Chapter 4. Sediment Characteristics

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 in 2011 at fixed benthic monitoring stations surrounding the PLOO. 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.

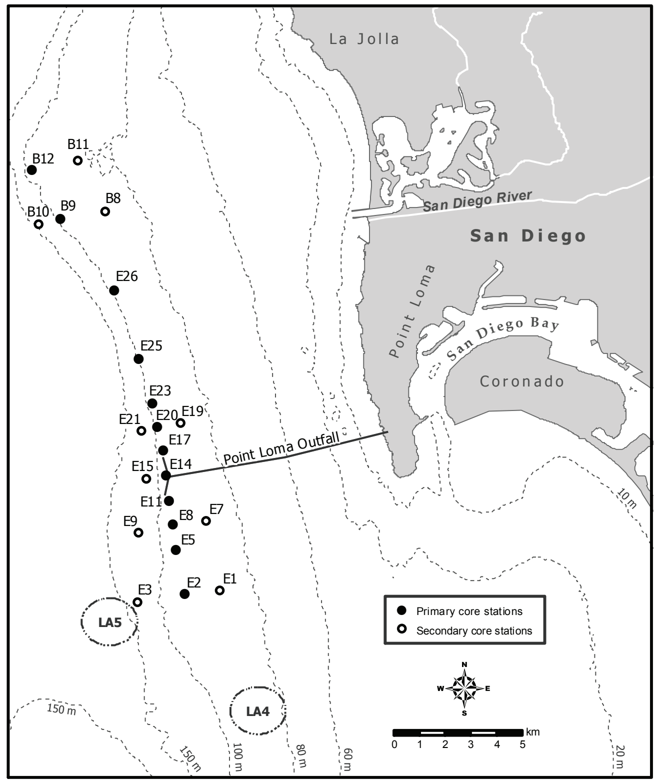

Figure 4.1
Benthic station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

Materials and Methods

Field Sampling

Sediment samples were collected at 22 fixed stations in the PLOO region during January and July 2011 (Figure 4.1). These stations range in depth from 88 to 116 m and are distributed along or adjacent to three main depth contours. These sites included 17 'E' stations ranging from approximately 5 km south to 8 km north of the outfall, and five 'B' stations located about 10−12 km north of the tip of the northern diffuser leg (see Chapter 1). The four stations considered to represent "nearfield" conditions (i.e., E11, E14, E15 and E17) are located within 1000 m of the outfall wye or diffuser legs.

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 analyses (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 biochemical oxygen demand, 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 2012a).

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). 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).

Results

Sediment Grain Size Distribution

Ocean sediments sampled off Point Loma ranged from 55 to 146 µm in 2011, indicating that they were composed predominantly of coarse silt and fine sands (Table 4.1, Appendix C.1). The fine and sand sediment fractions averaged 38% and 62% of each sample, respectively, while the average coarse fraction was only 1%. Despite the dominance of finer materials in PLOO sediments, visual observations of corresponding macrofaunal samples revealed the presence of coarse sands (including black sands), gravel, and/or shell hash at different 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 and coarse material at any one station differed by ≤4% between the January and July surveys, with only a few exceptions. One such exception occurred at station E2, which had 12% coarse material in July but none in January. Another exception occurred at station E9, which had 40% fines and 2% coarse materials in January, but only 4% fines and 27% coarse materials in July.

During 2011, there were no spatial patterns in the categorization of stations by sediment type relative to the PLOO discharge site (Figure 4.2). Instead, all but four samples contained 27–46% fines. The four exceptions were collected from stations E2 and E9 (July only, see above) and at station B8 (both surveys). The latter station averaged 58% fines for the year (Appendix C.5). There was no evidence that the amount of fine particles has increased at nearfield or farfield 98-m stations since the onset of wastewater discharge at the end of 1993 (Figure 4.3). Instead, sediment composition at these stations have remained fairly consistent over time, composed primarily of sand with high proportions of fine material (Appendix C.6). These results indicate that there is some long-term stability in the region in terms of the overall proportions of the major grain size fractions.

Table 4.1

Summary of sediment grain sizes and sediment chemistry concentrations in sediments from PLOO 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., 1991–1993) 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*)	—	93.0	55.0	85.6	146	na	na	na
Mean (*phi*)	—	4.10	1.05	4.16	4.80	na	na	na
SD (*phi*)	—	1.58	1.06	1.53	2.02	na	na	na
Coarse (%)	—	1.10	0.00	0.00	27.2	26.4	na	na
Sand (%)	—	61.5	40.5	61.9	73.3	79	na	na
Fines(%)	—	37.5	3.70	38.1	59.5	74.2	na	na
Organic Indicators								
BOD (*ppm*)[c]	100	374	251	365	541	656	na	na
Sulfides (*ppm*)	100	6.91	1.10	3.65	52.40	20	na	na
TN (*% weight*)	100	0.059	0.038	0.058	0.095	0.074	na	na
TOC (*% weight*)	100	0.79	0.32	0.51	4.18	1.24	na	na
TVS (*% weight*)	100	2.35	1.64	2.25	4.04	4.00	na	na
Trace Metals (*ppm*)								
Aluminum	100	6394	3270	5915	12,900	na	na	na
Antimony	98	0.48	nd	0.47	0.91	6	na	na
Arsenic	100	3.3	1.1	3.6	7.8	5.6	8.2	70
Barium	100	35.26	17.40	32.90	67.90	na	na	na
Beryllium	100	0.15	0.08	0.14	0.25	2.01	na	na
Cadmium	100	0.16	0.08	0.14	0.52	6.1	1.2	9.6
Chromium	100	15.36	9.24	14.65	24.10	43.6	81	370
Copper	100	7.7	4.9	7.0	13.8	34	34	270
Iron	100	10,794	5800	10,550	17,200	26,200	na	na
Lead	100	13.75	3.18	5.89	326.00	18	46.7	218
Manganese	100	79.67	45.30	75.20	140.00	na	na	na
Mercury	100	0.029	0.015	0.027	0.060	0.096	0.15	0.71
Nickel	100	6.87	4.37	6.71	11.60	14	20.9	51.6
Selenium	0	—	—	—	—	0.9	na	na
Silver	7	1.23	nd	nd	2.81	4	1	3.7
Thallium	2	0.99	nd	nd	0.99	113	na	na
Tin	100	1.01	0.54	0.91	2.74	na	na	na
Zinc	100	28.46	17.30	27.35	46.00	67	150	410
Pesticides (*ppt*)								
Total DDT	95	403	nd	330	1620	13,200	1580	46,100
HCB	11	432	nd	nd	680	nd	na	na
Total PCB (*ppt*)	23	10,914	nd	nd	63,890	na	na	na
Total PAH (*ppb*)	18	148	nd	nd	306.1	199	4022	44,792

na = not available; nd = not detected

[a] Minimum, median, and maximum values were calculated based on all samples ($n = 44$), whereas means were calculated on detected values only ($n \leq 44$).

[b] From Long et al. 1995

[c] BOD values are from January only ($n = 22$).

There also appears to be stability within sediment size fractions (e.g., types of sand present) at most stations, including B9, E5, E8, E11, E17, E20, E23, E25 and E26 (Appendix C.6). However, sediments from a few stations such as B12, E14 and E2 show substantial variability within sediment size categories, especially the size ranges indicative of sand and coarse fractions. This variability likely corresponds to patches of coarse sands (e.g., black sands) and other coarse materials (e.g., gravel, shell hash) encountered at various times. For example, coarse black sands were found at station E14 this year (Appendix C.5), but in 2010 sediments at this station also contained gravel and rocks (City of San Diego 2011). These coarse materials may be due in part to the presence of ballast or bedding material around the outfall, and are why the average percent fines are slightly lower at nearfield versus farfield stations over time (Figure 4.3; see also City of San Diego 2007).

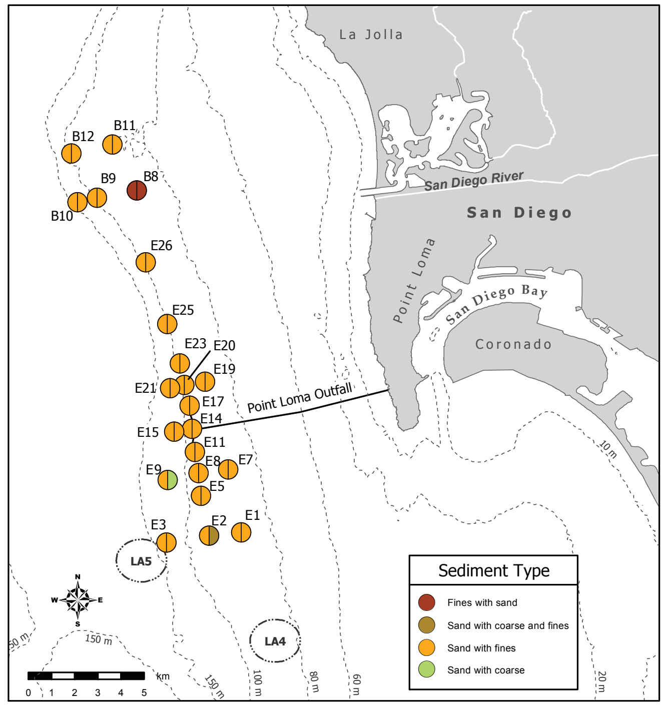

Figure 4.2
Distribution of sediment types at PLOO benthic stations sampled in 2011. Split circles show results of January (left) and July (right) surveys.

The sorting coefficient for sediments is calculated as the standard deviation (SD) in phi size units for each sample, and is considered indicative of the level of disturbance (e.g., variable currents, sediment deposition) in an area. The sediments collected off Point Loma in 2011 (including near the outfall) were poorly to very poorly sorted with sorting coefficients ranging from 1.06 to 2.02 phi (Table 4.1). The sediments most likely exposed to higher levels of disturbance (i.e., SD ≥2.0 phi) occurred at stations B11 and E3 in January (Appendix C.5).

Indicators of Organic Loading

Indicators of organic loading, including biochemical oxygen demand (BOD), sulfides, total nitrogen (TN), total organic carbon (TOC) and total volatile solids (TVS), had detection rates of 100% during 2011 (Table 4.1). Concentrations of BOD ranged from 251 to 541 ppm, while sulfides ranged from 1.1 to 52.4 ppm, TN ranged from 0.038 to 0.095% wt, TOC ranged from 0.32 to 4.18% wt and TVS ranged from 1.64 to 4.04% wt. All but BOD were detected at concentrations higher than the maximum values reported prior to wastewater discharge. The highest TN, TOC and TVS concentrations tended to occur at the northern 'B' stations located at least 10 km north of the outfall (Appendix C.7). In contrast, the highest sulfide and BOD concentrations recorded in 2011 were from station E14 located nearest the discharge site. In general, only sulfides, and to a lesser extent BOD, have shown changes near the outfall that appear to be associated with possible organic enrichment (Figure 4.3; see also City of San Diego 2007, 2011).

Trace Metals

Fourteen trace metals occurred in all sediment samples collected during 2011, including aluminum, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, tin, and zinc (Table 4.1). Antimony was also detected in almost all samples (98%), while silver and thallium occurred much less frequently at rates of 2–7%. Selenium was not detected in any sediment sample analyzed during the year. Almost all of the metals occurred at levels below both the ERL and ERM thresholds. The only exceptions were for silver and lead (Appendix C.8), as follows: (a) silver exceeded

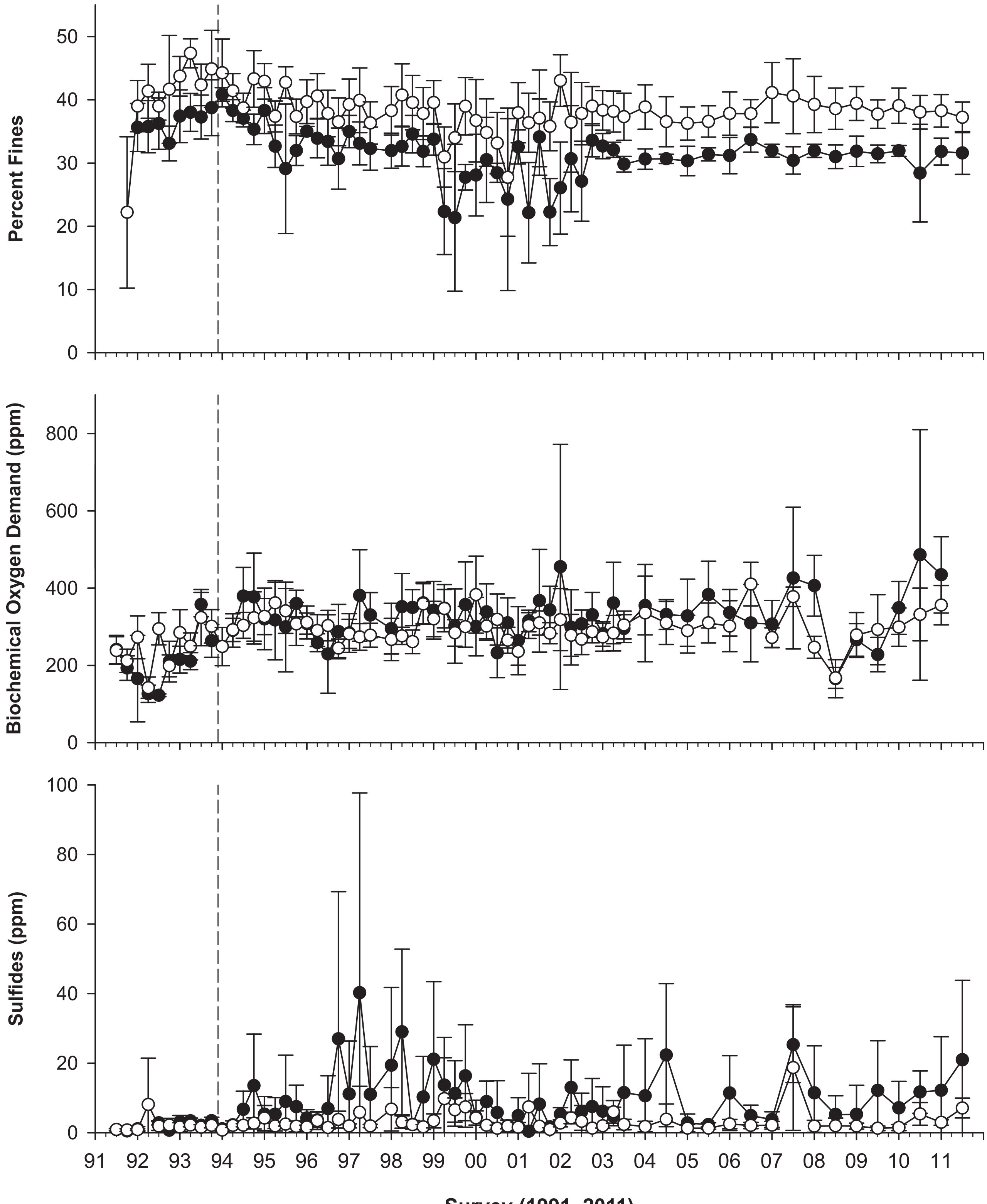

Figure 4.3

Sediment grain size and organic loading indicators at PLOO 98-m benthic stations sampled between 1991–2011. 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; $n=9$) for each survey. Dashed lines indicate onset of discharge from the PLOO extension.

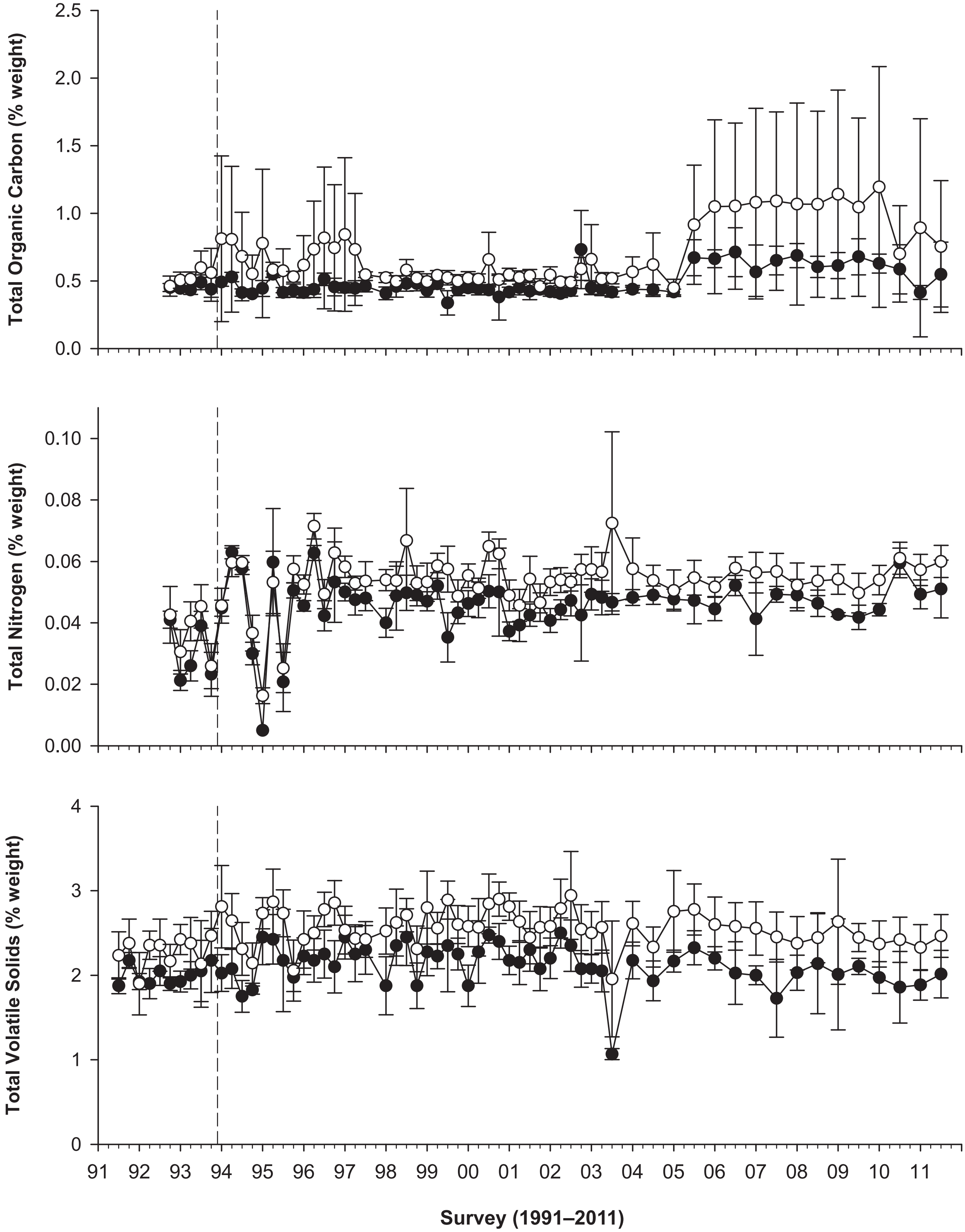

Figure 4.3 *continued*

the ERL (but not the ERM) at station E26 in January; (b) lead exceeded both the ERL and ERM at station E3 in January. Only arsenic and lead occurred at concentrations higher than reported during the pre-discharge period. For example, the concentration of lead in sediments from station E3 in January (326 ppm) is the highest value ever reported at the PLOO stations, and also exceeds average values reported for the SCB regional monitoring surveys conducted in 1994, 1998, 2003 and 2008 (City of San Diego 2007, Schiff et al. 2011).

In addition to overall low concentrations, metal distributions were spatially variable, with no discernible patterns relative to the outfall (Appendix C.8). The highest concentrations of several metals occurred in sediments from one or more of the northern 'B' stations or southern 'E' stations (e.g., E1, E2, E3, E9). Additionally, several metals, including aluminum, antimony, barium, beryllium, chromium, copper, iron, manganese and nickel were detected at relatively high concentrations in sediments from station E21 during January. The second highest concentration of cadmium was recorded at station E14 in January.

Pesticides

DDT and hexachlorobenzene (HCB) were the only two pesticides detected in PLOO sediments during 2011 (Appendix C.9). Total DDT, comprised primarily of p,p-DDE, occurred in 95% of the samples at concentrations up to 1620 ppt (Table 4.1). Although the highest DDT concentration measured during year (i.e., at station E1 in July) exceeded the ERL, all DDT values were below values reported prior to discharge. HCB was found in only five sediment samples at concentrations $\leq$680 ppt. These samples were all collected during July, and at five different stations (E1, E3, E7, E15, E26). No patterns indicative of an outfall effect were evident in the distribution of pesticides.

PCBs and PAHs

PCBs and PAHs occurred infrequently in PLOO sediments during 2011, with detection rates $\leq$23% (Table 4.1). Total PCB occurred at concentrations up to 63,890 ppt in samples from just six stations. These values could not be compared to threshold or pre-discharge values, because they were calculated based on PCB arochlors instead of congeners. The most commonly detected PCB congeners were PCB 110, PCB 118, and PCB 149. Total PAH occurred at concentrations up to 306 ppb in samples from just seven stations. While tPAH exceeded pre-discharge levels in one sample, all values were below ERL and ERM thresholds. The most commonly detected PAHs included 3,4-benzo (B) fluoranthene, benzo [A] anthracene, benzo [A] pyrene, benzo [G,H,I] perilyene, dibenzo (A,H) anthracene, fluoranthene, and indeno (1,2,3-CD) pyrene. No patterns indicative of an outfall effect were evident in the distribution of either tPCB or tPAH. Both were primarily found in sediments from stations located south of the outfall (e.g., E1, E2, E3, E9; Appendix C.9).

Discussion

Sediment grain size composition at the PLOO stations was similar in 2011 to that reported during recent years (City of San Diego 2007–2011), with fine sands and coarse silt composing the largest proportion of all samples. Most sediments were poorly sorted, consisting of particles of varied sizes, which suggest that sediments in the region were subject to low wave and current activity and/or variable physical disturbance (see Folk 1980). There was no evident spatial relationship between sediment composition and proximity to the outfall discharge site. Overall, variability in composition of sediments in the PLOO region is likely affected by both anthropogenic and natural influences, including outfall construction materials, offshore disposal of dredged materials, multiple geologic origins of different sediment types, and recent deposition of sediment and detrital materials (Emery 1960, City of San Diego 2007, Parnell et al. 2008). The outfall lies within the Mission Bay littoral cell (Patsch and Griggs 2007), with natural sources of sediments including outflows from Mission Bay, the San Diego River, and San Diego Bay. However, fine particles may also travel in suspension across littoral cell borders up and down the coast (Farnsworth and Warrick 2007, Svejkovsky 2012), thus widening the range of potential sediment sources to the region.

Various trace metals, pesticides, PCBs, and organic loading indicators were detected in sediment samples collected throughout the PLOO region in 2011, but in highly variable concentrations. Although some contaminants were detected at levels above pre-discharge maximums, there were very few exceedances of either ERL or ERM thresholds. Additionally, most parameters remained within ranges typical for other areas of the southern California continental shelf (see Schiff and Gossett 1998, City of San Diego 2000, 2012b, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009).

There were few spatial patterns in sediment contaminants relative to the PLOO discharge site in 2011. The only exceptions were slightly higher sulfide and BOD levels near the outfall as described in previous years (e.g., City of San Diego 2007, 2011). Instead, the highest concentrations of several organic indicators, trace metals, pesticides, PCBs, and PAHs were found in sediments from the southern and/or northern farfield stations. Historically, concentrations of contaminants have been higher in sediments at southern sites such as stations E1–E3, E5, and E7–E9 than elsewhere off San Diego (City of San Diego 2007–2011). This pattern may be due in part to short dumps of dredged materials destined originally for LA5 (Anderson et al. 1993, Steinberger et al. 2003, Parnell et al. 2008).

The frequent and wide-spread occurrences of various contaminants in sediments from the PLOO 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) concluded there are no areas off southern California that are sufficiently free of contaminants to be considered good reference sites. This conclusion 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 Point Loma outfall region as demonstrated by the presence of many contaminants in sediments prior to wastewater discharge (see City of San Diego 2007). Further, historical assessments of sediments off of Los Angeles have shown that as wastewater treatment improved, sediment conditions were more likely to be 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).

Overall, there is little evidence of contaminant loading or organic enrichment in sediments throughout the PLOO region after 18 years of wastewater discharge. For example, concentrations of most indicators continue to occur at low levels below available thresholds and within the range of variability typical for the San Diego region (e.g., see City of San Diego 2007, 2012b). The only sustained effects have been restricted to a few sites located within about 300 m of the outfall (i.e., stations E11, E14 and E17). These effects include measurable increases in sulfide concentrations, and smaller increases in BOD (City of San Diego 2007). However, there is no evidence to suggest that wastewater discharge is affecting the quality of benthic sediments in the region to the point that it will degrade the resident marine biota (e.g., see Chapters 5 and 6).

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