Chapter 4. Sediment Conditions

INTRODUCTION

Ocean sediment samples are collected and analyzed as part of the South Bay Ocean Outfall (SBOO) monitoring program to characterize the general sediment quality in the region and to assess the potential impacts of wastewater discharge to the marine benthos. Analysis of parameters such as sediment particle size, sorting coefficients, and the relative percentages of coarse (e.g., gravel and sand) and fine (e.g., silt and clay) fractions provide useful information about current velocity, wave action, and overall habitat stability. Additionally, particle size composition can often be used to explain concentrations of chemical constituents within sediments since levels of organic compounds and trace metals generally rise with increasing amounts of fine particles (Emery 1960, Eganhouse and Venkatesan 1993). 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 associated with outflows from rivers and bays, beach erosion, runoff from other terrestrial sources, 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. Primary productivity by marine phytoplankton and decomposition of marine and terrestrial organisms are also 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 the composition and distribution of sediments 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 organic compounds 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. For example, sulfides, which are the byproducts of the anaerobic breakdown of organic matter, can be toxic to some benthic species if the sediments become excessively enriched (Gray 1981). Additionally, nitrogen enrichment can lead to sudden phytoplankton blooms in coastal waters, resulting in further organic loading (see above). Other contaminants originating from anthropogenic sources, such as trace metals and pesticides, may become incorporated into the tissues of organisms living near or within these marine sediments, and accumulate within the food web (see Chapter 7). Lastly, the physical presence of a large outfall pipe

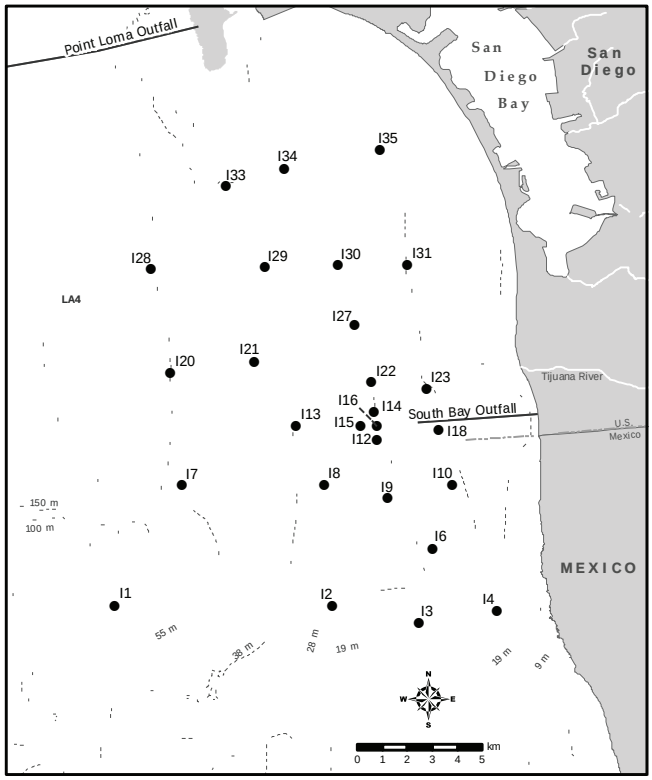

Figure 4.1
Benthic station locations sampled for the South Bay Ocean Outfall Monitoring Program.

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 particle size and chemistry data collected during 2010 at monitoring sites surrounding the SBOO. The primary goals of this chapter are to: (1) characterize the spatial and temporal variability of sediment parameters in order to assess possible effects of wastewater discharge on benthic habitats, (2) determine the presence or absence of sediment or contaminant deposition near the discharge site, and (3) evaluate overall sediment quality in the region.

Materials and Methods

Field Sampling

Sediment samples were collected at 27 benthic stations in the SBOO region during January and July 2010 (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 herein (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 particle size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Particle size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of six nested sieves. The Horiba analyzer measures particles ranging in size from 0.00049 mm to 2.0 mm (i.e., 11 to -1 phi). Coarser sediments from these samples were removed prior to laser analysis by screening the samples through a 2.0 mm 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 materials (e.g., coarse sand, gravel, shell hash) that would damage the Horiba analyzer and/or where the general distribution of sediment sizes would be poorly represented by laser analysis, a set of six nested sieves was instead used to separate the grain size fractions. The mesh sizes of the sieves are 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm, and separate a seventh fraction of all particles finer than 0.063 mm. In 2010, 51 samples were processed by laser analysis and 3 samples (I28 in January and July, and I23 in July) were processed by sieve analysis. Results from the sieve analysis and output from the Horiba were categorized into phi sizes based on the Wentworth scale (Appendix C.1). These phi sizes were then used in the calculation of various particle size parameters, which were determined using a normal probability scale (see

Folk 1980). Summaries of particle size parameters included overall mean particle size (mm), phi size (mean, standard deviation, skewness, kurtosis), and the proportion of coarse, sand, silt, and clay. Additionally, the proportion of fine particles (percent fines) was calculated as the sum of all silt and clay fractions for each sample.

Each sediment sample was chemically analyzed to determine concentrations of total organic carbon (TOC), total nitrogen (TN), total sulfides, trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis (see Appendix C.2). TOC, and TN were measured as percent weight (% wt) of the sediment sample; sulfides and metals were measured in units of mg/kg and are expressed in this report as parts per million (ppm); pesticides and PCBs were measured in units of ng/kg and are expressed as parts per trillion (ppt); PAHs were measured in units of µg/kg and are expressed as parts per billion (ppb). Reported values were generally limited to values above the method detection limit (MDL) for each parameter. However, concentrations below MDLs were included as estimated values if the 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 2011).

Data Analyses

Data summaries for the various sediment parameters measured during 2010 included detection rates, annual means of detected values for all stations combined (areal mean), and minimum, median, and maximum values during the year. Total chlordane, total DDT (tDDT), total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix C.3 for individual constituent values). Statistical analyses included Spearman rank correlation of percent fines with each chemical parameter. This non-parametric analysis accommodates non-detects (i.e., analyte concentrations measured below the 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. In addition, only parameters analyzed with a single MDL throughout the entire year were considered for correlation analysis (Helsel 2005). Correlation results were confirmed visually by graphical analyses.

Data from the 2010 surveys were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available to assess contamination levels. The National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA) originally established the ERLs and ERMs to provide a means for interpreting environmental monitoring data. The ERLs represent chemical concentrations below which adverse biological effects are rarely observed. Values above the ERL but below the ERM represent values 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). Contamination levels were further evaluated by comparing results for the current year with historical data, including comparisons between the maximum values for 2010 to those from the pre-discharge period (i.e., 1995–1998).

RESULTS

Particle Size Distribution

Ocean sediments were diverse at the benthic stations sampled around the SBOO in 2010. Sands composed the largest fraction at all stations, ranging from 65.2% to 98.7% of each sample, whereas fines (silt and clay) ranged from 0% to 31.5% (Table 4.1). Overall, there were no spatial patterns in particle size composition relative to the SBOO discharge site during the year

Table 4.1

Summary of particle size and sediment chemistry parameters at SBOO benthic stations during 2010. 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.

	2010 Summary*					Pre-discharge		
Parameter	**DR (%)**	**Areal Mean**	**Min**	**Median**	**Max**	**Max**	**ERL**	**ERM**
Particle Size								
Mean *(mm)*	**	0.269	0.080	0.143	0.660	0.758	na	na
Mean *(phi)*	**	2.27	0.60	2.81	3.65	4.20	na	na
SD *(phi)*	**	0.87	0.48	0.80	1.68	2.50	na	na
Coarse *(%)*	**	3.9	0.0	0.0	16.5	52.5	na	na
Sand *(%)*	**	87.2	65.2	89.3	98.7	100.0	na	na
Fines *(%)*	**	8.9	0.0	8.1	31.5	47.2	na	na
Organic Indicators								
Sulfides *(ppm)*	89	1.21	nd	0.81	4.72	222.00	na	na
TN *(% weight)*	98	0.019	nd	0.016	0.044	0.077	na	na
TOC *(% weight)*	98	0.140	nd	0.109	0.769	0.638	na	na
Trace Metals (ppm)								
Aluminum	100	3818	677	3265	9700	15,800	na	na
Antimony	24	0.53	nd	nd	1.18	5.60	na	na
Arsenic	98	2.16	nd	1.55	7.64	10.90	8.2	70
Barium	100	19.76	1.92	20.80	46.70	54.30	na	na
Beryllium	7	0.05	nd	nd	0.10	2.14	na	na
Cadmium	33	0.11	nd	nd	0.43	0.41	1.2	9.6
Chromium	100	9.1	3.5	9.5	16.9	33.8	81	370
Copper	91	3.78	nd	3.36	9.06	11.10	34	270
Iron	100	5393	1070	5465	11,700	17,100	na	na
Lead	100	2.29	1.01	1.83	5.22	6.80	46.7	218
Manganese	100	42.0	5.8	39.5	95.2	162.0	na	na
Mercury	41	0.008	nd	nd	0.021	0.078	0.15	0.71
Nickel	100	2.46	0.63	2.11	8.19	13.60	20.9	51.6
Selenium	0	—	nd	nd	nd	0.620	na	na
Silver	4	0.22	nd	nd	0.29	nd	1	3.7
Thallium	2	0.8	nd	nd	0.8	17.0	na	na
Tin	65	0.5	nd	0.4	1.2	nd	na	na
Zinc	100	11.7	2.2	10.0	31.9	46.9	150	410
Pesticides (ppt)								
Total DDT	26	319	nd	nd	1100	23,380	1580	46,100
HCB	20	100	nd	nd	220	nd	na	na
Total PCB (ppt)	4	182	nd	nd	290	na	na	na
Total PAH (ppb)	0	—	nd	nd	nd	636.5	4022	44,792

na = not available; nd = not detected

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

** Particle size parameters calculated for all samples.

(Figure 4.2). Sediments collected from the nearfield stations were similar to those from the surrounding area in that they contained low levels of fine material (i.e., ≤15.4% fines; Appendix C.4). Likewise, there has been no evidence of increased fine particles near the outfall (or in the region) since the onset of

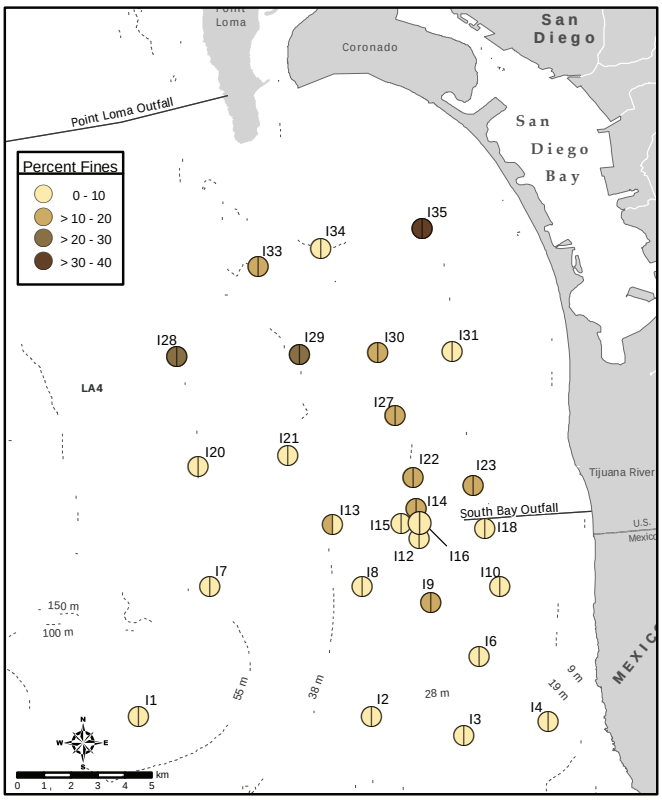

Figure 4.2
Distribution of fine sediments (percent fines) at SBOO benthic stations sampled during 2010. Split circles show results of January (left) and July (right) surveys.

wastewater discharge in 1999 (Figure 4.3). Instead, the highest percent fines tend to occur at stations I28, I29 and I35, located to the north in the survey region (Figure 4.2) (City of San Diego 2008–2010).

The diversity of sediments in the SBOO region reflects not just the variability in the amount of fine material present, but also the types of coarser materials. While most SBOO samples had similarly shaped unimodal particle size distributions, the single modal peak for these samples ranged from phi 1 to 4, thus indicating a wide range in the type of sands present (i.e., coarse to very fine; Appendix C.5). Visual observations confirm that there was substantial variability in the types of sands and coarse sediments making up the samples, including red relict sands, coarse black sands, gravel, and shell hash (Appendix C.4). The only deviation from the pattern described above occurred at station I28; sediments at this station appeared bimodal, with peaks around phi 1–2 (coarse and medium sand) and 4–5 (very fine sand and coarse silt).

Temporal differences in particle size distribution between the winter and summer surveys were minimal. For example, intra-station particle size composition differed by less than 10% at most sites between the January and July surveys (Appendix C.4). Only stations I3 and I13 displayed higher between-survey differences in the percent contribution of each size fraction. For example, the sand fraction at station I3 increased from 80.9% in January to 93.1% in July, while there were corresponding decreases in both the coarse and fine fractions between the surveys. At station I13, percent fines ranged from 11.2% in January to 0% in July, while the coarse and sand fractions both increased.

The sorting coefficient is calculated as the standard deviation (SD) in phi size units for each sample, therefore reflecting the range of particle 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, including at stations located near the outfall, were well to poorly sorted (i.e., sorting coefficients ranging from 0.48 to 1.68; Table 4.1). The sediments most likely exposed to higher levels of disturbance (i.e., with the highest sorting coefficients) occurred at station I28 during both the January and July surveys (Appendix C.4).

Indicators of Organic Loading

There was no evidence of organic enrichment that could be associated with wastewater discharge in South Bay sediments during 2010. Although detection rates for TN, TOC, and sulfides were high (i.e., ≥89%; Table 4.1), concentrations of these organic indicators were generally similar to values measured between 1995–1998 prior to the onset of discharge (Figure 4.3). In addition, TN and TOC concentrations were significantly correlated with the proportion of fine sediments in each sample (Table 4.2, Figure 4.4A). TN ranged from 0.007 to 0.044% wt, and was highest at station I28 during both surveys (Appendix C.6). TOC concentrations

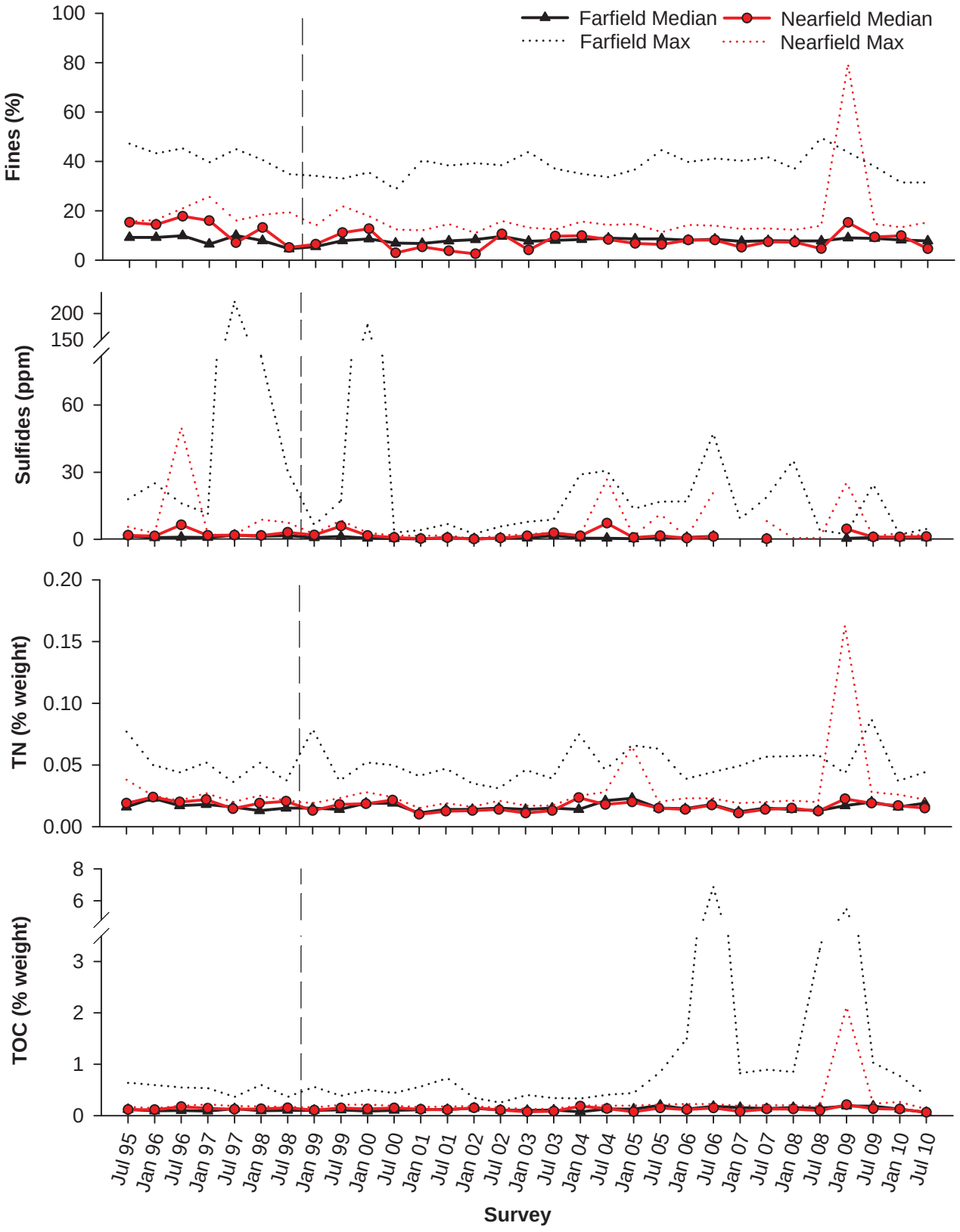

Figure 4.3

Particle size and organic indicator data from SBOO benthic stations sampled between 1995 and 2010. Parameters include: percent fines (Fines); sulfides; TN; TOC. Data are expressed as median and maximum values of all farfield ($n = 23$) and nearfield ($n = 4$) samples. Breaks in data lines represent surveys where the median or maximum value was below detection limits. Dashed lines indicate onset of discharge from the SBOO.

Table 4.2

Results of Spearman rank correlation analyses of percent fines and sediment chemistry parameters from SBOO benthic samples in 2010. Shown are analytes which had correlation coefficients $r_s(54) \geq 0.70$. For all analyses, $p < 0.001$. The strongest correlations with organic indicators and trace metals are illustrated graphically in Figure 4.4 below.

Analyte	r_s
Organic Indicators (% weight)	
Total Nitrogen	0.88
Total Organic Carbon	0.84
Trace Metals (ppm)	
Aluminum	0.86
Barium	0.83
Copper	0.70
Manganese	0.84
Nickel	0.91
Zinc	0.87

ranged from 0.014 to 0.769% wt throughout the year. The maximum TOC concentration in 2010 occurred at station I28 in January and slightly exceeded the pre-discharge maximum (0.638% wt) for this compound. TOC at this station was lower in July (0.395% wt). In contrast to TN and TOC, sulfides did not covary with percent fines. Concentrations of this organic indicator ranged from 0.16 to 4.72 ppm (Appendix C.6), with the highest concentrations (>4.0 ppm) occurring in samples from stations I27, I30, and I33 in July.

Trace Metals

Aluminum, barium, chromium, iron, lead, manganese, nickel and zinc were detected in all sediment samples collected in the SBOO region during 2010 (Table 4.1). Arsenic and copper also

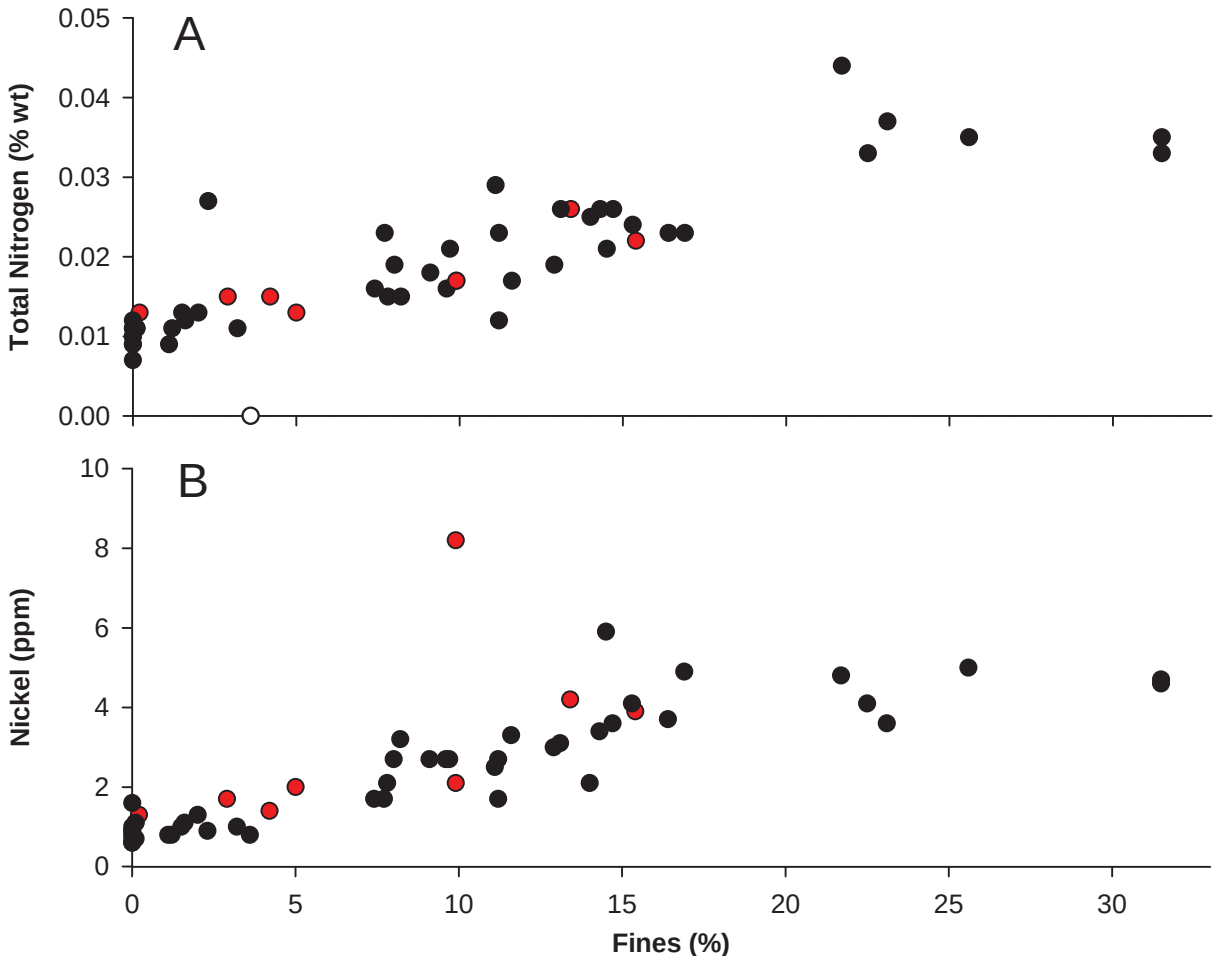

Figure 4.4

Scatterplot of percent fines and concentration of (A) total nitrogen and (B) nickel in SBOO sediments in 2010. Samples collected from nearfield stations are indicated in red. Open circles indicate samples with analyte concentrations below the method detection limit.

occurred frequently, in more than 90% of samples. In contrast, antimony, cadmium, mercury and tin were detected in less than 70% of the samples, while beryllium, silver, and thallium were detected very rarely (< 10%), and selenium was not detected at all. Concentrations of each metal were below both the ERL and ERM thresholds. In addition, there were no discernible patterns relative to the outfall (Appendix C.7). Instead, the concentrations for several metals were significantly correlated with the proportion of fine particles (Table 4.2). This trend was particularly pronounced for nickel (Figure 4.4B). However, the maximum concentrations of several metals (i.e., chromium, iron, manganese, nickel, tin, and zinc) were detected at station I12 during January despite relatively low percent fines (9.9%) (Table 4.1, Appendix C.7). Finally, most metal concentrations in 2010 were below values reported prior to discharge. The only exception occurred in sediments from station I27 in January, where the concentration of cadmium (0.43 ppm) was slightly higher than pre-discharge (0.41 ppm). Cadmium was not detected at all at this station in July.

Pesticides

Chlorinated pesticides were detected in up to 26% of the SBOO sediment samples collected in 2010 (Table 4.1, Appendix C.8). As with the various trace metals, pesticide concentrations did not appear to be associated with wastewater discharge. Total DDT (primarily p,p-DDE; Appendix C.3) was the most prevalent pesticide, occurring in sediments from 12 of 27 stations at concentrations ranging from 47 to 1100 ppt. The maximum concentrations of tDDT were detected at station I29 during both surveys. All DDT concentrations were below values reported pre-discharge, as well as the ERL biological threshold for this contaminant. Another pesticide, hexachlorobenzene (HCB), was detected in 20% of samples, at a total of 11 stations, with values ranging from 40 to 220 ppt. The two highest HCB concentrations occurred at stations I12 and I14 in January; however this pesticide was not detected at all during July.

PAHs and PCBs

PAHs were not detected in sediment samples collected during 2010 (Table 4.1). Similarly, PCBs were rarely detected, occurring at a single station (I28) located over 9 km from the outfall. Total PCB concentrations were 290 ppt at this station in January and 74 ppt in July (Appendix C.8). PCB 153/168 was detected at this station during both surveys, while the January sample also included the congeners PCB 138 and PCB 149.

Discussion

Sediment particle size distribution at SBOO stations sampled in 2010 was similar to that seen historically (Emery 1960, MBC-ES 1988) and in recent survey years (City of San Diego 2007–2010). Sands composed the largest fraction in all samples, with the amounts of coarser and finer particles being variable among sites. There was no evident spatial relationship between sediment particle size 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 (e.g., I3, I6, I7, I13, I20, I21) is indicative of minimal deposition of recent sediments to these areas. However, several other stations (e.g., I27, I29, I30, I31, I33, I34, I35) are located near or within an accretion zone for sediments moving within the Silver Strand littoral cell (MBC-ES 1988, Patsch and Griggs 2007). The higher proportions of fine sands, silts, and clays at some of these stations 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). In addition, SBOO sediments ranged from well to poorly sorted in 2010, further emphasizing the diverse conditions within the region. Well-sorted sediments (i.e., SD $\leq$ 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 $\geq$ 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 and variable throughout the South Bay outfall region since sampling first began in 1995 (City of San Diego 2000).

Various indicators of organic loading, trace metals, chlorinated pesticides, and PCBs were detected in sediment samples collected from SBOO benthic stations during 2010. There were no spatial patterns to indicate an impact of the ocean outfall on sediment chemistry as concentrations of most contaminants at nearfield stations were similar to those at stations located further away. Instead, concentrations of TOC, TN, and several metals were generally higher at sites characterized by finer sediments. This pattern is consistent with that found in other studies, in which the accumulation of fine particles has been shown to greatly influence the organic and trace metal content of sediments (Eganhouse and Venkatesan 1993). Overall, concentrations of these contaminants were highly variable, similar to particle size distribution, and within the range of predischarge values for the SBOO region (City of San Diego 2000). Only two analytes (i.e., TOC and cadmium) were detected above pre-discharge maximum values, and these slightly higher concentrations occurred only in the January survey. In addition, there were no exceedances of either the ERL or ERM biological thresholds in 2010, indicating a lack of chemical contamination.

In summary, sediment conditions in the South Bay outfall region were diverse in 2010, although temporal differences in the particle size distributions at individual stations were minimal. Generally, sediment particle size patterns in the region are 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 in 2010. Likewise, contaminant concentrations at nearfield stations were within the range of variability throughout the SBOO region and do not appear enriched. The quality of sediments in the South Bay outfall region was similar in 2010 to previous survey years, and overall concentrations of all chemical analytes remained relatively low compared to many other coastal areas off southern California (Schiff and Gossett 1998, Noblet et al. 2003, Schiff et al. 2006, 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.

City of San Diego. (2000). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 1999. 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 (International Wastewater Treatment 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 (International Wastewater Treatment 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 (International Wastewater Treatment 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). 2010 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.

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.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2003). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

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.

Rodriguez, J.G. and A. Uriarte. (2009). Laser diffraction and dry-sieving grain size analyses

undertaken on fine- and medium-grained sandy marine sediments: A note. Journal of Coastal Research, 25(1): 257–264.

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

[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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