Chapter 8. San Diego Regional Survey Sediment Conditions

INTRODUCTION

Ocean sediments are the primary habitat for macrobenthic invertebrate and demersal fish communities on the coastal shelf and slope. The physical and chemical conditions of these sediments can therefore influence the ecological health of marine communities by affecting the distribution and presence of various species (Gray 1981, Cross and Allen 1993, Snelgrove and Butman 1994). For this reason, sediments have been sampled extensively near Southern California Bight (SCB) ocean outfalls in order to monitor benthic conditions around these and other point sources over the past several decades (Swartz et al. 1986, Anderson and Gossett 1987, Finney and Huh 1989, Stull 1995, Bay and Schiff 1997). While such localized assessments are ongoing for the four largest wastewater dischargers in the region (see City of Los Angeles 2007, 2008, City of San Diego 2010a, b, LACSD 2010, OCSD 2011), larger-scale monitoring efforts from Point Conception to the Mexican border have also become an important tool for evaluating overall sediment conditions in the SCB (Schiff and Gossett 1998, Noblet et al. 2003, Schiff et al. 2006).

The City of San Diego has conducted annual regional benthic surveys off the coast of San Diego since 1994 (see Chapter 1). The primary objectives of these summer surveys, which typically range from Del Mar to the USA/Mexico border, are to (1) describe the overall condition and quality of the diverse benthic habitats that occur off San Diego, (2) characterize the ecological health of the soft-bottom marine benthos in the region, and (3) gain a better understanding of regional variation in order to distinguish anthropogenically-driven changes from natural fluctuations. These surveys typically occur at an array of 40 stations selected each year using a probability-based, random stratified sampling design as described in Bergen (1996), Stevens (1997), and Stevens and Olsen (2004). During 1995–1997, 1999–2002 and 2005–2007, the surveys off San Diego were restricted to continental shelf depths (<200 m), while the area of coverage was expanded in 2009 and 2010 to also include deeper habitats along the upper slope (200–500 m). No survey of randomly selected sites was conducted in 2004 due to sampling for a special sediment mapping project (Stebbins et al. 2004), while surveys in 1994, 1998, 2003 and 2008 were conducted as part of larger, multi-agency surveys of the entire SCB (Schiff and Gossett 1998, Noblet et al. 2003, Schiff et al. 2006, Maruya and Schiff 2009).

This chapter presents results of the analysis and interpretation of sediment particle size and chemistry data collected during the 2010 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, and comparisons of sediment characteristics and quality across the major depth strata defined by the SCB regional programs. Results of the macrofaunal community assessment for these same sites are presented in Chapter 9.

Materials and Methods

Field Sampling

The July 2010 regional survey covered an area ranging from off Del Mar in northern San Diego County south to the USA/Mexico border (Figure 8.1). A total of 40 sites were selected for the survey based on the United States Environmental Protection Agency (USEPA) probability-based Environmental Monitoring and Assessment Program (EMAP) sampling design. These stations ranged in depth from 9 to 433 m, and spanned four distinct depth strata as characterized by the SCB Regional Monitoring Programs (Schiff et al. 2006). These included 8 stations along the inner shelf (5–30 m), 19 stations along the mid-shelf (30–120 m), 6 stations along the outer shelf (120–200 m), and 7 stations on the upper slope (200–500 m).

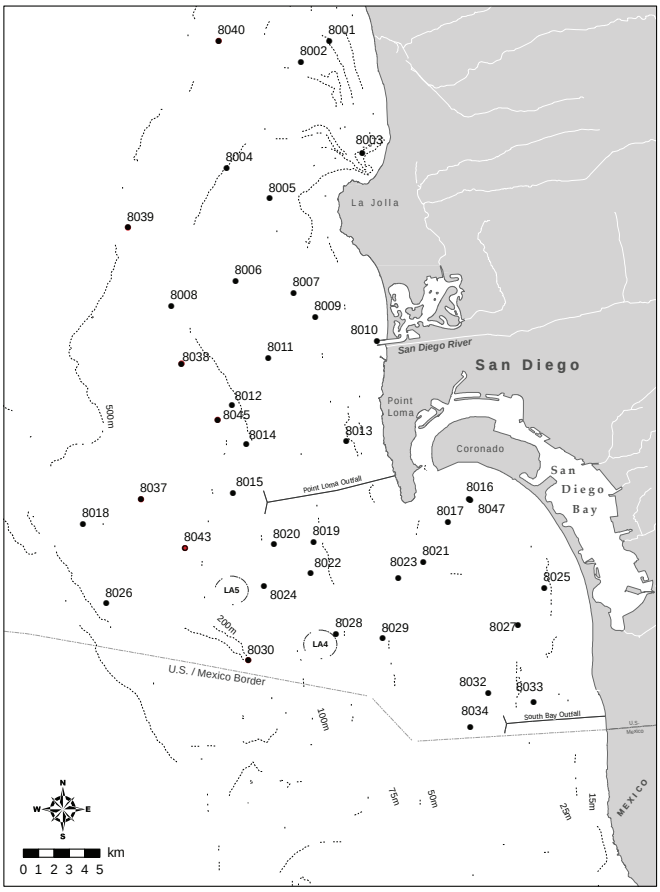

Figure 8.1
Regional benthic survey stations sampled during July 2010 as part of the South Bay Ocean Outfall Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

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

Laboratory Analyses

All sediment chemistry and 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) which 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 the 2010 regional survey, 36 samples were processed by laser analysis and four samples (8013, 8023, 8024, 8033) 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, biochemical oxygen demand (BOD), total volatile solids (TVS), 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, TN, and TVS were measured as percent weight (% wt) of the sediment sample; BOD, 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 HCH (tHCH), total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix G.1 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., 1991–1993).

Multivariate analyses were performed using PRIMER software (Plymouth, UK, 2006) to further explore spatial patterns in regional sediment conditions in 2010. A subset of particle size (e.g., median phi, sorting, percent fines) and chemistry parameters were first normalized and then analyzed by agglomerative hierarchical clustering using Euclidean distances as the basis for classification (Clarke and Gorley 2006). Chemistry parameters were selected for analysis which had detection rates $\geq 25\%$; zeros were substituted for non-detects before analysis. The non-random structure of the dendrogram resulting from cluster analysis was evaluated using similarity profile analysis (SIMPROF), and non-metric multidimensional scaling (nMDS) was used to visualize sample clustering in multivariate space. Specific parameters driving cluster group similarity and dissimilarity were identified using the 'similarity percentages' routine (SIMPER).

Results

Particle Size Distribution

As in previous surveys (e.g., City of San Diego 2010b), overall particle size composition of sediments off San Diego in 2010 consisted primarily of sands and fine particles (Table 8.1). In addition, visual observations of the sediments sampled from throughout the region revealed the presence of several unique types of sands and coarse materials including red relict sand, coarse black sand, gravel, and organic debris (Appendix G.2). The relative

Table 8.1

Summary of particle size and sediment chemistry parameters at regional benthic stations during 2010. Data include detected values averaged by depth stratum, as well as the detection rate, minimum, median, maximum, and mean values for the entire survey area. *n* = number of stations; SD = standard deviation.

	Depth Strata				2010 Survey Area*				
	Inner Shelf (5–30 m) *n* = 8	Mid-shelf (30–120 m) *n* = 19	Outer Shelf (120–200 m) *n* = 6	Upper Slope (200–500 m) *n* = 7	Detection Rate (%)	Min	Median	Max	Mean
Particle Size									
Mean (*mm*)	0.168	0.218	0.085	0.031	**	0.023	0.063	0.786	0.155
Mean (*phi*)	2.68	3.18	3.78	5.06	**	0.35	3.99	5.46	3.50
SD (*phi*)	0.75	1.35	1.68	1.69	**	0.49	1.50	1.97	1.34
Coarse (*%*)	2.4	6.6	0.7	0.0	**	0.0	0.0	43.1	3.7
Sand (*%*)	92.6	63.0	64.2	31.3	**	20.1	63.9	99.5	63.6
Fines (*%*)	5.0	30.4	35.1	68.7	**	0.0	34.6	79.9	32.7
Organic Indicators									
Sulfides (*ppm*)	3.22	4.45	6.23	10.27	93	nd	3.39	24.10	5.64
TN (*% weight*)	0.018	0.057	0.072	0.166	100	0.010	0.055	0.222	0.070
TOC (*% weight*)	0.104	0.808	1.692	2.014	100	0.022	0.604	4.470	1.011
Trace Metals (*ppm*)									
Aluminum	3156	7200	6738	14,107	100	1020	7320	19,400	7531
Antimony	0.43	0.49	0.52	0.89	70	nd	0.42	2.17	0.59
Arsenic	1.43	3.52	3.59	3.28	100	1.11	2.96	6.41	3.07
Barium	17.27	39.60	43.42	73.09	100	1.93	46.65	100.00	41.57
Beryllium	0.04	0.15	0.23	0.30	85	nd	0.16	0.37	0.18
Cadmium	0.06	0.15	0.20	0.39	73	nd	0.13	0.62	0.22
Chromium	7.1	15.1	21.4	28.3	100	3.5	17.5	33.4	16.7
Copper	2.63	8.32	7.37	19.61	100	0.29	7.09	31.20	9.02
Iron	4286	11,226	13,512	17,271	100	3170	12,250	21,400	11,239
Lead	2.29	9.51	4.24	6.33	100	0.89	4.65	91.60	6.72
Manganese	45.3	92.2	64.8	122.5	100	8.2	93.1	235.0	84.0
Mercury	0.018	0.032	0.023	0.052	83	nd	0.024	0.089	0.033
Nickel	1.69	6.04	6.87	16.11	100	0.77	6.06	21.20	7.06
Selenium	—	0.361	0.364	0.827	60	nd	0.268	1.160	0.498
Silver	0.30	0.33	—	—	5	nd	nd	0.33	0.31
Thallium	2.0	—	—	—	3	nd	nd	2.0	2.0
Tin	0.4	0.9	0.7	1.4	80	nd	0.8	2.6	0.9
Zinc	10.1	28.3	28.7	47.8	100	3.9	31.3	58.8	28.2
Pesticides (*ppt*)									
Total HCH	—	—	8500	—	3	nd	nd	8500	8500
Total DDT	—	8000	1307	218	48	nd	nd	75,920	4486
HCB	50	57	—	—	10	nd	nd	81	55
Total PCB (*ppt*)	—	1219	—	3813	20	nd	nd	7335	1867
Total PAH (*ppb*)	—	65.6	—	—	8	nd	nd	101.0	65.6

nd = not detected

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

** Particle size parameters calculated for all samples.

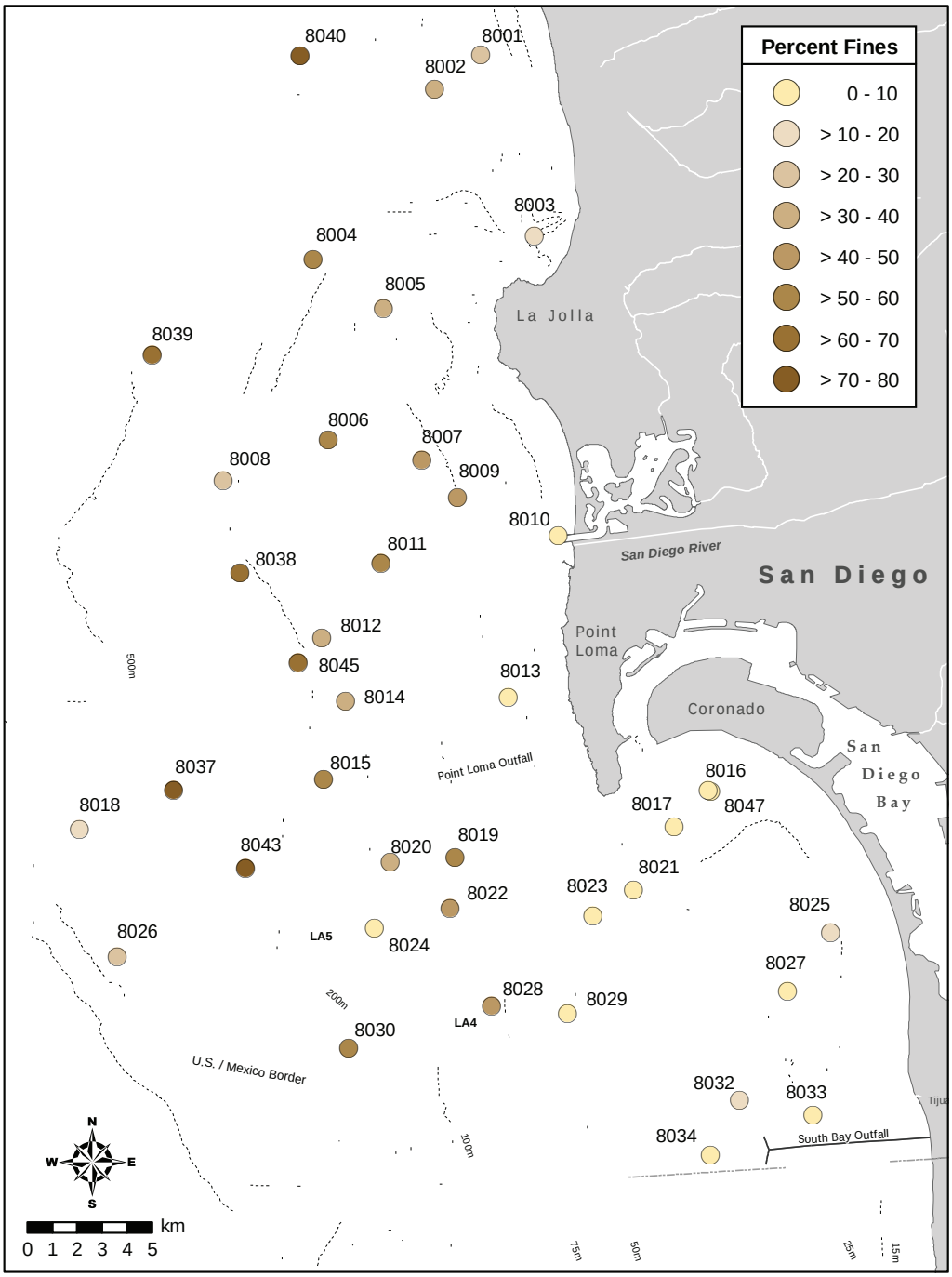

Figure 8.2
Distribution of fine sediments (percent fines) at regional benthic stations sampled during July 2010.

contribution of each particle size fraction varied between stations and by depth strata (Figure 8.2, Appendix G.3). For example, the eight sites located in shallow water along the inner shelf (i.e., ≤30 m) averaged about 5% fines, 93% sands, and 2% coarser particles, whereas the 19 sites located mid-shelf at depths between 31–112 m were characterized by finer sediments of about 30% fines. These results are similar to results of sediment analyses conducted at the SBOO fixed-grid monitoring stations at shallow and mid-shelf depths (see Chapter 4). The six regional sites located on the outer shelf at 123–196 m averaged 35% fines, while the seven sites located along the upper slope at depths >200 m contained the finest sediments of the region (i.e., 69% fines, 31% sands

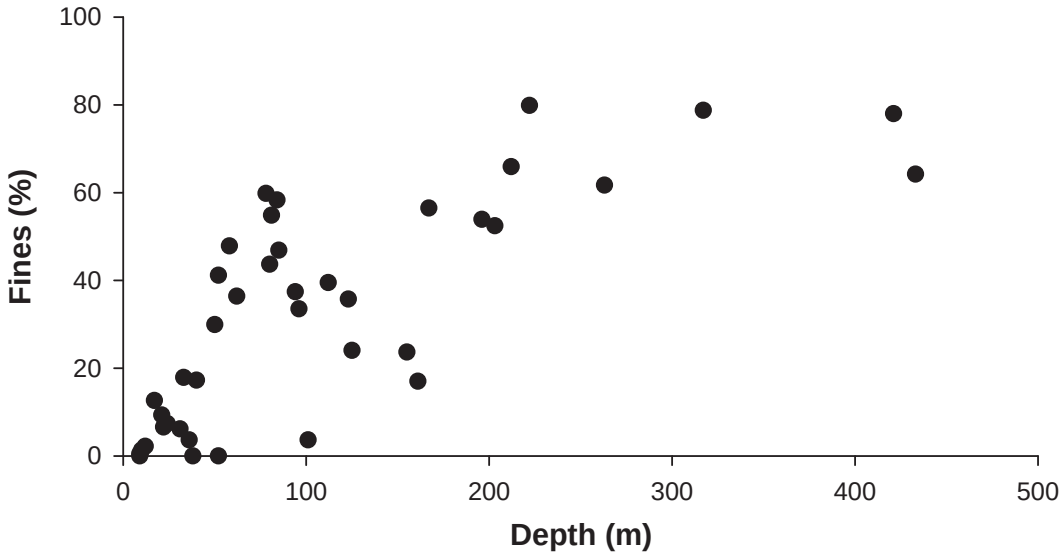

Figure 8.3
Scatterplot of percent fines and depth for regional benthic stations sampled in 2010.

and no coarse fraction). Correlation analysis confirmed that percent fines increased significantly with depth (Spearman Rank correlation coefficient $r_s(40) = 0.78$; $p < 0.001$.; Figure 8.3). The only notable exceptions to this pattern occurred at mid-shelf station 8024 (located ~900 m inshore of the LA-5 dredge material disposal site) and outer shelf station 8018 (located on the Coronado Bank), each of which had lower percent fines than other stations at similar depths (Appendix G.2).

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. Regional sediments ranged from well to poorly sorted, with sorting coefficients ranging from 0.5 to 2.0 (Appendices G.2, G.3). Sediments at shallow stations tended to be well to moderately sorted, with sorting generally decreasing (i.e., becoming more poorly sorted) with depth. These results are consistent with those from the regular SBOO monitoring survey (see Chapter 4). The most well sorted sediments (i.e., with the lowest sorting coefficients) were collected from shallow shelf station 8010, located near the mouth of Mission Bay, and mid-shelf station 8029. These low sorting coefficients are indicative of consistent moderate currents. Stations 8018 and 8030 located on or near the Coronado Bank had the most poorly sorted sediments in the region, which is indicative of more variable currents and sediment transport.

Organic Indicators

Sulfides were detected in 93% of the 2010 regional sediment samples, with average concentrations increasing with each depth stratum. For example, sulfide concentrations averaged about 3.2 ppm at the inner shelf stations, 4.5 ppm at the mid-shelf stations, 6.2 ppm at the outer shelf stations, and 10.3 ppm at upper slope stations (Table 8.1). The highest sulfide concentration (24.1 ppm) was detected at outer shelf station 8015 (Appendix G.4). Several additional stations located throughout the region on the mid-shelf (i.e., 8003, 8013) and upper slope (i.e., 8037, 8038, 8040, 8043, 8045) also contained sediments with relatively high sulfide concentrations (e.g., 10.4–17.5 ppm). Generally, region-wide sulfide concentrations from this study were consistent with those reported for the fixed-grid stations within the SBOO monitoring area (see Chapter 4).

Concentrations of another organic indicator, TN, increased significantly with the proportion of fine sediments in each sample (Table 8.2, Figure 8.4A). Similarly, concentrations of TN

Table 8.2

Results of Spearman rank correlation analyses of percent fines and sediment chemistry parameters from regional benthic samples collected in 2010. Shown are analytes that had correlation coefficients $r_s(40) \geq 0.70$. For all analyses, $p < 0.001$. The strongest correlations with organic indicators and trace metals are illustrated graphically in Figure 8.4 below.

Analyte	r_s
Organic Indicators (% weight)	
Total Nitrogen	0.95
Trace Metals (ppm)	
Aluminum	0.82
Barium	0.78
Beryllium	0.86
Cadmium	0.71
Chromium	0.84
Copper	0.83
Iron	0.73
Lead	0.75
Mercury	0.78
Nickel	0.95
Selenium	0.82
Tin	0.76
Zinc	0.86

tended to increase across depths. For example, TN ranged from 0.02% wt at the inner shelf stations to 0.17% wt at the upper slope stations on average (Table 8.1). The highest TN concentrations occurred at upper slope stations 8037 (0.22% wt) and 8043 (0.21% wt) (Appendix G.4). Unlike TN, TOC was not correlated with percent fines, although as with the pattern described for sulfides, it did generally increase across depth strata (i.e., 0.10% wt on the inner shelf to 2.01% wt on the upper slope). Exceptions to this overall pattern occurred at mid-shelf station 8013 and outer shelf station 8008, where TOC concentrations exceeded 4% wt. Concentrations of both TN and TOC measured at regional stations were similar to those measured at the regular fixed-grid SBOO monitoring stations (see Chapter 4).

Trace Metals

Aluminum, arsenic, barium, chromium, copper, iron, lead, manganese, nickel and zinc were detected in all sediment samples collected during the 2010 regional survey (Table 8.1). Antimony, beryllium, cadmium, mercury, selenium and

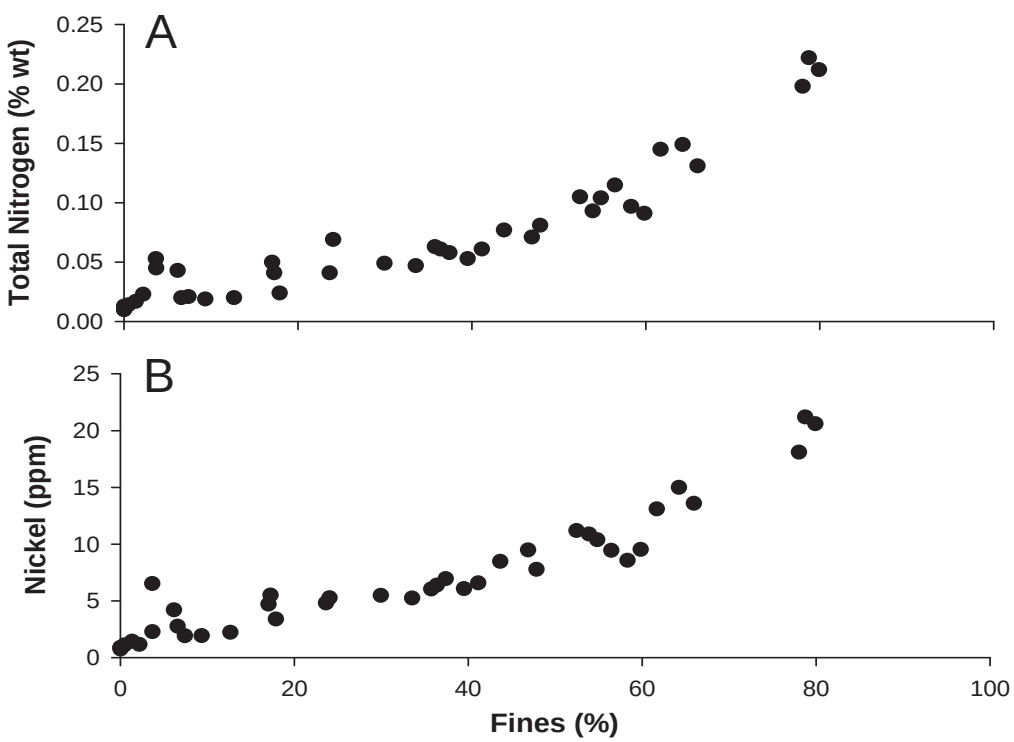

Figure 8.4

Scatterplot of percent fines and concentration of (A) total nitrogen and (B) nickel in regional sediments in 2010.

tin were detected less frequently (e.g., 60–85%), while silver and thallium were detected in fewer than 10% of samples. Concentrations of 13 metals (i.e., aluminum, barium, beryllium, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, tin, zinc) increased significantly with percent fines (Table 8.2, Figure 8.4B). The highest concentrations of these metals occurred at the deeper, upper slope stations where the greatest percent fines occurred (i.e., stations 8037, 8040, 8043). The single exception to this pattern was for lead, which was detected at its highest concentration of about 92 ppm at inner shelf site 8023 (6.1% fines). As with the regular fixed-grid SBOO monitoring sites, most metal concentrations across the region were below the ERL biological threshold (Appendix G.4). Only two exceptions to this occurred, including: (1) the ERL for lead (46.7 ppm) was exceeded at mid-shelf station 8023 (91.6 ppm); (2) the ERL for nickel (20.9 ppm) was exceeded at upper slope station 8037 (21.2 ppm). None of the samples collected during 2010 had metal concentrations that exceeded ERM thresholds.

Pesticides

Pesticides were detected in approximately half of the regional sediment samples collected during 2010 (Table 8.1, Appendix G.4) at concentrations generally comparable to those found at the regular fixed-grid SBOO monitoring stations. Total DDT (primarily p,p-DDE) was the most prevalent pesticide, occurring in sediments from 48% of the stations at concentrations averaging 8000 ppt along the mid-shelf, 1307 ppt along the outer shelf, and 218 ppt along the upper slope. This pesticide was not detected at inner shelf depths, and only two samples contained concentrations that exceeded threshold values. The latter included sediments from outer shelf station 8012, which contained concentrations of tDDT that exceeded the ERL of 1580 ppt, and sediments from the mid-shelf station 8028 that exceeded the ERM of 46,100 ppt.

Another pesticide, hexachlorobenzene (HCB), occurred in sediments from just 10% of the sites sampled during 2010. This pesticide occurred at four sites located at inner and mid-shelf depths, at concentrations somewhat lower than those found during the SBOO fixed-grid surveys (see Chapter 4). The highest concentration of HCB (81 ppt) occurred on the mid-shelf at station 8022. In addition, the pesticide hexachlorocyclohexane (HCH) was detected at a single station (8012), located on the outer shelf, at a total concentration of 8500 ppt. This pesticide was not detected during regular SBOO monitoring.

PCBs and PAHs

PCBs were detected in 20% of the regional survey sediment samples during 2010. These compounds were only detected at stations from mid-shelf and upper slope depths (Table 8.1, Appendix G.4). The highest total PCB concentration of 7335 ppt occurred in sediments from station 8045 located along the upper slope. Sediments from stations 8028 and 8024 also contained tPCB concentrations greater than 1200 ppt. The most prevalent congeners detected were PCB 138, PCB 149 and PCB 153/168, each occurring in four or more samples (Appendix G.1). Nineteen additional PCB congeners were detected throughout the region, but only in three samples or fewer for each. In general, regional PCB concentrations were higher than those found at the regular fixed-grid SBOO stations sampled during 2010, where this contaminant was detected in only 4% of samples with an areal mean of 182 ppt (see Chapter 4).

PAHs were detected in only 8% of the sediment samples collected from the regional stations in 2010, at three sites on the mid-shelf (i.e., stations 8019, 8024, and 8028) (Table 8.1, Appendix G.4). Sediments from stations 8024 and 8028 had the highest total PAH concentrations (71 and 101 ppb, respectively). The PAH compounds benzo[A]pyrene and 3,4-benzo(B)fluoranthene were each detected in two sediment samples, whereas the compounds benzo[A]anthracene, benzo[G,H,I]perylene, fluoranthene, and pyrene were each detected only once (Appendix G.1). The low incidence of PAHs detected in sediments sampled during 2010 was

consistent with findings from the regular fixed-grid SBOO monitoring where no PAHs were detected.

Classification of Sediment Conditions

Results of ordination and the cluster analysis discriminated five groups of sediment samples (Figure 8.5). These groups (cluster groups A–E) varied in terms of particle size composition and contaminant concentrations, and occurred at sites separated along a general depth gradient (Figure 8.5, Table 8.3). The SIMPROF procedure indicated statistically significant non-random structure of the cluster dendrogram (global test: $\pi = 1.37$, $p < 0.001$) and an nMDS ordination of samples supported the validity of the cluster groups (Figure 8.5B).

SIMPER analysis was used to identify parameters that were characteristic of samples within a cluster group (Table 8.3) and parameters that discriminated between cluster groups (Appendix G.5). Cluster group A comprised four samples collected from upper slope depths which contained the greatest average percent fines, the highest concentrations of organics (i.e., sulfides, TN, TOC), and 12 of the 16 metals included in the analysis (several of which correlate with fines; Table 8.2). These relatively high concentrations of organics and metals also distinguished this cluster group from groups B–E. Cluster group B consisted of a single sample, collected from mid-shelf station 8023, which had a concentration of lead ten times greater than other groups. Cluster group C also consisted of a single sample collected from mid-shelf station 8028. This sample had a concentration of tDDT (75,920 ppt) which was twenty-times higher than other tDDT concentrations measured during the survey (Appendix G.4). Cluster group D comprised 12 sediment samples from the inner and mid-shelf, including the majority of regional samples collected from within the regular SBOO monitoring area. This group was characterized by relatively low concentrations of contaminants. For example, this group contained the lowest average concentrations of TN, TOC, and of 14 of the 16 metals analyzed. Lastly, cluster group E consisted of 22 samples from the mid-shelf, outer shelf, and upper slope. This cluster group contained concentrations of most chemistry parameters that were intermediate relative to those characteristic of groups A and D.

Discussion

Sediment particle size conditions at the regional benthic stations sampled in 2010 were typical for the continental shelf and upper slope off the coast of southern California (Emery 1960), and consistent with results from previous surveys (e.g., City of San Diego 2008, City of San Diego 2010b). These sediments consisted mainly of sands, while silt and clay (percent fines) increased with sample depth. However, several exceptions to this overall pattern occurred throughout the region, particularly 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 tend to be coarser than stations at similar depths located off of Point Loma and further to the north. Similarly, much of the additional variability in particle size composition throughout the region may be due to the complexities of seafloor topography and current patterns, both of which affect sediment transport and deposition (Emery 1960, Patsch and Griggs 2007). For example, the presence of red relict sands, and lack of silt or clay, at station 8034 suggests this site receives or retains very little recent sediment deposition. In contrast, several other stations lie within accretion zones of coastal littoral cells and receive more frequent deposition of sands and fine particles. The diverse sediment transport and deposition patterns are further illustrated by the range of sorting coefficients measured in regional sediments in 2010. Well-sorted sediments (i.e., SD $\leq$0.5 phi) tended to occur at the inner shelf and shallow mid-shelf stations and are indicative of areas subject to consistent, moderate currents. In contrast, the most poorly sorted sediments (i.e., SD$\geq$1.5 phi) occurred at deeper stations of the outer shelf and upper slope. This level of sorting is typical of areas with fluctuating weak to violent currents or rapid deposition (e.g., resulting from storm surge or dredge material dumping) that often result in highly variable or patchy particle size distributions (Folk 1980).

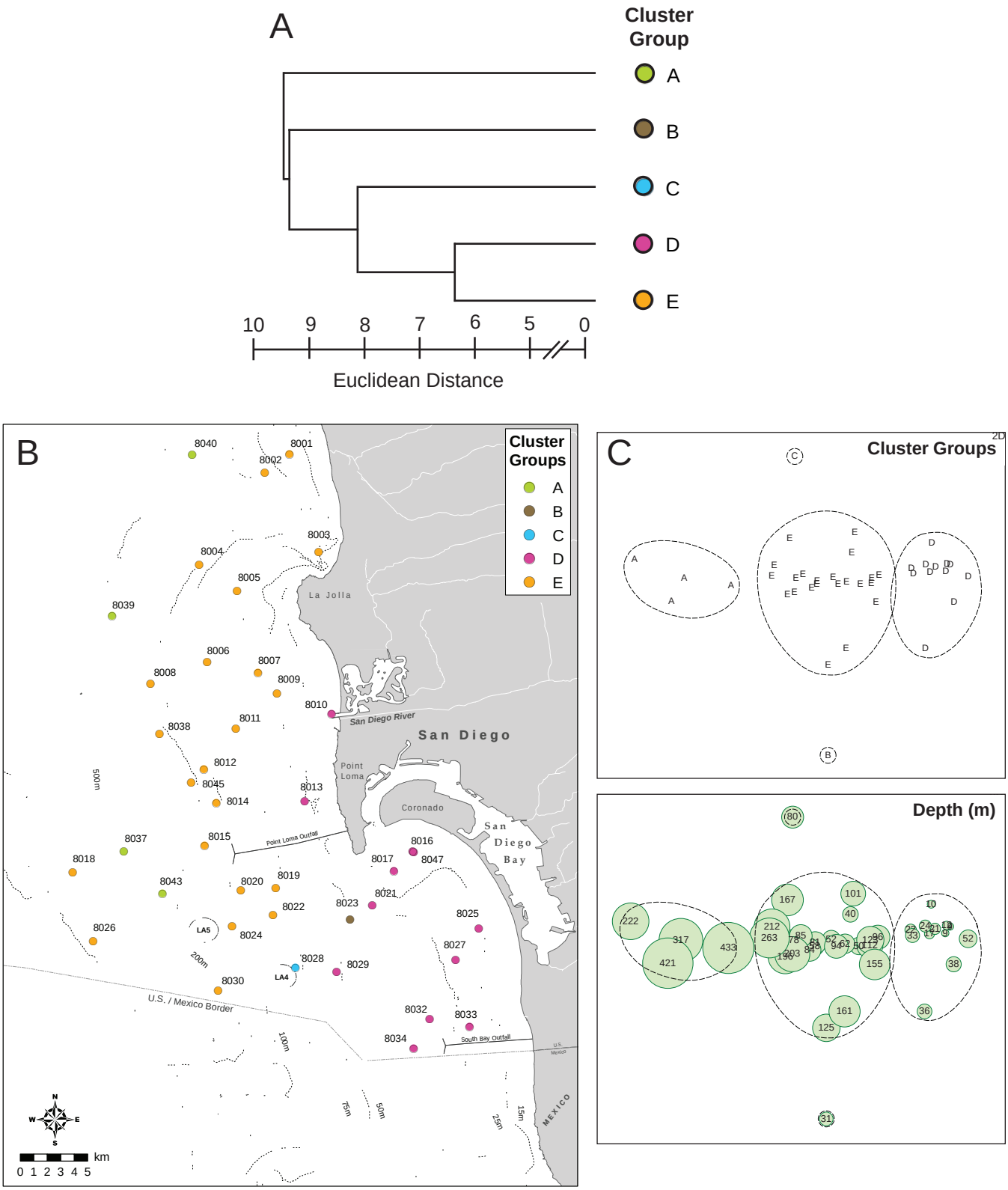

Figure 8.5

Results of multivariate analyses of sediment particle size and chemistry data for the regional benthic statons sampled during 2010. Data are presented as: (A) cluster results; (B) spatial distribution of sediment samples as delineated by cluster analysis; (C) nMDS ordination illustrating distribution of samples in multivariate space. The top panel illustrates the distribution of samples within each group while the lower panel shows a bubble plot of sample depth. nMDS plot stress = 0.08. Dashed ellipses enclose station groups within a Euclidean distance of 6.0.

Table 8.3

Description of cluster groups A–E defined in Figure 8.5. Data include number of samples, average depth (m), and the average percent or concentration of each parameter used in the multivariate analyses, summarized by cluster group. While analyses were conducted on normalised data, average values shown below were calculated using actual values for ease of interpretation. Zeros were substituted for non-detects for the purpose of analysis and data summary (see text). Bold values indicate the three parameters that were considered most characteristic of that group according to SIMPER analysis (i.e., greatest percent contribution to within-group similarity). SD = standard deviation.

	Group A	Group B	Group C	Group D	Group E
Number of Samples	4	1	1	12	22
Depth	348	31	80	24	118
Parameter	**Average Percentage/Concentration**				
Particle Size					
Median *(phi)*	5.4	1.0	3.7	2.2	3.6
SD *(phi)*	1.6	1.4	1.6	**0.8**	1.6
Fines *(%)*	75.2	6.1	43.7	5.1	40.8
Organic Indicators					
Sulfides *(ppm)*	9.38	0.69	3.91	2.55	**6.18**
TN *(% weight)*	0.195	0.043	0.077	0.020	0.076
TOC *(% weight)*	2.318	2.310	0.738	**0.449**	**1.033**
Trace Metals (ppm)					
Aluminum	17,400	4750	12,000	2858	8209
Antimony	**1.20**	0.50	0.60	0.18	0.37
Arsenic	3.41	6.41	3.95	**1.92**	3.45
Barium	87.3	22.5	44.9	15.3	48.3
Beryllium	0.33	0.12	0.19	0.02	0.19
Cadmium	**0.45**	0.17	0.12	0.02	0.18
Chromium	32.1	13.3	18.0	7.5	19.1
Copper	23.8	10.4	15.7	2.6	9.5
Iron	19,250	17,700	12,100	4509	13,120
Lead	7.01	**91.60***	9.36	2.37	5.06
Manganese	139.3	235.0	102.0	39.1	90.8
Mercury	0.066	0.000	0.062	0.008	**0.030**
Nickel	18.7	4.2	8.5	1.7	7.9
Selenium	1.05	0.00	0.28	0.02	0.33
Tin	**1.65**	1.70	1.50	0.12	0.85
Zinc	54.1	39.0	40.9	9.6	32.5
Pesticides (ppt)					
Total DDT	130	0	**75,920***	0	399

*Within-group similarity cannot be calculated for cluster groups consisting of a single sample. However, this parameter distinguished the cluster group from all others in between-group comparisons.

As with the particle size distribution, regional patterns of sediment contamination in 2010 were similar to patterns seen in previous years. For example, concentrations of total nitrogen and several trace metals were found to increase with increasing amounts of fine sediments (percent fines). As percent fines also increased with depth in the region, many contaminants were detected at higher concentrations in deeper strata compared to the shallow and mid-shelf. For example, the highest concentrations of most contaminants occurred in sediments along the upper slope, where some

of the finest sediments were measured. Results of the multivariate analyses also confirm this pattern. Sediment samples clustered along a general depth gradient, with the deeper cluster groups containing higher contaminant loads than samples from shallower stations. Exceptions to this included mid-shelf stations 8023 and 8028, which clustered as separate, single-sample groups due to anomalously high lead and tDDT concentrations, respectively, compared to the surrounding region during this survey and previous years (City of San Diego 2007, Maruya and Schiff 2009). Station 8028 also contained the highest levels of PAHs and the second-highest levels of PCBs measured in 2010. This station is located approximately 0.14 km from the LA-4 dredge material disposal site which has been out of use since the early 1980s (USEPA 1988). High levels of various contaminants have historically occurred in sediments from stations located near this site, 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 a small area of 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 (Parnell et al. 2008). Although LA-4 has not been studied as a potential source of contamination in the region, high concentrations of pesticides, PCBs and PAHs in sediments surrounding this location may be indicative of legacy contamination.

Overall, there was no evidence of substantial degradation of sediment quality in the general San Diego region during July 2010. For instance, the ERL biological threshold values for sediment contamination were only exceeded in four samples (i.e., lead at station 8023, nickel at station 8037, and DDT at stations 8012 and 8028). The tDDT concentration measured at station 8028 was also the only exceedance of the ERM biological threshold in regional sediments in 2010. The majority of samples collected during the survey contained relatively low contaminant concentrations for the region (City of San Diego 2007) as well as the greater Southern California Bight (Noblet et al. 2003, Maruya and Schiff 2009).

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