RMP Annual Monitoring Results

2006

San Francisco Estuary Institute
and the Regional Monitoring Program for Water Quality in the San Francisco Estuary

This report should be cited as:

San Francisco Estuary Institute (SFEI). 2007. The 2006 RMP Annual Monitoring Results. San Francisco Estuary and and the Regional Monitoring Program for Water Quality in the San Francisco Estuary. SFEI Contribution No. 542. San Francisco Estuary Institute, Oakland, CA.

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Tern at Arrowhead Marsh. Oakland, CA. Photograph by Linda Wanczyk. 2007.

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Acknowledgements

The authors would like to thank the Technical Review Committee and the Steering Committee for providing oversight and guidance to the RMP; RMP Contractors and Principal Investigators (Table 1.4) for providing quality analysis in a timely fashion; and the discharger community (Table 1.2) for providing funding. Special thanks are due to SFEI staff for data collection, management, quality assurance, and report preparation.

This report should be cited as:
SFEI. 2007. 2006 Annual Monitoring Results. The Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP). San Francisco Estuary Institute, Oakland, CA

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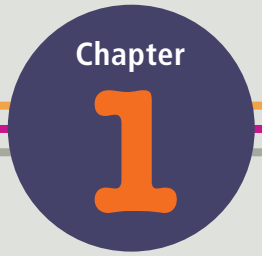

Introduction

1.0 Introduction

Cristina Grosso , Katie Harrold and Amy Franz

1.1 Program Structure and Objectives

The Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP) is the primary source for long-term contaminant monitoring information for the Estuary. The RMP is an innovative and collaborative effort between the scientific community, the San Francisco Bay Regional Water Quality Control Board (Water Board), and the regulated discharger community. The Program was initiated by the Water Board as a pilot study in 1989 and has been collecting water, sediment, and bivalve tissue data since 1993. The RMP's annual budget is currently approximately $3 million, which is primarily funded by the discharger community through wastewater discharge permits issued by the Water Board (refer to Table 1.1 for a list of participants).

The Technical Review Committee (TRC) and Steering Committee (SC) meet quarterly to provide oversight and guidance to the RMP. The committee members include representatives from the scientific, regulatory, stakeholder, and discharger communities. The TRC and SC assist in program development by prioritizing studies, suggesting new areas of research, and providing guidance on existing projects and the overall program. The RMP provides an important forum for collaborative research efforts, encouraging dialogue among scientists, regulators, and stakeholders, and facilitating sound environmental management decisions.

Every five years, the RMP undergoes a rigorous external review by national science and management experts to ensure that it is adapting to address current regulatory and scientific information needs. This review provides a forum for re-evaluating the programs management questions that guide the long-term Status and Trends Program and more focused Pilot and Special Studies. The second comprehensive five-year review of the RMP was conducted in 2003-2004. The workgroup's findings and recommendations are summarized in the *Report of the 2003 Program Review*.

As suggested by the last Program review, the RMP's management objectives were updated to the following in 2005:

1. Describe the distribution and trends of pollutant concentrations in the Estuary.

2. Project future contaminant status and trends using best understanding of ecosystem processes and human activities.

3. Describe sources, pathways, and loading of pollutants entering the Estuary.

4. Measure pollution exposure and effects on selected parts of the Estuary ecosystem (including humans).

5. Compare monitoring information to relevant benchmarks, such as TMDL targets, tissue screening levels, water quality objectives, and sediment quality objectives.

6. Effectively communicate information from a range of sources to present a more complete picture of the sources, distribution, fate, and effects of pollutants and beneficial use attainment or impairment in the Estuary ecosystem.

In 2007, in an effort to prioritize studies within the workgroups and RMP in general, the management questions and RMP Objectives were revisited. The process of refining the management questions and objectives will continue in 2008 and will be reviewed and approved by the TRC and SC.

The RMP addresses its objectives through the Status and Trends Program, focused workgroups, and pilot and special studies. The Status and Trends Program is comprised of the following four elements:

1) *Status and trends long-term monitoring* characterizes the status and trends for contaminants in water, sediment, and bivalves in the Estuary (Objectives 1, 2, 4, and 5).
2) *Sport Fish Contamination Study* triennially screens fish tissue for contaminants of concern to human health (Objectives 1, 2, 4, and 5).
3) *Toxicity studies* investigate episodic toxicity in Estuary tributaries and possible causes of observed toxicity through Toxicity Identification and Evaluation (TIE) methods (Objectives 1 and 3).
4) *USGS studies* collect monthly water quality measurements in the Estuary's deep channels from the Lower South Bay to the confluence of the Sacramento and San Joaquin Rivers, and perform sediment transport monitoring and modeling in the northern Estuary.

The Water Board uses Status and Trends data for regulatory purposes, such as evaluating the Estuary for 303(d) listing of water bodies, calculating National Pollutant Discharge Elimination System (NPDES) permit conditions, estimating Total Maximum Daily Loads (TMDL), and to evaluate whether management actions are successful in reducing contaminant loads to the Estuary through modeling.

Focused workgroups (Sources, Pathways and Loadings, Contaminant Fate, Exposure and Effects, and Emerging Contaminants) address contaminant sources and loadings (Objective 3), additional effects measures (Objective 4), and future contaminant status and trends (Objective 2) and help to develop pilot and special studies. These workgroups meet several times a year to review progress and make recommendations for further study.

Pilot studies are designed to investigate and develop new monitoring measures related to anthropogenic contamination or contaminant effects on biota in the Estuary. Special studies address specific scientific issues that the TRC, SC, or Water Board identify for further study. Section 1.4 below describes the Pilot and Special Studies conducted by the RMP in 2006. A summary of previous studies conducted by the RMP and specific details on the study development and selection processes are available on the RMP Pilot and Special Studies home page.

The RMP synthesizes and distributes its monitoring and study results (Objective 6) through conferences, workgroups, literature reviews, technical reports, newsletters, and the *Pulse of the Estuary*. This *Annual Monitoring Results* report focuses on the Status and Trends Program. The RMP publishes separate technical reports for the Sport Fish Contaminant Study and toxicity studies. These reports are available on the web at RMP Documents and Reports. A brief

description of those monitoring components and the USGS studies can be found in Chapter 1.3 below. For more information on the RMP, refer to the RMP home page.

1.2 The Status and Trends Program

The 2006 sampling was the fifth year of the new probabilistic sampling design for long-term water and sediment monitoring, which employs the EPA's Generalized Random Tessellation Stratified (GRTS) sample design (Stevens, 1997; Stevens and Olsen, 1999; Stevens and Olsen, 2000). This type of design is more appropriate for addressing the RMP's first objective to describe the spatial and temporal patterns of contamination in the Estuary (Lowe *et al*., 2005). Prior to 2003 a fixed site sampling design was used.

Sampling site information is presented in Table 1.2, and site location maps are included in Chapters 2.0-4.0. Subcontracting agencies perform the logistical planning, sampling, and laboratory analyses for trace contaminants and ancillary measures. Participating contractors for 2006 are listed in Table 1.3. A summary of the sampling and analytical methods used by the Status and Trends Program are included in Chapter 5.0. Monitoring data (since 1993) are available for downloading via the RMP website using the *Status and Trends Monitoring Data Query Tool*.

1.2.1 Random Sampling Design for Water and Sediment

With a randomized water and sediment sampling design, the RMP can better address Objectives 1 and 5, estimate the statistical basis from which to characterize spatial and temporal patterns of contamination in each region or the Estuary as a whole, determine if the mean contaminant concentrations within a region are above regulatory guidelines, estimate what proportion of the Estuary is toxic to laboratory test organisms, and provide a solid foundation for evaluating progress in reducing contaminant concentrations in water and sediment.

The RMP samples for water and sediment monitoring are allocated into five hydrographic regions of the Estuary plus the Rivers region. Those five regions are: Suisun Bay, San Pablo Bay, Central Bay, South Bay, and Lower South Bay (see Figure 1.1). The number of samples allocated to each region was determined by a power analysis that focused on contaminants and regions of greatest concern to the Water Board at the time of the 2002-2003 redesign effort. Seventy-five random water and sediment sites were allocated into each of the five hydrographic regions downstream from the confluence of the Sacramento and San Joaquin Rivers. The sampling frames for water and sediment monitoring are the three-foot and one-foot contour of the Estuary at mean lower low water, respectively (based on NOAA's NAD-83 bathymetry coverage). Each year, a subset of these sites is sampled in sequential order, increasing the spatial coverage of the Estuary over time.

Additionally, several historical fixed water and sediment sites were retained from the original RMP monitoring design to provide continuity between the two sampling designs. Sampling currently occurs once a year during the dry season when Estuary conditions are most consistent on an interannual basis. The sediment sample design incorporates re-sampling of sites for additional trends analyses. Six sites per region were selected for re-sampling - two sites each on annual, five-year, and ten-year cycles. The sites re-sampled annually are labeled XX001 and XX002, the sites re-sampled every five years are XX003 and XX004, and the sites sampled every 10 years are XX005 and XX006 (where XX stands for the region code). Repeated sampling reduces within-population variation if a population element retains much of its identity

through time. While this is assumed to be true for sediment, it is not true for water due to the constantly moving water masses within the Estuary. Therefore, the water sampling design does not include repeated sampling of randomly allocated sites, and trends in water will be tracked for each region as a whole based on estimates of population statistics.

For more information on the Status and Trends monitoring design, refer to the following articles and technical reports: *Re-design Process of the San Francisco Regional Monitoring Program for Trace Substances (RMP) Status and Trends Monitoring Component for Water and Sediment* (Lowe *et al*., 2005), *2000 Pulse of the Estuary* and *RMP News: Winter 2001/2002*.

1.2.2 Sampling Design for Bivalve Bioaccumulation Monitoring

The bivalve bioaccumulation sample design remains a convenient sample design because deployment of caged bivalves requires secure moorings. In 2003, several changes were made to the bivalve tissue monitoring component. Because it was determined that only two to three sites were required per region to track long-term changes in contaminant concentrations, three sites were discontinued at Napa River (BD50) and Petaluma River (BD15) in San Pablo Bay and Horseshoe Bay (BC21) in Central Bay. Based on a series of special studies in 2000-2002, only one transplanted bivalve species (*Mytilus californianus*) was deployed in four regions, which makes comparing the bioaccumulation results between regions possible. All bivalves are now deployed in cages, rather than mesh bags, to reduce the loss of organisms through predation.

Nine mooring sites (three in the Central Bay and San Pablo Bay regions, two in the South Bay, and one in the Lower South Bay) and two historic sites at the Sacramento River (BG20) and San Joaquin River (BG30) are monitored for bioaccumulative contaminants using transplanted and resident bivalves. Transplanted *Mytilus californianus* are deployed in cages for three months. Resident clams (*Corbicula fluminea*) are collected from the River sites.

Results from 1993-2001 indicated that trace metals do not appreciably accumulate in transplanted bivalve tissue at mid-channel locations in the RMP. Trace metals analyses were scaled back to a five year screening study. Next screening will occur in 2008. Tributyltin analysis was discontinued altogether. Since mercury bioaccumulation is included in the Sport Fish Contamination Study, mercury analysis in bivalves was discontinued.

1.3 2006 Annual Monitoring Results

1.3.1 Reporting of Results

Table 1.4 lists all parameters measured in water, sediment, and bivalve tissue samples in 2006. While only a subset of the parameters measured are presented in this report, all results, including data from previous years, can be downloaded from the web using the RMP Data Access Tool. In addition, Conductivity, Temperature, and Depth (CTD) profiles of the water column are collected at all RMP water, sediment, and bivalve tissue stations. CTD casts were collected during both the bivalve deployment and retrieval sampling efforts, and both depth and time casts were collected during water sampling. Although these data are not presented in this report, results are available upon request.

The *Annual Monitoring Results* includes only those results that have met specific data quality objectives and have passed a rigorous QA/QC evaluation as outlined in the RMP's Quality

Assurance Project Plan. Values reported as below the method detection limit (MDL) are estimated to be ½ of the MDL in all calculations and graphics. Some organic compounds are summed based on the target list of RMP congeners (Table 1.4) for that specific compound group (e.g., PBDEs, PAHs, and PCBs). When laboratory or field replicate data are available, the average of all the replicate concentrations is utilized in this report. This is consistent with the reporting of data from the web-based data access tool.

In this report, water, sediment, and bivalve tissue monitoring results from 2004 and 2005 are summarized graphically for many trace contaminants and important ancillary measures. The spatial distribution of contaminants is displayed in maps. Schematic box plots and cumulative distribution function (CDF) plots for water and sediment random samples provide simple summary statistics by region.

Several software programs were used to develop these graphics. Matlab (R2007a) was used to produce the maps and graphics for the schematic, box, cumulative distribution function, and time-series plots. The R statistical analysis software package, which is designed specifically by EPA for GRTS sample designs, and the psurvey.analysis statistical library (version 2.6) were used to calculate estimates of the regional and Estuary-wide contaminant mean, variance, standard deviation, standard error, and CDFs. The R program is an implementation of the S language developed at AT&T Bell Laboratories and can be downloaded for free from the Comprehensive R Archive Network (CRAN). The psurvey analysis library for the analysis of probability surveys is available from USEPA's Aquatic Resources Monitoring - Monitoring Design and Analysis.

Maps

A color gradient was used in the maps of this report (Figure 1.1) to depict the range of reported concentrations. A circle symbol (○) indicates a random site and a diamond symbol (◊) a historic site. Non-detected values are shown by the plus symbol (+). Results that did not pass the QA/QC review process are not shown. To create the underlying color contours, data were interpolated onto a regular 2km grid of San Francisco Bay using geospatial kriging, a method of interpolation that relies on the spatial correlation structure of the known data when estimating the value at unsampled locations (Journel and Huijbregts, 1981).

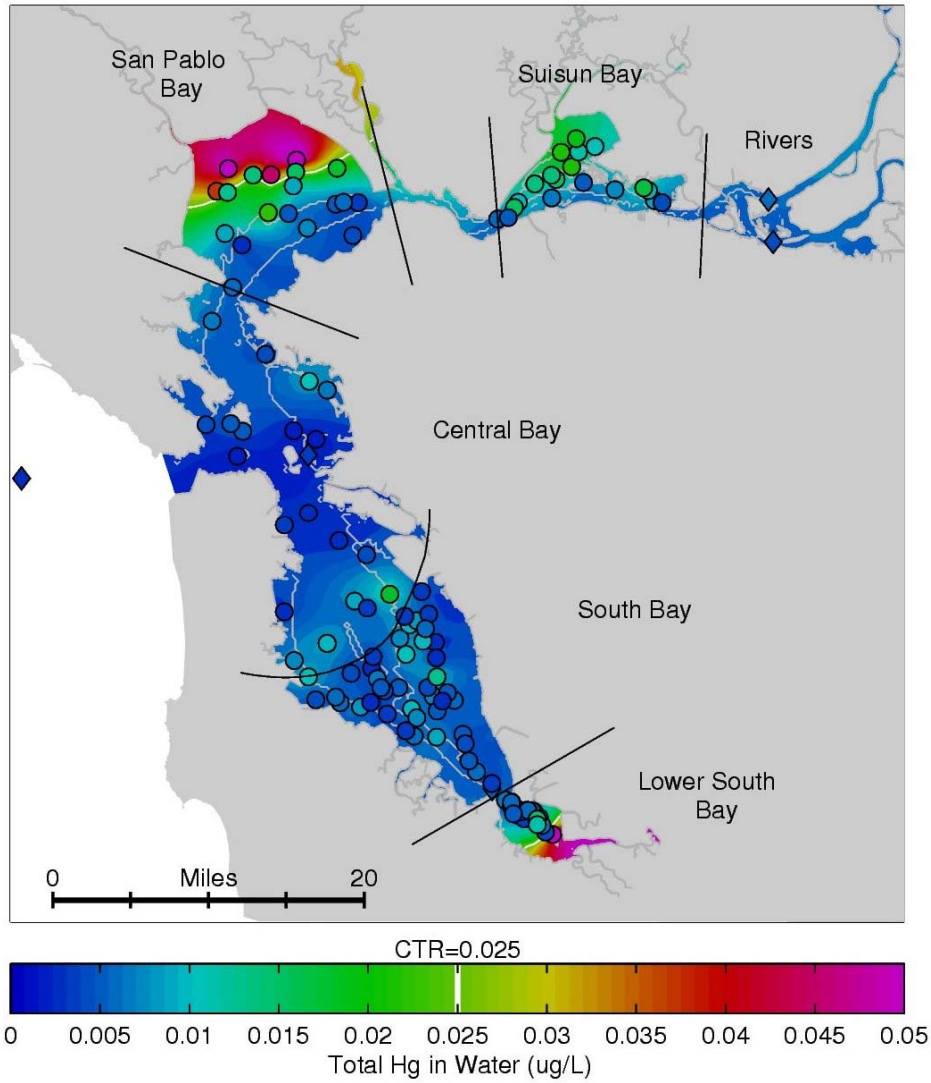

Figure 1.1. Map of Total Water Mercury concentrations in the Estuary.

Sample sizes varied by test material and region. The water maps represent data from twenty-six random and five historic sites at Dumbarton Bridge (BA30), Yerba Buena Island (BC10), Golden Gate (BC20), Sacramento River (BG20), and San Joaquin River (BG30). Nine sites were sampled in the South Bay region, five sites in the Lower South Bay region, and four sites in the Suisun Bay, San Pablo Bay, and Central Bay regions.

The sediment maps represent data from forty random and seven historic sites (per year) at Coyote Creek (BA10), Redwood Creek (BA41), Yerba Buena Island (BC11), Pinole Point (BD31), Grizzly Bay (BF21), San Joaquin River (BG30), and Sacramento River (BG20). Eight random sites and one historical fixed site were sampled per region, except for the Rivers region where only two historical sites were sampled.

The bivalve tissue maps represent data from nine fixed-mooring sites, where caged bivalves (*Mytilus californianus*) were deployed, and two historical River sites, where resident clams (*Corbicula fluminea*) were collected by a trawl. Bivalve samples deployed in 2006 are pending analysis until a lab is contracted to analyze the samples.

Time Series Plots
Time series plots (1993-2006) for the historic water and sediment sites are presented in this report. Detailed trend analyses are discussed in peer-reviewed journal articles as part of the Ten-Year Synthesis of Contaminant Status and Trends. These articles are included in a special issue of the scientific journal *Environmental Research* published in September 2007 (Volume 105, Issue 1) and available online at www.sciencedirect.com.

Schematic Box Plots
Figure 1.2 is an example of a schematic box plot used to present results by region. The horizontal line inside the box represents the median, and the mean is indicated by a blue "+". The top and bottom of the box represent the 3rd quartile (75th percentile) and the 1st quartile (25th percentile), respectively. The distance between these two is the interquartile range (IQR). A whisker is drawn from the upper edge of the box to the maximum value within the upper fence and from the lower edge of the box to the lowest value within the lower fence. The term "fence" refers to the distance from the 25th and 75th percentiles expressed in terms of the IQR.

For example, the lower fence is located at 1.5×IQR below the 25th percentile, and the upper fence is located at 1.5×IQR above the 75th percentile. The fences are not displayed in the plots in this report; however, observations that fall beyond these fences (outliers) are indicated by an open diamond " ◊ " symbol. Because there are a variable number of random water samples per segment, the width of the box in the water box plots is proportional to the number of samples reported per region.

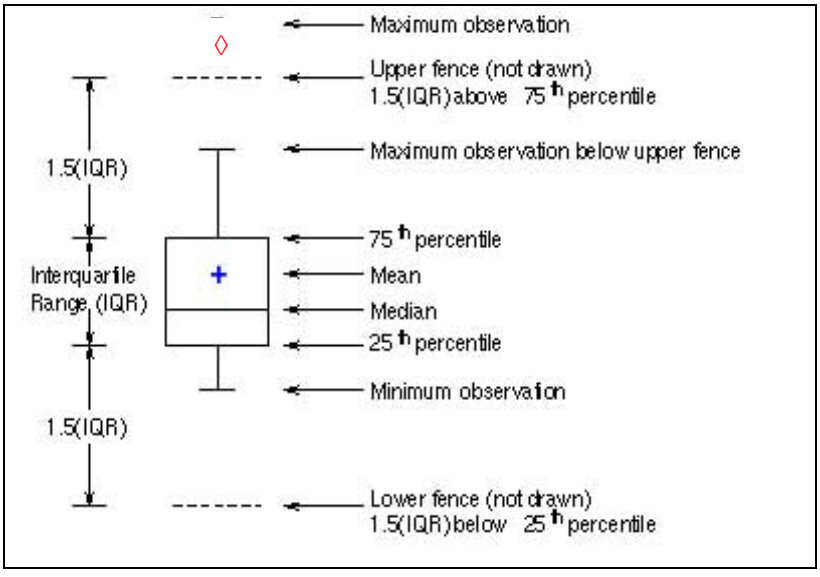

Figure 1.2. Illustration of a schematic box plot.

Cumulative Distribution Function (CDF) Plots
Cumulative distribution function plots (Figure 1.3) use the random sample results to show an estimate of the percentage of the total area sampled in the five Estuary regions combined (large graph) and parameter concentrations for each individual region (small graphs). The CDF analyses were performed using the R statistical software and the psurvey.analysis package.

The total area sampled is different for sediment and water samples because the sample frames were designed to be the 1-foot and 3-foot contour of the Estuary at mean lower low water, respectively. Each region's sample frame area is provided in Table 1.0. No random samples were allocated to the Rivers region; therefore, this region was not included in the total sample frame.

Table 1.0. Area of sample frames for water and sediment.

Region Name	Area of Sample Frame for Water (sq. km)	Area of Sample Frame for Sediment (sq. km)
Rivers	0	0
Suisun Bay	72	80
San Pablo Bay	181	227
Central Bay	382	396
South Bay	144	185
Lower South Bay	5	8
Total Area	784	896

The blue line is the CDF value, while the red lines represent the 95% confidence intervals. A horizontal black-dotted line is drawn as a reference to indicate 50% of the area sampled. Guideline values (e.g., TMDL, ERL, fish screening values) are represented as vertical blue-dashed lines when that value is within the range of the results reported. Since the Rivers region does not have random samples, a corresponding CDF plot was not generated.

CDF plots address questions such as what percentage of the Estuary is above a guideline for an analyte. For example in Figure 1.3, approximately 15% of the total sampled area in the Estuary has total water mercury concentrations above the California Toxics Rule (CTR) water quality criteria of 0.025 ug/L. Additionally, the small graphs indicate that Suisun Bay, Central Bay, and South Bay regions all have total mercury concentrations below the CTR.

Due to the small sample size of the sites sampled between 2002-2006 (202 sediment and 132 water random sites), the CDFs provide preliminary estimates of the percent area of the Estuary that is above a guideline or has a particular contaminant concentration. However, the power of this analysis will increase as the spatial coverage of the Estuary increases and more samples are collected over time.

In the initial sampling design, area weights were originally calculated for 100 sites per region. However, these area weights must be re-calculated each year according to the actual number of sites sampled. Area weights are calculated by dividing the product of the total sample frame area used for sample selection and the original area weights, by the sum of the original weights for the targeted sites. The targeted sites include sites that could not be sampled for any reason (e.g., inability to access a site) and replacement sites, since it is necessary to adjust for the area that could not be sampled. As the number of sites sampled increases over time, the area weight assigned to each sample will decrease, providing better resolution for the CDF estimates.

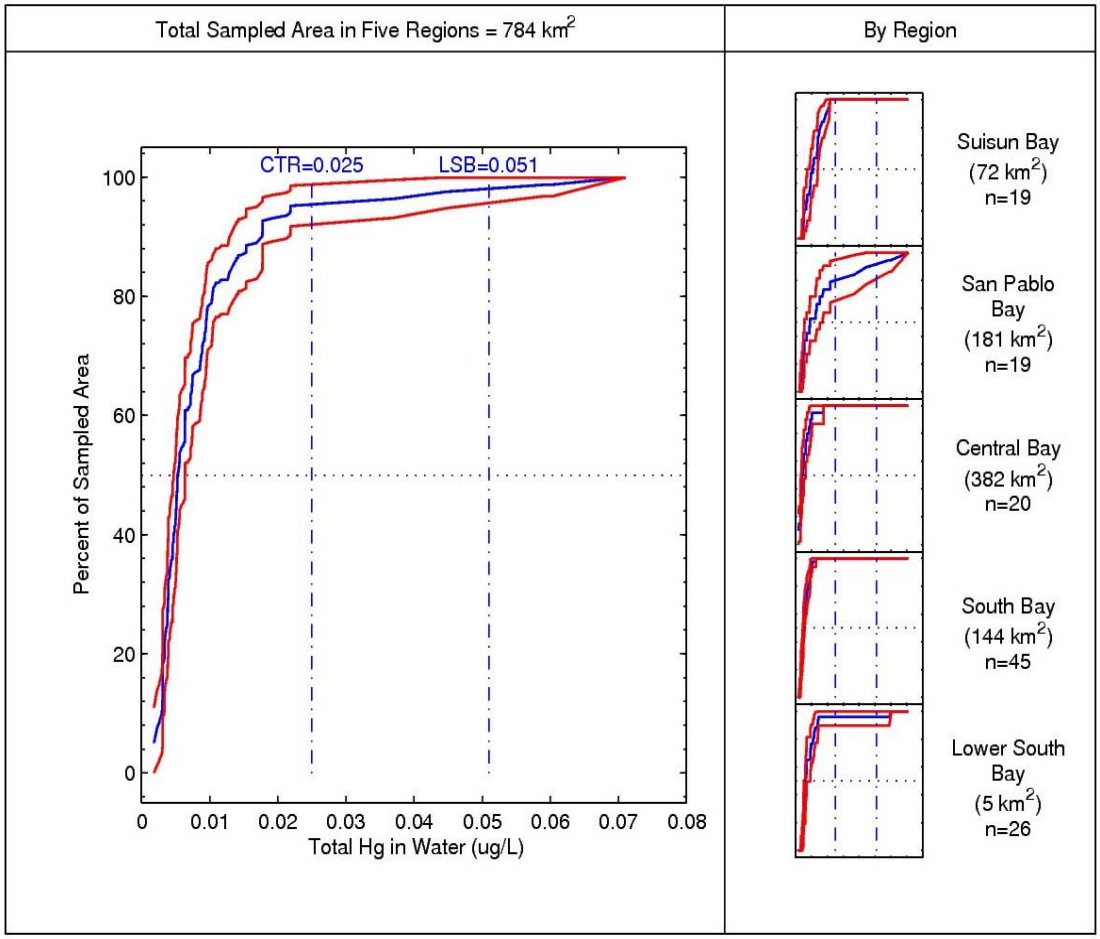

Figure 1.3. CDF plot for total water mercury concentrations.

1.3.2 Water Chemistry and Toxicity

Water sample collection occurred during the dry season in August 2006 at 31 sites throughout the Estuary. Twenty-six random sites were sampled (four to nine sites per region) and five historic sites were sampled.

The analyte list for conventional water quality, trace metals, and trace organics was the same as in 2005. Except for diazinon and chlorpyrifos, all data are available for reporting at this time.

No water samples were tested for ambient water toxicity in 2006. Since very little aquatic toxicity has been observed by the RMP in past monitoring years, ambient water toxicity testing will take place on a reduced five-year schedule. The next aquatic toxicity sampling of the Estuary surface waters is scheduled for 2007.

1.3.3 Sediment Chemistry and Toxicity

In 2006, sediment sample collection occurred during the dry season in August at 47 sites throughout the Estuary. Eight random sites and one historical fixed site were sampled per region, except for the Rivers region where only two historical sites were sampled.

The analyte list for sediment quality, trace metals, and trace organics was the same as in 2005. All of the data are available for reporting at this time.

Twenty-seven sediment samples were tested for toxicity in 2006. Toxicity tests included mean percent survival of the amphipods *Eohaustorius estuaries* after exposure to solid-phase sediments for 10 days and mean percent normal development of live Bay mussel *Mytilus galloprovincialis* larvae after exposure to sediment elutriates for 48 hours. Sediment monitoring results are discussed in more detail in Chapter 3.0.

1.3.4 Bivalve Bioaccumulation

In 2006, bivalve sample collection occurred in September and October at 11 sites throughout the Estuary. Trace metals were not analyzed in bivalve tissue in 2006. Trace organics are still pending analysis. Bivalve tissue monitoring results are discussed in more detail in Chapter 4.0.

1.3.5 Sport Fish Contaminant Study

Sport fish sampling, which occurs on a three-year cycle, was conducted in 2006. Popular sport fish species were sampled at several fishing locations, and tissue samples were analyzed for mercury, PCBs, organochlorine pesticides, and PBDEs. These results, along with data from 1994, 1997, 2000, and 2003 are available on the RMP Fish Tissue Data Page. For more information refer to the technical report *Contaminant Concentrations in Fish from San Francisco Bay 2003*.

1.3.6 Episodic Toxicity Monitoring

Episodic Toxicity Monitoring in 2006 was deferred until results from the 2004-5 PRISM study were available. For more information refer to the report Final Project Report: Investigations of Sources and Effects of Pyrethroid Pesticides in Watersheds of the San Francisco Estuary.

1.3.7 United States Geological Survey Studies

The United States Geological Survey (USGS) has been a collaborating agency in the RMP since the beginning of the Program. During 2006, it continued to supplement RMP monitoring with two special studies that address basic hydrographic and sediment transport processes.

Factors Controlling Suspended Sediment in San Francisco Bay

This sediment transport study examined the role of several physical factors controlling suspended sediment concentrations in the Estuary for a variety of hydrologic, tidal, and wind conditions and generated time series measurements for calibration and validation of sediment transport models. This monitoring element has taken on added importance because of its close relationship to episodic toxicity due to particle-bound contaminants and its relationship to the special study evaluating particle-associated contaminant load inputs from the Central Valley at Mallard Island. Time series measurements of suspended sediment concentrations were collected at six sites using optical backscatter sensors deployed at mid-depth and near the bottom. The following six sites were monitored in 2006: Alcatraz, Mallard, Benecia, Pt. San Pablo, Dumbarton, and Hamilton Aquatic Transfer Station in San Pablo Bay. Conductivity and temperature data were also collected at most sites. For more information refer to the *2003 Pulse of the Estuary* article Sediment Dynamics Drive Contaminant Dynamics.

Hydrography and Phytoplankton

This study collected monthly measurements of five water quality parameters at 38 stations throughout the Estuary to describe the changing spatial patterns of basic water quality from the lower Sacramento River to the southern limit of the South Bay. Measurements included:

salinity, temperature, and dissolved oxygen (which influence the chemical form and solubility of some trace contaminants); and suspended sediments and phytoplankton biomass (which influence the partitioning of reactive contaminants between dissolved and particulate forms). Primary production by phytoplankton is the principal source of food for aquatic life in the Estuary. Significant changes in phytoplankton population dynamics have been observed through this Program's monitoring in recent years, including larger spring blooms, blooms during other seasons, and a progressive increase in the amount of chlorophyll produced in the Estuary. For more information refer to the *2006 Pulse of the Estuary* article What is Causing the Phytoplankton Increase in San Francisco Bay?

1.4 RMP Pilot and Special Studies

While the Status and Trends is the core component of the RMP, providing long-term contaminant monitoring results, the adaptive management of the RMP is conducted through its Pilot and Special Studies, which allow for shorter-term changes based on the changing regulatory priorities, management of the Estuary, and scientific understanding of the Estuary.

1.4.1 Pilot Studies

Pilot studies augment Status and Trends monitoring by focusing on specific topics relating to contamination in the Estuary and provide a proactive approach to addressing management goals and needs. Pilot studies may eventually be incorporated into the Status and Trends Program (e.g., Episodic Toxicity Monitoring, Sport Fish Contamination Study).

Three pilot studies, Mercury Deposition Network, Exposure and Effects, and Winter pilot were conducted by the RMP in 2006.

Mercury Deposition Network (1999-2006)
Applicable RMP Objectives: 1, 3, and 6
Contact: Donald Yee (donald@sfei.org)

One pathway of pollutants to the Estuary is atmospheric deposition, which was examined in the RMP Atmospheric Deposition Pilot Study. That study was suspended after metals (including mercury) and PAH/PCB data were incorporated into the mass budget models, indicating that atmospheric deposition is not a primary source or pathway for most of these contaminants, with the exception of PAHs. The only remaining component of the study is the collaborative effort funded by the City of San Jose and the RMP to measure mercury in rain samples at a station at NASA Ames in San Jose.

The continuing objectives of this monitoring are (1) to evaluate concentrations of mercury in rainwater as part of TMDL refinement and (2) to contribute to the national Mercury Deposition Network (MDN) database to evaluate contributions of mercury from large urban areas and long-range aerial transport from outside the region to surface waters.

For more information, refer to the San Francisco Bay Atmospheric Deposition Pilot Study's final reports: *Part 1: Mercury (2001)*, *Part 2: Trace Metals (2001)*, and *Part 3: Dry Deposition of PAHs and PCBs (2005)*.

Exposure and Effects Pilot Study (2000-2008)
Applicable RMP Objectives: 1, 4, 5, and 6
Contact: Jay Davis (jay@sfei.org)

Beginning in 2000, the RMP implemented this multi-faceted pilot study to develop several indicators of contaminant exposure and effects of beneficial use impairment in the Estuary. Using resident species, this study measures exposure and effects at several trophic levels and at different levels of biological organization and spatial scales. Indicators being tested include: diving duck muscle (human exposure indicator); cormorant and Forster's tern eggs (chemical trend indicators); hatchability of Forster's terns, least terns, and clapper rails (effects indicators); blood chemistry and biomarkers in harbor seals (exposure and effects indicators); biomarker studies in fish, aquatic and sediment toxicity testing of resident species (effects indicators); and benthic community evaluations (effects indicators). Linking contaminant bioaccumulation with effects measurements at various levels of the food web can assist with establishing contaminant regulatory priorities and responding to emerging contaminants.

In 2006, EEPS funded the following projects:

Fish effects in shiner surfperch (2005 and 2006)
The main objective of the project was to determine if shiner surfperch (*Cymatogaster aggregata*; Embiotocidae) show effects of contamination on some aspect of their fitness, growth, or reproduction. A secondary objective was to synthesize the available information and data to develop a framework for understanding the relative contribution of contamination in the well-documented decline of the population in the San Francisco Estuary.

Mercury in small fish (2005, 2006, 2007, and 2008)
This project examines the uptake of mercury in small fish at seven sites in the Bay. The goal of this study is to better understand the temporal and spatial variation of mercury in biota in the Bay and to quantify exposure to mercury in piscivorious wildlife that may consume benthic or pelagic small fish as prey.

For more information, refer to the project's first year report Mercury in Biosentinel Fish in San Francisco Bay: First-Year Project Report. The report indicates initial spatial and species patterns in mercury in small fish, as well as sampling recommendations for future years of the study.

Sediment Assessments (2006)
The main objectives of this project are to verify the proposed Sediment Quality Objectives (SQO) for San Francisco Bay and identify specific contaminants that cause sediment impairment. The study will test and evaluate sediment effects thresholds identified for San Francisco Estuary sediment toxicity and benthic assemblage impacts by the State's SQO development program.

Endocrine Disruptors in shiner surfperch and Pacific staghorn sculpin (2006-2007)
The main objectives of this project are to 1) determine the incidence and magnitude of endocrine disrupting compounds in fish and how they affect stress hormones, growth, reproduction, and thyroid function, 2) look at spatial differences in these responses and contaminant levels, and 3) determine liver contaminant concentrations.

Winter Pilot Study (2005-2006)
A two-year winter pilot study was proposed for 2005 and 2006. The purpose of this pilot study is to characterize parameters that may reach concentrations of greater concern during winter months. In 2005, water samples from three historical RMP stations (i.e., Sacramento River (BG20), Yerba Buena Island (BC10), and Dumbarton Bridge (BA30)) were collected during the 2005 winter season (February 2005). These water samples were analyzed for contaminants on the California Toxics Rule priority pollutant list.

Based on discussions with the Water Board, it was decided to cancel the second year of this study. In future years, the RMP may revisit the issue of winter sampling.

1.4.2 Special Studies

Special Studies help the RMP address specific data gaps or management and scientific questions related to contaminants in the Estuary. For example, recent special studies identified and evaluated previously unknown organic contaminants and led to the addition of PBDEs to the RMP target analyte list to determine if they are prevalent in water, sediment, and tissue samples from the Estuary. For more information, refer to RMP Documents and Reports.

The following special studies were conducted in 2006:

- Contaminant Loads from the Sacramento and San Joaquin Rivers (2003-2009)
- Small Tributary Loading Study - Guadalupe (2003-2006)
- Sediment Coring Study (2006)
- Monitoring of Mercury in the South Bay (2006)
- Information Workshop on Benthic Assessments (2006)
- Flood Sampling at Mallard Island (2006)

Contaminant Loads from the Sacramento and San Joaquin Rivers (2003-2006)
Applicable RMP Objectives: 1, 3, and 6
Contact: Lester McKee (lester@sfei.org)

According to the Clean Water Act 303(d), the San Francisco Bay is listed as impaired for mercury, selenium, PCBs, and chlorinated pesticides. This study aims to address information gaps associated with loadings of these substances in order to develop a better understanding of relative inputs from urban point and non-point sources, industrial wastewater, erosion and resuspension in the Bay, atmospheric deposition and the inputs from the Central Valley rivers. During 2006, observations were made during a large storm event of approximately 1:8 year return interval, a lucky event that provided support for a hypothesis that mercury loads would be greater during "Yolo Bypass events". During 2008, water sampling for analysis of contaminant concentrations will only occur if discharge exceeds a threshold of 150,000 cfs (see below).

Flood Sampling at Mallard Island (2006)
Applicable RMP Objectives: 1, 3, and 6
Contact: Lester McKee (lester@sfei.org)

During December 2005, a series of storms of increasing intensity and duration occurred in California. The flow from these storms was anticipated to exceed 150,000 cfs, the trigger magnitude for sampling of large floods; the ultimate peak flow was 370,000 cfs. Using

contingency funding, this study sampled the peak flow at Mallard Island to estimate the magnitude of loading of priority particle-associated contaminants during such high flow events, when the majority of flow passes through the Yolo Bypass, an area known to be contaminated with mercury inputs from Cache Creek. Samples were collected every other day during peak flow and were analyzed for selenium, total mercury, PCBs, PBDEs, and PAHs, suspended sediment concentration, salinity, and dissolved and particulate organic carbon.

Small Tributary Loading Study at Guadalupe River (2003-2007)
Applicable RMP Objectives: 1, 3, and 6
Contact: Lester McKee (lester@sfei.org)

Small tributaries form a major pathway for loads of contaminants that enter the Bay each year. Models developed for the Bay are highly sensitive to the magnitude of loads from small tributaries, but prior to this study, the load estimates for this pathway lacked accuracy and precision. This study funded jointly by the CEP, RMP, Santa Clara Valley Water District (SCVWD), Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), and US Army Corps of Engineers, aimed to measure contaminant loads from a small tributary representative of one that may contribute significant loads of sediment and associated contaminants to the Bay, help evaluate the significance of this load as a means of prioritization of further loadings studies, demonstrate a new methodology, and compare these accurate loads measurements to existing simple model estimates. Flood events were sampled and analyzed for trace contaminant concentrations (total and dissolved inorganic mercury, total and dissolved methyl mercury, trace metals, PCBs, PBDEs, OC pesticides, SSC, DOC, and POC). With the exception of the first year of the study, all years observed so far have been either relatively dry or wet but with low intensity rainfall.

Sediment Coring Study (2006)
Applicable RMP Objectives: 1, 3, and 6
Contact: Donald Yee (donald@sfei.org)

This was a joint project between the Clean Estuary Partnership (CEP) and the RMP to collect information of contaminant distributions in deeper Bay sediments (RMP typically collects only the top 5cm). Sediment cores (four-inch diameter, 1.5-2 meter deep) were collected at 11 Bay sites (two per segment, with three in Central Bay) and two-meter wetland cores were collected at wetland sites (one per segment and Guadalupe River). In addition, six cores were advanced in wetlands at the following locations: Point Edith, Martinez; Wildcat Creek, Richmond; Martin Luther King Jr. Regional Park, Oakland; Alviso Slough, Alviso; Greco Island, Redwood City; and Coyote Creek, Alviso/Milpitas. These cores will be used to 1) provide a more comprehensive characterization of contamination with depth that can be used to assess future changes, 2) verify the historic loading of pollutants to the Bay and how those loads have changed in the last several decades, and 3) provide valuable data for parameterization and evaluation of the multi-box and other Bay models.

Results and final report are pending completion of radio-dating and chemical analyses.

Monitoring of Mercury in the South Bay (2006)
Applicable RMP Objectives: 1, 3, 4, and 6
Contact: Letitia Grenier (letitia@sfei.org)

The South Baylands Mercury Project (SBMP) began in 2006 to provide information to managers and other decision makers about how restoration actions may affect mercury in the food web. The project was funded in 2006 by the Santa Clara Valley Water District (SCVWD), the California Costal Conservancy, the San Francisco Bay Fund, and the RMP. The restoration of former commercial salt ponds to tidal wetlands (South Bay Salt Ponds Restoration Project) has raised concerns over potential changes in the accumulation of methyl mercury in South Bay fish and wildlife due to restoration actions. The SBMP is a collaboration between SFEI, USGS, and the SCVWD with each group working on biota, sediment, and water studies, respectively. This integrative effort seeks to answer 1) how much legacy mercury is contained in the sediment of Alviso Slough, 2) how readily available is this legacy mercury for conversion to toxic methyl mercury, 3) how effectively is methyl mercury incorporated into local food webs, and 4) how might restoration of managed ponds to tidal wetlands impact mercury uptake into the food web. The SFEI component is focused on sentinel species in the ponds and adjacent wetlands as indicators of habitat-specific mercury conditions before and after the restoration. For more information refer to the South Baylands Mercury Project 2006 Year-End Progress Report.

Information Workshop on Benthic Assessments (2006)
Applicable RMP Objectives: 4 and 5
Contact: Bruce Thompson (bruce@sfei.org)

The State Water Resources Control Board developed sediment quality objectives (SQOs) that are scheduled to be promulgated in 2008. An understanding of baseline conditions of benthic assemblages in the Bay, which did not exist, is necessary to implement the SQOs. Therefore, a workshop was held in 2006 to discuss benthic assessment. This workshop was developed to build consensus on a benthic assessment process that the RMP could use to begin studying benthic assemblages in the Bay in 2008.

1.5 Summary of Changes

There have been numerous changes over the years to the RMP in order to better address management questions and adapt to changing regulatory and scientific information needs. Table 1.5 summarizes the major changes since the RMP began in 1993. Tables 1.6 – 1.8 provide a list of reported data by matrix for all years. This provides a quick overview of when analytes were added and dropped from the RMP's target list.

1.6 References

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Table 1.1. RMP Program Participants in 2006.

Municipal Dischargers
Burlingame Waste Water Treatment Plant
Central Contra Costa Sanitary District
Central Marin Sanitation Agency
City of Benicia
City of Calistoga
City of Palo Alto
City of Petaluma
City of Pinole/Hercules
City of Saint Helena
City and County of San Francisco
City of San Jose/Santa Clara
City of San Mateo
City of South San Francisco/San Bruno
City of Sunnyvale
Delta Diablo Sanitation District
East Bay Dischargers Authority
East Bay Municipal Utility District
Fairfield-Suisun Sewer District
Las Gallinas Valley Sanitation District
Marin County Sanitary District #5, Tiburon
Millbrae Waste Water Treatment Plant
Mountain View Sanitary District
Napa Sanitation District
Novato Sanitation District
Rodeo Sanitary District
San Francisco International Airport
Sausalito/Marin City Sanitation District
Sewerage Agency of Southern Marin
Sonoma County Water Agency
South Bayside System Authority
Town of Yountville
Union Sanitary District
Vallejo Sanitation & Flood Control District
West County Agency

Industrial Dischargers
C & H Sugar Company
Chevron Products Company
ConocoPhillips Company
Crockett Cogeneration
Dow Chemical Company
General Chemical Corporation
Rhodia, Inc.
Shell – Martinez Refining Company
Tesoro Golden Eagle Refinery
USS – POSCO Industries
Valero Refining Company

Cooling Water
Mirant of California

Dredgers
Alameda Reuse and Redevelopment
Arques Shipyard and Marina
Caltrans
Chevron Richmond Long Wharf
City of Benicia
City of San Rafael
Clipper Yacht Club
ConocoPhillips Company
Corinthian Yacht Club
Paradise Cay Yacht Harbor
Port of Oakland
Port of San Francisco
Richmond Yacht Club
U.S. Army Corps of Engineers
Valero Refining Co.

Stormwater
Alameda Countywide Clean Water Program
Caltrans
City and County of San Francisco
Contra Costa Clean Water Program
Fairfield-Suisun Urban Runoff Management Program
Marin County Stormwater Pollution Prevention Program
San Mateo Countywide Stormwater Pollution Prevention Program
Santa Clara Valley Urban Runoff Pollution
Vallejo Sanitation and Flood Control District

Table 1.2. Summary of 2006 RMP sampling stations.

Latitude and longitude coordinates are reported in decimal degrees. Historic and random site coordinates are reported in WGS 84 and NAD 27 datum, respectively. Conductivity, Temperature, and Depth (CTD) profiles are collected at all sites. Site depth measurements are taken from the Cruise Reports for water and sediment sites. The bivalve site depths are estimated measurements relative to mean lower low water (MLLW) based on NOAA's nautical charts.

Region/Site Name	Site Code	Historic Site	Sample Type	Collection Date	Latitude	Longitude	Site Depth (m)	Type of Analysis			
								Trace Elements	Trace Organics	Ancillary	Toxicity
Central Bay/Yerba Buena Island	BC10	x	Water	21/Aug/2006	37.82348	-122.35	6.9	x	x	x	
Central Bay/Yerba Buena Island	BC11	x	Sediment	07/Aug/2006	37.82398	-122.3487	5.6	x	x	x	x
Central Bay/Golden Gate	BC20	x	Water	22/Aug/2006	37.7953	-122.671	29.3	x	x	x	
Central Bay	CB001S		Sediment	04/Aug/2006	37.87527	-122.3621	3.7	x	x	x	x
Central Bay	CB002S		Sediment	07/Aug/2006	37.62497	-122.3474	4.8	x	x	x	
Central Bay	CB017W		Water	21/Aug/2006	37.88445	-122.3282	2.9	x	x	x	
Central Bay	CB018W		Water	14/Aug/2006	37.64923	-122.3282	9.0	x	x	x	
Central Bay	CB019W		Water	22/Aug/2006	37.85263	-122.441	9.0	x	x	x	
Central Bay	CB020W		Water	21/Aug/2006	37.7437	-122.3139	8.0	x	x	x	
Central Bay	CB027S		Sediment	04/Aug/2006	37.94287	-122.4433	17.7	x	x	x	x
Central Bay	CB028S		Sediment	07/Aug/2006	37.70992	-122.3642	3.7	x	x	x	
Central Bay	CB029S		Sediment	04/Aug/2006	37.84675	-122.3521	4.8	x	x	x	x
Central Bay	CB030S		Sediment	07/Aug/2006	37.75817	-122.2749	2.3	x	x	x	
Central Bay	CB032S		Sediment	07/Aug/2006	37.67643	-122.3536	8.5	x	x	x	
Central Bay	CB082S		Sediment	07/Aug/2006	37.62567	-122.3277	5.5	x	x	x	x
Lower South Bay/Coyote Creek	BA10	x	Sediment	08/Aug/2006	37.46837	-122.0645	2.4	x	x	x	x
Lower South Bay	LSB001S		Sediment	08/Aug/2006	37.492	-122.0987	5.6	x	x	x	x
Lower South Bay	LSB002S		Sediment	08/Aug/2006	37.47838	-122.0786	2.5	x	x	x	
Lower South Bay	LSB022W		Water	16/Aug/2006	37.46602	-122.0647	1.4	x	x	x	
Lower South Bay	LSB023W		Water	17/Aug/2006	37.49137	-122.1101	2.2	x	x	x	
Lower South Bay	LSB024W		Water	16/Aug/2006	37.4856	-122.0819	5.0	x	x	x	
Lower South Bay	LSB025W		Water	16/Aug/2006	37.49063	-122.105	1.6	x	x	x	
Lower South Bay	LSB026W		Water	16/Aug/2006	37.48143	-122.0818	2.0	x	x	x	
Lower South Bay	LSB027S		Sediment	08/Aug/2006	37.50132	-122.1158	14	x	x	x	x
Lower South Bay	LSB028S		Sediment	08/Aug/2006	37.47688	-122.0954	1.8	x	x	x	
Lower South Bay	LSB029S		Sediment	08/Aug/2006	37.4914	-122.0952	5.6	x	x	x	x
Lower South Bay	LSB030S		Sediment	08/Aug/2006	37.47485	-122.0685	2.6	x	x	x	
Lower South Bay	LSB031S		Sediment	08/Aug/2006	37.49542	-122.1085	11.3	x	x	x	x
Lower South Bay	LSB032S		Sediment	08/Aug/2006	37.485	-122.0867	4	x	x	x	
Rivers/Sacramento River	BG20	x	Sediment	02/Aug/2006	38.05917	-121.8153	9.8	x	x	x	x
Rivers/Sacramento River	BG20	x	Water	24/Aug/2006	38.05947	-121.8117	9.6	x	x	x	
Rivers/San Joaquin River	BG30	x	Sediment	02/Aug/2006	38.02292	-121.8088	2.9	x	x	x	x

Region/Site Name	Site Code	Historic Site	Sample Type	Collection Date	Latitude	Longitude	Site Depth (m)	Type of Analysis			
								Trace Elements	Trace Organics	Ancillary	Toxicity
Rivers/San Joaquin River	BG30	x	Water	24/Aug/2006	38.02037	-121.8056	10.8	x	x	x	
San Pablo Bay/Pinole Point	BD31	x	Sediment	04/Aug/2006	38.024	-122.3633	6.8	x	x	x	x
San Pablo Bay	SPB001S		Sediment	03/Aug/2006	38.07137	-122.3868	3	x	x	x	x
San Pablo Bay	SPB002S		Sediment	04/Aug/2006	38.01653	-122.3402	3.3	x	x	x	
San Pablo Bay	SPB017W		Water	23/Aug/2006	38.08485	-122.3647	3.3	x	x	x	
San Pablo Bay	SPB018W		Water	23/Aug/2006	38.05655	-122.3087	9.3	x	x	x	
San Pablo Bay	SPB019W		Water	23/Aug/2006	38.06567	-122.4453	1.5	x	x	x	
San Pablo Bay	SPB020W		Water	23/Aug/2006	38.07217	-122.3675	3.2	x	x	x	
San Pablo Bay	SPB027S		Sediment	03/Aug/2006	38.06743	-122.462	1.5	x	x	x	x
San Pablo Bay	SPB028S		Sediment	04/Aug/2006	37.97495	-122.4404	23.6	x	x	x	
San Pablo Bay	SPB029S		Sediment	03/Aug/2006	38.10188	-122.337	1.5	x	x	x	x
San Pablo Bay	SPB030S		Sediment	04/Aug/2006	37.98577	-122.375	1.8	x	x	x	
San Pablo Bay	SPB031S		Sediment	03/Aug/2006	38.05708	-122.4525	1.9	x	x	x	x
San Pablo Bay	SPB032S		Sediment	03/Aug/2006	38.04768	-122.3779	3.8	x	x	x	
South Bay/Dumbarton Bridge	BA30	x	Water	17/Aug/2006	37.51323	-122.1344	2.5	x	x	x	
South Bay/Redwood Creek	BA41	x	Sediment	07/Aug/2006	37.55898	-122.211	2.5	x	x	x	x
South Bay	SB001S		Sediment	07/Aug/2006	37.61205	-122.2642	3.1	x	x	x	x
South Bay	SB002S		Sediment	09/Aug/2006	37.61013	-122.168	2.2	x	x	x	
South Bay	SB027S		Sediment	07/Aug/2006	37.62005	-122.3137	5	x	x	x	x
South Bay	SB028S		Sediment	07/Aug/2006	37.58787	-122.2351	3.7	x	x	x	
South Bay	SB029S		Sediment	09/Aug/2006	37.6227	-122.2392	2.7	x	x	x	x
South Bay	SB030S		Sediment	08/Aug/2006	37.5415	-122.1583	3.1	x	x	x	
South Bay	SB031S		Sediment	09/Aug/2006	37.64593	-122.2567	4.1	x	x	x	x
South Bay	SB032S		Sediment	09/Aug/2006	37.65725	-122.1754	1.6	x	x	x	
South Bay	SB038W		Water	17/Aug/2006	37.53975	-122.1622	2.9	x	x	x	
South Bay	SB039W		Water	15/Aug/2006	37.67437	-122.237	3.1	x	x	x	
South Bay	SB040W		Water	15/Aug/2006	37.5803	-122.2227	4.5	x	x	x	
South Bay	SB041W		Water	15/Aug/2006	37.6795	-122.2286	1.8	x	x	x	
South Bay	SB042W		Water	18/Aug/2006	37.56783	-122.2362	3.5	x	x	x	
South Bay	SB043W		Water	14/Aug/2006	37.61778	-122.3514	2.1	x	x	x	
South Bay	SB044W		Water	15/Aug/2006	37.6622	-122.2036	1.5	x	x	x	
South Bay	SB045W		Water	14/Aug/2006	37.60808	-122.2652	2.8	x	x	x	
South Bay	SB046W		Water	18/Aug/2006	37.57617	-122.1777	2.8	x	x	x	
Suisun/Grizzly Bay	BF21	x	Sediment	02/Aug/2006	38.11588	-122.04	2.2	x	x	x	x
Suisun	SU001S		Sediment	02/Aug/2006	38.09882	-122.0465	6.5	x	x	x	x

Region/Site Name	Site Code	Historic Site	Sample Type	Collection Date	Latitude	Longitude	Site Depth (m)	Type of Analysis			
								Trace Elements	Trace Organics	Ancillary	Toxicity
Suisun	SU002S		Sediment	02/Aug/2006	38.05875	-121.9802	11.2	x	x	x	
Suisun	SU019W		Water	25/Aug/2006	38.04255	-122.1165	11.8	x	x	x	
Suisun	SU020W		Water	25/Aug/2006	38.07518	-122.0278	6.3	x	x	x	
Suisun	SU021W		Water	25/Aug/2006	38.06118	-122.0653	8.3	x	x	x	
Suisun	SU022W		Water	24/Aug/2006	38.05662	-121.9355	1.6	x	x	x	
Suisun	SU027S		Sediment	03/Aug/2006	38.05545	-122.1119	10.9	x	x	x	x
Suisun	SU028S		Sediment	03/Aug/2006	38.06822	-122.0477	2.9	x	x	x	
Suisun	SU029S		Sediment	03/Aug/2006	38.0702	-122.0704	2.2	x	x	x	x
Suisun	SU030S		Sediment	02/Aug/2006	38.05698	-121.9477	7.4	x	x	x	
Suisun	SU031S		Sediment	02/Aug/2006	38.06803	-122.091	5.4	x	x	x	x
Suisun	SU077S		Sediment	02/Aug/2006	38.05432	-122.0833	9.8	x	x	x	

Table 1.3. RMP Contractors and Principal Investigators in 2006.

Logistical Coordinator and Ship Captain	Mr. Paul Salop and Dr. Andrew Gunther Applied Marine Sciences (AMS), Livermore, CA Mr. Nick Sakata US Bureau of Reclamation Captain, *RV Endeavor*
Water Trace Element Chemistry	Mr. Colin Davies and Ms. Elizabeth Madonick Brooks-Rand Ltd. (BRL), Seattle, WA
	Dr. Russ Flegal and Ms. Genine Scelfo UC Santa Cruz (UCSCDET), Santa Cruz, CA
Water Trace Organic Chemistry	Dr. Million Woudneh and Ms. Pam Riley AXYS Analytical Services, Inc. (AXYS), Sidney, BC
Water Ancillary Measurements	Water Cognates: Dr. Russ Flegal and Ms. Genine Scelfo UC Santa Cruz (UCSCDET), Santa Cruz, CA
	Water Hardness: Ms. Julia Halsne East Bay Municipal Utility District (EBMUD), Oakland, CA
Sediment Trace Element Chemistry	Mr. Colin Davies and Ms. Elizabeth Madonick Brooks-Rand Ltd. (BRL), Seattle, WA
	Dr. Russ Flegal and Ms. Genine Scelfo UC Santa Cruz (UCSCDET), Santa Cruz, CA
	Mr. Anthony Rattonetti and Mr. Lonnie Butler City and County of San Francisco (CCSF), San Francisco, CA
Sediment Trace Organics Chemistry	Mr. François Rodigari and Dr. Saskia van Bergen East Bay Municipal Utility District (EBMUD), Oakland, CA
Sediment Toxicity Testing	Mr. John Hunt, Dr. Brian Anderson, and Dr. Bryn Phillips Marine Pollution Studies Lab (MPSL), Granite Canyon, CA
Sediment Ancillary Measurements (Grainsize, TOC, TN)	Dr. Russ Flegal and Ms. Genine Scelfo UC Santa Cruz (UCSCDET), Santa Cruz, CA
Bivalve Trace Organics	Dr. Dave Crane, Mr. Abdu Mekebri, and Mr. Loc Nguyen California Dept. of Fish & Game, Water Pollution Control Laboratory (CDFG-WPCL), Rancho Cordova, CA
Bivalve Condition and Survival	Mr. Paul Salop Applied Marine Sciences (AMS), Livermore, CA
USGS Water Quality	Dr. James Cloern, USGS, Menlo Park, CA
USGS Sediment Transport	Dr. David Schoellhamer, USGS, Sacramento, CA

Table 1.4. RMP Target Parameter List in 2006.

Refer to Table 1.3 for laboratory names.

Conventional Water Quality Parameters	Lab(s)	Reporting Units
Conductivity	AMS/UCSCDET	µmho
Dissolved Ammonia	UCSCDET	mg/L (N)
Dissolved Nitrate	UCSCDET	mg/L (N)
Dissolved Nitrite	UCSCDET	mg/L (N)
Dissolved Organic Carbon	UCSCDET	µg/L
Dissolved Oxygen	UCSCDET	mg/L
Dissolved Phosphates	UCSCDET	mg/L
Dissolved Silicates	UCSCDET	mg/L
Hardness (when salinity is < 5 ‰)	CCSF/EBMUD	mg/L ($CaCO_3$)
PH	AMS/UCSCDET	pH
Phaeophytin	UCSCDET	mg/m^3
Salinity (by salinometer)	UCSCDET	psu
Salinity (by SCT)	AMS/UCSCDET	‰
Suspended Sediment Concentration	UCSCDET	mg/L
Temperature	AMS/UCSCDET	°C
Total Chlorophyll-*a*	UCSCDET	mg/m^3
Sediment Quality Parameters	**Lab(s)**	**Reporting Units**
% clay (< 4 µm)	UCSCDET	% dry weight
% silt (4 µm–63 µm)	UCSCDET	% dry weight
% sand (63 µm – 2 mm)	UCSCDET	% dry weight
% gravel + shell (> 2 mm)	UCSCDET	% dry weight
% solids	BRL/CCSF/EBMUD	% dry weight
Depth	AMS	m
Hydrogen Sulfide *(QAQC measurement)*	MPSL	µg/kg
pH (porewater, interstitial sediment)	AMS	pH
Total Ammonia *(QAQC measurement)*	MPSL	µg/kg
Total Organic Carbon	UCSCDET	%
Total Sulfide *(QAQC measurements)*	MPSL	µg/kg
Total Nitrogen	UCSCDET	%
Bivalve Tissue Parameters	**Lab(s)**	**Reporting Units**
% Lipid	CDFG-WPCL	%
% Moisture	CDFG-WPCL	%
Bivalve Percent Survival	AMS	%
Growth Mean (Change in internal shell volume)	AMS	g
Dry Flesh Weight	AMS	g
Toxicity Tests - Sediment	**Lab(s)**	**Reporting Units**
Sediment Toxicity – (Amphipod) % Survival	MPSL	%
Sediment Toxicity – (Bivalve) % Normal Development	MPSL	%

Table 1.4. RMP Target Parameter List in 2006 (cont'd).

Trace elements analyzed in water and sediment samples[1]
Target Method Detection Limits (MDLs) are in parentheses following the reporting units.

	Water (Dissolved and Total)	**Sediment** (dry weight)
Lab(s)	BRL/UCSCDET	BRL/CCSF/ UCSCDET
Aluminum (Al)*	-	mg/kg (200)
Arsenic (As)	µg/L (0.1)	mg/kg (0.2)
Cadmium (Cd)*	µg/L (0.001)	mg/kg (0.001)
Cobalt (Co)	µg/L (0.0005)	-
Copper (Cu)*	µg/L (0.01)	mg/kg (2)
Iron (Fe)*	µg/L (10)	mg/kg (200)
Lead (Pb)*	µg/L (0.001)	mg/kg (0.5)
Manganese (Mn)*	µg/L (0.01)	mg/kg (20)
Mercury (Hg)	µg/L (.0001)	mg/kg (0.00001)
Methylmercury (MeHg)	ng/L (0.005)	µg/kg (0.005)
Nickel (Ni)*	µg/L (0.01)	mg/kg (5)
Selenium (Se)	µg/L (0.02)	mg/kg (0.01)
Silver (Ag)*	µg/L (0.0001)	mg/kg (0.001)
Zinc (Zn)*	µg/L (0.005)	mg/kg (5)

- Parameter is not sampled for the matrix.

* Near-total instead of total concentrations are reported for water. Near-total metals are extracted with a weak acid (pH < 2) for a minimum of one month, resulting in measurements that approximate bioavailability of these metals to Estuary organisms.

[1] Beginning in 2002, trace elements in bivalve tissue will be analyzed on a five-year cycle.

Table 1.4. RMP Target Parameter List in 2006 (cont'd).

Trace organic parameters (lab; reporting units) analyzed in water (AXYS; pg/L), sediment (EBMUD; µg/kg), and bivalve tissue (CDFG-WPCL; µg/kg) samples: Organochlorines analyzed by GC-ECD will be determined using two columns of differing polarity.		
Polycyclic Aromatic Hydrocarbons* (PAHS) (Target MDLs: water – 200 pg/L, sediment and tissue – 5 µg/kg)		
Low molecular weight PAHs	**High molecular weight PAHs**	**Alkylated PAHs**
1-Methylnaphthalene	Benz(*a*)anthracene	C1-Chrysenes
1-Methylphenanthrene	Benzo(*a*)pyrene	C2-Chrysenes
2-Methylnaphthalene	Benzo(*b*)fluoranthene	C3-Chrysenes
2,6-Dimethylnaphthalene	Benzo(*e*)pyrene	C4-Chrysenes
2,3,5-Trimethylnaphthalene	Benzo(*ghi*)perylene	C1-Dibenzothiophenes
Acenaphthene	Benzo(*k*)fluoranthene	C2-Dibenzothiophenes
Acenaphthylene	Chrysene	C3-Dibenzothiophenes
Anthracene	Dibenz(*a,h*)anthracene	C1-Fluoranthene/Pyrenes
Biphenyl	Fluoranthene	C1-Fluorenes
Dibenzothiophene	Indeno(*1,2,3-cd*)pyrene	C2-Fluorenes
Fluorene	Perylene	C3-Fluorenes
Naphthalene	Pyrene	C1-Naphthalenes
Phenanthrene		C2-Naphthalenes
		C3-Naphthalenes
		C4-Naphthalenes
		C1-Phenanthrene/Anthracenes
		C2-Phenanthrene/Anthracenes
		C3-Phenanthrene/Anthracenes
		C4-Phenanthrene/Anthracenes
SYNTHETIC BIOCIDES (Target MDLs: water – 2 pg/L, sediment and tissue – 1 µg/kg)		
Cyclopentadienes	**DDTs***	**Other Synthetic Biocides**
Aldrin	o,p'-DDD	Chlorpyrifos *(water only))*
Dieldrin	o,p'-DDE	Dacthal *(water only)*
Endrin	o,p'-DDT	Diazinon *(water only)*
	p,p'-DDD	Endosulfan I *(water only)*
Chlordanes*	p,p'-DDE	Endosulfan II *(water only)*
alpha-Chlordane	p,p'-DDT	Endosulfan Sulfate *(water only)*
cis-Nonachlor		Hexachlorobenzene
gamma-Chlordane	**HCH***	Mirex
Heptachlor	alpha-HCH	Oxadiazon *(water only)*
Heptachlor Epoxide	beta-HCH	
Oxychlordane	delta-HCH	
trans-Nonachlor	gamma-HCH	

Table 1.4. RMP Target Parameter List in 2006 (cont'd).

OTHER SYNTHETIC COMPOUNDS

Polychlorinated Biphenyls* (PCBs)
(Target MDLs: water – 2 pg/L, sediment and tissue – 1 µg/kg)
IUPAC numbers listed.

PCB 008	PCB 066	PCB 118	PCB 170
PCB 018	PCB 070	PCB 128	PCB 174
PCB 028	PCB 074	PCB 132	PCB 177
PCB 031	PCB 087	PCB 138	PCB 180
PCB 033	PCB 095	PCB 141	PCB 183
PCB 044	PCB 097	PCB 149	PCB 187
PCB 049	PCB 099	PCB 151	PCB 194
PCB 052	PCB 101	PCB 153	PCB 195
PCB 056	PCB 105	PCB 156	PCB 201
PCB 060	PCB 110	PCB 158	PCB 203

Polybrominated Diphenyl Ethers* (PBDEs)
(Target MDLs: water – 1 pg/L, sediment and tissue – 1 µg/kg)
IUPAC number - compound name listed.

017 - [2,2',4-triBDE]	154 - [2,2',4,4',5,6'-hexaBDE]
028 - [2,4,4'-triBDE]	183 - [2,2',3,4,4',5',6-heptaBDE]
047 - [2,2',4,4'-tetraBDE]	190 - [2,3,3',4,4',5,6-heptaBDE]
066 - [2,3',4,4'-tetraBDE]	203 - [2,2',3,4,4',5,5',6-octa-BDE]
085 - [2,2',3,4,4'-pentaBDE]	204 - [2,2',3,4,4',5,6,6'-octaBDE]
099 - [2,2',4,4'5-pentaBDE]	205 - [2,3,3',4,4',5,5',6-octaBDE]
100 - [2,2',4,4',6-pentaBDE]	206 - [2,2',3,3',4,4',5,5',6-octaBDE]
128 - [2,2',3,3',4,4'-hexaBDE]	207 - [2,2',3,3',4,4',5,6,6'-octaBDE]
138 - [2,2',3,4,4',5'-hexaBDE]	208 - [2,2',3,3',4,5,5',6,6'-octaBDE]
153 - [2,2',4,4',5,5'-hexaBDE]	209 - [2,2',3,3',4,4',5,5',6,6'-decaBDE]

*Sum of these compounds refers to the particular subsets listed above as opposed to complete sets of all congeners in that category. Elsewhere in this report these sets are referred to as Sum of [compound] (SFEI).

Table 1.5. Summary of Major Changes to RMP (1993-2006).

Action Code A= Analyte added or removed from sampling design; DR= Data rejected; L= Change in laboratory conducting analysis or in laboratory methods; P= Change in program or sampling design; S= Station added or removed from sampling design

Action Code	Year	Action	Detail/Rationale
A	1996	Added trace organics analysis for Southern Slough stations Sunnyvale (C-1-3) and San Jose (C3-0)	Trace organics were not analyzed for Sunnyvale (C-1-3) during the 1996-07 or 1997-08 wet season cruises however samples were analyzed for trace metals and ancillary parameters. .
A	1997	Identified 40 target PCB congeners for labs to report: PCB 008, 018, 028, 031, 033, 044, 049, 052, 056, 060, 066, 070, 074, 087, 095, 097, 099, 101, 105, 110, 118, 128, 132, 138, 141, 149, 151, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, 203	Analysis of RMP data collected from 1993-1995 showed 40 congeners consistently quantified in Bay samples. It was found that 40 congeners would be a good representation (~80% representative) of the total mass of PCBs in the bay.
A	2000	Removed Mercury (Hg) and Arsenic (As) analysis in bivalve tissue samples	RMP results (1993-99) indicated that there was very little bioaccumulation of Hg beyond background concentrations and there was an absence of serious As contamination.
A	2000	Added gonadal index and growth analysis in bivalve tissue samples	Growth analysis calculated by SFEI in 2000 and 2001. AMS started calculating growth analysis in 2002.
A	2000	Added Cobalt (Co) analysis in water and sediment samples	Co is a useful marker of geochemical processes in the Estuary, particularly as an indicator of metal fluxes from sub-oxic sediments. Added as part of the Fe/Mn/Co group.
A	2000	Added Methyl Mercury analysis in water and sediment samples	Ratios of Methyl Mercury to Total Mercury can be used to determine environments that methylation is most likely to occur in.
A	2000	Removed chromium analysis in water, sediment and bivalve tissue samples	Technical Review Committee made decision based on findings by Khalil Abu-Saba which stated that the chromium found in the estuary was mostly of the trivalent form and none of the hexavalent form was detected. The concentrations in water and sediment were found to be essentially the same as those from the soils in the watersheds draining into the estuary.
A	2001	Removed Gonadal Index analysis in bivalve tissue samples	Unable to obtain sufficient level of precision in separating somatic and gonadal tissue.
A	2002	Added PBDEs, phthalates, and p-nonylphenol analysis in water and sediment samples	Added potential persistent pollutants with the ability to bioaccumulate and cause toxicity.
A	2002	Added PBDEs, phthalates, p-nonylphenol, triphenylphosphate and nitro and polycyclic musks analysis in bivalve tissue samples	Added potential persistent pollutants with the ability to bioaccumulate and cause toxicity.
A	2002	Reduced bivalve Trace Metals (Ag, Al, Cd, Cu, Ni, Pb, Se, Zn) analysis in bivalve tissue samples to 5 year cycle and removed tributyltin analysis in bivalve tissue samples	RMP results indicated that Trace Metals and tributyltin do not appreciably accumulate in bivalve tissue. Report link: http://www.sfei.org/rmp/Technical_Reports/RMP_2002_No109_RedesignProcess.pdf
A	2002	Changed health indicator from Condition Index Mean to Growth Mean in bivalve tissue samples	Condition index is the ratio of tissue mass to shell volume and may be affected by factors other than health. Growth compares the pre- and post- deployment weight of each mussel and is a more direct measurement of health.
A	2003	CTD Ccasts were not taken during 2003 bivalve tissue maintenance cruise	The water and bivalve maintenance cruise occurred concurrently and it was decided that it was more important to take casts on the water cruise.
A	2003	Added PBDE analysis in sport fish samples collected for the Sport Fish Contaminant Study	Increasing PBDE concentrations in the bay area coupled with concern about the health effects on humans and wildlife led to adding PDBEs.
A	2004	Added Particulate Organic Carbon (POC) analysis in water samples.	Began analyzing for POC in order to be able to calculate Total Organic Carbon values (DOC+POC).
A	2004	Removed phthalates and p-nonylphenol analysis in water and sediment samples	These analytes posed low levels of concern for the San Francisco Bay Region based on current literature.

Action Code	Year	Action	Detail/Rationale
A	2004	Removed PBDEs, phthalates, p-nonylphenol, triphenylphosphate and nitro and polycyclic musks analysis in bivalve tissue samples	These analytes posed low levels of concern for the San Francisco Bay Region based on current literature.
A	2004	Data unavailable for pesticides, PAHs, PCBs, and PBDEs in bivalve tissue samples	Samples will be reanalyzed.
A	2005	Removed Toxicity Identification Evaluations (TIEs) in sediment from will be conducted on an as needed basissediment toxicity analysis. If sufficient toxicity is observed, will use contingency funds.	Method development is needed to aid in understanding the toxicity found in the bay sediments. Toxicity Identification Evaluations (TIEs) will be conducted using contingency funds when sufficient toxicity is observed. .
A	2005	Expanded target BDE analyte list for sediment and water samples	Based on results from BDEs sampled in previous years and capabilities of the RMP laboratories, increased number of analytes.
A	2005	Data unavailable for PAHs in bivalve tissue samples	Samples will be reanalyzed.
A	2006	Removed BDE 82 from target analyte list	BDE 082 is not in any commercial mixtures and it is Rational for reporting it was unclear as it is not a major congener.
A	2006	Began collecting hardness data for all water stations where salinity <5ppt	Previously hardness data was collected at riverine stations where salinity <1ppt and estimated for estuarine sites.
A	2006	Data unavailable for all analytes in bivalve tissue samples	Not analyzed pending a decision on an analytical lab.
A	2006	Data unavailable for chlorpyrifos and diazinon water samples	Not analyzed pending a decision on an analytical lab.
DR	2002	Data rejected unavailable for PCB 132 analyzed in bivalve tissue samples	PCB 132 not analyzed in the lab due to co-elution problems.
DR	2002	Data unavailable/rejected for BDEs 82, 128, 203, 204, 205, 206, 207, and 209 for bivalve tissue samples	BDEs 82, 128, and 209 not part of standard mix reported by lab. BDEs 203, 204, 205, 206, 207 and 209 do not elute off of the GC-ECD columns.
DR	2003	Data unavailable/rejected for pesticide, PCB, and PBDE sediment samples	Samples are to be reanalyzed using HRGC/MS. since there has been a change in analytical method.
DR	2003	Data rejected for PAHs in bivalve tissue	Data was rejected by SFEI QA Officer due to many samples being qualified as Non Detect.
L	1997	Changed analytical lab for analysis of PCBs and PAHs in bivalve tissue samples	Central Contra Costa Sanitary District began analysis of PCBs and PAHs in bivalve tissue.
L	1999	Changed analytical lab for analysis of mercury in water samples	University of Maryland, Center of Environmental Studies began analysis of Hg in water.
L	2000	Changed analytical lab for analysis of PCBs and PAHs in bivalve tissue samples	Texas A&M Geochemical and Environmental Research began analysis of PCBs and PAHs in bivalve tissue.
L	2002	Changed analytical lab for analysis of mercury and methyl mercury in water	University of California, Santa Cruz Dept. of Environmental Toxicology began water Hg and MeHg analysis (formerly conducted by University of Maryland).
L	2002	Changed analytical lab for analysis of trace organics in bivalve samples	California Dept. of Fish and Game, Marine Pollution Control Laboratory began analysis of trace organics in bivalve tissue (including pesticides, PAHs, and PCBs).
L	2002	Changed method for analysis of Total Suspended Solids (TSS) in water to Suspended Solid Content (SSC) in water	The SSC method analyzes the whole sample while TSS is a subsetting method. SSC poses less variability by human interference and attains better precision because heavier sand and sticky clay particles are not lost during analysis.
L	2005	Changed method for extraction of organic analytes in water samples	High blank contamination in 2003 PAH samples led to a change from the Soxhlet extraction method to an ambient temperature extraction method.
L	2006	Changed method for analysis of arsenic in water samples	Method changed from HGAA to ICP-MS as a cost saving measure for method development.
P	1993	Implemented Regional Monitoring Program for Trace Substances in the San Francisco Estuary (RMP). Samples collected three times per year for conventional water quality	Samples were collected during the wet season (March), during declining Delta outflow (May), and during the dry season (Aug - Sept).

Action Code	Year	Action	Detail/Rationale
		parameters and trace analytes	
P	1993	Implemented Regional Monitoring Program for Trace Substances in the San Francisco Estuary (RMP.) Samples. Samples collected twice a year for sediment quality parameters and trace analytes	Samples were collected during the wet season (March) and during the dry season (Aug-Sept).
P	1993	Implemented Regional Monitoring Program for Trace Substances in the San Francisco Estuary (RMP). Bivalve samples collected twice a year for transplanted, bagged bivalve bioaccumulation and condition	Samples were deployed during the wet season (March-May) and during the dry season (Aug-Sept) and retrieved between 90 and 100 days after deployment.
P	1997	Implemented Sport Fish Contaminant Study - Sport Fish are to be collected on a three year cycle and analyzed for mercury, PCBs, legacy pesticides (DDT, dieldrin, chlordane), and Se	Study implemented as a follow up to a 1994 study conducted by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB).
P	2000	Changed frequency of sediment sampling to once a year for ancillary, trace metal and organic analytes	Samples collected during the dry season (Aug-Sept).
P	2000	Changed frequency of water sampling to twice a year for ancillary and trace metal analytes	Discontinued sampling during declining Delta outflow (May). Samples were collected during the wet season (March) and during the dry season (Aug-Sept). It was determined that samples collected during the dry season were most indicative of ambient concentrations.
P	2000	Changed frequency of water sampling to once a year for organic analytes	Samples collected during the dry season were analyzed for organic contaminants. Most organic contaminants are legacy pollutants which degrade slowly so analyzing more that once a year for these analytes was found to be unnecessary.
P	2002	Implemented new random sampling design. Random sampling design based on spatially balanced probabilistic sampling design. The bay was divided into 5 hydrographic regions plus the Rivers Region. segments. 7 Historic RMP sties were maintained in the program for sediment trends analysis and 3 (now 5) historic sites were maintained for water analysis	Sampling design will provide better statistical basis to answer regulatory questions. Will provide unbiased estimate of ambient conditions.
P	2002	Changed Aquatic Toxicity Testing from yearly to a five year cycle	From 1993 to 2002, a noticeable decline in aquatic toxicity to organisms was observed, especially during the dry season.
P	2003	Stopped deployment of bivalves *Corbicula fluminea* (CFLU) in the estuary. CFLU collection was continued in the delta by trawling at the Rivers sites BG20 (Sacramento River) and BG30 (San Joaquin River)	Findings from 2000-2002 special studies concluded that bioaccumulation of contaminants in the estuary could be monitored using only one species *Mytilus californianus* (MCAL).
P	2003	Changed container for bivalves deployed from bags to cages. Some of the cages were maintained and some were un-maintained at each site	Findings from side by side deployment of bivalves in cages and in bags indicated that cages reduced the effects of bivalve predation. Report link: http://www.sfei.org/rmp/reports/431_AMS_bivalvestudies.pdf.
P	2006	Stopped collecting the dissolved water fraction for analysis of organic analytes in water	California Toxics Rule (CTR) has only been established for the total fractions of organic contaminants. The dissolved fraction was removed as a cost saving measure.
P	2006	Changed program name to Regional Monitoring Program for Water Quality in the San Francisco Estuary	Previous name was the Regional Monitoring Program for Trace Substances in the San Francisco Estuary. This change is intended to more adequately express the objectives of the RMP.
S	1993	Collected samples along the spine of the	Original RMP sampling design.

Action Code	Year	Action	Detail/Rationale
		estuary at 16 set stations for water and sediment; Toxicity was measured at 8 of these stations for each matrix. Bivalves were deployed at 11 of the stations.	
S	1994	Added 6 stations for water and sediment sampling (previously 16): San Bruno Shoal (BB15), Alameda (BB70), Red Rock (BC60), Honker Bay (BF40), Petaluma River mouth (BD15), Coyote Creek mouth (BA10)	Sites selected to fill large areas in Estuary where no samples were taken and to better monitor areas around tributaries. Stations = 22.
S	1994	Added 2 stations for water and sediment sampling (previously 22) as part of the Local Effects Monitoring Program (LEMP): C-1-3 (Sunnyvale) and C-3-0 (San Jose)	Sites located by water pollution control plants. Added on a trial basis by Water Board. Sites were to be treated identically as RMP stations. Stations =24.
S	1994	Added 4 stations (previously 11) for bivalve tissue sampling	Stations = 15.
S	1996	Added 2 stations for water and sediment sampling (previously 24) as part the Estuary Interface Pilot Study: Standish Dam (BW10) and Guadalupe River (BW15)	Added as part of the Estuary Interface Pilot Study. Stations = 26.
S	1998	Removed 1 station (previously 15) for bivalve tissue sampling BF20 (Grizzly Bay)	A bivalve reference site could not be found for *Corbicula fluminea* (CFLU). Stations = 14.
S	2003	Removed water sampling from one random site in the South Bay segment and one random site in the Lower South Bay segment in order to add water sampling at historic sites BA30 (Dumbarton Bridge) in the South Bay and BC10 (Yerba Buena Island) in the Central Bay	Dropping these two random sites enabled the two historic sites to be added back into the sampling design at no additional cost to the program. These sites, along with BG20 (Sacramento River) are used by the Water Board for NPDES permit processing
S	2003	Removed two water and sediment stations (previously 24) C-1-3 (Sunnyvale) and C-3-0 (San Jose), part of the Local Effects Monitoring Program (LEMP)	Funding ended for monitoring of trace organics in water and sediment which began in 1996 at these stations as part of the NPDES. Stations = 24.
S	2003	Removed three stations (previously 14) BD50 (Napa River), BD15 (Petaluma River in San Pablo Bay), and BC21 (Horseshoe Bay in Central Bay) for bivalve tissue monitoring	Findings indicated that only 2-3 stations were required to track long term changes in contaminant concentrations in bivalves. Stations = 11.
S	2006	Changed bivalve tissue site BD20 (San Pablo Bay) by a nautical mile. BD20 will be renamed.	USGS replaced the channel marker where bivalve mooring BD20 was attached. The site was moved from Petaluma Light 1 to Petaluma Light 4. A new mooring will be installed at that sight.

Table 1.6. Analytes Reported in Water Samples (1993-2006).

Parameter	Parameter Type	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Ammonia as N	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Chlorophyll a	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SpecificConductivity	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Oxygen, Dissolved	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Dissolved Organic Carbon	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Hardness as CaCO3	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Nitrate as N	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Nitrite as N	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
pH	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Pheophytin a	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Phosphate as P	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Particulate Organic Carbon	ANC												■	■	■
Salinity (by salinometer)	ANC	■		■	■	■	■	■	■	■	■	■	■	■	■
Salinity (by SCT)	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Salinity (by Solomat)	ANC					■									
Silica	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Suspended Sediment Concentration	ANC										■	■	■	■	■
Total Suspended Solids	ANC	■	■	■	■	■	■	■	■	■				■	■
Temperature	ANC	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PAHs	ORGS	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PAHs Alkylated	ORGS						■	■	■	■	■	■	■	■	■
PBDEs	ORGS										■	■	■	■	■
PCBs	ORGS	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Phthalates	ORGS										■	■			
Chlordanes	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Chlorpyrifos	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	
Cyclopentadienes	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Dacthal	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	■
DDTs	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Diazinon	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	
Endosulfan I	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Endosulfan II	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Endosulfan Sulfate	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	■
HCHs	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Hexachlorobenzene	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Mirex	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Oxadiazon	PESTs	■	■	■	■	■	■	■	■	■	■	■	■	■	■
p-Nonylphenol	SYN										■	■			
Triphenylphosphate	SYN										■				
Arsenic	TE	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Cadmium	TE	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Cyanide	TE	■	■												
Cobalt	TE								■	■	■	■	■	■	■
Cromium	TE	■	■	■	■	■	■	■		■					
Copper	TE	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Iron	TE							■	■	■	■	■	■	■	■
Mercury	TE	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Mercury, Methyl	TE							■	■	■	■	■	■	■	■
Manganese	TE							■	■	■	■	■	■	■	■
Nickel	TE	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Lead	TE	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Selenium	TE	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Silver	TE	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Zinc	TE	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Cell Count	WaterTox	■													
Mean % Normal Development	WaterTox	■	■	■	■	■									

Gray = Analyte Reported for RMP Status and Trends Sampling.

Table 1.7. Analytes Reported in Sediment Samples (1993-2006).

Parameter	Parameter Type	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
% Solids	ANC														
Ammonia	ANC														
Clay <0.005 mm	ANC														
Fine <0.0625 mm	ANC														
Silt 0.0039 to <0.0625 mm	ANC														
Sand 0.0625 to <2.0 mm	ANC														
Granule + Pebble 2.0 to <64 mm	ANC														
Hydrogen Sulfide	ANC														
pH	ANC														
TOC	ANC														
Total Nitrogen	ANC														
Total Sulfide	ANC														
PAHs	ORGS														
PAHs Alkylated	ORGS														
PBDEs	ORGS														
PCBs	ORGS														
Phthalates	ORGS														
Chlordanes	PESTs														
Cyclopentadienes	PESTs														
DDTs	PESTs														
HCHs	PESTs														
Hexachlorobenzene	PESTs														
Mirex	PESTs														
Mean % Normal Alive	SedTox														
Mean % Survival	SedTox														
p-Nonylphenol	SYN														
Silver	TE														
Aluminum	TE														
Arsenic	TE														
Cadmium	TE														
Cromium	TE														
Copper	TE														
Iron	TE														
Mercury	TE														
Mercury, Methyl	TE														
Manganese	TE														
Nickel	TE														
Lead	TE														
Selenium	TE														
Zinc	TE														

Gray = Analyte Reported for RMP Status and Trends Sampling.

Table 1.8. Analytes Reported in Bivalve Tissue Samples (1993-2006).

Parameter	Parameter Type	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006*
% Moisture	ANC		■	■	■	■	■	■	■	■	■	■	■		
% Survival per Species	ANC	■	■	■	■	■	■	■	■	■	■	■	■		
Condition Index (CI)	ANC	■	■	■	■	■	■	■	■						
Growth Mean	ANC							■	■	■	■	■	■		
Dry Weight	ANC	■	■	■	■	■	■	■	■	■	■	■	■		
Gonad Index CI Mean	ANC							■	■						
Musks	ORGS										■	■	■		
PAHs	ORGS	■	■	■	■	■	■	■	■	■	■	■			
PAHs Alkylated	ORGS	■	■	■	■	■	■	■	■	■	■	■			
PBDEs	ORGS										■	■		■	
PCBs	ORGS	■	■	■	■	■	■	■	■	■	■	■		■	
Phthalates	ORGS										■	■	■		
Chlordanes	PESTs	■	■	■	■	■	■	■	■	■	■	■		■	
Cyclopentadienes	PESTs	■	■	■	■	■	■	■	■	■	■	■		■	
DDTs	PESTs	■	■	■	■	■	■	■	■	■	■	■		■	
HCHs	PESTs	■	■	■	■	■	■	■	■	■	■	■		■	
Hexachlorobenzene	PESTs	■	■	■	■	■	■	■	■	■	■	■		■	
Mirex	PESTs	■	■	■	■	■	■	■	■	■	■	■		■	
p-Nonylphenol	SYN										■	■	■		
Triphenylphosphate	SYN										■	■	■		
Silver	TE	■	■	■	■	■	■	■	■	■					
Aluminum	TE		■	■		■	■	■	■	■					
Arsenic	TE	■	■	■	■	■	■	■							
Cadmium	TE	■	■	■	■	■	■	■	■	■					
Cromium	TE	■	■	■	■	■	■	■							
Copper	TE	■	■	■	■	■	■	■	■	■					
DBT (Dibutyltin)	TE	■	■	■	■	■	■	■	■	■					
Iron	TE						■	■							
Mercury	TE	■	■	■	■	■	■	■							
MBT (Monobutyltin)	TE	■	■	■	■	■	■	■	■	■					
Methyl Mercury	TE	■													
Manganese	TE						■	■							
Nickel	TE	■	■	■	■	■	■	■	■	■					
Lead	TE	■	■	■	■	■	■	■	■	■					
Selenium	TE	■	■	■	■	■	■	■	■	■					
TBT (Tributyltin)	TE	■	■	■	■	■	■	■	■	■					
TTBT (Tetrabutyltin)	TE		■	■	■	■	■	■	■	■					
Zinc	TE	■	■	■	■	■	■	■	■	■					

Gray = Analyte Reported for RMP Status and Trends Sampling.
* 2006 Bivalve data was not analyzed pending analytical issues.

Chapter

2

Water Monitoring

2.0 Water Monitoring

Michelle Lent and John Oram

2.1 Background

Trace contaminants are introduced to the water column of the San Francisco Estuary through several major transport pathways, such as runoff from rivers and creeks, atmospheric deposition, municipal and industrial wastewater effluent discharge, and remobilization of contaminants from surface sediments to the overlying water column. Contaminants of current environmental concern in the Estuary primarily originate in areas of the watershed that have been altered or disturbed by human activities through urbanization, industrial development, and agriculture. Historic mining activities have also contributed contaminants to the Estuary (e.g., mercury). The transport of contaminants from these various sources and pathways, coupled with the dynamic nature of water and sediment movement, creates complex and constantly varying conditions of contamination throughout the Estuary. For over a decade, the Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP) has monitored waters of the Estuary for trace elements, organic contaminants, and conventional water quality parameters to develop a better understanding of the cycling and distribution of contaminants in the Estuary and the management actions necessary to reduce their potential exposure to wildlife and humans. Information gained from contaminant monitoring in Estuary water assists the RMP in addressing program objectives listed in the *Introduction*.

2.2 Approach

2.2.1 Methods

In 2006, RMP Status and Trends Program continued with implementation of the stratified, random sampling design started in 2002 (see Chapter 1, *Introduction*). A total of 132 randomly allocated stations and 27 historic stations (usually five historic sites per year) were monitored for contaminants in water between 2002 and 2006 (Figures 2.1-2.2 for site maps; Figures 2.3-2.35 for contaminant maps). The Status and Trends Program is currently only conducted during the dry season (July/August).

In 2003, the Status and Trends Program reduced the random sample size for water by one sample in the South Bay and Lower South Bay regions in order to add back two historic stations (BA30-Dumbarton Bridge and BC10-Yerba Buena Island) to the monitoring design because those stations, along with BG20-Sacramento River, are used by the Regional Water Board for NPDES (National Pollutant Discharge Elimination System) permit processing. As a result, five historic stations (BA30-Dumbarton Bridge, BC10-Yerba Buena Island, BC20-Golden Gate, BG20-Sacramento River, and BG30-San Joaquin River) are part of the continued historic water samples monitored by the Status and Trends Program annually.

Since 2004, 26 randomly allocated stations and five historic Status and Trends Program stations were sampled per year within the five major hydrographic regions of the Estuary: Suisun Bay, San Pablo Bay, Central Bay, South Bay, and Lower South Bay (Figure 2.1 and 2.2); four random stations were sampled in the Suisun Bay, San Pablo Bay, and Central Bay regions in each year; nine random stations were sampled in the South Bay region and five random sites were sampled in the Lower South Bay region in each year.

Station names, codes, location, and sampling dates for the 2006 monitoring effort are listed in Table 1.2 in the *Introduction* and shown in Figure 2.1. Station locations for 2002 to 2005 are shown in Figure 2.2. This Report presents results of the monitoring effort over the five-year period spanning from 2002 to 2006. Time-series plots are presented for the five historic stations that have been continued into the new monitoring program.

The Status and Trends Program measured 13 trace elements and a variety of organic contaminants, including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine pesticides, polybrominated diphenyl ethers (PBDEs), phthalates, and p-nonylphenol (Table 1.4 in the *Introduction*). Field and analytical methods are described in Chapter 5 – *Description of Methods*. Data are available for downloading via the RMP website using the *Status and Trends Monitoring Data Access Tool* at http://www.sfei.org/rmp/data.htm.

The Status and Trends Program measured trace elements in water as dissolved (0.45 µm filtered) and total (or near-total) concentrations. Trace organic contaminant concentrations were measured in water and reported as dissolved (operationally defined as water fraction that is filtered through a wound glass fiber filter with a nominal pore size of 1 µm) and total (dissolved + particulate) concentrations. The Status and Trends Program also measured conventional water quality parameters to relate contaminant concentrations to general water quality conditions at the time of sampling (Table 1.4). In addition, the U.S. Geological Survey (USGS) collects water quality data (salinity, temperature, dissolved oxygen, suspended sediments, and phytoplankton biomass) on a monthly basis along a transect of the deep water channels from the Lower South Bay to the confluence of the Sacramento and San Joaquin Rivers. Water quality data from the USGS are available on their website at http://sfbay.wr.usgs.gov/access/wqdata/.

2.2.2 Water Quality Guidelines

To evaluate potential ecological effects, contaminant concentrations were compared to various water quality guidelines. The Water Board uses Status and Trends Program water contaminant data (and other information) to make recommendations for changes to the State's 303 (d) list of impaired water bodies, and to evaluate "background" or ambient concentrations of regulated contaminants in their 'reasonable potential' analyses (see section 2.2.4 below).

Concentrations of dissolved trace elements and total organic contaminants were compared to the lower of the aquatic life and/or human health (consumption of organisms only) water quality effects thresholds listed in the U.S. Environmental Protection Agency's California Toxics Rule (CTR, U.S. EPA, 2000), the San Francisco Bay Water Quality Control Plan (Basin Plan, SFBRWQCB, 2004), and other relevant guidelines and thresholds. Table 2.1 lists the various guidelines used.

The CTR lists several effects thresholds aimed at protecting aquatic life or human health. Trace element data were compared to the lowest threshold reported for each contaminant (generally the four-day average aquatic life criteria). Trace organic contaminant concentrations were compared to the human health criteria for the consumption of aquatic organisms only, since Status and Trends Program stations are all downstream of drinking water intakes in the Delta.

Revised Basin Plan objectives in 2004 (and approved by EPA in 2005) clarify the definition of freshwater, marine, and estuarine waters for the Estuary to align with the CTR. These definitions are used to categorize dischargers and determine which set of water quality objectives form the basis of effluent limitations. The CTR defines freshwater as less than 1 part per thousand (‰) at

least 95% of the time and marine water as greater than 10 ‰ at least 95% of the time. Anything in between is defined as estuarine water, for which the lower of the marine or freshwater objectives apply. Where applicable, estuarine samples were compared to the lower freshwater or saltwater effects threshold for trace elements (see *Defining "Estuarine" Regions in the Estuary* section below). Concentrations of six trace elements (cadmium, copper, nickel, lead, silver, and zinc) were compared to the lower of the freshwater or saltwater criteria at sites considered "Estuarine" (see below). Freshwater effects thresholds were calculated for each sample using hardness data that were measured on site or (if data were not available) a hardness factor of 100 mg/L (the default value in the CTR, US EPA, 2000). A hardness cap of 400 mg/L was used for calculating freshwater thresholds (per recommendation of the Regional Water Board staff, 2003).

Regulatory Effects Thresholds

Only a subset of effects threshold comparisons in this report has regulatory implications. This subset consists of nine trace elements and twenty-six trace organic contaminants (Table 2.1). Arsenic, cadmium, copper, lead, silver, nickel, and zinc were compared to the dissolved water quality criteria (WQC) listed in the CTR. There are approved dissolved copper site-specific objectives for both north and south of the Dumbarton Bridge, as well as a dissolved nickel site-specific objective for south of the Dumbarton Bridge (see *Site-specific Objectives* section below). Total mercury concentrations were compared to the aquatic life objective for total recoverable mercury listed in the Basin Plan (0.025 µg/L), except for the Lower South Bay where the CTR criterion of 0.051 µg/L applies (which is the human health criterion (for the consumption of organisms only)). The CTR lists a selenium criterion of 5 µg/L for total recoverable selenium that was promulgated for all waters in San Francisco Bay and upstream, including the Delta, in the National Toxics Rule (NTR, U.S. EPA, 1992). Total (dissolved plus particulate fractions) organic contaminants were compared to the CTR human health criterion (for the consumption of organisms only) for those contaminants listed in Table 2.1. Additionally, sum of PAHs were compared to the Basin Plan objective of 15.0 µg/L.

Non-Statutory/Regulatory Effects Thresholds

Effects threshold comparisons of total trace element concentrations for the seven metals mentioned above (arsenic, cadmium, copper, lead, silver, nickel, and zinc), and total organic concentrations for diazinon, chlorpyrifos, and mirex are strictly for informational purposes and do not have regulatory implications. The total metals effects thresholds used in this report were calculated using the default CTR conversion factors to convert dissolved metals thresholds to total metals thresholds, except for the Lower South Bay where site-specific translators are available for copper and nickel (see below).

Some organic contaminants analyzed by the Status and Trends Program are not listed in the CTR or Basin Plan, but effects thresholds do exist. When results for the following contaminants were available, they were compared to effects thresholds from other sources (Table 2.1). Water quality criteria for total diazinon concentrations (40 ng/L effects threshold) are from the California Department of Fish and Game (Menconi and Cox, 1994). Recommended thresholds for chlorpyrifos and mirex are from the EPA (U.S. EPA, 1999).

Site-specific Objectives

Site-specific aquatic life water quality objectives for *dissolved* copper and nickel were adopted by the State of California in 2003 and approved by the U.S. EPA for Lower South San Francisco Bay (south of the Dumbarton Bridge). The Lower South San Francisco Bay dissolved copper objectives are 10.8 µg/L acute (exposure for one hour) and 6.9 µg/L chronic (exposure for four

days). The Lower South San Francisco Bay dissolved nickel objectives are 62.4 µg/L acute and 11.9 µg/L chronic. In 2007, site-specific objectives for dissolved copper were developed for regions of the Bay north of the Dumbarton Bridge: 9.4 ug/L acute and 6.0 ug/L chronic (SFBWRQCB, 2007).

Defining "Estuarine" Regions in the Estuary

In order to evaluate which regions should be considered estuarine by the new Basin Plan definition, SFEI reviewed the USGS long-term database for salinity data sampled between 1993 and 2002 and reported the findings in the 2002 RMP Annual Monitoring Results (SFEI, 2004). Based on this review, none of the Status and Trends Program sampling sites are located within a freshwater region and that the Rivers, Suisun Bay, San Pablo Bay, and the Lower South Bay regions are estuarine as defined by the revised Basin Plan and the CTR.

2.2.3 Aquatic Toxicity Testing

Ambient Water Toxicity

Between 1993 and 2002, the Status and Trends Program conducted ambient water toxicity testing on seasonal and annual time scales. A noticeable decline in aquatic toxicity in organisms during this time enabled toxicity testing to be reduced to a five-year cycle. Aquatic toxicity sampling within the Estuary occured in 2007.

2.2.4 Background Concentrations for Total-water-column Contaminants at Three Historic RMP Stations

The State Board adopted the *Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California* (SIP) effective as of May 22, 2000 (http://www.swrcb.ca.gov/iswp/final.pdf). Among other things, the SIP establishes implementation provisions for priority pollutant criteria promulgated by the U.S. EPA through the National and the California Toxics Rules, and for priority pollutant water quality objectives (WQO's) established by the Regional Water Boards in their Basin Plans. The SIP specifies how toxic water quality objectives are translated into effluent limitations.

The Regional Water Quality Control Board uses the Status and Trends Program's total-water-column data (dissolved plus particulate for organic and total-recoverable for trace element concentrations) to determine "background" contaminant levels in the Estuary. Three historic stations are used to estimate background contaminant concentrations (BA30-Dumbarton Bridge, BC10-Yerba Buena Island, and BG20-Sacramento River). This information serves as a reference for the Regional Water Board in their Reasonable Potential analyses, part of their National Pollutant Discharge Elimination System (NPDES) permitting program. "Reasonable Potential" is defined as the likelihood that the concentration of a pollutant in a discharge would cause or contribute to an exceedance of a water quality guideline. If the Regional Water Board determines that the pollutant has 'reasonable potential', the SIP requires the discharger to have an effluent limit for that pollutant in its NPDES permit (i.e., a limit is "triggered").

Overall, there are three triggers for effluent limits: (1) if the maximum effluent concentration exceeds the WQO, (2) if the maximum background concentration exceeds the WQO, or (3) if there is other information that would require the need for an effluent limit (e.g., 303(d) listing).

2.3 Results and Discussion

Results from the RMP Status and Trends water monitoring are presented in a series of figures that display the spatial distribution and concentration ranges of salinity (Figure 2.3), dissolved organic carbon (DOC; Figure 2.4), suspended solids concentration (SSC; Figure 2.5), trace elements (Figures 2.6 – 2.23), and organic contaminants (Figures 2.24 – 2.35) for randomly allocated stations and historic stations (2002 – 2006). Methylmercury (MeHg), chlorpyrifos and diazinon results were not available at the time of this report. The only dissolved organic contaminants available at the time of this report were Dieldrin, sum of Chlordanes, sum of DDTs, sum of HCHs, sum of PAHs, and sum of PCBs. The only reportable organic contaminants on a total basis were sum of Chlordanes, sum of DDTs, sum of HCHs, sum of PAHs, sum of PCBs, and BDE-47. As additional 2006 data are finalized, they will be made available through the Status and Trends Monitoring Data Access Tool (http://www.sfei.org/rmp/data.htm) on the RMP website. The list of parameters measured in water is included in Table 1.4 in the *Introduction*.

Graphics included in each figure include maps, box plots, and cumulative distribution function (CDF) plots. Maps illustrate the spatial distribution of contaminants for randomly allocated and historic stations. Box plots indicate interquartile ranges of contaminant concentrations, summarizing results from randomly allocated stations grouped into the five major hydrographic regions of the Bay: Suisun Bay (SU), San Pablo Bay (SPB), Central Bay (CB), South Bay (SB), and Lower South Bay (LSB). Cumulative distribution function plots provide an estimate of the square kilometers of the sampled Estuary that have a particular contaminant concentration based on results from the randomly allocated stations. These CDF plots were generated using the R statistical system and the psurvey.analysis statistical library. Please see section 1.3.1 in the *Introduction* for additional information about each graphic type.

Temporal trends were not evaluated for the random sampling design results as only five years of data have been collected to date. The RMP contributed to a special issue of the journal *Environmental Research* (Volume 105, Issue 1) published in 2007 and available online at ScienceDirect that includes articles synthesizing the ten years of the RMP's Status and Trends Program data (among other topics). Additionally, a statistical analysis of select contaminants in water and sediment is included as a supplemental chapter to this report (Chapter 6). For reporting continuity, time-series plots were generated and are presented here for the five historic stations that have been continued in the current monitoring program (Figures 2.36 – 2.66).

2.3.1 Spatial Distribution

Highest contaminant values

In previous years the highest concentrations of all dissolved trace element contaminants (except silver) were measured at stations in the southern Estuary regions. Between 2002 and 2006, dissolved trace metal levels were generally highest at the two extremes of the Bay (Suisun Bay and Lower South Bay). Dissolved concentrations of mercury, selenium, and zinc were highest in both Lower South Bay and Suisun Bay. Meanwhile, dissolved arsenic, copper, and nickel levels were highest in Lower South Bay and dissolved lead concentrations were highest in Suisun Bay. Dissolved cadmium levels were highest in the South Bay. The highest dissolved silver concentration sampled was in San Pablo Bay, but relatively high levels were also sampled in Central Bay and South Bay. Maximum and minimum dissolved contaminant concentrations for all measured contaminants are listed in Table 2.2 and Table 2.3.

Dissolved concentrations of trace elements were operationally defined as the fraction of sample that passes through a 0.45-µm filter, which also allows smaller particles and colloids to pass through. Thus, dissolved trace element concentrations measured in Status and Trends water samples may have been influenced by concentrations of dissolved organic carbon, or DOC (Kuwabara *et al.,* 1989) and colloids (Sañudo-Wilhelmy *et al.,* 1996). DOC concentrations were generally highest in the Lower South Bay region; however, the single highest sample concentration was, in fact, in the South Bay.

The cycling and distribution of many trace elements measured by the Status and Trends Program in Estuary water are greatly influenced by the transport of suspended particles (Schoellhamer, 1996a, Conaway *et al.,* 2003, Schoellhamer *et al.,* 2003). Between 2002 and 2006, maximum total concentrations of cadmium, copper, mercury, nickel, and zinc were measured in San Pablo Bay (Table 2.4), which also had the highest concentration of SSC. In Lower South Bay, which is surrounded by highly developed land and has low hydraulic flushing, maximum total concentrations of arsenic, lead and silver were sampled. While total concentrations for selenium were generally highest in Lower South Bay, the maximum sample concentration was in the Central Bay. Maximum and minimum total contaminant concentrations for all measured contaminants are listed in Table 2.4 and Table 2.5.

Concentrations of total organics showed similar spatial patterns in that most organics were present in relatively high levels in Lower South Bay (total sum of chlordanes, sum of DDTs, sum of HCHs, sum of PAHs, sum of PCBs, and BDE-47). Levels of dissolved organics varied more, but also tended to be high in Lower South Bay (dissolved sum of chlordanes, sum of DDTs, sum of HCHs, sum of PAHs, sum of PCBs, and dieldrin). Dissolved dieldrin and dissolved sum of DDTs were both high in Lower South Bay, but even higher in Suisun Bay and the rivers region. Dissolved sum of HCH concentrations were high in both Lower South Bay and Central Bay. Dissolved sum of PAHs concentrations varied widely throughout the bay.

Are the CDF Results Statistically Different Between Regions?
Cumulative distribution functions (CDFs) were calculated with the R system and the psurvey.analysis statistical library using untransformed contaminant concentrations, normality not being an issue. Differences between two CDFs were examined using a modified version of the Roa-Scott first-order corrected (mean eigen value corrected) statistic for categorical data (Kincaid, 2004). Overall, significant differences ($p<0.05$) were observed in 65% (104 out of 160) of the regional comparisons of dissolved contaminant concentrations (Table 2.6). The greatest number of significant regional differences was documented for nickel (10 out of 10), and the least for sum of DDTs (2 out of 10).

Statistical analysis of the CDFs for the total water samples showed significant regional differences in 71% (113 out of 160) of the comparisons (Tables 2.7). Copper and nickel were observed to have the largest number of significant differences, with 9 out of 10 (90%). Cadmium and sum of PAHs were observed to have the least number of significant differences, with 4 out of 10 (40%).

2.3.2 Temporal Trends

An objective of the RMP is to determine patterns and trends in contaminant concentrations and distribution in the San Francisco Estuary. A good summary of long-term trends in metal contamination in the Estuary was reported in the 2004 Pulse of the Estuary (Flegal *et al.* 2004).

Time-series plots were generated and are presented in Figures 2.36-2.66 for the five historic stations that have been continued in the current monitoring program. Analyses and discussion of the contaminant trends at the historic sites is deferred to the special issue of the journal *Environmental Research* published in 2007 (Volume 105, Issue 1) available online at ScienceDirect and Chapter 6 of this report.

2.3.3 Comparison to Water Quality Guidelines

Various water samples collected between 2002 and 2006 had contaminant concentrations that were above the water effects thresholds, some of which have regulatory implications. Three samples in South Bay and one river sample were above the regulatory dissolved metals water quality criterion for copper: 3.1 µg/L (or 6.9 µg/L for the Lower South Bay region; Figure 2.7). No other samples were above the regulatory water quality criteria for dissolved metals. Two samples in San Pablo Bay were above the total mercury criterion of 0.025 µg/L and one sample was above the site-specific criterion of 0.051 µg/L for the Lower South Bay region. No stations were above the regulatory total selenium effects threshold of 5 µg/L.

Calculated, *non-regulatory* CTR effects thresholds for total metals were compared to total metals concentrations for informational purposes only. Between 2002 and 2006, total copper concentrations were above the non-regulatory threshold of effect of 9.3 µg/L (or 13.02 µg/L for the Lower South Bay region) at 32 stations: one in the rivers region, sixteen in Suisun Bay, nine in San Pablo Bay, one in the Central Bay and five in the South Bay (Figure 2.17). One Suisun Bay and five San Pablo Bay stations were above the non-regulatory total nickel effects threshold of 7.1 µg/L (or 27.05 µg/L in the Lower South Bay region) (Figure 2.20). Three stations in San Pablo Bay and one in the Lower South Bay were above the non-regulatory salt or freshwater total lead effects thresholds of 5.6 or 3.2 µg/L respectively (Figure 2.18).

2.3.4 Toxicity of Water to Organisms

Ambient Water Toxicity

This measure has been reduced to a periodic five year screening effort as little ambient aquatic toxicity has been observed in Estuary samples during the dry season. The Status and Trends Program sampled for aquatic toxicity in the Estuary in 2007.

Episodic Water Toxicity

Episodic aquatic toxicity monitoring was conducted in April of 2005 to screen five tributaries that were sampled as part of another study to characterize sediment contamination (RMP analytes plus pyrethroids) and the potential to cause sediment toxicity in tributaries around the Estuary during the wet season. Results of that study are available through the SWRCB PRISM Grant reports (http://www.swrcb.ca.gov/funding/prism.html). Water samples were collected from the freshwater stations in San Lorenzo Creek, San Mateo Creek, Coyote Creek, Petaluma River, and Suisun Creek and tested using the following short-term chronic toxicity tests: the 3-brood (6-8 day) survival and reproduction test with the crustacean *Ceriodaphnia dubia*; the 7-day shrimp survival and growth test with *Americamysis bahia*; and the 7-day fish survival and growth test with *Menidia beryllina*. None of the water samples showed toxicity using the % survival endpoint for any test species which was the endpoint used in previous RMP Episodic Toxicity Monitoring studies. However, a new sub-lethal growth endpoint was also evaluated. San Lorenzo Creek and San Mateo Creek, showed significant reduction in *Menidia* growth and Coyote Creek showed a statistically significant reduction in *Ceriodaphnia* growth. Concurrent diazinon and

chlorpyriphos results were all below the method detection limit of .005ppb. The full laboratory report is available at SFEI upon request (sarahl@sfei.org).

Since episodic toxicity testing began in 1996, there has been an apparent reduction in aquatic toxicity in Estuary waters that has been attributed to reductions in the concentrations of organophosphate (OP) pesticides in the watershed (Ogle and Gunther, 2004). An overview of toxicity testing in water and sediment over the past ten years of Status and Trends monitoring was summarized by Anderson, Ogle, and Lowe (2003) in the 2003 Pulse of the Estuary (http://www.sfei.org/rmp/pulse/pulse2003.pdf).

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Table 2.1. Water quality guidelines. California Toxics Rule (CTR) water quality criteria (USEPA, 2000) are listed except where noted. Dissolved trace element criteria are listed (except for mercury and selenium). Criteria for organic compounds are listed on a total basis (dissolved + particulate). Bold and italicized concentrations are hardness dependent criteria and were calculated using a hardness concentration of 100 mg/L. Units are µg/L for all concentrations.

Parameter	Aquatic Life				Human Health (10^{-6} risk for carcinogens)	
	Fresh Water		Salt Water		Fresh Water	Salt & Fresh Water
	1-hour	4-day	1-hour	4-day	Water & Organisms	Organisms only
Ag	***3.4***	.	1.9	.	.	.
As	340	150	69.0	36.0	.	.
Cd	***4.3***	***2.2***	42.0	9.3	.	.
Cr VI	16.0	11.0	1100	50.0	.	.
Cu (North of Dumbarton Bridge) [F]	***13.4***	***9.0***	9.4	6.0	1300	.
Cu (South of Dumbarton Bridge) [F]			10.8	6.9		
Hg [A]	2.4	0.025	2.1	0.025	0.05	0.051
Ni	***470***	***52.0***	74.0	8.2	610	4600
Ni (South of Dumbarton Bridge)			62.4	11.9		
Pb	***64.6***	***2.5***	220	8.1	.	.
Se [B]		5.0	20	71.0	.	.
Zn	***120***	***120***	90.0	81.0	.	.
Alpha-HCH	.	.	.	.	0.0039	0.013
Acenaphthene	.	.	.	.	1200	2700
Anthracene	.	.	.	.	9600	110000
Benz(a)anthracene	.	.	.	.	0.0044	0.049
Benzo(a)pyrene	.	.	.	.	0.0044	0.049
Benzo(b)fluoranthene	.	.	.	.	0.0044	0.049
Benzo(k)fluoranthene	.	.	.	.	0.0044	0.049
Beta-HCH	.	.	.	.	0.014	0.046
Chlordane	2.4	0.0043	0.09	0.004	0.00057	0.00059
Chlorpyrifos [C]	0.083	0.041	0.011	0.0056	.	.
Chrysene	.	.	.	.	0.0044	0.049
Diazinon [D]	0.1	0.1	0.82	0.82	.	0.04
Dibenz(a,h)anthracene	.	.	.	.	0.0044	0.049
Dieldrin	0.24	0.056	0.71	0.0019	0.00014	0.00014
Endrin	0.086	0.036	0.037	0.0023	0.76	0.81
Fluoranthene	.	.	.	.	300	370
Fluorene	.	.	.	.	1300	14000
Gamma-HCH	0.95	.	0.16	.	0.019	0.063
Heptachlor	0.52	0.0038	0.053	0.0036	0.00021	0.00021
Heptachlor Epoxide	0.52	0.0038	0.053	0.0036	0.0001	0.00011
Hexachlorobenzene	.	.	.	.	0.00075	0.00077
Indeno(1,2,3-cd)pyrene	.	.	.	.	0.0044	0.049
p,p'-DDD	.	.	.	.	0.00083	0.00084
p,p'-DDE	.	.	.	.	0.00059	0.00059
p,p'-DDT	1.1	0.001	0.13	0.001	0.00059	0.00059
Pyrene	.	.	.	.	960	11000
Mirex [C]	.	0.001	.	0.001	0.000093	0.000097
Total PAHs [E]	.	.	.	.	0.031	0.031
Total PCBs	.	0.014	.	0.03	0.00017	0.00017

[A] Mercury guidelines are from the Basin Plan (SFBRWQB, 2004) and are for total recoverable mercury. The Lower South Bay region is compared to the Human Health (organisms only) mercury guideline of 0.051 µg/L.
[B] Selenium values are region-specific criteria as outlined in the National Toxics Rule (USEPA, 1992) and are for total recoverable selenium.
[C] Chlorpyrifos and mirex criteria from USEPA (1999).
[D] Diazinon guideline is from California Department of Fish and Game (Menconi and Fox, 1994).
[E] Total PAH guideline is from the footnote in the Basin Plan (SFBRWQB, 2004). However the current objective is 15 µg/L.
[F] Copper guidelines are from the Proposed Basin Plan Amendment (SFBRWQB, 2007).

Table 2.2. Maximum concentration of dissolved trace elements and trace organics for 2002-2006

Parameter	Site Code	Region	Year	Maximum Concentration
Ag	BA30	South Bay	2004	0.01751 ug/L
As	LSB008W	Lower South Bay	2003	5.92 ug/L
Cd	SB001W	South Bay	2002	0.129818 ug/L
Co	LSB002W	Lower South Bay	2002	0.652026 ug/L
Cu	LSB016W	Lower South Bay	2004	4.27016 ug/L
DOC	SB004W	South Bay	2002	7441.667 ug/L
Fe	SU012W	Suisun Bay	2004	478.422 ug/L
Hg	LSB001W	Lower South Bay	2002	0.003912 ug/L
MeHg	LSB008W	Lower South Bay	2003	0.085267 ng/L
Mn	LSB002W	Lower South Bay	2002	155.9017 ug/L
Ni	LSB002W	Lower South Bay	2002	4.130162 ug/L
Pb	SU012W	Suisun Bay	2004	0.32814 ug/L
Salinity (by salinometer)	BC20	Central Bay	2002	33.21 psu
Se	BG30	Rivers	2004	0.446 ug/L
Zn	LSB002W	Lower South Bay	2002	2.151199 ug/L
BDE 047	BG20	Rivers	2003	44.1 pg/L
BDE 209	BA30	South Bay	2004	96.5 pg/L
Dieldrin	BG20	Rivers	2003	95.6 pg/L
Sum of Chlordanes (SFEI)	LSB002W	Lower South Bay	2002	85.78 pg/L
Sum of DDTs (SFEI)	BG20	Rivers	2003	194.7 pg/L
Sum of HCHs (SFEI)	CB003W	Central Bay	2002	457.41 pg/L
Sum of PAHs (SFEI)	SU012W	Suisun Bay	2004	23573 pg/L
Sum of PBDEs (SFEI)	BA30	South Bay	2004	151.162 pg/L
Sum of PCBs (SFEI)	LSB001W	Lower South Bay	2002	718.908 pg/L

Table 2.3. Minimum concentration of dissolved trace elements and trace organics for 2002-2006

Parameter	Site Code	Region	Year	Maximum Concentration
Ag	SU014W	Suisun Bay	2004	0.00028 ug/L
As	BC20	Central Bay	2002	1.51 ug/L
Cd	BG30	Rivers	2003	0.007835 ug/L
Co	SB012W	South Bay	2003	0.01937 ug/L
Cu	BC20	Central Bay	2002	0.259944 ug/L
DOC	BC20	Central Bay	2002	866.5556 ug/L
Fe	SB019W	South Bay	2003	1.558744 ug/L
Hg	CB007W	Central Bay	2003	0.00022 ug/L
MeHg	LSB009W	Lower South Bay	2003	0.025697 ng/L
Mn	CB006W	Central Bay	2003	0.580179 ug/L
Ni	BC20	Central Bay	2002	0.39751 ug/L
Pb	BC20	Central Bay	2004	0.00573 ug/L
Salinity (by salinometer)	BG20/BG30	Rivers	2004	2 psu
Se	CB008W	Central Bay	2003	0.036 ug/L
Zn	SU006W	Suisun Bay	2003	0.148865 ug/L
BDE 047	BC10	Central Bay	2003	13.5 pg/L
BDE 209	BC10	Central Bay	2004	44.6 pg/L
Dieldrin	BC20	Central Bay	2002	5.8 pg/L
Sum of Chlordanes (SFEI)	BC20	Central Bay	2002	3.935 pg/L
Sum of DDTs (SFEI)	BC20	Central Bay	2002	12.38 pg/L
Sum of HCHs (SFEI)	BG30	Rivers	2003	87.34 pg/L
Sum of PAHs (SFEI)	SB016W	South Bay	2003	4461.9 pg/L
Sum of PBDEs (SFEI)	BC10	Central Bay	2004	96.406 pg/L
Sum of PCBs (SFEI)	BC20	Central Bay	2002	24.333 pg/L

Table 2.4. Maximum concentration of total trace elements and trace organics for 2002-2006

Parameter	Site Code	Region	Year	Maximum Concentration
Ag	LSB006W	Lower South Bay	2002	0.115592 ug/L
As	LSB006W	Lower South Bay	2002	7.23 ug/L
Cd	SPB003W	San Pablo Bay	2002	0.161805 ug/L
Chlorophyll-a	LSB002W	Lower South Bay	2002	11.65 mg/m^3
Co	SPB003W	San Pablo Bay	2002	3.993446 ug/L
Cu	SPB003W	San Pablo Bay	2002	13.425932 ug/L
Fe	SPB003W	San Pablo Bay	2002	9161.432207 ug/L
Hg	SPB001W	San Pablo Bay	2002	0.071049 ug/L
MeHg	LSB006W	Lower South Bay	2002	0.2036 ng/L
Mn	SU003W	Suisun Bay	2002	1212.984743 ug/L
Ni	SPB003W	San Pablo Bay	2002	20.211066 ug/L
Pb	LSB006W	Lower South Bay	2002	5.356038 ug/L
Phaeophytin	LSB006W	Lower South Bay	2002	9.315 mg/m^3
Se	CB003W	Central Bay	2002	0.631 ug/L
SSC	SPB003W	San Pablo Bay	2002	271.3 mg/L
Zn	SPB003W	San Pablo Bay	2002	26.581592 ug/L
BDE 047	SU012W	Suisun Bay	2004	337 pg/L
BDE 209	BC20	Central Bay	2004	696 pg/L
Dieldrin	SU012W	Suisun Bay	2004	107 pg/L
Sum of Chlordanes (SFEI)	LSB006W	Lower South Bay	2002	160.592 pg/L
Sum of DDTs (SFEI)	SU012W	Suisun Bay	2004	1590.74 pg/L
Sum of HCHs (SFEI)	CB003W	Central Bay	2002	455.9 pg/L
Sum of PAHs (SFEI)	LSB006W	Lower South Bay	2002	265279.2 pg/L
Sum of PBDEs (SFEI)	SU012W	Suisun Bay	2004	1374.44 pg/L
Sum of PCBs (SFEI)	LSB006W	Lower South Bay	2002	1702.749 pg/L

Table 2.5. Minimum concentration of total trace elements and trace organics for 2002-2006

Parameter	Site Code	Region	Year	Maximum Concentration
Ag	BG30	Rivers	2002	0.001453 ug/L
As	BC20	Central Bay	2004	1.5 ug/L
Cd	BG30	Rivers	2004	0.020645 ug/L
Chlorophyll-a	SPB004W	San Pablo Bay	2002	0.965 mg/m^3
Co	BC20	Central Bay	2002	0.046068 ug/L
Cu	BC20	Central Bay	2002	0.397006 ug/L
Fe	BC20	Central Bay	2002	36.974511 ug/L
Hg	BC20	Central Bay	2002	0.00134 ug/L
MeHg	SPB010W	San Pablo Bay	2004	0.02325 ng/L
Mn	BC20	Central Bay	2002	2.491933 ug/L
Ni	BC20	Central Bay	2002	0.479096 ug/L
Pb	BC20	Central Bay	2002	0.035211 ug/L
Phaeophytin	SU011W	Suisun Bay	2004	0.414513 mg/m^3
Se	SU014W	Suisun Bay	2004	0.043 ug/L
SSC	BC20	Central Bay	2002	1.6 mg/L
Zn	BC20	Central Bay	2002	0.296141 ug/L
BDE 047	SB001W	South Bay	2002	16.1 pg/L
BDE 209	CB004W	Central Bay	2002	12.2 pg/L
Dieldrin	BC20	Central Bay	2002	5.8 pg/L
Sum of Chlordanes (SFEI)	BC20	Central Bay	2002	1.91 pg/L
Sum of DDTs (SFEI)	BC20	Central Bay	2002	13.35 pg/L
Sum of HCHs (SFEI)	BG30	Rivers	2004	96.9 pg/L
Sum of PAHs (SFEI)	BG30	Rivers	2003	7778.2 pg/L
Sum of PBDEs (SFEI)	SPB004W	San Pablo Bay	2002	43.931 pg/L
Sum of PCBs (SFEI)	BC20	Central Bay	2002	47.826 pg/L

Table 2.6. Statistical comparisons of CDF results for dissolved contaminant concentrations among regions (2002-2006).
A p value < 0.05 indicates a statistically significant difference for the Roa-Scott test.

	Roa-Scott Test p Value															
Comparison	Ag	As	Cd	Cu	Hg	Ni	Pb	Se	Zn	PAHs	PCBs	HCHs	DDTs	Chlordanes	Dieldrin	DOC
CB vs LSB	0.06	**0.00**	0.81	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.87	**0.03**	**0.02**	0.92	**0.00**	**0.00**	**0.00**
CB vs SB	0.06	**0.00**	0.52	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.14	**0.03**	0.64	**0.02**	0.62	0.21	**0.00**	**0.00**
CB vs SPB	0.06	0.06	0.90	**0.00**	**0.02**	**0.00**	**0.00**	**0.02**	0.74	0.70	**0.00**	0.11	0.28	0.69	0.08	**0.00**
CB vs SU	0.06	**0.05**	**0.00**	**0.00**	**0.04**	**0.00**	**0.05**	0.19	**0.04**	**0.02**	**0.00**	**0.00**	**0.01**	0.35	**0.00**	**0.00**
LSB vs SB	0.15	**0.00**	0.93	**0.00**	0.28	**0.00**	**0.00**	**0.00**	**0.00**	**0.04**	**0.02**	0.99	0.19	**0.00**	**0.00**	**0.00**
LSB vs SPB	0.10	**0.00**	0.55	**0.00**	0.94	**0.00**	**0.00**	**0.00**	**0.01**	0.55	**0.00**	0.33	0.11	**0.00**	**0.00**	**0.00**
LSB vs SU	**0.00**	**0.00**	**0.00**	**0.00**	0.09	**0.00**	**0.00**	**0.00**	**0.00**	0.38	**0.00**	**0.00**	**0.01**	**0.00**	0.17	**0.00**
SB vs SPB	0.27	**0.00**	0.25	**0.00**	0.87	**0.02**	**0.00**	0.39	**0.01**	**0.04**	**0.00**	0.61	0.28	**0.00**	0.06	**0.00**
SB vs SU	**0.00**	**0.00**	**0.00**	**0.00**	0.64	**0.00**	**0.00**	0.12	**0.04**	**0.03**	**0.00**	**0.00**	0.06	0.69	**0.00**	**0.00**
SPB vs SU	**0.00**	0.40	**0.00**	0.34	0.75	**0.00**	0.50	0.89	**0.00**	0.89	**0.00**	**0.00**	0.91	0.33	**0.00**	0.06

Abbreviations: CB = Central Bay, LSB = Lower South Bay, SB = South Bay, SPB = San Pablo Bay, and SU = Suisun Bay.

Table 2.7. Statistical comparisons of CDF results for total contaminant concentrations among regions (2002-2006).
A p value < 0.05 indicates a statistically significant difference for the Roa-Scott test.

	Roa-Scott Test p Value															
Comparison	Ag	As	Cd	Cu	Hg	Ni	Pb	Se	Zn	PAHs	PCBs	HCHs	DDTs	Chlordanes	BDE-47	SSC
CB vs LSB	**0.00**	**0.00**	0.45	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.42	**0.00**	**0.00**	**0.00**	**0.01**
CB vs SB	**0.00**	**0.00**	0.91	**0.00**	0.13	**0.00**	0.69	**0.00**	0.52	0.67	0.64	**0.00**	**0.02**	0.25	0.09	0.91
CB vs SPB	0.29	0.13	0.49	**0.00**	**0.00**	**0.00**	**0.01**	0.08	**0.00**	0.58	0.90	**0.00**	**0.00**	**0.00**	0.20	**0.00**
CB vs SU	0.07	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.05**	**0.00**	0.59	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
LSB vs SB	**0.05**	**0.00**	0.73	**0.00**	**0.02**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.03**	**0.00**	**0.00**	**0.00**	**0.02**
LSB vs SPB	**0.00**	**0.00**	0.17	**0.01**	0.06	**0.02**	0.12	**0.00**	0.12	**0.01**	**0.00**	**0.00**	0.07	**0.00**	0.21	**0.00**
LSB vs SU	**0.00**	**0.00**	**0.00**	0.06	0.10	0.16	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
SB vs SPB	0.19	**0.00**	0.12	**0.00**	**0.00**	**0.01**	**0.00**	0.38	**0.00**	0.92	0.92	0.17	**0.00**	**0.00**	**0.00**	**0.00**
SB vs SU	**0.00**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.02**	**0.00**	0.55	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
SPB vs SU	0.07	0.59	**0.00**	**0.00**	0.24	**0.05**	**0.01**	0.18	0.11	0.73	**0.00**	**0.00**	0.16	0.58	0.08	0.06

Abbreviations: CB = Central Bay, LSB = Lower South Bay, SB = South Bay, SPB = San Pablo Bay, and SU = Suisun Bay.

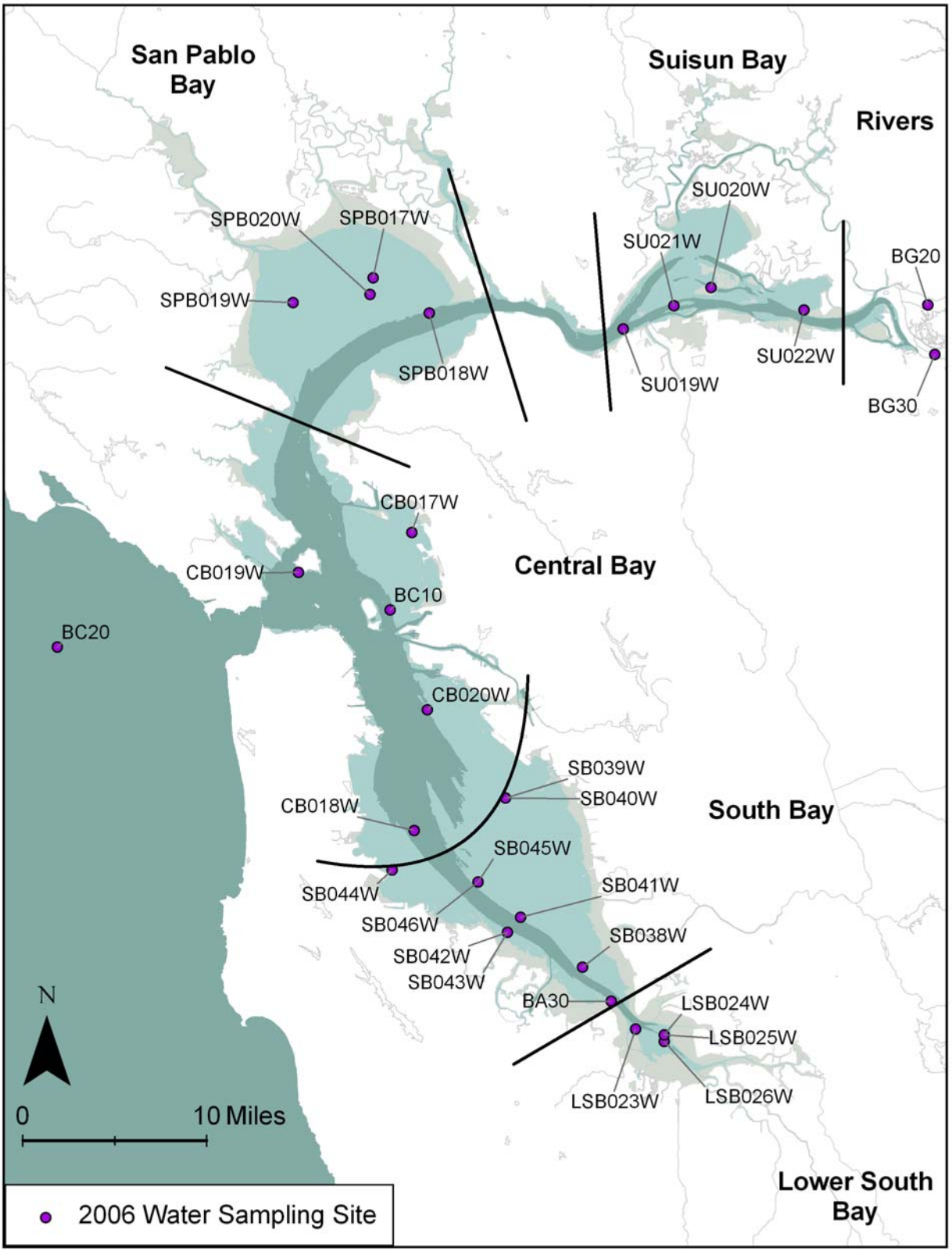


Figure 2.1. Map of the 2006 RMP Status and Trends water monitoring effort at randomly selected and historic sampling sites. A total of 26 random stations and 5 historic sites (sampled each year) were sampled in the San Francisco Estuary for analysis of water quality and trace contaminants.

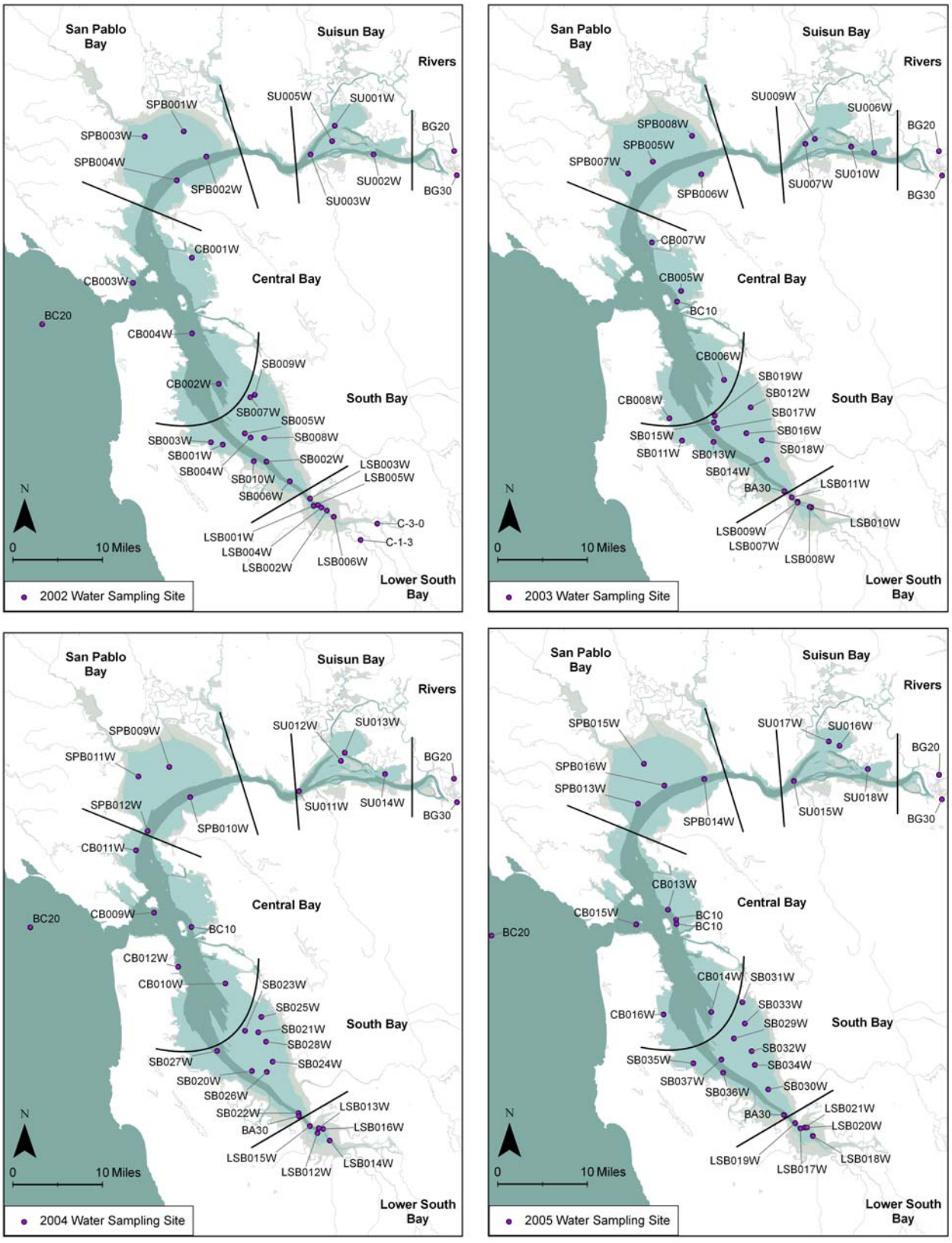
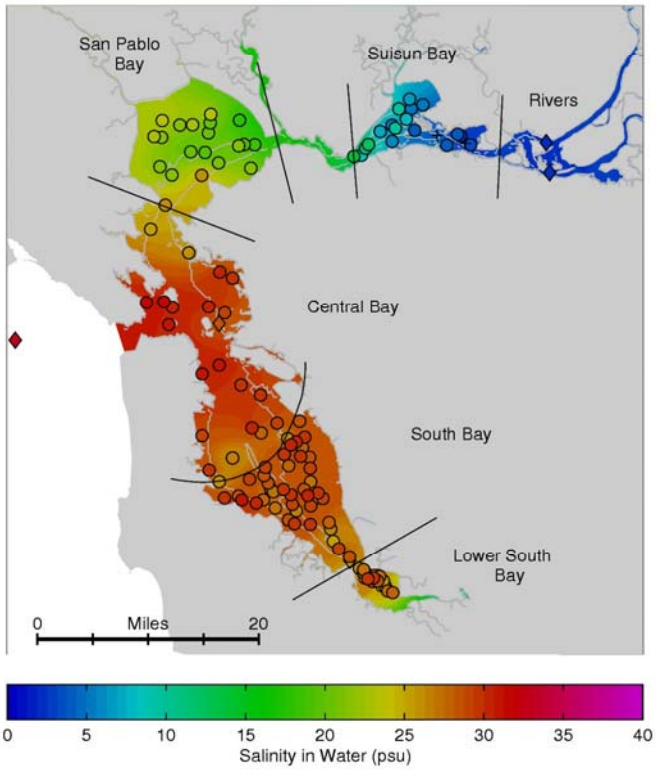


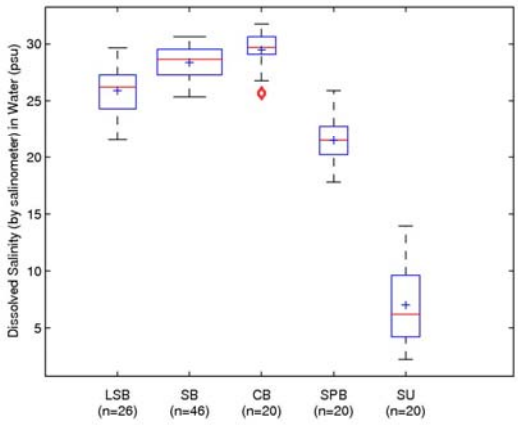
Figure 2.2. Maps of the RMP Status and Trends water monitoring effort from 2002 to 2005 at randomly selected and historic sampling sites. Each year a total of 26 random stations (exception: 28 sites in 2002) and 5 historic sites (exception: 4 sites in 2003) were sampled in the San Francisco Estuary for analysis of water quality and trace contaminants.

Dissolved Salinity in Water (2002-2006)



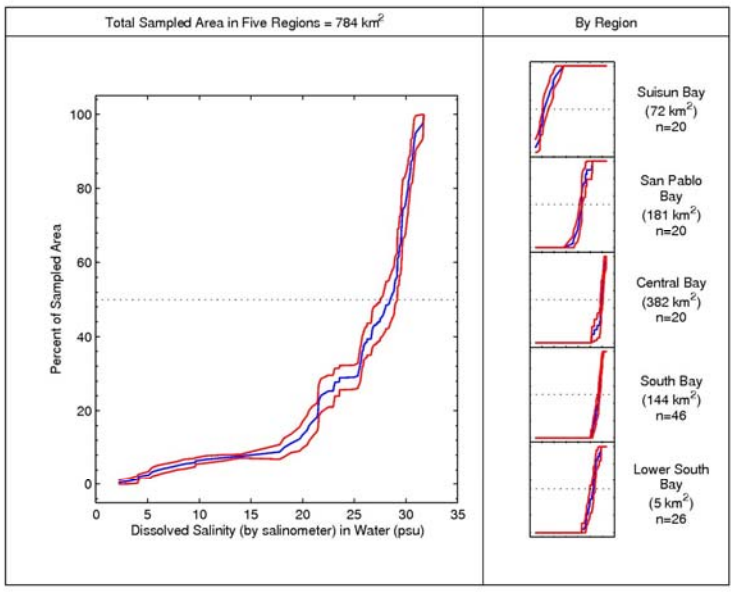
a) Map of dissolved concentrations in water (psu) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (psu) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



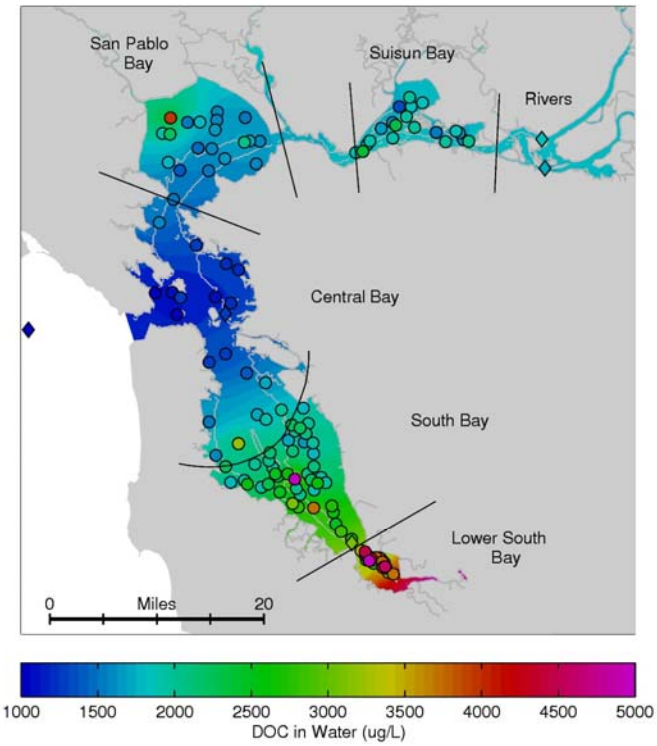
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (psu) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus salinity (by salinometer) concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

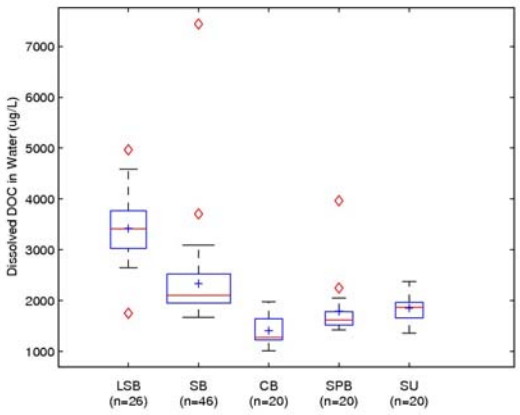
Figure 2.3

Dissolved Organic Carbon (DOC) in Water (2002-2006)



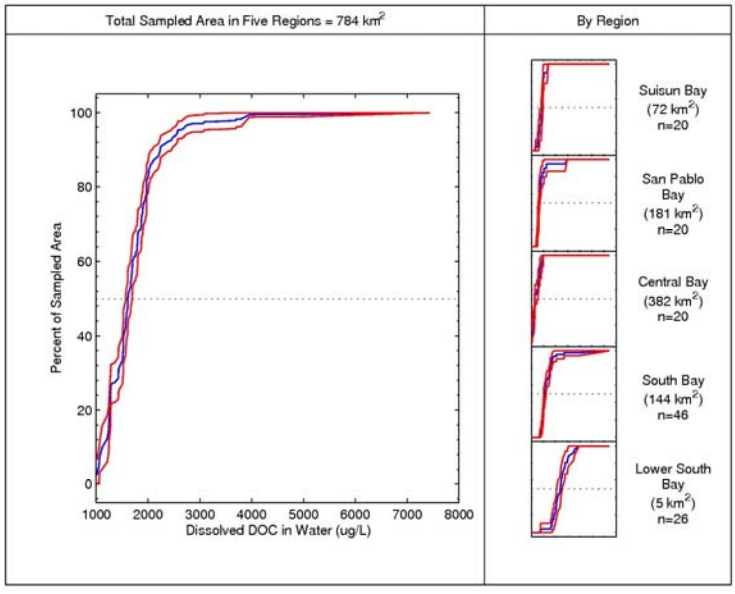
a) Map of dissolved concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 26 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



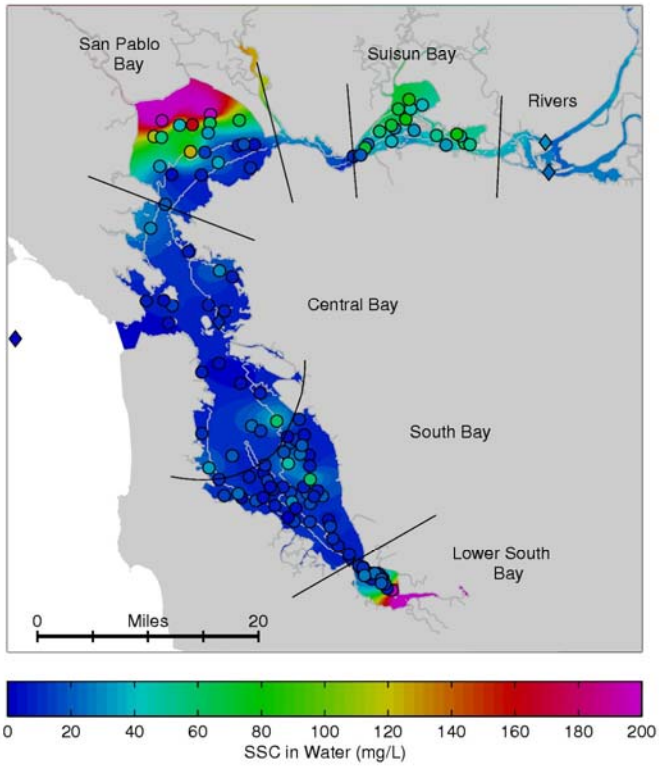
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus doc concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

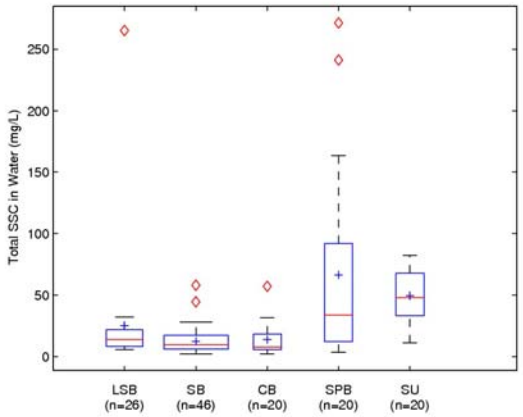
Figure 2.4

Total Suspended Sediment Concentration (SSC) in Water (2002-2006)



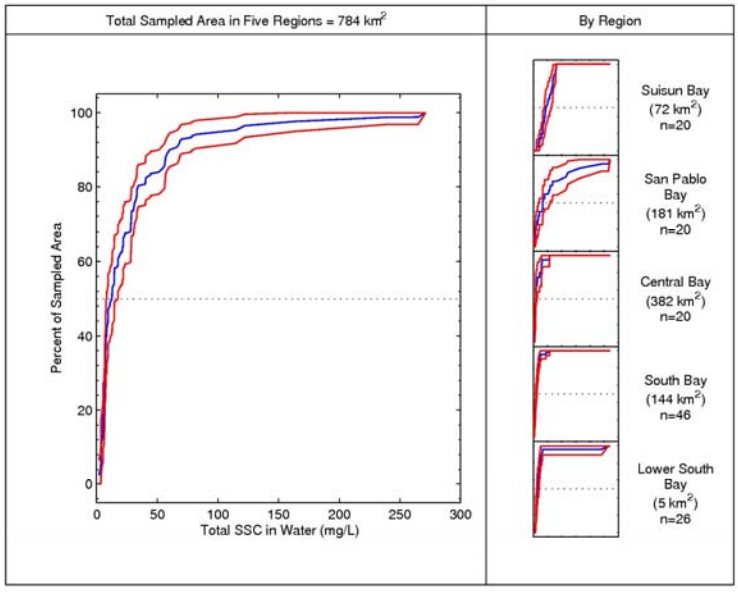
a) Map of total concentrations in water (mg/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (mg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



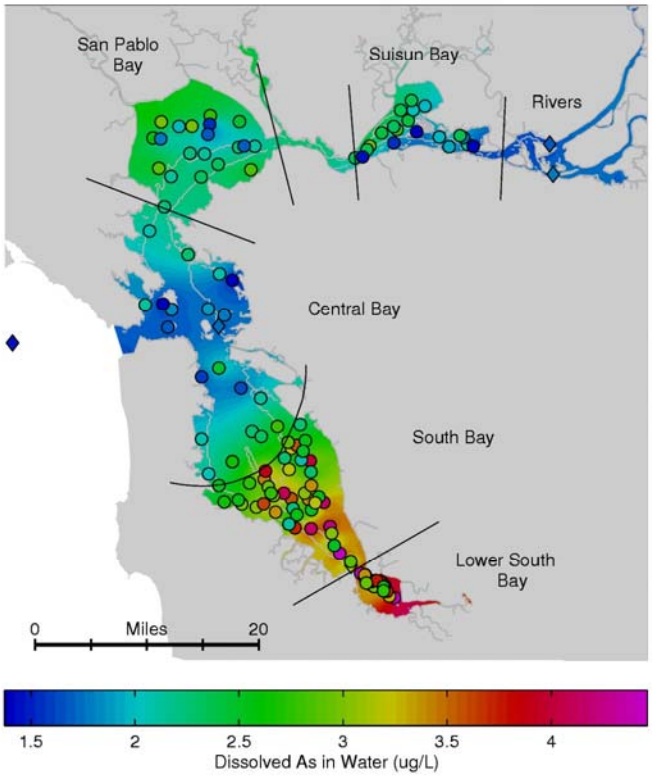
c) Cumulative distribution functions (CDFs) for total concentrations in water (mg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus suspended sediment concentration concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

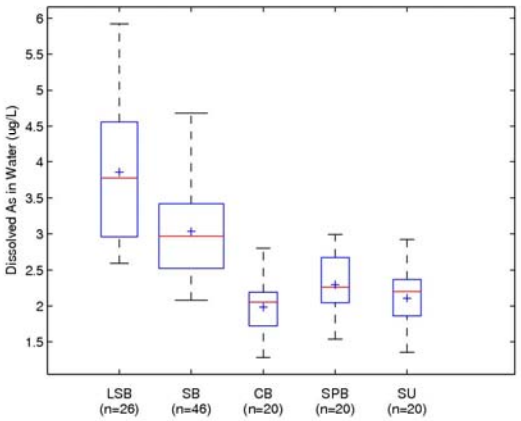
Figure 2.5

Dissolved Arsenic (As) in Water (2002-2006)



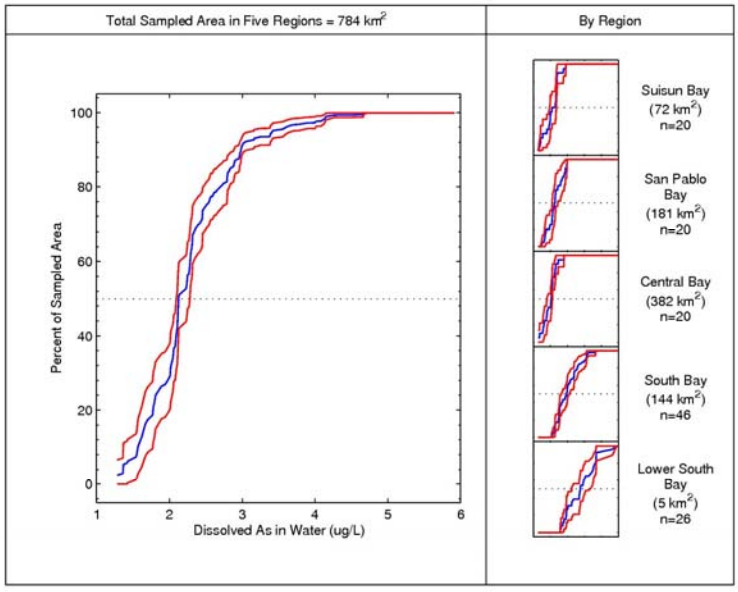
a) Map of dissolved concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



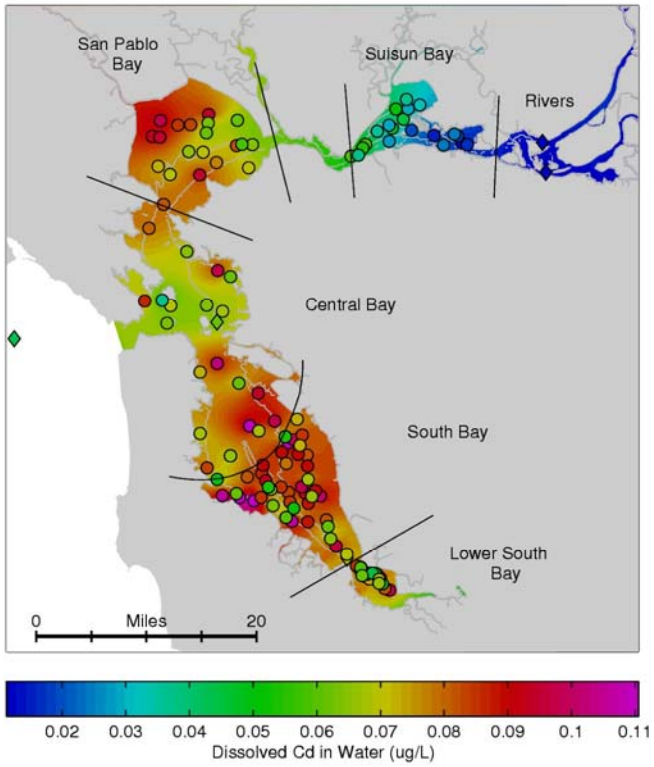
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus arsenic concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

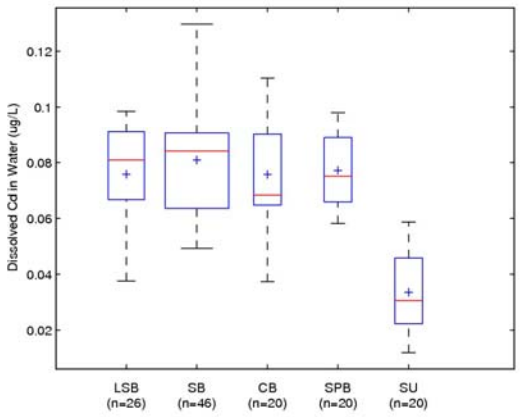
Figure 2.6

Dissolved Cadmium (Cd) in Water (2002-2006)



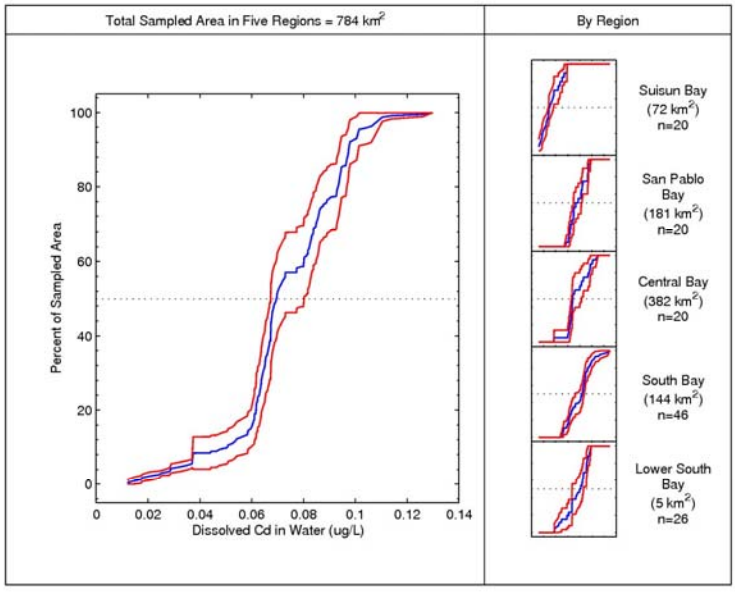
a) Map of dissolved concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



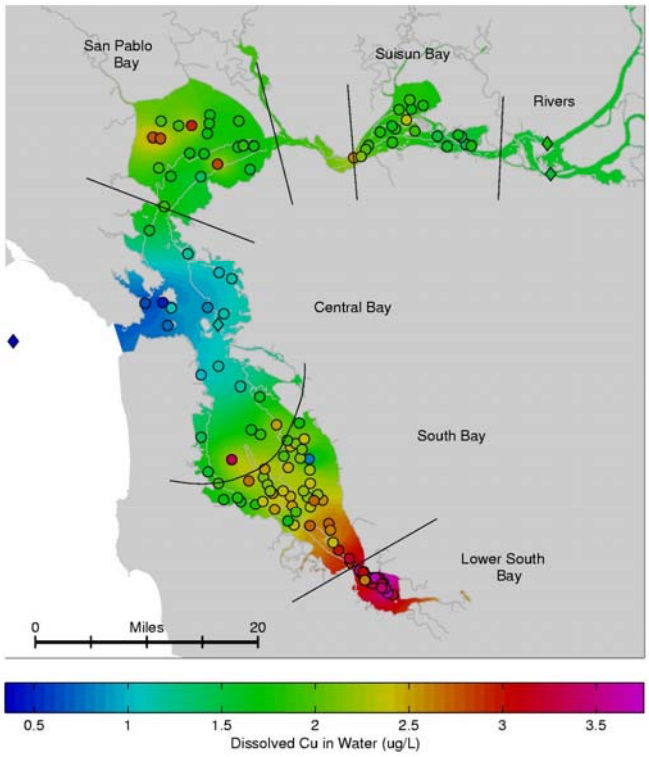
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus cadmium concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

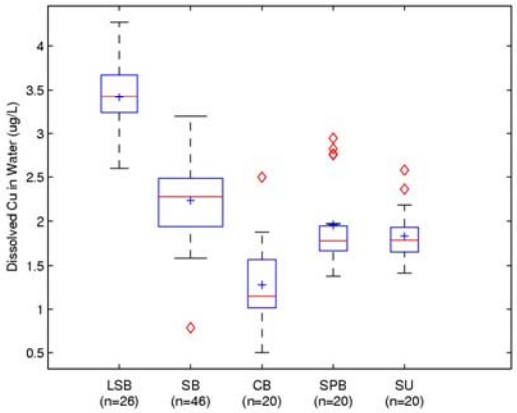
Figure 2.7

Dissolved Copper (Cu) in Water (2002-2006)



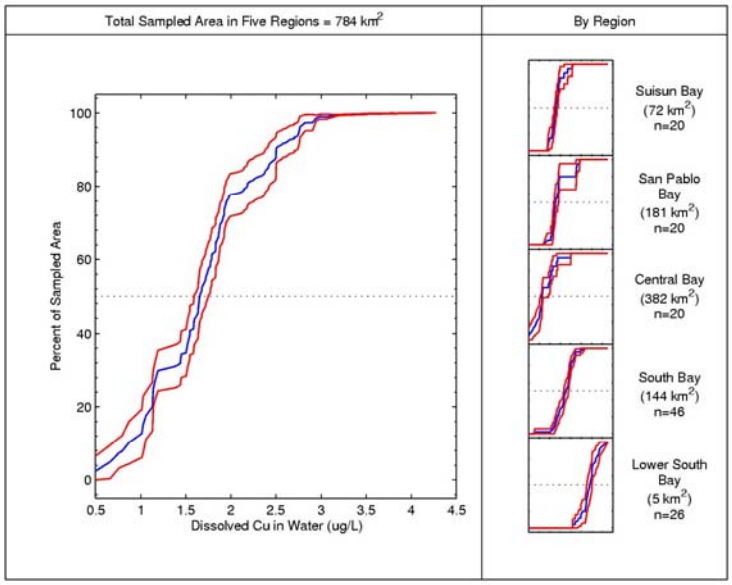
a) Map of dissolved concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ○ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



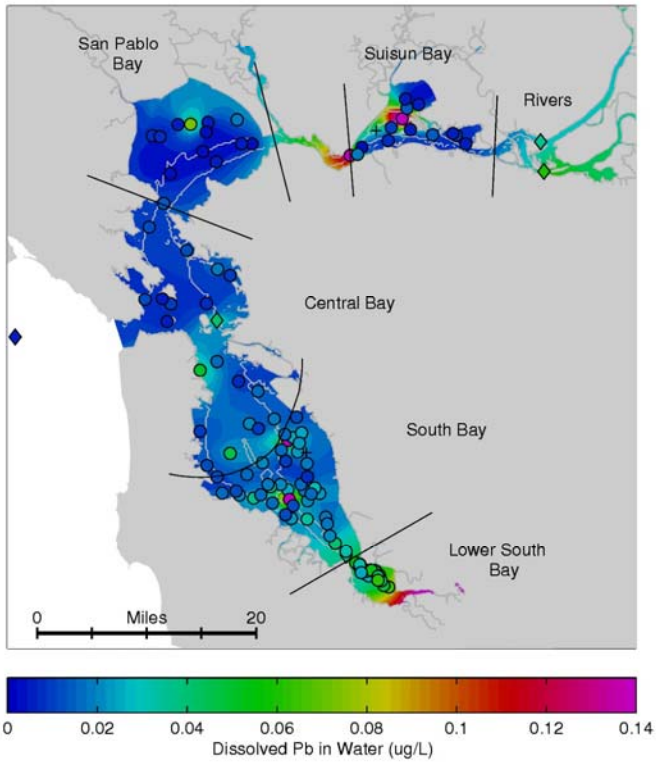
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus cu concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

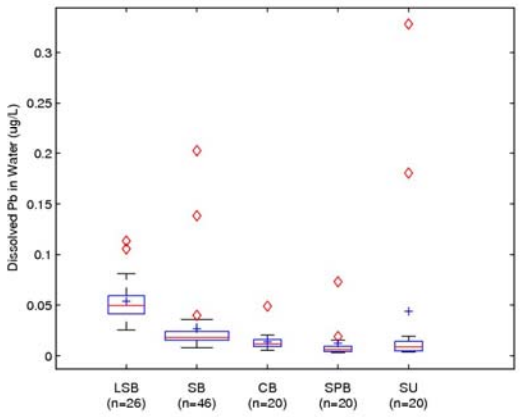
Figure 2.8

Dissolved Lead (Pb) in Water (2002-2006)



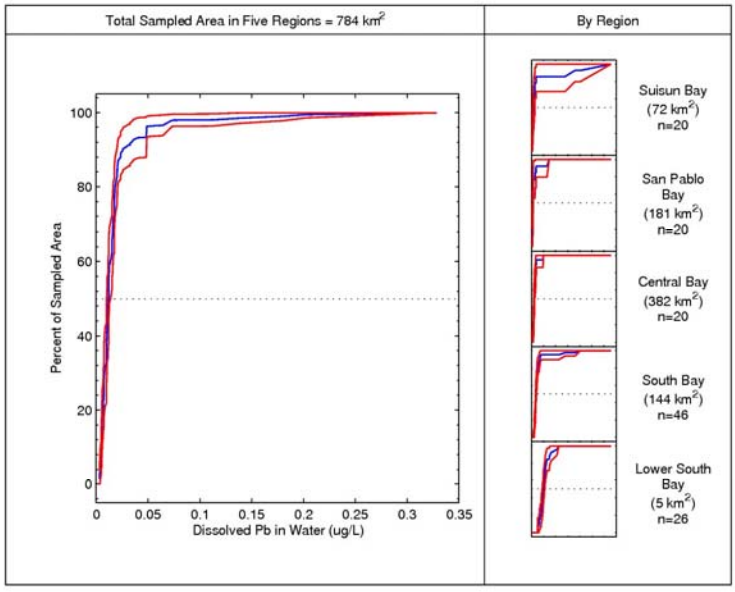
a) Map of dissolved concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



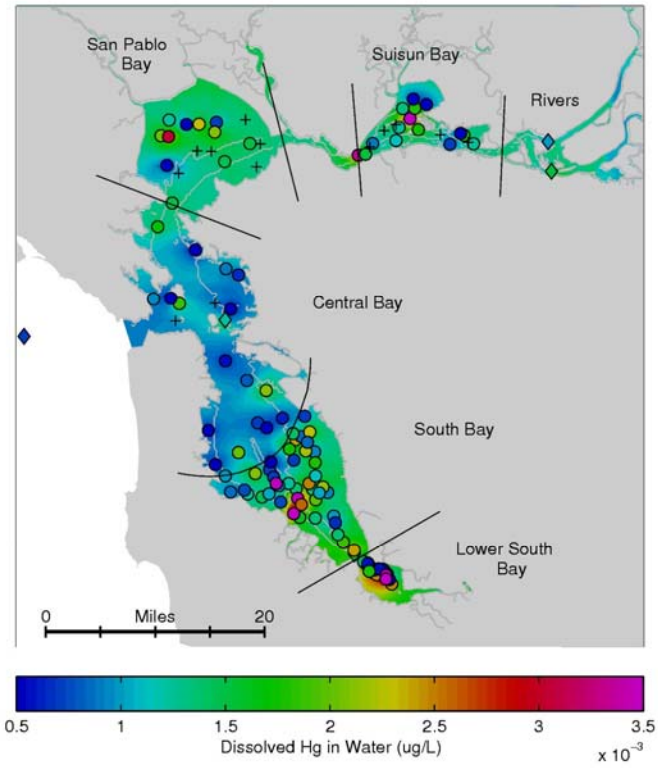
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus lead concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

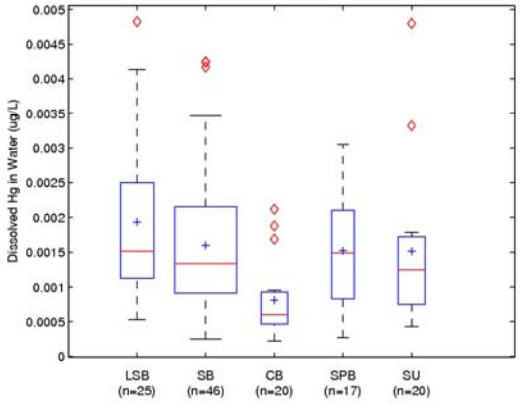
Figure 2.9

Dissolved Mercury (Hg) in Water (2002-2006)



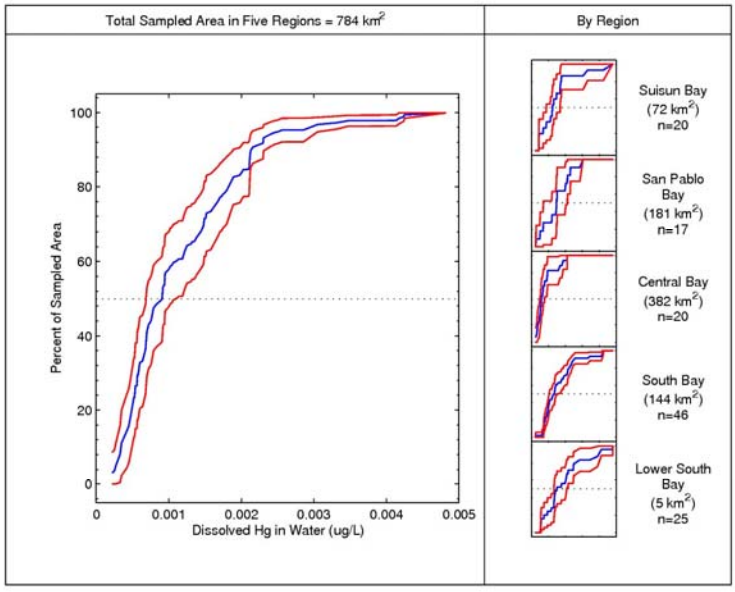
a) Map of dissolved concentrations in water (ug/L) in the six Estuary regions monitored. 128 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

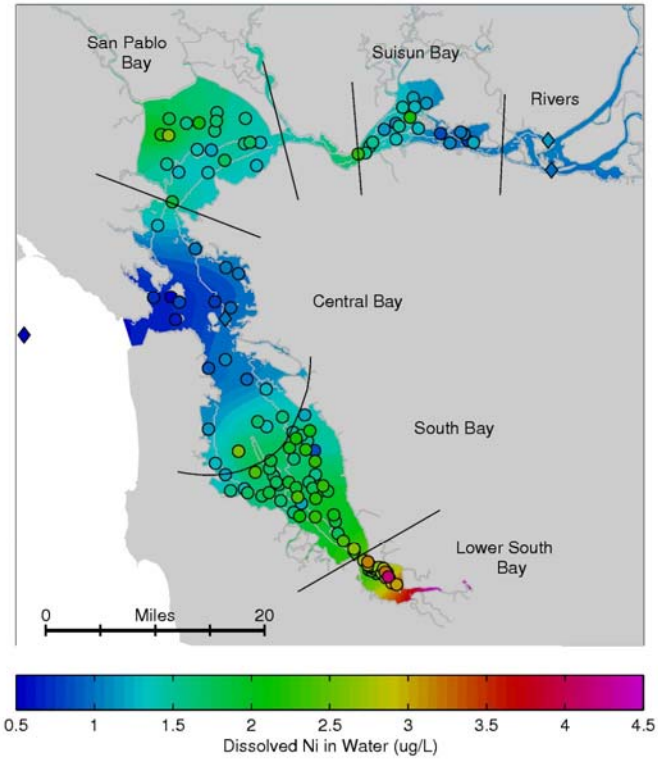
The large graph shows the percentage of the total area sampled in the five Estuary regions versus mercury concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : November 1, 2007 ∘

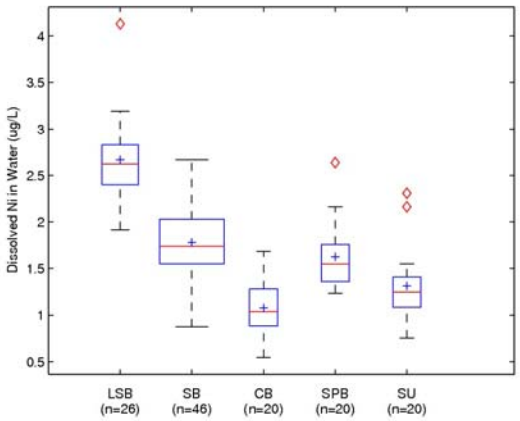
Figure 2.10

Dissolved Nickel (Ni) in Water (2002-2006)



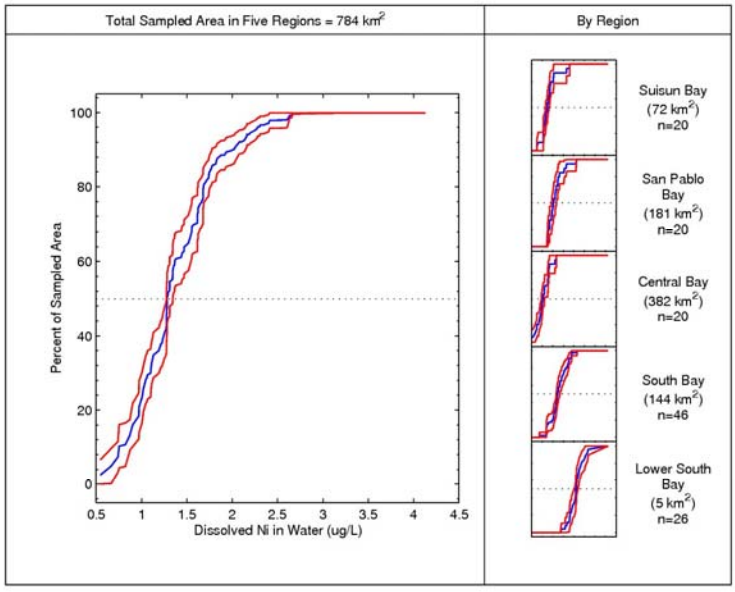
a) Map of dissolved concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



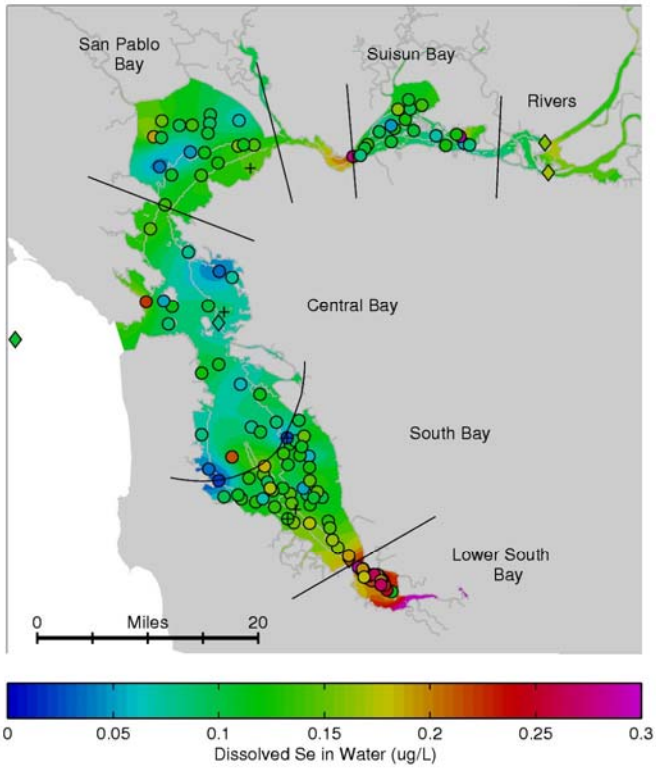
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus nickel concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

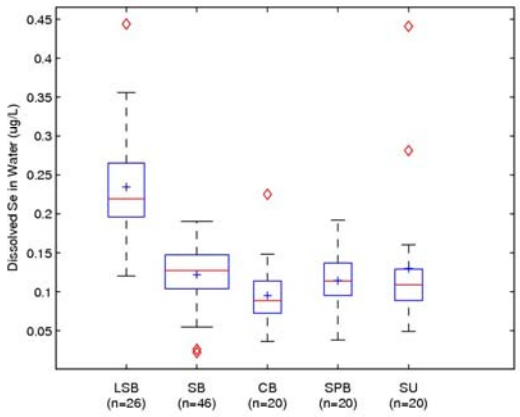
Figure 2.11

Dissolved Selenium (Se) in Water (2002-2006)



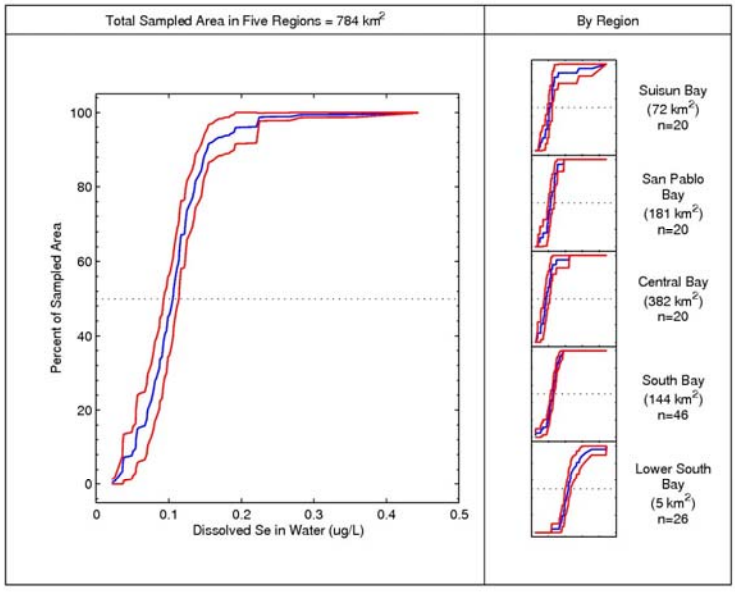
a) Map of dissolved concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



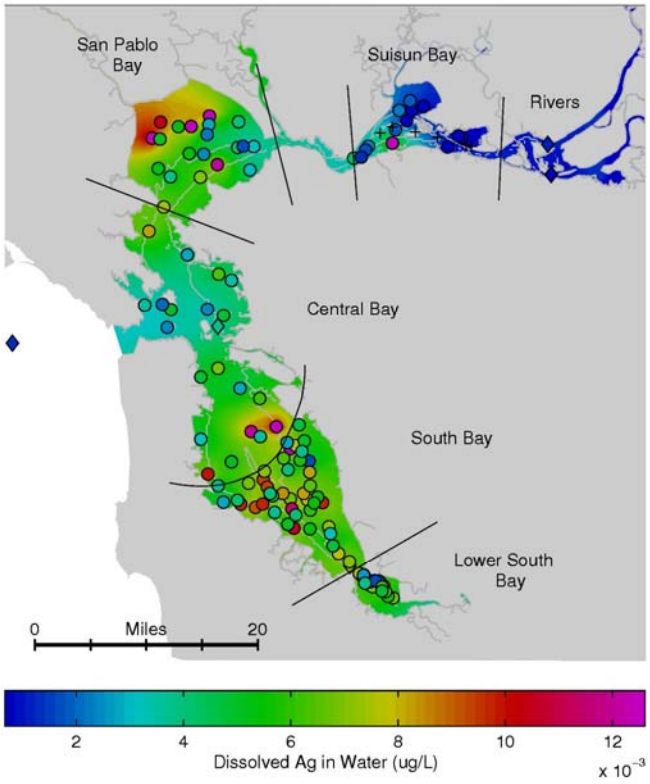
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus selenium concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

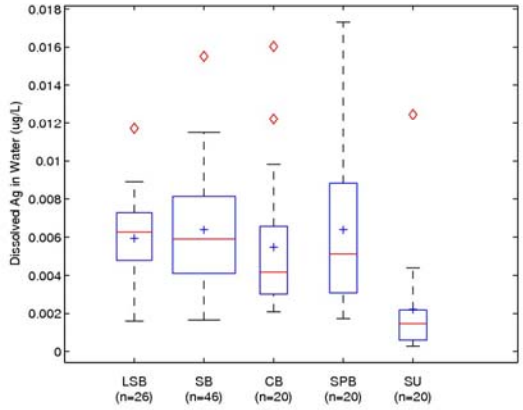
Figure 2.12

Dissolved Silver (Ag) in Water (2002-2006)



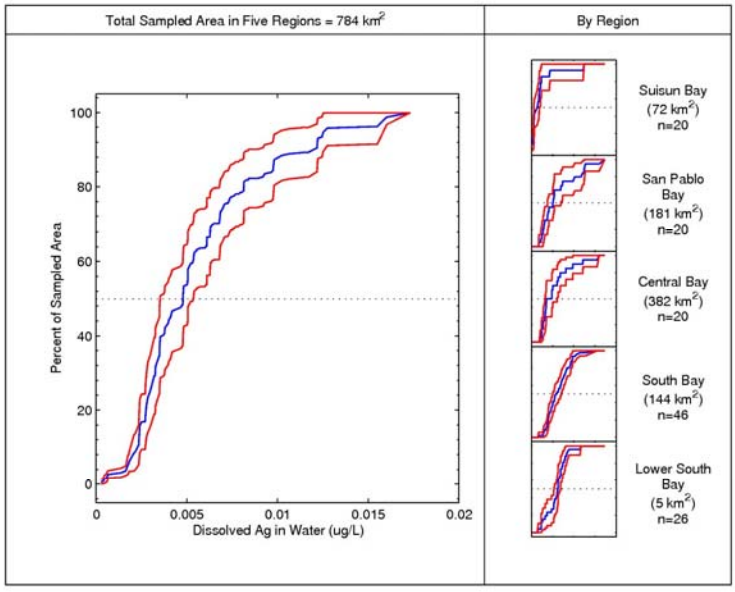
a) Map of dissolved concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



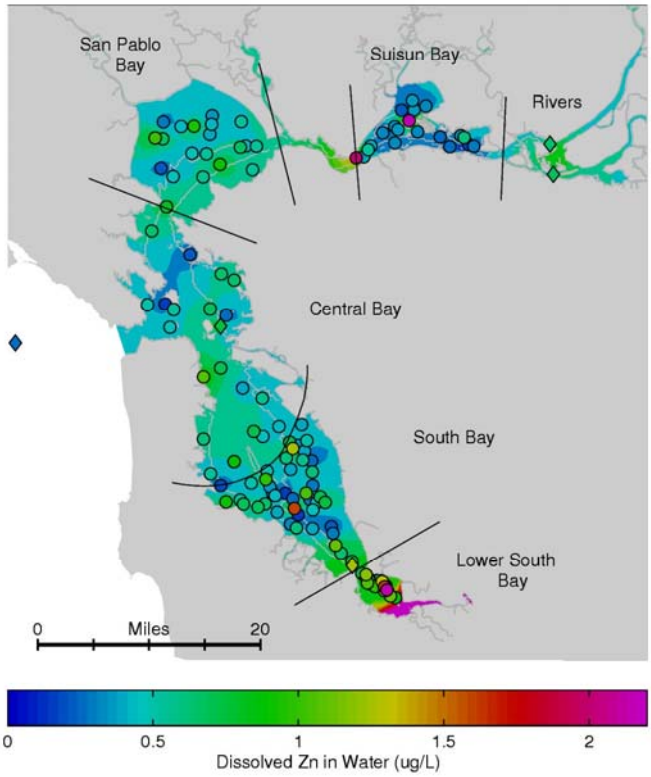
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus silver concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

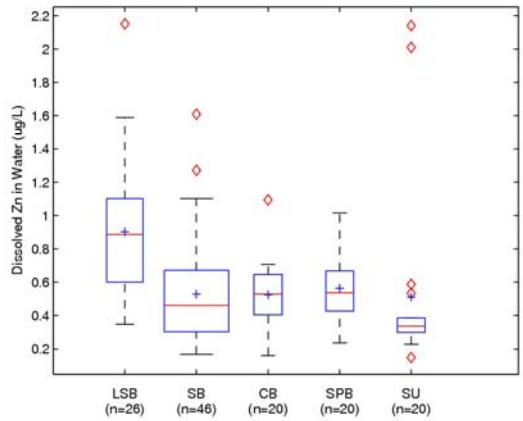
Figure 2.13

Dissolved Zinc (Zn) in Water (2002-2006)



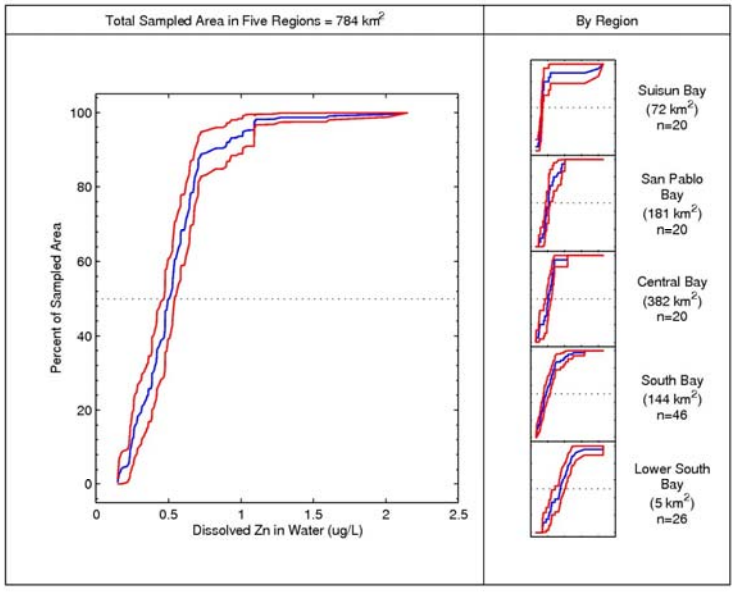
a) Map of dissolved concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



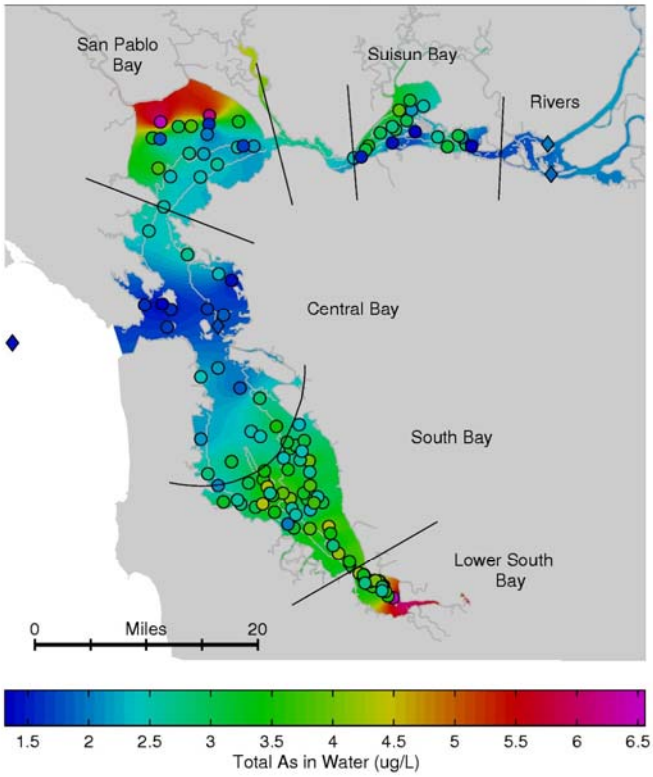
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus zn concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

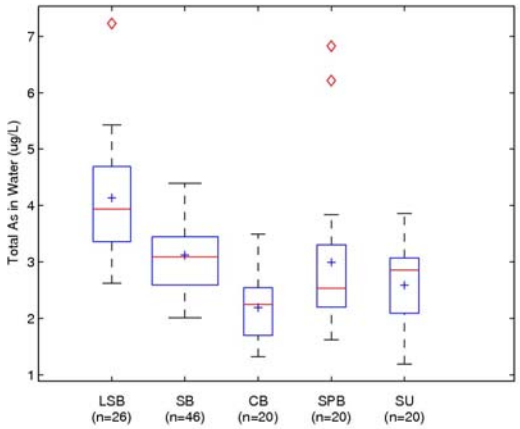
Figure 2.14

Total Arsenic (As) in Water (2002-2006)



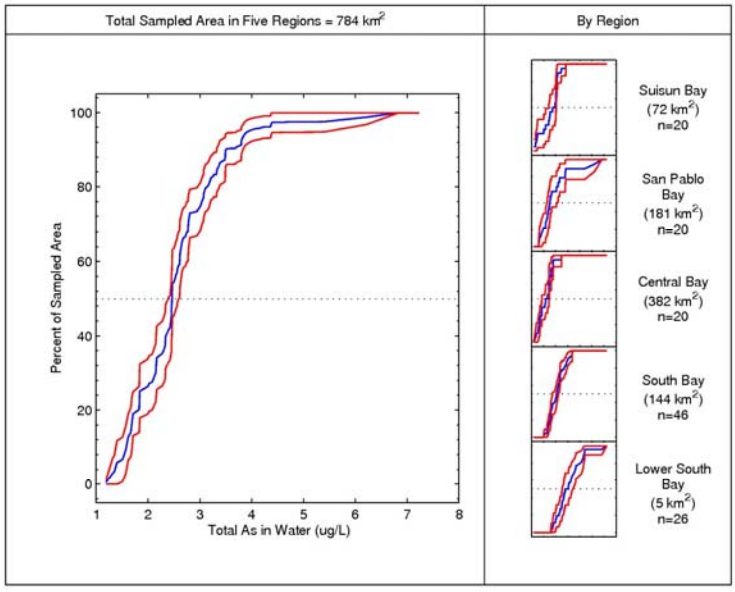
a) Map of total concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



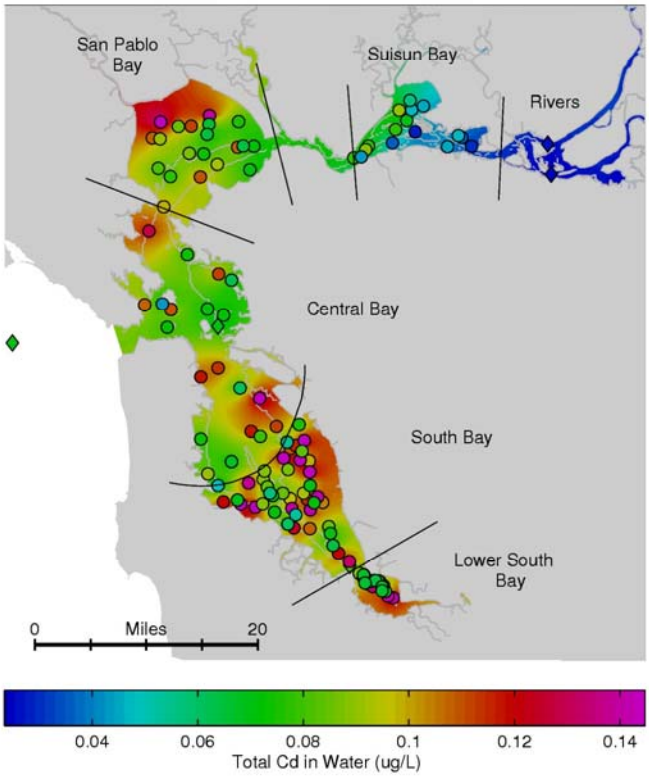
c) Cumulative distribution functions (CDFs) for total concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus arsenic concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

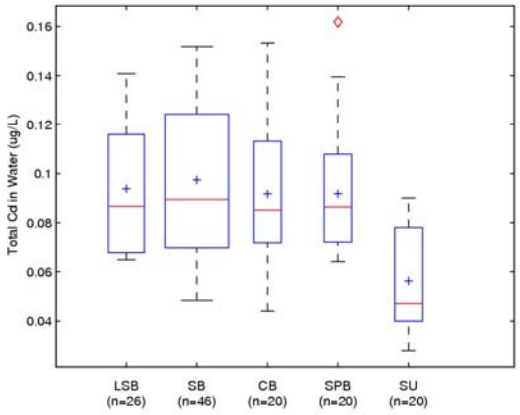
Figure 2.15

Total Cadmium (Cd) in Water (2002-2006)



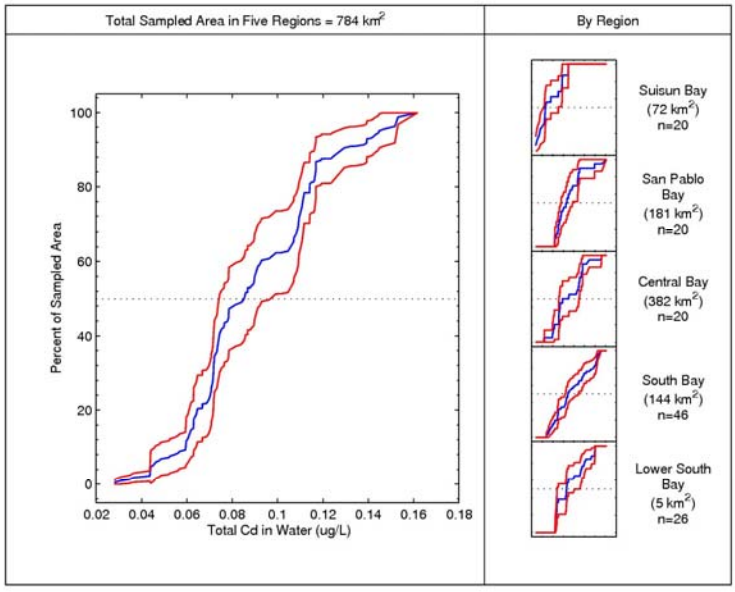
a) Map of total concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for total concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

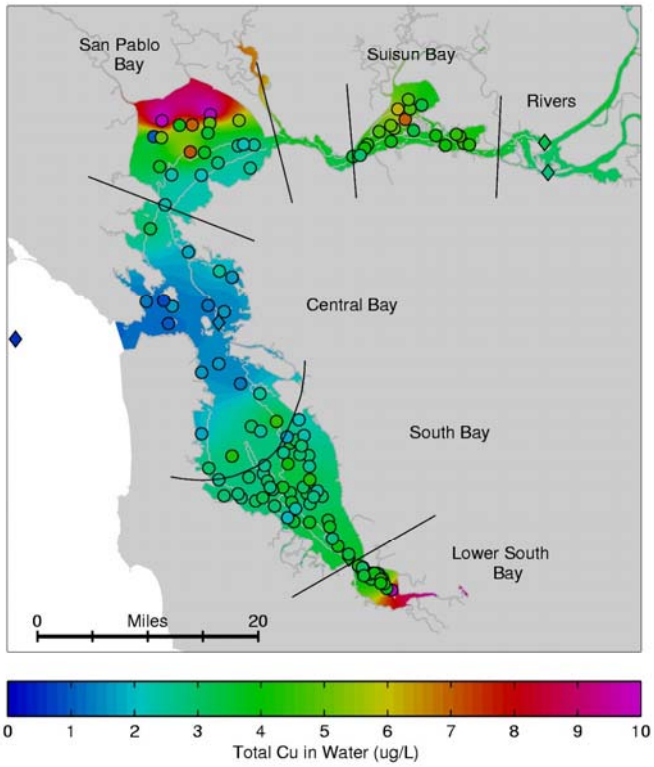
The large graph shows the percentage of the total area sampled in the five Estuary regions versus cadmium concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : November 1, 2007 ∘

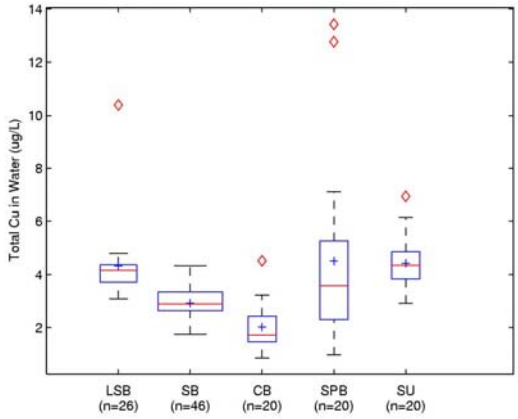
Figure 2.16

Total Copper (Cu) in Water (2002-2006)



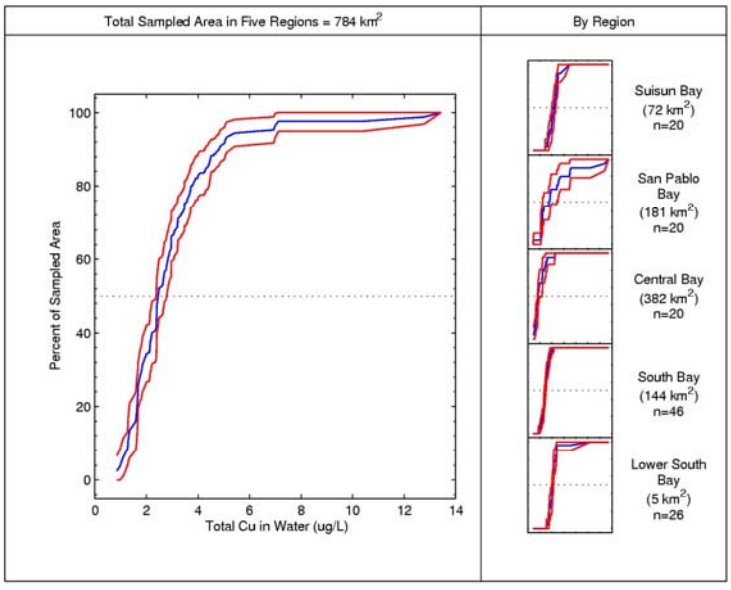
a) Map of total concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ○ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



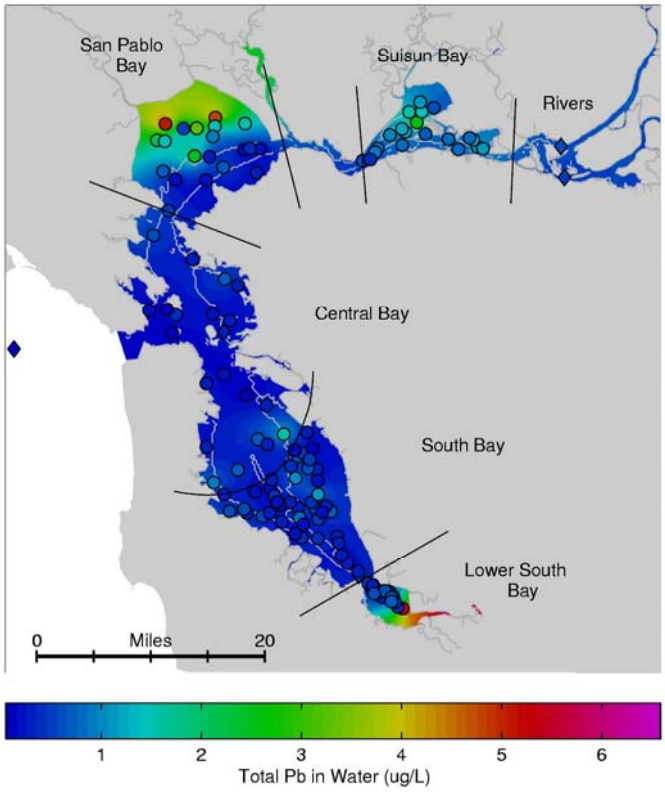
c) Cumulative distribution functions (CDFs) for total concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus cu concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

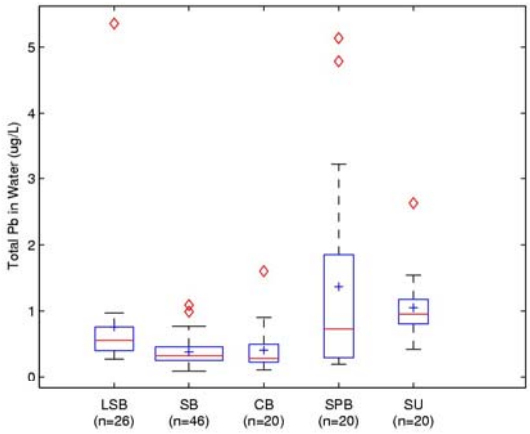
Figure 2.17

Total Lead (Pb) in Water (2002-2006)



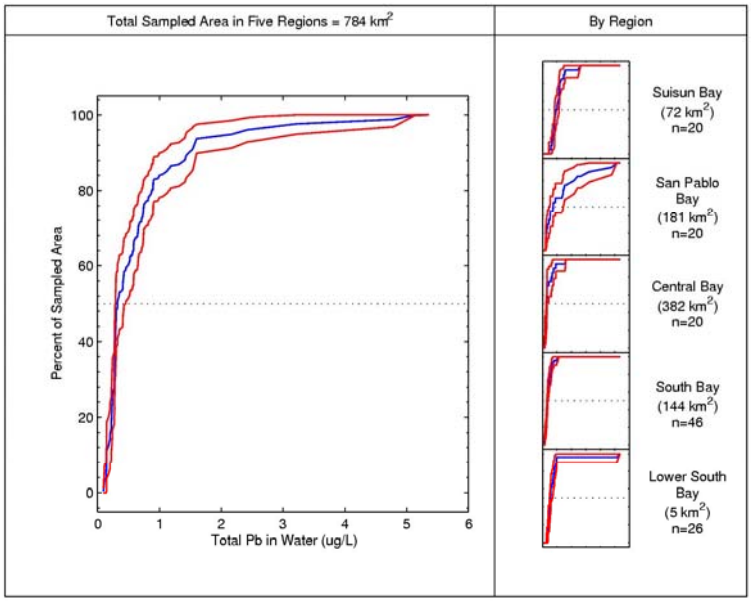
a) Map of total concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ○ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



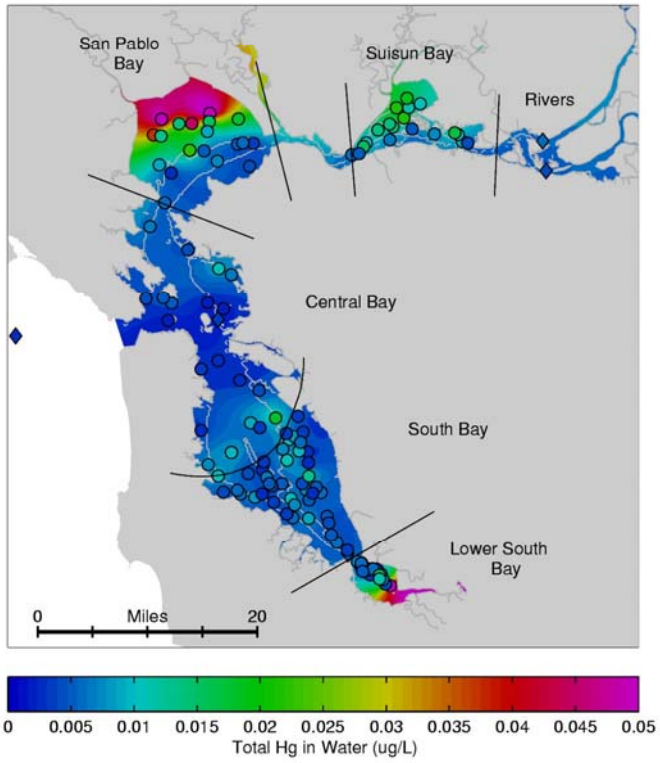
c) Cumulative distribution functions (CDFs) for total concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus pb concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

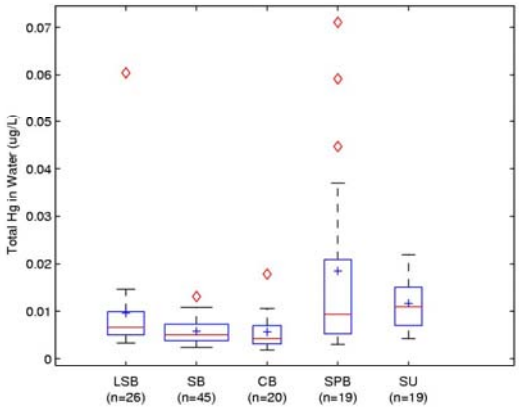
Figure 2.18

Total Mercury (Hg) in Water (2002-2006)



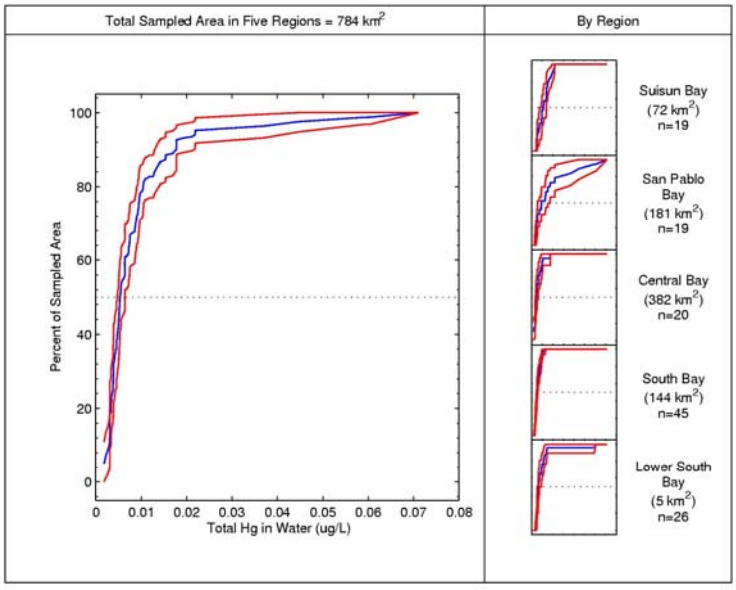
a) Map of total concentrations in water (ug/L) in the six Estuary regions monitored. 129 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites $= \circ$, Historic sites $= \diamond$, Non- detects $= +$



b) Boxplot of total concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



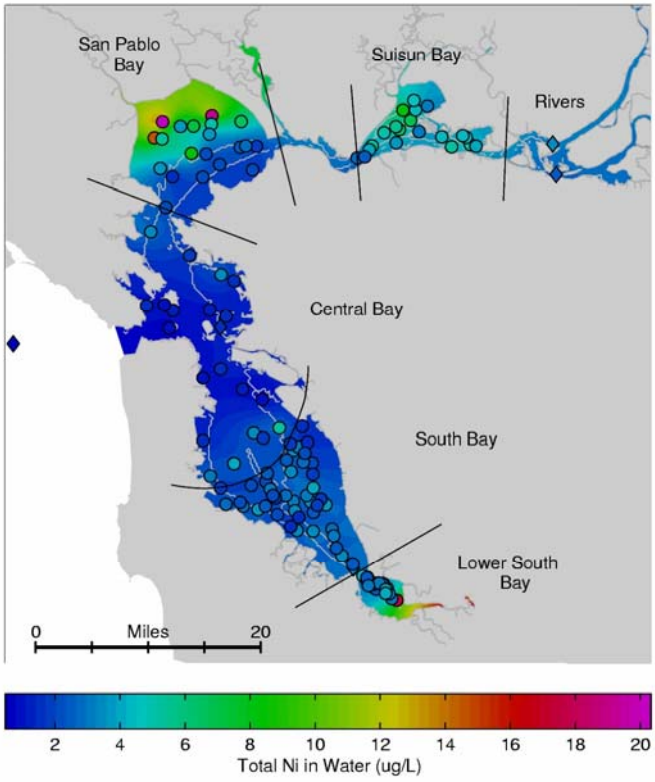
c) Cumulative distribution functions (CDFs) for total concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus hg concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

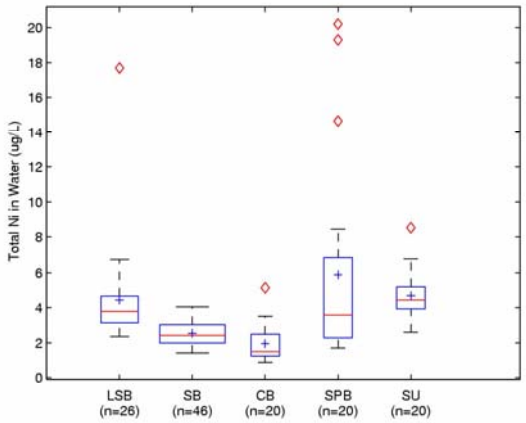
Figure 2.19

Total Nickel (Ni) in Water (2002-2006)



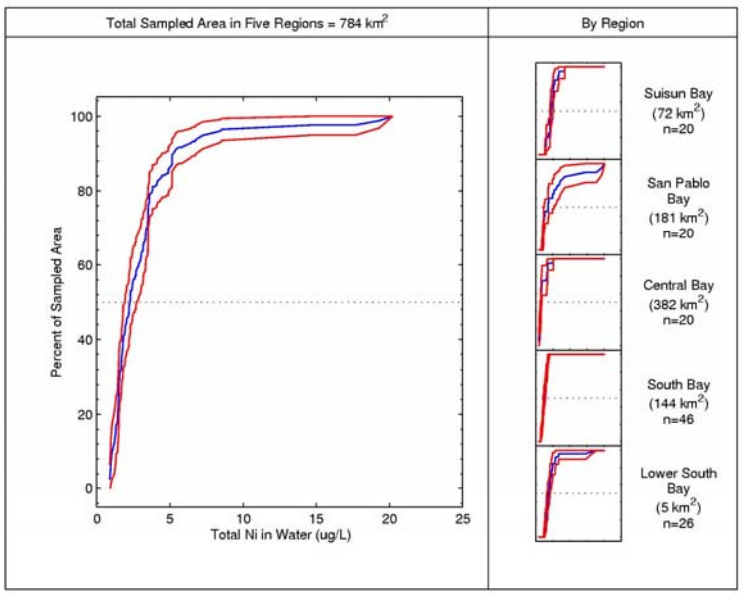
a) Map of total concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ○ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



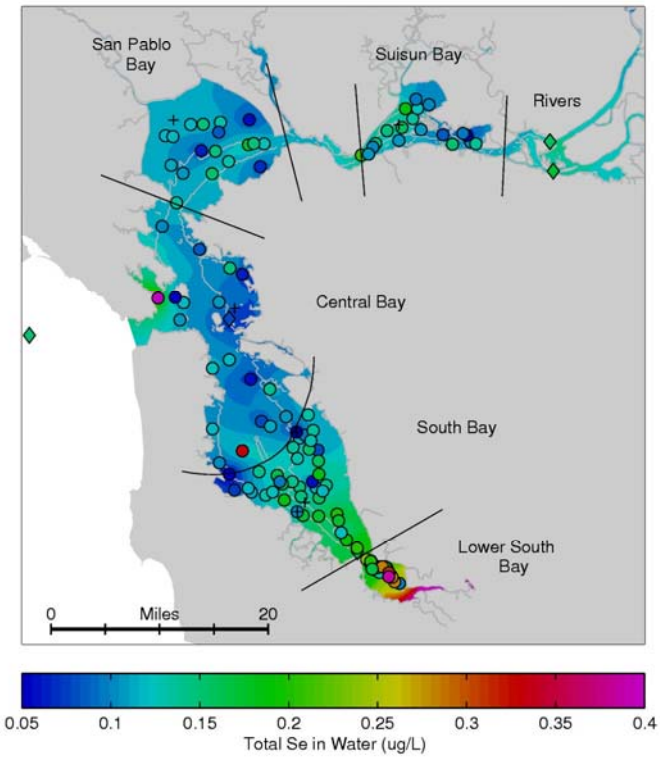
c) Cumulative distribution functions (CDFs) for total concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus ni concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

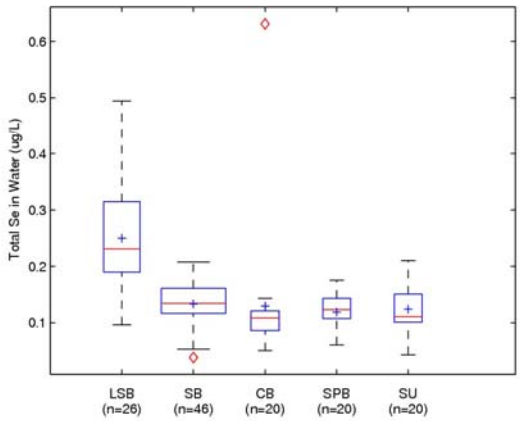
Figure 2.20

Total Selenium (Se) in Water (2002-2006)



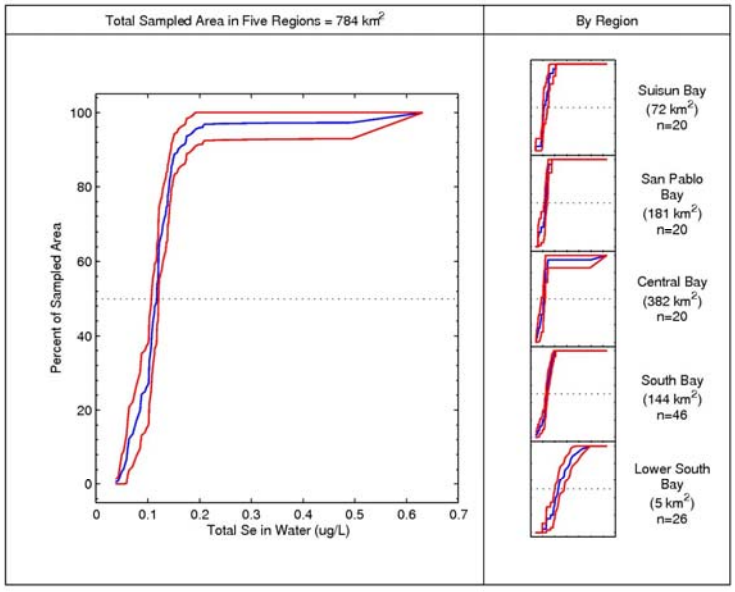
a) Map of total concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



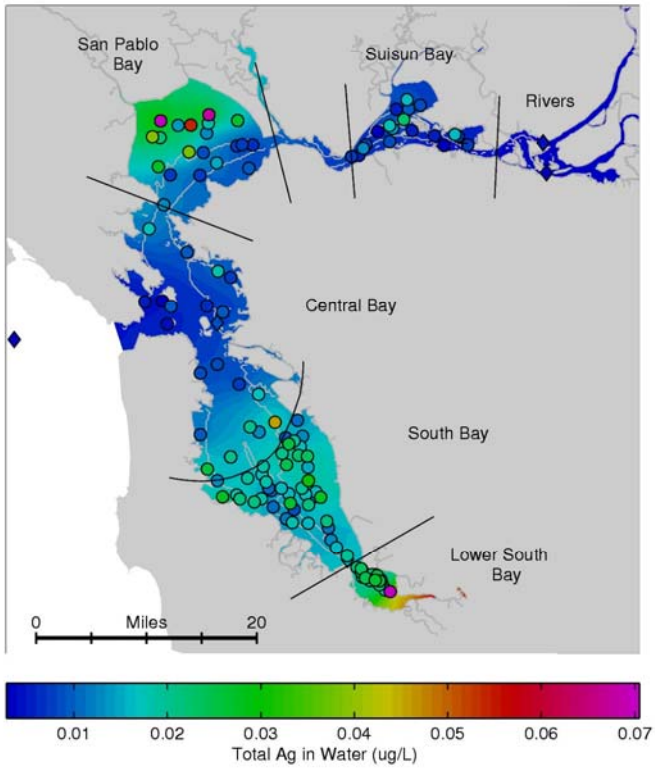
c) Cumulative distribution functions (CDFs) for total concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus selenium concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

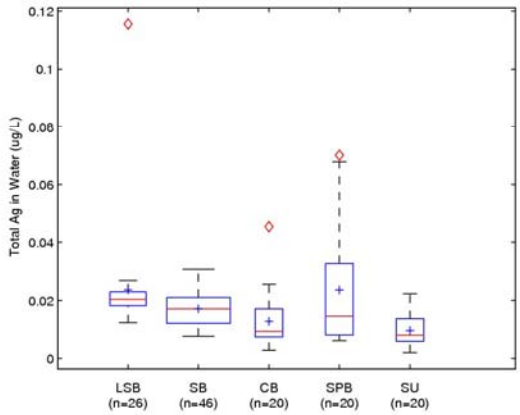
Figure 2.21

Total Silver (Ag) in Water (2002-2006)



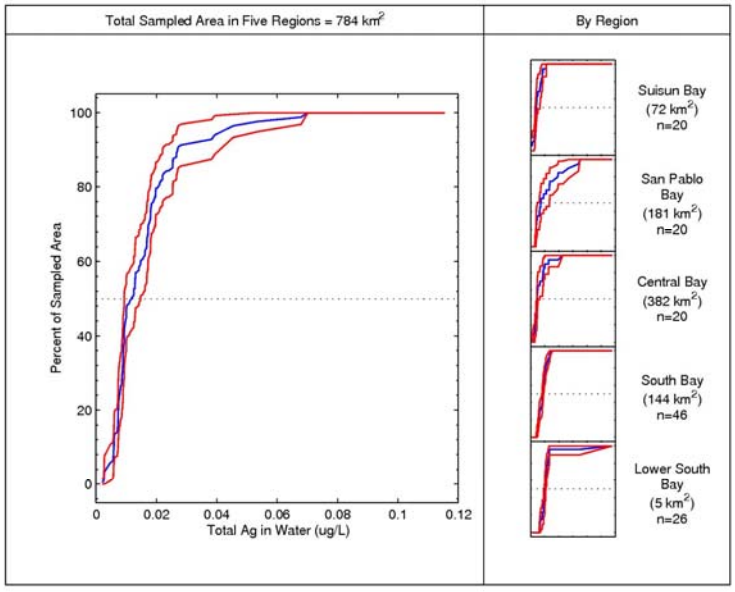
a) Map of total concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



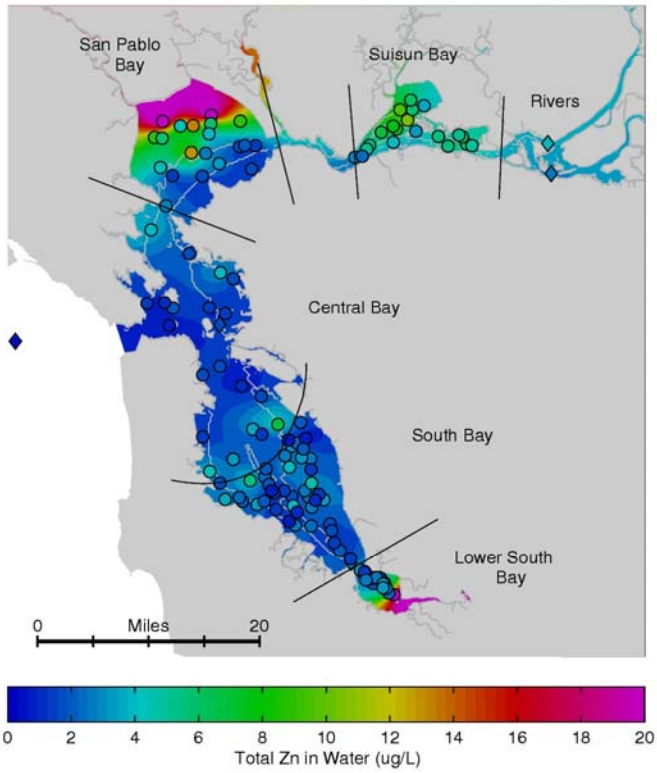
c) Cumulative distribution functions (CDFs) for total concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus silver concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

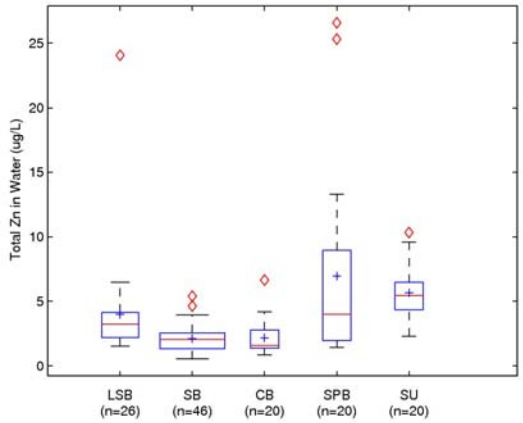
Figure 2.22

Total Zinc (Zn) in Water (2002-2006)



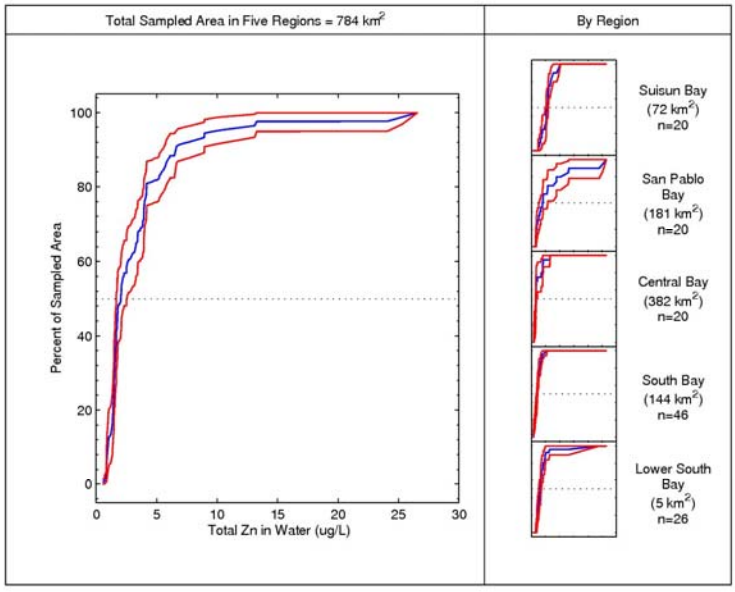
a) Map of total concentrations in water (ug/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (ug/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



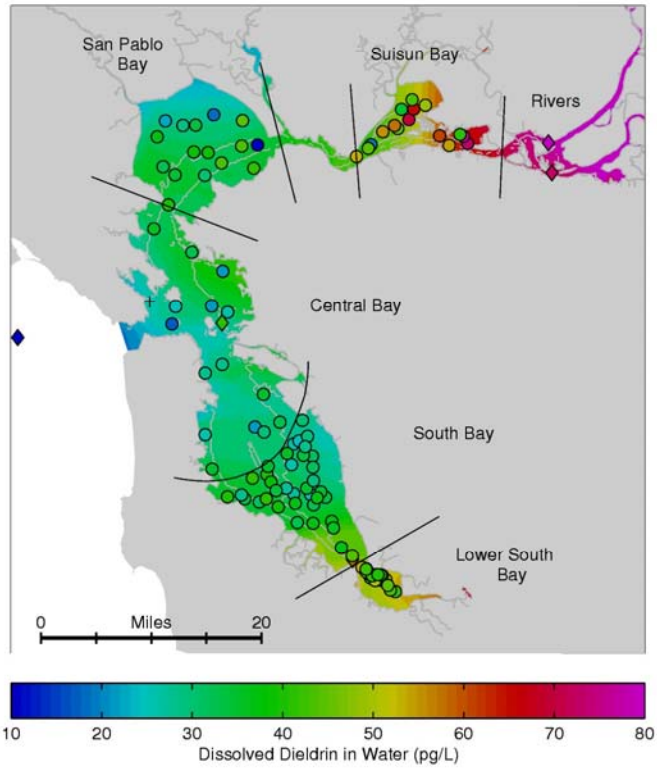
c) Cumulative distribution functions (CDFs) for total concentrations in water (ug/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus zinc concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

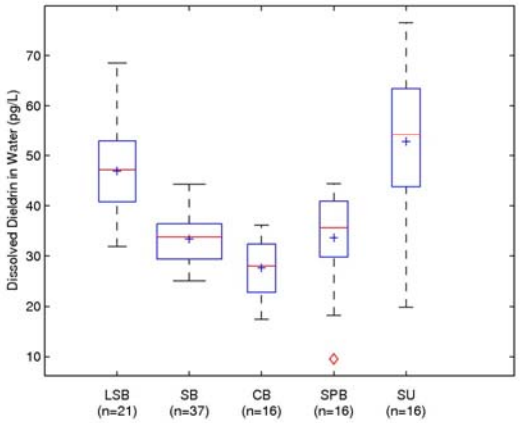
Figure 2.23

Dissolved Dieldrin in Water (2002-2006)



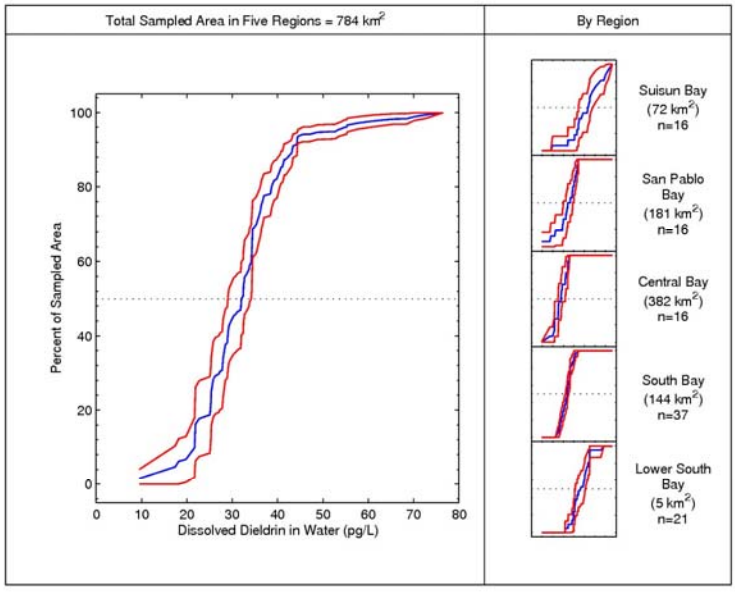
a) Map of dissolved concentrations in water (pg/L) in the six Estuary regions monitored. 106 randomly allocated sites and 25 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (pg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



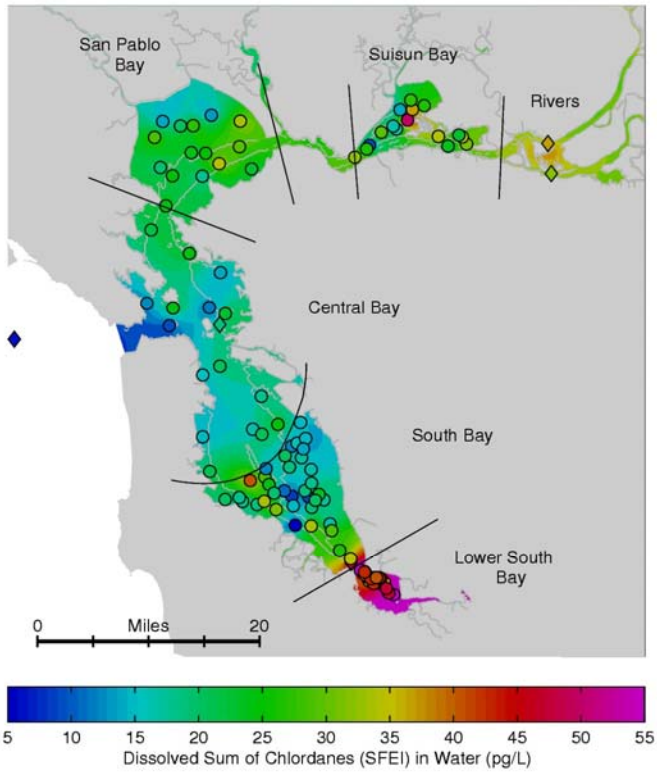
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (pg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus dieldrin concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

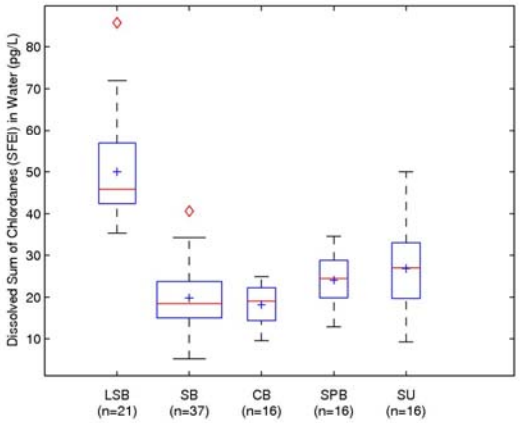
Figure 2.24

Dissolved Sum of Chlordanes (SFEI) in Water (2002-2006)



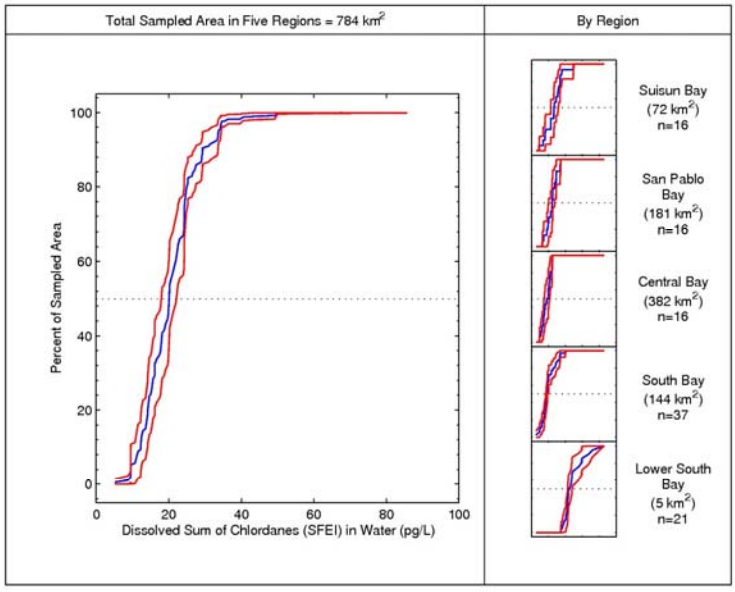
a) Map of dissolved concentrations in water (pg/L) in the six Estuary regions monitored. 106 randomly allocated sites and 22 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (pg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (pg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

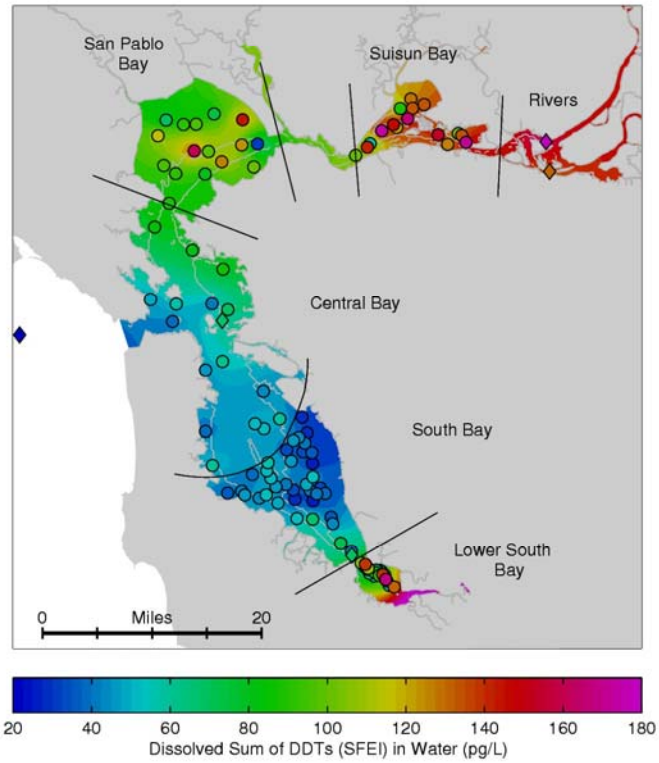
The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of chlordanes (sfei) concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : November 1, 2007 ∘

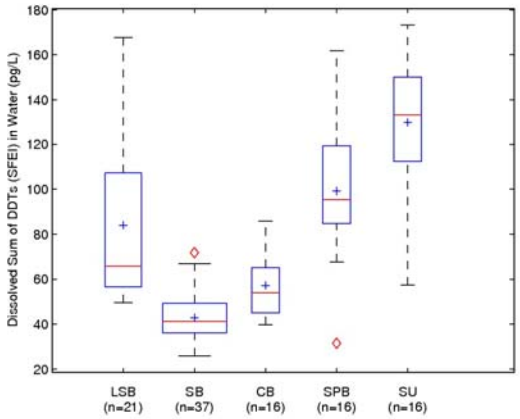
Figure 2.25

Dissolved Sum of DDTs (SFEI) in Water (2002-2006)



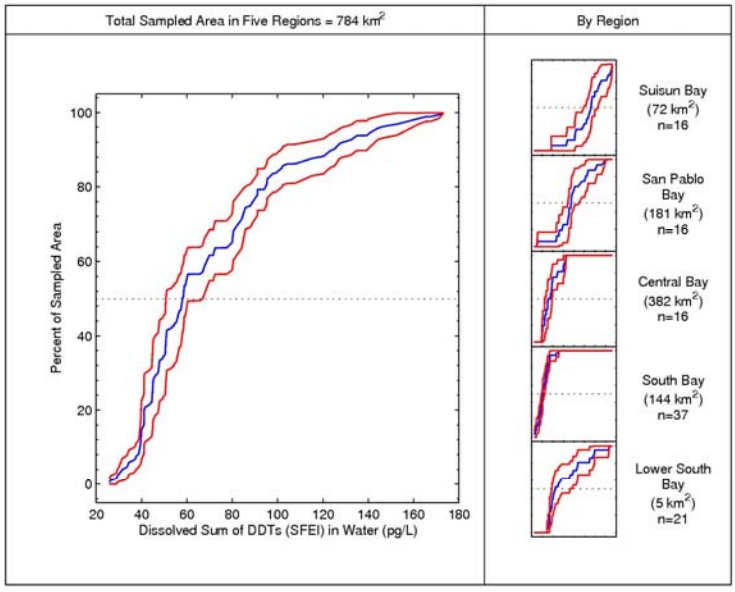
a) Map of dissolved concentrations in water (pg/L) in the six Estuary regions monitored. 106 randomly allocated sites and 25 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (pg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (pg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

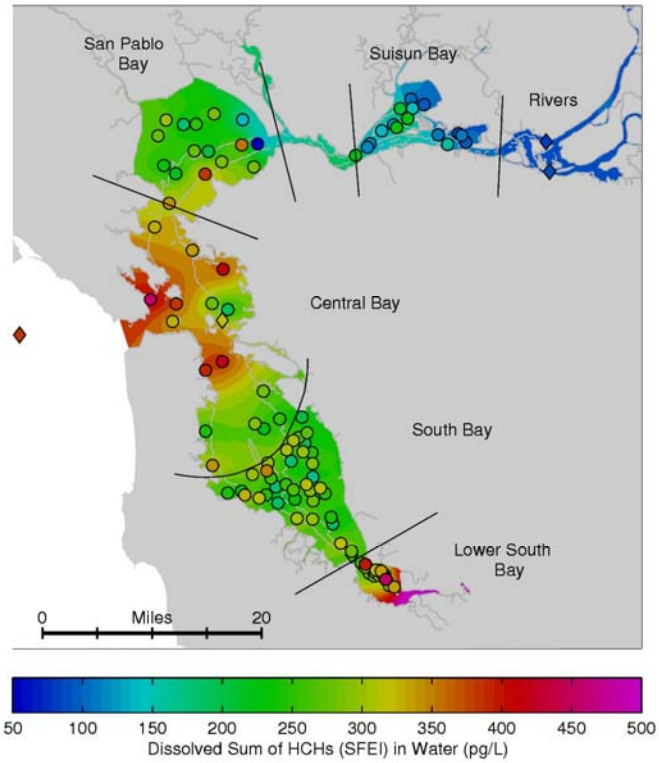
The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of ddts (sfei) concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : November 1, 2007 ∘

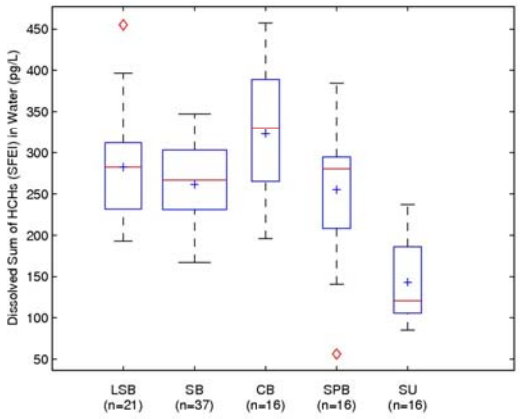
Figure 2.26

Dissolved Sum of HCHs (SFEI) in Water (2002-2006)



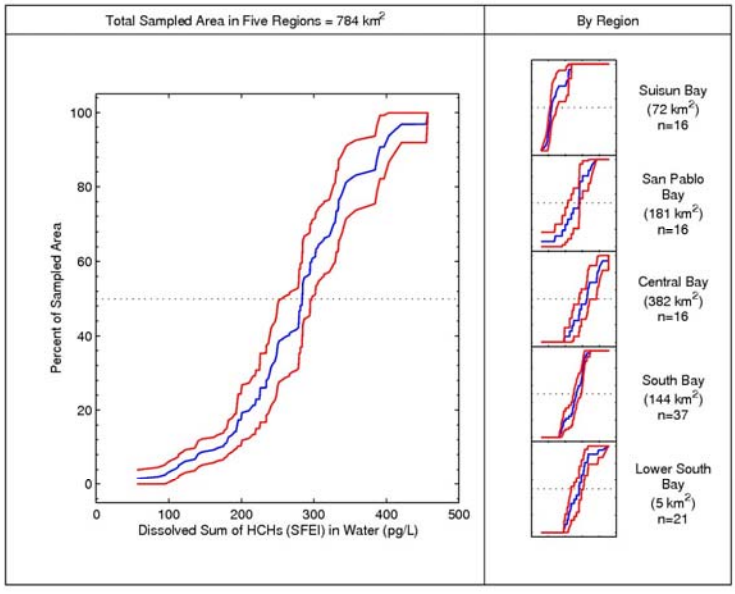
a) Map of dissolved concentrations in water (pg/L) in the six Estuary regions monitored. 106 randomly allocated sites and 25 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (pg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



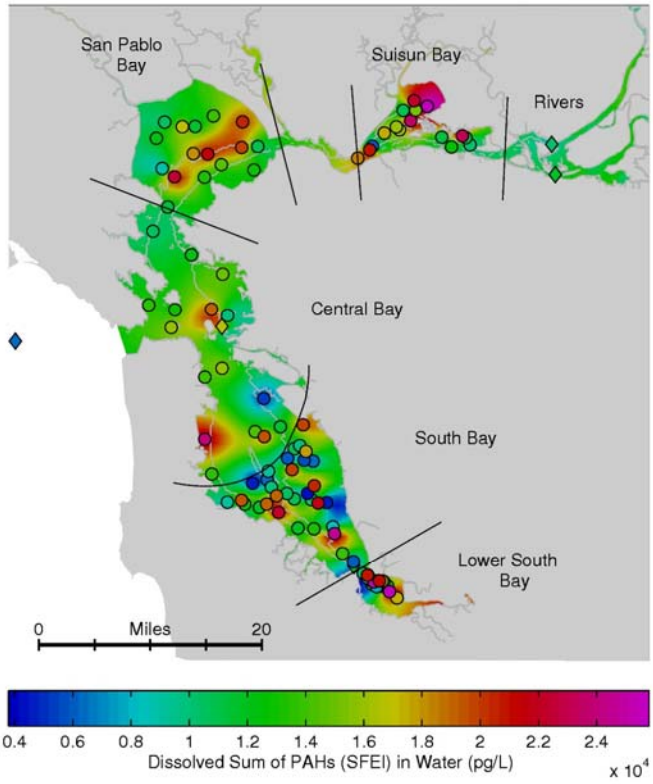
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (pg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of hchs (sfei) concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

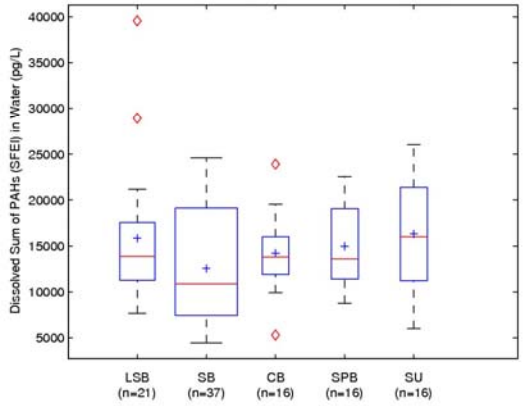
Figure 2.27

Dissolved Sum of PAHs (SFEI) in Water (2002-2006)



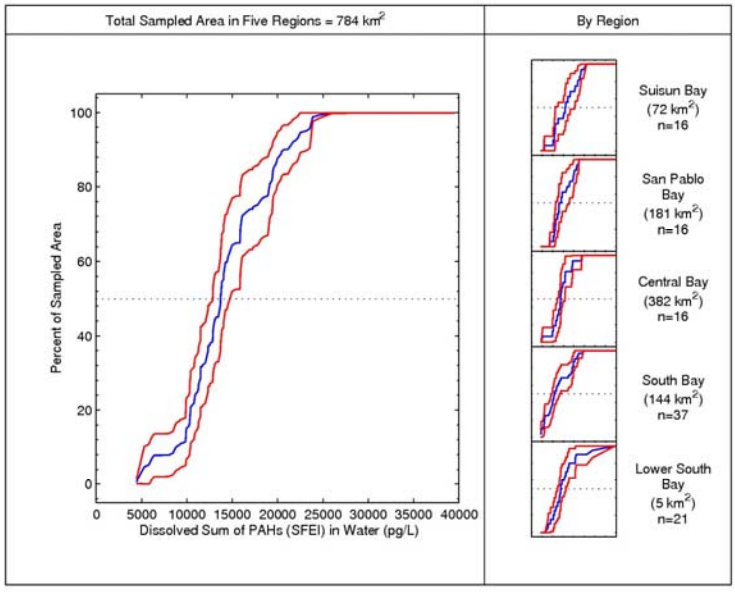
a) Map of dissolved concentrations in water (pg/L) in the six Estuary regions monitored. 106 randomly allocated sites and 25 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (pg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



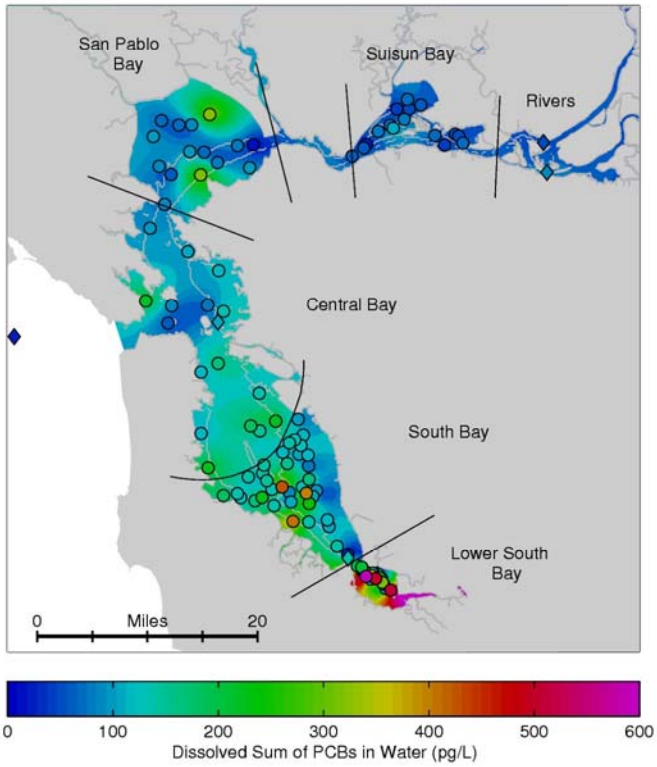
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (pg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of pahs (sfei) concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

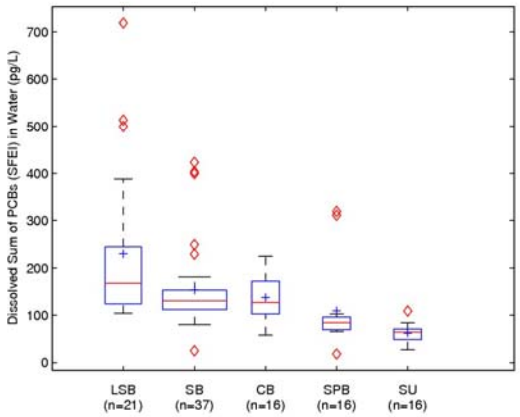
Figure 2.28

Dissolved Sum of PCBs (SFEI) in Water (2002-2006)



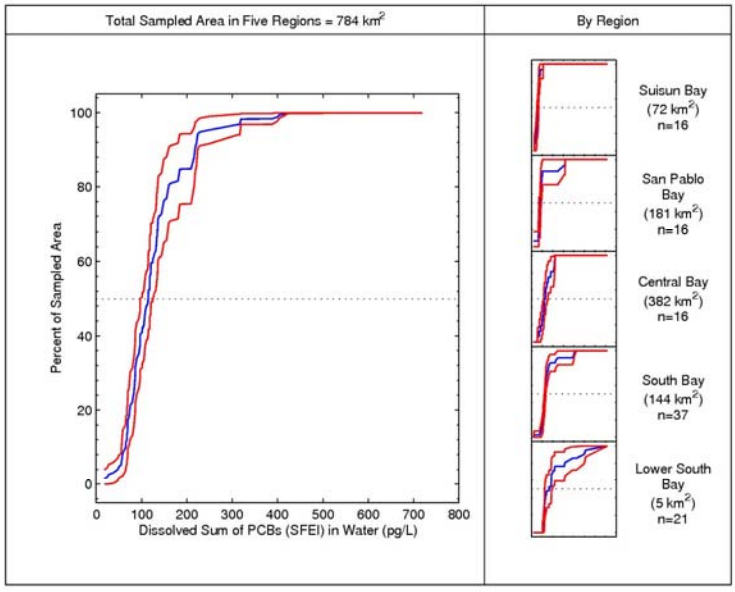
a) Map of dissolved concentrations in water (pg/L) in the six Estuary regions monitored. 106 randomly allocated sites and 25 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of dissolved concentrations in water (pg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



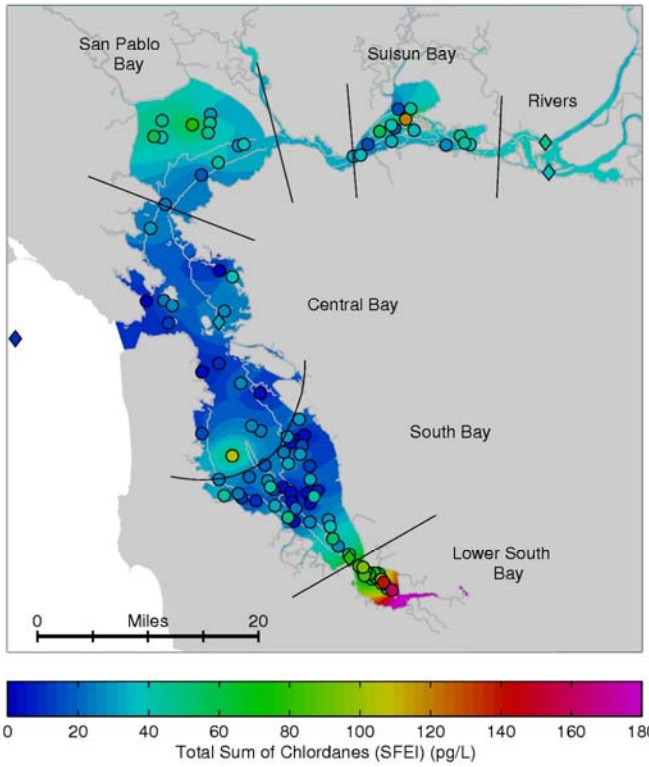
c) Cumulative distribution functions (CDFs) for dissolved concentrations in water (pg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of pcbs (sfei) concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

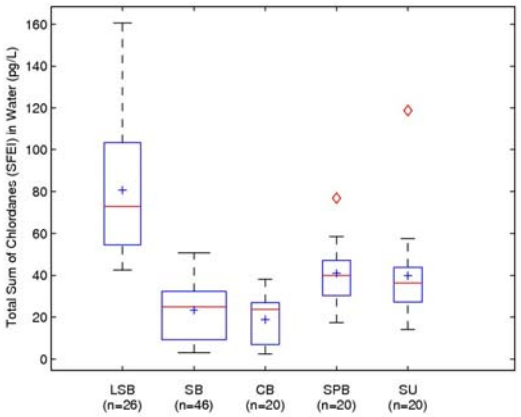
Figure 2.29

Total Sum of Chlordanes (SFEI) in Water (2002-2006)



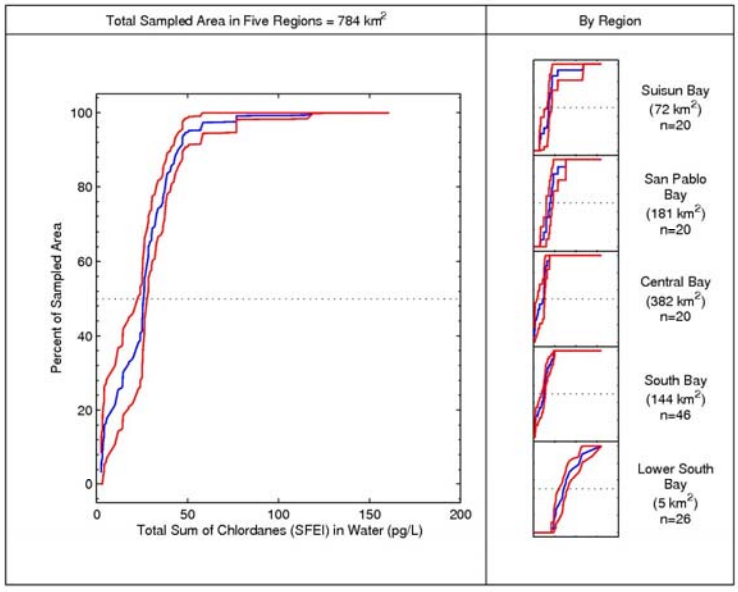
a) Map of total concentrations in water (pg/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (pg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for total concentrations in water (pg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

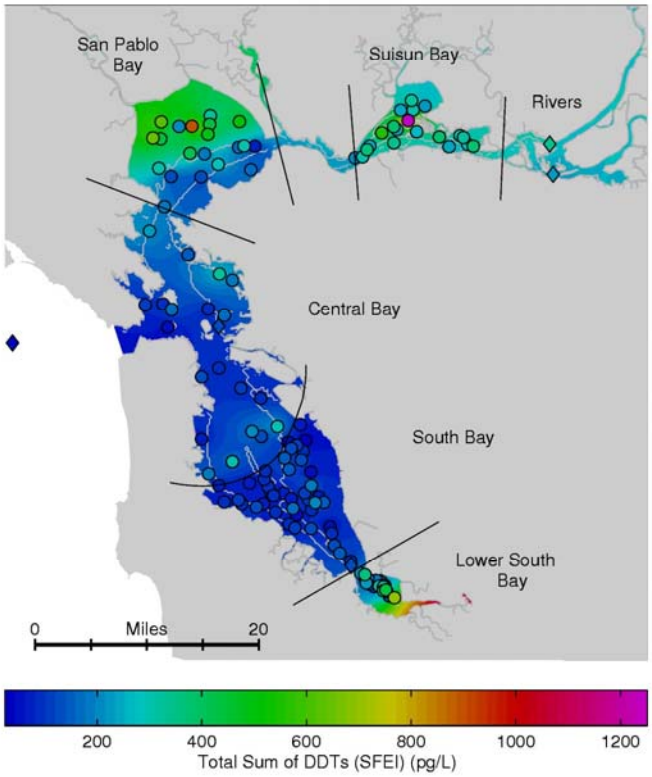
The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of chlordanes (sfei) concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : November 30, 2007 ∘

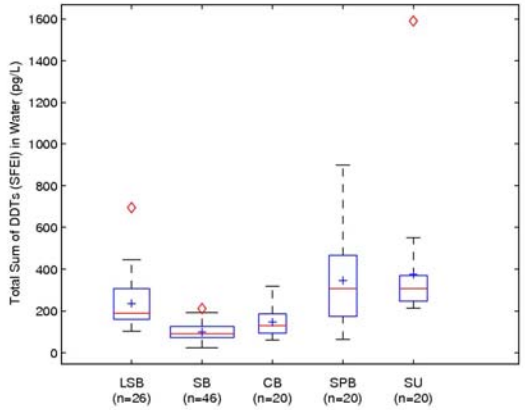
Figure 2.30

Total Sum of DDTs (SFEI) in Water (2002-2006)



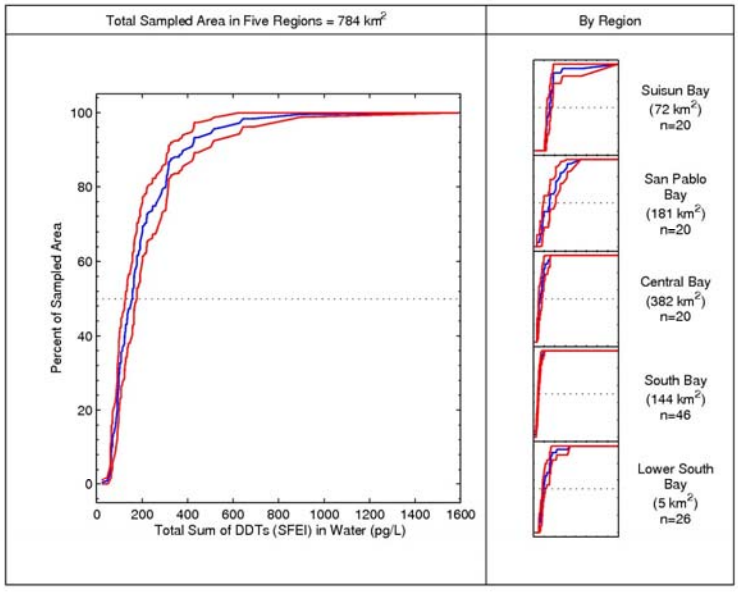
a) Map of total concentrations in water (pg/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. **Only results that passed QA/QC are reported.** Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (pg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for total concentrations in water (pg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

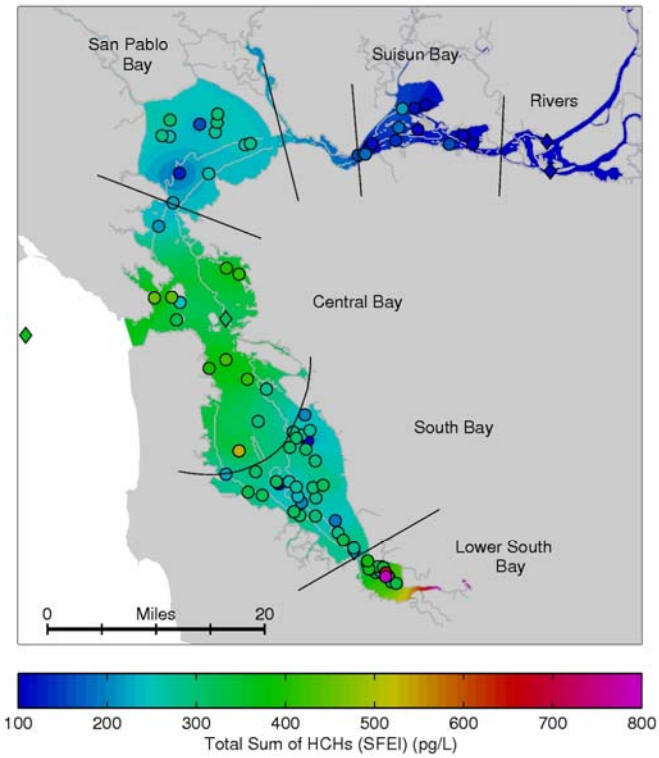
The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of ddts (sfei) concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : November 30, 2007 ∘

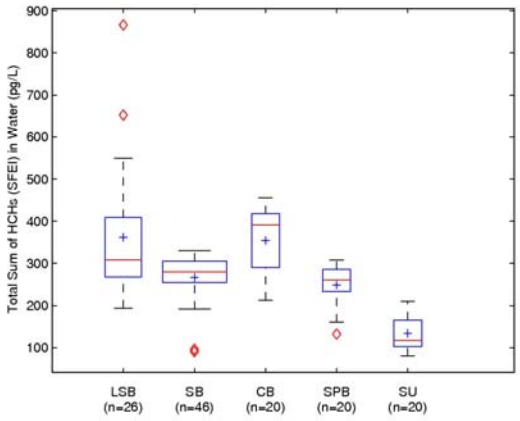
Figure 2.31

Total Sum of HCHs (SFEI) in Water (2002-2006)



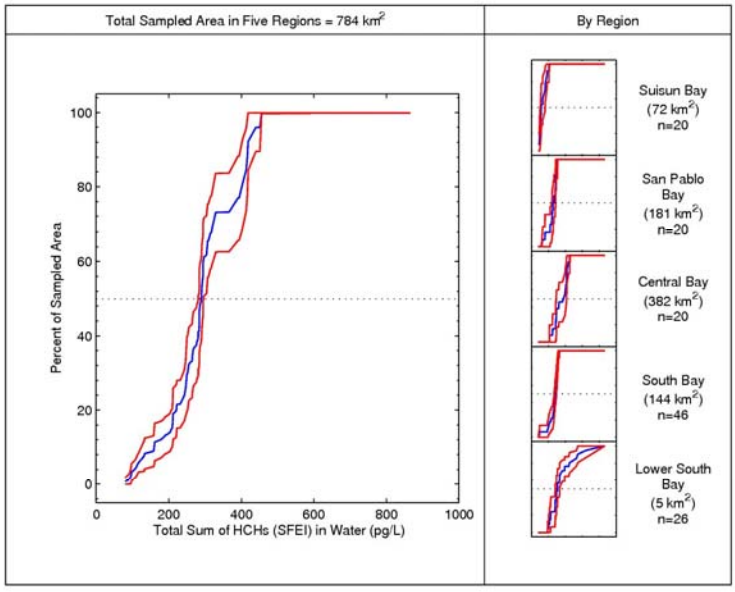
a) Map of total concentrations in water (pg/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (pg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



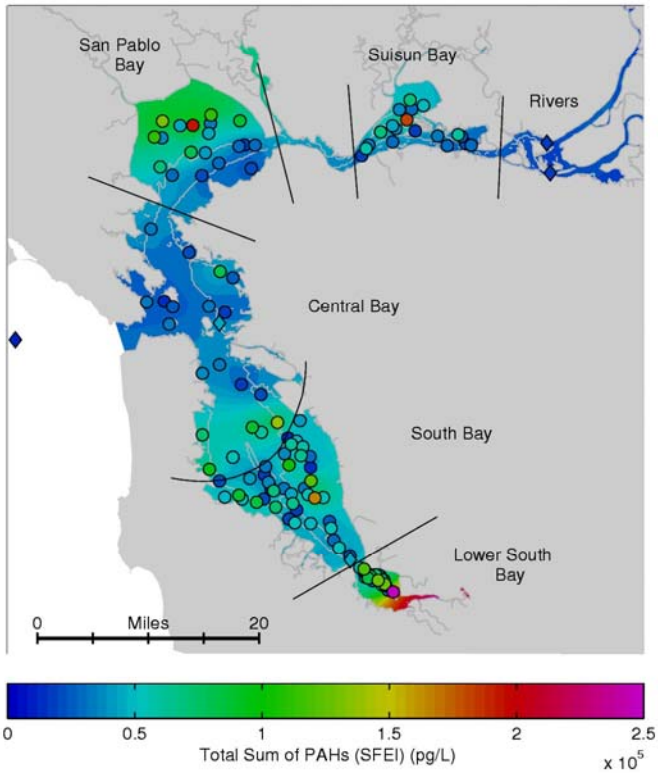
c) Cumulative distribution functions (CDFs) for total concentrations in water (pg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of hchs (sfei) concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

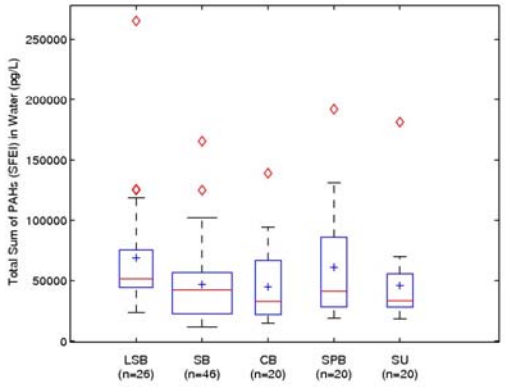
Figure 2.32

Total Sum of PAHs (SFEI) in Water (2002-2006)



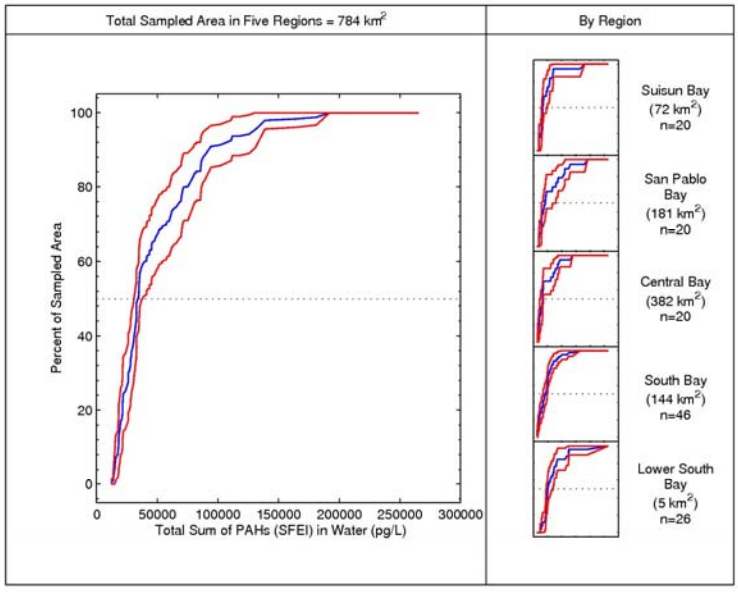
a) Map of total concentrations in water (pg/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. **Only results that passed QA/QC are reported.** Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (pg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



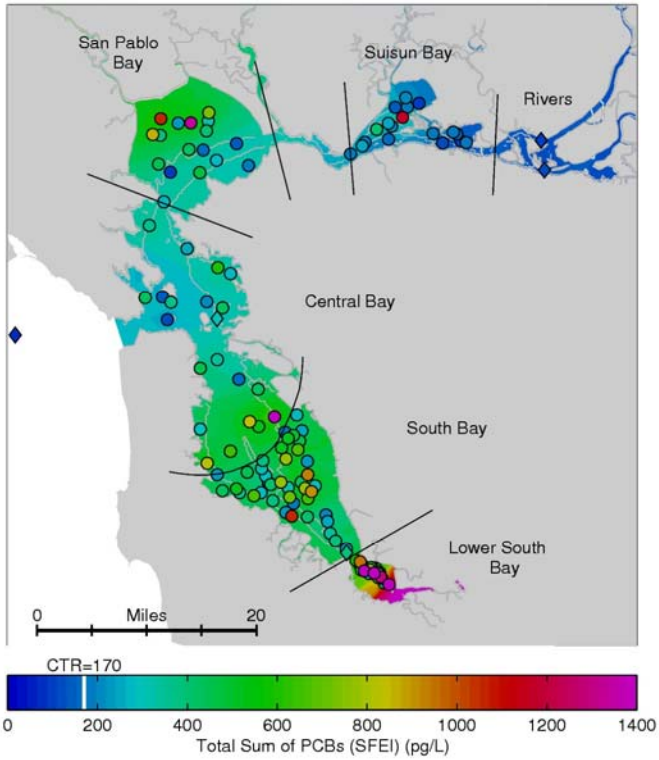
c) Cumulative distribution functions (CDFs) for total concentrations in water (pg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of pahs (sfei) concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

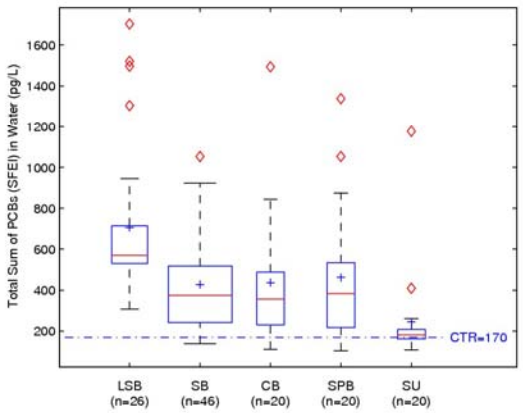
Figure 2.33

Total Sum of PCBs (SFEI) in Water (2002-2006)



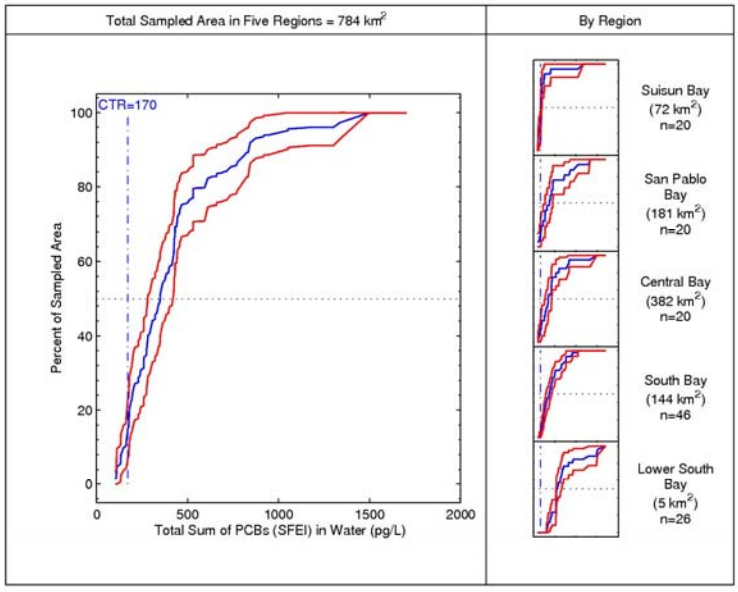
a) Map of total concentrations in water (pg/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (pg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for total concentrations in water (pg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

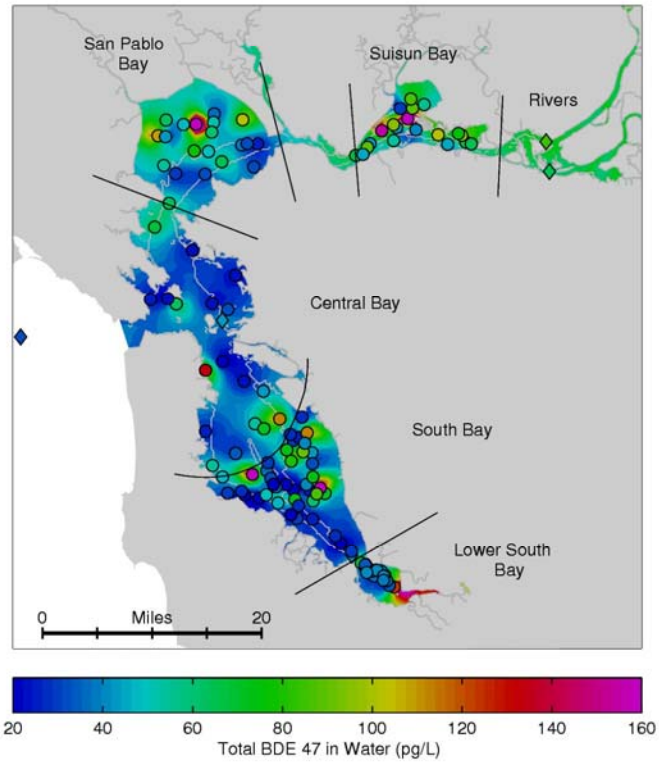
The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of pcbs (sfei) concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : November 30, 2007 ∘

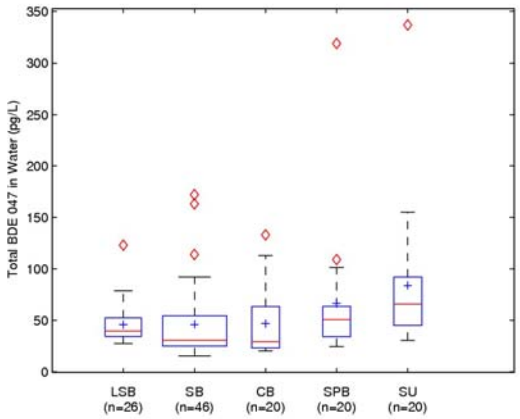
Figure 2.34

Total BDE 047 in Water (2002-2006)



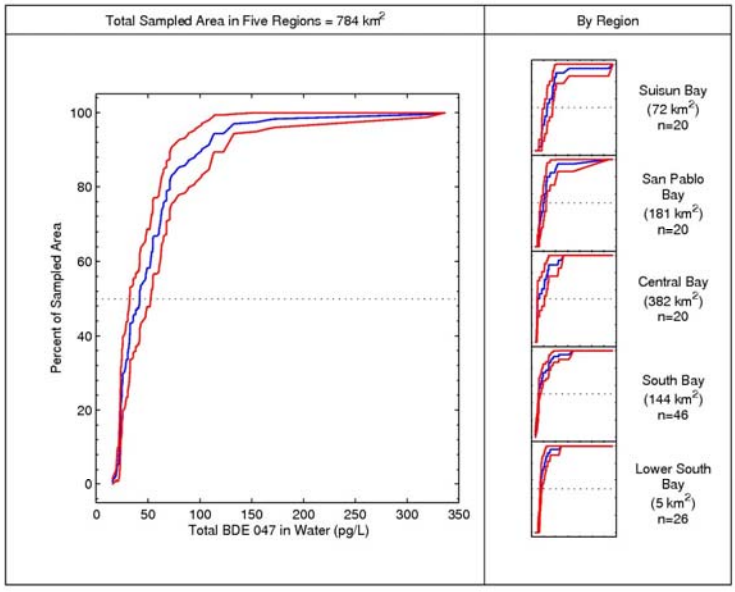
a) Map of total concentrations in water (pg/L) in the six Estuary regions monitored. 132 randomly allocated sites and 27 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of total concentrations in water (pg/L) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for total concentrations in water (pg/L) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus bde 047 concentrations in water.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

Figure 2.35

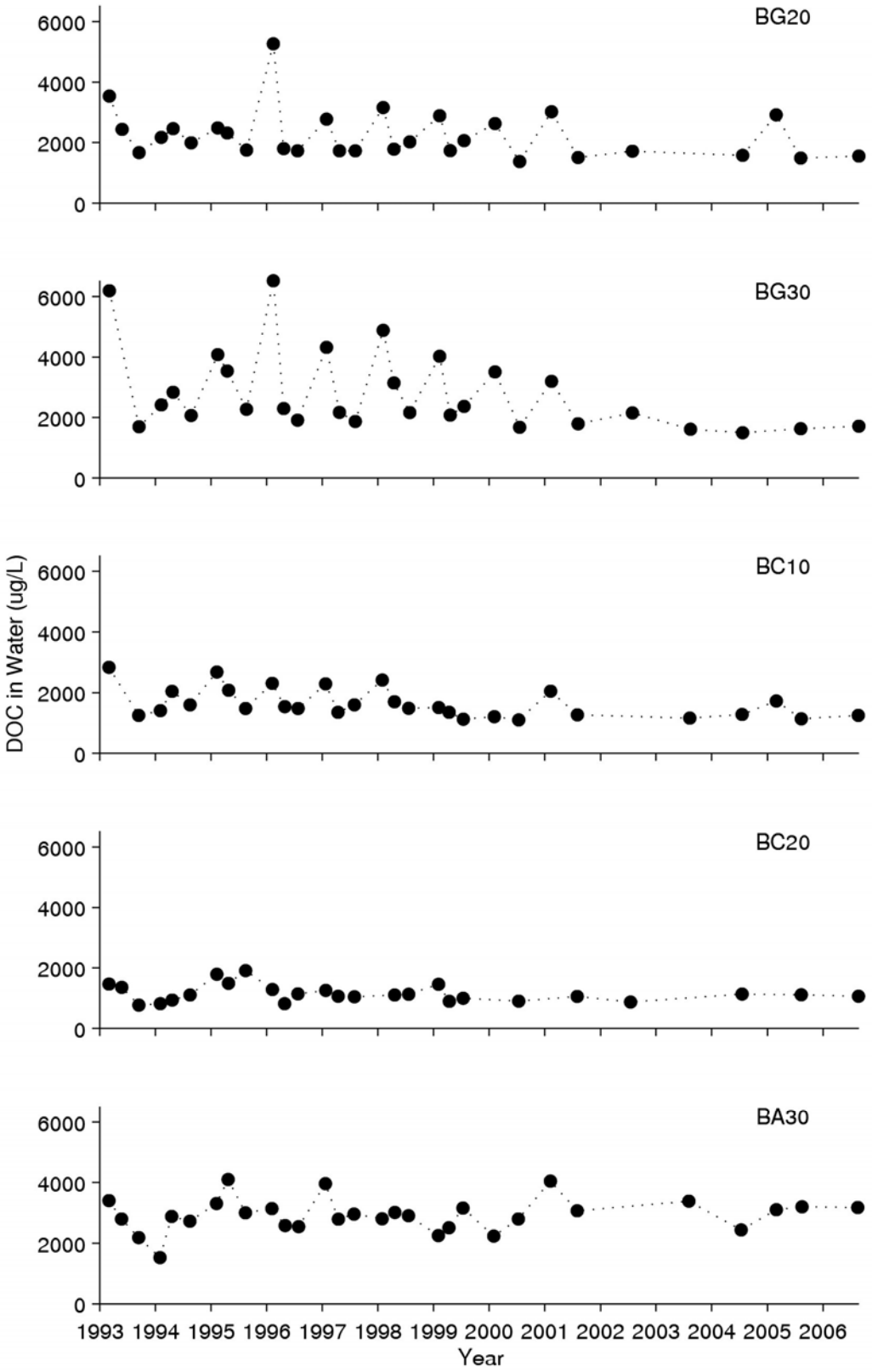


Figure 2.36. Time series plots for dissolved organic carbon (DOC) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

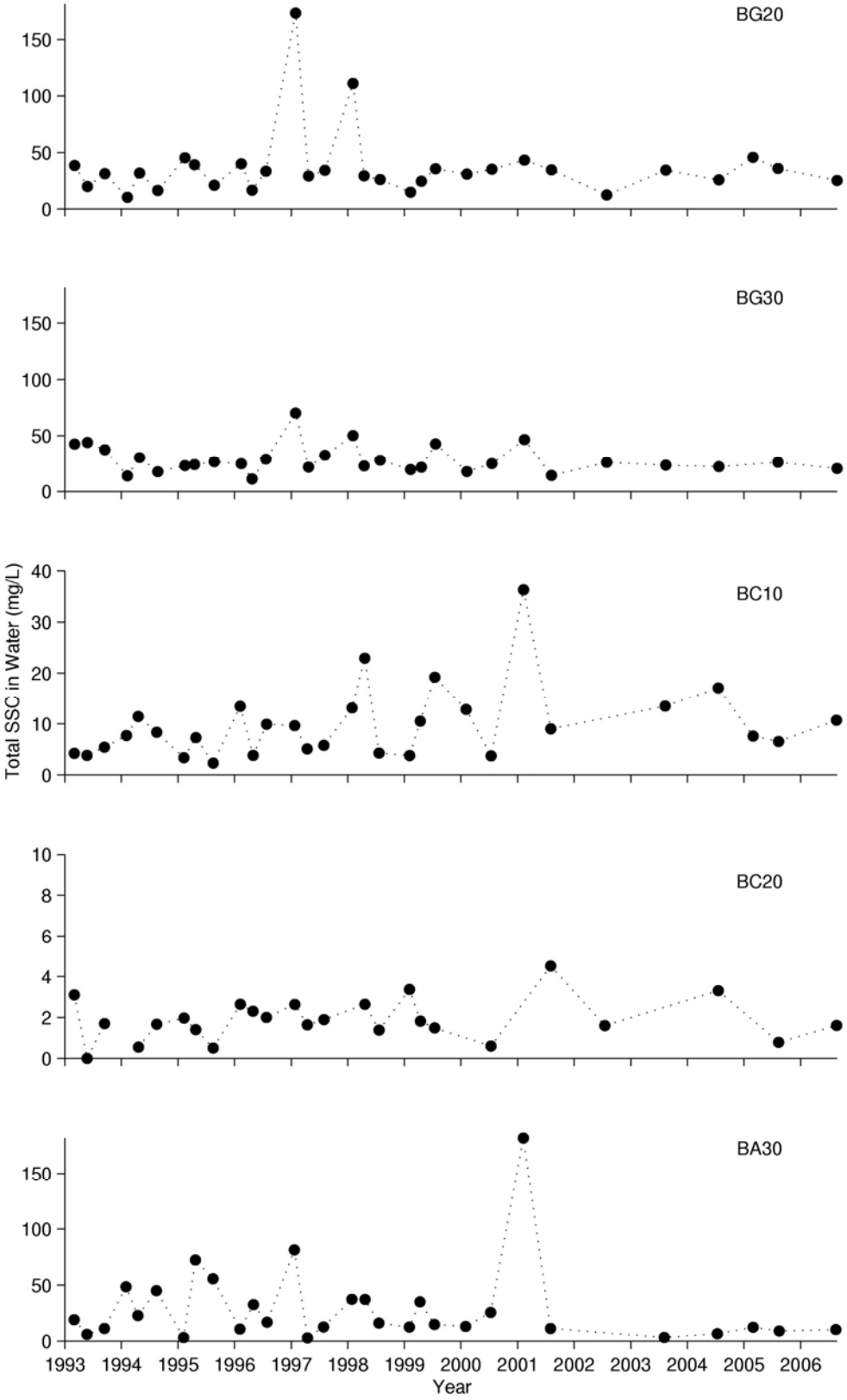


Figure 2.37. Time series plots for suspended sediment concentration (SSC) in water (mg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

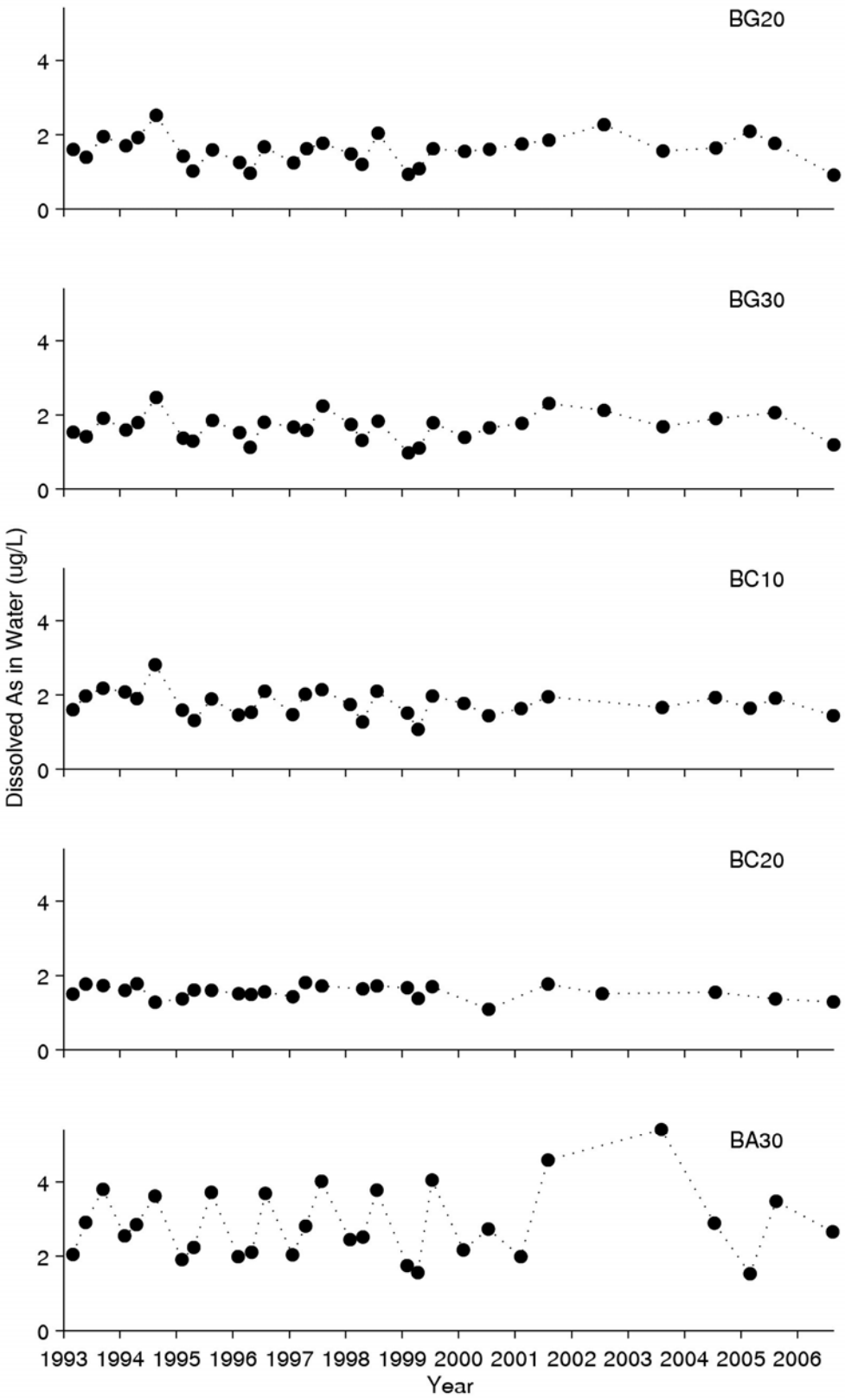


Figure 2.38. Time series plots for dissolved arsenic (As) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

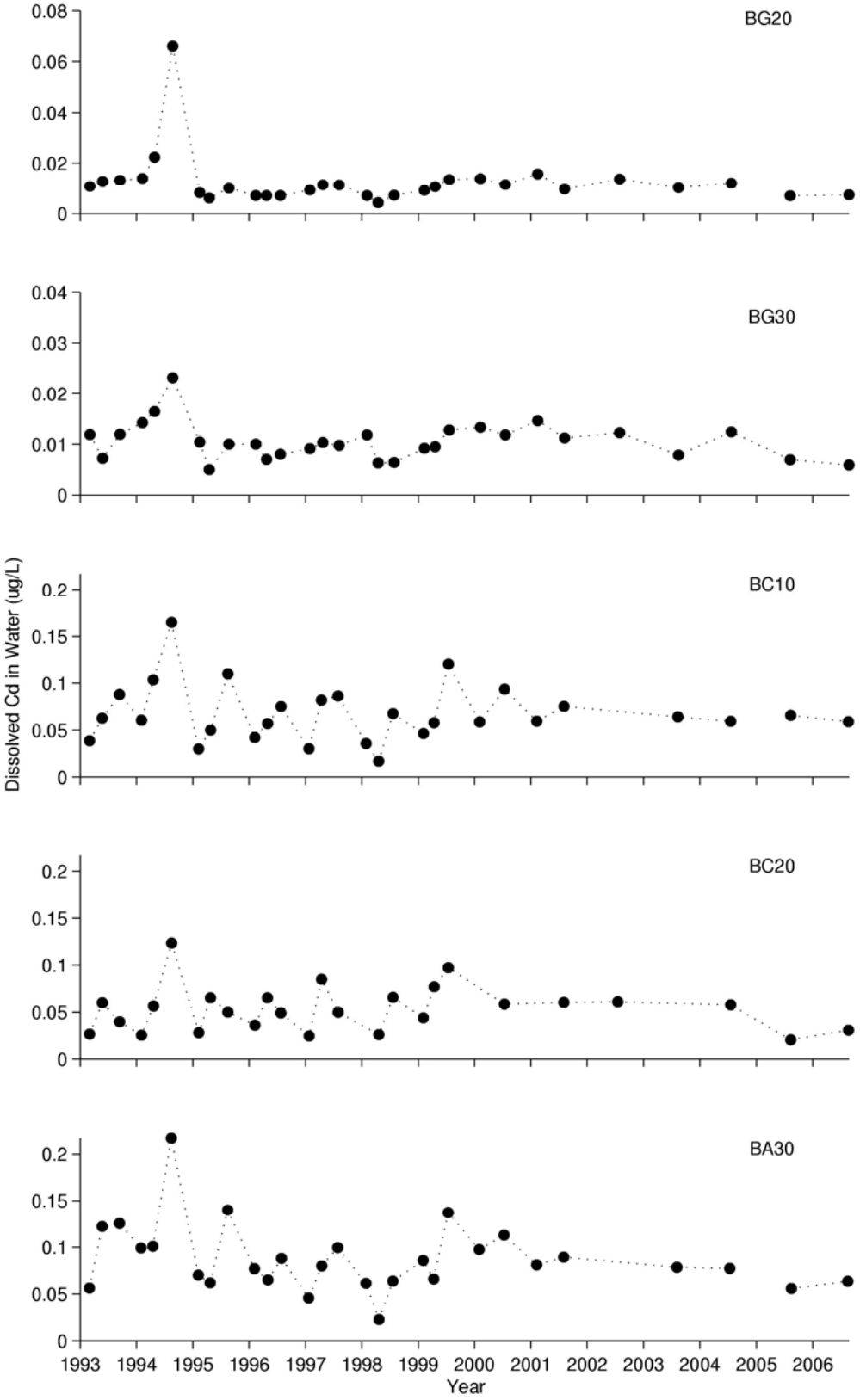


Figure 2.39. Time series plots for dissolved cadmium (Cd) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

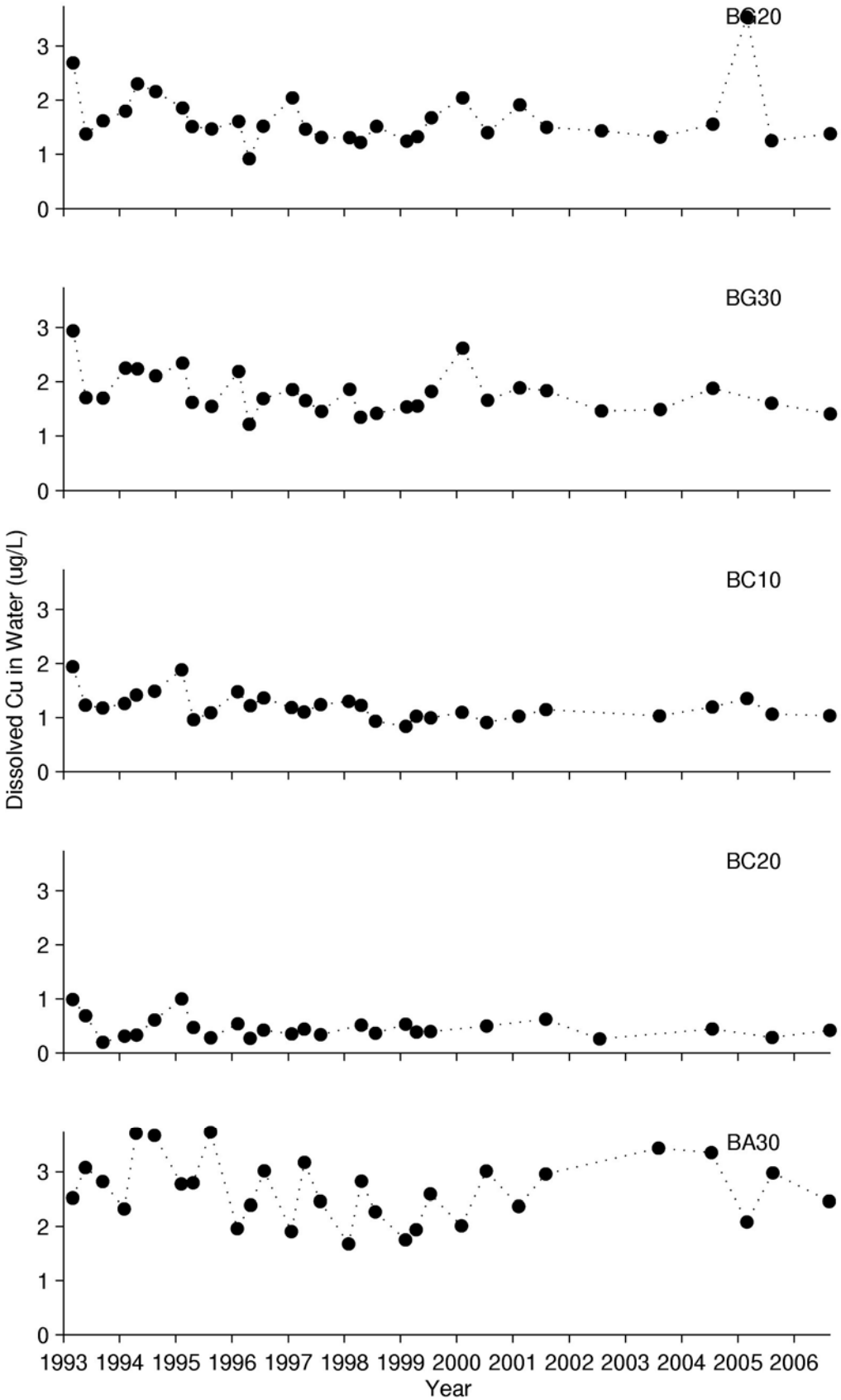


Figure 2.40. Time series plots for dissolved copper (Cu) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

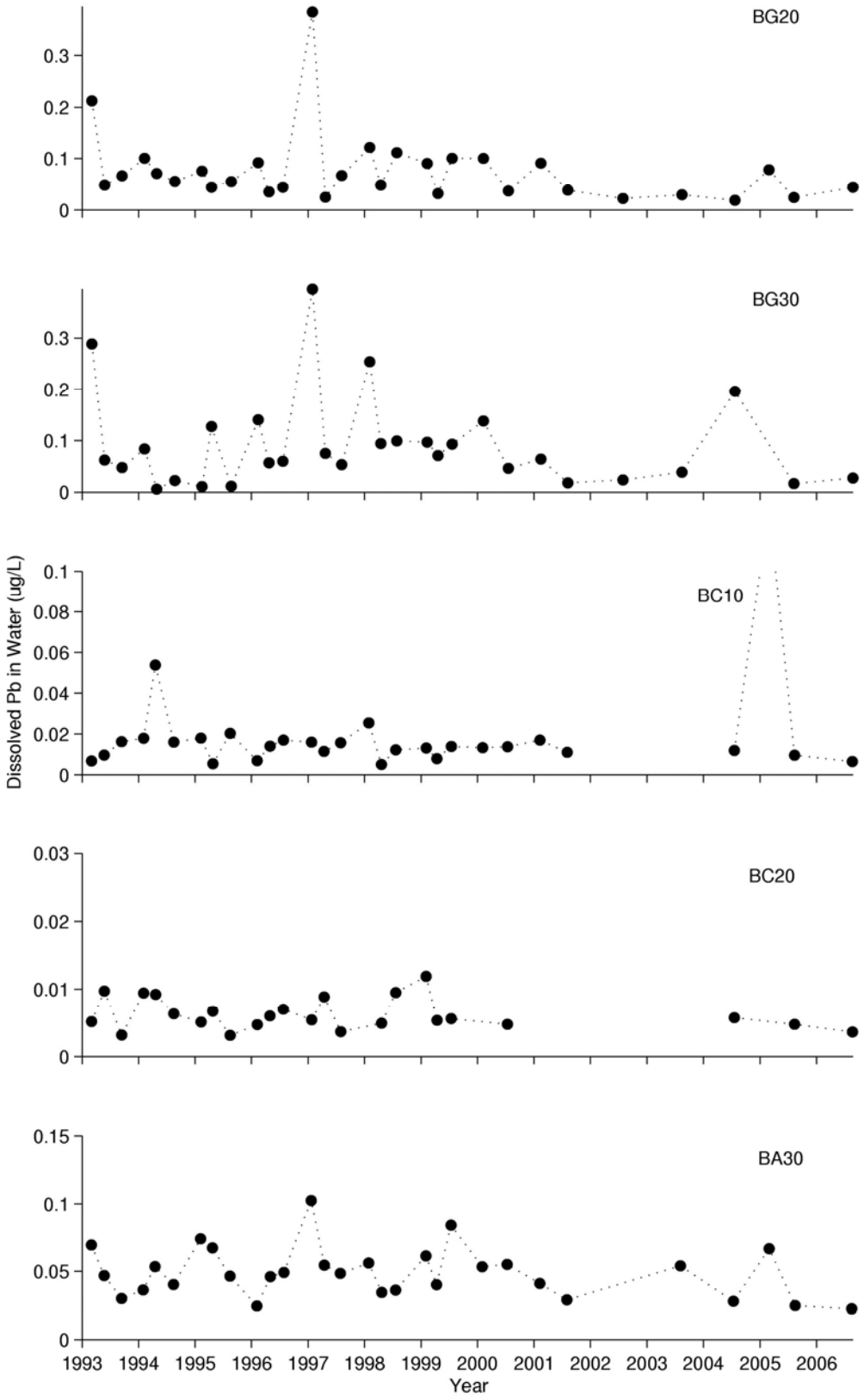


Figure 2.41. Time series plots for dissolved lead (Pb) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

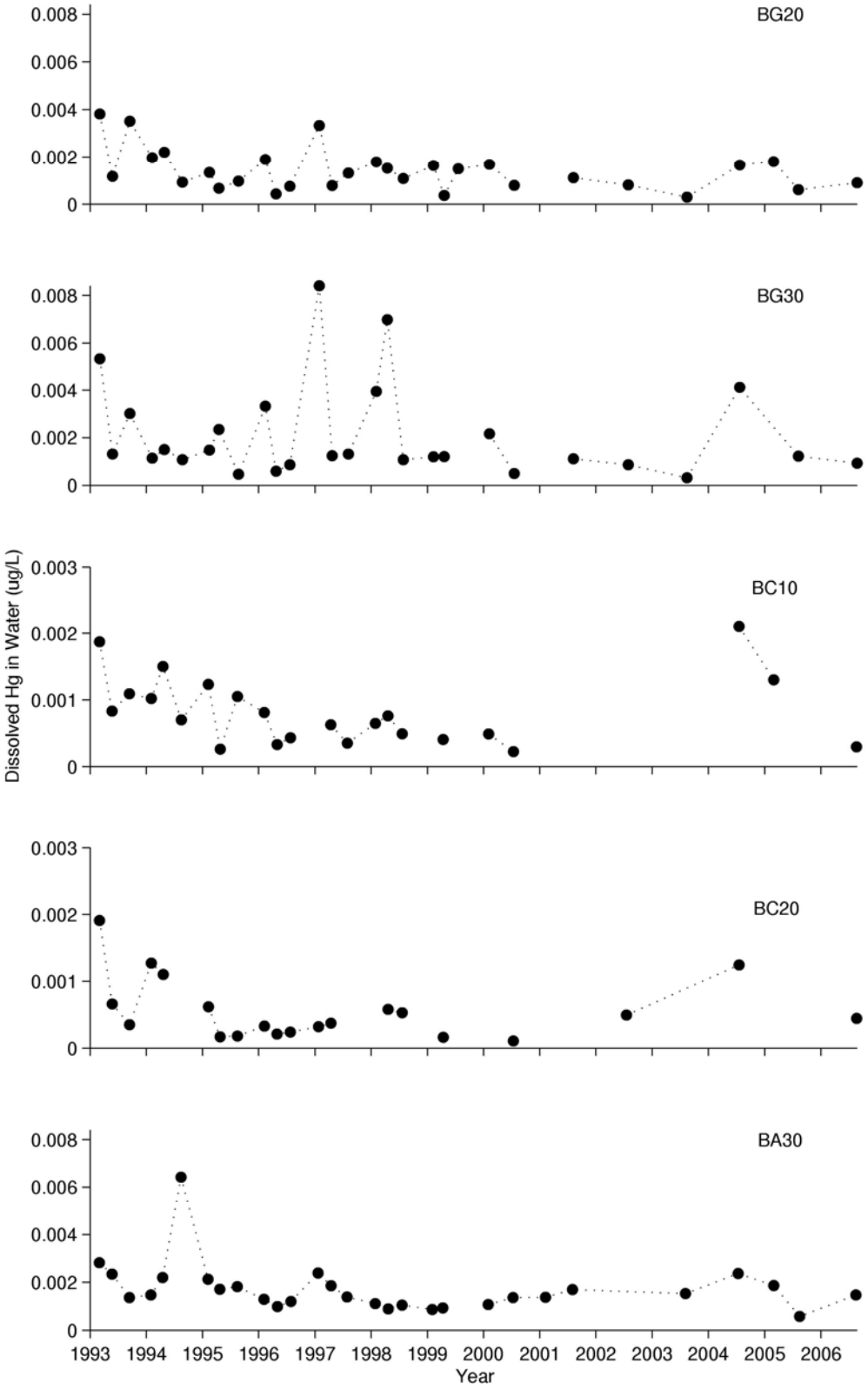


Figure 2.42. Time series plots for dissolved mercury (Hg) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

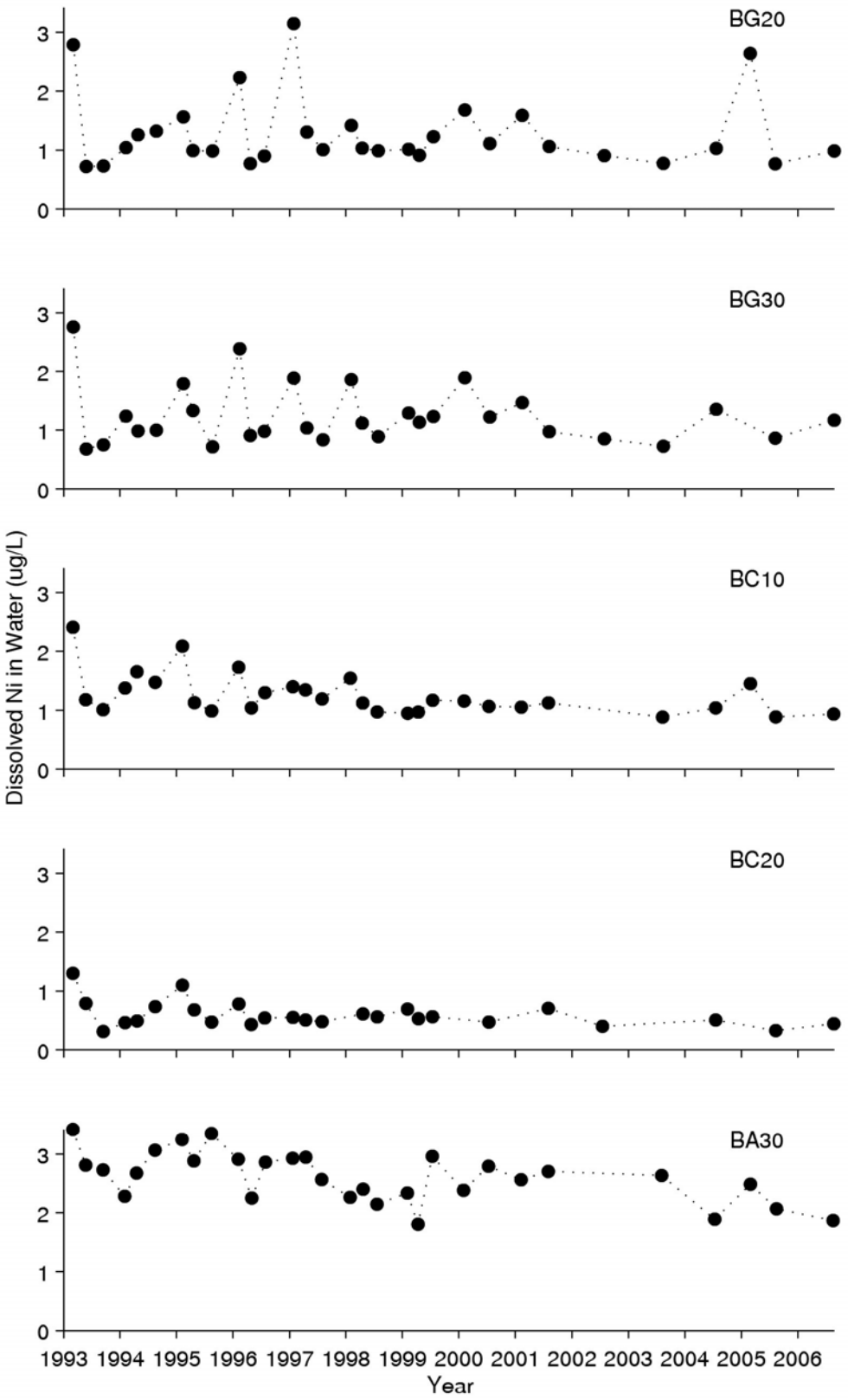


Figure 2.43. Time series plots for dissolved nickel (Ni) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

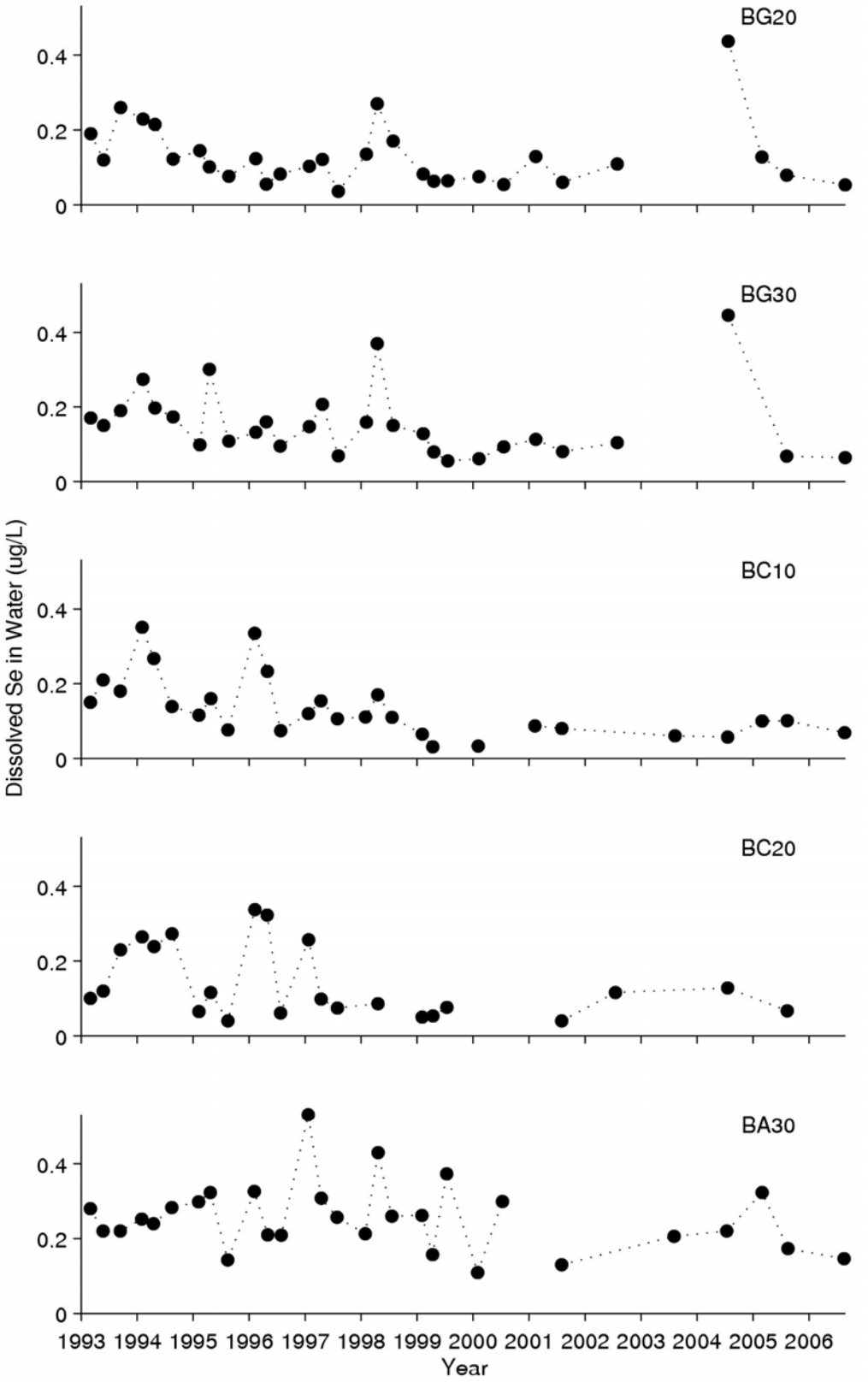


Figure 2.44. Time series plots for dissolved selenium (Se) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

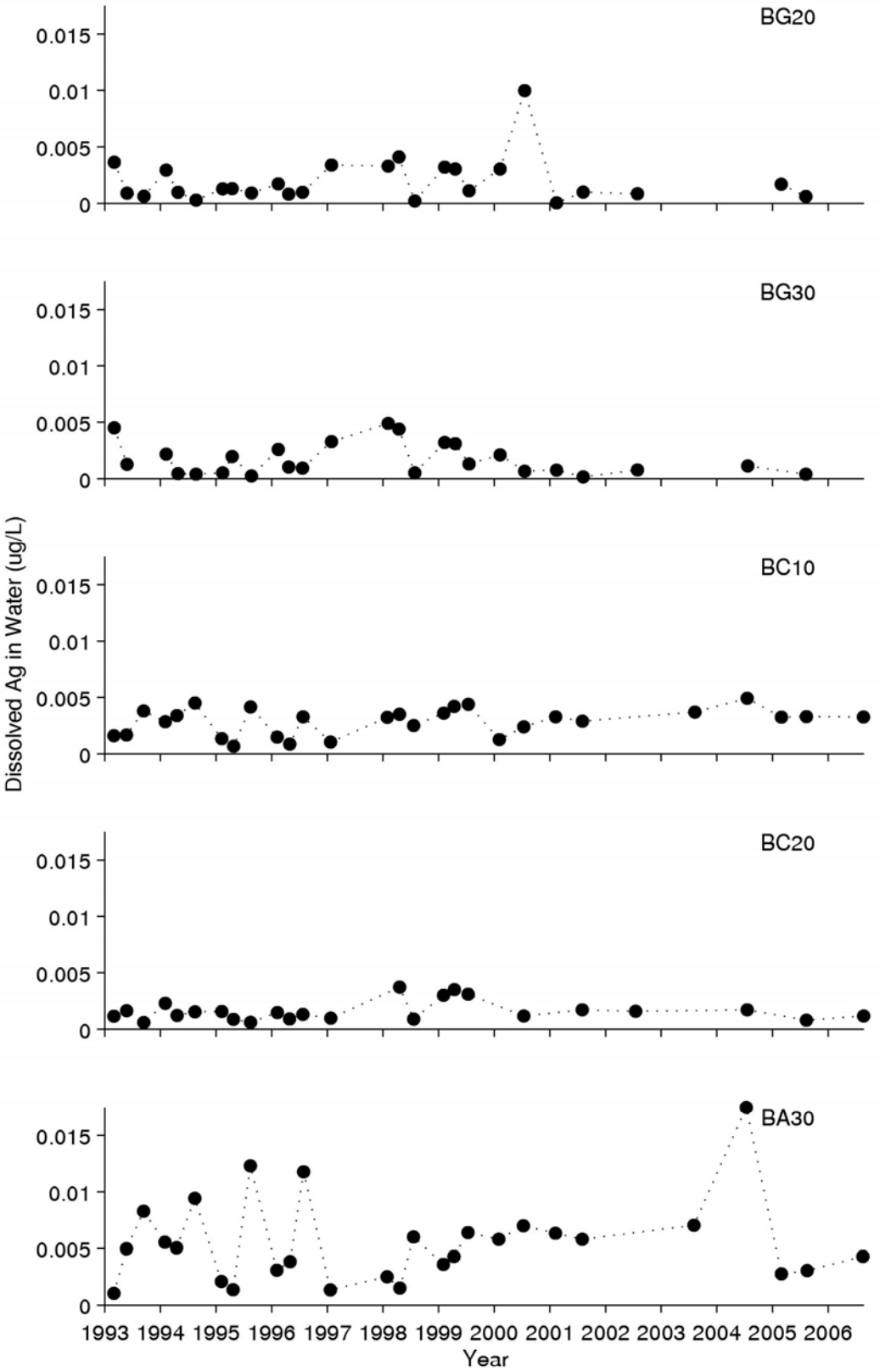


Figure 2.45. Time series plots for dissolved silver (Ag) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

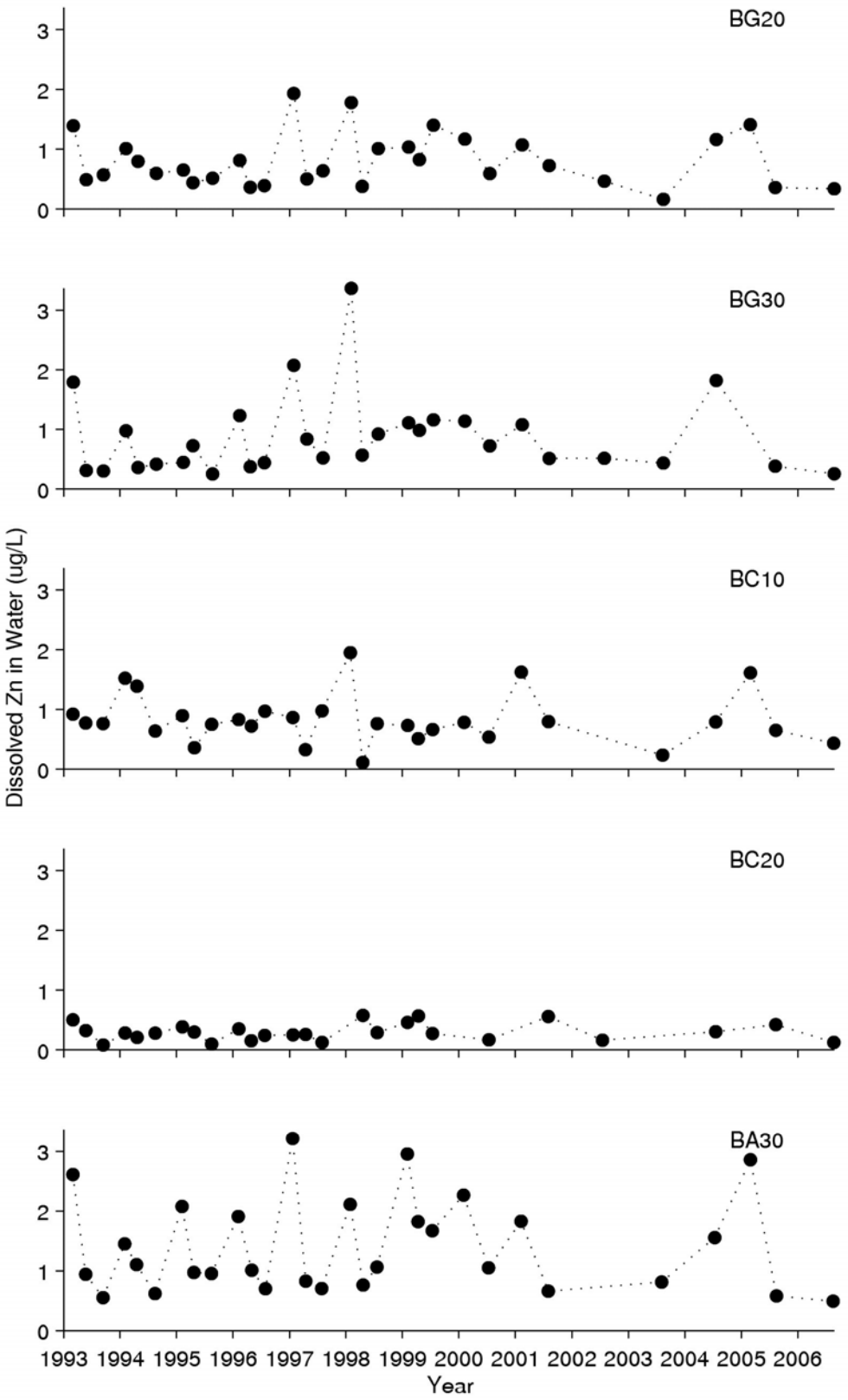


Figure 2.46. Time series plots for dissolved zinc (Zn) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

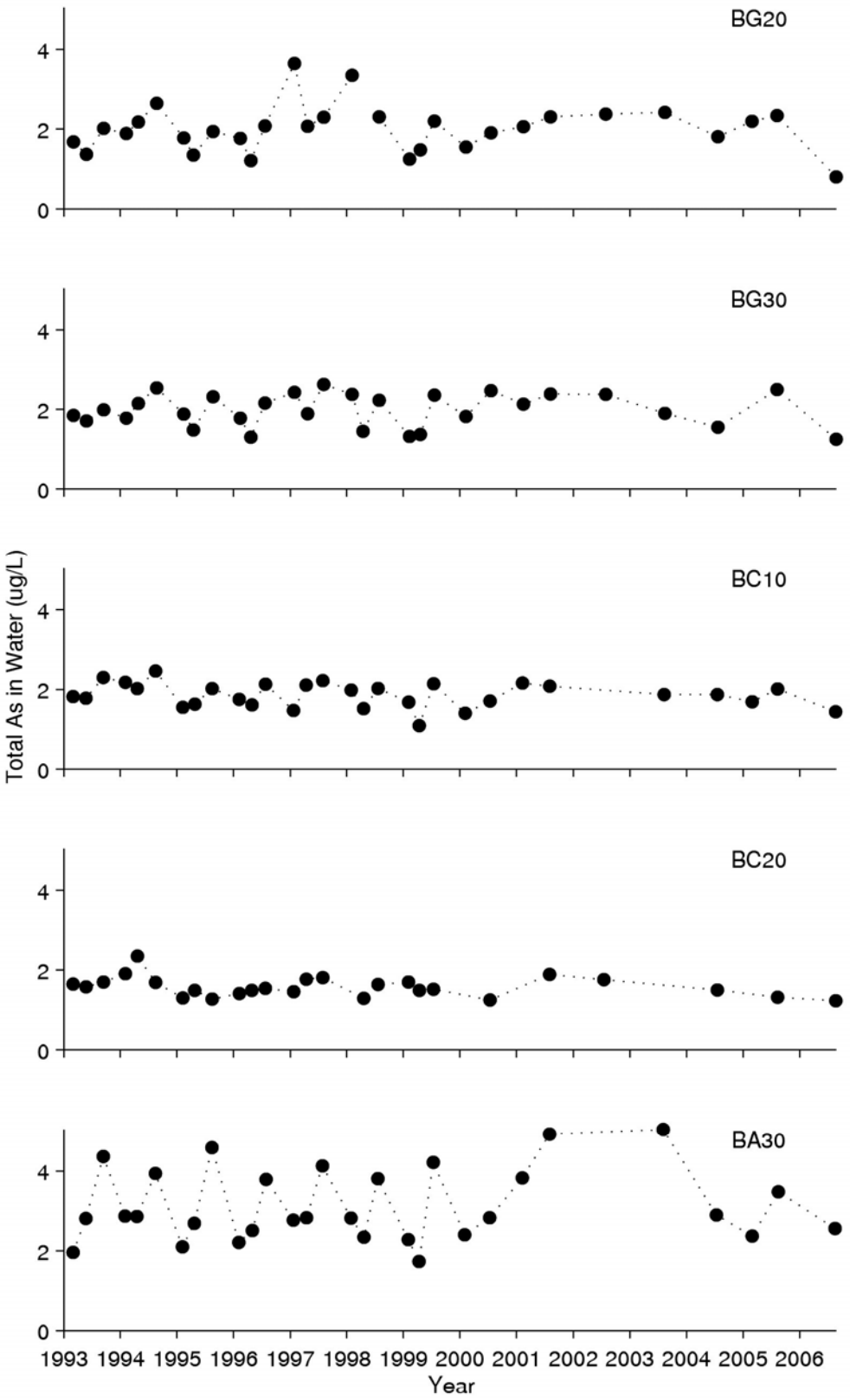


Figure 2.47. Time series plots for total arsenic (As) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

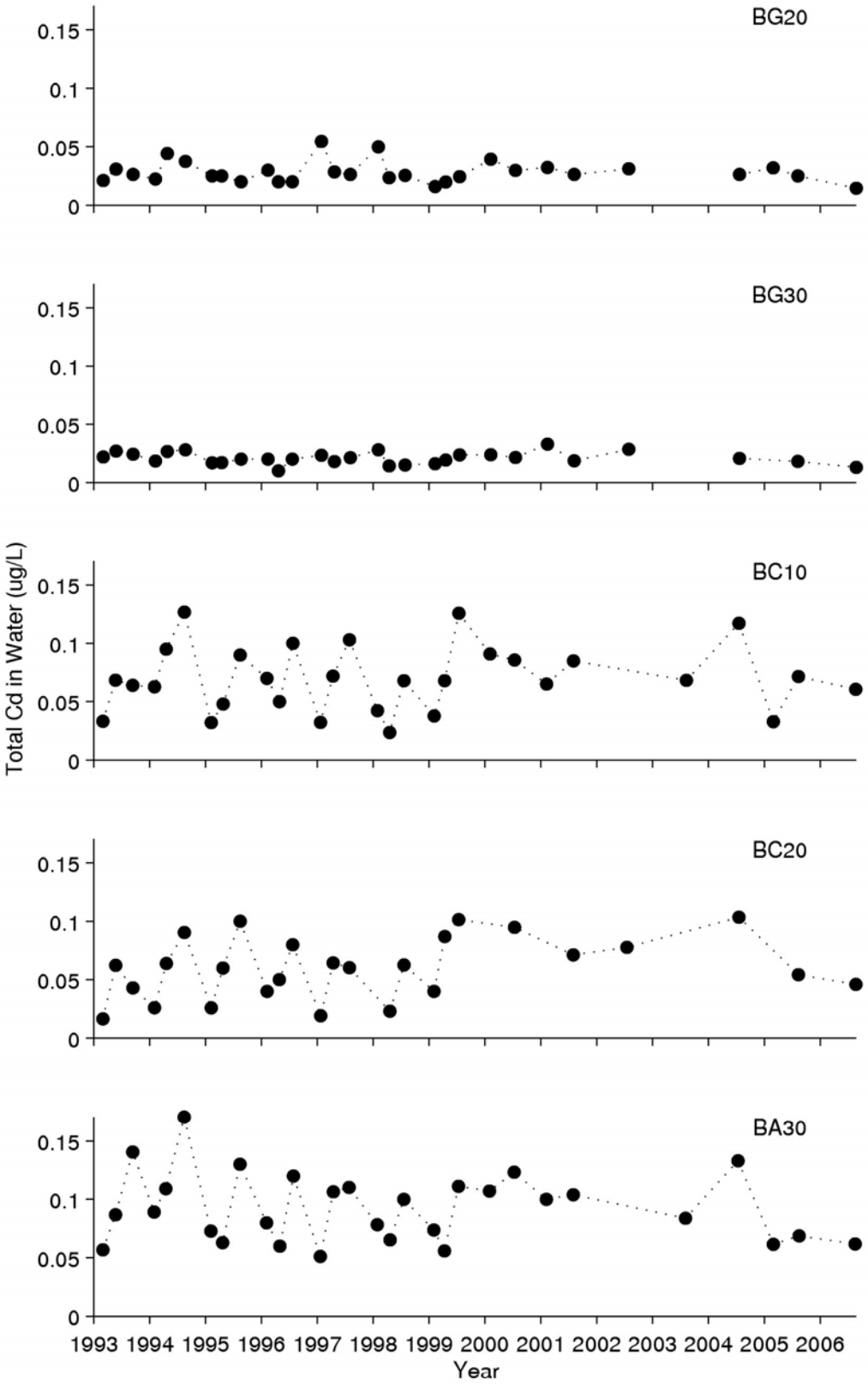


Figure 2.48. Time series plots for total cadmium (Cd) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

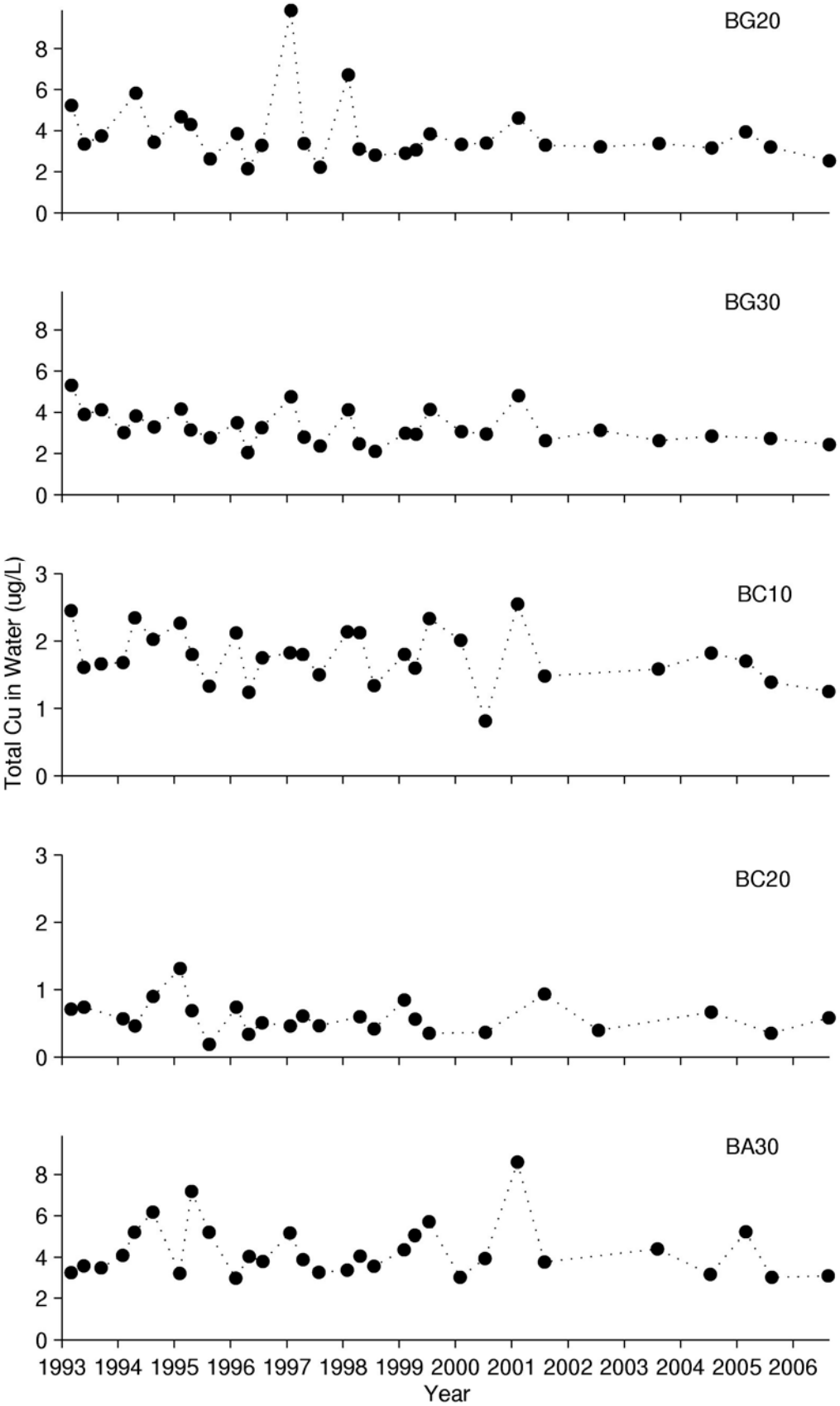


Figure 2.49. Time series plots for total copper (Cu) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

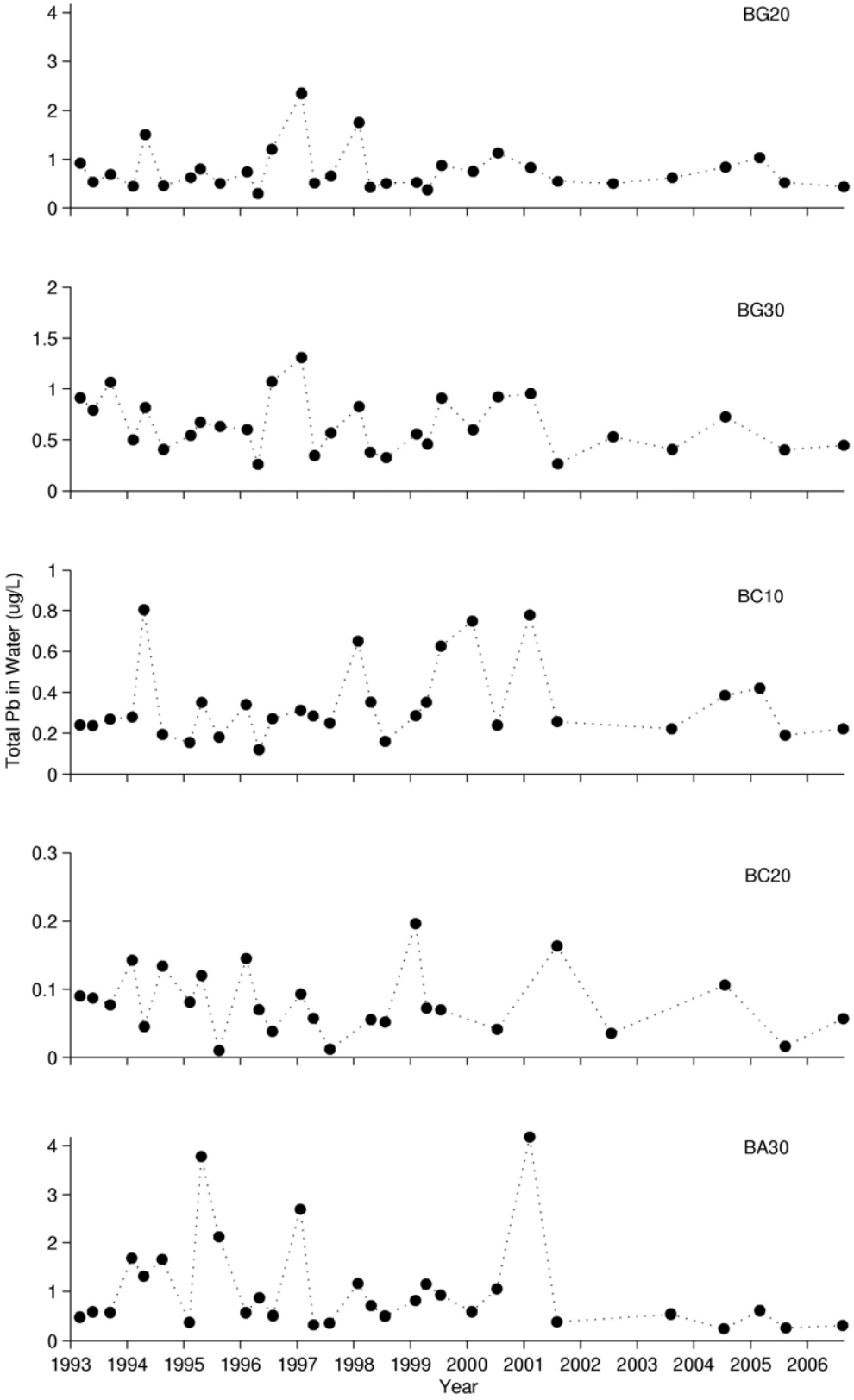


Figure 2.50. Time series plots for total lead (Pb) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

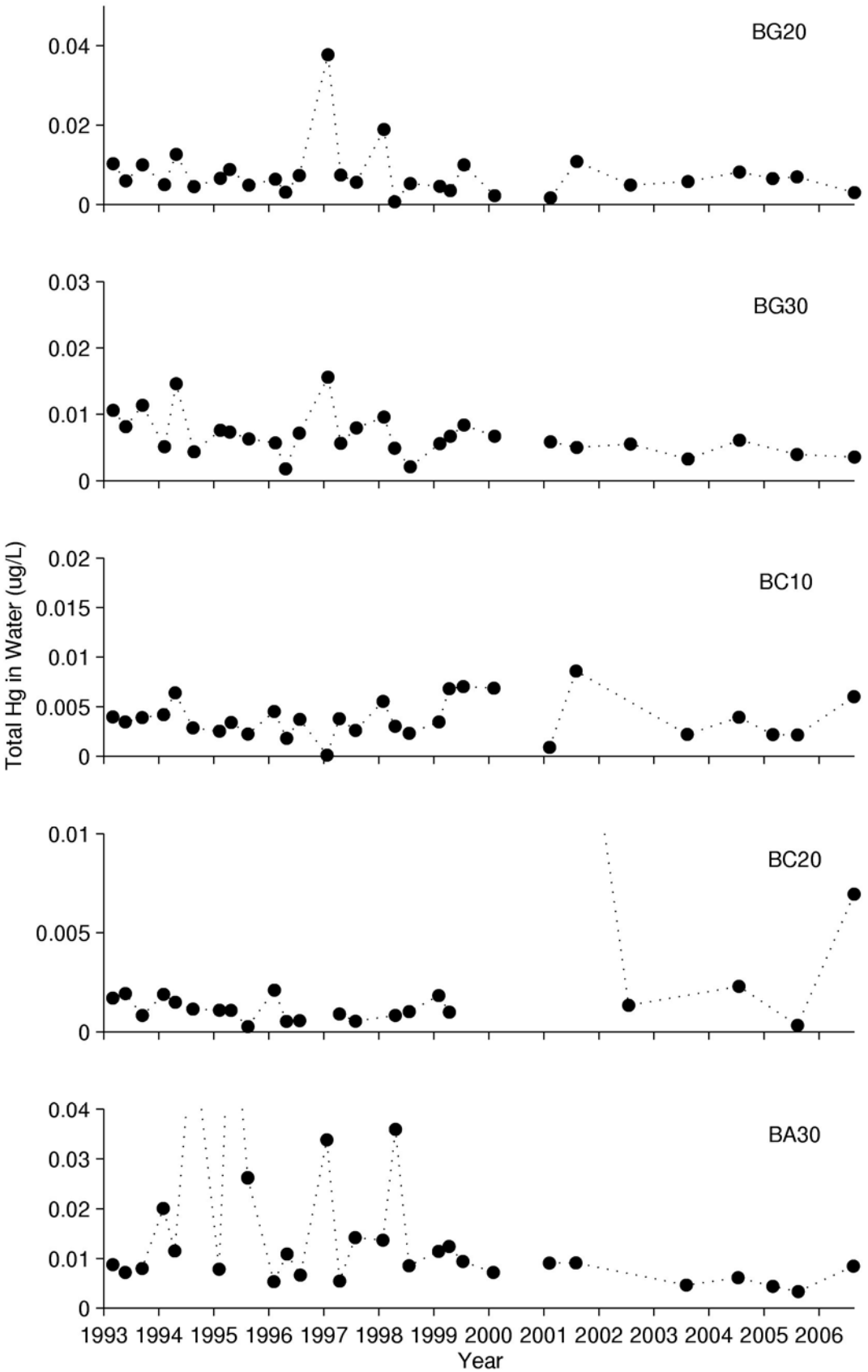


Figure 2.51. Time series plots for total mercury (Hg) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

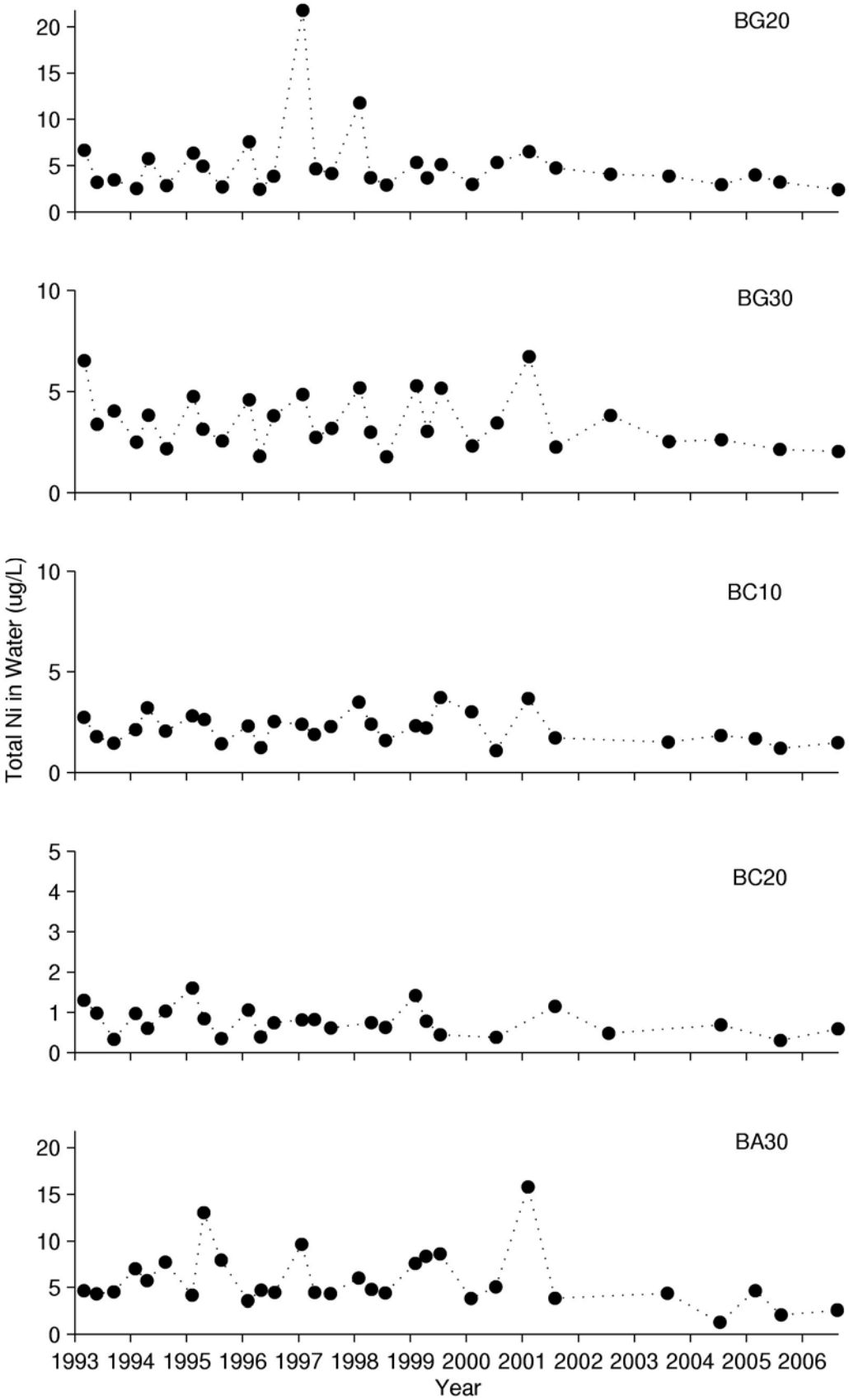


Figure 2.52. Time series plots for total nickel (Ni) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

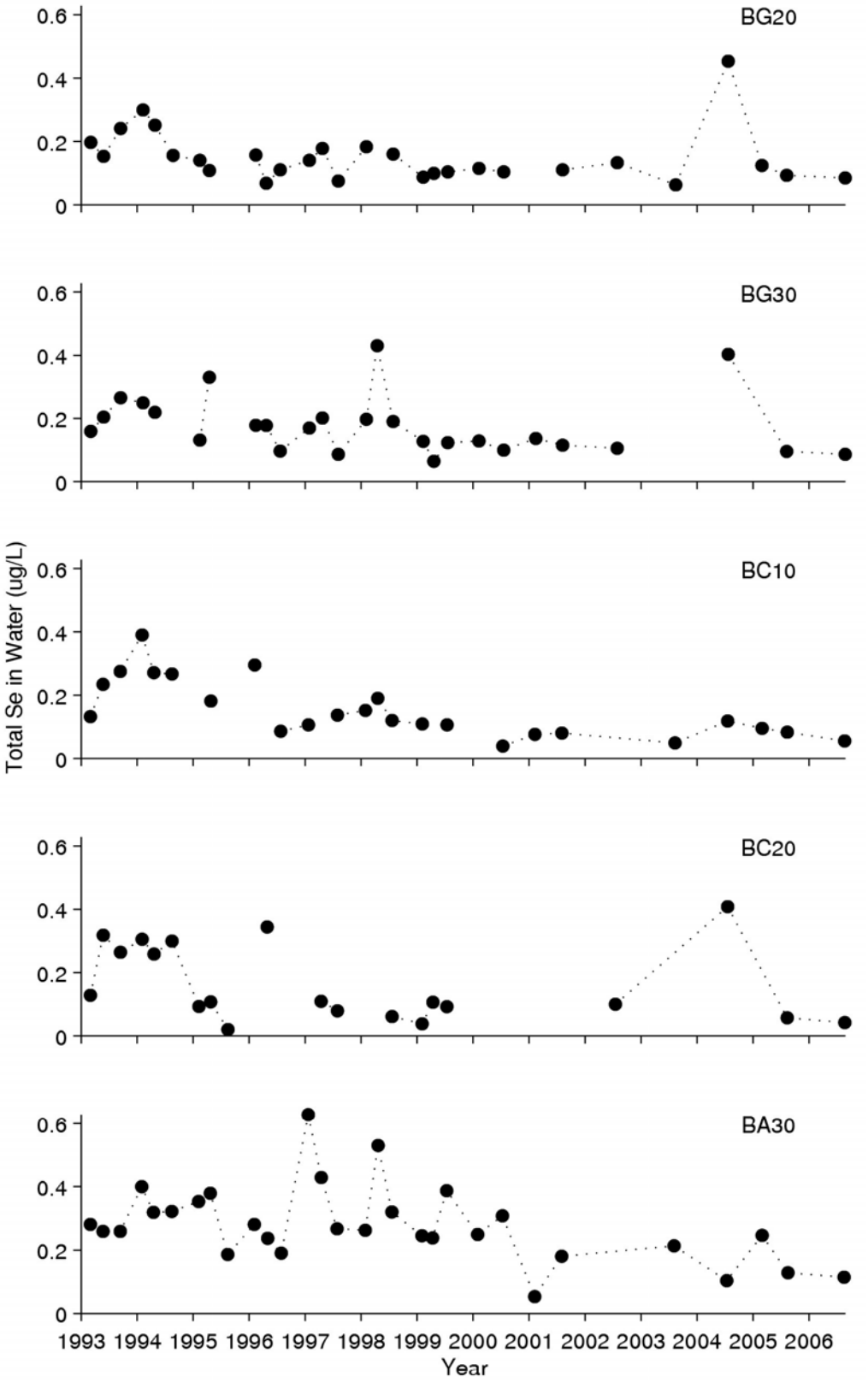


Figure 2.53. Time series plots for total selenium (Se) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

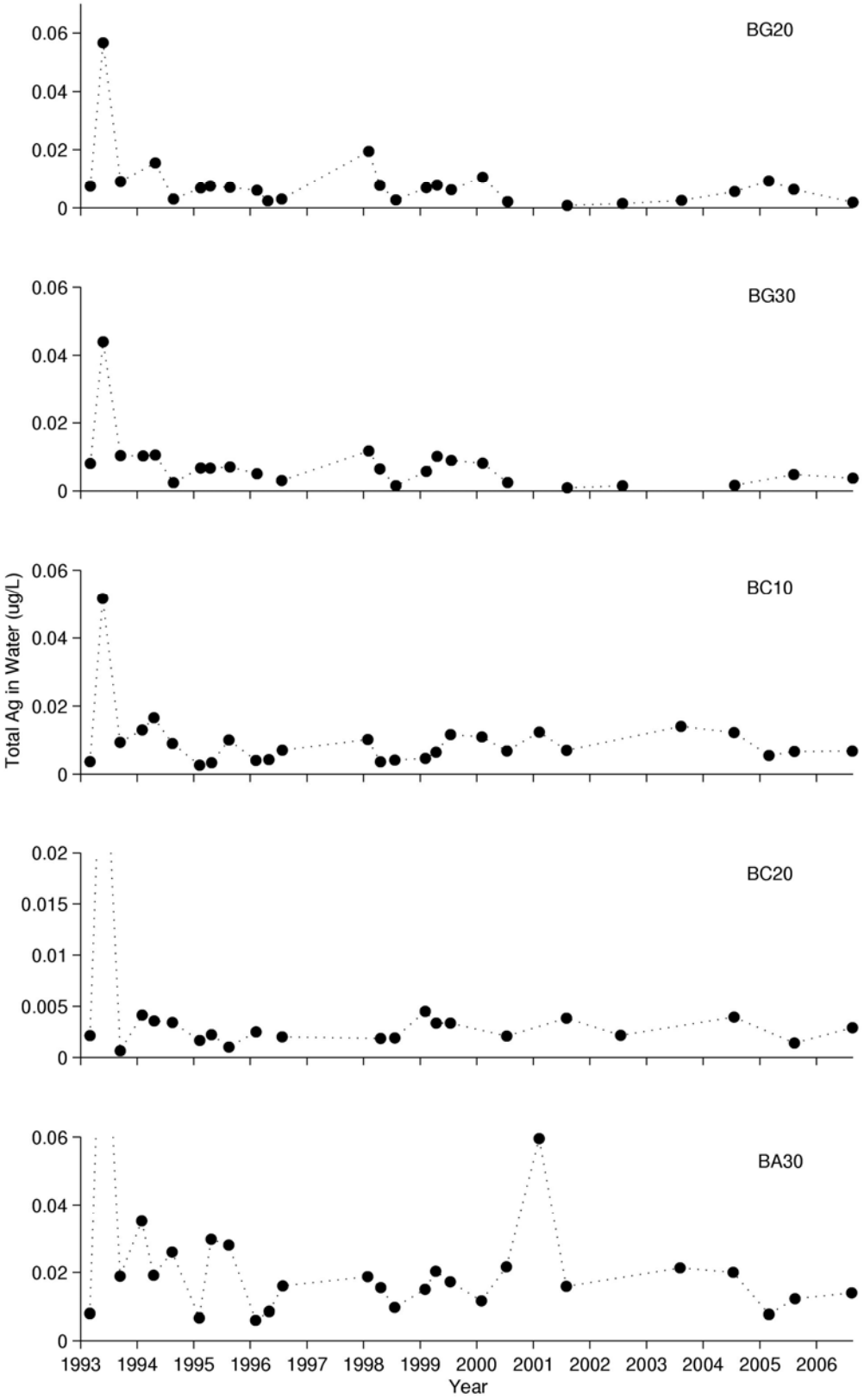


Figure 2.54. Time series plots for total silver (Ag) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

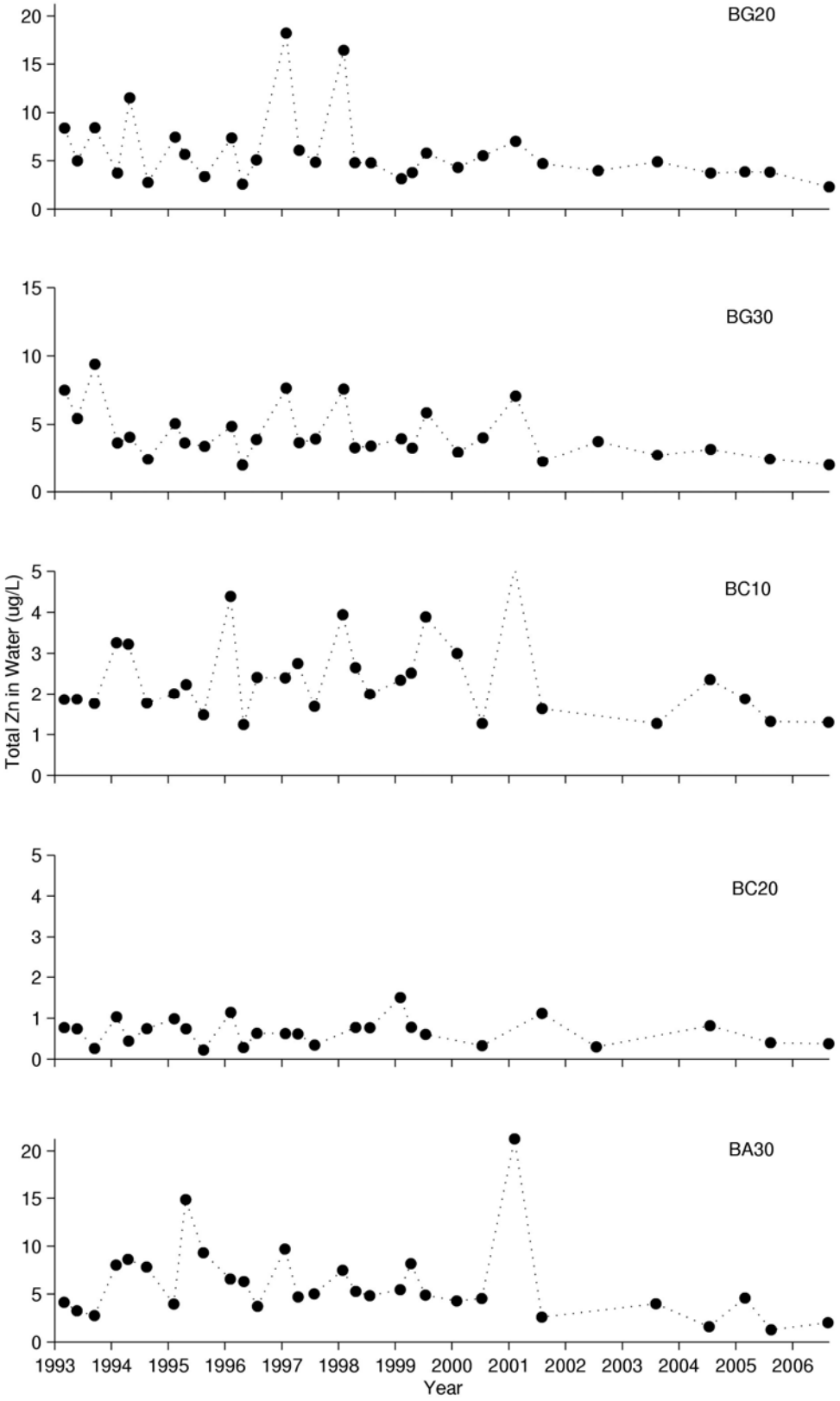


Figure 2.55. Time series plots for total zinc (Zn) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

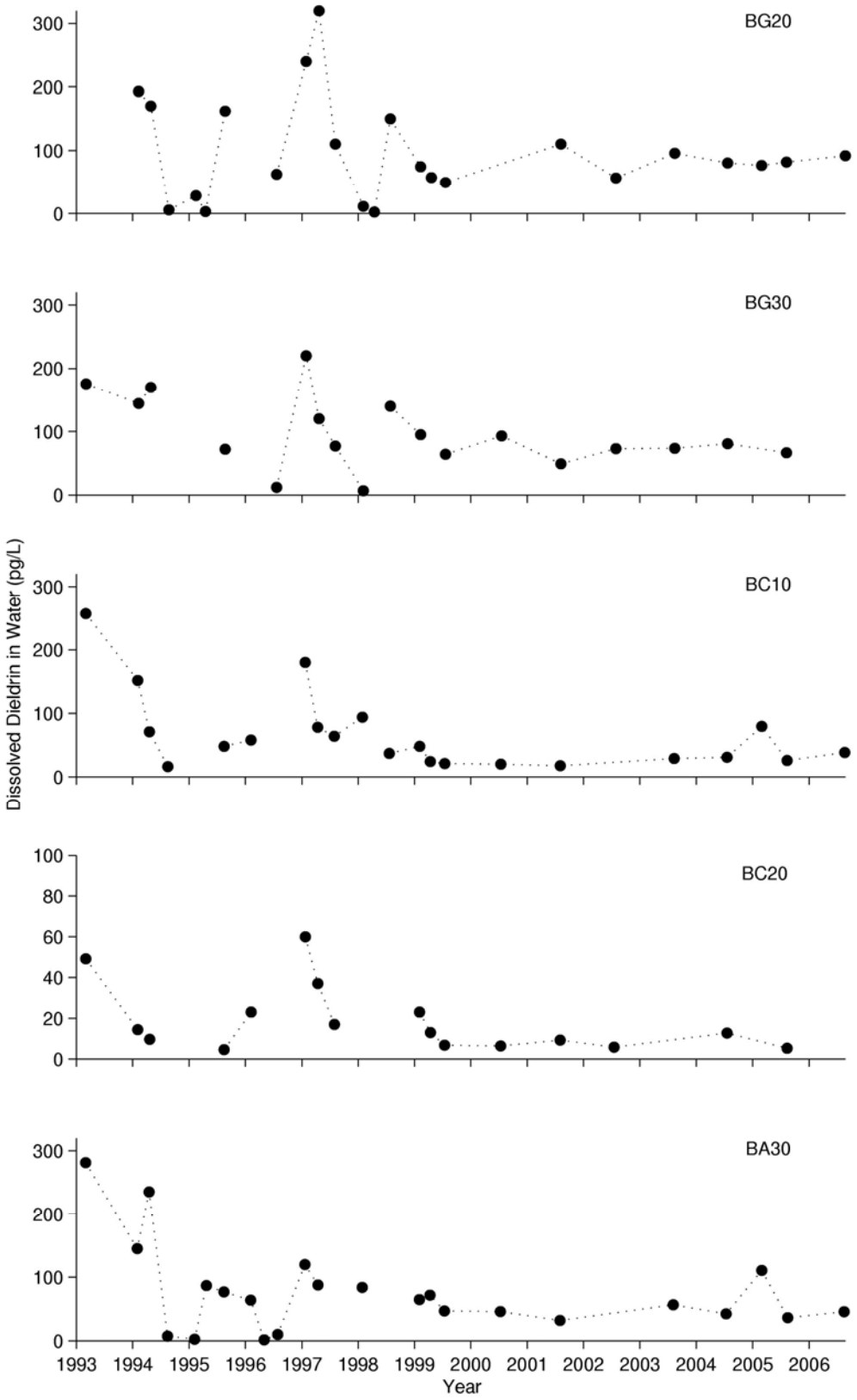


Figure 2.56. Time series plots for dissolved Dieldrin in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

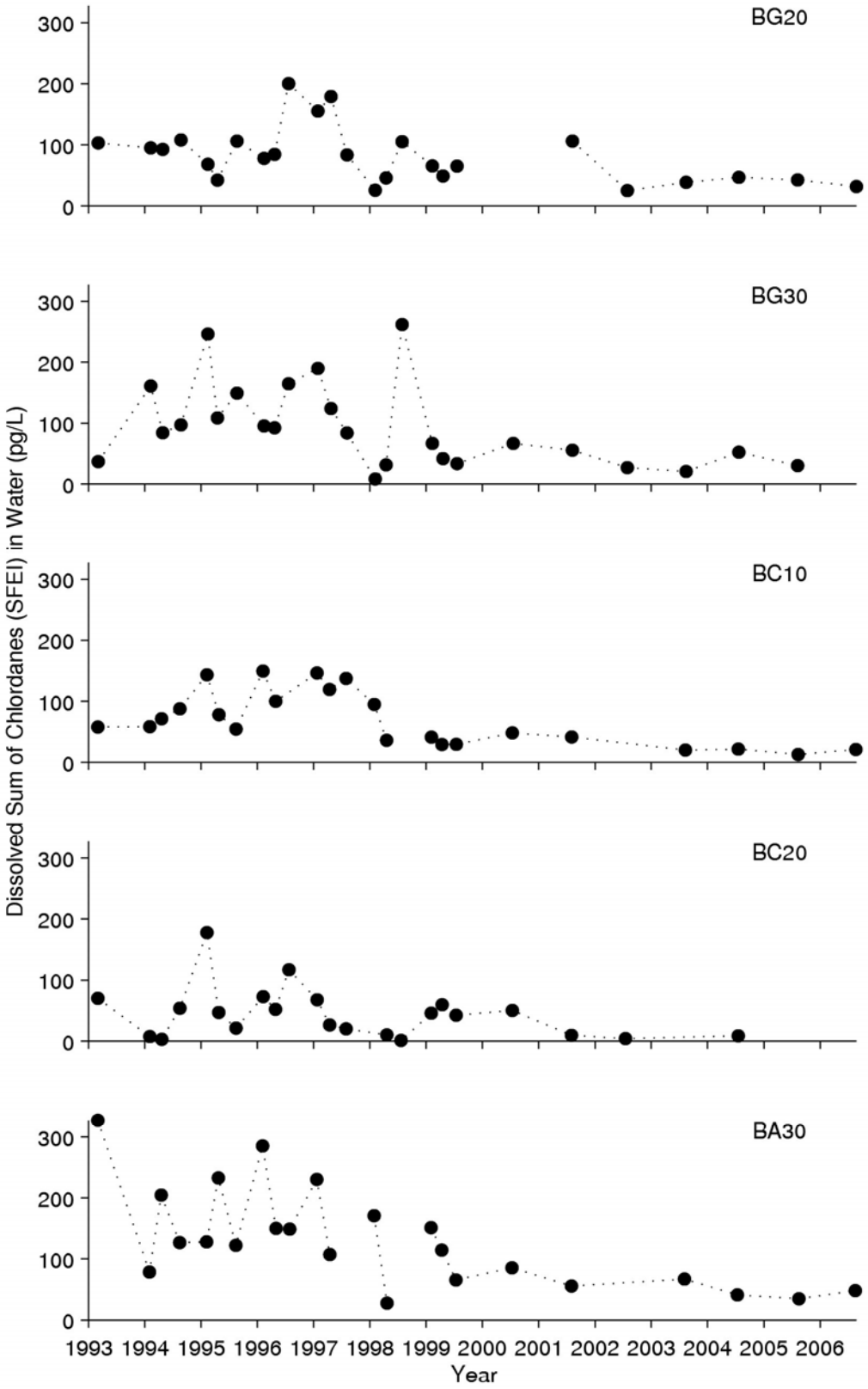


Figure 2.57. Time series plots for dissolved sum of Chlordanes in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

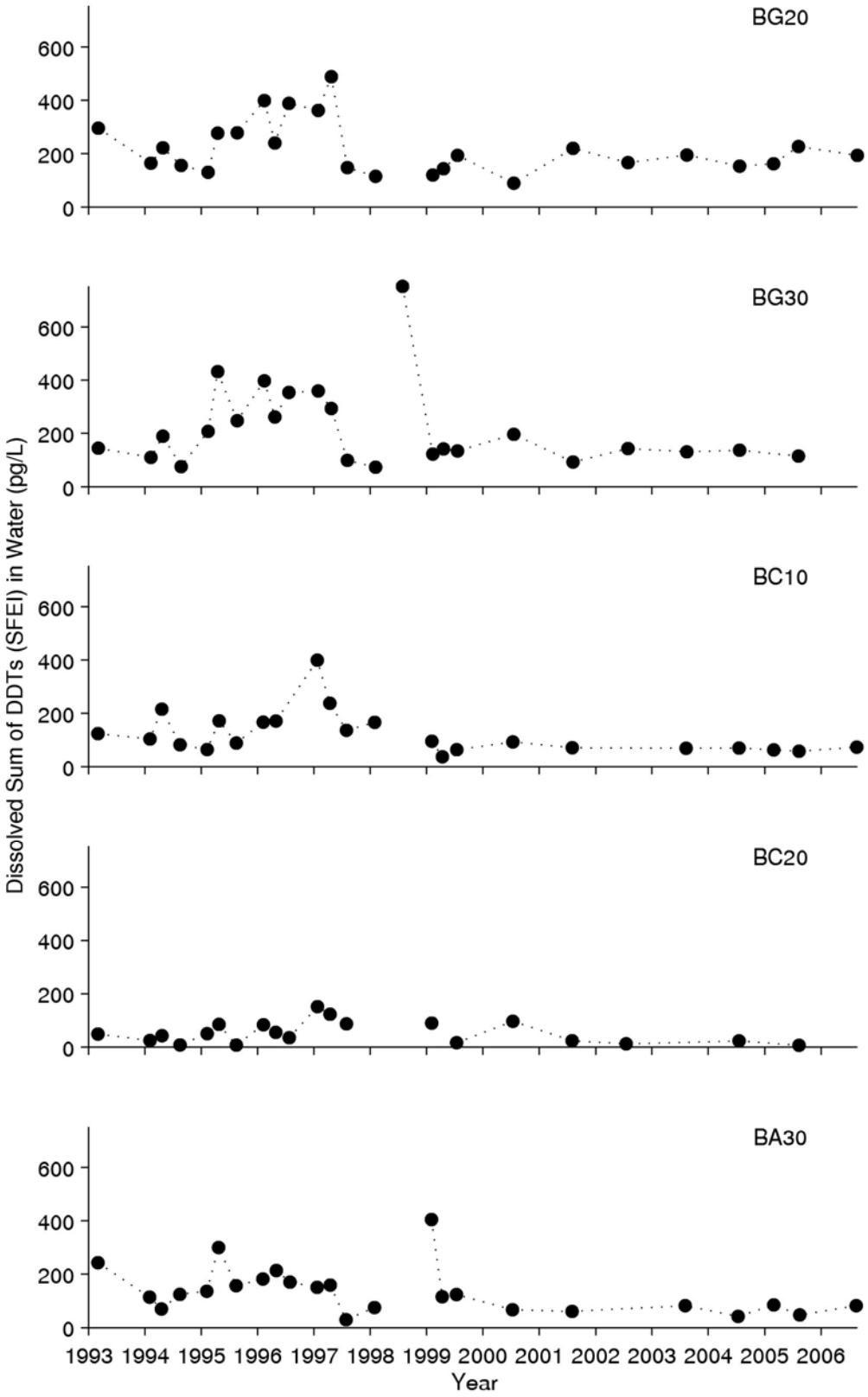


Figure 2.58. Time series plots for dissolved sum of DDTs in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

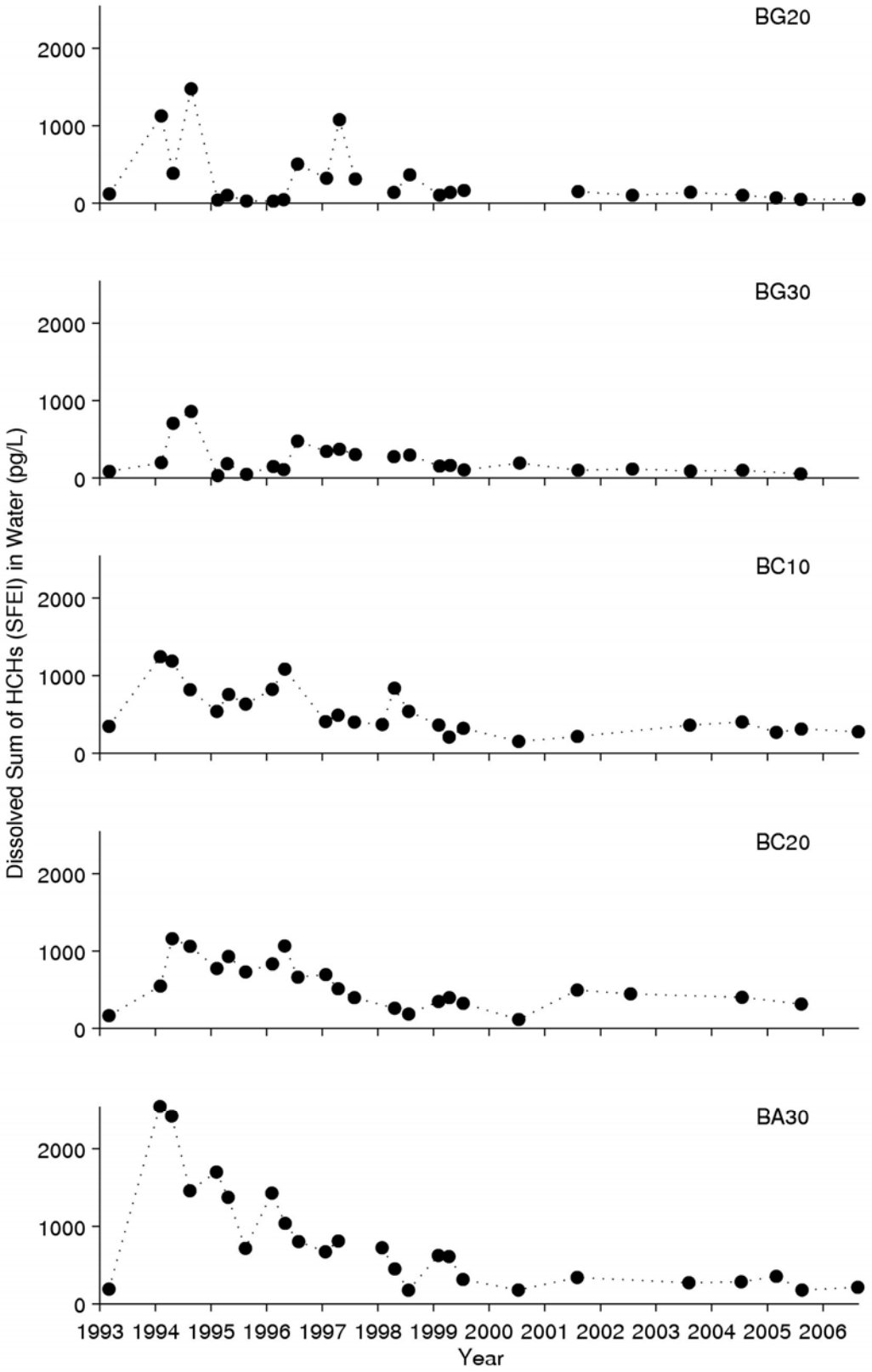


Figure 2.59. Time series plots for dissolved sum of HCHs in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

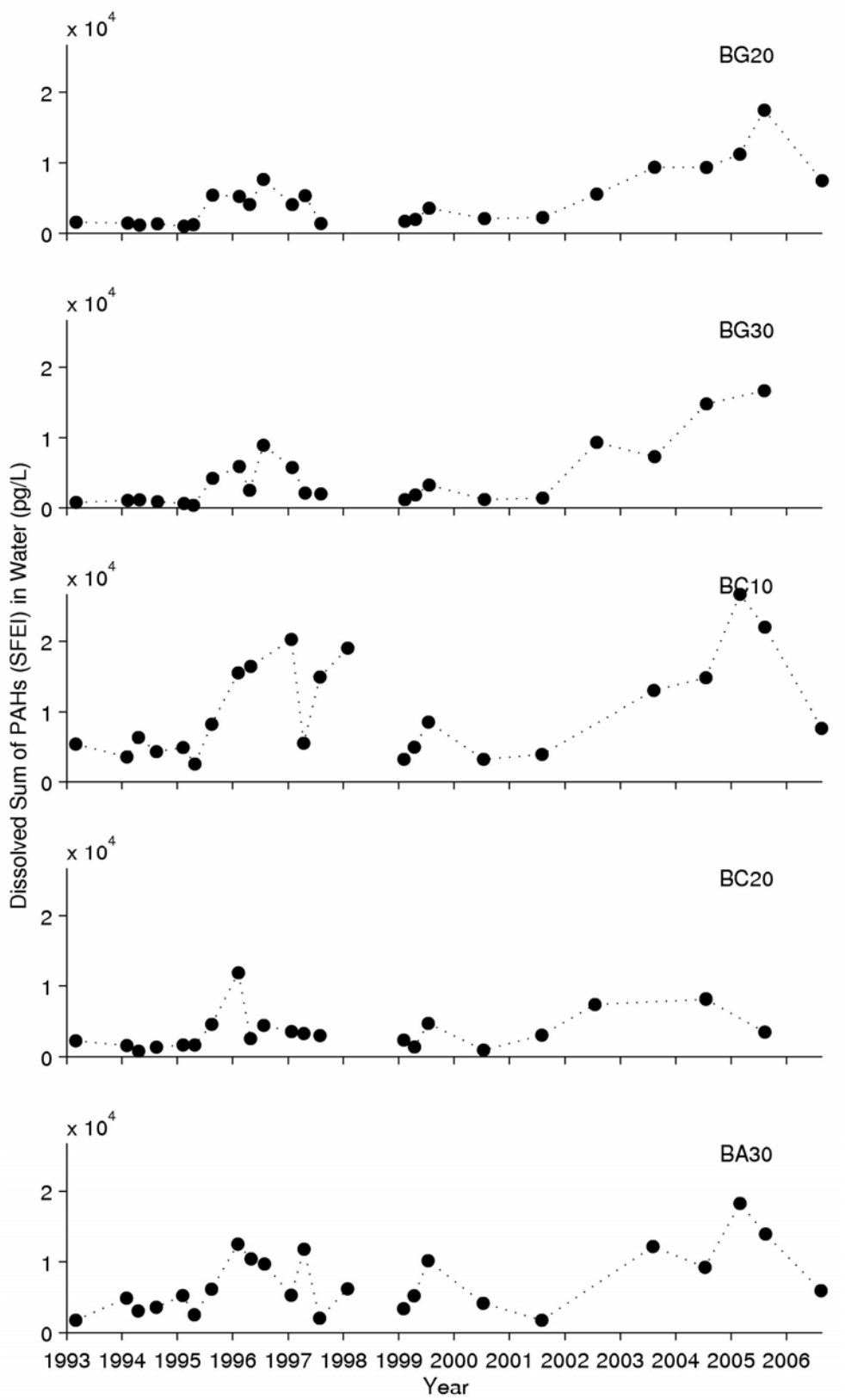


Figure 2.60. Time series plots for dissolved sum of PAHs in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

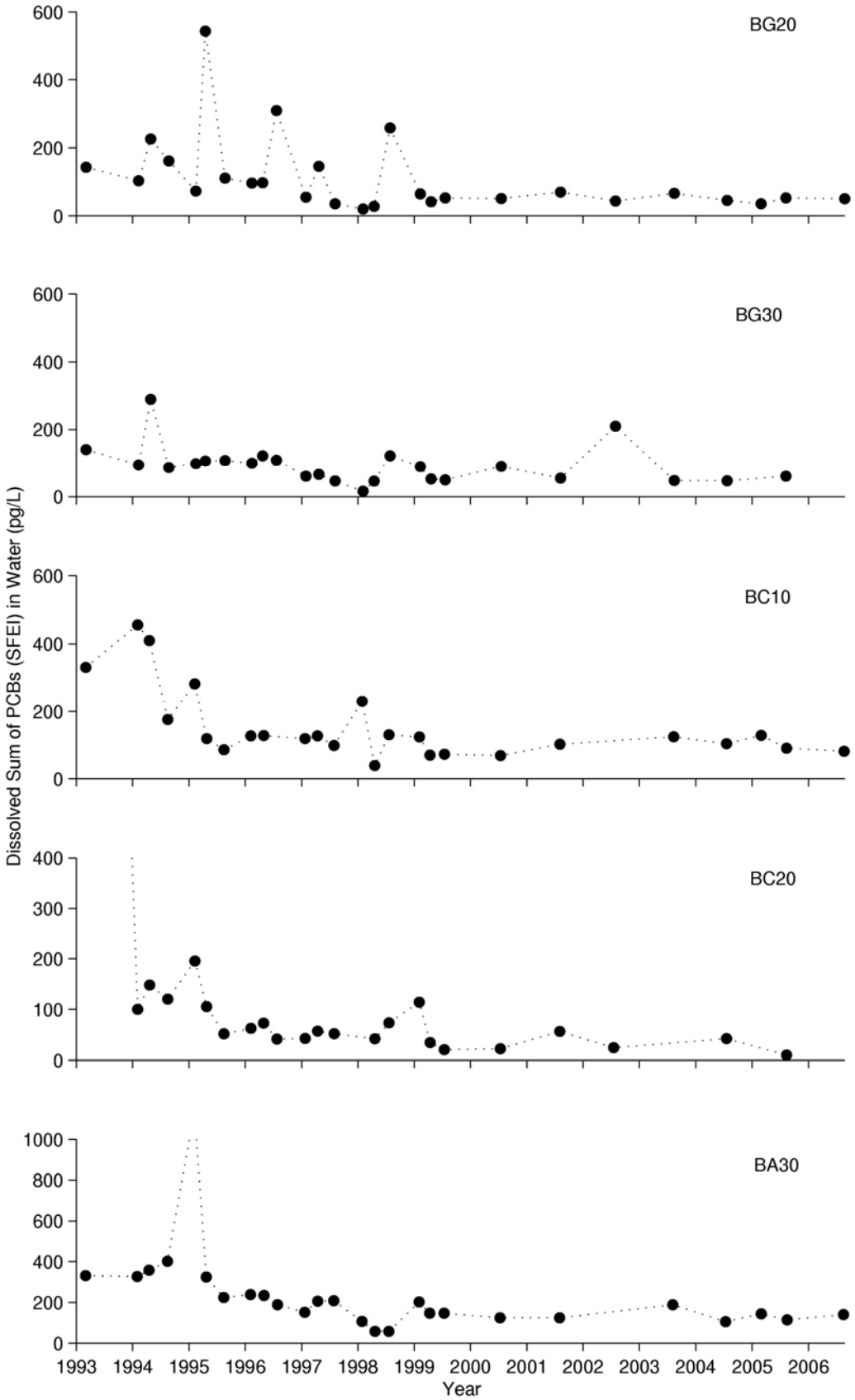


Figure 2.61. Time series plots for dissolved sum of PCBs in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

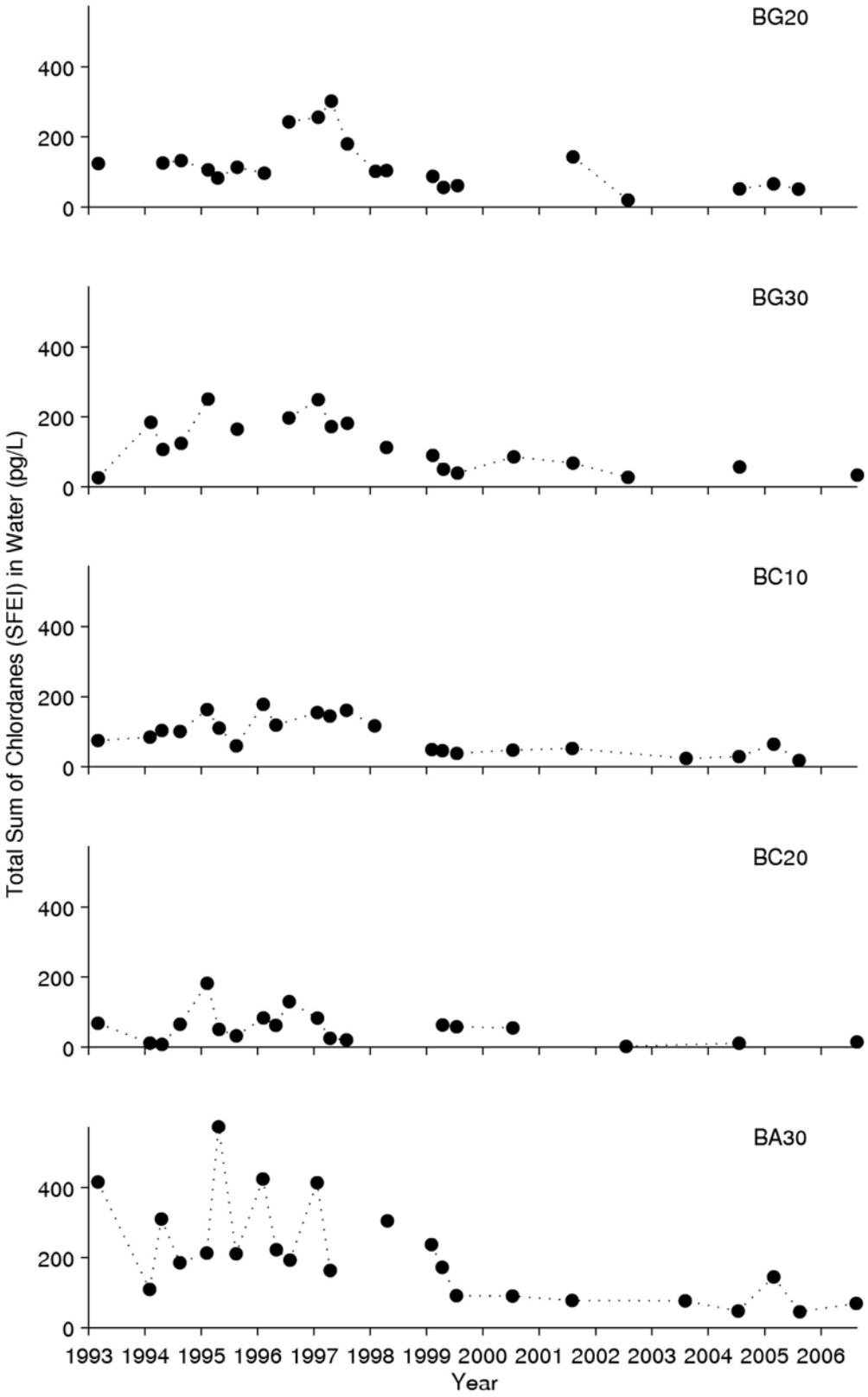


Figure 2.62. Time series plots for total sum of Chlordanes in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

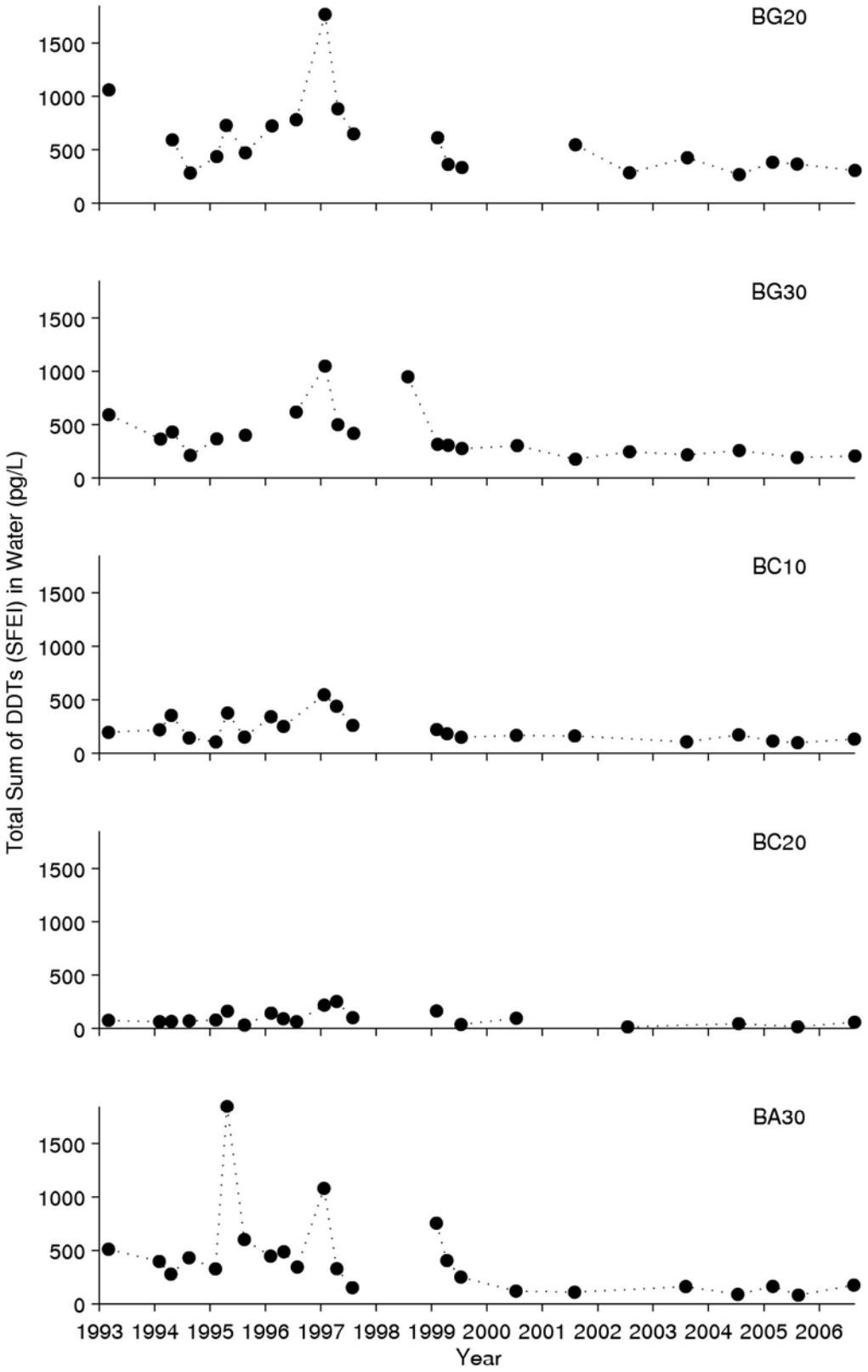


Figure 2.63. Time series plots for total sum of DDTs in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

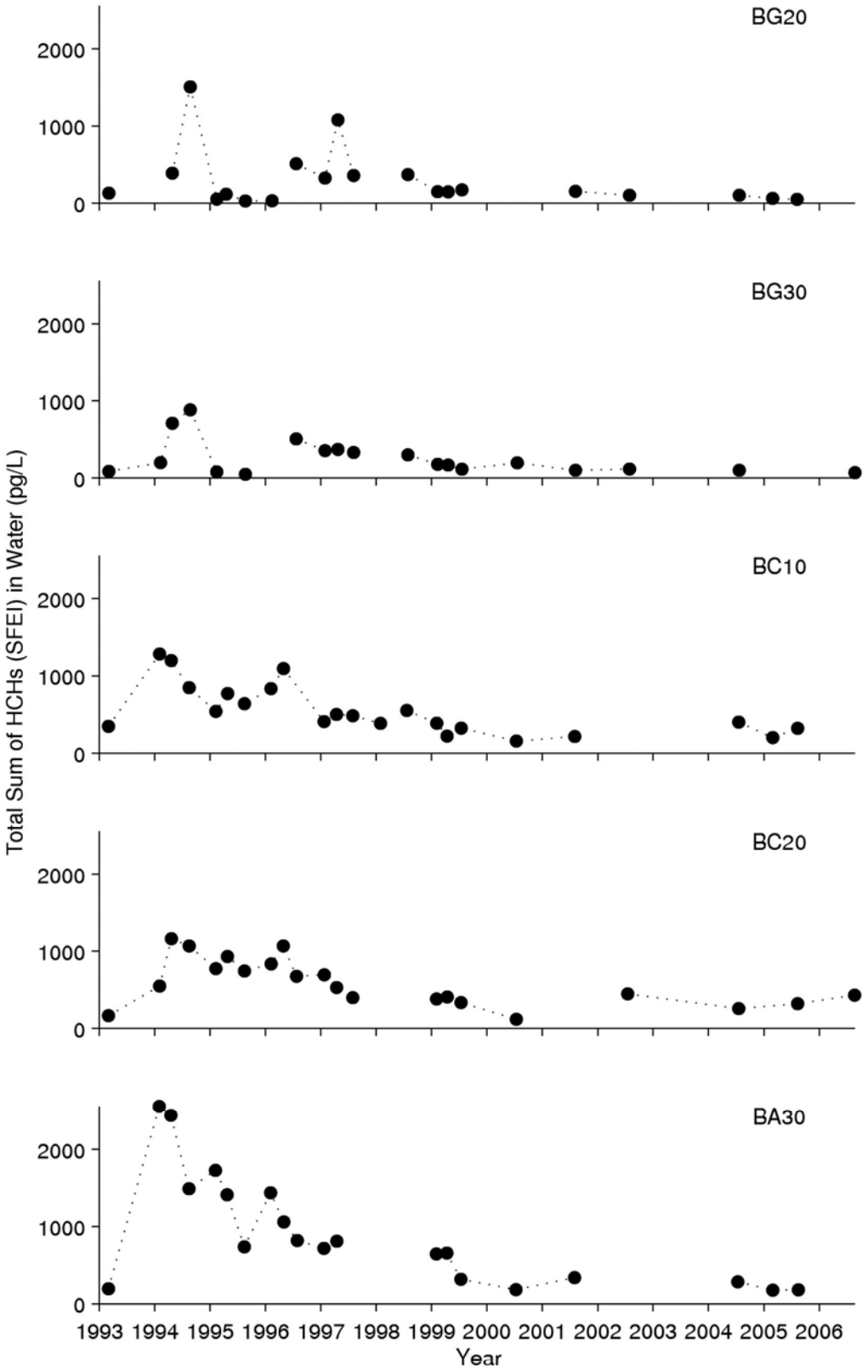


Figure 2.64. Time series plots for total sum of HCHs in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

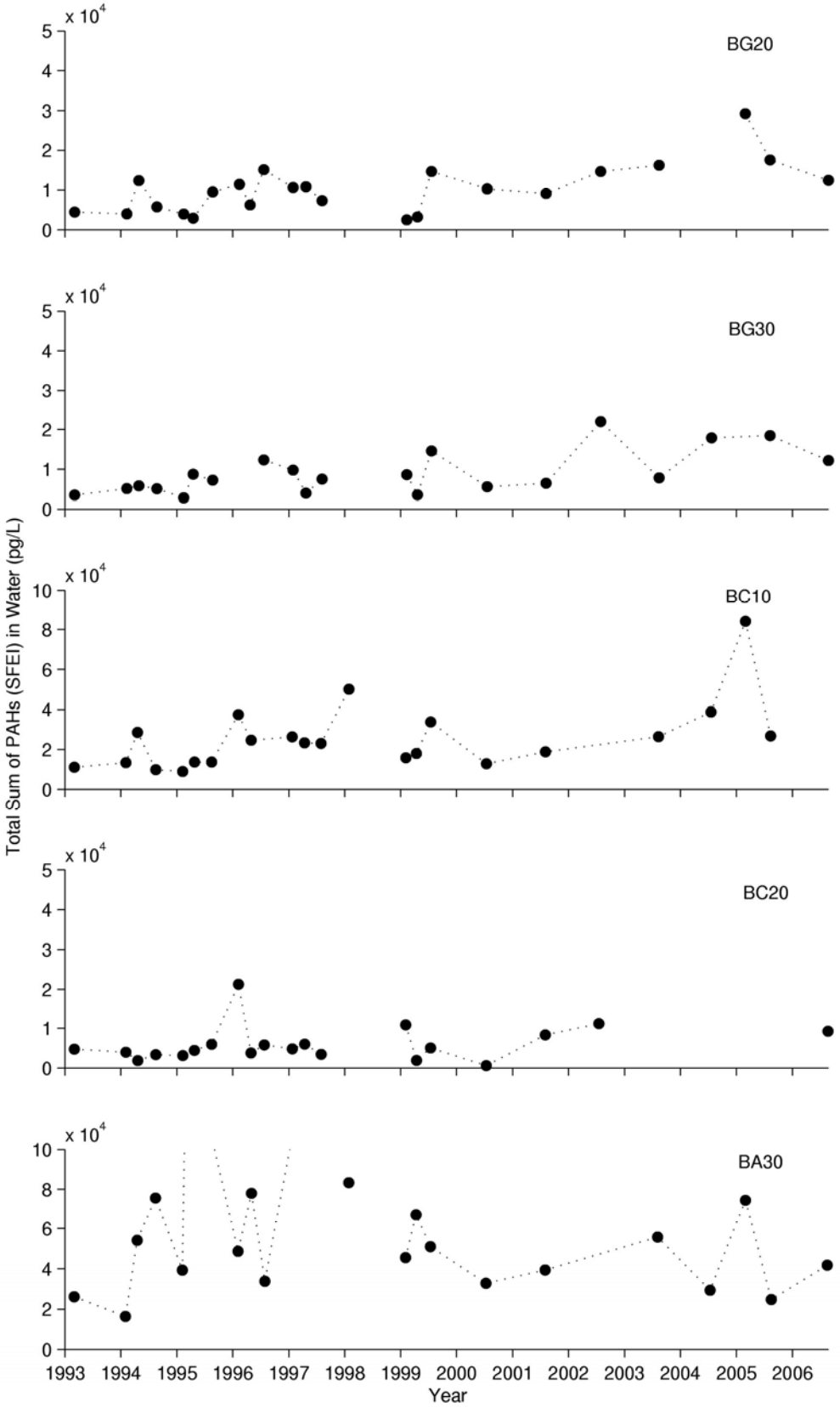


Figure 2.65. Time series plots for total sum of PAHs in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

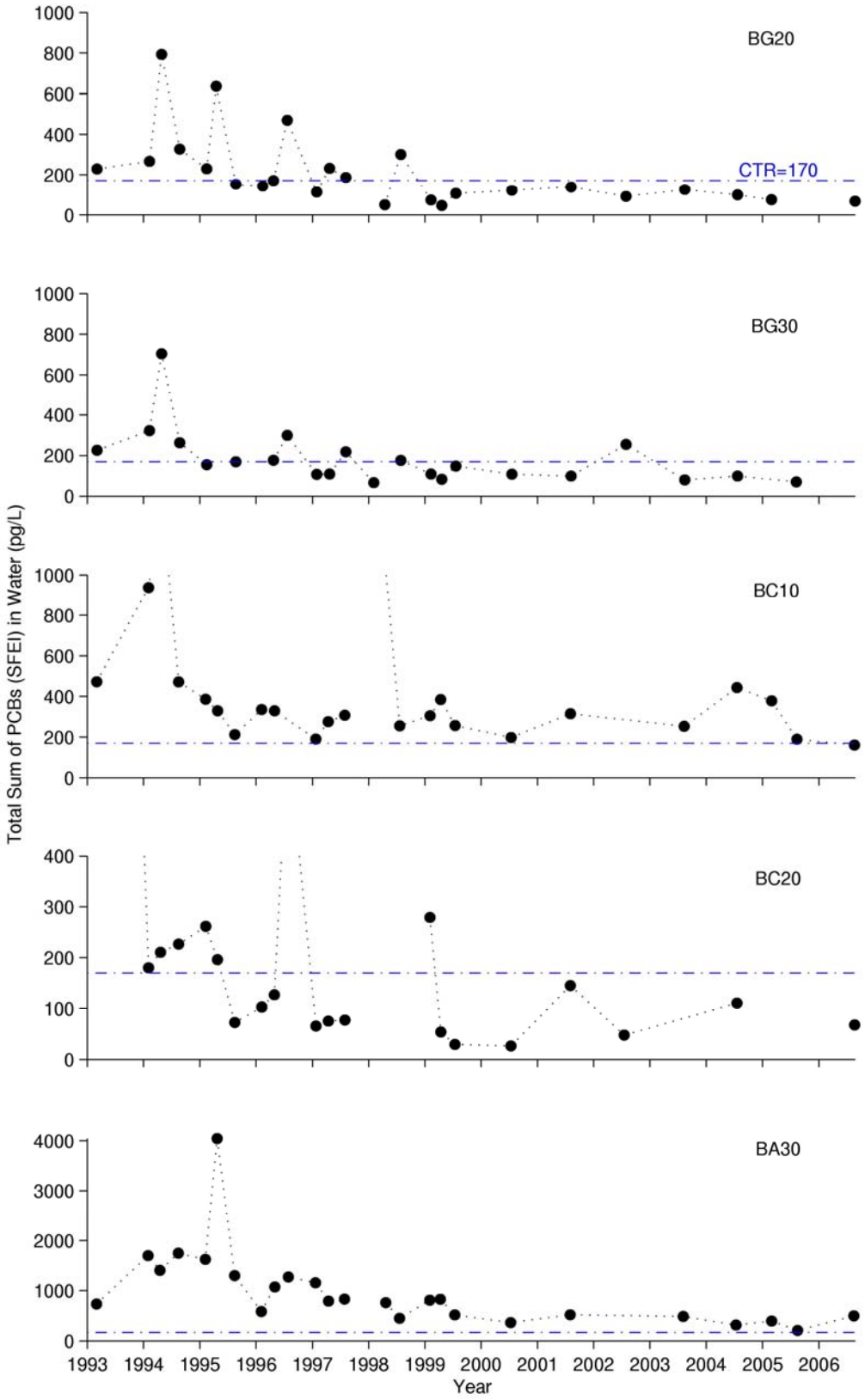


Figure 2.66. Time series plots for total sum of PCBs in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

Chapter

3

Sediment Monitoring

3.0 Sediment Monitoring

Amy Franz, Michelle Lent, John Ross, Sarah Lowe, and John Oram

3.1 Background

Since 1993, the Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP) has routinely monitored contaminants in surface sediments (top 5 cm) collected at stations throughout the San Francisco Estuary. Sediments are monitored because they are a fundamental component of the Bay ecosystem, and they play a key role in the fate and transport of contaminants. Sediments serve as contaminant sources and sinks, and most contaminants are usually found in concentrations orders of magnitude higher in the upper few centimeters of sediments than in the water column. Sediment contamination information is used in making decisions related to many important management concerns: the identification of sediment "toxic hot spots" and reference areas; the clean-up of numerous sites in the region that require information about background contaminant levels; and the continued dredging throughout the Estuary that requires testing and comparisons to a reference, or background concentration. Information about sediments addresses several of the RMP Objectives (see Chapter 1 *Introduction*). Patterns in sediment contamination are described (Objective 1) and compared to several sets of sediment quality guidelines (Objective 5), while sediment bioassays address contaminant effects (Objective 4).

3.2 Approach

3.2.1 Methods

This report presents results of the monitoring effort since the implementation of the stratified, random sampling design (see Chapter 1, *Introduction*) over the five-year period spanning 2002-2006. Since 2002 sediment contaminant monitoring has been conducted each year during the dry season (July/August) at 47 stations, including seven fixed historical stations. A total of 201 randomly allocated stations and 37 historic fixed stations (usually seven historic sites per year) were monitored for contaminants in sediment from 2002-2006.

In order to allow for analysis of long-term temporal trends, repeat sampling of a subset of random sites and continued (yearly) monitoring of historic sites in each of the six regions is conducted. The Rivers Region has two historic sites, the Sacramento River (BG20) and the San Joaquin River (BG30). All other regions have one historic site each: Suisun Bay (Grizzly Bay - BF21), San Pablo Bay (Pinole Point - BD31), Central Bay (Yerba Buena Island - BC11), South Bay (Redwood Creek - BA41) and Lower South Bay (Coyote Creek - BA10). Sites ending with 001S or 002S are randomly allocated sites sampled yearly and those ending in 003S and 004S are randomly allocated sites sampled every 5 years. The seven historic sites were picked because they have long-term synoptic chemistry and toxicity measures associated with them (SFEI, 2005). Sediments collected from a subset of 20 random sites and seven historic stations were used for conducting sediment bioassays (Figure 3.22). Time-series plots for the seven historic sites are presented in Figures 3.23-3.39. Station names, codes, location, and sampling dates for the 2006 monitoring effort are listed in Table 1.2 in the *Introduction* and shown in Figure 3.1. Station locations for 2002-2005 are shown in Figure 3.2. For the graphics presented in figures 3.3-3.21 results at repeat stations (i.e. historic stations) were averaged. Non-Detects were plotted as + in the maps, were excluded from the box plots and were included as missing values in the

cumulative distribution functions. Please see section 1.3.1 in the *Introduction* for additional information about each graphic type.

A complete list of all parameters measured in 2006 is included in Table 1.4 in the *Introduction*. Table 1.7 in the I*ntroduction* shows parameters measured in sediment for 1993-2006. Contaminant concentration data can be downloaded from the RMP website using the Status and Trends Monitoring Data Query Tool http://www.sfei.org/RMP/report.

A summary of the major changes that the Regional Monitoring Program has undergone is presented in Table 1.5 in the *Introduction.* A detailed description of sample collection and laboratory analytical methods is documented in Chapter 5, *Description of Methods*.

3.2.2 Sediment Quality Guidelines

Currently, no Basin Plan numerical objectives or other regulatory criteria for sediment contaminant concentrations exist for the San Francisco Estuary. However, sediment quality guidelines (SQOs) are currently being developed for the State of California by staff at the State Water Resources Control Board, the Southern California Coastal Water Research Project (SCCWRP) and the San Francisco Estuary Institute (SFEI). These objectives are based on a triad approach (e.g. review of sediment chemistry, toxicity, and benthos) and are expected to be promulgated in 2008. Several sediment quality guidelines that do not have regulatory status have been included in this report as informal screening tools for sediment contaminant concentrations (Table 3.1).

Sediment quality guidelines developed by Long *et al.* (1995) are based on data compiled from numerous studies in the U.S. that included sediment contaminant and biological effects information. The guidelines were developed to identify concentrations of contaminants that were associated with biological effects in laboratory, field, or modeling studies. The effects range-low (ERL) value is the concentration equivalent to the lower 10th percentile of the compiled study data, and the effects range-median (ERM) is the concentration equivalent to the 50th percentile of the compiled study data. Sediment concentrations below the ERL are interpreted as being "rarely" associated with adverse effects. Concentrations between the ERL and ERM are "occasionally" associated with adverse effects, and concentrations above the ERM are "frequently" associated with adverse effects. Effects-range values for mercury, nickel, total PCBs, and total DDTs have low levels of confidence associated with them. The effects-range values used for chlordanes and dieldrin are from Long and Morgan (1990). Presently, no effects-range guidelines exist for selenium, but the Water Board has suggested guidelines of 1.4 mg/kg (Wolfenden and Carlin, 1992), and 1.5 mg/kg (Taylor *et al*., 1992). The ERL guideline values of Long *et al*. (1995) are presented for comparative purposes on the sediment contaminant concentration graphics (Figures 3.3–3.21).

Sediment guidelines developed by the San Francisco Bay Regional Water Quality Control Board are also used to screen sediments (Gandesbery, 1998; Gandesbery *et al*., 1999). Ambient Sediment Concentration (ASC) values are derived from samples collected from the cleanest areas of the Estuary by the RMP (1991-1996) and by the Bay Protection and Toxic Cleanup Program (BPTCP) for their 1995 Reference Site study and are used to distinguish “ambient” from “contaminated” conditions. Given the fact that virtually no San Francisco Estuary mixed surface layer sediments are free of anthropogenic contaminants, this approach was thought to define contemporary ambient contaminant levels. Different ASC values are used for sandy

(>60% sand) and muddy (>40% fines) sediments. Table 3.2 compares the ERL, ERM and ASC guidelines to the stations sampled in 2006 and reports the number of parameters that exceeded these guidelines.

3.2.3 Sediment Toxicity Testing

Sediment bioassays are routinely conducted to determine the potential for adverse biological effects from the exposure to sediment contamination. Two types of sediment bioassays were conducted at 27 of the RMP stations in 2006 (Figure 3.22). Sampling dates are listed in Table 1.2 in Chapter 1, *Introduction*. Amphipods (*Eohaustorius estuarius*) were exposed to whole sediment for ten days with percent survival as the endpoint. Larval mussels (*Mytilus galloprovincialis*) were exposed to sediment elutriates (water-soluble fraction) for 48 hours with percent normal alive as the endpoint. The negative control for the *Eohaustorius* (amphipod) solid-phase test consisted of home sediment, which was clean, well-sorted fine-grained sand collected at the same place and time as the test amphipods. The *Mytilus* (mussel) sediment elutriate test negative control was clean seawater from Granite Canyon, California and *E. estuaries* home sediment. Methods of collection and testing are described in Chapter 5.0, *Description of Methods.*

When a sample is found to be toxic, it is interpreted as an indication of the potential for biological effects to estuarine organisms. However, since sediments contain numerous contaminants, it is difficult to determine which contaminant(s) may have caused the observed toxicity (see *3.3.3 Sediment Toxicity*).

A sample was considered toxic if:

1. There was a significant difference between the laboratory control and test replicates using a separate variance t-test (alpha = 0.01), and
2. The difference between the mean endpoint value (% survival for amphipods or % normal alive for bivalves) in the control and the mean endpoint value in the test sample was greater than the 90th percentile minimum significant difference (MSD).

A sample must meet both criteria to be considered toxic; the reason for this is that in many cases a small among-replicate variance will result in a significant t-test, even though the magnitude of the difference may be small. One way to ensure that statistical significance is determined based on large differences between means, rather than on small variation among replicates, is to use the MSD. MSD is a statistic that indicates the difference between the two means (the mean of the sample and control replicates) that will be considered statistically significant given the observed level of among-replicate variation and the alpha level chosen for the comparison. The detectable difference inherent to a bioassay protocol can be determined by identifying the magnitude of difference detected by the protocol 90% of the time (Schimmel *et al*., 1991; Thursby and Schlekat, 1993; Phillips *et al*., 2001). An additional set of t-tests (alpha = 0.05) is conducted and MSD values are calculated for each comparison. The MSDs are ranked in ascending order, and the 90th percentile value is identified. This value is greater than or equal to 90% of the MSD values generated. The 90th percentile MSD value is the difference that 90% of the t-tests will be able to detect as statistically significant and is equivalent to setting the level of statistical power at 0.90. The 90th percentile MSD threshold was established from 119 bioassay results for San Francisco Estuary (Bryn Phillips, Department of Environmental Toxicology, University of California, Davis unpublished data; Hunt *et al*., 1996). A recalculation in 2003 for the years 1993-2001 confirmed the 90th percentile MSD for *Eohaustorius* was 18.8%, but determined that

it should be revised to 15.2% for the bivalve larvae test. For the 2006 sediment bioassays, an amphipod bioassay was toxic if it had below 75.2% survival while the larval bivalve bioassay was toxic if it had less than 74.8% normal alive. In both years there also had to be a significant difference between the mean of the control and the sample replicates using a separate variance t-test (alpha = 0.01).

3.3 Results and Discussion

The geochemistry of sediments is complex, and in order to interpret contaminant concentrations measured in sediments, it is necessary to understand how hydrology and physical sediment characteristics may affect contaminant concentrations. Conductivity, temperature, and depth (CTD) profiles of the water column were collected at all RMP sediment stations. Although not presented in this report, these data are available upon request from the San Francisco Estuary Institute (cristina@sfei.org). Several sediment quality parameters that may affect sediment contaminant concentrations (for example grain-size and total organic carbon (TOC)) were also monitored. Percent fines and TOC are presented in Figures 3.3 and 3.4, respectively. The list of parameters measured in the 2006 sediment samples is included in Table 1.4 in the *Introduction*. Sediment quality parameters, station depths, and all available contaminant concentrations are accessible through the RMP Web Query Tool (http://www.sfei.org/rmp/data.htm).

Graphics included in each figure include maps, box plots, and cumulative distribution function (CDF) plots. Maps illustrate the spatial distribution of contaminants for randomly allocated and historic stations. Box plots indicate interquartile ranges of contaminant concentrations, summarizing results from randomly allocated stations grouped into the five major hydrographic regions of the Bay: Suisun Bay (SU), San Pablo Bay (SPB), Central Bay (CB), South Bay (SB), and Lower South Bay (LSB). Cumulative distribution function (CDF) plots provide an estimate of the square kilometers of the sampled Estuary that have a particular contaminant concentration based on results from the randomly allocated stations. These CDF plots were generated using the R system and version 2.9 of the psurvey.analysis statistical library using untransformed contaminant concentrations, normality not being an issue. The R statistical analysis program is an implementation of the S language developed at AT&T Bell Laboratories by Rick Becker, John Chambers, and Allan Wilks. R is free software downloadable through the Comprehensive R Archive Network (CRAN) web site at http://cran.r-project.org/. The psurvey.analysis library for the analysis of probability surveys may be obtained from the Monitoring Design and Analysis section of the U.S. Environmental Protection Agency Aquatic Resources Monitoring web site (http://www.epa.gov/nheerl/arm/analysispages/software.htm). Please see section 1.3.1 in the *Introduction* for additional information about each graphic type.

3.3.1 Spatial Distributions

Sediment contaminant concentrations measured in the San Francisco Estuary exhibit considerable spatial and temporal variation. High contaminant concentrations can reflect proximity to a source, anthropogenic or otherwise, as illustrated by the RMP's Estuary Interface Pilot Study results from Coyote Creek and Guadalupe River in the South Bay (SFEI, 1999; Leatherbarrow *et al*., 2002). However, complex sediment transport dynamics within the Estuary confound this simplistic model. For example, sediments with more silt- and clay-sized particles contain higher concentrations of most contaminants than coarser, sandier sediments because of their physical properties (Luoma, 1990; Horowitz, 1991). The strength and magnitude of freshwater inflows to the estuary, which transport sediments and contaminants in both the

dissolved and particulate fractions of the flows, may radically alter sediment type and contaminant distribution (Krone, 1979). As a consequence, RMP sediment monitoring provides information only about the condition of surface sediments (upper 5 cm) at the time and location of sampling.

For the years 2002-2006 Suisun Bay sites had the highest concentration of copper (SU015S) and nickel (SU008S). The sites with the highest concentration for arsenic (SPB032S), cadmium, mercury, lead, Sum of DDTs and Sum of PCBs (SPB018S) were found within the San Pablo Bay region. Central Bay sites had the highest concentration of methyl mercury (CB003S), selenium (CB075S) and Sum of PAHs (CB080S). Sites within the South Bay had the highest concentration for silver (SB002S), aluminum (SB025S), Sum of Chlordanes (SB006S), BDE 047 (SB005S) and BDE 209 (SB027S). The highest concentration for iron (BA10), manganese (LSB002S) and zinc (LSB026S) was measured at sites within the Lower South Bay Region (Table 3.3).

During the years 2002-2006 the lowest concentration for silver, Sum of Chlordanes and Sum of PAHs was measured in the Rivers Region at the historic Sacramento River station (BG20). The lowest concentration for mercury (SU024S), methyl mercury, selenium, Sum of DDTs, Sum of PCBs (SU002S), lead (SU010S), BDE 047 (SU077S), and dieldrin (SU001S) was found in the Suisun Bay Region. BDE 209 concentrations were found to be the lowest in both the Rivers (BG20) and Suisun Bay (SU030S) regions. The Central Bay had the lowest measured concentration of cadmium (CB027S). The South Bay had the lowest measured concentration for aluminum, copper, iron, manganese, nickel and zinc (SB073S) and the lowest concentration for arsenic (SB015S) (Table 3.4).

In order to compare sediment contaminant concentrations the RMP sampling stations were grouped into five regions. These regions, each containing eight random stations, are: Lower South Bay (LSB*nnn*S), South Bay (SB*nnn*S), Central Bay (CB*nnn*S), San Pablo Bay (SPB*nnn*S), and Suisun Bay (SU*nnn*S).

Differences between two CDFs were examined using a modified version of the Roa-Scott first order corrected (mean eigenvalue corrected) statistic for categorical data (Kincaid, 2004). Significant differences ($p < 0.05$) were observed in 66% of the comparisons (Table 3.5). The only regional comparisons where significant differences were not observed for >50% of the parameters (more than 19 out of 17) were Central Bay vs South Bay and Central Bay vs San Pablo Bay.

3.3.2 Temporal Trends

The yearly monitoring of fixed historical sampling stations, at least one per region, permits the analysis of long-term temporal trends. Time-series plots were generated and are presented here for the five historic stations that have been continued in the current monitoring program (Figures 3.23-3.39). Temporal trends were not evaluated here for the random sampling design results. The RMP has contributed to a special issue for the journal *Environmental Research* (Volume 105, Issue 1) published in 2007 that includes articles synthesizing the ten years of the RMP's Status and Trends Program data (among other topics). Additionally, a statistical analysis of select contaminants in water and sediment is included as a supplemental chapter to this report (Chapter 6).

3.3.3 Sediment Toxicity

Toxicity tests, described in *Section 3.2.3*, were conducted to determine whether sediments were toxic to sensitive benthic organisms. Since these bioassays were conducted using non-resident organisms exposed in laboratory conditions, the results may not necessarily indicate the occurrence of actual ecological impacts.

Estuary sediments were toxic to either amphipods or larval mussels in 11 out of 27 (41%) of the 2006 RMP samples (Table 3.2). Patterns of toxicity for the two test organisms vary within the Estuary (Figure 3.22). Historical stations located in the Rivers and Suisun Bay regions of the Estuary, Sacramento River (BG20), San Joaquin River (BG30), and Grizzly Bay (BF21) have been consistently toxic to bivalve larvae since 1994. A pattern repeated again in 2006 with bivalve toxicity occurring at BG20, BG30 and BF21. All 2006 Suisun Bay stations tested for toxicity were toxic to bivalves (BF21, SU001S, SU027S, SU029S, and SU031S). Bivalve toxicity was also found for two Lower South Bay stations LSB029 and LSB031. Amphipod toxicity was observed at two stations Yerba Buena Island (BC11) and in the South Bay at SB031S. There were no sites toxic to both amphipods and bivalves. Sixteen sites had no toxicity associated with them for either amphipods or bivalves (Table 3.2). Seasonal patterns were not examined due to the discontinuance in 2002 of winter sampling, but prior to 2000 sediments were usually more toxic during the wet season (SFEI, 2000; 2001).

Causes of toxicity to the amphipods and bivalve larvae are poorly understood. Analyses using several years of monitoring data suggest that amphipod toxicity is associated with the cumulative effects of mixtures of contaminants (Thompson *et al.*, 1999). Several individual contaminants were identified as probable determinants of toxicity at some sites. For example, toxicity at Grizzly Bay (BF21) was related to covarying patterns of total chlordane, silver, and cadmium from 1991 through 1996. Seasonal variation in PAHs at some stations was related to survival. Sediment elutriates (water soluble fraction) have been observed as being toxic to bivalve larvae for the Sacramento and San Joaquin Rivers, and Grizzly Bay samples since 1993 (SFEI 2000, 2001). Toxicity identification evaluations (TIEs) conducted on the sediment elutriates from the Sacramento and San Joaquin Rivers and Grizzly Bay in 1997 and 1998 indicated that dissolved trace metals, particularly copper, could be partially responsible for the toxicity, but organic contaminants were also identified as possible toxic components from the Sacramento River site (Phillips *et al*., 2000). These results suggest that sediment toxicity at the different RMP stations may be related to different contaminants and may vary with time.

Studies by RMP investigators demonstrate the complex nature of sediment toxicity due to the numerous contaminant and non-contaminant factors in Estuary sediments. Solid phase sediment toxicity to amphipods has been frequently observed at Redwood Creek (BA41) and Grizzly Bay (BF21). Although exposure to pore water from these sites did not produce toxicity, exposure to bulk sediment did, suggesting that the toxicity is associated with ingestion and assimilation of contaminants in sediment. Amphipods accumulated PAHs, organochlorine pesticides, and PCBs from exposures to both bulk sediment and pore water, but not at levels known to cause mortality. The majority of the contaminants accumulated in amphipods were PAHs, which may have been a key causative agent of the observed toxicity. However, mixtures of contaminants are also believed to be important (Anderson *et al*., 2000). Anderson *et al.* (2003) summarized ten years of toxicity testing by the RMP (http://www.sfei.org/rmp/pulse/pulse2003.pdf).

3.3.4 Assessment of Sediment Quality

Estuary sediments are evaluated through comparisons to several sets of sediment quality guidelines described in *Section 3.2.2 Sediment Quality Guidelines*. Although these guidelines hold no regulatory status, they provide concentration guidelines that are useful in assessing the potential for toxic and benthic effects.

Sediment contamination and toxicity results were used to evaluate the quality of the 2006 Regional Monitoring Program samples (Table 3.2). Detailed tables for 2002-2005 are available in their respective Annual Monitoring Results available online SFEI: Documents & Reports. Sediment contamination was estimated for each site by considering the number of contaminants in a sample that exceeded the San Francisco Estuary Ambient Sediment Concentration (ASC: Gandesbery *et al.*, 1999), Effects-Range guidelines (ERL and ERM: Long *et al.*, 1995), and the ERM quotients (Long *et al*., 1998). The number of sediment contaminants above the ERL or ERM guidelines has been used previously to predict potential biological effects (Long *et al*., 1998). Long *et al*. (1998) found that samples with more than four ERM exceedances showed toxicity in 68% of amphipod tests, while 51% of samples were toxic to amphipods when more than nine ERLs were above the guidelines. Based on these results the 2006 RMP sediment samples were considered potentially toxic if either four or more ERMs, nine or more ERLs, or half (20) of the ASC values were exceeded. Samples that did not have values for at least 80% of the parameters (32 of 40 for ASC, and 24 of 30 for ERL and ERM) were not included in the calculations.

ERM values were used to calculate a mean ERM quotient (mERMq) for each sample. The mERMq has been used in previous RMP reports and San Francisco Estuary publications as an index of cumulative sediment contaminant concentrations (Thompson *et al.*, 1999; Hunt *et al*., 2001a,b; Fairey *et al*., 2001; Thompson and Lowe, 2004). The primary reason for using the mERMq is that it provides a measure of potential additive contaminant effects. For example, amphipod survival has been found to be significantly and inversely correlated to mERMq (Thompson *et al.*, 1999), suggesting that contaminants individually present in relatively low concentrations in sediments may act together to adversely influence amphipod survival. In these past reports and publications, however, the mERMq has been calculated in several different ways. However, if comparisons to other U.S. estuaries are to be accomplished, a standard method of calculation is necessary. Therefore, the calculation of mERMq was changed in order to make the RMP ERM quotients comparable to other studies from around the U.S. (Hyland *et al.*, 1999; Long *et al*., 2002; Hyland *et al.*, 2003). The 2006 mERMqs were calculated using 24 contaminants as indicated in table 3.1 per the Hyland method (Hyland *et al.*, 1999). Samples that did not have at least 19 of the 24 parameters were not included in the calculations. All 2006 sediment samples had between 21 and 24 parameters reported.

Long *et al*. (1998) showed that 49% of sediment samples were toxic to amphipods when mERMq values were above 0.5, and 71% of samples were toxic when mERMq values were greater than 1.0. Mean ERM quotients, calculated with 24 contaminants, were used in a previous study of the San Francisco Estuary in which values greater than 0.15 were associated with increased risks of benthic impact (Thompson and Lowe, 2004). These values were used to evaluate the 2006 RMP sediment samples for potential adverse ecological effects. Only one station had a mERMq value greater than 0.15 and also had 22 results above the ASC guidelines (CB028S) see Table 3.2. Two stations (CB030S and SB001S) had relatively low mERMq values but a high number of ASC exceedances.

In 2006, two stations were considered potentially toxic by the RMP (CB028S and SB030S) because they had nine or more contaminants above the ERL guidelines.. There were no stations sampled in 2006 that showed ERM exceedences greater than 4 (Table 3.2). In general for 2002-2006, stations located in the Cental Bay region had the highest incidence of ERL guideline exceedances while stations that had very few ERL guideline exceedances were located within the Suisun Bay Region.

Sediment evaluations are useful tools that incorporate sediment contamination and toxicity into a weight of evidence assessment of the condition of sediments in the Estuary. Each component is analyzed independently and weighted equally, but although they should be related the results do not always agree. The complexity of sediment evaluations demonstrate the need to consider as much data as possible in assessing the condition of Estuary sediments and the importance of performing future studies to reconcile and understand the observed contradictions.

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Table 3.1. Guidelines to evaluate chemical concentrations in sediment (in dry weight).

Effects Range-Low (ERL) and Effects Range-Median (ERM) values from Long *et al.* (1995, 1998).
Effects Range-Low; values between this and the ERM are in the possible effects range.
Effects Range-Median; values above this are in the probable effects range.

San Francisco Bay Ambient Sediment Concentrations (ASC) from Gandesbery *et al* . (1999).
Ambient sediment levels from background sediments in the Estuary allow one to assess whether a site has elevated levels or is "degraded".

Background sediment concentrations for selected trace elements in the San Francisco Bay, from Hornberger *et al* . (1999)
Chromium and nickel concentrations observed throughout the core. All trace elements, except Ag, measured by Inductively Coupled Argon Plasma Emission Spectroscopy (ICAPES). Ag measured by Graphite Furnace Atomic Absorption Spectrometry (GFAAS).

Near total metals are extracted with a weak acid for a minimun of one month, therefore, concentrations approximate the bioavailability of these metals to Estuary biota.

Parameter	unit	ERL	ERM	ASC-sandy <40% fines	ASC-muddy >40% fines	Background Concentrations (Bay wide ranges)	
						Total	Near Total
Arsenic	mg/Kg	8.2	70 †	13.5	15.3		
Cadmium	mg/Kg	1.2	9.6 †	0.25	0.33		
Chromium	mg/Kg	81	370 †	91.4	112	110 - 170	70 - 120
Copper	mg/Kg	34	270 †	31.7	68.1	20 - 55	20 - 41
Mercury	mg/Kg	0.15	0.71 †	0.25	0.43		0.05 - 0.07
Nickel	mg/Kg	20.9	51.6	92.9	112	70 - 100	50 - 100
Lead	mg/Kg	46.7	218 †	20.3	43.2	20 - 40	10 - 20
Selenium	mg/Kg			0.59	0.64		
Silver	mg/Kg	1	3.7 †	0.31	0.58	0.7 - 0.11	0.7 - 0.11
Zinc	mg/Kg	150	410 †	97.8	158	60 - 70	50 - 100
Sum of HPAHs (SFEI)	µg/Kg	1700	9600	256	3060		
Fluoranthene	µg/Kg	600	5100 †	78.7	514		
Perylene	µg/Kg			24	145		
Pyrene	µg/Kg	665	2600 †	64.6	665		
Benz[*a*]anthracene	µg/Kg	261	1600 †	15.9	244		
Chrysene	µg/Kg	384	2800 †	19.4	289		
Benzo[*b*]fluoranthene	µg/Kg			32.1	371		
Benzo[*k*]fluoranthene	µg/Kg			29.2	258		
Benzo[*a*]pyrene	µg/Kg	430	1600 †	18.1	412		
Benzo[*e*]pyrene	µg/Kg			17.3	294		
Dibenz[*a,h*]anthracene	µg/Kg	63.4	260 †	3	32.7		
Benzo[*g,h,i*]perylene	µg/Kg			22.9	310		
Indeno[1,2,3-*c,d*]pyrene	µg/Kg			19	382		
Sum of LPAHs (SFEI)	µg/Kg	552	3160	37.9	434		
1-Methylnaphthalene	µg/Kg			6.8	12.1		
1-Methylphenanthrene	µg/Kg			4.5	31.7		
2,3,5-Trimethylnaphthalene	µg/Kg			3.3	9.8		
2,6-Dimethylnaphthalene	µg/Kg			5	12.1		
2-Methylnaphthalene	µg/Kg	70	670 †	9.4	19.4		
Naphthalene	µg/Kg	160	2100 †	8.8	55.8		
Acenaphthylene	µg/Kg	44	640 †	2.2	31.7		
Acenaphthene	µg/Kg	16	500 †	11.3	26.6		
Fluorene	µg/Kg	19	540 †	4	25.3		
Phenanthrene	µg/Kg	240	1500 †	17.8	237		
Anthracene	µg/Kg	85.3	1100 †	9.3	88		
Sum of PAHs (SFEI)	µg/Kg	4022	44792	211	3390		
p,p'-DDE	µg/Kg	2.2	27 †				
Sum of DDTs (SFEI)	µg/Kg	1.58	46.1 †	1.58	46.1		
Total Chlordanes (SFEI)	µg/Kg	0.5	6	0.42	1.1		
Dieldrin	µg/Kg	0.02	8	0.18	0.44		
TOTAL PCBs (NIST 18)	µg/Kg			5.9	14.8		
Sum of PCBs (SFEI)	µg/Kg	22.7	180 †	8.6	21.6		

† Values used to calculate mean ERM quotients (Hyland *et al* . 1999).

Table 3.2. Summary of sediment quality for the RMP in 2006.

Detailed tables for 2002-2005 are available in their respective Annual Monitoring Results.
The numbers represent the number of parameters that exceeded guidelines for a particular station.
NA = not available, . = not tested, * indicates number of exceedances above ASC guidelines for sandy samples.

Code	Site Name	Region	Date	% Fines	mERMq	No. of parameters above ASC Guidelines	No. of parameters above ERL Guidelines	No. of parameters above ERM Guidelines	Toxic to Amphipods?	Toxic to Bivalves?
BC11	Yerba Buena Island	Central Bay	8/7/2006	94	0.0721	0	4	1	yes	no
CB001S	Central Bay	Central Bay	8/4/2006	55	0.1035	0	6	1	no	no
CB002S	Central Bay	Central Bay	8/7/2006	97	0.1133	9	8	1	.	.
CB027S	Central Bay	Central Bay	8/4/2006	31	0.0322	0*	2	1	no	no
CB028S	Central Bay	Central Bay	8/7/2006	91	0.2263	22	18	2	.	.
CB029S	Central Bay	Central Bay	8/4/2006	57	0.0897	1	5	1	no	no
CB030S	Central Bay	Central Bay	8/7/2006	22	0.0263	14*	1	0	.	.
CB032S	Central Bay	Central Bay	8/7/2006	93	0.1049	5	6	1	.	.
CB082S	Central Bay	Central Bay	8/7/2006	96	0.1072	7	8	1	no	no
BA10	Coyote Creek	Lower South Bay	8/8/2006	98	0.0869	1	7	1	no	no
LSB001S	Lower South Bay	Lower South Bay	8/8/2006	99	0.0855	2	5	1	no	no
LSB002S	Lower South Bay	Lower South Bay	8/8/2006	99	0.0850	0	4	1	.	.
LSB027S	Lower South Bay	Lower South Bay	8/8/2006	99	0.0838	0	4	1	no	no
LSB028S	Lower South Bay	Lower South Bay	8/8/2006	98	0.0767	0	4	1	.	.
LSB029S	Lower South Bay	Lower South Bay	8/8/2006	85	0.0829	0	4	1	no	yes
LSB030S	Lower South Bay	Lower South Bay	8/8/2006	98	0.0903	0	5	1	.	.
LSB031S	Lower South Bay	Lower South Bay	8/8/2006	99	0.0841	1	4	1	no	yes
LSB032S	Lower South Bay	Lower South Bay	8/8/2006	70	0.0754	0	3	1	.	.
BG20	Sacramento River	Rivers	8/2/2006	9	0.0178	0*	1	1	no	yes
BG30	San Joaquin River	Rivers	8/2/2006	58	0.1010	8	8	1	no	yes
BD31	Pinole Point	San Pablo Bay	8/4/2006	78	0.0584	0	5	1	no	no
SPB001S	San Pablo Bay	San Pablo Bay	8/3/2006	99	0.0809	0	5	1	no	no
SPB002S	San Pablo Bay	San Pablo Bay	8/4/2006	90	0.0645	1	4	1	.	.
SPB027S	San Pablo Bay	San Pablo Bay	8/3/2006	97	0.0771	2	5	1	no	no
SPB028S	San Pablo Bay	San Pablo Bay	8/4/2006	42	0.0397	0	1	1	.	.
SPB029S	San Pablo Bay	San Pablo Bay	8/3/2006	99	0.0594	0	6	1	no	no
SPB030S	San Pablo Bay	San Pablo Bay	8/4/2006	54	0.0546	0	3	1	.	.
SPB031S	San Pablo Bay	San Pablo Bay	8/3/2006	99	0.0751	0	5	1	no	no
SPB032S	San Pablo Bay	San Pablo Bay	8/3/2006	97	0.1027	3	7	1	.	.
BA41	Redwood Creek	South Bay	8/7/2006	77	0.0704	0	3	1	no	no
SB001S	South Bay	South Bay	8/7/2006	39	0.0486	19*	3	1	no	no
SB002S	South Bay	South Bay	8/9/2006	94	0.0920	2	6	1	.	.
SB027S	South Bay	South Bay	8/7/2006	93	0.0982	8	8	1	no	no
SB028S	South Bay	South Bay	8/7/2006	90	0.0961	6	6	1	.	.
SB029S	South Bay	South Bay	8/9/2006	61	0.0870	0	4	1	no	no
SB030S	South Bay	South Bay	8/8/2006	95	0.1196	9	11	1	.	.
SB031S	South Bay	South Bay	8/9/2006	56	0.0572	0	2	1	yes	no
SB032S	South Bay	South Bay	8/9/2006	90	0.0705	0	6	1	.	.
BF21	Grizzly Bay	Suisun Bay	8/2/2006	98	0.0666	1	4	1	no	yes
SU001S	Suisun Bay	Suisun Bay	8/2/2006	40	0.0221	1*	1	1	no	yes
SU002S	Suisun Bay	Suisun Bay	8/2/2006	20	0.0164	1*	1	1	.	.
SU027S	Suisun Bay	Suisun Bay	8/3/2006	92	0.0423	0	5	1	no	yes
SU028S	Suisun Bay	Suisun Bay	8/3/2006	58	0.0251	1	1	1	.	.
SU029S	Suisun Bay	Suisun Bay	8/3/2006	47	0.0531	1	4	1	no	yes
SU030S	Suisun Bay	Suisun Bay	8/2/2006	86	0.0550	1	4	1	.	.
SU031S	Suisun Bay	Suisun Bay	8/2/2006	29	0.0334	5*	3	1	no	yes
SU077S	Suisun Bay	Suisun Bay	8/2/2006	21	0.0223	0*	2	1	.	.

Table 3.3. Maximum concentration of trace elements and trace organics in sediment 2002-2006.

Parameter	Site Code	Region	Year	Maximum Concentration
Ag	SB002S	South Bay	2002	0.52 mg/kg
Al	SB025S	South Bay	2005	61154.941 mg/kg
As	SPB032S	San Pablo Bay	2006	24.1 mg/kg
Cd	SPB018S	San Pablo Bay	2004	0.725874 mg/kg
Cu	SU015S	Suisun	2004	76.069502 mg/kg
Fe	BA10	Lower South Bay	2002	58974.73 mg/kg
Hg	SPB018S	San Pablo Bay	2004	0.780475 mg/kg
MeHg	CB003S	Central Bay	2002	2.379367 ug/kg
Mn	LSB002S	Lower South Bay	2002	6409.11 mg/kg
Ni	SU008S	Suisun	2002	154.32 mg/kg
Pb	SPB018S	San Pablo Bay	2004	46.066913 mg/kg
Se	CB075S	Central Bay	2004	1.702128 mg/kg
Zn	LSB026S	Lower South Bay	2005	219.569 mg/kg
Sum of Chlordanes (SFEI)	SB006S	South Bay	2002	17.77 ug/kg
Sum of DDTs (SFEI)	SPB018S	San Pablo Bay	2004	14.6876 ug/kg
Sum of PAHs (SFEI)	CB080S	Central Bay	2005	12210.3 ug/kg
Sum of PCBs (SFEI)	SPB018S	San Pablo Bay	2004	25.1293 ug/kg
BDE 047	SB005S	South Bay	2002	100 ug/kg
BDE 209	SB027S	South Bay	2006	19.3 ug/kg
Dieldrin	SB006S	South Bay	2002	4.82 ug/kg

Table 3.4. Minimum detectable concentration of trace elements and trace organics in sediment 2002-2006.

Parameter	Site Code	Region	Year	Minimum Concentration
Ag	BG20	Rivers	2006	0.018845 mg/kg
Al	SB073S	South Bay	2002	7306.33 mg/kg
As	SB015S	South Bay	2004	2.328431 mg/kg
Cd	CB027S	Central Bay	2006	0.071383 mg/kg
Cu	SB073S	South Bay	2002	5.26 mg/kg
Fe	SB073S	South Bay	2002	9014.83 mg/kg
Hg	SU024S	Suisun	2005	0.012447 mg/kg
MeHg	SU002S	Suisun	2003	0.005221 ug/kg
Mn	SB073S	South Bay	2002	151.35 mg/kg
Ni	SB073S	South Bay	2002	15.67 mg/kg
Pb	SU010S	Suisun	2003	3.104449 mg/kg
Se	SU002S	Suisun	2004	0.016206 mg/kg
Zn	SB073S	South Bay	2002	23.37 mg/kg
Sum of Chlordanes (SFEI)	BG20	Rivers	2006	0.02208 ug/kg
Sum of DDTs (SFEI)	SU002S	Suisun	2006	0.05444 ug/kg
Sum of PAHs (SFEI)	BG20	Rivers	2002	7.2875 ug/kg
Sum of PCBs (SFEI)	SU002S	Suisun	2006	0.00118 ug/kg
BDE 047	SU077S	Suisun	2006	0.04415 ug/kg
BDE 209	BG20	Rivers	2006	0.02 ug/kg
BDE 209	SU030S	Suisun	2006	0.02 ug/kg
Dieldrin	SU001S	Suisun	2005	0.00899 ug/kg

Table 3.5. Statistical comparisons of cumulative distribution function (CDF) results for sediment contaminant concentrations among regions (2002-2006).
A p value < 0.05 indicates a statistically significant difference for the Roa-Scott test.

	Roa-Scott Test p Value																
Comparison	Ag	As	Cd	Cu	Hg	MeHg	Ni	Pb	Se	Zn	PAHs	PCBs	DDTs	Chlordanes	Dieldrin	BDE-47	BDE-209
CB vs LSB	**0.00**	**0.00**	0.21	**0.01**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.40	0.92	**0.00**	0.69	**0.01**	**0.00**
CB vs SB	**0.01**	**0.01**	0.86	**0.03**	**0.03**	**0.05**	**0.04**	0.84	0.14	0.34	**0.00**	1.00	0.62	0.21	0.27	0.12	0.09
CB vs SPB	0.58	**0.00**	0.34	**0.00**	**0.01**	**0.00**	**0.00**	0.50	0.10	**0.00**	**0.00**	**0.00**	0.28	0.69	0.17	0.48	0.42
CB vs SU	**0.03**	0.28	**0.04**	**0.00**	**0.00**	**0.00**	0.36	**0.00**	0.10	**0.00**	**0.00**	**0.00**	**0.01**	0.35	0.07	**0.01**	**0.03**
LSB vs SB	0.08	0.32	0.80	**0.00**	**0.00**	0.49	**0.00**	**0.00**	0.11	**0.00**	**0.04**	0.10	0.19	**0.00**	0.12	**0.00**	**0.00**
LSB vs SPB	**0.00**	**0.00**	**0.00**	**0.00**	0.39	**0.00**	**0.04**	**0.00**	**0.03**	**0.00**	**0.00**	**0.00**	0.11	**0.00**	**0.02**	**0.00**	**0.00**
LSB vs SU	**0.00**	0.07	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.00**	0.06	**0.00**	**0.00**
SB vs SPB	0.07	**0.00**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	0.24	0.35	**0.00**	**0.00**	**0.00**	0.28	**0.00**	0.15	0.65	0.09
SB vs SU	**0.01**	0.07	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.00**	0.17	0.49	**0.00**	**0.00**	0.06	0.69	**0.05**	**0.02**	**0.00**
SPB vs SU	0.35	**0.00**	0.07	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.70	**0.00**	**0.00**	**0.00**	0.91	0.33	0.50	**0.01**	0.07

Abbreviations: CB = Central Bay, LSB = Lower South Bay, SB = South Bay, SPB = San Pablo Bay, and SU = Suisun Bay.

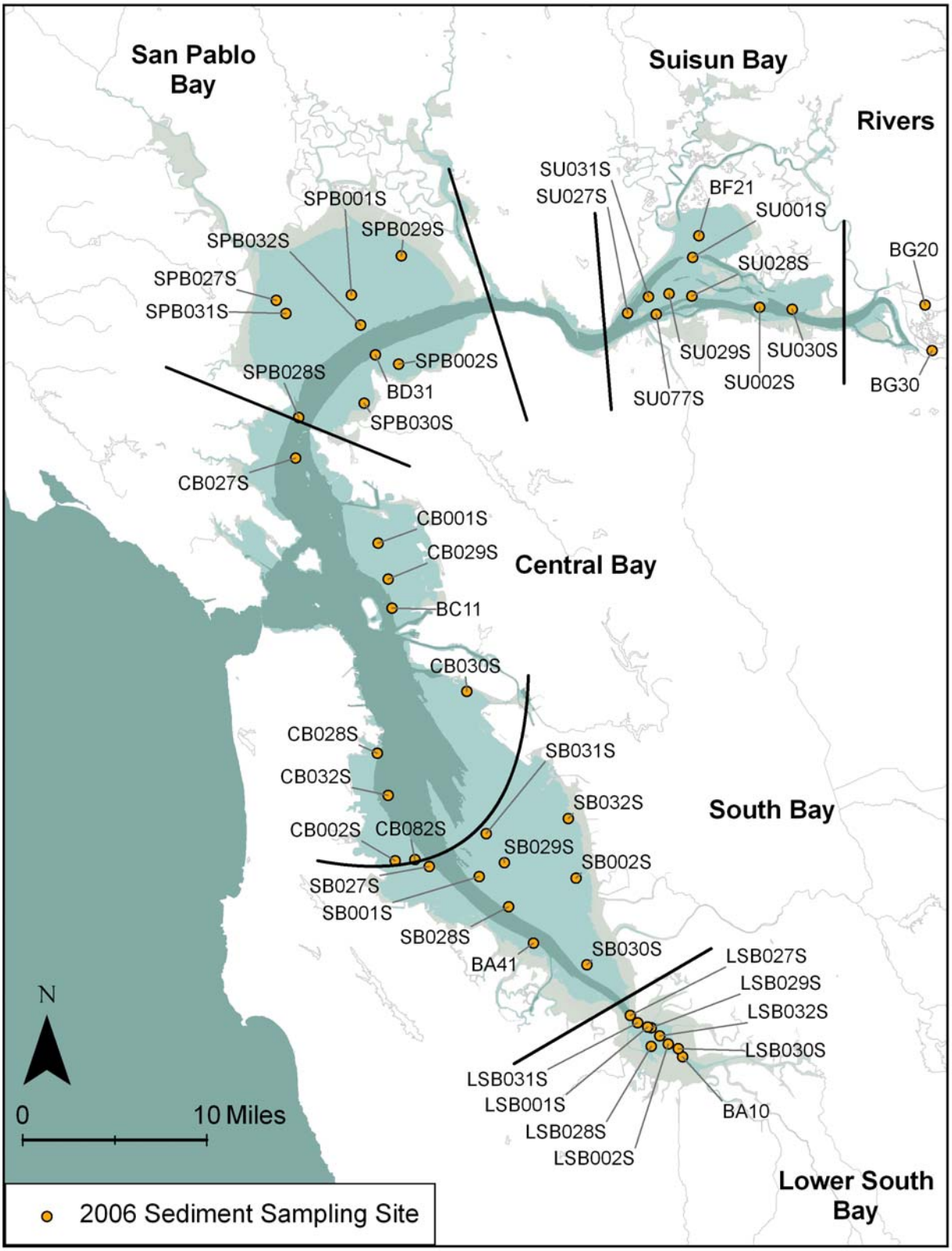


Figure 3.1. Map of the 2006 RMP Status and Trends sediment monitoring effort at randomly selected and historic sampling sites. A total of 40 random sites and seven historic sites (sampled each year) were sampled in the San Francisco Estuary for analysis of water quality and trace contaminants.

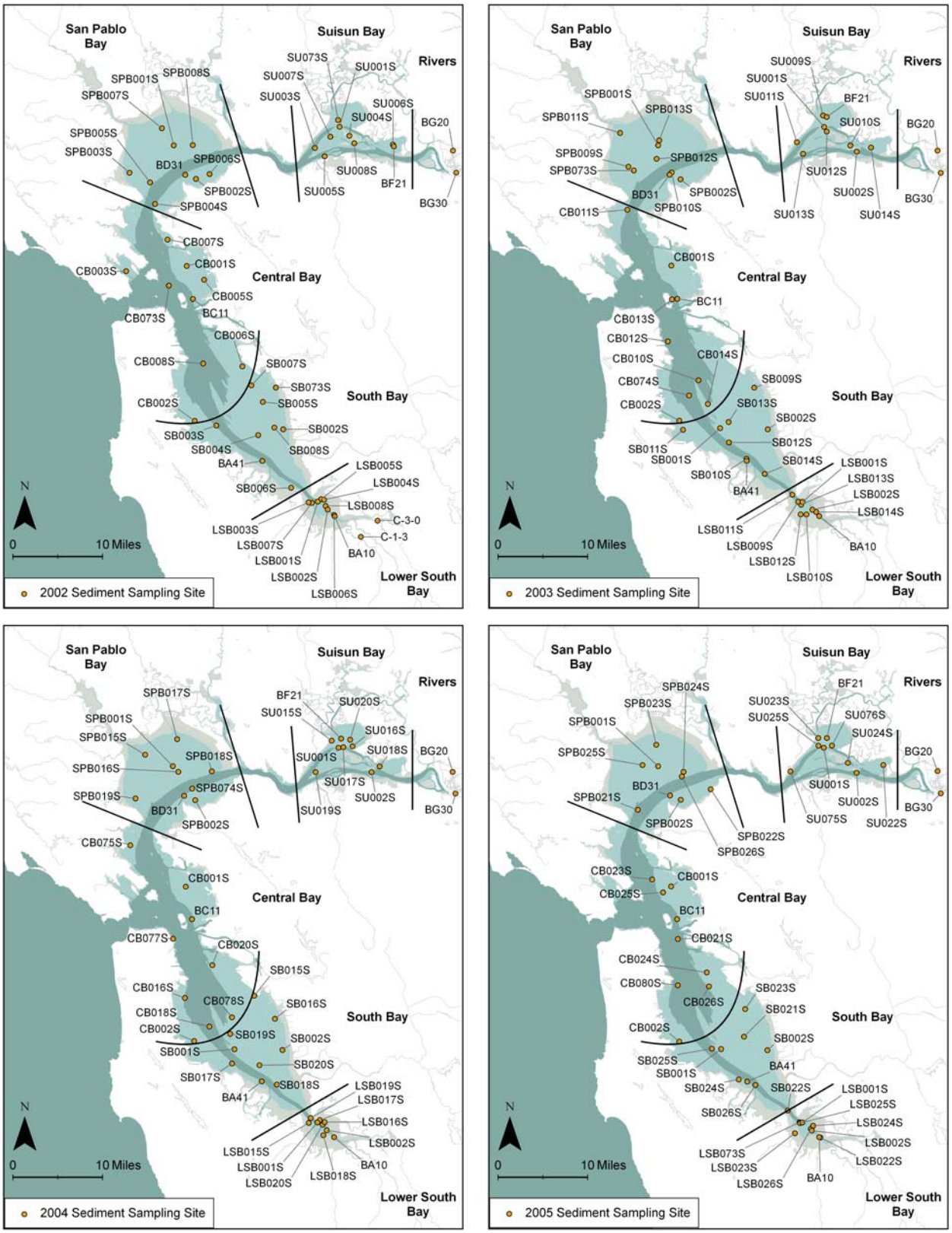
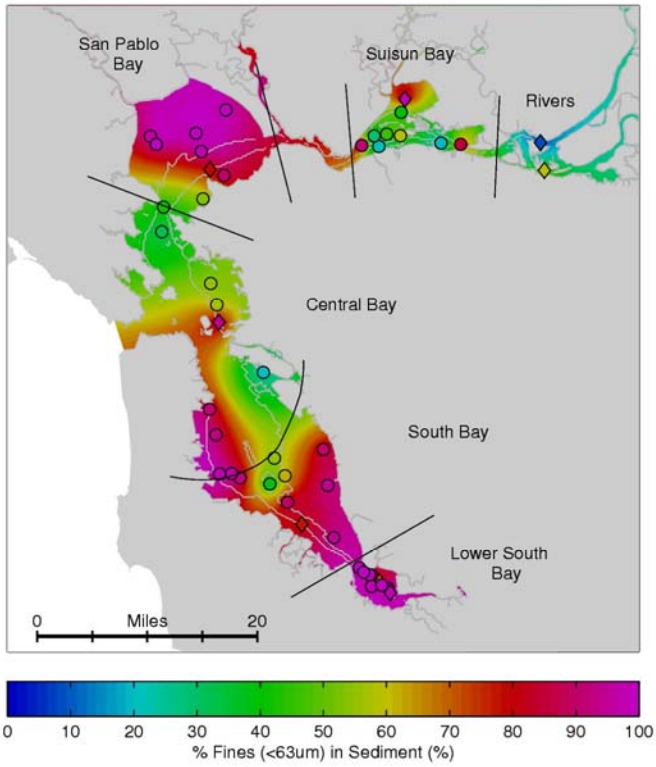


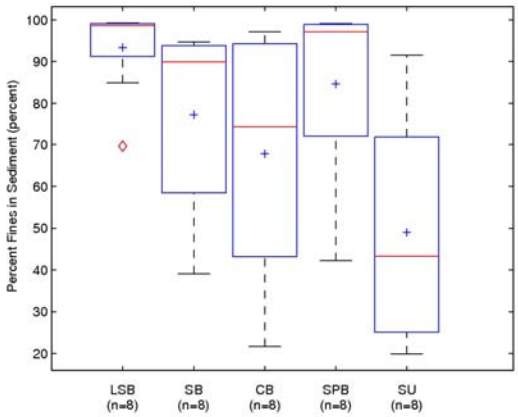
Figure 3.2. Maps of the RMP Status and Trends sediment monitoring effort from 2002 to 2005 at randomly selected and historic sampling sites. Each year a total of 40 random stations and 7 historic sites (exception: 9 sites in 2002) were sampled in the San Francisco Estuary.

Percent Fines in Sediment (2002-2006)



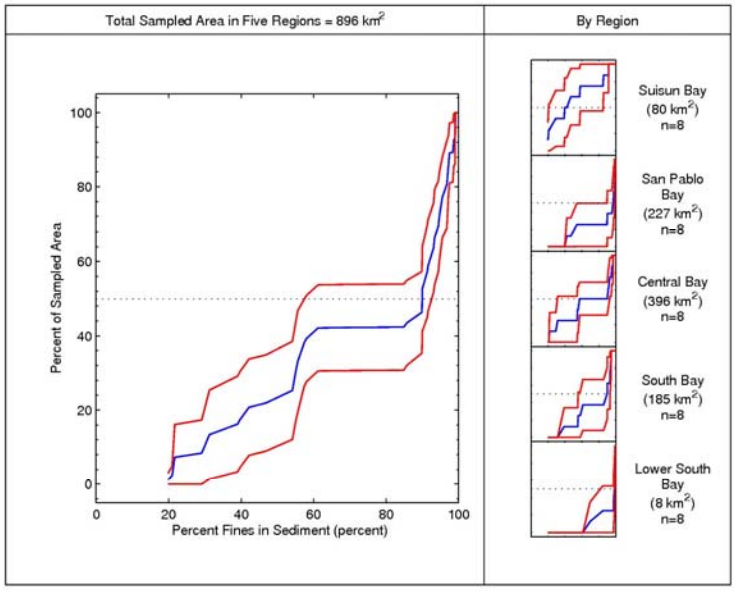
a) Map of concentrations in sediment $(percent)$ in the six Estuary regions monitored. 40 randomly allocated sites and 7 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment $(percent)$ for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



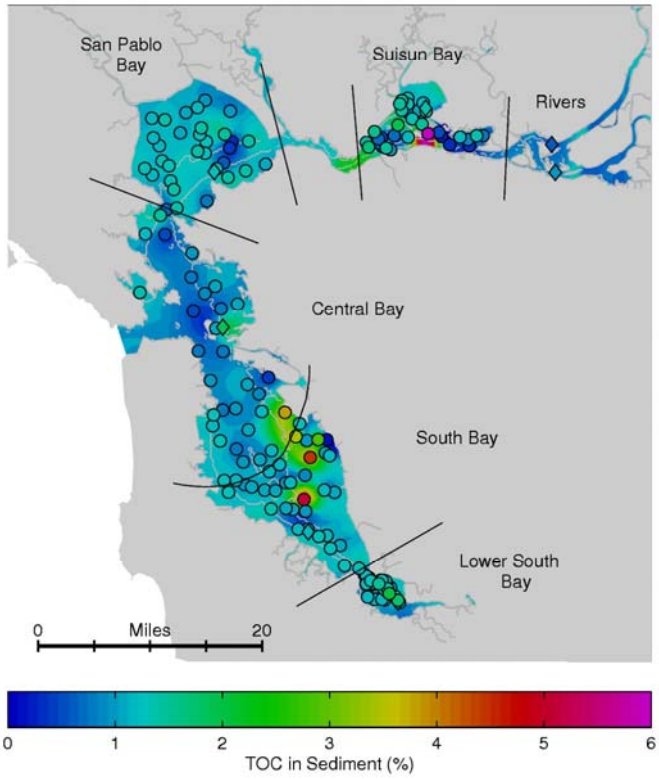
c) Cumulative distribution functions (CDFs) for concentrations in sediment $(percent)$ from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus percent fines concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

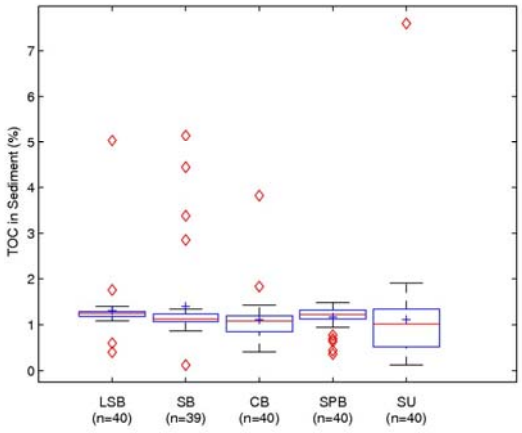
Figure 3.3

TOC in Sediment (2002-2006)



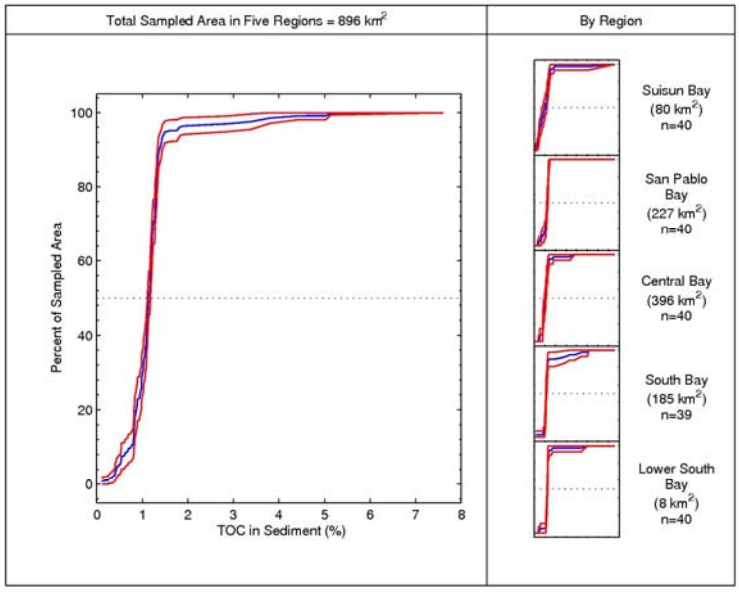
a) Map of concentrations in sediment $(percent)$ in the six Estuary regions monitored. 199 randomly allocated sites and 37 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment $(percent)$ for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



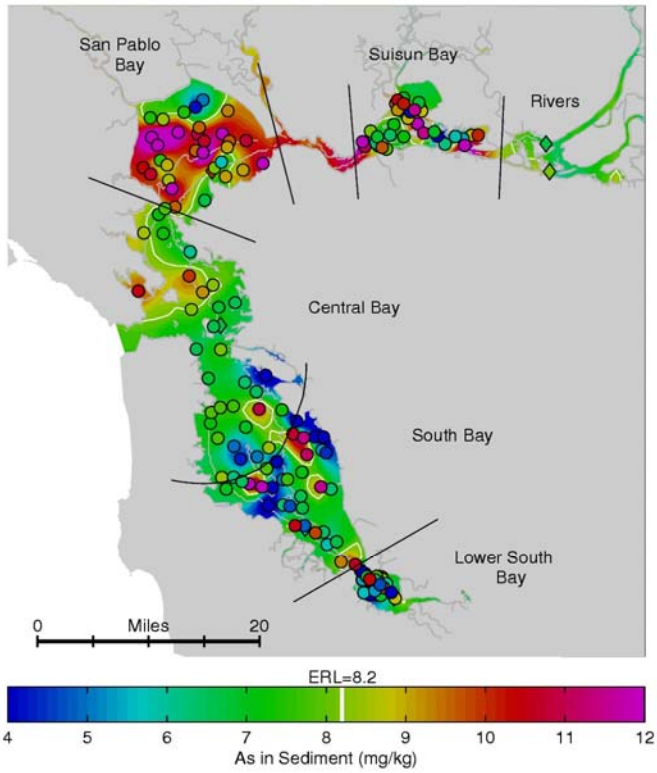
c) Cumulative distribution functions (CDFs) for concentrations in sediment $(percent)$ from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus toc concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

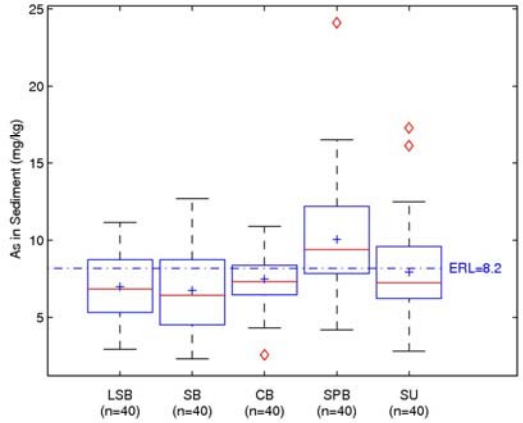
Figure 3.4

Arsenic (As) in Sediment (2002-2006)



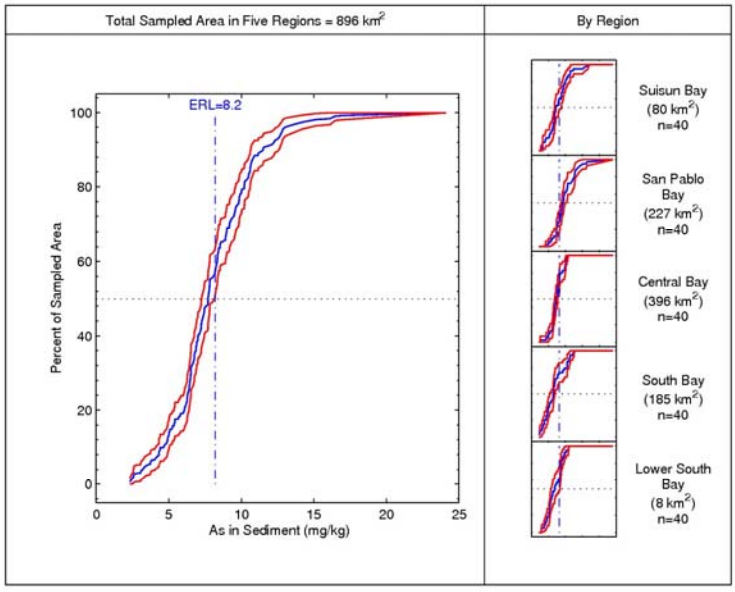
a) Map of concentrations in sediment (mg/kg) in the six Estuary regions monitored. 200 randomly allocated sites and 37 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (mg/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for concentrations in sediment (mg/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

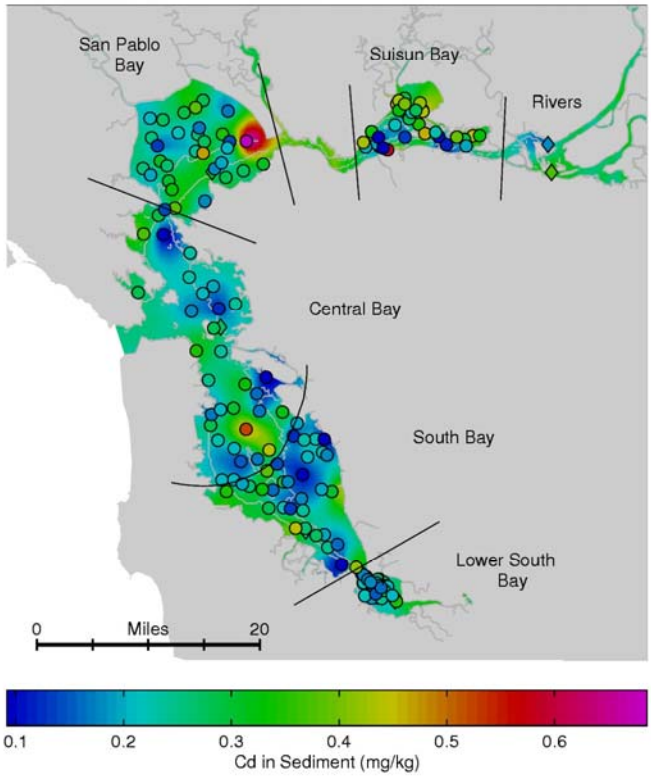
The large graph shows the percentage of the total area sampled in the five Estuary regions versus arsenic concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : November 1, 2007 ∘

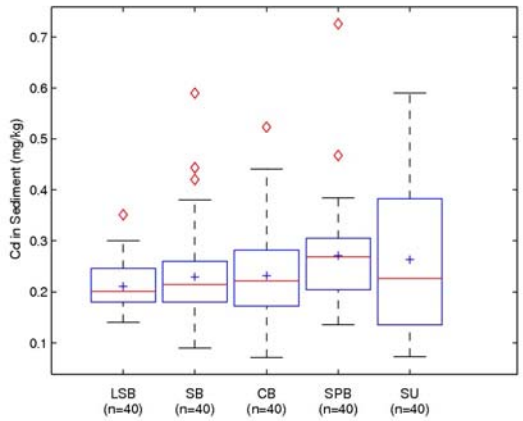
Figure 3.5

Cadmium (Cd) in Sediment (2002-2006)



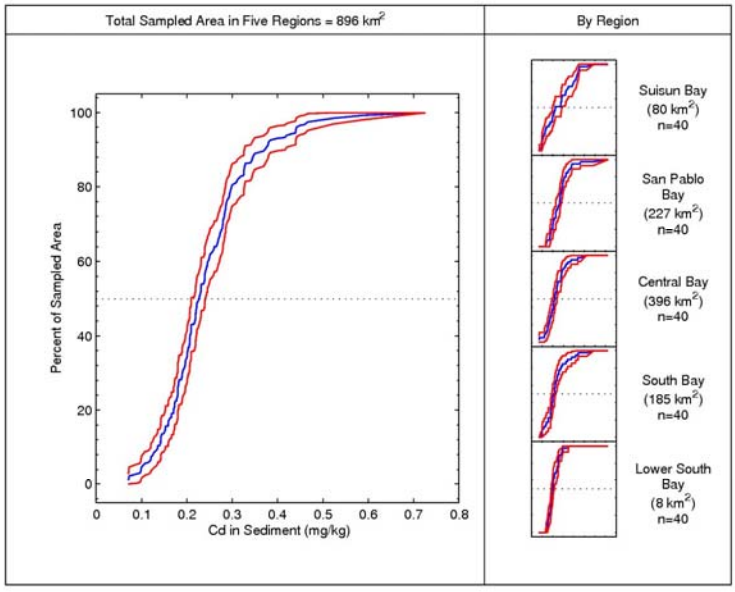
a) Map of concentrations in sediment (mg/kg) in the six Estuary regions monitored. 200 randomly allocated sites and 37 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (mg/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



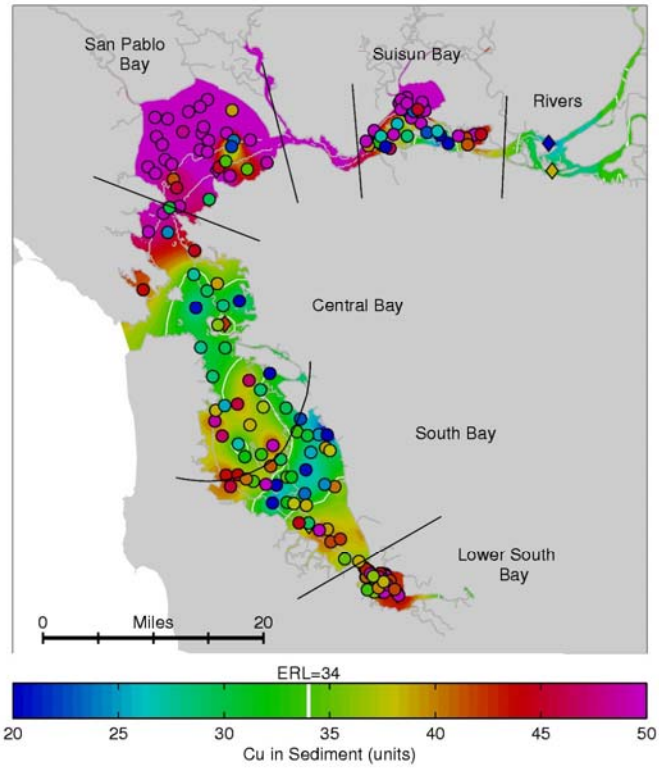
c) Cumulative distribution functions (CDFs) for concentrations in sediment (mg/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus cadmium concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

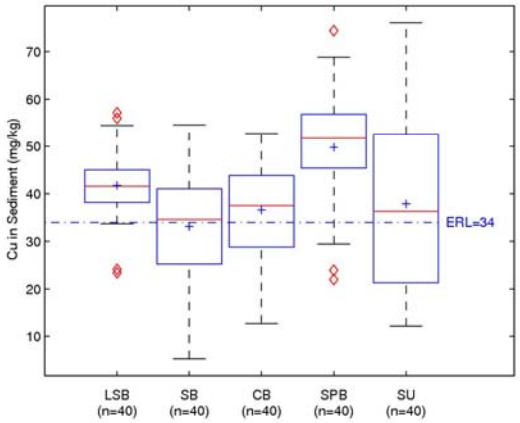
Figure 3.6

Copper (Cu) in Sediment (2002-2006)



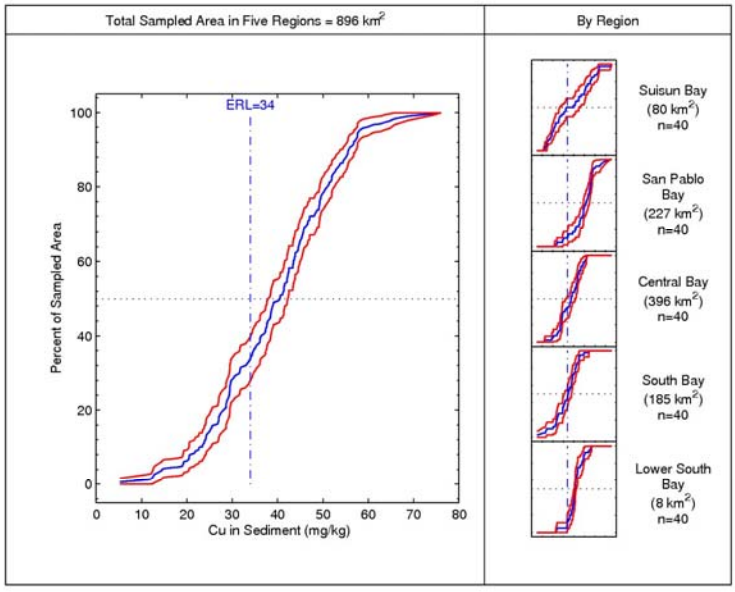
a) Map of concentrations in sediment (mg/kg) in the six Estuary regions monitored. 200 randomly allocated sites and 37 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (mg/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



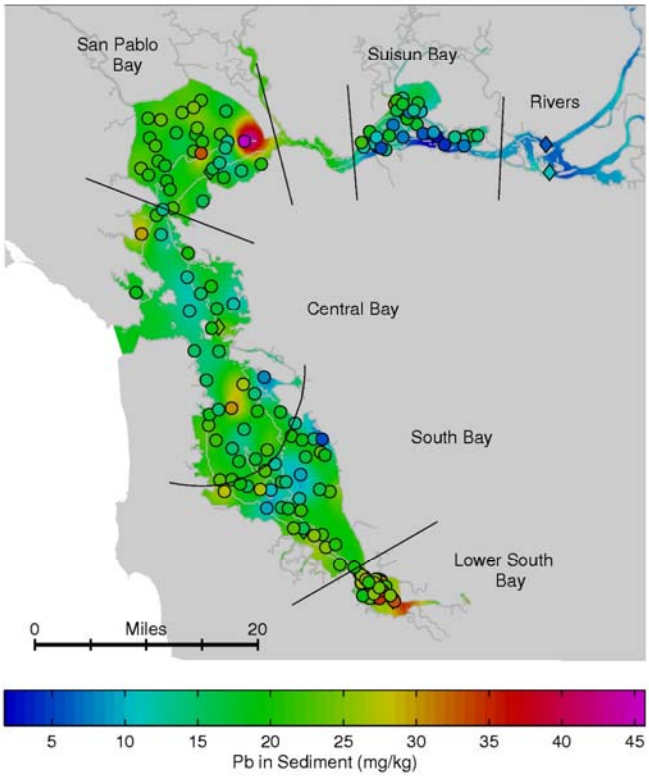
c) Cumulative distribution functions (CDFs) for concentrations in sediment (mg/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus copper concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

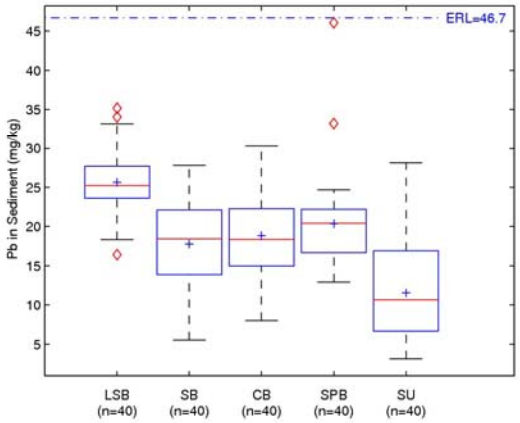
Figure 3.7

Lead (Pb) in Sediment (2002-2006)



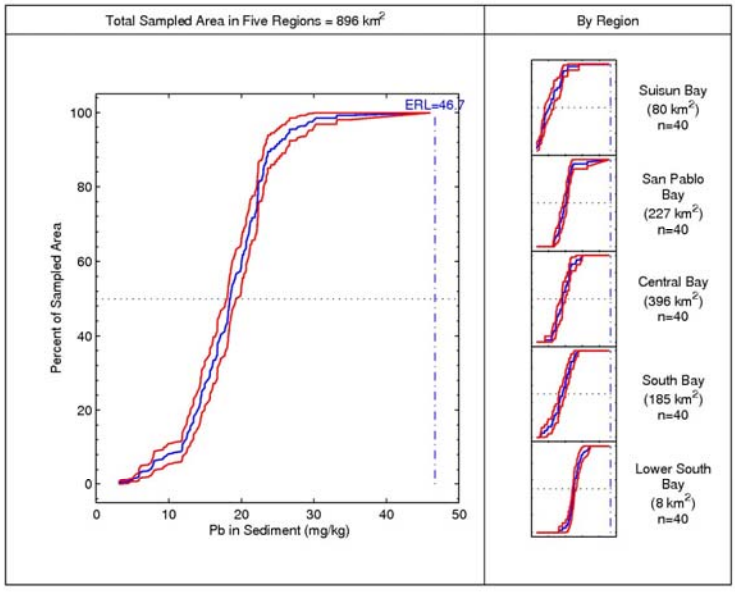
a) Map of concentrations in sediment (mg/kg) in the six Estuary regions monitored. 200 randomly allocated sites and 37 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (mg/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



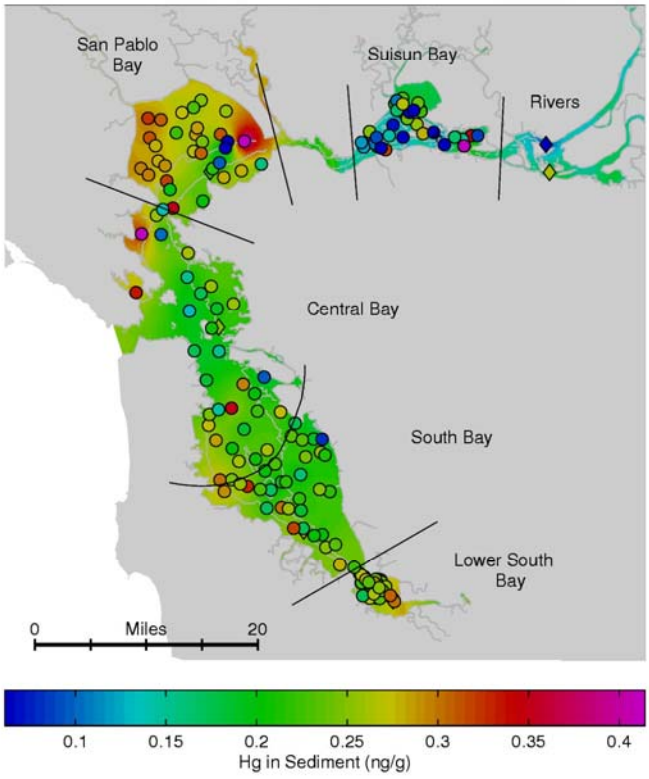
c) Cumulative distribution functions (CDFs) for concentrations in sediment (mg/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus lead concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

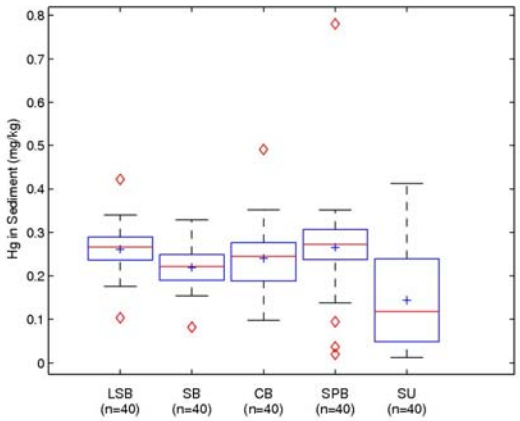
Figure 3.8

Mercury (Hg) in Sediment (2002-2006)



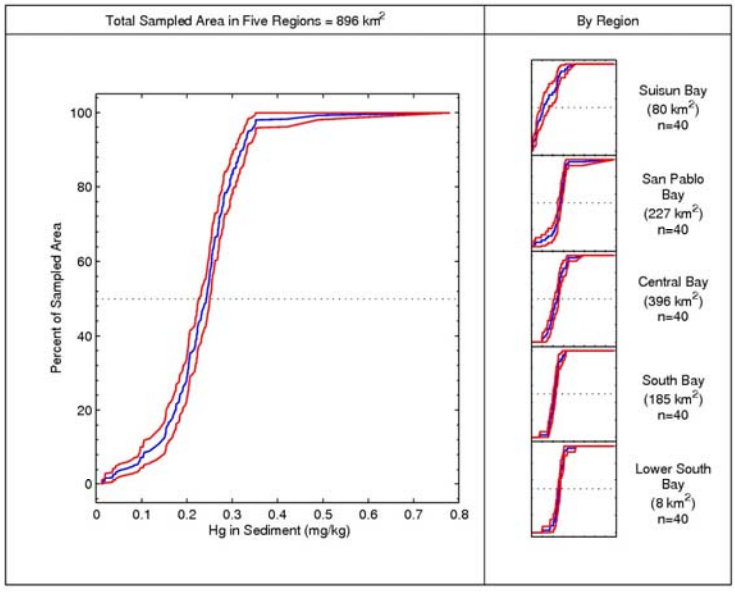
a) Map of concentrations in sediment (mg/kg) in the six Estuary regions monitored. 200 randomly allocated sites and 37 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (mg/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for concentrations in sediment (mg/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

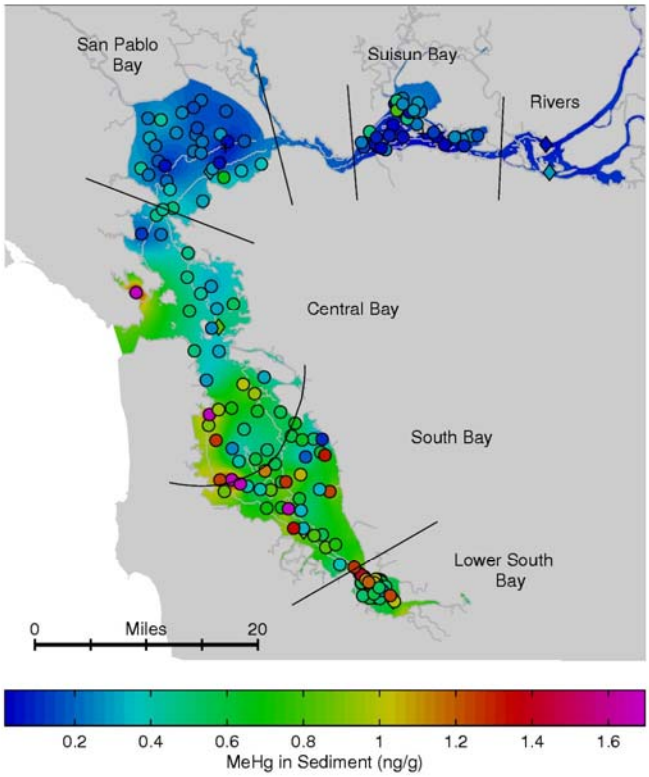
The large graph shows the percentage of the total area sampled in the five Estuary regions versus mercury concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : November 1, 2007 ∘

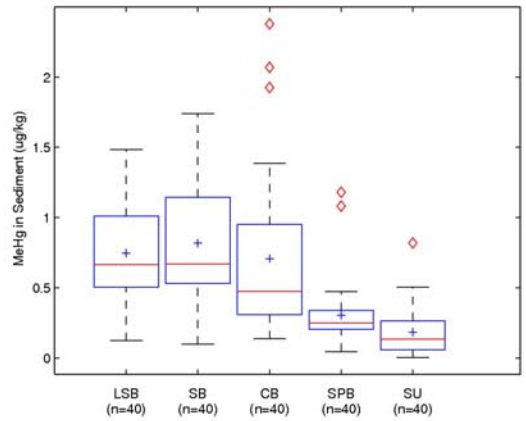
Figure 3.9

Methylmercury (MeHg) in Sediment (2002-2006)



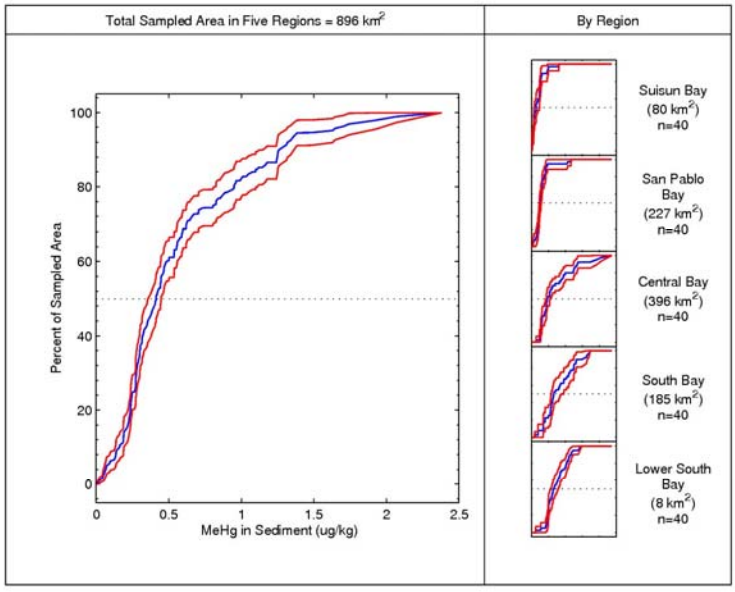
a) Map of concentrations in sediment (ug/kg) in the six Estuary regions monitored. 200 randomly allocated sites and 37 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (ug/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



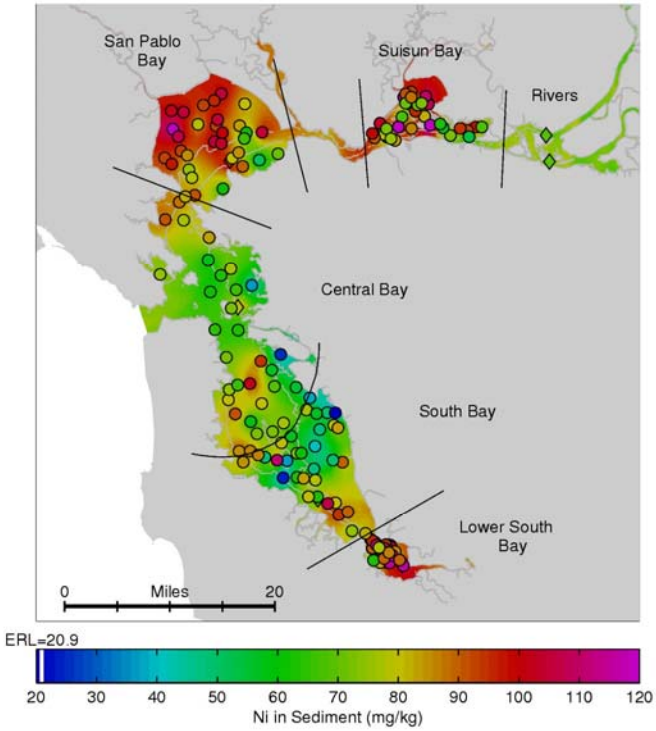
c) Cumulative distribution functions (CDFs) for concentrations in sediment (ug/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus methylmercury concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

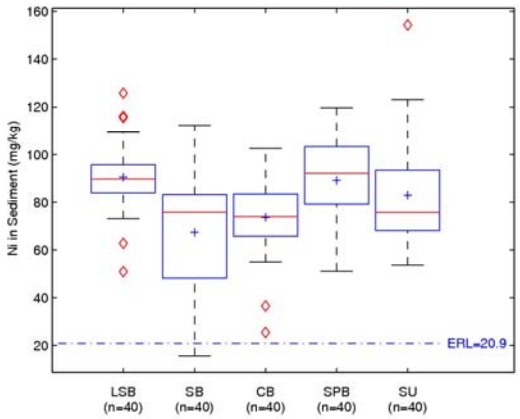
Figure 3.10

Nickel (Ni) in Sediment (2002-2006)



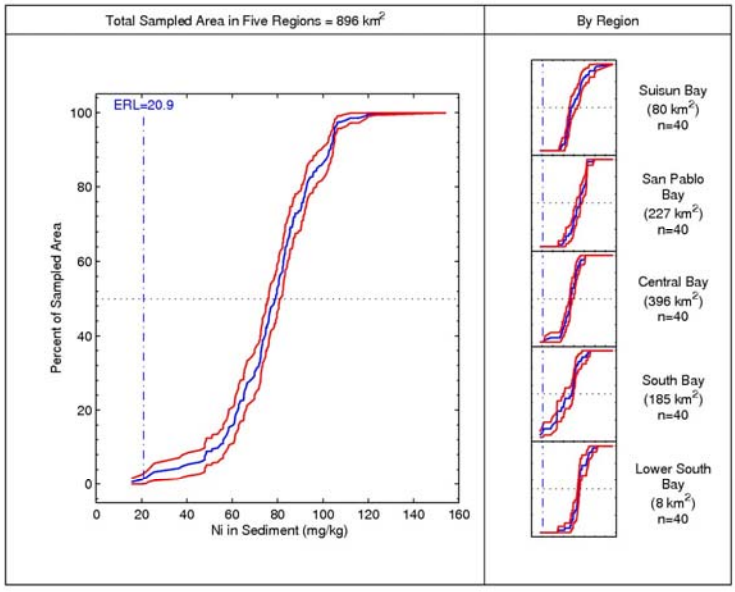
a) Map of concentrations in sediment (mg/kg) in the six Estuary regions monitored. 200 randomly allocated sites and 37 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (mg/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for concentrations in sediment (mg/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

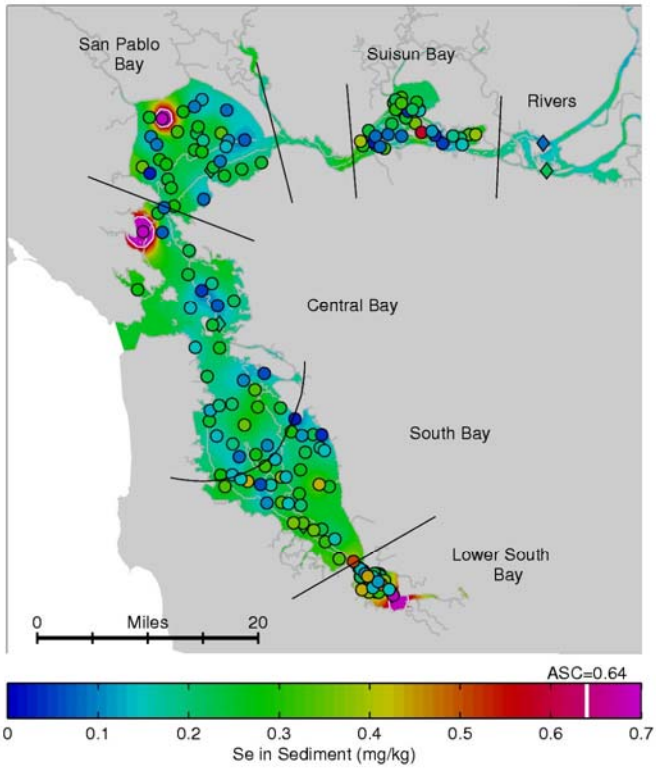
The large graph shows the percentage of the total area sampled in the five Estuary regions versus nickel concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : November 1, 2007 ∘

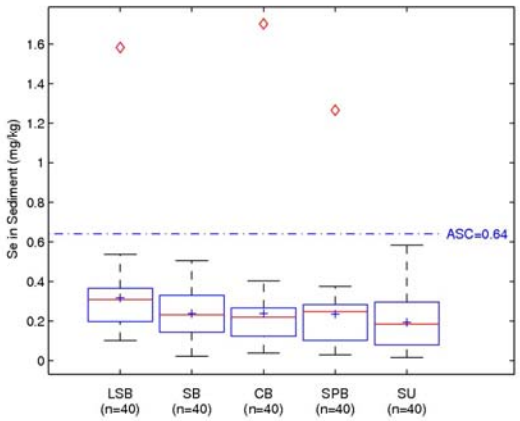
Figure 3.11

Selenium (Se) in Sediment (2002-2006)



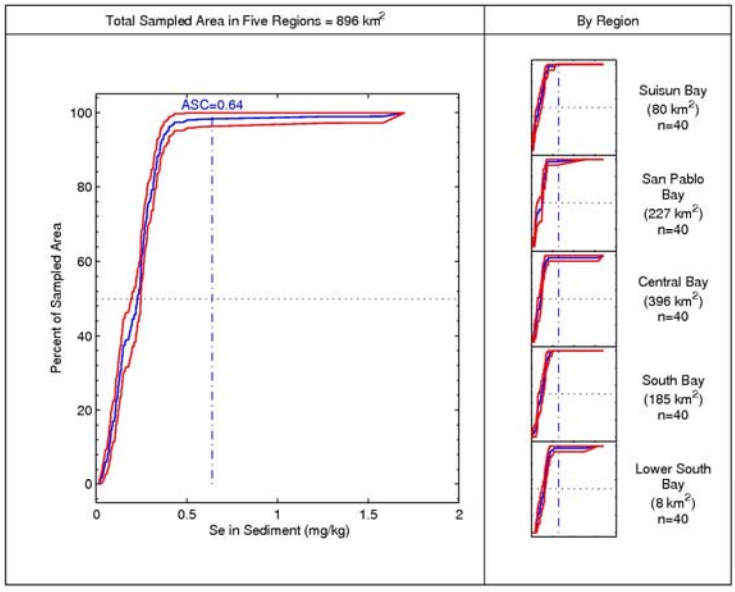
a) Map of concentrations in sediment (mg/kg) in the six Estuary regions monitored. 200 randomly allocated sites and 37 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (mg/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



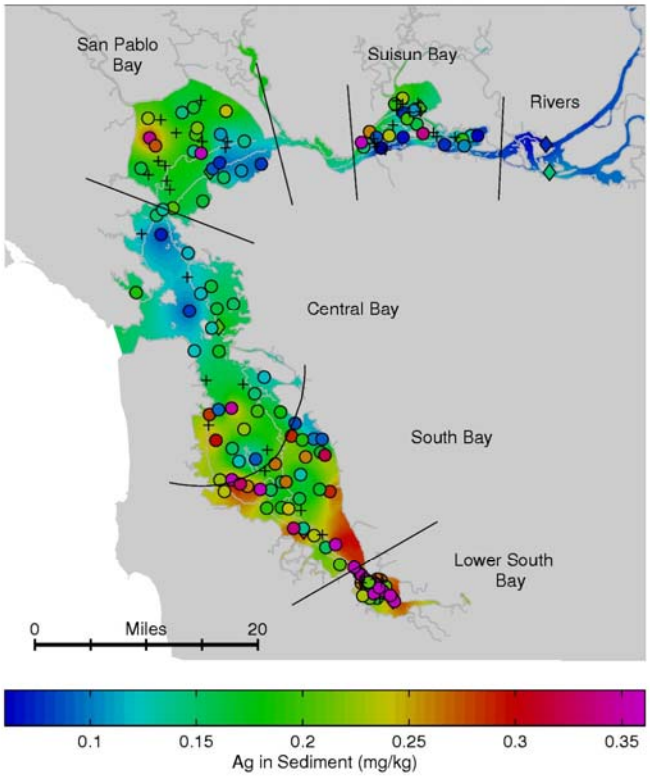
c) Cumulative distribution functions (CDFs) for concentrations in sediment (mg/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus selenium concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

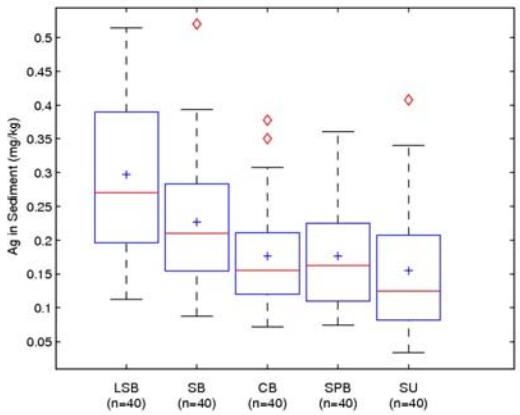
Figure 3.12

Silver (Ag) in Sediment (2002-2006)



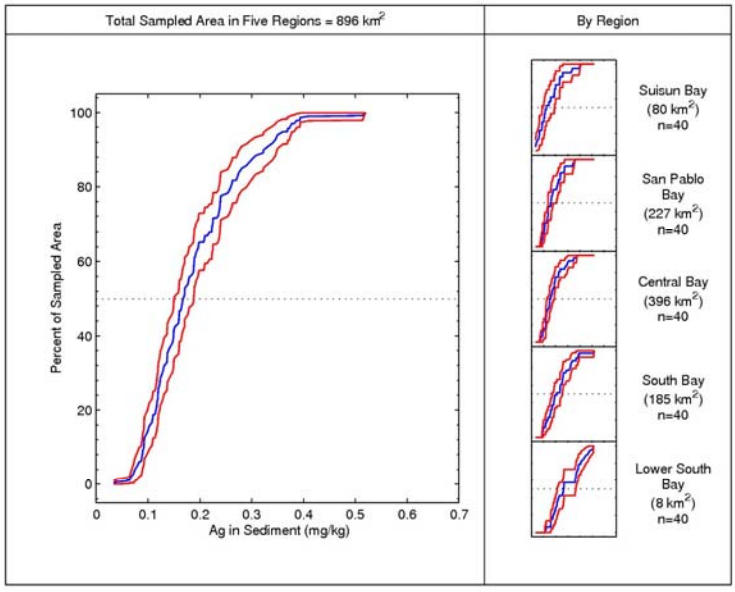
a) Map of concentrations in sediment (mg/kg) in the six Estuary regions monitored. 200 randomly allocated sites and 37 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (mg/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for concentrations in sediment (mg/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

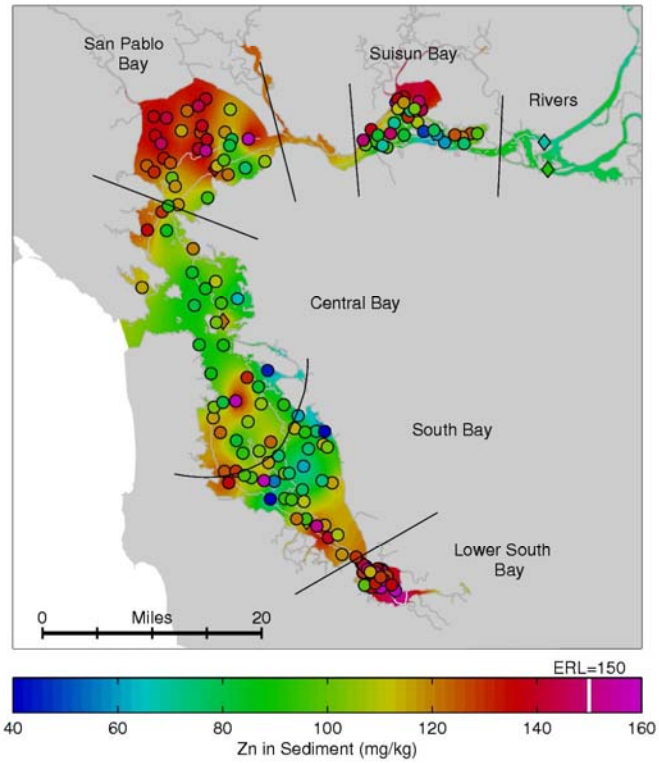
The large graph shows the percentage of the total area sampled in the five Estuary regions versus silver concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : November 1, 2007 ∘

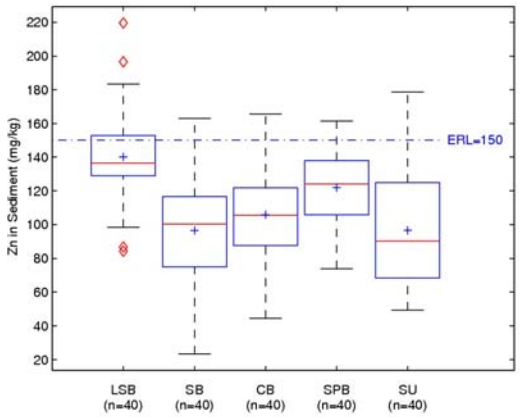
Figure 3.13

Zinc (Zn) in Sediment (2002-2006)



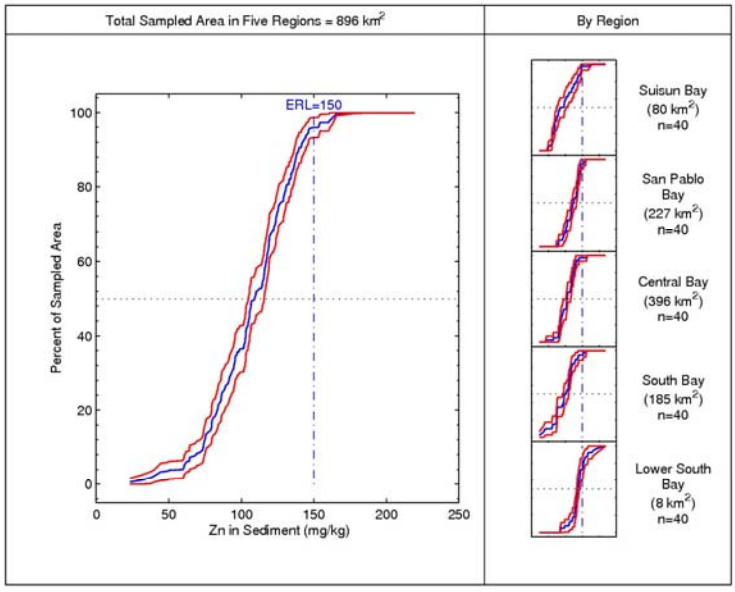
a) Map of concentrations in sediment (mg/kg) in the six Estuary regions monitored. 200 randomly allocated sites and 37 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (mg/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



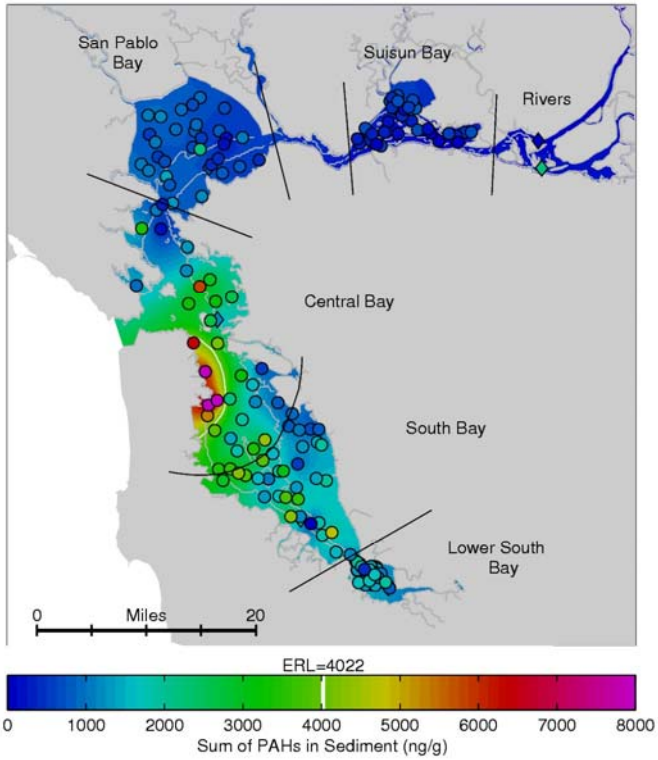
c) Cumulative distribution functions (CDFs) for concentrations in sediment (mg/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus zinc concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

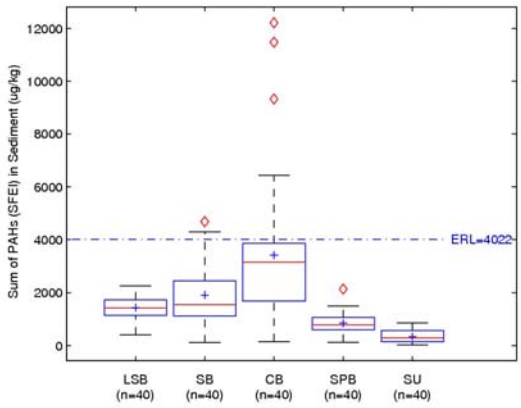
Figure 3.14

Sum of PAHs (SFEI) in Sediment (2002-2006)



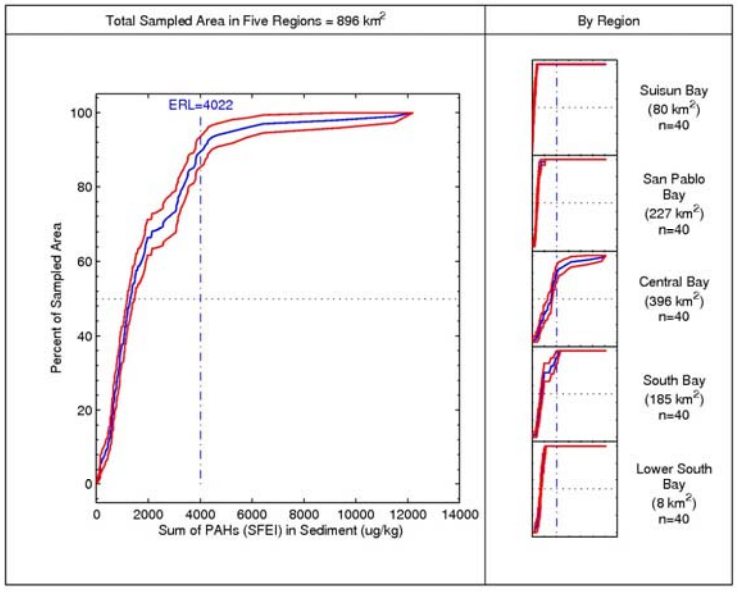
a) Map of concentrations in sediment (ug/kg) in the six Estuary regions monitored. 200 randomly allocated sites and 36 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (ug/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for concentrations in sediment (ug/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of pahs (sfei) concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

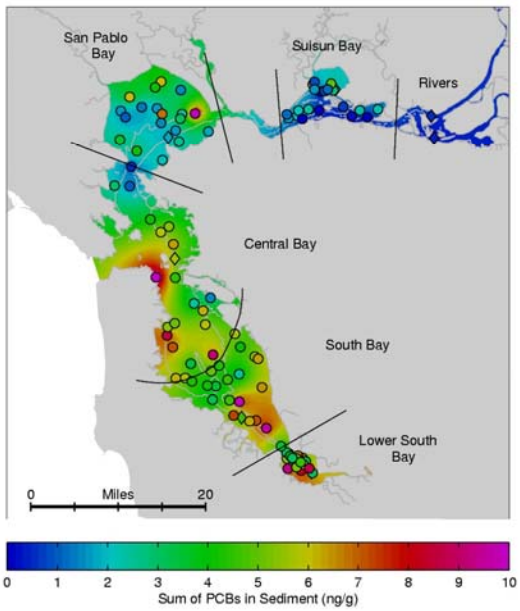
∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : November 1, 2007 ∘

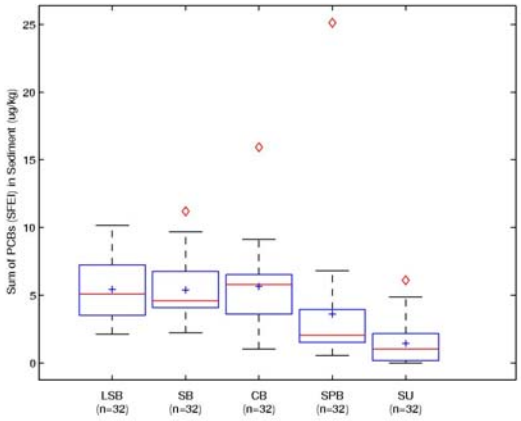
Figure 3.15

Sum of PCBs (SFEI) in Sediment (2002-2006)

a) Map of concentrations in sediment (ug/kg) in the six Estuary regions monitored. 160 randomly allocated sites and 29 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

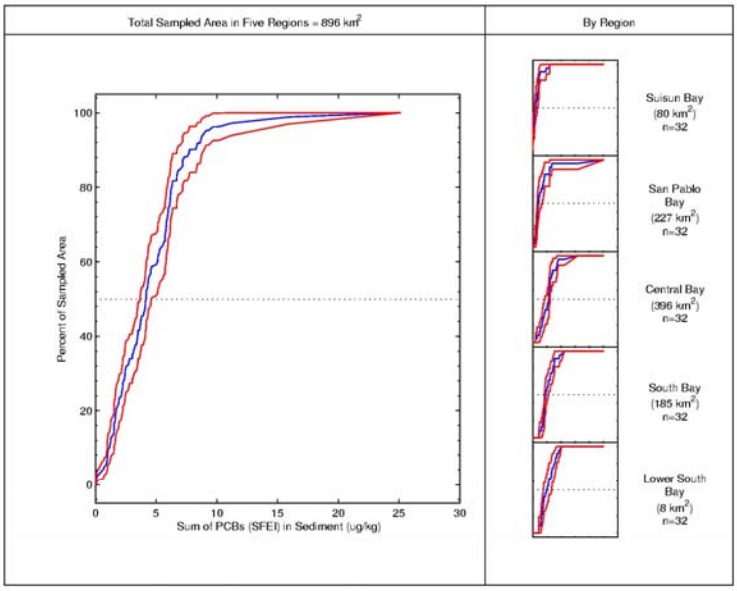
Random sites = ○ , Historic sites = ◇, Non- detects = +





b) Boxplot of concentrations in sediment (ug/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



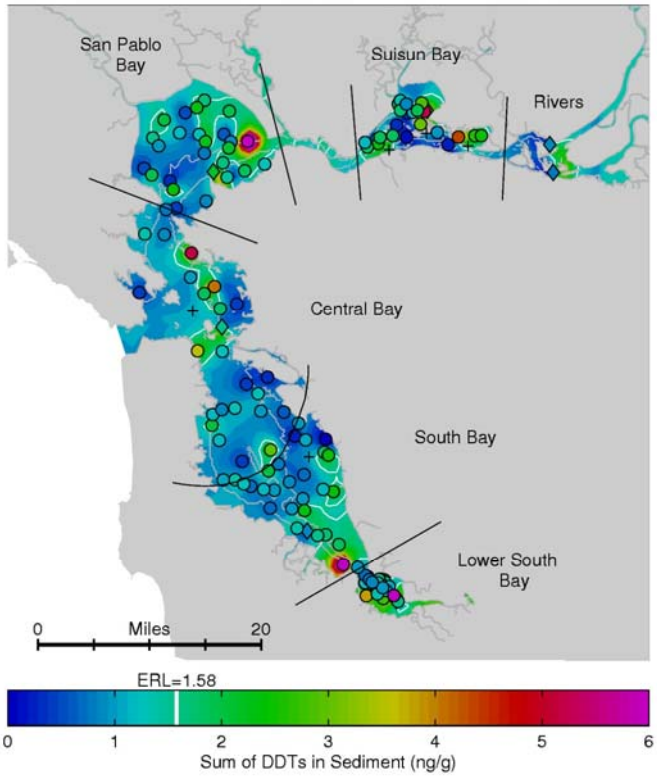
c) Cumulative distribution functions (CDFs) for concentrations in sediment (ug/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of pcbs (sfei) concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

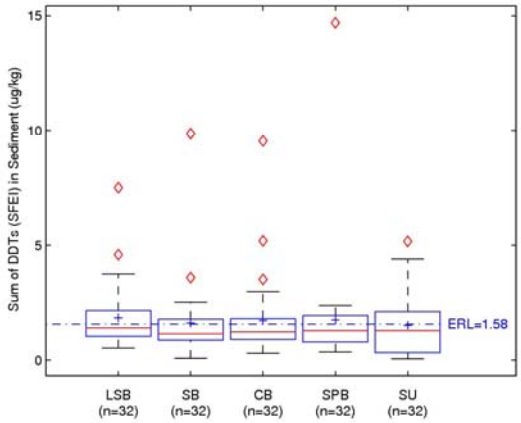
Figure 3.16

Sum of DDTs (SFEI) in Sediment (2002-2006)



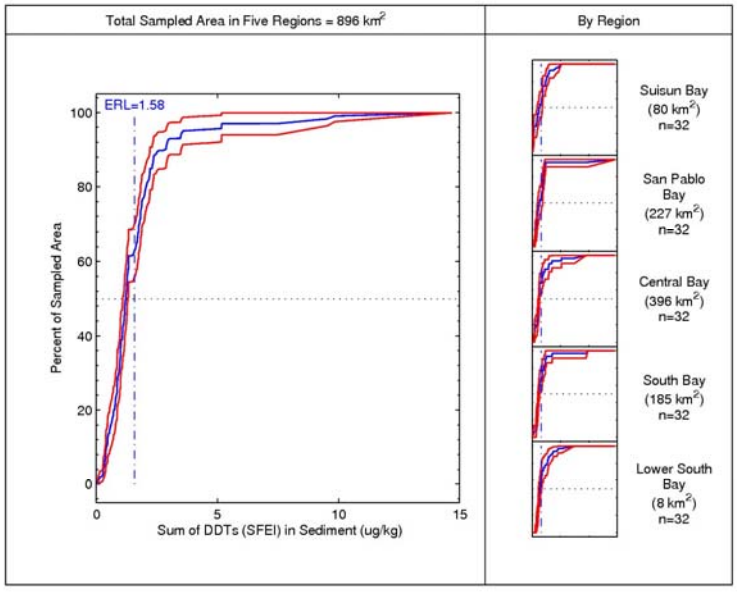
a) Map of concentrations in sediment (ug/kg) in the six Estuary regions monitored. 160 randomly allocated sites and 29 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (ug/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for concentrations in sediment (ug/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

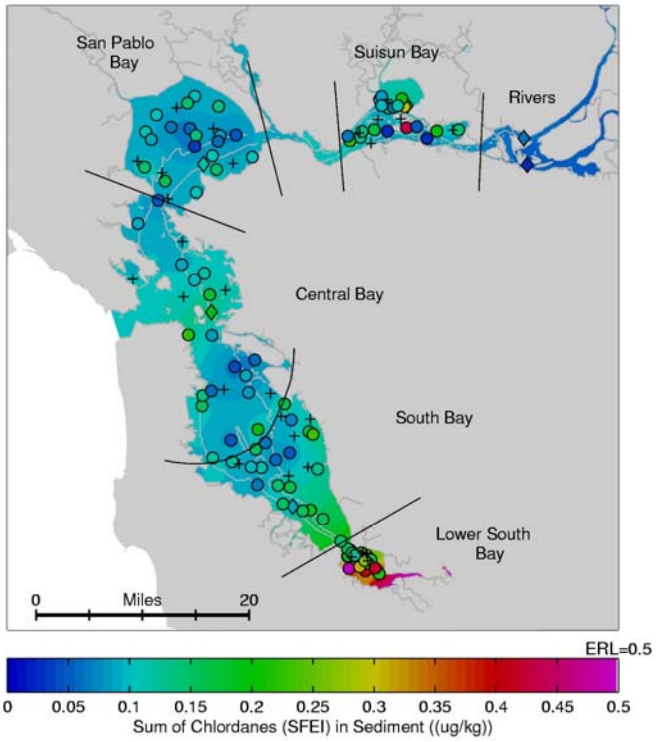
The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of ddts (sfei) concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

∘ Regional Monitoring Program for Water Quality in San Francisco Estuary : www.sfei.org/rmp : December 11, 2007 ∘

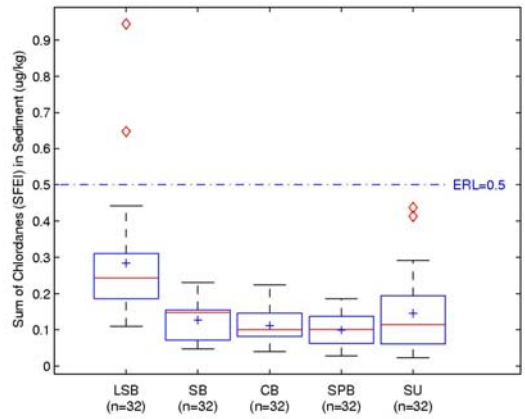
Figure 3.17

Sum of Chlordanes (SFEI) in Sediment (2002-2006)



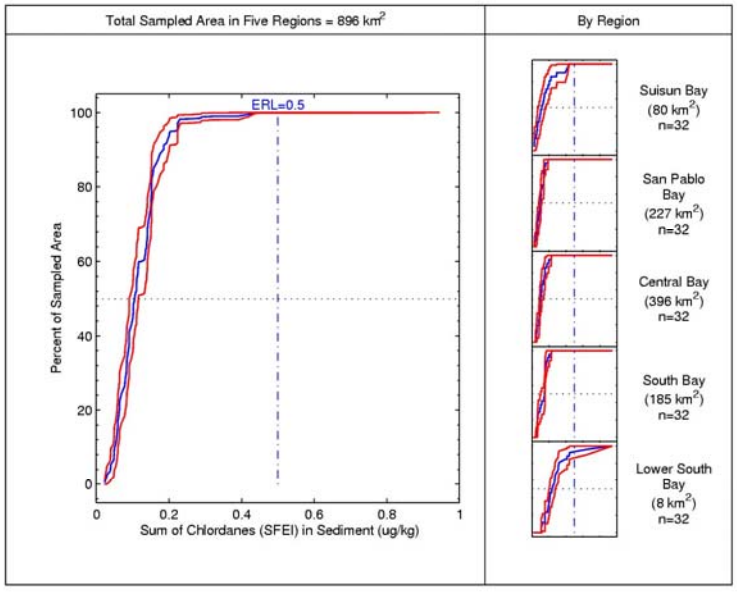
a) Map of concentrations in sediment (ug/kg) in the six Estuary regions monitored. 160 randomly allocated sites and 29 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ○ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (ug/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



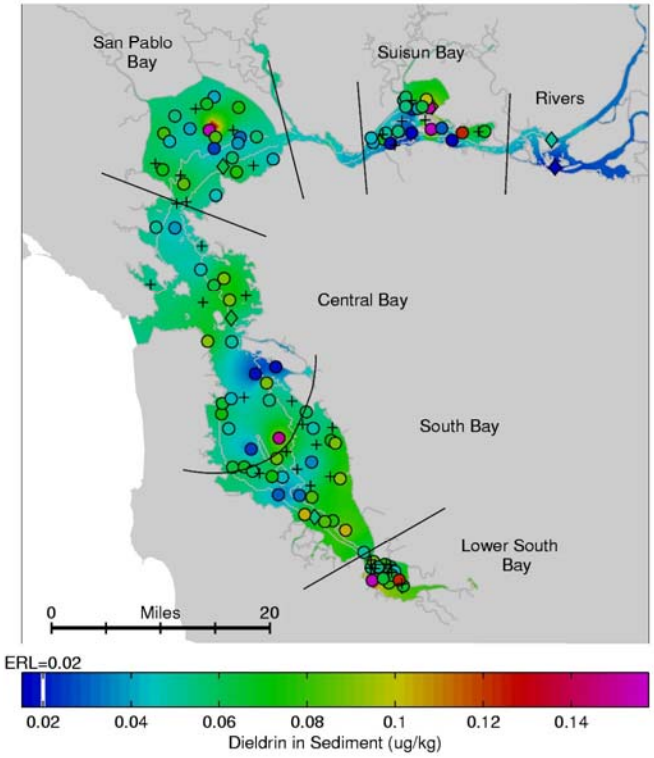
c) Cumulative distribution functions (CDFs) for concentrations in sediment (ug/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus sum of chlordanes (sfei) concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

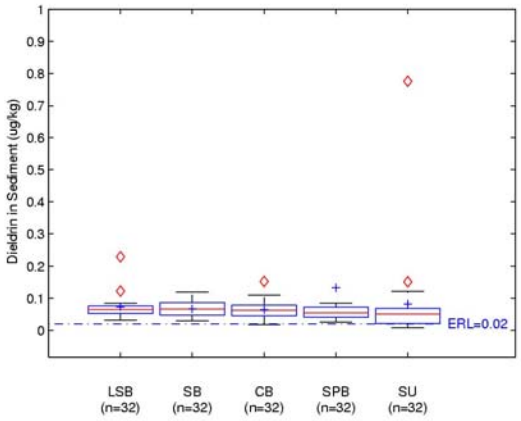
Figure 3.18

Dieldrin in Sediment (2002-2006)



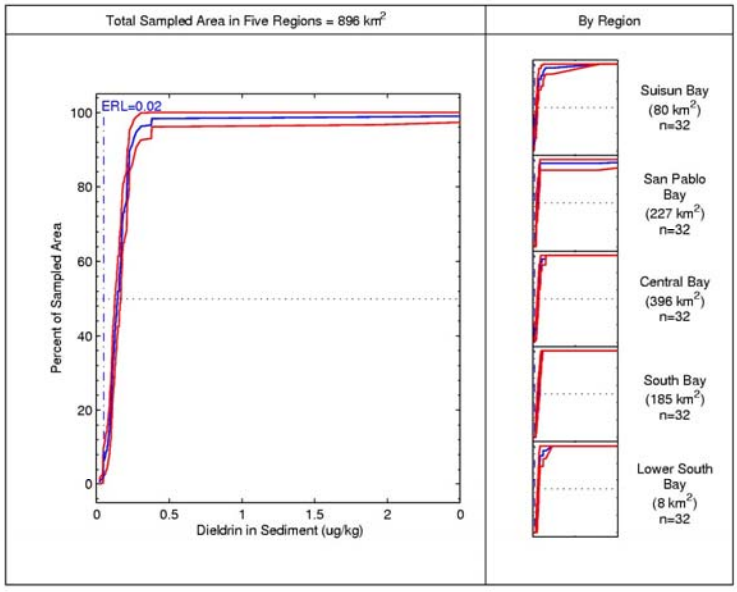
a) Map of concentrations in sediment (ug/kg) in the six Estuary regions monitored. 160 randomly allocated sites and 29 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ○ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (ug/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



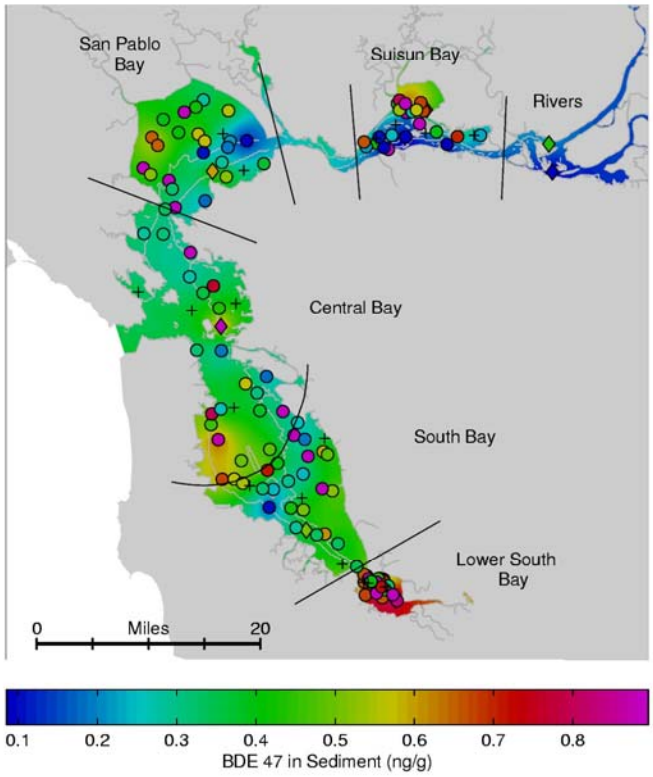
c) Cumulative distribution functions (CDFs) for concentrations in sediment (ug/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus dieldrin concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

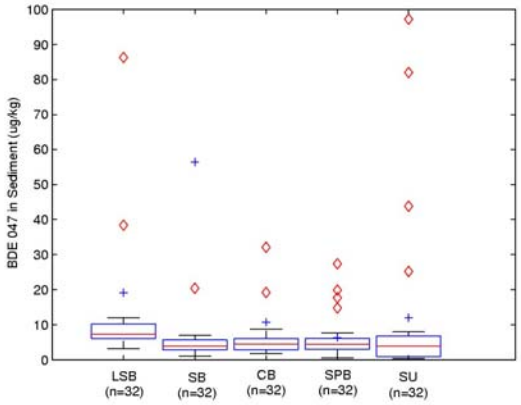
Figure 3.19

BDE 047 in Sediment (2002-2006)



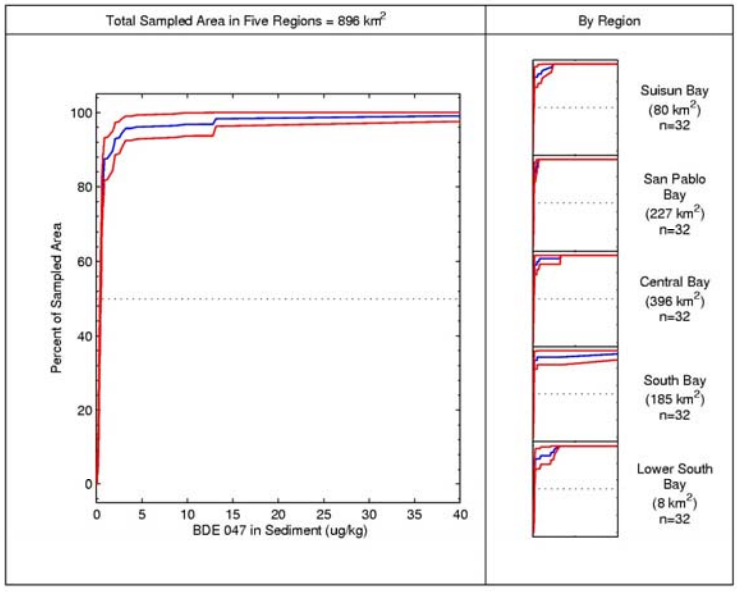
a) Map of concentrations in sediment (ug/kg) in the six Estuary regions monitored. 160 randomly allocated sites and 29 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ○ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (ug/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



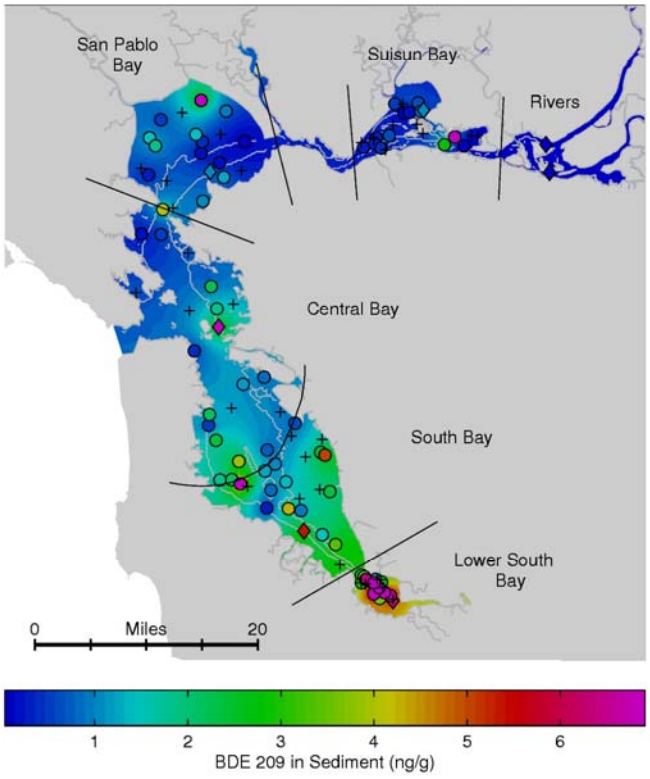
c) Cumulative distribution functions (CDFs) for concentrations in sediment (ug/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus bde 047 concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

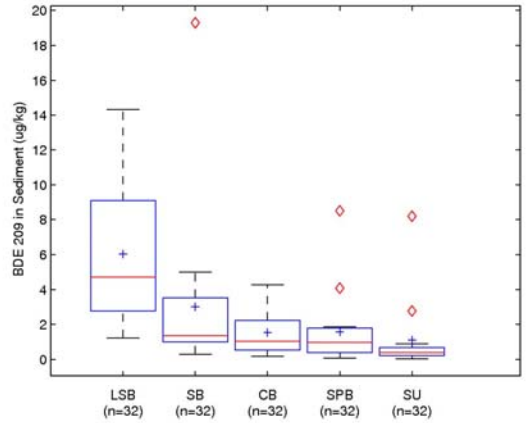
Figure 3.20

BDE 209 in Sediment (2002-2006)



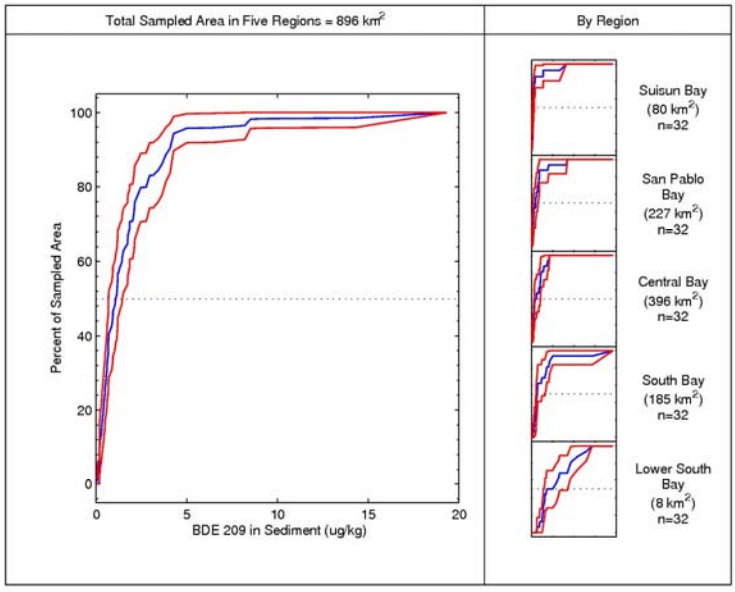
a) Map of concentrations in sediment (ug/kg) in the six Estuary regions monitored. 160 randomly allocated sites and 29 historic sites were sampled from 2002 to 2006. Only results that passed QA/QC are reported. Replicate stations are averaged.

Random sites = ∘ , Historic sites = ◇, Non- detects = +



b) Boxplot of concentrations in sediment (ug/kg) for random sites sampled in the five Estuary regions from 2002 to 2006.

Region codes: LSB=Lower South Bay, SB=South Bay, CB=Central Bay, SPB=San Pablo Bay, SU=Suisun Bay.



c) Cumulative distribution functions (CDFs) for concentrations in sediment (ug/kg) from the random sites in the five Estuary regions monitored from 2002 to 2006.

The large graph shows the percentage of the total area sampled in the five Estuary regions versus bde 209 concentrations in sediment.

The small graphs show the same for each individual Estuary region monitored (scales are identical to the large graph).

Figure 3.21

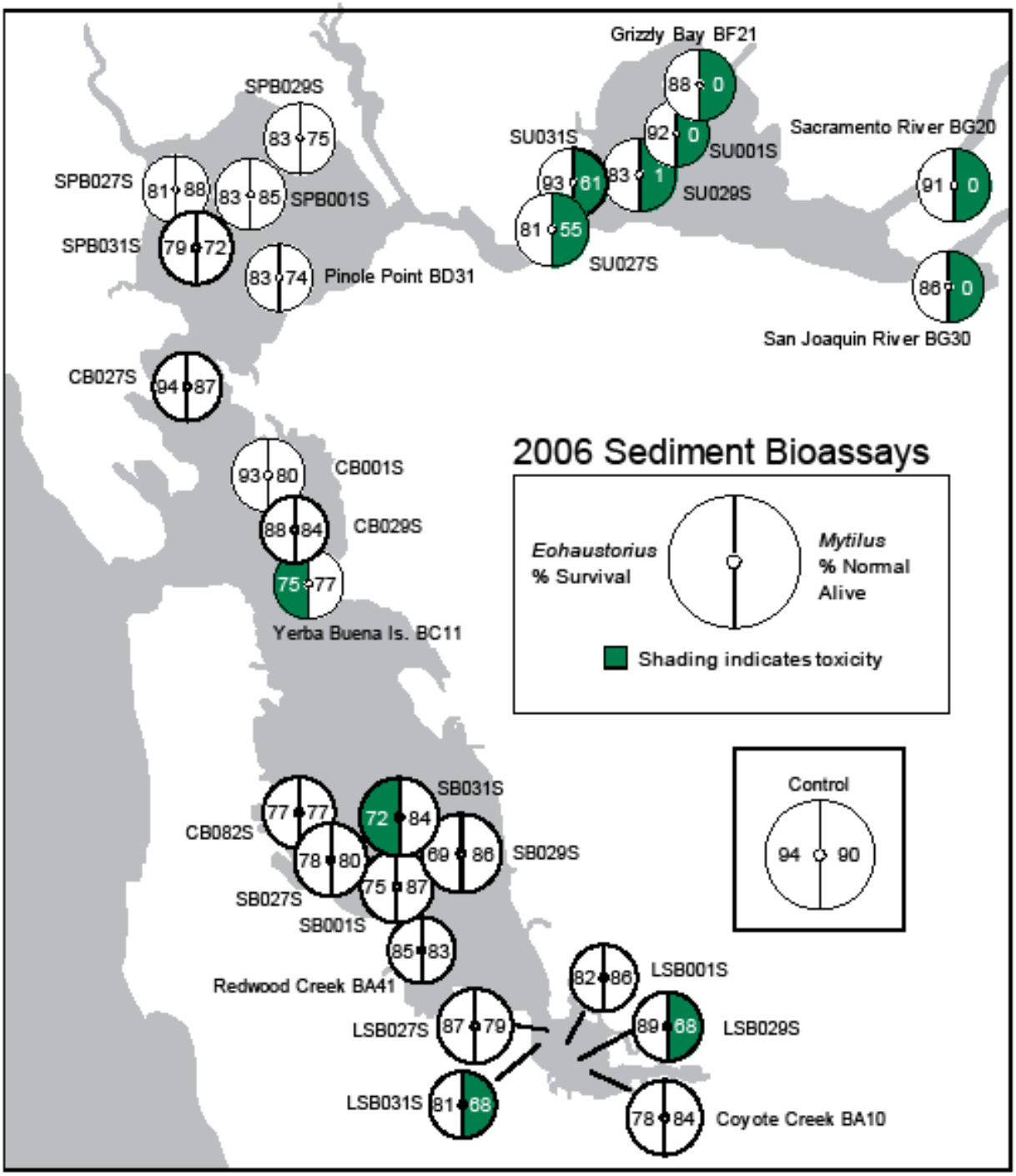


Figure 3.22. Sediment bioassay results for 2006. Sediments were not toxic (see Section 3.4 Sediment Toxicity) to either amphipods, *Eohaustorius estuarius*, or mussel, *Mytilus galloprovincialis*, larvae at 16 out of 27 stations. Amphipod toxicity was observed at two station: Central Bay (Yerba Buena Island (BC11)) and South Bay (SB031S). Sediment samples from nine stations were toxic to larval mussels: Sacramento River (BG20), San Joaquin River (BG30), Suisun Bay (Grizzly Bay (BF21), SU001S, SU027S, SU029S, and SU031S), and Lower South Bay (LSB029S and LSB031S).

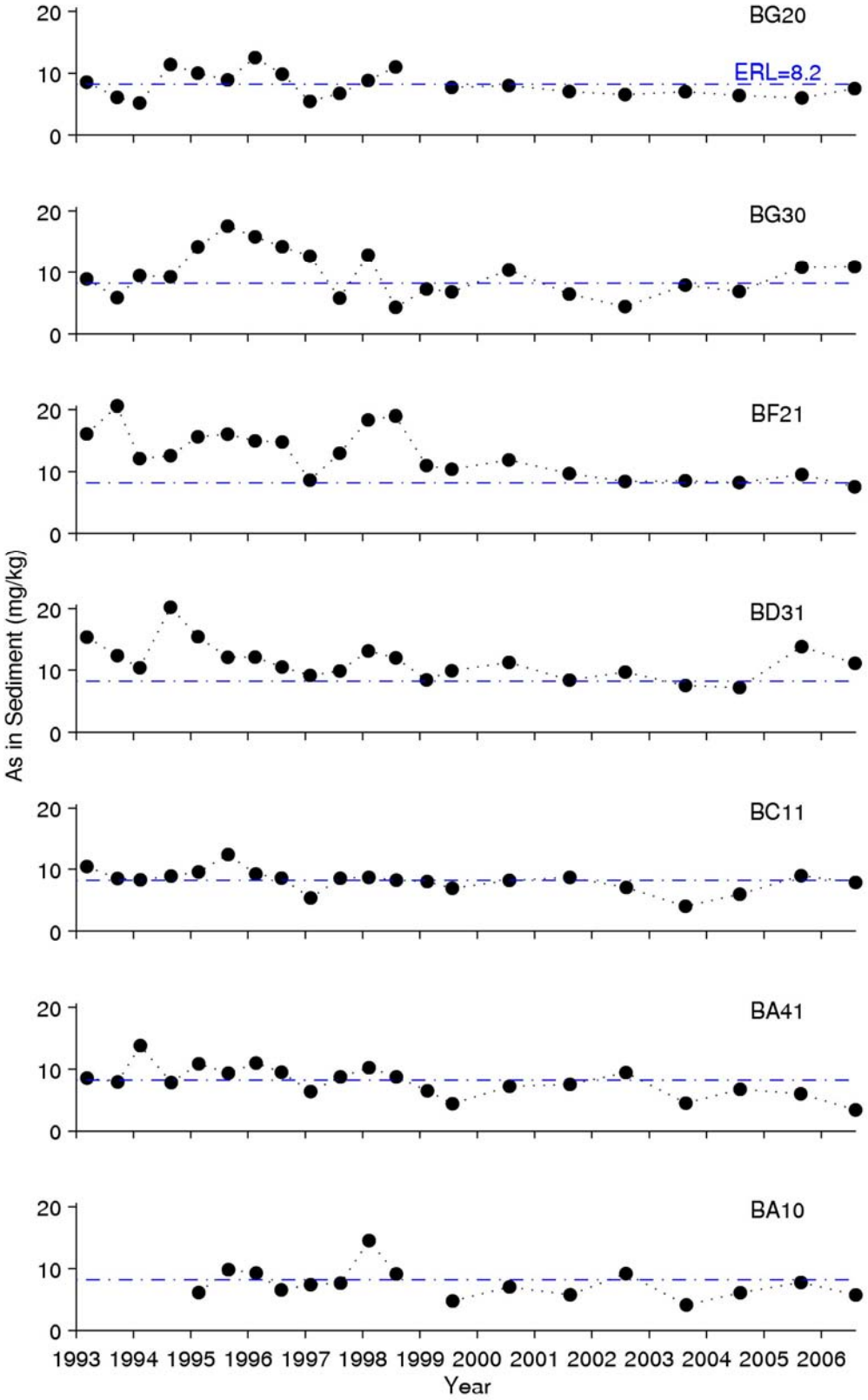


Figure 3.23. Time series plots for arsenic (As) in sediment (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

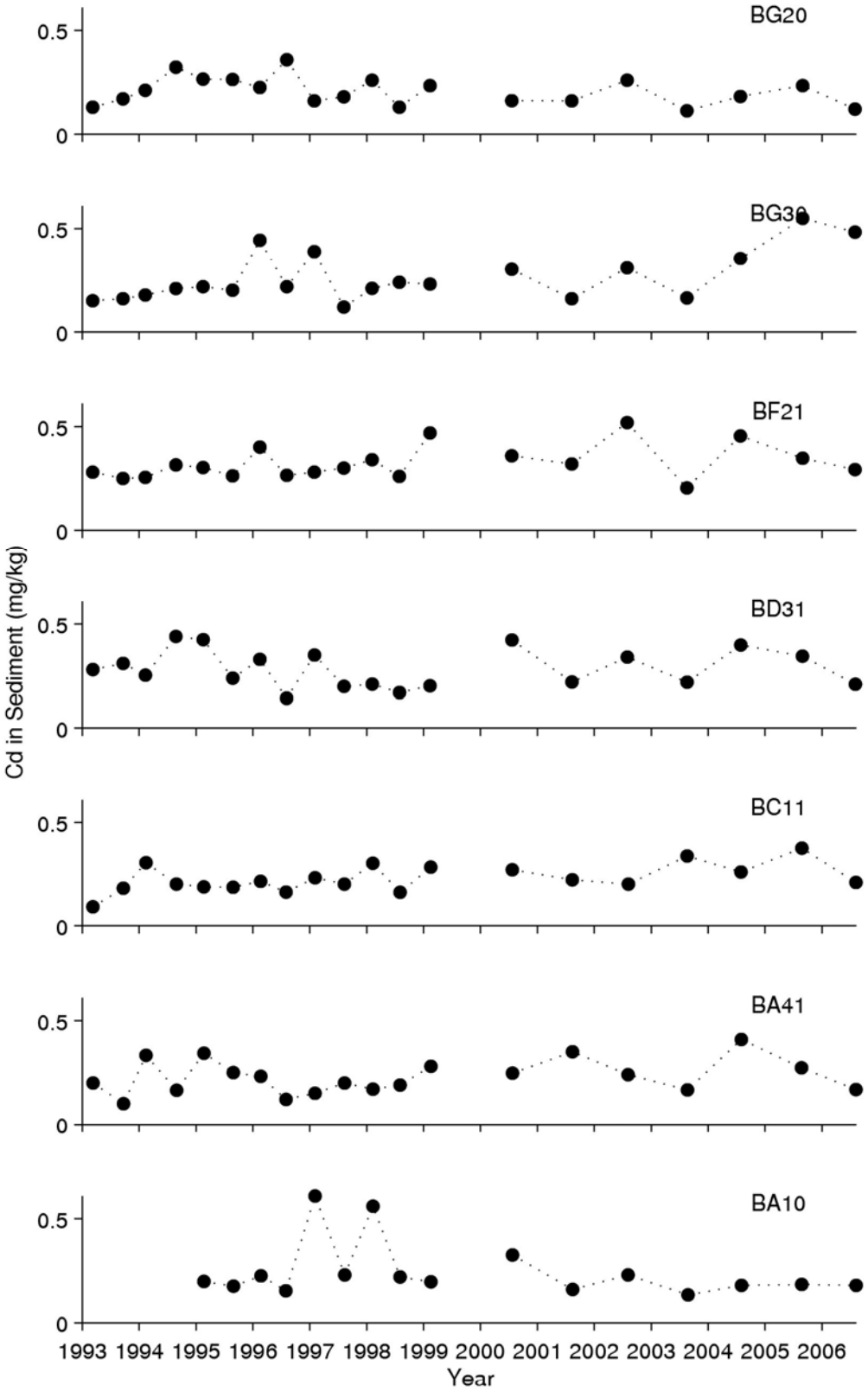


Figure 3.24. Time series plots for cadmium (Cd) in sediment (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

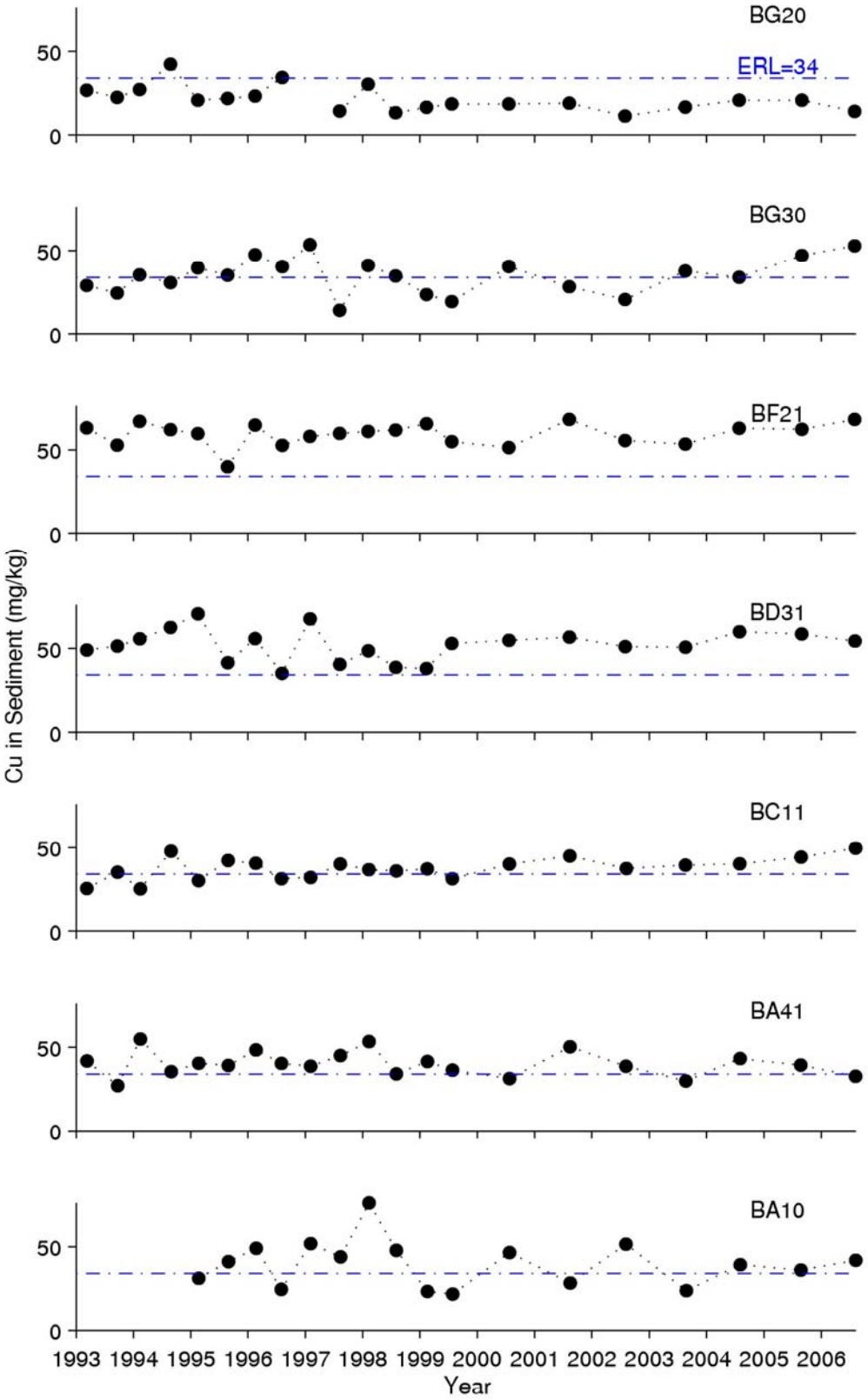


Figure 3.25. Time series plots for copper (Cu) in sediment (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

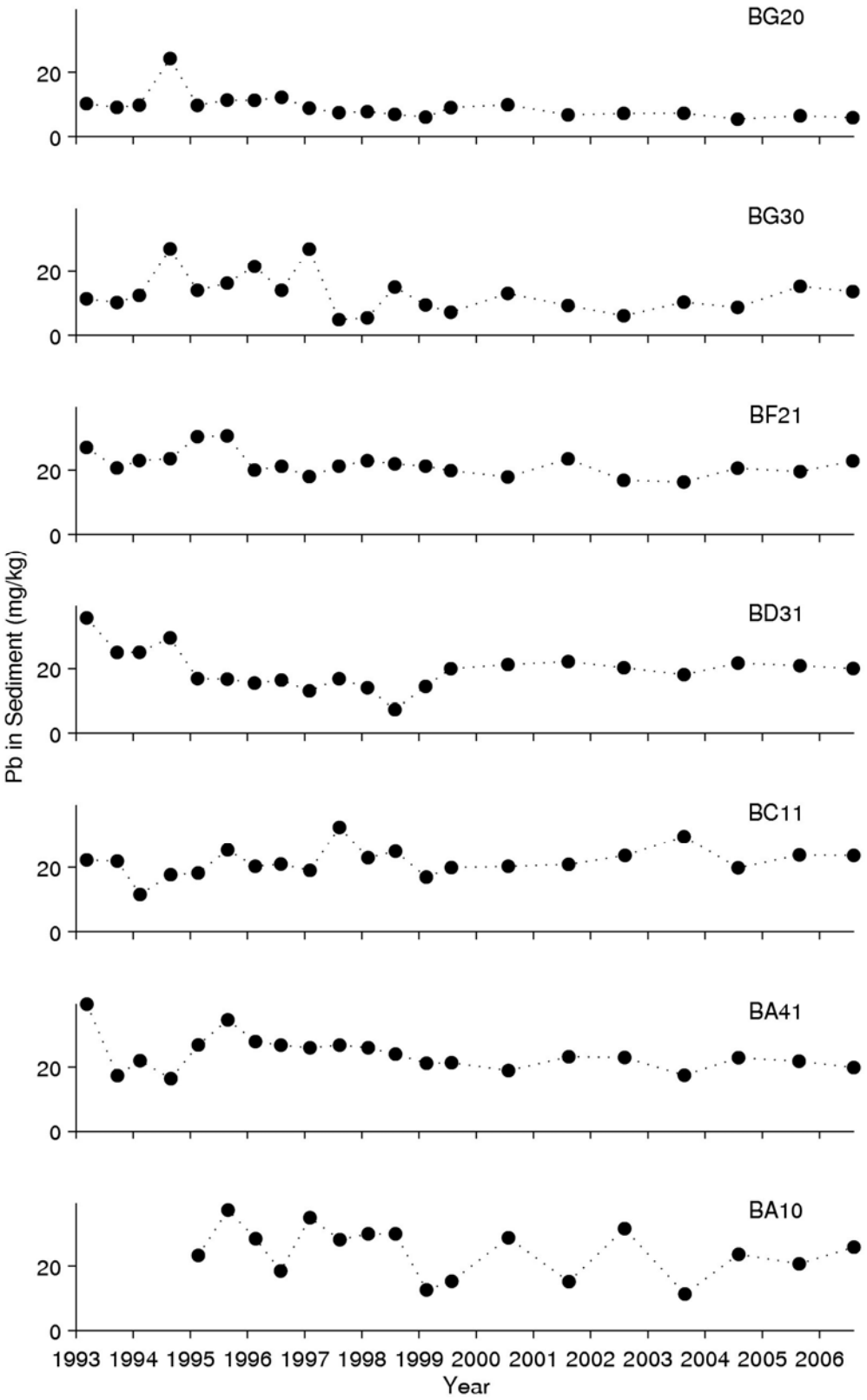


Figure 3.26. Time series plots for lead (Pb) in sediment (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

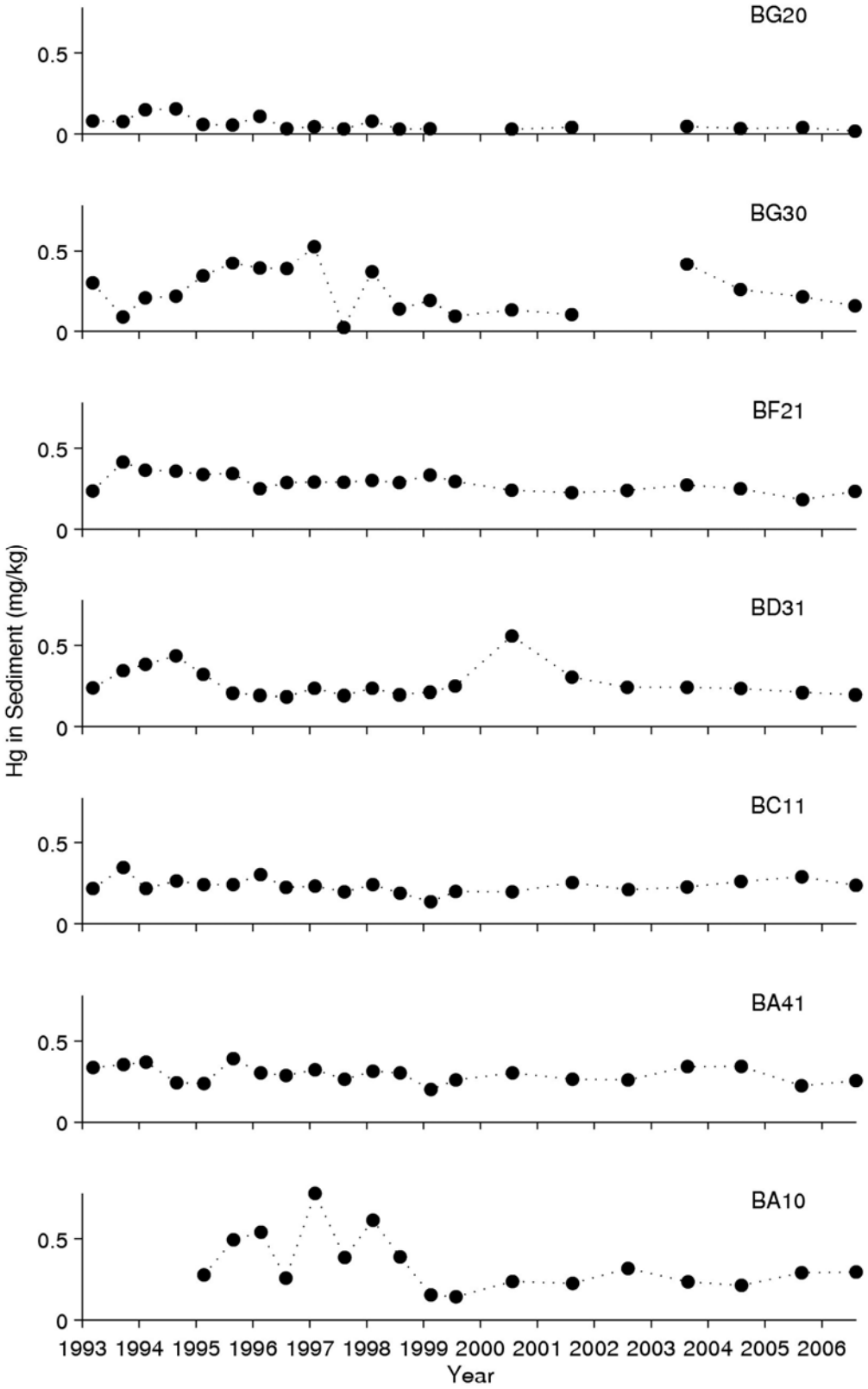


Figure 3.27. Time series plots for mercury (Hg) in sediment (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

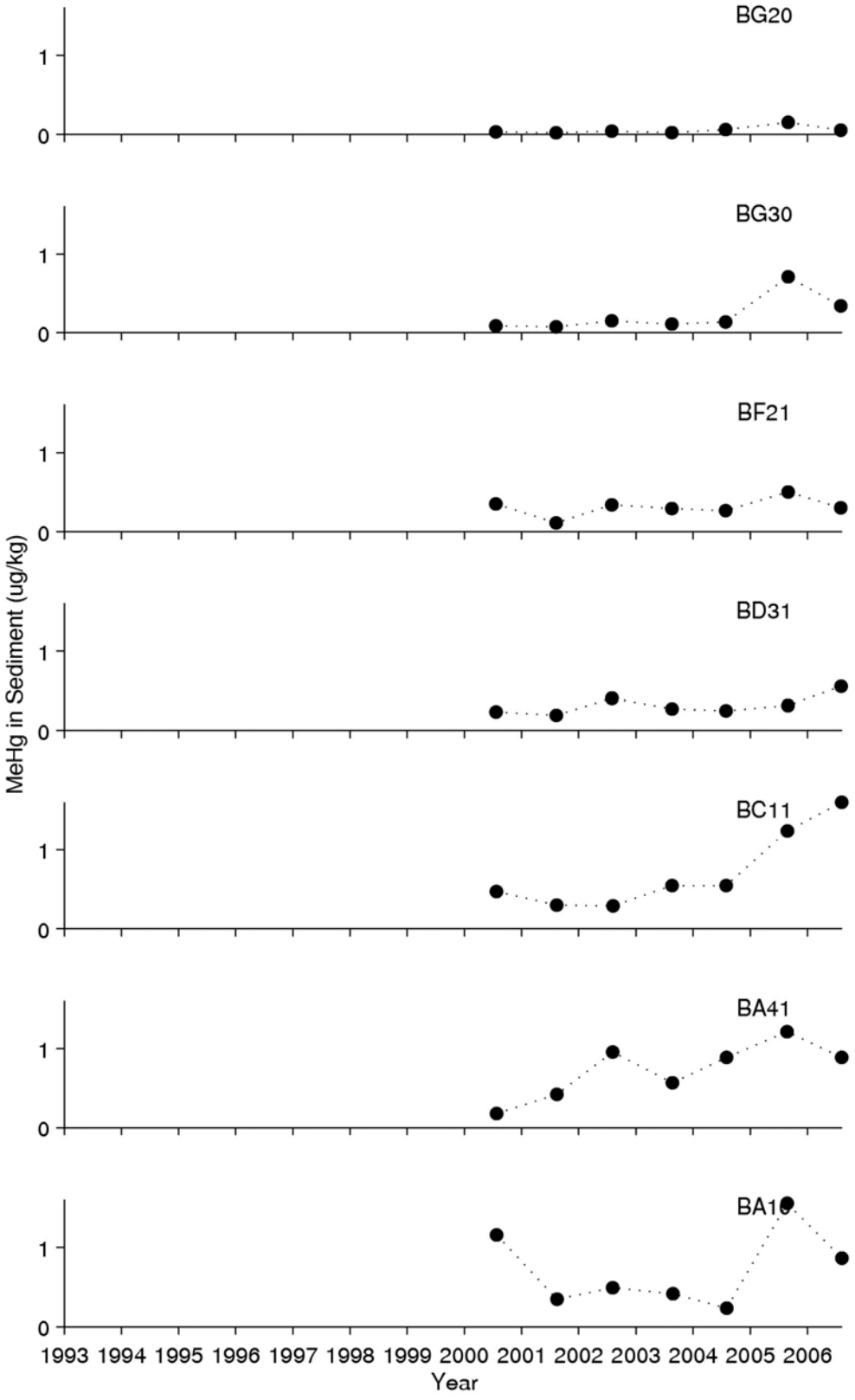


Figure 3.28. Time series plots for methyl mercury (MeHg) in sediment (ug/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

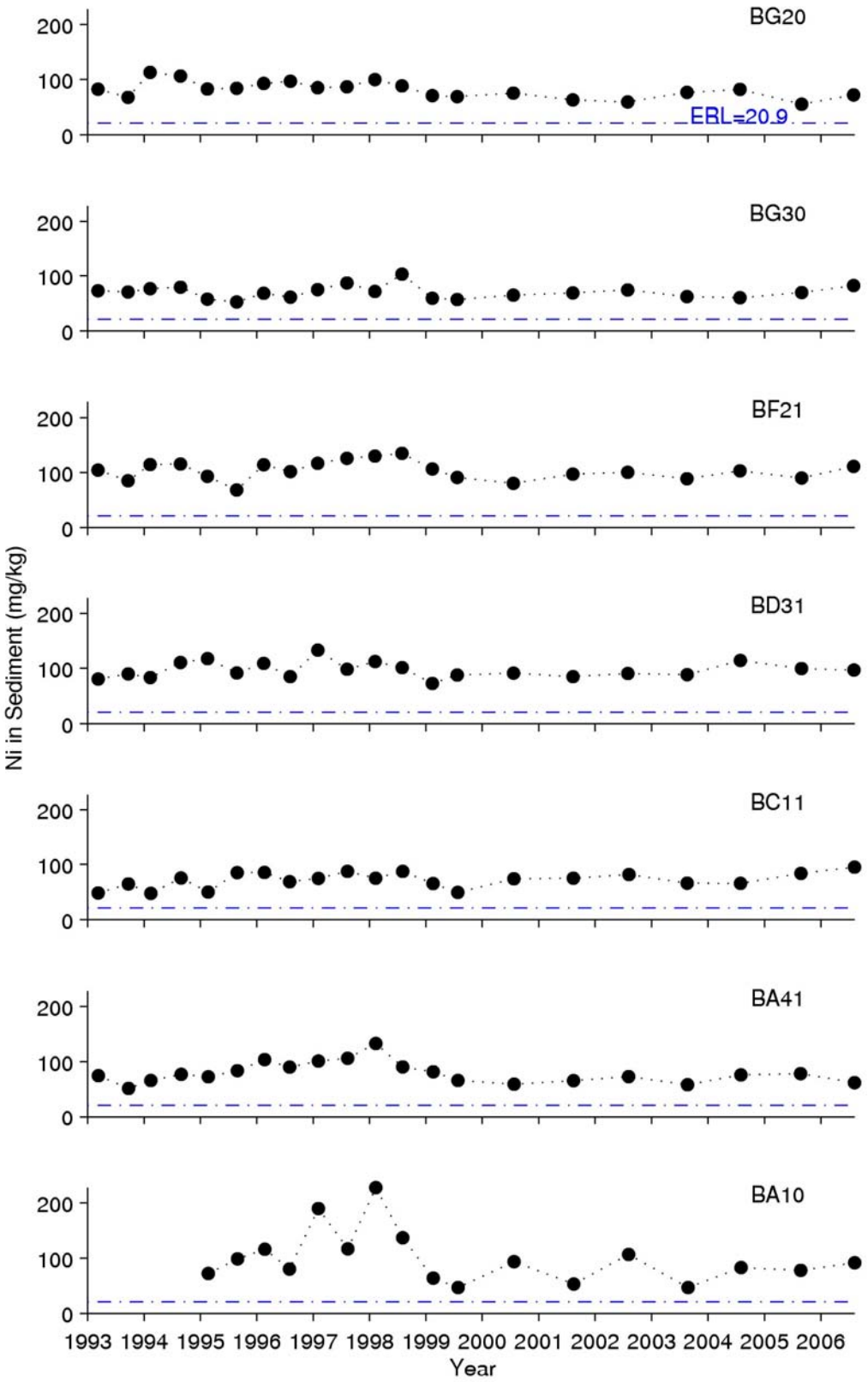


Figure 3.29. Time series plots for nickel (Ni) in sediment (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

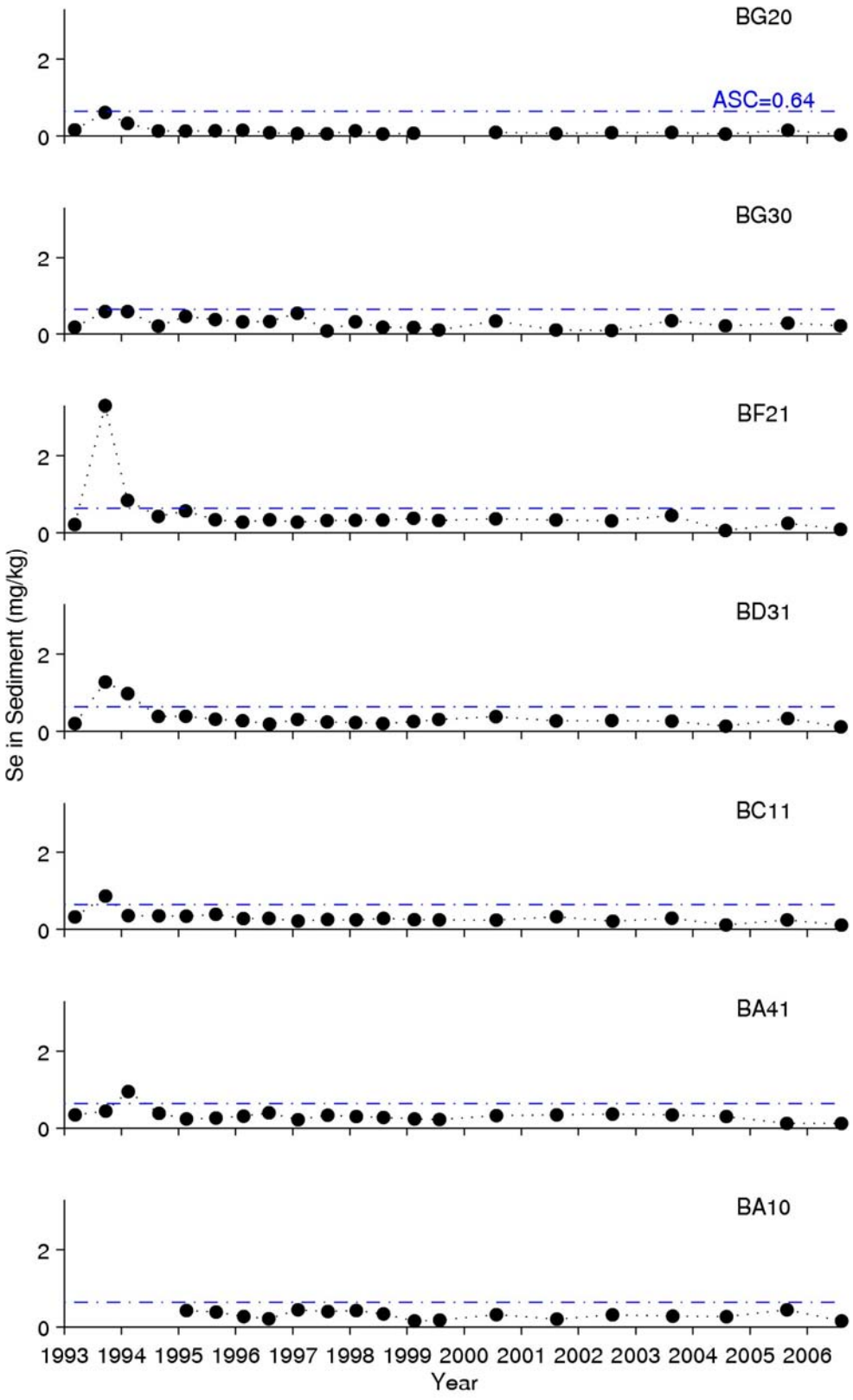


Figure 3.30. Time series plots for selenium (Se) in sediment (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

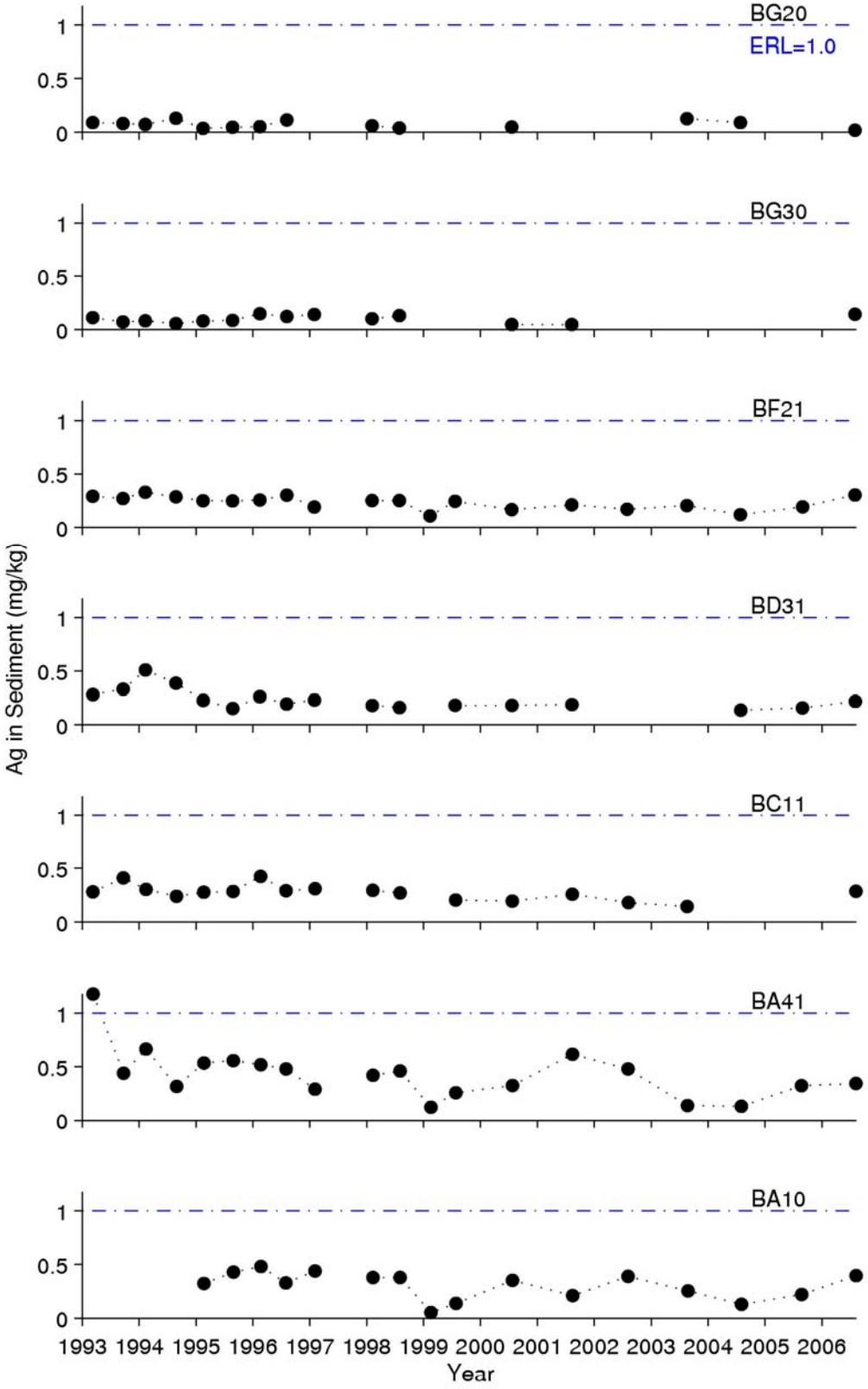


Figure 3.31. Time series plots for silver (Ag) in sediment (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

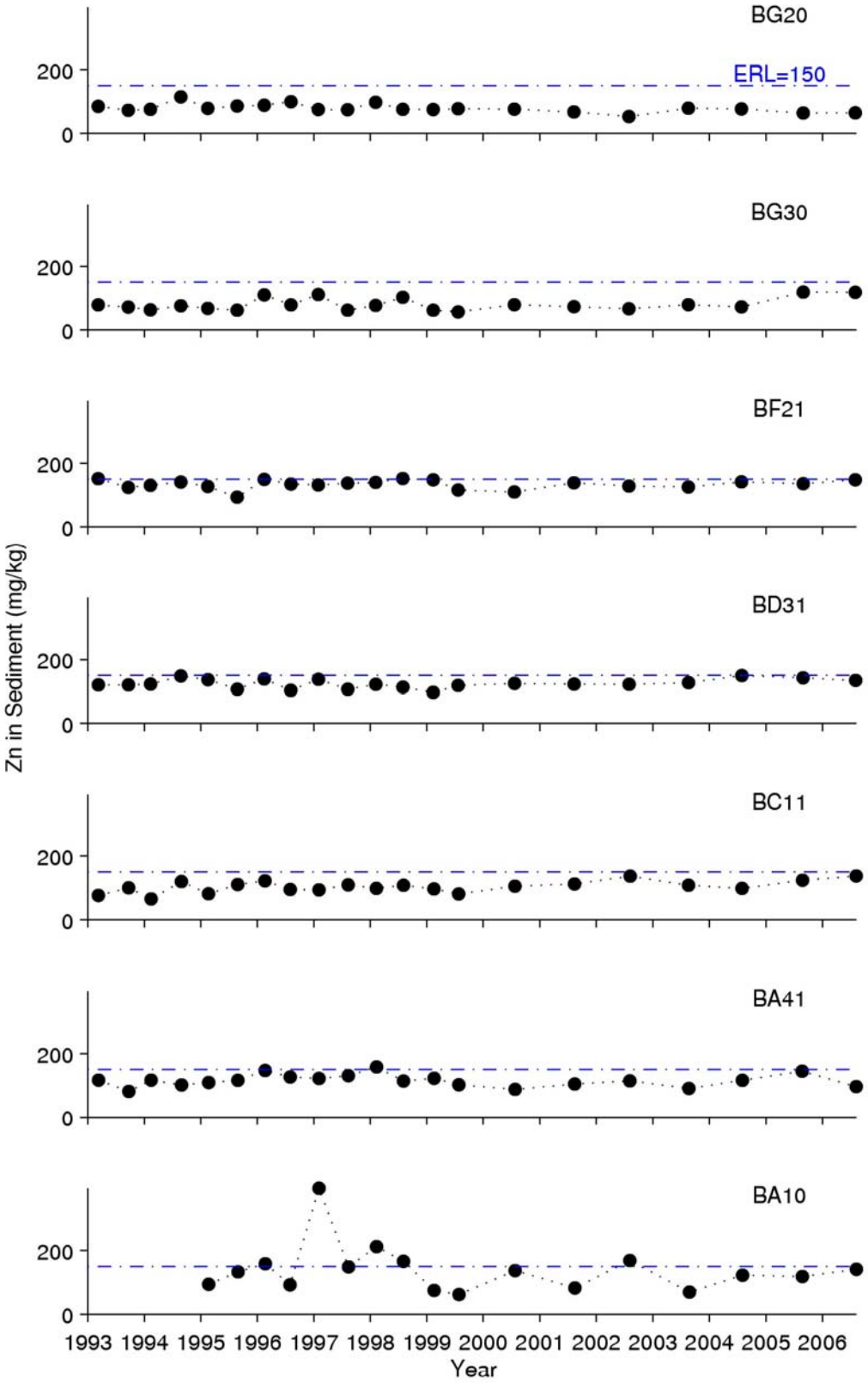


Figure 3.32. Time series plots for zinc (Zn) in sediment (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

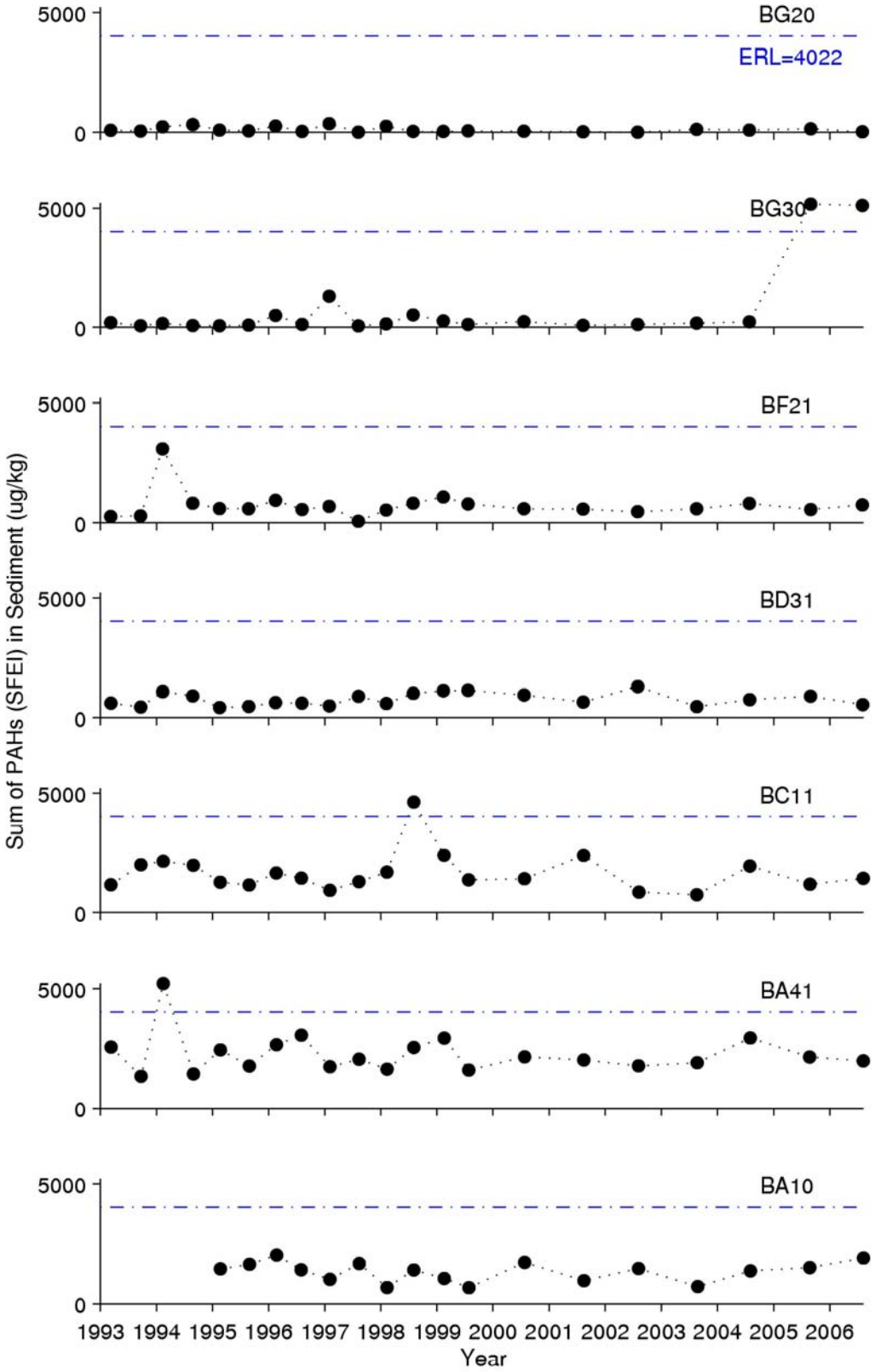


Figure 3.33. Time series plots for sum of PAHs in sediment (ug/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

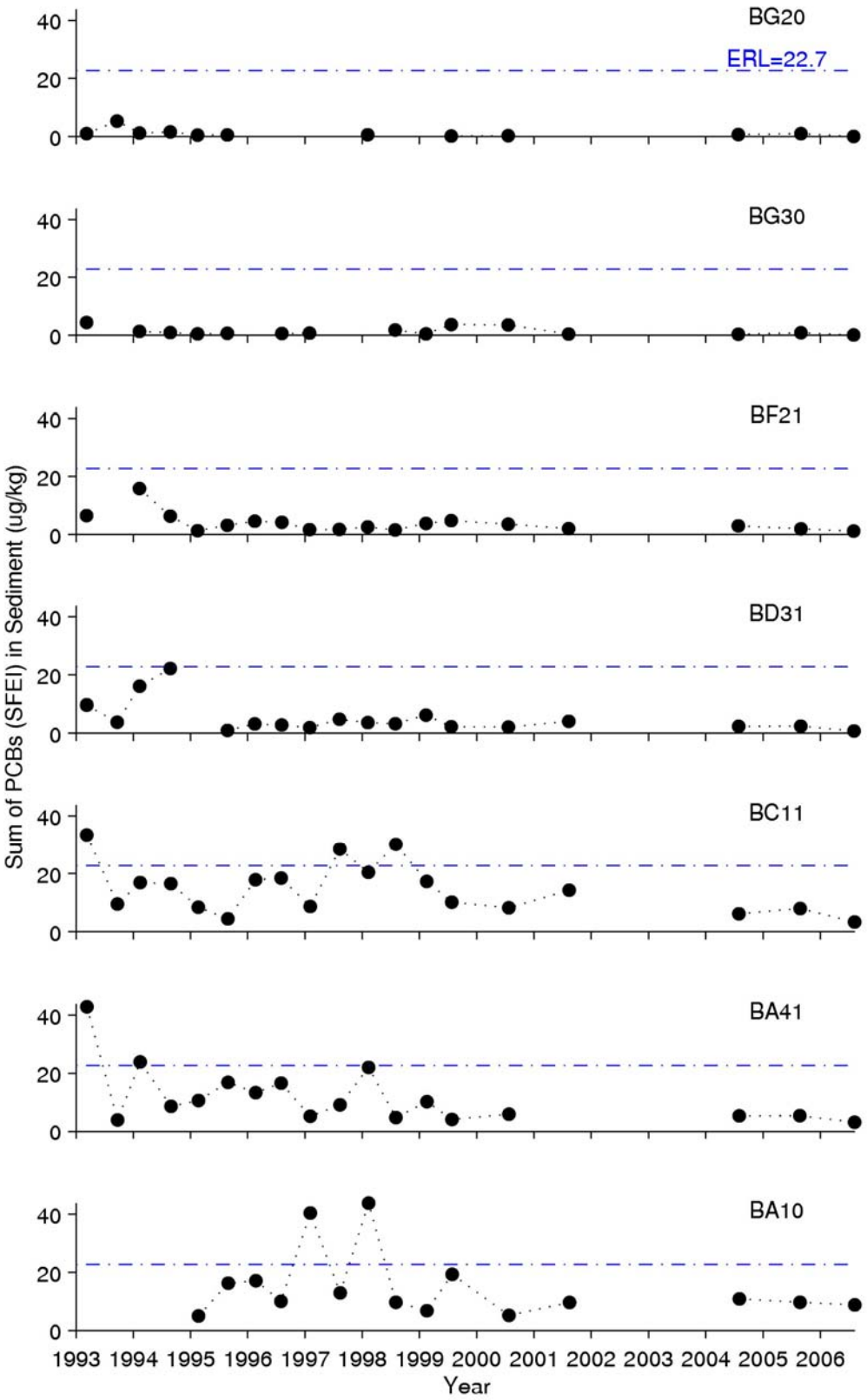


Figure 3.34. Time series plots for sum of PCBs in sediment (ug/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

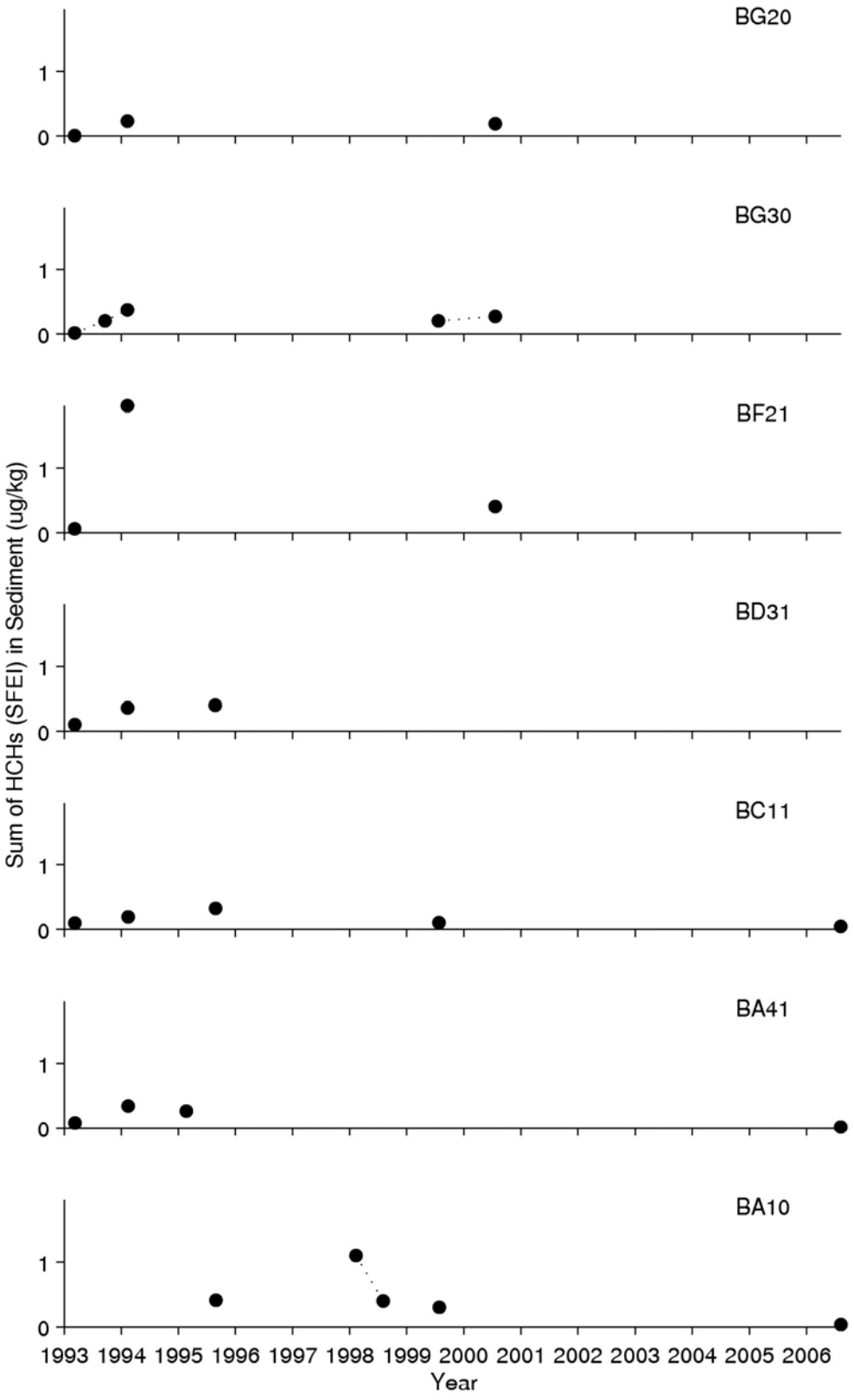


Figure 3.35. Time series plots for sum of HCHs in sediment (ug/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

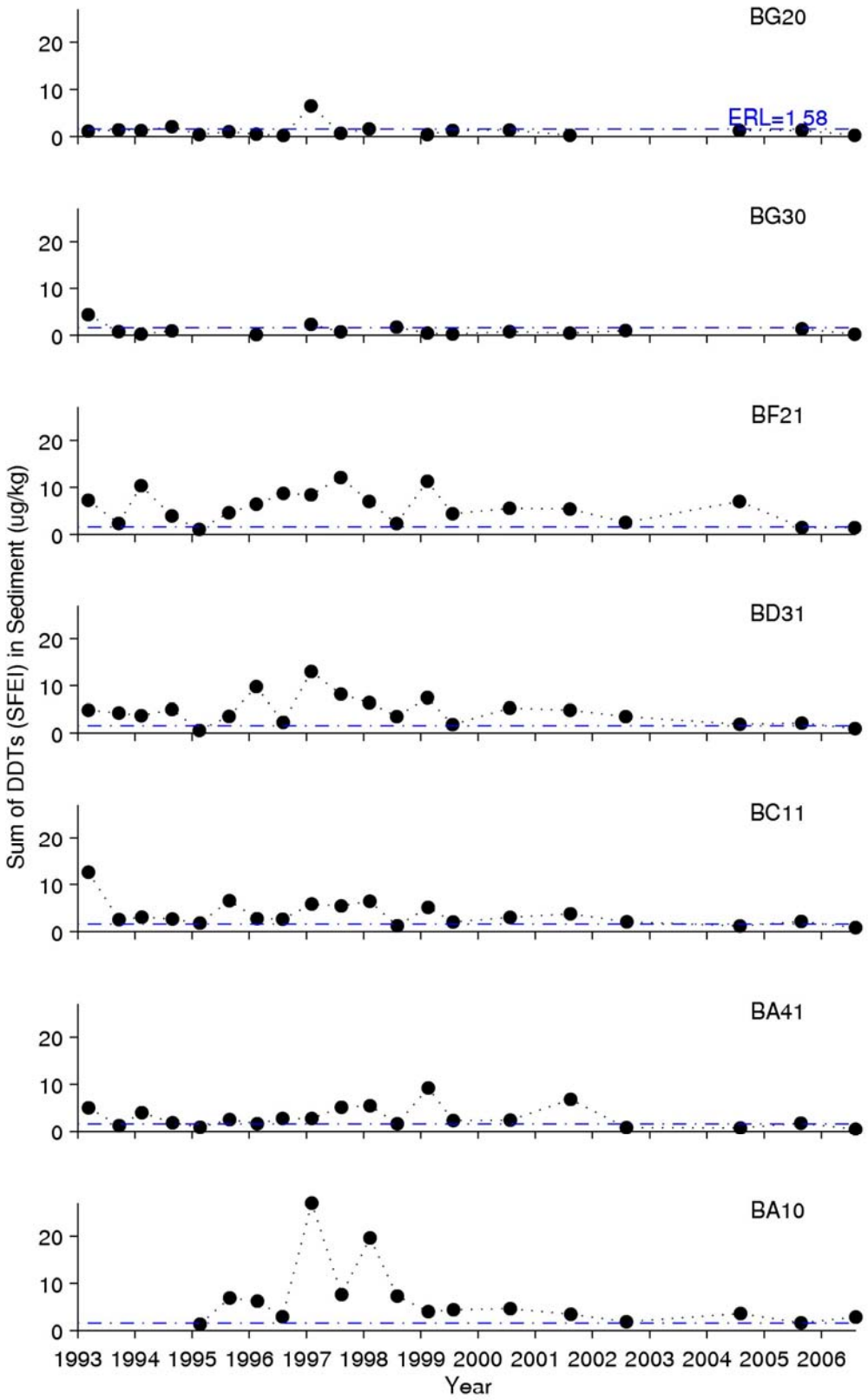


Figure 3.36. Time series plots for sum of DDTs in sediment (ug/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

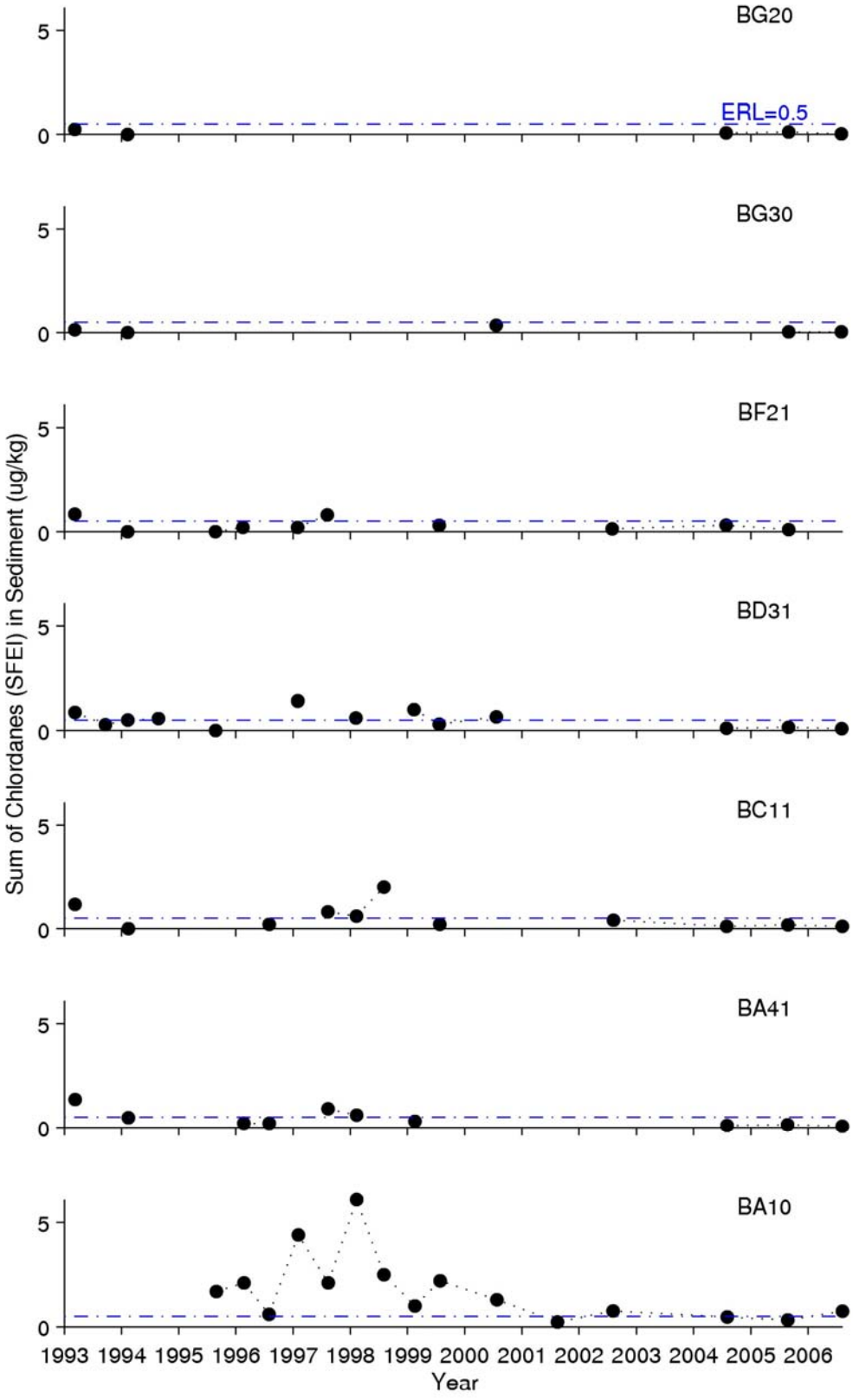


Figure 3.37. Time series plots for sum of Chlordanes in sediment (ug/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

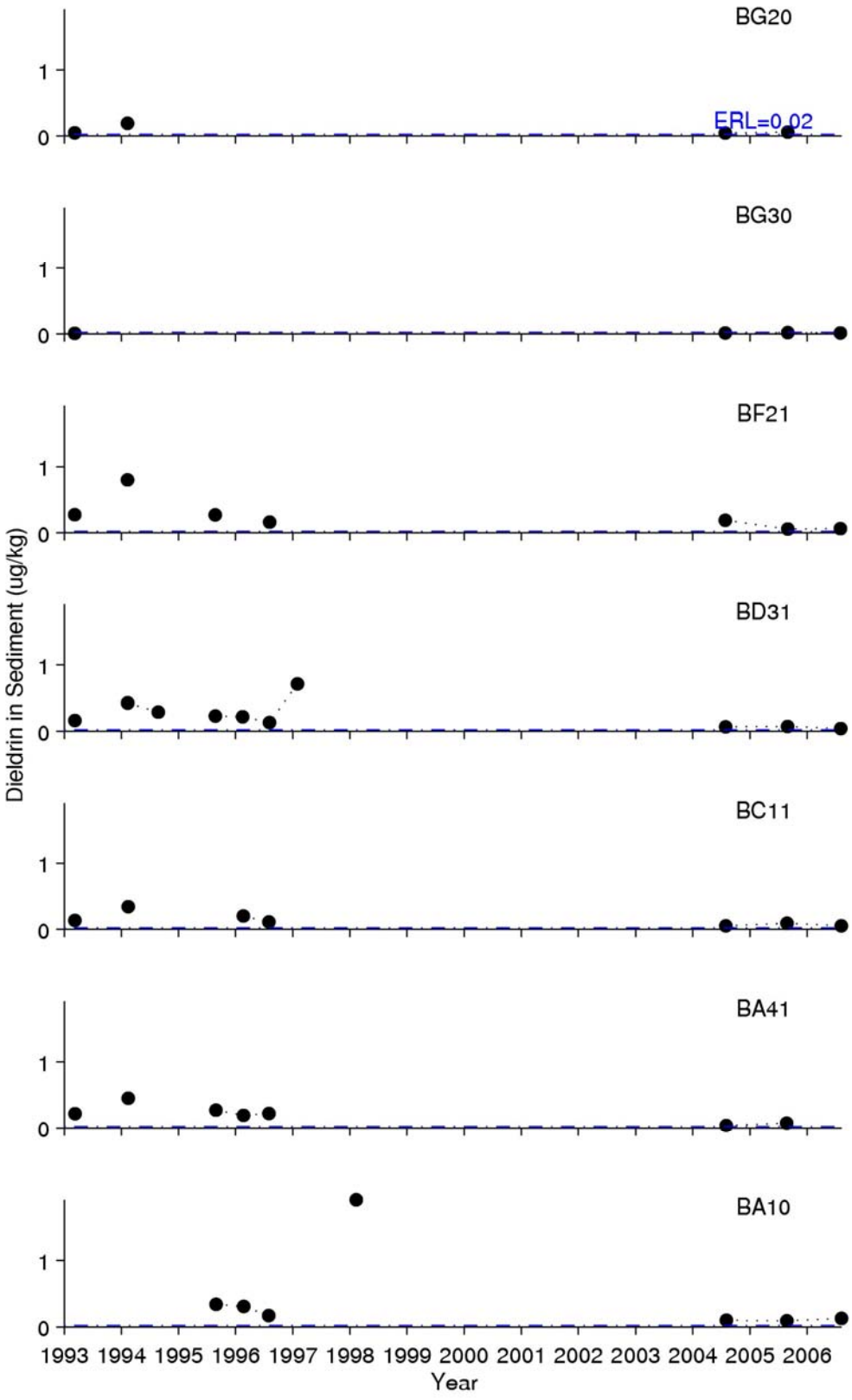


Figure 3.38. Time series plots for dieldrin in sediment (ug/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

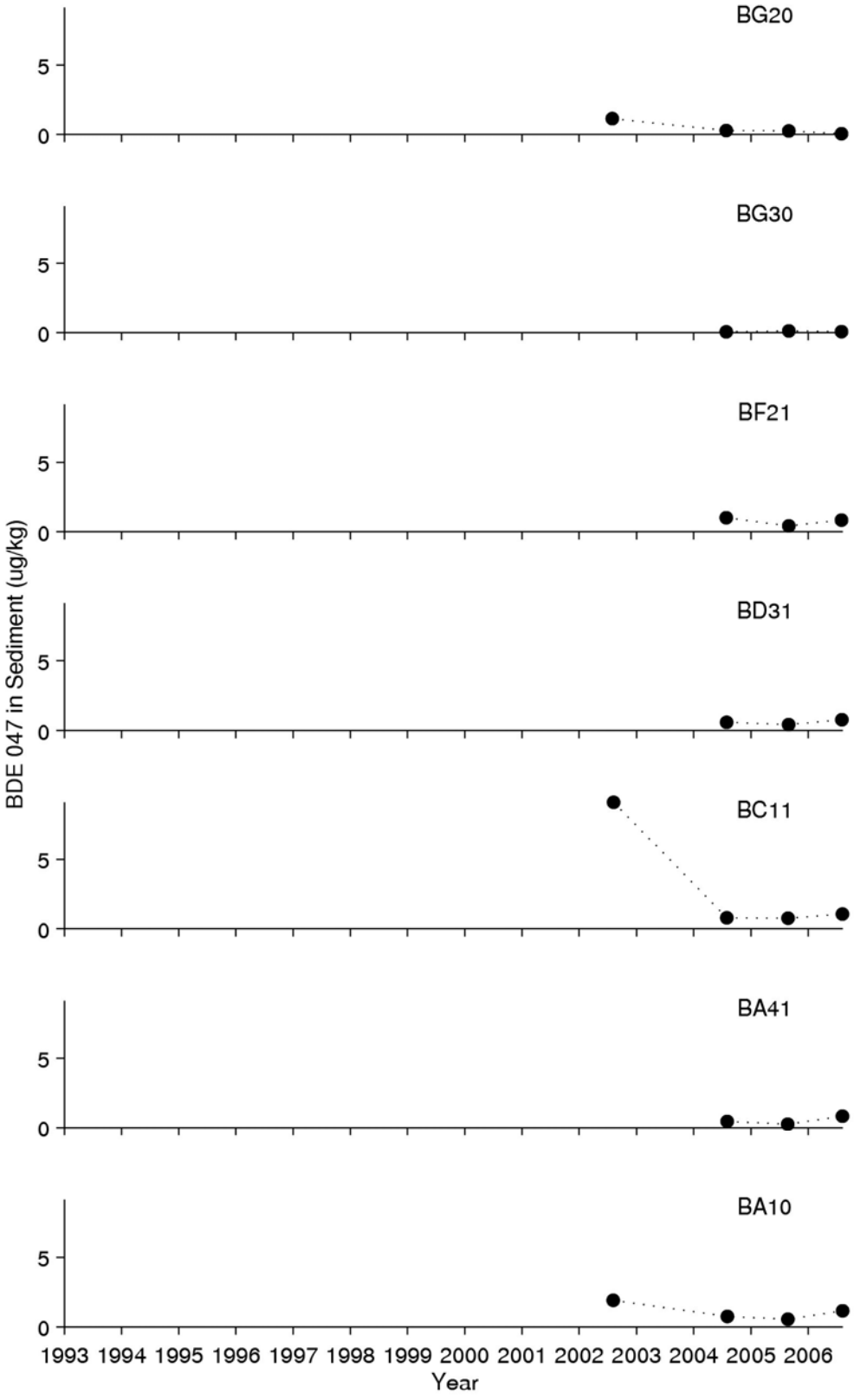


Figure 3.39. Time series plots for BDE-47 in sediment (ug/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2006).

Chapter 4

Bivalve Monitoring

4.0 Bivalve Monitoring

The History of the RMP Bivalve Bioaccumulation Monitoring Program: Using Adaptive Management to Better Understand Contaminant Bioaccumulation in the Estuary

Michelle Lent, Jennifer Hunt, Dane Hardin, Paul Salop, and Bryan Bemis

4.1 Introduction

Since its inception in 1993, the RMP Bivalve Bioaccumulation Monitoring Program has undergone numerous changes in response to program findings and identified needs. This report summarizes and documents the various changes that have occurred in the Program, presents justification for these changes and identifies ongoing investigations that may result in changes to the Program in the near term.

There are currently no new bivalve contaminant data for this edition of the Annual Monitoring Results. Bivalves were deployed in 2006 at nine fixed locations and retrieved from two river stations. Bivalves were retrieved from eight of the nine deployment sites. At the San Pablo Bay site the mooring was lost. At the Coyote Creek site, there was insufficient survival (<1%) due to biotoxicity and sediment. The samples are in storage and are pending chemical analysis. Data from 2006 will be reported in the next edition of the Annual Monitoring Results. Bivalves were not deployed in 2007.

4.2 Objectives of the Bioaccumulation Program

The objectives of the RMP Bioaccumulation Monitoring Program are to:

- Describe the distribution and trends of pollutant concentrations in the Estuary
- Measure pollution exposure and effects on selected parts of the Estuary ecosystem
- Compare monitoring information to relevant benchmarks, such as TMDL targets, tissue screening levels, water quality objectives, and sediment quality objectives

These general goals implicitly address the RMP objectives of determining seasonal and long-term trends in chemical and biological water quality. This program component also complements the water and sediment sampling. Unlike the water quality sampling, which gives an indication of water quality at one particular point in time, contaminant concentrations measured in transplanted bivalves serve to integrate water quality over the period of deployment (typically 90 to 100 days). Also, while measurement of contaminant concentrations in water and sediment are useful for trend monitoring over time, they do not reveal the extent to which various contaminants are able to transfer into the food web and pose risks to consumers.

4.3 Initial Program Design

The RMP Bivalve Bioaccumulation Monitoring Program was initiated in 1993 as a transplant study in which bivalves were collected from "clean" locations (*i.e.*, those with relatively low concentrations of specific pollutants) and transplanted to fixed sites within the Estuary. Due to

substantial spatial and temporal variation in salinity, the program initially used three bivalve species, which were deployed according to the salinity range expected at each site:

- *Mytilus californianus*, the California mussel, deployed at the most saline sites;
- *Crassostrea gigas*, the Japanese oyster, deployed at sites of intermediate salinity;
- *Corbicula fluminea*, a freshwater clam, deployed at sites of lowest salinity.

Bivalves were initially deployed at eleven sites throughout the Estuary to represent both the spine and margins of the Estuary. In 1994, four deployment sites were added, for a total of 15. Specific site locations were heavily influenced by the availability of a fixed structure to easily relocate the subsurface moorings.

Bivalves were deployed for 90 to 100-day periods with deployment beginning in February and June. These deployment periods were chosen to encompass the range of hydrographic conditions in the Estuary and to allow comparisons of within-season variation in addition to trend monitoring over time. At the conclusion of deployments, bivalves are retrieved, processed using clean techniques, and aliquoted for eventual analysis. Generally, 30–40 bivalves are composited from each site for each type of analysis, although high bivalve mortality sometimes reduces the number of organisms in a composite sample.

4.4 Bivalve Bioaccumulation Monitoring Program Changes

The Program has evolved since its inception in 1993. The number of transplant stations, species deployed, deployment apparatus, and parameters measured have changed over the years. Below is a summary of the changes that have occurred (based on a report by Applied Marine Sciences (Hardin *et al*., 2005)), as well as the current status of the Program:

- From 1999 to 2002, several bivalve species were deployed in side-by-side experiments to evaluate which species had the best survival and growth across all sites during dry-season deployments. Results from the study showed that the mussel *M. californianus,* was the best candidate for Estuary wide deployment. This change was instituted in 2003. The main factors in the decision included the following:
    - Lower survival of the oyster *C gigas*,
    - Essentially equivalent survival between *M. californianus* and *M. edulis* across all sites,
    - Better growth at many sites for *M. californianus*, and
    - Extensive historic data for transplanted *M. californianus* in San Francisco Bay.
- Based on a new biogeographical delineation of the Estuary, it was apparent that the newly defined segments were not represented equally by the original 15-station bivalve deployment design. Consequently, an analysis was undertaken to determine the optimum number and distribution of bivalve deployment sites needed to track trends in bioavailable contaminants in the Estuary. Based on this analysis, several sites were removed from the project and, in 2003, the design of the Program study sites was modified to its current configuration, consisting of three transplant sites within the Lower South Bay-South Bay, Central Bay and San Pablo Bay Estuary segments, respectively, and collection of resident bivalves at two sites within the Rivers segment.
- A side–by-side study was conducted from 1999-2002 in order to assess the effectiveness of a new bivalve deployment structure. Initially, transplanted bivalves were deployed in plasticized nylon mesh bags, attached to mooring systems on the Estuary bottom. At times,

predation, as indicated by torn mesh bags and broken mussel shells, led to an insufficient number of bivalves to support all desired analyses and at other times causing loss of entire deployments at a site. Deployment cages were tested during this period and showed reduced mortality at two of the most predated sites. Beginning in 2003, all transplanted bivalves were deployed in cage-type structures.

- The original design of the RMP transplanted bivalve program implemented in 1993 included a maintenance cruise near the midpoint of the deployment period to reduce mooring loses by checking their integrity and to improve bivalve survival and health by removing biological and physical fouling. From 2002-2005, a side-by-side comparison between maintained and un-maintained cages indicated only slight differences in the survival or growth of *M. californianus*. Since differences were minimal the maintenance cruise was discontinued in 2006.
- Starting with the 1999 dry season (summer) deployments, CTD profiles were collected at each bivalve site to help determine how ambient environmental factors affect the transplanted bivalves. Salinity, dissolved oxygen, temperature, and total suspended solids impact bivalve health and could affect contaminant bioaccumulation rates.
- In 1999, a comparison of growth and condition was begun to investigate whether growth was a more appropriate measure of bivalve health during deployment. Condition is a ratio of tissue mass to shell volume. Using condition as a metric of health can be confounded by changes in mass or volume that aren't necessarily tied to health. Growth is a more direct measurement which compares the pre- and post-deployment weight of the individual mussel. As a result of this study, the health indicator was changed from condition to growth in 2002.
- In 2000, the wet-season bivalve deployment was discontinued since long-term temporal trends in contaminant concentrations were more consistently observed in dry-season data than in wet-season data.
- In 2000, the analysis of mercury and arsenic in bivalves was discontinued since concentrations were similar in the transplanted bivalves and in the reference bivalves. In the case of mercury, there is evidence that bivalves are not the best indicators of bioavailability, especially for methylmercury.
- In 2001, trace metals measurements in bivalves were reduced from every year to every fifth year as a cost reduction measure for metals not on the 303(d) list or the Water Board's "pollutants of concern" for San Francisco Bay list.

4.5 Conclusions

Further optimization of the program under consideration includes re-instituting a wet-season deployment of transplanted *M. californianus* at Yerba Buena Island. Salinity remains relatively high during the wet season at this site, which would enable monitoring of the effect of delta outflow on contaminant concentrations in transplanted mussels, while minimizing the effects of wet-season salinity variation on mussel survival and growth. The Program will continue to use adaptive management to review and refine the questions we are asking and to further optimize our sampling regime by continuing short-term comparison studies.

4.6 References

Hardin, D. Salop, P. and B. Bemis. 2005. Optimizing Transplanted Bivalve Studies for the Regional Monitoring Program for Trace Substances. Applied Marine Sciences. Livermore, CA.

Chapter

5

Description of Methods

5.0 Description of Methods

Nicole David, Sarah Lowe, Cristina Grosso, and Donald Yee

The purpose of this chapter is to provide brief descriptions on the sample collection and analytical methods used in Status and Trends Monitoring component of the RMP and to highlight any changes that may occur each year. Water, sediment, and bivalve tissue samples were collected and analyzed for trace elements, trace organics, and conventional water and sediment quality parameters, and tested for sediment toxicity. Information on sampling methods and analytical procedures for RMP pilot and special studies and fish contamination monitoring are provided in separate technical reports available on the RMP Reports and Publications page at http://www.sfei.org/rmp/reports.htm, or by contacting the RMP Manager.

Other resources related to the RMP field and analytical methods include:

1. *Field Sampling Manual for the Regional Monitoring Program for Trace Substances* provides standard operating procedures for sampling of water, sediment, and bivalve tissue (http://www.sfei.org/rmp/documentation/fom/FOM2001.pdf).
2. *Quality Assurance Project Plan for the Regional Monitoring Program for Trace Substances* describes the quality assurance and quality control (QA/QC) protocols and requirements for RMP field sampling and laboratory analyses (http://www.sfei.org/rmp/reports/1999_QAPP/1999_QAPP.pdf).
3. Standard Operating Procedures for each analytical laboratory are on file at SFEI.

5.1 Field Sampling Methods

Background

Monitoring programs such as the RMP help to track contaminant concentrations and trends in a water body and are a useful tool for identifying potential health risks that humans may be exposed to. Furthermore, they can help to estimate and address the severity of a pollution problem. However, for providing scientifically sound and useful results, these programs need to go through changes and adapt to the conditions of the water body they monitor and implement improved technologies. Updating and redesigning programs is one of the key aspects for scientists and water managers, although it is, at the same time, one of the most challenging ones.

For meeting the Regional Monitoring Program objectives to describe distribution and trends of pollutant concentrations and to evaluate if water and sediment quality guidelines as well as tissue screening levels are being met, the sample collection and the analytical methods in this Program were constantly adjusted to reflect advanced technologies and cleaner sampling methods. While phasing in new sampling techniques or equipment, side-by-side comparisons were often conducted to evaluate new methods, with both results being reported, before it was decided to phase out an old method.

For over 13 years of sample collection for the RMP, logistical planning and field sampling was implemented by Applied Marine Sciences Inc. who has systematically improved the field sampling logistics and sampling methods each year since the inception of the program in 1993.

Starting in 1993, the RMP was designed to sample parameters determined mainly by a pilot study conducted by the Water Board. Sixteen locations in the San Francisco Estuary were sampled for water quality parameters, water chemistry, and toxicity, sediment quality

parameters, sediment chemistry, and toxicity, as well as transplanted bivalve for bioaccumulation in tissue and condition. Water samples were collected three times during the year. The first sampling was conducted during the wet, the second one during the decline of Delta outflow, and the third one during the dry season. No replicates were collected. Sediment and bioaccumulation samples were only collected during the wet and the dry season.

Changes in Water Sampling

The RMP used a polyurethane foam plug sampler to collect water for trace organics analyses during the first four years of the Program (Risebrough *et al.,* 1976; de Lappe *et al.,* 1980, 1983) and phased in a new, modified, commercially available resin (XAD) extraction sampler in 1996, beginning with side-by-side comparisons of both sampling systems. XAD resins have been used throughout the world to measure synthetic organic contaminants in both water and air (Infante *et al.,* 1993). The sampler comparisons were continued in 1997, and results from both years were presented in the RMP 1997 Annual Report (SFEI, 1999). Since 1997, an AXYS Infiltrex system (AXYS Environmental Systems, Ltd., Sidney, B.C.) has been used to collect all RMP water samples for analysis of trace organic contaminants.

Changes in Bivalve Sampling

The RMP started in 1993, continuing the long-term data collection effort conducted for the California State Mussel Watch Program (SMWP). The SMWP was initiated in the late 1970s to detect and evaluate toxic substances in the waters of bays, harbors, and estuaries. While the RMP has changed over the years to incorporate results and findings, it was initially designed to monitor three bivalve species twice a year: a mussel, *Mytilus californianus*, an oyster, *Crassostrea gigas*, and a clam, *Corbicula fluminea*. Reflecting their different salinity tolerances, the bivalves were deployed from near the Golden Gate (high salinity) to Redwood Creek and Coyote Creek, as well as to the Napa River and Petaluma River mouths (low salinity). Three sampling cruises in the wet season and three in the dry season were conducted. For the first trip, about 80 individuals of each species were retrieved from uncontaminated reference sites, outside the San Francisco Bay, placed in mesh bags, and deployed at 15 sites throughout the Bay. After 45 days, another cruise was conducted where divers revisited the sites to clean the bags of algae and other attached organisms so that water circulation and food supply inside the bags was guaranteed. Ninety days after deployment of the bivalves, all organisms were retrieved and their tissues analyzed in the laboratory for 14 trace metals and about 85 synthetic organic chemicals.

Consistent results over the years showed that bivalves did not accumulate arsenic, mercury, or chromium to a significant degree. Although these metals were present in water and sediment samples, they were not found in tissue samples and monitoring for these three trace metals was discontinued after 1999.

One of the major setbacks in this Program was the loss of the “clean” reference sites for clams when the *Corbicula* population crashed in Lake Isabella in 1997 and clams could no longer be found. Putah Creek and Lake Chabot clams were used in the following year, but even there the clam population soon decreased to insufficient numbers for deployment. As a result of the decline, resident clams had to be used from the Sacramento and the San Joaquin River sites. When assessing changes in contaminant concentrations, it is important to have potentially uncontaminated individuals at the beginning of each study period, so that a gain in toxic concentration, or accumulation factor, can be calculated. Since this was no longer feasible for clams, Grizzly Bay was dropped as a sampling site in 1998 and currently only resident clams are analyzed at the Sacramento and San Joaquin River sites.

Several comparison studies were performed to address specific research questions to evaluate the effectiveness of the Program, and to determine where costs could be reduced. One study examined if only one bivalves species, which is more adaptable and salinity range tolerant, could be used throughout the entire Bay, so that results would be more comparable within sites. Since different species have different metabolisms, a comparison in contaminant accumulation is not recommended between species. On the other hand, salinity ranges that occur throughout the Bay can generate non-contaminant related, physiological stress in animals, which can confound the interpretation of bioaccumulation and interfere with the usefulness of the results.
With this in mind, the Bay mussel (*Mytilus edulis*) was deployed and analyzed side by side with oysters and California mussels at several sites. Since 2003, only the California mussel, *Mytilus californianus,* was used for deployment since it can tolerate short-term exposure to higher salinities and bioaccumulation results of individuals within the same species are more comparable.

The second comparison study was conducted to evaluate the efficiency of bags versus sturdier cages. The goal was to minimize predation by crabs that cut through the mesh bags and satisfied their appetite with RMP test organisms. Cages showed reduced mortality in bivalves at sites where predation was often a problem. The cages also seemed to have an additional advantage. When comparing cages cleaned with cages that were un-maintained, the survival and growth rates did not seem to be adversely affected. Therefore, the extra effort of cleaning the cages in the middle of the study period was discontinued.

Another objective of the redesign was to simplify the indicator for health of test organisms. Initially a measure, called condition index (CI), was calculated to implement the relation of tissue dry weight to shell cavity volume at the end of the deployment period. An easier method, called growth index, measures the difference of mean dry weight before and after deployment, and is as reliable a measurement for determining health as the condition index.

In addition, it was determined that sampling during the wet season caused noise in the results, since precipitation is one of the major stressors in mussels. Only one sampling period per year, when the estuarine conditions are more stable and rather consistent on an inter-annual basis, seemed more appropriate and was implemented.

To improve the cost-effectiveness of the Program, the number of sampling sites was reduced from 14 to nine. The RMP sampling locations were selected to characterize background contaminant levels in the Bay. Eliminating the sampling sites at Petaluma River, Napa River, Sacramento River, San Joaquin River, and Horseshoe Bay, as well as grouping Coyote Creek with Dumbarton Bridge and Redwood Creek, still guarantees a precise overview of contamination patterns in given Bay segments.

Anthropogenic organic compounds, including PCBs, PAHs and certain pesticides have been routinely monitored in this Program. But it is also important to evaluate fairly new pollutants that cause concerns because of their potential to persist in the environment, to bioaccumulate, and to have adverse effects to humans and wildlife. The RMP extended the list of target chemicals it analyzes to include compounds that are used as fire retardants in fabrics and electronic equipment, plasticizers that increase flexibility in plastics, surfactants that reduce water surface tension, and compounds that derive from personal care products. A different study showed the abundance of these organic constituents in water and sediment samples from previous years. This

proactive approach to monitoring is important to help avoid more recently used chemicals becoming the "legacy" pollutants of the future. Organic chemicals that do not break down or dissolve and therefore persist in sediment for several decades, such as polychlorinated biphenyls (PCBs) are currently among the legacy pollutants of greatest concern.

5.1.1 Water Sampling

One of the RMP objectives is to evaluate if water quality guidelines are being met in the Estuary. Therefore, the sampling and analytical methods must be able to detect and, when analytically possible, quantify substances below guideline levels. In order to attain the low detection limits used in the RMP, ultra-clean sampling methods were used in all trace metal and organic sampling procedures (Flegal and Stukas, 1987; U.S. EPA, 1995).

Water samples were collected approximately one meter below the water surface using peristaltic and gear-driven pumps. The sampling intake ports for both the trace organic and trace element samplers were attached to aluminum poles that were oriented up-current from the vessel and upwind from equipment and personnel. The vessel was anchored and the engines turned off before the sampling begins. Total and dissolved fractions of Estuary water were collected for trace element analyses. Particulate and dissolved fractions were collected for trace organics analyses.

Collection of Samples for Trace Organics

Since 1997, an AXYS Infiltrex system (AXYS Environmental Systems, Ltd., Sidney, B.C.) has been used to collect all RMP water samples for analysis of trace organic contaminants. It consists of a constant-flow, gear-driven positive displacement pump, 1/2 inch Teflon® tubing, 1 µm glass fiber cartridge particulate filter, and two parallel Teflon® columns filled with XAD-2 resin with a particle size range of 300-900 µm. Amberlite XAD-2 resin is a macroreticular, styrene-divinyl benzene copolymer, nonionic bead, and each bead is an agglomeration of microspheres. This sponge-like structure offers excellent physical and chemical stability. The discrete pores allow rapid mass transfer of analytes, and the mesh size ensures very little, if any, back pressure during use. The hydrophobic nature of the resin leads to excellent capability of concentrating hydrophobic contaminants.

Collection of Particulate and Dissolved Fractions

To remove large debris that may interfere with sample collection, the sample water was first passed through a coarse screen before the Teflon® intake line. Particles greater than 140 µm were removed by a second inline pre-filter. The water then passes through the pump head and a pressure gauge, before it goes through a four-inch diameter, wound glass fiber filter (1 µm nominal pore size). Flow may be redirected without interruption to a second installed filter if the first filter becomes clogged. Material retained on the glass fiber filter (or filters) was designated the particulate fraction. After passing through the filter, the water was split and routed through two Teflon® columns, packed with 75 mL of XAD-2 resin. Two columns were used simultaneously to permit a flow of approximately 1.5 L/min. The compounds adsorbed to the XAD-2 resin are designated as the dissolved fraction. Lastly, the water passes through a flow meter and out the exit tube, where the extracted water volume (97.5 L per sample) was verified by filling five pre-measured (19.5 L) carboys.

Collection of Field Blanks for Trace Organics

Field blanks were taken for both the resin columns and the glass fiber filters. The two column blanks were collected by opening and closing both ends of a column to simulate loading of columns into the sampler. Similarly, a glass fiber filter blank was collected by exposing a filter to the air to mimic loading the sample filters into the cartridges. The field blanks receive the same analytical treatment in the laboratory as the field samples.

Collection of Samples for Trace Metals

Collection of Total and Dissolved Fractions

For trace metals, water samples were collected using a peristaltic pump system equipped with C-Flex tubing in the pump head. Sample containers were filled on deck on the windward side of the ship to minimize contamination from shipboard sources (Flegal and Stukas, 1987). Unfiltered (total) water samples were pumped directly into acid-cleaned containers. Filtered (dissolved fraction) water samples were obtained by placing an acid-cleaned polypropylene filter cartridge (Micron Separations, Inc., 0.45 μm pore size) on the outlet of the pumping system. Prior to collecting water, several liters of water were pumped through the system, and sample bottles were rinsed five times with site water before filling. The bottles were always handled with polyethylene-gloved "clean hands". The sample tubing and fittings were acid-cleaned polyethylene or Teflon®, and the inlets and outlets were kept covered except during actual sampling. Samples were acidified within two weeks in a Class 100 trace metal clean laboratory.

For the analysis of total mercury, water samples (500 mL, minimum) were collected into Hg-clean Teflon bottles, then double-bagged in zip-lock bags. The samples were immediately placed in a cooler with dry ice. Samples were stored frozen until analysis.
For methylmercury analysis, PFA Teflon (125 to 500 mL) was used for sample containers. Samples were frozen in the field, preserved with 0.2% sulfuric (v/v) in the laboratory, and stored in the dark at ambient temperature once preserved.

Collection of Field Blanks for Trace Metals

During the collection of one sample, a pre-cleaned bottle filled with a dilute acid was opened and exposed to the air as a field blank. Field blanks were collected during the sampling periods of both the total (unfiltered) and dissolved (filtered) fractions and receive the same handling and analyses in the laboratory as the field samples.

Collection of Water Quality Samples

Samples for conventional water quality parameters were collected using the same apparatus as for trace metals. However, containers were rinsed only three times, and the "clean hands" procedure was unnecessary.

Collection of Aquatic Bioassay Samples

In the previous year, aquatic bioassays (toxicity tests) were only conducted for shallow sites in the Estuary, and the frequency of sampling for aquatic toxicity testing was reduced. No aquatic bioassays were conducted in 2004 and 2005. In March of 2007, the Technical Review Committee decided that aquatic bioassays would be conducted at a fixed interval (e.g., five years) to assure that no significant aquatic toxicity would be missed. It was scheduled to conduct aquatic bioassay sampling at 9 sites (one per segment with 4 historical sites) in 2007.

5.1.2 Sediment Sampling

Sediment sampling was conducted using a Young-modified Van Veen grab with a surface area of 0.1 m^2. The grab is made of stainless steel, and the jaws and doors are coated with Dykon® (formerly known as Kynar®) to make them chemically inert. All scoops, buckets, and stirrers used to collect and homogenize sediments are also constructed of Teflon® or stainless steel coated with Dykon®. Sediment sampling equipment was thoroughly cleaned (sequentially with detergent, acid, methanol, and rinsed with ultrapure water) at each sampling location prior to each sampling event. In order to further minimize sample contamination, personnel handling samples wear gloves.

If the sediments at a station were primarily fine, plastic floats may be attached to the grab frame and secured so they do not interfere with grab operation. Likewise, if the sediments were primarily coarse, weights were added to the grab frame to assist penetration of the sediments. To ensure the quality of the sediment samples, each grab must satisfy several criteria in order to be accepted: complete closure, no evidence of sediment washout through the doors, even distribution of sediment in the grab, minimum disturbance of the sediment surface, and minimum overall sediment depth appropriate for the sediment type.

Collection of Sediment Samples

Multiple (two to three) sediment grabs were taken at each site, with sediment sub-samples collected for chemical analyses and toxicity tests. Overlying water was drained off an accepted grab, and a probe was inserted directly into the sediment to measure pH. Using pre-cleaned coring tubes, cores were taken near the sides in the deepest section of the grab for measurement of oxidation-reduction potential, and sub-samples for special studies requiring unmixed material were taken. Starting in 2002, hydrogen sulfide analyses of field sample porewater was no longer performed in the S&T component of the RMP, as those data were most relevant for interpreting potential benthic community effects.

The top 5 cm of sediment was scooped from the remaining area (avoiding portions cored or probed) in each of the grabs and placed in a compositing bucket to provide a single composite sample for each site. Between sample grabs, the compositing bucket was covered with aluminum foil to prevent airborne contamination. After all sediment grabs (or at least two grabs, if complications prevent collection of sufficient material within 20 minutes) have been placed into the compositing bucket, the bucket was taken into the ship's cabin and thoroughly mixed to obtain a uniform, homogeneous mixture. Aliquots were subsequently split into appropriate containers for sediment quality, trace metal, trace organics, and toxicity analyses for archive samples.

For total mercury analysis, high density polyethylene wide mouth jars (60 mL) with screw-cap lids were used. New bottles/caps were soaked for one week in micro-soap to remove oils associated with manufacture. Bottles and caps were thoroughly rinsed with Tap/DI water to remove all soap residues. Jars were soaked in 6 N hydrochloric acid bath for at least one week. Bottles were rinsed with ultra-pure (MQ) water five times, to remove all acid residue and then allowed to air dry in HEPA area. The batch of jars was double bagged. Samples were immediately placed in a cooler with dry ice. Samples were stored frozen until analysis.

For methylmercury (MeHg) analysis, sampling and handling procedures are the most important factors influencing the accuracy and uncertainty of MeHg in sediments (Horvat *et al.,* 2004). The transformation and degradation of MeHg can also occur during sample storage and pretreatment,

so great care was taken to minimize disturbance and exposure of the sediments to environmental factors that could alter the MeHg concentrations. These factors include light, temperature and atmosphere. As there is usually only one MeHg analysis per sample, multiple smaller volume samples were collected.

For methylmercury analysis, borosilicate glass vials (40 mL) with Teflon lined screw-caps or screw-cap polypropylene jars (30mL) were used. New glass vials/caps were rinsed in DI water, while reused vials were soaked in detergent overnight (Formula 409). Polypropylene jars were soaked in HCl. Bottles were rinsed with ultra-pure (MQ) water five times, to remove all detergent or acid residue and then allowed to air dry in a HEPA filtered area. The batch of jars was double bagged. After collection, samples were immediately placed in a cooler with dry ice. Samples were stored frozen until analysis.

Collection of Sediment Cores for Toxicity Sampling
Solid-phase amphipod and bivalve elutriate sediment toxicity tests were performed for sediment toxicity.

Eohaustorius % survival and *Mytilus* % normal development tests (including ammonia and H_2S measurements) were performed on 3 liters of sediments sampled from 27 sites:

- 20 random sites (1/2 of the random sampling sites; one from each panel in each segment)
- 7 fixed historical samples (BG20, BG30, BF21, BD41, BC11, BA41, & BA10).

2 amphipod and 3 bivalve TIEs, and TIE chemistry studies, were included on samples that showed the most toxicity (e.g. less than ~ 50 % survival or normal development (for amphipod and bivalve tests, respectively).

Solid-phase samples were prepared as described in the amphipod protocols (U.S. EPA 1994, U.S. EPA 2000). Sediment was re-homogenized in the sample jar with a polypropylene spoon and then distributed to replicate test beakers. Overlying water was added to the test containers, and sediment and overlying water was allowed to equilibrate overnight before the amphipods were added.

Elutriate solutions were prepared by adding 50 grams of sediment to 200 mL of Granite Canyon seawater in a clean 250 mL borosilicate glass jar with a Teflon-lined lid (1:4 volume to volume ratio; U.S. EPA/ACOE 1991). The 250 mL elutriate mixture was shaken vigorously for 10 seconds and then allowed to settle for 24 hours (Tetra Tech 1986). The elutriate solution was pipetted into replicate containers for testing.

Mussel test containers were inoculated with 231 ± 16 (n = 5 initial counts) embryos for a 48-hour exposure. All mussel larvae were counted in each test container at the end of the exposure to determine the percentage of embryos that developed into live normal larvae. This value was determined by dividing the observed number of live embryos inoculated at the beginning of the test.

5.1.3 Bivalve Tissue Sampling

Source of Bivalves
Bioaccumulation was evaluated by collecting mussels (*Mytilus californianus*) from uncontaminated "background" sites of known chemistry and deploying these bivalves at nine locations in the Estuary for approximately 100 days. Resident clams (*Corbicula fluminea*) were

also collected from one site on the Sacramento River and one site on the San Joaquin River. Bivalves are deployed once each year during the dry season, usually in June. Starting in 2003, *Mytilus californianus* was the only transplanted species in the Estuary to ensure higher comparability between sites. *Mytilus californianus* is a salt tolerant species that can also handle salinities as low as 15ppt (Bayne, 1976). Trace element and trace organic tissue concentrations are more comparable throughout the San Francisco Estuary when they are accumulated by the same species because metabolism rates would be similar in all deployed organisms.

Mussels (*Mytilus californianus*) were collected from Bodega Head and stored in running seawater at the Bodega Marine Laboratory until deployment at stations in San Pablo Bay, Central Bay, South Bay, and Lower South Bay, which were expected to have the highest salinities. *Mytilus californianus* will survive short-term exposure to salinities as low as 5 ppt (Bayne, 1976).

Resident freshwater clams were collected from near the RMP historic bivalve deployment sites in the Sacramento River and San Joaquin River. Resident clams were collected using a clam dredge approximately two feet wide by three feet long and 50 pounds in weight. The dredge was deployed from a boat and was dragged along the bottom. When brought to the surface, the clams were placed into a clean plastic container and packaged for organics analysis.

Deployment of Transplanted Bivalves

160 mussels were randomly allocated and placed into predator resistant cages for deployment. Animals of approximately the same shell length were used (49-81 mm). The same number was also used for the reference (time zero) sample, which was analyzed for tissue condition before deployment.

A pilot study conducted in 2001 and 2002 showed that survival rates were generally higher in cages than in the originally used mesh bags. Based on these results, deployment in mesh bags was discontinued in 2003. The cages now used are fairly similar to the original bags with rigid plastic mesh around sections of PVC. The mesh overlapped around itself to keep predators from slipping through any gaps between the edges. After the cages were built they were soaked in water for at least a day to remove any potential signal associated with the adhesives used for the construction.

At each site, a line ran from the bottom of the fixed structure out to the bivalve mooring, which consisted of a large screw (earth anchor) that was threaded into the bottom and was associated with pilings or other permanent structures. A large subsurface buoy was attached to the earth anchor by a 1-2 meter line. The bivalves were in enclosures (mesh bags or cages) attached to the buoy line, which kept the bivalves off the bottom to prevent smothering. In one hundred and fifty individual deployments, loss of a mooring has occurred on only two occasions, probably due to being ripped out by a vessel anchor. Mooring installation, bivalve deployment, maintenance, and retrieval were all accomplished by SCUBA divers.

Maintenance of Transplanted Bivalves

The comparison between maintained cages and un-maintained cages to evaluate whether survival rates were significantly different was discontinued in 2006. It was decided after two years of a side-by-side study that the survival rate of the organisms did not improve through cleaning of the cages. As a result, the deployed samples were not checked and cleaned halfway through deployment to ensure consistent exposure.

Retrieval of Transplanted Bivalves
Upon retrieval, the bivalve enclosures were placed into polyethylene bags and taken to the surface. On the vessel, the number of dead organisms was recorded. Twenty percent of the live organisms were allocated for condition measurement, and the remainder was equally split for analyses of trace metal and organic compounds. Bivalves used for trace organic analyses were rinsed with reagent grade water to remove extraneous material, shucked using a stainless steel knife (acid-rinsed), and homogenized (until liquefied) in a combusted mason jar using a Tissumizer® or Polytron® blender. Bivalves used in trace element analyses were shucked with stainless steel knives, and the gonads were removed. The remaining tissue was rinsed with ultrapure water and placed in acid-cleaned, plastic coated, glass jars. The sample was then homogenized (until liquefied) using a Brinkmann homogenizer equipped with a titanium blade.

Based on findings by Stephenson (1992) during the RMP Pilot Program, bivalve guts were not depurated before homogenization for tissue analyses, although the gonads were removed from organisms for trace metal analyses. With the exception of lead and selenium, no significant differences existed in trace metal concentrations between mussels depurated for 48 hours in clean Granite Canyon seawater before homogenization and undepurated mussels. However, sediment in bivalve guts may contribute to the total tissue concentration for trace organic contaminants.

5.2 Laboratory Methods

For a list of analytes measured in 2006 please refer to the Table 1.4 in the Introduction. SFEI maintains SOPs for all laboratory analyses. Please contact SFEI for more details.

5.2.1 Water and Sediment Quality

No significant changes were made to the analytical methods in 2006 for water or sediment quality.

Water Quality Parameters
In 2006, conventional water quality parameters were measured by the University of California Santa Cruz, Department of Environmental Toxicology (UCSCDET) and by Applied Marine Sciences (AMS). Hardness was measured by the Union Sanitary District, which is part of the Bay Area Clean Water Agencies (BACWA).

Dissolved nutrients in samples were analyzed using the Lachat QuikChem 800 System Nutrient Autoanalyzer (Ranger and Diamond, 1994). The QuickChem methods used were:

Silicates	31-114-27-1
Ammonia	31-107-06-1
nitrate/nitrite	31-107-04-1
Phosphate	31-115-01-3

Chlorophyll and phaeophytin were measured using a fluorometric technique with filtered material from 200 mL samples (Parsons *et al.,* 1984). Shipboard measurements for temperature, salinity, pH, and dissolved oxygen content were made using a hand-held Solomat 520 C multi-functional chemistry and water quality monitor. Dissolved organic carbon (DOC) was measured using high-temperature catalytic oxidation with a platinum catalyst (Fitzwater and Martin, 1993). In 2003, total suspended solids (TSS) were replaced with the measurement of suspended

sediment concentration (SSC), using method 2540D in Standard Methods for the Examination of Water and Wastewater (APHA, 1992). Hardness was determined by Method 2340C as described by the 18th Edition of Standard Methods, a titrimetric procedure using EDTA.

Sediment Quality Parameters
Two measurements of *in situ* pH were recorded on board the sampling vessel by submerging a Hach™ pH probe directly into the sediment sample to approximately 1" in depth after the Van Veen grab was brought on deck. A total of four measurements were recorded for each station. Starting in 2002, porewater hydrogen sulfide analyses of field samples were no longer performed. Measurement of sediment ORP was resumed in 2003, measured in a cored sub-sample of the van Veen by probe inserted (WTW Sentix ORP, KCl electrolyte) to depths of 1cm and 6cm from the sediment surface, and 1cm from the core bottom. The probe was equilibrated for 10 minutes before recording each measurement.

UCSCDET measured most other sediment quality parameters in 2006.
Sediment size fractions were determined with a grain-size analyzer based on x-ray transmission (Sedigraph 5100). Total organic carbon was analyzed according to the standard method for the Carlo Erba 2500 Elemental Analyzer, which pyrolizes the sample and measures combustion products by a thermal conductivity meter.

Conductivity, Temperature, and Depth (CTD) Casts
CTD casts were taken by AMS at each site during water, sediment, and tissue sampling. A Sea-Bird SBE19 CTD probe was used to measure water quality parameters at depths throughout the water column. At each site, the CTD was lowered to approximately one meter below the water surface and allowed to equilibrate to ambient temperature for 3 minutes. Following the sampling, the CTD was then lowered to the bottom at approximately 0.15 meters per second and raised. However, only data from the down cast were kept. Data were downloaded onboard the ship and processed in the laboratory using Sea-Bird software.

The CTD probe measured temperature, conductivity, pressure, dissolved oxygen, and backscatter at a sampling rate of two scans per second. These data were compiled and averaged into 0.25 m depth bins during processing. At this time, salinity (based on conductivity measurements), and depth (based on pressure) are calculated from the indicated measures. Although the CTD data are not included in the 2006 RMP Monitoring Results, SFEI maintains these data in a database. Data are available upon request.

5.2.2 Trace Elements

Starting in 2001/2002 UCSCDET's analytical methods for water trace metals changed as described below. Tissue trace metals were not analyzed in 2006 as the Redesign Workgroup decided to conduct analyses of metals on a periodic basis only. The next year of tissue trace metal analysis is planned for 2008.

Analysis of Water Samples
As in previous years, UCSCDET conducted trace metals analyses with the exception of As and Se. UCSCDET used ICP-OES analysis for Fe and Mn and ICP-MS analysis for Cu, Ni, Zn, Cd, Co,Pb, and Ag in 2006. Methods are described below.

Sample Preservation:

Within one week of collection, samples were acidified to ~ 24 mM with trace metal grade hydrochloric acid (HCl).

Ultraviolet Digestion:
The field and QA (blanks, reference materials) samples were oxidized with ultraviolet (UV) radiation to 'digest' any organo-metallic complexes.

Inductively-coupled plasma - optical emission spectroscopy (ICP-OES) analysis for Fe and Mn:
The irradiated field and QA samples were analyzed on the Perkin Elmer ICP-OES (model 430 DV) for Fe and Mn; although UV-digestion was not required for these elements.

Inductively-coupled plasma - mass spectrometry (ICP-MS) analysis for Trace Metals (Cu, Ni, Zn, Cd, Co, Pb, Ag):
The UV-oxidized undiluted samples were analyzed directly by ICP-MS. The metals of interest 'stick' on the conditioned column and were eluted off with specific pH buffer prior to entering the analytical system. A cationic resin was used to retain Cu, Ni, Zn, Co, Cd and Pb; an anionic resin column retained Ag.

In some instances, reported dissolved metal concentrations were higher than total (ostensibly including dissolved and particulate fractions) metal concentrations. This was due to expected analytical variation, which was proportionally larger at concentrations near the detection limits. Such results should be interpreted as showing no difference between dissolved and total concentrations, with all the metal in the dissolved phase.

Arsenic and selenium were analyzed by BRL. The methods employed in 2006 were slightly changed to improve the control of nitrate/nitrite interferences. Samples were analyzed by Hydride Generation Atomic Absorption Spectrometry with Cryogenic Trap (HGAAS, Brooks Rand SOP BR-0020, a modified EPA Method 1632). Arsenic samples were digested with nitric acid, hydrochloric acid and heating following U.S. EPA Method 200.2. Hydroxylamine hydrochloride (NH_2OH HCL) was added prior to sample analysis.
Selenium samples were digested with hydrochloric acid, potassium persulfate solution, and heating. To destroy any nitrites that hinder hydride formation, 2.5% sulfanilamide was added. Similar to the arsenic samples, NH_2OH HCL was added to the selenium samples prior to analysis. Analysis was performed using hydride generation with $NaBH_4$ addition, cryogenic trap pre-collection, H_2/Air flame quartz furnace decomposition, and Atomic Absorption (HGAAS) detection.

Total Mercury Analysis in Water Samples
In 2006, total mercury analysis of water samples was conducted by UCSCDET. Samples were collected in acid-cleaned Teflon (PFA) bottles.

Sample digestion and analysis was accomplished utilizing a modification of EPA Method 1631. Samples were digested by 24 hour oxidation using 0.2N bromine monochloride. Analyses of digests were performed by tin-chloride reduction, gold-amalgamation, and detection by cold vapor atomic fluorescence spectrometry.

Methylmercury Analysis in Water Samples
Methylmercury Separation from Water by Distillation

Prior to analysis of MeHg by ethylation, separation of MeHg from the sample matrix was required to reduce interferences during derivitization, particularly from chloride and organic matter. The method outlined below was suitable for seawater or estuarine samples with sample concentrations as low as ~10 pg/L.

Samples were distilled by heating the solution to a low boil in acid (and chloride) under inert gas in Teflon vessels. Steam was released through Teflon lines and distillate was trapped in receivers chilled on ice. Matrix modifiers may be added to distillations for some sample types. This method is based on Horvat *et al.* (1993a).For samples with low dissolved organic carbon or low ionic strength as well as sulfidic or freshwater samples, additional manipulations were performed to improve extraction.

Analysis of methylmercury by Aqueous Phase Ethylation
UC-Santa Cruz WIGS laboratory determined methylmercury by aqueous phase ethylation and room temperature trapping, followed by gas chromatography separation and cold vapor atomic fluorescence spectrometry detection (GC-CVAFS).

The pH of the analyte solution was adjusted to 4.9 using acetate buffer. The solution was then ethylated using sodium tetraethyl borate (NaTEB) and allowed to react for 15 minutes. Following reaction with NaTEB the solution was purged with nitrogen gas (N2) for 15 minutes and the MeHg was collected on a Tenax trap after which tubes were dried for 15 minutes. Mercury species were thermally desorbed from the Tenax trap, separated using a gas chromatography (GC) column, reduced using a pyrolytic column, and detected by cold vapor atomic fluorescence spectrometry (CVAFS). The method is based on the Bloom and Fitzgerald (1988) method and is similar to EPA Method 1630.

Analysis of Sediment Samples
In 2006, trace metals in sediment were analyzed by the City and County of San Francisco (CCSF), which is part of the Bay Area Clean Water Agencies (BACWA), BRL, and UCSCDET. Since 2005, BRL analyzed arsenic by ICPMS and selenium by GFAAS (see below). No further changes were made in methodology compared to previous years.

Homogenized sediments were digested in nitric/hydrochloric acids to obtain “near-total” concentrations of trace metals using a method comparable to U.S. EPA Standard Methods (Tetra Tech, 1986) that does not decompose the silicate matrix of the sediment. Because of this, any element that is tightly bound as a naturally occurring silicate may not be fully recovered. Extracts were analyzed for silver by Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS) and for aluminum, cadmium, copper, iron, manganese, nickel, lead, and zinc by inductively coupled plasma atomic emission spectrometry (ICP-AES) with cyclonic nebulization.

BRL digested sediment samples with a heated nitric:hydrochloric acid mix by EPA Method 200.2. Previously, arsenic samples were analyzed by Stabilized Temperature Platform Graphite Furnace Atomic Spectrometry (STP-GFAA) (equivalent to EPA Method 200.9) and since 2005 by Inductively Coupled Plasma - Mass Spectrometry (ICPMS). For selenium analysis, sample aliquots were digested with a HNO_3:$HClO_4$ acid mixture in a heated sand bath. The samples were then diluted with HCl and deionized water. The samples were reduced with NH_2-OH-HCl, heated in a water bath at 95°C for 20 minutes and then allowed to cool prior to analysis. Analysis was performed using Graphite Furnace Atomic Absorption Spectrometry (GFAAS) starting in 2005, replacing the hydride generation with $NaBH_4$ addition, cryogenic trap pre-collection,

H_2/Air flame quartz furnace decomposition, and Atomic Absorption detection (HGAAS, similar to EPA 1632).

UCSCDET analyzed methylmercury and total mercury in sediment.
Sediment samples for total mercury analysis were freeze dried and stored until analysis. Samples were digested using a weak acid (60:40 solution of HNO_3:H_2SO_4) and oxidized with bromine monochloride (BrCl). Analysis of sediment digests was accomplished utilizing a modified EPA 1631 method, using tin-chloride reduction, gold-amalgamation, and detection by cold vapor atomic fluorescence spectrometry.

Methylmercury in sediment was first separated by acid digest-organic extraction
A known mass of sediment was digested in a Teflon centrifuge tube using an acidic mixture of potassium chloride (KCl), copper sulfate (CuSO4), and sulfuric acid (H2SO4). An organic solvent, methylene chloride (CH2Cl2) a.k.a. dichloromethane (DCM), was added to the mixture, into which MeHg and other organomercury species (and other organic compounds), preferentially partition. This acid-organic extraction was performed for one hour using a wrist shaker to agitate samples. After centrifugation to separate the aqueous, sediment, and organic phases, an aliquot of the organic phase was transferred to a glass centrifuge tube containing ultra-pure water for back-extraction into an aqueous phase. The organic solvent was volatilized by placing samples in a warm sand bath and bubbling with inert Hg free gas (N_2 or Ar). The soluble MeHg remained in the aqueous phase and was analyzed by Aqueous Phase Ethylation (see method for methylmercury in water samples above).

Analysis of Bivalve Tissue Samples
In previous years, trace metals in bivalve tissue samples were analyzed by CCSF and BRL. However, from 2002 through 2006 trace metals in tissue were not analyzed. The next trace metal monitoring will be conducted 2008. Analytical methods described here are for informational purposes for samples from prior years.

Bivalve tissue samples were homogenized and then digested with aqua regia to obtain near-total concentrations of trace elements. Digestion techniques are similar to the California State Mussel Watch Program (Flegal *et al.,* 1981; Smith *et al.,* 1986) and consistent with the RMP Pilot Program (Stephenson, 1992). Sample aliquots were extracted with dichloromethane using a Tissumizer®. Extracts were then concentrated and purified by various chromatographic techniques prior to instrumental analyses.

The trace metals were quantified by Inductively-Coupled Plasma - Atomic Emission spectrometry (ICP-AES) or Inductively-Coupled Plasma - Mass Spectrometry (ICP-MS). Selenium was quantified by hydride generation coupled with atomic absorption spectroscopy. Arsenic was analyzed by U.S. EPA Method 200.9 (stabilized temperature platform graphite furnace atomic absorption spectrometry, STP- GFAA) (U.S. EPA, 1994a). Butyltins were measured following NOAA's National Status and Trends Mussel Watch Project methods (NOAA, 1993). This technique involves extracting the sample with hexane and the chelating agent tropolone and then measuring the butyltin residues by capillary gas chromatography. Concentrations were expressed in total tin per gram of tissue dry weight.

5.2.3 Trace Organics

Since 2002, AXYS Analytical Services, Ltd. (AXYS) analyzed water samples for trace organics with the exception of diazinon and chlorpyrifos, which were analyzed by the California

Department of Fish and Game – Water Pollution Control Laboratory (CDFG-WPCL). The dissolved and particulate fractions were combined for all but three sites to reduce the analytical costs for "new" (other than PAHs, PCBs, and organochlorine pesticides) analytes in water. CDFG-WPCL has also analyzed the tissue organics since 2002. Sediment organics were analyzed by EBMUD.

Analysis of Water Samples

In 2006, trace organics analyses of water samples were conducted by AXYS. A brief overview of the extraction and analytical methods used for the target trace organics are described below. The SOPs that describe the laboratory methods in more detail are on file at SFEI.

Two parallel XAD-2 resin columns and one wound glass filter contained the organic compounds extracted from ~100 L of water at each site. The XAD and the filter samples were generally analyzed separately. Each XAD-2 column and filter sample was spiked with labeled surrogate standards, with filter extracted by repeated acetonitrile ambient temperature sonication, and XAD-2 columns with soxhlet extraction. In 2005, this filter extraction method replaced the soxhlet extraction with toluene. The sonication extraction was repeated with hexane, followed by a liquid/ liquid extraction. The resulting extracts were split into five portions for separate analyses of PAHs, PCBs, OC pesticides, diazinon and chlorpyrifos. PBDEs, phthalates, and nonylphenol, the "new" analytes, were analyzed as combined (total) extracts for each site. Four of the five portions were analyzed and one was saved as back-up. Target concentrations were determined by isotope dilution or internal standard quantification against the labeled surrogate compounds added at the beginning of the analysis, a procedure that yields recovery corrected results. The recoveries of the labeled surrogates were determined against the labeled internal standards and were used as general indictors of data quality.

Extract subsamples were subject to different cleanup procedures and analytical instrumentation, depending up on the target analytes.

PCBs: A florisil chromatographic column was used for the clean-up of the extract of PCBs. The analytical procedure was in accordance with US EPA Method 1668, Revision A. Analysis was performed using a Micromass Ultima high resolution MS equipped with a Hewlett Packard 6890 GC and a CTC autosampler.

Organochlorine Pesticides: A florisil chromatographic column was also used for cleaning the extract of chlorinated pesticides. High resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS) analysis was conducted using a VG 70 VSE HRMS equipped with a HP 5890 gas chromatograph.

PAHs: PAH extractes were cleaned up on silica and analyzed by high resolution gas chromatography/low resolution mass spectrometry (HRGC/LRMS) using Agilent 6890N GC equipped with an Agilent 5973MSD, an Agilent 7683 Series Autosampler, and a HP Chemstation.

PBDEs: A portion of PBDE extract was cleaned up using gel permeation and separated into two fractions, which were further cleaned using a Florisil chromatographic column. Additional cleanup used layered acid/base silica and alumina chromatographic columns. The extraction and cleanup procedures were in general accordance with U.S. EPA Method 1668 Revision A, followed by instrumental analysis in accordance with AXYS Method MLA-025. Samples were analyzed by HRGC/HRMS on an AUTOSPEC ULTIMA high resolution MS equipped with an

HP 6890 gas chromatograph, a CTC autosampler, and an Alpha data system running Micromass software.

Analyses of phthalates and p-nonylphenol were discontinued in 2004. The description of analytical methods remains in this document for informational purposes.

Phthalate Esters: Phthalates were analyzed using the same portion of the original extract that was used for PAH analyses. The extract was cleaned up on silica and analyzed by HRGC/LRMS using either: an Agilent 5973 MSD equipped with an Agilent 6890N GC, an Agilent 7683 autosampler and a HP Chemstation; or a Finnigan Incos 50 MS equipped with a Varian 3400 GC, a CTC autosampler, and a HP Chemstation.

p-Nonylphenol: A portion of the original extract was reserved for p-nonylphenol analysis, with XAD and filter portions combined for p-nonylphenol analysis. The extracts were reduced to dryness and underwent non-aqueous acetylation using pyridine and acetic anhydride. Sample extracts were loaded onto 5% deactivated silica for chromatographic cleanup. Instrumental analysis was conducted by HRGC/LRMS using an Agilent 5973 mass spectrometer equipped with an Agilent 5890 gas chromatograph, a CTC autosampler, and an Agilent Chemstation data system.

Analytical methods for diazinon and chlorpyrifos were not available from CDFG at the time of publication.

Analysis of Sediment Samples

In 2006, trace organics analyses of sediment samples were conducted by the East Bay Municipal Utility District (EBMUD, Oakland, CA), which is a part of BACWA. A brief overview of the extraction procedures and analyses used for the target trace organics are described below. The laboratory SOPs, which describe the methods in detail, are on file at SFEI. Sediment samples are generally analyzed based on the methods followed by NOAA's National Status and Trends Program. PAHs were analyzed using gas chromatography/mass spectrometry (GC/MS) and PCBs, PBDEs, and organochlorine pesticides were analyzed using high resolution gas chromatography – mass spectrometry (HRGCMS).

Although the same analytical methods were utilized in 2003 as in the past by EBMUD (the RMP lab for sediment organics since 1997), results for PCBs, PBDEs and OC pesticides in 2003 were largely below detection limits. As a result, data were not reported in 2003. Samples are scheduled to be re-analyzed with a new method (HRGCMS) with lower detection limits that was already used for the analysis of 2004 - 2006 organics.

Sediment Extraction (all organic analytes): Samples were homogenized and then extracted using a Dionex Accelerated Solvent Extraction, ASE (U.S. EPA Method 3545). The sample extracts were dried with anhydrous granular Na_2SO_4. Extracts were cleaned up with an alumina/copper column and concentrated to 1 ml in DCM. This extraction and concentration procedure was used for all trace organic compounds of interest in the sediment samples.

PAHs: Just prior to analysis the sample extracts were spiked with deuterated internal standards (fluorine-d10 and benzo[a]pyrene-d12). PAHs were then analyzed using U.S. EPA Method 8270 (Semi-volatile Organic Compounds by Gas Chromatography), which was slightly modified to provide sufficient sensitivity for PAHs in sediments.

Organochlorine Pesticides: Just prior to analyses, injection internal standards were added to the sample extracts, and then an aliquot of the extract was injected into the gas chromatograph. The analytes were separated by the gas chromatograph and detected by a high resolution (>8,000) mass spectrometer (HRMS). Two exact m/z's were monitored throughout a predetermined detention time.

PCBs: A cleanup standard was spiked into the extract prior to analyses. The extract was then put through a drying column and concentrated. After drying and concentrating, the samples were cleaned up using gel permeation and activated alumina column chromatography. After cleanup, the solvent was exchanged to hexane. Injection internal standards were added to each extract before injection into the gas chromatograph. The analytes were separated by gas chromatography and detected by a high-resolution (>10,000) mass spectrometer (HRMS). Similar to the oc-pesticide analyses, two exact m/z's were monitored throughout a predetermined detention time.

PBDEs: A cleanup standard was spiked into the extract, which was then dried and concentrated. The samples were then purified using an activated alumina column, and the solvent in the samples was exchanged to hexane. Just prior to the analysis, injection internal standards were added to each extract and an aliquot was injected into the gas chromatograph. Similar to oc-pesticide and PCB analysis, the PBDE congeners were separated by the gas chromatograph and detected by a high-resolution (>5,000) mass spectrometer (HRMS) with two exact m/z's monitored for each compound.

Phthalates and p-nonylphenol analyses were discontinued in 2004.

Analysis of Bivalve Tissue Samples

In the past, trace organics analyses of bivalve tissue samples were conducted by CDFG-WPCL. A brief overview of the extraction and analyses used for the target trace organics are described below. Extract cleanup and partitioning methods are modifications of the multi-residue methods for fatty and non-fatty foods described in the U.S. Food and Drug Administration, Pesticide Analytical Manual, Vol. 1, 3 rd Edition 1994, Chapter 3, Multi-residue Methods, Section 303-C1. The laboratory SOPs that describe the methods in more detail are on file at SFEI.

Tissue Extraction: Samples were removed from the freezer and allowed to thaw. Prior to extraction, bivalve tissue samples were homogenized using a Büchi B-400 homogenizer. A 10 g sample was mixed with approximately 7 g of pre-extracted Hydromatrix® until the mixture was free flowing. The mixture was then extracted using U.S. EPA Method 3545 (Pressurized Fluid Extraction) with a 50/50 mixture of acetone/dichloromethane. The samples were extracted a second time using the same conditions. The extracts were dried and filtered through a 0.45 µm syringe filter into J2 Scientific AccuPrep 170 (GPC) autosampler tubes. Two milliliters each of the filtered extracts were removed and placed in a pre-weighed aluminum planchet for percent lipid determination.

All sample extracts were cleaned-up using a J2 Scientific GPC (Autoinject 110, AccuPrep 170, DFW-20 Fixed Wavelength Detector, 1" i.d. glass column with 70 g Bio-Beads SX-3 in 100% DCM). For pesticides, PCBs, and PBDEs the GPC purified extracts were then fractionated into 4 separate fractions on a Florisil column using petroleum ether (F1), 6% diethyl ether/petroleum ether (F2), 15% diethyl ether/petroleum ether (F3), and 50% diethyl ether/petroleum ether (F4)

elution. For PAHs, the GPC purified extracts were further cleaned-up with silica/alumina column chromatography using DCM:pentane (1:1) as the solvent.

Organochlorine Pesticide, PCB, and PBDE Analyses in Tissue: Cleaned-up extracts were evaporated and fractionated. The fractions were concentrated to an appropriate volume using K-D/micro K-D apparatus prior to analysis by dual column high resolution gas chromatography with electron capture detection. A mixture of synthetic organic standards was eluted through the Florisil 7 column to determine the recovery and separation characteristics of the column.

In 2004 and 2005, a large number of the results were non detects and will not be recorded in the Annual Results. 2004/05 samples are considered for re-analysis, and 2006 samples were not analyzed yet. SFEI is in the process of selecting a new laboratory for tissue analysis.

Analysis of Extractable PAH Compounds in Tissue: Extraction methods for homogenized tissue samples were identical to those for PCBs, PBDEs, and organochlorine pesticides. All samples were then cleaned up using a large (1 inch i.d.) GPC column. The extracts were evaporated using a K-D apparatus to 5 mL. The extracts were then fractionated. The fractions were concentrated to 1 mL using K-D/nitrogen blow down apparatus prior to analysis by gas chromatography/mass spectrometry.

Phthalate, nitro and polycyclic musk, and p-nonylphenol analyses were discontinued in 2004.

5.2.4 Toxicity Testing

Sediment Bioassays

In 2006, sediment toxicity was tested by UC Davis - Marine Pollution Studies Laboratories (UCD-MPSL), similar to previous years.

The RMP uses three sediment bioassays: (1) a ten-day acute mortality test, where the estuarine amphipod *Eohaustorius estuarius* was exposed to whole sediment using ASTM method E 1367 (ASTM 1992), (2) a sediment elutriate test, where larval bivalves (*Mytilus spp*.) were exposed to the material dissolved from whole sediment in a water extract using ASTM method E 724-89 (ASTM 1991) and percent normally developed larvae measured as the endpoint, and (3) sediment-water interface core (SWIC) test, where *Mytilus galloprovincialis* larvae were exposed to SWI for 48 hours and percent normally developed larvae measured as the endpoint.

Solid-phase samples were prepared as described in the amphipod protocol (U.S. EPA, 1994b). Sediment was re-homogenized in the sample jar with a polypropylene spoon and then distributed to form a layer 2 cm deep in each of five one-liter replicate beakers. Overlying water was added to the test containers, and sediment and overlying water were allowed to equilibrate overnight before the amphipods were added.

Elutriate solutions were prepared by adding 50 g of sediment to 200 mL of Granite Canyon seawater or freshwater in a clean 250 mL borosilicate glass jar with a Teflon-lined lid (1:4 volume to volume ratio; U.S. EPA and ACOE, 1991). The elutriate mixture was shaken vigorously for 10 seconds and allowed to settle for 24 hours (Tetra Tech, 1986) before being transferred into replicate containers for testing.

5.2.5 Bivalve Growth and Survival

Applied Marine Sciences (AMS) conducted the bivalve health measure evaluations as in previous years.

Analysis of contaminant concentrations was conducted on a subset of the transplanted bivalves (composites contain 40-60 individual bivalves from each site) prior to deployment in Estuary locations (T-0) and after the 100-day deployment period. The differences between pre- and post-deployment concentrations allow determination of contaminant uptake during the period of deployment. A new batch of bivalves were also collected from the original T-0 transplanted bivalve collection sites at the end of the deployment period to obtain information on uptake variables that may have affected wild populations during the deployment period.

In 2001 AMS began calculating the growth mean in addition to the condition index (CI) for the RMP as an indicator of bivalve health. The CI interpretation of bivalve health can be confounding when ambient conditions (i.e., salinity) are more uniform such as during the summer deployment period. In 2002, the RMP discontinued the condition index measure in favor of the growth mean as the only health indicator. Because the CI is the ratio of dry tissue weight to shell cavity volume, it could be affected by changes in either tissue weight or shell size. For example, either a decrease in tissue weight with stable shell size or an increase in shell size with stable tissue weight could be interpreted as a decrease in CI. Consequently, the interpretation of CI as an indicator of health can be problematic. The growth mean is a measure of growth of the composite of bivalves at a particular site in comparison to the T-0. The growth mean was determined by taking the dry weight of each individual and subtracting the mean dry weight of the T-0 for that species. This calculation was done for each individual bivalve. The mean of the difference of all the individuals at a particular site was then calculated to give the growth mean.

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Chapter

6

Statistical Analysis of RMP Data from 1993 to 2006

6.0 Statistical Analysis of RMP data from 1993 to 2006.

Ben Greenfield, John Ross, Aroon Melwani, John Oram

6.1 Introduction

The Regional Monitoring Program has been collecting annual data on contaminant concentrations from 1993 until the present. In 2002, the program switched from a fixed station design focusing on the "spine" of the Bay to a probabilistic sampling design, in which all portions of the Bay were represented. The primary purpose of this switch was to better characterize expected concentrations for the entire Bay, including deep water areas sampled with the fixed design, as well as shallow areas, such as shoals and Bay margins (Lowe *et al.* 2004). Now that five years of data are available using the probabilistic sampling design, we can determine whether the representative samples captured in the new design indicate substantially different contaminant concentrations than the fixed station design. However, this question is confounded by the different time periods surveyed with the fixed design (1993-2001) versus the probabilistic design (2002-2006).

We performed analyses to determine whether concentrations differ, either as a result of the new probabilistic sampling scheme, or due to long-term trends in concentrations. We evaluated two hypotheses: 1. Concentrations differ significantly between the historical fixed sampling sites and the current probabilistic sites; 2. Concentrations have changed significantly over the entire duration of the sampling program. To address the confounding of time trends and design type, we evaluated long-term trends using a subset of fixed monitoring stations that have been monitored annually over the entire program duration (i.e., 1993-2006). Because they have been sampled continuously, these stations indicate exclusively trends over time. We also compared concentrations over all fixed stations, versus all probabilistic stations. Finally, we evaluated probabilistic stations to determine the effect of station depth on contaminant concentrations. We use this information in combination to develop hypotheses regarding the spatial and temporal variation of multiple contaminants in the Bay (Table 6.1). For example, if the probabilistic stations were significantly lower than the fixed stations, but the continuously monitored (i.e., 1993-2006) fixed stations exhibited no trends, this would indicate overall lower concentrations Bay-wide than at the fixed stations (Table 6.1).

One rationale for switching over to probabilistic design is the expectation that shallow stations in the Bay margins may have different concentrations than the deep, mid-channel, fixed stations (Lowe *et al.* 2004). For example, nearshore areas may be more heavily impacted by industrial activity, and therefore exhibit higher concentrations of industrial legacy pollutants such as PCBs (Davis *et al.* 2007). We evaluated this hypothesis by statistically determining whether the sediment concentrations of selected contaminants vary significantly by bathymetry. This information may also be used to

determine whether probabilistic stations are capturing significantly different contaminant exposure, via the inclusion of shallow areas (Table 6.1).

Table 6.1. Interpretations of potential results from the three analyses performed in this study.

Which have higher concentrations: fixed or probabilistic stations?	Are there trends in fixed monitoring stations?	Which stations are higher: shallow or deep?	Interpretation
Probabilistic stations higher	Increasing with time	No difference	Concentrations in Bay (or segment) have been increasing over time
Probabilistic stations higher	No trend	Shallow higher or no difference	Probabilistic design samples more contaminated areas (e.g., shallow stations)
Fixed stations higher	No trend	Deep higher or no difference	Historic (fixed) stations sample more contaminated areas
Fixed stations higher	Decreasing with time	No difference	Concentrations in Bay (or segment) have been decreasing over time
Either	Decreasing with time	Shallow higher	Concentrations have been decreasing over time but probabilistic design samples more contaminated areas (e.g., shallow stations)
Probabilistic stations higher	Increasing with time	Shallow higher	Concentrations have been increasing over time and probabilistic design samples more contaminated areas (e.g., shallow stations)

6.2 Methods

6.2.1 Trend analysis at long-term fixed stations

Time trends in water and sediment concentrations were evaluated by linear regression at fixed stations sampled from 1994 – 2006. Statistical analysis of trends was performed at stations where more than 5 detectable concentrations were present for a parameter (PCBs, PAHs, DDTs, MeHg, Hg, Se, Cu, and Ni). Concentrations below detection were generally infrequent and excluded for this analysis. In the case of methylmercury, data have only been collected since 2000; therefore this analysis represents a shorter time

frame relative to the other comparisons. Regressions were performed on log-transformed data, and the residuals of the analysis tested for normally distributed values using the Anderson-Darling test. If the null hypothesis stating that the error values follow a normal distribution was rejected ($p<0.05$), then the raw data or other transformations were used to obtain a normal distribution. In a few cases (see footnote to Table 6.2), results are flagged because neither transformations nor raw data values were sufficient to achieve normally distributed residuals. Deviations from normality in these few cases are not of major concern since the regressions are not being used for prediction of future trends. Regressions analysis on individual data values were used to determine whether significant trends over time existed, and if the trends were positive or negative in direction.

6.2.2 Comparison of fixed vs. probabilistic stations

The comparison of fixed versus probabilistic stations was performed using the R statistical program (www.r-project.org) and the psurvey.analysis package developed specifically for analysis of Generalized Random Tessellation Survey design (www.epa.gov/nheerl/arm/analysispages/software.htm). The analysis used Wald, Roa-Scott first-order corrected, and Rao-Scott second order corrected statistics for categorical data to test for differences between two cumulative distribution functions (Kincaid, 2007).

Raw (i.e., un-normalized) contaminant concentration data for the two sampling designs were input into the software program along with ancillary information describing the location (latitude/longitude) and spatial weighting of each site. Spatial weights describe the area of the Estuary for which a given site is meant to represent. Weights for probabilistic stations were determined during initial study design (Lowe *et al.*, 2004). A weight of one was used for all fixed stations, thereby giving each station equal weighting in the psurvey.analysis algorithms.

6.2.3 Comparison of stations based on depth

In order to examine bathymetric distributions, RMP sediment samples collected between 2002 and 2006 at stratified random sampling stations were grouped into five regions: the Lower South Bay, South Bay, Central Bay, San Pablo Bay, and Suisun Bay (Lowe *et al.* 2004). Sediments were classified based on station water depth at mean lower low water (MLLW) into four depth strata: 1 to 3 feet, 3 to 6 feet, 6 to 12 feet, and 12+ feet. Individual depth strata were further combined into shallow (1 to 6 feet) and deep (6+ feet) strata. Contaminant descriptive statistics were estimated within each region and for the Estuary as a whole by depth strata. When the data contained censored values, nondetects (NDs), descriptive statistics were estimated using the Kaplan-Meier method (Helsel 2005). Statistical comparisons of sediment concentrations by depth strata within each region and for the Estuary as a whole were conducted based on parameter type (trace metals or trace organics), normality, equality of variance, and the presence of censored data.

If there were no NDs, then the data were examined for normality using the Anderson-Darling test. If the null hypothesis stating that the sample distributions follow a normal distribution was rejected ($p<0.05$), then the data were transformed in order to obtain a normal distribution. Differences between depth strata were examined using a general linear model (GLM) analysis of variance (ANOVA) followed by a post hoc comparison if a significant difference was found. If no transformation was successful in obtaining a normal distribution, differences between the four individual depth strata (1 to 3, 3 to 6, 6 to 12, and 12+ feet) were investigated using the nonparameteric Kruskal-Wallis test for multiple comparisons followed by a Dunn's test, with a family error rate set at 0.05 and Bonferroni correction. Comparisons between shallow (1 to 6 feet) and deep (6+ feet) strata were conducted using the Mann-Whitney test.

The results for mercury (Hg), monomethyl mercury (mmHg), and polybrominated diphenyl ethers (PBDE 047 and PBDE 209) included NDs, therefore, comparisons between the four individual depth strata were investigated using the nonparametric Kruskal-Wallis test to determine whether the cumulative distribution functions (cdfs) are similar, or if at least one is different. This was accomplished by setting all censored observations below the highest detection limit to the same value. Dunn's multiple comparison test, with an overall (family) error rate specified as 0.05, was conducted if a significant difference was found (Helsel 2005). Differences between shallow and deep strata were examined by censoring all values below the highest detection limit to a common value and computing a Mann-Whitney test. Although the Kruskal-Wallis and Mann Whitney tests are less powerful than their parametric equivalents, they accurately capture the information in the data, representing what is actually known about the data, without having to meet assumptions of a normal distribution and equal variance. Assumptions difficult to check with censored data, as the entire distribution of the data, cannot be determined.

Statistical tests for analyzing censored data require detection limits, therefore, they could not be used to analyze the trace organic sums (Chlordanes, DDTs, PAHs, and PCBs) as no detection limits are reported. Instead, NDs were replaced with 0 for statistical analysis. Data were then investigated for normality using the Anderson-Darling test, and transformed if necessary in order to obtain a normal distribution. Differences between depth strata were examined using a GLM ANOVA followed by post hoc comparisons. In the event no transformation was successful, differences between the four depth strata (1 to 3, 3 to 6, 6 to 12, and 12+ feet) were investigated using the nonparameteric Kruskal-Wallis test for multiple comparisons followed by a Dunn's test, with a family error rate set at 0.05 and Bonferroni correction. Differences between shallow (1 to 6 feet) and deep (6+ feet) strata were examined using the Mann-Whitney test.

6.3 Results

6.3.1 Long-term trends in fixed monitoring stations

Table 6.2 indicates results of linear regression analysis for fixed monitoring stations over the entire duration of the RMP (1994 to 2006). Because all collections were performed at the same station, these are unbiased indicators of trends in water and sediments.

When evaluating individual fixed stations monitored from 1993 to 2006 (MeHg for 1999 to 2006), statistically significant ($p < 0.05$) trends were observed for a number of pollutants and matrices (Table 6.2). For total PCBs, significant declining trends (R^2 = 0.20 to 0.61) were found for total in water, dissolved in water, and total in sediments. This significant decline was observed in 15 of 17 station-matrix combinations (Table 6.2a). Total DDTs in water also declined significantly in all five stations, with R^2 ranging from 0.19 to 0.46 (Table 6.2a). Selenium in sediments declined significantly in five of seven stations (R^2 = 0.28 to 0.53; Table 6.2c).

Regression slopes were generally negative for Hg, DDTs, PCBs, Cu, Ni, and Se, indicating generally declining trends, though many of the declines were not statistically significant (Table 6.2). In contrast, total and dissolved PAHs in water, and methylmercury in sediments exhibited positive regression slopes, with several significant increases. The strongest increase for PAH was dissolved PAH at Sacramento River (BG20; R^2 = 0.49; Table 6.2a). The strongest increase for methylmercury in sediments was at Yerba Buena Island (BC11; R^2 = 0.71; Table 6.2b).

6.3.2 Comparison of fixed vs. probabilistic stations

Comparison of CDF results for fixed vs. probabilistic stations indicated significant differences for almost all segments and Bay wide, in all matrices (Table 6.3). Most contaminants were lower in the probabilistic stations (collected 2002-2006) than the fixed stations (collected 1993 – 2001), across most segments, and Bay-wide. Probabilistic stations were lower for PCBs, DDTs, and Se in all matrices, total and dissolved Ni and Cu in water, and total mercury in water and sediments. For dissolved PAHs in water and methylmercury in sediments, probabilistic stations were higher (Tables 6.3 and 6.4).

6.3.3 Bathymetry comparisons

Organic pollutants

Concentrations of chlordanes in the Lower South Bay, after reciprocal root transformation, were found to be significantly different between individual depth strata (GLM ANOVA, $F_{3,22} = 3.210$, $p = 0.043$). Post hoc comparison revealed that sediments collected at sites located in water depths of 3 to 6 feet (MLLW) were significantly higher in Chlordanes than those sampled in water depths greater than 12 feet (MLLW) (Table 6.5).

Estuarywide DDT concentrations were found to be significantly higher in sediments located in water depths between 1 and 3 feet (MLLW) compared to samples collected at

sites greater than 12 feet (Kruskal-Wallis, H = 13.01, df = 3, p = 0.005) (Table 6.6). Concentrations of DDTs were higher in sediment samples from water less than 6 feet compared to those from waters greater than 6 feet, but not significantly so (Mann-Whitney, W = 4845, p = 0.056).

After square root transformation, concentrations of DDTs in Suisun Bay were found to be significantly different for the individual (GLM ANOVA, $F_{3,27} = 6.205$, p = 0.002) and combined (GLM ANOVA, $F_{1,29} = 16.875$, $p < 0.0005$) depth strata. Post hoc comparison revealed that sediments collected at sites located in water depths of 3 to 6 feet (MLLW) were significantly higher in DDTs than those sampled in water depths greater than 12 feet, and sediments from sites in water depths of 1 to 6 feet were significantly higher than from locations sampled in water depths greater than 6 feet (Table 6.6).

Central Bay sediments from sites located between 3 and 6 feet (MLLW) were significantly higher in DDTs than those from waters between 6 and 12 feet (Kruskal-Wallis, H = 8.14, df = 3, p = 0.017), and sediments from waters greater than 6 feet in depth were significantly higher than those from waters less than or equal to 6 feet (Mann-Whitney, W = 7, p = 0.047). However, only two samples were collected in the 3 to 6 feet depth stratum (Table 6.6).

Lower South Bay sediment samples from sites located in water depths between 6 and 12 feet (MLLW) were significantly higher in DDTs than those from locations deeper than 12 feet (reciprocal root transformation, GLM ANOVA, $F_{3,28} = 4.602$, $p < 0.010$), even though only two samples were collected in the 6 to 12 feet depth stratum (Table 6.6).

After square root transformation, concentrations of PAHs in Suisun Bay were found to be significantly different for the individual (GLM ANOVA, $F_{3,36} = 6.429$, p = 0.001) and combined (GLM ANOVA, $F_{1,38} = 12.268$, p = 0.001) depth strata (Table 6.7). Post hoc comparison revealed that sediments collected at sites located in water depths of 3 to 6 feet (MLLW) were significantly higher in PAHs than those sampled in water depths greater than 12 feet, and sediments from sites in water depths of 1 to 6 feet were significantly higher than from locations sampled in water depths greater than 6 feet. Conversely, concentrations of PAHs in Central Bay sediments were significantly higher at sites located in water depths greater than 6 feet compared to 1 to 6 feet (MLLW) (Mann-Whitney, W = 6, p = 0.032), however only two samples were collected in the 1 to 6 feet depth stratum (Table 6.7).

Like PAHs, concentrations of PCBs in Suisun Bay, after square root transformation, were found to be significantly different for the individual (GLM ANOVA, $F_{3,20} = 3.653$, p = 0.03) and combined (GLM ANOVA, $F_{1,22} = 7.898$, p = 0.01) depth strata (Table 6.8). Post hoc comparison revealed that sediments collected at sites located in water depths of 3 to 6 feet (MLLW) were significantly higher in PCBs than those sampled in water depths greater than 12 feet, and sediments sampled in water 1 to 6 feet deep were significantly higher than those from water deeper than 6 feet.

No significant differences were found for either the individual or shallow versus deep comparisons for PBDE 47 (Table 6.9) or PBDE 209 (Table 6.10).

Metals

Suisun Bay sediments from sites in water depths greater than 12 feet (MLLW) were found to be significantly higher in total mercury concentrations than those from water depths between 3 and 6 feet (censored Kruskal-Wallis, H = 8.49, df = 3, p = 0.037) (Table 6.11). Mercury concentrations were significantly higher in sediment samples from waters less than 6 feet compared to those from deeper waters (censored Mann-Whitney, W = 293, p = 0.006).

Suisun Bay sediments from sites in water depths between 3 and 6 feet (MLLW) were found to be significantly higher in methylmercury concentrations than those from water depths greater than 12 feet (censored Kruskal-Wallis, H = 8.76, df = 3, p = 0.033) (Table 6.12). Methylmercury concentrations were significantly higher in sediment samples from waters less than 6 feet compared to those from deeper waters (censored Mann-Whitney, W = 281, p = 0.018).

South Bay sediments from sites in water depths greater than 12 feet (MLLW) were found to be significantly higher in selenium concentrations than those from water depths between 6 and 12 feet (GLM ANOVA, $F_{3,36} = 3.712$, p = 0.02) (Table 6.13). Selenium concentrations were higher in sediment samples from waters greater than 6 feet compared to those from water 1 to 6 feet, but not significantly so (GLM ANOVA, $F_{1,38} = 2.865$, p = 0.099).

Summary of bathymetry comparison results

Statistically significant bathymetric differences in sediment concentrations were found for some of the investigated contaminants. Estuarywide, only one difference was found in the spatial distribution between depth strata with the concentration of the DDTs significantly higher in the 1 to 3 feet MLLW stratum versus the 12+ feet stratum. Suisun Bay sediment concentrations for the DDTs, PAHs, PCBs, mercury, and methylmercury were all found to be significantly higher at shallow (1-6 feet MLLW) compared to deep (6+ feet) stations, and except for mercury, concentrations were also significantly greater in the 3 to 6 feet compared to the 12+ depth stratum. Concentrations of the DDTS and PAHs in the Central Bay were found to be significantly higher at deep water (6+ feet MLLW) compared to shallow water (1 to 6 feet) sediments. Only one significant difference was found in the South Bay, where sediment selenium concentrations were significantly higher in the 12+ feet MLLW compared to the 6 to 12 feet depth stratum stations. Lower South Bay sediments were found to be significantly higher in the concentration of the Chlordanes at 3 to 6 feet compared to 12+ feet depth stratum stations, as well as being significantly higher in the concentration of the DDTs in the 6 to 12 feet versus 12+ strata.

6.4 Discussion

6.4.1 General findings

The comparison of the probabilistic vs. fixed stations indicates a combination of two factors: 1. spatial differences between the two types of stations; and 2. long-term trends. Trends are a concern because the types of stations were monitored at different times (1994 to 2001 for fixed stations vs. 2002 to 2006 for probabilistic stations). Significant differences between the two types of stations in the absence of long-term trends would indicate that the types of stations sampled are intrinsically different in their exposure to the contaminants of concern. In contrast, if both spatial and temporal differences were observed in the same direction, this suggests that long term trends are present, and is inconclusive regarding the relative exposure of the two station types (Table 6.1).

Examination of Tables 6.2, 6.3, and 6.4 in combination with the hypothesis table (Table 6.1) reveals multiple patterns in contamination. The most striking observation is that the data suggest declining trends in multiple contaminants and matrices (Table 6.14). In water, total and dissolved PCBs, DDTs, Ni, and Se exhibit significant declines in some or all of the fixed monitoring stations. This corresponds with generally lower concentrations in the more recently monitored probabilistic stations than the historic stations. These two results in combination suggest a general decline in waterborne concentrations of these contaminants. The same pattern is observed for PCBs, total Hg, and Se in sediments (Table 6.14), and has been observed in long-term bivalve monitoring studies of San Francisco Bay and elsewhere (Davis et al. 2006, O'Connor and Lauenstein 2006, Davis et al. 2007). The opposite pattern (increases in the long-term monitoring stations, and elevated concentrations in the probabilistic stations) is observed for total and dissolved PAH in water and methylmercury in sediments, suggesting that these contaminants may be increasing in these matrices.

For many pollutants, declines have likely resulted from source control and management efforts. The production and use of PCBs and DDTs was largely phased out in the mid to late 20th century (Connor et al. 2007, Davis et al. 2007). For selenium, refinery effluents and discharge from the San Joaquin River have dramatically reduced since the 1980s (Cutter and Cutter 2004).

Overall, the available data did not provide strong evidence of contaminant concentration differences between the fixed vs. probabilistic sampling locations. With the exception of DDTs, the Bay-wide depth comparison among probabilistic sediment locations generally did not indicate differences among depths. The general lack of depth-based differences suggested that the ability of probabilistic stations to represent a range of depths (as opposed to the fixed stations only representing deep channels) did not result in measured concentration differences. This may result from the dynamic and well-mixed environment that affects the Bay water column and sediments (Davis 2004). Nevertheless, in principle, the probabilistic stations are more robust indicators of Bay-wide conditions (Stevens 2002, Lowe et al. 2004).

6.4.2 PAHs

Results for specific contaminants are sometimes inconsistent among matrices, suggesting that trends and mechanisms may be matrix and source-specific. This is particularly true for PAHs, which increased over time in water but exhibited no trends in sediments. Furthermore, sediment concentrations were lower in the probabilistic stations in most Bay segments (Tables 6.3 and 6.4), but shallow stations were significantly higher than deep stations within the Suisun Bay segment (Table 6.7). This puzzling combination of results may indicate source- specific PAH trends. For example, storm water runoff and tributary inflow, considered the major sources of PAHs to the Estuary (Gunther et al. 1991, Oros et al. 2007), are likely to be increasing due to urbanization and population growth, greater reliance on automobile and diesel-based shipment and transportation, and consequent deposition onto urban surfaces. These factors may have resulted in increased water column concentrations. In contrast, PAHs in sediments include large historic deposits from combustion of fuels, coal, and wood (Pereira et al. 1999, Oros and Ross 2004). Due to this large mass of historically deposited PAH and the spatially variable environment of deposition and erosion (Jaffe et al. 1998), sediment PAHs may be less responsive to recent changes in watershed loading than water column concentrations. Simulations using the RMP multibox model may help to test this prediction.

Interpretation of results for PAHs and other contaminants has likely been impeded by the lack of shallow station data from Central Bay. PAHs in Central Bay are among the few classes of pollutants where available data suggest that the probabilistic design samples more contaminated locations (Table 6.14). But in the current RMP design, Central Bay is the largest segment, but has the smallest number of shallow monitoring stations. From 2002 to 2006, only two samples were collected from depth between 1 and 6 feet. Deepwater portions of Central Bay are relatively low in contaminant concentrations, as a result of loss due to tidal exchange and outflow through the Golden Gate (Davis 2004). However, Central Bay contains several highly industrialized locations having elevated contaminant concentrations (Lee et al. 1994, Hunt et al. 1998, McCain et al. 2000, Ghosh et al. 2003). Future RMP redesign efforts should consider the potential benefit of generating further data on contaminant distributions and concentrations in the shallow portion of this segment.

6.4.3 Total mercury vs. methylmercury

Another noteworthy pattern was the difference between total mercury and methylmercury. Total mercury decreased in some long-term sediment monitoring stations, but MeHg increased in other stations (Table 6.2). Additionally, in Suisun Bay, shallow sediments (3 to 6 ft depth) were significantly higher than deep sediments (=>12 ft depth) for total mercury, but significantly lower for methylmercury. A weak and variable association between total and methylmercury has been documented in the Estuary and elsewhere, resulting from variable net methylation efficiency. For example, the Central Delta exhibits relatively low THg but high MeHg (Heim et al. 2007), and MeHg is not statistically associated with THg in southern reaches of San Francisco Bay (Conaway et al. 2003). Although the total mercury declines were observed at some

stations by Conaway et al. (2007), methylmercury trends have not been previously reported.

The decoupling of total vs. methylmercury trends in the historic monitoring stations is particularly important, given the current efforts to control the amount of bioavailable methylmercury by reducing loading of total mercury into the estuary (SFBRWQCB 2006). Among many possible mechanisms, the increases in methylmercury in some stations could be related to recent increases in phytoplankton bloom strength (SFEI 2006), resulting in loading of organic material to sediments, and reduced redox conditions favoring methylation. At the San Joaquin River site (BG30), reduced Delta outflow and increased nutrient concentrations may favor sediment anoxia and bacterial methylation activity (Marvin-DiPasquale and Agee 2003, Lehman et al. 2004). Similarly, wetland restoration activities near Redwood Creek (BA41) may have increased nutrient loading and consequent sediment methylation. These hypotheses could be evaluated by assessing temporal trends in hydraulic residence and nutrient concentrations at the sites with increasing sediment methylmercury concentrations.

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Table 6.2. Time trends for pollutants in long-term (1993 – 2006) fixed monitoring stations. Log transformed data were used unless otherwise indicated. A. Organic pollutants. B. Mercury and methylmercury. C. Other metals.

Table 6.2a.

Contaminants >>		**Total DDTs**			**Total PCBs**			**Total PAHs**		
Station	**Matrix**	**slope**	**p-value**	**R2**	**slope**	**p-value**	**R2**	**slope**	**p-value**	**R2**
BA30	Total Water	-0.059	**0.00**	0.46	-0.058	**0.00**	0.61	-0.014	0.36	0.04
BC10	Total Water	-0.027	**0.01**	0.26	-0.027	**0.03**^	0.20	0.038	**0.00**	0.34
BC20	Total Water	-0.039	**0.05**	0.19	-0.068	**0.02**	0.27	0.021	0.38^	0.04
BG20	Total Water	-0.028	**0.01**	0.29	-0.058	**0.00**	0.43	0.041	**0.01**	0.31
BG30	Total Water	-0.032	**0.00**^	0.33	-0.048	**0.00**	0.42	0.040	**0.00**	0.39
BA30	Dissolved Water	-0.035	**0.01**	0.25	-0.040	**0.00**	0.31	0.033	**0.03**	0.19
BC10	Dissolved Water	-0.031	**0.02**	0.26	-0.034	**0.01**	0.26	0.032	0.06	0.16
BC20	Dissolved Water	-0.033	0.26	0.07	-0.010	**0.00**^	0.47	0.035	0.08	0.15
BG20	Dissolved Water	-0.013	0.18	0.08	-0.050	**0.00**	0.30	0.065	**0.00**	0.49
BG30	Dissolved Water	-0.020	0.22	0.07	-0.030	0.06	0.15	0.087	**0.00**	0.42
BA10	Sediment	-0.040	0.13	0.16	-0.018	0.42	0.05	-3.462	0.91[x]	0.00
BA41	Sediment	-0.033	0.12	0.13	-0.046	**0.01**	0.33	-0.002	0.79	0.00
BC11	Sediment	-0.040	**0.02**	0.28	-0.035	**0.03**	0.24	-0.008	0.46	0.03
BD31	Sediment	-0.027	0.17	0.10	-0.052	**0.02**	0.30	0.007	0.41	0.04
BF21	Sediment	-0.025	0.20	0.09	-0.039	**0.03**	0.27	0.006	0.74^	0.01
BG20	Sediment	-0.021	0.38	0.05	-0.087	**0.03**	0.39	-0.035	0.26	0.07
BG30	Sediment	-0.019	0.53	0.03	-0.097	**0.03**	0.31	0.083	**0.01**	0.32

^ failed normality test on residuals (unable to resolve using log, log+1 or sqrt tranform)
x raw data used

Table 6.2b.

Contaminants >>		Mercury			Methyl-mercury*		
Station	**Matrix**	**slope**	**p-value**	**R2**	**slope**	**p-value**	**R2**
BA30	Total Water	-0.038	**0.01**	0.21	0.005	0.91	0.00
BC10	Total Water	0.000	0.72[x]	0.01	0.003	0.95	0.00
BC20	Total Water	0.029	0.20	0.08	0.010	0.90	0.01
BG20	Total Water	-0.016	0.31	0.04	0.015	0.69	0.02
BG30	Total Water	-0.023	**0.03**	0.16	-0.022	0.49	0.08
BA30	Dissolved Water	-0.018	0.06	0.12	0.056	0.14	0.95
BC10	Dissolved Water	-0.013	0.41	0.03	0.011	0.82	0.08
BC20	Dissolved Water	-0.010	0.66	0.01	NA	NA	NA
BG20	Dissolved Water	-0.020	0.08	0.11	0.031	0.20	0.37
BG30	Dissolved Water	-0.019	0.30	0.04	0.000	0.99	0.00
BA10	Sediment	-0.023	0.12	0.15	0.021	0.74	0.02
BA41	Sediment	-0.006	0.15	0.11	0.106	**0.03**	0.65
BC11	Sediment	-0.002	0.72	0.01	0.112	**0.02**	0.71
BD31	Sediment	-0.008	0.27	0.06	0.048	0.11	0.44
BF21	Sediment	-0.015	**0.00**	0.50	0.036	0.39	0.15
BG20	Sediment	-0.043	**0.00**	0.45	0.092	0.10	0.45
BG30	Sediment	-0.005	0.79	0.00	0.134	**0.03**	0.66

* Only 1999 - 2006 for water and 2000 - 2006 for sediment
x raw data used
NA insufficient data for test

Table 6.2c.

Contaminants >>		Copper			Nickel			Selenium		
Station	**Matrix**	**slope**	**p-value**	**R2**	**slope**	**p-value**	**R2**	**slope**	**p-value**	**R2**
BA30	Total Water	-0.003	0.63^	0.01	-0.023	**0.03**	0.16	-0.031	**0.00**	0.29
BC10	Total Water	-0.008	0.15	0.07	-0.010	0.16	0.07	-0.047	**0.00**	0.55
BC20	Total Water	-0.008	0.46	0.02	-0.016	0.15	0.09	-0.032	0.12	0.13
BG20	Total Water	-0.008	0.23^	0.05	-0.008	0.46	0.02	-0.016	0.10	0.10
BG30	Total Water	-0.011	**0.04**	0.14	-0.012	0.16	0.07	-0.021	0.06	0.13
BA30	Dissolved Water	-0.003	0.46	0.02	-0.012	**0.00**	0.36	-0.011	0.16	0.07
BC10	Dissolved Water	-0.010	**0.02**	0.19	-0.014	**0.01**	0.25	-0.040	**0.00**	0.34
BC20	Dissolved Water	-0.007	0.42	0.03	-0.015	**0.05**	0.15	-0.034	0.07	0.15
BG20	Dissolved Water	-0.003	0.65^	0.01	-0.002	0.78^	0.00	-0.015	0.23	0.05
BG30	Dissolved Water	-0.008	0.06	0.12	-0.003	0.71	0.00	-0.024	**0.05**^	0.13
BA10	Sediment	-0.003	0.76	0.01	-0.017	0.23	0.10	-0.014	0.23	0.09
BA41	Sediment	-0.003	0.53	0.02	-0.005	0.45	0.03	-0.027	**0.01**	0.32
BC11	Sediment	0.011	**0.01**	0.31	0.01	0.07	0.17	-0.034	**0.00**^	0.53
BD31	Sediment	0.002	0.61	0.01	0.000	0.92	0.00	-0.032	**0.01**	0.28
BF21	Sediment	0.003	0.36	0.04	-0.001	0.78	0.00	-0.052	**0.00**	0.37
BG20	Sediment	-0.020	**0.01**	0.31	-0.012	**0.01**	0.35	-0.044	**0.01**	0.36
BG30	Sediment	0.007	0.44	0.03	0.000	0.97	0.00	-0.016	0.07[x]	0.17

^ failed normality test on residuals (unable to resolve using log, log+1 or sqrt tranform)
x raw data used

Table 6.3. Statistical comparison of CDF results for total contaminant concentrations between the historic and random designs. Results are p-values determined by the Roa-Scott test. Significant comparisons (95% confidence interval) are shown in bold. The column following each contaminant result column indicates whether concentrations increased when switching from the historic fixed design to the current probabilistic design. (–) concentrations are significantly lower with the current probabilistic design. (+) concentrations are significantly higher with the current probabilistic design

Total Water	PCBs		DDTs		PAHs		Nickel		Copper		Selenium		Hg		MethylHg	
BAY-WIDE	**0.001**	-	**0.000**	-	**0.000**	+	**0.000**	-	**0.000**	-	**0.000**	-	**0.000**	-	**0.002**	-
CB	0.383		**0.026**	-	**0.000**	+	**0.000**	-	0.559		**0.003**	-	0.054		**0.035**	+
LSB	**0.000**	-	**0.000**	-	**0.000**	+	**0.000**	-	**0.000**	-	**0.000**	-	**0.000**	-	0.306	
SPB	0.451		**0.000**	-	0.083		**0.001**	-	0.161		**0.000**	-	0.243		0.287	
SB	**0.000**	-	**0.000**	-	0.643		**0.000**	-	**0.000**	-	**0.000**	-	**0.000**	-	0.080	
SU	**0.002**	-	**0.000**	-	**0.022**	+	**0.000**	-	**0.001**	-	**0.001**	-	**0.046**	-	0.267	
Dissolved Water																
BAY-WIDE	0.557		**0.000**	-	**0.000**	+	**0.000**	-	**0.011**	-	**0.000**	-	0.216		**0.002**	+
CB	0.108		**0.000**	-	**0.000**	+	**0.002**	-	0.740		**0.004**	-	0.447		0.129	
LSB	**0.031**	-	**0.000**	-	**0.000**	+	**0.000**	-	**0.000**	+	**0.000**	-	0.582		0.077	
SPB	0.070		**0.000**	-	**0.000**	+	**0.044**	-	**0.000**	-	**0.001**	-	0.897		NA	
SB	**0.000**	-	**0.000**	-	**0.000**	+	**0.000**	-	0.240		**0.000**	-	**0.025**	-	0.112	
SU	**0.001**	-	**0.000**	-	**0.000**	+	0.140		**0.011**	-	**0.046**	-	0.220		0.168	
Sediment																
BAY-WIDE	**0.000**	-	**0.000**	-	0.082		0.061		0.906		**0.000**	-	**0.000**	-	**0.005**	+
CB	**0.000**	-	**0.000**	-	**0.000**	+	0.790		0.074		**0.000**	-	0.576		0.218	
LSB	**0.000**	-	**0.000**	-	**0.016**	-	**0.002**	-	0.653		**0.036**	-	**0.000**	-	0.243	
SPB	0.224		**0.000**	-	**0.000**	-	0.413		0.055		**0.040**	-	**0.001**	+	**0.000**	+
SB	**0.000**	-	**0.000**	-	**0.001**	-	**0.008**	-	**0.001**	-	**0.000**	-	**0.000**	-	**0.041**	+
SU	**0.001**	-	**0.000**	-	**0.044**	-	**0.022**	-	**0.000**	-	**0.003**	-	**0.000**	-	0.546	

Table 6.4. Comparison of mean and standard deviations for total contaminant concentrations between the historic and random designs. Statistics for random design have accounted for area weighting.

	PCBs		DDTs		PAHs		Nickel		Copper		Selenium		Mercury		Methylmercury	
T WATER	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	Fixed Design						Fixed Design									
BAY-WIDE	842	1,102	621	732	46,475	64,562	6.23	6.36	4.01	3.09	0.207	0.127	0.013	0.017	0.085	0.070
CB	419	473	209	129	19,761	31,412	2.41	1.27	1.86	0.77	0.162	0.098	0.005	0.004	0.059	0.060
LSB	2,567	2,092	1,222	907	128,579	100,776	8.40	4.00	5.19	1.85	0.402	0.201	0.020	0.017	0.125	0.087
SPB	872	1,089	882	911	51,094	68,135	11.29	9.81	6.35	4.36	0.202	0.082	0.024	0.025	0.092	0.071
SB	999	750	415	343	61,854	61,641	5.56	3.05	3.83	1.42	0.259	0.106	0.013	0.013	0.091	0.070
SU	507	496	971	648	29,456	21,780	8.42	4.83	5.78	2.43	0.173	0.063	0.018	0.013	0.095	0.052
	Random Design						Random Design									
BAY-WIDE	427	304	204	176	49,126	36,580	3.22	3.27	2.98	2.04	0.128	0.091	0.009	0.011	0.067	0.029
CB	436	313	146	69	44,795	32,379	1.95	1.12	2.02	0.85	0.130	0.121	0.006	0.004	0.061	0.023
LSB	707	373	236	126	68,935	47,629	4.43	2.86	4.32	1.30	0.250	0.095	0.010	0.011	0.106	0.045
SPB	461	335	346	208	61,112	45,664	5.88	5.52	4.50	3.28	0.119	0.031	0.018	0.019	0.063	0.018
SB	427	226	98	38	46,788	30,737	2.55	0.70	2.92	0.56	0.133	0.039	0.006	0.003	0.080	0.043
SU	244	236	375	289	45,970	35,427	4.68	1.40	4.42	0.92	0.124	0.038	0.012	0.005	0.075	0.029
D WATER	Fixed Design						Fixed Design									
BAY-WIDE	164	218	170	123	5,626	5,510	1.99	2.11	1.81	0.84	0.182	0.119	0.0016	0.0027	0.030	0.023
CB	163	326	111	72	5,434	4,435	1.30	0.47	1.25	0.51	0.150	0.101	0.0009	0.0009	0.036	0.033
LSB	263	90	245	182	9,240	10,064	3.25	0.92	2.93	0.87	0.371	0.171	0.0021	0.0017	0.024	0.015
SPB	131	116	197	120	5,106	5,688	2.82	4.12	2.00	0.81	0.162	0.064	0.0022	0.0052	0.019	0.010
SB	219	172	146	96	5,619	3,895	2.46	0.45	2.40	0.56	0.220	0.087	0.0017	0.0014	0.032	0.005
SU	104	60	237	145	5,238	4,464	1.51	0.67	1.86	0.46	0.142	0.065	0.0017	0.0014	0.034	0.017
	Random Design						Random Design									
BAY-WIDE	129	71	71	34	14,311	4,782	1.37	0.46	1.68	0.61	0.108	0.049	0.0012	0.0008	0.038	0.013
CB	138	50	57	15	14,216	4,179	1.08	0.29	1.28	0.46	0.095	0.042	0.0008	0.0005	0.035	0.012
LSB	230	162	84	34	15,819	7,320	2.67	0.42	3.42	0.38	0.234	0.065	0.0019	0.0012	0.048	0.017

SPB	109	83	99	30	14,967	4,224	1.63	0.34	1.96	0.45	0.114	0.036	0.0015	0.0008	0.038	0.012
SB	154	86	43	10	12,538	5,936	1.78	0.39	2.24	0.41	0.122	0.037	0.0016	0.0010	0.045	0.016
SU	62	19	130	30	16,301	5,550	1.31	0.37	1.83	0.28	0.130	0.086	0.0015	0.0011	0.042	0.004
SEDIMENT	Fixed Design						Fixed Design									
BAY-WIDE	8.5	8.2	4.4	4.0	1,777	1,400	85	23	39	14	0.320	0.256	0.251	0.119	0.374	0.372
CB	10.0	7.5	4.2	4.4	2,116	1,185	76	16	33	10	0.283	0.131	0.219	0.091	0.472	0.401
LSB	14.5	10.0	6.5	5.5	2,016	1,291	103	40	43	12	0.387	0.208	0.356	0.147	0.839	0.519
SPB	3.9	3.7	3.8	3.1	1,545	1,832	89	18	43	15	0.318	0.261	0.258	0.136	0.139	0.084
SB	14.1	10.5	4.1	2.6	2,494	836	85	19	41	6	0.347	0.137	0.315	0.063	0.435	0.162
SU	3.0	2.9	4.4	3.2	568	497	95	22	47	20	0.361	0.476	0.220	0.117	0.212	0.103
	Random Design						Random Design									
BAY-WIDE	4.7	3.6	1.7	1.9	2,079	2,113	77	20	40	13	0.234	0.202	0.235	0.090	0.582	0.477
CB	5.6	3.0	1.7	1.8	3,422	2,591	74	15	37	10	0.238	0.251	0.241	0.075	0.709	0.532
LSB	5.4	2.3	1.8	1.4	1,398	489	90	14	42	7	0.317	0.230	0.262	0.050	0.747	0.307
SPB	3.6	4.8	1.8	2.4	846	372	89	15	50	11	0.235	0.195	0.266	0.110	0.306	0.217
SB	4.8	2.2	1.6	1.7	1,910	1,174	67	24	33	11	0.238	0.114	0.220	0.047	0.818	0.436
SU	1.4	1.5	1.5	1.3	341	238	83	20	38	18	0.193	0.128	0.145	0.105	0.185	0.169

Table 6.5. Descriptive statistics for Sum of Chlordanes (SFEI).

Region	Strata						
						Shallow	Deep
Estuarywide	1 - 3 ft	3 – 6 ft	6 - 12 ft	12+ ft		1 - 6 ft	6+ ft
n	25	29	39	59		54	98
Mean	0.821	0.1213	0.340	0.1332		0.445	0.2155
Stdev	3.533	0.1281	1.466	0.1137		2.405	0.9276
Median	0.132	0.1091	0.082	0.1106		0.113	0.1004
Suisun Bay							
n	3	4	6	14		7	20
Mean	0.0929	0.1617	0.0651	0.1236		0.1322	0.1060
Stdev	0.0807	0.1208	0.0432	0.1465		0.1040	0.1262
Median	0.1322	0.1776	0.0754	0.0590		0.1464	0.0653
San Pablo Bay							
n	5	9	13	5		14	18
Mean	0.0674	0.1133	0.758	0.0756		0.0969	0.569
Stdev	0.0639	0.0514	2.540	0.0589		0.0584	2.157
Median	0.0948	0.1167	0.060	0.0617		0.1054	0.061
Central Bay							
n	na	2	12	15		2	27
Mean	na	0.0284	0.0781	0.0900		0.0284	0.0847
Stdev	na	0.0402	0.0637	0.0692		0.0402	0.0658
Median	na	0.0284	0.0900	0.0841		0.0284	0.0893
South Bay							
n	9	12	6	5		21	11
Mean	2.07	0.774	0.1200	0.1107		0.931	0.1158
Stdev	5.89	0.0737	0.0507	0.0655		3.859	0.0550
Median	0.15	0.0676	0.1278	0.1464		0.0704	0.1418
Lower South Bay							
n	8	2	2	20		10	22
Mean	0.1626	0.433	0.680	0.1923		0.2167	0.2367
Stdev	0.1522	0.303	0.374	0.1157		0.2030	0.1985
Median	0.1758	0.433	0.680	0.2003		0.2095	0.2099

Table 6.6. Descriptive statistics for Sum of DDTs (SFEI).

Region	Strata						
						Shallow	Deep
Estuarywide	1 - 3 ft	3 - 6 ft	6 - 12 ft	12+ ft		1 - 6 ft	6+ ft
N	25	29	39	66		54	105
Mean	2.143	1.421	2.205	1.214		1.755	1.582
Stdev	1.845	1.008	2.757	0.949		1.487	1.890
Median	1.883	1.175	1.342	1.044		1.515	1.152
Suisun Bay							
N	3	4	6	18		7	24
Mean	2.625	3.108	1.197	0.837		2.901	0.927
Stdev	0.381	1.448	0.644	1.097		1.079	1.003
Median	2.465	2.734	1.258	0.330		2.590	0.786
San Pablo Bay							
N	5	9	13	5		14	18
Mean	1.079	1.528	2.27	1.478		1.368	2.049
Stdev	0.655	0.599	3.78	0.827		0.634	3.222
Median	0.857	1.563	1.13	1.642		1.414	1.221
Central Bay							
N	na	2	12	18		2	30
Mean	na	0.3529	2.504	1.254		0.3529	1.754
Stdev	na	0.0780	2.545	0.838		0.0780	1.804
Median	na	0.3529	1.725	1.128		0.3529	1.240
South Bay							
N	9	12	6	5		21	11
Mean	2.705	0.924	1.335	1.289		1.688	1.314
Stdev	2.876	0.472	0.607	0.528		2.061	0.544
Median	2.175	1.018	1.136	1.152		1.092	1.152
Lower South Bay							
N	8	2	2	20		10	22
Mean	1.994	1.609	5.63	1.434		1.917	1.816
Stdev	0.769	0.200	2.65	0.983		0.701	1.653
Median	1.993	1.609	5.63	1.12		1.718	1.134

Table 6.7. Descriptive statistics for Sum of PAHs (SFEI).

Region	Strata						
						Shallow	Deep
Estuarywide	1 - 3 ft	3 - 6 ft	6 - 12 ft	12+ ft		1 - 6 ft	6+ ft
n	32	33	49	86		65	135
Mean	1310	1121	1860	1723		1214	1773
Stdev	575	954	1901	1988		790	1951
Median	1297	871	1323	1247		1076	1264
Suisun Bay							
n	4	6	8	22		10	30
Mean	497	574	422	219		543	273
Stdev	184	179	270	182		175	223
Median	501	587	364	155		565	190
San Pablo Bay							
n	6	10	18	6		16	24
Mean	986	800	908	595		869	830
Stdev	162	266	440	424		245	449
Median	1025	776	776	474		933	733
Central Bay							
n	na	2	13	25		2	38
Mean	na	743	3477	3608		743	3563
Stdev	na	287	2699	2628		287	2617
Median	na	743	3094	3415		743	3190
South Bay							
n	11	13	7	9		24	16
Mean	1602	1576	3016	1908		1588	2393
Stdev	649	1333	994	1256		1053	1248
Median	1499	1089	3065	1726		1329	1863
Lower South Bay							
N	11	2	3	34		13	27
Mean	1491	1782	1703	1350		1536	1390
Stdev	349	476	198	508		364	494
Median	1389	1782	1663	1393		1423	1422

Table 6.8. Descriptive statistics for Sum of PCBs (SFEI).

Region	Strata						
						Shallow	Deep
Estuarywide	1 - 3 ft	3 - 6 ft	6 - 12 ft	12+ ft		1 - 6 ft	6+ ft
N	16	21	30	53		37	83
Mean	4.859	3.686	5.136	3.916		4.193	4.357
Stdev	2.247	2.213	4.698	3.136		2.274	3.793
Median	5.382	3.516	4.600	3.637		3.804	3.934
Suisun Bay							
N	2	3	5	14		5	19
Mean	2.086	3.320	1.899	0.793		2.826	1.081
Stdev	0.227	1.355	2.40	0.803		1.178	1.411
Median	2.086	2.707	1.16	0.680		2.379	0.729
San Pablo Bay							
n	3	8	9	4		11	13
Mean	3.23	2.450	5.31	2.371		2.662	4.41
Stdev	2.42	1.218	7.72	1.587		1.531	6.51
Median	2.17	2.135	1.96	2.366		2.165	1.96
Central Bay							
n	na	1	8	15		1	23
Mean	na	1.5424	5.329	6.088		1.5424	5.824
Stdev	na	*	1.418	3.578		*	2.987
Median	na	1.5424	5.881	5.733		1.5424	5.820
South Bay							
n	6	8	6	4		14	10
Mean	5.781	4.952	6.03	4.754		5.307	5.521
Stdev	1.871	2.531	2.75	1.181		2.231	2.262
Median	5.950	4.286	4.60	4.656		5.507	4.600
Lower South Bay							
n	5	1	2	16		6	18
Mean	5.840	6.6910	8.990	4.790		5.982	5.256
Stdev	1.812	*	0.491	2.309		1.658	2.562
Median	5.568	6.6910	8.990	3.935		6.129	4.246

Table 6.9. Descriptive statistics for PBDE 047. Highlighted statistics were estimated using the Kaplan-Meier method.

Region	Strata						
						Shallow	Deep
Estuarywide	1 - 3 ft	3 - 6 ft	6 - 12 ft	12+ ft		1 - 6 ft	6+ ft
N	25	29	39	66		54	105
Mean	1.619	5.2757	0.964	0.890		3.582	0.918
Stdev	2.8656	19.788	2.1092	2.0005		14.6018	2.0302
Median	0.489	0.366	0.444	0.388		0.428	0.417
Suisun Bay							
N	3	4	6	18		7	24
Mean	2.947	0.456	0.840	0.967		1.532	0.937
Stdev	4.550	0.2676	0.8617	2.4165		2.9888	2.1110
Median	0.413	0.673	0.661	0.212		0.413	0.220
San Pablo Bay							
N	5	9	13	5		14	18
Mean	1.047	0.511	0.474	0.621		0.697	0.513
Stdev	1.0770	0.1103	0.4551	0.7674		0.6655	0.5346
Median	0.554	0.527	0.403	0.317		0.554	0.399
Central Bay							
n	na	2	12	18		2	30
Mean	na	0.184	1.825	0.458		0.184	1.004
Stdev	na		3.6920	0.2017			2.3761
Median	na	0.184	0.431	0.457		0.184	0.431
South Bay							
n	9	12	6	5		21	11
Mean	0.427	12.113	0.461	0.408		7.0957	0.439
Stdev	0.2349	30.163	0.1141	0.1719		23.1915	0.1362
Median	0.484	0.287	0.503	0.332		0.33	0.395
Lower South Bay							
N	8	2	2	20		10	22
Mean	2.836	0.457	0.862	1.41		2.36	1.361
Stdev	4.1340		0.2652	2.7975		3.7987	2.6642
Median	0.694	0.457	1.05	0.73		0.666	0.73

Table 6.10. Descriptive statistics for PBDE 209. Highlighted statistics were estimated using the Kaplan-Meier method.

Region	Strata						
						Shallow	Deep
Estuarywide	1 - 3 ft	3 - 6 ft	6 - 12 ft	12+ ft		1 - 6 ft	6+ ft
N	22	22	28	46		44	74
Mean	2.1865	1.0198	1.9387	2.4018		1.6045	2.23
Stdev	2.5438	0.7306	3.7698	3.5349		1.9187	3.5949
Median	1.04	0.87	1.07	0.673		0.922	0.694
Suisun Bay							
n	2	4	2	14		6	16
Mean	0.3415	0.7223	0.522	0.966		0.6271	0.9056
Stdev		0.1622		2.2453		0.2722	2.0964
Median	0.3415	0.667	0.522	0.268		0.667	0.268
San Pablo Bay							
n	5	6	10	3		11	13
Mean	2.4868	1.1057	0.5949	1.5153		1.7103	0.8103
Stdev	3.6896	0.7332	0.6747	2.5647		2.3693	1.1763
Median	1.04	1.51	0.424	0.233		1.04	0.424
Central Bay							
n	na	2	9	13		2	22
Mean	na	0.87	1.0287	1.328		0.87	1.2555
Stdev	na		1.5159	1.1440			1.2416
Median	na	0.87	0.185	0.694		0.87	0.673
South Bay							
n	8	8	6	2		16	8
Mean	1.8328	1.1425	4.7377	1.308		1.4889	3.8708
Stdev	1.8589	1.0905	7.2407			1.4777	6.3932
Median	1.14	0.663	1.44	1.308		1.14	1.42
Lower South Bay							
n	7	2	1	14		9	15
Mean	3.7614	1.23	6.67	5.6175		2.6889	5.6877
Stdev	2.4280			4.5258		2.6254	4.3591
Median	2.76	1.23	6.67	3.16		1.23	3.16

Table 6.11. Descriptive statistics for mercury (Hg). Highlighted statistics were estimated using the Kaplan-Meier method.

Region	Strata						
						Shallow	Deep
Estuarywide	1 - 3 ft	3 - 6 ft	6 - 12 ft	12+ ft		1 - 6 ft	6+ ft
N	32	33	49	86		65	135
Mean	0.2393	0.2368	0.2460	0.2022		0.2380	0.2181
Stdev	0.0669	0.0622	0.1160	0.0984		0.0640	0.1068
Median	0.2508	0.2392	0.2550	0.2236		0.2426	0.2387
Suisun Bay							
N	4	6	8	22		10	30
Mean	0.1747	0.2364	0.1237	0.1055		0.2117	0.1094
Stdev	0.0907	0.0649	0.0801	0.1131		0.0781	0.1049
Median	0.2490	0.2392	0.1186	0.0624		0.2392	0.0696
San Pablo Bay							
N	6	10	18	6		16	24
Mean	0.2667	0.2668	0.2963	0.1727		0.2668	0.2654
Stdev	0.0411	0.0503	0.1386	0.1100		0.0456	0.1408
Median	0.2630	0.2733	0.2824	0.1673		0.2698	0.2778
Central Bay							
n	na	2	13	25		2	38
Mean	na	0.217	0.2595	0.2326		0.217	0.2418
Stdev	na	0.168	0.0807	0.0681		0.168	0.0727
Median	na	0.217	0.2450	0.2460		0.217	0.2455
South Bay							
n	11	13	7	9		24	16
Mean	0.2085	0.2110	0.2342	0.2346		0.20984	0.2344
Stdev	0.0518	0.0482	0.0372	0.0508		0.04875	0.0439
Median	0.2140	0.2174	0.2320	0.2250		0.21571	0.2270
Lower South Bay							
N	11	2	3	24		13	27
Mean	0.2786	0.2755	0.2480	0.2544		0.2781	0.25371
Stdev	0.0548	0.0466	0.0672	0.0490		0.0518	0.04978
Median	0.2650	0.2755	0.2590	0.2681		0.2650	0.26800

Table 6.12. Descriptive statistics for monomethyl mercury (mmHg). Highlighted statistics were estimated using the Kaplan-Meier method.

Region	Strata						
						Shallow	Deep
Estuarywide	1 - 3 ft	3 - 6 ft	6 - 12 ft	12+ ft		1 - 6 ft	6+ ft
n	32	33	49	86		65	135
Mean	0.5811	0.6145	0.4564	0.5644		0.5981	0.5252
Stdev	0.3818	0.4973	0.4470	0.4444		0.4411	0.4467
Median	0.5023	0.4135	0.2866	0.4829		0.4885	0.4075
Suisun Bay							
n	4	6	8	22		10	30
Mean	0.2307	0.2762	0.2105	0.1194		0.2580	0.1438
Stdev	0.1735	0.1280	0.1652	0.1737		0.1403	0.1733
Median	0.2335	0.2824	0.2666	0.0730		0.2454	0.0807
San Pablo Bay							
n	6	10	18	6		16	24
Mean	0.2750	0.4629	0.2228	0.2805		0.3924	0.2369
Stdev	0.0875	0.3599	0.0918	0.1855		0.2985	0.1194
Median	0.2767	0.3291	0.2270	0.3729		0.3160	0.2326
Central Bay							
n	na	2	13	25		2	38
Mean	na	1.35	0.520	0.7554		1.35	0.6750
Stdev	na	1.46	0.469	0.4657		1.46	0.4741
Median	na	1.35	0.388	0.5928		1.35	0.4753
South Bay							
n	11	13	7	9		24	16
Mean	0.881	0.732	1.006	0.720		0.8004	0.845
Stdev	0.468	0.426	0.568	0.319		0.4424	0.453
Median	0.964	0.633	0.866	0.653		0.6697	0.731
Lower South Bay							
n	11	2	3	24		13	27
Mean	0.5754	0.890	0.953	0.7882		0.6238	0.8065
Stdev	0.1240	0.194	0.393	0.3453		0.1729	0.3466
Median	0.5523	0.890	1.110	0.7928		0.5900	0.8042

Table 6.13. Descriptive statistics for selenium (Se).

Region	Strata						
						Shallow	Deep
Estuarywide	1 - 3 ft	3 - 6 ft	6 - 12 ft	12+ ft		1 - 6 ft	6+ ft
N	32	33	49	86		65	135
Mean	0.2435	0.2103	0.2687	0.2433		0.2267	0.2525
Stdev	0.1111	0.1133	0.2749	0.1930		0.1126	0.2255
Median	0.2676	0.2286	0.2349	0.2369		0.2479	0.2368
Suisun Bay							
N	4	6	8	22		10	30
Mean	0.2568	0.2335	0.2214	0.1603		0.2428	0.1766
Stdev	0.1661	0.0951	0.1212	0.1331		0.1199	0.1309
Median	0.3072	0.2606	0.2155	0.1176		0.2606	0.1544
San Pablo Bay							
N	6	10	18	6		16	24
Mean	0.1946	0.1848	0.2941	0.1826		0.1885	0.2662
Stdev	0.1167	0.1359	0.2576	0.0912		0.1251	0.2308
Median	0.1878	0.1325	0.2632	0.1898		0.1405	0.2523
Central Bay							
N	na	2	13	25		2	38
Mean	na	0.174	0.297	0.2121		0.174	0.2413
Stdev	na	0.154	0.432	0.0886		0.109	0.0421
Median	na	0.174	0.221	0.2202		0.174	0.2206
South Bay							
N	11	13	7	9		24	16
Mean	0.2128	0.2134	0.1915	0.3392		0.2131	0.2746
Stdev	0.0995	0.1115	0.0732	0.1197		0.1039	0.1246
Median	0.2271	0.2250	0.1500	0.3376		0.2260	0.3180
Lower South Bay							
N	11	2	3	24		13	27
Mean	0.2962	0.2845	0.2976	0.3311		0.2944	0.3274
Stdev	0.0877	0.0561	0.1408	0.2936		0.0818	0.2791
Median	0.3134	0.2845	0.3077	0.2871		0.3134	0.2980

Table 6.14. Summary of results and interpretations corresponding to initial hypotheses.

Which have higher concentrations: fixed or probabilistic stations?	Trend in fixed monitoring stations?	Which stations are higher: shallow or deep?	Interpretation	Contaminants
Fixed stations higher	Decreasing with time		Concentrations in Bay (or segment) have been decreasing over time	Total and dissolved PCBs, DDTs, Ni, and Se in water. PCBs, Se, and Hg* in sediments
Fixed stations higher	Decreasing with time	Shallow higher	Concentrations have been decreasing over time but probabilistic design samples more contaminated areas (e.g., shallow stations)	PCBs in sediments (Suisun Bay only)
Probabilistic stations higher or no difference	Increasing with time	No difference	Concentrations in Bay (or segment) have been increasing over time	Total and dissolved PAH in water. MeHg in sediments
Probabilistic stations higher	No trend	Shallow higher or no difference	Probabilistic design samples more contaminated areas (e.g., shallow stations)	PAH in sediments in Central Bay
No significant difference	No trend	No difference	No long-term trend or evidence of differences between sampling designs	PAH in sediments Bay-wide
Fixed stations higher	No trend	Deep higher or no difference	Historic (fixed) stations sample more contaminated areas	Total and dissolved Cu in water Bay-wide
Probabilistic stations higher	Decreasing with time	Shallow higher	Concentrations have been decreasing over time but probabilistic design samples more contaminated areas (e.g., shallow stations)	None
Probabilistic stations higher	Increasing with time	Shallow higher	Concentrations have been increasing over time and probabilistic design samples more contaminated areas (e.g., shallow stations)	None
Weak or inconsistent differences	No trend		No apparent long-term trend or difference between designs	Total and dissolved MeHg in water. Cu in sediments.

*Trends are weak and inconsistent

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