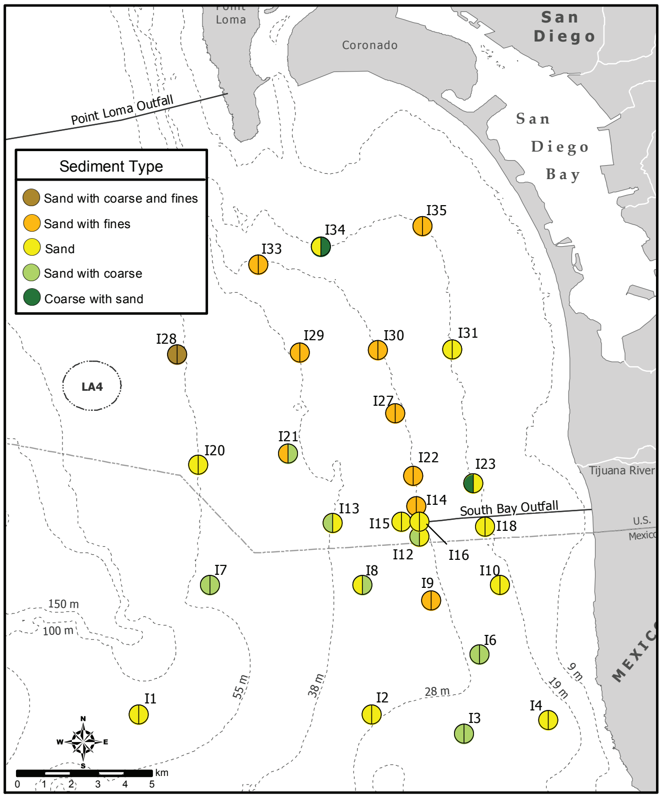

Figure 4.2

Distribution of sediment types at SBOO benthic stations sampled in 2011. Split circles show results of January (left) and July (right) surveys.

stations (see Appendix C.5). Differences in grain size composition between the winter and summer surveys tended to be minimal. For example, the percent of fine material at any one station differed by ≤8% between the January and July surveys, while coarse fractions differed by ≤7% with only a few exceptions. These exceptions included samples from stations I21 and I34, which had substantial coarse fractions in July (i.e., 12% and 39%, respectively) but no coarse sediments in January. In contrast, station I23 had 32% coarse sediments in January but none in July.

During 2011, there were no spatial patterns in the categorization of stations by sediment type relative to the SBOO discharge site (Figure 4.2). For example, sediments collected from the nearfield stations were similar to those from surrounding areas in containing low levels of fine material (i.e., <15% fines; Appendix C.5). Most stations located near or to the south of the outfall had sediments composed predominantly of sand with variable amounts of coarse material. In contrast, several stations to the north had mostly sandy sediments with variable amounts of fine material. One exception to these patterns occurred at station I9, which had sediments with a higher percent fines content compared to other nearby sites. Other exceptions occurred at station I28 which had relatively high proportions of both coarse and fine materials, and station I34 which had more coarse and less fine material than other nearby stations in July only.

There was no evidence that the amount of fine particles has increased at any of the nearfield or farfield 28-m contour stations since the onset of wastewater discharge in 1999 (Figure 4.3). Instead, the patterns described above appear to be consistent over time (Appendix C.6). For example, historical analyses reveal sediments throughout the SBOO region have predominantly consisted of sand with variable amounts fine and coarse materials. The highest percent fines have consistently occurred at northern stations I29, I30 and I35. Additionally, station I9 has consistently had higher percent fines versus other nearby stations, and station I28 has consistently had relatively high proportions of both coarse and fine materials. These results indicate that there is some stability in the region over time in terms of the overall proportions of the major sediment grain size fractions.

There also appears to be stability within sediment size fractions (e.g., types of sand present) at some stations, including I1, I2, I7, I9, I10, I30 and I35 (Appendix C.6). In contrast, sediments from other stations (e.g., I4, I12, I20, I28, I29) show significant variability within sediment size categories, especially the size ranges indicative of sand and coarse fractions. This variability likely corresponds to patches of red relict sands, coarse black sands and other coarse materials (e.g., pea gravel, shell hash, pebbles, rocks) that are encountered at various times.

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

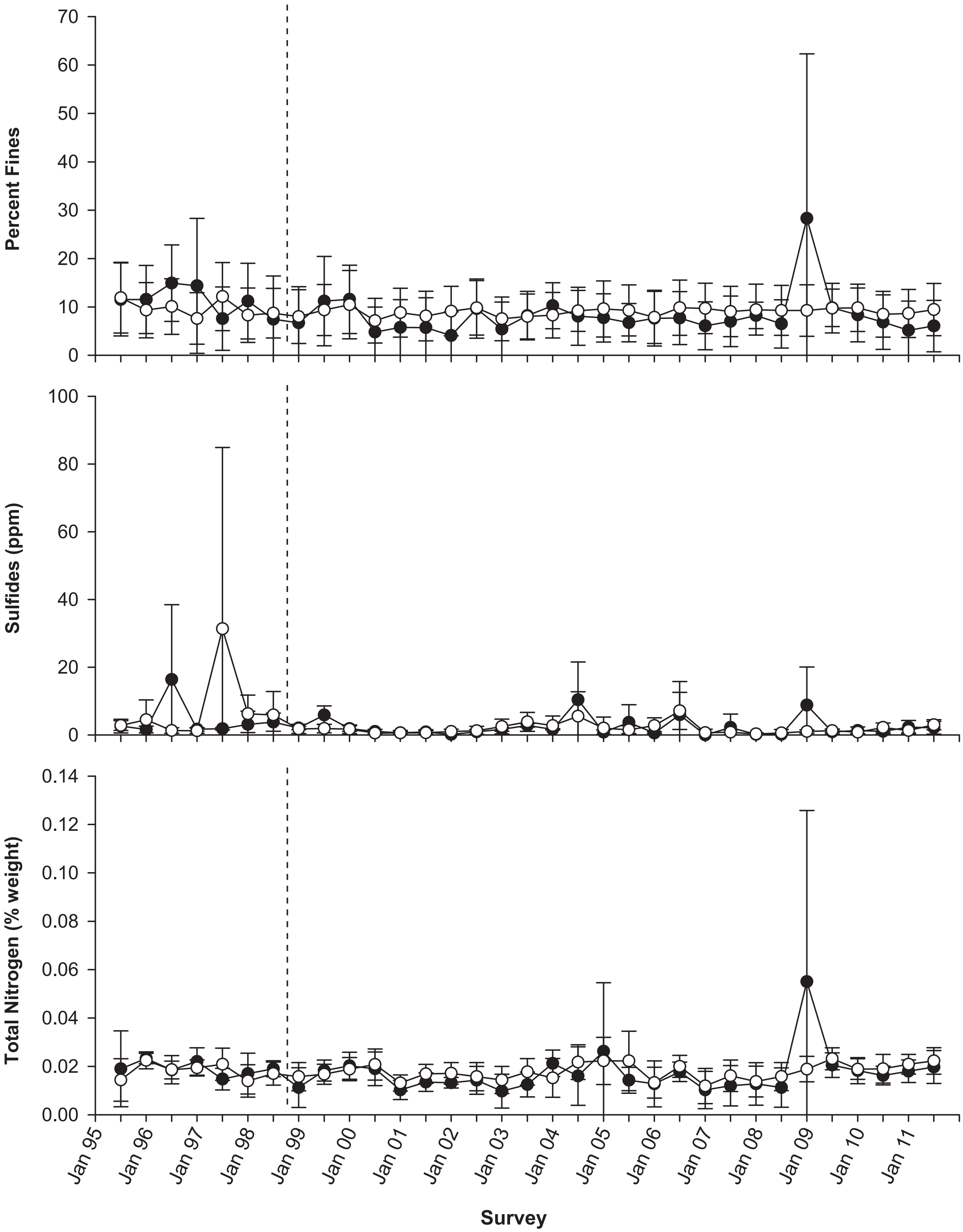

Figure 4.3

Sediment grain size and organic loading indicators at SBOO 28-m benthic stations sampled between 1995–2011. Data are expressed as means of detected values ±95% confidence intervals for samples pooled over nearfield stations (filled circles; *n*=4) versus farfield stations (open circles; *n*=8) for each survey. Dashed lines indicate onset of discharge from the SBOO.

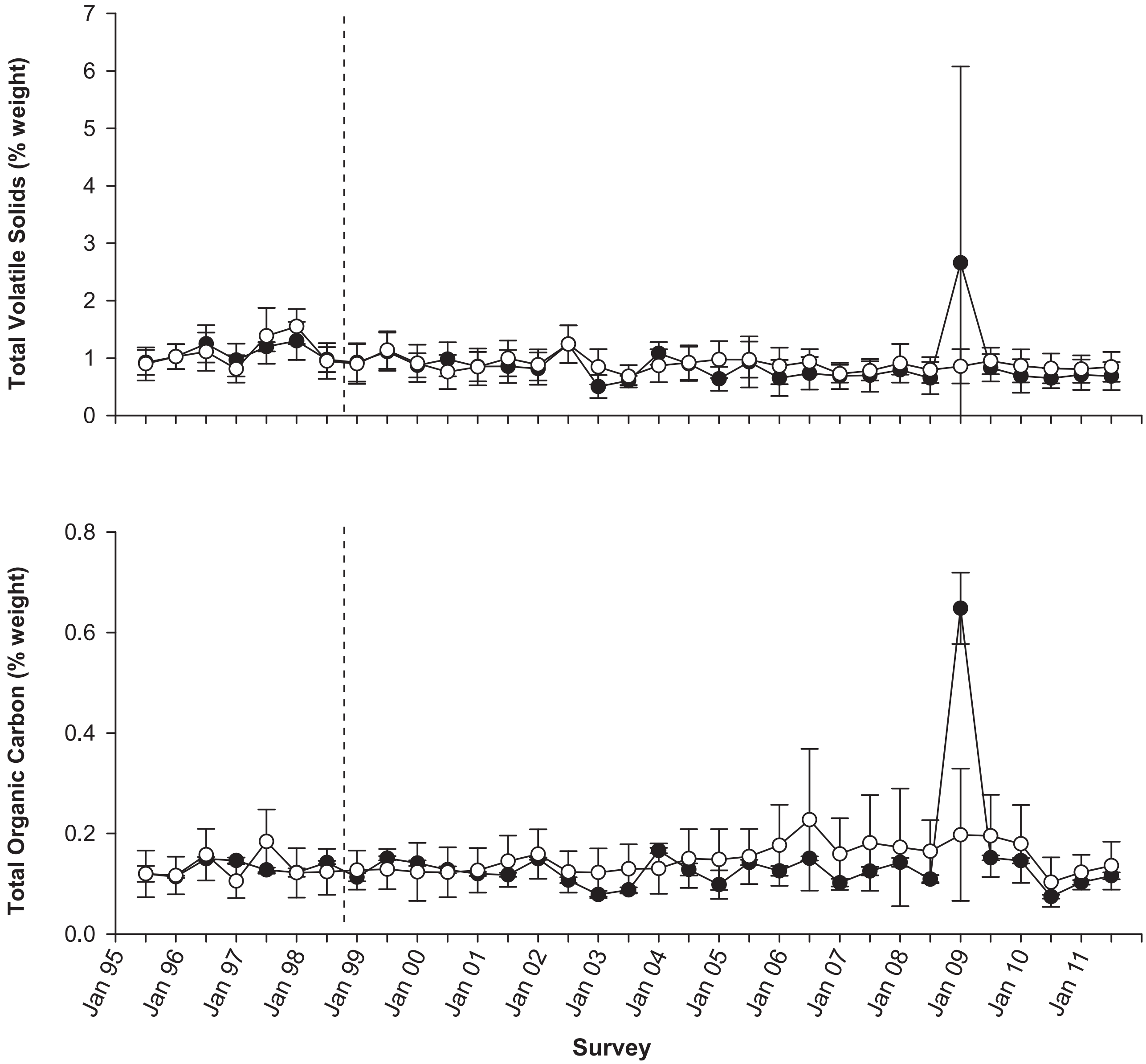

Figure 4.3 *continued*

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. Sediments collected throughout the South Bay outfall region during 2011, including at stations located near the outfall, were moderately well to poorly sorted with sorting coefficients ranging from 0.7 to 1.8 phi (Table 4.1). The sediments most likely exposed to higher levels of disturbance (i.e., SD >1.5 phi) occurred at station I28 during both the January and July surveys, and at station I29 during July (Appendix C.5).

Indicators of Organic Loading

There was no evidence of organic enrichment in SBOO sediments that could be associated with wastewater discharge in sediments in 2011. Although detection rates were high (≥89%) for sulfides, total nitrogen (TN), total organic carbon (TOC) and total volatile solids (TVS; Table 4.1), concentrations of all but TOC were far below maximum values detected prior to wastewater discharge. For example, values were ≤9.09 ppm for sulfides, ≤0.051% wt for TN, and ≤1.89% wt for TVS. As already mentioned, the maximum TOC value of 1.92% wt exceeded pre-discharge values; this value was also relatively high compared to the areal mean and median values for this and previous years (e.g., City of San Diego 2011).

Further evidence of the lack of organic enrichment included the absence of spatial patterns relative to the discharge site during the year. Instead, higher TN, TOC and TVS concentrations tended to correspond to relatively high proportions of fine sediments in the SBOO region. For example, TN and TVS were positively correlated with the percent fines in each sample (Figure 4.4A, 4.4B). Although sulfides did not co-vary with percent fines, the highest sulfide concentrations occurred far north of the outfall at station I33 in July and station I35 in both January and July (Appendix C.7). Additionally, there was no evidence of organic enrichment at any of the nearfield or farfield 28-m depth contour stations since discharge began, despite a spike in values at nearfield stations in January 2009 (Figure 4.3). This spike was due to an anomalous sample with ~79% fines collected at station I16 during this survey (see multi-year analyses below).

Trace Metals

Twelve trace metals occurred in ≥61% of sediment samples collected in 2011, including aluminum, arsenic, barium, beryllium, chromium, copper, iron, lead, manganese, nickel, tin, and zinc (Table 4.1, Appendix C.8). Another five metals (antimony, cadmium, mercury, selenium, thallium) were also detected, but less frequently at rates between 2–48%. Silver went undetected. Almost all metals were detected at low levels below both ERL and ERM thresholds. The only exception was arsenic, which exceeded the ERL (but not ERM) at station I21 during both surveys. In contrast to previous years, 50% of the metals were found to exceed levels reported prior to wastewater discharge (Table 4.1), and only concentrations of nickel correlated positively with percent fines (Figure 4.4C). However, these relatively high values tended to be wide-spread throughout the region and several of the highest values corresponded to samples with percent fines >20%. No patterns indicative of an outfall effect were evident in the distribution of metals; a conclusion further supported by multi-year analyses (see below).

Pesticides, PCBs, and PAHs

Chlorinated pesticides were detected infrequently in SBOO sediments in 2011, with detection rates ≤15% (Table 4.1, Appendix C.9). Total DDT (primarily p,p-DDE; Appendix C.4) occurred in sediments from 5 of 27 stations at concentrations up to 5270 ppt. Although the highest DDT concentration exceeded its ERL threshold (detected at station I29 in January), all DDT values were below values reported prior to discharge. The only other pesticide detected during the year was hexachlorobenzene (HCB), which was found in just two samples at concentrations up to 2700 ppt. These samples were collected at stations I30 and I8 in July. Similarly, PCBs were very rarely detected, occurring in a single sample from station I29 in January. No PAHs were detected in any sediment samples collected during the year. No patterns indicative of an outfall effect were evident in the distribution of pesticides or PCBs during 2011.

Classification of Sediment Conditions

Results of cluster analyses performed on all sediment chemistry data collected between 2007 and 2011 discriminated six groups of sediment samples (Figure 4.5). These groups (cluster groups A–F) differed in relative concentrations of metals, pesticides, total PCB, and total PAH in each sample (Appendices C.10, C.11). Contaminant levels present in 2011 were generally similar to previous years, and no spatial patterns were apparent relative to the outfall. Over 97% of the 270 samples, including all but two of the samples collected in 2011 comprised a single group (cluster group F). This group represents typical background conditions for the region with highly variable amounts of fine sediments (0–50%) and contaminant levels. Only about 16% of the samples in group F had contaminant concentrations that exceeded accepted thresholds; these included arsenic, silver,

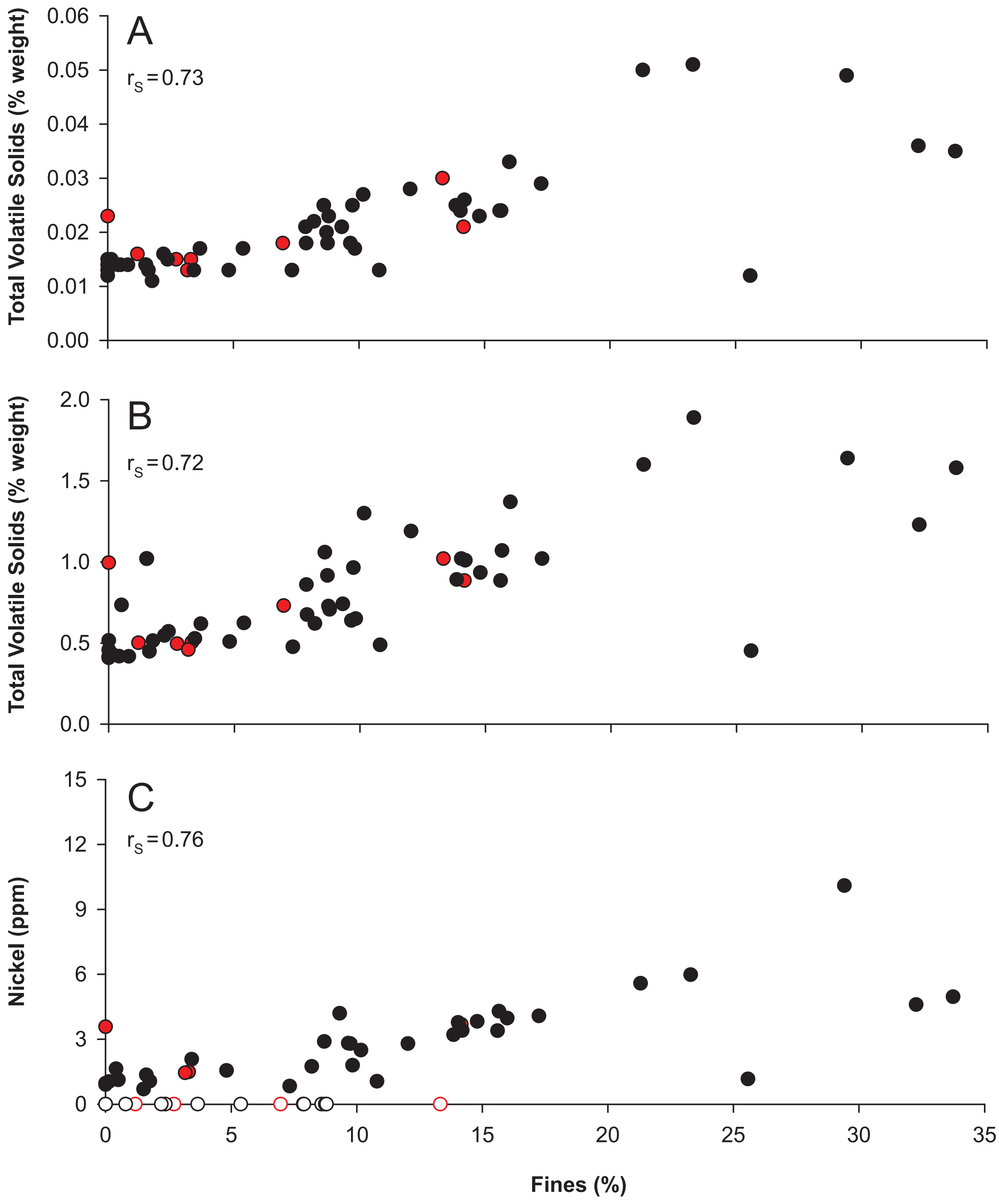

Figure 4.4
Scatterplots of percent fines versus concentrations of (A) total nitrogen, (B) total volatile solids, and (C) nickel in sediments from SBOO stations sampled during 2011. These are the only three parameters that were stongly correlated with percent fines during 2011 (i.e., $r_s \geq 0.70$, $p < 0.001$). Samples collected from nearfield stations are indicated in red. Open circles indicate samples with analyte concentrations below the method detection limit.

and DDT, which exceeded their ERLs in 7, 31, and 3 samples, respectively. Three of the silver values also exceeded the ERM for this parameter. Cluster group E represented the remaining two 2011 samples collected at station I29 in January and station I12 in July, along with a sample collected

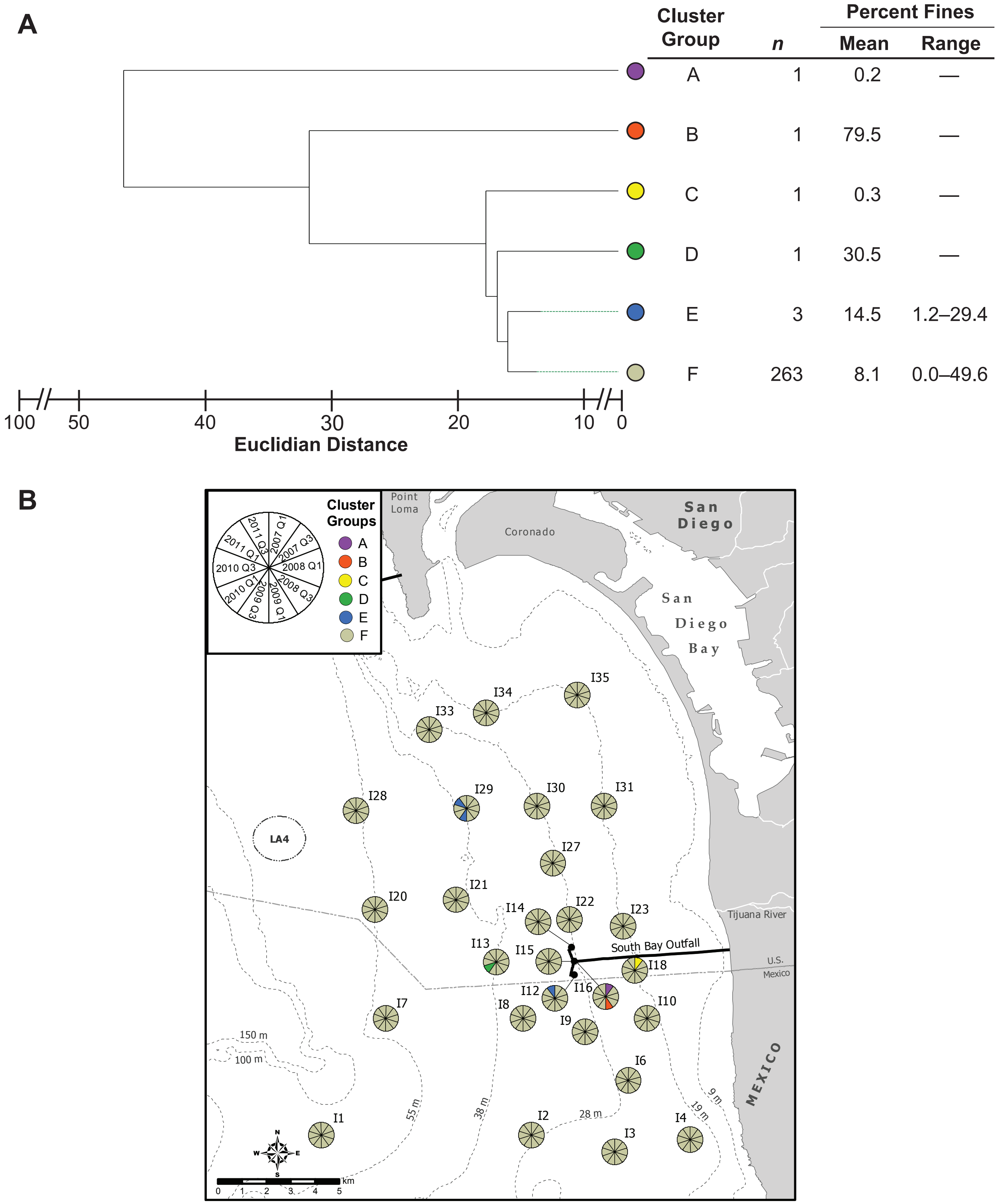

Figure 4.5

Cluster analyses of sediment chemistry data from SBOO benthic stations sampled between 2007–2011. Data are presented as: (A) cluster results; (B) spatial distribution of sediment samples as delinated by cluster analysis. Data for percent fines include the mean and range of values calculated over all stations within each group (*n*).

at station I29 in July 2009. While sediments in this small group had concentrations of most chemistry parameters that were intermediate to those characteristic of groups F and B (see below), the two samples from I29 had DDT levels higher than its ERL. The four remaining cluster groups represented single sample outliers collected during 2007 or 2010, which differed from group F primarily by having higher values of a few select contaminants. The outliers from station I16 in January 2007 (group A), station I18 in January 2007 (group C), and station I13 in January 2010 (group D) were characterized by sediments of ≤30% fines, low concentrations of most organic indictors and metals (i.e., none that exceeded ERLs), but relatively high concentrations of pesticides, tPCB and tPAH or TVS (groups A, C, D, respectively). In contrast, the fourth outlier collected at station I16 in January 2009 (group B) had the highest percent fines reported over the 5-year period (~79%), and also contained the highest concentrations of sulfides, TN, TOC, and several metals; a number of these metals, including aluminum, antimony, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, tin, zinc have been known to co-vary with percent fines (see City of San Diego 2011, and Chapter 8 herein).

Discussion

Sediment grain size composition at the SBOO stations sampled in 2011 was similar to that seen historically (Emery 1960, MBC-ES 1988) and in recent survey years (City of San Diego 2007–2011). Sands made up the largest proportion of all samples, with the amounts of coarser and finer particles varying among sites. There was no evident spatial relationship between sediment composition and proximity to the outfall discharge site, nor has there been any substantial increase in fine sediments at nearfield stations or throughout the region since wastewater discharge began in 1999. Instead, the diversity of these sediments reflects multiple geologic origins and complex patterns of transport and deposition. In particular, the presence of red relict sands at some stations is indicative of minimal sediment deposition in recent years. Several other stations are located near or within an accretion zone for sediments moving within the Silver Strand littoral cell (MBC-ES 1988, Patsch and Griggs 2007). Therefore, the higher proportions of fine sands, silts, and clays that occur at these sites are likely associated with the transport of fine materials originating from the Tijuana River, the Silver Strand beach, and to a lesser extent from San Diego Bay (MBC-ES 1988). The diverse sediment composition within the region was further emphasized by sorting coefficients that ranged from moderately well to poorly sorted in 2011. Well-sorted sediments (i.e., SD ≤ 0.5 phi) are composed of particles of similar size and are indicative of areas subject to consistent, moderate currents. In contrast, poorly sorted sediments (i.e., SD ≥ 1.0 phi) typically indicate areas of fluctuating weak to violent currents or rapid deposition (e.g., dredged material dumping) that often result in highly variable or patchy particle size distributions (Folk 1980). In general, sediment composition has been highly diverse throughout the South Bay outfall region since sampling first began in 1995 (City of San Diego 2000).

Various trace metals, pesticides, PCBs, and organic loading indicators were detected in sediment samples collected throughout the SBOO region in 2011, but in highly variable concentrations. Although several contaminants were detected at levels above pre-discharge maximums, there were very few exceedances of either ERL or ERM thresholds. Additionally, there have been no spatial patterns indicative of an outfall impact over the past several years, with concentrations of most contaminants at nearfield stations falling within the range of values at the farfield stations. Instead, relatively high values of most parameters were spread throughout the region, and several co-occurred at sites characterized by finer sediments. This association is expected due to the known correlation between particle size and concentration of organics and trace metals (Eganhouse and Venkatesan 1993).

The frequent and wide-spread occurrences of various contaminants in sediments from the SBOO region are likely derived from several different sources. Mearns et al. (1991) described the distribution of contaminants such as arsenic, mercury, DDT and PCBs as being ubiquitous in the SCB, while Brown et al. (1986) determined that no areas off southern California are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent surveys of SCB continental shelf habitats (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011). The lack of contaminant-free reference areas clearly pertains to the South Bay outfall region as demonstrated by the presence of many contaminants in sediments prior to wastewater discharge (see City of San Diego 2000). Further, historical assessments of sediments off of Los Angeles have shown that as wastewater treatment has improved, sediment conditions are more likely affected by other factors (Stein and Cadien 2009). Such factors include bioturbative re-exposure of buried legacy sediments (Niederoda et al. 1996, Stull et al. 1996), large storms that assist redistribution of legacy contaminants (Sherwood et al. 2002), and stormwater discharges (Schiff et al. 2006, Nezlin et al. 2007). Possible non-outfall sources and pathways of contaminant dispersal off San Diego include transport of contaminated sediments from San Diego Bay via tidal exchange, offshore disposal of sediments dredged from the Bay, and surface runoff from local watersheds (see Parnell et al. 2008).

In summary, sediment conditions in the South Bay outfall region were diverse in 2011, although temporal differences in the sediment grain size composition at many individual stations were minimal. Generally, the distribution of sediment types in the region is indicative of a diverse geologic history and complex transport patterns along this section of the coast. There was no evidence of fine-particle loading related to wastewater discharge during the year. Likewise, contaminant concentrations at nearfield stations were within the range of variability observed throughout the region and do not appear organically enriched. Finally, the quality of SBOO sediments in 2011 was similar to previous years, and overall concentrations of all chemical contaminants remained relatively low compared to other southern California coastal areas (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009).

Literature Cited

Anderson, J.W., D.J. Reish, R.B. Spies, M.E. Brady, and E.W. Segelhorst. (1993). Human Impacts. 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 682–766.

Brown, D.A., R.W. Gossett, G.P. Hershelman, C.G. Word, A.M. Westcott, and J.N. Cross. (1986). Municipal wastewater contamination in the Southern California Bight: Part I–metal and organic contaminants in sediments and organisms. Marine Environmental Research, 18: 291–310.

City of San Diego. (2000). International Wastewater Treatment Plant Final Baseline Ocean Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, 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. (2011). 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 Wastewater 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.

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.

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.

Mann, K.H. (1982). The Ecology of Coastal Marine Waters: A Systems Approach. University of California Press, Berkeley, CA.

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.

[MBC-ES] MBC Applied Environmental Sciences and Engineering-Science. (1988). Part F: Biological studies. In: Tijuana Oceanographic Engineering Study, Volume 1. Ocean Measurement Program. Prepared for the City of San Diego, CA.

Mearns, A.J., M. Matta, G. Shigenaka, D. MacDonald, M. Buchman, H. Harris, J. Golas, and G. Lauenstein. (1991). Contaminant Trends in the Southern California Bight: Inventory and Assessment. NOAA Technical Memorandum NOS ORCA 62. Seattle, WA.

Nezlin, N.P., P.M. DiGiacomo, S.B. Weisberg, D.W. Diehl, J.A. Warrick, M.J. Mengel, B.H. Jones, K.M. Reifel, S.C. Johnson, J.C. Ohlmann, L. Washburn, and E.J. Terrill. (2007). Southern California Bight 2003 Regional Monitoring Program: V. Water Quality. Southern California Coastal Water Research Project. Costa Mesa, CA.

Niedoroda, A.W., D.J.P. Swift, C.W. Reed, and J.K. Stull. (1996). Contaminant dispersal on the Palos Verdes continental margin. Science of the Total Environment, 179:109–133.

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.

Parnell, P.E., A.K. Groce, T.D. Stebbins, and P.K. Dayton. (2008). Discriminating sources of PCB contamination in fish on the coastal shelf off San Diego, California (USA). Marine Pollution Bulletin, 56: 1992–2002.

Parsons, T.R., M. Takahashi, and B. Hargrave (1990). Biological Oceanographic Processes 3rd Edition. Pergamon Press, Oxford.

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: III. 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.

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.

Sherwood, C.R., D.E. Drake, P.L. Wiberg, and R.A. Wheatcroft. (2002). Prediction of the fate of p,p'-DDE in sediment on the Palos Verdes shelf, California, USA. Continental Shelf Research, 32:1025–1058.

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.

Stein, E.D. and D.B. Cadien. (2009). Ecosystem response to regulatory and management actions: The Southern California experience in long-term monitoring. In: K. Schiff (ed.). Southern California Coastal Water Research Project Annual Report 2009. Southern California Coastal Water Research Project, Costa Mesa, CA.

Stull, J.K., D.J.P. Swift, and A.W. Niedoroda. (1996). Contaminant dispersal on the Palos Verdes Continental margin. Science of the Total Environment, 179:73–90.

[USEPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuary Protection, Washington, DC.

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