The Geological Society of America
Special Paper 454
2009

The extent and magnitude of sediment contamination in the Southern California Bight

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ABSTRACT

More than 30 million dollars are expended annually to assess environmental quality of the Southern California Bight, yet only 5% of the Bight area is surveyed on an ongoing basis. Because decision makers lacked the data to make regional assessments of ecosystem condition, multiple stakeholders collaborated to create a Southern California Bight Regional Monitoring Program. The third survey in this program was conducted in 2003. A primary goal of this regional monitoring program was to determine the extent and magnitude of sediment contamination in the Southern California Bight, and to compare these assessments among several different habitats. A stratified random design was selected to provide unbiased areal assessments of environmental condition; 359 surficial sediments were collected, representing 12 different habitats that extend from shallow embayments and estuaries to deep offshore basins. Each sample was analyzed for grain size, total organic carbon and nitrogen (TOC/TN), 15 trace metals, and a suite of persistent organic constituents (total dichloro-diphenyl-trichloroethane [DDT], total polychlorinated biphenyl [PCB], and total polynuclear aromatic hydrocarbon [PAH]). The greatest accumulated mass of these constituents (76% on average; range 70% to 87%) was located at depths >200 m, which was proportional to its relatively large area (67% of entire Southern California Bight). The greatest sediment concentrations of trace metals, total PAH, and total PCB were observed in embayments (e.g., marinas, estuaries draining urbanized watersheds, and industrialized port facilities). These shallow habitats also contained a disproportionately high mass of contaminants relative to their area. Despite the relatively widespread anthropogenic enrichment of Southern California Bight sediments, only 1% of the Southern California Bight was at a moderate to high risk of adverse biological effects based on empirically derived sediment quality guidelines. Risk, however, was not evenly distributed throughout the Southern California Bight. The greatest risk of adverse biological effects was found in sediments of marinas, Los Angeles estuaries, and large publicly owned treatment works (POTWs); these were the only habitats for which the mean effects range-median quotient (ERMQ) exceeded 0.5. The least risk was observed in sediments associated with the Channel Islands and small POTWs, for which all sites were considered to be at low risk of adverse biological effects.

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Maruya, K.A., and Schiff, K., 2009, The extent and magnitude of sediment contamination in the Southern California Bight, *in* Lee, H.J., and Normark, W.R., eds., Earth Science in the Urban Ocean: The Southern California Continental Borderland: Geological Society of America Special Paper 454, p. 399–412, doi: 10.1130/2009.2454(6.2).

INTRODUCTION

The open embayment between Point Conception, California, and Cape Colnett, Baja California, otherwise known as the Southern California Bight is an important and unique ecological and economic resource (Fig. 1). The Southern California Bight is a transitional area where currents carrying cooler, temperate ocean waters from the north meet warmer, tropical waters from the south. The complex and varied topography of the Bight, with its offshore islands, submarine canyons, ridges, and basins, supports a variety of nearshore and offshore marine habitat. These characteristics allow for a high degree of biodiversity, with more than 500 species of fish and 1500 species of invertebrates inhabiting these waters (Dailey et al., 1993). As a major migration route, transient populations of marine birds and mammals add species richness to the Bight, making it among the most diverse of all Northern Hemisphere temperate coastal systems.

Home to the nation's largest commercial port (Los Angeles and Long Beach Harbor) and one of the largest U.S. Naval complexes, the Southern California Bight is a tremendous economic resource as well. More than 175 million beach-goer days in the Southern California coastal areas annually bring an estimated $9 billion into the regional economy (Schiff et al., 2000; National Research Council, 1990). Recreational activities such as diving, swimming, surfing, and boating also fuel the economy, with recreational fishing alone accounting for more than $500 million per year (Kildow and Colgan, 2005). As a result, the land margin of the Bight is one of the most densely populated coastal regions in the country, with ~16.5 million people inhabiting five coastal counties bordering its waters, a number projected to increase to over 20 million by 2020 (Fig. 1; State of California, 2001)

Large population centers attract industry and have historically experienced large-scale conversion of open land into nonpermeable surfaces. More than 75% of Southern Californian bays and estuaries have been dredged and filled for conversion into harbors and marinas (Horn and Allen, 1985). This "hardening of the coast" increases the rate of runoff and can impact water quality through the addition of sediment, toxic chemicals, pathogens, and nutrients to the ocean. In addition to increased nonpoint source loading, the Southern California Bight is home to 15 municipal wastewater treatment facilities, eight power-generating stations, ten industrial treatment facilities, and 18 oil platforms that discharge to the open coast (Schiff et al., 2001). Thus, anthropogenic activities can greatly impact the quality of the coastal marine environment.

Each year, local, state, and federal agencies spend in excess of $31 million to monitor the environmental quality and the health of natural resources in the Southern California Bight

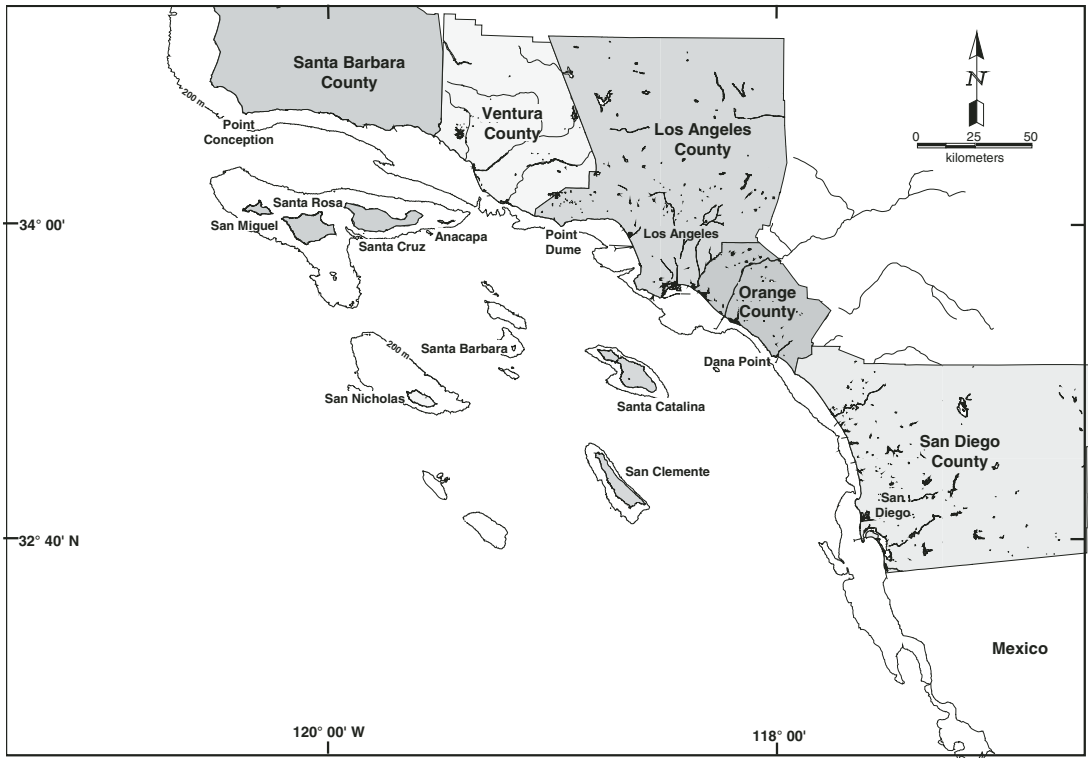

Figure 1. The Southern California Bight (SCB) extends from Point Conception, California, to Cabo Colnett (near Ensenada), Baja California, Mexico. The northern Channel Islands (Anacapa, Santa Cruz, Santa Rosa, and San Miguel) are within the borders of the Channel Islands National Marine Sanctuary.

(Schiff et al., 2002). The majority of this effort is intended to assess compliance of waste discharge, as specified in National Pollutant Discharge Elimination System (NPDES) permits, with water-quality standards for effluent and receiving waters from the California Ocean Plan and Federal Clean Water Act. These monitoring programs have value in addressing specific point-source impacts, but their spatial coverage is small, representing ~5% of the total Southern California Bight area. Moreover, commonality among methods and data quality is not required, resulting in a geographical database that is not easily merged.

In response, a Bight-wide regional monitoring survey designed to assess the extent and magnitude of impacts for several indicators of environmental quality, including sediment (trace metal and organic) contaminants, was first carried out as a pilot project in 1994 (Schiff and Gossett, 1998) and then again in 1998 (Noblet et al., 2002). Since both surveys included participation by multiple analytical laboratories, extensive intercalibration studies were performed to increase data comparability and accuracy (Gossett et al., 2003). Whereas the 1994 pilot study sampled some 264 sites distributed throughout the mainland continental shelf, the 1998 survey was expanded to include embayments.

The purpose of this study was to expand previous regional surveys and assess the extent and magnitude of sediment contamination in the Southern California Bight. The expansion moves the survey from the mainland continental shelf and large embayments to estuaries, mainland continental slopes and basins, and offshore islands. Assessing the extent and magnitude of sediment contamination allows environmental managers to more effectively gauge the overall environmental health of the Southern California Bight, compare the relative risk from sediment contamination among habitats, describe regional reference condition, and evaluate the potential for cumulative effects from multiple sources of potential pollutants.

MATERIALS AND METHODS

Sampling Design

A stratified random design was selected to provide areal assessments of contamination (Stevens, 1997) among 12 geographical strata, including three mainland shelf (5–30 m, 30–120 m, and 120–200 m water depth), upper mainland slope (200–500 m), lower slope and basin (500–1000 m), embayments (marinas, other ports, bays, and/or harbors), estuaries (Los Angeles area estuaries and other Southern California Bight estuaries), large (>100 mgd [million gallons per day]) and small (<100 mgd) publicly owned treatment works (POTWs), and the Channel Islands National Marine Sanctuary (30–120 m, surrounding Santa Barbara, Anacapa, Santa Cruz, Santa Rosa, and San Nicolas Islands) (Fig. 1 and Table 1). Assuming a binomial probability distribution and p value of 0.2, the goal of this sampling design was to allocate ~30 sites to each stratum, yielding a 90% confidence interval of ±10% around estimates of areal extent.

Sediment Collection

Grab samples were collected within 100 m of the location specified by the sampling design from the top 2 cm of sediment using a 0.1 m^2 modified VanVeen sampler (Stubbs et al., 1987). After compositing, samples were placed in pre-cleaned, Environmental Protection Agency (EPA)–certified glass containers with Teflon®-lined closures (500 mL) and kept cold (4 °C) during transport from the field to the laboratory. All samples for trace constituent and total organic carbon (TOC) analyses were frozen at –20 °C within 24 h. Subsamples for grain size analysis were stored at 4 °C (Bight'03 Field Sampling and Logistics Committee, 2003). After collection, samples were distributed to the appropriate participating laboratories for analysis. A total of 359 sediment samples (26–33 samples per stratum) were collected.

Laboratory Analysis

Fifteen trace metals, 24 polynuclear aromatic hydrocarbons (PAHs), 41 polychlorinated biphenyl (PCB) congeners selected for their potential toxicity and likelihood of occurrence (McFarland and Clarke, 1989), eight chlorinated pesticide compounds, six dichloro-diphenyl-trichloroethane (DDTs), and two chlordanes were targeted in this study (Table 2). Specific analytical methods were employed at the discretion of the participating laboratories, contingent upon their ability to demonstrate acceptable performance as specified through a performance-based quality assurance and quality control (QA/QC) program. This program included guidelines for determining analyte-specific method detection limits (MDLs) per EPA 40 CFR Part 136, analysis of procedural blanks, matrix spikes, and standard reference materials (SRMs), and participation in a project intercalibration exercise. Detailed analytical QA/QC performance criteria are specified elsewhere (Bight'03 Coastal Ecology Committee, 2003).

TABLE 1. ESTIMATED DISTRIBUTION OF AREA BY SAMPLING STRATA FOR THE SOUTHERN CALIFORNIA BIGHT

Stratum	Area (km^2)	Total Bight (%)
Inner shelf (5–30 m)	1065	7.0
Mid shelf (30–120 m)	1782	11.8
Outer shelf (120–200 m)	552	3.6
Upper slope and basin (200–500 m)	2952	19.5
Lower slope and basin (500–1000 m)	7318	48.3
Marinas	16	0.10
Estuaries	6.3	0.04
Los Angeles estuaries	1.2	0.01
Ports/bays/harbors	77	0.51
Small POTW outfalls	26	0.17
Large POTW outfalls	166	1.1
Channel Islands (30–120 m)	1208	8.0
Southern California Bight	15,169.5	100.0

Note: POTW—publicly owned treatment works.

TABLE 2. TRACE CONSTITUENTS ANALYZED IN SEDIMENTS COLLECTED FOR THE BIGHT'03 STUDY

Trace metals	PAHs	PCBs	Pesticides	Other constituents
Aluminum	Low molecular weight	PCB-18	4,4'-DDT	Grain size
Antimony		PCB-28	2,4'-DDT	Total organic carbon
Arsenic	Acenaphthene	PCB-37	4,4'-DDD	Total nitrogen
Barium	Acenaphthylene	PCB-44	2,4'-DDD	
Beryllium	Anthracene	PCB-49	4,4'-DDE	
Cadmium	Biphenyl	PCB-52	2,4'-DDE	
Chromium	Fluorene	PCB-66	alpha-chlordane	
Copper	2-Methylnapthalene	PCB-70	gamma-chlordane	
Iron	1-Methylphenanthrene	PCB-74		
Lead	Naphthalene	PCB-77		
Mercury	1-Methylnapthalene	PCB-81		
Nickel	2,6-Dimethylnaphthalene	PCB-87		
Selenium	1,6,7-Trimethylnaphthalene	PCB-99		
Silver	Phenanthrene	PCB-101		
Zinc		PCB-105		
		PCB-110		
	High molecular weight	PCB-114		
		PCB-118		
	Benz[a]anthracene	PCB-119		
	Benzo[a]pyrene	PCB-123		
	Benzo[b]fluoranthene	PCB-126		
	Benzo[e]pyrene	PCB-128		
	Benzo[g,h,i]perylene	PCB-138		
	Benzo[k]fluoranthene	PCB-149		
	Chrysene	PCB-151		
	Dibenz[a,h]anthracene	PCB-153		
	Fluoranthene	PCB-156		
	Indeno[1,2,3-c,d] pyrene	PCB-157		
	Perylene	PCB-158		
	Pyrene	PCB-167		
		PCB-168		
		PCB-169		
		PCB-170		
		PCB-177		
		PCB-180		
		PCB-183		
		PCB-187		
		PCB-189		
		PCB-194		
		PCB-201		
		PCB-206		

Note: PAH—polynuclear aromatic hydrocarbons; PCB—polychlorinated biphenyl; DDT—dichloro-diphenyl-trichloroethane; DDD—dichloro-diphenyl-dichloroethane; DDE—dichloro-diphenyl-dichloroethylene.

Metals

Sediment samples for trace-metal analytes (except mercury) were digested in strong acid according to EPA Method 3050B (formerly 3055) and analyzed by inductively coupled plasma–mass spectrometry (ICP-MS) and/or flame, graphite furnace, and/or hydride generation atomic absorption spectroscopy (AAS). Mercury was analyzed by cold vapor–atomic fluorescence spectroscopy (CVAFS). The required trace-metal reporting levels (RLs) for this study were specified as one-fifth the effects range-low (ERL) sediment quality guideline (Long et al., 1995).

Organics

Dried sediment samples were extracted using an organic solvent (typically CH_2Cl_2), cleaned up and/or fractionated using preparative solid-liquid chromatography, and analyzed by dual-column gas chromatography with electron capture detection (GC-ECD) and/or gas chromatography–mass spectrometry (GC-MS). The required RLs for individual PAHs, PCB congeners, and other organochlorine pesticides were 50–100, 7.5, and 1 ng/g dry weight (wt.), respectively.

Grain Size

Particle-size distribution was measured using a Coulter LS230 or Horiba LA900 instrument, both of which are based on light-scattering technology and have a minimum effective measurement size range of 0.04–1000 μm. Because the maximum particle-size detection threshold differed between instruments, all samples were screened through 1000 μm and 2000 μm sieves prior to analysis to ensure comparability of data, with the fraction greater than 2000 μm designated as gravel.

Total Organic Carbon and Nitrogen

Thawed sediments were homogenized and oven dried at 60 °C overnight prior to removal of inorganic carbon with concentrated HCl. Total organic carbon (TOC) and total nitrogen (TN) were then determined for the acid-treated samples using a Carlo Erba 1108 CHN Elemental Analyzer.

Data Analysis

To assess the extent and magnitude of sediment contamination: (1) distributions and central tendencies of parameter values (i.e., trace contaminant concentrations) including the area-weighted mean and confidence interval for each of the strata of interest as well as the entire Southern California Bight; (2) geographical distributions of contaminant concentrations, including thematic maps of sediment contaminant concentrations; (3) the proportion of contaminant mass for each constituent relative to the fractional area associated with individual strata; and (4) a comparison of sediment concentrations with various sediment quality thresholds and the extent of sediment contamination were generated, computed, and/or performed. All sediment concentrations were reported on a dry weight basis.

Calculation of Area-Weighted Means and Confidence Intervals

The area-weighted mean for each stratum was calculated using a ratio estimator approach (Thompson, 2002):

$$m = \frac{\sum_{i=1}^{n} (p_i * w_i)}{\sum_{i=1}^{n} w_i}, \quad (1)$$

where:
m = area-weighted mean concentration for population j,
p_i = parameter value (e.g., concentration) at station i,
w_i = area weight for station i,
n = number of stations in population j.

The ratio estimator was used in lieu of a stratified mean because an unknown portion of each stratum was not represented in the sampling design (e.g., areas of hard bottom). Thus, the estimated area (a random variable) was used in the denominator rather than the (unknown) true area. The standard error (SE) of the mean was calculated using the following equation:

$$\text{Standard error (SE)} = \sqrt{\frac{\sum_{i=1}^{n} ((p_i - m) * w_i)^2}{\left(\sum_{i=1}^{n} w_i\right)^2}}, \quad (2)$$

where:
m = area-weighted mean concentration for population j,
p_i = parameter value (e.g., concentration) at station i,
w_i = area weight for station i,
n = number of stations in population j.

The 95% confidence interval about the mean was calculated as 1.96 * SE. Use of the ratio estimator for the SE approximates joint inclusion probabilities among samples and assumes a negligible spatial covariance, which appeared to be valid after examination of the data. This assumption is also conservative, in that its violation would lead to overestimation of the confidence intervals (Stevens and Kincaid, 1997).

Estimating Sediment Contaminant Mass

The total mass of each constituent residing in the top 2 cm of sediment was calculated as follows:

$$\text{Mass}_y = \text{AWM}_x * \delta * A_y * D * CF,$$

where:
AWM_x = area-weighted mean of constituent x in stratum y,
δ = dry density of the sediment,
A_y = area of stratum y,
D = depth of sample (2 cm),
CF = cumulative unit conversion factor.

The total mass (by constituent) for the Southern California Bight was calculated by summing the mass from all strata. To assess for disproportionate contaminant accumulation among stratum, the ratio of percent mass of a given constituent to percent area for a given stratum was computed; a ratio of unity indicated a mass contribution in proportion with the stratum area.

Comparison to Sediment Quality Guidelines (SQGs)

The effects range-low (ERL) and the effects range-median (ERM) concentrations developed by Long et al. (1995) were used to assess the areal extent of individual chemicals. These empirically derived guidelines are based on relationships between observed biological responses and measured concentrations of sediment contaminants. Based on a nationwide data set, the ERL and ERM values correspond to the tenth and 50th percentiles of sediment concentrations in samples with significant biological response (i.e., toxicity) (Table 3). Concentrations <ERL represent sediments that likely will not result in adverse biological effects, whereas concentrations >ERM represent those that likely will result in adverse biological effects. Since ERLs and ERMs are based solely on coincidental occurrence and do not imply a cause-and-effect relationship, they are subject to some level of prediction error (Long et al., 1995).

A second approach, developed by Long and MacDonald (1998), was used to assess the areal extent of sediment contamination based on a composite of several constituents. The effects range median quotient (ERMQ) was computed as the ratio of the mean contaminant concentration and the ERM (Table 3). Mean SQG quotients account for the possible additive toxic effects of chemical mixtures in sediments and have been shown to improve predictive capability. The mean ERMQ was calculated as follows:

$$\text{ERMQ} = \frac{1}{N} \sum_{x=1}^{N} \left(\frac{C_x}{ERM_x} \right), \quad (3)$$

where:
N = number of contaminants evaluated,

C_x = sediment concentration for constituent x,
ERM_x = ERM value for contaminant x.

The mean SQG quotients were calculated for all sediment samples with each station then assigned to one of four possible levels of risk for adverse biological impact: Level I (ERMQ <0.25) "low"; Level II (0.25 < ERMQ <0.5) "low to moderate"; Level III (0.51 < ERMQ <1.50) "moderate to high"; and Level IV (ERMQ >1.51) "high" (Long et al., 1998).

RESULTS

Contaminant Concentrations

Overall, Southern California Bight sediments were relatively fine-grained (73 ± 4.3% fines) with average TOC and TN contents of 2.3 ± 0.16% and 0.23 ± 0.03%, respectively (Table 4). For the mainland shelf, slope, and basin, sediment fines clearly increased with depth, averaging 31 ± 9.2% for the shallowest (inner shelf; 30–120 m) stratum and increasing to 92 ± 1.5% for the deepest (lower slope and basin) stratum. For the other strata, sediment fines ranged from a low of 32 ± 6.3%, for the Channel Islands, to highs of 68 ± 9.0% and 72 ± 7.0%, for embayments (ports, bays, and/or harbors and marinas, respectively). Relatively high sediment fines for the embayments are not surprising in that they represent environments that are physically protected from waves and strong currents.

TABLE 3. SEDIMENT QUALITY GUIDELINES FOR ASSESSMENT OF POTENTIAL ADVERSE BIOLOGICAL IMPACTS DUE TO SEDIMENT CONTAMINATION

Contaminant	ERL	ERM	ERMQ
Metals (mg/dry kg)			
Arsenic	8.2	70	70
Cadmium	1.2	9.6	9.6
Chromium	81	370	370
Copper	34	270	270
Lead	46.7	218	218
Mercury	0.15	0.71	0.71
Nickel	20.9	51.6	51.6
Silver	1	3.7	3.7
Zinc	150	410	410
Organics (µg/dry kg)			
2-Methylnaphthalene	-	-	670
Acenaphthene	-	-	500
Acenaphthylene	-	-	640
Anthracene	-	-	1100
Benz(a)anthracene	-	-	1600
Benzo(a)pyrene	-	-	1600
Chrysene	-	-	2800
Dibenz(a,h)anthracene	-	-	260
Dieldrin*	-	-	8
Fluoranthene	-	-	5100
Fluorene	-	-	540
Naphthalene	-	-	2100
Phenanthrene	-	-	1500
Pyrene	-	-	2600
Total PAH (µg/dry kg)	4022	44,792	-
Total DDT (µg/dry kg)	1.58	46.1	46.1
Total PCB (µg/dry kg)	22.7	180	180
Total Chlordane (µg/dry kg)	-	-	6

Note: PAH—polynuclear aromatic hydrocarbon; DDT—dichlorodiphenyl-trichloroethane; PCB—polychlorinated biphenyl; ERL—effects range-low; ERM—effects range-median (Long et al., 1995); ERMQ—effects range-median quotient (Long and MacDonald, 1998).
*Not measured in this study.

The TOC and TN measurements varied three orders of magnitude, from 0.004% to >7% TOC. In general, TOC and TN covaried with sediment fines for the offshore (shelf, slope and basin) strata but not for the inshore, POTW, and Channel Islands strata (Table 4).

With few exceptions, trace-metal concentrations for shelf strata increased with increasing depth (and sediment fines) (Table 4). Average concentration for seven of the 15 metals increased monotonically from shallow mainland shelf to the deepest slope and basin strata. For the remaining metals, average concentrations more than tripled along this transect. For example, aluminum increased from 9210 ± 2230 to 21800 ± 1290 mg/kg dry wt., whereas copper increased from 6.6 ± 1.8 to 34 ± 2.8 mg/kg. The greatest average trace-metal concentrations were observed in embayments (marinas, ports, bays, and/or harbors) and urban estuaries. For example, the highest average concentrations of arsenic (7.3 ± 1.1 mg/kg), copper (116 ± 30 mg/kg), and mercury (0.42 ± 0.17 mg/kg) were observed in marinas, whereas the greatest average concentrations of antimony (0.94 ± 0.34 mg/kg), lead (68 ± 37 mg/kg), silver (0.78 ± 0.33 mg/kg), and zinc (190 ± 69 mg/kg) were observed in the Los Angeles estuaries. The lowest concentrations of trace metals were observed in the Channel Islands and shallow mainland shelf strata (e.g., 6.6 ± 0.97 and 6.6 ± 1.8 mg Cu/kg, respectively).

Unlike trace metals, organic contaminant concentrations did not consistently covary with depth, sediment fines, or TOC (Table 4). Rather, their distribution was largely stratum specific. Total DDT on average was greatest in the large POTW stratum (316 ± 52 µg/kg dry wt.), exceeding the next highest strata averages (upper slope; Los Angeles estuaries) by a factor of four. Total PAH, PCBs, and chlordanes were highest on average for the Los Angeles estuaries (2170 ± 972, 66 ± 3.8, and 11 ± 7.9 µg/kg, respectively). These values exceeded the next highest concentrations (large POTW, marinas, ports, bays, and/or harbors) by factors ranging between 2 and 10. The patterns of organic contaminants along the shelf transect were more variable, with some evidence of universal accumulation in the upper slope stratum (200–500 m depth). Like the metals, PAH also appeared elevated in the lower slope and basin stratum (580 ± 113 µg/kg) and to a lesser extent in the Channel Islands stratum (338 ± 69.6 µg/kg).

The geographical distribution of most constituents was indicative of their most likely sources. For example, the highest copper concentrations were observed in embayments (e.g., Los Angeles and Long Beach Harbor and San Diego Bay) and at the mouths of urban watersheds in the southern region of the Bight (Fig. 2). Other metals that are typically enriched in anthropogenically influenced sediments, including zinc and

TABLE 4. AREA-WEIGHTED MEAN CONCENTRATIONS (DRY WEIGHT) AND 95% CONFIDENCE INTERVALS (IN PARENTHESES) BY GEOGRAPHICAL STRATA

Parameter	Entire SCB	Inner shelf (5–30 m)	Mid shelf (30–120 m)	Outer shelf (120–200 m)	Upper slope (200–500 m)	Lower slope and basin (500–1000 m)
Fines (%)	73 (4.3)	31 (9.2)	45 (8.4)	59 (6.4)	79 (6.9)	92 (1.5)
TOC (%)	2.3 (0.16)	0.27 (0.08)	0.75 (0.19)	1.0 (0.19)	1.9 (0.29)	3.3 (0.30)
TN (%)	0.23 (0.03)	0.03 (0.01)	0.05 (0.01)	0.1 (0.02)	0.2 (0.04)	0.35 (0.03)
Aluminum (mg/kg)	17,224 (886)	9212 (2233)	13,165 (3651)	11,693 (2072)	17,359 (2168)	21,770 (1293)
Antimony (mg/kg)	0.62 (0.11)	0.14 (0.04)	0.10 (0.05)	0.08 (0.04)	0.20 (0.10)	0.68 (0.23)
Arsenic (mg/kg)	5.7 (0.61)	4.2 (1.2)	4.1 (1.1)	6.1 (2.2)	6.1 (1.3)	6.5 (1.1)
Barium (mg/kg)	220 (22)	99 (26)	153 (70)	113 (18.1)	168 (30)	306 (39)
Beryllium (mg/kg)	0.71 (0.13)	0.47 (0.22)	0.62 (0.44)	0.58 (0.20)	1.1 (0.58)	0.66 (0.06)
Cadmium (mg/kg)	1.1 (0.13)	0.20 (0.06)	0.36 (0.11)	0.54 (0.11)	1.4 (0.49)	1.30 (0.18)
Chromium (mg/kg)	62 (11)	27 (6.8)	36 (8.0)	38 (8.1)	61 (15)	82 (21)
Copper (mg/kg)	24 (1.5)	6.6 (1.8)	12 (2.1)	15 (5.8)	19 (2.5)	34 (2.8)
Iron (mg/kg)	26,436 (1775)	12,952 (2784)	19,511 (4219)	27,590 (8546)	28,760 (2885)	31,782 (3238)
Lead (mg/kg)	11 (1.0)	4.7 (1.1)	7.4 (1.5)	8.3 (1.2)	11 (1.6)	15 (2)
Mercury (mg/kg)	0.11 (0.02)	0.03 (0.01)	0.10 (0.03)	0.10 (0.07))	0.09 (0.03)	0.13 (0.03)
Nickel (mg/kg)	31 (2.1)	13 (3.8)	14 (3.7)	18 (2.4)	29 (4.2)	44 (3.9)
Selenium (mg/kg)	2.1 (0.22)	0.69 (0.22)	1.2 (0.43)	0.82 (0.37)	1.3 (0.31)	2.8 (0.43)
Silver (mg/kg)	0.38 (0.07)	0.13 (0.06)	0.11 (0.06)	0.35 (0.31)	0.24 (0.13)	0.46 (0.13)
Zinc (mg/kg)	81 (3.2)	34 (7.8)	47 (8.4)	55 (5.7)	82 (9.3)	107 (4.8)
Total DDT (μg/kg)	20 (17)	2.3 (0.40)	36 (6.3)	11 (2.3)	88 (25)	19 (2.5)
Total PCB (μg/kg)	2.5 (2.7)	0.24 (0.01)	2.4 (0.13)	4.6 (0.27)	7.6 (0.44)	0.28 (0.02)
Total PAH (μg/kg)	342.9 (72.6)	51.2 (44.9)	60.3 (43.3)	68.6 (40.6)	75.3 (56.2)	579.5 (112.9)
Total Chlordane (μg/kg)	0.03 (0.03)	0.01 (0.01)	0.02 (0.03)	<0.01 (0.00)	0.08 (0.13)	<0.01 (0.00)

Parameter	Marinas	Estuaries	Los Angeles estuaries	Ports/bays/harbors	Small POTW	Large POTW	Channel Islands (30–120 m)
Fines (%)	72 (7)	53 (12)	41 (11)	68 (9)	40 (9.2)	38 (6.5)	32 (6.3)
TOC (%)	1.6 (0.36)	1.1 (0.4)	1.6 (0.58)	1.3 (0.24)	0.54 (.016)	0.83 (0.22)	2.0 (0.58)
TN (%)	0.2 (0.5)	0.02 (1.6)	0.1 (0.04)	0.1 (0.02)	0.05 (0.02)	0.08 (0.04)	0.1 (0.02)
Aluminum (mg/kg)	22,203 (3083)	23,182 (5450)	11,473 (3149)	23,761 (3273)	13,244 (3585)	10,519 (1662)	5439 (730)
Antimony (mg/kg)	0.38 (0.09)	0.28 (0.06)	0.94 (0.34)	0.11 (0.14)	0.15 (0.02)	0.03 (0.02)	0.27 (0.06)
Arsenic (mg/kg)	7.3 (1.13)	5.8 (1.4)	5 (1.4)	4.3 (1.2)	4.6 (0.67)	3.2 (0.69)	3.2 (0.34)
Barium (mg/kg)	111 (22)	95 (21)	84 (23)	109 (21)	84 (15)	351 (235)	75 (20)
Beryllium (mg/kg)	0.64 (0.13)	0.67 (0.16)	0.4 (0.12)	0.21 (0.08)	0.35 (0.07)	0.64 (0.38)	0.22 (0.03)
Cadmium (mg/kg)	0.65 (0.18)	0.57 (0.23)	0.92 (0.37)	0.86 (0.32)	0.22 (0.05)	0.76 (0.32)	0.76 (0.14)
Chromium (mg/kg)	48 (8.7)	33 (7)	47 (21)	39 (5.8)	27 (5.6)	37 (9.3)	27 (4.4)
Copper (mg/kg)	116 (30)	28 (7.7)	55 (21)	70 (19)	9.0 (2.5)	20 (4.9)	6.6 (0.97)
Iron (mg/kg)	27,761 (3449)	22,150 (4707)	17,034 (3830)	30,254 (4063)	16,255 (3655)	15,228 (1767)	11,473 (1482)
Lead (mg/kg)	43 (12)	19 (8.1)	68 (37)	29 (8.5)	4.9 (0.81)	9.2 (2.0)	4.8 (0.62)
Mercury (mg/kg)	0.42 (0.17)	0.05 (0.02)	0.14 (0.05)	0.28 (0.1)	0.05 (0.03)	0.14 (0.05)	0.02 (0.003)
Nickel (mg/kg)	20 (3.9)	14 (3)	19 (5)	18 (3.7)	11 (2.0)	10 (2.1)	13 (1.7)
Selenium (mg/kg)	1.3 (0.58)	1.5 (0.45)	0.77 (0.25)	2.7 (0.98)	0.55 (0.12)	0.98 (0.37)	0.45 (0.13)
Silver (mg/kg)	0.73 (0.55)	0.33 (0.08)	0.78 (0.33)	0.2 (0.27)	0.14 (0.06)	0.39 (0.21)	0.06 (0.03)
Zinc (mg/kg)	183 (29)	94 (26)	190 (69)	128 (24)	40 (8.0)	51 (11)	30 (3.4)
Total DDT (μg/kg)	21 (3.1)	8.8 (1.7)	78 (12)	25 (3.8)	1.2 (0.18)	316 (52)	1.6 (0.23)
Total PCB (μg/kg)	11 (0.57)	2.7 (0.2)	66 (3.75)	7.7 (0.44)	0.13 (0.01)	29 (1.5)	0.24 (0.02)
Total PAH (μg/kg)	796 (428.9)	192.5 (91.4)	2168.3 (971.7)	1229.4 (653.0)	24.9 (8.7)	117.7 (51.5)	337.8 (69.6
Total Chlordane (μg/kg)	1.2 (0.98)	0.08 (0.14)	11 (7.9)	0.14 (0.26)	<0.01 (0.0)	0.50 (0.61)	<0.01 (0.0)

Note: SCB—Southern California Bight; TOC—total organic carbon; TN—total nitrogen; DDT—dichloro-diphenyl-trichloroethane; PCB—polychlorinated biphenyl; PAH—polynuclear aromatic hydrocarbons; POTW—publicly owned treatment works.

lead, follow a similar spatial distribution. On the other hand, those metals that are considered naturally abundant (e.g., iron and aluminum) do not follow this pattern and are associated with sediment fines (Table 4). For DDT, the highest concentrations were clustered at sites off the Palos Verdes Peninsula west of the Los Angeles and Long Beach Harbor (Fig. 3). A gradient of steadily decreasing sediment DDT concentrations in the northerly direction through central and northern Santa Monica Bay was consistent with the prevailing northerly direction of nearshore ocean currents. Sediment DDT concentrations to the south of Palos Verdes and far to the northwest were low to nondetectable. Interestingly, higher concentrations of both copper and total DDT were found in deeper waters of the slope and basin strata directly offshore of the Palos Verdes POTW outfall area (Figs. 2 and 3). Spatial plots for all constituents listed in Table 2 are in Appendix B of Schiff et al. (2006).

Contaminant Mass Inventories

The greatest mass of sediment constituents was estimated to occur in the slope and basin strata, both the largest in terms of total area (69% of Southern California Bight) and deepest (200–1000 m) strata surveyed. On average, 77% of the total constituent mass in surficial Southern California Bight sediments was associated with these strata (Table 5), with individual constituent mass inventories ranging from 71% (aluminum) to 86% (cadmium, nickel, silver, and total PAH). For trace metals, the lower slope and basin housed the greatest mass and also represented the stratum with the greatest area (48% of Southern California Bight) and with the finest grained sediments on average (Table 4). Conversely, surficial sediments of the upper slope (200–500 m) contained greater total masses of total DDT, total PCBs and total chlordane, even though its area was less than half (20%) of that for the lower slope and basin.

With only one exception (beryllium), the lower slope and basin had disproportionately greater mass of trace metals relative to its percent area (Table 5). For copper, mercury, and lead, disproportionally greater mass was observed in marinas and ports, bays, and/or harbors. In contrast, the mass percentage of organic contaminants within the Southern California Bight was disproportionally higher in Los Angeles estuaries, embayments, and the upper slope (Table 5). Mass inventories of total DDT and total chlordane were also disproportionally high for large POTWs. Not surprisingly, however, this inventory estimate was largely influenced by high sediment DDT levels near the POTW outfalls in Santa Monica Bay (city of Los Angeles) and near Palos Verdes (Los Angeles County Sanitation District) (Fig. 3). The continental shelf (Inner, Mid, and Outer), small POTW, and Channel Islands strata consistently exhibited nonenriched mass inventories relative to their respective areas.

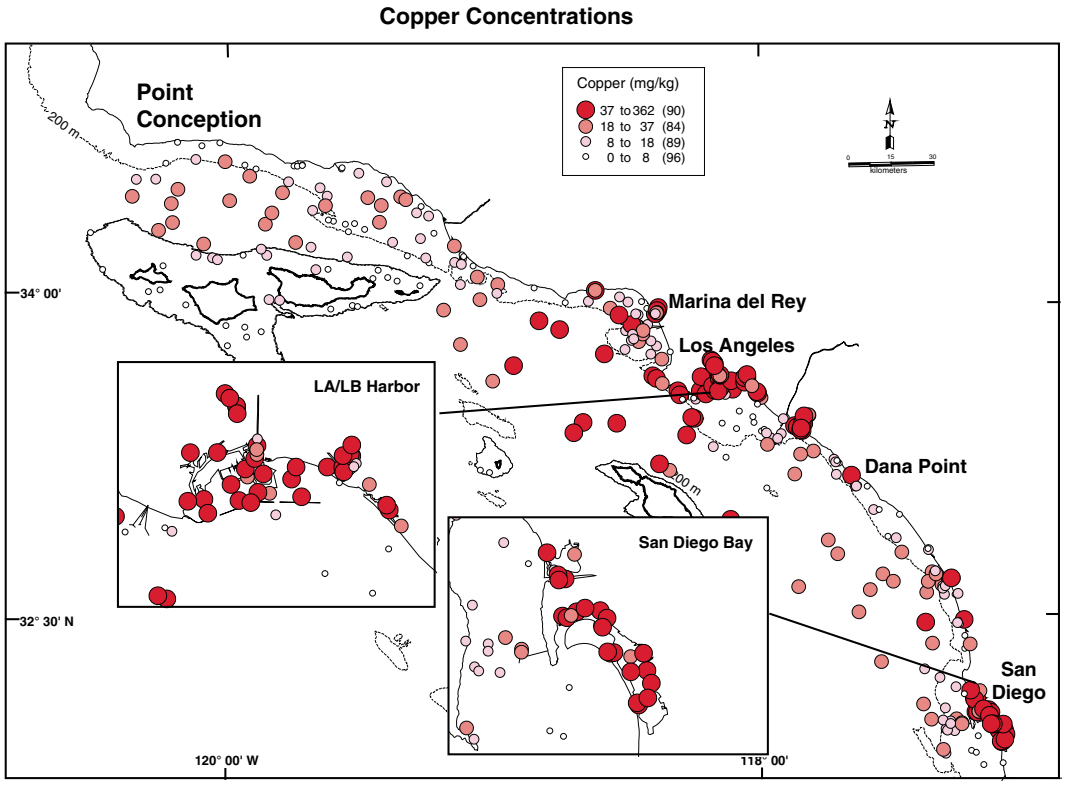

Figure 2. Geographical distribution of copper concentrations in sediment during the 2003 Southern California Bight regional monitoring survey. LA/LB—Los Angeles and Long Beach.

Assessment of Sediment Quality

Considering all target constituents measured in this study using the ERMQ approach, 65% of the sediments in the Southern California Bight would be classified as low risk for adverse biological impacts. Another 34% would be ranked as low to moderate risk, with the remaining 1% representing a moderate to high risk (Table 6). The relative risk of adverse biological impacts was, however, not evenly distributed among strata. For example, large POTWs had the greatest relative risk with 18% of its area exceeding ERMQs that predict moderate to high risk for adverse biological impacts (Levels III and IV; Table 6). The Los Angeles estuaries ranked second in terms of elevated risk, with 13% of its area in these categories. In contrast, 100% of the areas for the (non-Los Angeles) estuaries, shelf, small POTW, and Channel Islands had ERMQs that suggest low to moderate risk (Levels I and II). Embayments (i.e., marinas and ports, bays, and/or harbors) had sediments of intermediate quality; approximately two-thirds (63% to 68%, respectively) of the area in these strata had ERMQs suggestive of low to moderate risk of adverse biological effects.

Apportioning exceedences of sediment quality guidelines to specific contaminants clearly shows that organic constituents measured in this study contribute the bulk of exceedences for the Southern California Bight (Table 7). Seven of nine strata exceeded ERMs over a greater area for organic contaminants compared with trace metals, the exceptions being the lower slope and basin and marinas. The latter exceedences were due largely to nickel (lower slope and basin) and mercury, copper, and silver (marinas). The strata with the highest area exceeding ERMs for any contaminant were large POTWs, marinas, and lower slope and basin (39%, 38%, and 33% area, respectively). Organic contaminants were responsible for 100% of the ERM exceedences in five strata. These ERM exceedences were solely due to total DDT, including the 39% of the large POTW stratum (Table 7). Although total PCBs exceeded the ERM in three strata (upper slope, Los Angeles estuaries, and large POTW), total DDT also exceeded the ERM in these areas. No exceedences of the ERM were observed for total PAH.

ERM exceedences most frequently occurred near the Los Angeles and San Diego metropolitan areas (Fig. 4). A small number of sediments (four of 359; 1.1%), all of which were from sites in the Los Angeles coastal area, exceeded ERMs for three or more constituents. Twelve sites (3.3%) exceeded ERMs for two constituents with the majority of these sites located in Los Angeles estuaries or embayments including San Diego Bay. The vast majority of sites in deeper water (>200 m) that had any ERM exceedence were located in Santa Monica Bay, San Pedro Channel, or offshore of the Palos Verdes (large POTW) outfall. ERM exceedences were rarely observed north of Santa Monica Bay or,

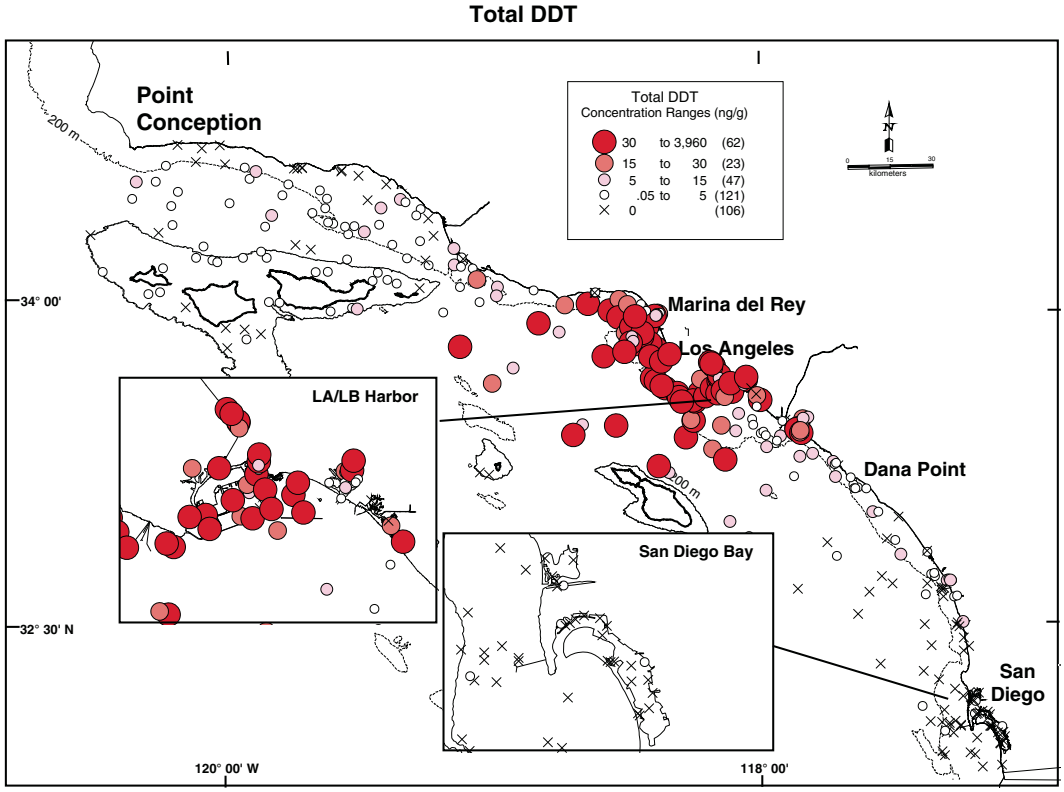

Figure 3. Geographical distribution of total DDT concentrations in sediment during the 2003 Southern California Bight regional monitoring survey. LA/LB—Los Angeles and Long Beach.

TABLE 5. PERCENT OF TOTAL BIGHT-WIDE MASS FOR EACH CONSTITUENT BY GEOGRAPHICAL STRATA

Stratum	Percent area*	Percent mass														
		Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Se	Ag	Zn
Inner shelf (5–30 m)	7.0	3.8	2.4	5.2	3.2	4.8	1.3	3.1	1.97	3.49	2.0	2.9	2.9	2.7	2.2	2.9
Mid-shelf (30–120 m)	11.8	8.8	2.8	8.5	8.2	10.6	4.0	6.8	5.8	8.7	11.4	5.3	7.6	7.7	3.6	6.8
Outer shelf (120–200 m)	3.6	2.5	0.7	3.9	1.9	3.1	1.9	2.2	2.3	3.8	3.5	2.1	2.6	1.6	4.5	2.5
Upper slope (200–500 m)	19.5	19.6	9.39	21.0	14.9	31.2	25.9	19.2	15.4	21.2	17.0	18.2	18.9	13.8	12.0	19.8
Lower slope and basin (500–1000 m)	48.3	61	79.1	55.5	67.1	46.4	59.7	64.0	69.2	58.0	61.0	67.3	61.9	70.9	74.3	63.3
Total slope and basin (200–1000 m)†	68	81	88	76	81	78	76	83	85	79	78	76	80	84	86	83
Marinas	0.10	0.1	0.09	0.1	0.05	0.10	0.06	0.08	0.51	0.1	0.42	0.07	0.4	0.07	0.2	0.2
Estuaries	0.04	0.05	0.03	0.04	0.02	0.04	0.02	0.02	0.049	0.03	0.02	0.01	0.07	0.03	0.04	0.05
Los Angeles estuaries	0.01	0.01	0.02	0.01	0.003	0.005	0.007	0.006	0.02	0.01	0.01	0.004	0.05	0.003	0.02	0.02
Ports/bays/harbors	0.51	0.7	0.1	0.4	0.3	0.15	0.4	0.3	1.5	0.6	1.4	0.3	1.3	0.7	0.3	0.8
Small POTW	0.17	0.1	0.06	0.1	0.07	0.09	0.04	0.08	0.07	0.1	0.08	0.06	0.07	0.06	0.05	0.08
Large POTW	1.1	0.7	0.08	0.6	1.7	1.0	0.79	0.65	0.92	0.6	1.5	0.4	0.9	0.6	1.3	0.7
Channel Islands (30–120 m)	8.0	2.5	5.2	4.5	2.7	2.6	5.8	3.5	2.2	3.5	1.5	3.4	3.3	1.9	1.5	2.8

Stratum	Percent area*	Percent mass			
		Total DDT	Total PAH	Total PCB	Total chlordane
Inner shelf (5–30 m)	7.0	0.5	1.0	0.8	2.6
Mid-shelf (30–120 m)	11.8	12.1	2.1	13.1	8.7
Outer shelf (120–200 m)	3.6	1.1	0.7	7.8	0.0
Upper slope (200–500 m)	19.5	49.2	4.3	68.5	57.8
Lower slope and basin (500–1000 m)	48.3	26.3	81.5	6.3	0.0
Total slope and basin (200–1000 m)†	68	76	86	75	58
Marinas	0.10	0.06	0.2	0.5	4.6
Estuaries	0.04	0.01	0.02	0.05	0.1
Los Angeles estuaries	0.01	0.02	0.05	0.2	3.2
Ports/bays/harbors	0.51	0.4	1.8	1.8	2.6
Small POTW	0.17	0.006	0.01	0.0	0.0
Large POTW	1.1	9.9	0.4	0.1	20.2
Channel Islands (30–120 m)	8.0	0.4	7.8	0.9	0.0

Note: Those strata where percent mass exceeds the corresponding percent area contain a disproportionate amount of the total mass for that contaminant. DDT—dichloro-diphenyl-trichloroethane; PCB—polychlorinated biphenyl; PAH—polynuclear aromatic hydrocarbon; POTW—publicly owned treatment works.

*Based on a total Southern California Bight area of 15,169 km^2 (see Table 1).

†Sum of upper slope and lower slope and basin strata.

with the exception of San Diego Bay, south of Los Angeles and Long Beach Harbor.

DISCUSSION

The majority of accumulated contaminants in surficial (<2 cm) sediments of the Southern California Bight were found in the deep ocean of the mainland slope and basins. Nearly all of the sediment at these depths was enriched in at least one constituent and, for all of the individual constituents measured, between 58% and 86% of the contaminant mass in the top 2 cm was found in depths greater than 200 m. Because sediments sampled at these depths were the finest grained and most organically enriched in this study, the observed enrichment of contaminants was consistent with a previous study on particle-size association of TOC and PAH (Evans et al., 1990). The significance of this accumulation is attributed to the fact that little to no ongoing monitoring occurs in these strata. Except for total DDT, less than 2% of the sediment contaminant mass was found in the POTW strata where the vast majority of monitoring occurs. Other investigators have observed the potential for pollutants to be transported downslope. Zeng and Venkatesan (1999) have observed total DDT accumulating in the surface sediments of cores collected from the San Pedro Basin. Likewise, Finney and Huh (1989) observed an accumulation of anthropogenic trace metals in another set of sediment cores from the San Pedro Basin. Whereas the sediment cores provide invaluable insight into the temporal accumulation of sediment contaminants, none of the previous investigators were able to assess the spatial extent of this accumulation, particularly in the deeper basins of the Bight. This survey was the first to recognize the truly widespread distribution of anthropogenic enrichment in these largely unexplored areas of the Southern California Bight. There are several potential sources of anthropogenic contaminants that can be transported to the deep ocean. Large POTW discharges, located between 60 and 100 m in the Southern California Bight, are often located near submarine canyons that form a conduit to the deep ocean. Runoff plumes from urban and agricultural watersheds can extend to the mainland slope and basin (Nezlin et al., 2005), not to mention the secondary transport of settled particulates from the plumes (Kolpack and Drake, 1984; Schiff and Bay, 2003). All three of the currently designated dredge material disposal sites are located in depths greater than 200 m (Steinberger et al., 2003). As many as 14 ocean disposal sites have been used historically, including one in the San Pedro Basin exclusively for DDT manufacturing waste. Once accumulated in the deep oceans, anthropogenic contaminants are unlikely to be advected because most basins lack significant mixing and dispersion. In fact, water in the deep part of the Santa Barbara Basin rarely exchanges with surface water (Dailey et al., 1993).

Although the mass of most constituents was greatest in the deep ocean, it was the shallowest areas of the Southern California Bight that were perhaps subject to the greatest ecological risk from sediment contamination. Embayments of the Southern California Bight had the greatest relative areal extent of ERMQ exceedence; more than one-third of the embayment area was predicted to have a moderate to high risk of adverse biological effect. The greatest sediment concentrations of trace metals and several organic constituents were observed in sediments sampled from marinas, estuaries draining urbanized watersheds, and industrialized port facilities. Finally, marinas, estuaries, and ports, bays, and/or harbors all had significantly elevated mass to area ratios indicating that they were predisposed to accumulating sediment contaminants. This information is supported by the relatively high concentrations of metals and organics measured in these areas by others (Anderson et al., 1988; Fairey et al., 2001). Additionally, marinas, estuaries, and ports, bays, and/or harbors (in that order) had the greatest frequency of sediment toxicity for the Bight'03 study (Bay et al., 2005).

Los Angeles estuaries appeared to have greater sediment contamination than other estuaries of the Southern California Bight. This may be due, in part, to two overriding factors. First, these estuaries drain some of the largest, most urbanized

TABLE 6. PERCENT AREA OF THE SOUTHERN CALIFORNIA BIGHT AND ASSOCIATED GEOGRAPHICAL STRATA THAT FALL WITHIN THE FOUR RISK LEVELS OF ADVERSE BIOLOGICAL EFFECTS USING THE EFFECTS RANGE-MEDIAN QUOTIENT (ERMQ) SEDIMENT QUALITY GUIDELINE APPROACH

Stratum	Level I (<0.1)	Level II (0.11–0.5)	Level III (0.51–1.5)	Level IV (>1.5)
Entire Southern California Bight	64.8	34.3	0.1	0.8
Ports/bays/harbors	32.1	67.9	0.0	0.0
Marinas	34.4	62.5	3.1	0.0
Estuaries	88.0	12.0	0.0	0.0
Los Angeles estuaries	57.3	29.7	8.7	4.3
Inner shelf (5–30 m)	88.9	11.1	0.0	0.0
Mid shelf (30–120 m)	65.6	34.4	0.0	0.0
Outer shelf (120–200 m)	92.6	7.4	0.0	0.0
Upper slope (200–500 m)	92.9	3.6	0.0	3.6
Lower slope and basin (500–1000 m)	42.4	57.6	0.0	0.0
Small POTW	100.0	0.0	0.0	0.0
Large POTW	51.5	30.3	12.1	6.1
Channel Islands (30–120 m)	100.0	0.0	0.0	0.0

Note: Potential acute toxicity categories: Level I—low; Level II—low-moderate; Level III—moderate to high; Level IV—high; for amphipod mortality (Long et al., 1998). POTW—publicly owned treatment works.

TABLE 7. PERCENT AREA EXCEEDING THE EFFECTS RANGE-MEDIAN (ERM) SEDIMENT QUALITY GUIDELINE (LONG ET AL., 1995) BY TRACE CONSTITUENT FOR STRATA WITHIN THE SOUTHERN CALIFORNIA BIGHT

Parameter	Inner shelf (5–30 m)	Mid shelf (30–120 m)	Outer shelf (120–200 m)	Upper slope (200–500 m)	Lower slope and basin (500–1000 m)	Marinas	Estuaries	Los Angeles estuaries	Ports/bays/ harbors	Small POTW	Large POTW	Channel Islands (30–120 m)
Metals												
Arsenic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cadmium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chromium	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper	0.0	0.0	0.0	0.0	0.0	6.3	0.0	0.0	0.0	0.0	0.0	0.0
Lead	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0
Mercury	0.0	0.0	3.7	0.0	0.0	21.9	0.0	0.0	10.7	0.0	0.0	0.0
Nickel	0.0	0.0	0.0	0.0	24.2	0.0	0.0	2.1	0.0	0.0	0.0	0.0
Silver	0.0	0.0	3.7	0.0	0.0	6.3	0.0	4.3	3.6	0.0	0.0	0.0
Zinc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.6	0.0	0.0	0.0	0.0
Organics												
Total DDT	0.0	15.6	7.4	3.6	12.1	15.6	7.9	19.2	17.9	0.0	39.4	0.0
Total PCB	0.0	0.0	0.0	3.6	0.0	0.0	0.0	13.0	0.0	0.0	3.0	0.0
Total PAH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Any metal	0.0	0.0	3.7	0.0	27.3	28.1	0.0	12.6	10.7	0.0	0.0	0.0
Any organic	0.0	15.6	7.4	3.6	12.1	15.6	7.9	19.2	17.9	0.0	39.4	0.0
Any parameter	0.0	15.6	7.4	3.6	33.3	37.5	7.9	23.3	28.6	0.0	39.4	0.0

Note: DDT—dichloro-diphenyl-trichloroethane; PCB—polychlorinated biphenyl; PAH—polynuclear aromatic hydrocarbon; POTW—publicly owned treatment works.

watersheds in the Southern California Bight. For example, four of the five watersheds in the Los Angeles estuary stratum are more than 50% developed, with two (Ballona Creek and Dominguez Channel) exceeding 85% urban land uses. In contrast, the watersheds of the remaining six estuaries in the Southern California Bight have much lower levels of urbanization with the majority being less than 50% developed. The second factor that may have contributed to the notably increased sediment contamination of the Los Angeles estuary stratum was estuarine morphology. The Los Angeles estuaries were distinct in that most were characterized by long, parallel rocky levees extending through the surfzone. While this morphology is extremely efficient for hydrodynamic transport and reduced flooding, it almost completely lacks any of the estuarine processes associated with brackish water and/or mudflat fauna and flora. Only a single Los Angeles estuary exhibited this morphology (Malibu Lagoon), and it contained the lowest sediment contaminant concentrations of all Los Angeles estuaries. In contrast, nearly all of the remaining estuaries not found in Los Angeles, at least to some degree, exhibited the more typical brackish water and/or mudflat morphology (Dailey et. al, 1993).

Total DDT was the most widespread contaminant in the Southern California Bight. Seventy-one percent of the Southern California Bight was enriched in this legacy pesticide that was manufactured by Montrose Chemical Corporation, in Torrance, California, and discharged from 1943 to 1971 (Chartrand et al., 1988). The spatial distribution of total DDT in sediments follows an expected pattern emanating from the Los Angeles County Sanitation District outfall at White Point (Palos Verdes), the sewage treatment plant that received much of the manufacturing waste, northwestward in the direction of the predominant ocean current (Hickey, 1993; Noble et al., this volume, Chapter 3.3). This is the same pattern observed in earlier regional surveys (Schiff and Gossett, 1998). Other investigators have estimated as much as 70 mt remains buried on the Palos Verdes shelf (Lee and Wiborg, 2002).

The ongoing risk of sediments contaminated by total DDT is still unknown. We used the sediment quality guidelines developed by National Oceanic and Atmospheric Administration (NOAA) (i.e., ERL and ERM) (Long et al., 1995) to determine that 20% of the Southern California Bight was expected to have high likelihood of adverse biological impacts based on total DDT alone. However, this specific ERM is known to have low precision for predicting biological impacts; therefore, additional DDT-specific thresholds were applied, and the areal extent of potential impact was significantly decreased (data not shown). Using these additional sediment quality guidelines, between one and nine percent of the Southern California Bight was at risk from DDT or its metabolites. While these additional guidelines provide alternative predictions for the acute or chronic impact to marine life, there are no guidelines that currently exist for impacts due to bioaccumulation. Earlier regional surveys reported detectable DDT concentrations in nearly 100% of the flatfish in the Southern California Bight (Schiff and Allen, 2000).

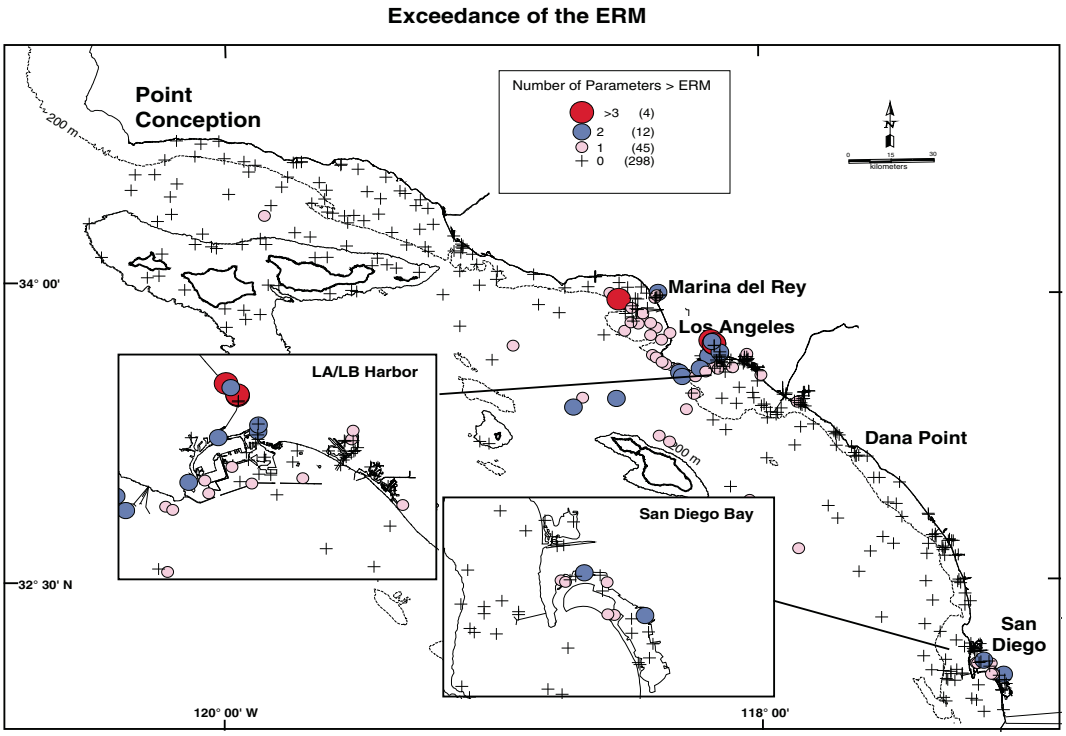

Figure 4. Geographical distribution and number of effects range-median (ERM) exceedences in sediment collected for the Southern California Bight Regional Monitoring Survey. LA/LB—Los Angeles and Long Beach.

Moreover, these levels were significantly correlated with sediment concentrations near sites where the fish had been collected. Furthermore, no regional survey of total DDT bioaccumulation in pelagic fish or recreationally caught fish has been published. However, there are site-specific warnings for fish consumption, and food chain biomagnification of total DDT is still observed in specific locations (Allen et al., 2004).

CONCLUSIONS

This study assessed the extent and magnitude of surficial (≤2 cm) sediment contamination in the Southern California Bight. Although anthropogenic sediment contamination was widespread, most of the Southern California Bight was below concentrations of concern for toxicity to benthic organisms. Only 1% of the Southern California Bight was at a moderate to high risk of adverse biological effects based on a national sediment quality guideline of complex chemical mixtures (mean ERMQ).

The greatest mass accumulation of contaminants was associated with the fine-grained sediments of the mainland slope and basins of the Southern California Bight. More than 80% of the contaminant mass measured in the top 2 cm of sediments Bight-wide was found at depths from 200 to 1000 m. These habitats likely accumulate anthropogenic inputs from shallower depths and have little to no capability for advection to remove them. The sediments at these depths are rarely, if ever, monitored.

The highest average concentrations, disproportionately large accumulations of contaminant mass, and greatest frequency of sediment quality guideline exceedences were associated with embayments (i.e., estuaries, marinas, and ports, bays, and/or harbors) and areas in proximity to large POTW outfalls. In contrast, the lowest average concentrations, disproportionately small accumulations of contaminant mass, and lack of sediment quality guideline exceedences were associated with the Channel Islands and areas in proximity to small POTW outfalls.

ACKNOWLEDGMENTS

The data presented herein were the product of a large number of collaborators who, in the interest of brevity, cannot be acknowledged individually. The authors thank members of the Bight'03 Steering Committee and Coastal Ecology Planning Committee, as well as field sampling and/or laboratory personnel from the city of San Diego, Weston Solutions, CRG Marine Labs, Orange County Sanitation District, County Sanitation Districts of Los Angeles County, city of Los Angeles, Southern California Coastal Water Research Project, Aquatic Bioassay and Consulting Laboratories, Channel Islands Marine Sanctuary, and Moss Landing Marine Laboratories. The authors would also like to thank L. Sabin, S. Moore, M. Jarvis Z. Simon, and J. Noblet for their specific contributions. Most of all, this study is indebted to those personnel that contributed to the success of the sediment chemistry portion of Bight'03.

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Manuscript Accepted by the Society 5 November 2008

Printed in the USA