Southern California Bight 1994 Pilot Project:

III. Sediment Chemistry

Kenneth C. Schiff[1] and Richard W. Gossett[2]

[1] Southern California Coastal Water Research Project
[2] CRG Marine Laboratories, Incorporated

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Southern California Coastal Water Research Project
7171 Fenwick Lane, Westminster, CA 92683
Phone: (714) 894-2222 • FAX: (714) 894-9699
http://www.sccwrp.org

Participating Agencies in the SCBPP

United States Environmental Projection Agency, Office of Research and Development
United States Environmental Projection Agency, Region IX
City of Los Angeles, Environmental Monitoring Division
County Sanitation Districts of Los Angeles County
County Sanitation Districts of Orange County
City of San Diego, Metropolitan Wastewater Department
State Water Resources Control Board
Regional Water Quality Control Board, Los Angeles Region
Regional Water Quality Control Board, Santa Ana Region
Regional Water Quality Control Board, San Diego Region
Santa Monica Bay Restoration Project
Southern California Coastal Water Research Project

CHEMISTRY WORKING GROUP MEMBERS

Rodger Baird	County Sanitation Districts of Los Angeles County
Laurie Bluestein	County Sanitation Districts of Orange County
Don Chappelle	City of Los Angeles
Kimberly Christensen	County Sanitation Districts of Orange County
C.C. Chou	City of San Diego
Diane Estburg	City of San Diego
Raymond Huang	City of Los Angeles
Elly Gabrielian	County Sanitation Districts of Los Angeles County
Richard Gossett	CRG Marine Laboratories, Incorporated
Connie Lillis	County Sanitation Districts of Los Angeles County
Ron Lilienthal	City of San Diego
Debra Lee Lindel	County Sanitation Districts of Orange County
Lucy Jao	City of Los Angeles
Ron Jardeen	City of San Diego
Lori McKinley	County Sanitation Districts of Orange County
Farhana Mohamed	City of Los Angeles
Canh Nguyen	County Sanitation Districts of Orange County
Maria Pang	City of Los Angeles
Charles Phillips	Science Applications International Corporation
Sumitra Roy-Burman	City of Los Angeles
Kim Rushton	City of Los Angeles
Mike Sagata	County Sanitation Districts of Orange County
Kenneth Schiff	Southern California Coastal Water Research Project
David Schlickman	City of San Diego
Rudy Schneider	County Sanitation Districts of Los Angeles County
Parvaneh Shoja	City of Los Angeles
David Thomas	City of Los Angeles
Yu-Li Tsai	County Sanitation Districts of Orange County
Demetri Zadelis	County Sanitation Districts of Los Angeles County
Eddy Zeng	Southern California Coastal Water Research Project

ANALYTICAL LABORATORIES

City of Los Angeles, Environmental Monitoring Division Laboratory
City of San Diego, Environmental and Technical Services Laboratory
County Sanitation Districts of Los Angeles County, San Jose Creek Laboratory
County Sanitation Districts of Orange County, Environmental Sciences Laboratory
Pace Analytical Laboratories, Incorporated
Southern California Coastal Water Research Project
Texas A&M, Trace Element Research Laboratory

FOREWORD

More than $10 million is spent annually monitoring southern California's coastal waters, yet the existing information and knowledge is inadequate to answer basic questions about the ocean's condition, such as how many acres of ocean bottom are impaired. The principal limitation is that less than 5% of the area on the mainland shelf of the Southern California Bight (SCB) is routinely monitored. Moreover, the constituents measured, as well as the frequency of measurement and methodology used, typically differ among monitoring programs in the SCB. These limitations reflect the predominant association of monitoring in southern California with discharge permit requirements that are focused on site-specific, single-source issues. While these programs generally collect high quality data, they are not designed to describe changes that occur on a regional scale or to assess cumulative impacts from multiple sources whose fates commingle.

Recognizing the need for an integrated assessment of the southern California coastal ocean, 12 governmental organizations, including the 4 largest municipal dischargers and the 5 regulators of discharge in southern California, collaborated to conduct a comprehensive regional monitoring survey in the summer of 1994. Referred to as the Southern California Bight Pilot Project (SCBPP), the monitoring survey included measures of the water quality, sediment chemistry, sediment toxicity, benthic infauna, and demersal fishes. This report summarizes the sediment chemistry portion of the study. Other reports are available on the worldwide web (http://www.sccwrp.org) or from the Southern California Coastal Water Research Project (SCCWRP).

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This report is the culmination of the dedication and hard work of many outstanding individuals. Integrated, coordinated regional monitoring is as much an ongoing process as a single scientific study. Much of the learning and exploration came not just from sampling new areas and interpreting unique analytical results, but from the interaction and dialogue of the most prolific laboratories and knowledgeable chemists in southern California and around the nation. We wish to extend our gratitude to those individuals whose commitment to the environment and to their professions has enabled the production this report. In terms of both science and communication, this work represents a large milestone on the path towards useful, useable regional monitoring. All raw data from this survey, meeting notes, and upcoming laboratory intercalibrations can be obtained by visiting the SCCWRP worldwide web site at http://www.sccwrp.org.

EXECUTIVE SUMMARY

Sediments represent one fate for contaminants that are discharged from urbanized areas and anthropogenic activities along the coast of the Southern California Bight (SCB). These contaminants have the potential to reside in the sediments for long periods of time, exerting acute and chronic effects at various levels of biological organization. Although tremendous effort and resources are expended annually to measure the inputs and effects of these contaminants, less than 10% of the area on the mainland shelf of the SCB is actually monitored. Recognizing the need for integrated regional monitoring to document, analyze, and understand large-scale ecological changes and cumulative effects from multiple contaminant sources, 12 agencies representing large wastewater dischargers, regulatory authorities, and monitoring facilitators joined together to assess the environmental condition of the SCB. Their objectives were: 1) to estimate the extent and magnitude of sediment contamination, 2) to assess whether contamination was similar throughout the SCB or more severe in particular areas, and 3) to associate the contamination with identifiable sources of pollution such as publicly owned treatment works (POTWs) or stormwater discharges.

In the summer of 1994, 248 sites were sampled from the SCB using a stratified-random study design. Sites were located between Point Conception and the U.S.-Mexico international border at depths ranging from 10 to 200 m. Five agencies collected the samples using standardized field protocols, and seven laboratories participated in the chemical analysis guided by a performance-based quality assurance project plan (QAPP). Sediment samples were analyzed for grain size, total organic carbon (TOC), total nitrogen (TN), 14 major and trace elements (aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, and zinc), and 3 classes of organic compounds (total DDT, total PCB, total PAH).

Bight-wide data distributions for most sediment parameters including TOC, TN, 12 of the 14 major and trace elements, total DDT, and total PCB were positively skewed. Spatial patterns of these parameters indicated that the highest bulk sediment concentrations were located near Los Angeles either in Santa Monica Bay or nearby on the Palos Verdes Shelf. Concentrations of total PAH were uniformly below method reporting limits. Cumulative distribution functions (CDFs) for concentrations of sediment parameters provided in this report allow for direct comparison between individual programs and site-specific projects with Bight-wide results. We encourage resource managers to utilize this new data analysis tool.

Based on at least one constituent, 89% of the SCB area had some evidence of sediment contamination. Eighty-two percent of the SCB was contaminated with chlorinated hydrocarbons including total DDT (82%) and total PCB (46%). Utilizing iron as a conservative tracer of natural contributions for eight metals of interest, it was estimated that 50% of the SCB was anthropogenically enriched in at least one trace metal. Cadmium, chromium, copper, lead, silver, zinc, and possibly mercury showed the greatest degree of anthropogenic enrichment; arsenic and nickel showed the least enrichment.

Sediment quality screening level thresholds developed by NOAA (effects range low [ERL], effects range median [ERM]) (Long *et al*. 1995) were used to assess the areal extent of predicted biological effects for 13 constituents. Approximately 12% of the SCB exceeded thresholds where biological effects would likely occur (433 km^2 > ERM); 55% of the SCB exceeded screening thresholds where biological effects may occasionally occur (ERL < 1,919 km^2 < ERM); and 33% of the SCB had sediments where biological effects would be rare (1,169 km^2 < ERL). The constituent that exceeded these screening level thresholds most often was total DDT. Unfortunately, the correspondence of the screening level threshold for total DDT and toxic effects is poor. The unreliability of the screening level threshold for total DDT was exacerbated by the lack of correlation between sediment chemistry and other biological indicators measured as part of this study including sediment toxicity and benthic infaunal assemblages.

Since total DDT was the most widespread pollutant of concern, and the predictability of its screening level threshold was low, a sensitivity analysis was conducted to compare 11 biological effects thresholds for this constituent. As expected, when the threshold of concern changed, so did the estimate of areal extent. Thresholds for total DDT based upon bulk sediment concentrations were generally higher than the ERL. Hence, the estimate of areal extent decreased, sometimes by as much as 20% of the SCB. However, thresholds based upon TOC normalization (analogous to an equilibrium partitioning approach) resulted in areal extents of biological concern that were greater than the ERL. Based upon the data available, we are unable to assess which threshold is most accurate since these values do not measure biological impairment directly, but are used as screening values to predict potential impairment. As the science regarding sediment toxicity evolves and predictability improves, we can apply new threshold values to our data set retroactively and more accurately assess biological impairment.

The magnitude of sediment contamination inside Santa Monica Bay was greater than other geographic regions of the SCB. Although grain size was similar between these two regions, mean sediment concentrations of all constituents were higher inside of than outside of the Bay; 12 of 14 constituents were significantly higher. The relative extent of sediment contamination inside of the Bay was also greater than outside of the Bay. Approximately 50% of the area inside of the Bay exceeded screening level thresholds of likely biological impairment for at least one constituent, compared to only 7% of the area outside of the Bay.

Although the proportion of area with sediment contamination near anthropogenic sources of pollutants was similar to the proportion of area distant from these sources, areas near pollutant sources generally had a greater magnitude (i.e. higher levels) of contamination. For example, areas near POTW outfall discharges and distant from these discharges were relatively similar in the extent of contamination; anthropogenic enrichment was evident in approximately 90% of the sediments from both subpopulations. However, 36% of the sediments near POTW outfall discharges exceeded screening levels for likely biological impairment, whereas 13% of the sediments distant from POTW outfalls exceeded this threshold. Similarly, the areal extent of sediments exceeding screening level thresholds for occasional biological impairment near stormwater discharge areas was comparable to the proportion of area distant from

stormwater discharges (50 *versus* 43%, respectively). The mean concentrations of those trace metals near stormwater discharges, however, were approximately double the mean concentrations in sediments distant from stormwater discharges.

To view the SCB in the context of a larger spatial scale, Bight-wide sediment concentrations were compared with the results of the National Status and Trends Program (NS&T, Daskalakis and O'Conner 1995), which summarizes sediment contamination throughout the country. Nationally, concentrations of arsenic, chromium, copper, lead, mercury, selenium, and zinc were comparable to concentrations observed in the SCB. Concentrations of cadmium, silver, and total DDT were three-fold higher in the SCB than other areas of the nation. Concentrations of antimony, total PCB, and total PAH were three-fold higher nationwide than in the SCB.

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INTRODUCTION

Background and Purpose

The Southern California Bight (SCB) represents an important ecological, economic, and recreational resource for the nearly 15 million people who inhabit its coastal communities. This dense coastal human population, and accompanying rapid urbanization, has resulted in large ecological stresses affecting the marine ecosystem of the SCB. For example, several sources of pollutants are discharged to the SCB including treated municipal and industrial wastewater, stormwater runoff from urbanized areas, disposal of dredged materials, aerial fallout, oil and hazardous material spills, boating, and other sources (SCCWRP 1973). Sediments are often the fate of these anthropogenic inputs, where they can reside for long periods of time (NOAA 1991, Finney and Huh 1989, Bertine and Goldberg 1977), exerting effects at various levels of biological organization.

National Pollutant Discharge Elimination System (NPDES) regulatory permits for the discharge of treated municipal and industrial wastewater effluent, power generating station effluent, dewatering waste, and untreated stormwater require the measurement of dozens of organic and inorganic constituents for compliance with the regulatory guidelines designed to protect human health and aquatic biota (SWRCB 1990). Concentrations in sediments have been shown to covary with effluent emissions near their discharge locations (Phillips and Hershelman 1996, Bay and Schiff 1997). Self-monitoring programs for the largest publicly owned treatment works (POTWs) have observed a gradient of decreasing contaminants away from their outfalls (Stull *et al*. 1986a; Stull 1995, Diener *et al*. 1995) and statistical associations of sediment contaminant concentrations with changes in benthic community assemblages are used to identify whether NPDES discharges alter the marine habitat. Furthermore, contaminants in sediments from southern California are correlated with toxicity observed in sediment-dwelling invertebrates (Swartz *et al*. 1985, Bay 1995) and bioaccumulation in flatfish (Schiff and Allen 1997, Young *et al*. 1991).

These NPDES self-monitoring programs, however, typically focus on the single source being regulated. The result is that less than 10% of the area on the mainland shelf of the SCB is actually being monitored. Furthermore, there are four different regulatory jurisdictions responsible for coastal NPDES discharges in the SCB. Consequently, the self-monitoring programs have become a series of disconnected projects which do not necessarily analyze the same constituents, at similar frequencies, or with similar methodology, accuracy, or precision. Ultimately, NPDES monitoring programs are not designed to distinguish changes that occur on a region-wide scale or assess cumulative impacts from multiple sources whose fates commingle (NRC 1990).

Recognizing the need for integrated regional monitoring, 12 agencies joined in a collaboration to assess the condition of the mainland shelf in the SCB. This group of

participants represented a common venture between the largest NPDES regulated dischargers (City of Los Angeles, County of Los Angeles, County of Orange, and City of San Diego) and the regulators that issue their permits (Regional Water Quality Control Boards of Los Angeles, Santa Ana, and San Diego; State Water Resources Control Board; and U.S. EPA - Region IX), as well as other monitoring facilitators (Santa Monica Bay Restoration Project, U.S. EPA ORD - Environmental Monitoring and Assessment Project).

Objectives of the Current Study

Sediment contamination will be used in this report to assess the environmental condition of the mainland shelf in the SCB by:

1) Estimating the extent and magnitude of sediment contamination,

2) Measuring if contamination is similar throughout the Bight or more severe in particular areas, and

3) Associating the contamination with identifiable sources of pollution such as POTWs or stormwater discharges.

This report is organized into five general sections to address these objectives. The first section, Descriptive Results, presents concentration ranges, means, and spatial distributions of sediment contaminants. The second section, Assessment Results, evaluates sediment contamination in terms of concentration thresholds and estimates the areal extent of potential impact in the SCB. The third section, Discussion, critiques our ability to make valid assessments. The fourth and fifth sections, Conclusions and Recommendations, summarize the important findings and provide guidance for future regional monitoring programs to better address the study objectives.

MATERIALS AND METHODS

Two hundred and sixty-one sites were sampled on the continental shelf (defined as 10 to 200 m deep) from Point Conception, California, to the United States-Mexico international border between July 13 and August 22, 1994. Sites were selected using a stratified random design, with depth zone (the inner shelf from 10-25 m, the middle shelf from 26-100 m, and the outer shelf from 101-200 m), geography (Santa Monica Bay), and proximity to input sources (wastewater and stormwater outfalls) as the primary strata (Figure 1) The POTW wastewater stratum was defined as the area encompassed by the current NPDES ocean monitoring programs; the stormwater stratum was defined as the area within 3 km of the 11 largest river and creek mouths which empty directly to the SCB (Table 1). Details of site selection are provided in Bergen (1996) and Stevens (1997).

Field Sampling Methods, Sample Handling, and Storage

Sediment samples were obtained using a 0.1 m^2 modified Van Veen grab and surficial sediments (top 2 cm) from undisturbed, representative samples were collected using a Teflon or HDPE scoop or syringe. Sediments not in contact with the wall of the grab were placed in separate pre-cleaned containers for analysis of grain size (1 L plastic), TOC/TN (500 mL glass), trace organics (500 mL glass), and trace metals (500 mL glass). Samples were transported on ice and then frozen (-20 ± 2° C) prior to trace contaminant analysis or refrigerated (4 ± 1° C) prior to grain size analysis.

Analytical Chemistry

Sediment samples were distributed among participating laboratories which included the City of San Diego Environmental Monitoring and Technical Services Department, City of Los Angeles Environmental Monitoring Division, County Sanitation Districts of Los Angeles County, County Sanitation Districts of Orange County Environmental Sciences Laboratory, Pace Analytical Inc., and Texas A&M University Trace Element Research Laboratory (Table 2). All facilities that provided analytical results were certified by the State of California Environmental Laboratory Accreditation Program (ELAP) and/or the U.S. Environmental Protection Agency (U.S. EPA) Contract Laboratory Programs (CLP) for the appropriate analyses.

Grain Size

Grain size analysis was performed using a Horiba Model LA-900 Laser Scattering Particle Size Distribution Analyzer in conjunction with Horiba Data Systems software. A sediment sample was first homogenized at room temperature and a representative aliquot introduced to the instrument's sample reservoir. The sample was then dispersed and circulated through the measuring cell and the various particle sizes were determined by detection of scattered (refracted and reflected) laser light. Data were reported as frequency (percent) of particles for 74 different diameters between 0.88 and 1,000 microns. Significant interferences included scratches or bubbles in the measuring cell or particles greater than 1,000 microns. For samples with coarse grained materials, wet sieving through a 1,000 micron screen was required. During this study, these samples were re-screened using a 63 µm screen to determine the percent of fine-grained materials for a mass-based measurement.

Total Organic Carbon and Total Nitrogen

Total organic carbon (TOC) and total nitrogen (TN) analysis was performed using a Carlo Erba 1108 CHN Elemental Analyzer equipped with an AS/23 Autosampler in conjunction with Carlo Erba Data Systems software (Castillo and Khan 1992). Frozen sediments were thawed and homogenized at room temperature, then dried at 60° C overnight. After taring, an aliquot of each sample was digested with concentrated HCl vapors to remove inorganic carbon. The acidified sample was again dried and weighed, then crimped in a tin boat. The Carlo Erba CHN Analyzer oxidizes each sample boat in a

quartz combustion chamber and, using Poropak QS packed column, reaction products were separated and then quantified using a thermal conductivity detector. Acetanilide was used as the external standard. Acetanilide and cyclohexanone were used for Quality Control (QC) check standards. The certified reference material was PACS-1 (3.69% C, National Research Council).

Trace Metals

Major and trace element analysis was performed for aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, and zinc (Table 3). Sample preparation followed a modification of EPA Method 200.2 (U.S. EPA 1991). Approximately 0.5 g of freeze-dried, fine-ground sediment was digested using 5 mL of 1:1 trace metal grade nitric acid and 10 mL of 1:4 hydrochloric acid. The digested samples were heated to a gentle boil and swirled periodically for two hours. Samples were then transferred to polypropylene centrifuge tubes and brought to a volume of 30 mL with reagent grade water. Solids were removed by centrifugation. The supernatant with sample digest was transferred to new polyethylene bottles prior to analysis.

Inductively coupled plasma-mass spectroscopy (ICP-MS) was used to determine concentrations of aluminum, antimony, beryllium, cadmium, [total] chromium, copper, iron, lead, nickel, silver, and zinc from sample digest solutions utilizing a Hewlett Packard Model 4500 with Hewlett Packard Data Systems software and following protocols established by EPA Method 200.8 (U.S. EPA 1991). The internal standard solution included scandium, gallium, rhodium, and bismuth. Major interferents included argon, sodium, and magnesium. Instrument blanks were run to identify sample carry-over. The certified reference material was MESS-2 (National Research Council).

Graphite furnace atomic absorption spectrometry (GFAAS) was used for analysis of arsenic and selenium sample digest solutions utilizing a Perkin Elmer Model Z-3030 and Model 4100-Z instruments with Zeeman background correctors and following protocols established by EPA Method 200.9 (U.S. EPA 1991). The background correctors adjusted for interferents such as smoke and molecular absorption. Instrument blanks were run to identify sample carry-over. The certified reference material was MESS-2 (National Research Council).

Cold vapor atomic absorption spectrometry (CVAAS) was used for analysis of mercury from sample digest solutions utilizing a LDC Mercury Monitor attached to a TRC Model 4511 Strip Chart Recorder equipped with a 30 cm absorption cell and volume reaction cell. Most interference resulted from matrix effects, which were adjusted for by sample dilution or increasing concentrations of the $SnCl_2$ reductant solution. Instrument blanks were run to identify sample carry-over. The Certified Reference Material was MESS-2 (National Research Council).

Organic Compounds

All laboratories quantified six DDT isomers and metabolites (o,p'-DDT, p,p'-DDT, o,p'-DDE, p,p'-DDE, o,p'-DDD, p,p'-DDD). Four of five laboratories quantified at least three Aroclor mixtures (Aroclor 1242, 1254, 1260). Two of five laboratories quantified 27 individual PCB Congeners (Congeners 8, 18, 28, 29, 44, 50, 52, 66, 77, 87, 101, 104, 105, 118, 126, 128, 138, 153, 154, 170, 180, 187, 188, 195, 201, 206, 209). At least 13 additional pesticides were quantified from various laboratories participating in this study, but no pesticide was reported consistently for all samples. Between 16 and 25 polynuclear aromatic hydrocarbons (PAHs) were analyzed by participating laboratories. A complete list of target analytes and reporting limits are summarized in Table 3.

Samples were thawed and homogenized with anhydrous sodium sulfate at room temperature, spiked with surrogate standards, and solvent extracted using either a soxhlet apparatus (SW-846, Method 3540) or roller table (Anderson and Gossett 1987), or by sonication. Extracts were then dried with anhydrous sodium sulfate, treated with copper or mercury for sulfur removal, and subjected to Florisil and/or alumina/silica gel packed columns for clean-up/fractionation (SW-846, Method 3620) (U.S. EPA 1986, 1983). Each extract was concentrated and internal standards were added to the final extract prior to instrumental analysis. Internal and surrogate standards varied between laboratories. No samples were reported as having matrix-related interferences.

Chlorinated pesticide and PCB measurements were conducted using gas chromatographs equipped with electron capture detectors (GC-ECD) (SW-846, Methods 8080 or 8081) (U.S. EPA 1986, 1983). Typically, DB-5 and DB-17/608/1701 columns were used for analyte identification and confirmation, respectively. The PAH compounds were measured using gas chromatography/mass spectroscopy (GC-MS) equipped with DB-5 columns (SW-846, Method 8270) (U.S. EPA 1986, 1983). The chromatographic conditions varied among laboratories, but were chosen based upon the equipment used to provide sufficient separation efficiency for the target analytes.

Data Analysis

Data were analyzed in two ways: 1) calculation of mean parameter response (e.g., cadmium concentration) in the SCB and in various subpopulations (such as Santa Monica Bay); and 2) assessment of the fractional area within each population exceeding selected parameter thresholds of interest.

Mean parameter values were calculated using a ratio estimator (Thompson 1992):

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

where:

m = Mean concentration for population j

p_i = Parameter value (e.g., concentration) at station i

w_i = Weighting for station i, equal to the inverse of the inclusion probability for the site

n = Number of stations sampled in population j.

The ratio estimator was used in lieu of a stratified mean because an unknown fraction of each stratum was unsampleable (e.g., hard bottom). Thus, the estimated area, a random variable, was used as a divisor in place of the unknown true area. Standard error of the mean response was calculated as:

$$\text{Standard Error} = \sqrt{\frac{\sum_{i=1}^{n} ((p_i - m) * w_i)^2}{(\sum_{i=1}^{n} w_i)^2}}$$

Confidence intervals were calculated as 1.96 times the standard error. Statistical differences between populations of interest were defined on the basis of nonoverlapping confidence intervals. Use of the ratio estimator for the standard error approximates joint inclusion probabilities among samples and assumes a negligible spatial covariance, an assumption that appears warranted based on preliminary examination of the data. The assumption, though, is conservative in that its violation would lead to an overestimate of the confidence interval (Stevens and Kincaid 1997).

The percent of area exceeding a selected threshold was estimated in the same fashion after converting the data to a binomial form. For any sample observation, p_i was 1 if it exceeded the threshold value and 0 otherwise. The proportion of area that exceeded the selected threshold was taken as the mean of the indicator variable y_i.

For the purposes of this study, four thresholds were identified including: 1) detectable quantities of analytes, 2) anthropogenic enrichment of analytes, and 3) and 4) two screening levels of biological concern. Since chlorinated hydrocarbons are a synthetic pollutant, sediments were considered anthropogenically enriched wherever they

were detected. Trace metals, however, are a naturally occurring component of marine sediments. Anthropogenic enrichment of trace metal constituents was assessed by conducting reference element normalization using iron (Schiff and Weisberg 1997, Appendix C).

Two screening level thresholds developed by Long *et al*. (1995) were used for examining sediment contamination levels of biological concern (Table 4). The effects range low (ERL) represents the concentration below which adverse biological effects should rarely be observed. The effects range median (ERM) represents the concentration above which adverse biological effects should frequently be observed. Concentrations between the ERL and ERM represent the level where adverse biological effects should occasionally be observed. The ERL and ERM were derived from a biological effects database comprised of 89 studies and hundreds of samples from marine and estuarine sediments throughout the United States. Biological effects included acute and chronic toxicity in laboratory bioassays from field-collected sediments or clean sediments spiked with contaminants, histopathological disorders in bottom-dwelling fish, and demonstrated benthic community impacts. The ERL and ERM are not regulatory sediment quality criteria; these thresholds are merely guidelines for assessing potential impacts resulting from contaminated marine or estuarine sediments and can be used to assess if additional evaluations are necessary.

QUALITY ASSURANCE/QUALITY CONTROL

Field Sampling

Of the 261 sites targeted, 248 sites were sampled which exceeded the study data quality objective (DQO) of > 90% completeness. For the 13 missing sites, 2 were the result of an incorrect sample frame (1 site in Mexico, 1 site too deep); 10 were a result of improper substrate (i.e., rocks, cobbles, or hard-packed sand); and 1 was the result of improper vessel positioning. Audits of field collection procedures on-board each vessel did not identify any significant deviations from accepted protocols for required equipment and sample processing (Bergen *et al*. 1997).

Laboratory Analysis

Each of the participating laboratories had ongoing marine monitoring programs that included analysis of sediments using well-established analytical methods. However, these programs were specifically tailored to each facility. Therefore, a "performance-based" Quality Assurance Project Plan (QAPP) was instituted that accommodated individual flexibility, while maintaining predetermined levels of quality assurance. This process reduced the significant resources required to standardize methods, detection limits, and QA/QC programs among labs. The basic QAPP framework for this study was based on the National Oceanic and Atmospheric Administration (NOAA) National Status

and Trends Program and the U.S. EPA Environmental Monitoring and Assessment Program (U.S. EPA 1993 a,b).

The QAPP specified 14 data quality objectives (DQOs) (Table 5). Trace metal analysis satisfied the completeness, frequency, accuracy, and precision requirements for 13 of the 14 DQOs. Accuracy of reference material analysis was low due to the variability introduced by sediment digestion methods. The procedures utilized for this study employed partial sediment digestions with strong acids (HCl and HNO_3) while the reference material concentrations were certified using total dissolution with hydrofluoric acid (HF). The two digestion techniques will result in differential recovery of reference materials (Figure 3) as has been noted by others (Bothner *et al.* 1980, Cook *et al.* 1997). Organic analysis satisfied the completeness, frequency, accuracy, and precision requirements for 13 of 14 DQOs (Table 5). The TOC analysis satisfied the completeness, frequency, accuracy, and precision requirements for 10 of 10 DQOs (Table 5). All the participating laboratories performed exceptionally well with regards to the DQOs identified at the outset of this study.

While the performance-based QAPP addressed issues regarding completeness, frequency, accuracy, and precision, it did not address issues regarding data comparability. Three comparability issues affected the quality of this study: 1) method detection limits/quantitation limits, 2) target analytes, and 3) sediment digestion techniques. For some compounds, particularly PAHs, detection limits varied by two orders of magnitude (Table 3). To compensate, all data were censored below the highest detection limit for any individual PAH to make data sets comparable. Target analytes sometimes varied between labs, particularly for PCBs (Table 2). To compensate, total PCB was utilized for assessing extent and magnitude of contamination. Total PCB, however, could represent the sum of Aroclors (1242, 1254, 1260) or congeners (27 total). Scientists have shown that there is some bias associated with the differences in these methods (Eganhouse and Gossett 1991). Sediment digestion techniques for trace metal analysis varied between laboratories; some samples were digested using HF and other samples were digested using HCl and HNO_3. As noted above, the various techniques have differential digestion efficiencies, resulting in data sets that were not comparable (Figure 3). To compensate, all samples were re-analyzed using a single digestion technique (HCl and HNO_3), the common technique used for current ocean monitoring programs in the SCB.

DESCRIPTIVE RESULTS

Concentration Means, Ranges, and Spatial Distributions

Table 6 lists the area weighted mean and area weighted 95% confidence limits for three general sediment characteristics (fine grained material, TOC, TN); 14 major and trace elements (Al, Sb, As, Be, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Se, Hg, Zn); and 3 classes of organic compounds (total DDT, total PCB, total PAH). Also presented are the minima, maxima, median, and quartile ranges for each constituent. This table allows direct comparison of sediment chemistry results derived from other programs that use similar analytical techniques with Bight-wide distributions of sediment contaminant concentrations from the mainland shelf of the SCB. Cumulative distribution functions (CDFs) are presented for each constituent in Appendix A.

General sediment parameters such as the fraction of fine-grained materials (< 63 μm diameter), TOC, and TN were measured as percent of dry bulk sediment sample (Table 6). Samples ranged from 0% fines (all sand and gravel) to 100% fines (all silt and clay). Throughout the entire SCB, the fine grained fraction averaged 42.5% of each sample. The distribution of TOC, which ranged from 0.04 to 5.12% of bulk sediments, was positively skewed. Concentrations of TOC greater than 1.5% represented only 10% of the SCB. Like TOC, TN in bulk sediments ranged over two orders of magnitude from < 0.008 to 0.24% and was also positively skewed. The TN concentrations were approximately one order of magnitude lower than the TOC concentrations.

The finest grained sediments were found in deeper waters and locations where net deposition occurs (Figure 4, Appendices A and B). The Santa Barbara Channel contained extremely fine-grained sediments, as did locations near submarine canyons offshore Pt. Hueneme and Santa Monica Bay. Shallower areas typically contained more coarse-grained sediments. Predominantly sandy sediments were found inshore where waves resuspend fine-grained sediments and transport them farther offshore.

Sediment throughout the SCB contained measurable quantities of trace metals, however, concentrations were positively skewed, particularly for cadmium, chromium, copper, iron, lead, mercury, and silver (Table 6, Appendix A). The range of concentrations for all analytes spanned between two and three orders of magnitude. The highest sediment concentrations were typically found in locations where inputs of these constituents were greatest and in sediments where silts and clays were abundant (Appendix B). Lead concentrations exemplified the spatial pattern typical of most trace metals (Figure 5). Santa Monica Bay is an example where large anthropogenic inputs of trace metals such as lead can occur. The highest concentrations of lead, and nine other trace metals, were all located within Santa Monica Bay.

Since trace metals are a natural component of silt and clay-bearing sediment deposits, iron was used as a conservative tracer to differentiate between natural levels and

anthropogenic additions of trace metals (Figure 6). All eight trace metals assessed contained Bight-wide concentrations above background levels (Appendix C). Arsenic (n=8) and nickel (n=10) had the smallest number of anthropogenically enriched sites and, where observed, the magnitude of enrichment was relatively low. In contrast, cadmium (n=100), chromium (n=88), and silver (n=86) had the largest number of enriched sites, at times exceeding contaminant thresholds by an order of magnitude. The difference between naturally occurring trace metal concentrations and anthropogenic additions of trace metals also substantially changed the spatial pattern of trace metal distributions (Figure 7). For lead, the highest concentrations were still found in Santa Monica Bay, clustered near the 7-mile sludge disposal line that was decommissioned in 1987. This finding was true for the majority of the other trace metals as well. Other locations also exhibited significant anthropogenic enrichment of lead including areas near the Ballona Creek, Santa Ana River, and San Gabriel River mouths.

Distributions of sediment concentrations for the organic compounds total DDT and total PCB were positively skewed. Since Bight-wide sediment concentrations of total DDT and total PCB spanned five orders of magnitude, the CDFs were plotted on log scale (Appendix A). Sediment concentrations of total PAH were uniformly below data reporting limits.

The spatial pattern of sediment concentrations for total DDT showed that the highest concentrations in the SCB were located on the Palos Verdes shelf (Figure 8). This area was the site of large historical discharges and a large reservoir still exists in subsurface sediments. The concentrations of total DDT decreased towards the north, declining as one approached Point Dume. However, detectable quantities of this pesticide were found throughout the SCB, even though use and discharge through the sewerage system has been banned for 25 years.

Evaluation of Subpopulations

This study identified two general groups of stations, or "subpopulations of interest," for which to compare sediment chemistry results (Table 1). These two general groups included geographic strata (Santa Monica Bay *versus* remainder of SCB) and anthropogenic strata (POTW *versus* non-POTW and stormwater *versus* nonstormwater). The CDFs by subpopulation are given in Appendix A. It is important to note that the subpopulations of interest were selected *a priori* based upon scientific experience and best professional judgment since the regional information required for subpopulation demarcation was nonexistent prior to this survey.

Santa Monica Bay

Area-weighted mean sediment concentrations inside of Santa Monica Bay were higher for every constituent measured than sediment concentrations outside of Santa Monica Bay (Table 7). Both regions had similar grain sizes (44.8 *versus* 42.2 % fines), indicating the composition and texture of the sediments were comparable among regions.

However, 12 of the remaining 13 constituents measured contained significantly higher concentrations inside than outside of the Bay, including TOC, TN, cadmium, chromium, copper, lead, mercury, nickel, silver, zinc, total DDT, and total PCB. Mean sediment concentrations for these constituents were 50% to 1,000% higher inside than outside of the Bay.

POTW Outfall Areas

Area-weighted mean sediment concentrations near POTW outfall areas were higher for 10 of 14 constituents than sediment concentrations distant from POTW outfall areas (Table 7, Appendix A). Grain size was similar among regions (40.8 *versus* 47.9% fines), indicating that the texture of the respective substrates was comparable. Although mean TOC and TN content were higher in sediments near POTW outfall areas, the difference was not significant. Likewise, mean concentrations of cadmium, chromium, and lead were higher in sediments near POTW outfalls, but not significantly different. Concentrations of copper, mercury, silver, total DDT, and total PCB were significantly higher in sediments nearest POTW outfalls compared to sediments farther away; mean sediment concentrations were higher by a factor of 100% to 1,000% for these constituents. In contrast, sediment concentrations of arsenic, nickel, and zinc were higher distant from POTW outfall areas than closer; mean concentrations of arsenic and nickel were significantly higher.

Stormwater Discharge Areas

Weighted mean sediment concentrations in areas near stormwater discharges were higher for every constituent measured compared to sediments farther from stormwater discharges (Table 7). Sediments near stormwater discharges were 50% finer than sediments farther away (31.7 *versus* 20.2 % fines, respectively). Likewise, the mean TOC and TN contents of these stormwater-influenced sediments were 50% higher than sediments farther from stormwater discharges. Although the trace metal concentrations averaged 60% higher in sediments near stormwater discharges, only copper concentrations were significantly higher than sediment concentrations farther away. Sediment concentrations of chlorinated hydrocarbons were similar between regions. Mean concentrations of total DDT and total PCB were only marginally higher near stormwater discharges than mean sediment concentrations farther away.

ASSESSMENT RESULTS

Extent of Bight-wide Sediment Contamination

Nearly 90% of SCB sediments were considered to be anthropogenically enriched by at least one trace metal and/or organic pollutant (Figure 9). Although every sample contained measurable quantities of some pollutants, over 10% of SCB sediments were not considered anthropogenically enriched. For those samples that were considered enriched, the level of contamination was classified into three categories based upon Long

et al. (1995) biological effects screening criteria (Figure 9, Table 4). One-third (33.2% < ERL) of the SCB area was contaminated at a level where biological effects would not be expected, one-sixth (12.3% > ERM) of the SCB was contaminated to a level at which biological effects could be likely, and over half (ERL > 54.5% > ERM) of the SCB had sediment contamination where biological effects might occasionally occur.

Anthropogenic enrichment extended the entire length of the SCB, from Point Conception to the U.S.-Mexico international border (Figure 10). Likewise, the sites that exceeded thresholds of occasional biological impairment (>ERL) were also widespread. However, the sites that exceeded thresholds of likely impairment (> ERM) were most often located in Santa Monica Bay. Furthermore, the sites sampled from Santa Monica Bay contained sediments that were enriched with the greatest number of constituents (Figure 11). Of the 35 sites that were anthropogenically enriched in 9 to 10 parameters (including As, Cd, Cr, Cu, Pb, Ni, Ag, Zn, total DDT, and total PCB), all were located in Santa Monica Bay. Three sites were contaminated by 9 to 10 constituents at levels that exceeded screening levels for adverse biological effects (>ERL). Each of these sites were also located in Santa Monica Bay (Figure 12). Finally, all eight sites with multiple constituents that exceeded screening levels for frequent adverse biological effects were located inside Santa Monica Bay (Figure 13).

To assess the relative risk from different classes of pollutants, the extent of sediment contamination was compared between trace metals and organic constituents (Figure 14). Despite 100% of the SCB having detectable quantities of trace metals, only half (50.1%) was at a level considered to be anthropogenically enriched. Trace metals are naturally occurring components of the earth's crust and background levels are measurable in this, and other, monitoring programs within the region. In contrast, man-made synthetic organic compounds were considered enriched wherever they were detected (82.1% of the SCB). The largest disparity in sediment contamination between trace metals and organic compounds was at levels where biological effects screening thresholds were exceeded. The potential of adverse biological effects resulting from trace metal contamination was expected occasionally (concentrations > ERL) in 13.7% of the SCB and expected frequently (concentrations > ERM) in 2.8% of the SCB. For organic contaminants, the potential for occasional adverse biological effects was more widespread. Thresholds of occasional adverse biological effects were exceeded in 63.7% of the SCB. Thresholds of frequently occurring adverse biological effects were exceeded in 10.4% of the SCB due to one or more organic contaminants.

To determine which particular constituent was responsible for the greatest degree of sediment contamination, the extent of detectable measurements and magnitude of enrichment were assessed in the SCB on an analyte-by-analyte basis (Table 8). Trace metals were detected very frequently in sediments of the SCB. In fact, 5 of 9 trace metals were detected in every sample analyzed. The trace metal detected least frequently was mercury; this trace metal was measured in approximately 96% of the SCB.

Although trace metals were detected very frequently in sediments of the SCB, only 50% of the SCB area was anthropogenically enriched in any of the eight metals assessed based upon normalization by iron (Table 8). The trace metals that showed the greatest extent of anthropogenic enrichment were cadmium, chromium, and silver (31.2, 21.4, and 20.2% of the SCB, respectively). The trace metals with the least enrichment were nickel and arsenic (3.2 and 6.8% of the SCB, respectively). All eight of the trace metals assessed were anthropogenically enriched to some degree. The range of detectable organic contaminants was much greater. For example, PAHs were below reporting limits in all of the areas we sampled. However, total DDT (primarily p,p'-DDE) was detected (and therefore enriched) in 81.8% of the SCB. Total PCB was detected in 45.6% of the SCB area.

The constituent which had the greatest areal extent for potential biological impairment was total DDT (Table 8). Total DDT exceeded screening levels for occasional sediment toxicity in 63.7% of the SCB (2,242 km^2 > ERL); the screening level threshold for likely sediment toxicity was exceeded in 10.4% of the SCB (366 km^2 > ERM). Total PCB was the next constituent with the greatest areal extent of potential biological impairment. Total PCB exceeded screening levels for occasional sediment toxicity in 15.3% of the SCB; the screening level thresholds for likely sediment toxicity was exceeded in 0.7% of the SCB. Every trace metal evaluated exceeded screening level thresholds where biological effects may occasionally occur. The area exceeding these thresholds varied from metal to metal, ranging from 0.5 to 7.3% of the SCB for lead and chromium, respectively. However, only nickel (1.8% of the SCB) and silver (1.0% of the SCB) exceeded thresholds where biological effects might be likely. The remaining metals did not exceed thresholds of likely biological impairment.

Extent of Sediment Contamination by Subpopulation

Santa Monica Bay

The extent of sediment contamination inside of Santa Monica Bay was much greater relative to the extent of contamination outside of Santa Monica Bay (Figure 15). One hundred percent of the area inside of Santa Monica Bay was enriched in at least one sediment contaminant. At least 13% of the area outside Santa Monica Bay was not enriched in any contaminant. Not only was the relative areal extent of sediment contamination greater inside of Santa Monica Bay compared to outside of the Bay, but the magnitude of this contamination was also greater (Figure 15). Fifty percent of the area inside the Bay contained sediment concentrations of at least one constituent that exceeded sediment quality screening levels likely to induce biological effects (> ERM). In contrast, only 7% of the areas outside the Bay contained sediment concentrations that exceeded this criterion.

Santa Monica Bay sediments were contaminated by a larger number of inorganic constituents, and to a greater magnitude, than sediments outside of the Bay (Table 9). Trace metals contaminated 96% of the Bay sediments; only arsenic and nickel were

enriched in less than 50% of the Bay. In contrast, 43% of the area outside of Santa Monica Bay was enriched in trace metals; no single metal was enriched in more than 25% of the remaining SCB sediments. The constituents that significantly contaminated large portions of the Bay included cadmium, chromium, copper, lead, silver, zinc, and possibly mercury. Chromium, copper, mercury, and silver contaminated 30 to 48% of the Bay sediments at levels where the potential for biological effects may occasionally occur. No trace metal exceeded this initial biological screening level by more than 3% in the remaining sediments of the SCB.

Organic constituents contaminated large areas of Santa Monica Bay (98%), as well as the remaining SCB sediments (80%) (Table 9). Most of this sediment contamination exceeded screening levels where biological effects may occasionally occur (90% of Bay sediments > ERL), and significant portions exceeded screening levels where sediment effects were likely to occur (44% of Bay sediments > ERM). The relative extent of sediment contamination beyond screening levels of likely impairment was much reduced outside of Santa Monica Bay (6% of remaining SCB > ERM). Total DDT was responsible for most of these exceedances, although total PCB also contaminated nearly three-quarters (72%) of the Bay sediments. Often, these contaminated sites were at the same locations as the total DDT enrichment.

POTW Outfall Areas

Approximately 90% of the mid-depth (25-100 m) area near to and distant from outfalls was enriched in at least one sediment contaminant (Figure 16). Although the relative extent of sediment contamination was similar between POTW outfall areas and areas farther from outfalls, the magnitude of the sediment contamination near outfall areas was greater. Nearly 35% of the area near POTW outfalls was enriched to a level where biological effects might be likely (105 km^2 > ERM) compared to less than 13% of the area distant from POTW outfalls (215 km^2 > ERM).

Trace metals were enriched in approximately half of the mid-depth areas near and distant from POTW outfalls (54.8 and 51.4%, respectively) (Table 10). Between 3 and 4% of the area close to POTW outfall discharges exceeded screening levels for trace metals where biological effects might be likely (> ERM), which was similar to the areal extent of sediment contamination distant from these discharges. However, over one-third of the outfall areas exceeded screening level thresholds for trace metals where biological effects may occasionally occur (> ERL) as opposed to less than 13% of the areas farther away. The trace metals responsible for this disparity included chromium, copper, mercury, and silver, which individually contaminated between 13 and 30% of the POTW outfall areas. Silver was the only trace metal responsible for enrichment beyond a level where biological effects might be likely, extending to 4% of the area near POTW outfalls.

Organic constituents enriched similarly large proportions of POTW outfall and nonoutfall areas (80 *versus* 86% of areas, respectively) (Table 10). Unlike trace metals, however, the greatest disparity in areal extent of contamination was beyond sediment

screening levels where biological effects might frequently occur (> ERM). The proportion of area near POTW outfalls was more than three-fold greater than areas distant from POTW outfalls. Almost 35% of the POTW outfall areas exceeded these thresholds of biological concern, in most part due to total DDT.

Stormwater Discharge Areas

The extent of sediment contamination near stormwater discharge areas was similar relative to other shallow water areas of the SCB (70 *versus* 82%, respectively) (Figure 17). The magnitude of contamination was also similar between the two areas; approximately half of the area near or distant from stormwater discharges was enriched in at least one contaminant beyond the screening level threshold where adverse biological effects may occasionally occur. Unlike the Santa Monica Bay or POTW outfall subpopulation comparisons, however, no shallow water areas - near or distant from stormwater discharges - exceeded screening level criteria where biological effects were likely.

The greatest disparity between stormwater discharge areas and shallow water areas more distant was the enrichment of trace metals (Table 11). Stormwater discharge areas were enriched nearly twice as often as nondischarge areas (47 *versus* 25%, respectively). In particular, cadmium, chromium, copper, lead, and zinc were responsible for this increased sediment contamination. Ten percent of the stormwater discharge area was enriched in at least one trace metal to the point where biological effects may occasionally occur (> ERL). In sediments distant from stormwater discharges, no exceedances of screening level criteria for occasional biological effects were found.

Organic contaminants were enriched in approximately similar proportions from stormwater discharge areas and other shallow water areas farther away (67 *versus* 72%, respectively) (Table 11). Similar proportions of enrichment were also observed at levels that exceeded screening level criteria (> ERL) where biological effects may occasionally occur (50 *versus* 43%, respectively). Most of this contamination resulted from enrichment by total DDT.

DISCUSSION

Use of Screening Level Thresholds

At the time of this study, no regulatory sediment quality criteria had been promulgated by the State of California for which to compare regional monitoring results and assess the extent of sediment contamination in the SCB. Establishing numerical thresholds at which sediment contaminants are in excess and detrimental to marine life has been the subject of extensive debate for many years (Chapman 1989; DiToro *et al*. 1991; Hoke *et al*. 1994; U.S. EPA 1993c, 1993d, 1993e). This study utilized several

pollutant thresholds of increasing severity to assess the extent and magnitude of sediment contamination. These pollutant thresholds included: 1) could contaminants be measured (detectable), 2) were contaminants measurable above background levels or naturally occurring concentrations (anthropogenically enriched), 3) did the contaminants exceed screening level values which may indicate occasional biological effects (> ERL), or 4) did the contaminants exceed screening level values which may indicate frequent biological effects (> ERM). It was assumed that the extent of sediment contamination derived from these thresholds is valid only if the predictability of the threshold is reliable.

Long *et al.* (1995) has developed and evaluated the reliability of the ERL and ERM for the constituents which were assessed in this study. The screening level values appear to be highly predictive of adverse biological effects for some constituents including PAH, arsenic, cadmium, chromium, copper, lead, silver, and zinc. The screening level values for other constituents assessed in this study were less predictive of adverse biological effects including total DDT, total PCB, mercury, and nickel. One consequence of unpredictability is an increase in Type I errors; a false positive would indicate a potential for biological impairment when none may actually occur (Long *et al.* in press). This lack of reliability affects assessments of sediment contamination in the SCB, particularly since total DDT was such a widespread contaminant and often exceeded the screening level values for adverse biological effects.

Several biological indicators measured as part of regional monitoring did not entirely corroborate the widespread potential for occasional adverse biological effects predicted by threshold exceedences. None of the 71 whole sediment samples from the SCB tested with the amphipod *Ampelisca abdita* exhibited acute toxicity (Bay 1996), although 17 of these samples exceeded the ERM for at least one constituent. Eleven of these 17 samples exceeded the ERM solely for total DDT. Approximately 90% of the SCB area was determined to have ecologically healthy benthic community assemblages indicative of reference areas (Bergen *et al.* 1997). The remaining 10% of the SCB was characterized by a low degree of impact; benthic community responses indicated only marginal deviation from reference conditions (8% of SCB area) and exclusion of some sensitive species (2% of SCB area). Moreover, there was a low correspondence between changes in benthic community assemblages and exceedances of the ERM at individual sites. Although no specific measure was derived to indicate degradation of demersal fish and megabenthic invertebrate populations from an individual site, assessments of regional monitoring results did not show large-scale impacts for trawl studies (Allen *et al.* 1997), even when sediment contaminants exceeded the ERM. Moreover, the prevalence of epidermal fish lesions and tumors was extremely low.

Regional monitoring did find widespread bioaccumulation of total DDT and total PCB in livers of three flatfish species (Pacific sanddab [*Citharichthys sordidus*], longfin sanddab [*Citharichthys xanthostigma*], and Dover sole [*Microstomus pacificus*]) throughout the SCB (Schiff and Allen 1997). Total DDT was detected in all 78 liver tissue samples analyzed and the concentration in all three species of flatfish was

significantly correlated to concentrations measured in sediments. However, the adversity of this biological effect is unclear, since these species are not commonly caught by recreational anglers or part of a large commercial market (Allen *et al*. 1996), and there are no ecotoxicological benchmarks for the target tissues examined (Allen *et al*. 1997).

There are several potential reasons why the ERL and ERM screening level thresholds do not correspond to the biological indicators assessed for regional monitoring. One reason might be that our biological indicators are not sensitive to contaminant changes. In the case of sediment toxicity tests, *Ampelisca* was less sensitive than toxicity tests using the purple sea urchin (*Strongylocentrotus purpuratus*) (Bay 1996). A second explanation for the unreliability of the ERL and ERM might be that the thresholds are not good predictors of adverse biological effects.

Comparison of Thresholds

Since the reliability of the ERL and ERM screening level thresholds of adverse biological effects for total DDT was questionable, a sensitivity analysis was conducted whereby several different thresholds were applied to the distribution of sediment total DDT in the SCB (Table 12). The thresholds were derived from the literature by many investigators including NOAA (Daskalakis and O'Conner 1995, MacDonald 1994a), U.S. EPA (Swartz *et al*. 1994), other states (MacDonald 1994b, MacDonald *et al*. 1996), and private industry (Chapman 1996). The investigations encompassed a wide variety of approaches, locations, and endpoints. All of the thresholds that were based upon bulk sediment concentrations were higher than the comparable ERL or ERM; all but one were within a factor of four. Three of the thresholds were based upon TOC content as a normalizing parameter. These thresholds were all within 50% of each other.

The assessment of areal extent for total DDT contamination varied depending upon which threshold was applied (Table 12). Unlike California, the State of Florida has regulatory sediment quality criteria that it uses to assess sediment degradation, termed the threshold effects level (TEL) and probable effects level (PEL). These values are analogous to ERL and ERM levels, respectively (MacDonald 1994b). Using these thresholds, the area in which biological effects may occur was reduced by 14.5%, or approximately 520 km^2. The area where biological effects were likely to occur changed little, however, decreasing 1.3%, or approximately 4.6 km^2.

Potential biological effects thresholds were compared for total DDT sediment contamination from three studies derived, at least in part, from southern California (Table 12). The first study used a similar approach as the ERL and TEL thresholds for biological effects, but reported two screening levels; one for bulk sediment concentrations and the other for TOC normalized sediment concentrations (MacDonald 1994a). Applying both thresholds to the distribution of total DDT sediment concentrations (appropriately normalized) resulted in two estimates of areal extent. The first estimate of areal extent based upon bulk sediment concentrations was lower than the ERL (41.7% of the SCB). The second estimate based upon TOC normalization was higher than the ERL (71.5% of the SCB). The second study from southern California

also reported two thresholds for biological effects comparable to the ERL, but based them upon sediment toxicity tests exclusively (Chapman 1996). Once again, two different thresholds resulted in two different assessments of areal extent for total DDT sediment contamination. The first estimate, which used a bulk sediment concentration, was lower than the ERL (40% of the SCB). The second estimate, which used a TOC normalized threshold, was higher than the ERL (65% of the SCB). The third study derived thresholds based upon laboratory and field data from three sites with significant DDT contamination located in southern California (Palos Verdes Shelf), San Francisco Bay (Lauritzan Canal), and Huntsville, Alabama (Swartz *et al*. 1994). This threshold was based solely on TOC normalized sediment concentrations and was comparable to the ERL. After applying the threshold to normalized total DDT concentrations, 63.6% of the area in the SCB was deemed contaminated. This finding was almost identical to the estimate of areal extent based upon the ERL.

The problem with assessing contaminated sediments using biological effects thresholds is that some uncertainty will always be associated with a single concentration. Many factors contribute to the overall toxicity observed in an individual sediment sample, and the state of the science does not provide an assessment of accuracy. However, the data distributions developed for this study are robust enough to apply any threshold of interest. As the science regarding thresholds advances, new findings can be applied to this data set retroactively to assess areal extent of biological impairment.

Comparison to Nationwide Surveys of Sediment Contamination

To place the SCB within a larger perspective, we compared regional monitoring results with nationwide summaries of sediment contamination from the NOAA Status and Trends Program (NS&T) (Daskalakis and O'Conner 1995). Since 1984, the NS&T program has sampled 212 sites around the country, 22 of which were from the SCB. These 22 sites were situated within harbors, near offshore islands, proximal to submarine canyons, and on the mainland shelf. NOAA (1990) has shown that results for sediment contaminants from their survey typically fit a lognormal distribution and has described "high" concentrations as the geometric mean plus one standard deviation. In addition, NOAA normalizes sediment contamination to the percent of fine-grained material in each sample and only includes samples with more than 20% fines. This method assumes that contaminants preferentially bind to the silts and clays, and that sand or gravel are diluents in the bulk sediments which may bias results. Our data were calculated in the same manner for direct comparability of results.

With the exception of a handful of constituents, sediment contamination found Bight-wide appeared to be similar to the contamination level observed nationwide by NOAA (Table 13). High concentrations of sediment contaminants were similar between this study and NS&T for arsenic, chromium, copper, lead, mercury, selenium, and zinc. Sediment contamination levels reported by each survey were within 5 to 37% of each other for these constituents. In contrast, high concentrations of antimony, total PCB, and

total PAH nationwide were at least three times greater than high concentrations measured from the SCB. Conversely, high concentrations of cadmium, silver, and total DDT in the SCB were at least three times greater than high concentrations found in other areas around the country. The NS&T program has identified the 20 sites which have the greatest mean concentrations for each constituent. In the case of total DDT, 10 of these 20 NS&T stations were located in the SCB. Similarly, 6 of the 20 highest cadmium and 3 of the 20 highest silver concentrations were found in the SCB.

The results of this comparison are potentially confounded by differences between our study and the NS&T program. Many of the NS&T sites are located in habitats, such as estuaries and harbors, which we did not sample. These locations may differ in their physical characteristics and contamination sources. Furthermore, the NS&T program does not use equivalent analytical methodology to those used for regional monitoring in the SCB. For example, NS&T uses a more rigorous sediment digestion for trace metal analysis and has established their own list of PCB target analytes which varies slightly from those selected in our study.

Ability to Address Regional Monitoring Objectives

Magnitude and Extent of Sediment Contamination

Regional monitoring was used to estimate the magnitude and extent of sediment contamination on the mainland shelf of the SCB. The significance of this approach is two-fold: 1) determination of summary statistics such as mean concentrations for the region, and 2) to estimate the areal extent of contamination as a result of a new study design. Summary statistics such as mean, minima, maxima, and quartile distributions of sediment concentrations not only provide estimates of Bight-wide contaminant magnitude, but also permit other site-specific monitoring programs to evaluate the magnitude of their individual site relative to other regions of the SCB. This point is especially salient for ANOVA-based monitoring programs that compare localized impacted sites to individual locations which may or may not provide representative reference conditions. The comparison of site-specific results to Bight-wide data distributions (i.e., CDFs in Appendix A) significantly contributes to the interpretation of sediment chemistry data; Bight-wide data distributions encompass the breadth of natural variability and impact from other sources of contamination. Since the entire range of natural variability was encompassed, new reference-based tools could be developed for evaluating data. Most notably, reference element normalization was used for assessment of anthropogenic enrichment in trace metal concentrations.

The new study design utilized for this regional monitoring project was pivotal for estimating the magnitude (high or low concentrations) and extent (how widespread or how much area) of sediment contamination. Perhaps the best illustration of extent was sediment contaminated with total DDT. Although measurable quantities of total DDT were known to be widespread, not until this study was there an estimate of the percent of SCB area contaminated or, more specifically, an estimate of the square kilometers of the mainland continental shelf contaminated with this persistent pesticide.

Contamination Throughout the SCB

A second objective of regional monitoring was to assess whether sediment contamination was similar throughout the SCB, or more severe in particular areas. Relative to the rest of the SCB, the magnitude of sediment contamination was greater in Santa Monica Bay than elsewhere. Mean sediment concentrations of every constituent measured were higher inside than outside of Santa Monica Bay; 12 of 13 constituents were significantly higher. Maximum concentrations of most sediment contaminants were found inside of Santa Monica Bay, including concentrations of all trace metals after normalizing by iron to assess the fraction of pollutant that was anthropogenically enriched. The extent of sediment contamination in Santa Monica Bay was also greater than other regions of the SCB; 100% of Bay sediments were enriched in at least one contaminant and approximately 80% were enriched in at least five contaminants. This proportion was much higher than sediments outside of the Bay (87 and 7%, respectively). Furthermore, 50% of Santa Monica Bay contained sediments that exceeded screening level threshold for potentially inducing biological effects. This proportion of sediment contamination was eight-fold greater than the extent of sediment contamination outside of the Bay (approximately 7%). Finally, where sediment contamination did exceed thresholds of concern, the sampling sites inside of Santa Monica Bay contained sediments that were most often contaminated by multiple constituents.

Association of Sediment Contaminants with Known Sources

One objective of this study was to associate sediment contaminants with identifiable sources of pollution. This objective was partially accomplished by creating maps and looking for gradients in contamination magnitude. For example, when examining Bight-wide gradients of total DDT during this study, the highest sediment concentrations were measured on the Palos Verdes Shelf. This location is the subject of an EPA Superfund site investigation as a result of historical discharges by Montrose Chemical Corporation which, until 1971, sent DDT manufacturing waste through Los Angeles County's ocean outfall from the Joint Water Pollution Control Plant. Although estimates of up to 1,800 metric tons of total DDT were discharged by Montrose per annum prior to 1971 (Chartrand 1988), current POTW emissions are extremely low or nondetectable (Raco-Rands 1996). The sediment concentrations resulting from these historical discharges steadily declined moving northward, through Santa Monica Bay and beyond, which is the net direction of the oceanic currents in the region (Hickey 1993). Sediment concentrations of total DDT remained uniformly low to the south of Palos Verdes. Other examples of constituents that showed spatial patterns relative to large POTWs were total PCB, silver, and cadmium. Although large quantities of these constituents have been discharged through POTW outfalls, more than 99% of the mass emissions occurred prior to 1988. Historical discharges of some contaminants have accumulated in sediments near POTW outfalls and can remain there for decades (Zeng *et al*. 1995, Stull *et al*. 1986b). However, geographic associations are circumstantial evidence and do not necessarily represent the only sources of these constituents.

Measurement of the extent and magnitude of sediment contamination among the subpopulations of interest (i.e., POTW outfall and stormwater discharge areas) was a second technique utilized to associate certain pollutants with specific sources. Interestingly, large differences were not observed in relative extent, but rather changes in relative magnitude of sediment contamination. For example, sediments in stormwater discharge areas had higher concentrations of nearly all constituents than other shallow areas (10-25 m) in the SCB distant from stormwater discharges. In particular, stormwater areas were enriched twice as often for trace metals (specifically cadmium, chromium, copper, lead, and zinc) as nonstormwater areas; 50% of the sediments surrounding stormwater discharges were enriched in at least one of these trace metals. Stormwater effluents are known to discharge large quantities of these trace metals annually (Schiff and Stevenson 1996). In 1994-95, the cumulative mass emissions of these metals from the largest rivers and creeks in the SCB exceeded the mass emissions from the four largest POTWs (Schiff 1997). Similar to the maps showing spatial relationships between sources and sediment contaminants, this evidence is circumstantial. Other sources, both present-day and/or historical, can contribute to the sediment contamination measured Bight-wide.

CONCLUSIONS

1. Sediment contaminants were widespread in the SCB.

- Nearly 90% of the SCB area had evidence of anthropogenic contamination by at least one chemical.

2. Total DDT was the most widespread anthropogenic contaminant.

- Approximately 82% of the SCB area (roughly 2,878 km^2) contained measurable quantities of this persistent pesticide.
- The use of total DDT in the U.S. was banned in 1972 and present-day discharges are extremely low or nondetectable.

3. Although sediment contaminants were widespread, most of the Bight was below concentrations of biological concern.

- The effects range median concentration (ERM; Long *et al*. 1995) was used as a screening level threshold of potentially adverse biological effects for 13 separate contaminants.
- Approximately 12% of the SCB area (roughly 433 km^2) had at least one constituent above the ERM.
- Most of these threshold exceedances were for total DDT (approximately 10% of SCB area or 366 km^2).

- Most of the sites that exceeded the ERM had healthy benthic communities and did not result in bulk sediment toxicity using the amphipod *Ampelisca abdita.*

4. **The extent and magnitude of sediment contamination was greater in Santa Monica Bay than other regions of the SCB.**

    - Area-weighted mean concentrations of TOC, TN, total DDT, total PCB, and eight of nine trace metals were significantly higher in Santa Monica Bay.
    - 100% of Santa Monica Bay sediments were anthropogenically contaminated by at least one chemical.
    - 49% of Santa Monica Bay sediments exceeded the screening level threshold for potentially adverse biological effects (ERM) by at least one chemical, compared to 7% in other regions of the SCB.

5. **The proportion of sediments enriched by anthropogenic contaminants was similar between areas near POTW discharges and areas distant from POTW discharges. However, average contaminant concentrations were generally higher in areas near POTW discharges.**

    - Area-weighted mean concentrations of total DDT, total PCB, copper, mercury, and silver measured near POTW outfall areas were significantly greater than areas distant from POTW outfalls at similar depths (25-100 m).
    - Approximately 87% of the POTW outfall area was anthropogenically enriched compared to 90% of the area distant from POTW outfalls at similar depths (25-100 m).
    - Based upon mass emission measurements from these POTWs, much of this contamination can be attributed to historical rather than present-day discharges.

6. **Sediments near stormwater discharges were enriched by anthropogenic trace metals at twice the frequency of areas distant from stormwater discharges. However, contaminant concentrations did not exceed screening level thresholds of adverse biological effects.**

    - Anthropogenic additions of cadmium, chromium, copper, lead, nickel, silver, and zinc enriched 47% of SCB sediments near stormwater discharges compared to only 24% of the SCB sediment distant from stormwater discharges at similar depths (10-25 m).
    - No sample exceeded the screening level threshold for adverse biological effects (ERM) in shallow water (10-25 m) regardless of proximity to stormwater discharges.

7. **Except for a handful of constituents, sediment contamination measured throughout the SCB was similar to contamination levels measured around the country by the National Status and Trends Program (NS&T).**

- High concentrations (equal to the geometric mean plus one standard deviation) of arsenic, chromium, copper, lead, mercury, nickel, selenium, and zinc measured in the SCB were within 50% of the high concentrations measured by NS&T.
- High concentrations of total DDT, cadmium, and silver were three times greater in the SCB than high concentrations measured by NS&T.
- High concentrations of total PAH, total PCB, and antimony were at least three times greater nationwide than measured in the SCB.

RECOMMENDATIONS

The regional monitoring program in 1994 was very successful in achieving its objectives of estimating the magnitude and extent of sediment contamination on the mainland shelf of the SCB. Summary statistics such as mean, minima, maxima, and quartile distributions of sediment concentrations not only provide estimates of Bight-wide contaminant magnitude, but also permit other site-specific monitoring programs to evaluate the magnitude of their individual site relative to other regions of the SCB. However, mass emissions of pollutants from various sources are expected to decrease in the future as more effective controls, treatment, and best management practices are implemented. Presumably, these changes will also be reflected in varying levels of sediment contamination over time. Therefore, future regional surveys should be conducted to assess these changing levels of sediment contamination. The benefit will be two-fold. First, future surveys will keep the baseline information current for those monitoring programs that require the Bight-wide data distributions to assess their specific sites. Second, environmental managers will have the ability to determine if the large resources that they invest in reducing pollutant loads have resulted in improved conditions near their input locations and throughout the SCB.

Building upon the overwhelming success of the 1994 regional monitoring survey, we recommend several study design and QA/QC elements that should be implemented prior to future surveys. These specific recommendations are:

1. Assess temporal changes in sediment contamination due to historical discharges.

Since spatial associations indicate that large-scale distributions of contaminants may result from historical discharges, we recommend adding sediment coring as an additional study design element. Sediment coring methods sample and analyze surface and subsurface sediments, providing a technique to assess these retrospective changes over time. Buried sediments represent older deposits, and

research tools are available to the determine their approximate age (i.e., Finney and Huh 1989). Changes in the extent and magnitude of sediment contamination at each layer (representing specific time periods) would indicate whether conditions are getting worse, staying the same, or improving along the mainland shelf of the SCB.

2. **Improve techniques to associate sediment contaminants with anthropogenic sources.**

A definitive association of sediment contaminants with specific sources was not achieved with this survey. Potential sources were inferred by creating maps and observing spatial gradients, or by comparing the relative magnitude of mean sediment concentrations between areas near sources and areas distant from the discharges. This type of evidence, however, is largely circumstantial. We recommend that source-specific tracers be used in the next regional survey to quantify the contribution of contaminants from these specific sources. Source-specific tracers encompass a wide variety of techniques including dyes, radioisotope ratios, and molecular markers. The main requirements of a useful source-specific tag are: 1) they must be unique to a single source, and 2) they must possess chemical and physical properties similar to the constituents of concern. Unique, source-specific tracers would be definitive evidence in associating particular constituents with individual sources. Where multiple markers are found, cumulative impacts can be assessed. Until direct evidence can be secured through the use of source-specific tags, spatial associations of contaminants with sources will be inferential, and thus open to dispute.

3. **Use comparable methodology for sediment digestion/extraction among laboratories to maintain comparability of data. Different analytical methods should be permitted provided they produce comparable results.**

The performance-based QAPP developed for this survey did not specify detailed methods for digestion/extraction of sediment samples prior to instrumental analysis. As a result, comparability was limited. For example, strong acid digestions were used in one laboratory while total dissolution digestions were used in another laboratory. Because the differential recovery of trace metals depends upon the rigor of the digestion method, reanalysis of samples for trace metals was required.

We recommend that a common digestion/extraction technique be employed to maintain comparability among participating laboratories. Other techniques and methods should be permitted, but the comparability of the new technique must be evaluated relative to the common method.

4. **Quantify a common list of target analytes. Target analytes should include those analytes that have threshold values, ecotoxicological benchmarks, or serve as normalizing tools.**

   In the 1994 survey, not all labs quantified the same target analytes. For example, one laboratory quantified PCBs using the congener method, others used the Aroclor method, and another quantified PCBs using both methods. These differences limited the comparability of the results among laboratories. We recommend a common list of target analytes be quantified for the next survey. In the case of PCBs, Aroclor methods are the preferred technique for screening samples for additional analysis and creating maps of relative concentrations. This first tier of analysis emphasizes the ease and relative cost reduction of the Aroclor method. As a second tier of analysis, however, the PCB congener method is the preferred technique in tissue matrices and synoptically sampled sediments, since Aroclor methods are less accurate and congener methods provide better assessments of bioaccumulation.

5. **Establish minimum levels of data reporting with specified levels of precision and accuracy.**

   Minimum levels of data reporting should be established based upon the threshold values of interest, and not on technical attainment. We recommend that reporting levels be set at, or preferably below, concentrations of ecological/biological concern. Moreover, the current regulatory framework established by the U.S. EPA requires minimum reporting levels based upon annual assessments of analytical precision. While these are important goals, our recommendation also includes an assessment of accuracy near the reporting limit for the next survey.

6. **Locally derived reference materials should be analyzed by all participating laboratories and potential partners as a means to provide initial and ongoing assessments of performance as determined by specified data quality objectives.**

   We recommend a locally derived reference material be made available to every laboratory to mimic the matrix and concentration ranges being measured in native samples. In the 1994 survey, not all laboratories analyzed the same reference material. For those laboratories which did analyze the same reference material, many of the target analytes were extremely low. Common reference materials will also improve assessments of inter-laboratory comparability. Moreover, re-analysis of a common reference material by the participating laboratories will enable statistically based QA/QC criteria for the next survey, rather than the fixed-range criteria established in the last QAPP.

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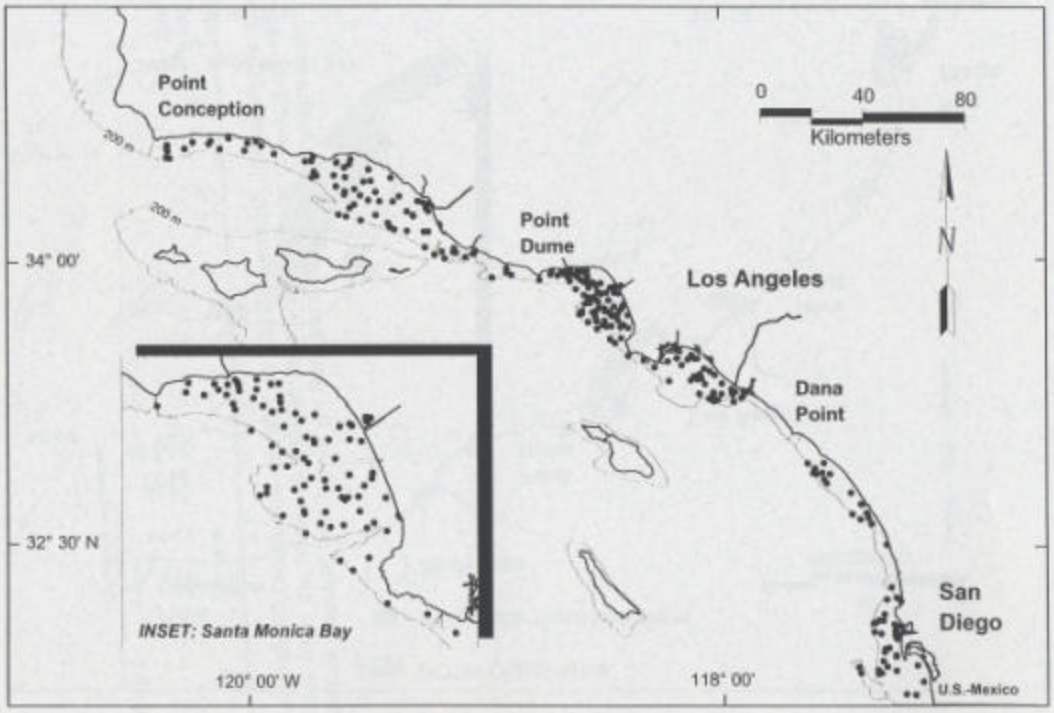


FIGURE 1. Sampling sites for regional monitoring of the Southern California Bight in 1994.

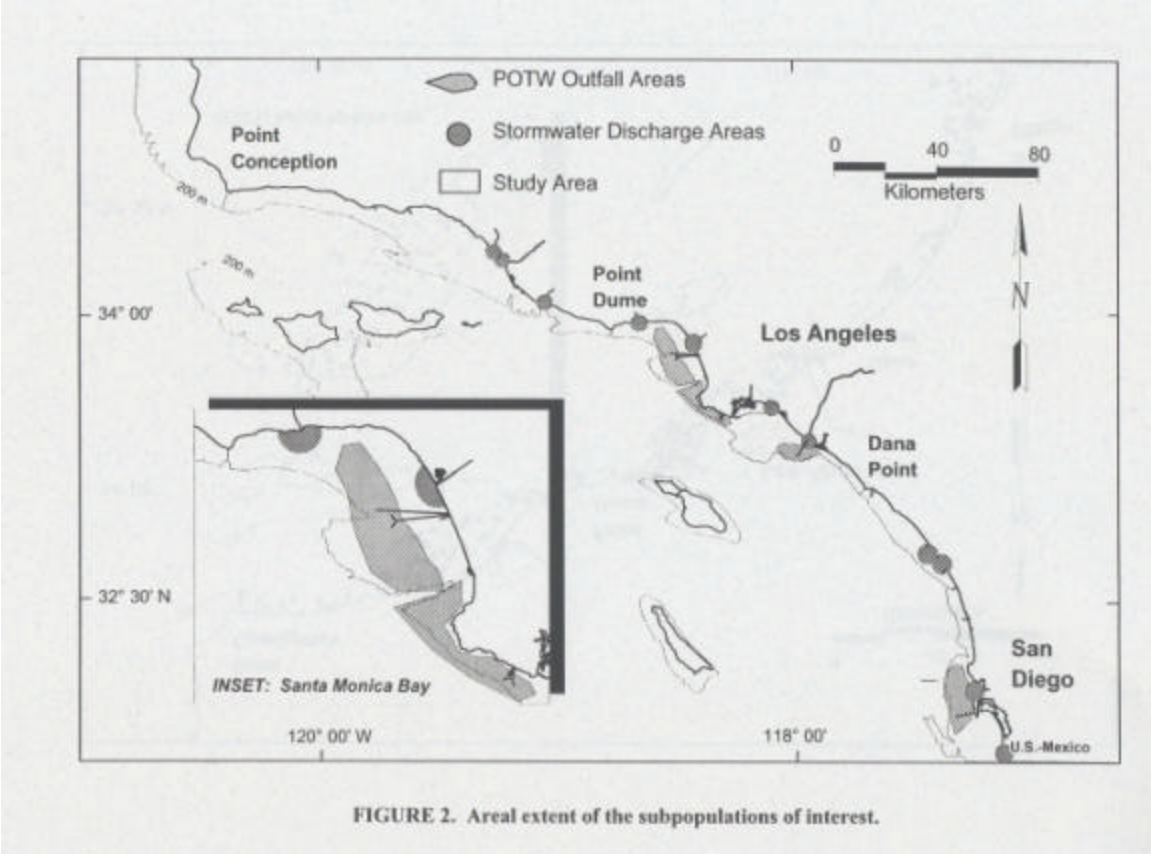


FIGURE 2. Areal extent of the subpopulations of interest.

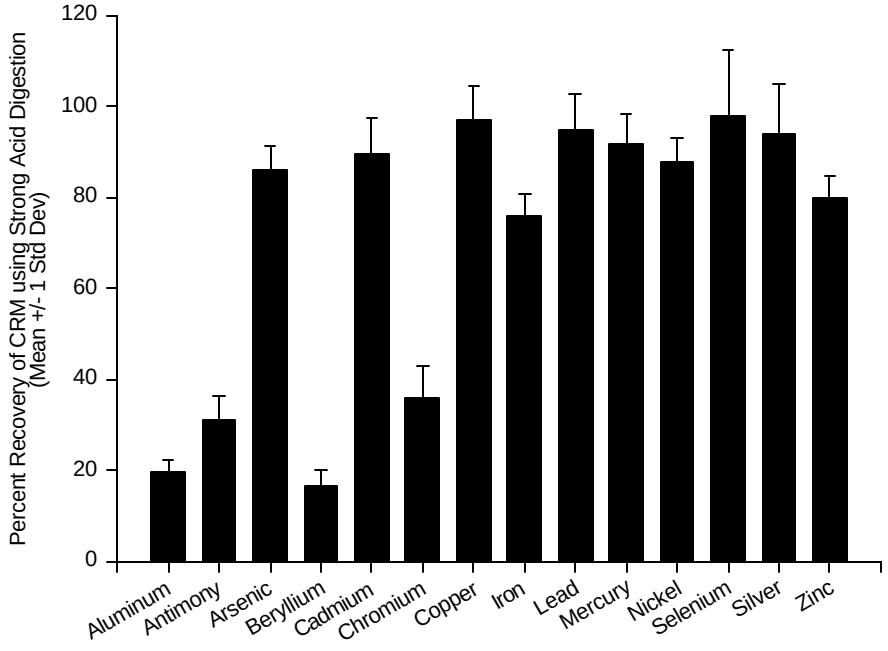


FIGURE 3. Recovery of trace metals from a certified reference material (CRM) using a strong acid digestion. The reference material (MESS-1), was certified using total dissolution digestions.

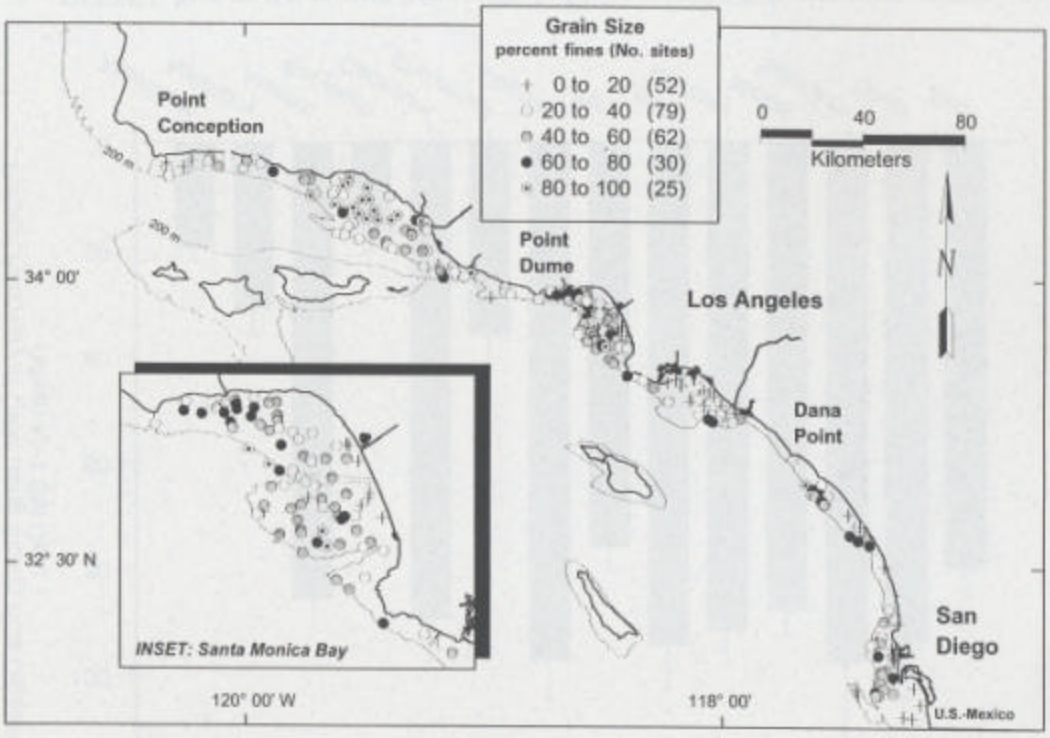


FIGURE 4. Spatial distribution of grain size (percent fines < 0.063 mm diameter) in sediments from the Southern California Bight mainland shelf in 1994.

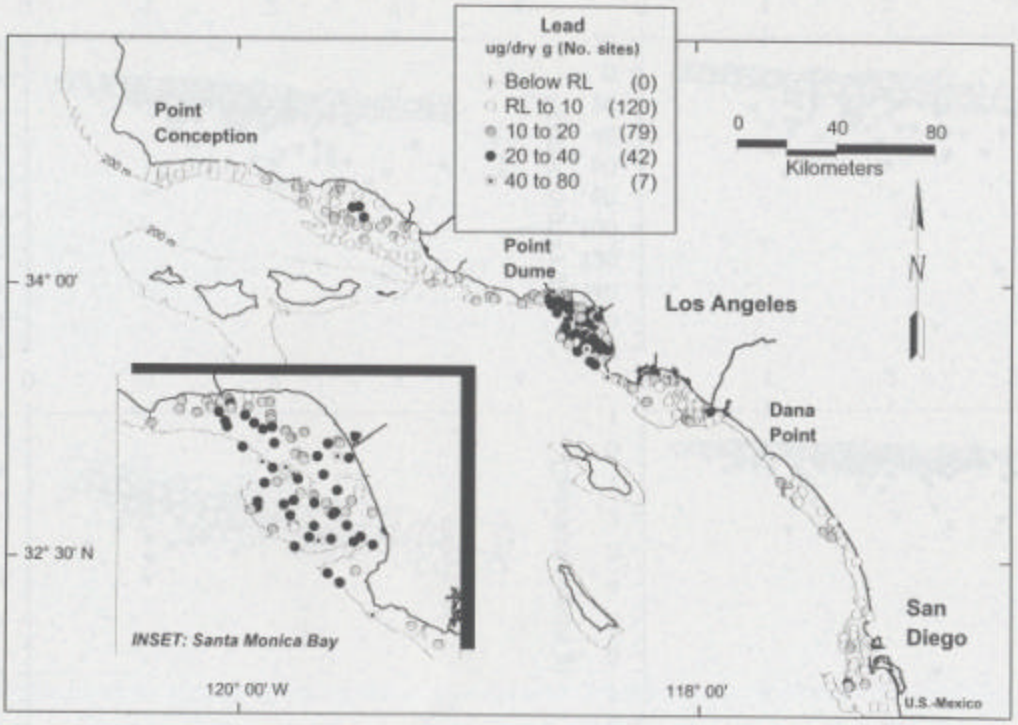
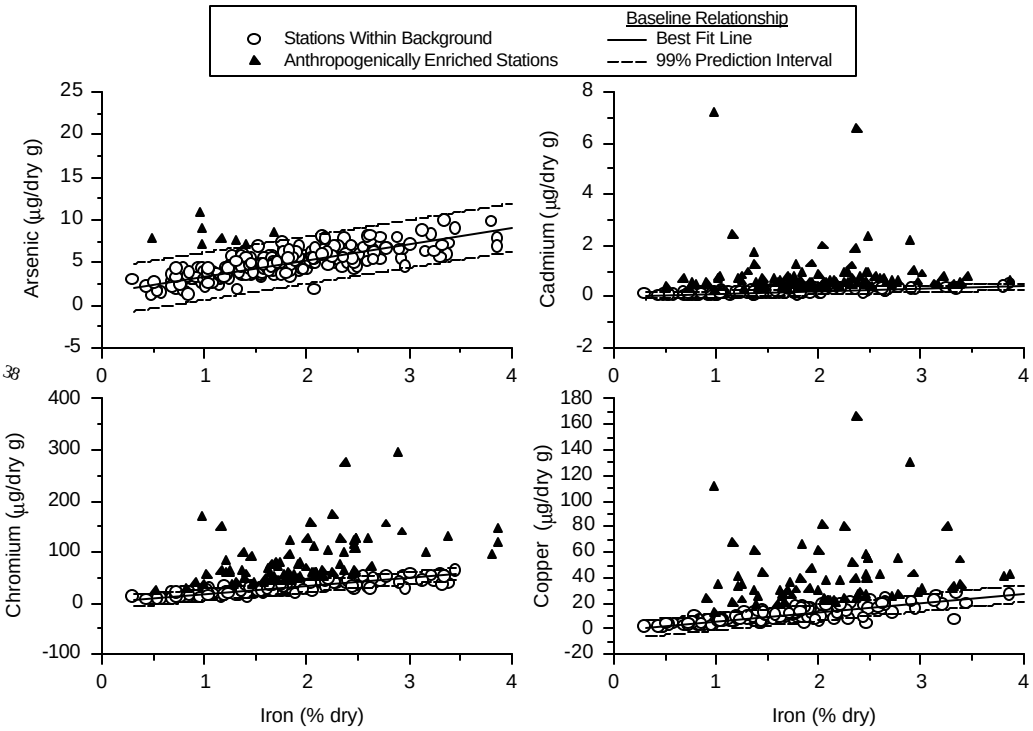


FIGURE 5. Spatial distribution of lead in sediments from the Southern California Bight mainland shelf in 1994.


Baseline Relationship
Stations Within Background
Anthropogenically Enriched Stations
Best Fit Line
99% Prediction Interval
Arsenic (µg/dry g)
Cadmium (µg/dry g)
Chromium (µg/dry g)
Copper (µg/dry g)
Iron (% dry)
Iron (% dry)

6a

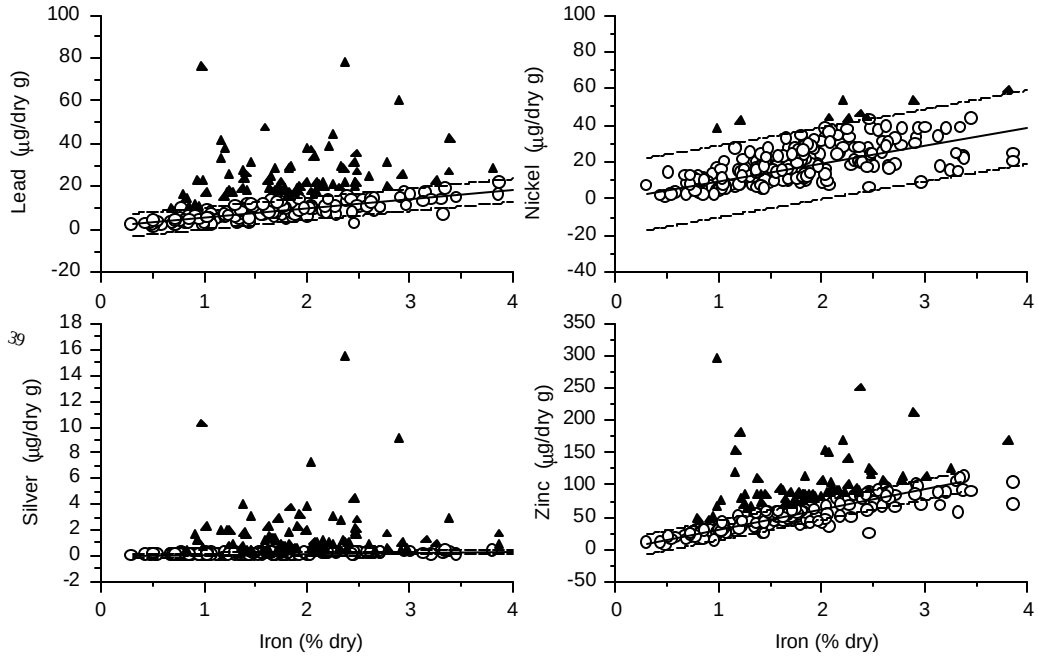


FIGURE 6. Reference element normalization using iron as a conservative tracer of natural metal concentrations on the mainland shelf of the Southern California Bight.

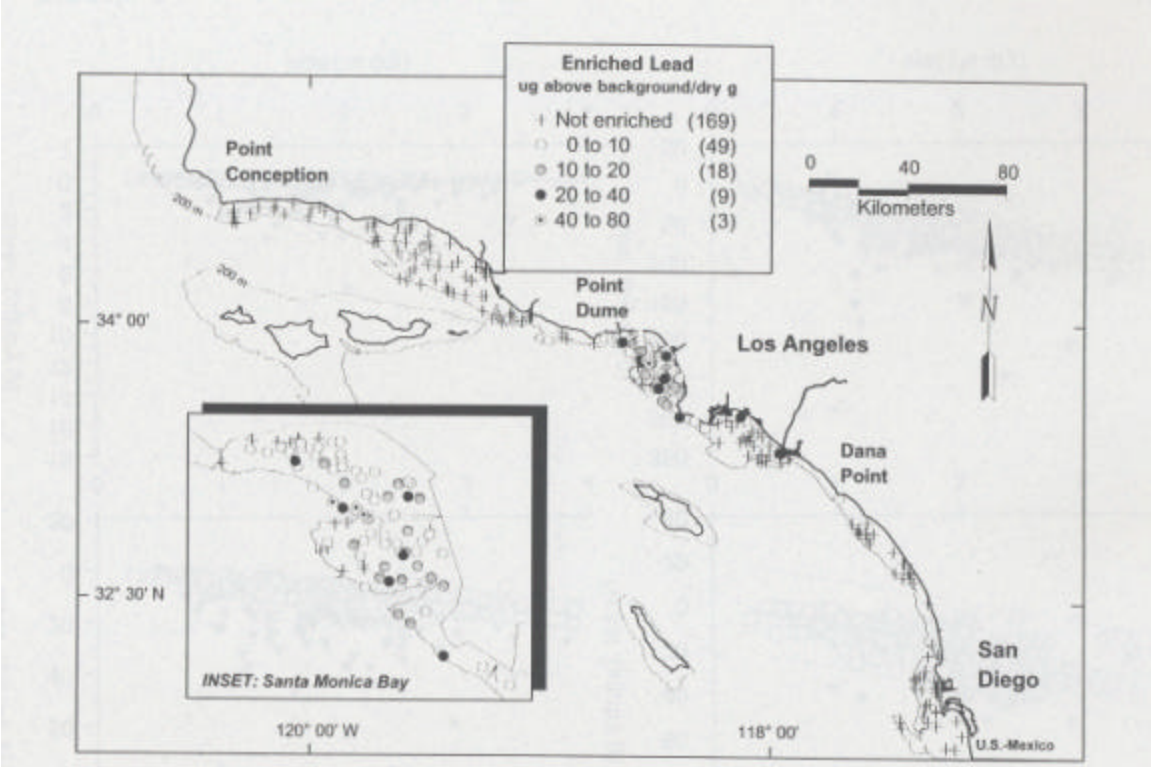


FIGURE 7. Spatial distribution of anthropogenically enriched lead (determined by iron normalization) in sediments from the Southern California Bight mainland shelf in 1994.

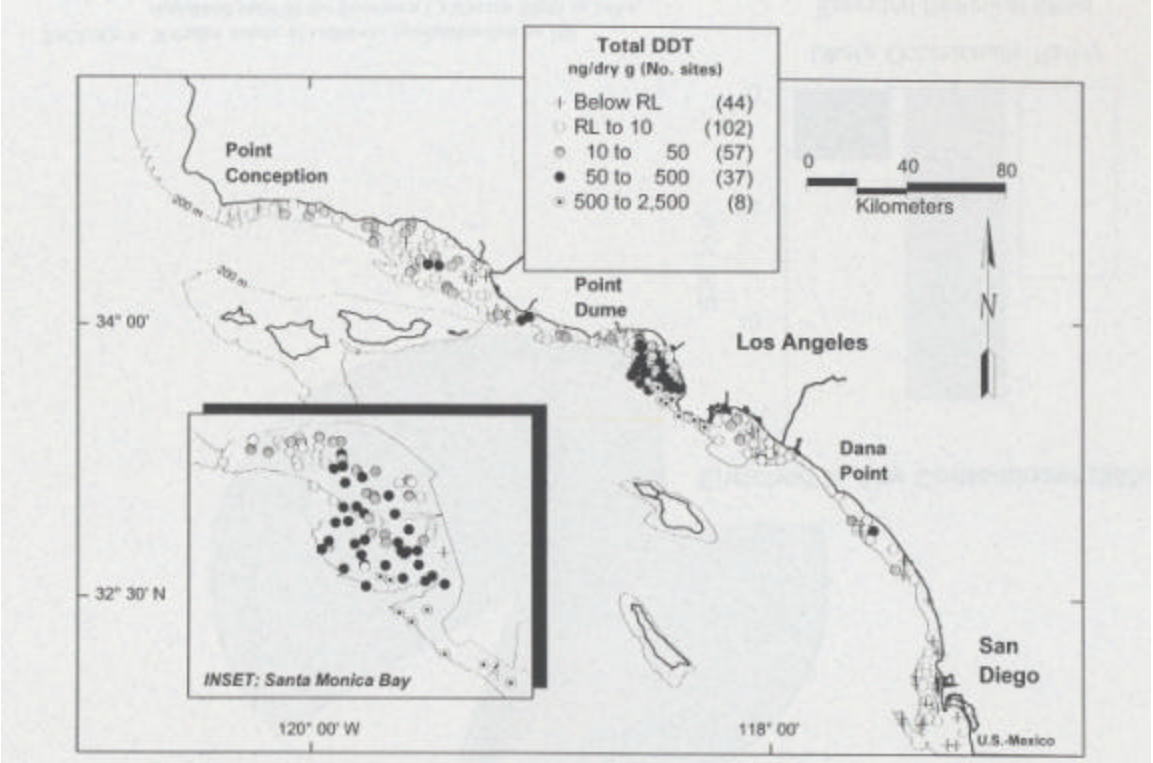


FIGURE 8. Spatial distribution of total DDT in sediments from the Southern California Bight mainland shelf in 1994.

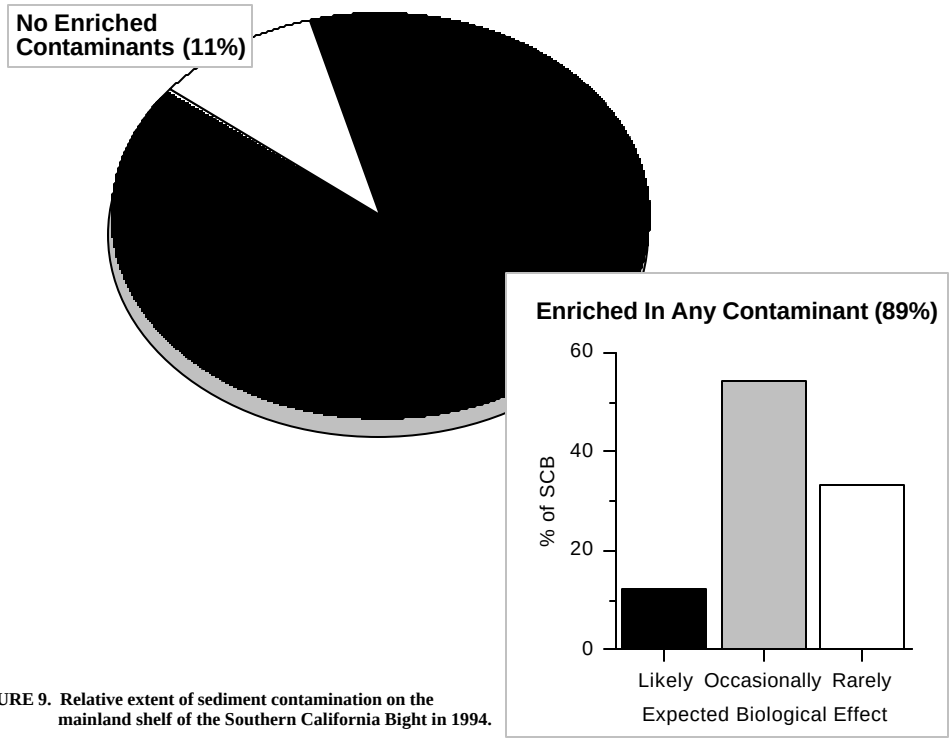


FIGURE 9. Relative extent of sediment contamination on the mainland shelf of the Southern California Bight in 1994.

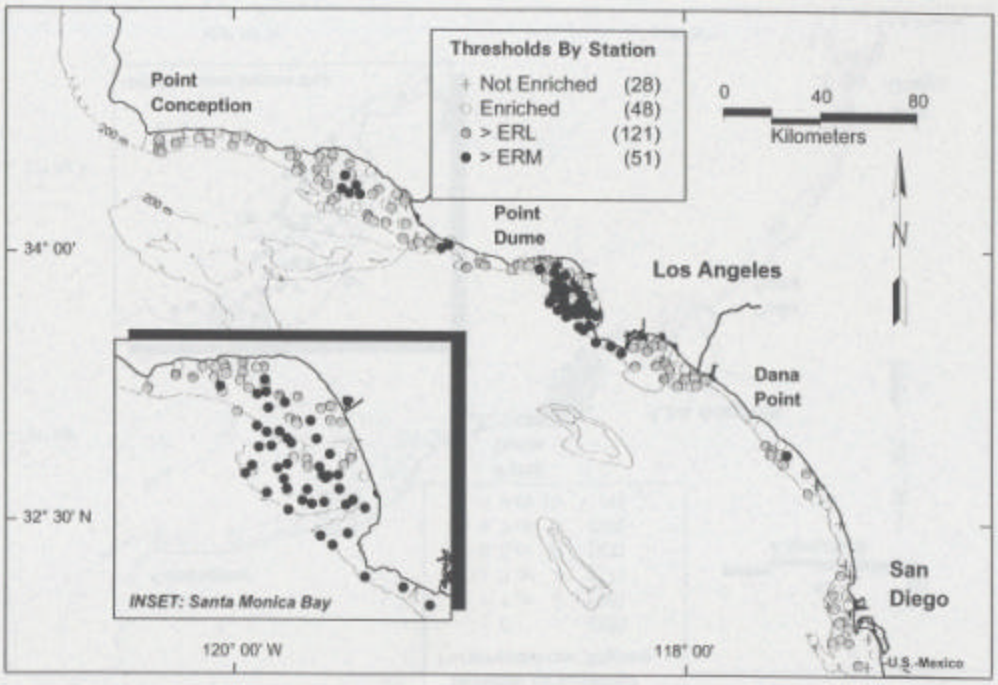


FIGURE 10. Spatial distribution of relative sediment contamination on the mainland shelf of the Southern California Bight in 1994.

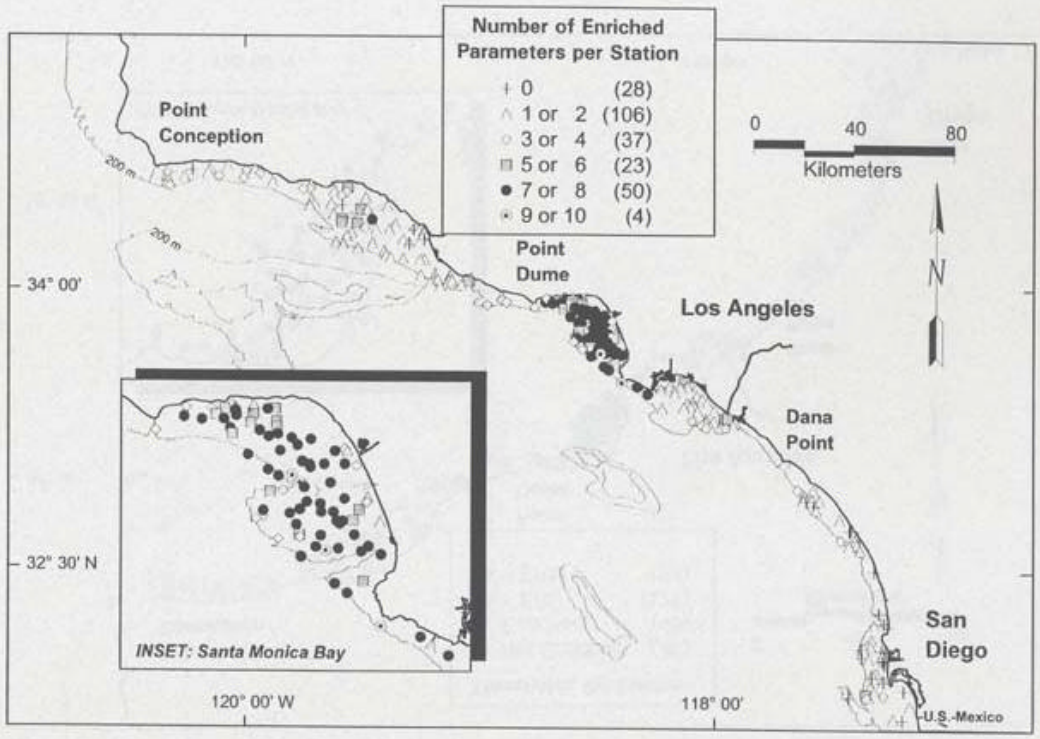


FIGURE 11. Number of constituents (n=10) anthropogenically enriched at each site sampled during regional monitoring of the Southern California Bight in 1994.

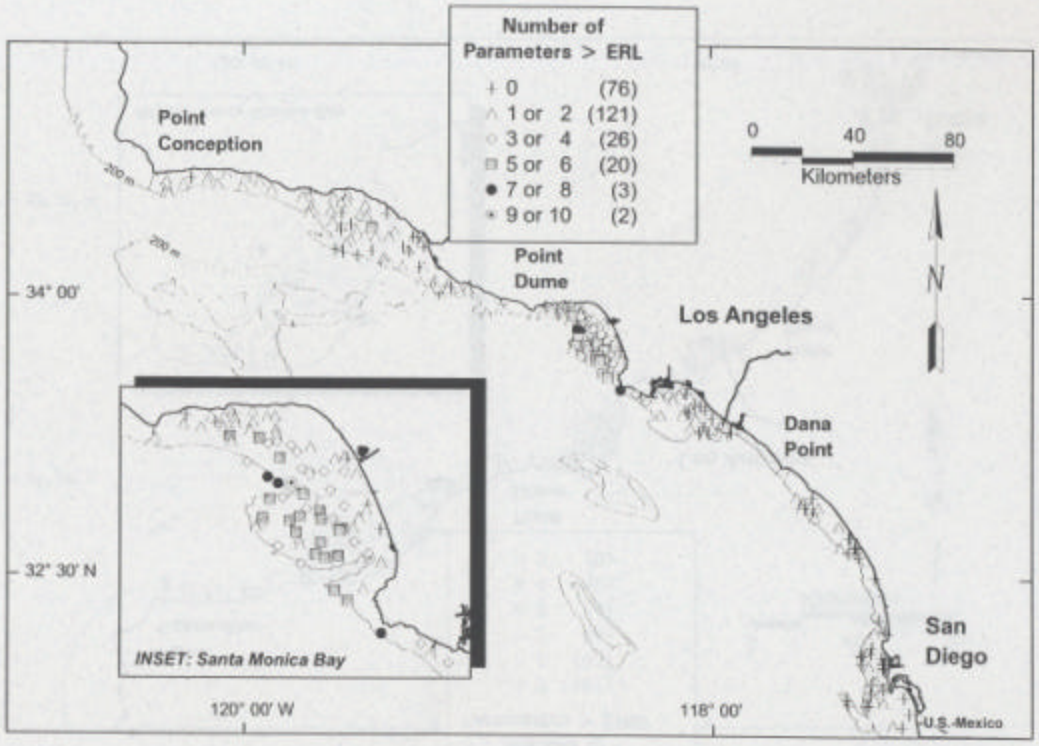


FIGURE 12. Number of constituents (n=10) exceeding concentrations where biological effects may occasionally occur (>ERL) at each site sampled during regional monitoring of the Southern California Bight in 1994.

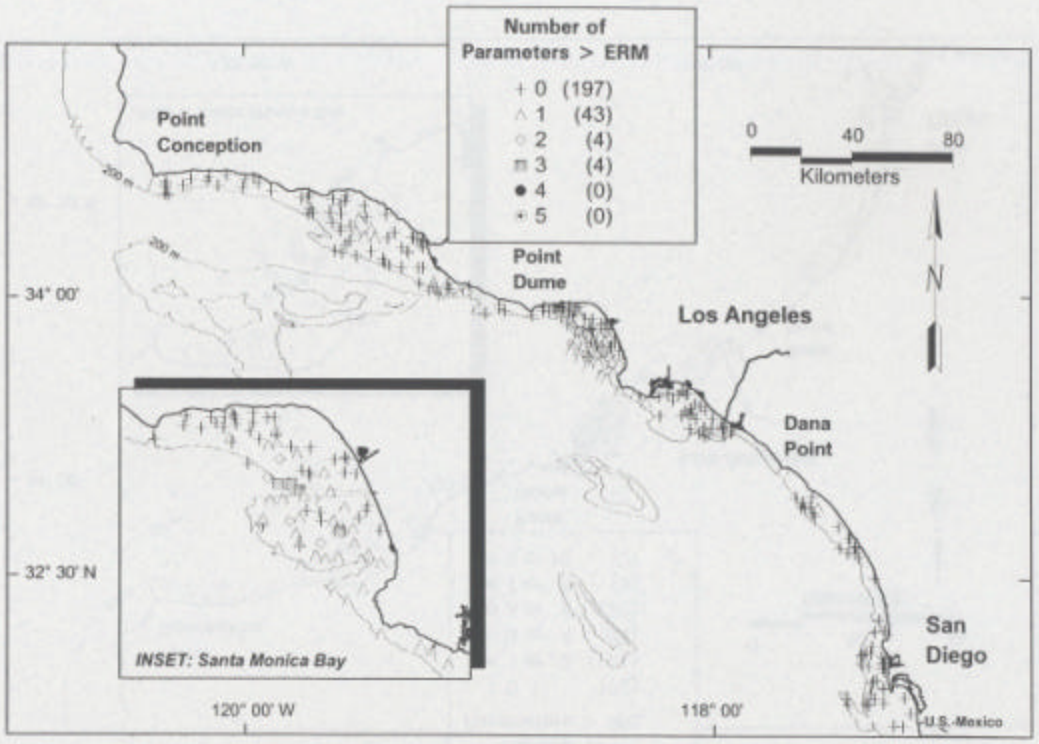


FIGURE 13. Number of constituents (n=10) exceeding concentrations where biological effects may likely occur (>ERM) at each site sampled during regional monitoring of the Southern California Bight in 1994.

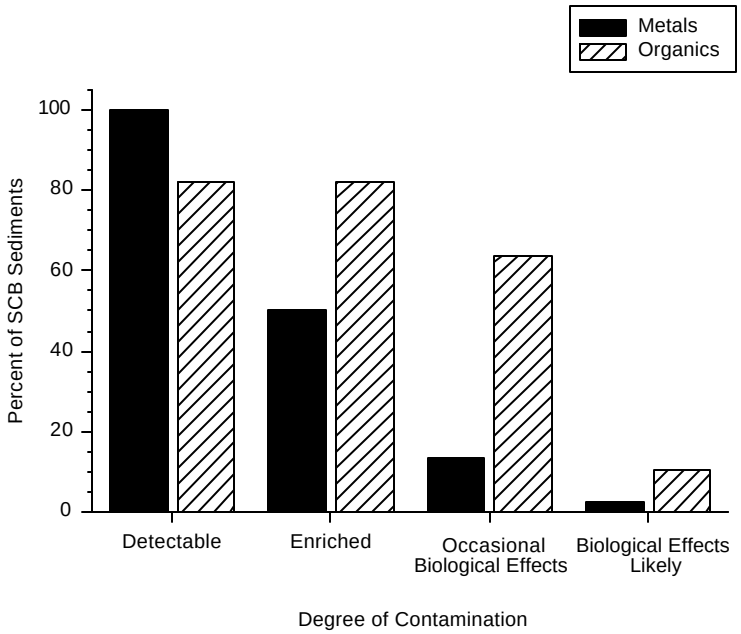


FIGURE 14. Relative extent of sediment contamination by either inorganic (trace metals) or organic (total DDT or total PCB) constituents on the mainland shelf of the Southern California Bight in 1994.

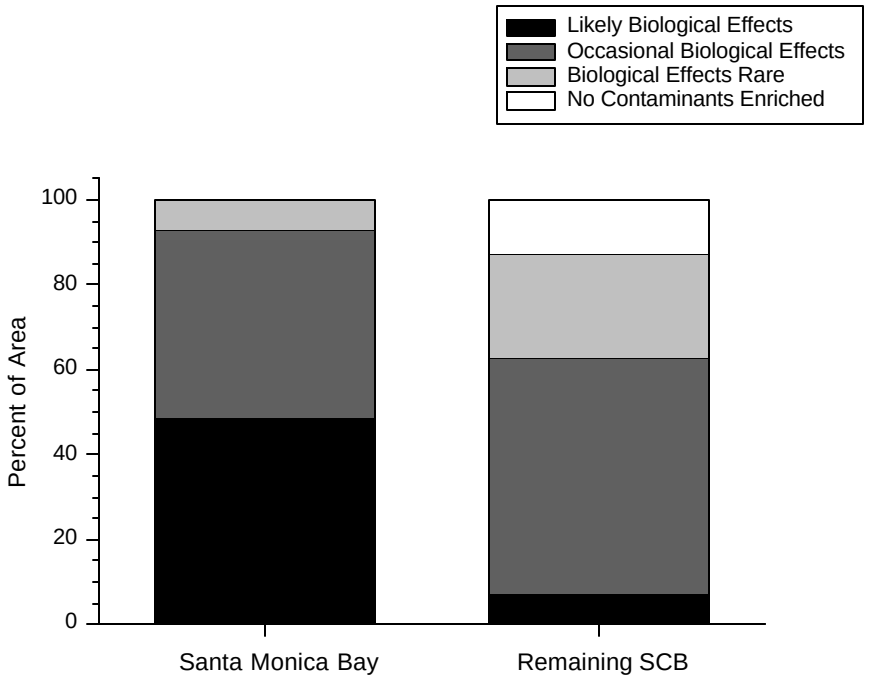


FIGURE 15. Relative extent of sediment contamination in Santa Monica Bay (449 km^2) compared to the remaining Southern California Bight (3,071 km^2) in 1994.

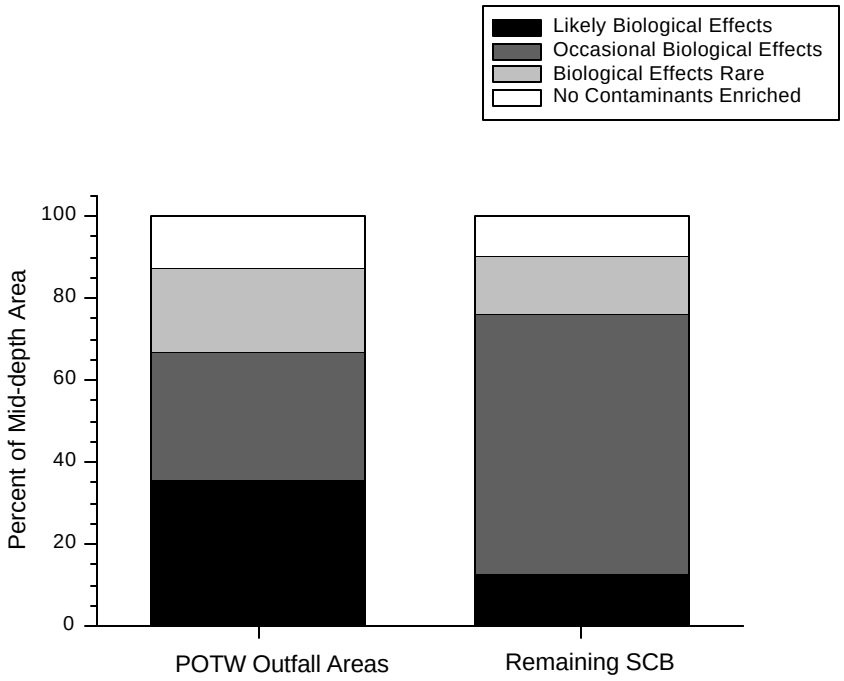
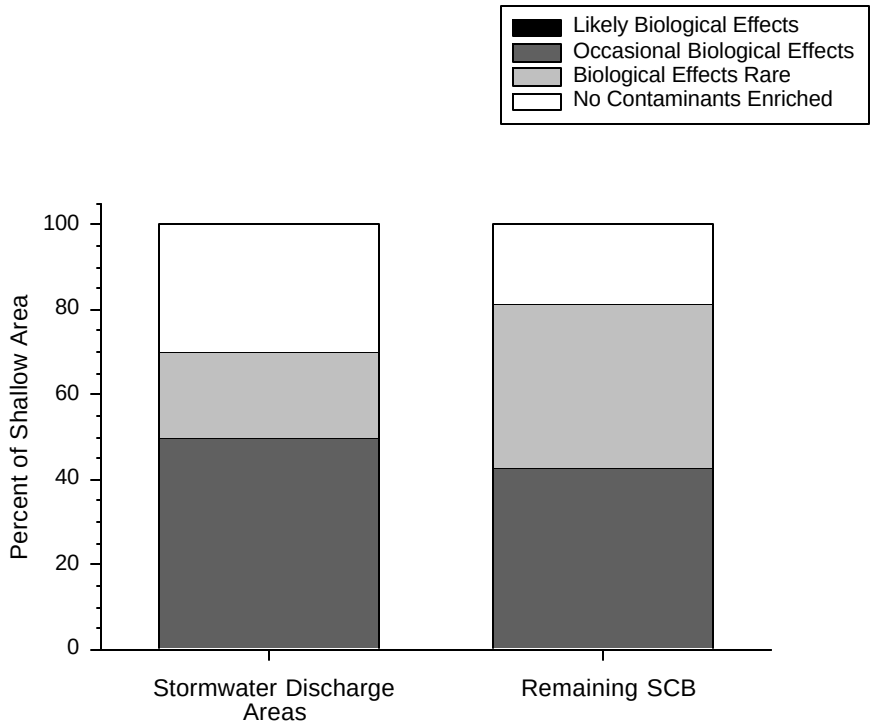


FIGURE 16. Relative extent of sediment contamination in POTW outfall discharge areas (293 km^2) compared to the remaining mid-depth areas of the Southern California Bight (1,707 km^2) in 1994.



FIGUR E 17. Relative extent of sediment contamination in stormwater discharge areas (81 km^2) compared to the remaining shallow water areas of the Southern California Bight (612 km^2) in 1994.

TABLE 1. Areal extent of the Southern California Bight and subpopulations of interest.

		Area (km^2)
Entire SCB		3,520.3
Deep	(100 - 200 m)	827.1
Mid-depth	(30 - 100 m)	1,999.9
Shallow	(10 - 30 m)	693.3
Santa Monica Bay		449.1
Remaining SCB		3,071.1
Mid-depth Areas		
	Hyperion	100.9
	JWPCP	37.8
	CSDOC	47.3
	Pt. Loma	106.8
	Sum POTW	292.8
	Non-POTW	1,707.1
Shallow Areas		
	Ventura River	8.1
	Santa Clara River	10.8
	Calleguas Creek	2.7
	Malibu Creek	10.8
	Ballona Creek	10.8
	San Gabriel River	8.1
	Santa Ana River	8.1
	Santa Margarita River	5.4
	San Luis Rey River	5.4
	San Diego River	10.8
	Sum Stormwater	81.1
	Nonstormwater	612.2

Hyperion = Hyperion Treatment Plant, City of Los Angeles.
JWPCP = Joint Water Pollution Control Plant, County Sanitation Districts of Los Angeles County.
CSDOC = County Sanitation Districts of Orange County.
Pt. Loma = Point Loma Treatment Plant,City of San Diego.
POTW = Publicly owned treatment works.

TABLE 2. Sample analysis and loading by laboratory.

Laboratory	Grain Size	TOC/TN	Pesticides	PCB		PAH	Metals
				Aroclor	Congener		
SCCWRP	3	249	-	-	-	-	-
City of Los Angeles	-	-	70	70	-	70	-
County of Los Angeles	-	-	15	15	-	15	-
County of Orange	-	-	53	-	53	53	-
City of San Diego	246	-	35	35	-	35	-
Pace Analytical, Inc.	-	-	76	76	76	76	5
Texas A&M University	-	-	-	-	-	-	244
Total Number of Samples	249	249	249	196	129	249	249

TOC = Total organic carbon.
TN = Total nitrogen.
PCB = Polychlorinated biphenyls.
PAH = Polynuclear aromatic hydrocarbon.
SCCWRP = Southern California Coastal Water Research Project.

TABLE 3. Method reporting limits from regional monitoring of the Southern California Bight in 1994.

	Range of Reporting Limits				Range of Reporting Limits		
Inorganics (mg/dry g)				**Polynuclear Aromatic Hydrocarbons (ng/dry g)**			
Aluminum	1,580	-	5,000	Acenaphthene	1	-	330
Antimony	0.1	-	0.5	Acenaphthalene	1	-	330
Arsenic	0.1	-	0.5	Anthracene	1	-	330
Beryllium	0.05	-	0.1	Naphthalene	1	-	330
Cadmium	0.05	-	0.05	Phenanthrene	1	-	350
Chromium	0.5	-	5	Dibenz[*ah*]anthracene	5	-	400
Copper	1	-	3	Benz[*a*]anthracene	1	-	400
Iron	1,000	-	5,000	Benzo[*a*]pyrene	1	-	330
Lead	0.5	-	1.5	Benzo[*b*]fluoranthene	1	-	550
Mercury	0.05	-	0.02	Benzo[*ghi*]perylene	5	-	990
Nickel	0.5	-	3	Benzo[*k*]fluoranthene	1	-	360
Selenium	0.05	-	0.5	Chrysene	1	-	330
Silver	0.05	-	0.05	Fluoranthene	1	-	330
Zinc	2	-	2.5	Fluorene	1	-	330
				Indeno[*1,2,3-cd*]pyrene	5	-	400
				Pyrene	1	-	330
Aroclor PCB (ng/dry g)							
PCB-1242	2	-	10				
PCB-1254	2	-	10	**Chlorinated Pesticides (ng/dry g)**			
PCB-1260	2	-	15	*o,p'* - DDD	0.04	-	4
				o,p' - DDE	0.02	-	4
Congener PCB (ng/dry g)				*o,p'* - DDT	0.03	-	4
PCB-18,126,128,195, 201,206,209	0.01	-	1	*p,p'* - DDD	0.04	-	4
				p,p' - DDE	0.10	-	4
PCB-29,44,50,105,154	0.02	-	1	*p,p'* - DDT	0.03	-	4
PCB-87,101,180	0.03	-	1				
PCB-8,66,104,118, 138,170,187	0.04	-	1				
PCB-28,188	0.05	-	1				
PCB-77	0.06	-	1				
PCB-52,133	0.07	-	1				

TABLE 4. Screening level thresholds used for assessing the potential of adverse biological effects[1].

	Effects Range Low (ERL)	Effects Range Median (ERM)
Organic Constituents (ng/dry g)		
Low Molecular Weight PAH	552	3,160
High Molecular Weight PAH	1,700	9,600
Total PAH	4,022	44,792
Total PCB	22.7	180
p,p' - DDE	2.2	27
Total DDT	1.58	46.1
Inorganic Constituents (μg/dry g)		
Arsenic	8.2	70
Cadmium	1.2	9.6
Chromium	81	370
Copper	34	270
Lead	46.7	218
Mercury	0.15	0.71
Nickel	20.9	51.6
Silver	1.0	3.7
Zinc	150	410

[1] Long *et al.* 1995.

TABLE 5. Comparison of quality assurance plan data quality objectives (DQOs) with results reported by participating laboratories.

QA/QC Parameter	TOC		Metals		Organics	
	DQO	Success	DQO	Success	DQO	Success
Completeness	90%	100%	90%	100%	90%	100%
Holding Time	6 months	100%	6 months	100% [1]	6 months	90%
Sample Loading	25 samples/batch	100%	25 samples/batch	100%	25 samples/batch	100%
Inst Cal Frequency	1-3 times/batch	100%	1-3 times/batch	100%	1-3 times/batch	100%
Inst Cal Accuracy	< 25%/analyte	100%	< 25%/analyte	NR	< 25%/analyte	NR
CRM Frequency	1/batch	100%	1/batch	100%	1/batch	100%
CRM Accuracy	85-115% of Certified Value	100%	80-120% of Certified Value	43% [2]	70-130% of Certified Value	100%
CRM Precision	< 20% RSD	100%	< 30% RSD	100%	< 30% RSD	100%
Blank Frequency	1/batch	100%	1/batch	100%	1/batch	100%
Blank Accuracy	No analyte > 3 MDL	100%	No analyte > 3 MDL	100%	No analyte > 3 MDL	99%
MS/MSD Frequency	NA	-	1/batch	93%	1/batch	100%
MS/MSD Accuracy	NA	-	70-120% for 80% of analytes	100%	50-120% for 80% of analytes	70%
MS/MSD Precision	NA	-	< 30% RSD	100%	< 30% RSD	100%
Lab Duplicates	< 30% RSD	100%	< 30% RSD	100%	< 30% RSD	98%

[1] Initial analysis < 6 months; re-analysis < 14 months.
[2] Low recovery due to digestion technique, see text for details.
NA = Not applicable.
NR = Not reported.
CRM = Certified reference material.
MS/MSD = Matrix spike/matrix spike duplicate.
RSD = Relative standard deviation.
MDL = Method detection limit.

TABLE 6. Area-weighted mean (±95% confidence intervals) and ranges of sediment parameters from the Southern California Bight in 1994.

	Area Weighted Mean	95% Confid. Interval	Min.	25th Percentile	Median	75th Percentile	Max.
Percent (%), Dry Weight							
Fines (Silt+Clay)	42.53	3.97	0.00	24.30	38.49	57.61	99.97
TOC	0.748	0.088	0.041	0.307	0.597	1.043	5.115
TN	0.051	0.004	< 0.008	0.030	0.050	0.088	0.242
Aluminum	1.05	0.09	0.16	0.69	0.94	1.27	3.73
Iron	1.86	0.15	0.31	1.20	1.68	2.21	10.46
g/g (ppm), Dry Weight							
Antimony	0.21	0.02	< 0.04	0.14	0.19	0.27	0.84
Arsenic	5.1	0.3	1.0	3.7	4.8	6.0	20.4
Beryllium	0.24	0.02	0.01	0.16	0.26	0.32	1.30
Cadmium	0.33	0.04	< 0.02	0.14	0.29	0.51	7.18
Chromium	39	4	7	21	34	57	361
Copper	15	2	1	7	12	23	166
Lead	10.9	1.0	0.9	6.6	10.2	17.9	77.7
Mercury	0.050	0.007	< 0.005	0.020	0.040	0.090	0.580
Nickel	18.1	1.9	0.9	9.8	16.3	24.8	84.7
Selenium	0.30	0.03	< 0.02	0.20	0.29	0.45	1.65
Silver	0.34	0.08	< 0.01	0.08	0.17	0.60	15.37
Zinc	59	5	6	38	56	84	294
ng/dry g (ppb), Dry Weight							
Total DDT	40.8	18.3	< 0.1	1.9	10.0	40.6	2,082.9
Total PCB	13.3	3.0	< 0.06	5.7	26.0	69.8	572.3
Total PAH	brl	-	-	-	-	-	-

brl = below reporting limit of 330 ng/ dry g.

TABLE 7. Area-weighted mean sediment concentrations (±95% confidence intervals) for three subpopulations in the Southern California Bight, 1994.

		Geographic Subpopulation				POTW Subpopulation				Stormwater Subpopulation			
		SMB		Non-SMB		Outfall		Nonoutfall		Stormwater		Nonstormwater	
		Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Fines	% dry	44.8	5.1	42.2	4.5	40.8	5.2	47.9	6.1	31.7	9.2	20.2	5.5
TOC	% dry	***1.200***	0.209	0.682	0.094	1.051	0.273	0.734	0.103	0.330	0.105	0.212	0.038
TN	% dry	***0.093***	0.012	0.045	0.005	0.065	0.009	0.053	0.006	***0.034***	0.010	0.022	0.005
Arsenic	g/dry g	5.6	0.7	5.0	0.4	4.5	0.4	***5.7***	0.5	4.1	0.7	3.9	0.7
Cadmium	g/dry g	***0.66***	0.19	0.28	0.04	0.43	0.13	0.30	0.05	0.21	0.06	0.15	0.06
Chromium	g/dry g	***85***	16	32	3	48	9	39	6	27	6	18	3
Copper	g/dry g	***30***	6	12	2	***21***	4	13	2	***11***	3	6	1
Lead	g/dry g	***22***	3	9	0	14	2	11	1	***12***	4	6	1
Mercury	g/dry g	***0.146***	0.024	0.036	0.006	***0.100***	0.023	0.037	0.005	0.032	0.013	0.028	0.008
Nickel	g/dry g	***24***	3	17	2	14	2	***21***	3	15	4	10	3
Silver	g/dry g	***1.58***	0.48	0.16	0.03	***0.90***	0.28	0.21	0.04	0.15	0.10	0.06	0.01
Zinc	g/dry g	***84***	10	55	5	60	7	61	8	51	13	34	6
Total DDT	ng/dry g	***120.5***	48.0	29.2	19.5	***146.8***	96.3	15.3	4.3	5.1	3.0	4.1	2.2
Total PCB	ng/dry g	***57.6***	17.8	6.8	2.4	***43.0***	16.2	8.0	2.7	4.3	3.6	3.9	3.1

Note: ***Bold*** indicates significantly higher concentrations between subpopulation strata.
POTW = Publicly owned treatment works.
SMB = Santa Monica Bay.
TOC = Total organic carbon.
TN = Total nitrogen.

TABLE 8. Percent of area in the Southern California Bight exceeding contaminant thresholds in 1994.

	Detectable	Enriched	Effects Range Low	Effects Range Median
Arsenic	100.0	6.8	1.5	0.0
Cadmium	99.1	31.2	2.1	0.0
Chromium	100.0	21.4	7.3	0.0
Copper	100.0	16.4	6.8	0.0
Lead	100.0	16.5	0.5	0.0
Mercury	95.7	-[1]	6.3	0.0
Nickel	99.9	3.2	3.2	1.8
Silver	98.5	20.2	7.3	1.0
Zinc	100.0	16.5	2.7	0.0
LMW PAH	0.0	0.0	0.0	0.0
HMW PAH	0.0	0.0	0.0	0.0
Total DDT	81.8	81.8	63.7	10.4
Total PCB	45.6	45.6	15.3	0.7
Any Trace Metal	100	50.1	13.7	2.8
Any Organic	82.1	82.1	63.7	10.4
Any Contaminant	100	89	66.8	12.3

[1] No iron:mercury baseline relationship to assess enrichment.

TABLE 9. Percent of area exceeding contaminant thresholds in Santa Monica Bay *versus* other regions of the Southern California Bight (SCB) in 1994.

	Enriched		Effects Range Low		Effects Range Median	
	Santa Monica Bay	Other Regions of SCB	Santa Monica Bay	Other Regions of SCB	Santa Monica Bay	Other Regions of SCB
Arsenic	0.9	4.2	0.9	3.2	0.0	0.0
Cadmium	70.6	25.5	5.6	1.5	0.0	0.0
Chromium	87.8	11.7	34.2	3.3	0.0	0.0
Copper	56.4	10.5	30.6	3.3	0.0	0.0
Lead	79.2	7.3	4.3	0.0	0.0	0.0
Mercury	-	-	30.2	2.8	0.0	0.0
Nickel	8.3	2.4	8.3	2.4	3.7	1.5
Silver	85.4	10.6	48.5	1.2	7.4	0.0
Zinc	63.6	9.6	8.3	1.9	0.0	0.0
Total DDT	98.2	79.0	90.3	59.9	44.1	5.5
Total PCB	72.0	41.5	59.2	8.6	5.6	0.0
Any Trace Metal	96.3	43.4	57.7	7.3	11.2	1.5
Any Organic	98.2	79.8	90.3	59.9	44.1	5.5
Any Contaminant	100.0	87.3	92.7	63.0	48.7	7.0

TABLE 10. Percent of area exceeding contaminant thresholds near publicly owned treatment works (POTW) outfalls *versus* the remaining mid-depth areas of the Southern California Bight in 1994.

	Enriched		Effects Range Low		Effects Range Median	
	Near POTWs	Other Areas of SCB	Near POTWs	Other Areas of SCB	Near POTWs	Other Areas of SCB
Arsenic	0.9	2.8	0.0	2.8	0.0	0.0
Cadmium	43.4	30.5	7.9	0.0	0.0	0.0
Chromium	47.4	22.3	12.9	6.1	0.0	0.0
Copper	39.8	10.4	17.2	4.2	0.0	0.0
Lead	45.9	12.5	0.0	0.0	0.0	0.0
Mercury	-	-	16.2	1.9	0.0	0.0
Nickel	0.0	5.1	0.0	5.1	0.0	3.3
Silver	57.1	17.6	30.2	3.4	4.3	0.0
Zinc	37.0	13.3	0.0	3.7	0.0	0.0
Total DDT	79.7	86.1	66.8	70.3	34.5	9.3
Total PCB	50.6	48.6	47.4	10.5	2.9	0.0
Any Trace Metal	54.8	51.4	36.6	12.6	4.3	3.3
Any Organic	79.7	86.1	66.8	76.3	34.5	9.3
Any Contaminant	87.1	90.3	66.8	76.3	35.9	12.6

TABLE 11. Percent of area exceeding contaminant thresholds near stormwater discharges *versus* the remaining shallow areas of the Southern California Bight (SCB) in 1994.

	Enriched		Effects Range Low		Effects Range Median	
	Near Storm	Other Areas of SCB	Near Storm	Other Areas of SCB	Near Storm	Other Areas of SCB
Arsenic	0.0	11.6	0.0	0.0	0.0	0.0
Cadmium	26.7	10.4	0.0	0.0	0.0	0.0
Chromium	16.7	1.3	3.3	0.0	0.0	0.0
Copper	13.3	0.0	3.3	0.0	0.0	0.0
Lead	26.7	4.0	3.3	0.0	0.0	0.0
Mercury	-	-	3.3	0.0	0.0	0.0
Nickel	3.3	0.0	3.3	0.0	0.0	0.0
Silver	6.7	1.3	6.7	0.0	0.0	0.0
Zinc	20.0	2.7	3.3	0.0	0.0	0.0
Total DDT	66.7	68.5	43.3	42.7	0.0	0.0
Total PCB	36.7	38.8	6.7	10.4	0.0	0.0
Any Trace Metal	46.7	24.7	10.0	0.0	0.0	0.0
Any Organic	66.7	72.4	50.0	42.7	0.0	0.0
Any Contaminant	70.0	81.5	50.0	42.7	0.0	0.0

TABLE 12. Areal extent of sediment contamination for total DDT in the Southern California Bight (SCB) utilizing various threshold values.

Source	Units	Total DDT Threshold Number		Percent of SCB Exceeding Threshold	
		Low	High	Low	High
NOAA [1] (ERL/ERM)	mg/dry kg	1.58	46.1	63.7	10.4
State of Florida[2] (TEL/PEL)	mg/dry kg	3.89	51.7	49.2	9.1
NOAA [3] (COSED High/5xHigh)	mg/dry kg	22	110	19.1	5.1
SCB Damage Assessment [4]	mg/dry kg	7.12	-	41.7	-
(Sediment Effect Criterion)	mg/kg TOC	199	-	71.5	-
Swartz *et al*. 1994	mg/kg TOC	300	-	63.6	-
Chapman, 1996	mg/dry kg	8.51	-	40	-
	mg/kg TOC	269	-	65	-

[1] Long *et al.*1995.
[2] MacDonald *et al.* 1996.
[3] Daskalakis and O'Conner 1995b.
[4] MacDonald *et al.* 1994b.

TABLE 13. Comparison of Bight-wide results to nationwide surveys of sediment contamination.

Analyte	Units	SCBPP		NOAA NS&T
		Geometric Mean	"High"	"High"
TOC	% dry	1.55	2.54	-
TN	% dry	0.118	0.182	-
Aluminum	ug/dry g	23,133	31,906	-
Antimony	ug/dry g	0.5	0.7	2.1
Arsenic	ug/dry g	11.4	17.3	13
Beryllium	ug/dry g	0.57	0.94	-
Cadmium	ug/dry g	0.7	1.4	0.54
Chromium	ug/dry g	79	131	125
Copper	ug/dry g	30	48	42
Iron	ug/dry g	41,766	60,593	-
Lead	ug/dry g	23	37	45
Mercury	ug/dry g	0.12	0.25	0.22
Nickel	ug/dry g	39	61	42
Selenium	ug/dry g	0.68	1.08	0.92
Silver	ug/dry g	0.6	1.4	0.52
Zinc	ug/dry g	133	190	135
Total DDT	ng/dry g	14	70	22
Total PCB	ng/dry g	4	25	80
Total PAH	ng/dry g	< 330	-	2,180

"High" categories are the geometric mean + 1 Std Dev.
All data are normalized to % fines. Only samples >20% fines included.
NOAA NS&T from Daskalalis and O'Conner, 1995.