Chapter 8. San Diego Regional Survey Sediment Conditions

INTRODUCTION

The City of San Diego has conducted regional benthic monitoring surveys off the coast of San Diego since 1994 (see Chapter 1). The main objectives of these surveys are: (1) to describe benthic conditions of the large and diverse coastal region off San Diego; (2) to characterize the ecological health of the marine benthos in the area; (3) to gain a better understanding of regional conditions in order to distinguish between areas impacted by anthropogenic versus natural events.

These regional surveys are comprised of an array of stations that are randomly selected for each year using the U.S. Environmental Protection Agency's (EPA) probability-based EMAP sampling design. The 1994, 1998, 2003, and 2008 surveys off San Diego were conducted as part of larger, multi-agency surveys of the entire Southern California Bight (SCB), including the 1994 Southern California Bight Pilot Project (SCBPP), and the 1998, 2003 and 2008 SCB Regional Monitoring Programs (i.e., Bight'98, Bight'03, and Bight'08 respectively). Sediment chemistry results for the 1994–2003 bight-wide surveys are available in Schiff and Gossett (1998), Noblet et al. (2003), and Schiff et al. (2006), while data for the Bight'08 project are not yet available. The same randomized sampling design was used to select 40 new stations per year along the continental shelf (i.e., depths < 200 m) for each of the other surveys restricted to the San Diego region in 1995–1997 and 1999–2002. Beginning in 2005, however, an agreement was reached between the City, the San Diego Regional Water Quality Control Board, and the EPA to revisit the same sites that were successfully sampled 10 years earlier in order to facilitate comparisons of long-term changes in benthic conditions for the region. Thus, 36 sites were successfully revisited in 2005, 34 sites in 2006, and 39 sites in 2007. In 2009, the 34 stations originally sampled in 1999 were revisited. In addition, six new sites were selected to bring the sample size back up to 40 stations and to expand the survey into deeper continental slope waters between 200−500 m in depth.

This chapter presents analysis and interpretation of sediment particle size and chemistry data collected during the 2009 regional survey of continental shelf and upper slope benthic habitats off San Diego. Included are descriptions of the region's sediment conditions during the year, comparisons of sediment characteristics across the major depth strata defined by the SCB regional programs, and evaluation of long-term changes between the 2009 and 1999 surveys.

Materials and Methods

Field Sampling

The July 2009 regional survey covered an area ranging from off La Jolla in northern San Diego County south to the U.S./Mexico border (Figure 8.1). This survey revisited the same 34 sites that were successfully sampled in 1999 based on the EPA probability-based EMAP sampling design (see City of San Diego 2000). Although 40 sites were initially selected in 1999, sampling was unsuccessful at six sites due to the presence of rocky reefs or substrates. In order to augment the sampling design in 2009, six new stations were added using the same selection method, thus bringing the sample size back up to 40 sites. However, these new sites were targeted for continental slope depths (> 200 m) to extend the monitoring program into deeper waters. Overall, the 2009 survey included stations ranging in depth from 11 to 413 m and spanning four distinct strata as characterized by the SCB Regional Monitoring Programs (see 'Data Analyses' section below).

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

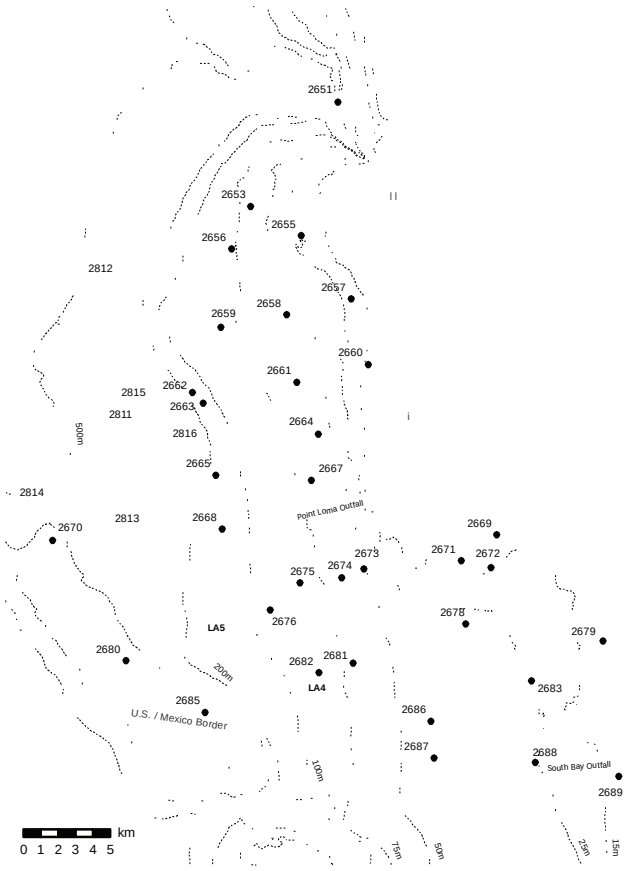

Figure 8.1
Regional benthic survey stations sampled during July 2009 as part of the South Bay Ocean Outfall Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

cast was used for macrofaunal community analysis (see Chapter 9) and visual observations of sediment composition. Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to EPA guidelines (U.S. EPA 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. Sieves were used when a sample contained substantial amounts of coarse material (e.g., coarse sand, gravel, shell hash) which would damage the Horiba analyzer and/or where the general distribution of sediment sizes in the sample would be poorly represented by laser analysis. 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 thus separate a seventh fraction of all particles finer than 0.063 mm. In the 2009 regional survey, samples from two stations (i.e., 2663 and 2670) were processed by sieve analysis. All other particle size analyses were performed on the Horiba analyzer, which measures particles ranging in size from 0.00049 mm to 2.0 mm (i.e., 11 to -1 phi). Prior to laser analysis, coarser sediments were removed by screening the samples through a 2.0-mm mesh sieve; these data are expressed herein as the "coarse" fraction of the total sample sieved. Results from sieve analysis and output from the Horiba were categorized into sand, silt, and clay fractions as follows: sand was defined as particles ranging between 2.0 and >0.0625 mm in diameter, silt as particles between 0.0625 and >0.0039 mm, and clay as particles between 0.0039 mm and >0.00049 mm. These data were standardized and combined with any sieved coarse fraction (i.e., particles >2.0 mm) to obtain a distribution of coarse, sand, silt and clay fractions totaling 100%. These four size fractions were then used in the calculation of various particle size parameters, which were determined using a normal probability scale (see Folk 1968). These parameters were then summarized and expressed as overall mean particle size (mm), phi size (mean, standard deviation), and the proportion of coarse materials, 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 analyzed for 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.1). 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 expressed as parts per trillion (ppt); PAHs were measured in units of µg/kg and expressed as parts per billion (ppb).

The data for each parameter reported herein were generally limited to values above method detection limits (MDL). However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry (i.e., spectral peaks confirmed). A detailed description of the analytical protocols is available in City of San Diego (2010).

Data Analyses

Data summaries for particle size and chemistry parameters included detection rates (i.e., number of reported values/number of samples), annual means of detected values for all stations combined (areal mean), and minimum, median and maximum values during the year. Data were also summarized according to the following four depth strata used in the SCB regional surveys: inner shelf (5–30 m), mid-shelf (30–120 m), outer shelf (120–200 m), and upper slope (200–500 m). Total PAH, total DDT, total HCH, total chlordane, and total PCB were calculated for each sample as the sum of all constituents with reported values; values for each individual constituent are listed in Appendix G.1. Statistical analyses included Spearman Rank correlation of all sediment chemistry parameters with percent fines. This non-parametric analysis accommodates nondetects (i.e., analytes measured below MDLs) 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 (see Conover 1980). Therefore, a criterion of <50% non-detects was used to screen eligible constituents for this analysis. Results from the correlation analyses were confirmed by graphical analyses.

In addition, data from the 2009 survey 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 calculated the ERLs and ERMs to provide a means for interpreting monitoring data. The ERLs are considered to 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). Levels of contamination were further evaluated by comparing 2009 data to those from 1999 for the 34 shelf stations sampled in both surveys.

Results and Discussion

Particle Size Analysis

As in previous surveys (e.g., see City of San Diego 2008), the overall composition of sediments off San Diego in 2009 consisted primarily of sands and fine particles (Table 8.1), although the relative contribution of each size fraction varied by depth and/or by region (e.g., north vs. south; see Figure 8.2). For example, the 11 sites located in shallow water along the inner shelf (i.e., ≤30 m) were composed of about 3% coarse particles, 89% sands, and 8% fines on average, whereas the 15 sites located mid-shelf at depths between 43–95 m and the eight sites located on the outer shelf at 122–177 m had finer sediments (i.e., 41% and 38% fines, respectively). The six sites located along the upper slope at depths >200 m contained the finest sediments, with 69% fines, 31% sands and no coarse fraction.

Correlation analysis confirmed that the proportion of fine sediments increased with depth (Figure 8.3), although some sites along the Coronado Bank (stations 2670, 2680 and 2685) and on the upper slope (station 2814) had higher proportions of sand than sites at similar depths (Appendix G.2). In addition, several sites located south of Point Loma had coarser sediments (<20% fines) than expected for their depth (see Figure 8.2). These results are similar to those from sediments at the fixed-grid monitoring stations surrounding the SBOO (see Chapter 4). Sediments from deeper mid-shelf sites in this South Bay region tend to be coarser and have less fine materials than regional stations at similar depths located off Point Loma and further

Table 8.1

Summary of particle size and sediment chemistry parameters at regional benthic stations during 2009. Data include detected values averaged by depth stratum, as well as the detection rate, minimum (Min), median, maximum (Max), and mean values for the entire survey area. TN = total nitrogen; TOC = total organic carbon; HCH = hexachlorocyclohexane; HCB = hexachlorobenzene; nd = not detected.

	Depth Strata				2009 Survey Area*				
	Inner Shelf	Mid-shelf	Outer Shelf	Upper Slope	Detection Rate (%)	Min	Median	Max	Mean
Particle Size Fractions (%)									
Coarse	3	1	1	0	**	0	0	26	1
Sand	89	58	61	31	**	17	56	99	63
Fines	8	41	38	69	**	0	43	83	36
Organic Indicators									
Sulfides (ppm)	3.4	1.0	8.3	9.0.	90	nd	1.3	33.4	4.3
TN (% weight)	0.02	0.06	0.08	0.20	100	0.01	0.07	0.30	0.08
TOC (% weight)	0.25	0.81	3.18	2.87	100	0.09	0.81	8.82	1.44
Trace Metals (ppm)									
Aluminum	4990	9241	8531	14167	100	1450	9295	18900	8669
Antimony	0.42	0.55	0.50	—	58	nd	0.42	0.64	0.51
Arsenic	2.32	3.90	3.91	3.93	100	0.74	3.16	9.02	3.47
Barium	27.8	45.3	50.0	82.3	100	3.3	48.7	115.0	47.0
Beryllium	0.07	0.21	0.27	0.40	100	0.02	0.22	0.49	0.21
Cadmium	0.09	0.18	0.22	0.41	78	nd	0.17	0.51	0.22
Chromium	9.3	18.6	20.4	38.0	100	4.8	18.6	68.2	19.3
Copper	3.1	9.8	6.5	17.1	95	nd	8	25.8	8.3
Iron	7005	13983	13685	19033	100	3910	13850	27400	12762
Lead	2.07	5.61	3.92	6.80	100	1.21	4.80	12.10	4.48
Manganese	72.7	98.4	80.5	132.3	100	19.7	98.2	171.0	92.8
Mercury	0.007	0.039	0.026	0.046	80	nd	0.027	0.080	0.032
Nickel	2.8	7.3	7.5	18.0	100	1.0	7.5	22.5	7.7
Selenium	—	0.27	0.33	1.05	35	nd	nd	1.37	0.63
Silver	—	—	—	—	0	nd	nd	nd	—
Thallium	—	—	—	—	0	nd	nd	nd	—
Tin	0.64	1.29	0.85	1.18	98	nd	1.06	1.67	1.00
Zinc	16.5	38.5	32.8	55.6	100	7.1	36.5	81.8	33.9
Pesticides (ppt)									
Total HCH	—	—	—	5050	5	nd	nd	6700	5050
Total Chlordane	—	—	—	1545	5	nd	nd	1760	1545
Total DDT	130	794	540	855	48	nd	nd	1950	664
HCB	177	332	860	335	43	nd	nd	1400	367
Total PCB (ppt)	—	8235	673	880	23	nd	nd	34730	5737
Total PAH (ppb)	—	124.3	—	53.2	15	nd	nd	187.9	88.8

* Minimum, maximum, and median values were calculated based on all samples ($n = 40$), whereas means were calculated on detected values only ($n \leq 40$).

** Particle size parameters calculated for all samples.

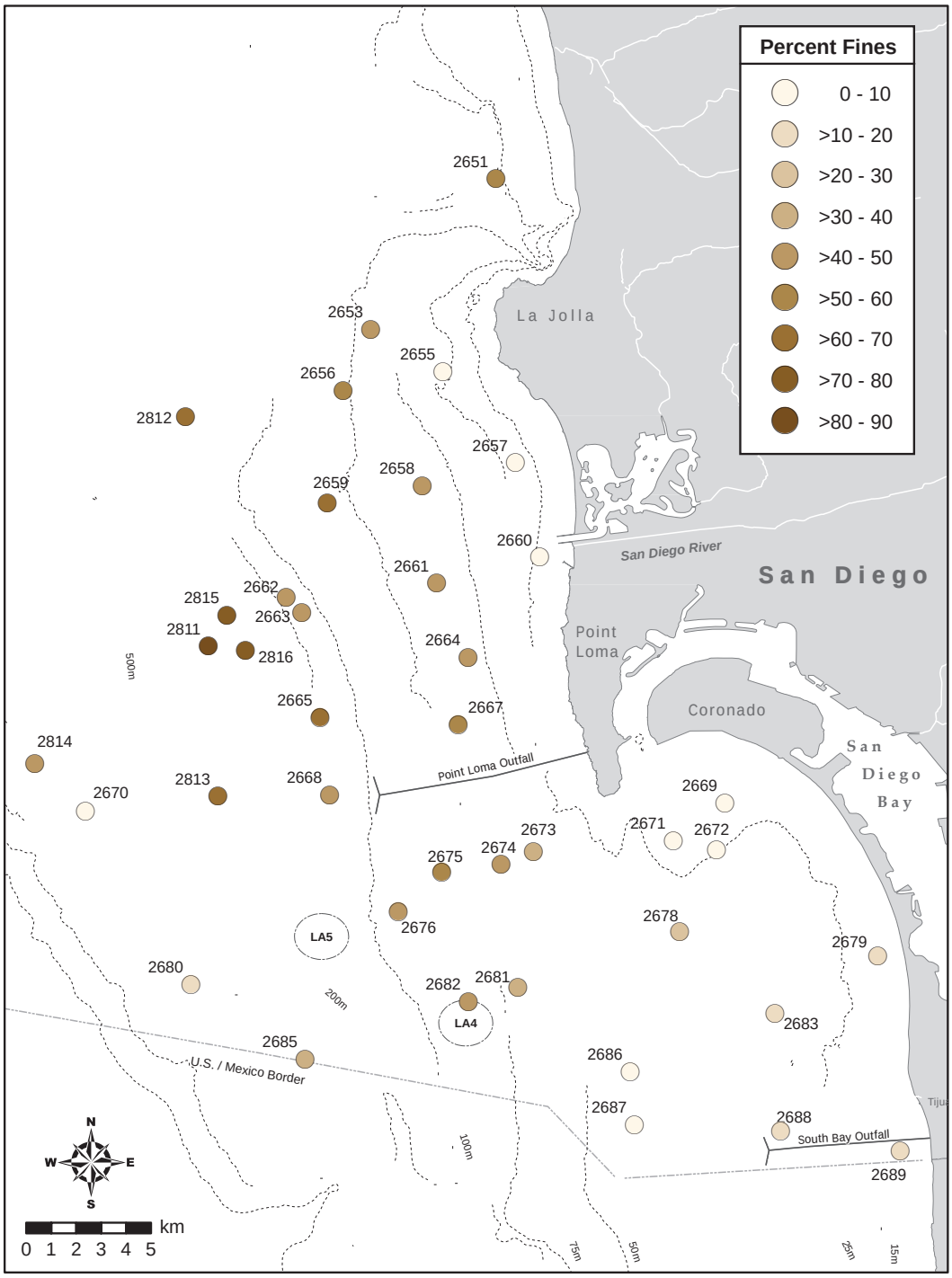

Figure 8.2
Distribution of fine sediments (percent fines) at regional benthic stations sampled during July 2009.

to the north. This may be due, at least in part, to the different geological origins of red relict sands, other coarse sands, shell hash, and detrital sediments in the South Bay region (see Emery 1960).

Sediment particle size composition along the San Diego shelf in 2009 was generally similar to that sampled at the same sites in 1999. Only five of the stations sampled in 2009 (i.e., 2655, 2669, 2672, 2680, 2686) had sediments that differed by 0.1 mm or more in mean particle size when compared to the 1999 samples (see Appendices G.2, G.3). Of these five samples, most exhibited a smaller average particle size in 2009.

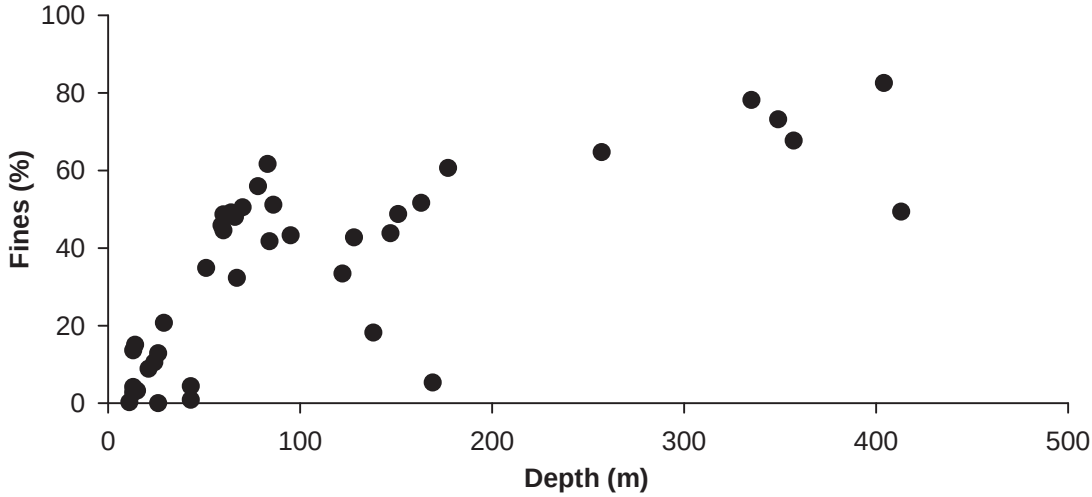

Figure 8.3
Scatterplot of percent fines and depth for regional benthic stations sampled in 2009. Spearman Rank correlation coefficient ($r_s = 0.77$); $p < 0.001$.

Organic Indicators

Sulfides were detected at 90% of the 2009 regional stations, with average concentrations of 3.4 ppm at the inner shelf stations, 1.0 ppm at the mid-shelf stations, 8.3 ppm at the outer shelf stations, and 9.0 ppm at upper slope stations (Table 8.1). The three highest sulfide concentrations were found in sediments from stations located throughout the survey area, including station 2651 (located along the La Jolla Canyon wall at 163 m), station 2665 (located north and offshore of the PLOO at 177 m), and station 2678 (located between the mouth of San Diego Bay and the SBOO at 29 m) (Appendix G.4). Region-wide sulfide concentrations from this study were similar to those reported for the stations within the SBOO monitoring area (Chapter 4) and well within the range of values reported for 1999 (Figure 8.4, Appendix G.5).

Concentrations of TN and TOC co-varied with the proportion of fine sediments in each sample (Table 8.2), and because of this relationship, values for both indicators tended to increase across the continental shelf. For example, TN was found to be correlated tightest with percent fines (Figure 8.5A) and ranged from 0.02% wt at the inner shelf stations to 0.20% wt at the upper slope stations on average (Table 8.1). TOC was also tightly correlated to percent fines, and ranged from 0.25% wt at the inner shelf stations to 3.18% wt at the outer shelf stations on average. TOC concentrations were higher at the outer shelf stations than along the upper slope because sediment samples from two sites along the Coronado Bank (i.e., stations 2680 and 2685) contained the highest TOC levels in the region. The TOC concentrations measured in sediments at these two stations (8.820% and 8.030%, respectively, Appendix G.4) caused the overall TOC range for 2009 to be substantially higher than in 1999, when TOC values ranged from 0.015% to 1.190% (Figure 8.4, Appendix G.5). In contrast, TN did not differ substantially between 1999 and 2009 on a region-wide basis (i.e., values ranged between 0.010–0.125% in 1999, vs. 0.014–0.134% in 2009) (Figure 8.4, Appendix G.4, G.5). Both parameters were generally similar in sediments sampled as part of the regional survey to those sampled within the regular SBOO monitoring area (see Chapter 4).

Trace Metals

Aluminum, arsenic, barium, beryllium, chromium, iron, lead, manganese, nickel and zinc were detected in all sediment samples collected during the 2009 regional survey (Table 8.1). Antimony, cadmium, copper, mercury, selenium and tin were detected less frequently at rates of 35–98%, while

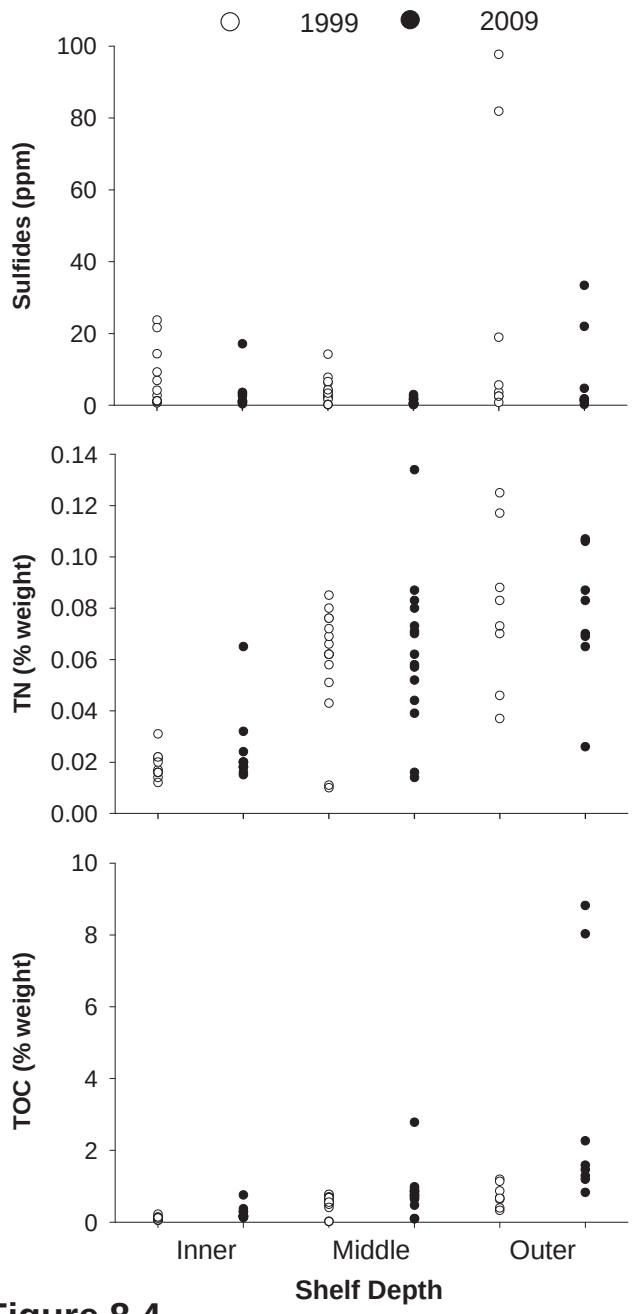

Figure 8.4
Comparison of organic indicator concentrations by shelf depth stratum at regional benthic stations in 1999 vs. 2009. TN=total nitrogen; TOC=total organic carbon; *n*=11 (inner), *n*=15 (middle), *n*=8 (outer); missing values=non-detects.

silver and thallium were not detected at all. As with many of the metals detected within the SBOO monitoring area (see Chapter 4), concentrations of several metals, including aluminum, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, tin, and zinc increased with percent fines (Table 8.2). This relationship was strongest for aluminum (see Figure 8.5B). For these metals, the highest concentrations tended to occur at the deeper sites that had the largest proportion of fine particles (see above). Moreover, the highest values for 15 of the 16 metals detected during the 2009 survey occurred at stations located along the upper slope where the highest levels of percent fines occurred.

Concentrations of some metals also appeared to be associated with the active LA-5 and defunct LA-4 dredge spoils disposal sites. Stations 2674, 2675 and 2676 located between LA-5 and San Diego Bay, and stations 2681 and 2682 located nearest LA-4, had sediments with some of the highest concentrations of several metals, including antimony, copper, lead, mercury, tin and zinc (Appendix G.4). However, sediments at these sites had only moderate proportions of fine particles (i.e., 32–51%) (Appendix G.3). Although some of these stations are located over a kilometer away from the designated disposal sites, the presence of "short dumps" in the region is well documented. For example, mounds of dredged sediments from San Diego Bay have been identified inshore of LA-5, and are therefore considered to be sources of contaminants to the region (Gardner et al. 1998; Parnell et al. 2008). Less is known about the defunct LA-4 dump site as a potential source of contaminated sediments to the survey area. Despite these relatively high values in 2009, only two metals exceeded environmental threshold values. The ERL for arsenic was exceeded at stations 2655 and 2670, while the ERL for nickel was exceeded at stations 2811 and 2816. No samples collected during 2009 had metal concentrations that exceeded ERM thresholds. In addition, most sediment samples collected during 2009 had levels of metals similar to, or lower than, values detected in 1999 (Figure 8.6, Appendix G.5). Exceptions included arsenic, beryllium, chromium, lead, mercury, tin and zinc, each of which were detected above 1999 values (or MDLs) at one or more stations.

Pesticides

Pesticides were detected in less than half of the regional sediment samples collected during 2009 (Table 8.1). Total DDT (primarily p,p-DDE) was

Table 8.2

Results of Spearman Rank correlation analyses of percent fine material with sediment chemistry parameters from regional benthic samples collected in 2009. Shown are analytes which had correlation coefficients (r_s) ≥ 0.60. For all analyses, $p < 0.001$. The strongest correlations with organic indicators and trace metals are illustrated graphically in Figure 8.5 below.

	Analyte	r_s
Organic Indicators (% weight)	Total Nitrogen	0.88
	Total Organic Carbon	0.72
Trace Metals (ppm)	Aluminum	0.92
	Barium	0.80
	Beryllium	0.81
	Cadmium	0.80
	Chromium	0.80
	Copper	0.87
	Iron	0.75
	Lead	0.85
	Manganese	0.91
	Mercury	0.85
	Nickel	0.89
	Tin	0.68
	Zinc	0.86

the most prevalent pesticide, occurring in sediments from 48% of the stations at concentrations averaging about 130 ppt along the inner shelf, 794 ppt along the mid-shelf, 540 ppt along the outer shelf, and 855 ppt along the upper slope. While the upper slope stations had the highest average DDT values, the highest individual concentrations (i.e., >1000 ppt) occurred at mid-shelf stations 2674, 2675, 2681 and 2682 (Appendix G.4). Of these, only a single sample from station 2682 exceeded the ERL for DDT. However, all values reported for the 2009 survey were quite low compared to values reported at some of the regular fixed grid SBOO stations where DDT levels as high as 9400 ppt were detected. These values seemed to be associated with anomalously high levels of percent fines (see Chapter 4). In comparison to the 1999 regional survey, detection rates for DDT were much higher in 2009, but at concentrations within the range of the values reported previously (Figure 8.7, Appendix G.5). The increase in DDT detection rate in 2009 is likely due to the inclusion of estimated values in the analyses (see Methods), a practice that did not begin until 2003.

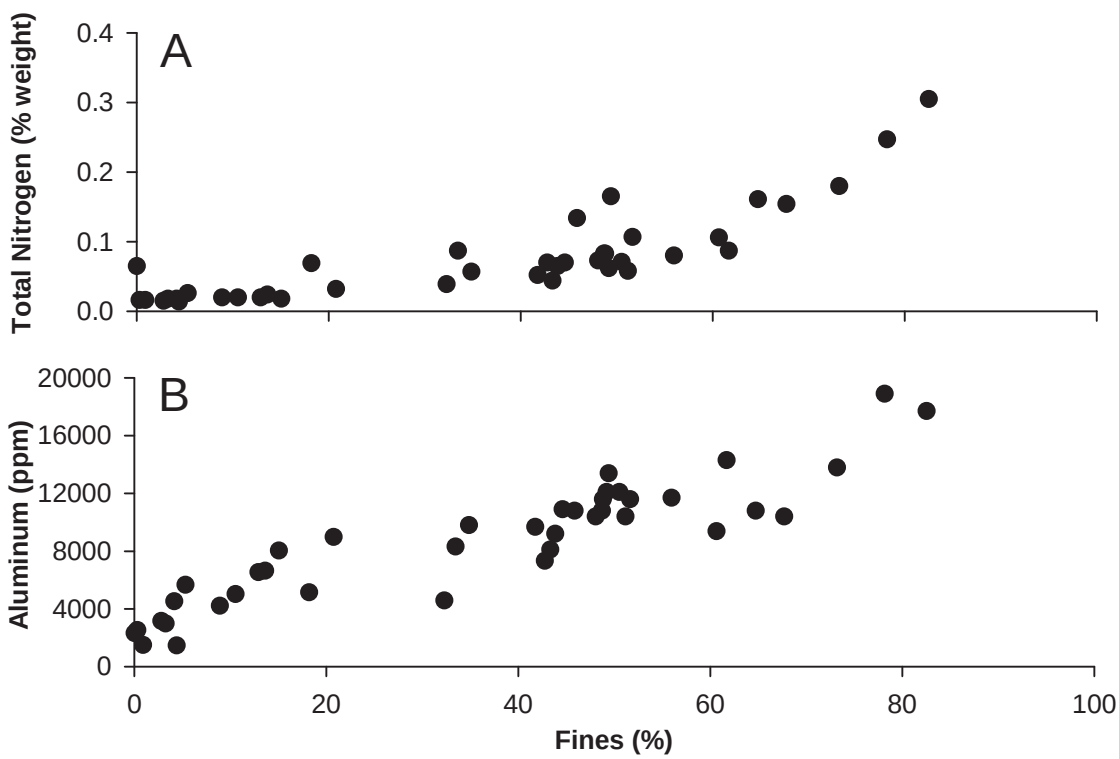

Figure 8.5

Scatterplot of percent fines and concentration of total nitrogen (A) and aluminum (B) in regional sediments in 2009.

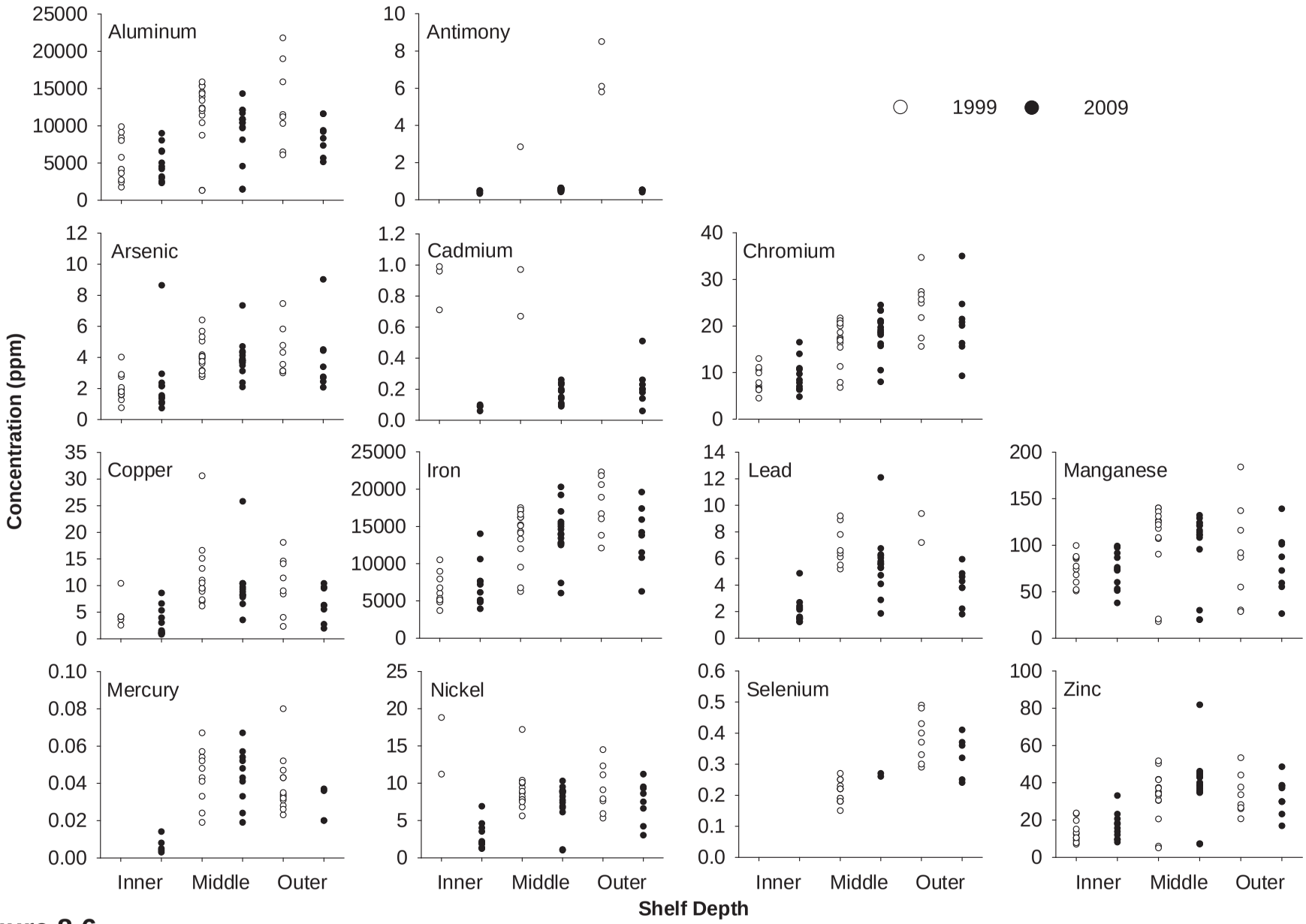

Figure 8.6

Comparison of trace metal concentrations by shelf depth stratum at regional benthic stations in 1999 vs. 2009. Barium was not analyzed in 1999 and is not shown. Four metals (i.e., beryllium, silver, thallium, tin) were not detected in 1999 and are not shown; n=11 (inner), n=15 (middle), n=8 (outer); missing values=non-detects.

Another pesticide, hexachlorobenzene (HCB), was detected almost as frequently as DDT, occurring in sediments from 43% of the stations sampled during the 2009 regional survey. This pesticide occurred throughout the San Diego region, with the highest concentrations occurring at station 2668 (1400 ppt) on the outer shelf and station 2676 (780 ppt) on the mid-shelf. All other samples had HCB concentrations <460 ppt. Concentrations of HCB detected in sediments from the regular SBOO stations were lower overall than those found during the regional survey (see Chapter 4), while analyses were not performed for HCB in 1999. Finally, the pesticides HCH and chlordane were also detected, but at only two sites located at slope depths (i.e., stations 2812 and 2814) that were not sampled in 1999. These two pesticides were not detected in samples collected as part of the SBOO fixed grid survey in 2009.

PCBs and PAHs

PCBs were detected in 23% of the 2009 regional survey sediment samples, most of which came from stations located at mid-shelf depths (Table 8.1, Appendix G.4). The highest total PCB concentration of 34,730 ppt was found in sediments from station 2682 located near the boundary of the inactive LA-4 disposal site. Three additional sites located near LA-4 or between the active LA-5 disposal site and San Diego Bay (i.e., stations 2675, 2676 and 2681) had total PCBs between 2332 and 5867 ppt. In contrast, all other sediment samples had PCB concentrations <2000 ppt. Although the LA-5 site and associated short-dumps are presumed sources of PCB contamination to the region (Parnell et al. 2008), far less is known about the persistence of contaminants in sediments associated with the LA-4 area. Concentrations of PCBs in sediments from regular SBOO monitoring stations were lower overall than those found during the regional survey (see Chapter 4), and no PCBs were detected in sediments during the 1999 regional survey. This lack of PCBs in 1999 may be due in part to the higher MDLs in use at that time.

PAHs were detected in only 15% of the regional stations in 2009, including three sites on the mid-shelf (stations 2675, 2676 and 2682) and three sites along the upper slope (stations 2811, 2815 and 2816) (Table 8.1, Appendix G.4). Sediments from station 2676 located within 1 km of LA-4, and station 2682 located inshore of LA-5, had the highest total PAH levels (165 and 188 ppb, respectively). For these two samples, several constituents comprised total PAH, including benzo[A]anthracene, benzo[A]pyrene, 3,4-benzo[B]fluoranthene, anthracene, chrysene, fluoranthene, and pyrene. In contrast, the other four sites had sediments with PAH concentrations <65 ppb; this consisted primarily of chrysene which may have been due to sample contamination during chemical analysis (see Appendix G.1). The low incidence of PAHs detected in sediments sampled during the 2009 regional survey was consistent with findings from the regular fixed

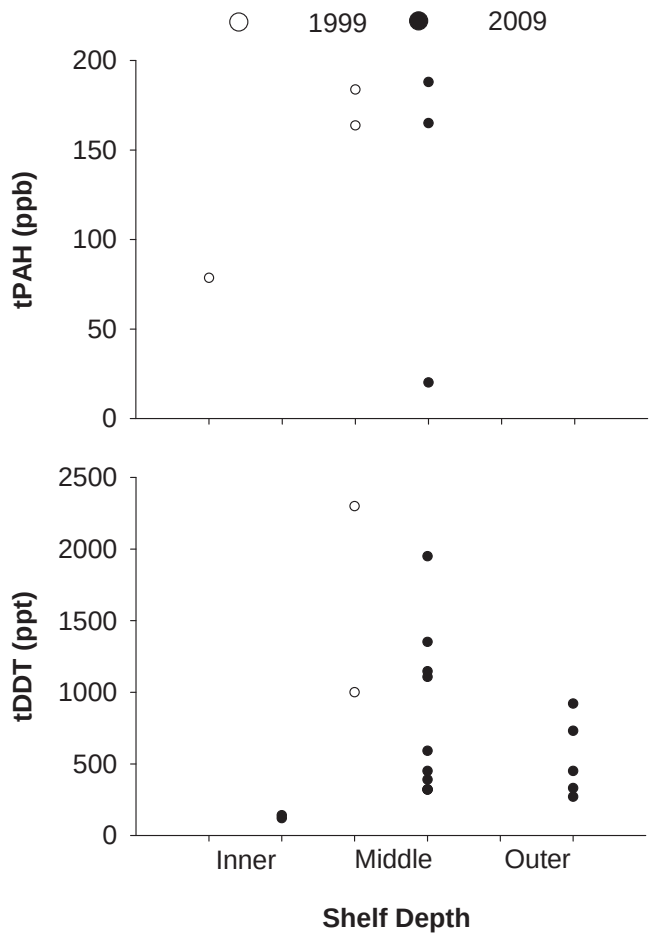

Figure 8.7
Comparison of total PAH (tPAH) and total DDT (tDDT) concentrations by shelf depth stratum at regional benthic stations in 1999 vs. 2009. n = 11 (inner), n =15 (middle), n = 8 (outer); missing values = non-detects.

grid SBOO monitoring where no PAHs were detected. However, PAHs that were detected in sediments during 2009 were generally similar to concentrations found during the 1999 regional survey (Figure 8.7, Appendix G.5).

Summary and Conclusions

Sediment particle size distribution at the regional benthic stations sampled in 2009 was similar to that seen in previous years. For example, substantial changes in average particle size between 1999 and 2009 were observed for only five sites. As in the past, there was a trend towards higher sand content in nearshore areas compared to finer sands and silt at deeper offshore sites, especially along the upper slope. Exceptions to this general pattern occurred along the Coronado Bank, a southern rocky ridge located southwest of Point Loma at a depth of 150–170 m. Sediment composition at stations from this area tended to be coarser than regional mid-shelf stations located off of Point Loma and further to the north.

As with the particle size distribution, regional patterns of sediment contamination in 2009 were consistent with patterns seen in previous years. Total nitrogen, TOC, and many trace metals generally followed the expected pattern of increasing concentrations with decreasing particle size. As the percent fine fraction of the sediments in this region also increased with depth, many contaminants were detected at higher concentrations in deeper strata compared to the shallow and mid-shelf. For example, the highest concentrations of most contaminants occurred in the sediments of the upper slope, which consisted primarily of very fine particles. High levels of various contaminants also occurred in sediments from stations located near the defunct LA-4 disposal sites, and/or between the active LA-5 disposal site and San Diego Bay. Although these disposal sites were intended to contain contaminated dredged material in deep water, "short dumps" have been recorded inshore of LA-5, as far as 2.5 kilometers from the designated site (Gardner et al. 1998). Increased sediment movement in the inshore area of the mid-shelf could result in the re-suspension and transport of contaminated sediments even further from the intended disposal sites (e.g., Parnell et al. 2008). LA-4 has not been studied as a potential source of contamination in the region, and is no longer an active disposal site. However, high concentrations of trace metals, pesticides, PCBs, and PAHs in sediments surrounding this location may be indicative of persistent contamination. Overall, contaminant concentrations were unremarkable when compared to those from other parts of the Southern California Bight (see Noblet et al. 2003, Maruya and Schiff 2009) and the ERL biological threshold values for sediment contamination were only exceeded in five samples (i.e., arsenic at stations 2655 and 2670, nickel at stations 2811 and 2810, DDT at station 2682).

Literature Cited

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. (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. (2010). 2009 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Point Loma 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.

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

Folk, R. L. (1968). Petrology of Sedimentary Rocks. Hemphill, Austin, Texas.

Gardner, J.V., P. Dartnell, and M.E. Torresan. (1998). LA-5 Marine Disposal Site and Surrounding Area, San Diego, California: Bathymetry, Backscatter, and Volumes of Disposal Materials. Administrative Report, July 1998. US Geological Survey, Menlo Park, CA.

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.

Maruya, K.A. and K. Schiff. (2009). The extent and magnitude of sediment contamination in the Southern California Bight. In: H.J. Lee and W.R. Normark (eds.). Earth Science in the Urban Ocean: The Southern California Continental Borderland: Geological Society of America Special Paper 454. p 399–412.

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.

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.

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

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

[U.S. EPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control (QA/QC) for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuarine Protection.