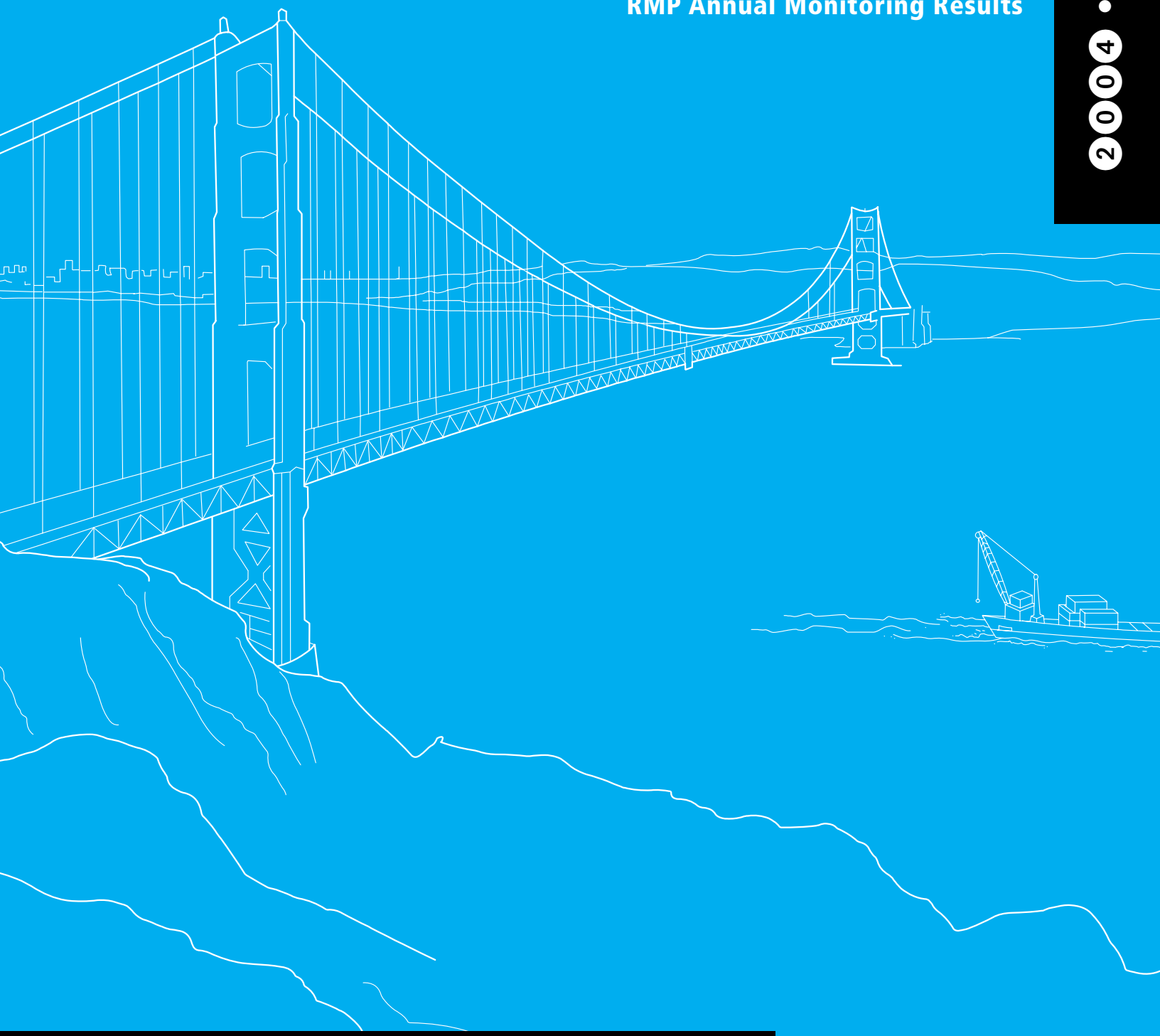
2004 • 2005

RMP Annual Monitoring Results



San Francisco Estuary Institute and the

Regional Monitoring Program for Water Quality in the San Francisco Estuary

2004 • 2005

RMP Annual Monitoring Results

December 2006

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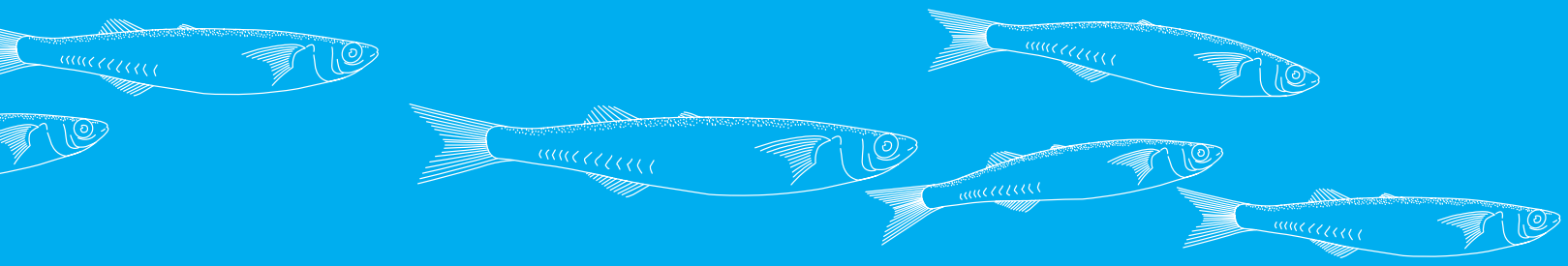
Contribution No. 519

Acknowledgements

The authors would like to thank Dr. Don L. Stevens, Jr. for his assistance with the R-programming language and statistical analysis advice; Mike Conner, Meg Sedlak, Sarah Lowe, John Ross, and Daniel Oros for providing valuable review comments on the draft report; Linda Wanczyk for the cover and chapter title page graphics design; Predrag Stevanovic for mapping assistance; RMP Contractors and Principal Investigators listed in Table 1.4 of the *Introduction* for providing quality analysis in a timely fashion; all members of the Technical Review Committee and the Steering Committee for providing oversight and guidance to the RMP; and the discharger community listed in Table 1.2 of the *Introduction* for providing funding.

This report should be cited as:
SFEI. 2006. 2004-2005 Annual Monitoring Results. The Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP).
San Francisco Estuary Institute, Oakland, Ca.

Chapter 1



Introduction

1.0 INTRODUCTION

Cristina Grosso and Sarah Lowe

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 about $3 million, which is primarily funded by the discharger community through wastewater discharge permits issued by the Water Board (refer to Table 1.2 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 monitoring topics, and providing guidance on existing projects and the overall program. The RMP provides an important forum for collaborative monitoring 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 the 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.

The RMP addresses these 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:http://www.sfei.org/rmp/rmp_prog_info.html - top

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) *Episodic Toxicity Monitoring* investigates potential toxic effects in the Estuary's tributaries (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.

The Water Board uses Status and Trends data for regulatory purposes including: 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 evaluating 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) and additional effects measures (Objective 4) and help to develop Pilot and Special Studies. These workgroups meet once or twice 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. Chapter 1.4 below describes the Pilot and Special Studies conducted by the RMP in 2004-2005. 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, workshops, literature reviews, technical reports, peer-reviewed journal articles, 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 Episodic Toxicity Monitoring effort. 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

In 2003, the Status and Trends Program switched from a fixed site sampling design for long-term water and sediment monitoring to 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).

Sampling site information is presented in Table 1.3, and site location maps are included in Chapters 2.0-4.0. Subcontractors perform the logistical planning, sampling, and laboratory analyses for trace contaminants and ancillary measures. The 2004-2005 subcontractors are listed in Table 1.4. 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 using the *Status and Trends Monitoring Data Access Tool* at http://www.sfei.org/rmp/data.htm.

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, and 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 were allocated into five hydrographic regions of the Estuary. Those five regions are: Suisun Bay, San Pablo Bay, Central Bay, South Bay, and Lower South Bay. The original sample design allocated 75 sampling sites to each region to be sampled over time. The number of sampling sites visited annually in 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. See section 1.3.2 - 1.3.4 for the number of sites sampled during 2004 and 2005. The sampling frame for water and sediment monitoring is the 3-foot and 1-foot contour of the Estuary at mean lower low water, respectively (based on NOAA's NAD-83 bathymetry coverage).

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 sampling design incorporates repeated measurements at two random sites per region on an annual, five-year, and ten-year cycle to allow additional trends analyses. 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. Trends analyses are not attempted in this report for the GRTS design samples as only two years of data are presented.

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 Tissue

The bivalve bioaccumulation sample design remains a convenience 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 (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 conducted during 2000-2002, only one transplanted bivalve species (*Mytilus californianus*) is deployed in four regions facilitating comparison among segments. As of 2005, all bivalves are 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 potential bioaccumulative contaminants using transplanted and resident bivalves. Transplanted *Mytilus californianus* are deployed in cages for three months (June to September) and maintained halfway through at 45 days. Resident clams (*Corbicula fluminea*) are collected from the River sites.

Since data from 1993-2001 indicate that trace metals do not appreciably accumulate in transplanted bivalve tissue at mid-channel locations, trace metals analyses were scaled back to once every five years as a periodic screening measure, and tributyltin analysis was discontinued. Since mercury bioaccumulation is included in the Sport Fish Contamination Study, mercury analysis in bivalves was discontinued.

1.3 2004-2005 Annual Monitoring Results

1.3.1 Reporting of Results

Table 1.5 lists all parameters measured in water, sediment, and bivalve tissue samples in 2004-2005. While only a subset of the parameters measured is presented in this report, all results, including data from previous years, can be downloaded from the web using the RMP website using the *Status and Trends Monitoring Data Access Tool* @ http://www.sfei.org/rmp/data.htm. 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 one half of the MDL in all calculations and graphics. Some organic compounds are summed based on the target list of RMP congeners (Table 1.5) 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 used in this report. This is consistent with how the web-based data access tool reports the data.

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 are 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 was used to produce the maps and graphics for the schematic box, CDF, 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 free of charge 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 is available at the USEPA's Aquatic Resources Monitoring - Monitoring Design and Analysis web site (http://www.epa.gov/nheerl/arm/designpages/design&analysis.htm).

Bubble Maps

A color gradient was used in the maps of this report (Figure 1.1) to depict the range of reported concentrations, from the minimum detected to the maximum values. 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.

The color scheme of yellow/tan indicates results that were below the guideline and reddish browns indicate results above the guideline. The yellow/tan color scheme was also used when no guideline was available for comparison (e.g., percent fines, methyl mercury, percent lipids, and total organic carbon).

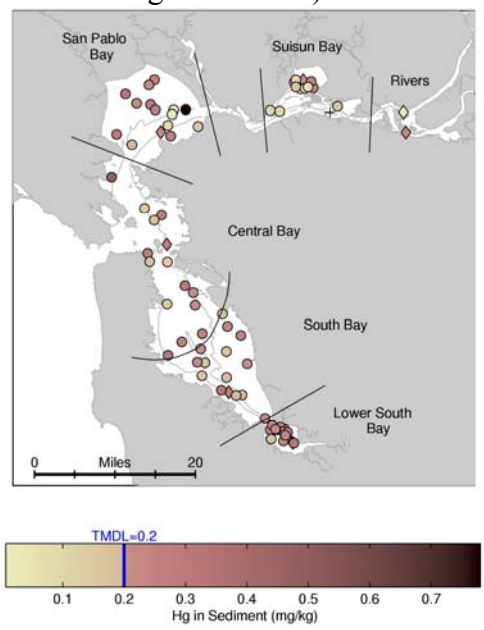


Figure 1.1. Map of sediment mercury concentrations in the Estuary.

Sample sizes varied by test material and region. The water maps represent data from fifty-two random (26 sites per year) and five historic sites at Dumbarton Bridge (BA30), Yerba Buena Island (BC10), Golden Gate (BC20), Sacramento River (BG20), and San Joaquin River (BG30). Each year, 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 eighty random (40 sites per year) and seven historic sites 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 each year, 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.

Time Series Plots

Time series plots (1993-2005) for the historic water and sediment sites are presented in this report. Detailed trend analyses will be discussed in peer-reviewed journal articles as part of the Ten-Year Synthesis of Contaminant Status and Trends. A special issue of the scientific journal *Environmental Research* is scheduled for publication later this year.

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.

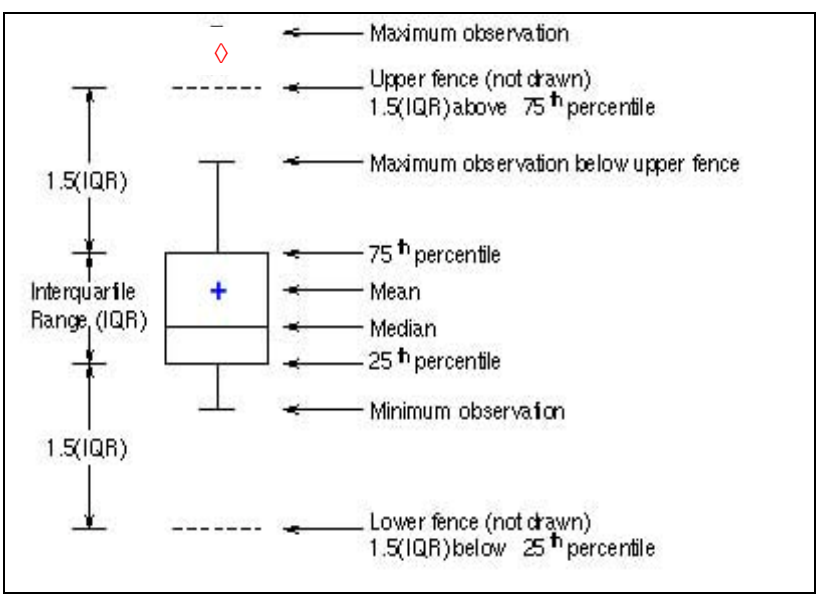


Figure 1.2. Illustration of a schematic box plot.

Cumulative Distribution Function (CDF) Plots

Cumulative distribution function plots (Figure 1.3) use the random sample results to show an estimate 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 plot for the total area sampled in the five Estuary regions is adjusted for regional area weights using the R-program function, while the CDFs for the individual regions are not.

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 1.1 below. No random samples were allocated to the Rivers region; therefore, this region was not included in the total sample frame.

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 60% of the total sampled area in the Estuary has sediment mercury concentrations above the TMDL target of 0.2 mg/kg. Additionally, the small graphs indicate that approximately half of San Pablo Bay, Central Bay, and Lower South Bay regions are above the TMDL target.

Due to the small sample size (eighty sediment and fifty-two 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.

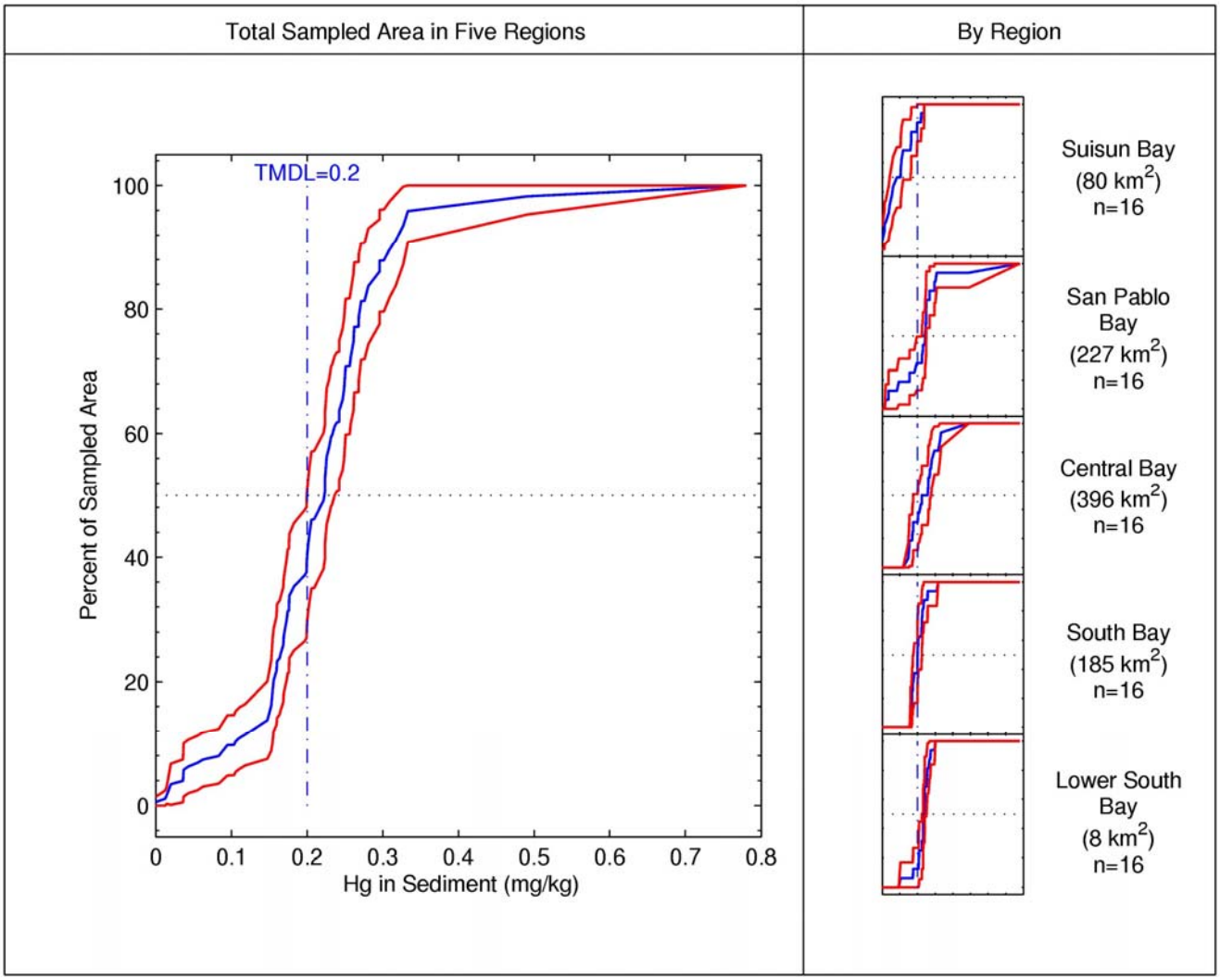


Figure 1.3. CDF plot for sediment mercury concentrations.

In the initial sampling design, area weights were originally calculated for100 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 for each of the five Bay segments by dividing the total sample frame area for a given segment by the number of sites targeted for that segment during a given sampling event. Refer to Table 1.1 for 2004-2005 water and sediment area weights. 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.

Table 1.1 Areas of Sample Frame and Weights for Water and Sediment

Region Name	Total Sample Frame Area for Water(sq. km)	Total Sample Frame Area for Sediment (sq. km)	Water Weights		Sediment Weights	
			2004	2005	2004	2005
Rivers	0	0	--	--	--	--
Suisun Bay	72	80	18.12	18.12	10.04	7.31
San Pablo Bay	181	227	45.2	45.2	25.2	28.35
Central Bay	382	396	95.5	95.5	33.04	39.64
South Bay	144	185	15.96	15.96	23.12	23.15
Lower South Bay	5	8	1.1	1.1	0.96	0.85
Total Area	784	896	--	--	--	--

1.3.2 Water Chemistry and Toxicity

Water sample collection occurred during the dry season in July 2004 and August 2005 at 31 sites throughout the Estuary. Twenty-six random sites were sampled (four to nine sites per region) and five historic sites were sampled per year.

The analyte list for conventional water quality, trace metals, and trace organics was the same as in 2003, except the new classes of compounds (phthalates and p-nonylphenols) were discontinued. However, not all the results are available for reporting at this time.

No water samples were tested for ambient water toxicity in 2004 and 2005. 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 2004 and 2005, 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 2003, except the new classes of compounds (phthalates and p-nonylphenols) were discontinued.

Twenty-four and twenty-five sediment samples were tested for toxicity in 2004 and 2005, respectively. Toxicity tests included mean percent survival of the amphipods *Eohaustorius estuaries* after exposure to solid-phase sediments for 10 days and mean percent normal alive of live Bay mussel *Mytilus galloprovincialis* larvae after exposure to sediment elutriates for 48 hours. Phase I toxicity identification evaluations (TIEs) were conducted at three sites in 2004 (BG20, BG30, and SU015S) to investigate possible causes of toxicity. No TIEs were performed in 2005. Sediment monitoring results are discussed in more detail in Chapter 3.0.

1.3.4 Bivalve Bioaccumulation

In 2004 and 2005, bivalve sample collection occurred in September at eleven sites throughout the Estuary. The analyte list for tissue quality and trace organics was the same as in 2003, except the new classes of compounds (phthalates, p-nonylphenol, triphenylphosphate, and nitro and aromatic musks) were discontinued. Trace metals were not analyzed in bivalve tissue in 2004-5. 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 2003. 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, and 2000, are available on the RMP Fish Tissue Data Page. The technical report, *Contaminant Concentrations in Fish from San Francisco Bay 2003*, is available at RMP Documents and Reports.

1.3.6 Episodic Toxicity Monitoring

The RMP is re-scoping the Episodic Toxicity Monitoring component to better address the changing patterns of pesticide usage in urban and agricultural areas. A summary of findings from 1996-2001 was reported in the *2003 Pulse of the Estuary* article "Ten Years of Testing for the Effects of Estuary Contamination". In addition, technical reports from this program are available on the web at RMP Documents and Reports.

During 2004-2005, the Episodic Toxicity Monitoring component turned its efforts to screen bedded sediments entering the Estuary for potential toxic effects and to characterize those sediments for the full suite of RMP contaminants (Table 1.5) and pyrethroids. The Toxicity workgroup met in 2005 to discuss the various aquatic and sediment toxicity components of the RMP. The group recommended that the RMP focus on methods to investigate the causes of the persistent sediment toxicity seen in the Estuary through wet season sampling within the tidal prism of tributaries known to be toxic.

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 2004-2005, 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. In 2004, time series measurements of suspended sediment concentrations were collected at ten sites in each major region of the Bay using optical backscatter sensors deployed at mid-depth and near the bottom. In 2005, as a result of funding cuts, four sites were eliminated (Carquinez Channel Marker 1, San Mateo Bridge, Channel Marker 17, and Mare Island Causeway). The following six stations were sampled: Mallard Island, Benecia Bridge, Point San Pablo, Dumbarton Bridge, Alcatraz Island and San Pablo Bay (Hamilton Aquatic Transfer Station). 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).

Two Pilot Studies, Mercury Deposition Network and Exposure and Effects, were conducted by the RMP in both 2004 and 2005. A third study, the Winter Pilot Study, was conducted in 2005.

Mercury Deposition Network (1999-2005)
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, Caspian tern, least tern and Forster's tern eggs (chemical trend indicators); hatchability of Forster's terns, least terns, and Caspian terns(effects indicators); blood chemistry and biomarkers in harbor seals (exposure and effects indicators); biomarker studies in fish (effects indicators), 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 2004 and 2005, EEPS funded the following projects:

Conceptual Model Report for EEPS (2004)
The Exposure and Effects Advisory Panel met in 2004 and provided input on a conceptual framework for the study. The Panel stated that biological effects research should be a priority and recommended narrowing the focus to the following topics: fish, birds, benthos, and toxicity. In response to the Review Panel recommendation, the SC and TRC extended the duration of the study for another two years through 2008. For more information, refer to RMP Documents and Reports.

Contaminants in Diving Ducks (2002 and 2005)
Selenium concentrations in diving ducks are arguably the most important indicator for selenium in the Bay. Concentrations were low relative to historic data, but high interannual variation has been observed in the past. Surf scoters and greater and lesser scaup were collected in Suisun Bay, San Pablo Bay, and South Bay. Ten ducks of each species were collected from each area and their muscle tissue analyzed for selenium and other persistent contaminants to evaluate trends in potential human exposure due to duck consumption. This study was performed in collaboration with USGS and used their existing studies of contaminants in diving ducks. Samples were collected and analyzed in 2002 and 2005. In 2004 the samples were not analyzed due to a refrigerator malfunctioning. Based on a recommendation from the EEPS Science Advisory Panel, this element will not be continued. For further information on this please contact Jennifer Hunt (jhunt@sfei.org).

Contaminants in Cormorant Eggs (2002 and 2004)
Cormorant eggs can be collected with a minimal amount of effort and are potentially the best bioindicator for long-term trends in persistent, bioaccumulative toxicants (PBTs) in the Estuary. Colonies on the Richmond Bridge, the Bay Bridge, and near the San Mateo Bridge were sampled, providing coverage of most of the Bay and allowing for spatial comparisons. Eggs were analyzed for PCBs, organochlorine pesticides, dioxins, mercury, selenium,

PBDEs, and other PBTs. With the collection of eggs in 2002 (EEPS) and historical data from the CISNET program, we are beginning to develop a long term data set. A draft report summarizing these results was prepared in June 2006.

Sediment Toxicity – Sensitivity of Estuarine Species (2004)
Sediment toxicity in the Estuary has been shown by the RMP to be persistent. In order to begin to address the possible causes of toxicity to estuarine species, we need to better understand their sensitivity to contamination. EEPS contributed additional funds to a PRISM study to develop dose-response information (LC50s) for standard EPA sediment toxicity testing species and ecologically relevant species to the Estuary. The following toxicity assessments were performed: (1) cypermethrin, bifenthrin and permethrin to address potential risk of pyrethroids to resident species (*Ampelisca*) and RMP monitoring species (*Eohaustorius*), and (2) three chemicals of concern (copper, chlorpyrifos, and a PAH) to *Eohaustorius*, *Ampelisca*, and another resident species. A final report will be available in January 2007.

Contaminants and Hatchability in Terns (2002 and 2003)
As part of a larger USFWS study on terns, EEPS studies in 2002, 2003, and 2005 investigated tern egg contaminant concentrations and egg hatchability. Three tern species (Forster's, Caspian, and least) were collected at several Bay locations and analyzed for Hg in 2002 and 2003. Trace organics were analyzed by USFWS. In 2004, EEPS funds were allocated to prepare a technical report on the study, which will be available later this year.

Egg contaminant concentrations will be compared to effects threshold levels determined from laboratory-feeding experiments of a range of bird species, since there are no data for the study species, and to measurements of hatchability based on field observations.

Fish effects in shiner surfperch (2005 and 2006)
The main objective of the project is to determine if shiner surfperch (*Cymatogaster aggregata*; Embiotocidae) show effects of contamination on some aspect of their fitness, growth, or reproduction. Fish were collected in 2005 and 2006. Analyses for this study include sex ratios, egg protein (i.e., vitellogenin) induction, measure p4501A enzyme activity, and histopathology. A lab culture was established at Bodega Marine Lab in 2006 to evaluate the effects of contaminants. A secondary objective is 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. A final report will be available in January 2007.

Mercury in small fish (2005, 2006, 2007, and 2008)
This project examines the uptake of mercury in small fish at eight 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.

The project's first year report is currently in review and will be available later this year. The report describes spatial and species patterns in mercury in small fish, as well as sampling recommendations for future years of the study.

Review of benthic archives (2005)
In 2003, benthic samples from five sites in the Estuary were collected as part of the State Sediment Quality Objective program. For comparability to other state benthic data, funding was made available to identify the organisms from only the 1.0 mm screen fraction. (The 0.5 mm fraction has not been identified.) This study completes the laboratory analysis of these archived samples. The information from these samples will be used in the on-going development of benthic assessment methods by the RMP for the San Francisco Estuary.

Sediment Assessment Report (2005)
This project will apply the Sediment Quality Objectives (SQO) methodology in the San Francisco Estuary. However, completion of this report depends upon the final SQO report and database, which have not been made available yet.

Winter Pilot Study (2005)
Applicable RMP Objectives: 1, 2, 4, and 5
Contact: Sarah Lowe (Sarahl@sfei.org)

The purpose of this Pilot Study was to comply with an NPDES permit provision for ambient water monitoring for dischargers in the San Francisco Bay Area. During February 2005, estuarine water samples were collected at three historical RMP stations: Sacramento River (BG20), Yerba Buena Island (BC10), and Dumbarton Bridge (BA30). These water samples were analyzed for contaminants on the California Toxics Rule priority pollutant list.

Currently, the Status and Trends sampling design does not capture seasonal variation since sampling occurs only during the dry season. The results from this Pilot Study will provide the Water Board with important wet weather contaminant information. This Pilot Study is in an interim monitoring effort until the TRC and a specialized work group can convene in late 2006 to evaluate the Status and Trends Program's design and address long-term contaminant monitoring of the Estuary, including the need for a seasonal monitoring component.

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 2004-2005:

- Dredge Material Testing Data Evaluation (2004)
- Contaminant Loads from the Sacramento and San Joaquin Rivers (2004-2005)
- Ten-Year Synthesis of Contaminant Status and Trends (2004-2005)
- Small Tributary Loading Study - Guadalupe (2004-2005)
- Identifying PBDE Information Gaps (2005)
- Linkage Analysis of Possible Dredging Effects on Contaminants Bioaccumulation in the San Francisco Bay Food Web (2005)
- Reconnaissance Work to Identify Appropriate Sediment Loading Sites (2005)

Dredge Material Testing Data Evaluation (2004)
Applicable RMP Objectives: 1, 2, 4, and 6
Contact: Donald Yee (donald@sfei.org)

This special study collected data from recent dredged material testing and compared them to data from other monitoring efforts to determine their suitability for evaluating ecosystem status and fate processes. A report comparing the differences among data sets, advantages and disadvantages to the various collection and analysis methods used, and caveats for use and incorporation of these data will be available later this year.

This study coordinated an effort to present dredge material testing data to the public via the web. These data, if publicly available, would benefit future dredging proponents, the regulatory agencies, interested environmental groups, researchers on overall environmental state of the Estuary, and Estuary habitat restoration entities. A majority of sediment contaminant monitoring conducted in the Estuary has focused on surface sediment contamination, and the integration of dredge testing contaminant and toxicity data would be useful for supplementing data collected for the RMP and other environmental monitoring programs and projects.

Contaminant Loads from the Sacramento and San Joaquin Rivers (2003-2009)
Applicable RMP Objectives: 1, 3, and 6
Contact: Lester McKee (lester@sfei.org)

The San Francisco Bay is listed as impaired for mercury, selenium, PCBs, and chlorinated pesticides. This study aimed to address information gaps associated with loadings of these substances (with the exception of selenium) to develop a better understanding of relative inputs from urban point and non-point sources, erosion and resuspension in the Bay, and the inputs from the Central Valley rivers. In addition, in 2005 PBDEs were also measured. The RMP TRC endorsed the continuation of this study in future water years 2006 and 2009.

Ten-Year Synthesis of Contaminant Status and Trends (2003-2005)
Applicable RMP Objectives: 1, 2, 3, 4, 5, and 6
Contact: Jay Davis (jay@sfei.org)

Prior to the implementation of the new random sampling design in 2002, the RMP employed a fixed station sampling design from 1993-2001. The *2004 Pulse of the Estuary* was the first part of a two part series highlighting key findings related to the Status and Trends monitoring efforts. Currently, the RMP is in the process of synthesizing and reporting on those results for a special issue of the scientific journal *Environmental Research*. The topics of the manuscripts include sediments, metals, legacy pesticides, PAHs, invasive species, and emerging organic contaminants. The articles will address the Program's objectives to provide a rigorous evaluation of long-term trends and to synthesize RMP and non-RMP data into an integrated assessment of contamination status and trends in the Estuary.

Small Tributary Loading Study at Guadalupe River (2003-2005)
Applicable RMP Objectives: 1, 3, and 6
Contact: Lester McKee (lester@sfei.org)

Small tributaries are a major pathway for loads of contaminants that enter the Bay. Models developed for the Bay are highly sensitive to the magnitude of loads from small tributaries, but present load estimates for this pathway lack accuracy and precision. This study aimed to

accurately measure contaminant loads from a small tributary that has significant loads of sediment and contaminants, demonstrate a new methodology, and compare the loading measurements to existing model estimates. Flood events were sampled and analyzed for trace contaminant concentrations (mercury, trace metals, PCBs, OC pesticides, SSC, DOC, and POC). In 2005, OC pesticides were eliminated in favor of analyzing for PBDEs.

Identifying PBDE Information Gaps (2005)
Applicable RMP Objectives: 1, 2, 3, 5, and 6
Contact: Meg Sedlak (meg@sfei.org)

This was a joint project between the Clean Estuary Partnership (CEP) and the RMP to develop a conceptual model and impairment assessment (CM/IA) for the San Francisco Bay. The CM/IA included an initial information gathering effort by critically analyzing the published peer-reviewed scientific literature to identify possible PBDE sources, loadings from those sources, transport pathways, behavior, and fate in various matrices. Additional field samples were collected for sediments from small tributaries (in coordination with a PRISM Study), sludge and wastewater effluent from three POTWs, and water from Guadalupe River, Mallard Island, and Coyote Creek (in coordination with the RMP River Studies) to fill critical information gaps). A final CM/IA report will be submitted to the CEP Technical Committee later this year and will address data gaps, including key uncertainties and information needs.

Linkage Analysis of Possible Dredging Effects on Contaminants Bioaccumulation in the San Francisco Bay Food Web (2005)
Applicable RMP Objectives: 2 and 4
Contact: John Oram (joram@sfei.org)

The question of incremental contaminant loads to the ecosystem from dredging and in-bay disposal activities is frequently raised in discussions regarding regulatory policy development (e.g., TMDLs). Impairment assessments for the Bay (e.g., mercury, PCBs, and dioxins) have focused on accumulation of contaminants in sport fish, and several of the most contaminated fish are benthic foragers that frequent harbors and marinas. This study developed a conceptual model of contaminant transfer to benthic-foraging fish species from dredging activities, including in-bay disposal, and attempted to identify the steps necessary to estimate the incremental contribution of dredging activities to identified impairments. By focusing on pathways, this work helped to refine the box models that are the main tool for understanding the fate of contaminants in the Bay.

For more information, refer to the final report available from the SFEI website: *Dredging Impacts on Food-Web Bioaccumulation of DDTs in San Francisco Bay, CA*.

Reconnaissance Work to Identify Appropriate Sediment Loading Sites (2005)
Applicable RMP Objectives: 1 and 3
Contact: Lester McKee (lester@sfei.org)

This study recommended potential sampling locations in watersheds that can be used to form a regional network of contaminant load monitoring stations. Existing information on contaminant sources and pathways, hydrology, watershed physiography, and land use were synthesized to prioritize potential watersheds for water quality and loads observations. A site reconnaissance of the top six watersheds was performed to further evaluate the watersheds for suitability. A network of observation watersheds will provide better load estimates of mercury, PCBs, and

other trace contaminants entering the Bay annually or at other time scales, and provide local agencies with a means of measuring success of management actions (Davis *et al.,* 2000). The results of this study were presented in 2005 to the Sources Pathways and Loadings Workgroup. Based on the recommendations of the workgroup, a watershed in Hayward will be the subject of a Special Study in 2007.

1.5 References

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Stevens, Jr., D.L. 1997. Variable density grid-based sampling designs for continuous spatial populations. Environmetrics 8:167-195.

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Table 1.2. RMP Program Participants in 2004-2005.

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
Crockett Cogeneration
Dow Chemical Company
General Chemical Corporation
Rhodia, Inc.
Shell – Martinez Refining Company
Tesoro Golden Eagle Refinery
TOSCO – Rodeo Refinery
USS – POSCO Industries
Valero Refining Company

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

Cooling Water
Mirant of California

Dredgers
Ballena Bay Townhouse Association
Benicia Port Terminal Company, Pier 95
Boat Dock, Robert Cummings, San Rafael Creek
Boat Dock, Ernie Gabiati, San Rafael Creek
Boat Dock, Steven Gilley, San Rafael Creek
Boat Dock, M. Meenan & E. Brello, San Rafael Creek
Boat Dock, John Perry, San Rafael Creek
Boat Dock, Gary Scheier, San Rafael Creek
Boat Dock, Lloyd Watson, San Rafael Creek
Boat Dock, Warren Weisenburg, San Rafael Creek
Boy Scouts of America, Marin Council, Larkspur Sea
Caltrans Bay Bridge, East Span
Caltrans Benicia-Martinez Bridge Retrofit & New
Chevron Richmond Long Wharf
City of Benicia Marina
City of Emeryville Marina
City of San Rafael, San Rafael Creek Berths
City of Vallejo Ferry Terminal
City of Vallejo Marina
Conoco Phillips
County of Marin, Park District, Black Point Boat Ramp
Coyote Point Marina
Mare Island
Marin County Service Area 29, Paradise Cay
Marina Plaza Harbor
Marina Vista Homeowners Association
Oyster Cove Marina
Port of Oakland
Port of Redwood City
Port of San Francisco
Ryer Island Boat Harbor
San Francisco Drydock Berth 2
San Francisco Drydock Berth 3 & 4
San Rafael Rock Quarry
Shoonmaker Point Marina
U.S. Army Corps of Engineers
Valero Refining Co.

Table 1.3. Summary of RMP sampling stations, 2004-2005.

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/Alameda	BB71	x	Bivalve Tissue	9/29/2004	37.6955	-122.33967	9		x	x	
Central Bay/Alameda	BB71	x	Bivalve Tissue	9/28/2005	37.6955	-122.33967	9		x	x	
Central Bay/Yerba Buena Island	BC10	x	Bivalve Tissue	9/29/2004	37.81867	-122.34683	3		x	x	
Central Bay/Yerba Buena Island	BC10	x	Bivalve Tissue	9/28/2005	37.81867	-122.34683	3		x	x	
Central Bay/Yerba Buena Island	BC10	x	Water	7/19/2004	37.8223	-122.3506	8	x	x	x	
Central Bay/Yerba Buena Island	BC10	x	Water	8/12/2005	37.83017	-122.3513	10	x	x	x	
Central Bay/Yerba Buena Island	BC11	x	Sediment	7/30/2004	37.82303	-122.3499	6	x	x	x	x
Central Bay/Yerba Buena Island	BC11	x	Sediment	8/25/2005	37.82313	-122.3499	7	x	x	x	x
Central Bay/Golden Gate	BC20	x	Water	7/19/2004	37.82297	-122.6798	29	x	x	x	
Central Bay/Golden Gate	BC20	x	Water	8/12/2005	37.806	-122.7282	38	x	x	x	
Central Bay/Red Rock	BC61	x	Bivalve Tissue	9/29/2004	37.92833	-122.46883	4		x	x	
Central Bay/Red Rock	BC61	x	Bivalve Tissue	9/28/2005	37.92833	-122.46883	4		x	x	
Central Bay	CB001S		Sediment	7/29/2004	37.87587	-122.3621	4	x	x	x	x
Central Bay	CB001S		Sediment	8/26/2005	37.87613	-122.3617	4	x	x	x	x
Central Bay	CB002S		Sediment	7/30/2004	37.62573	-122.3474	6	x	x	x	
Central Bay	CB002S		Sediment	8/25/2005	37.62487	-122.3472	5	x	x	x	
Central Bay	CB009W		Water	7/20/2004	37.84585	-122.4271	28	x	x	x	
Central Bay	CB010W		Water	7/15/2004	37.73092	-122.282	5	x	x	x	
Central Bay	CB011W		Water	7/20/2004	37.9474	-122.4631	2	x	x	x	
Central Bay	CB012W		Water	7/15/2004	37.7586	-122.3784	11	x	x	x	
Central Bay	CB013W		Water	8/11/2005	37.8465	-122.3675	9	x	x	x	
Central Bay	CB014W		Water	8/17/2005	37.68162	-122.2809	5	x	x	x	
Central Bay	CB015W		Water	8/11/2005	37.82288	-122.4331	21	x	x	x	
Central Bay	CB016S		Sediment	7/30/2004	37.696	-122.3654	8	x	x	x	
Central Bay	CB016W		Water	8/18/2005	37.67817	-122.3784	4	x	x	x	
Central Bay	CB018S		Sediment	7/30/2004	37.64928	-122.316	12	x	x	x	
Central Bay	CB020S		Sediment	7/30/2004	37.749	-122.3089	7	x	x	x	
Central Bay	CB021S		Sediment	8/25/2005	37.7915	-122.3485	12	x	x	x	x
Central Bay	CB023S		Sediment	8/26/2005	37.88775	-122.4004	8	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
Central Bay	CB024S		Sediment	8/25/2005	37.73685	-122.2902	4	x	x	x	
Central Bay	CB025S		Sediment	8/25/2005	37.86668	-122.3784	6	x	x	x	x
Central Bay	CB026S		Sediment	8/25/2005	37.71415	-122.2857	5	x	x	x	
Central Bay	CB075S		Sediment	7/29/2004	37.94352	-122.4751	4	x	x	x	x
Central Bay	CB077S		Sediment	7/30/2004	37.7922	-122.3889	4	x	x	x	x
Central Bay	CB078S		Sediment	7/30/2004	37.664	-122.2696	7	x	x	x	x
Central Bay	CB080S		Sediment	8/25/2005	37.71623	-122.3494	16	x	x	x	
Lower South Bay/Coyote Creek	BA10	x	Bivalve Tissue	9/28/2004	37.46983	-122.06383	6		x	x	
Lower South Bay/Coyote Creek	BA10	x	Bivalve Tissue	9/27/2005	37.46983	-122.06383	6		x	x	
Lower South Bay/Coyote Creek	BA10	x	Sediment	8/3/2004	37.4676	-122.0643	2	x	x	x	x
Lower South Bay/Coyote Creek	BA10	x	Sediment	8/24/2005	37.46772	-122.064	4	x	x	x	x
Lower South Bay	LSB001S		Sediment	8/3/2004	37.49162	-122.098	5	x	x	x	x
Lower South Bay	LSB001S		Sediment	8/24/2005	37.49182	-122.0984	6	x	x	x	x
Lower South Bay	LSB002S		Sediment	8/3/2004	37.47918	-122.0787	7	x	x	x	
Lower South Bay	LSB002S		Sediment	8/24/2005	37.47863	-122.0787	4	x	x	x	
Lower South Bay	LSB012W		Water	7/12/2004	37.48643	-122.0972	3	x	x	x	
Lower South Bay	LSB013W		Water	7/13/2004	37.4944	-122.0945	8	x	x	x	
Lower South Bay	LSB014W		Water	7/12/2004	37.47408	-122.0723	6	x	x	x	
Lower South Bay	LSB015S		Sediment	8/3/2004	37.49122	-122.1154	3	x	x	x	x
Lower South Bay	LSB015W		Water	7/13/2004	37.4979	-122.1124	16	x	x	x	
Lower South Bay	LSB016S		Sediment	8/3/2004	37.49215	-122.083	2	x	x	x	
Lower South Bay	LSB016W		Water	7/12/2004	37.49305	-122.0858	3	x	x	x	
Lower South Bay	LSB017S		Sediment	8/3/2004	37.49578	-122.0927	2	x	x	x	x
Lower South Bay	LSB017W		Water	8/15/2005	37.4927	-122.1018	8	x	x	x	
Lower South Bay	LSB018S		Sediment	8/2/2004	37.471	-122.0857	3	x	x	x	
Lower South Bay	LSB018W		Water	8/15/2005	37.48017	-122.0764	6	x	x	x	
Lower South Bay	LSB019S		Sediment	8/3/2004	37.49928	-122.1112	16	x	x	x	x
Lower South Bay	LSB019W		Water	8/16/2005	37.50137	-122.1124	15	x	x	x	
Lower South Bay	LSB020S		Sediment	8/3/2004	37.48803	-122.0871	4	x	x	x	
Lower South Bay	LSB020W		Water	8/15/2005	37.494	-122.0882	5	x	x	x	
Lower South Bay	LSB021W		Water	8/15/2005	37.49418	-122.0927	7	x	x	x	
Lower South Bay	LSB022S		Sediment	8/24/2005	37.46708	-122.062	3	x	x	x	
Lower South Bay	LSB023S		Sediment	8/24/2005	37.47435	-122.1136	2	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
Lower South Bay	LSB024S		Sediment	8/24/2005	37.48643	-122.0762	2	x	x	x	
Lower South Bay	LSB025S		Sediment	8/24/2005	37.49093	-122.1027	5	x	x	x	x
Lower South Bay	LSB026S		Sediment	8/24/2005	37.48115	-122.0812	2	x	x	x	
Lower South Bay	LSB073S		Sediment	8/24/2005	37.49205	-122.1039	9	x	x	x	x
Rivers/Sacramento River	BG20	x	Bivalve Tissue	10/8/2004	38.05967	-121.79167	8		x	x	
Rivers/Sacramento River	BG20	x	Bivalve Tissue	9/30/2005	38.05967	-121.79167	8		x	x	
Rivers/Sacramento River	BG20	x	Sediment	7/27/2004	38.05808	-121.8137	10	x	x	x	x
Rivers/Sacramento River	BG20	x	Sediment	8/30/2005	38.05943	-121.8142	9	x	x	x	x
Rivers/Sacramento River	BG20	x	Water	7/23/2004	38.05868	-121.8103	9	x	x	x	
Rivers/Sacramento River	BG20	x	Water	8/8/2005	38.05958	-121.8112	10	x	x	x	
Rivers/San Joaquin River	BG30	x	Bivalve Tissue	10/8/2004	38.02117	-121.80533	6		x	x	
Rivers/San Joaquin River	BG30	x	Bivalve Tissue	9/30/2005	38.02117	-121.80533	6		x	x	
Rivers/San Joaquin River	BG30	x	Sediment	7/27/2004	38.02265	-121.8087	11	x	x	x	x
Rivers/San Joaquin River	BG30	x	Sediment	8/30/2005	38.02308	-121.8081	1	x	x	x	x
Rivers/San Joaquin River	BG30	x	Water	7/23/2004	38.0206	-121.805	7	x	x	x	
Rivers/San Joaquin River	BG30	x	Water	8/8/2005	38.02	-121.8059	15	x	x	x	
San Pablo Bay	BD20	x	Bivalve Tissue	9/30/2004	38.04533	-122.4285	2		x	x	
San Pablo Bay	BD20	x	Bivalve Tissue	9/29/2005	38.04533	-122.4285	2		x	x	
San Pablo Bay/Pinole Point	BD30	x	Bivalve Tissue	9/30/2004	38.01667	-122.3675	3		x	x	
San Pablo Bay/Pinole Point	BD30	x	Bivalve Tissue	9/29/2005	38.01667	-122.3675	3		x	x	
San Pablo Bay/Pinole Point	BD31	x	Sediment	7/29/2004	38.0233	-122.3642	7	x	x	x	x
San Pablo Bay/Pinole Point	BD31	x	Sediment	8/29/2005	38.02403	-122.3627	7	x	x	x	x
San Pablo Bay/Davis Point	BD40	x	Bivalve Tissue	9/30/2004	38.05433	-122.2605	7		x	x	
San Pablo Bay/Davis Point	BD40	x	Bivalve Tissue	9/29/2005	38.05433	-122.2605	7		x	x	
San Pablo Bay	SPB001S		Sediment	7/28/2004	38.07177	-122.3871	4	x	x	x	x
San Pablo Bay	SPB001S		Sediment	8/29/2005	38.07167	-122.3867	4	x	x	x	x
San Pablo Bay	SPB002S		Sediment	7/29/2004	38.01613	-122.3415	2	x	x	x	
San Pablo Bay	SPB002S		Sediment	8/26/2005	38.0168	-122.3407	3	x	x	x	
San Pablo Bay	SPB009W		Water	7/21/2004	38.08242	-122.3939	2	x	x	x	
San Pablo Bay	SPB010W		Water	7/21/2004	38.03317	-122.3513	8	x	x	x	
San Pablo Bay	SPB011W		Water	7/21/2004	38.06732	-122.4574	2	x	x	x	
San Pablo Bay	SPB012W		Water	7/20/2004	37.97855	-122.4388	23	x	x	x	
San Pablo Bay	SPB013W		Water	8/11/2005	38.01757	-122.428	6	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
San Pablo Bay	SPB014W		Water	8/10/2005	38.05652	-122.2918	12	x	x	x	
San Pablo Bay	SPB015S		Sediment	7/28/2004	38.09052	-122.4435	5	x	x	x	x
San Pablo Bay	SPB015W		Water	8/10/2005	38.08207	-122.415	3	x	x	x	
San Pablo Bay	SPB016S		Sediment	7/28/2004	38.06253	-122.3758	4	x	x	x	
San Pablo Bay	SPB016W		Water	8/10/2005	38.04667	-122.3735	3	x	x	x	
San Pablo Bay	SPB017S		Sediment	7/28/2004	38.11563	-122.3779	2	x	x	x	x
San Pablo Bay	SPB018S		Sediment	7/28/2004	38.0631	-122.3072	5	x	x	x	
San Pablo Bay	SPB019S		Sediment	7/29/2004	38.01973	-122.4639	3	x	x	x	x
San Pablo Bay	SPB021S		Sediment	8/29/2005	38.00097	-122.4288	12	x	x	x	x
San Pablo Bay	SPB022S		Sediment	8/26/2005	38.0335	-122.2793	3	x	x	x	
San Pablo Bay	SPB023S		Sediment	8/26/2005	38.10645	-122.3903	2	x	x	x	x
San Pablo Bay	SPB024S		Sediment	8/26/2005	38.06243	-122.3343	3	x	x	x	
San Pablo Bay	SPB025S		Sediment	8/26/2005	38.07383	-122.4185	3	x	x	x	x
San Pablo Bay	SPB026S		Sediment	8/29/2005	38.05455	-122.338	17	x	x	x	
San Pablo Bay	SPB074S		Sediment	7/29/2004	38.03532	-122.3476	10	x	x	x	
South Bay/Dumbarton Bridge	BA30	x	Bivalve Tissue	9/28/2004	37.51333	-122.13467	5		x	x	
South Bay/Dumbarton Bridge	BA30	x	Bivalve Tissue	9/27/2005	37.51333	-122.13467	5		x	x	
South Bay/Dumbarton Bridge	BA30	x	Water	7/13/2004	37.51425	-122.1348	10	x	x	x	
South Bay/Dumbarton Bridge	BA30	x	Water	8/16/2005	37.51452	-122.1351	10	x	x	x	
South Bay/Redwood Creek	BA40	x	Bivalve Tissue	9/28/2004	37.547	-122.195	3		x	x	
South Bay/Redwood Creek	BA40	x	Bivalve Tissue	9/27/2005	37.547	-122.195	3		x	x	
South Bay/Redwood Creek	BA41	x	Sediment	8/2/2004	37.55933	-122.2102	2	x	x	x	x
South Bay/Redwood Creek	BA41	x	Sediment	8/23/2005	37.55902	-122.2093	3	x	x	x	x
South Bay	SB001S		Sediment	8/2/2004	37.61203	-122.2651	4	x	x	x	x
South Bay	SB001S		Sediment	8/23/2005	37.61217	-122.2621	3	x	x	x	x
South Bay	SB002S		Sediment	8/2/2004	37.61015	-122.1674	3	x	x	x	
South Bay	SB002S		Sediment	8/23/2005	37.60992	-122.168	3	x	x	x	
South Bay	SB015S		Sediment	8/2/2004	37.69858	-122.224	2	x	x	x	x
South Bay	SB016S		Sediment	8/2/2004	37.66085	-122.1824	2	x	x	x	
South Bay	SB017S		Sediment	7/30/2004	37.58873	-122.2704	2	x	x	x	x
South Bay	SB018S		Sediment	8/2/2004	37.55415	-122.1796	3	x	x	x	
South Bay	SB019S		Sediment	8/2/2004	37.63692	-122.2733	6	x	x	x	x
South Bay	SB020S		Sediment	8/2/2004	37.58558	-122.2145	3	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
South Bay	SB020W		Water	7/16/2004	37.58828	-122.2293	2	x	x	x	
South Bay	SB021S		Sediment	8/23/2005	37.63213	-122.2151	3	x	x	x	x
South Bay	SB021W		Water	7/14/2004	37.65093	-122.2158	3	x	x	x	
South Bay	SB022S		Sediment	8/23/2005	37.51162	-122.1275	13	x	x	x	
South Bay	SB022W		Water	7/13/2004	37.51915	-122.1352	12	x	x	x	
South Bay	SB023S		Sediment	8/23/2005	37.67698	-122.2124	2	x	x	x	x
South Bay	SB023W		Water	7/14/2004	37.65352	-122.2428	5	x	x	x	
South Bay	SB024S		Sediment	8/23/2005	37.56267	-122.2265	4	x	x	x	
South Bay	SB024W		Water	7/16/2004	37.60322	-122.1871	2	x	x	x	
South Bay	SB025S		Sediment	8/23/2005	37.61297	-122.281	13	x	x	x	x
South Bay	SB025W		Water	7/14/2004	37.67597	-122.2092	3	x	x	x	
South Bay	SB026S		Sediment	8/23/2005	37.55308	-122.193	14	x	x	x	
South Bay	SB026W		Water	7/16/2004	37.58647	-122.1992	3	x	x	x	
South Bay	SB027W		Water	7/15/2004	37.6212	-122.3001	12	x	x	x	
South Bay	SB028W		Water	7/14/2004	37.63552	-122.2001	3	x	x	x	
South Bay	SB029W		Water	8/17/2005	37.6387	-122.2356	4	x	x	x	
South Bay	SB030W		Water	8/16/2005	37.55597	-122.1664	3	x	x	x	
South Bay	SB031W		Water	8/17/2005	37.69677	-122.2175	4	x	x	x	
South Bay	SB032W		Water	8/19/2005	37.61793	-122.1994	2	x	x	x	
South Bay	SB033W		Water	8/17/2005	37.66247	-122.213	3	x	x	x	
South Bay	SB034W		Water	8/18/2005	37.59547	-122.1932	4	x	x	x	
South Bay	SB035W		Water	8/18/2005	37.59925	-122.3183	4	x	x	x	
South Bay	SB036W		Water	8/18/2005	37.58342	-122.2577	13	x	x	x	
South Bay	SB037W		Water	8/19/2005	37.60495	-122.261	3	x	x	x	
Suisun/Grizzly Bay	BF21	x	Sediment	7/27/2004	38.11415	-122.0416	3	x	x	x	x
Suisun/Grizzly Bay	BF21	x	Sediment	8/30/2005	38.11508	-122.0401	3	x	x	x	x
Suisun	SU001S		Sediment	7/28/2004	38.09937	-122.0472	8	x	x	x	x
Suisun	SU001S		Sediment	8/30/2005	38.09943	-122.0469	7	x	x	x	x
Suisun	SU002S		Sediment	7/27/2004	38.059	-121.9799	13	x	x	x	
Suisun	SU002S		Sediment	8/29/2005	38.05805	-121.9802	12	x	x	x	
Suisun	SU011W		Water	7/22/2004	38.04152	-122.1283	21	x	x	x	
Suisun	SU012W		Water	7/22/2004	38.08972	-122.0417	2	x	x	x	
Suisun	SU013W		Water	7/22/2004	38.10328	-122.0337	3	x	x	x	
Suisun	SU014W		Water	7/22/2004	38.06782	-121.9515	2	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	SU015S		Sediment	7/27/2004	38.11107	-122.0611	4	x	x	x	x
Suisun	SU015W		Water	8/9/2005	38.05215	-122.1086	6	x	x	x	
Suisun	SU016S		Sediment	7/27/2004	38.10152	-122.0184	3	x	x	x	
Suisun	SU016W		Water	8/9/2005	38.10827	-122.0144	2	x	x	x	
Suisun	SU017S		Sediment	7/28/2004	38.10035	-122.037	8	x	x	x	x
Suisun	SU017W		Water	8/9/2005	38.11547	-122.0363	2	x	x	x	
Suisun	SU018S		Sediment	7/27/2004	38.06843	-121.9631	3	x	x	x	
Suisun	SU018W		Water	8/9/2005	38.07022	-121.957	3	x	x	x	
Suisun	SU019S		Sediment	7/28/2004	38.05992	-122.0943	2	x	x	x	x
Suisun	SU020S		Sediment	7/27/2004	38.1123	-122.0231	3	x	x	x	
Suisun	SU022S		Sediment	8/29/2005	38.0702	-121.9254	3	x	x	x	
Suisun	SU023S		Sediment	8/30/2005	38.11527	-122.0577	4	x	x	x	x
Suisun	SU024S		Sediment	8/29/2005	38.07443	-121.9976	8	x	x	x	
Suisun	SU025S		Sediment	8/30/2005	38.10285	-122.0577	5	x	x	x	x
Suisun	SU075S		Sediment	8/29/2005	38.06155	-122.1157	3	x	x	x	x
Suisun	SU076S		Sediment	8/30/2005	38.10278	-122.03	3	x	x	x	

Table 1.4. RMP Contractors and Principal Investigators in 2004-2005.

Principal Contractor	AMS	Mr. Paul Salop and Dr. Andrew Gunther Applied Marine Sciences (AMS), Livermore, CA Mr. Nick Sakata US Bureau of Reclamation Captain, *RV Endeavor*
BACWA Coordination	EBMUD	Mr. William Ellgas and Ms. Julia Halsne East Bay Municipal Utility District (EBMUD), Oakland, CA
Water Trace Element Chemistry	BRL	Dr. Colin Davies and Ms. Elizabeth Madonick Brooks-Rand Ltd. (BRL), Seattle, WA
	UCSCDET	Dr. Russ Flegal and Ms. Genine Scelfo UC Santa Cruz (UCSCDET), Santa Cruz, CA
Water Trace Organic Chemistry	AXYS	Dr. Million Woudneh and Mr. Todd Fisher AXYS Analytical Services, Inc. (AXYS), Sidney, BC
	CDFG-WPCL	Dr. Dave Crane, Mr. Abdu Mekebri, and Mr. Loc Nguyen California Dept. of Fish & Game, Water Pollution Control Laboratory (CDFG-WPCL), Rancho Cordova, CA
Water Hardness	CCSF/ EBMUD	Ms. Julia Halsne City and County of San Francisco (CCSF), San Francisco, CA – 2004 East Bay Municipal Utility District (EBMUD), Oakland, CA – 2005
Sediment Trace Element Chemistry	BRL	Dr. Colin Davies and Ms. Elizabeth Madonick Brooks-Rand Ltd. (BRL), Seattle, WA
	UCSCDET	Dr. Russ Flegal and Ms. Genine Scelfo UC Santa Cruz (UCSCDET), Santa Cruz, CA
	CCSF	Mr. Anthony Rattonetti and Mr. Lonnie Butler City and County of San Francisco (CCSF), San Francisco, CA
Sediment Trace Organics Chemistry	EBMUD	Mr. François Rodigari and Dr. Saskia van Bergen East Bay Municipal Utility District (EBMUD), Oakland, CA
Sediment Toxicity Testing	MPSL	Mr. John Hunt, Mr. Brian Anderson, and Mr. Bryn Phillips Marine Pollution Studies Lab (MPSL), Granite Canyon, CA
Bivalve Trace Organics	CDFG-WPCL	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	AMS	Mr. Paul Salop Applied Marine Sciences (AMS), Livermore, CA
USGS Water Quality	USGS	Dr. James Cloern, USGS, Menlo Park, CA

Table 1.5. RMP Target Parameter List in 2004-2005.

Refer to Table 1.4 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 Alive	MPSL	%

Table 1.5. RMP target parameter list in 2004-2005 (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	-
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 1.5. RMP target parameter list in 2004-2005 (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 1.5. RMP target parameter list in 2004-2005 (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]
028 - [2,4,4'-triBDE]
047 - [2,2',4,4'-tetraBDE]
066 - [2,3',4,4'-tetraBDE]
082 - [2,2',3,3',4-pentaBDE]
085 - [2,2',3,4,4'-pentaBDE]
099 - [2,2',4,4'5-pentaBDE]
100 - [2,2',4,4',6-pentaBDE]
128 - [2,2',3,3',4,4'-hexaBDE]
138 - [2,2',3,4,4',5'-hexaBDE]
153 - [2,2',4,4',5,5'-hexaBDE]
154 - [2,2',4,4',5,6'-hexaBDE]
183 - [2,2',3,4,4',5',6-heptaBDE]
190 - [2,3,3',4,4',5,6-heptaBDE]
203 - [2,2',3,4,4',5,5',6-OCTABDE]
204 - [2,2',3,4,4',5,6,6'-OCTABDE]
205 - [2,3,3',4,4',5,5',6-OCTABDE]
206 - [2,2',3,3',4,4',5,5',6-NONABDE]
207 - [2,2',3,3',4,4',5,6,6'-NONABDE]
208 - [2,2',3,3',4,5,5',6,6'-NONABDE]
209 - [2,2',3,3',4,4',5,5',6,6'-decaBDE]

Chapter 2

Water Monitoring

2.0 Water Monitoring

John Oram, Sarah Lowe, and Cristina Grosso

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 San Francisco Estuary 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 2004 and 2005, RMP Status and Trends Program continued with implementation of the stratified, random sampling design started in 2002 (see Chapter 1, *Introduction*). A total of 62 stations were monitored for contaminants in water in 2004 and 2005 (31 stations each year). 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.

In both 2004 and 2005, 26 randomly allocated stations and five historic Status and Trends Program stations were sampled 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); 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 2004 and 2005 monitoring effort are listed in Table 1.3 in the *Introduction* and shown in Figure 2.1. This Report presents results of the 2004 and 2005 monitoring efforts. Results at repeat stations (i.e., historic stations) were

averaged. 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 1.5 in the *Introduction*).

The Status and Trends Program measures 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 1.5). 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/.

Field and analytical methods are described in Chapter 5 – *Description of Methods*. This section also provides information on additional Status and Trends Program sampling and analysis reference documentation. Data are available for downloading via the RMP website using the *Status and Trends Monitoring Data Access Tool* @ http://www.sfei.org/rmp/data.htm.

2.2.2 Water Quality Guidelines

To evaluate potential ecological effects, contaminant concentrations were compared to various water quality guidelines. The Regional 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" 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. There are no regulatory effects thresholds for total trace elements (except for mercury and selenium) and comparisons are made in this report for illustrative purposes only.

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. The Lower South Bay (south of the Dumbarton Bridge) has site-specific objectives approved for that region for copper, nickel, and mercury (see *Site-specific Objectives for the Lower South Bay* 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. The following contaminants were compared to effects thresholds from other sources (Table 2.1). Total diazinon concentrations were compared to an effects threshold concentration of 40 ng/L, developed by the California Department of Fish and Game (Menconi and Cox, 1994). Chlorpyrifos and mirex were compared to the EPA recommended thresholds for these contaminants (U.S. EPA, 1999).

Site-specific Objectives for the Lower South Bay

There are site-specific aquatic life water quality objectives for *dissolved* copper and nickel 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 dissolved copper objective changed from 4.8 µg/L to 10.8 µg/L acute (exposure for one hour) and from 3.1 µg/L to 6.9 µg/L chronic

(exposure for four days). The dissolved nickel objectives changed from 74 µg/L to 62.4 µg/L acute and from 8.2 µg/L to 11.9 µg/L chronic. Additionally there are site-specific translators to convert the objective from dissolved to total. The translators for copper and nickel are 0.53 and 0.44 respectively (dissolved objective / translator value = site-specific total objective).

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
Since 1993, the Status and Trends Program has conducted ambient water toxicity testing on seasonal to annual time scales. The Status and Trends Program did not sample water toxicity in the Estuary in 2003, 2004 and 2005. Aquatic toxicity sampling within the Estuary is scheduled to occur 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 (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 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 2.2), dissolved organic carbon (DOC; Figure 2.3), suspended solids concentration (SSC; Figure 2.4), trace elements (Figures 2.5 – 2.22), and dissolved organic contaminants (Figures 2.23 – 2.28) for randomly allocated stations and historic stations (2004-2005). Methylmercury (MeHg) 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 contaminant on a total basis was total BDE-47 (Figure 2.29). As additional 2004 and 2005 data are finalized, they will be made available through the Status and Trends Monitoring Data Access Tool on the RMP website. The list of parameters measured in water is included in Table 1.5 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 (2004-2005). Box plots indicate interquartile ranges of contaminant concentrations, summarizing results from randomly allocated stations (2004-2005) 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 (2004-2005). 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 four years of data have been collected to date. The RMP is working on a special issue for the journal *Environmental Research* that will include articles synthesizing the ten years of the RMP's Status and Trends Program data (among other topics). That report was submitted to the journal in the Fall of 2005 and is in the review process. We decided to defer any analyses of temporal trends in results from the historic sample design to that reporting effort. However, 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 2.30 – 2.55).

2.3.1 Spatial Distribution

Highest contaminant values

In previous years the highest dissolved concentrations of all dissolved trace element contaminants (except silver) were measured at stations in the southern Estuary regions. In the five major segments in 2002 and 2003, dissolved concentrations of arsenic, copper, nickel, lead, and zinc were highest at one station in the Lower South Bay (LSB008W). Maximum dissolved contaminant concentrations measured in 2004 and 2005 showed much more spatial variability (Table 2.2). No clear pattern was observed in maximum dissolved contaminant concentrations (i.e., as a whole, maximum dissolved concentrations were observed in both 2004 and 2005 and in all estuary segments except San Pablo Bay).

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 DOC (Kuwabara *et al.,* 1989) and

colloids (Sañudo-Wilhelmy *et al.,* 1996). DOC concentrations were highest in the Lower South Bay region, the same region that was highest in four dissolved metals (silver, arsenic, copper, and nickel).

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). Maximum total concentrations of silver, copper, mercury, nickel, lead, and zinc were measured in San Pablo Bay (Table 2.3), which also had the highest concentration of SSC (163 mg/L at SPB009W). Maximum total contaminant concentrations for all measured contaminants are listed in Table 2.3.

The 2002 Annual Monitoring Results reported that concentrations of most trace elements and contaminants were highest in the southern regions of the Estuary. This observation was attributed to the fact that much of South Bay and Lower South Bay lie adjacent to watersheds with regions of urbanization, agriculture, and historic mercury mining and that the hydraulic flushing of the southern estuary is slow. Monitoring results for 2004 and 2005 did not show this same pattern of maximum contaminant concentrations in the southern regions. Instead, 2004 and 2005 results showed maximum concentrations for many contaminants in the northern estuary regions (San Pablo Bay, Suisun Bay, and the Rivers region).

Are the CDF Results Statistically Different Between Regions?
Cumulative distribution function's (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 59% (141 out of 240) of the dissolved water comparisons: 53% of the regional and 69% of the interannual (Table 2.4). The greatest number of significant differences was documented for Dieldrin (15 out of 16), and the least for PAHs (4 out of 16). Significant interannual differences in the dissolved water contaminant CDFs were observed for at least one interannual comparison for each contaminant. Zn showed significant interannual differences in dissolved concentrations for all interannual comparisons.

Statistical analysis of the CDFs for the total water samples showed significant differences in 51% (82 out of 160) of the comparisons: 56% of the regional and 43% of the interannual (Tables 2.5). Cadmium was observed to have the largest number of significant differences, with 13 out of 16 (81%). Silver and BDE-47 were observed to have the least number of significant differences, with 5 out of 16 (31%). Copper was the only contaminant that did not show any significant interannual differences.

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).

Temporal trends were not evaluated for the random sampling design at this time as only four years of data have been collected to date. For reporting continuity, time-series plots were generated and are presented in Figures 2.30-2.56 for the five historic stations that have been

continued in the current monitoring program. However, analyses and discussion of the contaminant trends at the historic sites is deferred to the special issue of the journal *Environmental Research* to be published later this year.

2.3.3 Comparison to Water Quality Guidelines

Various water samples collected in 2004 and 2005 had contaminant concentrations that were above the water effects thresholds (some of which have regulatory implications, see Table 2.6). Two samples, BA30 and SB022W in the South Bay region, 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. In 2004 and 2005 two samples, SPB009W and SPB011W in San Pablo Bay, were above the total mercury criterion of 0.025 µg/L (or 0.051 µg/L for the Lower South Bay region). No stations were above the regulatory total selenium effects threshold of 5 µg/L in either year.

Calculated, *non-regulatory* CTR effects thresholds for total metals were compared to total metals concentrations for informational purposes only. In 2004 and 2005, 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 ten stations: six in Suisun Bay, two in San Pablo Bay, and two in the South Bay (Figure 2.16). Two 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). One station in San Pablo Bay was above the non-regulatory salt or freshwater total lead effects thresholds of 5.6 or 3.2 µg/L respectively (Figure 2.17).

2.3.4 Toxicity of Water to Organisms

Ambient Water Toxicity

This measure has been reduced to a periodic screening effort as little ambient aquatic toxicity has been observed in Estuary samples during the dry season. No aquatic toxicity monitoring occurred in 2004 or 2005. The Status and Trends Program is scheduled to sample aquatic toxicity in the Estuary next in 2007.

Episodic Water Toxicity

Episodic aquatic toxicity monitoring was conducted in April of 2005 to screen 5 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

2.4 References

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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). Total trace element criteria (not shown) were calculated using procedures specified in the CTR. 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***	43.0	9.3	.	.
Cr VI	16.0	11.0	1100	50.0	.	.
Cu	***13.4***	***9.0***	4.8	3.1	1300	.
Cu (lower South Bay only)			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 (lower South Bay only)			62.4	11.9		
Pb	***64.6***	***2.5***	220	8.1	.	.
Se [B]		5.0	290	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]	.	.	.	.	.	0.04
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	0.095	0.08	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	.	.
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, 2004 (SFBRWQB, 2004). However the current objective is 15 µg/L.

Table 2.2. Maximum concentration of dissolved trace elements and dissolved trace organics water.

Parameter	Site Code	Region	Year	Maximum Concentration
Ag	LSB018W	Lower South Bay	2005	0.0069 ug/L
As	LSB017W	Lower South Bay	2005	3.94 ug/L
Cd	CB010W	Central Bay	2004	0.094 ug/L
Cu	LSB016W	Lower South Bay	2004	4.27 ug/L
Hg	SU012W	Suisun Bay	2004	0.005 ug/L
Ni	LSB014W	Lower South Bay	2004	3.006 ug/L
Pb	SU012W	Suisun Bay	2004	0.328 ug/L
Se	BG30	Rivers	2004	0.446 ug/L
Zn	SU012W	Suisun Bay	2004	2.141 ug/L
Dieldrin	BG20	Rivers	2005	81.6 pg/L
Sum of Chlordanes (SFEI)	BG30	Rivers	2004	52.06 pg/L
Sum of DDTs (SFEI)	BG20	Rivers	2005	226.93 pg/L
Sum of HCHs (SFEI)	BC10	Central Bay	2004	402.65 pg/L
Sum of PAHs (SFEI)	LSB017W	Lower South Bay	2005	39,554 pg/L
Sum of PCBs (SFEI)	SB026W	South Bay	2004	249.397 pg/L

Table 2.3. Maximum concentration of total trace elements and total trace organics water.

Parameter	Site Code	Region	Year	Maximum Concentration
Ag	SPB009W	San Pablo Bay	2004	0.0537 ug/L
As	LSB017W	Lower South Bay	2005	4.12 ug/L
Cd	CB010W	Central Bay	2004	0.153 ug/L
Cu	SPB009W	San Pablo Bay	2004	6.997 ug/L
Hg	SPB009W	San Pablo Bay	2004	0.045 ug/L
Ni	SPB011W	San Pablo Bay	2004	14.652 ug/L
Pb	SPB009W	San Pablo Bay	2004	3.219 ug/L
Se	BG20	Rivers	2004	0.453 ug/L
Zn	SPB009W	San Pablo Bay	2004	13.293 ug/L
BDE 047	SU012W	Suisun Bay	2004	337 pg/L

Table 2.4. Statistical comparison of CDF results for dissolved contaminant concentrations among regions and between years. Results are p-values determined by the Roa-Scott Test. Significant comparisons (95% confidence level) are shown in bold.

Comparison	Ag	As	Cd	Cu	Hg	Ni	Pb	Se	Zn	BDE-47	Dieldrin	Sum of Chlordanes (SFEI)	Sum of DDTs (SFEI)	Sum of HCHs (SFEI)	Sum of PAHs (SFEI)	Sum of PCBs (SFEI)	
CB vs LSB	**0.02**	**0.00**	**0.03**	**0.00**	0.24	**0.00**	**0.00**	**0.00**	0.78	-	**0.00**	**0.00**	**0.03**	0.14	0.60	0.23	**2004 and 2005**
CB vs SB	0.49	**0.00**	0.16	**0.00**	0.16	**0.00**	**0.00**	0.22	**0.02**	-	**0.03**	0.40	**0.01**	**0.01**	0.19	0.36	
CB vs SPB	0.20	0.11	0.10	**0.00**	0.73	**0.00**	0.24	0.13	0.22	-	0.09	**0.00**	**0.01**	0.11	0.80	**0.01**	
CB vs SU	**0.01**	**0.00**	**0.00**	0.07	0.35	0.13	0.06	0.46	0.17	-	**0.00**	**0.00**	**0.00**	**0.00**	0.11	**0.00**	
LSB vs SB	0.52	**0.00**	0.19	**0.00**	0.10	**0.00**	**0.00**	**0.00**	0.09	-	**0.00**	**0.00**	**0.00**	0.39	0.38	0.06	
LSB vs SPB	0.32	**0.00**	0.13	**0.00**	0.21	**0.00**	**0.00**	**0.00**	0.34	-	**0.00**	**0.00**	**0.00**	0.77	0.43	**0.00**	
LSB vs SU	**0.00**	**0.00**	**0.00**	**0.00**	0.64	**0.00**	**0.00**	**0.00**	0.33	-	0.36	**0.00**	**0.00**	**0.00**	0.40	**0.00**	
SB vs SPB	0.29	0.07	0.27	**0.01**	0.49	0.50	**0.00**	0.76	0.22	-	0.47	**0.01**	**0.00**	0.75	0.79	**0.00**	
SB vs SU	**0.00**	**0.02**	**0.00**	**0.00**	0.48	**0.00**	0.06	0.74	0.25	-	**0.00**	**0.01**	**0.00**	**0.00**	0.35	**0.00**	
SPB vs SU	**0.00**	0.53	**0.00**	0.51	0.79	0.17	0.79	0.79	0.18	-	**0.00**	0.11	**0.00**	0.10	0.10	0.09	
2002 vs 2003 *	**0.02**	0.90	**0.00**	0.37	**0.00**	0.29	0.14	**0.00**	**0.05**	-	**0.00**	**0.00**	0.06	**0.00**	**0.01**	0.21	
2002 vs 2004	0.74	**0.03**	**0.02**	**0.05**	**0.00**	0.07	0.08	0.78	**0.01**	-	**0.00**	**0.00**	**0.00**	0.43	0.06	**0.00**	
2002 vs 2005	**0.00**	**0.01**	**0.00**	0.72	**0.00**	**0.00**	**0.00**	**0.02**	**0.01**	-	0.15	0.85	**0.01**	**0.00**	**0.00**	**0.02**	
2003 vs 2004	**0.00**	0.24	0.20	0.09	**0.00**	**0.04**	**0.04**	**0.00**	**0.00**	-	0.26	0.25	**0.03**	0.09	0.80	0.08	
2003 vs 2005	0.08	**0.05**	**0.00**	0.44	0.47	0.42	**0.00**	**0.00**	**0.04**	-	**0.05**	**0.00**	**0.00**	**0.03**	**0.00**	**0.05**	
2004 vs 2005	**0.00**	0.82	**0.00**	**0.04**	**0.00**	**0.02**	**0.00**	**0.00**	**0.00**	-	**0.00**	**0.01**	**0.04**	**0.00**	**0.00**	**0.02**	

* Roa-Scott Test p Values for 2002 vs 2003 comparison presented here do not match those presented in the 2003 Annual Monitoring Results due to an adjustment to the spatial weighting.

Table 2.5. Statistical comparison of CDF results for total contaminant concentrations among regions and between years. Results are p-values determined by the Roa-Scott Test. Significant comparisons (95% confidence level) are shown in bold.

Comparison	Ag	As	Cd	Cu	Hg	Ni	Pb	Se	Zn	BDE-47	Dieldrin	Sum of Chlordanes (SFEI)	Sum of DDTs (SFEI)	Sum of HCHs (SFEI)	Sum of PAHs (SFEI)	Sum of PCBs (SFEI)	
CB vs LSB	**0.00**	**0.00**	**0.03**	**0.00**	**0.03**	**0.00**	0.30	**0.00**	**0.02**	0.06	-	-	-	-	-	-	**2004 and 2005**
CB vs SB	**0.01**	**0.01**	0.16	**0.00**	0.42	**0.00**	0.15	**0.00**	0.14	0.19	-	-	-	-	-	-	
CB vs SPB	0.54	0.10	**0.05**	0.06	0.10	**0.01**	0.20	0.12	0.20	0.30	-	-	-	-	-	-	
CB vs SU	0.54	0.12	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.13	-	-	-	-	-	-	
LSB vs SB	0.92	**0.00**	0.23	**0.00**	0.48	**0.00**	0.52	**0.00**	0.48	**0.01**	-	-	-	-	-	-	
LSB vs SPB	0.34	**0.00**	**0.03**	**0.03**	0.34	**0.00**	0.76	**0.01**	**0.03**	**0.00**	-	-	-	-	-	-	
LSB vs SU	0.18	**0.00**	**0.02**	**0.02**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	-	-	-	-	-	-	
SB vs SPB	0.75	0.46	**0.00**	0.23	0.46	0.89	0.47	0.06	0.47	0.37	-	-	-	-	-	-	
SB vs SU	0.23	0.49	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.09	-	-	-	-	-	-	
SPB vs SU	0.80	0.53	**0.01**	**0.01**	0.21	**0.00**	**0.01**	**0.01**	0.21	0.23	-	-	-	-	-	-	
2002 vs 2003 *	0.07	0.15	**0.00**	0.53	0.98	0.67	0.09	**0.01**	0.67	0.07	-	-	-	-	-	-	
2002 vs 2004	0.95	0.16	0.24	0.41	0.56	0.17	0.36	0.25	0.61	**0.00**	-	-	-	-	-	-	
2002 vs 2005	**0.01**	**0.02**	**0.00**	0.52	**0.04**	**0.00**	**0.02**	0.15	0.11	0.26	-	-	-	-	-	-	
2003 vs 2004	0.13	**0.03**	**0.00**	0.27	**0.02**	0.19	**0.02**	**0.00**	0.38	0.18	-	-	-	-	-	-	
2003 vs 2005	**0.00**	0.13	**0.00**	0.16	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	0.77	-	-	-	-	-	-	
2004 vs 2005	**0.04**	0.30	**0.00**	0.34	**0.00**	**0.04**	0.17	0.07	0.07	**0.00**	-	-	-	-	-	-	

* Roa-Scott Test p Values for 2002 vs 2003 comparison presented here do not match those presented in the 2003 Annual Monitoring Results due to an adjustment to the spatial weighting.

Table 2.6. Summary of trace organic and trace element contaminants that were above water quality guidelines. Only compounds that were above guidelines are listed. An asterisk indicates a guideline exceedance.

			Cu (total)	Hg (total)	Ni (total)	Pb (total)	Cu (dissolved)
	SiteCode	Region	**A**	**A**	**A**	**A**	**A**
Rivers	BG20	Sacramento River					
	BG30	San Joaquin River					
Suisun Bay	SU011W	Suisun Bay					
	SU012W	Suisun Bay	*				
	SU013W	Suisun Bay	*				
	SU014W	Suisun Bay	*				
	SU015W	Suisun Bay	*				
	SU016W	Suisun Bay					
	SU017W	Suisun Bay	*				
	SU018W	Suisun Bay	*				
San Pablo Bay	SPB009W	San Pablo Bay	*	*	*	*	
	SPB010W	San Pablo Bay					
	SPB011W	San Pablo Bay		*	*		
	SPB012W	San Pablo Bay					
	SPB013W	San Pablo Bay					
	SPB014W	San Pablo Bay					
	SPB015W	San Pablo Bay	*				
	SPB016W	San Pablo Bay					
Central Bay	BC10	Yerba Buena Island					
	BC20	Golden Gate					
	CB009W	Central Bay					
	CB010W	Central Bay					
	CB011W	Central Bay					
	CB012W	Central Bay					
	CB013W	Central Bay					
	CB014W	Central Bay					
	CB015W	Central Bay					
	CB016W	Central Bay					
South Bay	BA30	Dumbarton Bridge					*
	SB020W	South Bay					
	SB021W	South Bay					
	SB022W	South Bay					*
	SB023W	South Bay					
	SB024W	South Bay					
	SB025W	South Bay					
	SB026W	South Bay					
	SB027W	South Bay					
	SB028W	South Bay					
	SB029W	South Bay	*				
	SB030W	South Bay					
	SB031W	South Bay					
	SB032W	South Bay	*				
	SB033W	South Bay					
	SB034W	South Bay					
	SB035W	South Bay					
	SB036W	South Bay					
	SB037W	South Bay					
Lower South Bay	LSB012W	Lower South Bay					
	LSB013W	Lower South Bay					
	LSB014W	Lower South Bay					
	LSB015W	Lower South Bay					
	LSB016W	Lower South Bay					
	LSB017W	Lower South Bay					
	LSB018W	Lower South Bay					
	LSB019W	Lower South Bay					
	LSB020W	Lower South Bay					
	LSB021W	Lower South Bay					

A. The guidelines used for these comparisons varied by site. The sites within estuarine regions were compared to the lower of the hardness dependendent fresh or salt water guideline and/or the Lower South Bay has a different site-specific objective.

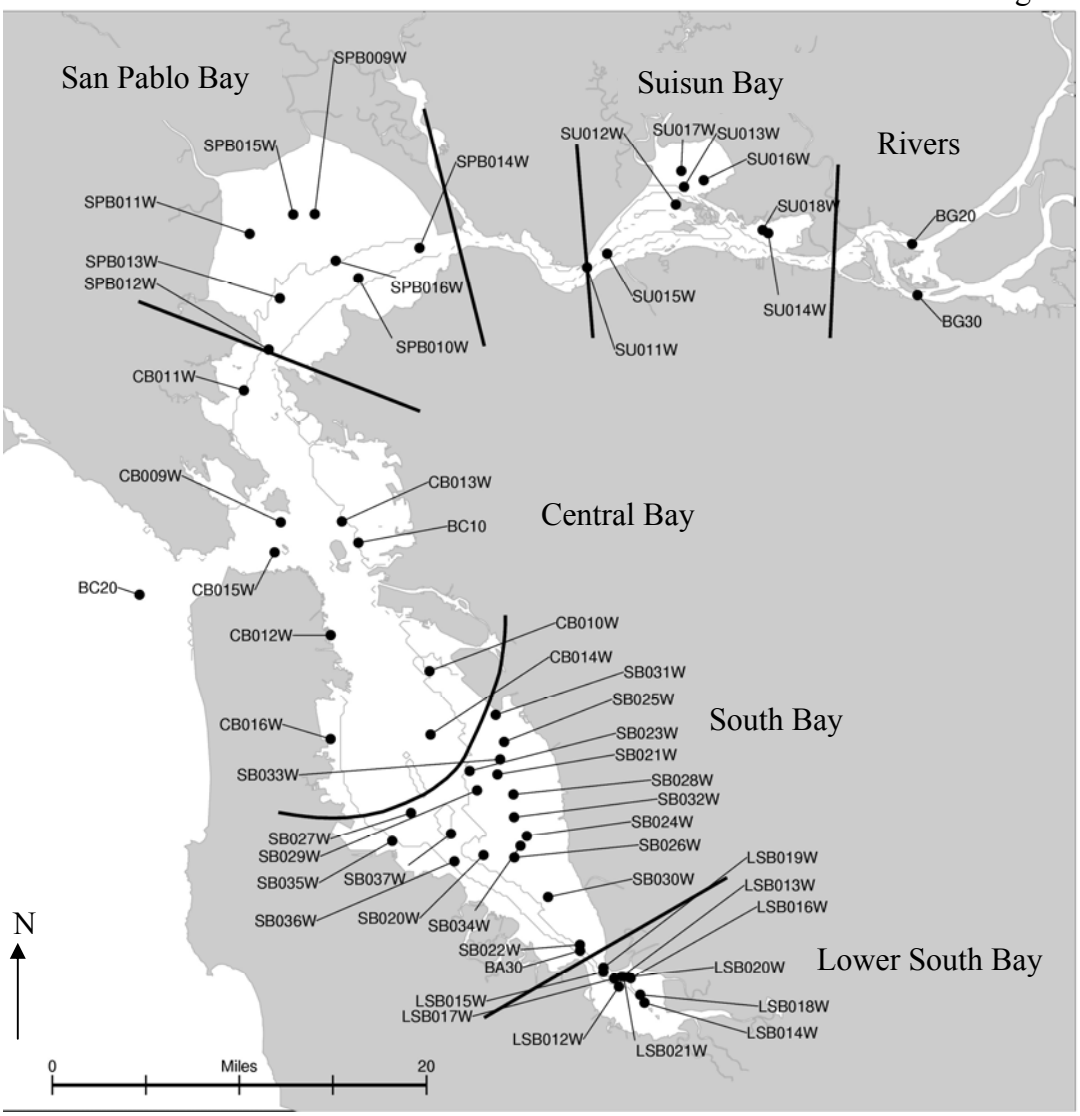
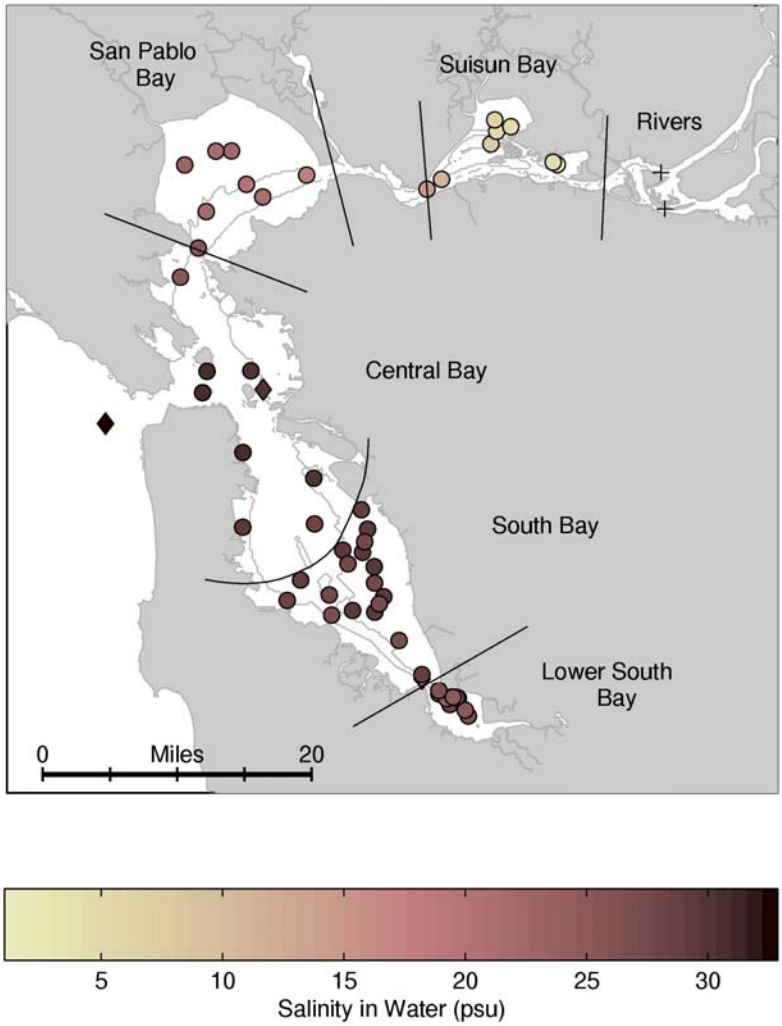


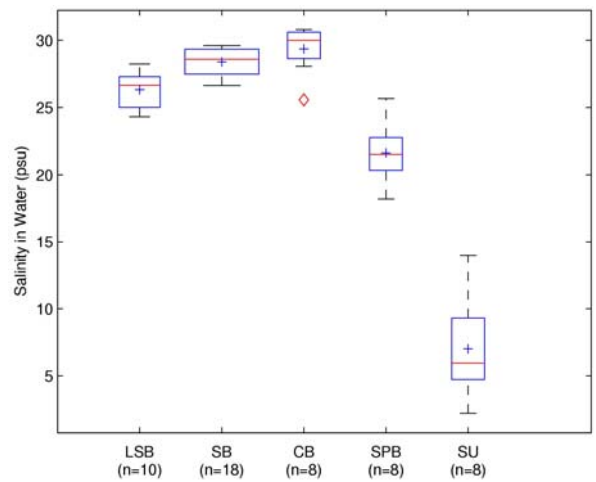
Figure 2.1 Map of the 2004 and 2005 RMP Status and Trends water monitoring effort at randomly selected and historic sampling sites. A total of 52 random stations (26 each year) and 5 historic sites (sampled each year) were sampled in the San Francisco Estuary for analysis of water quality and trace contaminants.

Figure 2.2a-c. Salinity in Water (2004-2005)



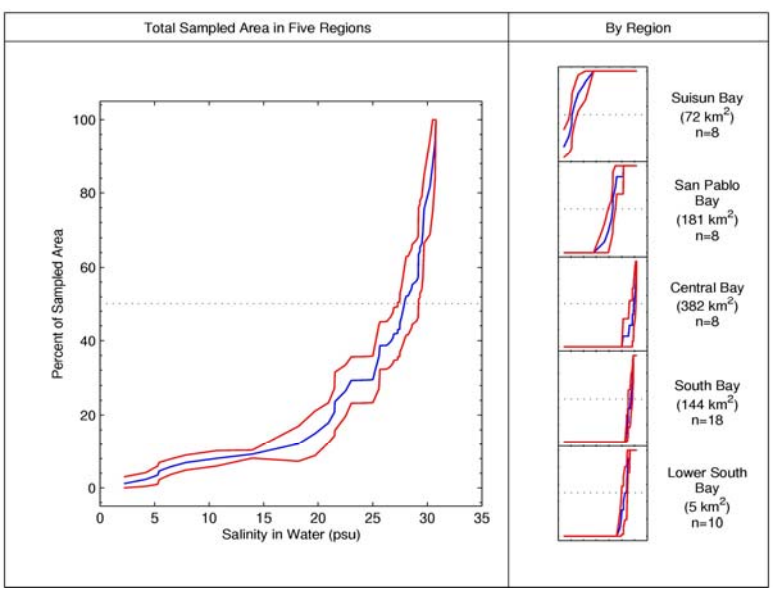
a) Map of salinity concentrations in water (practical salinity units - psu) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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



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

b) Schematic Box Plot of salinity concentrations for the random sites in the five Estuary regions (2004-2005).

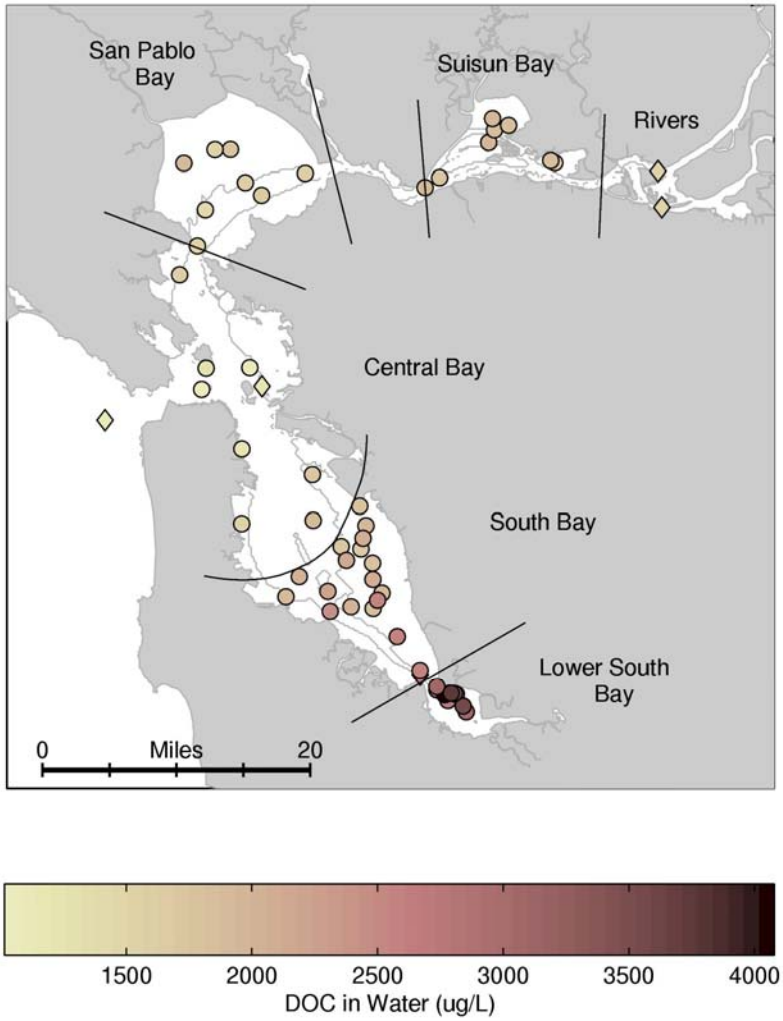


c) Cumulative distribution function (CDF) plots for salinity concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the salinity concentrations in water.

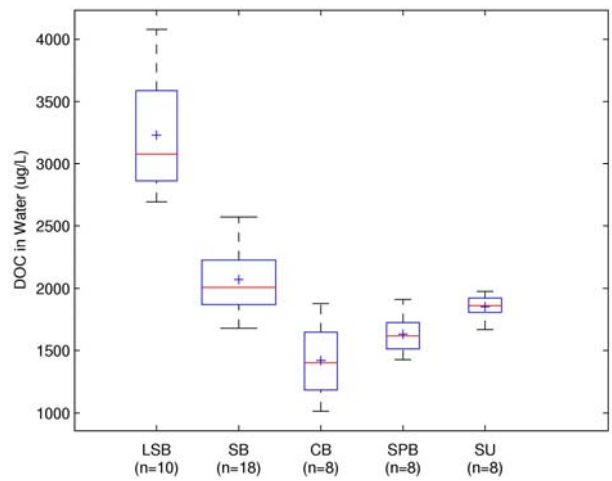
The small graphs show the same for each individual region (scales are identical to the large graph).

Figure 2.3a-c. Dissolved Organic Carbon (DOC) in Water (2004-2005)



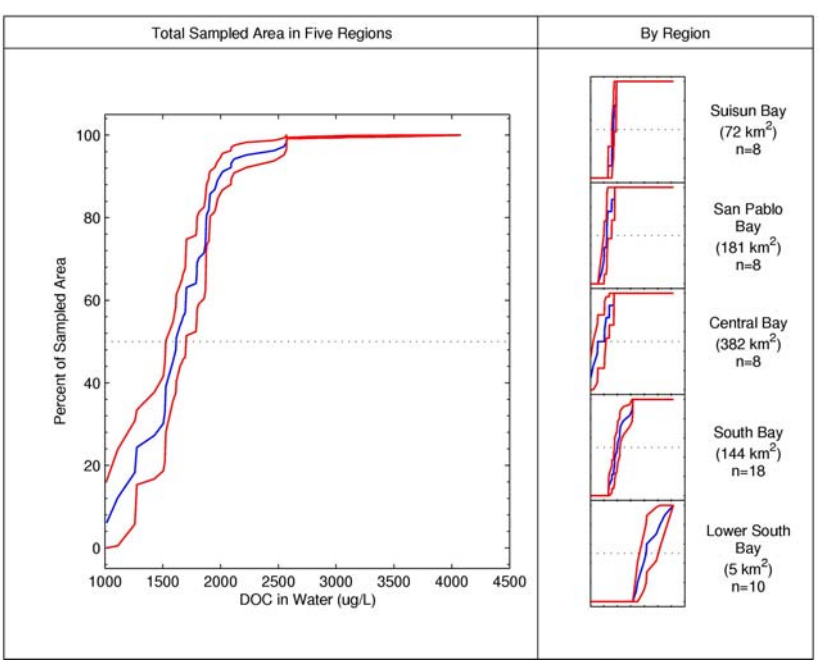
a) Map of dissolved organic carbon concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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



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

b) Schematic Box Plot of dissolved organic carbon concentrations for the random sites in the five Estuary regions (2004-2005).

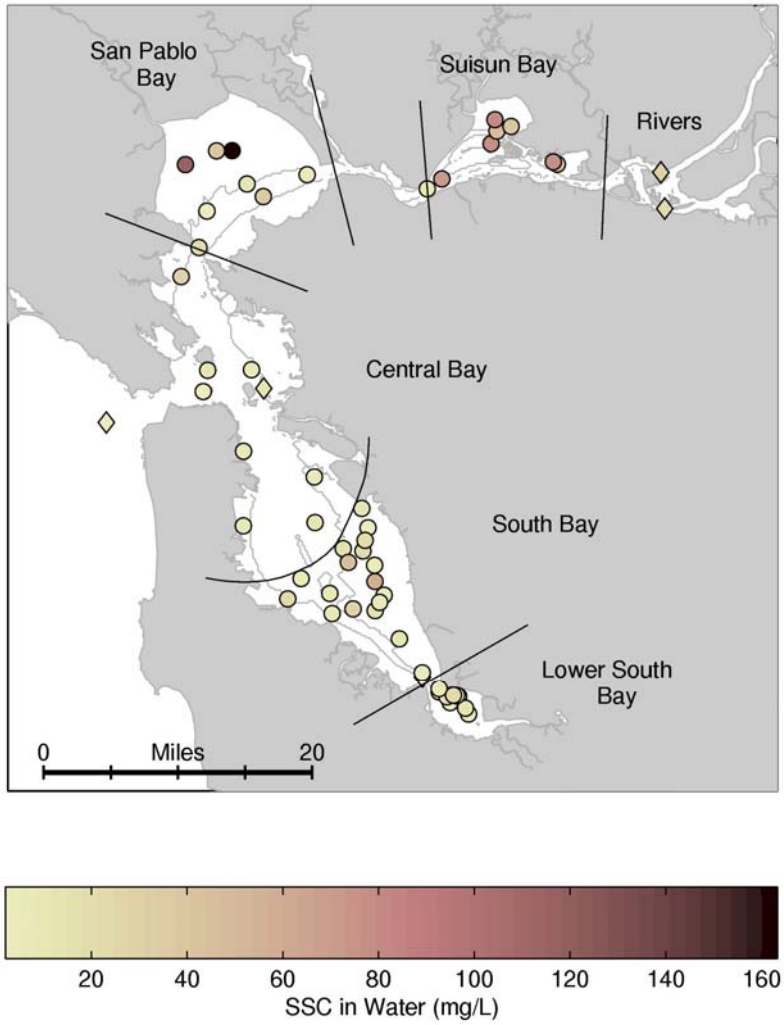


c) Cumulative distribution function (CDF) plots for dissolved organic carbon concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved organic carbon concentrations in water.

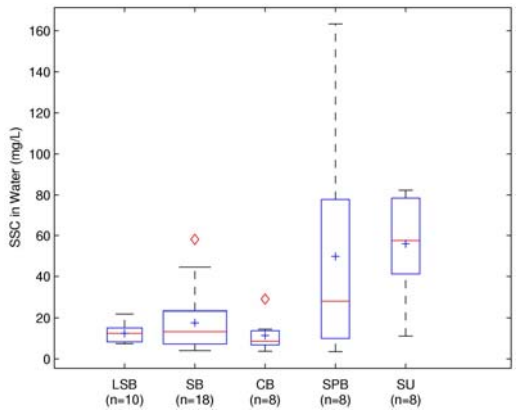
The small graphs show the same for each individual region (scales are identical to the large graph).

Figure 2.4a-c. Suspended Solids Concentration (SSC) in Water (2004-2005)



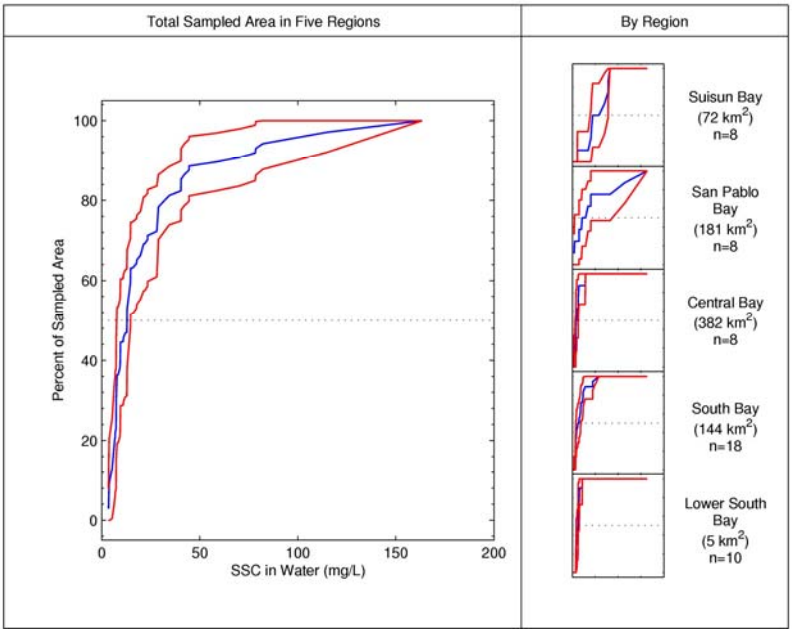
a) Map of suspended solids concentrations in water (mg/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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



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

b) Schematic Box Plot of suspended solids concentrations for the random sites in the five Estuary regions (2004-2005).

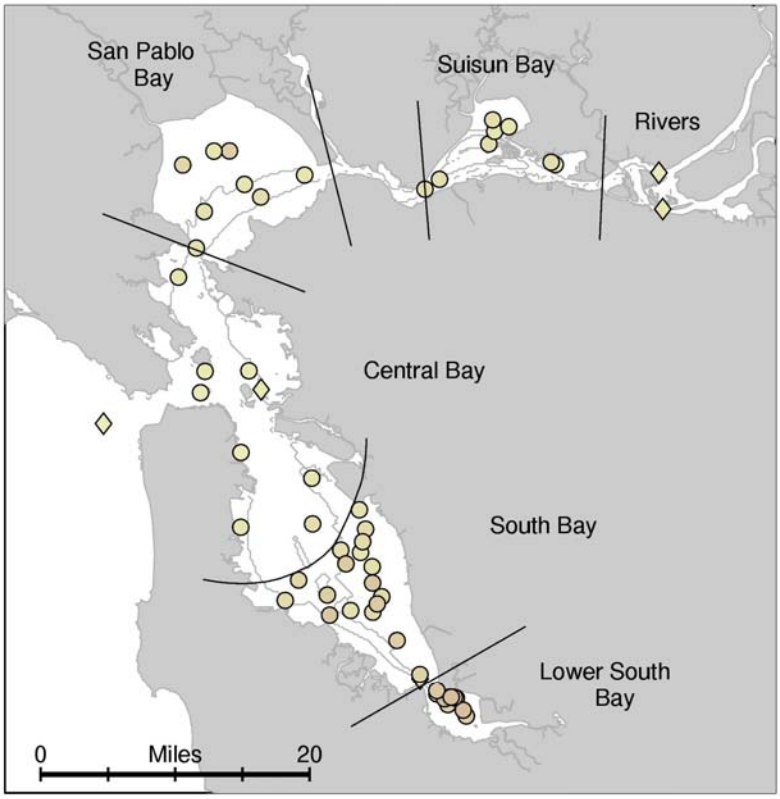


c) Cumulative distribution function (CDF) plots for suspended solids concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the suspended solids concentrations in water.

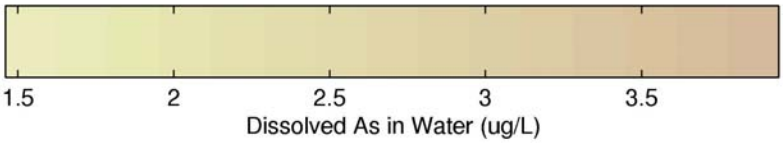
The small graphs show the same for each individual region (scales are identical to the large graph).

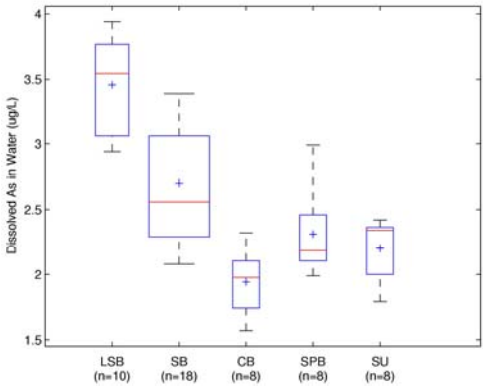
Figure 2.5a-c. Dissolved Arsenic (As) in Water (2004-2005)



a) Map of dissolved arsenic concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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

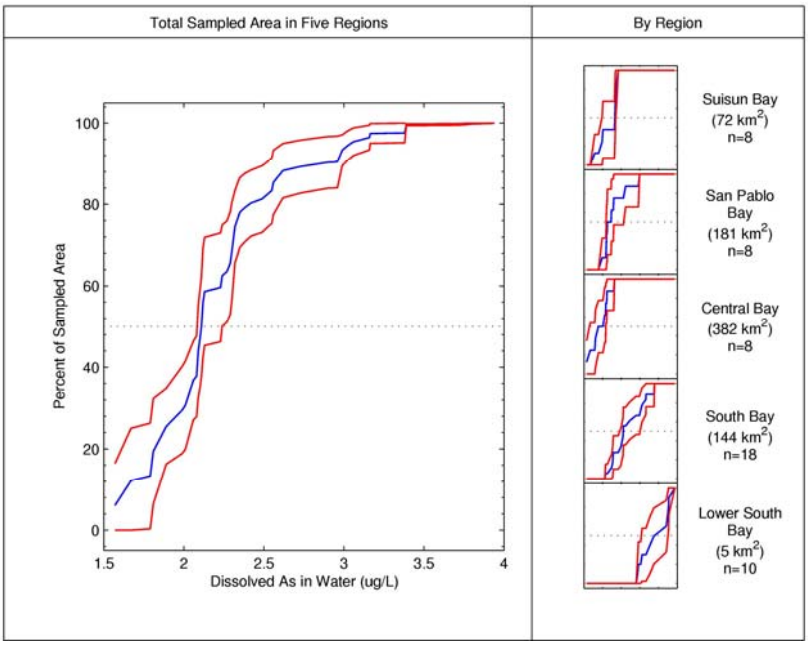




All samples were below the CTR 4-day Aquatic Life saltwater criterion of 36 ug/L.

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

b) Schematic Box Plot of dissolved arsenic concentrations for the random sites in the five Estuary regions (2004-2005).



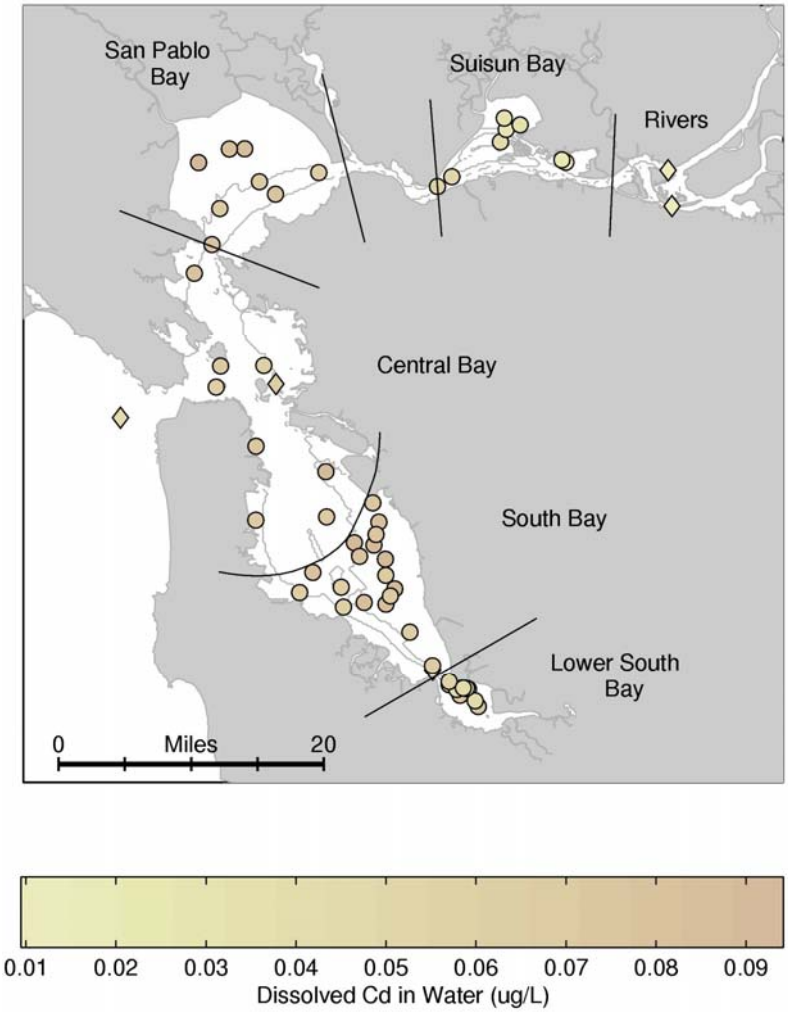
c) Cumulative distribution function (CDF) plots for dissolved arsenic concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved arsenic concentrations in water.

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

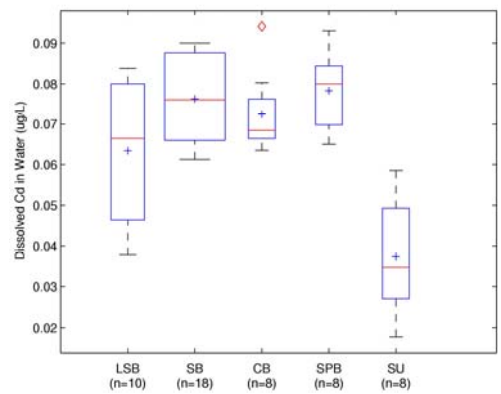
The large plot indicates that about 50% of the Estuary regions sampled had dissolved arsenic concentrations of approximately 2.2 ug/L or less.

Figure 2.6a-c. Dissolved Cadmium (Cd) in Water (2004-2005)



a) Map of dissolved cadmium concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

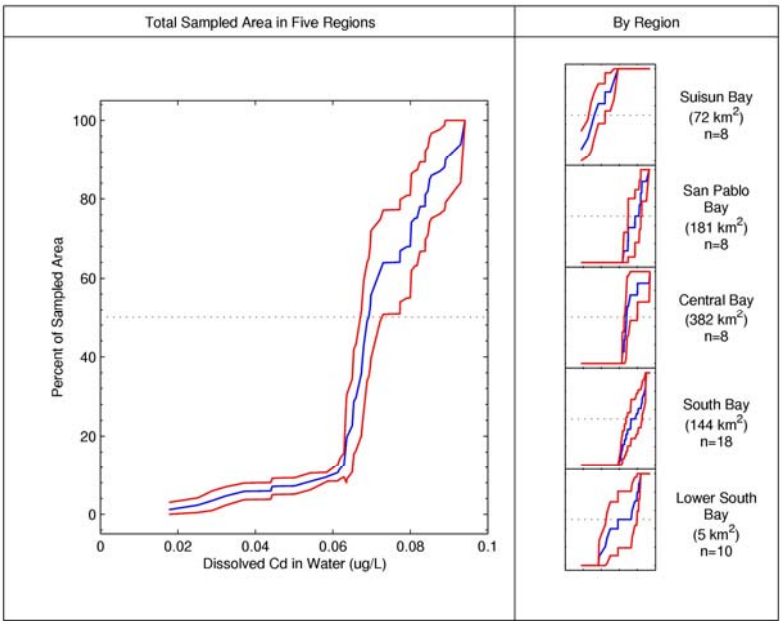
Random sites = ○, Historic sites = ◊, Non-detects = +



All samples were below the CTR 4-day Aquatic Life saltwater or calculated freshwater criterion of 9.3 or 2.2 ug/L.

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

b) Schematic Box Plot of dissolved cadmium concentrations for the random sites in the five Estuary regions (2004-2005).



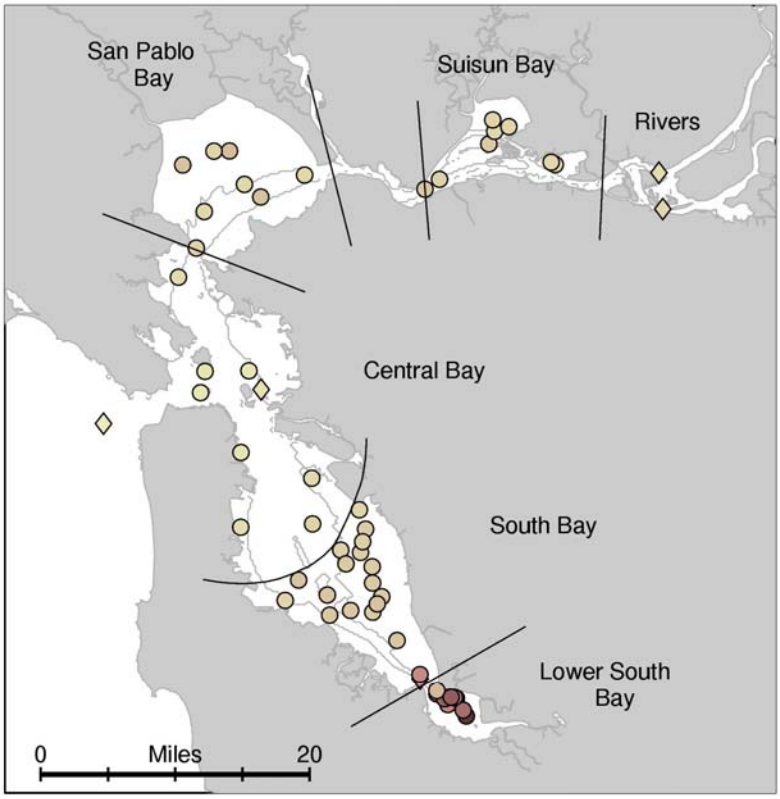
c) Cumulative distribution function (CDF) plots for dissolved cadmium concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved cadmium concentrations in water.

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

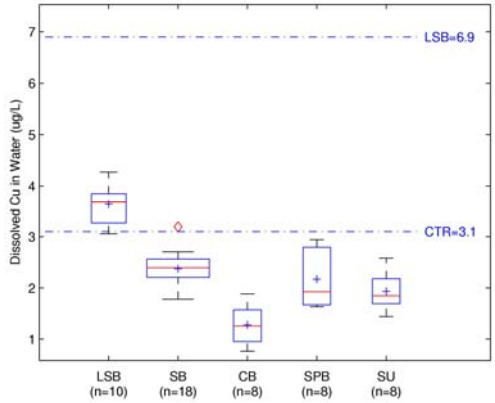
The large plot indicates that about 50% of the Estuary regions sampled had dissolved cadmium concentrations of 0.07 ug/L or less.

Figure 2.7a-c. Dissolved Copper (Cu) in Water (2004-2005)



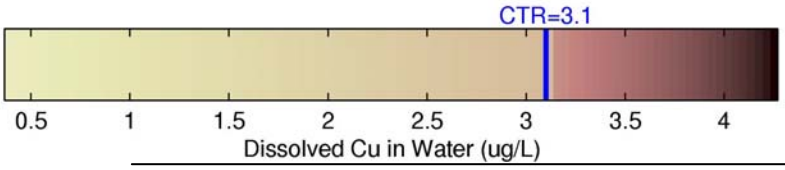
a) Map of dissolved copper concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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

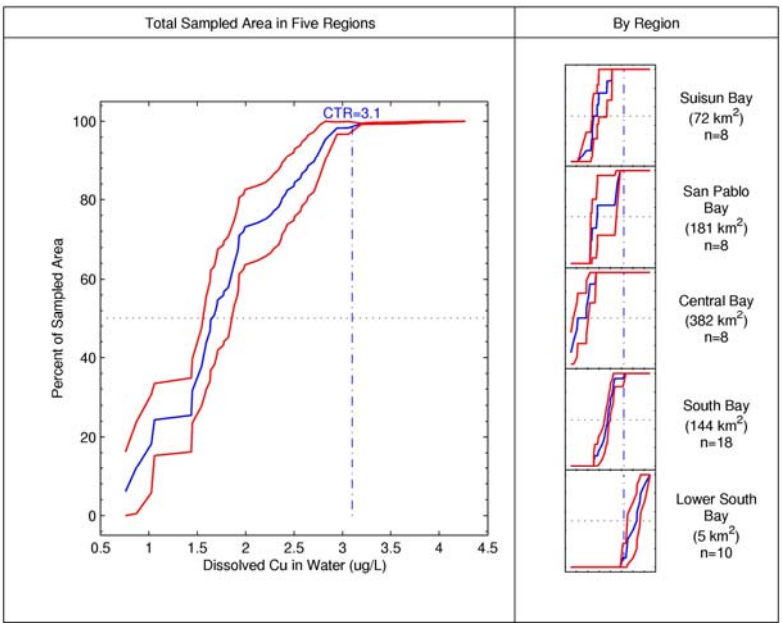


The Lower South Bay has a site-specific objective of 6.9 ug/L. The CTR 4-day Aquatic Life saltwater criterion of 3.1 ug/L applies to all other Estuary regions.

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



b) Schematic Box Plot of dissolved copper concentrations for the random sites in the five Estuary regions (2004-2005).



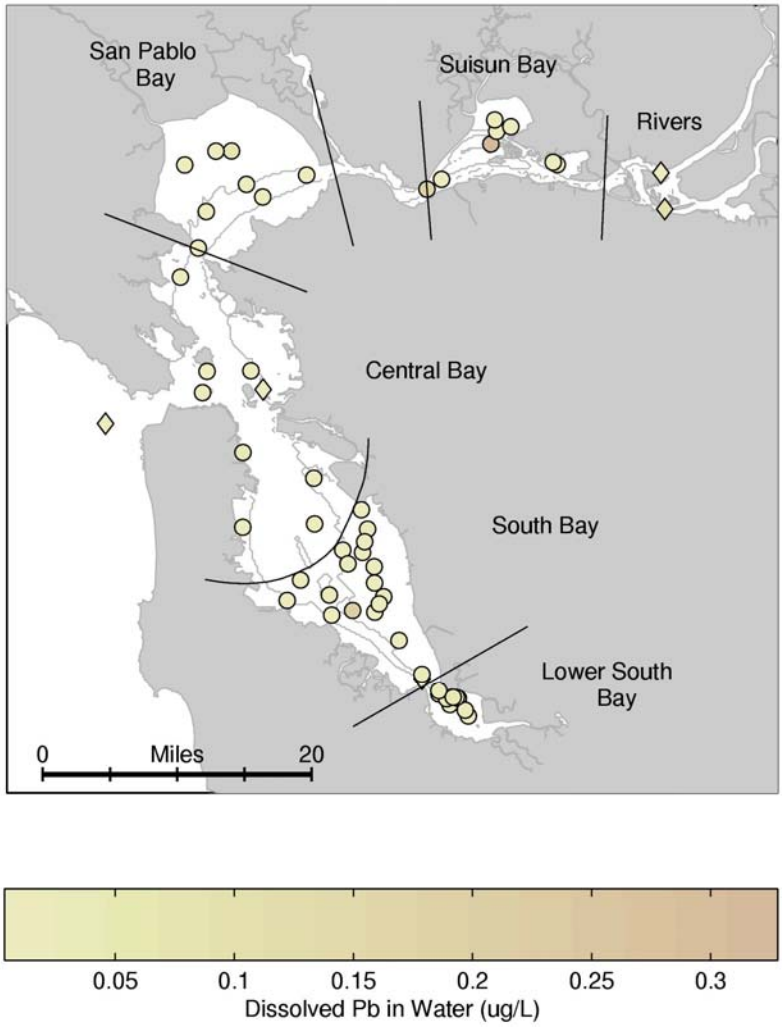
c) Cumulative distribution function (CDF) plots for dissolved copper concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved copper concentrations in water.

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

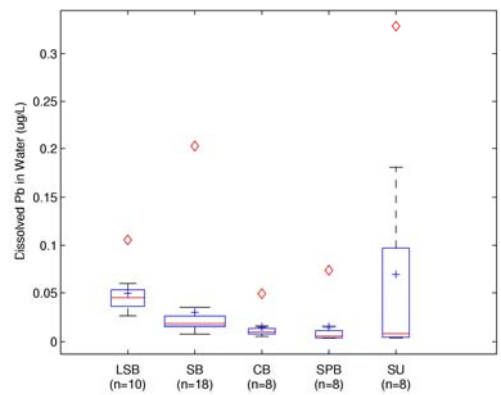
The large plot indicates that about 50% of the Estuary regions sampled had dissolved copper concentrations of ~1.7 ug/L or less. All Lowers South Bay samples were below the site-specific objective of 6.9 ug/L.

Figure 2.8a-c. Dissolved Lead (Pb) in Water (2004-2005)



a) Map of dissolved lead concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

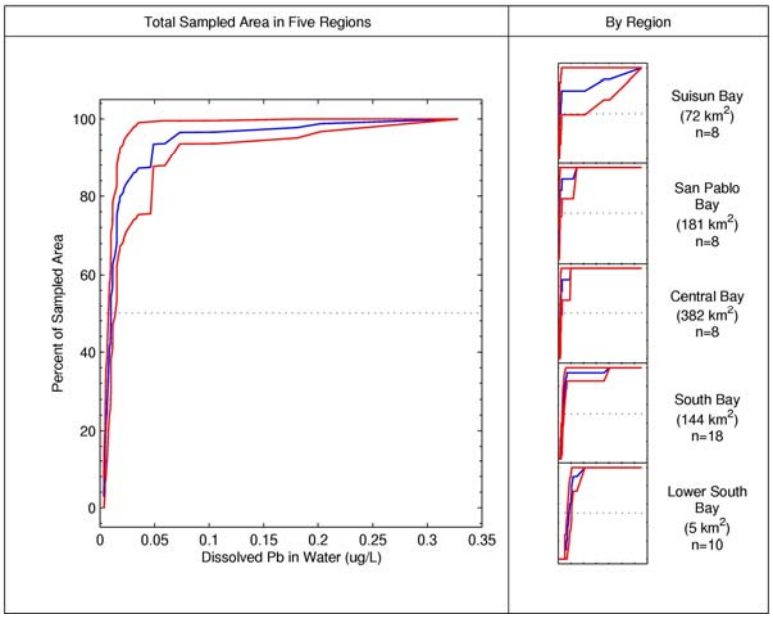
Random sites = ○, Historic sites = ◊, Non-detects = +



All samples were below the CTR 4-day Aquatic Life saltwater or calculated freshwater criterion of 8.1 or 2.5 ug/L.

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

b) Schematic Box Plot of dissolved lead concentrations for the random sites in the five Estuary regions (2004-2005).



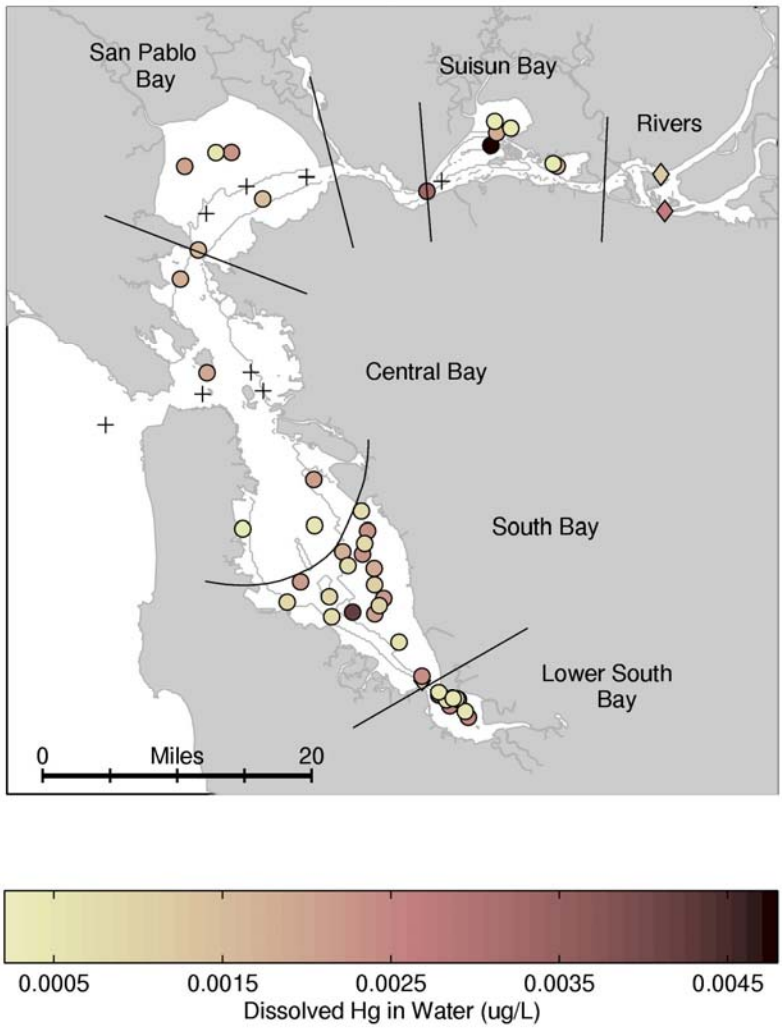
c) Cumulative distribution function (CDF) plots for dissolved lead concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved lead concentrations in water.

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

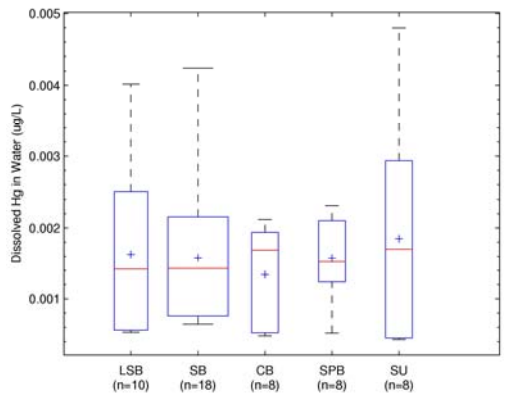
The large plot indicates that about 50% of the Estuary regions sampled had dissolved lead concentrations of ~0.02 ug/L or less..

Figure 2.9a-c. Dissolved Mercury (Hg) in Water (2004-2005)



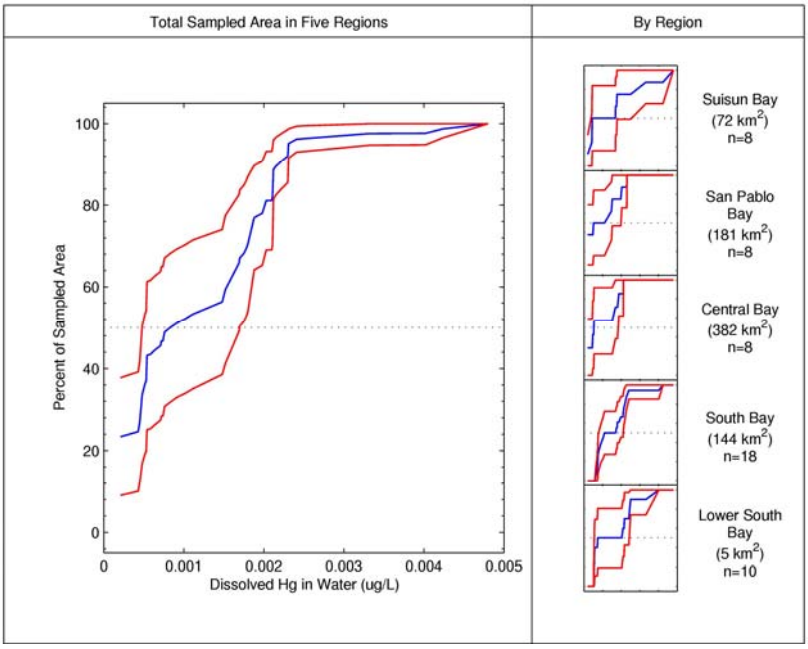
a) Map of dissolved mercury concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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



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

b) Schematic Box Plot of dissolved mercury concentrations for the random sites in the five Estuary regions (2004-2005).



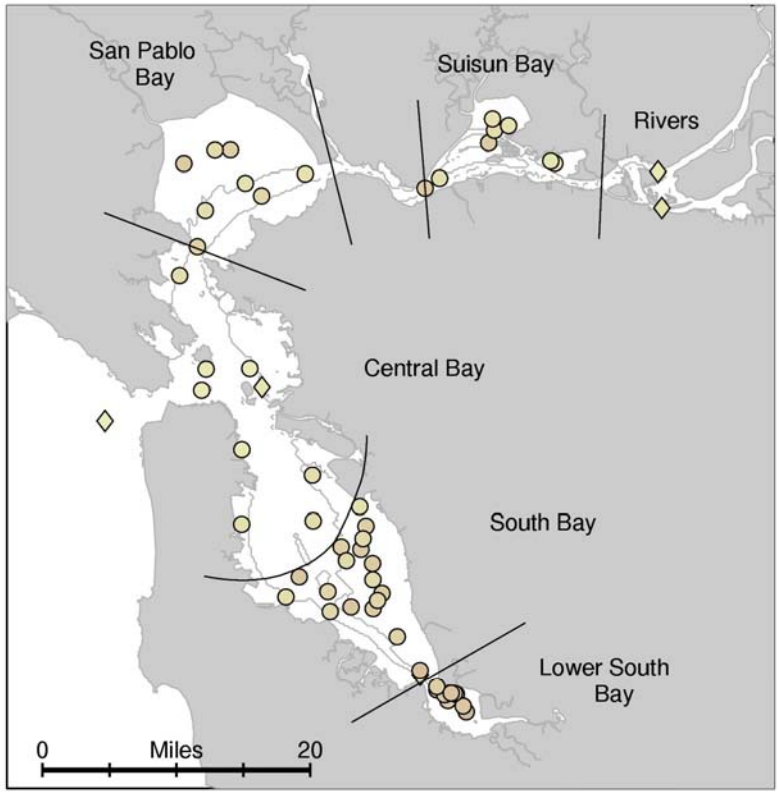
c) Cumulative distribution function (CDF) plots for dissolved mercury concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved mercury concentrations in water.

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

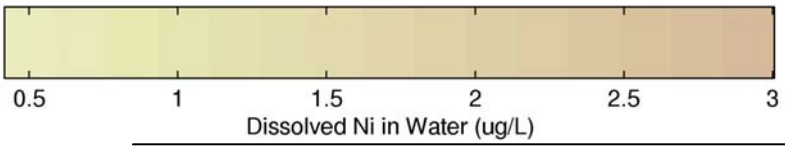
The large plot indicates that about 50% of the Estuary regions sampled had dissolved mercury concentrations of ~0.0007 ug/L or less..

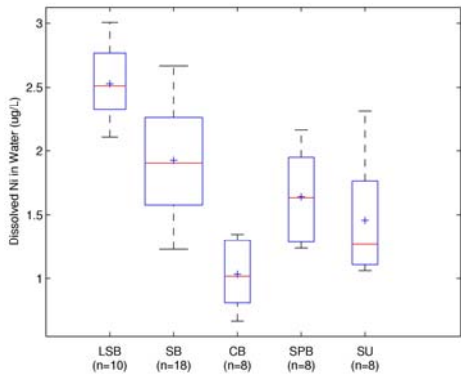
Figure 2.10a-c. Dissolved Nickel (Ni) in Water (2004-2005)



a) Map of dissolved nickel concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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

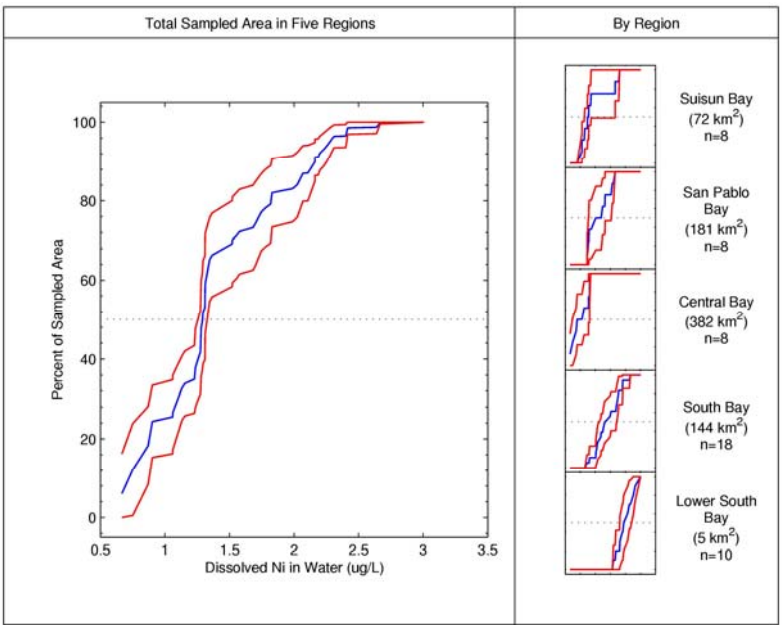




All samples were below the CTR 4-day Aquatic Life saltwater criterion of 8.2 ug/L. The Lower South Bay has a site-specific objective of 11.9 ug/L.

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

b) Schematic Box Plot of dissolved nickel concentrations for the random sites in the five Estuary regions (2004-2005).



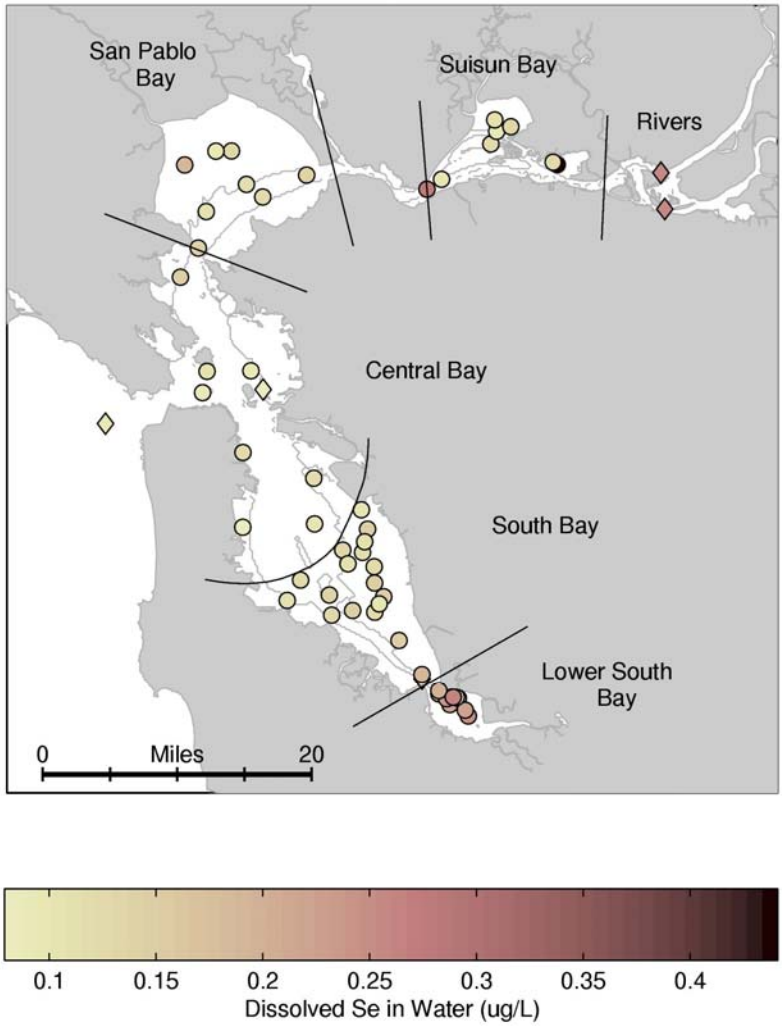
c) Cumulative distribution function (CDF) plots for dissolved nickel concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved nickel concentrations in water.

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

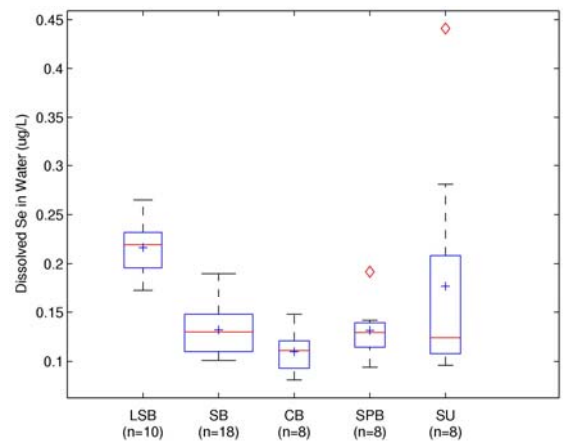
The large plot indicates that about 50% of the Estuary regions sampled had dissolved nickel concentrations of ~1.3 ug/L or less.

Figure 2.11a-c. Dissolved Selenium (Se) in Water (2004-2005)



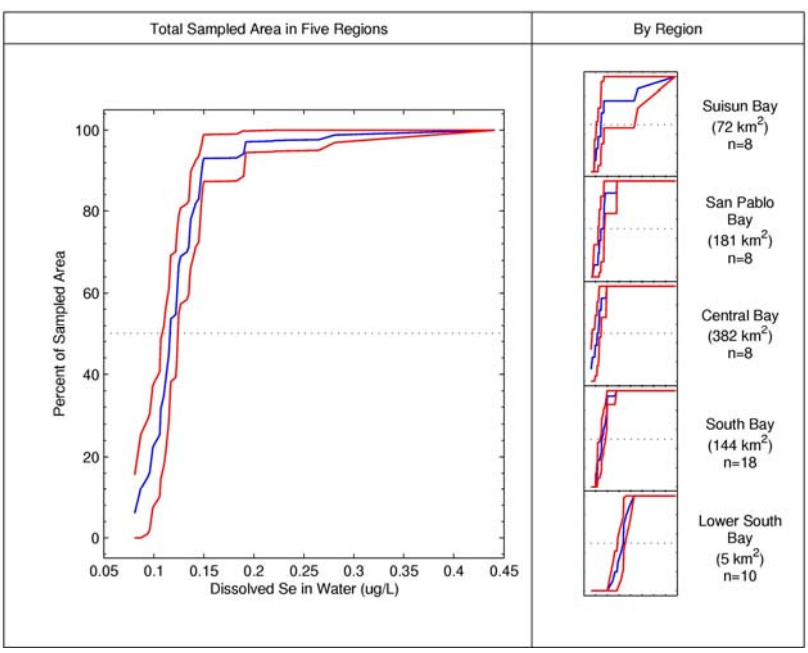
a) Map of dissolved selenium concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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



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

b) Schematic Box Plot of dissolved selenium concentrations for the random sites in the five Estuary regions (2004-2005).



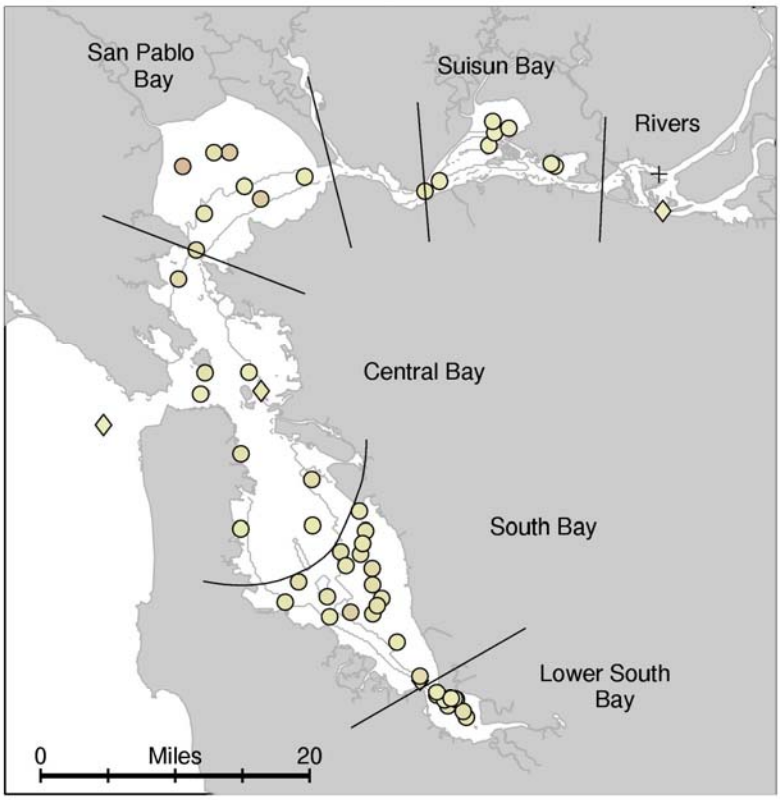
c) Cumulative distribution function (CDF) plots for dissolved selenium concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved selenium concentrations in water.

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

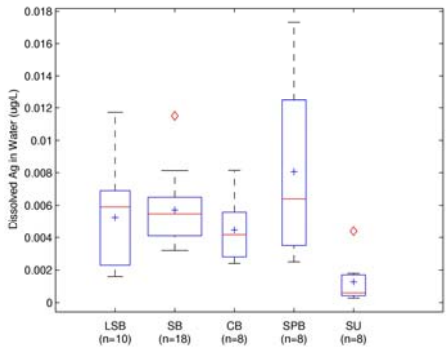
The large plot indicates that about 50% of the Estuary regions sampled had dissolved selenium concentrations of ~0.104 ug/L or less.

Figure 2.12a-c. Dissolved Silver (Ag) in Water (2004-2005)



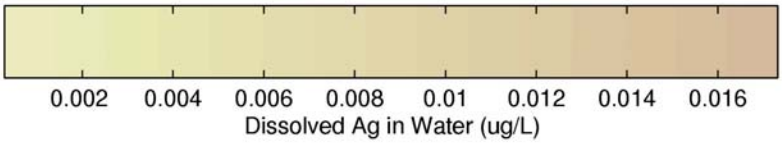
a) Map of dissolved silver concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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

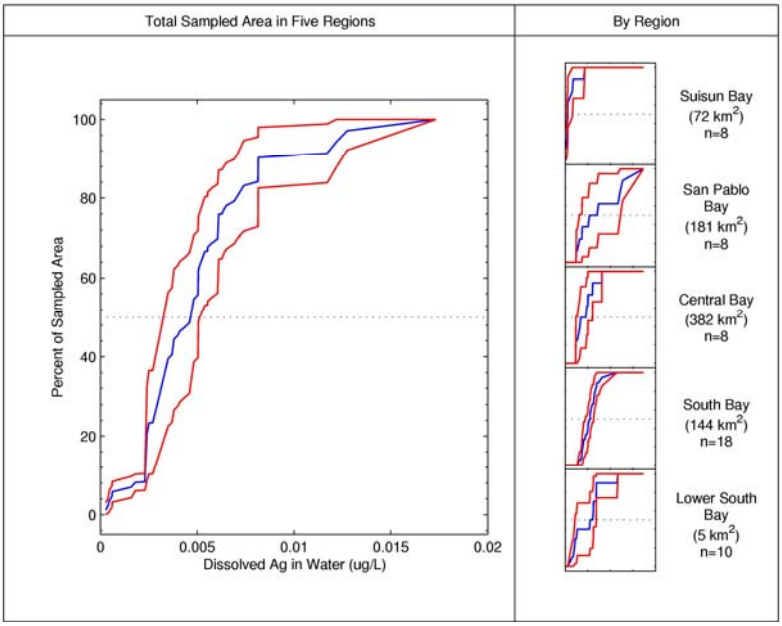


All samples were below the CTR 1-hour Aquatic Life saltwater criterion of 1.9 ug/L.

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



b) Schematic Box Plot of dissolved silver concentrations for the random sites in the five Estuary regions (2004-2005).



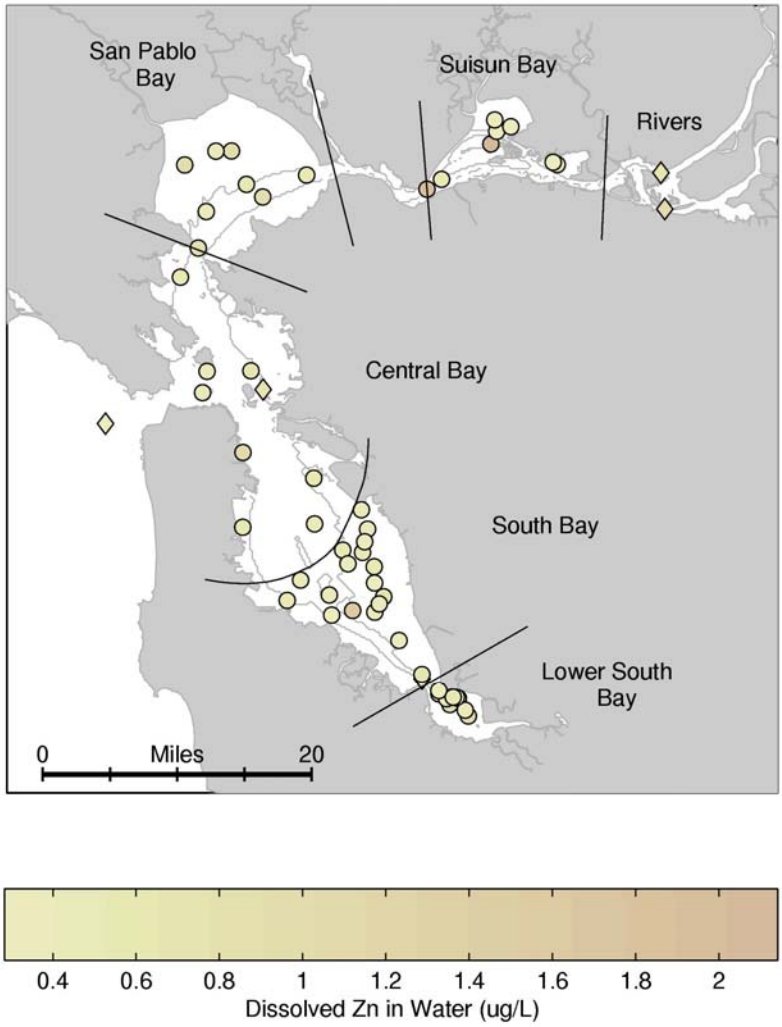
c) Cumulative distribution function (CDF) plots for dissolved silver concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved silver concentrations in water.

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

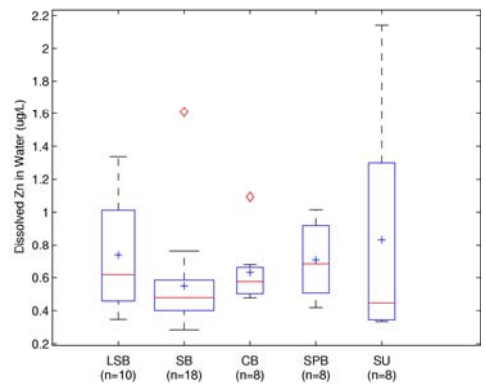
The large plot indicates that 100% of the Estuary regions sampled had dissolved silver concentrations below the CTR 1-hour Aquatic Life saltwater criterion of 1.9 ug/L.

Figure 2.13a-c. Dissolved Zinc (Zn) in Water (2004-2005)



a) Map of dissolved zinc concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

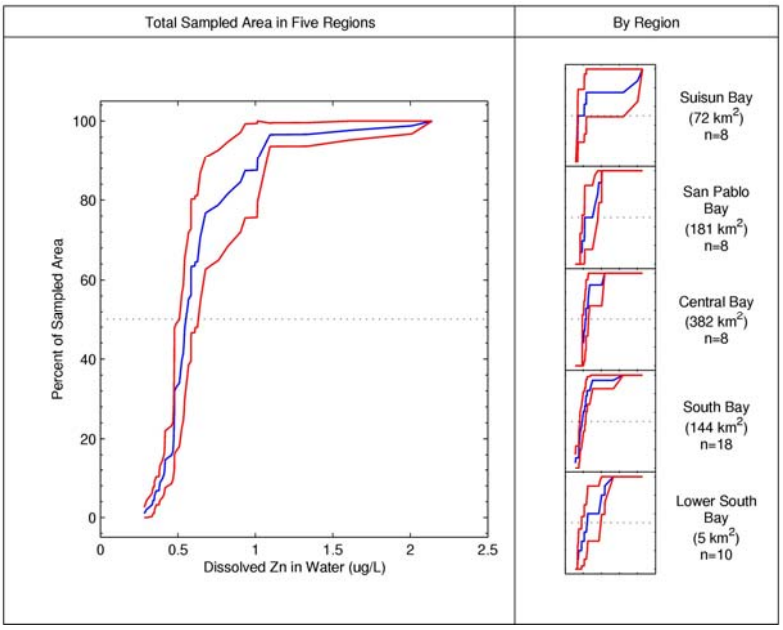
Random sites = ○, Historic sites = ◊, Non-detects = +



All samples were below the CTR 4-day Aquatic Life saltwater criterion of 81 ug/L.

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

b) Schematic Box Plot of dissolved zinc concentrations for the random sites in the five Estuary regions (2004-2005).



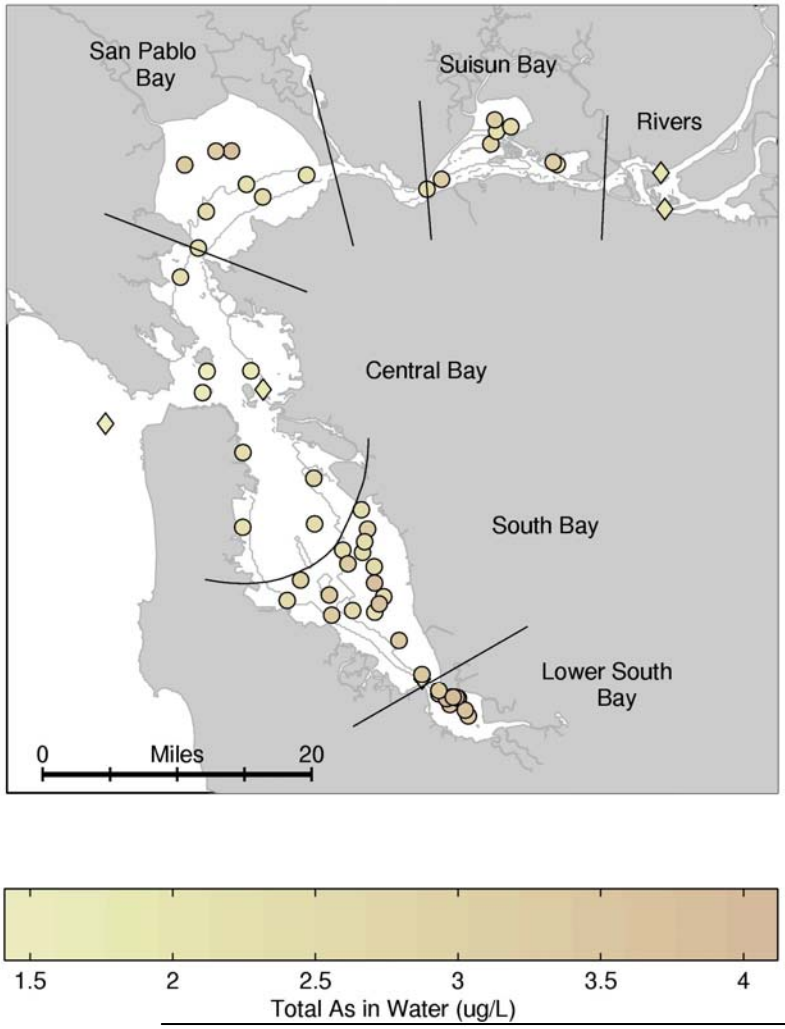
c) Cumulative distribution function (CDF) plots for dissolved zinc concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved zinc concentrations in water.

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

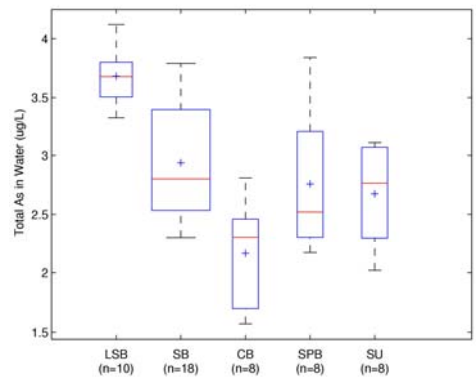
The large plot indicates that about 50% of the Estuary regions sampled had dissolved zinc concentrations of ~0.5 ug/L or less.

Figure 2.14a-c. Total Arsenic (As) in Water (2004-2005)



a) Map of total arsenic concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

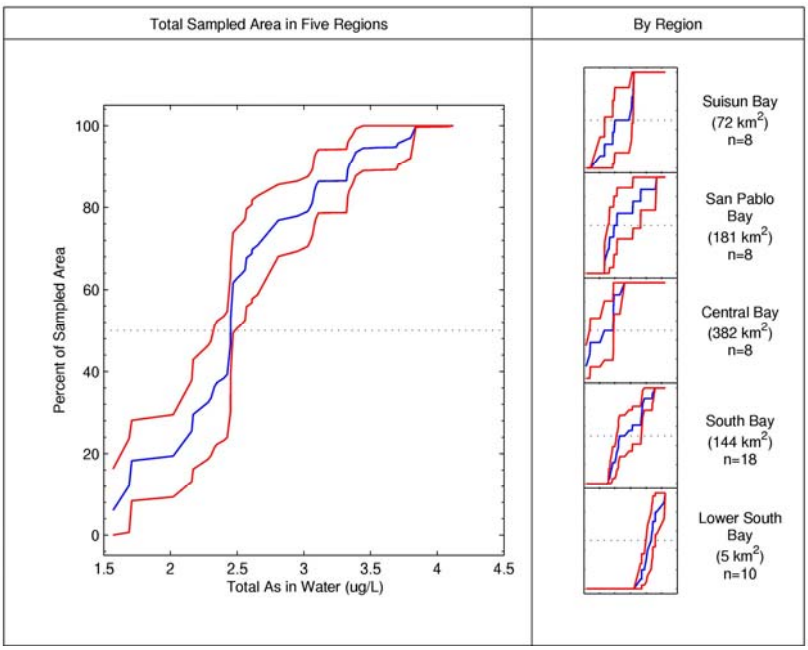
Random sites = ○, Historic sites = ◊, Non-detects = +



Default CTR conversion factors were used to calculate the total effects threshold value. All samples were below the non-regulatory effects threshold of 36 ug/L.

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

b) Schematic Box Plot of total arsenic concentrations for the random sites in the five Estuary regions (2004-2005).



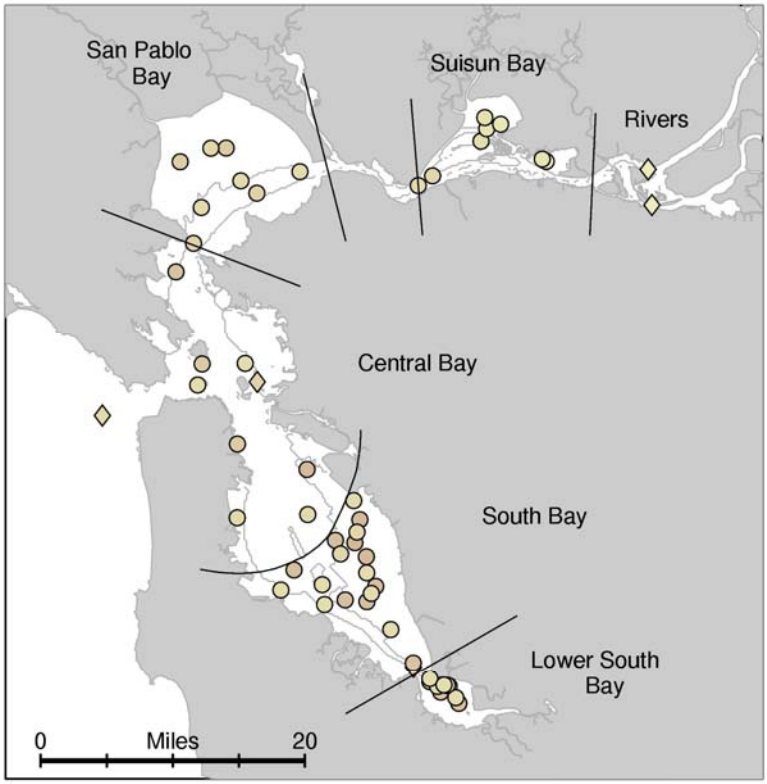
c) Cumulative distribution function (CDF) plots for total arsenic concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the total arsenic concentrations in water.

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

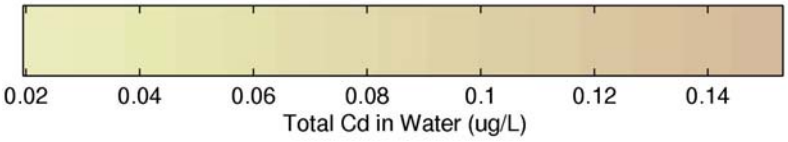
The large plot indicates that about 50% of the Estuary regions sampled had total arsenic concentrations of ~2.5 ug/L or less.

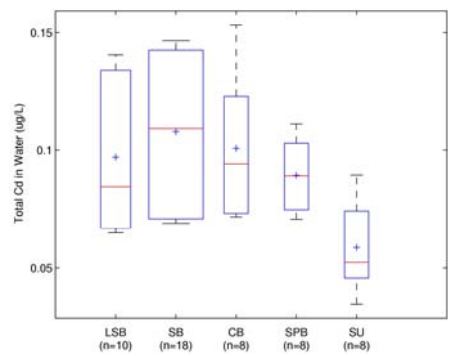
Figure 2.15a-c. Total Cadmium (Cd) in Water (2004-2005)



a) Map of total cadmium concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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

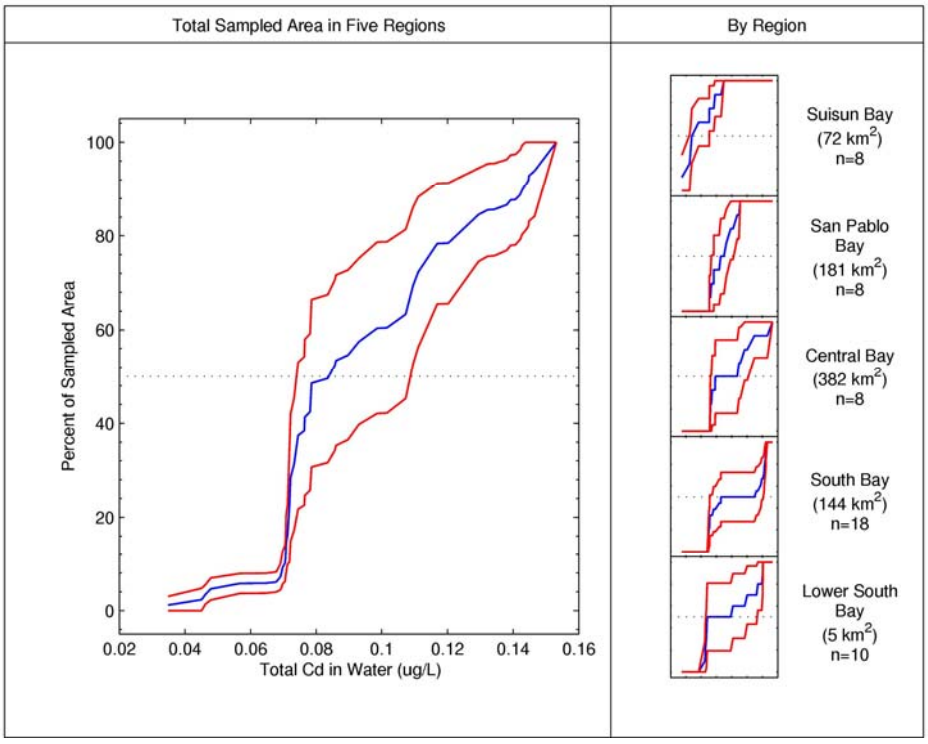




Default CTR conversion factors were used to calculate the total effects threshold value. All samples were below the non-regulatory saltwater or calculated freshwater effects threshold of 9.4 or 2.5 ug/L.

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

b) Schematic Box Plot of total cadmium concentrations for the random sites in the five Estuary regions (2004-2005).



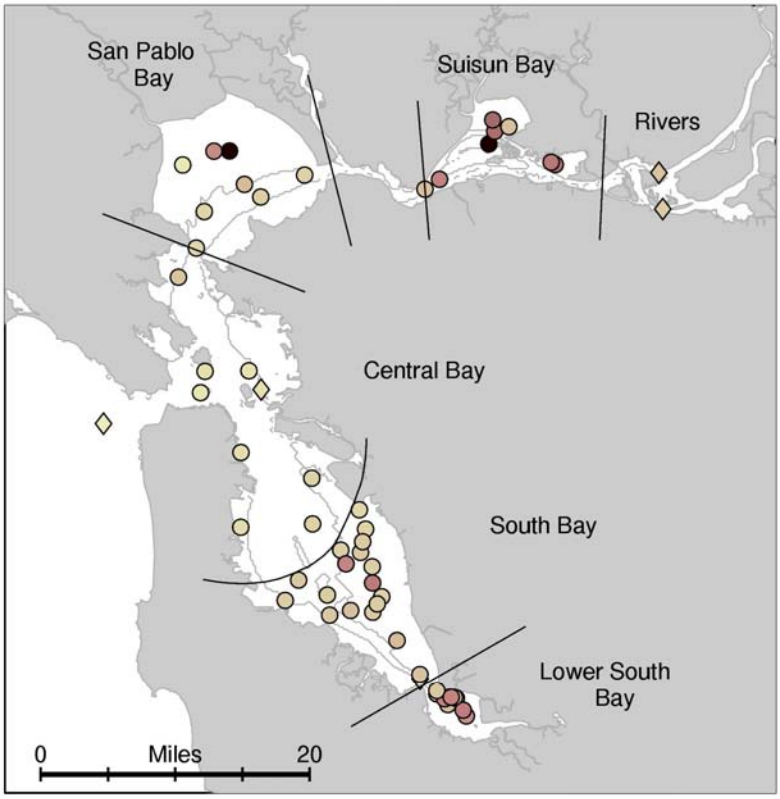
c) Cumulative distribution function (CDF) plots for total cadmium concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the total cadmium concentrations in water.

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

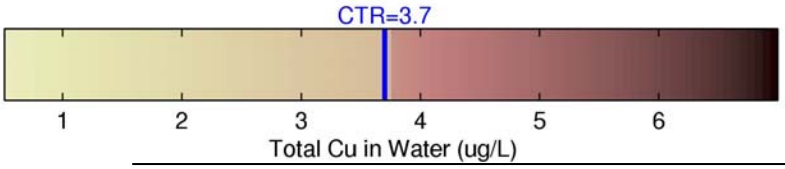
The large plot indicates that about 50% of the Estuary regions sampled had total cadmium concentrations of ~0.08 ug/L or less.

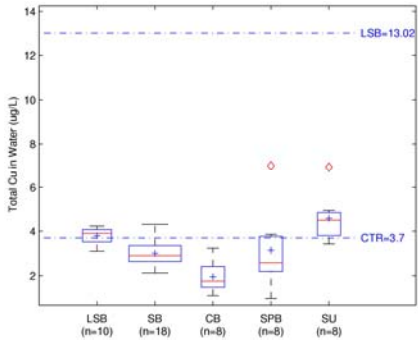
Figure 2.16a-c. Total Copper (Cu) in Water (2004-2005)



a) Map of total copper concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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

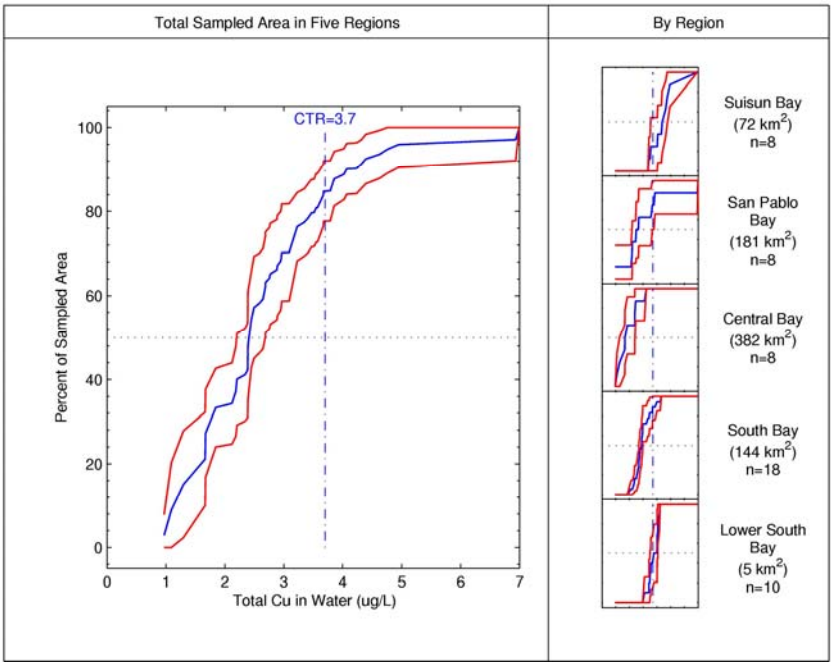




Default CTR conversion factors were used to calculate the total effects threshold value. The Lower South Bay has a site-specific criterion of 13.02 ug/L. The non-regulatory saltwater effects threshold of 3.7 ug/L applies to all other regions.

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

b) Schematic Box Plot of total copper concentrations for the random sites in the five Estuary regions (2004-2005).



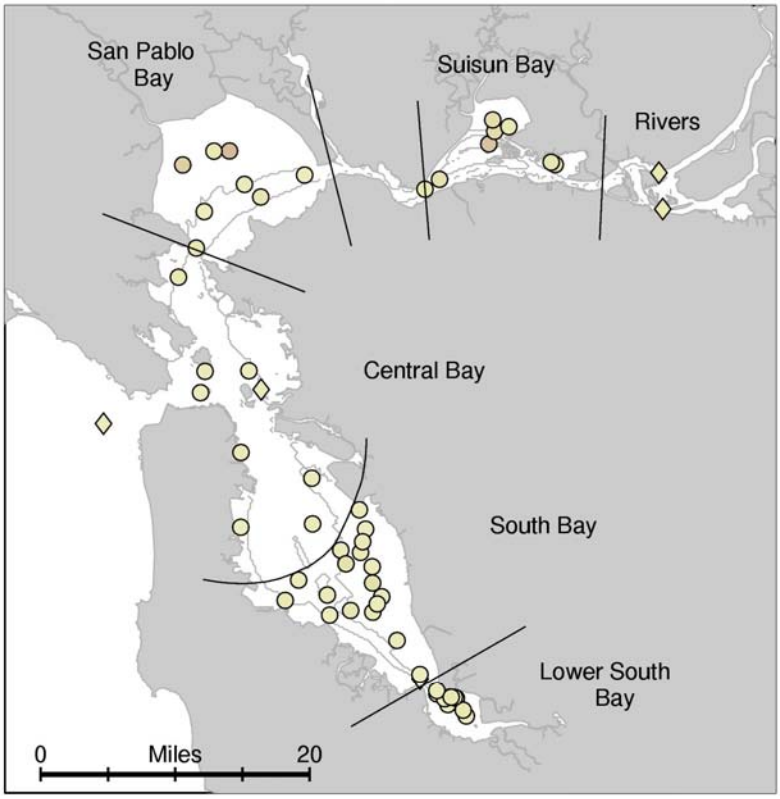
c) Cumulative distribution function (CDF) plots for total copper concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the total copper concentrations in water.

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

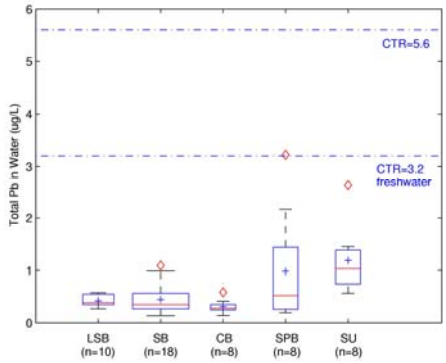
The large plot indicates that about 50% of the Estuary regions sampled had total copper concentrations of ~2.5 ug/L or less.

Figure 2.17a-c. Total Lead (Pb) in Water (2004-2005)



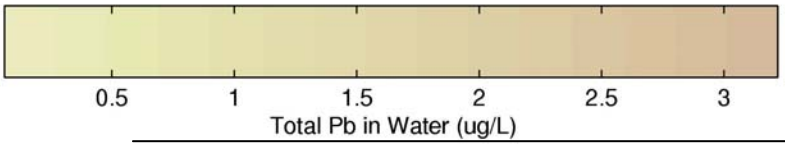
a) Map of total lead concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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

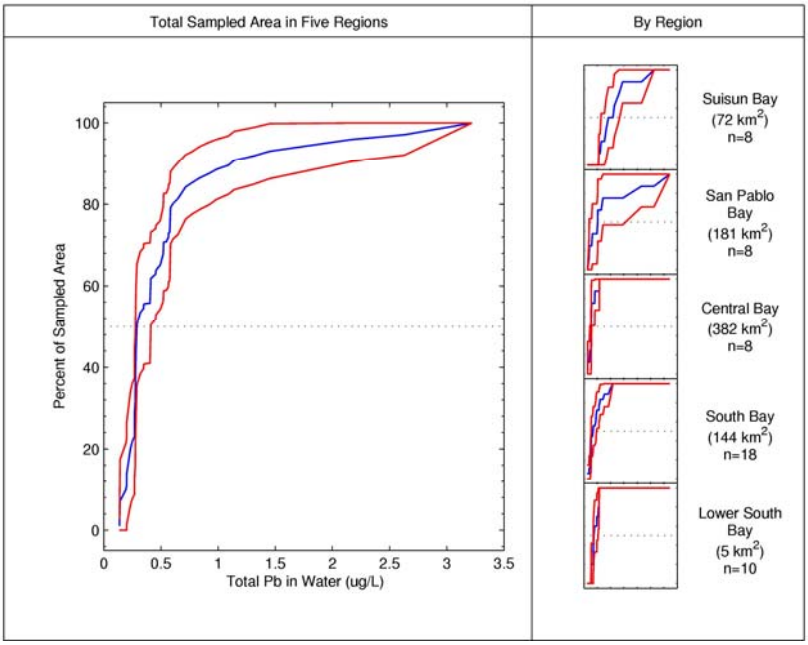


Default CTR conversion factors were used to calculate the total effects threshold value. The calculate non-regulatory freshwater criterion of 3.2 ug/L applies to estuarine regions of the Estuary.

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



b) Schematic Box Plot of total lead concentrations for the random sites in the five Estuary regions (2004-2005).



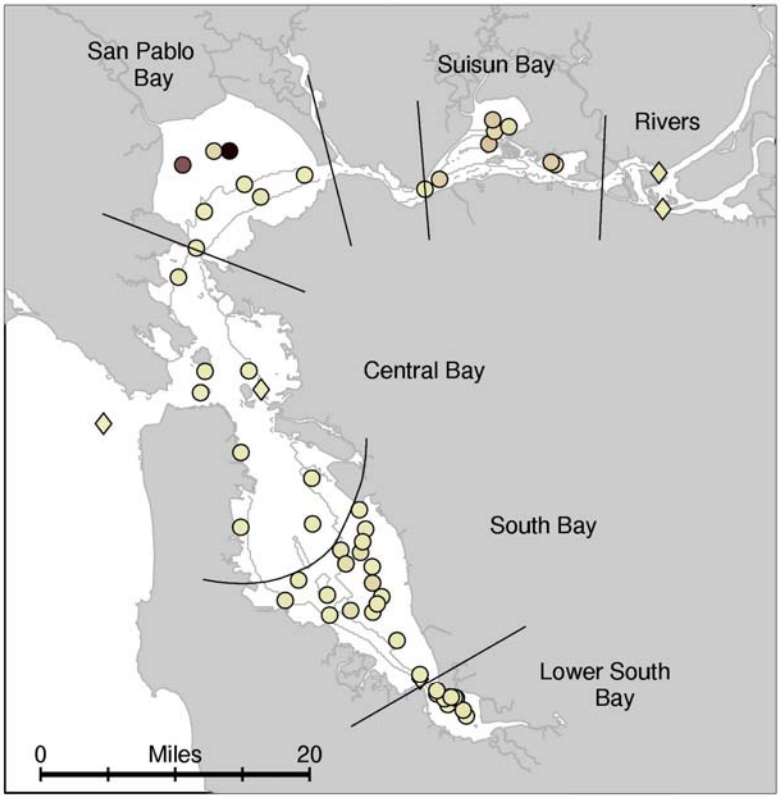
c) Cumulative distribution function (CDF) plots for total lead concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the total lead concentrations in water.

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

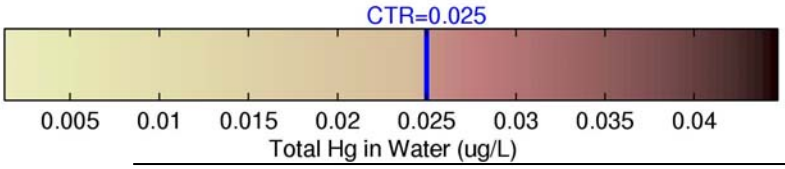
The large plot indicates that about 50% of the Estuary regions sampled had total lead concentrations of ~0.3 ug/L or less.

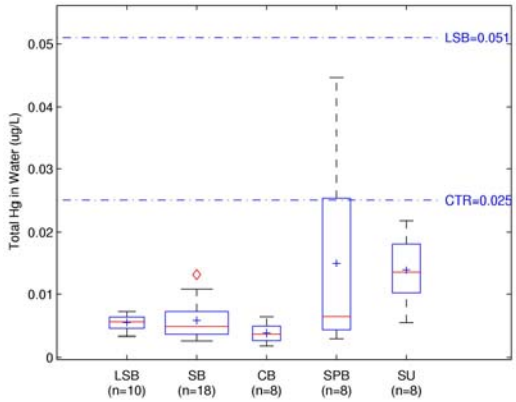
Figure 2.18a-c. Total Mercury (Hg) in Water (2004-2005)



a) Map of total mercury concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

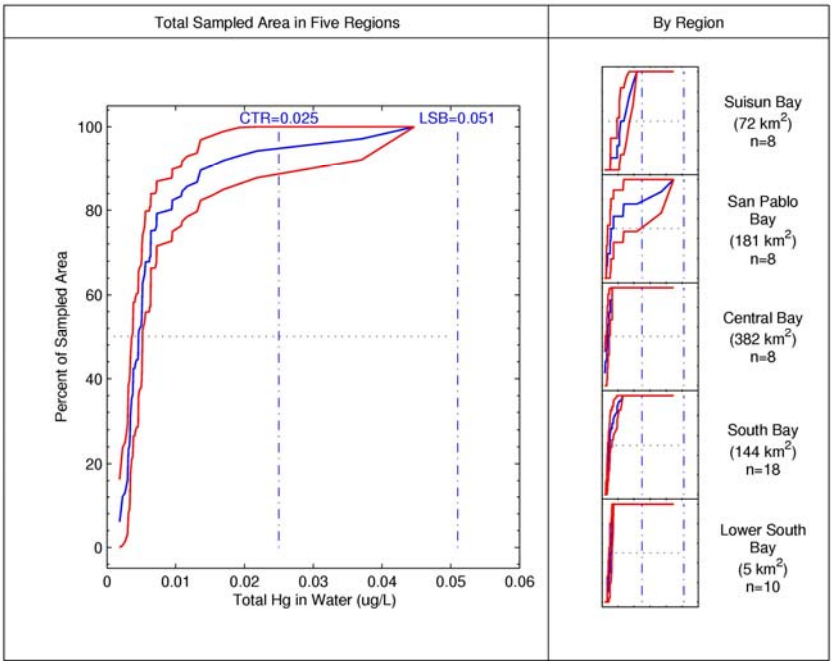
Random sites = ○, Historic sites = ◊, Non-detects = +





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

b) Schematic Box Plot of total mercury concentrations for the random sites in the five Estuary regions (2004-2005).



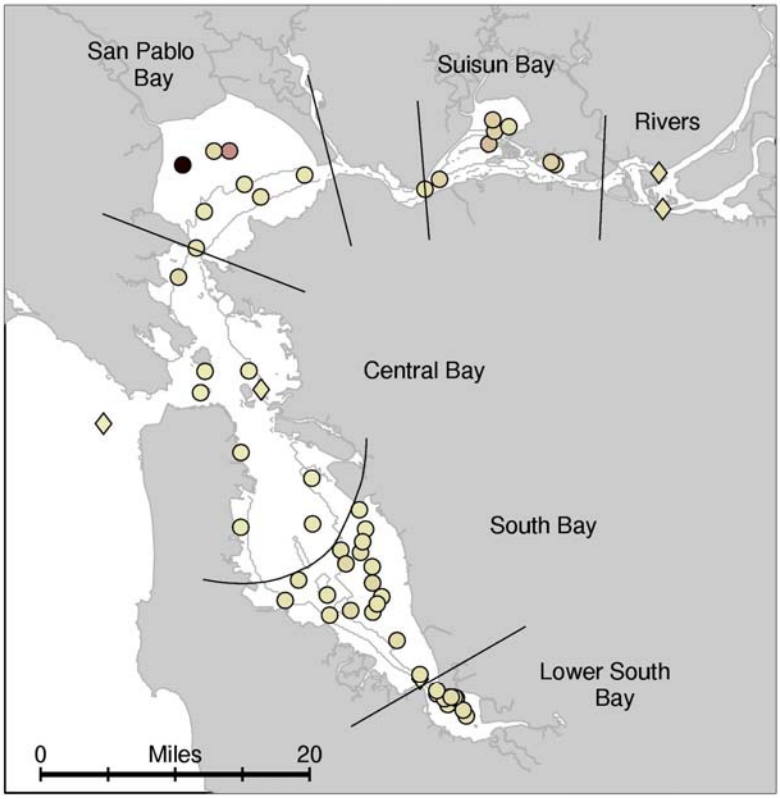
c) Cumulative distribution function (CDF) plots for total mercury concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the total mercury concentrations in water.

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

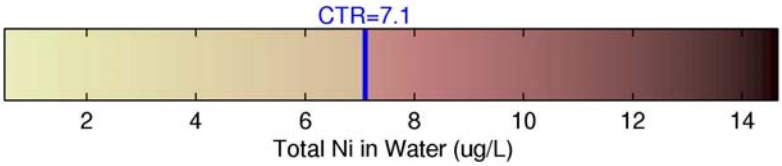
The large plot indicates that about 90% of the Estuary regions sampled had total mercury concentrations below the regulatory CTR objective of 0.025 ug/L. All samples were below the Lower South Bay site-specific objective of 0.051 ug/L.

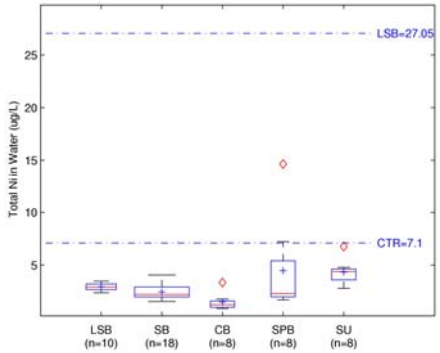
Figure 2.19a-c. Total Nickel (Ni) in Water (2004-2005)



a) Map of total nickel concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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

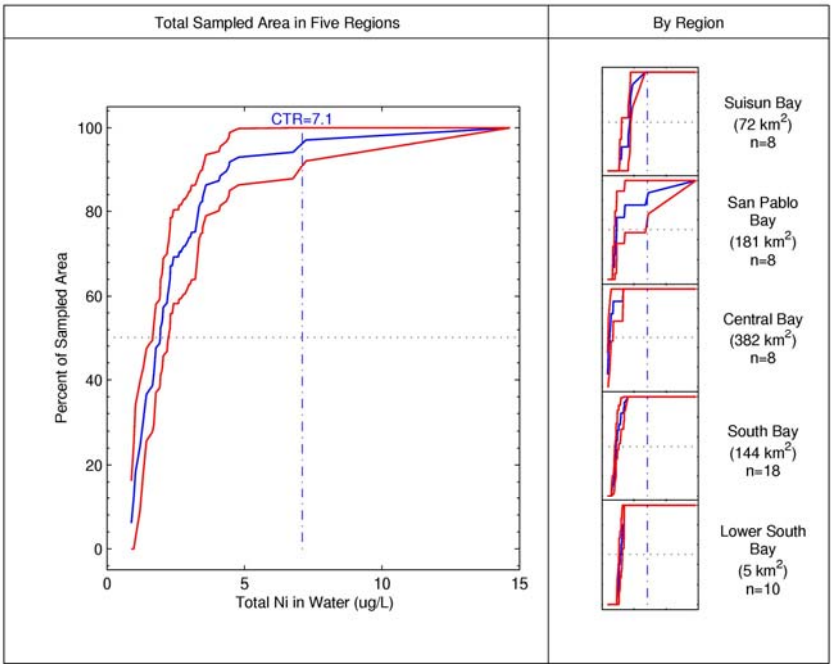




Default CTR conversion factors were used to calculate the total effects threshold value of 7.1 ug/L. The Lower South Bay has a site-specific objective of 27.05 ug/L.

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

b) Schematic Box Plot of total nickel concentrations for the random sites in the five Estuary regions (2004-2005).



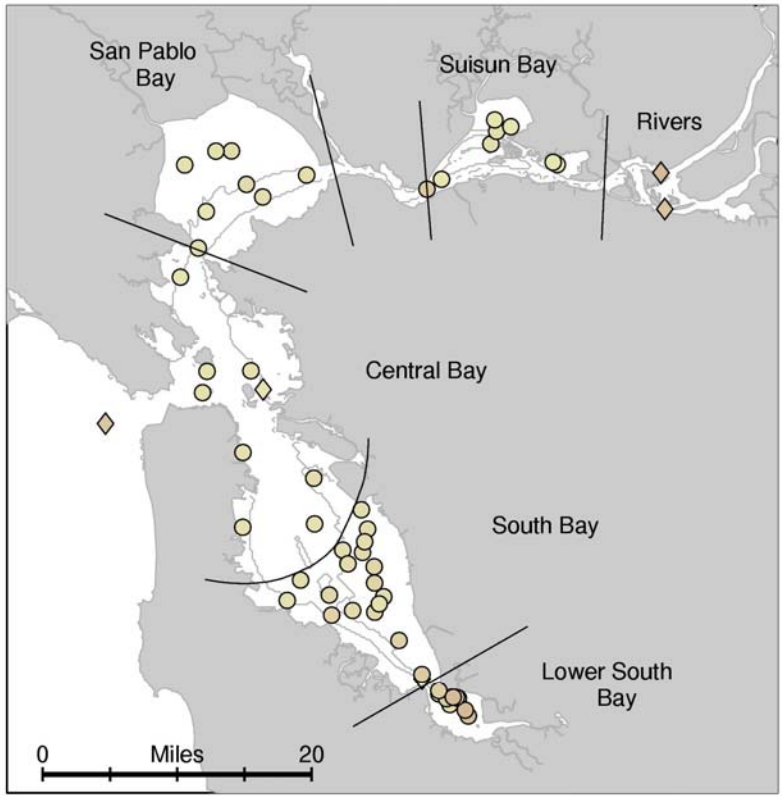
c) Cumulative distribution function (CDF) plots for total nickel concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the total nickel concentrations in water.

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

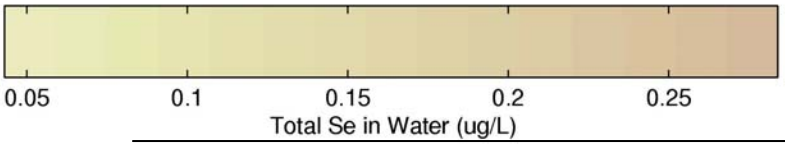
The large plot indicates that about 90% of the Estuary regions sampled had total nickel concentrations below the non-regulatory CTR objective of 7.1 ug/L. All samples were below the Lower South Bay site-specific objective of 27.05 ug/L.

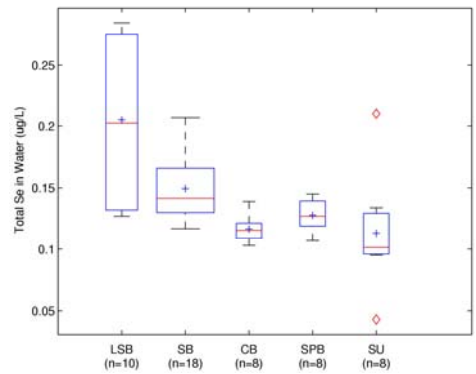
Figure 2.20a-c. Total Selenium (Se) in Water (2004-2005)



a) Map of total selenium concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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

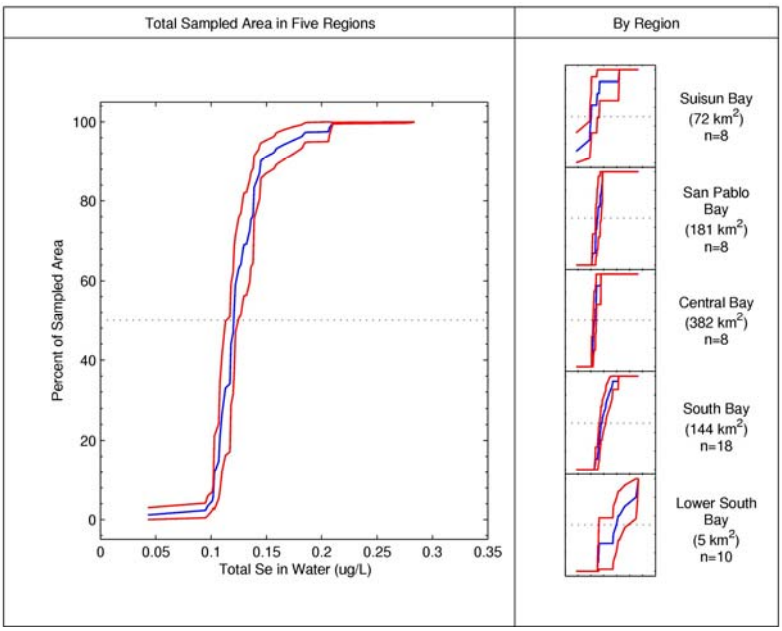




All samples were below the regulatory CTR region specific Aquatic Life criterion of 5 ug/L.

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

b) Schematic Box Plot of total selenium concentrations for the random sites in the five Estuary regions (2004-2005).



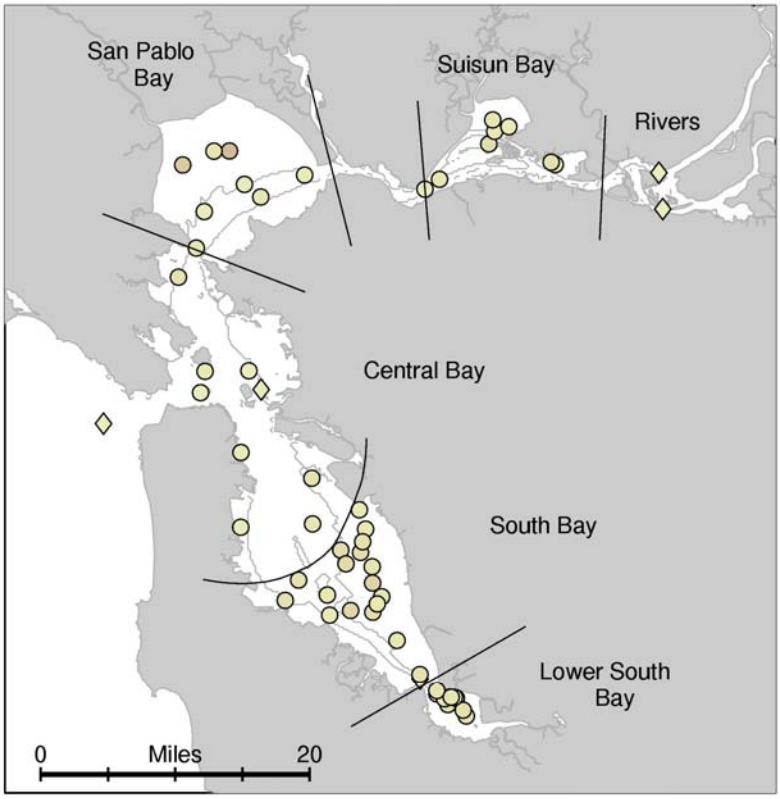
c) Cumulative distribution function (CDF) plots for total selenium concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the total selenium concentrations in water.

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

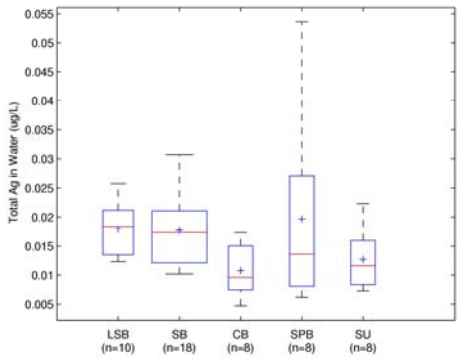
The large plot indicates that about 50% of the Estuary regions sampled had total selenium concentrations of ~0.125 ug/L or less.

Figure 2.21a-c. Total Silver (Ag) in Water (2004-2005)



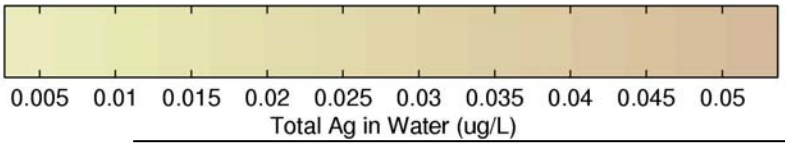
a) Map of total silver concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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

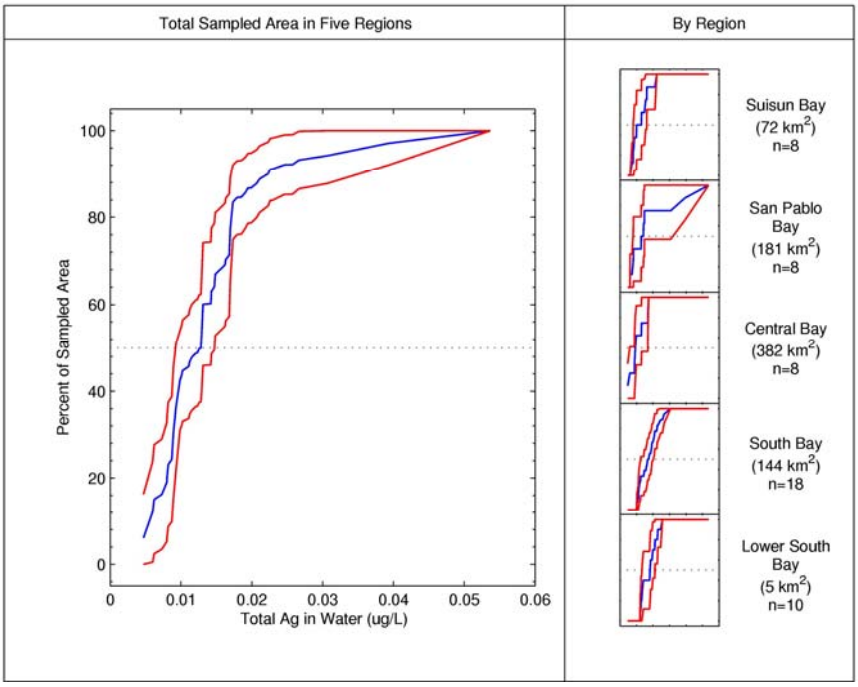


Default CTR conversion factors were used to calculate the total effects threshold value of 2.3 ug/L. All samples were below the threshold.

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



b) Schematic Box Plot of total silver concentrations for the random sites in the five Estuary regions (2004-2005).

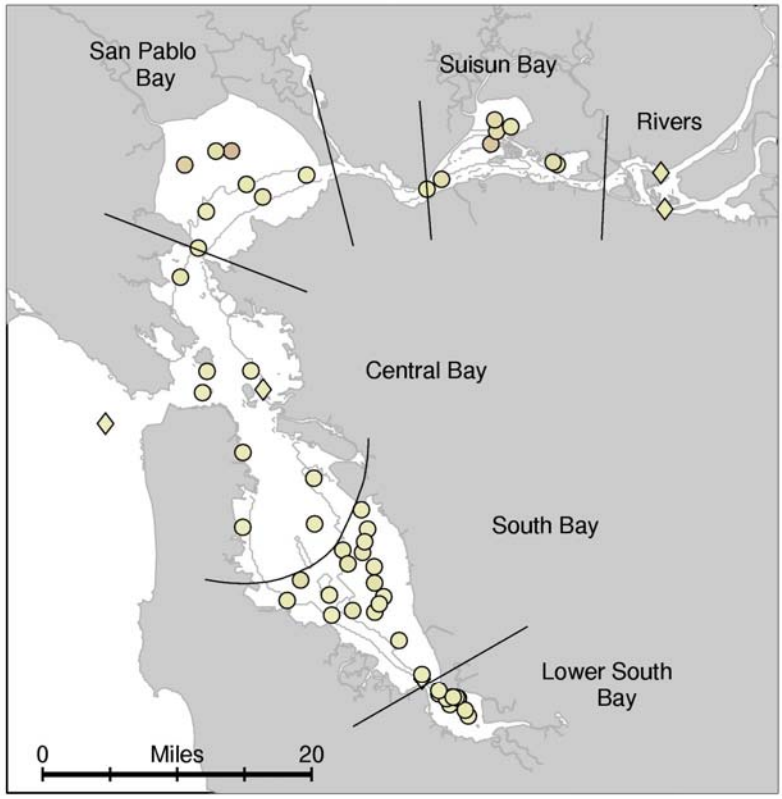


c) Cumulative distribution function (CDF) plots for total silver concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the total silver concentrations in water.

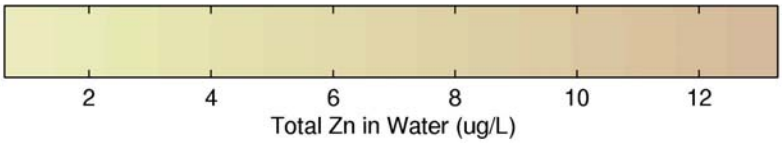
The small graphs show the same for each individual region (scales are identical to the large graph).

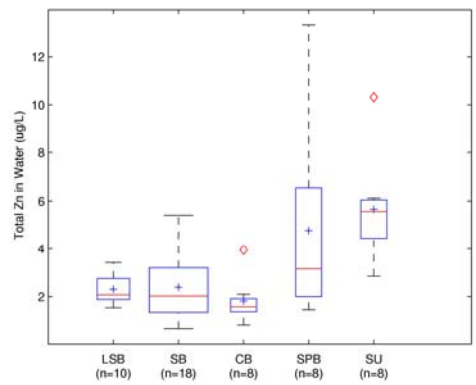
Figure 2.22a-c. Total Zinc (Zn) in Water (2004-2005)



a) Map of total zinc concentrations in water (ug/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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

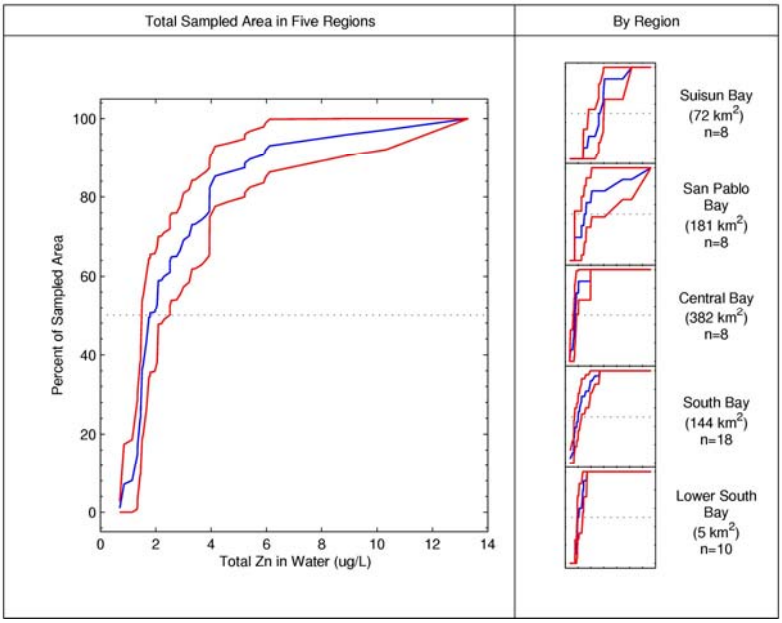




Default CTR conversion factors were used to calculate the total effects threshold value. All samples were below the non-regulatory saltwater effects threshold of 58 ug/L.

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

b) Schematic Box Plot of total zinc concentrations for the random sites in the five Estuary regions (2004-2005).



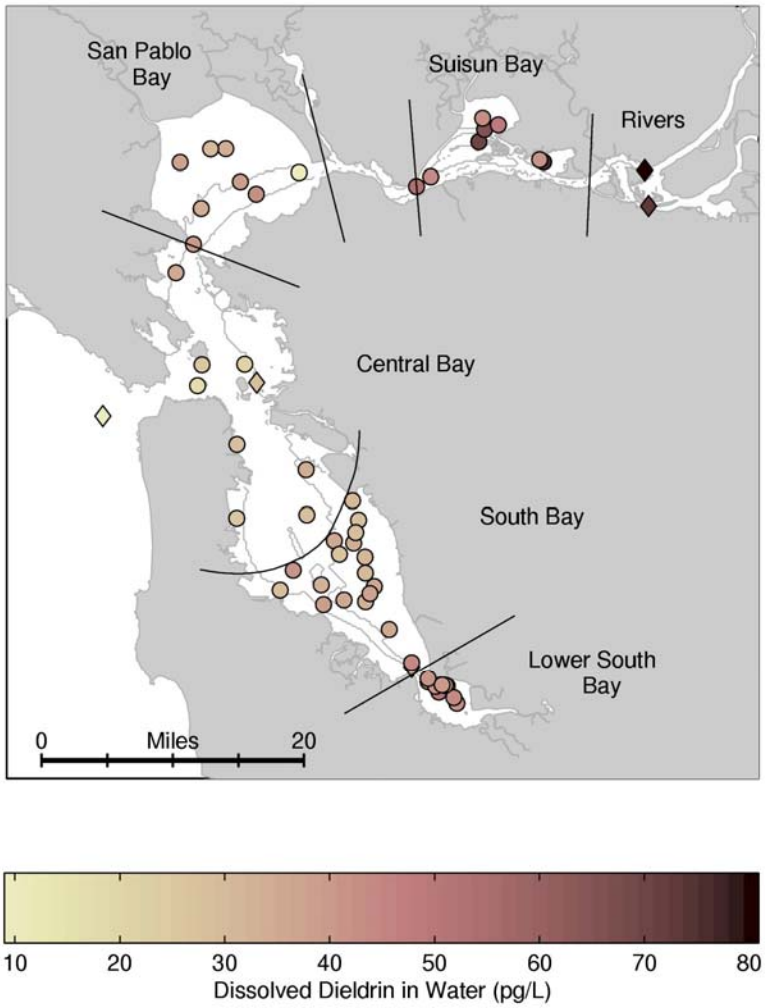
c) Cumulative distribution function (CDF) plots for total zinc concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the total zinc concentrations in water.

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

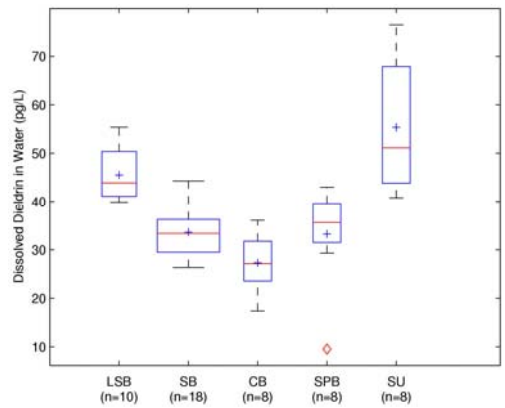
The large plot indicates that about 50% of the Estuary regions sampled had total zinc concentrations of ~2 ug/L or less.

Figure 2.23a-c. Dissolved Dieldrin in Water (2004-2005)



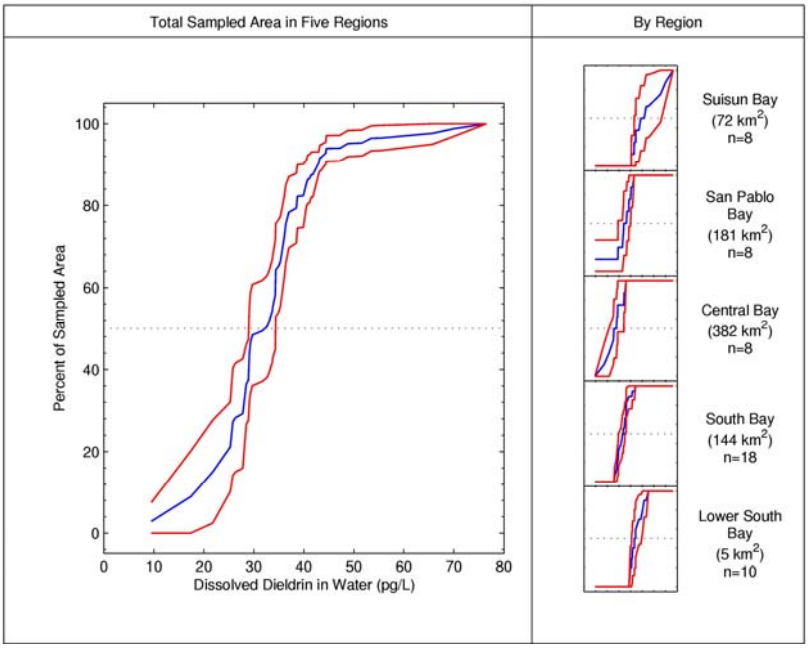
a) Map of dissolved Dieldrin concentrations in water (pg/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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



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

b) Schematic Box Plot of dissolved Dieldrin concentrations for the random sites in the five Estuary regions (2004-2005).



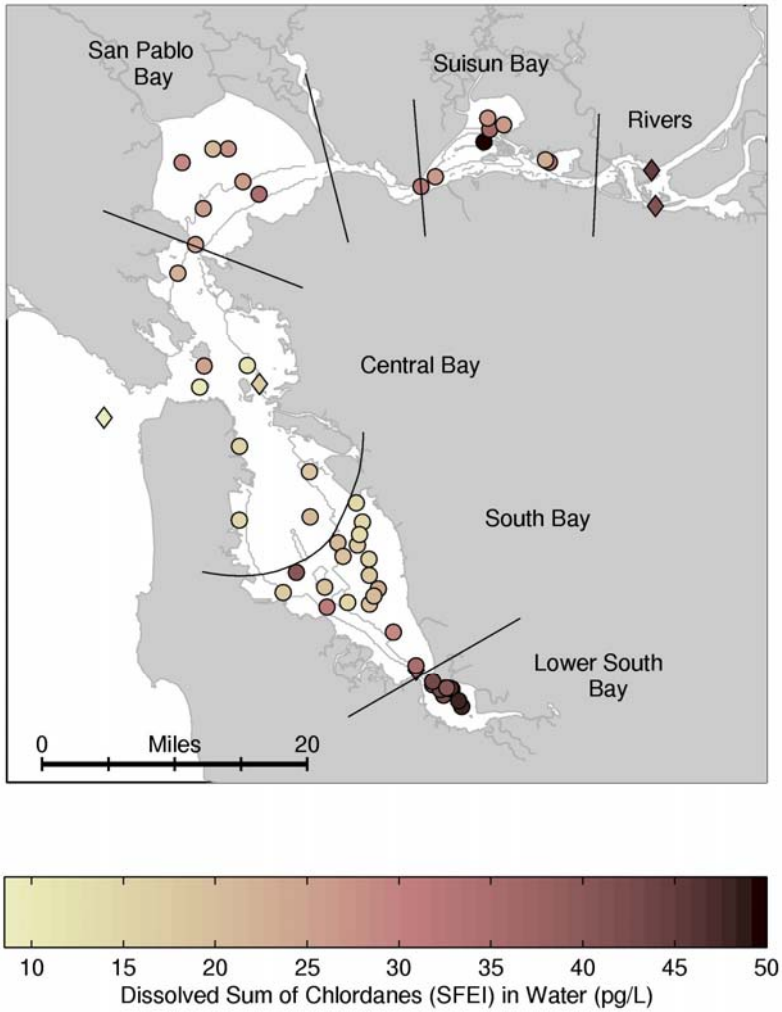
c) Cumulative distribution function (CDF) plots for dissolved Dieldrin concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved Dieldrin concentrations in water.

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

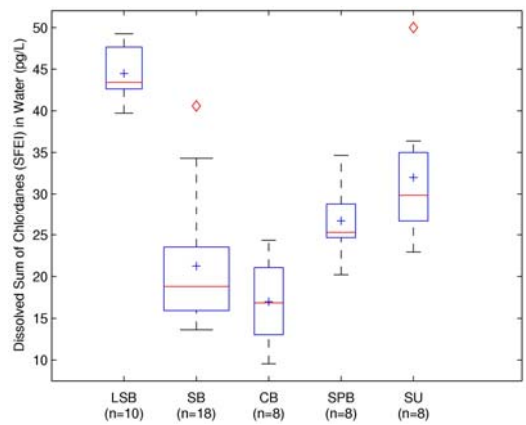
The large plot indicates that about 50% of the Estuary regions sampled had dissolved Dieldrin concentrations of ~30 pg/L or less.

Figure 2.24a-c. Dissolved Sum of Chlordanes in Water (2004-2005)



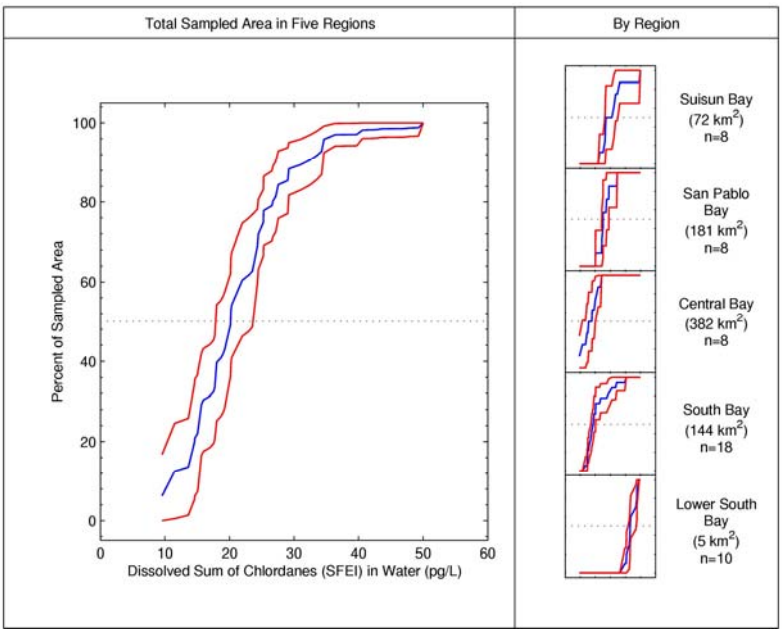
a) Map of dissolved Sum of Chlordanes concentrations in water (pg/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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



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

b) Schematic Box Plot of dissolved sum of Chlordanes concentrations for the random sites in the five Estuary regions (2004-2005).



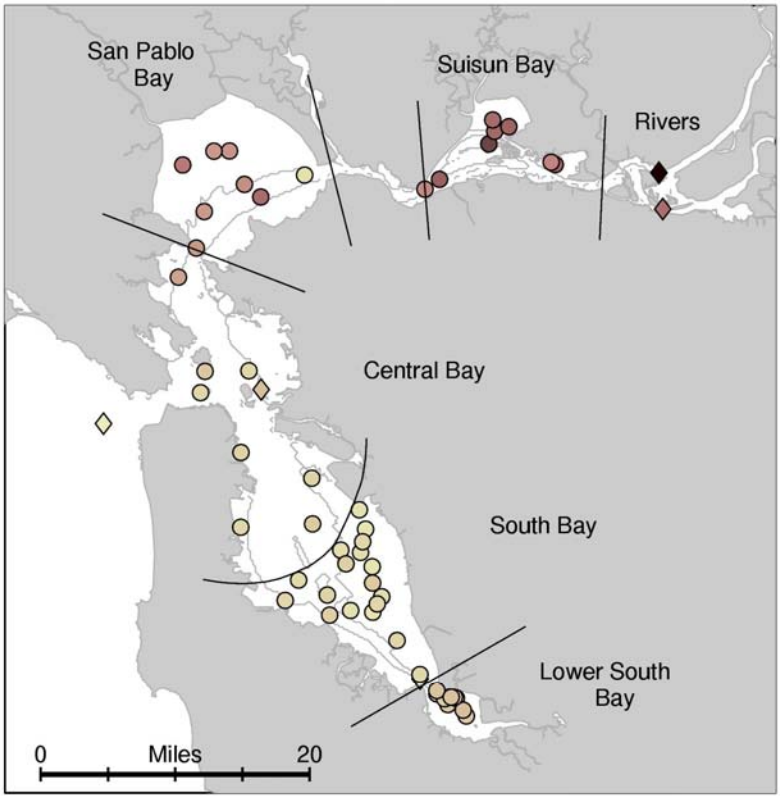
c) Cumulative distribution function (CDF) plots for dissolved sum of Chlordanes concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved sum of Chlordanes concentrations in water.

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

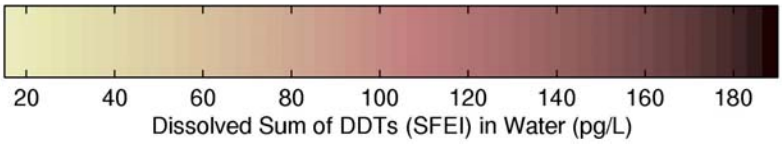
The large plot indicates that about 50% of the Estuary regions sampled had dissolved sum of Chlordanes concentrations of ~20 pg/L or less.

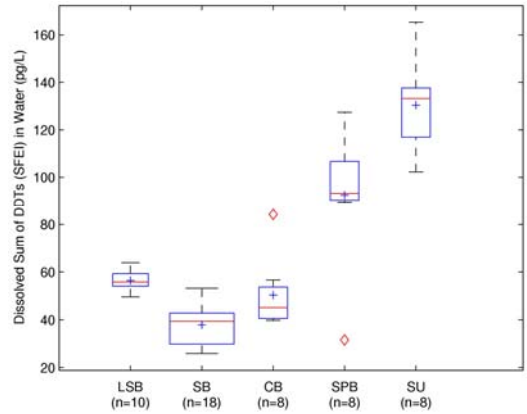
Figure 2.25a-c. Dissolved Sum of DDTs in Water (2004-2005)



a) Map of dissolved Sum of DDTs concentrations in water (pg/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

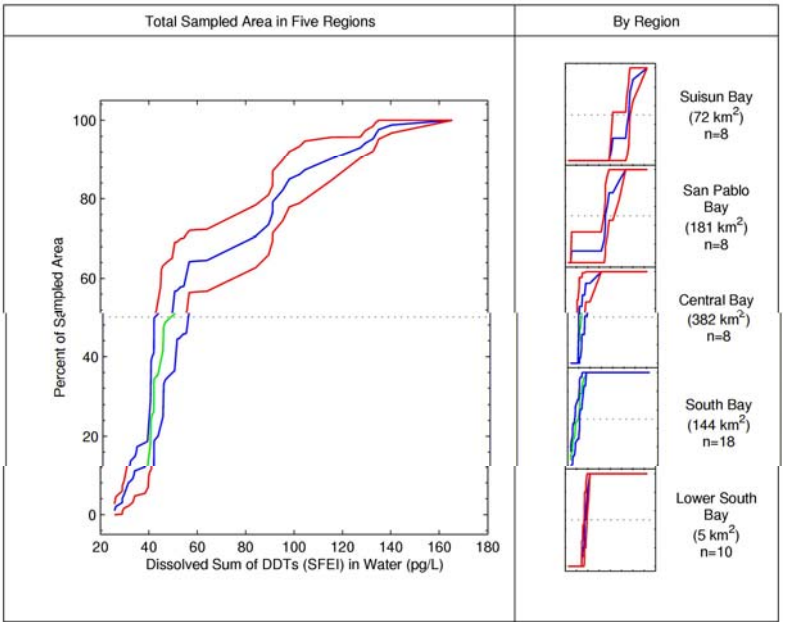
Random sites = ○, Historic sites = ◊, Non-detects = +





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

b) Schematic Box Plot of dissolved sum of DDTs concentrations for the random sites in the five Estuary regions (2004-2005).



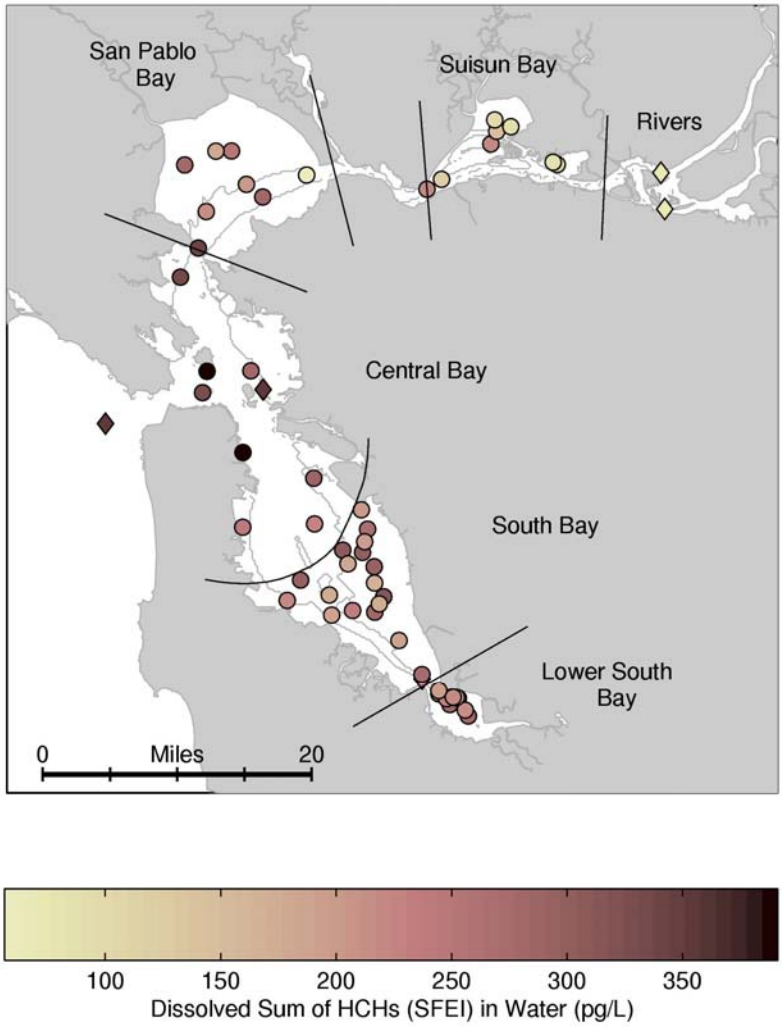
c) Cumulative distribution function (CDF) plots for dissolved sum of DDTs concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved sum of DDTs concentrations in water.

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

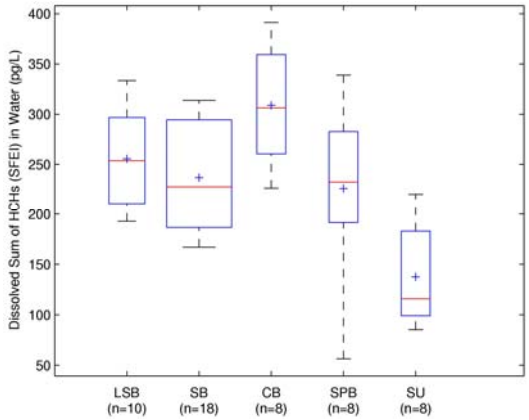
The large plot indicates that about 50% of the Estuary regions sampled had dissolved sum of DDTs concentrations of ~45 pg/L or less.

Figure 2.26a-c. Dissolved Sum of HCHs in Water (2004-2005)



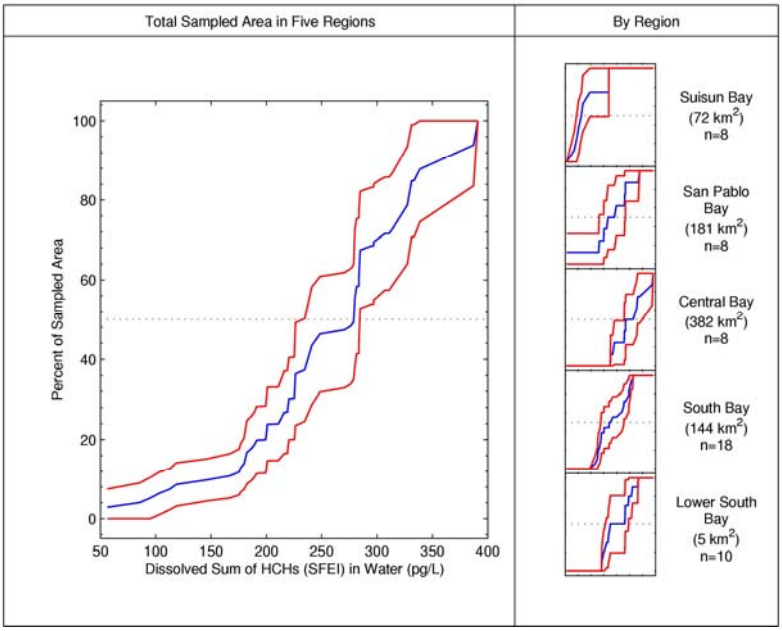
a) Map of dissolved Sum of HCHs concentrations in water (pg/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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



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

b) Schematic Box Plot of dissolved sum of HCHs concentrations for the random sites in the five Estuary regions (2004-2005).



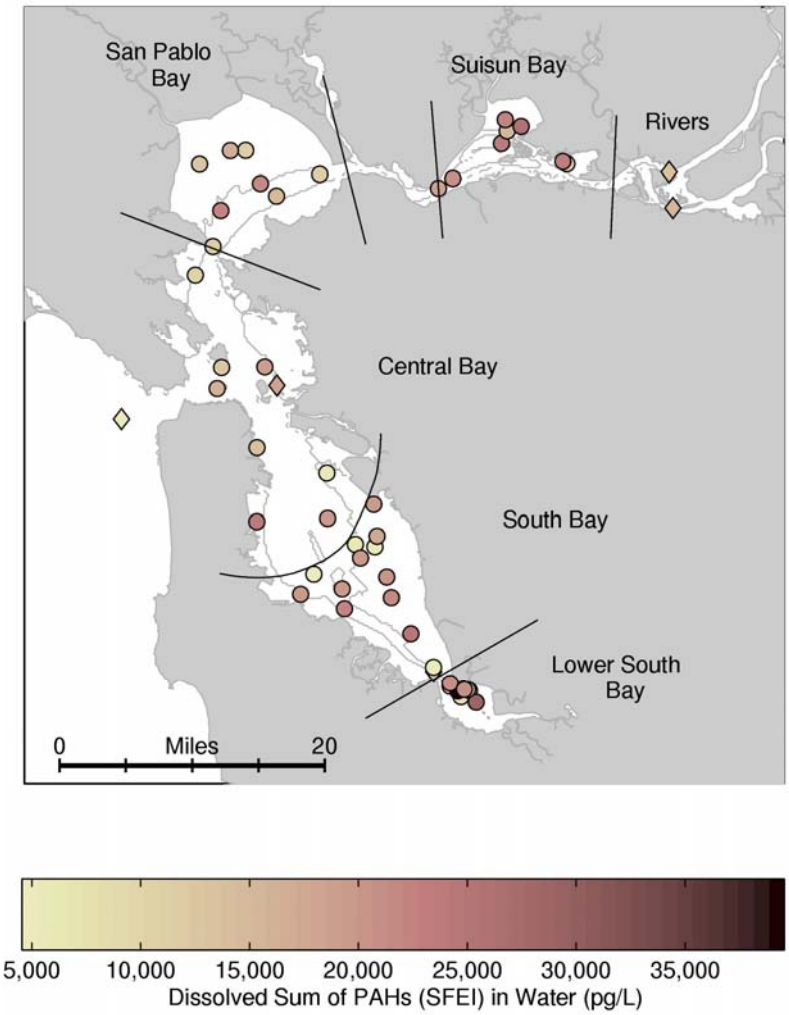
c) Cumulative distribution function (CDF) plots for dissolved sum of HCHs concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved sum of HCHs concentrations in water.

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

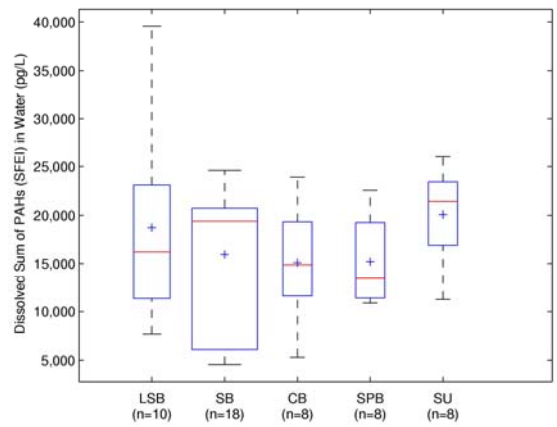
The large plot indicates that about 50% of the Estuary regions sampled had dissolved sum of HCHs concentrations of ~280 pg/L or less.

Figure 2.27a-c. Dissolved Sum of PAHs in Water (2004-2005)



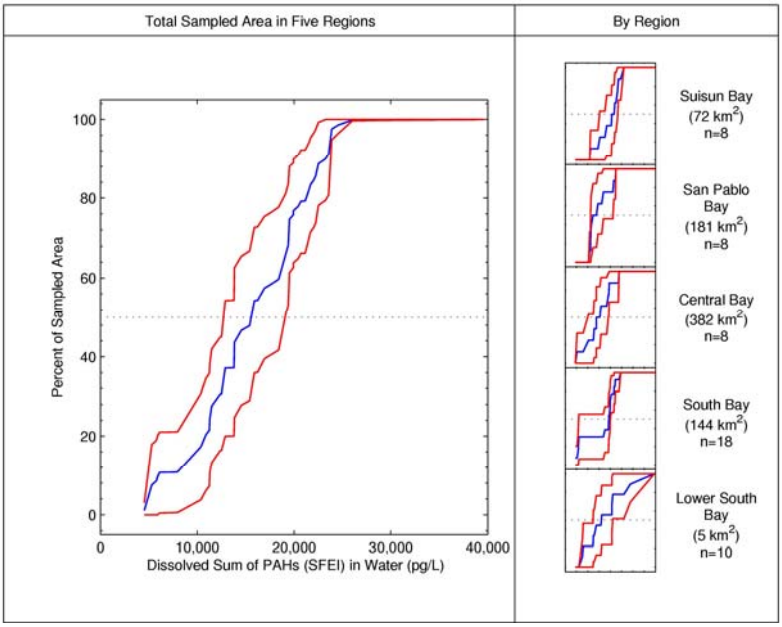
a) Map of dissolved Sum of PAHs concentrations in water (pg/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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



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

b) Schematic Box Plot of dissolved sum of PAHs concentrations for the random sites in the five Estuary regions (2004-2005).



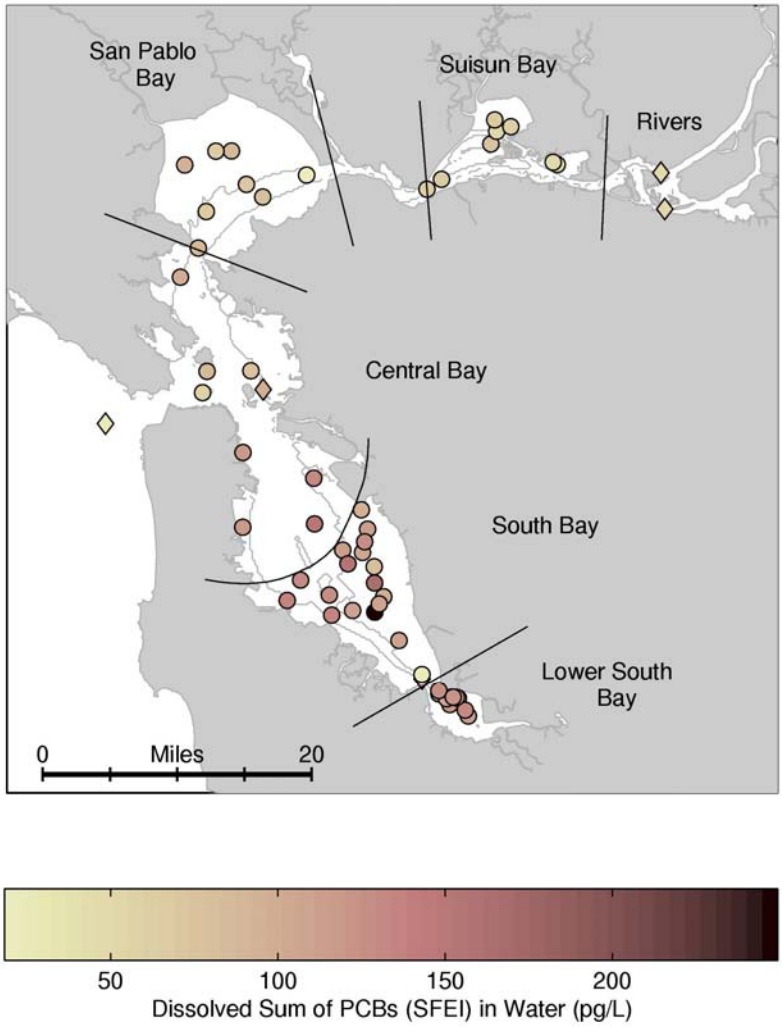
c) Cumulative distribution function (CDF) plots for dissolved sum of PAHs concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved sum of PAHs concentrations in water.

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

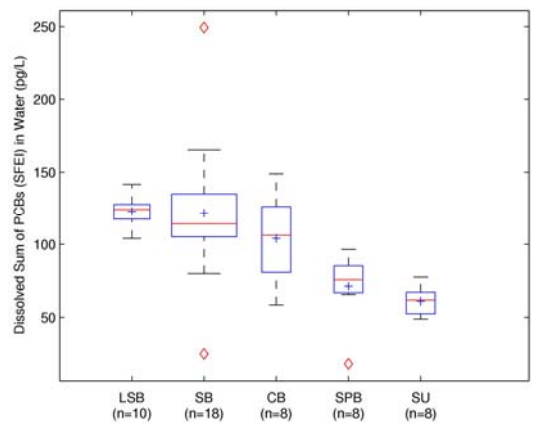
The large plot indicates that about 50% of the Estuary regions sampled had dissolved sum of PAHs concentrations of ~16,000 pg/L or less.

Figure 2.28a-c. Dissolved Sum of PCBs in Water (2004-2005)



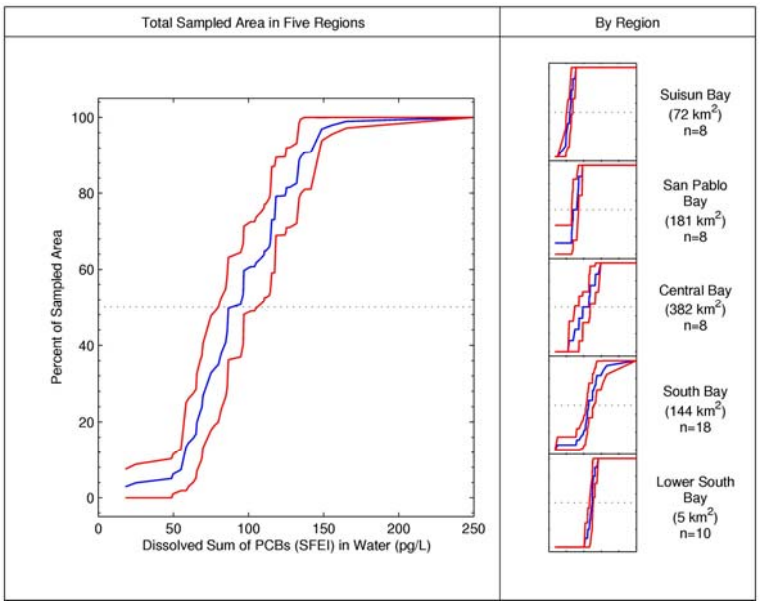
a) Map of dissolved Sum of PCBs concentrations in water (pg/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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



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

b) Schematic Box Plot of dissolved sum of PCBs concentrations for the random sites in the five Estuary regions (2004-2005).



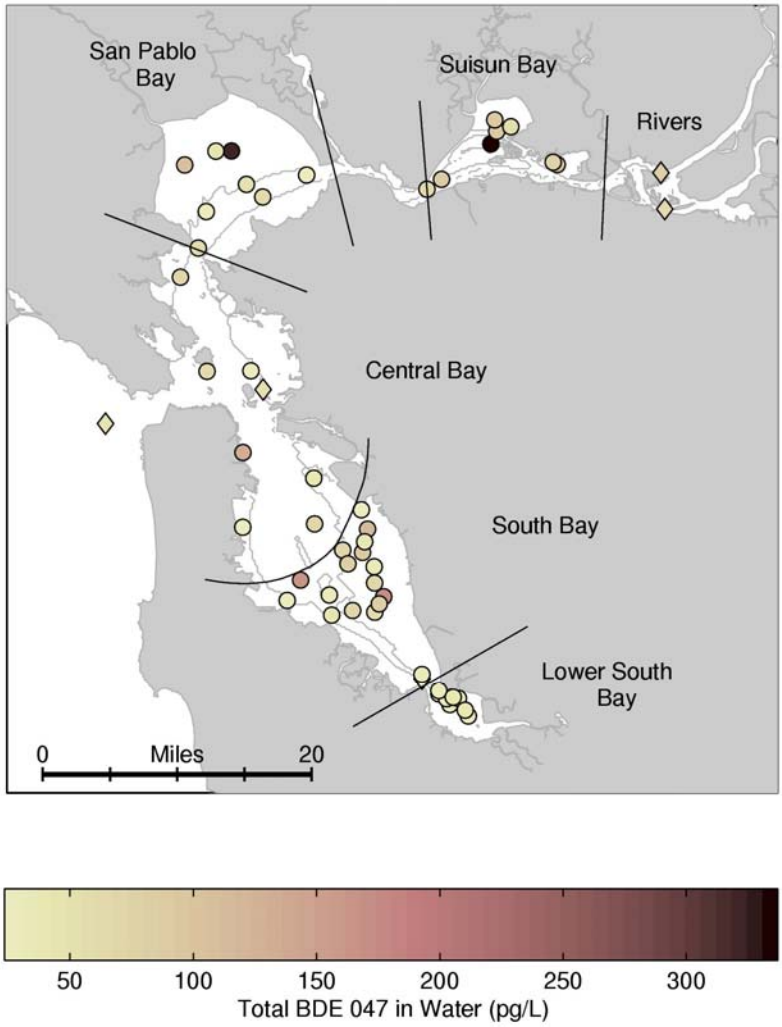
c) Cumulative distribution function (CDF) plots for dissolved sum of PCBs concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the dissolved sum of PCBs concentrations in water.

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

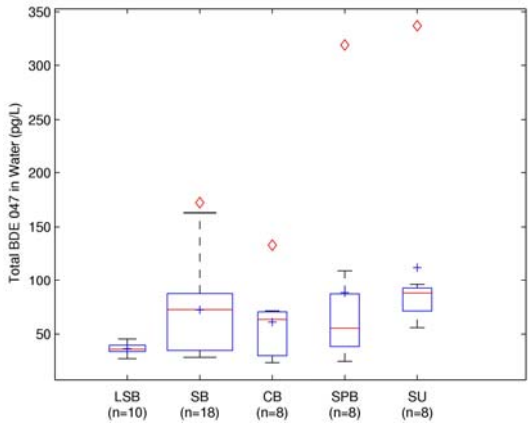
The large plot indicates that about 50% of the Estuary regions sampled had dissolved sum of PCBs concentrations of ~90 pg/L or less.

Figure 2.29a-c. Total BDE-47 in Water (2004-2005)



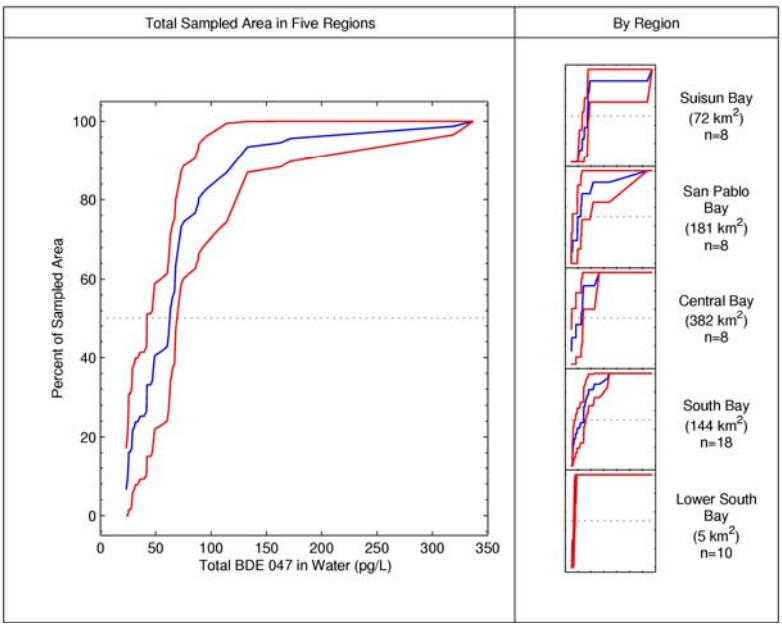
a) Map of total BDE-47 concentrations in water (pg/L) in the six Estuary regions monitored. Fifty-two randomly allocated sites (based on the EMAP sample design) and five historic RMP sites (sampled in 2004 and 2005) were sampled and only results that passed QA/QC are reported here. Note that only historic sites were sampled in the Rivers region. For further explanations of these graphics please refer to section 1.3.1.

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



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

b) Schematic Box Plot of total BDE-47 concentrations for the random sites in the five Estuary regions (2004-2005).



c) Cumulative distribution function (CDF) plots for total BDE-47 concentrations in water from the random samples in the five Estuary regions (2004-2005).

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 784 square kilometers) vs. the total BDE-47 concentrations in water.

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

The large plot indicates that about 50% of the Estuary regions sampled had total BDE-47 concentrations of ~60 pg/L or less.

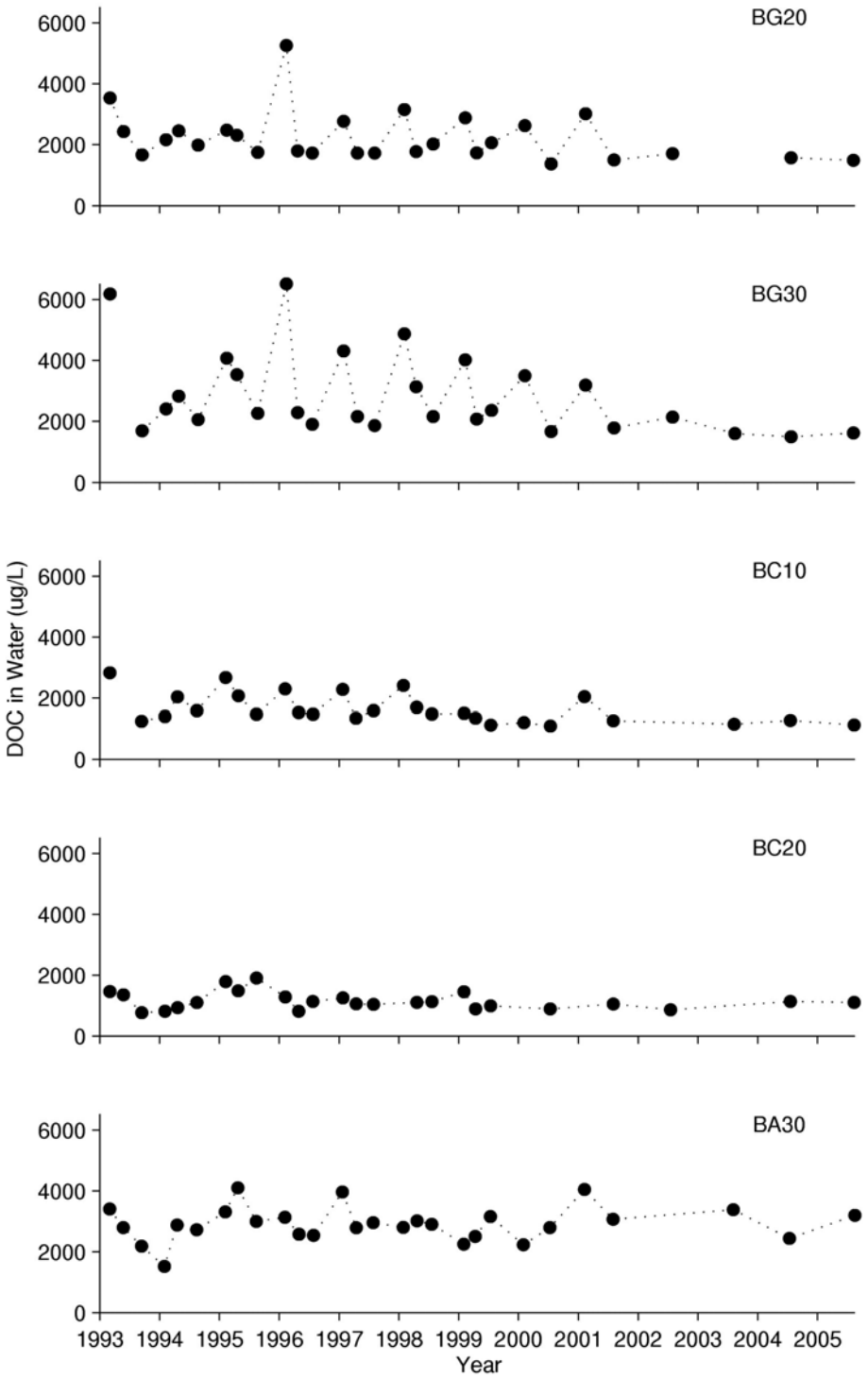


Figure 2.30. Time series plots for dissolved organic carbon (DOC) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

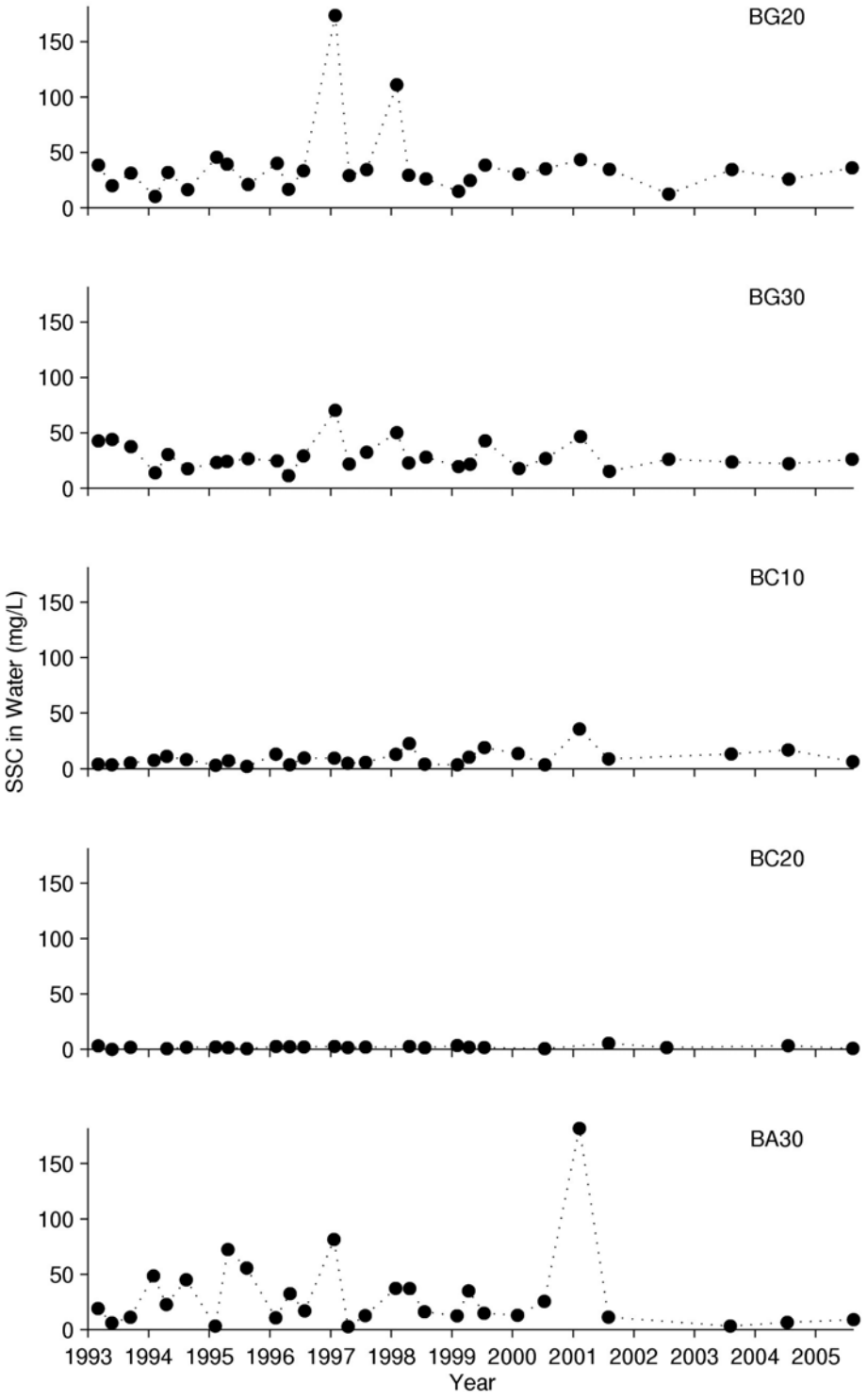


Figure 2.31. Time series plots for suspended sediment concentration (SSC) in water (mg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

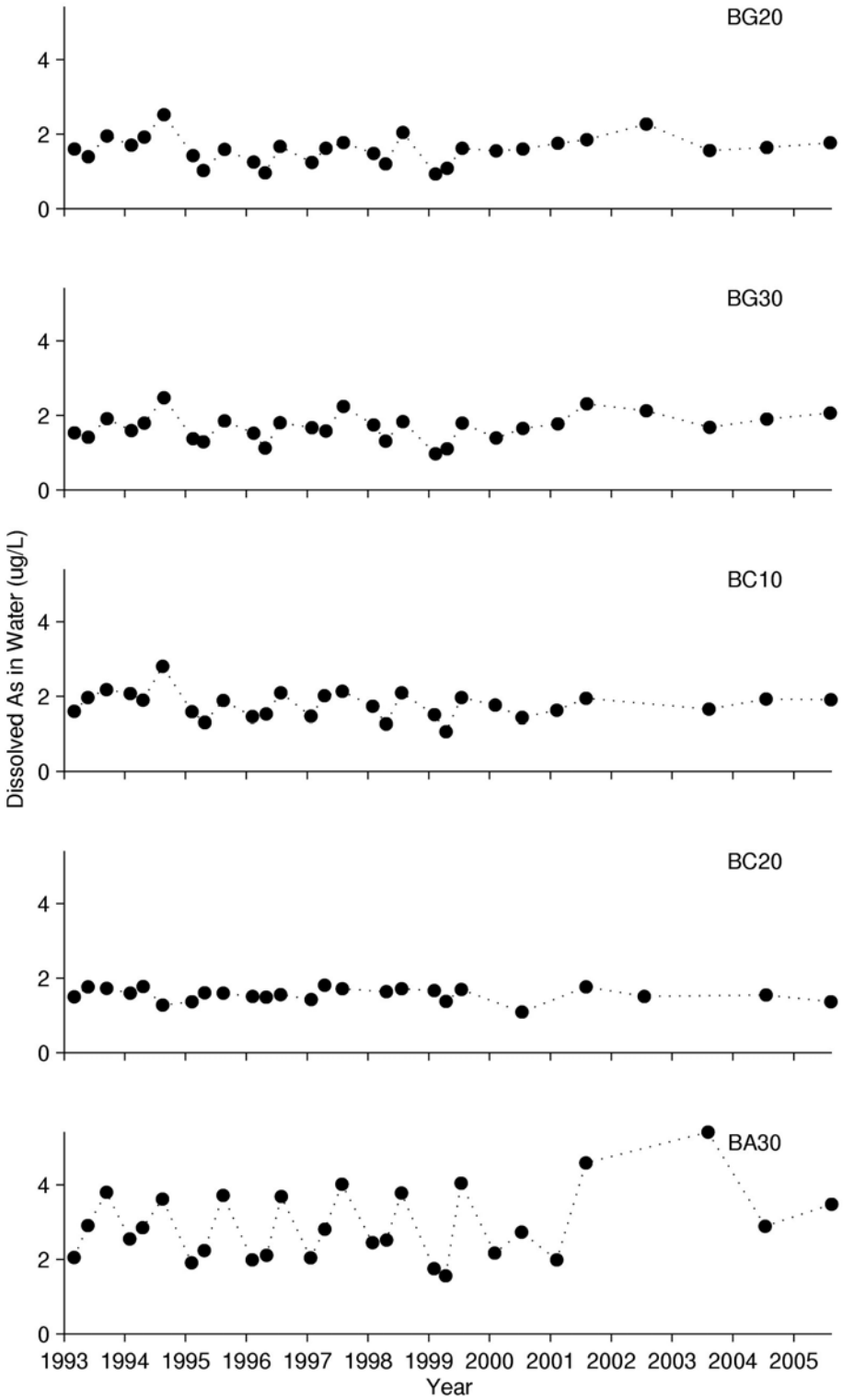


Figure 2.32. Time series plots for dissolved arsenic (As) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

All samples were below the CTR 4-day Aquatic Life saltwater criterion of 36 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

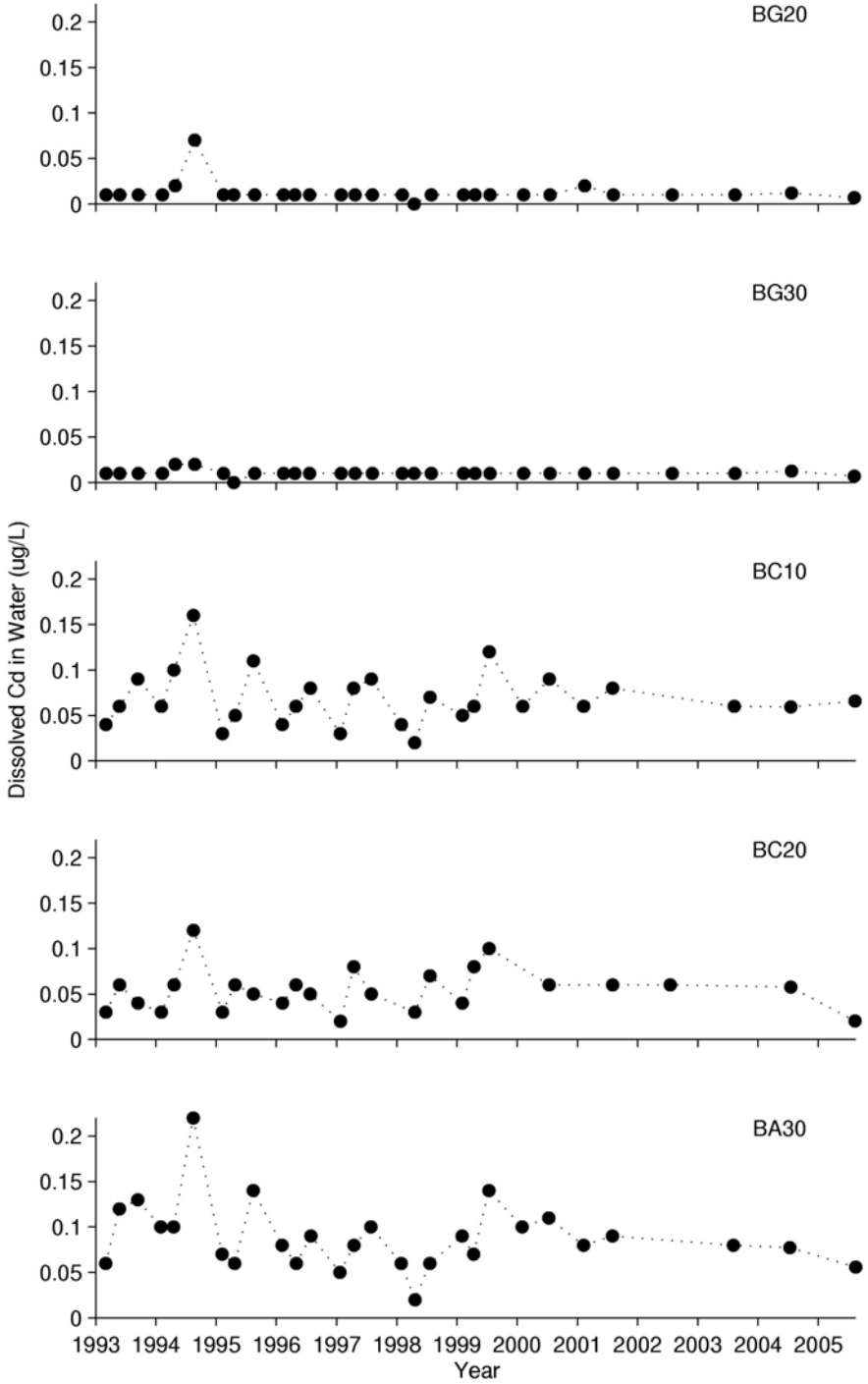


Figure 2.33. Time series plots for dissolved cadmium (Cd) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

All samples were below the CTR 4-day Aquatic Life saltwater or calculated freshwater criterion of 9.3 or 2.2 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

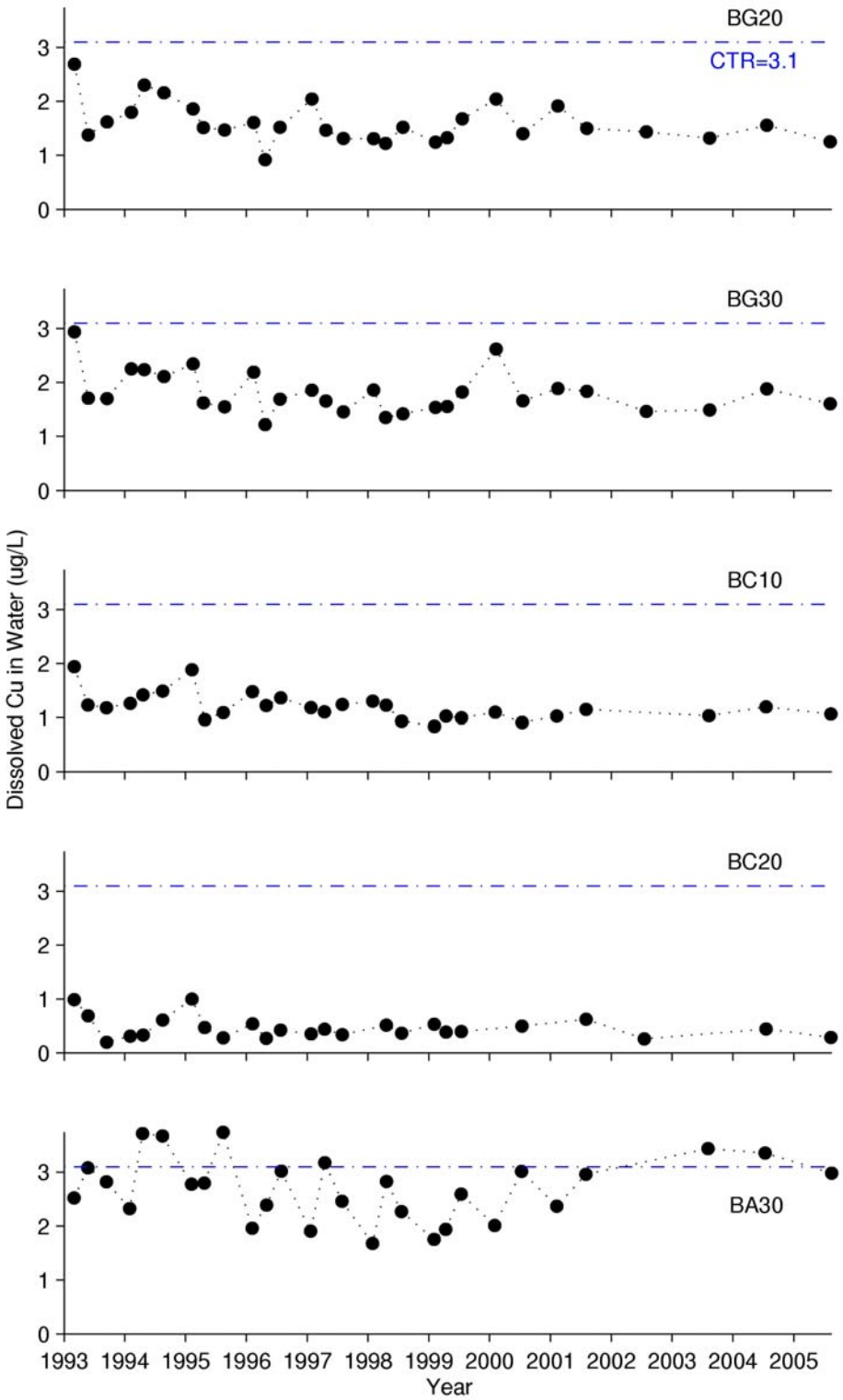


Figure 2.34. Time series plots for dissolved copper (Cu) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The dashed blue reference line is the CTR 4-day Aquatic Life saltwater quality criterion of 3.1 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

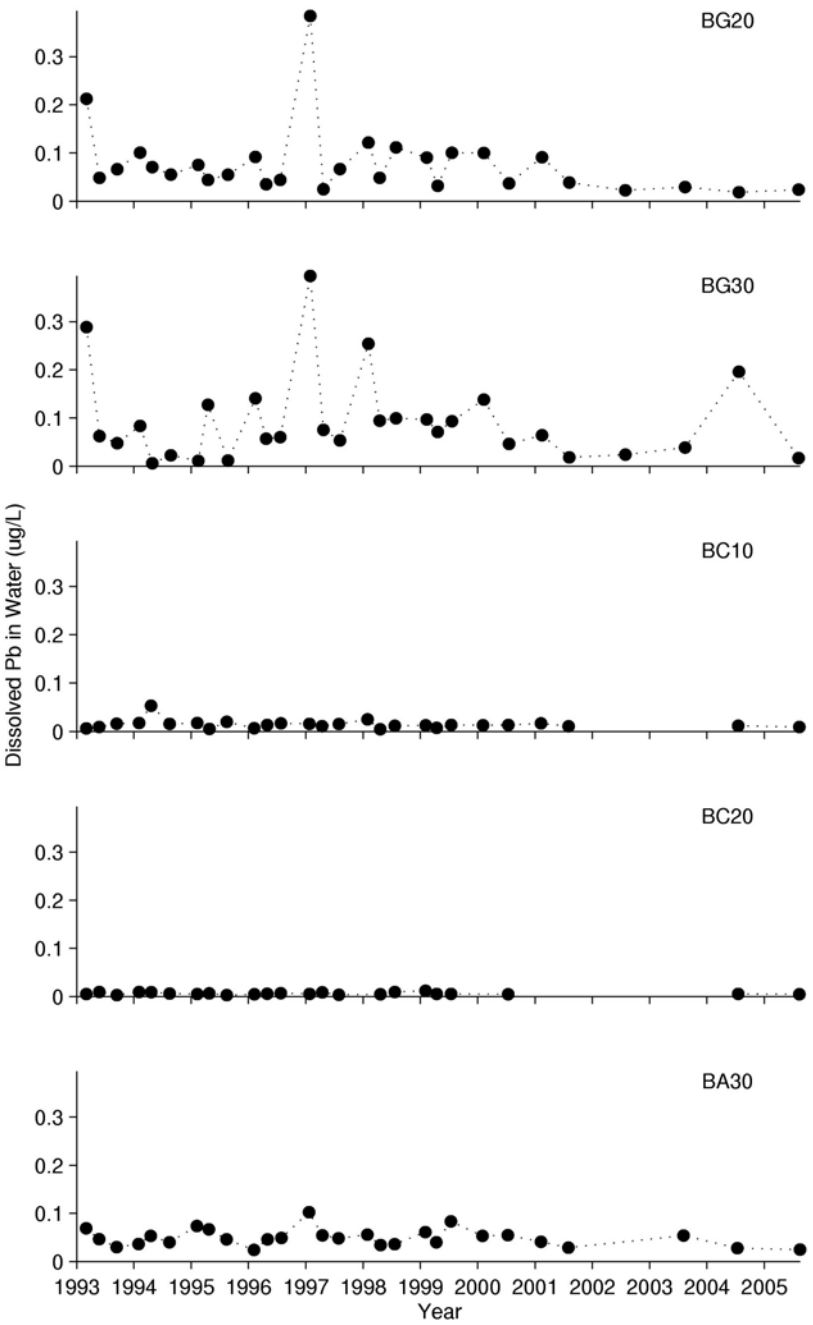


Figure 2.35. Time series plots for dissolved lead (Pb) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

All samples were below the CTR 4-day Aquatic Life saltwater or calculated freshwater criterion of 8.1 or 2.5 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

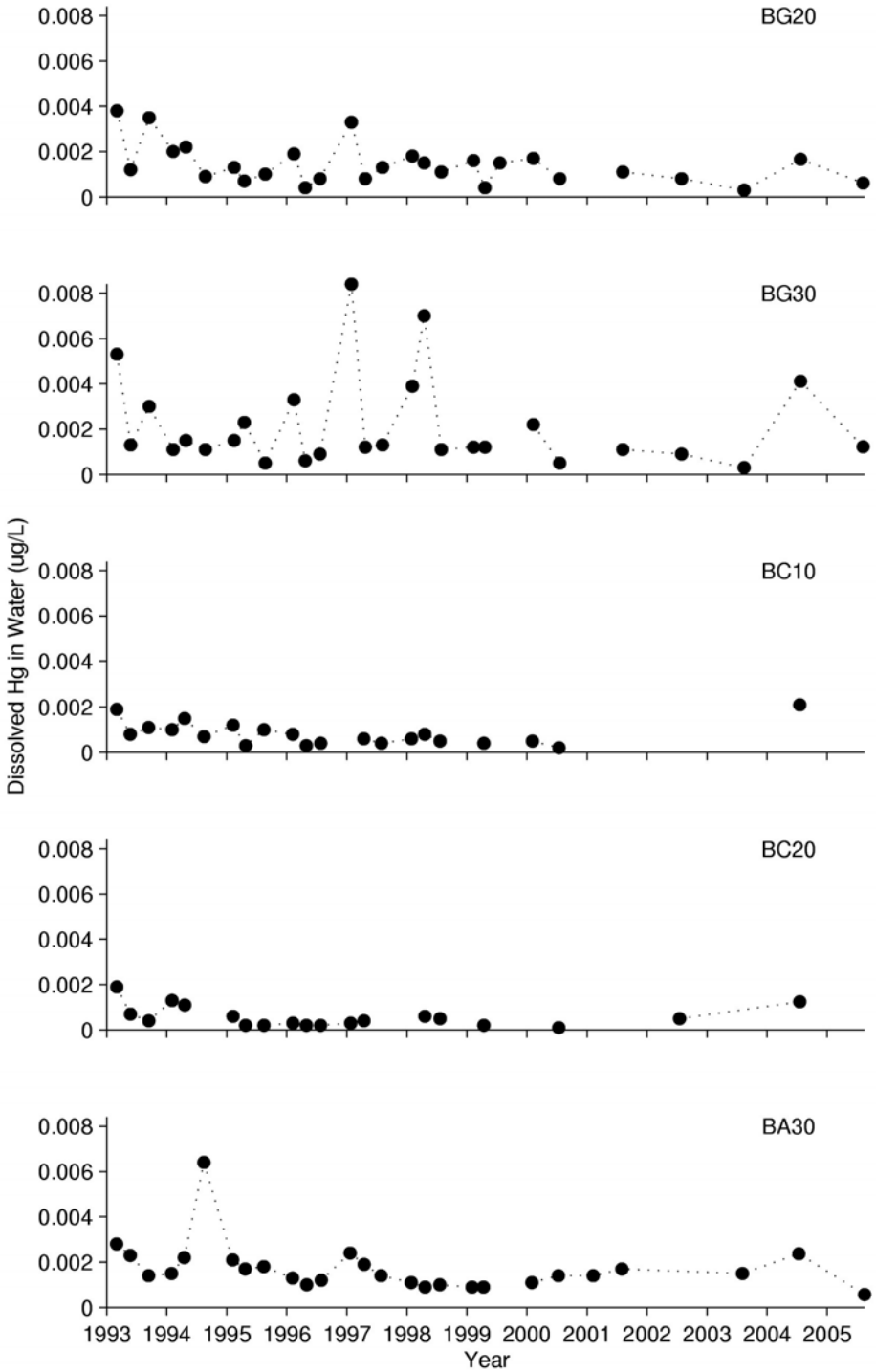


Figure 2.36. Time series plots for dissolved mercury (Hg) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

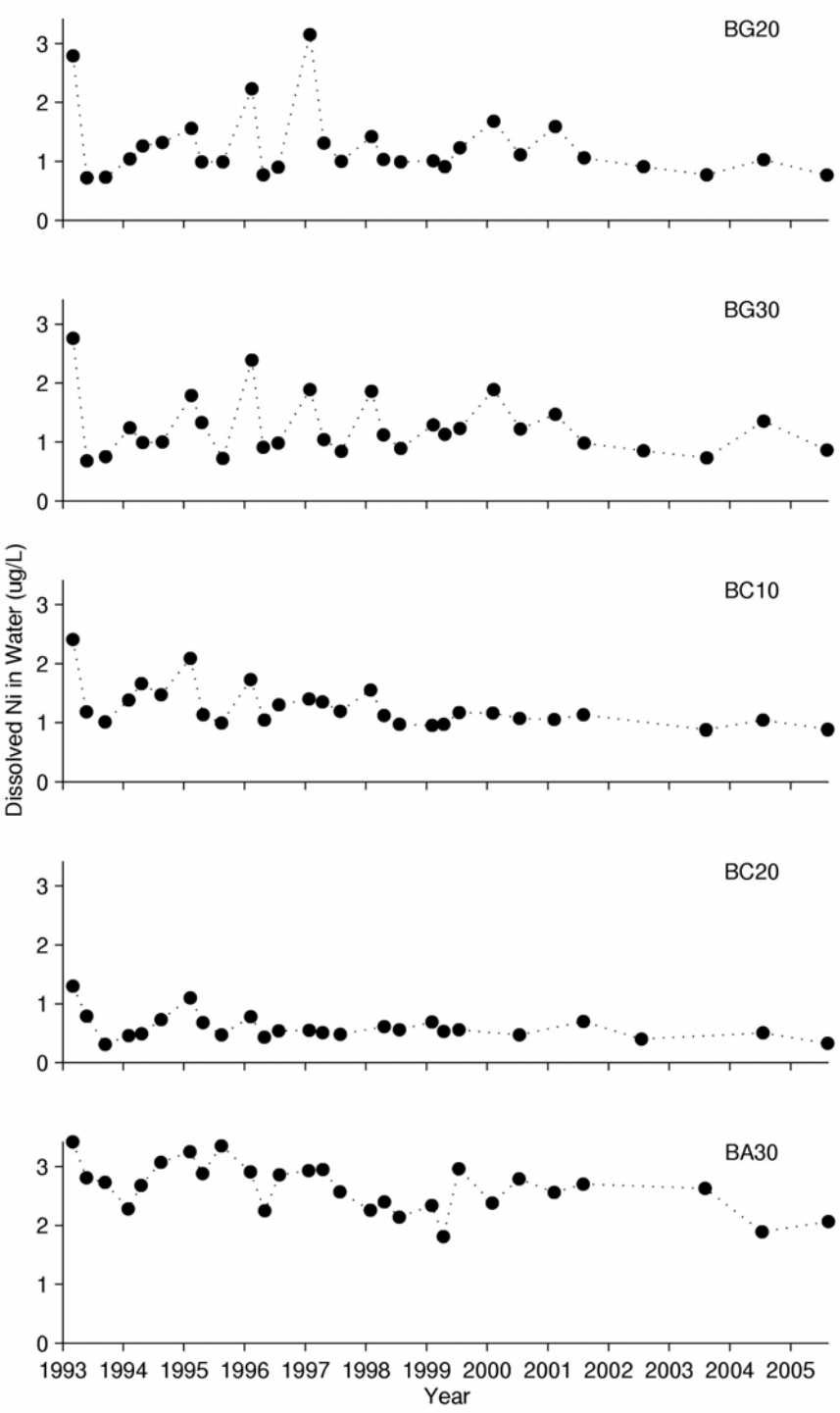


Figure 2.37. Time series plots for dissolved nickel (Ni) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

All samples were below the CTR 4-day Aquatic Life saltwater criterion of 8.2 ug/L. (The Lower South Bay has a site-specific objective of 11.9 ug/L.)

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

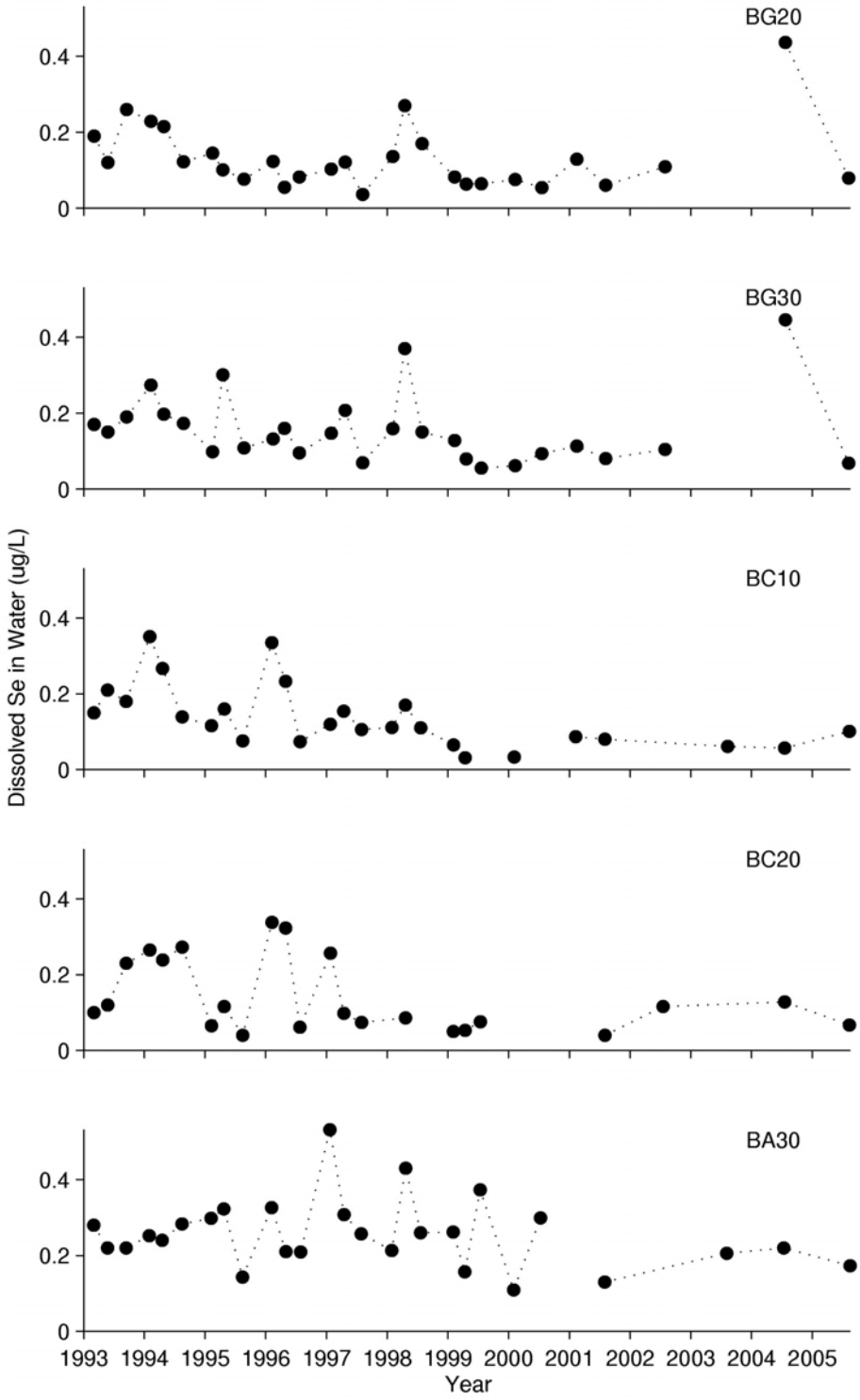


Figure 2.38. Time series plots for dissolved selenium (Se) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

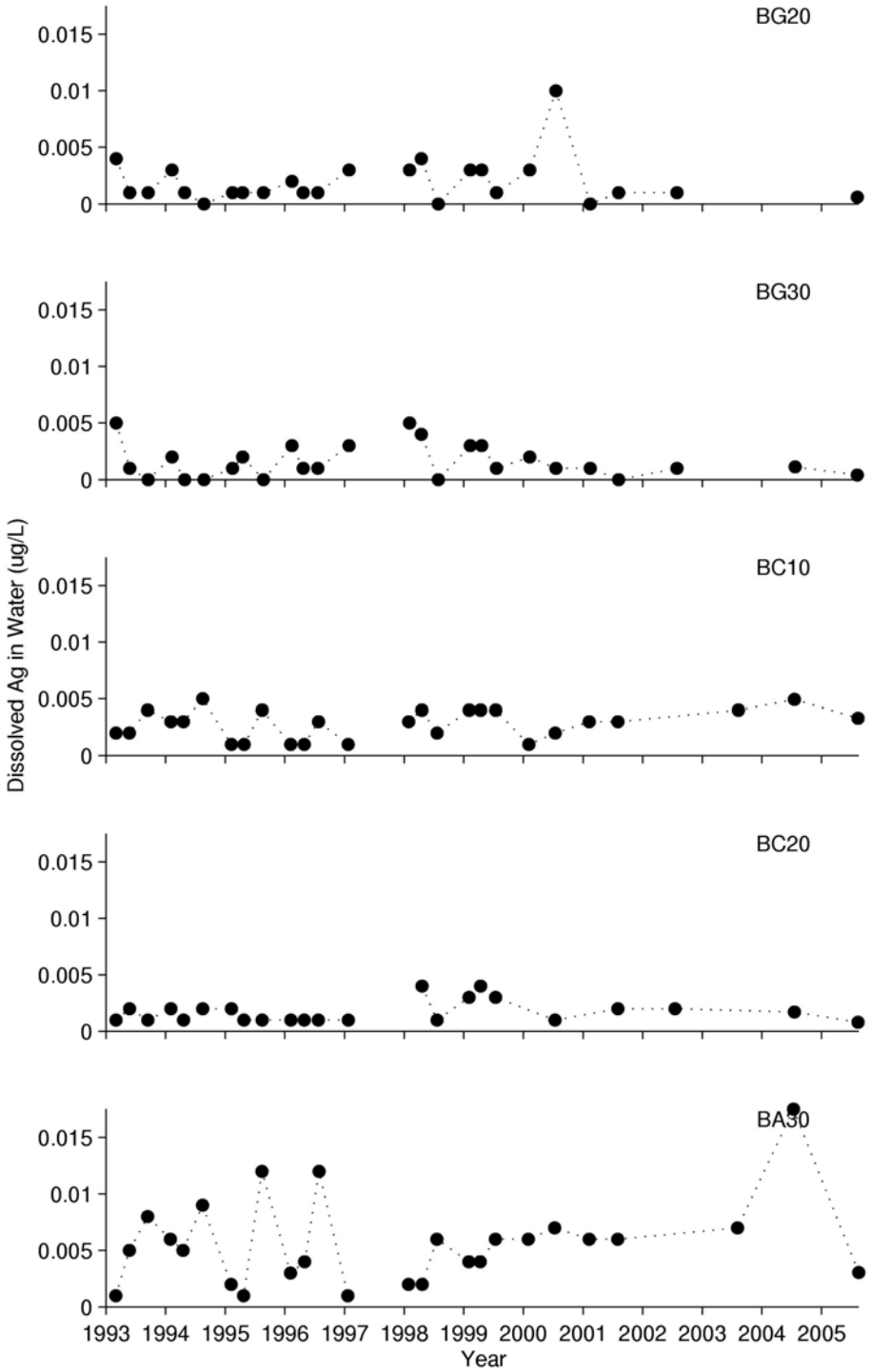


Figure 2.39. Time series plots for dissolved silver (Ag) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The CTR 4-day Aquatic Life saltwater criterion is 1.9 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

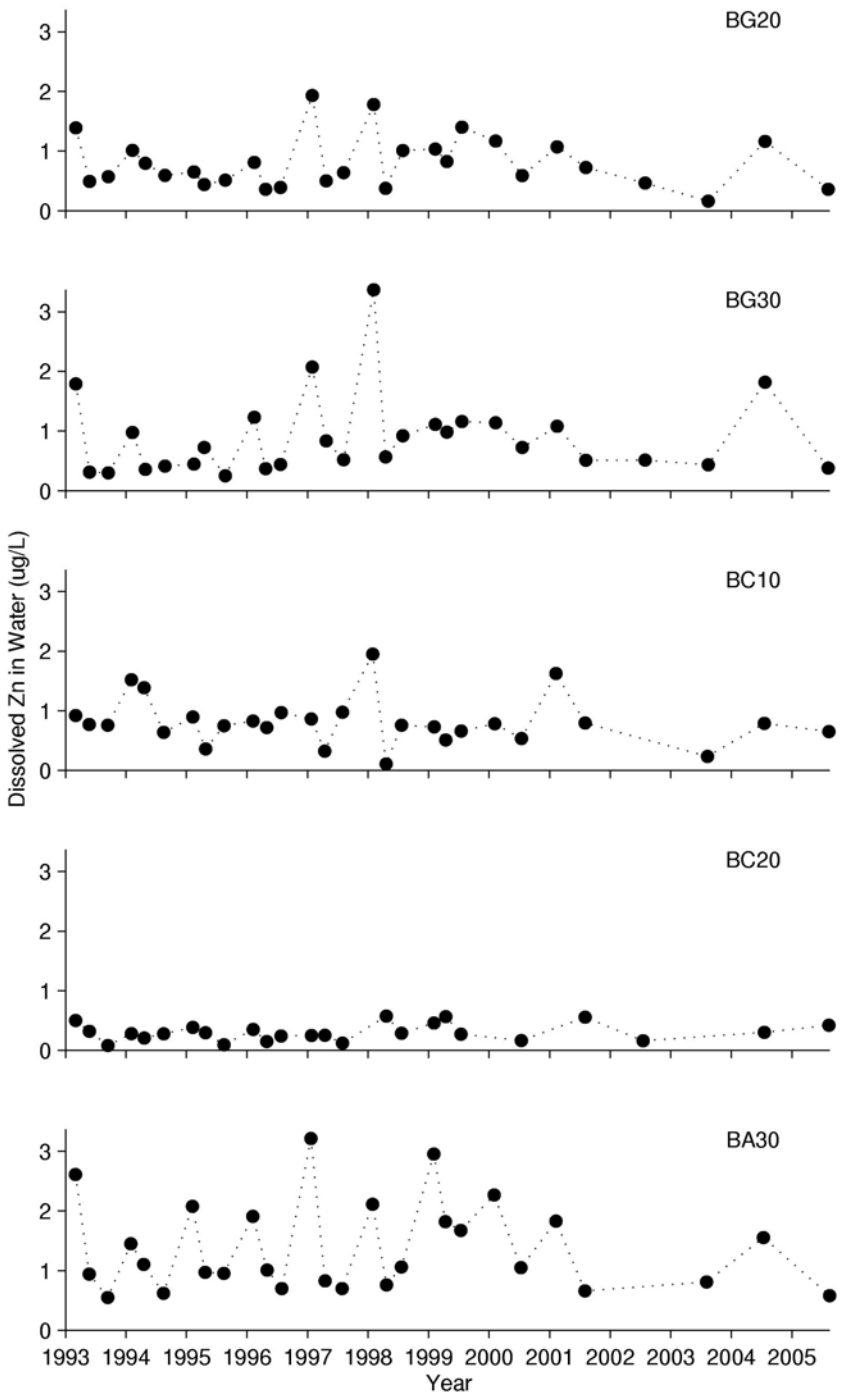


Figure 2.40. Time series plots for dissolved zinc (Zn) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

All samples were below the CTR 4-day Aquatic Life saltwater criterion of 81 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

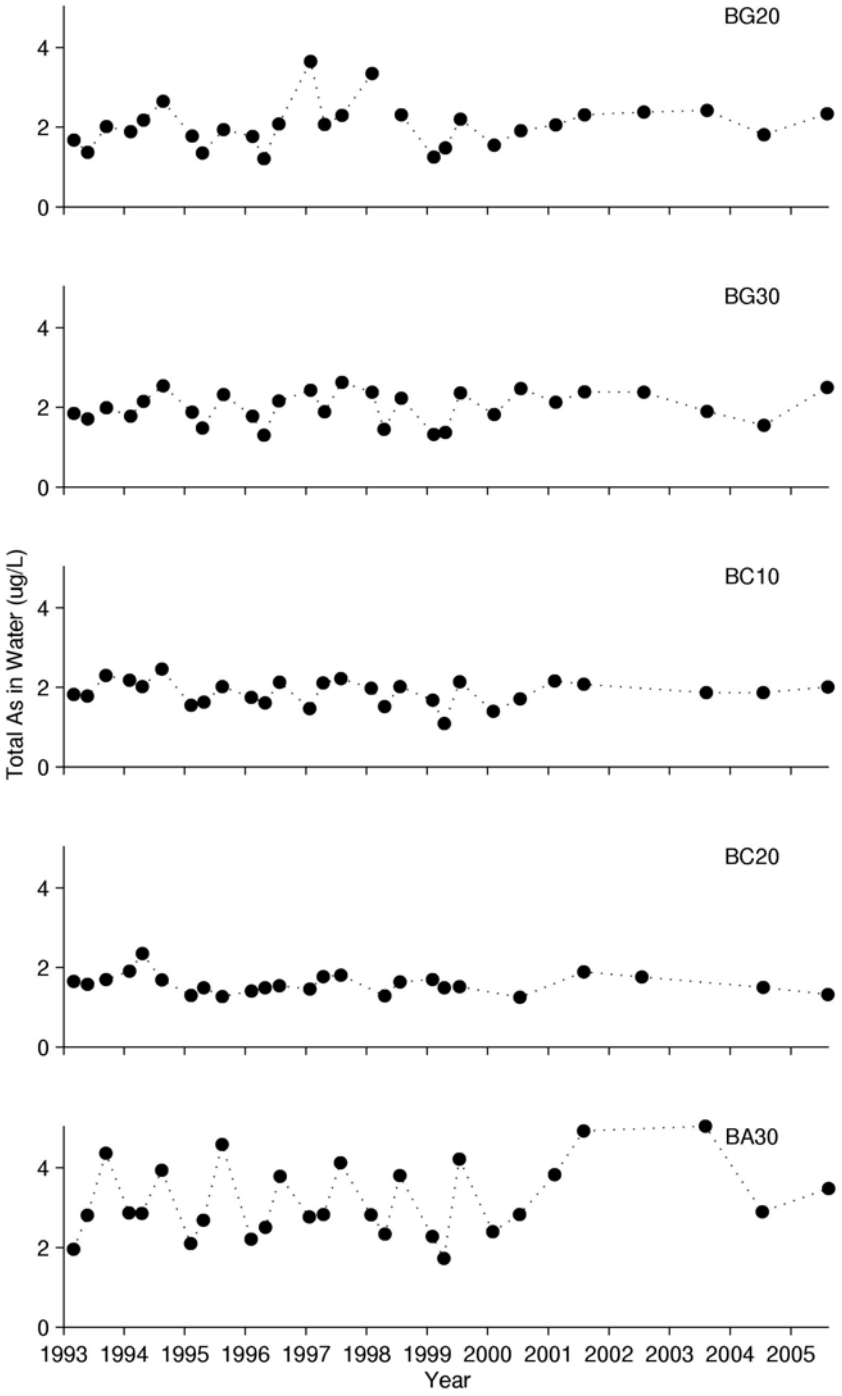


Figure 2.41. Time series plots for total arsenic (As) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Default CTR conversion factors were used to calculate the total effects threshold value. All samples were below the non-regulatory effects threshold of 36 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

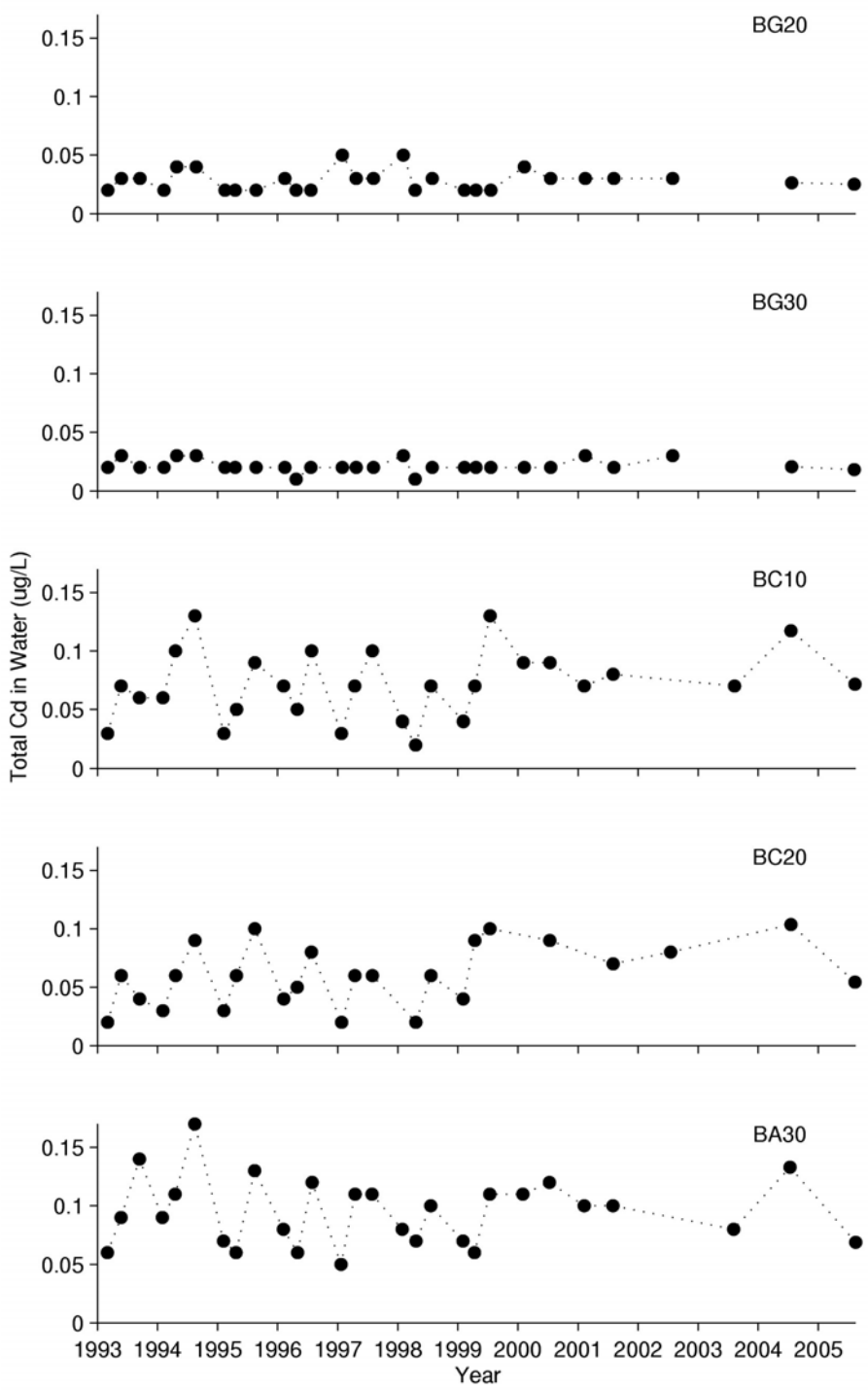


Figure 2.42. Time series plots for total cadmium (Cd) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Default CTR conversion factors were used to calculate the total effects threshold value. All samples were below the non-regulatory saltwater or calculated freshwater effects threshold values of 9.4 or 2.5 ug/L. (2.5 ug/L applies to estuarine regions of the Estuary.)

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

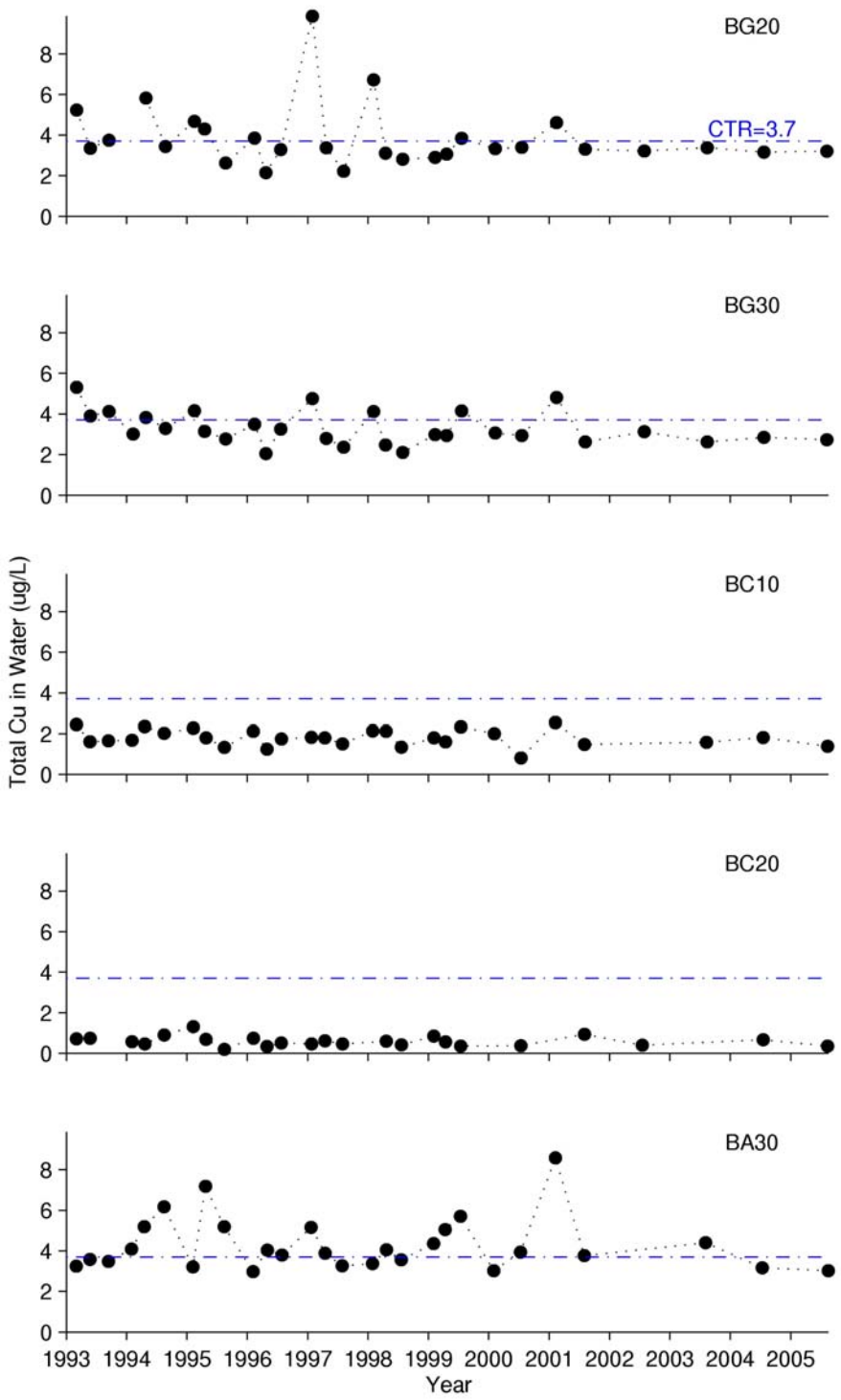


Figure 2.43. Time series plots for total copper (Cu) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The dashed blue reference line indicates the calculated, non-regulatory saltwater effects threshold of 3.7 ug/L from the CTR.

The Lower South Bay has a site-specific objective of 13.02 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

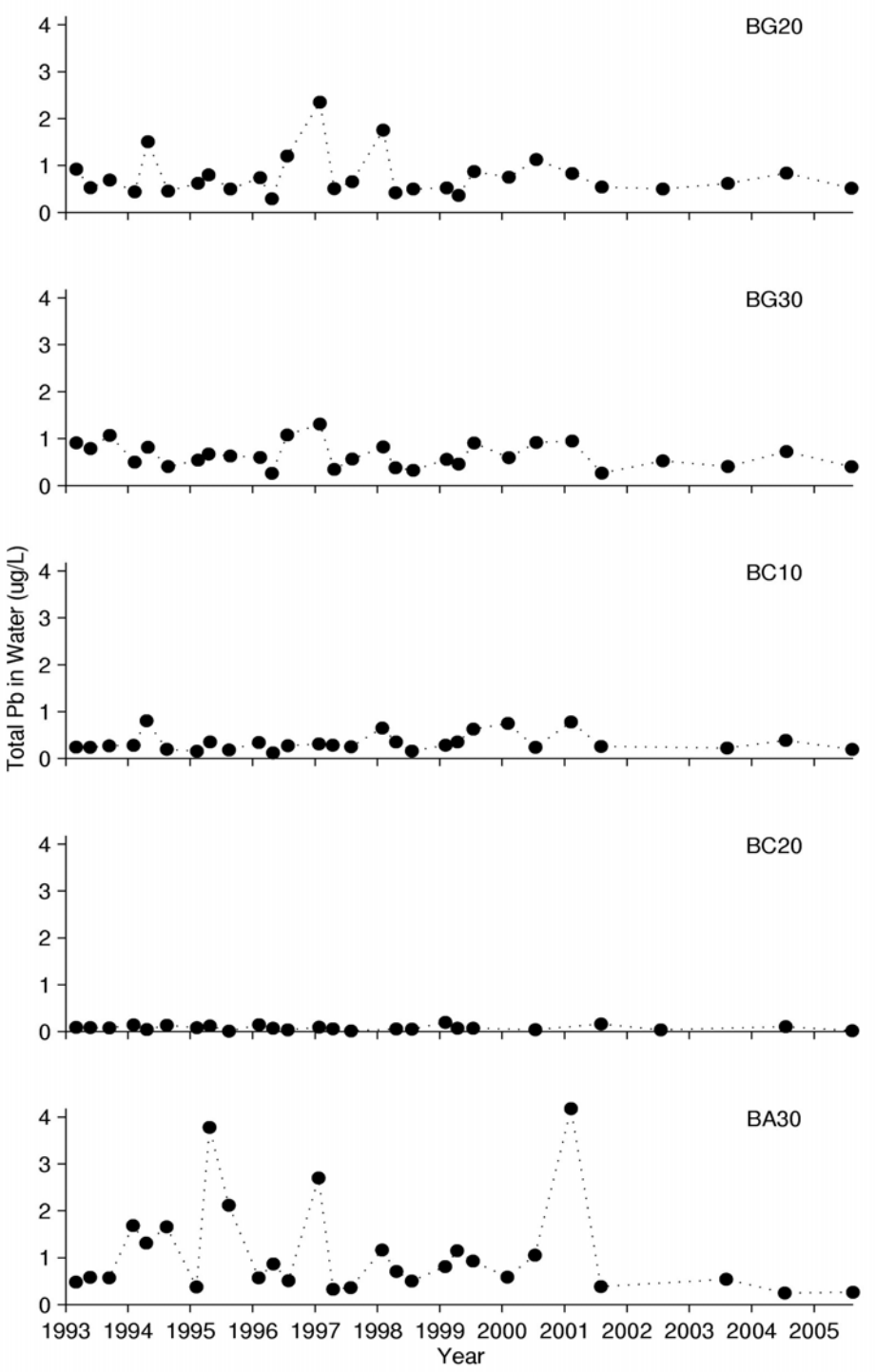


Figure 2.44. Time series plots for total lead (Pb) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Default CTR conversion factors were used to calculate the total effects threshold value. All samples were below the calculated non-regulatory effects thresholds of 5.6 or 3.2 ug/L. (3.2 ug/L applies to estuarine regions of the Estuary.)

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

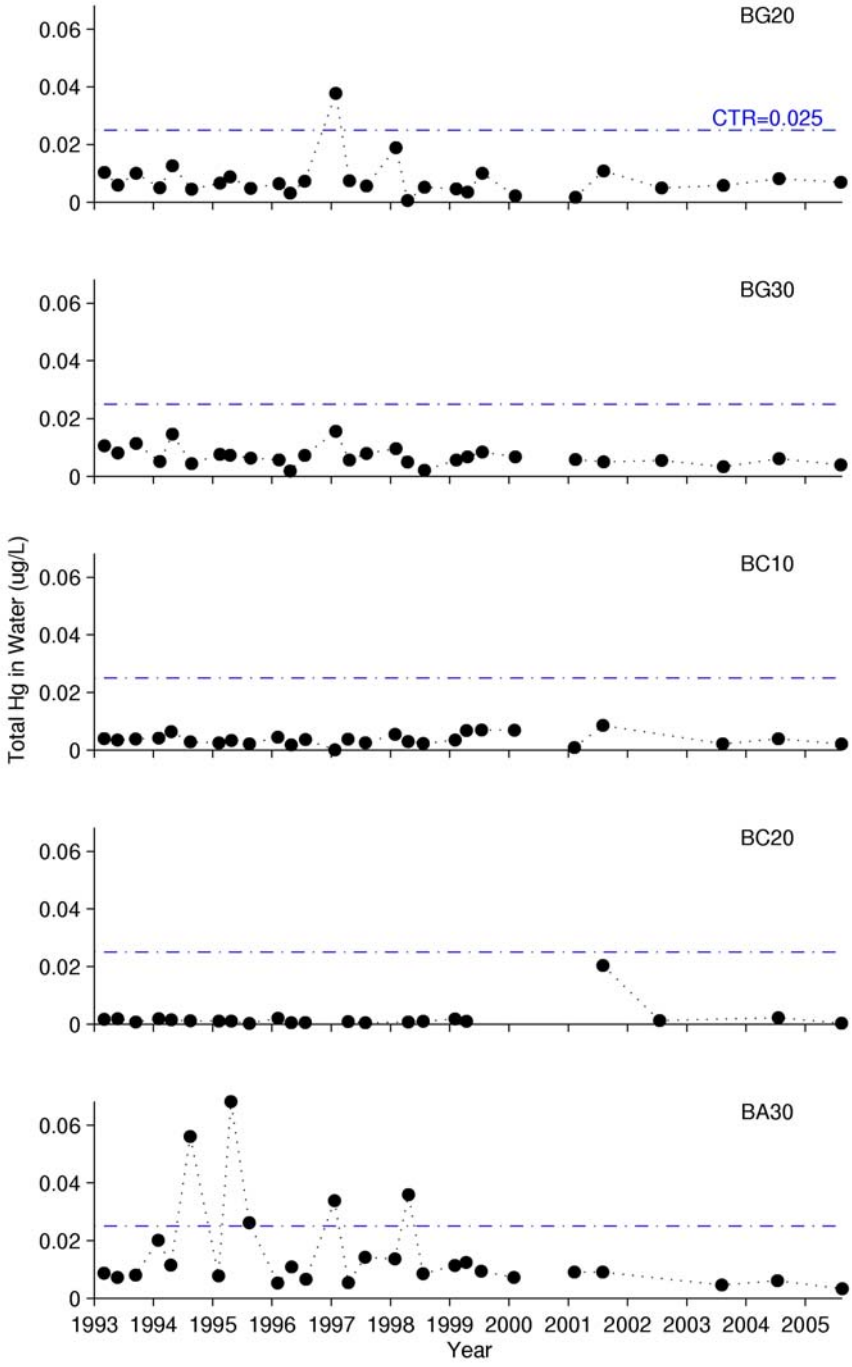


Figure 2.45. Time series plots for total mercury (Hg) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The dashed blue reference line indicates the water quality guideline of 0.025 ug/L.

The Lower South Bay has a site-specific objective of 0.051 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

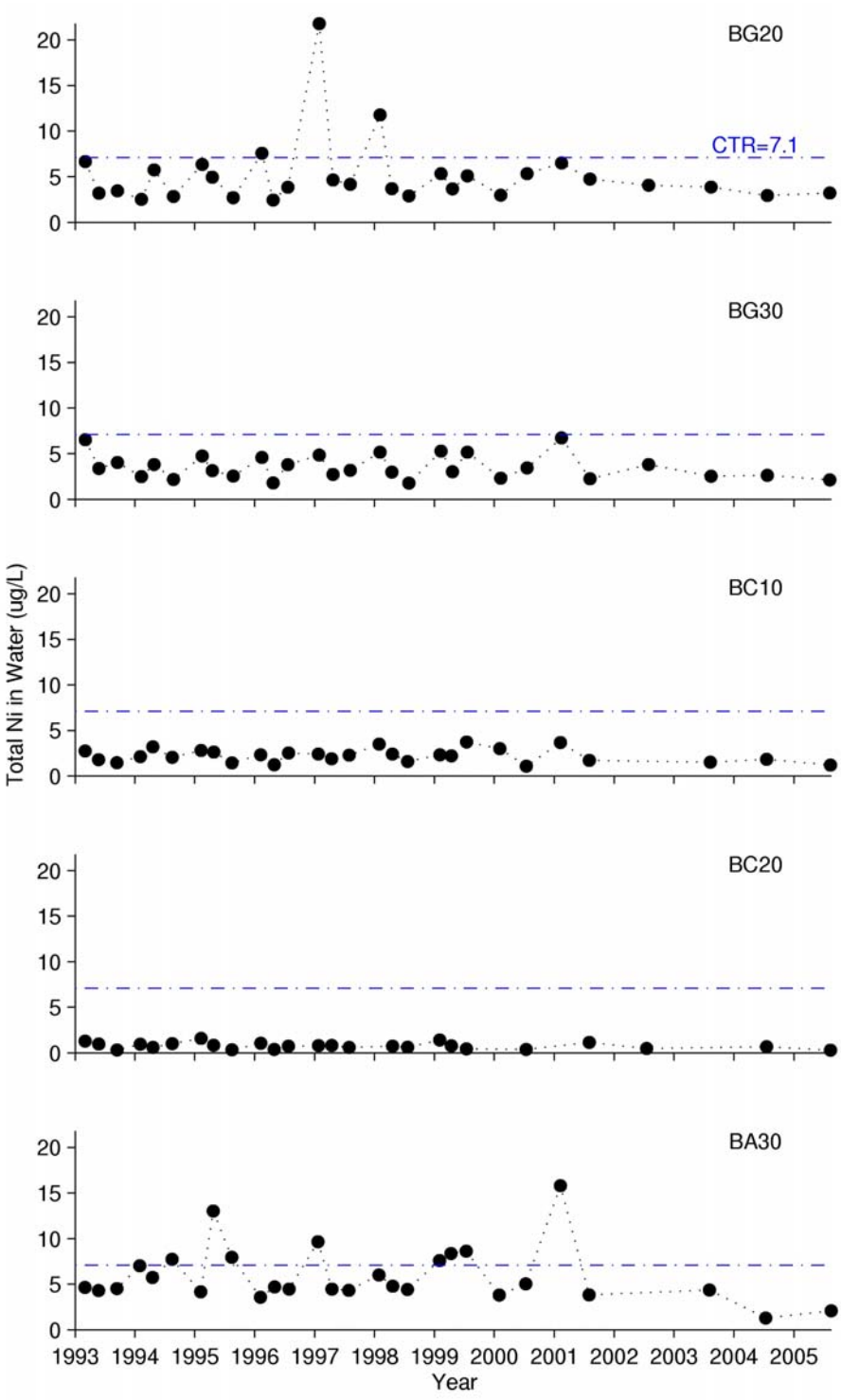


Figure 2.46. Time series plots for total nickel (Ni) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The dashed blue reference line indicates the water quality guideline of 7.1 ug/L.

Default CTR conversion factors were used to calculate the total effects threshold value of 7.1 ug/L. The Lower South Bay has a site-specific objective of 27.05 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

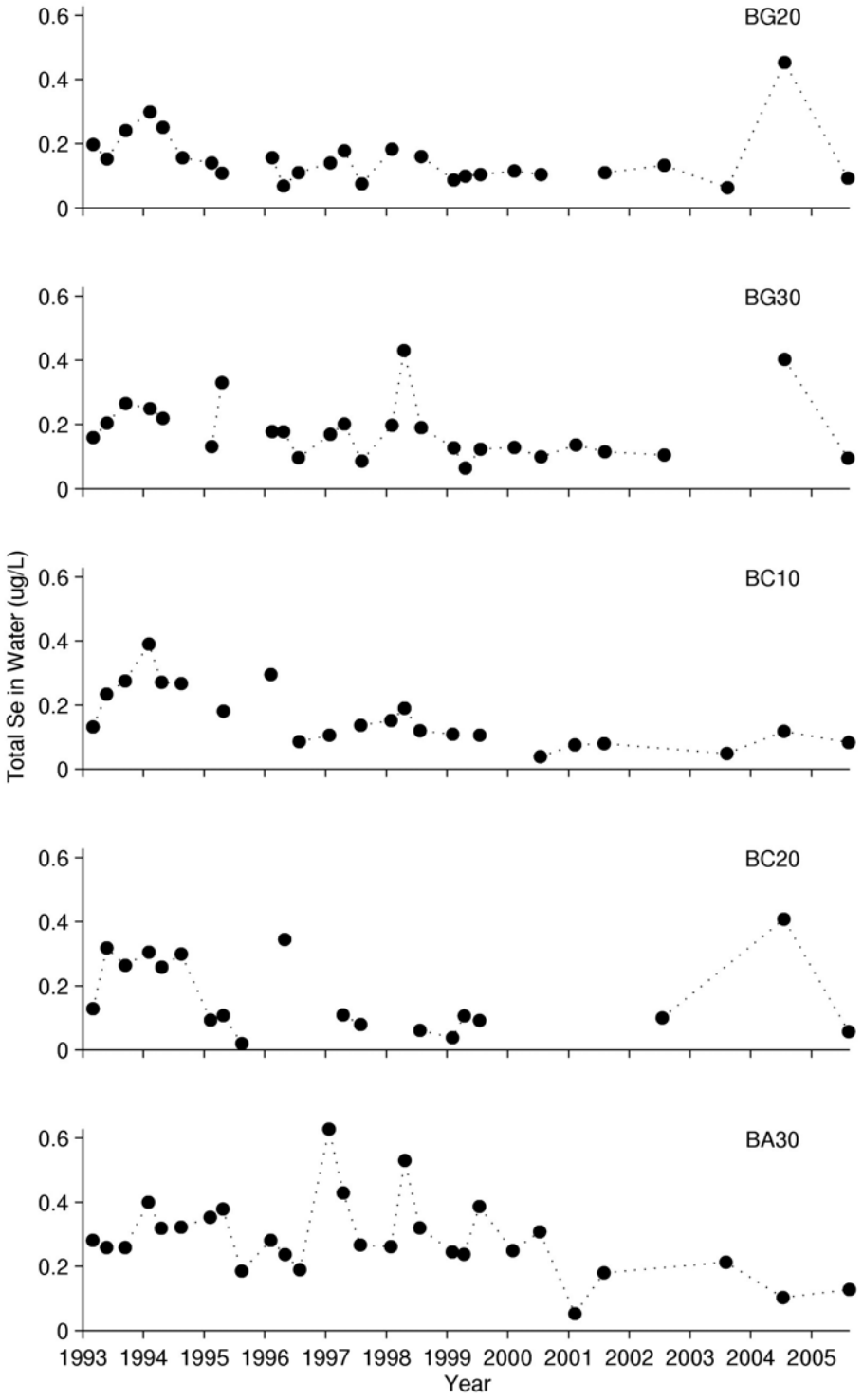


Figure 2.47. Time series plots for total selenium (Se) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

All samples were below the regulatory CTR region specific Aquatic Life criterion of 5 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

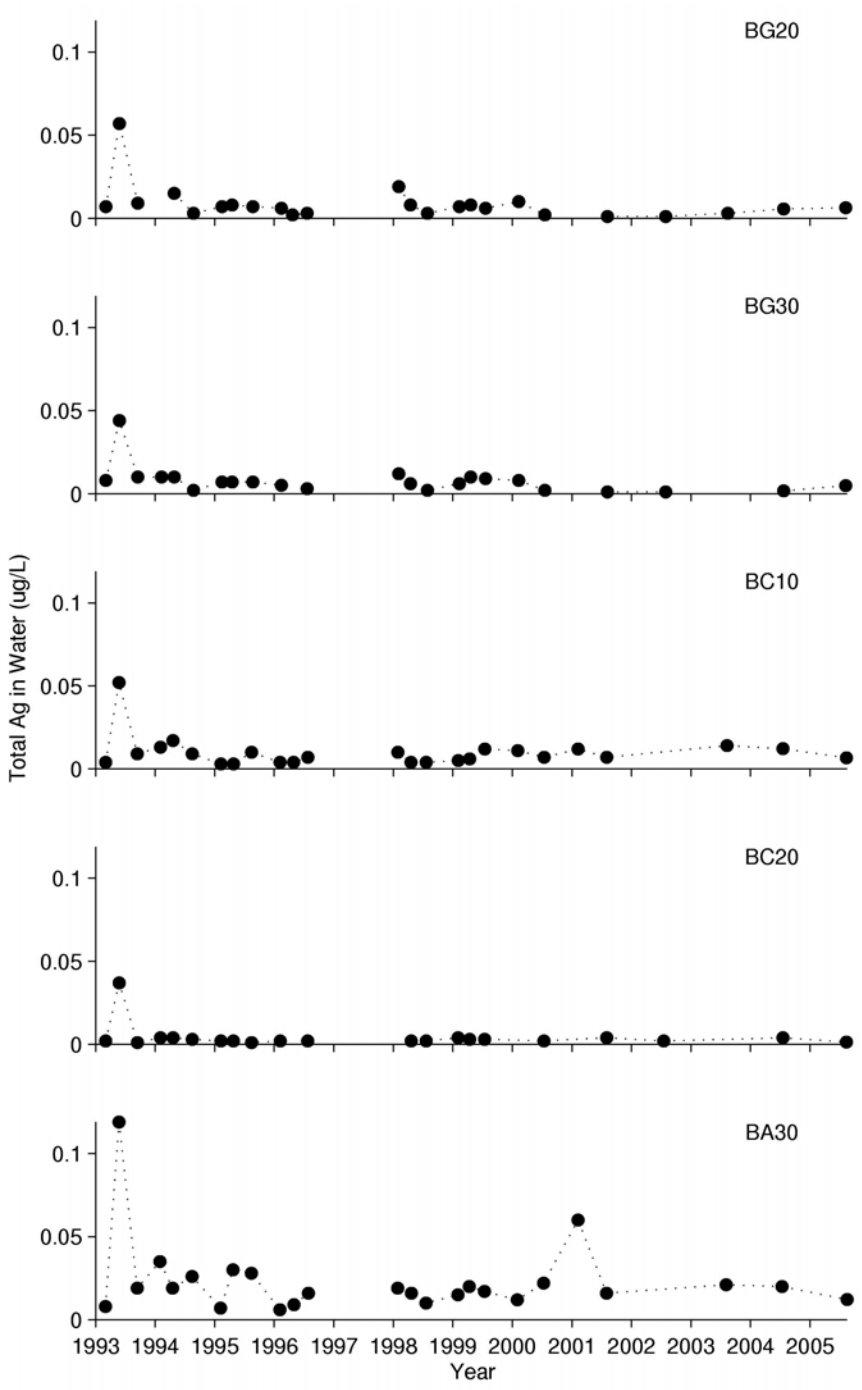


Figure 2.48. Time series plots for total silver (Ag) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Default CTR conversion factors were used to calculate the total effects threshold value. The calculated non-regulatory 1-hour saltwater effects threshold is 2.3 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

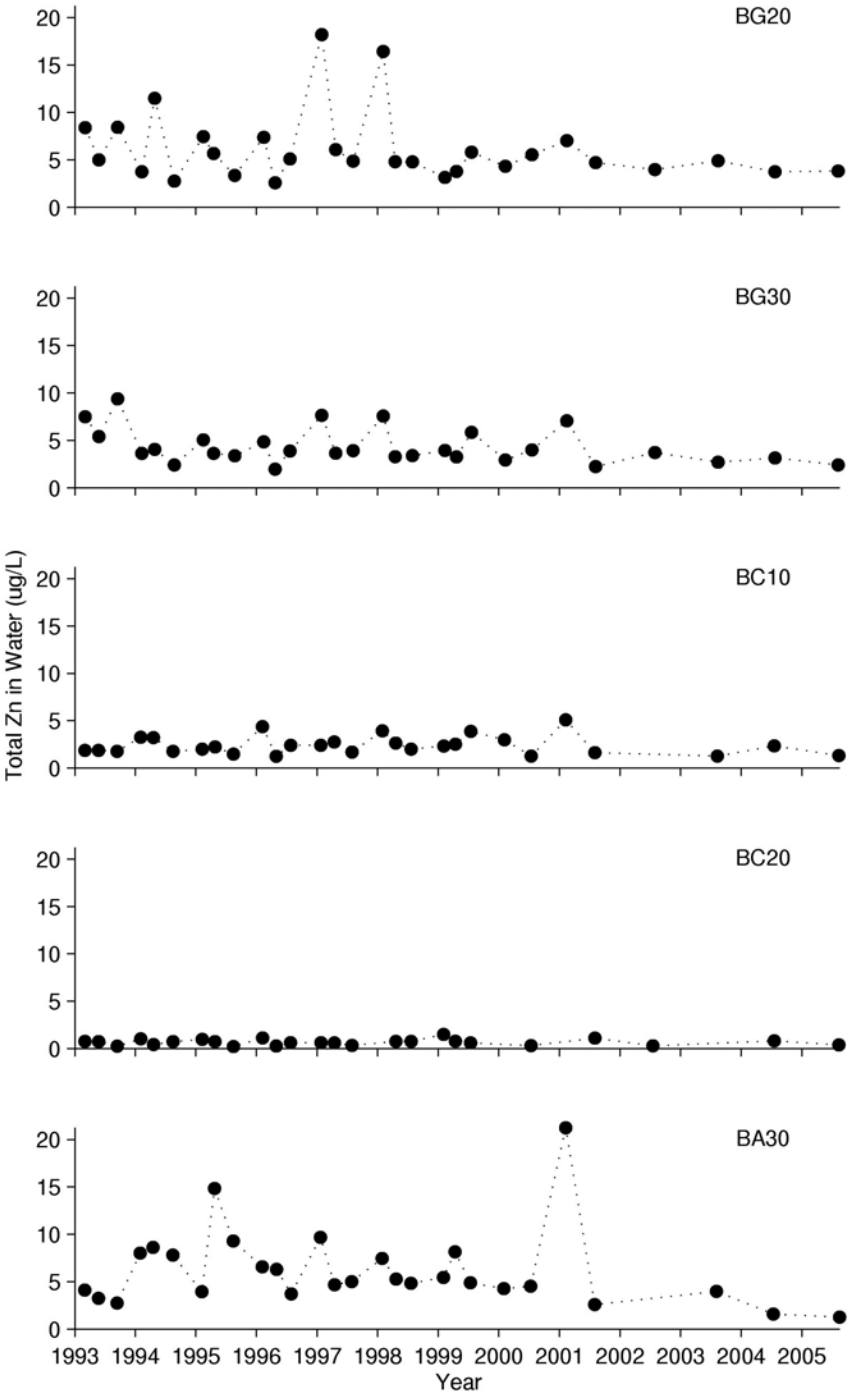


Figure 2.49. Time series plots for total zinc (Zn) in water (ug/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Default CTR conversion factors were used to calculate the total effects threshold value. All samples were below the non-regulatory saltwater effects threshold of 58 ug/L.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

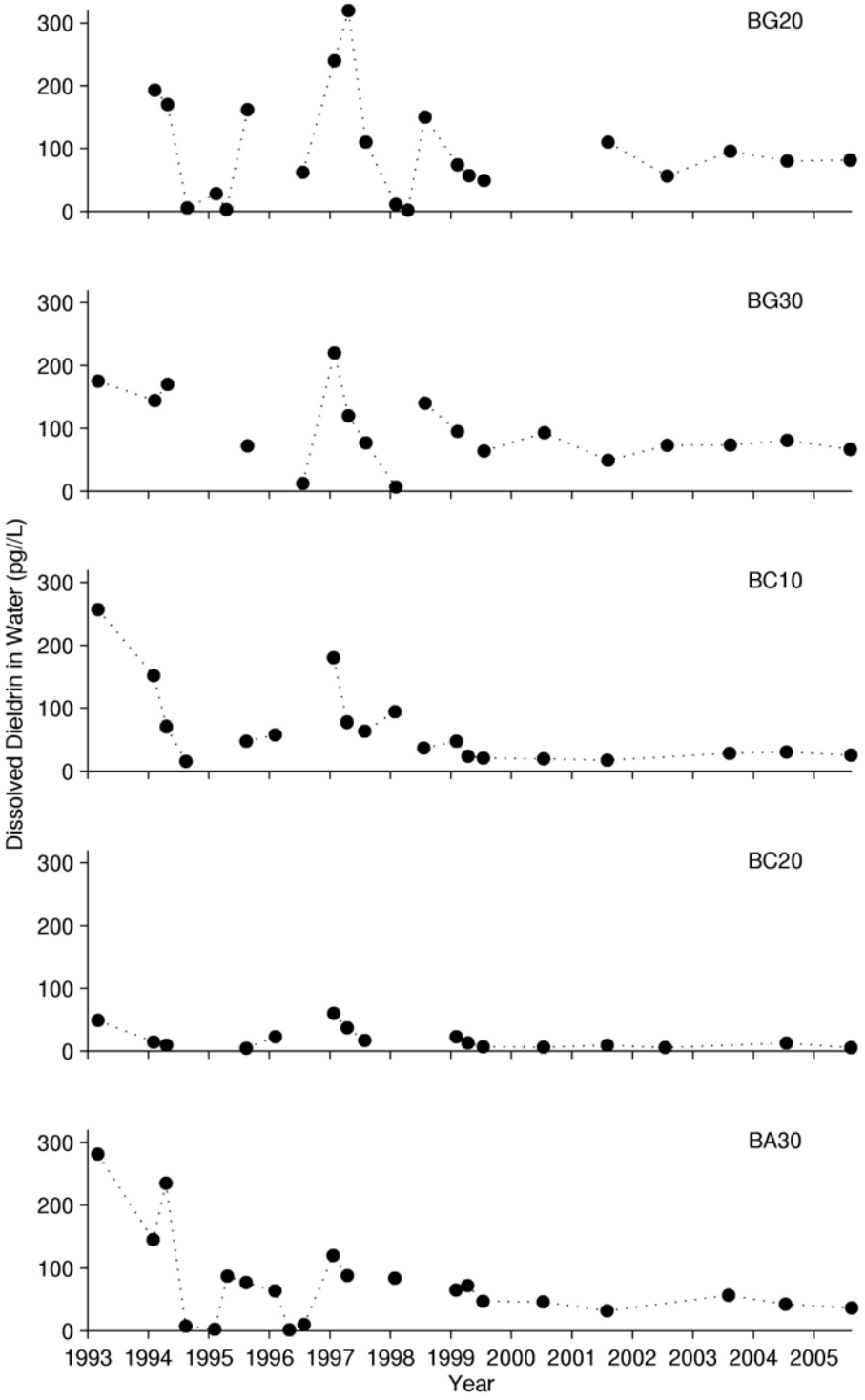


Figure 2.50. Time series plots for dissolved Dieldrin in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Organic contaminants are compared to the CTR water quality criteria on a total basis only.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

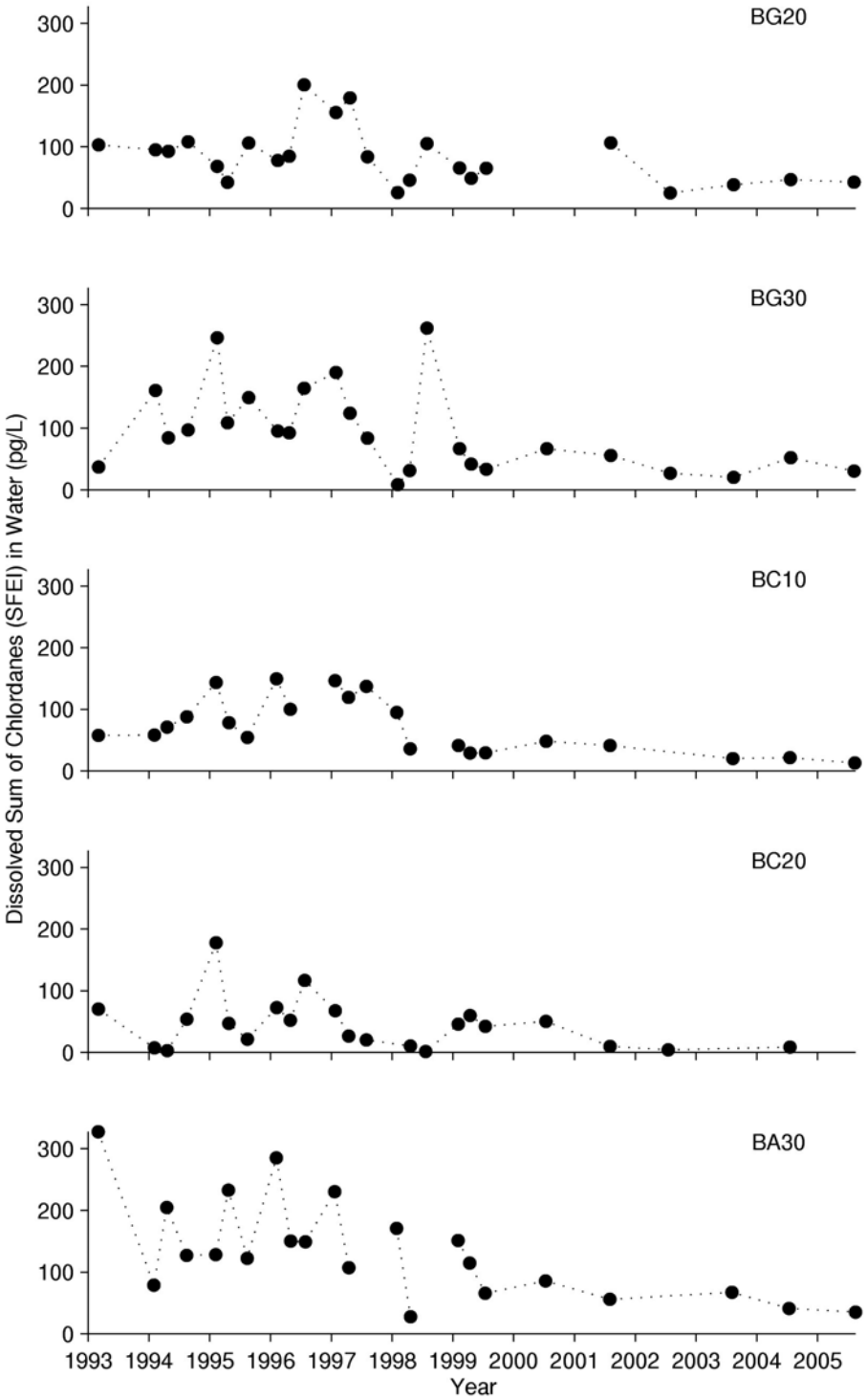


Figure 2.51. Time series plots for dissolved sum of Chlordanes in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Organic contaminants are compared to the CTR water quality criteria on a total basis only.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

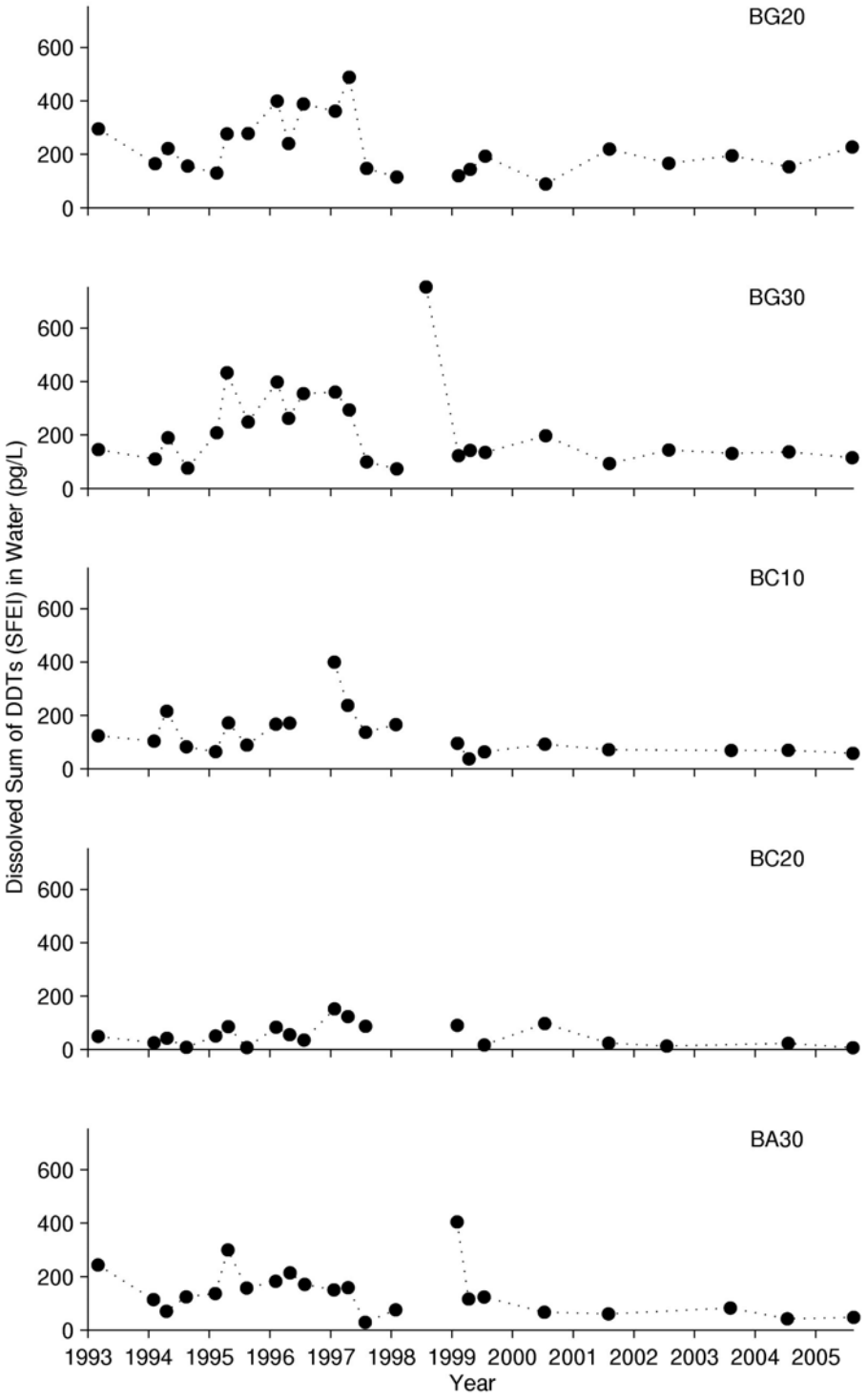


Figure 2.52. Time series plots for dissolved sum of DDTs in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Organic contaminants are compared to the CTR water quality criteria on a total basis only.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

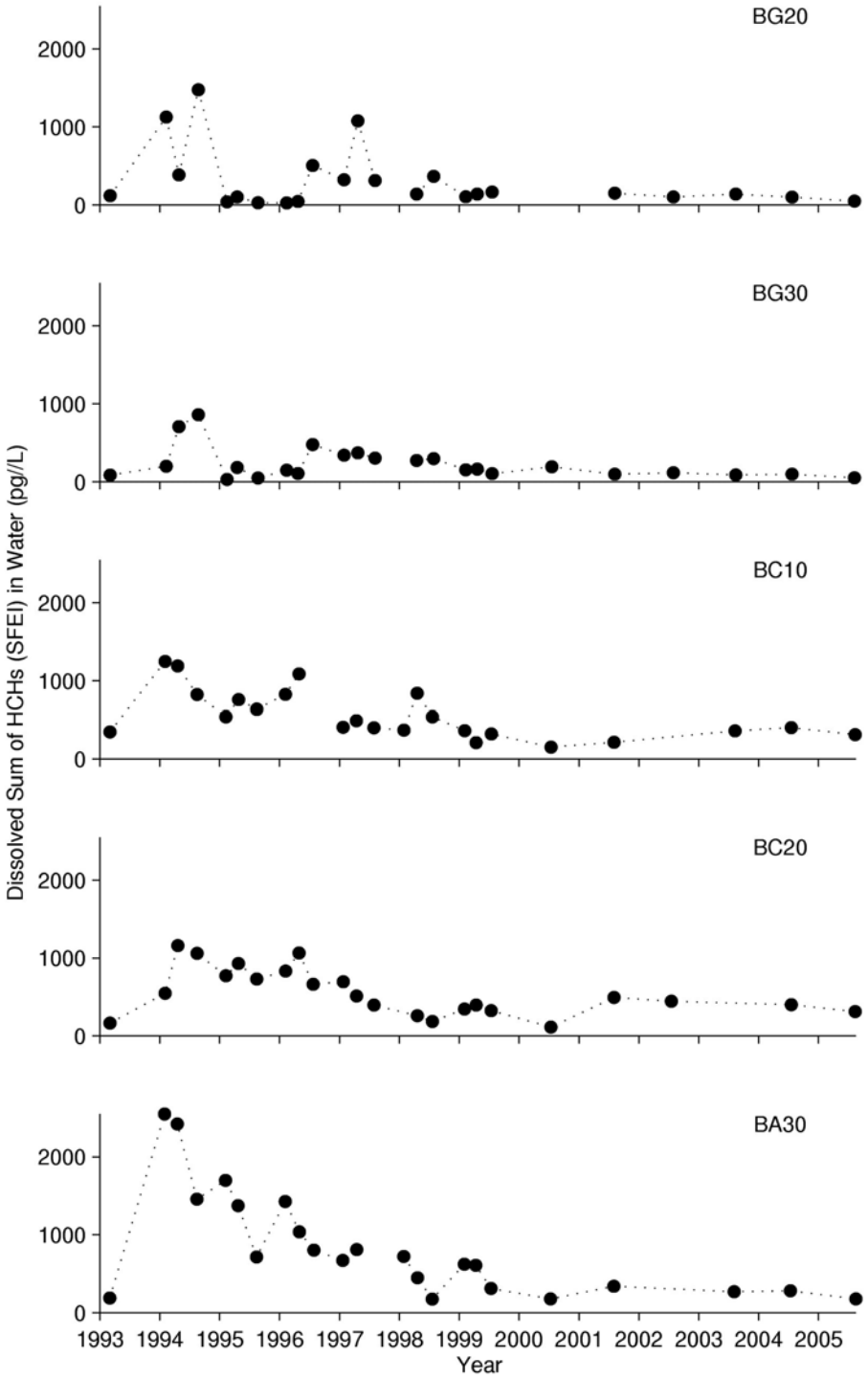


Figure 2.53. Time series plots for dissolved sum of HCHs in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Organic contaminants are compared to the CTR water quality criteria on a total basis only.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

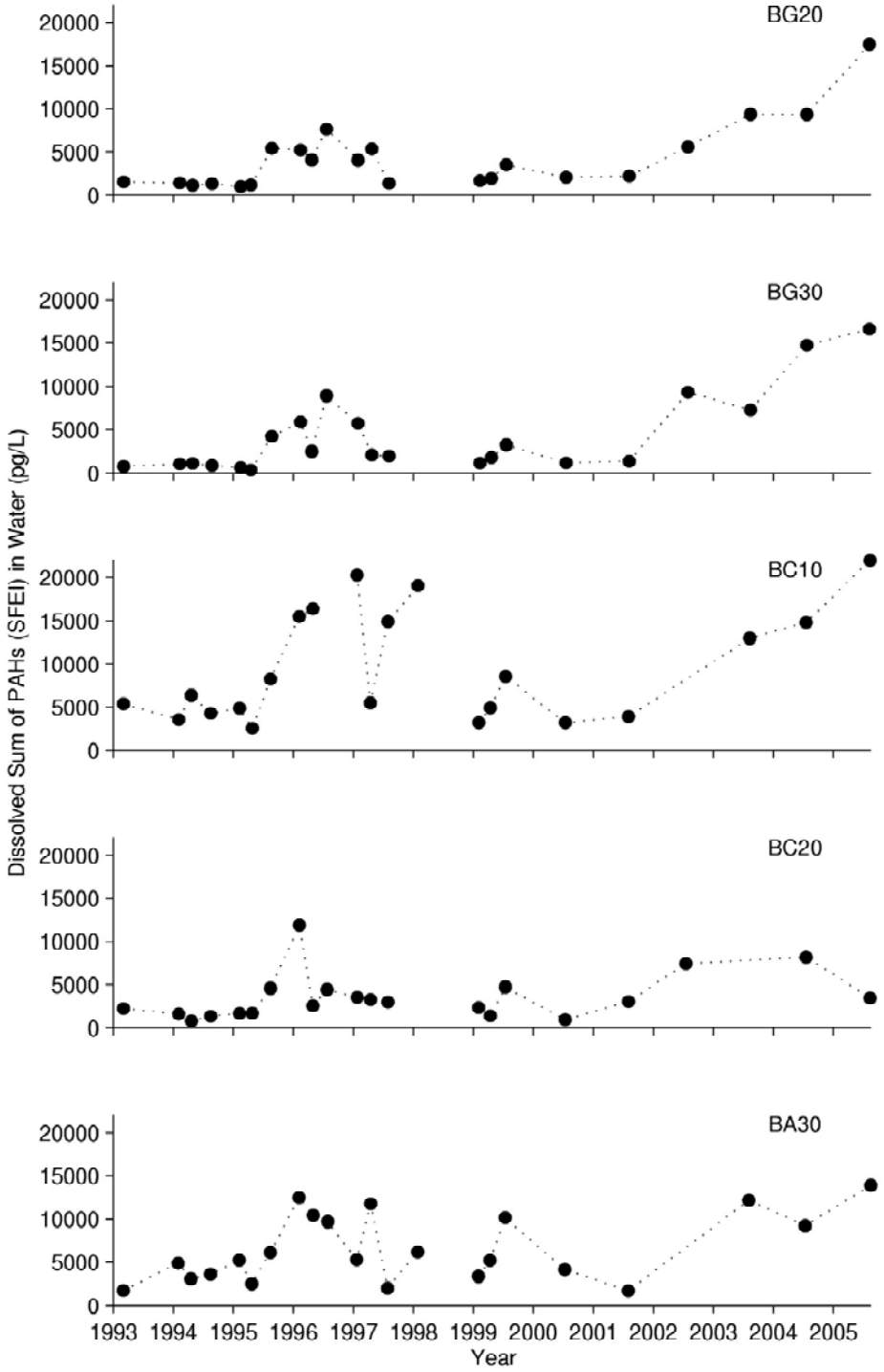


Figure 2.54. Time series plots for dissolved sum of PAHs in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Organic contaminants are compared to the CTR water quality criteria on a total basis only.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

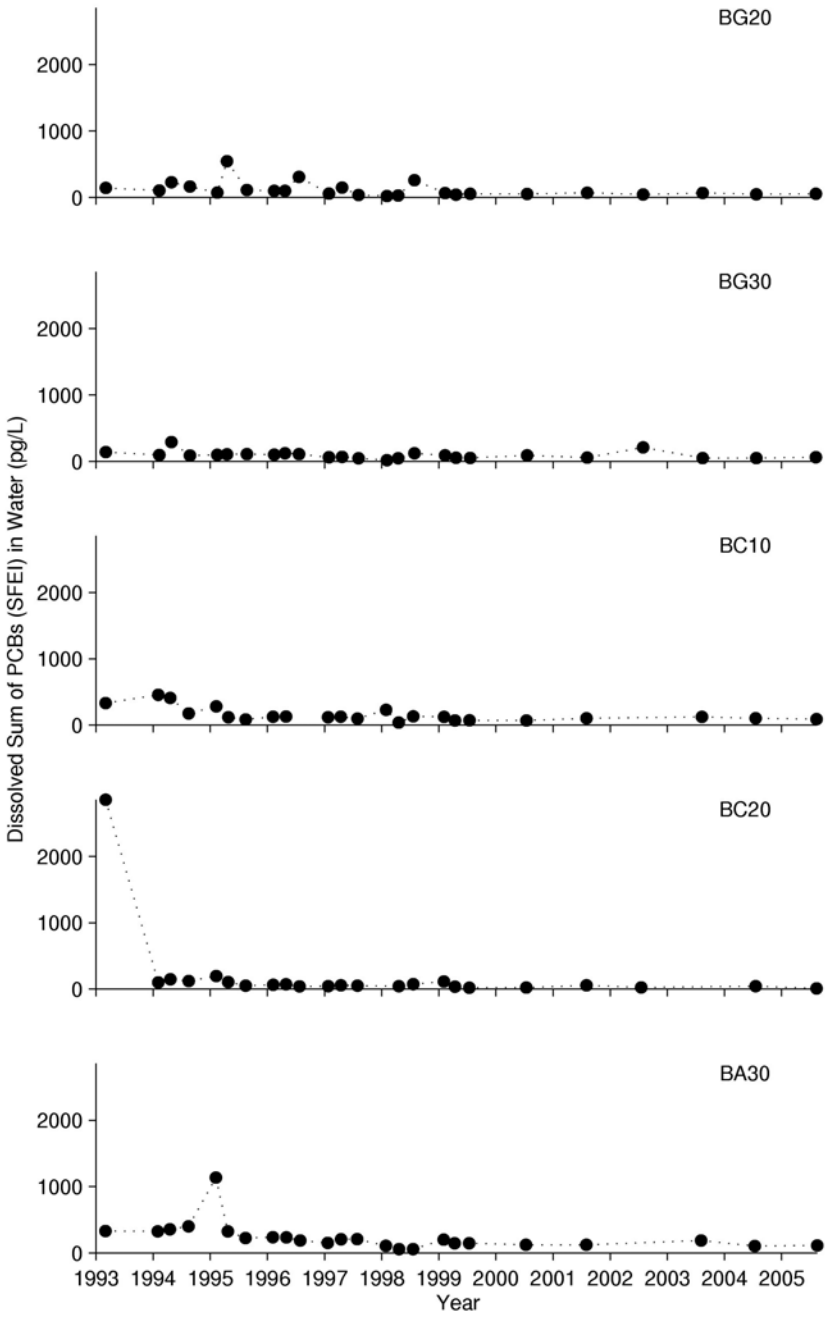


Figure 2.55. Time series plots for dissolved sum of PCBs in water (pg/L) at five historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005).

Organic contaminants are compared to the CTR water quality criteria on a total basis only.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BC10 Yerba Buena Island
BC20 Golden Gate
BA30 Dumbarton Bridge

Chapter 3

Sediment Monitoring

3.0 SEDIMENT MONITORING

Amy Franz, John Ross, Sarah Lowe, Cristina Grosso, 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 1.0 *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

In 2004 and 2005, the RMP Status and Trends Program continued with implementation of the stratified, random sampling design started in 2002 (see Chapter 1, *Introduction*). Sediment contaminant monitoring in 2004 and 2005 was conducted in the dry season (July-August) at 47 stations, including seven fixed historical stations (Sacramento River (BG20), San Joaquin River (BG30), Grizzly Bay (BF21), Pinole Point (BD31), Yerba Buena Island (BC11), Redwood Creek (BA41), and Coyote Creek (BA10)). At least one historic station was maintained per region to allow for analysis of long-term temporal trends. Monitoring of two stations at the southern end of the Estuary, San Jose (station C-3-0) and Sunnyvale (station C-1-3), was discontinued in 2003. Sediments collected from a subset of 27 random stations were used for conducting sediment bioassays. Station names, codes, location, and sampling dates are listed in Table 1.3 in the *Introduction* and shown in Figure 3.1.

3.2.1 Methods

A complete list of all parameters measured in the 2004 and 2005 sediment samples are included in Table 1.5 in the *Introduction*. A detailed description of sample collection and laboratory analytical methods is documented in Section 5 *Description of Methods*. Contaminant concentration data can be downloaded from the RMP website using the *Status and Trends Monitoring Data Access Tool* (http://www.sfei.org/rmp/data.htm).

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 are currently being developed for the State of California by staff at the Southern California Coastal Water Research Project (SCCWRP) (http://www.SCCWRP.org/) and the San Francisco Estuary Institute. Several sets of sediment quality guidelines (Table 3.1) are generally

used as informal screening tools for sediment contaminant concentrations, even though they have no regulatory status.

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 Regional Board has suggested guidelines of 1.4 mg/kg (Wolfenden and Carlin, 1992), and 1.5 mg/kg (Taylor *et al*., 1992).

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) as part of the 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. The ERL guideline values of Long *et al*. (1995) are presented for comparative purposes on the sediment contaminant concentration charts (Figures 3.4–3.19).

Although the Regional Board has proposed sediment targets for mercury of 0.2 mg/kg (Johnson and Looker, 2003), and 2.5 ug/kg for PCBs (CRWQCB, 2004) based on the development of Total Maximum Daily Loads (TMDLs), the Board is presently not using these values, but is instead moving towards the use of biota based guidelines.

3.2.3 Sediment Toxicity

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 both 2004 and 2005 (Figures 3.20 and 3.21, respectively). Sampling dates are listed in Table 1.3 in Section 1.0 *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 Section 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 July 2004 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 55.8% normal alive. Whereas the August 2005 amphipod sediment bioassay was toxic if it had below 76.2% survival, and the larval bivalve sediment bioassay was toxic if it had less than 81.8% normal alive for one batch and 75.8% for the other. 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. 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 Figure 3.2 and Figure 3.3, respectively. The list of parameters measured in the sediment samples is included in Table 1.5 in the *Introduction*. Analysis of chromium was discontinued in 2000. Sediment quality parameters, station depths, and all available contaminant concentrations are accessible through the RMP website using the *Status and Trends Monitoring Data Access Tool* @ http://www.sfei.org/rmp/data.htm.

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 combined years 2004-2005, the highest sediment contaminant concentrations (eleven out of sixteen parameters) were measured at stations in San Pablo Bay and the Lower South Bay (Figures 3.4–3.19). One station in San Pablo Bay (SPB018S) had the highest concentrations of cadmium, lead, mercury, DDTs and PCBs, while one station in the Lower South Bay (LSB026S) had the highest concentrations of nickel, silver, and zinc. The highest concentrations of arsenic (SU075S) and copper (SU015S) were measured in Suisun Bay, and the highest concentration of methylmercury was observed in the South Bay (SB001S). Lower South Bay sediments had the highest concentrations of BDE-47 (LSB002S), chlordanes (LSB023S), and dieldrin (LSB023S). The highest concentration of PAHs was documented in the Central Bay (CB080S).

The lowest contaminant concentrations (fifteen out of sixteen parameters) were measured in Suisun Bay and San Pablo Bay sediments. The measured concentrations of lead, selenium, chlordane, and PAHs were lowest within Suisun Bay at station SU002S, with the lowest levels of methylmercury, DDTs, dieldrin, and PCBs documented at station SU001S. Cadmium, copper, and silver concentrations were the lowest at station SU022S, and mercury at SU024S. South Bay sediment samples were found to have the lowest concentrations of nickel (SB001S), zinc (SB001S), and arsenic (SB015S). The lowest measured concentration of BDE-47 was observed at one of the river stations, San Joaquin River (BG30).

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). Non-detects (NDs) were replaced with a value of one-half the method detection limit (MDL) for trace metals, and for the organic totals NDs were estimated as one-half the average MDL of the summed parameters. Cumulative distribution functions (CDFs) were calculated 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).

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). Overall, significant differences ($p < 0.05$) were observed in 41% of the comparisons: 41.3% of the regional and 40.5% of the interannual (Table 3.3). The greatest number of combined regional and interannual differences was found for mercury (12 out of 16) and PAHs (11 out of 16).

Regional comparisons where significant differences were observed for >50% of the parameters (more than 8 out of 16) were the Lower South Bay vs. Suisun Bay (cadmium, copper, mercury, methylmercury, lead, selenium, silver, zinc, chlordanes, PAHs, and PCBs), Central Bay vs. Lower South Bay (mercury, methylmercury, nickel, lead, selenium, silver, zinc, BDE-47, chlordanes, and PAHs), and Lower South Bay vs. San Pablo Bay (cadmium, copper, methylmercury, lead, selenium, silver, BDE-47, chlordanes, and PAHs). Interannual comparisons where significant differences were documented for >50% of the parameters were 2002 vs. 2004 for arsenic, copper, nickel, selenium, silver, zinc, BDE-47, chlordanes, DDTs, and dieldrin.

In 2004, the highest numbers of ERL exceedances were observed in the Central Bay (CB077S, and CB016S) (Table 3.2a). 2004 ERL guideline exceedances and sediment contaminant concentrations were found to be lowest in Suisun Bay (SU002S), and the San Joaquin River (BG30). The same pattern was seen during 2005 (Table 3.2b) with the highest numbers of ERL exceedances observed in the Central Bay (CB025S, CB080S, and CB021S). Similar to 2004, the 2005 ERL sediment guideline exceedances and contaminant concentrations were found to be lowest at stations located within Suisun Bay (SU002S, SU024S, and SU001S) and in the Sacramento River (BG20).

3.3.2 Temporal Trends

The maintenance of fixed historical sampling stations, at least one per region, permits the analysis of long-term temporal trends.

Trace Elements

A method commonly used to improve the comparison of trace element and organic contaminant concentrations in sediments is to normalize them to a sediment component unaffected by anthropogenic activities (Luoma, 1990; Hanson, 1993; Daskalakis and O'Connor, 1995). Site-specific relationships between sediment trace element concentrations and possible independent variables, including % fines, % silt, % clay, total organic carbon (TOC), % iron and % aluminum were evaluated using Pearson correlation coefficients (Table 3.4); a significant positive correlation ($p < 0.05$) indicating a relationship where normalization is appropriate (Hebert & Keenleyside, 1995). Sediment trace element concentrations were normalized using linear regression analysis. Trace element concentrations were the dependent variable and the normalizer results the independent variable. Residuals from this analysis represent the variation in sediment trace element contaminant concentration that remains after normalization. Residuals were examined for normality using the Anderson-Darling test, and if sufficient evidence was

found to reject the null hypothesis of normality, trace element and normalizer results were log transformed as appropriate, and the normalization rerun.

Site-specific temporal trends were then investigated by conducting a linear regression analysis using the residuals as the dependent variable, and sampling date as the independent variable. The presence of first-order autocorrelation was examined using the Durbin-Watson test, and residuals evaluated for normality using the Anderson-Darling test. For linear regressions where the residuals were normally distributed, but first-order autocorrelation was found, the data were corrected using the Hildreth-Lu procedure. When insufficient evidence was documented of first-order autocorrelation, but the residuals were not normally distributed, a robust regression analysis was conducted using an *M*-estimation robust regression technique called iteratively reweighted least squares (Chatterjee and Machler, 1997). This procedure evaluates potential outlier and heteroskedasticity problems by down weighting influential residuals.

When normalization was not appropriate, a linear regression analysis was conducted using trace element concentrations as the dependent variable and sampling date as the independent variable. First-order autocorrelation and the normality of residuals were evaluated using the Durbin-Watson and Anderson-Darling test, respectively. When the linear regression residuals were normally distributed, but first-order autocorrelation was documented the data were corrected using the Hildreth-Lu procedure. When no conclusive evidence of first-order autocorrelation was observed, but the residuals were not normally distributed, the trace element concentrations were log transformed, and the linear regression rerun. If the residuals still lacked normality a robust regression analysis was conducted using iteratively reweighted least squares (Chatterjee and Machler, 1997). For all regressions a significantly positive slope ($p < 0.05$) was assumed to indicate an increase in the concentration of the contaminant at the station over time. Similarly, a significant negative slope assumes a decrease over time, while a lack of significance indicates no change in sediment concentration.

Significant long-term trends for one or more contaminants were found at all historical sites (Figures 3.22-3.36 and Table 3.5). Overall, significant long-term (five to thirteen year) trends were observed in 29% of the trace element contaminant analyses. Silver, arsenic, selenium, and mercury exhibit significant decreases at five, four, three, and two stations, respectively. The decline in silver surface sediment concentrations may be due to the decrease in silver loadings from wastewater treatment plants (Squire *et al*., 2002). Significant long-term decreases in lead, manganese, and nickel were documented at one station. Cadmium showed significant increases at two stations, while copper and monomethylmercury increased over time at one station. No significant trends were seen in sediment zinc concentrations.

Significant decreases in contaminant concentrations were observed over time at the Coyote Creek (BA10), Redwood Creek (BA41), and Yerba Buena Island (BC11) stations, five, three, and three, respectively. Two significant decreases were observed at the Pinole Point (BD31) and San Joaquin River (BG30) stations. Grizzly Bay (BF21) and Sacramento River (BG20) showed one significant decrease. Significant increases in two trace element concentrations were documented at the Yerba Buena Island (BC11) station, while one significant increase was observed at the Redwood Creek (BA41), Grizzly Bay (BF21), and San Joaquin River (BG30) stations.

Trace Organics

Site-specific relationships between the sum of sediment PAHs, PCBs, and DDTs and possible independent variables: % fines, % silt, % clay, and total organic carbon (TOC) were evaluated

using Pearson correlation coefficients (Table 3.6); a significant positive correlation ($p < 0.05$) indicating a relationship where normalization is appropriate (Hebert and Keenleyside, 1995). Chlordanes and HCHs have a high proportion of non-detects (>15%), and PBDEs have only been measured in sediments since 2002, therefore, analysis of temporal trends was not conducted for these contaminants.

As appropriate, sediment trace organic concentrations at each station were normalized using linear regression analysis. Trace organic concentrations were the dependent variable and the normalizer values the independent variable. Residuals from this analysis represent the variation in sediment trace element contaminant concentration that remains after normalization. Residuals were examined for normality using the Anderson-Darling test, and if sufficient evidence was found to reject the null hypothesis of normality, trace organic concentrations were log transformed, and the normalization rerun. First order kinetic processes are natural log (ln) - linear with respect to time (Sericano *et al*., 1996). Therefore, since the residuals falling above or below the regression line have positive or negative values, respectively, a constant was added to rescale each residual. Temporal trends were then examined for each station by conducting a linear regression analysis using the ln(rescaled residual) as the dependent variable, and sampling date as the independent variable. The presence of first-order autocorrelation was investigated using the Durbin-Watson test, but no conclusive evidence of first-order autocorrelation was found in the data. Residuals were evaluated for normality using the Anderson-Darling test, and when sufficient evidence was observed to reject the null hypothesis of normality, a robust regression analysis was conducted using an *M*-estimation robust regression technique (Chatterjee and Machler, 1997).

When normalization was not appropriate, a linear regression analysis was conducted using the natural log of the trace organic concentrations as the dependent variable and sampling date as the independent variable. The presence of first-order autocorrelation was examined using the Durbin-Watson test, and residuals evaluated for normality using the Anderson-Darling test. The Hildreth-Lu procedure was used to correct linear regressions when the residuals were normally distributed, but first-order autocorrelation was found in the data. When insufficient evidence of first-order autocorrelation was observed, but the residuals were not normally distributed, a robust regression analysis was conducted using iteratively reweighted least squares (Chatterjee and Machler, 1997). For all regressions a significantly positive slope ($p < 0.05$) was assumed to indicate an increase in the concentration of the contaminant at the station over time. Similarly, a significant negative slope assumes a decrease over time, while a lack of significance indicates no change in sediment concentration.

Significant long-term trends for trace organic contaminant were found at 2 out of 7 historical stations (Figures 3.22-3.36 and Table 3.7). Overall, significant long-term (five to thirteen year) trends were observed in only 10% of the trace organic contaminant analyses. Sum of PAHs increased significantly at the San Joaquin River (BG30) station, while the sum of PCBs showed a significant decrease at Redwood Creek (BA41). No significant trends were documented for the other trace organic contaminants or stations.

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 7 out of 27 (26%) of the 2004 RMP samples (Table 3.2a) and 19 out of 27 (70%) of the 2005 RMP samples (Table 3.2b). Patterns of toxicity for the two test organisms vary within the Estuary (Figures 3.20 and 3.21). 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. This pattern was observed again in 2004 and 2005. As shown in Figures 3.20 and 3.21, the random sites in Suisun Bay also support this trend (toxicity to larval mussels was observed at SU015S, SU001S, SU023S, SU025S, and SU075S). Similar to 2003 results, Central Bay sediments in 2004 did not show evidence of amphipod toxicity. In 2004, amphipod toxicity was only observed at one station, Yerba Buena Island (BC11) while toxicity to larval mussels was observed in the South Bay (SB017S) and the Lower South Bay (LSB001) as well as Suisun Bay and the rivers.

There was a 59% increase in the number of sites showing toxicity to either amphipod or larval mussels in 2005 than in 2004 (23 sites in 2005 compared to 7 sites in 2004). Sediments were found to be toxic in 2005 to both amphipods and larval mussels at four stations (SU023S, SPB023S, CB025S, and SB023S). Sites toxic to either amphipod or larval mussels in 2005 were the Sacramento River (BG20), San Joaquin River (BG30), Grizzly Bay (BF21), Suisun Bay (SU025S, SU075S), San Pablo Bay (SPB001S), Yerba Buena Island (BC11), Redwood Creek (BA41), the South Bay (SB001S, SB025S), the Lower South Bay (LSB001S, LSB025S, and LSB073S) and Coyote Creek (BA10). Bioassay results for 2005 indicate that sediments from San Pablo Bay (Pinole Point (BD31) SPB021S, and SPB025S), Central Bay (CB001S, CB021S, and CB023S), South Bay (SB021S), and Lower South Bay (LSB023S) were not toxic to either amphipods or larval mussels. 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 2004 and 2005 RMP samples (Table 3.2a and 3.2b). 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 2004 and 2005 RMP sediment samples were considered potentially toxic if either four or more ERMs, nine or more ERLs, or half (22) 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). In the past, RMP mERMqs were calculated using 13 contaminants, including nickel, but the revised calculations use 24 contaminants (Hyland *et al.*, 1999), excluding nickel (Table 3.1). Samples that did not have values for at least 19 of the 24 parameters were not included in the calculations. The resulting values are considerably lower than the values calculated in previous years, and are heavily weighted with PAHs. Chromium was not analyzed in 2004 and 2005 and therefore is not included in the calculations.

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 2004 and 2005 RMP sediment samples for potential adverse ecological effects. Mean ERM quotients were compared between estuary regions (random stations only) using the non-parametric Kruskal-Wallis test for multiple comparisons (Zar, 1984). If the null hypothesis, stating that the sample distributions were from the same population, was rejected ($p < 0.05$), then a non-parametric multiple comparison was performed on the ranks using Tukey's honestly significant difference (HSD) test. Statistical analysis reveals that the mERmq values were significantly higher in the Central Bay compared to the South Bay, San Pablo Bay, and Suisun Bay (Kruskal-Wallis, H = 31.81, $df = 4$, $p < 0.0005$), a mERMq value greater than 0.15 was documented for CB080S in 2005 (Table 3.2b).

In 2004, stations in the Central Bay (CB001S, CB016S, CB077S, CB078S), South Bay (SB019S, SB020S), and San Pablo Bay (SPB018S) had nine or more contaminants above the ERL guidelines. Seven sediment samples were toxic to either amphipods or larval mussels (Sacramento River (BG20), San Joaquin River (BG30), Grizzly Bay (BF21), SU011S, SU015S, Yerba Buena Island (BC11), SB017S, and LSB001S); however, all had mERMq values below 0.15, and except for SB017S, all had ERL, ERM, and ASC exceedences below the number considered to be potentially toxic. Sediments from CB016S, SPB018S, and SB020S had a high number of ERL exceedences (17, 10, and 9, respectively), but were not tested for toxicity.

In 2005, stations in the Central Bay (CB021S, CB025S, CB080S), and the River station San Joaquin River (BG30) had nine or more contaminants above the ERL guidelines. Nineteen sediment samples were toxic to either amphipods or larval mussels (Sacramento River (BG20), San Joaquin River (BG30), Grizzly Bay (BF21), SU001S, SU023S, SU025S, SU075S, SPB001S, SPB023S, Yerba Buena Island (BC11), CB025S, Redwood Creek (BA41), SB001S, SB023S, SB025S, LSB001S, LSB025S, LSB073S, and Coyote Creek (BA10)); however, all had mERMq values below 0.15, and except for San Joaquin River (BG30) and CB025S, all had ERL, ERM, and ASC exceedences below the number considered to be potentially toxic. Sediments from the Central Bay stations (CB080S, CB021S) had a high number of ERL exceedences (16 and 13, respectively), and CB080S had a high number of ASC exceedences (25), but these sediments were not tested for toxicity.

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		

* Chromium concentrations were not measured in 2004 and 2005 sediment samples.

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

Table 3.2a. Summary of sediment quality for the RMP in 2004.

. = not tested, * indicates number of exceedances above ASC guidelines for sandy samples.

Code	Site Name	Date	% Fines	mERMq	No. of ASC above Guidelines	No. of ERL above Guidelines	No. of ERM above Guidelines	Toxic to Amphipods?	Toxic to Bivalves?
BG20	Sacramento River	7/27/04	15	0.0240	1*	3	1	no	yes
BG30	San Joaquin River	7/27/04	49	0.0416	2	2	1	no	yes
BF21	Grizzly Bay	7/27/04	98	0.0763	2	8	1	no	yes
SU001S	Suisun Bay	7/28/04	28	0.0216	2*	3	1	no	no
SU002S	Suisun Bay	7/27/04	8	0.0154	0*	1	1	.	.
SU015S	Suisun Bay	7/27/04	100	0.0730	6	8	1	no	yes
SU016S	Suisun Bay	7/27/04	91	0.0676	3	8	2	.	.
SU017S	Suisun Bay	7/28/04	23	0.0250	2*	3	1	no	no
SU018S	Suisun Bay	7/27/04	80	0.0557	2	7	1	.	.
SU019S	Suisun Bay	7/28/04	41	0.0384	1	4	1	no	no
SU020S	Suisun Bay	7/27/04	96	0.0654	2	6	1	.	.
BD31	Pinole Point	7/29/04	92	0.0647	3	6	2	no	no
SPB001S	San Pablo Bay	7/28/04	99	0.0626	1	5	2	no	no
SPB002S	San Pablo Bay	7/29/04	94	0.0706	1	6	1	.	.
SPB015S	San Pablo Bay	7/28/04	98	0.0753	2	7	1	no	no
SPB016S	San Pablo Bay	7/28/04	99	0.0643	1	7	2	.	.
SPB017S	San Pablo Bay	7/28/04	94	0.0666	1	6	2	no	no
SPB018S	San Pablo Bay	7/28/04	81	0.1347	8	10	3	.	.
SPB019S	San Pablo Bay	7/29/04	44	0.0695	1	7	2	no	no
SPB074S	San Pablo Bay	7/29/04	43	0.0385	1	5	1	.	.
BC11	Yerba Buena Island	7/30/04	83	0.0743	1	5	1	yes	no
CB001S	Central Bay	7/29/04	67	0.1037	2	9	1	no	no
CB002S	Central Bay	7/30/04	95	0.1134	6	7	2	.	.
CB016S	Central Bay	7/30/04	80	0.1302	20	17	2	.	.
CB018S	Central Bay	7/30/04	70	0.0637	1	4	2	.	.
CB020S	Central Bay	7/30/04	86	0.0975	1	5	1	.	.
CB075S	Central Bay	7/29/04	83	0.1173	8	7	1	no	no
CB077S	Central Bay	7/30/04	49	0.1493	27	19	1	no	no
CB078S	Central Bay	7/30/04	89	0.1208	13	13	2	no	no
BA41	Redwood Creek	8/2/04	24	0.0943	30*	6	2	no	no
SB001S	South Bay	8/2/04	46	0.0478	1	4	1	no	no
SB002S	South Bay	8/2/04	99	0.0653	1	6	1	.	.
SB015S	South Bay	8/2/04	56	0.0443	1	4	1	no	no
SB016S	South Bay	8/2/04	89	0.0679	1	6	1	.	.
SB017S	South Bay	7/30/04	37	0.0427	23*	4	0	no	yes
SB018S	South Bay	8/2/04	97	0.0729	1	6	1	.	.
SB019S	South Bay	8/2/04	89	0.1115	12	13	2	no	no
SB020S	South Bay	8/2/04	84	0.0995	7	9	1	.	.
LSB001S	Lower South Bay	8/3/04	99	0.0794	1	7	2	no	yes
LSB002S	Lower South Bay	8/3/04	99	0.0708	1	5	2	.	.
LSB015S	Lower South Bay	8/3/04	99	0.0663	1	5	2	no	no
LSB016S	Lower South Bay	8/3/04	99	0.0780	1	8	1	.	.
LSB017S	Lower South Bay	8/3/04	96	0.0725	1	5	2	no	no
LSB018S	Lower South Bay	8/2/04	98	0.0801	3	7	2	.	.
LSB019S	Lower South Bay	8/3/04	98	0.0772	1	6	2	no	no
LSB020S	Lower South Bay	8/3/04	73	0.0623	1	5	2	.	.
BA10	Coyote Creek	8/3/04	95	0.0718	1	6	1	no	no

Table 3.2b. Summary of sediment quality for the RMP in 2005.

NA = not available, . = not tested, * indicates number of exceedances above ASC guidelines for sandy samples.

Code	Site Name	Date	% Fines	mERMq	No. of ASC above Guidelines	No. of ERL above Guidelines	No. of ERM above Guidelines	Toxic to Amphipods?	Toxic to Bivalves?
BG20	Sacramento River	8/30/05	26	0.0251	3*	2	1	no	yes
BG30	San Joaquin River	8/30/05	48	0.1054	9	9	1	no	yes
BF21	Grizzly Bay	8/30/05	98	0.0589	1	5	1	no	yes
SU001S	Suisun Bay	8/30/05	64	0.0278	1	2	1	no	yes
SU002S	Suisun Bay	8/29/05	8	0.0155	0*	1	1	.	.
SU022S	Suisun Bay	8/29/05	68	0.0441	1	5	1	.	.
SU023S	Suisun Bay	8/30/05	94	0.0530	1	4	1	yes	yes
SU024S	Suisun Bay	8/29/05	39	0.0248	1*	2	1	.	.
SU025S	Suisun Bay	8/30/05	90	0.0501	0	6	1	no	yes
SU075S	Suisun Bay	8/29/05	95	0.0612	2	4	1	no	yes
SU076S	Suisun Bay	8/30/05	91	0.0445	0	5	1	.	.
BD31	Pinole Point	8/29/05	89	0.0683	1	6	1	no	no
SPB001S	San Pablo Bay	8/29/05	99	0.0652	0	5	1	yes	no
SPB002S	San Pablo Bay	8/26/05	95	0.0636	0	6	1	.	.
SPB021S	San Pablo Bay	8/29/05	79	0.0613	0	6	1	no	no
SPB022S	San Pablo Bay	8/26/05	89	0.0517	0	5	1	.	.
SPB023S	San Pablo Bay	8/26/05	94	0.0641	1	5	1	yes	yes
SPB024S	San Pablo Bay	8/26/05	71	0.0286	0	3	1	.	.
SPB025S	San Pablo Bay	8/26/05	95	0.0612	0	5	1	no	no
SPB026S	San Pablo Bay	8/29/05	27	0.0298	1*	4	1	.	.
BC11	Yerba Buena Island	8/25/05	92	0.0736	1	6	1	no	yes
CB001S	Central Bay	8/26/05	83	0.0954	2	8	1	no	no
CB002S	Central Bay	8/25/05	98	0.0794	0	5	1	.	.
CB021S	Central Bay	8/25/05	58	0.1053	11	13	1	no	no
CB023S	Central Bay	8/26/05	55	0.0530	0	4	1	no	no
CB024S	Central Bay	8/25/05	77	0.0616	0	3	1	.	.
CB025S	Central Bay	8/25/05	72	0.1306	19	16	1	yes	yes
CB026S	Central Bay	8/25/05	96	0.0654	0	5	1	.	.
CB080S	Central Bay	8/25/05	55	0.2538	25	16	1	.	.
BA41	Redwood Creek	8/23/05	80	0.0802	0	6	1	yes	no
SB001S	South Bay	8/23/05	39	0.0409	18*	3	0	no	yes
SB002S	South Bay	8/23/05	95	0.0700	0	5	1	.	.
SB021S	South Bay	8/23/05	48	0.0377	0	3	0	no	no
SB022S	South Bay	8/23/05	99	0.0689	1	5	1	.	.
SB023S	South Bay	8/23/05	53	0.0599	0	4	1	yes	yes
SB024S	South Bay	8/23/05	95	0.1147	8	8	1	.	.
SB025S	South Bay	8/23/05	99	0.0828	2	6	1	no	yes
SB026S	South Bay	8/23/05	NA	0.0571	NA	7	1	.	.
LSB001S	Lower South Bay	8/24/05	99	0.0634	1	4	1	no	yes
LSB002S	Lower South Bay	8/24/05	100	0.0687	1	6	1	.	.
LSB022S	Lower South Bay	8/24/05	99	0.0795	4	7	1	.	.
LSB023S	Lower South Bay	8/24/05	87	0.0691	0	5	1	no	no
LSB024S	Lower South Bay	8/24/05	97	0.0648	0	4	1	.	.
LSB025S	Lower South Bay	8/24/05	100	0.0845	0	6	1	no	yes
LSB026S	Lower South Bay	8/24/05	99	0.0825	2	6	1	.	.
LSB073S	Lower South Bay	8/24/05	100	0.0554	0	5	1	no	yes
BA10	Coyote Creek	8/24/05	98	0.0751	0	5	1	no	yes

Table 3.3 Statistical comparisons among regions (2004-2005) and between years (2002-2005).

A p value < 0.05 indicates a statistically significant difference for the Roa-Scott test.

* Roa-Scott Test p Values for 2002 vs 2003 comparison presented here do not match those presented in the 2003 Annual Monitoring Results due to an adjustment to the spatial weighting.

	Roa-Scott Test p Value															
Comparison	Ag	As	Cd	Cu	Hg	MeHg	Ni	Pb	Se	Zn	PAHs	PCBs	DDTs	Chlordanes	Dieldrin	BDE-47
CB vs LSB	**0.00**	0.69	0.90	0.45	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.00**	**0.00**	0.21	0.89	**0.00**	0.70	**0.00**
CB vs SB	0.10	0.44	0.89	0.68	0.06	**0.01**	0.67	0.89	0.90	0.67	**0.01**	0.43	0.89	0.06	0.69	0.66
CB vs SPB	0.10	0.06	0.34	**0.01**	0.18	**0.00**	**0.01**	**0.04**	0.90	**0.01**	**0.00**	0.11	0.09	0.69	0.44	0.65
CB vs SU	0.06	0.23	0.41	0.44	**0.00**	**0.00**	0.42	**0.00**	0.70	0.70	**0.00**	**0.00**	0.67	0.28	0.43	0.17
LSB vs SB	0.19	0.44	0.70	0.33	**0.01**	0.45	0.10	**0.01**	**0.00**	**0.00**	0.41	0.22	0.47	**0.00**	0.69	**0.01**
LSB vs SPB	**0.01**	0.09	**0.01**	**0.04**	0.69	**0.00**	0.69	**0.01**	**0.00**	0.43	**0.00**	0.12	0.10	**0.00**	0.72	**0.00**
LSB vs SU	**0.00**	0.21	**0.01**	**0.03**	**0.00**	**0.00**	0.08	**0.00**	**0.01**	**0.01**	**0.00**	**0.00**	0.43	**0.00**	0.09	0.35
SB vs SPB	**0.01**	0.10	0.44	**0.00**	**0.00**	**0.00**	0.09	0.18	0.36	**0.00**	**0.00**	0.08	0.05	**0.00**	0.09	0.89
SB vs SU	**0.01**	0.89	0.43	0.07	**0.00**	**0.00**	0.89	0.05	0.88	0.66	**0.00**	**0.00**	0.43	0.28	0.28	0.18
SPB vs SU	**0.00**	0.12	0.21	0.08	**0.00**	0.07	0.10	**0.00**	0.89	0.10	**0.01**	**0.00**	0.44	0.84	0.88	0.16
2002 vs 2003 *	0.60	**0.00**	0.46	0.93	**0.00**	0.16	0.54	0.25	**0.04**	0.12	**0.01**	-	-	-	-	-
2002 vs 2004	**0.00**	**0.00**	0.84	**0.00**	0.11	0.17	**0.00**	0.17	**0.00**	**0.00**	0.23	-	**0.00**	**0.00**	**0.00**	**0.00**
2002 vs 2005	0.10	0.53	0.72	0.35	**0.00**	0.60	0.87	0.45	0.77	0.65	0.05	-	**0.00**	**0.00**	**0.00**	**0.00**
2003 vs 2004	**0.00**	0.69	0.09	0.17	**0.01**	0.58	0.18	0.09	**0.00**	0.06	0.27	-	-	-	-	-
2003 vs 2005	0.49	**0.00**	0.77	0.45	**0.00**	0.11	**0.00**	0.38	0.10	0.21	0.51	-	-	-	-	-
2004 vs 2005	**0.00**	**0.00**	0.52	0.08	**0.00**	0.23	**0.00**	**0.00**	**0.00**	0.13	0.09	0.08	0.06	**0.00**	0.12	0.12

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

PBDEs, PCBs, and pesticide results for 2003 not available at time of reporting.

Table 3.4. Pearson correlation coefficients for trace elements and independent variables in RMP sediment samples, 1993-2005. Variable used in sediment normalization of trace metal temporal analyses appear in bold text. No normalization was conducted for non-significant relationships.

	BA10	BA41	BC11	BD31	BF21	BG20	BG30
	Coyote Creek	Redwood Creek	Yerba Buena Is.	Pinole Pt.	Grizzly Bay	Sacramento River	San Joaquin River
Ag	**Fe**	% Fines	Al	TOC	**% Clay**	**Al**	**% Clay**
r	**0.667**	0.429	-0.494	0.330	**0.608**	**0.584**	**0.543**
p	**0.009**	0.067	0.044	0.168	**0.006**	**0.014**	**0.016**
n	**14**	19	17	19	**19**	**17**	**19**
As	**Fe**	**Fe**	% Clay	TOC	**% Clay**	Fe	**% Fines**
r	**0.814**	**0.576**	0.325	0.432	**0.555**	0.436	**0.772**
p	**0.000**	**0.012**	0.175	0.057	**0.011**	0.080	**0.000**
n	**14**	**18**	19	20	**20**	17	**20**
Cd	**Fe**	Al	Al	**% Fines**	Al	Fe	**TOC**
r	**0.583**	0.081	0.413	**0.789**	0.328	0.291	**0.600**
p	**0.029**	0.757	0.099	**0.000**	0.199	0.257	**0.007**
n	**14**	17	17	**19**	17	17	**19**
Cu	**Fe**	**Fe**	**Fe**	**% Fines**	**Fe**	**Fe**	**% Fines**
r	**0.910**	**0.805**	**0.658**	**0.817**	**0.651**	**0.753**	**0.828**
p	**0.000**	**0.000**	**0.003**	**0.000**	**0.003**	**0.000**	**0.000**
n	**15**	**18**	**18**	**20**	**18**	**17**	**20**
Hg	**Fe**	% Clay	**% Silt**	**% Fines**	**% Clay**	**% Fines**	**% Fines**
r	**0.663**	0.158	**0.614**	**0.550**	**0.469**	**0.852**	**0.835**
p	**0.007**	0.506	**0.005**	**0.012**	**0.037**	**0.000**	**0.000**
n	**15**	20	**19**	**20**	**20**	**19**	**20**
MeHg	% Fines	Fe	**% Clay**	% Clay	% Silt	**TOC**	**TOC**
r	0.452	0.772	**0.948**	0.625	0.260	**0.965**	**0.986**
p	0.368	0.126	**0.004**	0.185	0.619	**0.002**	**0.000**
n	6	5	**6**	6	6	**6**	**6**
Mn	**% Fines**	TOC	TOC	**TOC**	Fe	**TOC**	TOC
r	**0.687**	0.423	0.197	**0.633**	0.459	**0.637**	0.246
p	**0.003**	0.071	0.419	**0.004**	0.064	**0.003**	0.309
n	**16**	19	19	**19**	17	**19**	19
Ni	**Fe**	**Fe**	**Fe**	**Fe**	**Al**	**Fe**	TOC
r	**0.803**	**0.755**	**0.813**	**0.547**	**0.633**	**0.800**	0.423
p	**0.000**	**0.000**	**0.000**	**0.019**	**0.005**	**0.000**	0.063
n	**15**	**18**	**18**	**18**	**18**	**18**	20
Pb	**% Fines**	**TOC**	**Fe**	**TOC**	**% Clay**	**% Clay**	**% Clay**
r	**0.816**	**0.524**	**0.471**	**0.607**	**0.477**	**0.709**	**0.462**
p	**0.000**	**0.018**	**0.048**	**0.005**	**0.033**	**0.000**	**0.040**
n	**16**	**20**	**18**	**20**	**20**	**20**	**20**
Se	**% Fines**	% Clay	% Clay	% Clay	% Clay	**% Silt**	**% Clay**
r	**0.699**	0.267	0.091	0.314	0.388	**0.494**	**0.647**
p	**0.003**	0.255	0.710	0.178	0.091	**0.027**	**0.002**
n	**16**	20	19	20	20	**20**	**20**
Zn	**% Clay**	**Fe**	**Fe**	**Fe**	**Fe**	**Fe**	**TOC**
r	**0.625**	**0.878**	**0.861**	**0.789**	**0.656**	**0.678**	**0.834**
p	**0.010**	**0.000**	**0.000**	**0.000**	**0.003**	**0.002**	**0.000**
n	**16**	**18**	**18**	**18**	**18**	**18**	**20**

Table 3.5. Temporal trends in sediment trace elements, 1993-2005.
A significantly positive linear regession slope (p<0.05) was assumed to indicate an increase in the concentration of the contaminant at the station over time. Similarly, a significant negative slope assumes a decrease over time, with a lack of significance indicating no change in sediment contaminant concentration. * indicates contaminant data were log transformed.

Station Code	BA10	BA41	BC11	BD31	BF21	BG20	BG30
Name	Coyote Creek	Redwood Creek	Yerba Buena Island	Pinole Point	Grizzly Bay	Sacramento River	San Joaquin River
Ag	**decrease**	**decrease**	**decrease**	**decrease**	no trend	no trend	**decrease**
As	**decrease**	**decrease**	**decrease**	no trend*	no trend	no trend	**decrease**
Cd	no trend	no trend	**increase**	no trend	**increase**	no trend	**increase**
Cu	no trend	no trend	**increase***	no trend	no trend	no trend	no trend
Hg	**decrease**	no trend	no trend	**decrease***	no trend	no trend	no trend
MeHg	no trend	**increase**	no trend	no trend	no trend	no trend	no trend
Mn	no trend*	no trend*	no trend*	no trend*	no trend*	**decrease***	no trend*
Ni	**decrease**	no trend	no trend	no trend	no trend	no trend	no trend
Pb	**decrease**	no trend	no trend	no trend	no trend*	no trend	no trend*
Se	no trend	**decrease***	**decrease***	no trend*	**decrease***	no trend*	no trend*
Zn	no trend*	no trend	no trend	no trend	no trend*	no trend	no trend

MeHg data only available for 2000-2005.

Table 3.6. Pearson correlation coefficients for trace organics and independent variables in RMP sediment samples, 1993-2005. Variable used in sediment normalization of trace organic temporal analyses appear in bold text. No normalization was conducted for non-significant relationships.

	BA10	BA41	BC11	BD31	BF21	BG20	BG30
	Coyote Creek	Redwood Creek	Yerba Buena Is.	Pinole Pt.	Grizzly Bay	Sacramento River	San Joaquin River
PAHs	% Fines	% Clay	% Fines	% Silt	% Clay	**% Silt**	**TOC**
r	0.419	-0.036	0.098	0.110	0.232	**0.645**	**0.745**
p	0.107	0.880	0.691	0.645	0.325	**0.002**	**0.000**
n	16	20	19	20	20	**20**	**20**
PCBs	% Fines	% Silt	TOC	TOC	% Clay	**% Fines**	TOC
r	0.405	0.455	0.053	0.189	0.375	**0.490**	0.042
p	0.151	0.058	0.834	0.452	0.126	**0.039**	0.867
n	14	18	18	18	18	**18**	18
DDTs	% Fines	% Silt	TOC	% Silt	% Fines	% Silt	TOC
r	0.382	0.378	0.000	0.022	0.309	0.171	0.445
p	0.160	0.111	0.999	0.930	0.198	0.485	0.064
n	15	19	19	19	19	19	18

Table 3.7. Temporal trends in sediment trace organics, 1993-2005.

A significantly positive linear regession slope (p<0.05) was assumed to indicate an increase in the concentration of the contaminant at the station over time. Similarly, a significant negative slope assumes a decrease over time, with a lack of significance indicating no change in sediment contaminant concentration. * indicates contaminant data were log transformed.

Station Code	BA10	BA41	BC11	BD31	BF21	BG20	BG30
Name	Coyote Creek	Redwood Creek	Yerba Buena Island	Pinole Point	Grizzly Bay	Sacramento River	San Joaquin River
PAHs	no trend	no trend	no trend	no trend	no trend	no trend*	**increase***
PCBs	no trend	**decrease**	no trend	no trend	no trend	no trend*	no trend
DDTs	no trend	no trend	no trend	no trend	no trend	no trend	no trend

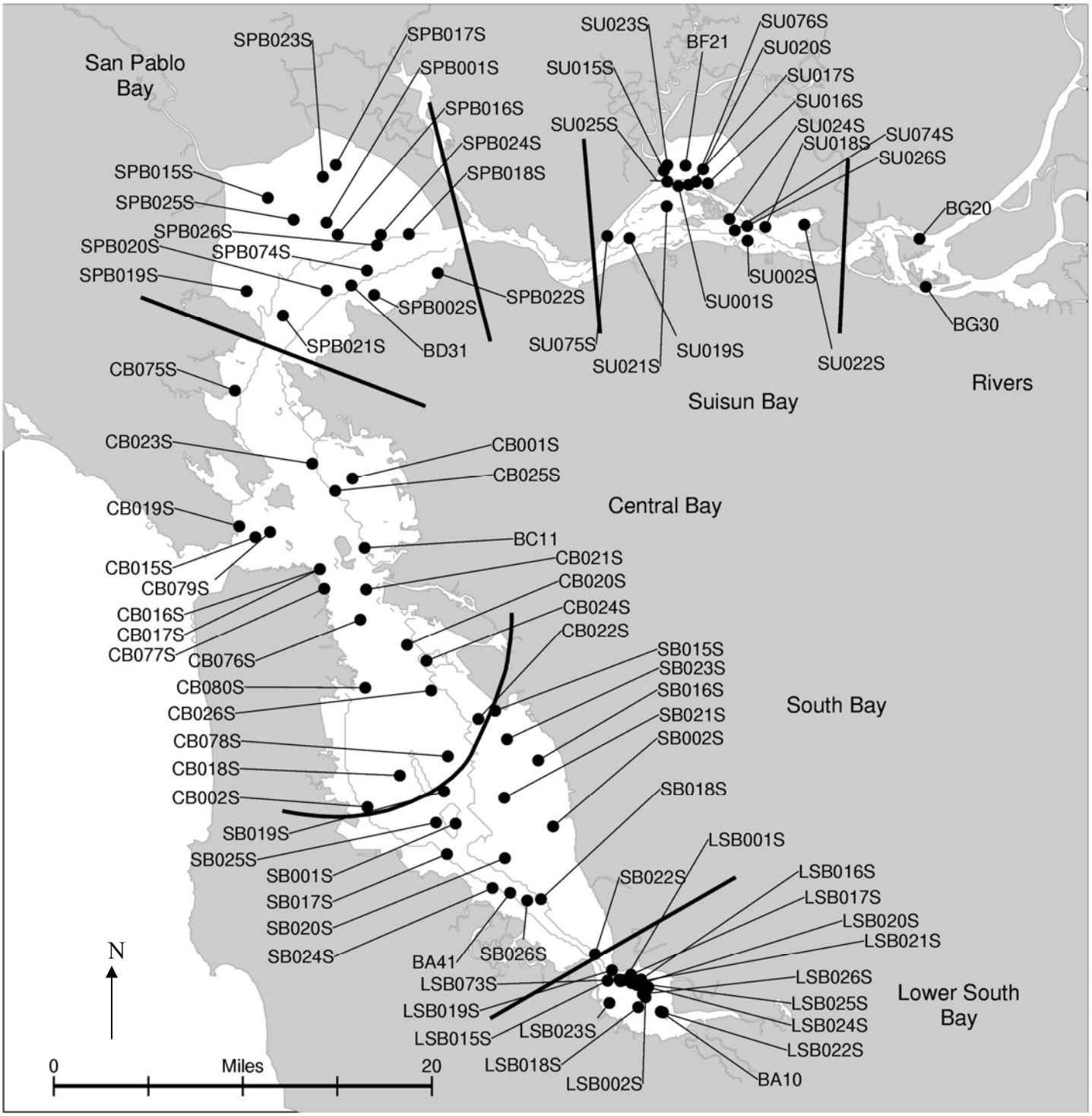
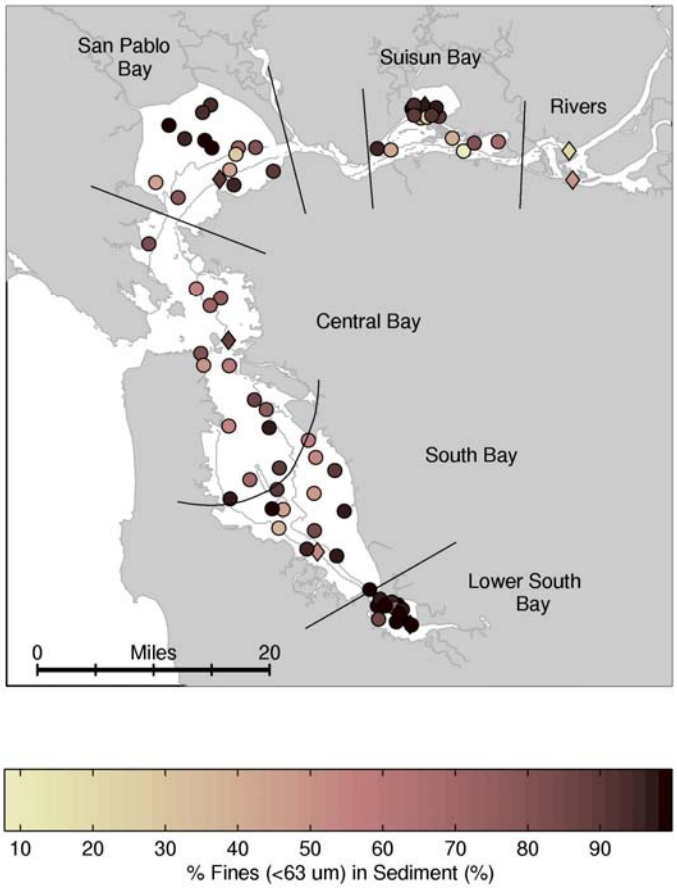


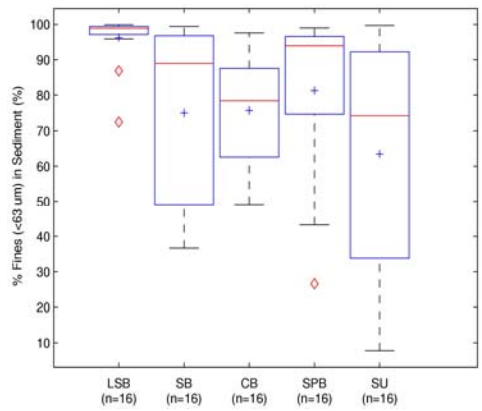
Figure 3.1. Map of the RMP Status and Trends sediment monitoring effort at both randomly selected and historic fixed sampling sites. 47 stations were sampled in the San Francisco Estuary in both 2004 and 2005.

Figure 3.2a-c. Percent Fines (<63 um) in Sediments (2004-2005)



a) Map of percent fines in sediments (%) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

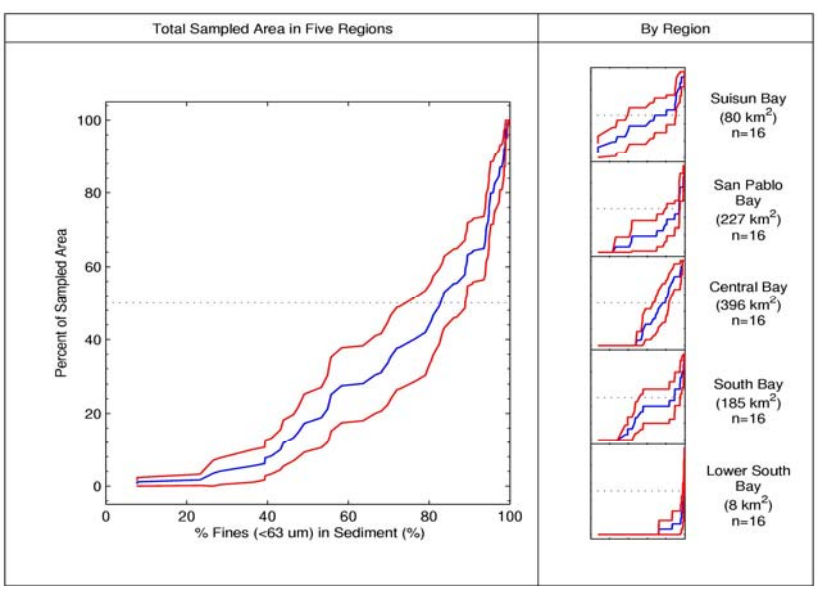
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment percent fines for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percent of the Estuary is composed of fine sediments?

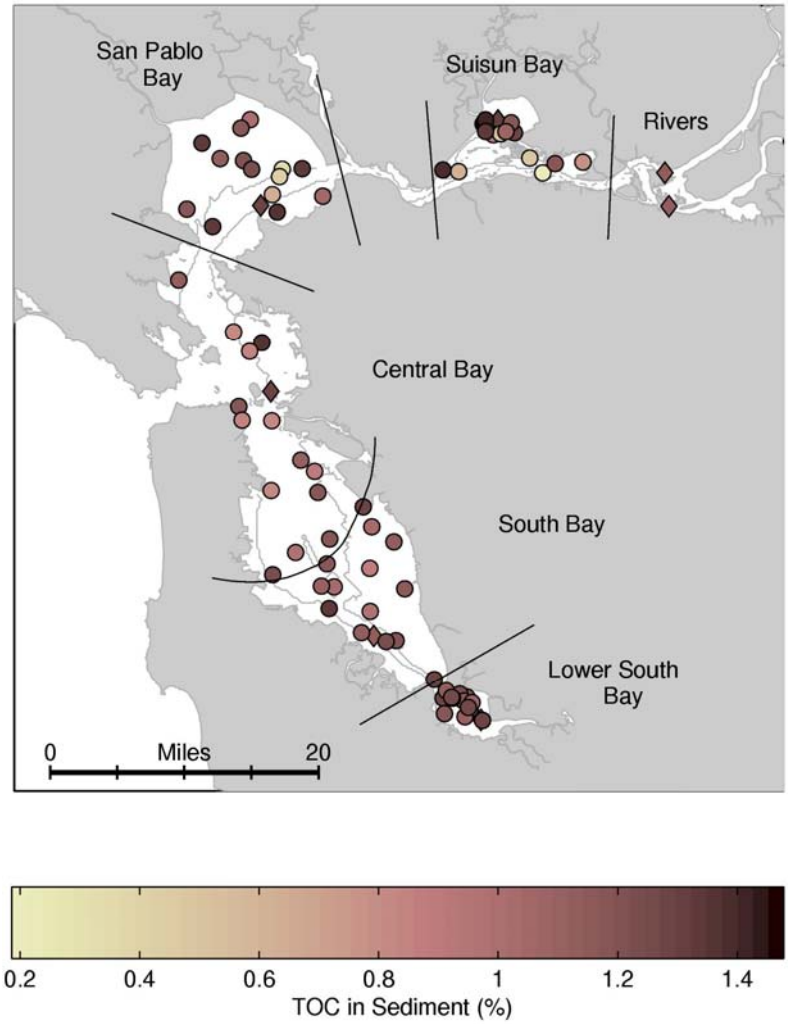


c) Cumulative distribution function (CDF) plots for sediment percent fines from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment percent fines.

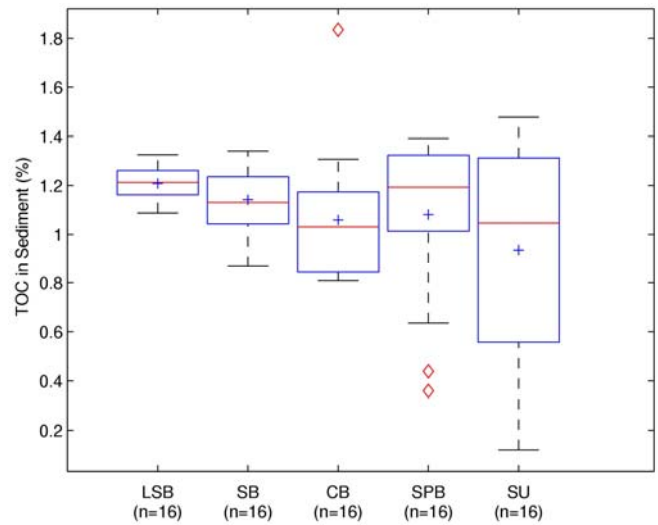
The small graphs show the same for each individual region (scales are identical to the large graph).

Figure 3.3a-c. Total Organic Carbon (TOC) in Sediments (2004-2005)



a) Map of TOC concentrations in sediments (%) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

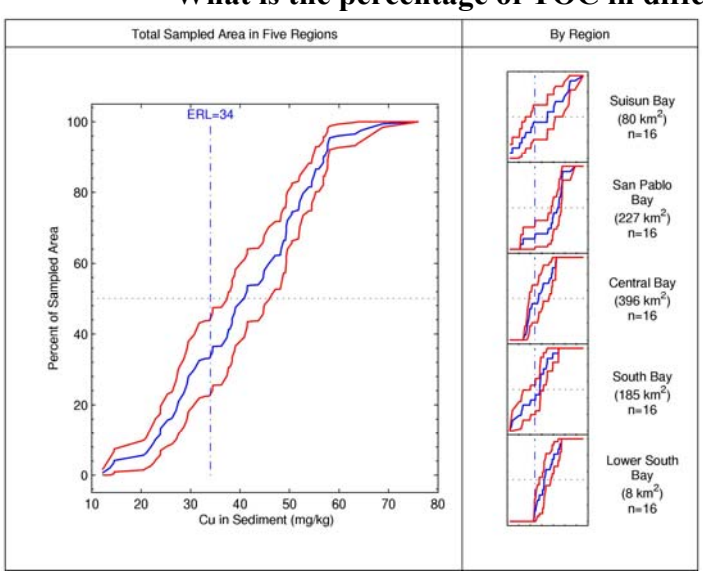
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment TOC for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What is the percentage of TOC in different regions of the Estuary?

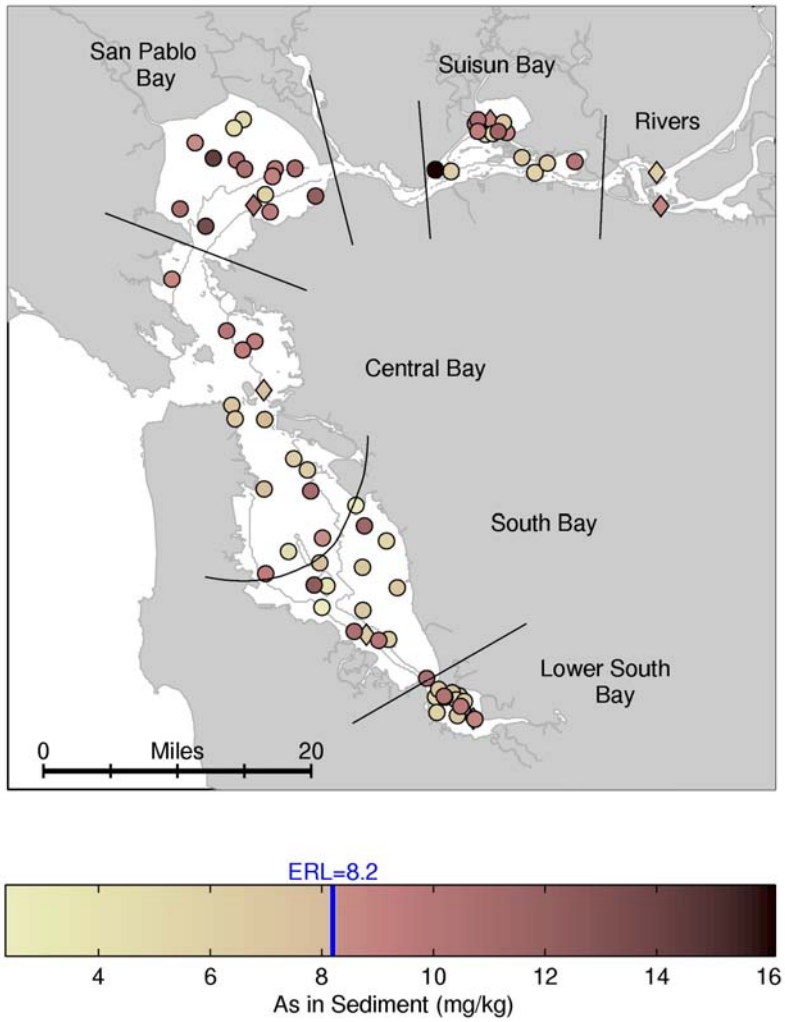


c) Cumulative distribution function (CDF) plots for sediment TOC concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment TOC.

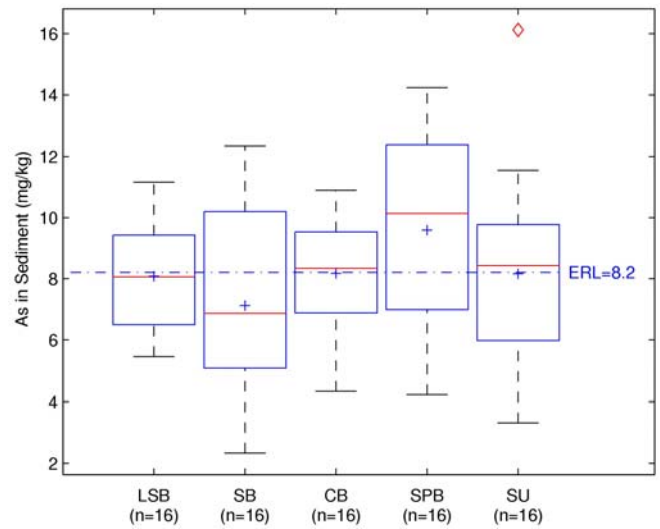
The small graphs show the same for each individual region (scales are identical to the large graph).

Figure 3.4a-c. Arsenic (As) in Sediments (2004-2005)



a) Map of arsenic concentrations in sediments (mg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

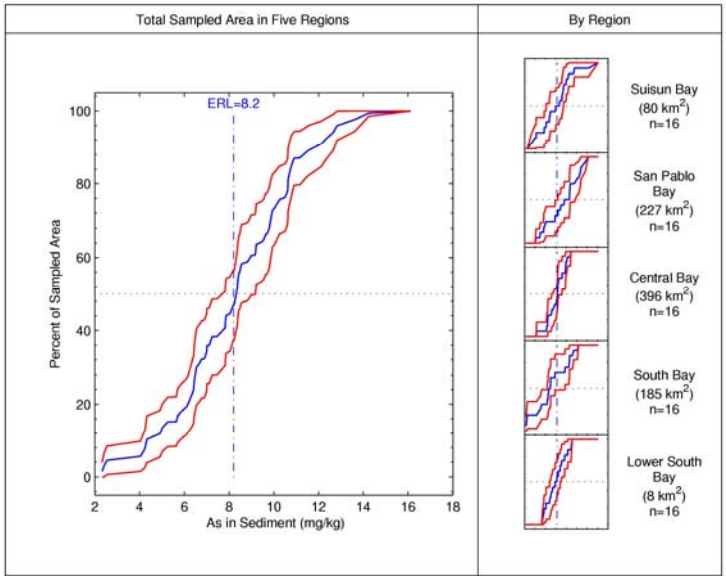
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment arsenic concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the arsenic ERL guideline?



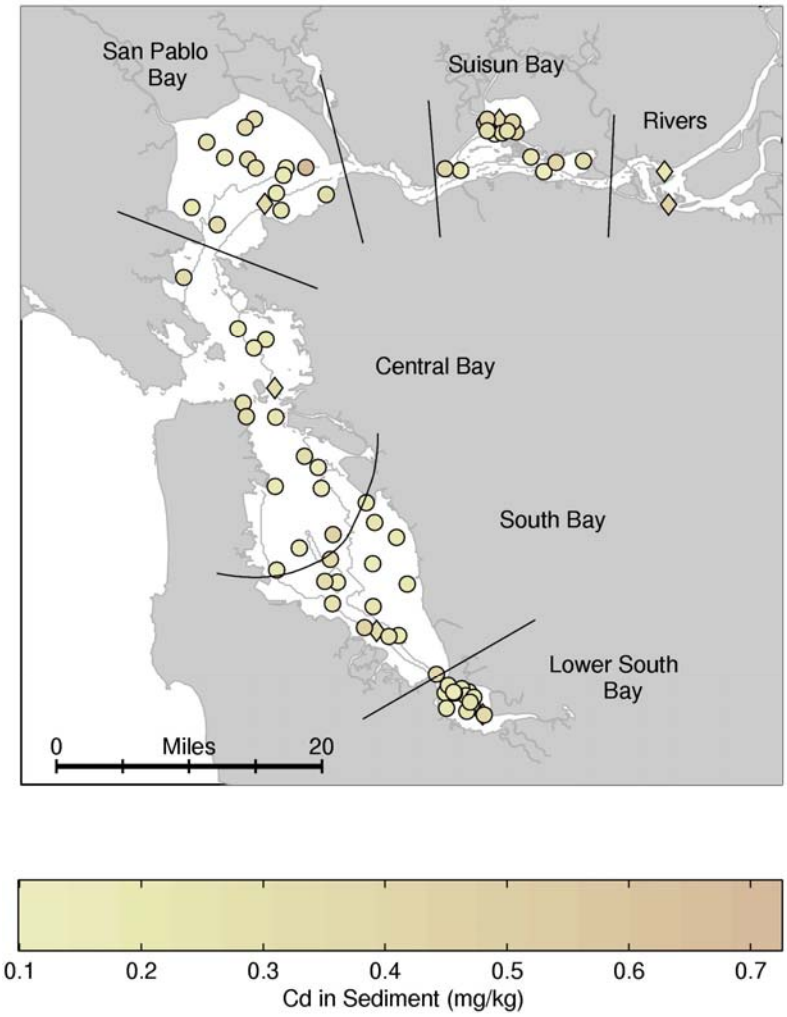
c) Cumulative distribution function (CDF) plots for sediment arsenic concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment arsenic concentrations.

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

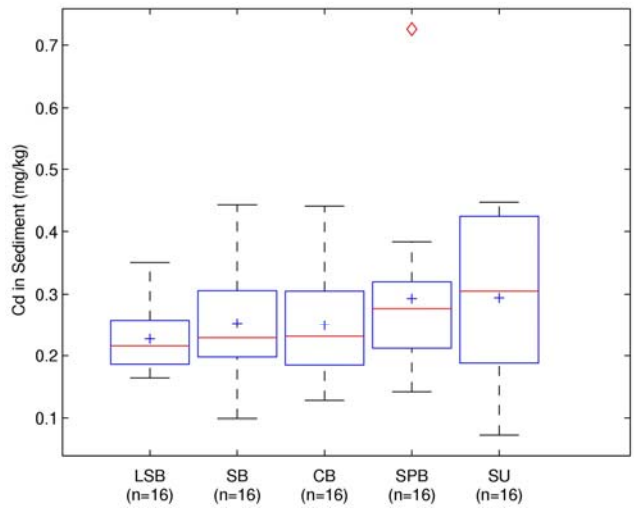
About 50% of the total sampled area in the Estuary had sediment arsenic concentrations above the ERL guideline of 8.2 mg/kg.

Figure 3.5a-c. Cadmium (Cd) in Sediments (2004-2005)



a) Map of cadmium concentrations in sediments (mg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

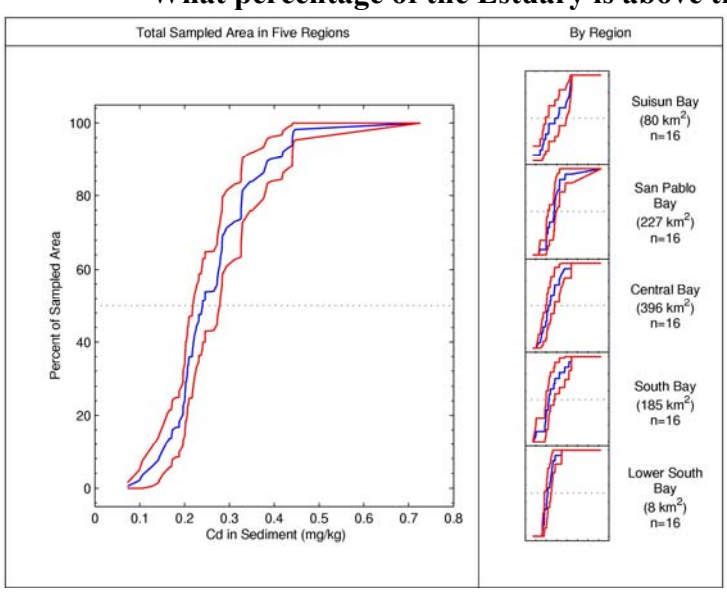
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment cadmium concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the cadmium ERL guideline?

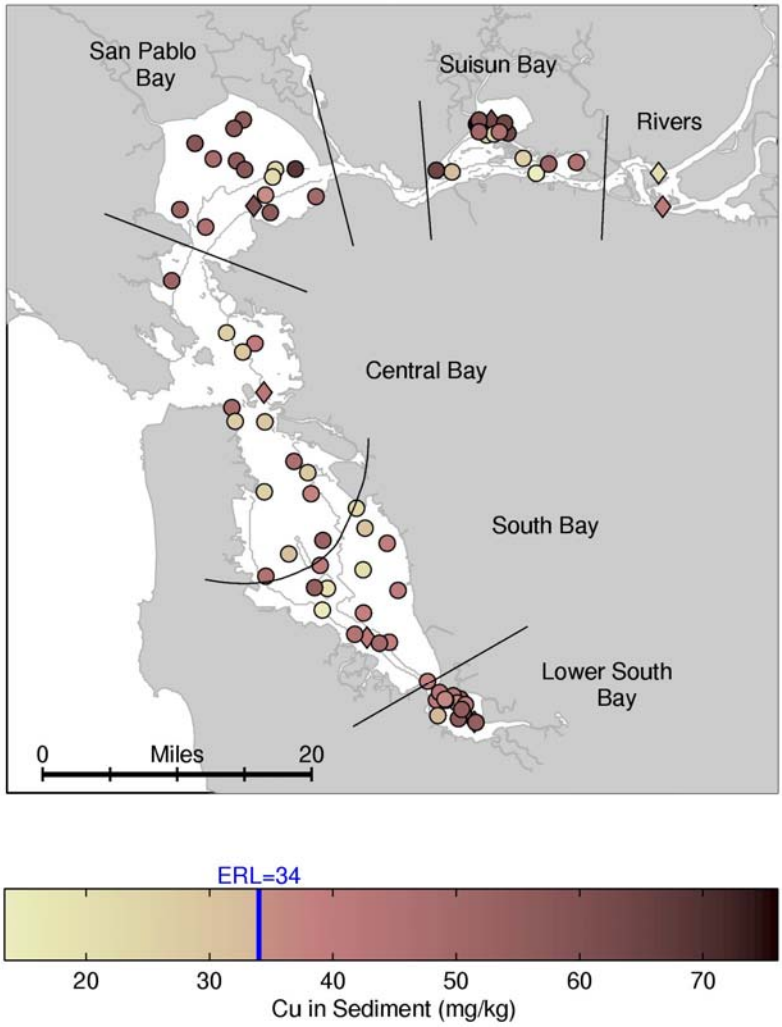


c) Cumulative distribution function (CDF) plots for sediment cadmium concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment cadmium concentrations. The small graphs show the same for each individual region (scales are identical to the large graph).

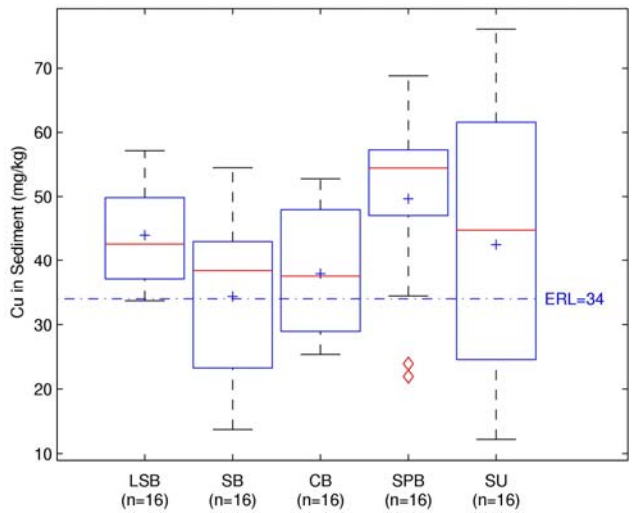
None of the total sampled area in the Estuary had sediment cadmium concentrations above the ERL guideline of 1.2 mg/kg.

Figure 3.6a-c. Copper (Cu) in Sediments (2004-2005)



a) Map of copper concentrations in sediments (mg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

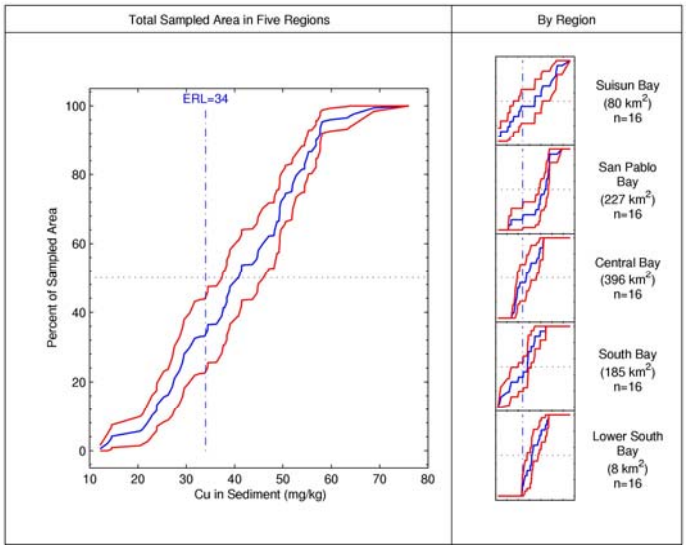
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment copper concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the copper ERL guideline?

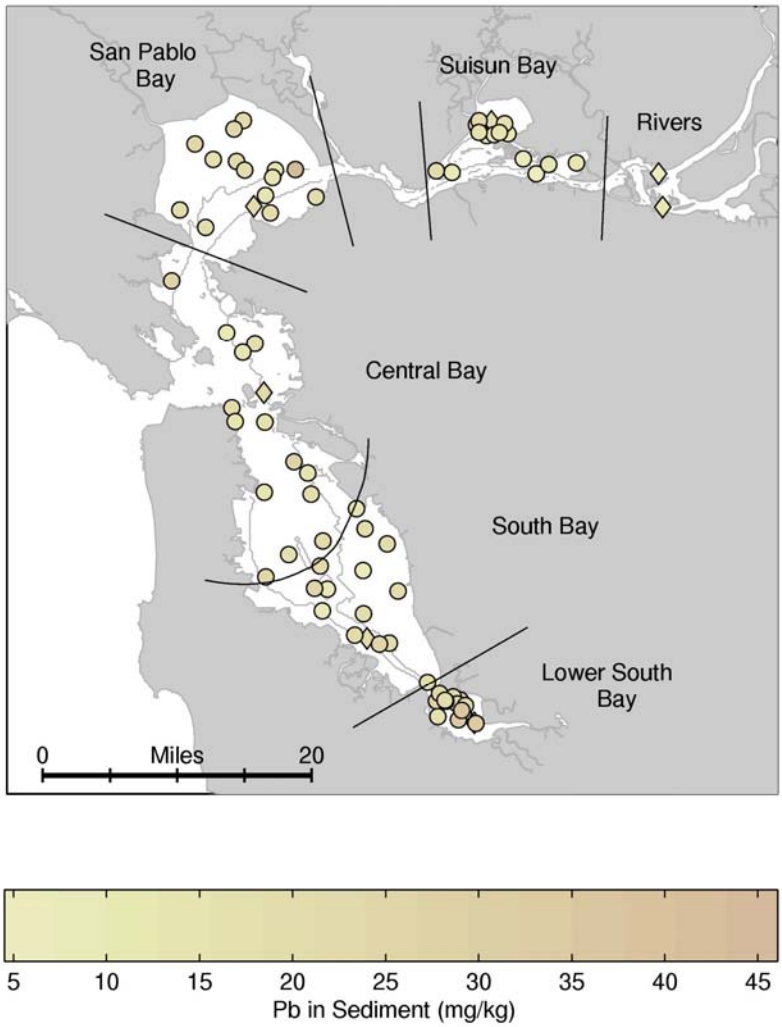


c) Cumulative distribution function (CDF) plots for sediment copper concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment copper concentrations. The small graphs show the same for each individual region (scales are identical to the large graph).

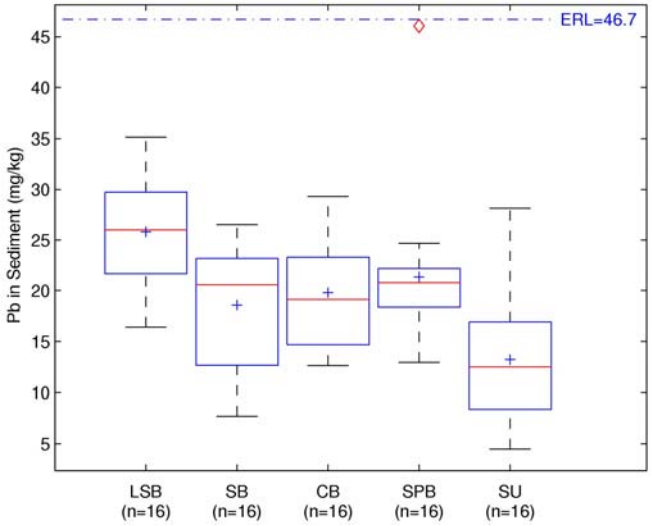
About 65% of the total sampled area in the Estuary had sediment copper concentrations above the ERL guideline of 34 mg/kg.

Figure 3.7a-c. Lead (Pb) in Sediments (2004-2005)



a) Map of lead concentrations in sediments (mg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

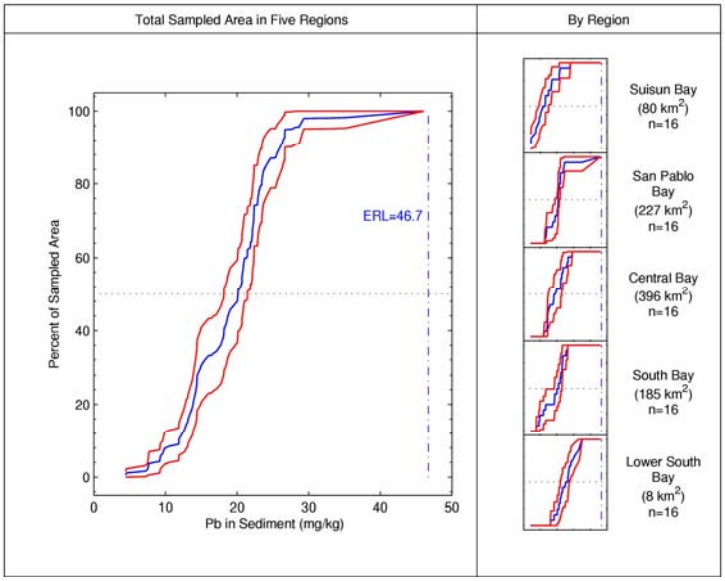
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment lead concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the lead ERL guideline?



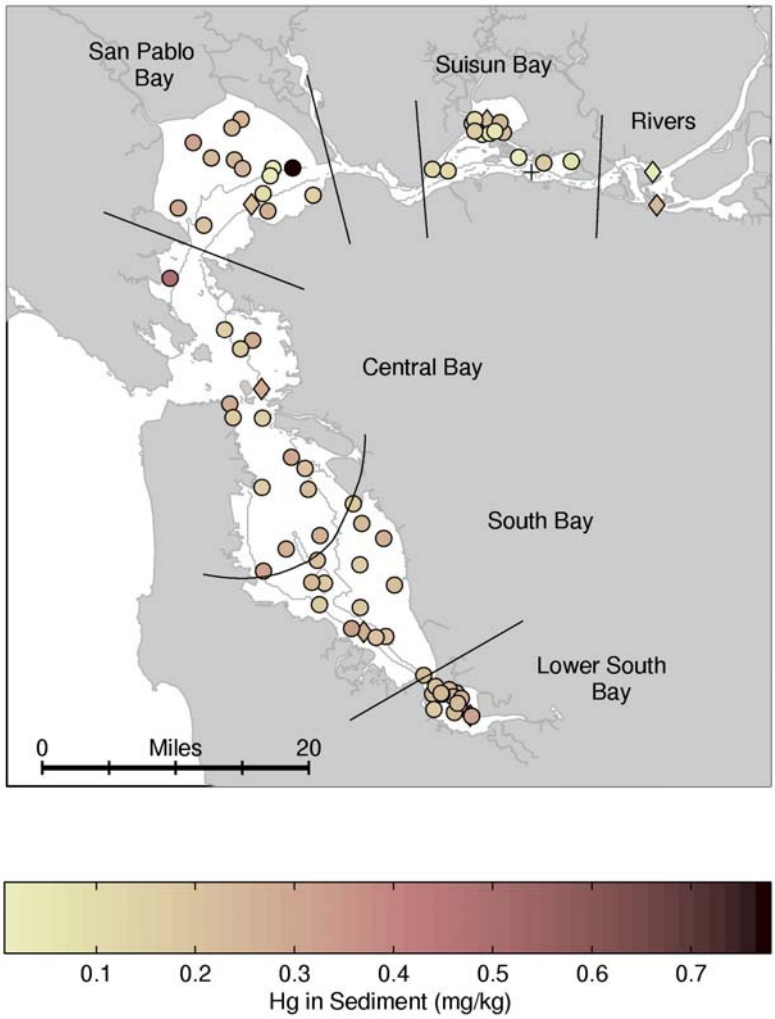
c) Cumulative distribution function (CDF) plots for sediment lead concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment lead concentrations.

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

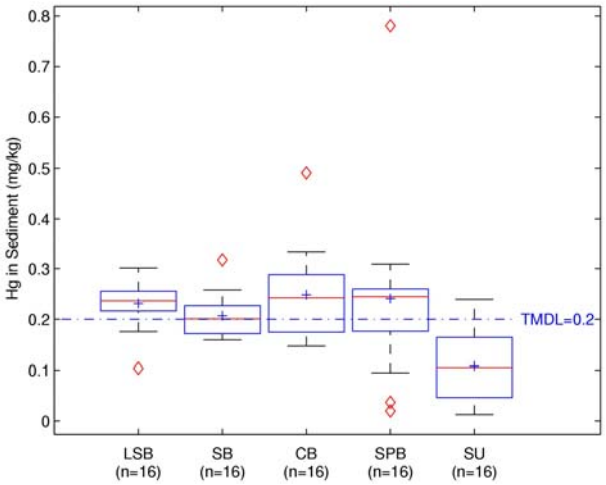
None of the total sampled area in the Estuary had sediment lead concentrations above the ERL guideline of 46.7 mg/kg.

Figure 3.8a-c. Mercury (Hg) in Sediments (2004-2005)



a) Map of mercury concentrations in sediments (mg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

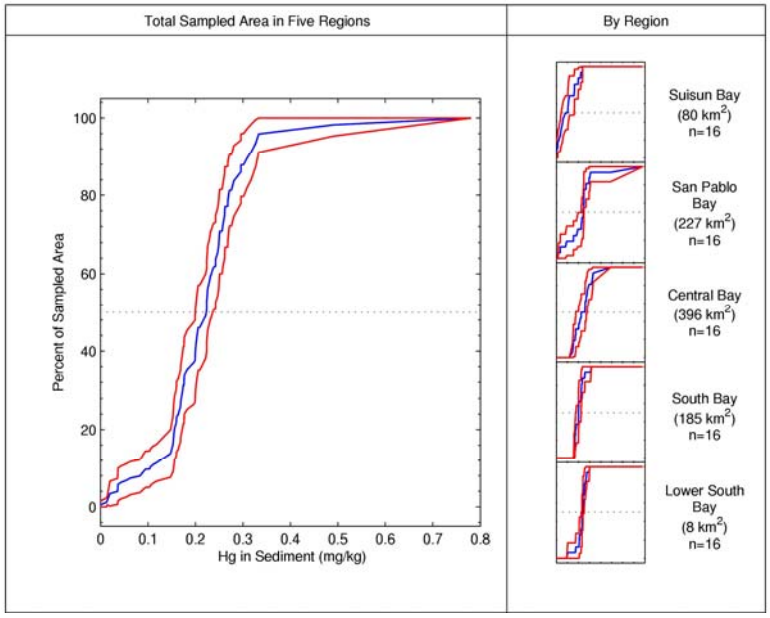
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment mercury concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the mercury TMDL target?

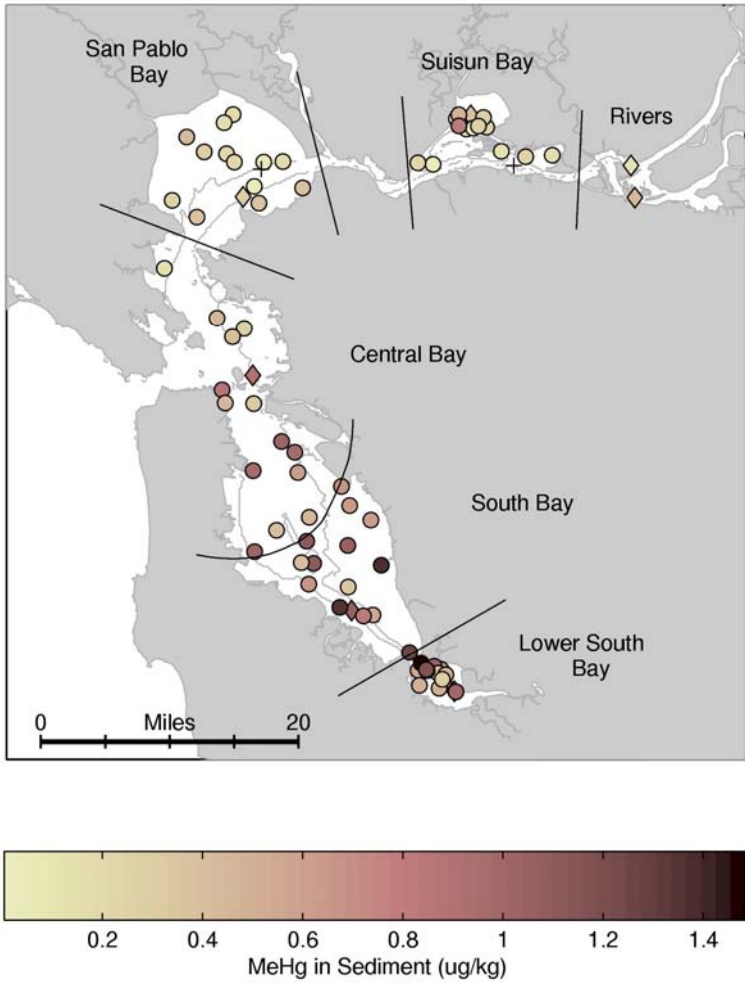


c) Cumulative distribution function (CDF) plots for sediment mercury concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment mercury concentrations. The small graphs show the same for each individual region (scales are identical to the large graph).

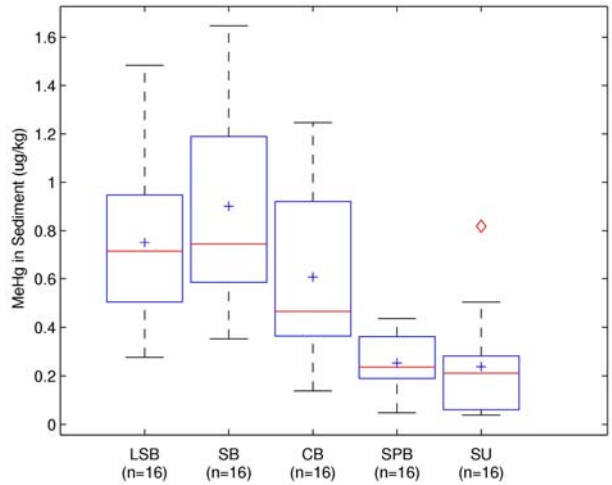
About 60% of the total sampled area in the Estuary has sediment mercury concentrations above the TMDL target of 0.2 mg/kg.

Figure 3.9a-c. Methylmercury (MeHg) in Sediments (2004-2005)



a) Map of methylmercury concentrations in sediments (µg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

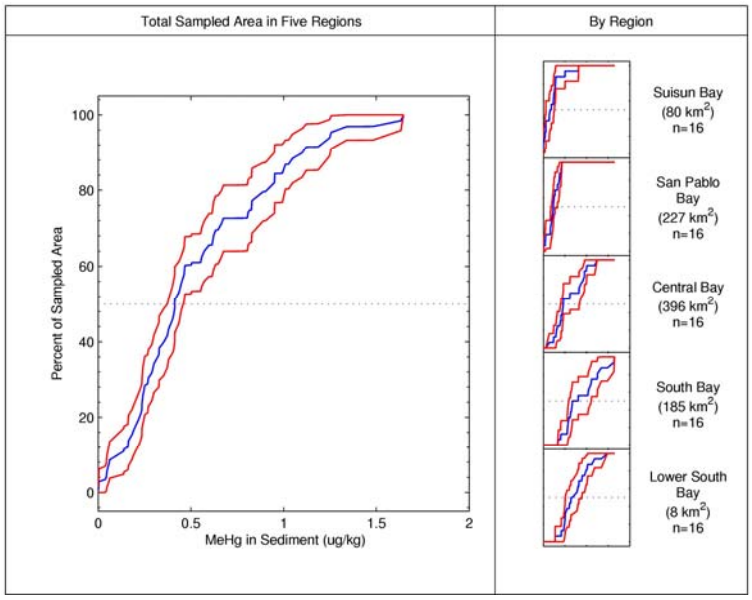
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment methylmercury concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

Cumulative distribution of methylmercury in the Estuary sediments.

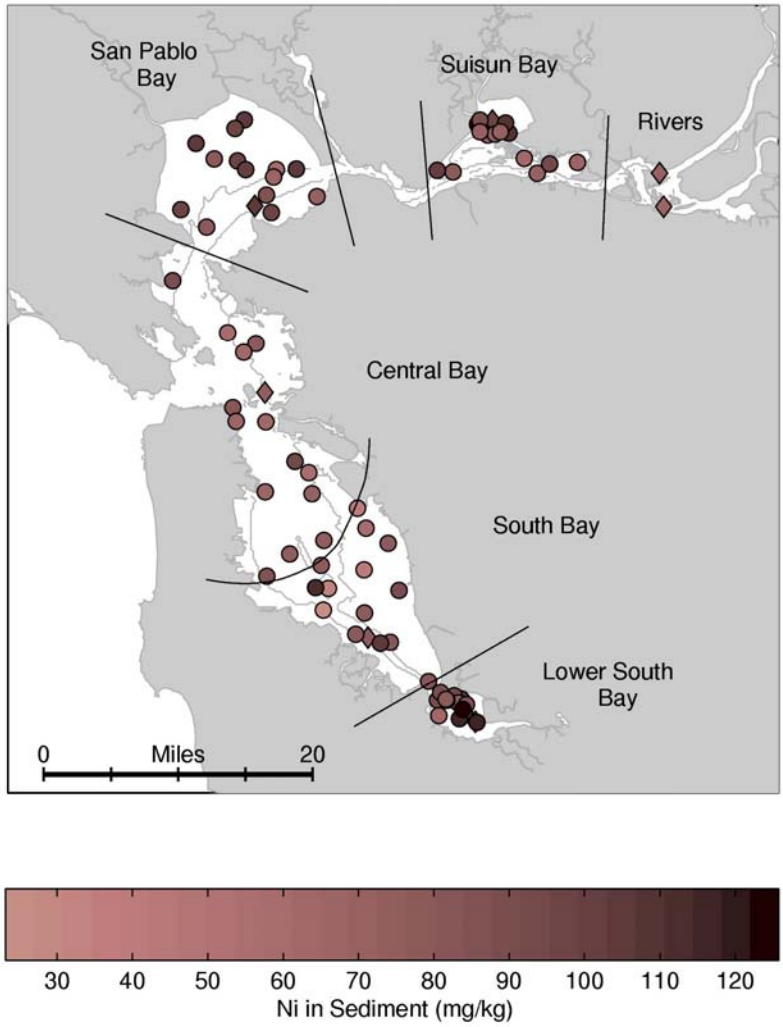


c) Cumulative distribution function (CDF) plots for sediment methylmercury concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment methylmercury concentrations.

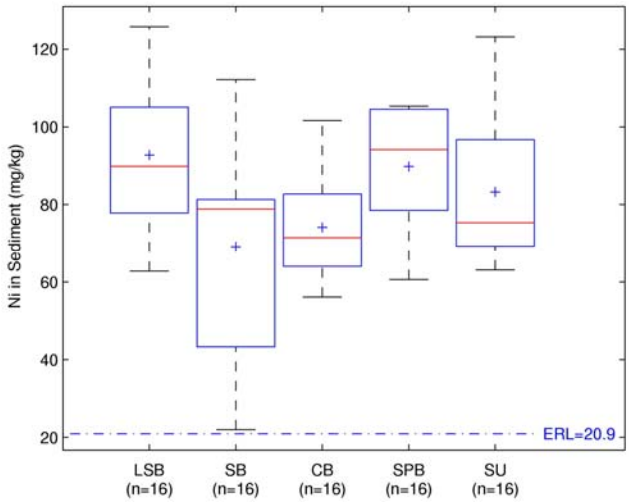
The small graphs show the same for each individual region (scales are identical to the large graph).

Figure 3.10a-c. Nickel (Ni) in Sediments (2004-2005)



a) Map of nickel concentrations in sediments (mg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

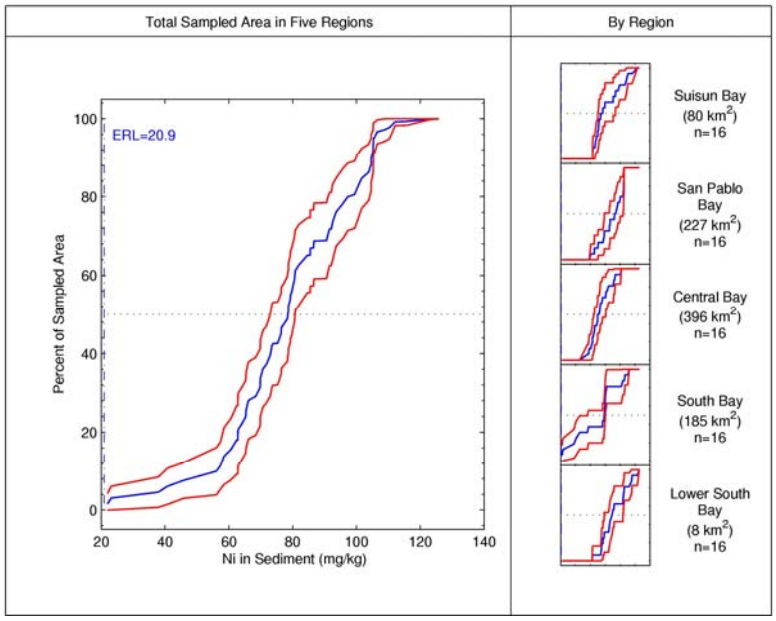
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment nickel concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the nickel ERL guideline?



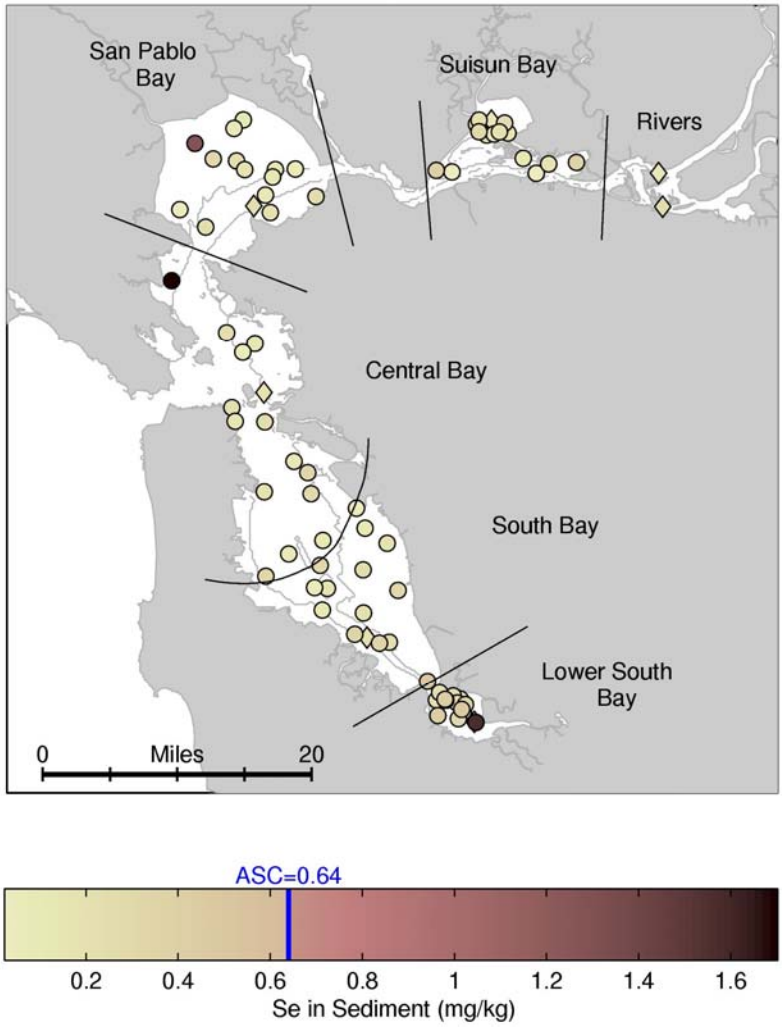
c) Cumulative distribution function (CDF) plots for sediment nickel concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment nickel concentrations.

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

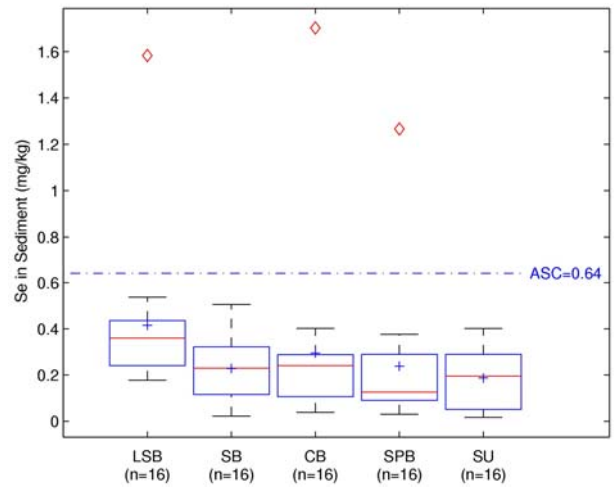
All of the total sampled area in the Estuary had sediment nickel concentrations above the ERL guideline of 20.9 mg/kg.

Figure 3.11a-c. Selenium (Se) in Sediments (2004-2005)



a) Map of selenium concentrations in sediments (mg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

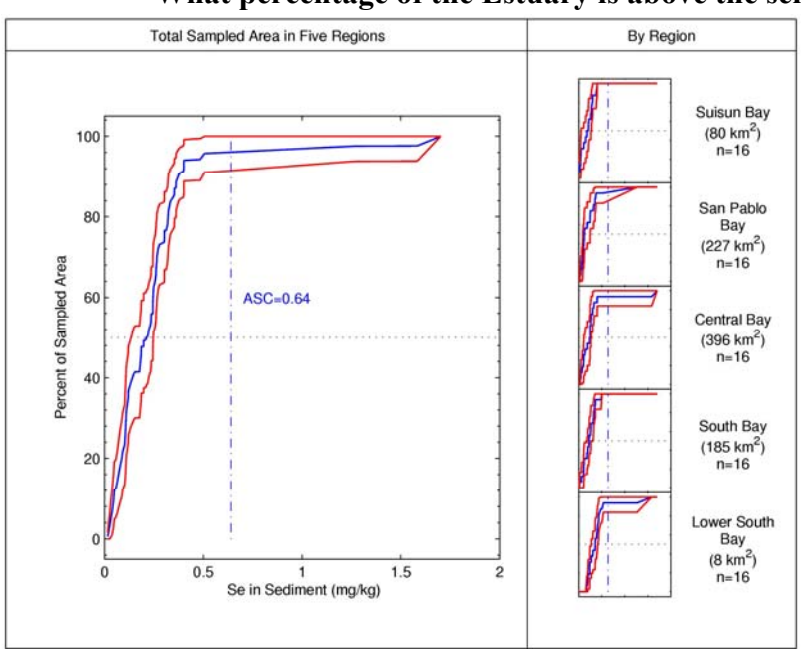
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment selenium concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the selenium ASC guideline?

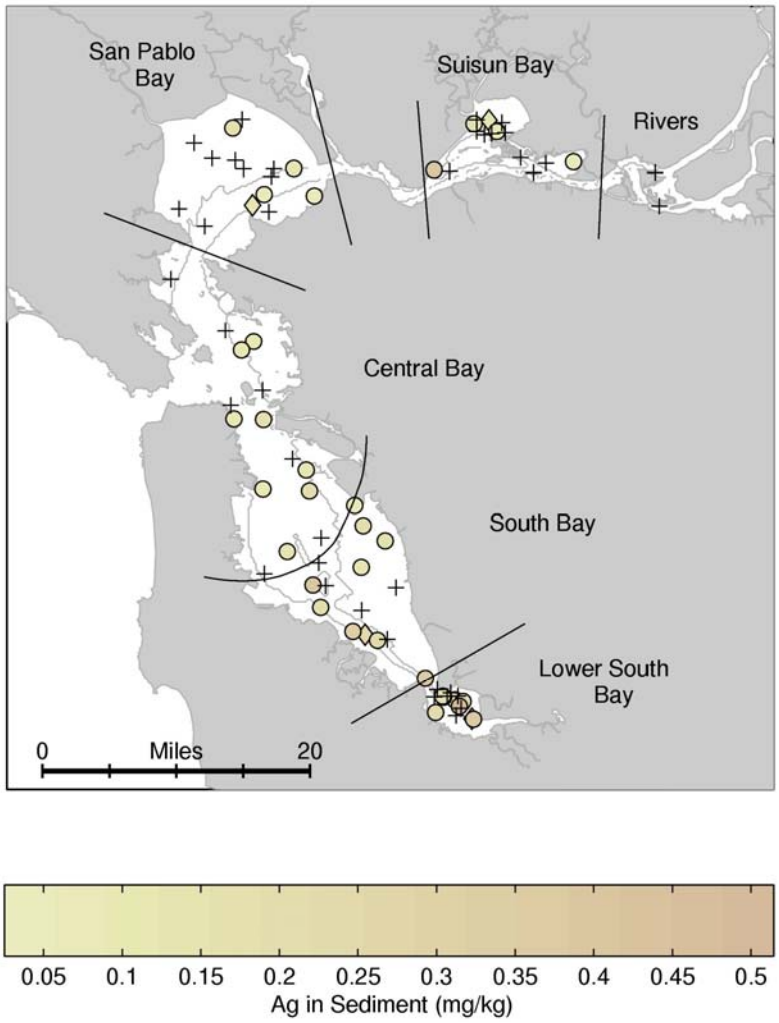


c) Cumulative distribution function (CDF) plots for sediment selenium concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment selenium concentrations. The small graphs show the same for each individual region (scales are identical to the large graph).

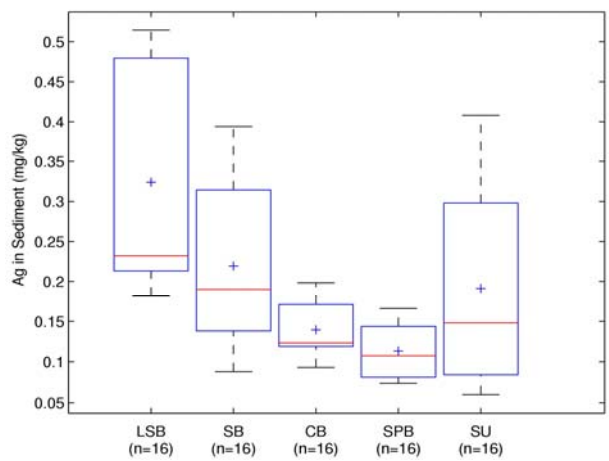
Less than 5% of the total sampled area in the Estuary had sediment selenium concentrations above the ASC of 0.64mg/kg.

Figure 3.12a-c. Silver (Ag) in Sediments (2004-2005)



a) Map of silver concentrations in sediments (mg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for Rivers region.

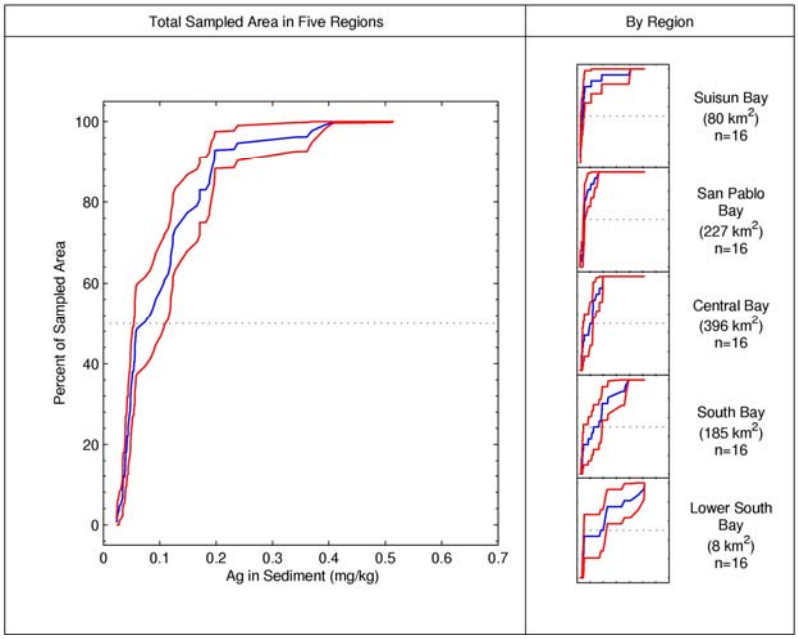
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment silver concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the silver ERL guideline?



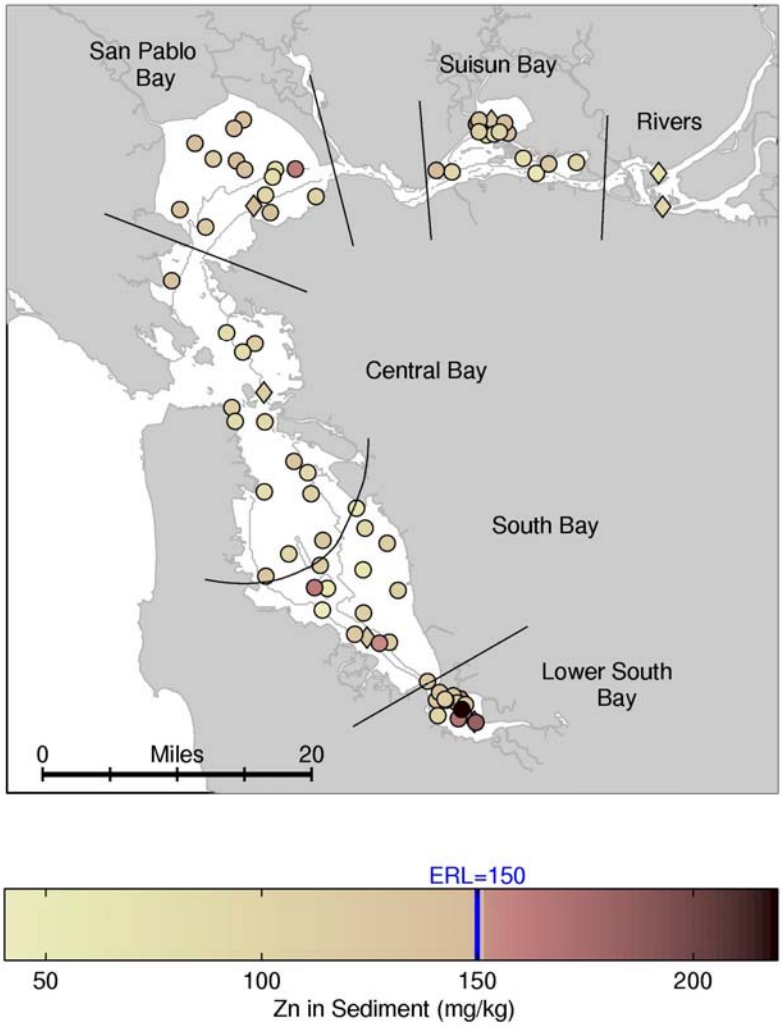
c) Cumulative distribution function (CDF) plots for sediment silver concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment silver concentrations.

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

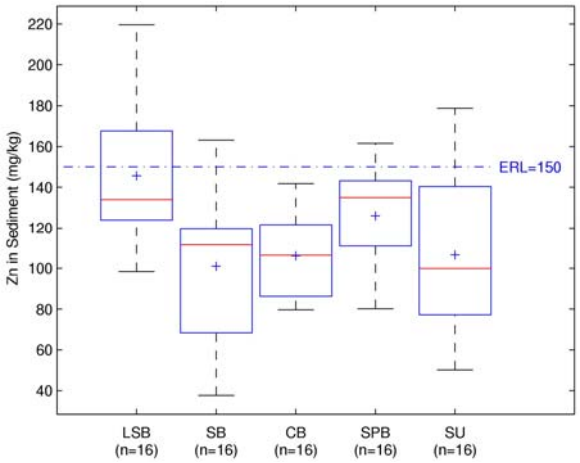
None of the total sampled area in the Estuary had sediment silver concentrations above the ERL guideline of 1 mg/kg.

Figure 3.13a-c. Zinc (Zn) in Sediments (2004-2005)



a) Map of zinc concentrations in sediments (mg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

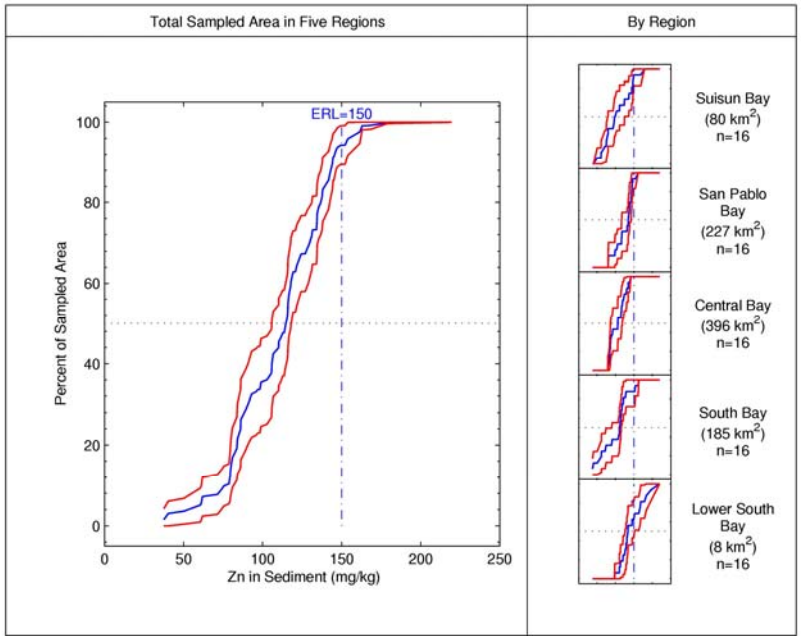
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment zinc concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the zinc ERL guideline?

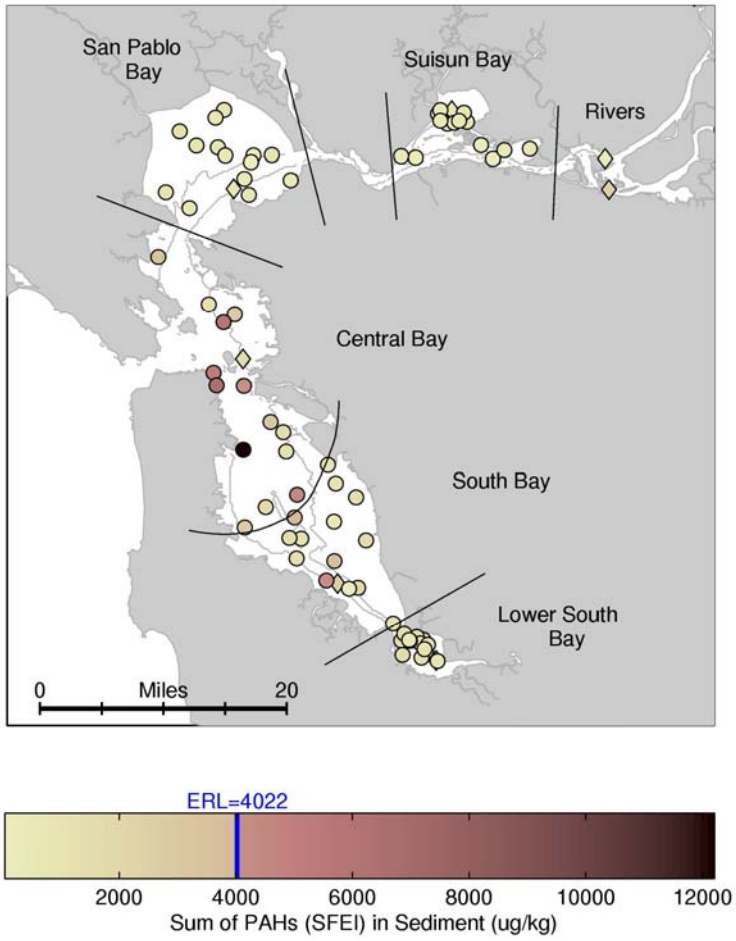


c) Cumulative distribution function (CDF) plots for sediment zinc concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment zinc concentrations. The small graphs show the same for each individual region (scales are identical to the large graph).

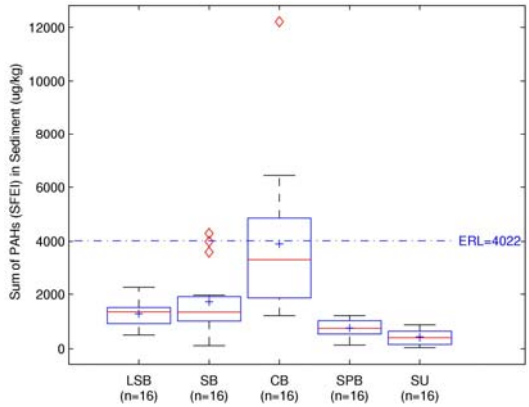
About 10% of the total sampled area in the Estuary had sediment zinc concentrations above the ERL guideline of 150 mg/kg.

Figure 3.14a-c. Sum of PAHs in Sediments (2004-2005)



a) Map of sum of PAH concentrations in sediments (µg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

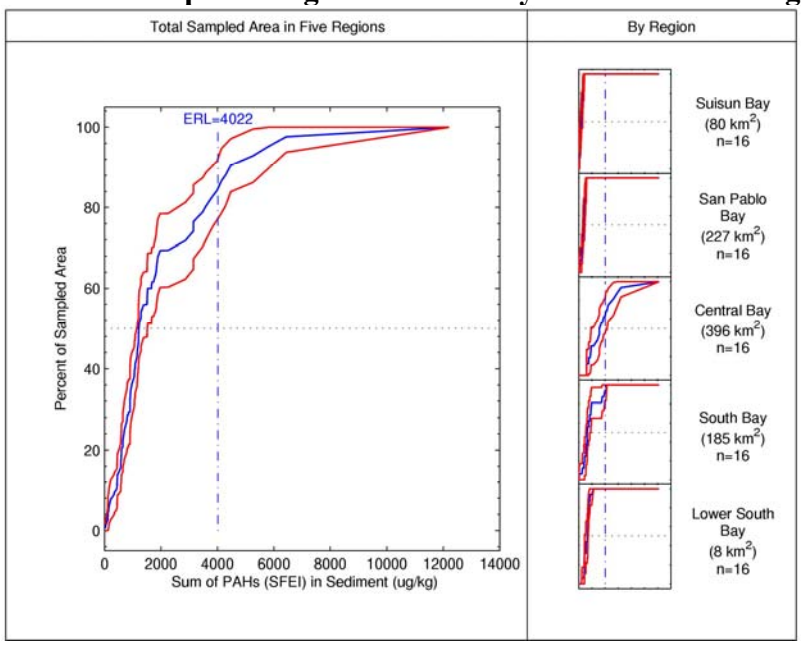
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment sum of PAH concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the ERL guideline for sum of PAHs?

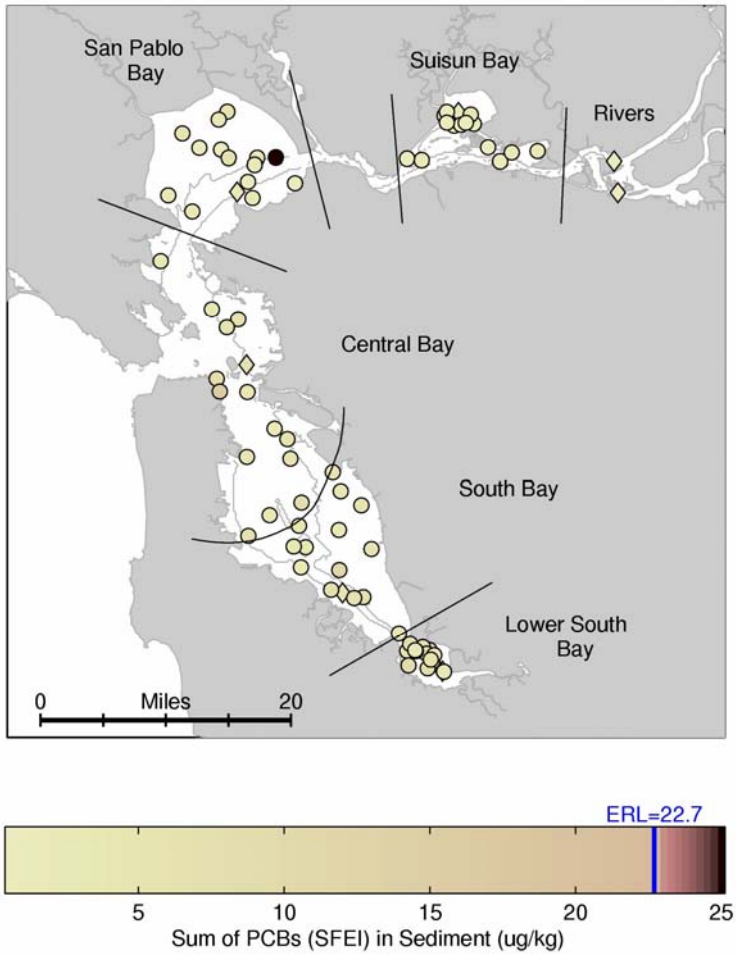


c) Cumulative distribution function (CDF) plots for sediment sum of PAH concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment sum of PAH concentrations. The small graphs show the same for each individual region (scales are identical to the large graph).

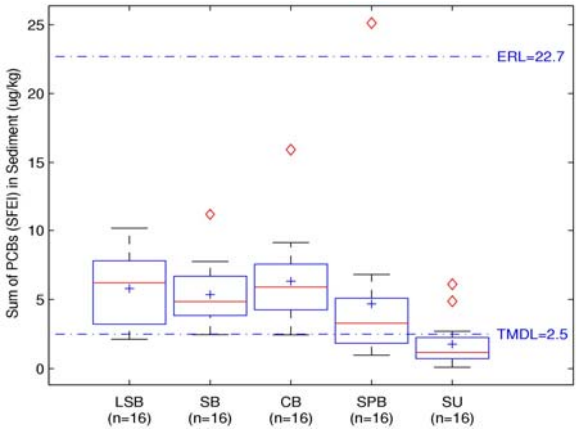
About 15% of the total sampled area in the Estuary had sediment sum of PAH concentrations above the ERL guideline of 4022 ug/kg. The small graphs indicate that about 30% of the Central Bay and 10% of the South Bay is above the ERL guideline.

Figure 3.15a-c. Sum of PCBs in Sediments (2004-2005)



a) Map of sum of PCB concentrations in sediments (µg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

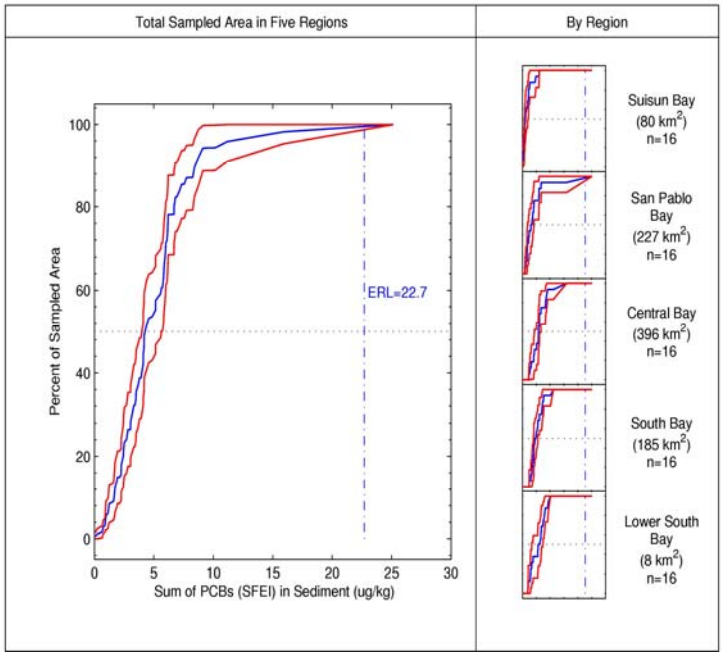
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment sum of PCB concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the ERL guideline for sum of PCBs?

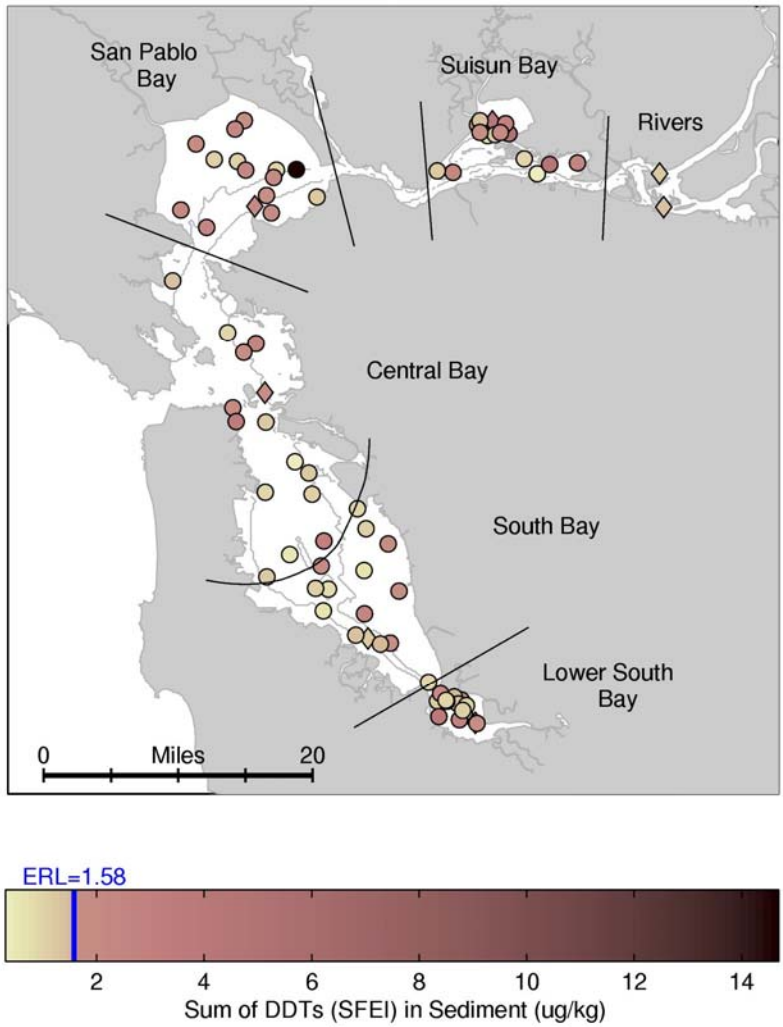


c) Cumulative distribution function (CDF) plots for sediment sum of PCB concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment sum of PCB concentrations.The small graphs show the same for each individual region (scales are identical to the large graph).

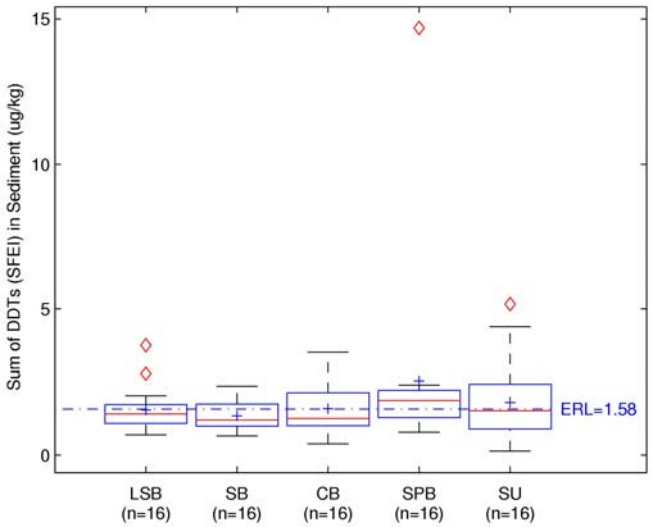
About 80% of the total sampled area in the Estuary had sediment sum of PCB concentrations above the TMDL target of 2.5 ug/kg.

Figure 3.16a-c. Sum of DDTs in Sediments (2004-2005)



a) Map of sum of DDT concentrations in sediments (µg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

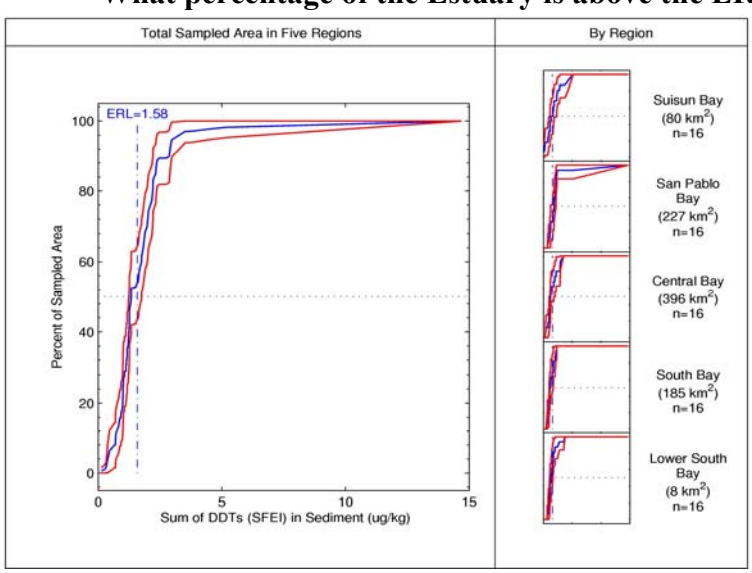
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment sum of DDT concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the ERL guideline for sum of DDTs?

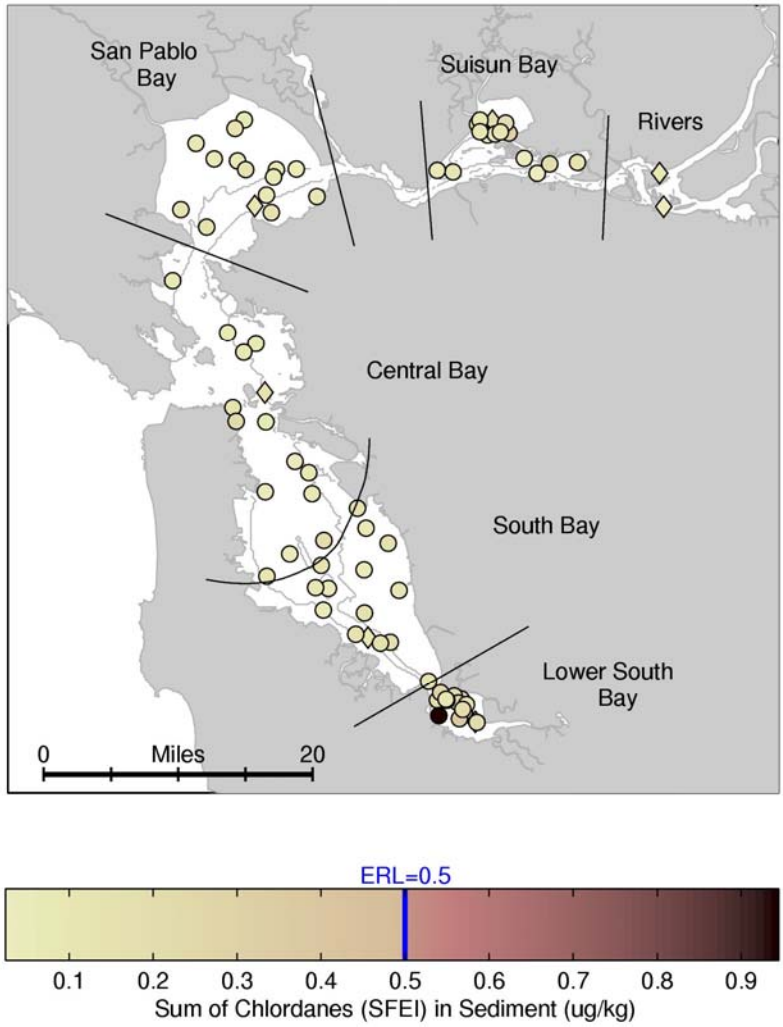


c) Cumulative distribution function (CDF) plots for sediment sum of DDT concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment sum of DDT concentrations. The small graphs show the same for each individual region (scales are identical to the large graph).

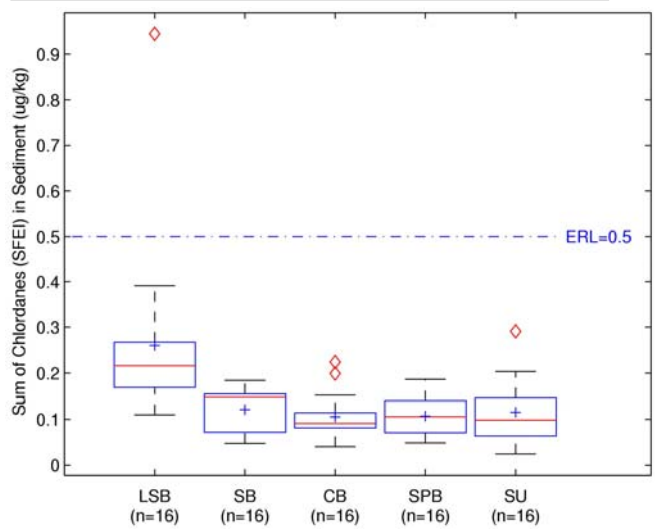
About 55% of the total sampled area in the Estuary had sediment sum of DDTs concentrations above the ERL guideline of 1.58 ug/kg. All of the regions had DDT concentrations 50% or above the ERL guideline.

Figure 3.17a-c. Sum of Chlordanes in Sediments (2004-2005)



a) Map of sum of chlordane concentrations in sediments (µg/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

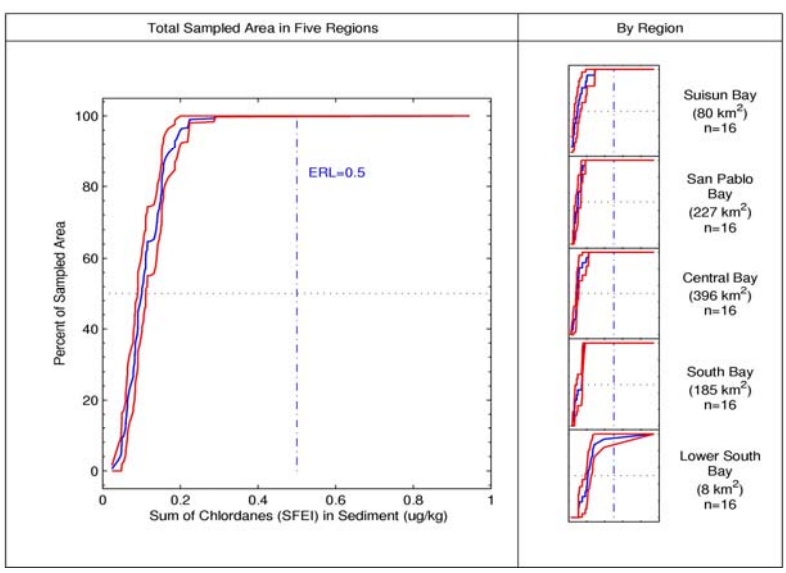
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment sum of chlordane concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the ERL guideline for sum of chlordanes?

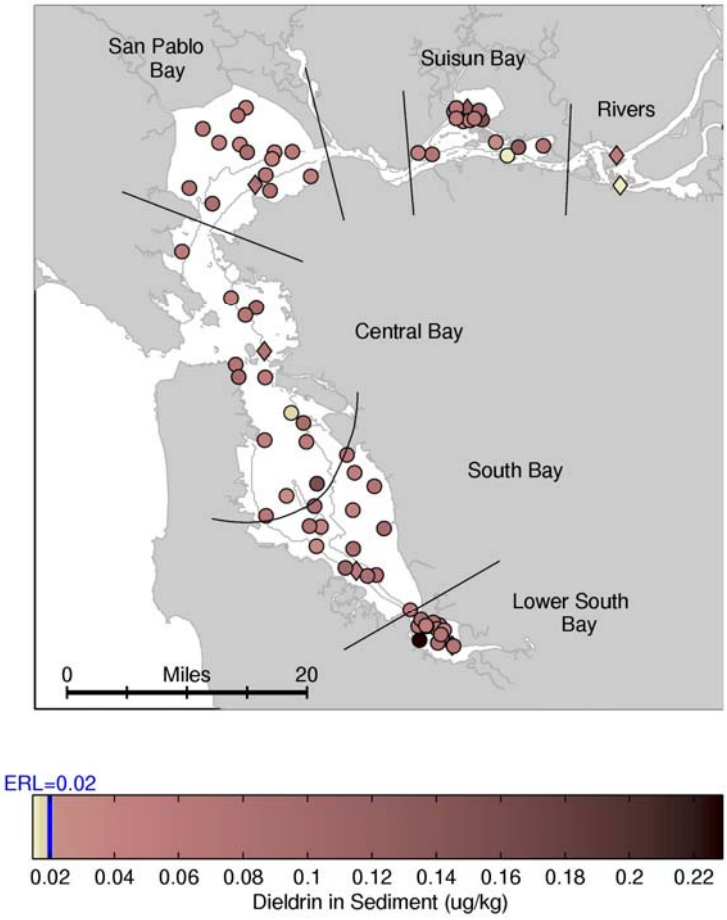


c) Cumulative distribution function (CDF) plots for sediment sum of chlordane concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment sum of chlordane concentrations. The small graphs show the same for each individual region (scales are identical to the large graph).

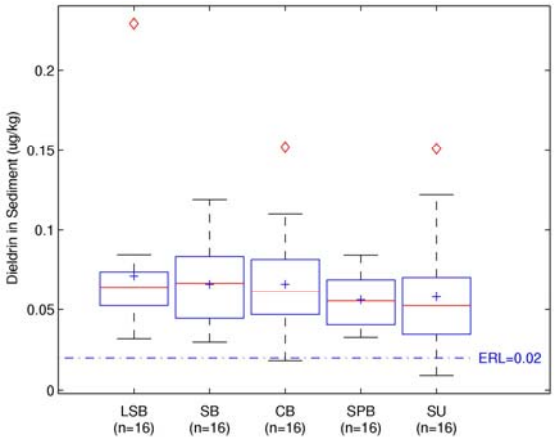
None of the total sampled area in the Estuary had sediment sum of chlordane concentrations above the ERL guideline of 0.5 ug/kg.

Figure 3.18a-c. Dieldrin in Sediments (2004-2005)



a) Map of dieldrin concentrations in sediments (ug/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated sites (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the Rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

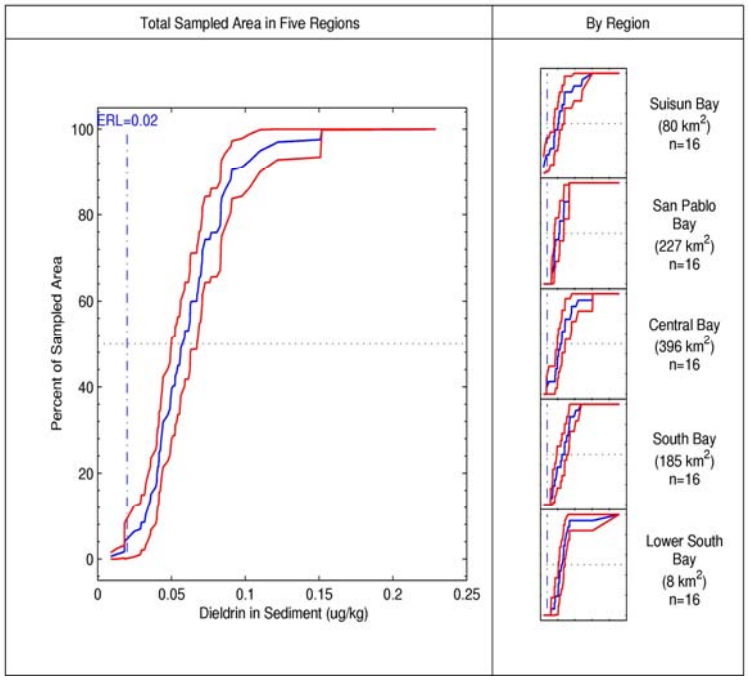
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment dieldrin concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the Estuary is above the dieldrin ERL guideline?

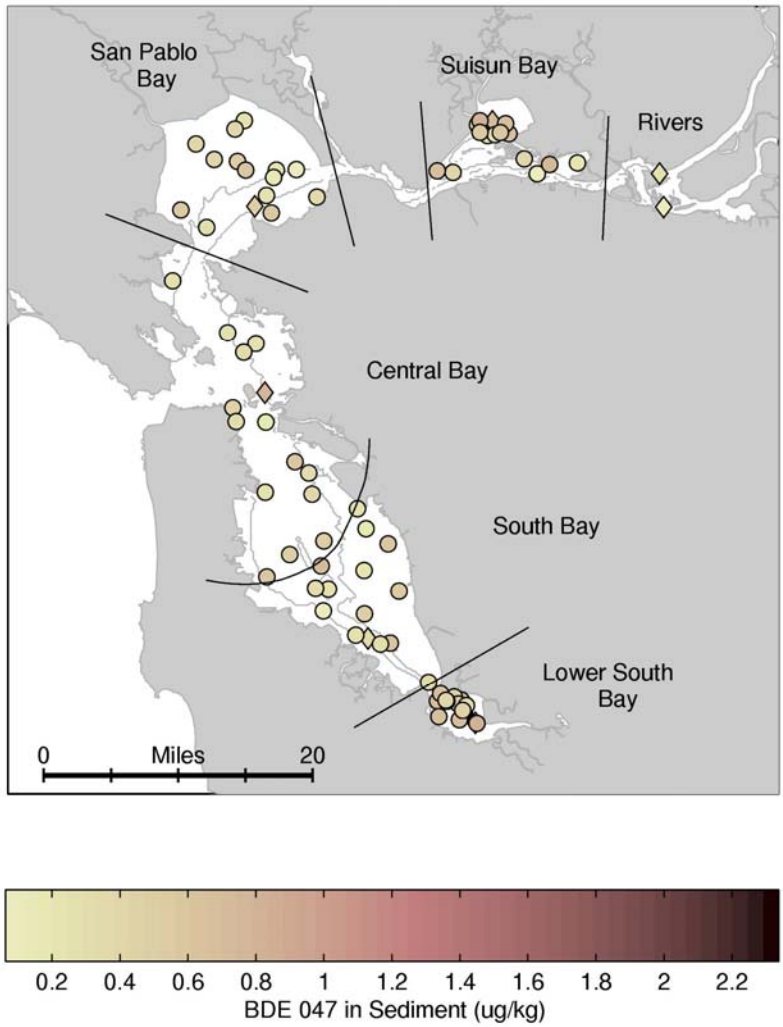


c) Cumulative distribution function (CDF) plots for sediment dieldrin concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment nickel concentrations. The small graphs show the same for each individual region (scales are identical to the large graph).

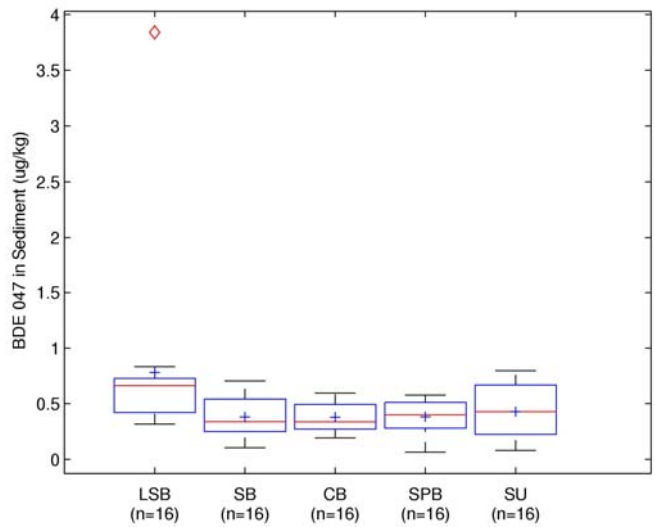
About 98% of the total sampled area in the Estuary had sediment dieldrin concentrations above the ERL guideline of 0.02 ug/kg. The small graphs indicate that all of the regions are above the ERL guide line except Suisun Bay.

Figure 3.19a-c. BDE-47 in Sediments (2004-2005)



a) Map of BDE-47 concentrations in sediments (ug/kg dry weight) in the six Estuary regions monitored. Eighty randomly allocated (based on the EMAP sample design) and seven historical RMP sites are represented here. Only historic sites were sampled in the rivers region. See Section 1.3.1 for further explanation of the map. Number of samples: random =16/region; historic = 1/region except n=2 for the Rivers region.

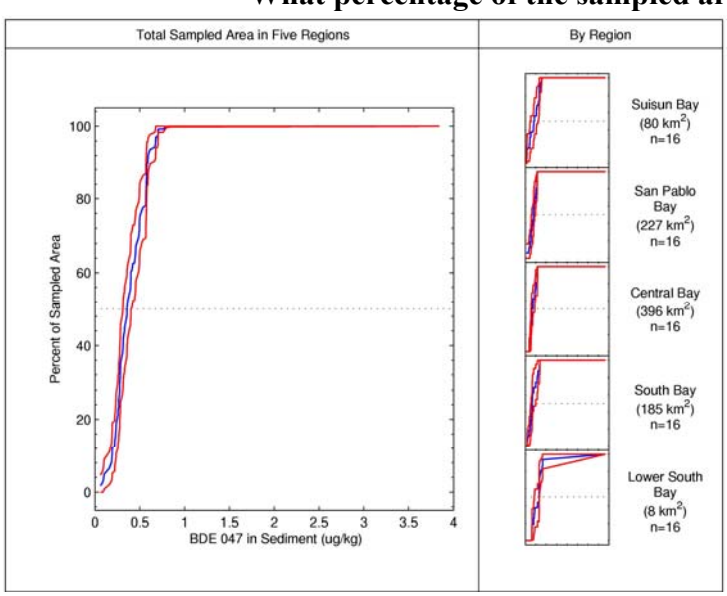
Random sites = ○, Historic sites = ◊, Non-detects = +



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

b) Schematic Box Plot of sediment BDE-47 concentrations for the random sites in five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the schematic box plot.

What percentage of the sampled area contains BDE-47?



c) Cumulative distribution function (CDF) plots for sediment BDE-47 concentrations from the random samples in the five Estuary regions (2004-2005). See Section 1.3.1 for an explanation of the CDF plot.

The large graph shows the percentage of the total area sampled in the five Estuary regions (totaling 896 square kilometers) vs. sediment BDE-47 concentrations. The small graphs show the same for each individual region (scales are identical to the large graph).

100% of the total sampled area in the Estuary contains BDE-47.

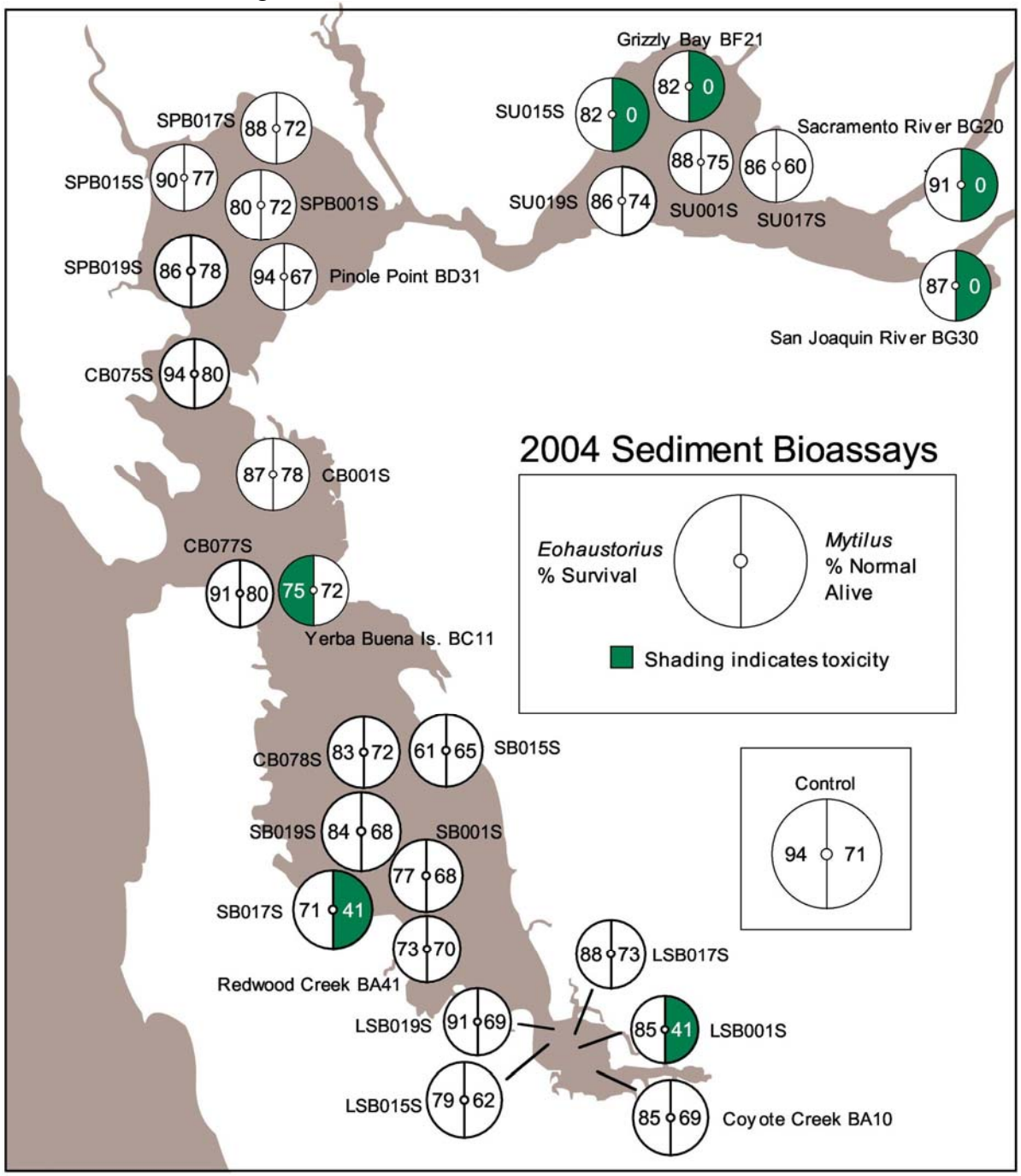


Figure 3.20. Sediment bioassay results for 2004. Sediments were not toxic (see Section 3.4 Sediment Toxicity) to either amphipods, *Eohaustorius estuarius*, or mussel, *Mytilus galloprovincialis*, larvae at 20 out of 27 stations. Amphipod toxicity was observed at one station in the Central Bay (Yerba Buena Island (BC11)). Sediment samples from six stations were toxic to larval mussels: Sacramento River (BG20), San Joaquin River (BG30), Suisun Bay (Grizzly Bay (BF21), and SU015S), South Bay (SB017S), and Lower South Bay (LSB001S).

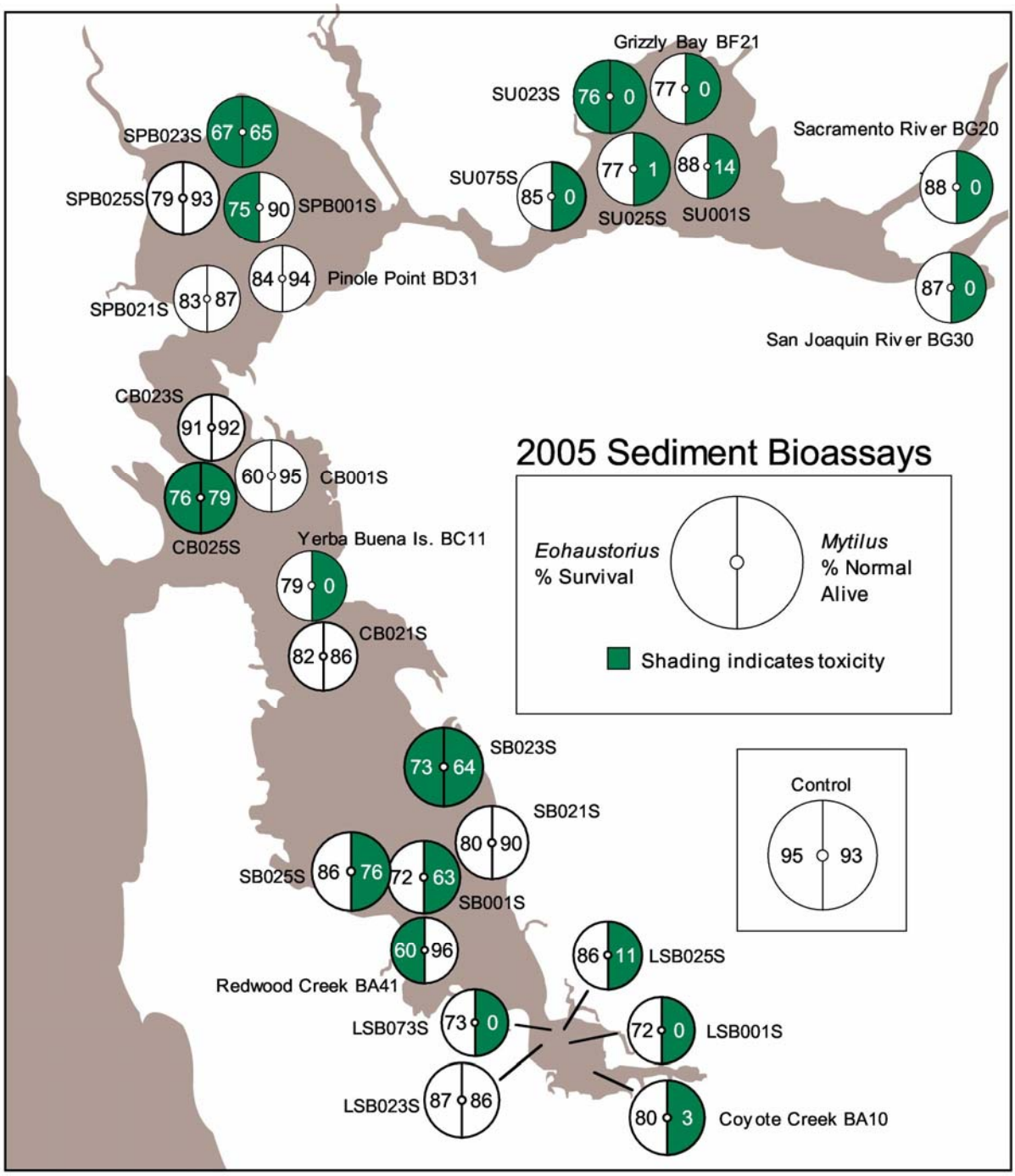


Figure 3.21. Sediment bioassay results for 2005. Sediments were not toxic (see Section 3.4 Sediment Toxicity) to either amphipods, *Eohaustorius estuarius*, or mussel, *Mytilus galloprovincialis*, larvae at 8 out of 27 stations.

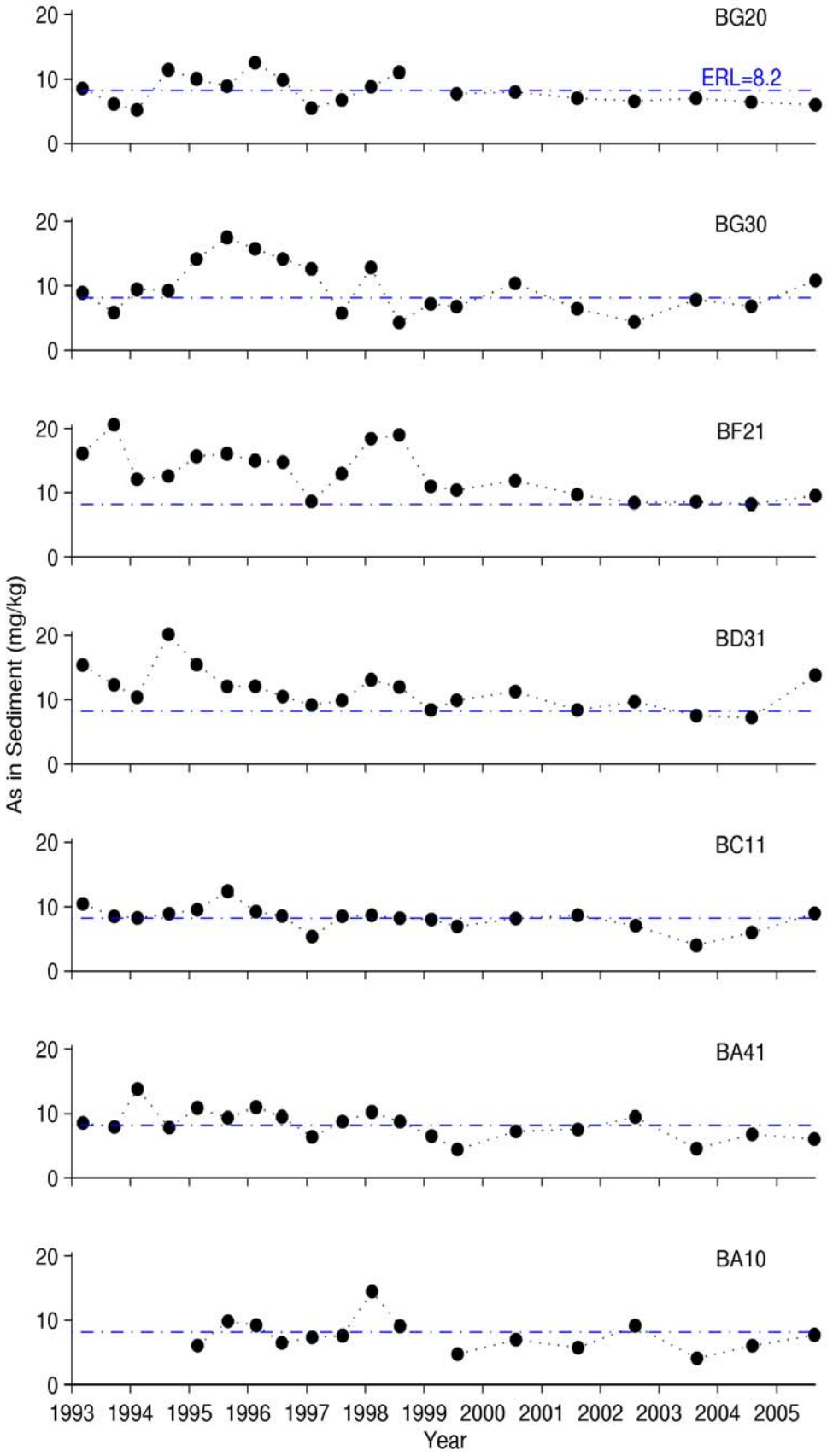


Figure 3.22. Time series plots for arsenic (As) in sediments (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The dashed blue reference line is the ERL guideline of 8.2 mg/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

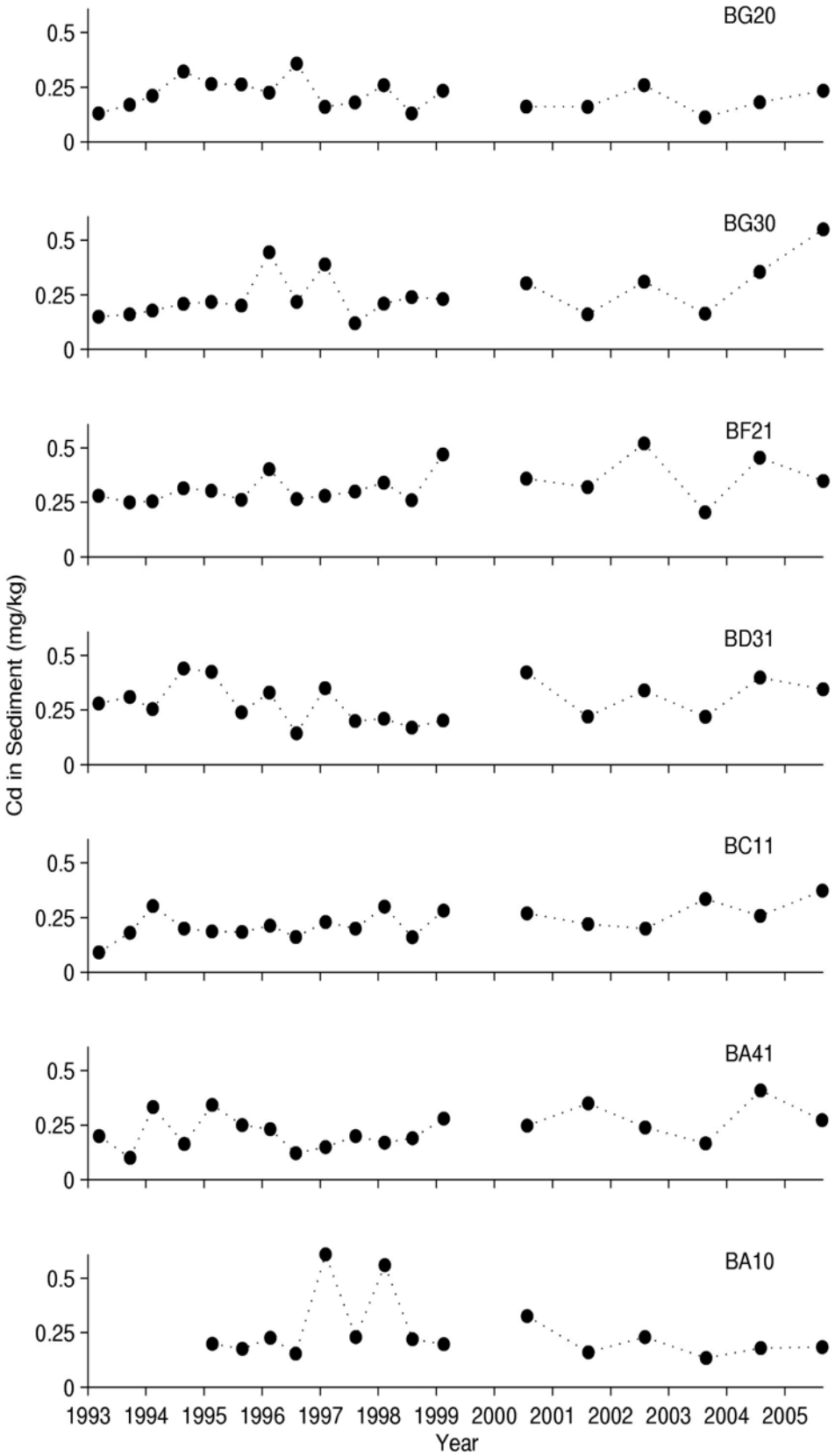


Figure 3.23. Time series plots for cadmium (Cd) in sediments (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The ERL guideline is 1.2 mg/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

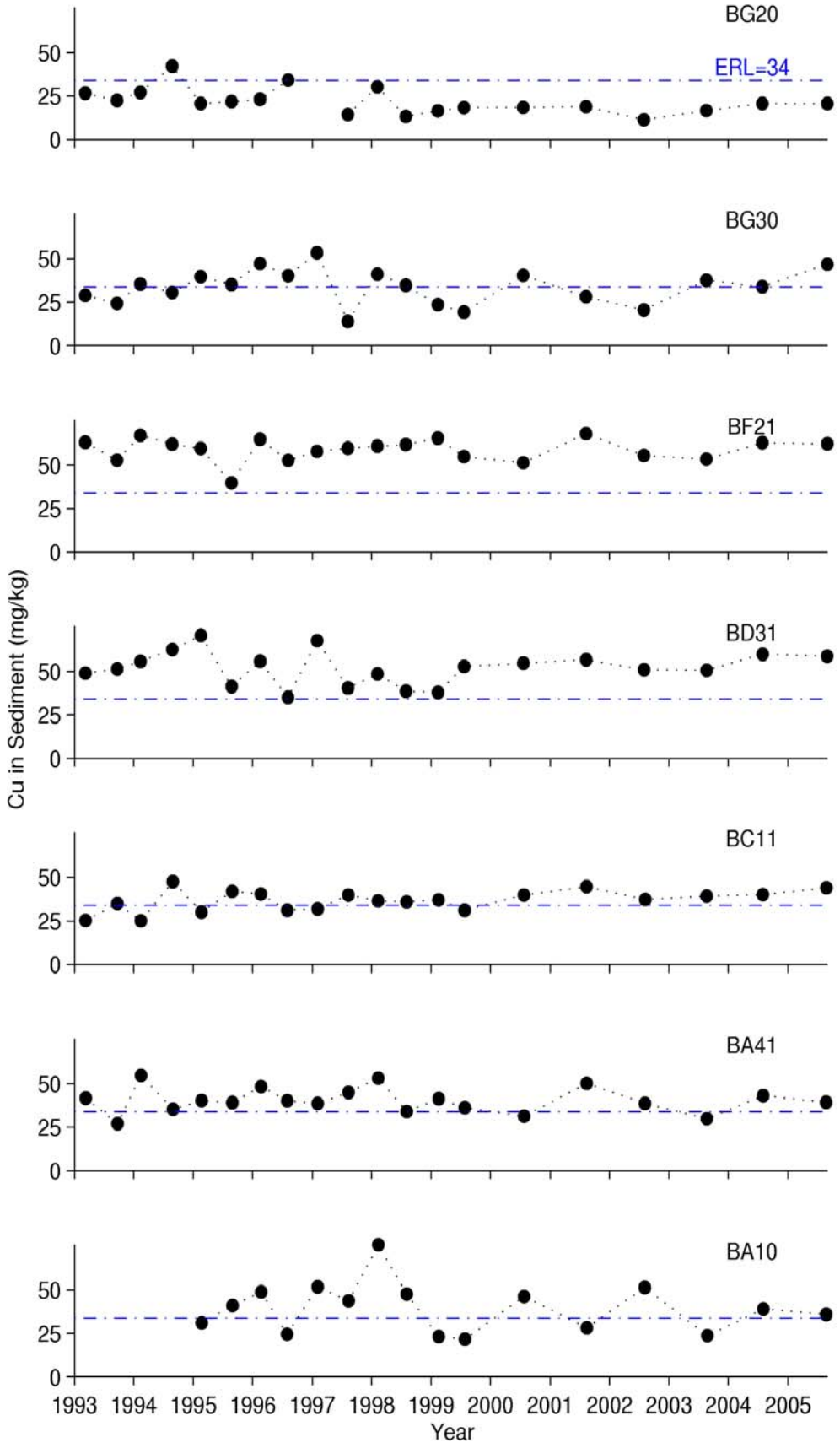


Figure 3.24. Time series plots for copper (Cu) in sediments (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The dashed blue reference line is the ERL guideline of 34 mg/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

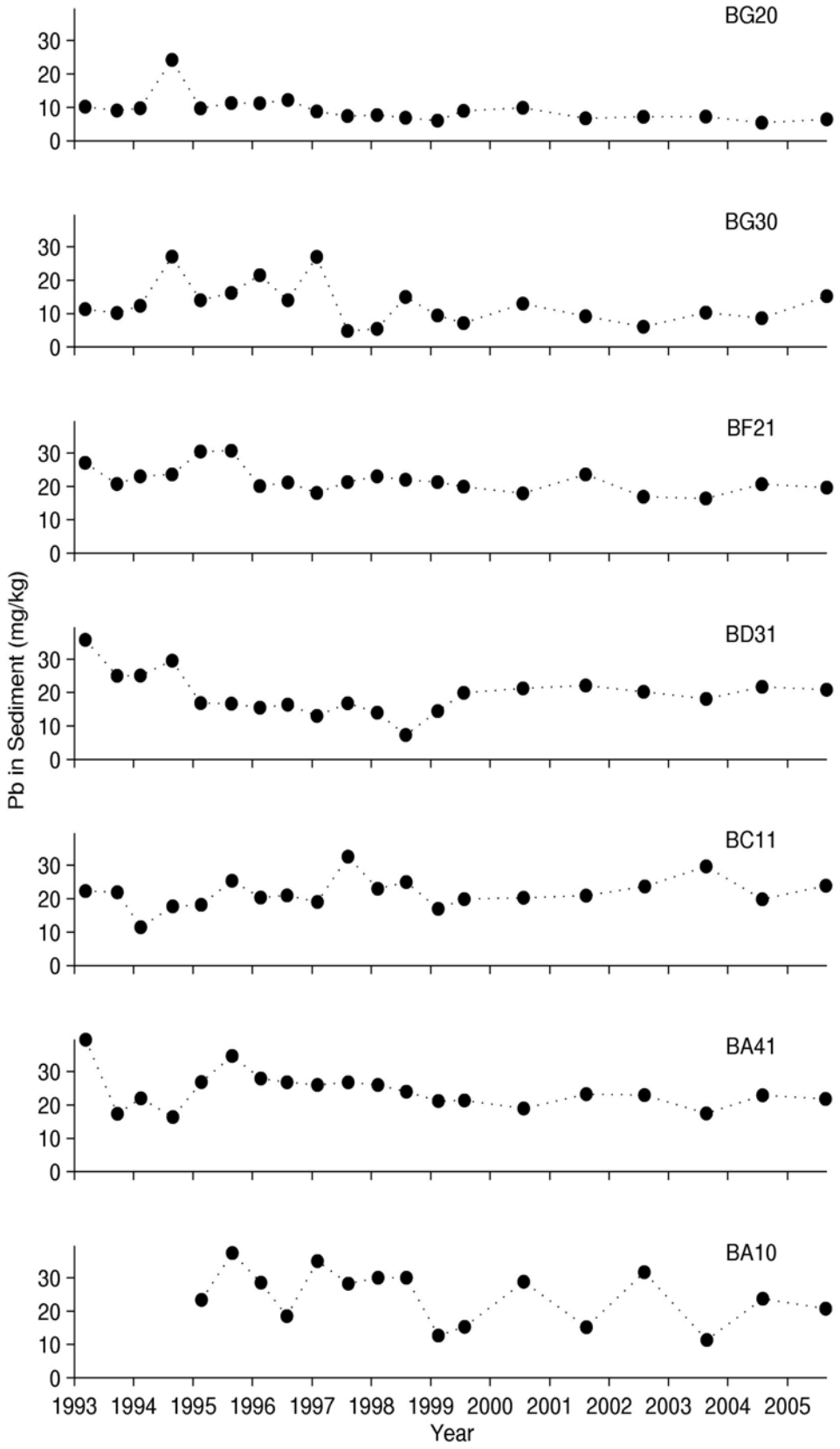


Figure 3.25. Time series plots for lead (Pb) in sediments (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The ERL guideline is 46.7 mg/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

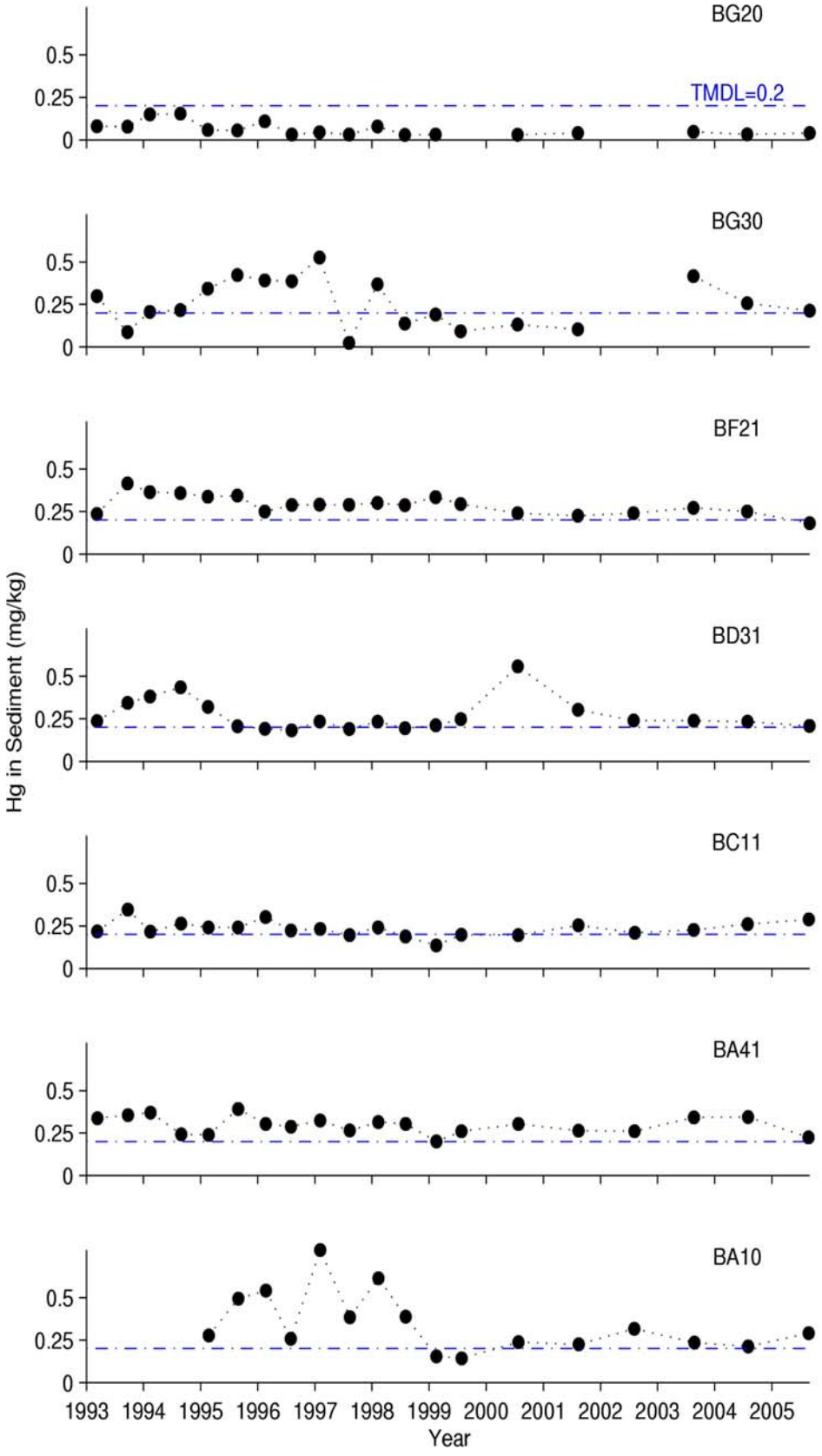


Figure 3.26. Time series plots for mercury (Hg) in sediments (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The dashed blue reference line is the TMDL target of 0.2 mg/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

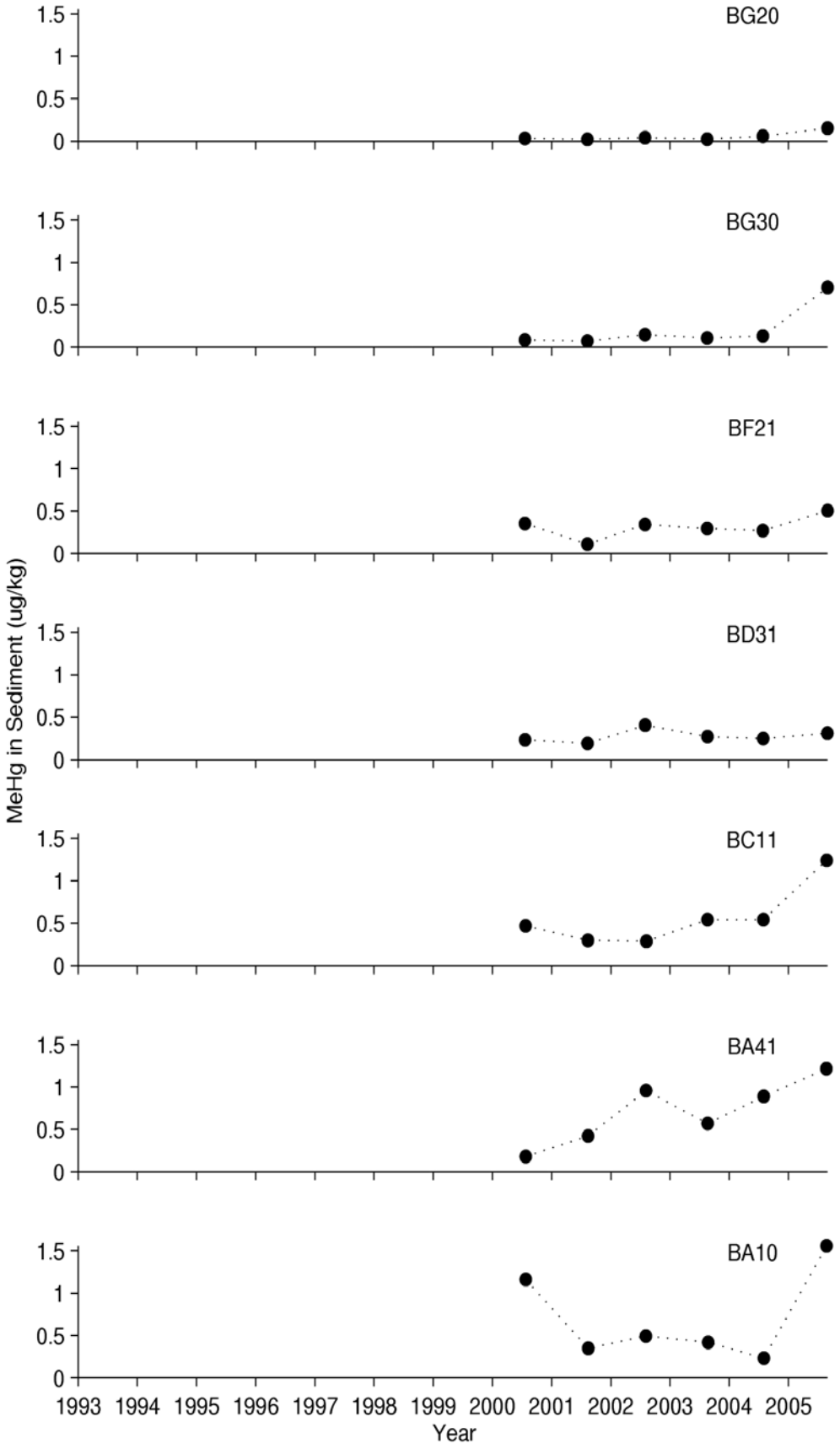


Figure 3.27. Time series plots for methyl mercury (MeHg) in sediments (ug/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (2000-2005).

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

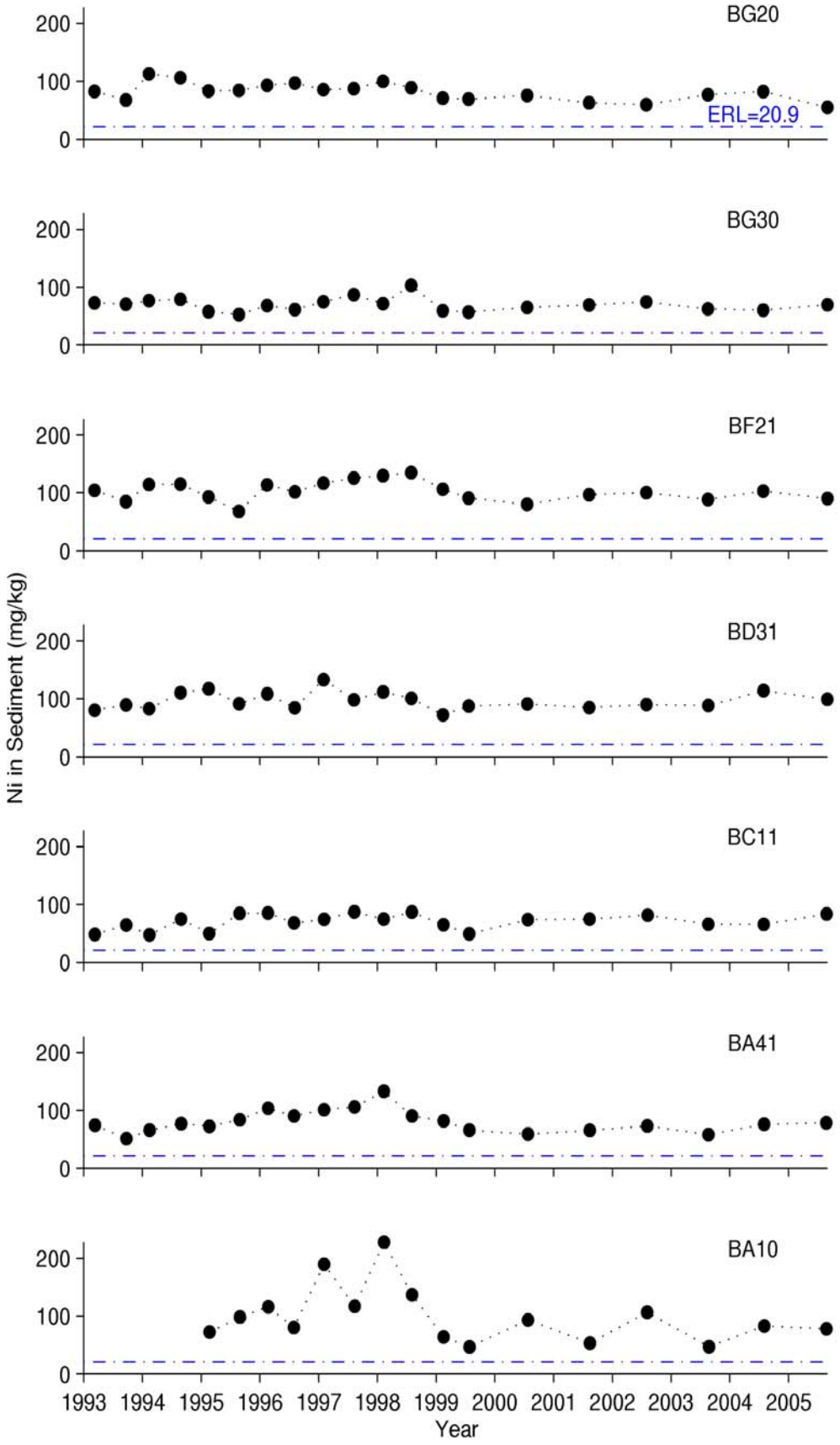


Figure 3.28. Time series plots for nickel (Ni) in sediments (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The ERL guideline is 20.9 mg/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

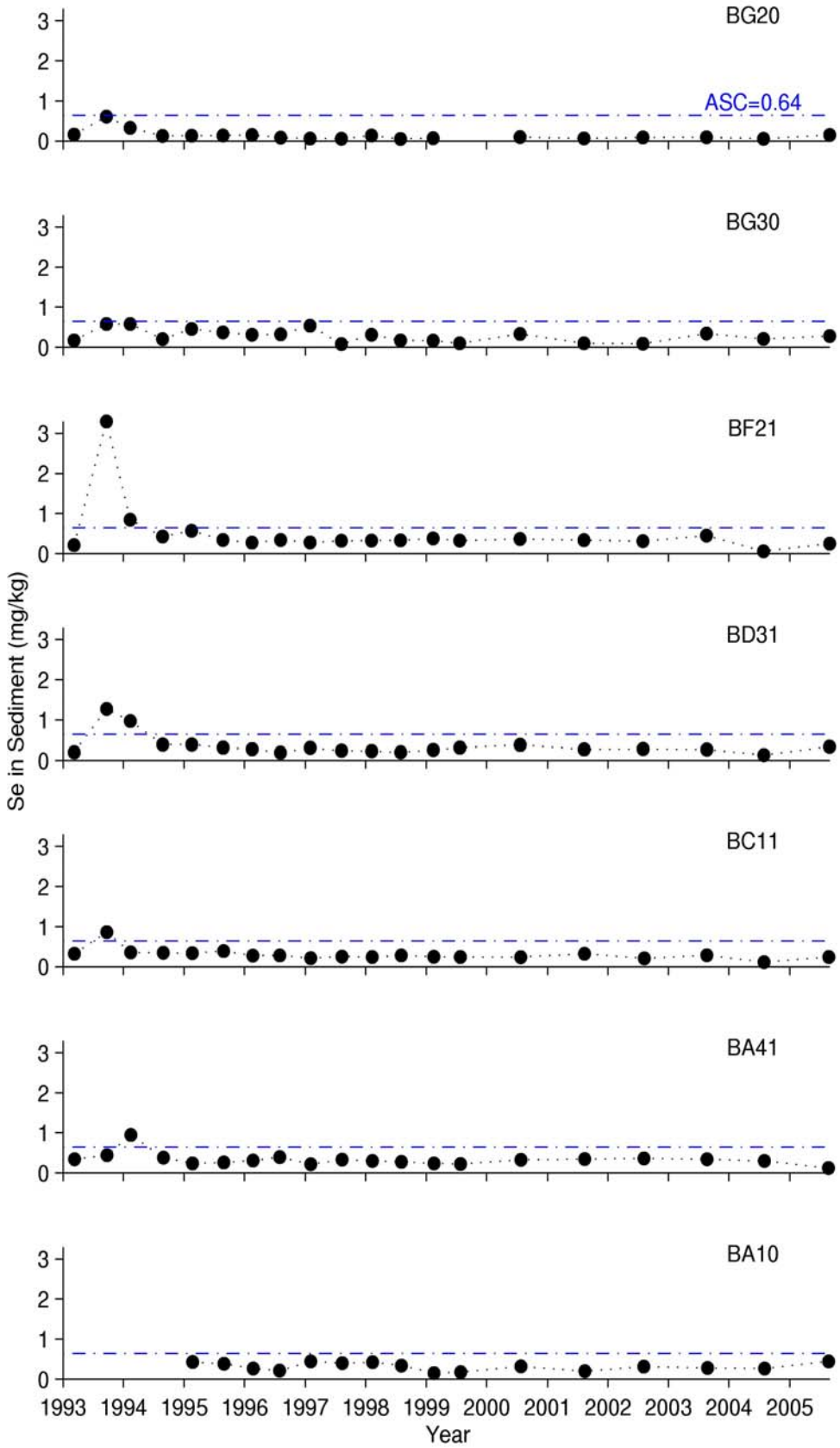


Figure 3.29. Time series plots for selenium in sediments (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The dashed blue reference line is the ASC guideline of 0.64 mg/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

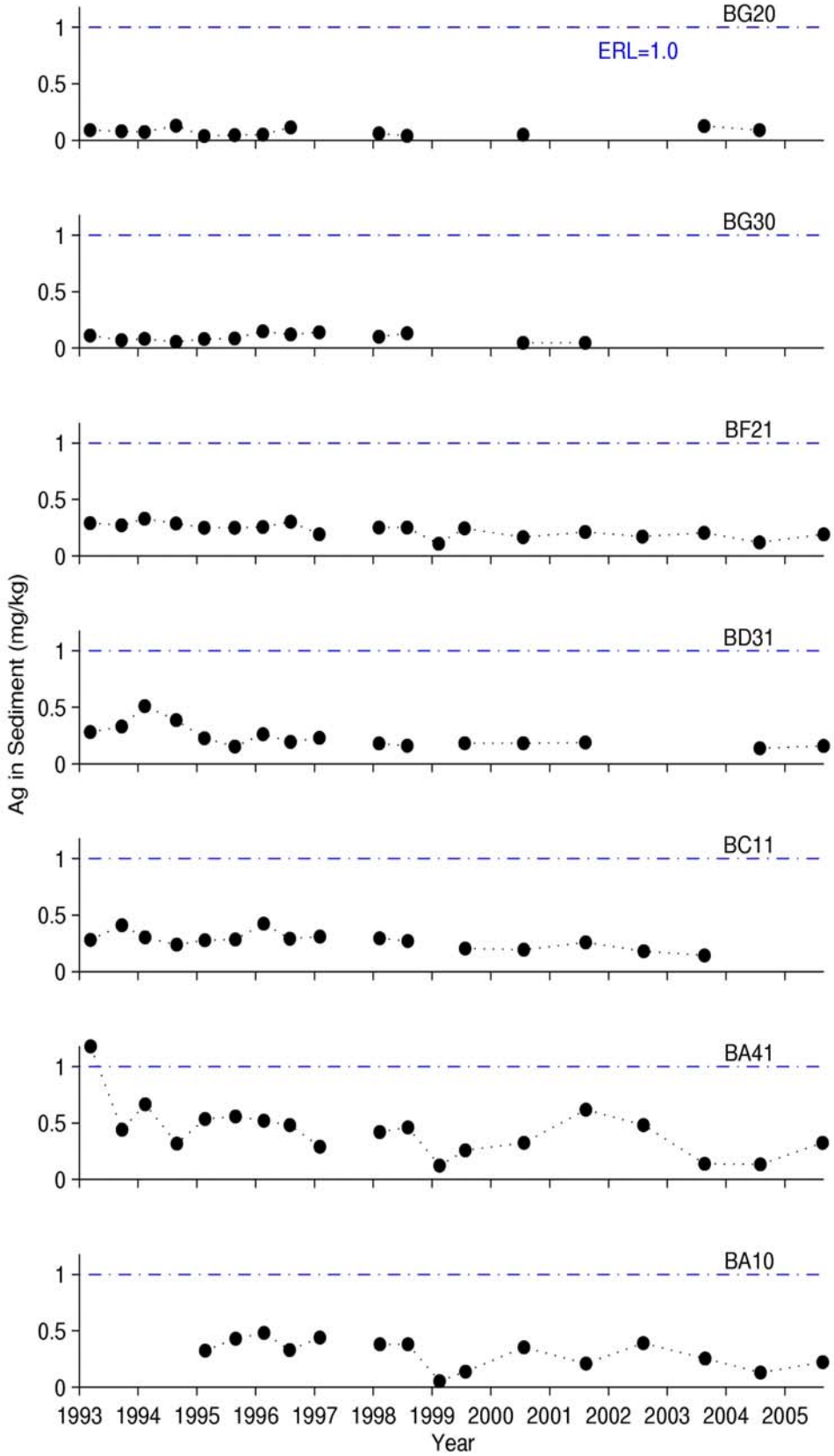


Figure 3.30. Time series plots for silver (Ag) in sediments (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status & Trends Program (1993-2005). The dashed blue reference line is the ERL guideline of 1 mg/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

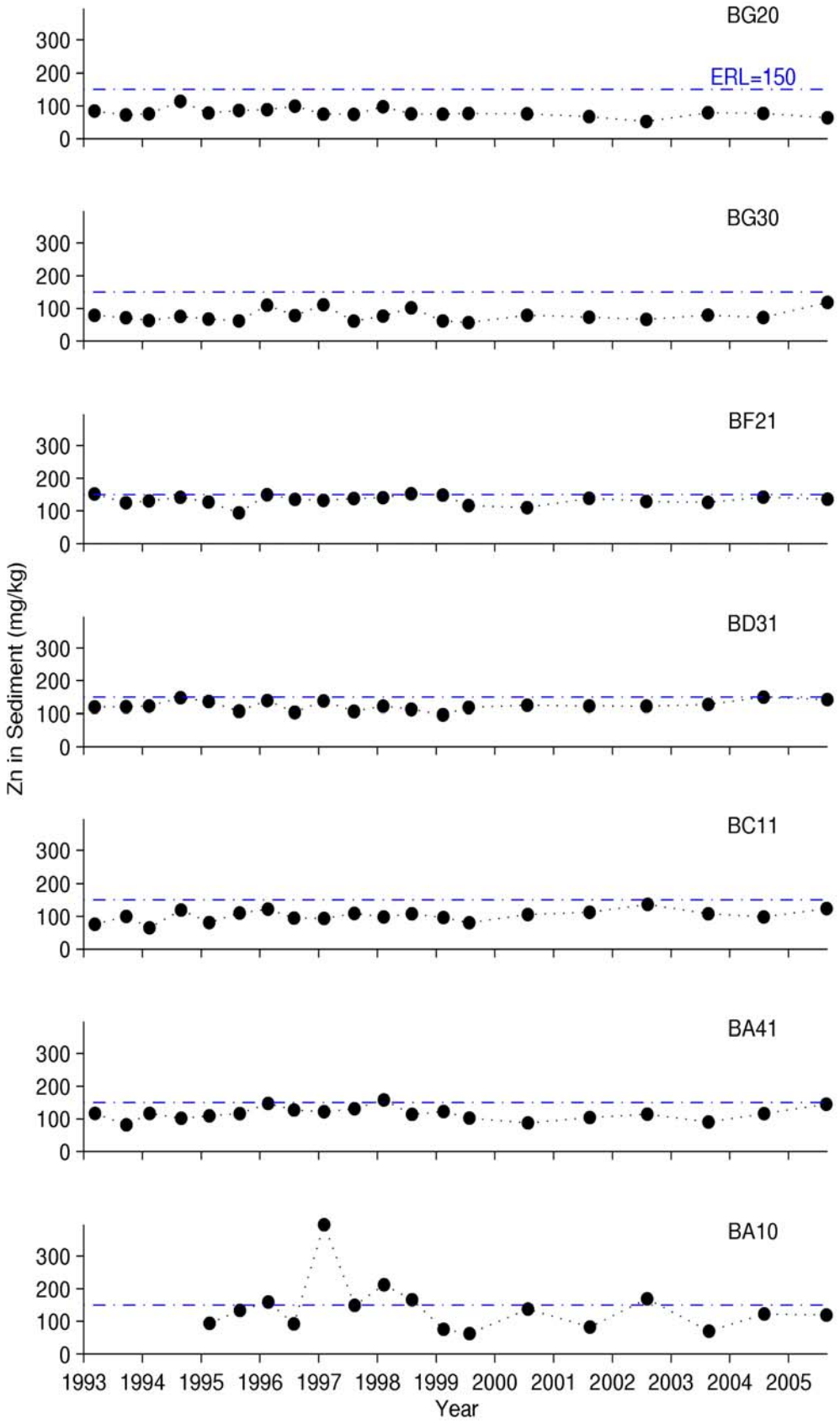


Figure 3.31. Time series plots for zinc (Zn) in sediments (mg/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The ERL guideline is 150 mg/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

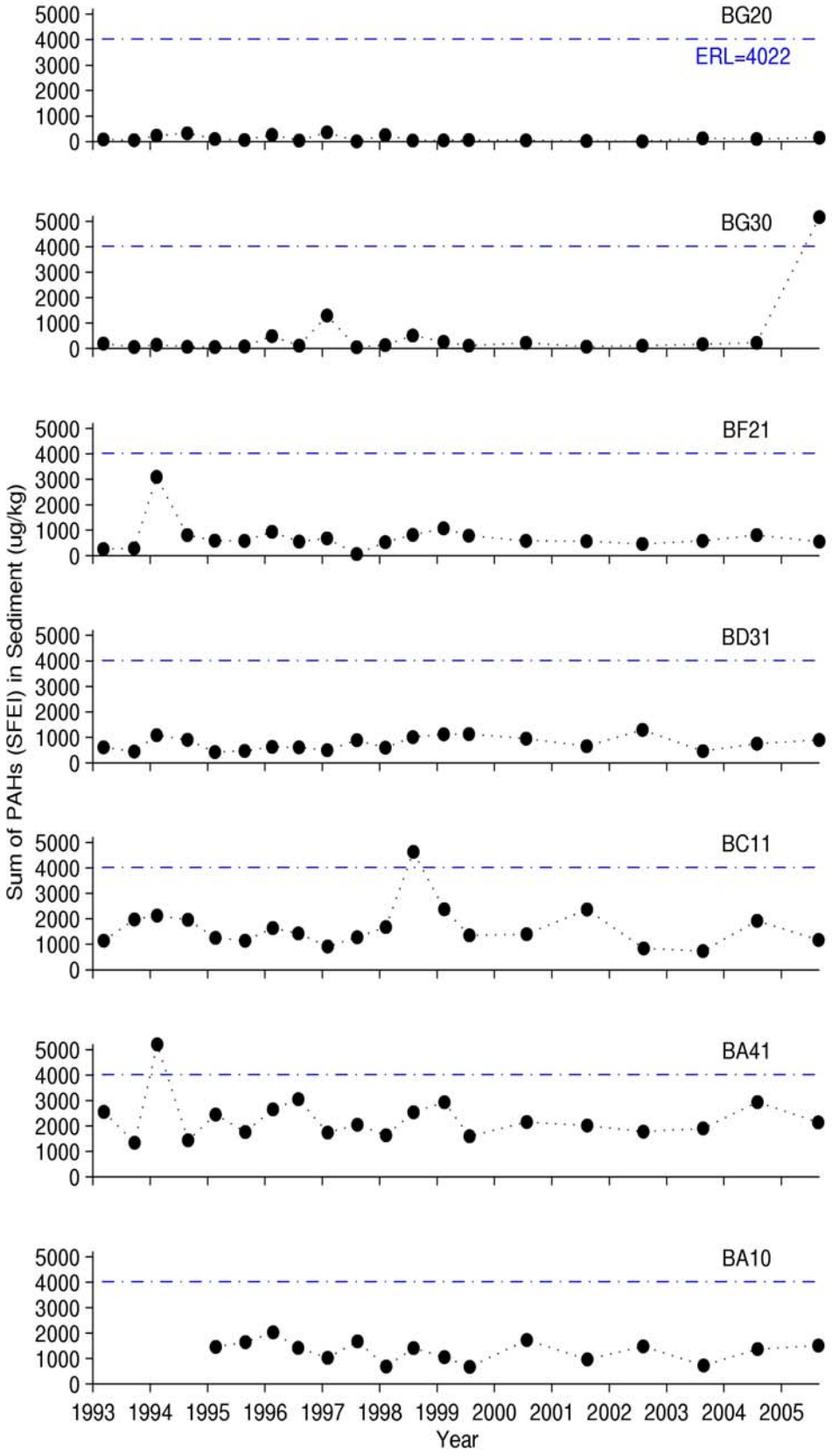


Figure 3.32. Time series plots for sum of PAHs in sediments (ug/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The ERL guideline is 4022 ug/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

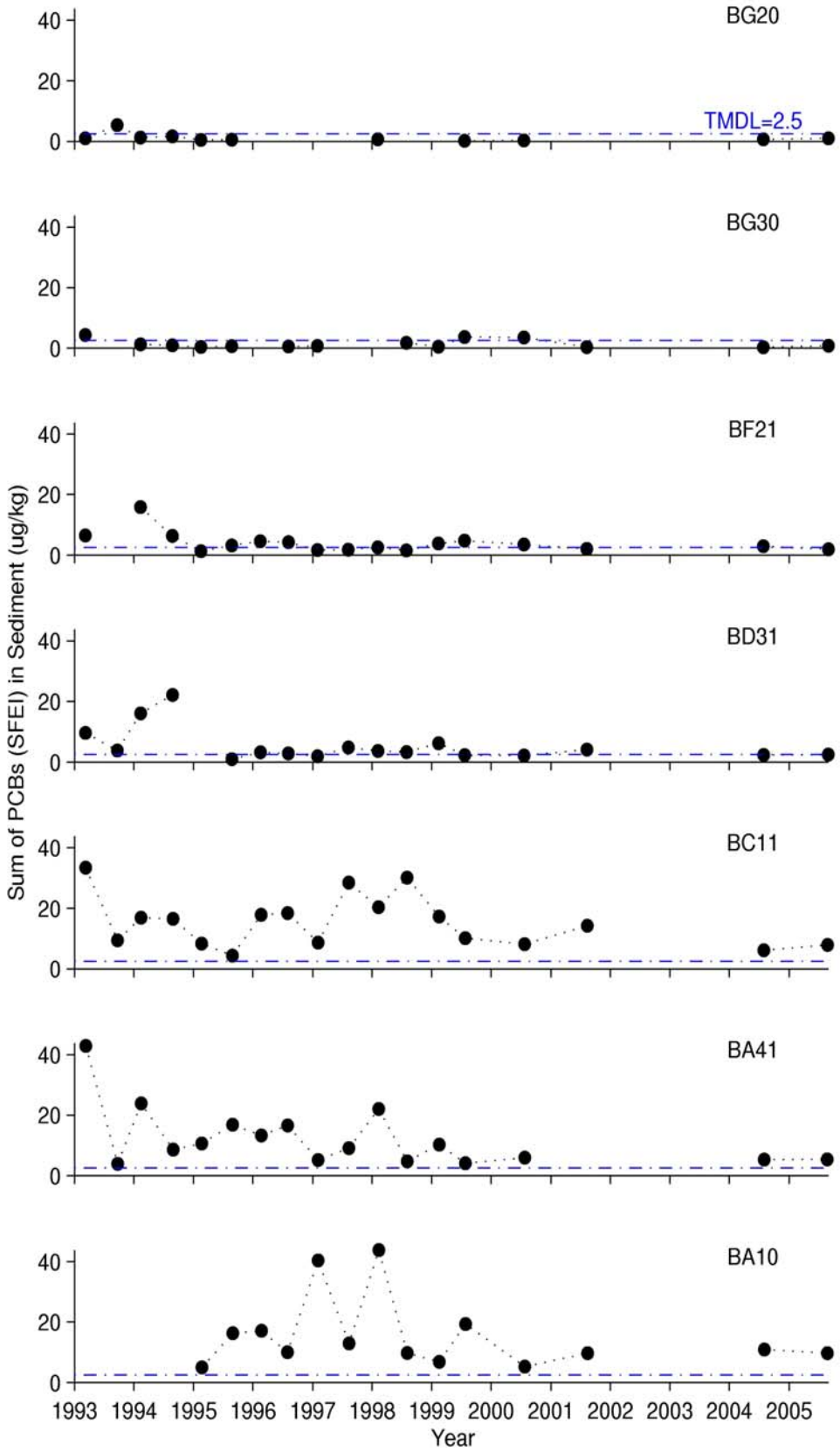


Figure 3.33. Time series plots for sum of PCBs in sediments (ug/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The dashed blue reference line is the TMDL target of 2.5 ug/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

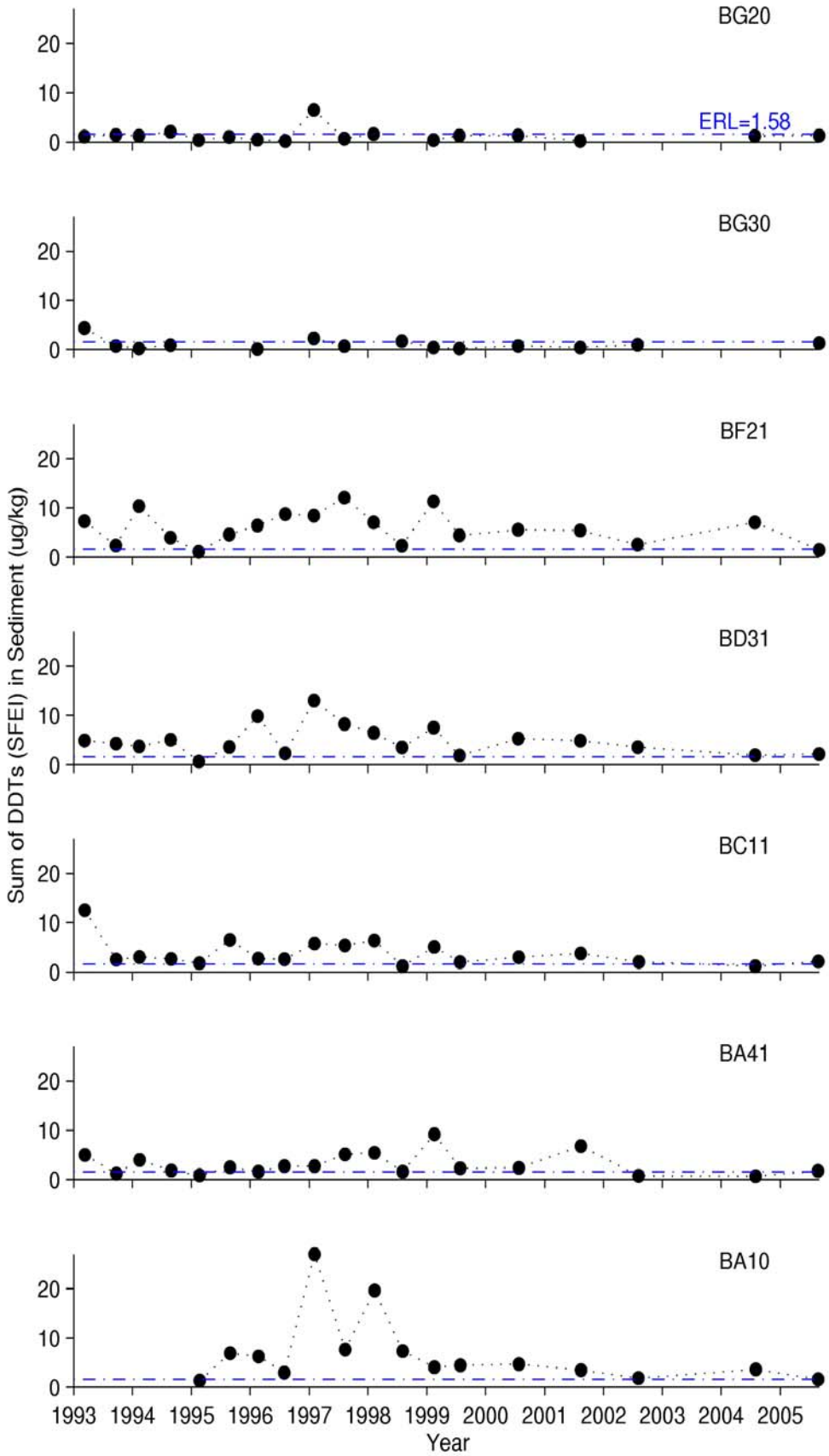


Figure 3.34. Time series plots for sum of DDTs in sediments (ug/kg dry weight) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The ERL guideline is 1.58 ug/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

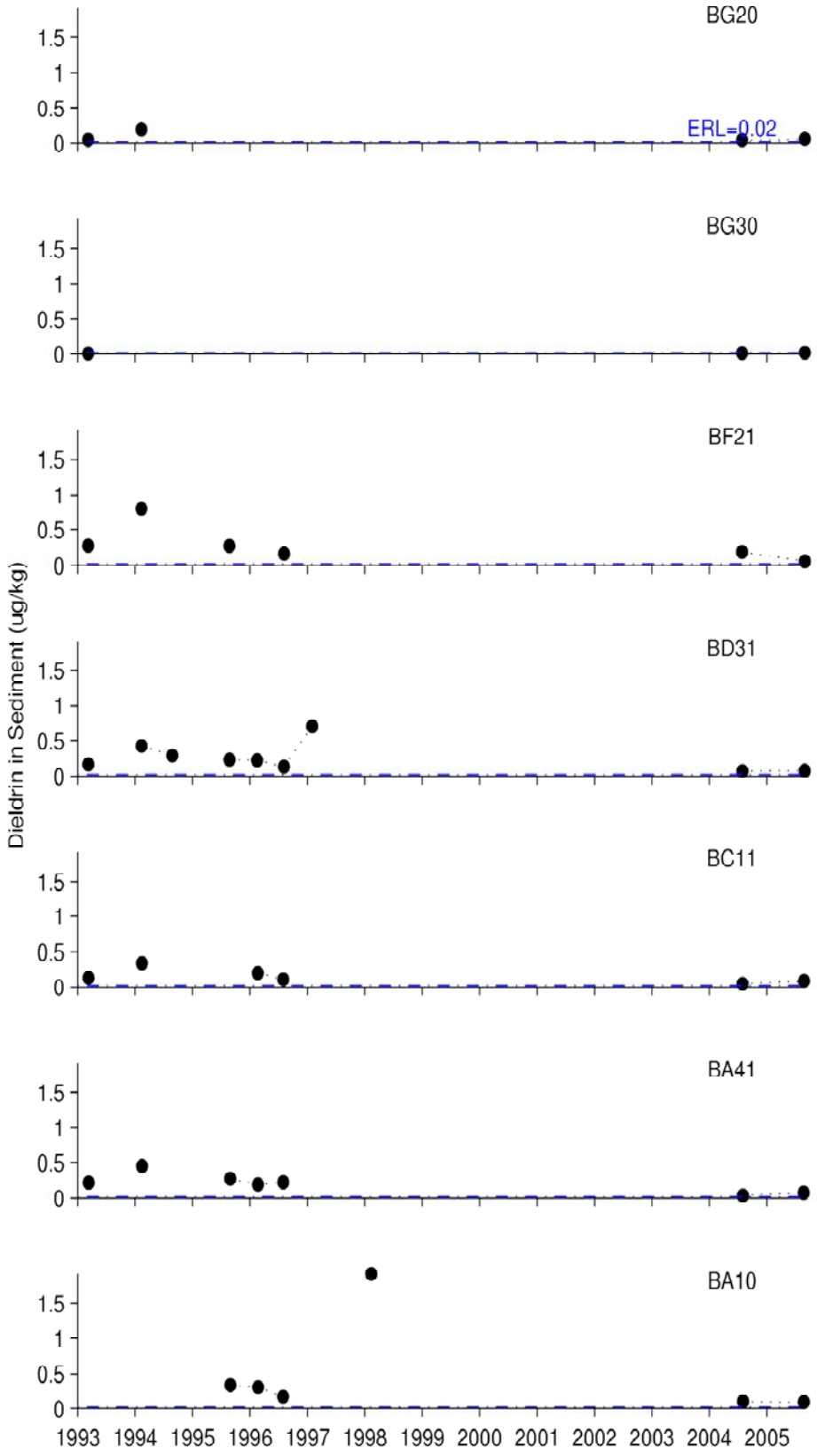


Figure 3.36. Time series plots for dieldrin in sediments (ug/kg) at seven historical sites, arranged from north to south, monitored by the RMP Status and Trends Program (1993-2005). The dashed blue reference line is the ERL guideline of 0.02 ug/kg.

Historical Sites:
BG20 Sacramento River
BG30 San Joaquin River
BF21 Grizzly Bay
BD31 Pinole Point
BC11 Yerba Buena Island
BA41 Redwood Creek
BA10 Coyote Creek

Chapter 4

Bivalve Monitoring

4.0 BIVALVE MONITORING

Jennifer Hunt, Sarah Lowe, Paul Salop, and Predrag Stevanovic

4.1 Background

The RMP has been analyzing bivalve tissue samples for trace contaminants since 1993. Bivalves bioaccumulate chemical contaminants through their food, by ingesting sediment and assimilating contaminants that are sorbed to particles, and by filtering dissolved contaminants directly from the water column. Bivalves act as transfer vectors of contaminants to higher trophic levels of the aquatic and sediment food webs. Contaminant concentrations in living organisms can accumulate to levels much greater than those found in ambient water and sediment due to an organism's inability to metabolize certain contaminants (Vinogradov, 1959) and a high affinity of some contaminants for lipid rich tissue in bivalves (Stout and Beezhold, 1981). Biomonitoring using bivalves has been widely applied by the California State Mussel Watch Program (Phillips, 1988; Rasmussen, 1994) and other studies (Young *et al.,* 1976; Wu and Levings, 1980; Hummel *et al*., 1990; Martincic *et al.,* 1992, Gunther *et al.,* 1999; O'Connor, 2002).

Bivalves are excellent organisms for biomonitoring of contaminants since they accumulate contaminants from the ambient environment, have limited mobility and are fairly resistant to contaminant effects (O'Connor, 2002). The RMP is continuing the long-term monitoring of the State Mussel Watch Program, which monitored sites throughout the Estuary beginning in 1976. Comparable RMP stations that are still monitored include Pinole Point, Red Rock, Yerba Buena Island, Alameda, Redwood Creek and Dumbarton Bridge. Biomonitoring using bivalves has been documented in the literature (see for example Luoma and Linville, 1996; Gunther and Davis, 1997; Gunther *et al.,* 1999).

4.2 Approach

There were no changes made to sampling locations in 2004 or 2005. Mussels (*Mytilus californianus*) were deployed at nine stations and resident clams collected from two locations, Sacramento River and San Joaquin River. Clams from these stations were not transplanted and therefore were exposed to contaminants across their lifetime. Bivalves were deployed at a total of nine fixed mooring stations within the Estuary for a period of 90 to 100 days. Bivalve monitoring was conducted during the dry season months (June through August). The RMP Design Integration Workgroup determined that it is sufficient to analyze tissue concentrations in bivalves only once per year during the dry season, when Estuary conditions are more consistent on an interannual basis.

All mussels were deployed in cages. In 2004 and 2005, the RMP continued with the deployment of unmaintained cages and maintained cages (maintained approximately 45 days into deployment) at all deployment sites to determine if the mid-deployment maintenance cruise was necessary. One hundred *M. californianus* were deployed in four compartments of twenty-five each, to be maintained midway through deployment, with bivalves to be analyzed for trace organics, survival, and growth. Fifty *M. californianus* were deployed in a cage that is not cleaned midway through the deployment. Bivalves were deployed in two compartments of twenty-five each, to be used for analysis of survival and growth only. All bivalves collected from reference stations were kept on ice and deployed within 72 hours.

4.2.1 Methods

Table 1.5 in the *Introduction* lists the parameters measured in bivalve tissue samples in 2004 and 2005. Section 5, *Description of Methods,* summarizes field and analytical methods and provides information on additional RMP sampling and analysis reference documentation. Data are available for downloading via the RMP website using the Web Query Tool at http://www.sfei.org/rmp/data.htm.

Due to analytical issues the 2004 bivalve organics data are not being reported. Archived tissue from 2004 may be analyzed at a future date but data for this year are currently not available. This summary is inclusive only of the 2005 data. Samples were analyzed for synthetic trace organics, which included PAH, PCBs, pesticides, and polybrominated diphenyl ethers (PBDEs). The PAH data for 2005 are also not available due to analytical problems.

Contaminant concentrations in tissue of transplanted bivalves were measured before deployment (T-0 or background concentrations) and at the end of the 90-100 day deployment period. Resident clams from the Sacramento River and San Joaquin River stations were collected at the end of the three month period. Survival and growth indices were also measured on the deployed bivalves. Because of potential individual variability in contaminant concentrations and the small tissue mass, composites of up to 30 individual bivalves were made for each species from each deployment site for analyses of trace contaminants. RMP tissue concentrations are reported in ng/g dry weight or ppb. Conversion to dry weight reduces the variability in results that could occur due to variable moisture and lipid content of the samples.

Calculated Measures of Bioaccumulation

Accumulation Factors

In addition to reporting the measured tissue concentrations prior to and following deployment, this report uses accumulation factors (AF) to indicate accumulation or depuration (loss of contaminants from bivalve tissue by metabolism) during the 90-100 day deployment period (Table 4.2). The accumulation factor is calculated by dividing the final contaminant concentration in transplants by the initial bivalve concentration (T-0) for that species. For example, an accumulation factor of 1 indicates that the concentration of a specific contaminant at the end of the deployment period was the same compared to the T-0 contaminant concentration. AFs less than 1 indicate that the bivalves decreased in contaminant concentration during the deployment period due to depuration, while an AF greater than 1 indicates accumulation. Accumulation factors are not calculated in *C. fluminea* for the Sacramento and San Joaquin River stations, since they were collected as resident species at these stations and not transplanted, like mussels, from a background site outside of the Estuary. If there is an ND for either quotient concentration then the accumulation factor was not determined.

4.2.2 Biological Growth and Survival

The growth mean is a measure of growth of the bivalves at a particular station in comparison to the initial T-0 mean dry weight. The growth of each mussel was estimated by subtracting the T-0 mean dry weight from the dry weight of the individual mussel. The mean of the difference for all the individuals at a particular station (up to 30 individuals/site) was then determined to give the growth mean for that station. A negative growth mean indicates that the deployed bivalves had reduced weight in comparison to the T-0 sample. A negative growth mean could indicate stress in the organism or weight loss due to reproductive processes. Percent lipid and percent moisture measurements were also made before and after deployment.

Percent survival was determined on both maintained and unmaintained caged bivalves. Percent survival is a measure of how many individual bivalves were alive at the end of the 90-100 day deployment period compared to the total number deployed. Mortality can occur for a variety of reasons including: predation and intolerance to water column salinity and temperature regimes. Only bivalves that were alive at the end of the deployment period were included in the composites for contaminant analyses.

4.2.3 Guidelines

The RMP has used various screening values and guidelines to assess contaminant concentrations in bivalve tissue samples. Starting with the 2001 monitoring results, the RMP began using screening values (Table 4.1) developed by Brodberg and Pollock, (1999) for monitoring contaminant concentrations in finfish. These values are, on the whole, more conservative than other screening values previously used by the RMP and are also used by the Office of Environmental Health Hazard Assessment (OEHHA) in screening contaminants in shellfish and finfish for human consumption advisories. These screening values were developed following U.S. EPA guidance (U.S. EPA, 1995) for evaluation of contaminants in fish tissue in a study from two California Lakes and are defined as concentrations of target analytes in fish or shellfish tissue that are of potential public health concern (Brodberg and Pollack, 1999). Exceedance of screening values is considered an indication that more intensive site-specific monitoring and/or an evaluation of human health risk should be conducted. The calculations were based on a 70 kg adult, using a cancer risk of 10^{-5} for carcinogens. A consumption rate of 21 grams of fish per day was used. Although these screening values are applied to human consumption of contaminated fish/shellfish, exceedance of the screening value may also indicate the potential for health risks in wildlife that consume contaminated fish/shellfish. The screening values are used for comparison purposes only and do not suggest a possible public health concern. The transplanted bivalves in the RMP are temporary residents of the Estuary and are used as indicators of bioavailable contaminants for status and trends analyses. No follow-up action is triggered when bivalve values exceed guidelines. A wet-to-dry weight conversion was applied to the guideline values for comparative purposes, using a multiplication factor of 7, which is based on average moisture content in bivalves of 85% (SFEI, 1998).

4.3 Results and Discussion

Bivalve monitoring is conducted in the Estuary to measure contaminant accumulation during the dry season as a measure of the potential bioavailability of contaminants of concern. The combination of recent Special Studies to improve deployment methods and evaluate salinity tolerances of deployed species has helped the RMP refine the bivalve monitoring component of the Status and Trends program. The RMP will continue to use the study results to adjust future bivalve monitoring effort. As noted above there are no organics data from 2004 due to analytical issues. PAH data from 2005 is also not available.

4.3.1 Spatial Distributions

Trace Organics

In 2005, only one transplanted bivalve sample from Redwood Creek exceeded the PCB screening value. This is in contrast to the 2003 results where mussels from Coyote Creek, Dumbarton Bridge, Redwood Creek, Alameda, and Yerba Buena Island stations, exceeded the total PCB concentration screening value (Table 4.2 and Figure 4.2). Note that transplanted bivalves are deployed in the Estuary for a 90-100 day period (except stations BG20 and BG30) and therefore are indicators of bioavailable contaminant accumulation over this time period.

High contaminant concentrations indicate the potential for contaminant exposure in the Estuary for resident organisms. Also note that the bivalves collected from the San Joaquin and Sacramento River sites integrate contaminants over a longer time-scale than do the transplanted bivalves. *Corbicula* can live up to seven years (Hall, 1984) but a more average life span is 3-4 years (Sites *et al*., 1995; McMahon, 1991). Ages of the *Corbicula* collected for this study are not known.

Accumulation factors (AF) ranged from 1.0 to 54 for all species and all analytes. The highest AF, indicating accumulation, was for total PCBs at the Redwood Creek station. The highest calculated AFs were for total PCBs at Dumbarton Bridge, Redwood Creek, and Alameda stations. PCBs (total) ranged from 3.0 - 161 ppb with the highest concentrations found at Redwood Creek. Trace organic analytes detected in resident clams from the San Joaquin and Sacramento River stations included: Dieldrin, DDTs, and PBDEs. PBDEs (total) ranged from ND (not detected) to 46 ppb with the highest PBDE concentrations found in resident *Corbicula* from the Sacramento River station (Table 4.2 and Figure 4.4). Total PBDE concentrations were lower in 2005 than in other years at the river sites. Concentrations at the Sacramento River site from 2001-2005 (no data for 2004) were 72, 85, 96, and 46 ppb dry weight, respectively. At the San Joaquin site, PBDE concentrations over the same time period were 63, 106, 104, and 38 ppb dry weight, respectively. Sample sizes are too small to determine if concentrations were statistically lower in 2005 sampling.

Chlordanes (total) were only found in bivalves transplanted at the Redwood Creek, Coyote Creek, Dumbarton Bridge and Red Rock sites. All other bivalves were below the detection limit for chlordanes. There were no exceedances of the chlordane screening value. DDTs (total) ranged from 17-64 ppb with the highest concentrations found at the Sacramento site (Table 4.2 and Figure 4.3). None of the samples exceeded the DDT screening value (SV) of 700 ppb. Dieldrin concentrations ranged from DNQ (detected but not quantifiable) to 7.9 ppb. All stations were below the SV of 14 ppb. There is evidence of DDT and chlordane declines in some sport fish species sampled from San Francisco Bay (Davis *et al*., 2006 at http://www.sfei.org/rmp/reports/fish_contamination/2003_Report/No432_RMPFishReport_complete.pdf). Recent concentrations measured in some sport fish were statistically lower than previously measured concentrations of DDT and chlordanes. This is an indication that concentrations of some of the legacy pesticides may be declining in the Bay. Endrin, gamma-HCH, heptachlor epoxide and hexachlorobenzene were not detected at any site.

Growth and Survival

The mean survival in unmaintained cages was slightly, although not statistically significant, higher than survival in maintained cages. In addition, growth was lower in the maintained than in the unmaintained cages (not statistically significant). Both of these results suggest no difference in survival and growth between maintained and unmaintained cages. Based on the findings, the RMP will discontinue the mid-deployment maintenance cruise in 2006. Survival for both maintained and unmaintained cages were lower in 2005 than other years.

4.3.2 Bivalve Trends

Temporal trends are important in determining if contaminant concentrations are decreasing to levels below concern. There is evidence of decline in PCBs in transplanted bivalves. Two distinct general patterns are evident in the PCB data (Davis *et al*., in prep). For the northern Estuary locations (Pinole Point, Richmond Bridge/Red Rock, and Fort Baker/Horseshoe Bay), concentrations have declined from approximately 4,000 ng/g lipid in 1982 to 1,000 ng/g lipid in

2003. For the southern Estuary locations (Treasure Island/Yerba Buena Island, Hunter's Point/Alameda, Redwood Creek, and Dumbarton Bridge), concentrations have declined from approximately 6,000 ng/g lipid in 1982 to 2000 ng/g lipid in 2003. PCBs at Pinole Point, Red Rock, Horseshoe Bay, Yerba Buena Island, Alameda, Redwood Creek, and Dumbarton Bridge have shown statistically significant declines over the period of record.

Statistical projections for southern Estuary locations indicate that a twenty-fold reduction in concentration (to 100 ng/g lipid) will take approximately another 40 years at Yerba Buena Island and Alameda, 80 years at Redwood Creek, and 70 years at Dumbarton Bridge. For the northern Estuary locations where present concentrations are lower, it will take approximately 45 years at Pinole Point, 40 years at Richmond Bridge/Red Rock, and 25 years at Fort Baker/ Horseshoe Bay to reach 100 ng/g lipid. These are uncertain estimates, based on extrapolation of noisy datasets far into the future. Nevertheless, this is perhaps the best trend information presently available for PCBs in the Bay.

The National Oceanic and Atmospheric Administration (NOAA), as part of their Mussel Watch Program, has also generated a valuable time series of contaminant concentrations in resident mussels (*Mytilus edulis*) from three Bay locations (O'Connor and Lauenstein, 2006). At the Emeryville location, the data suggest declines in PCBs (at the 90% confidence level) and mercury (at the 95% confidence level) over the 14 year period. The Dumbarton Bridge site had declines in dieldrin (at the 95% confidence level) and mercury (at the 90% confidence level). At the San Mateo Bridge site, declines were seen in dieldrin and PCBs (at the 95% confidence level) and mercury (at the 90% confidence level). Future monitoring will provide more evidence on the state of contaminants in the Bay and will help determine, with higher confidence, rates of decline and the time period for concentrations to fall below levels of concern.

4.4 References

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Table 4.1. California Screening Values calculated according to U.S. Environmental Protection Agency guidance (U.S. EPA, 1995). Calculations were based on a 70 kg adult and a fish consumption value of 21 g/day. Guidelines were specifically developed for a California lake fish study and should be used as reference values in bivalve tissue concentrations only (Brodberg and Pollack, 1999). No follow-up actions are associated with bivalve tissue concentrations above these screening values. Screening values have been converted to dry weight using a conversion factor of 7, which is based on an 85% average moisture content in bivalves.

PARAMETER	*Screening Value* (dry weight)	Unit
Cd	21	ppm
Se*	14	ppm
Dieldrin	14	ppb
Endrin	7,000	ppb
gamma-HCH	210	ppb
Heptachlor Epoxide	28	ppb
Hexachlorobenzene	140	ppb
Total Chlordanes (SFEI)	210	ppb
Total DDTs (SFEI)	700	ppb
Total PCBs (SFEI)	140	ppb

* The RMP uses the selenium screening value recommended by the California Office of Environmental Health Hazard Assessment from Fan *et al*., 1988. All other analyte screening values are from the California lake fish study (Brodberg and Pollack, 1999). The Se SV for the lake study is 140 ppm dry weight.

Table 4.2. 2005 bivalve accummulation factors (AF) and final contaminant concentrations (ng/g dry weight) that were above the method detection limit (MDL) and had screening values. Endrin, gamma-HCH, Heptachlor Epoxide, and Hexachlorobenzene were not detected (ND) at any site. If either the final concentration or the T-0 reference concentrations was ND, no AF was calculated and the result is reported as NA. Results are in ng/g dry weight. Growth mean (g) is determined by subtracting the average T-0 dry weight from each individual bivalve at each station and then taking the mean of the differences.
ND=not detected, NA=not available, DNQ=analyte was detected but not quantifiable therefore value is an estimate.
2004 Pesticides, PCBs, and PBDEs are not available.

									Dieldrin		Sum Chlordanes		Sum DDTs		Sum PCBs		Sum PBDEs	
SITE CODE	SITE NAME	DATE	CRUISE NUMBER	MATRIX	% Survival	% Lipids	% Moisture	Growth Mean	AF	Result	AF	Result	AF	Result	AF	Result	AF	Result
BA10	Coyote Creek	9/27/2005	2005-09	MCAL	56	5.11	89.6	-0.09	1.2	5.5	NA	2.1	1.2	24	32	96	NA	8
BA30	Dumbarton Bridge	9/27/2005	2005-09	MCAL	79	6.89	86.4	0.25	1.2	5.3	NA	5.6	1.3	25	43	129	NA	13
BA40	Redwood Creek	9/27/2005	2005-09	MCAL	73	7.3	87.3	0.27	1.6	7.0	NA	6.3	1.3	25	54	161	NA	26
BB71	Alameda	9/28/2005	2005-09	MCAL	57	6.91	86.8	0.23	1.1	5.1	NA	ND	1.3	25	43	130	NA	17
BC10	Yerba Buena Island	9/28/2005	2005-09	MCAL	52	6.64	85.6	0.73	1.3	5.9	NA	ND	1.3	25	32	95	NA	22
BC61	Red Rock	9/28/2005	2005-09	MCAL	48	7.76	85.9	0.49	1.5	6.7	NA	2.6	1.3	25	22	66	NA	13
BD20	San Pablo Bay	9/29/2005	2005-09		64	4.17	92.7	-0.17	1.7	7.9	NA	ND	1.3	25	12	35	NA	4
BD30	Pinole Point	9/29/2005	2005-09	MCAL	69	4.54	92	-0.13	1.7	7.6	NA	ND	0.9	17	13	38	NA	4
BD40	Davis Point	9/29/2005	2005-09	MCAL	32	4.68	91.7	-0.26	1.4	6.5	NA	ND	1.2	25	12	36	NA	10
BG20	Sacramento River	9/30/2005	2005-09	CFLU	NA	6.49	94.4	NA	NA	DNQ 4.13	NA	ND	NA	64	NA	85	NA	46
BG30	San Joaquin River	9/30/2005	2005-09	CFLU	NA	5.8	92.6	NA	NA	DNQ 3.16	NA	ND	NA	20	NA	60	NA	38
T-0	Bodega Head	6/22/2005	2005-09	MCAL	NA	5.41	87.2	NA	NA	4.5	NA	ND	NA	20	NA	3	NA	ND

[1] T-0 samples were collected from the reference/source sites and archived for later growth & chemical analysis

Table 4.3. 2004 & 2005 bivalve percent surival by site and species for maintained caged deployment methods and unmaintained caged methods.

Species include: transplanted mussels *Mytilus californianus* (MCAL) and resident clams *Corbicula fluminea* (CFLU).

SITE_CODE	SITE_NAME	SPECIES	COLLECTION_YEAR	Survival per Species Caged Maintained (%)	Survival per Species Caged Unmaintained (%)
Coyote Creek	BA10	MCAL	2004	77	85
Dumbarton Bridge	BA30	MCAL	2004	46	46
Redwood Creek	BA40	MCAL	2004	97	100
Alameda	BB71	MCAL	2004	98	100
Yerba Buena Island	BC10	MCAL	2004	77	70
Red Rock	BC61	MCAL	2004	91	100
San Pablo Bay	BD20	MCAL	2004	99	98
Pinole Point	BD30	MCAL	2004	99	98
Davis Point	BD40	MCAL	2004	NA	94
Sacramento River	BG20	CFLU	2004	NA	NA
San Joaquin River	BG30	CFLU	2004	NA	NA
Coyote Creek	BA10	MCAL	2005	56	50
Dumbarton Bridge	BA30	MCAL	2005	79	68
Redwood Creek	BA40	MCAL	2005	73	78
Alameda	BB71	MCAL	2005	57	62
Yerba Buena Island	BC10	MCAL	2005	52	46
Red Rock	BC61	MCAL	2005	48	50
San Pablo Bay	BD20	MCAL	2005	64	58
Pinole Point	BD30	MCAL	2005	69	72
Davis Point	BD40	MCAL	2005	32	38
Sacramento River	BG20	CFLU	2005	NA	NA
San Joaquin River	BG30	CFLU	2005	NA	NA

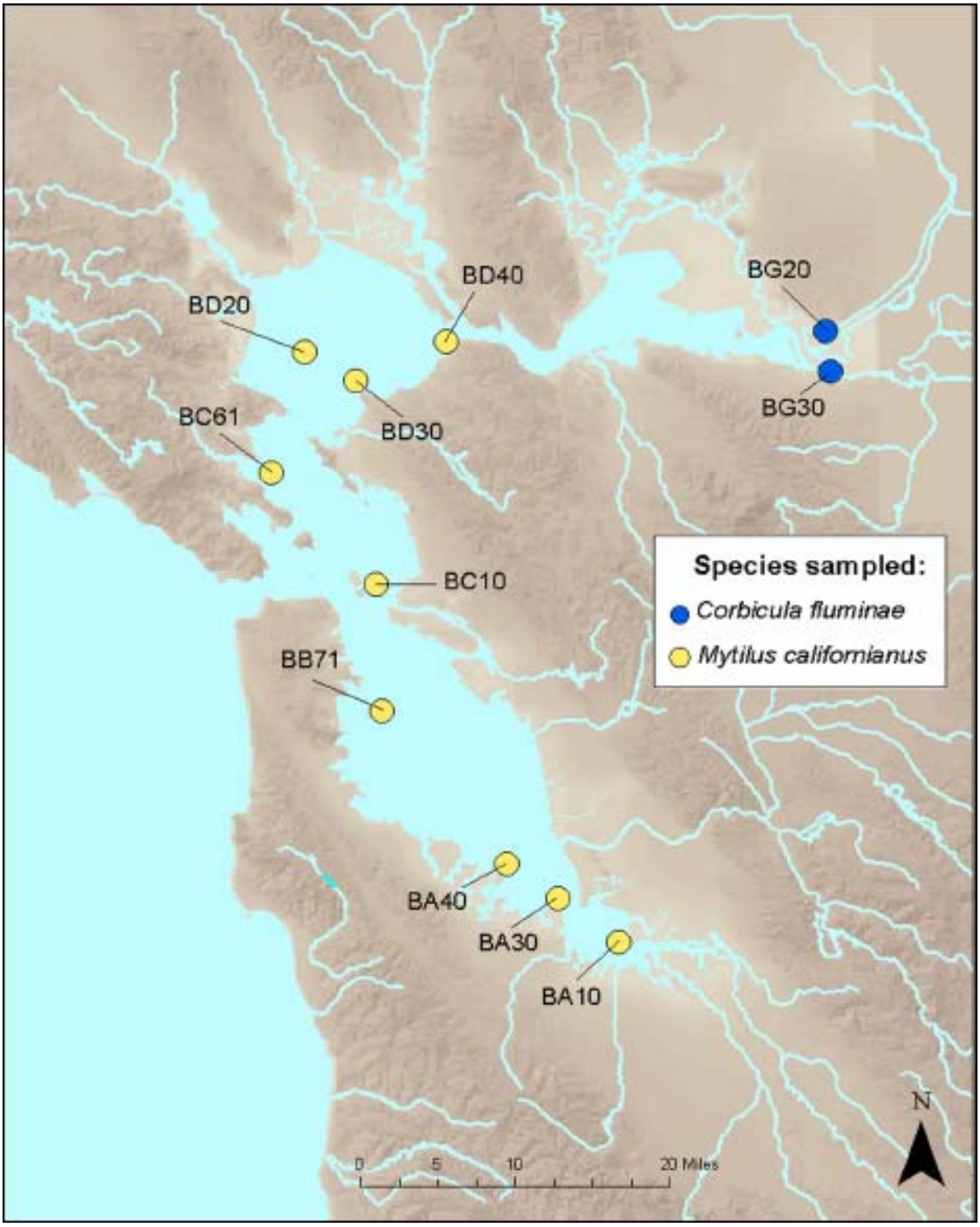


Figure 4.1 Map of 2004-2005 RMP Status and Trends bivalve monitoring sites at 11 locations in the San Francisco Estuary. *Mytilus* species were deployed in cages for a three-month period at mooring locations within the Estuary, while resident *Corbicula* species were collected using a trawl at the end of the deployment period.

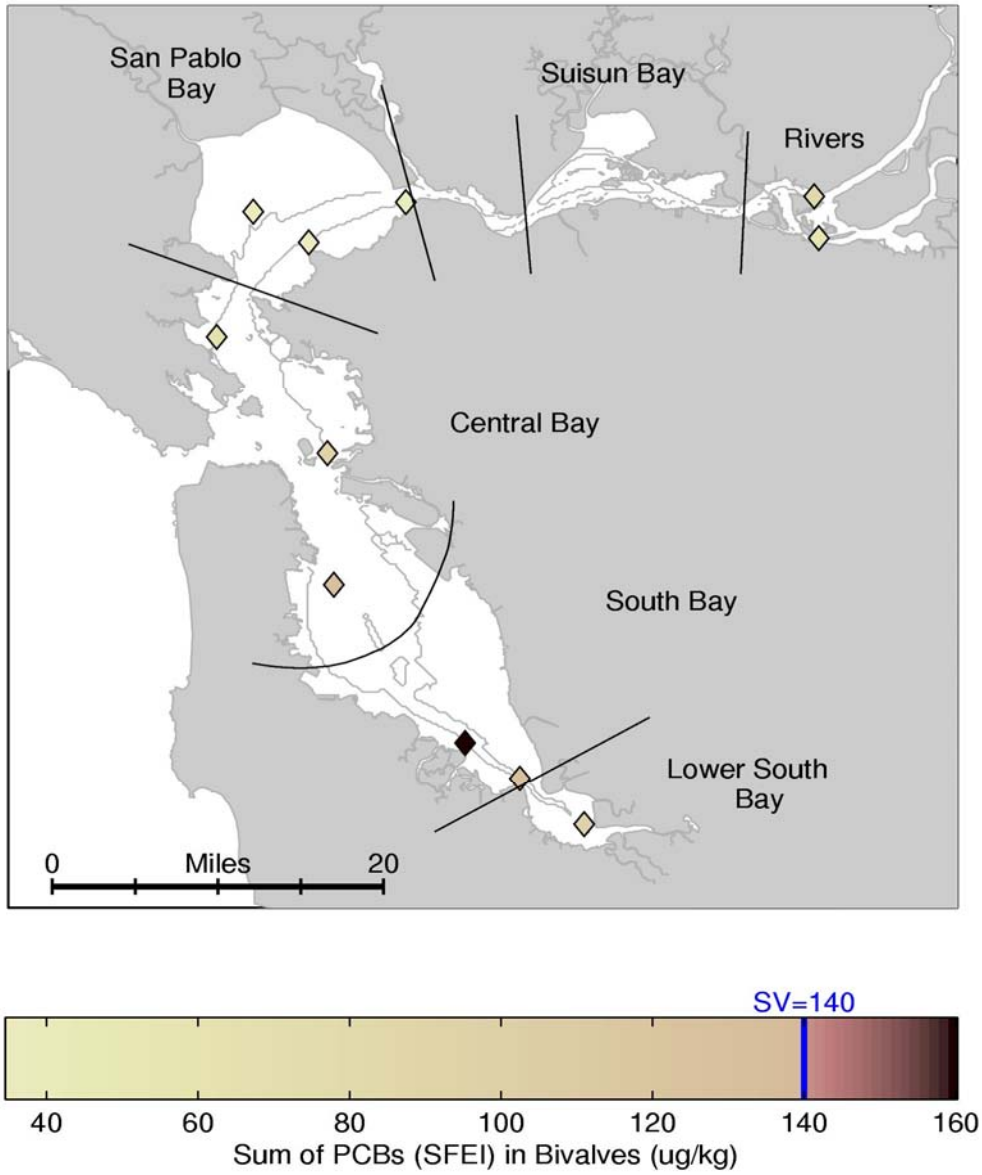


Figure 4.2 Bivalve tissue concentrations for Total PCBs at 11 sites sampled in the San Francisco Estuary in 2005. Black triangles denote concentrations above the screening value (140 ng/g).

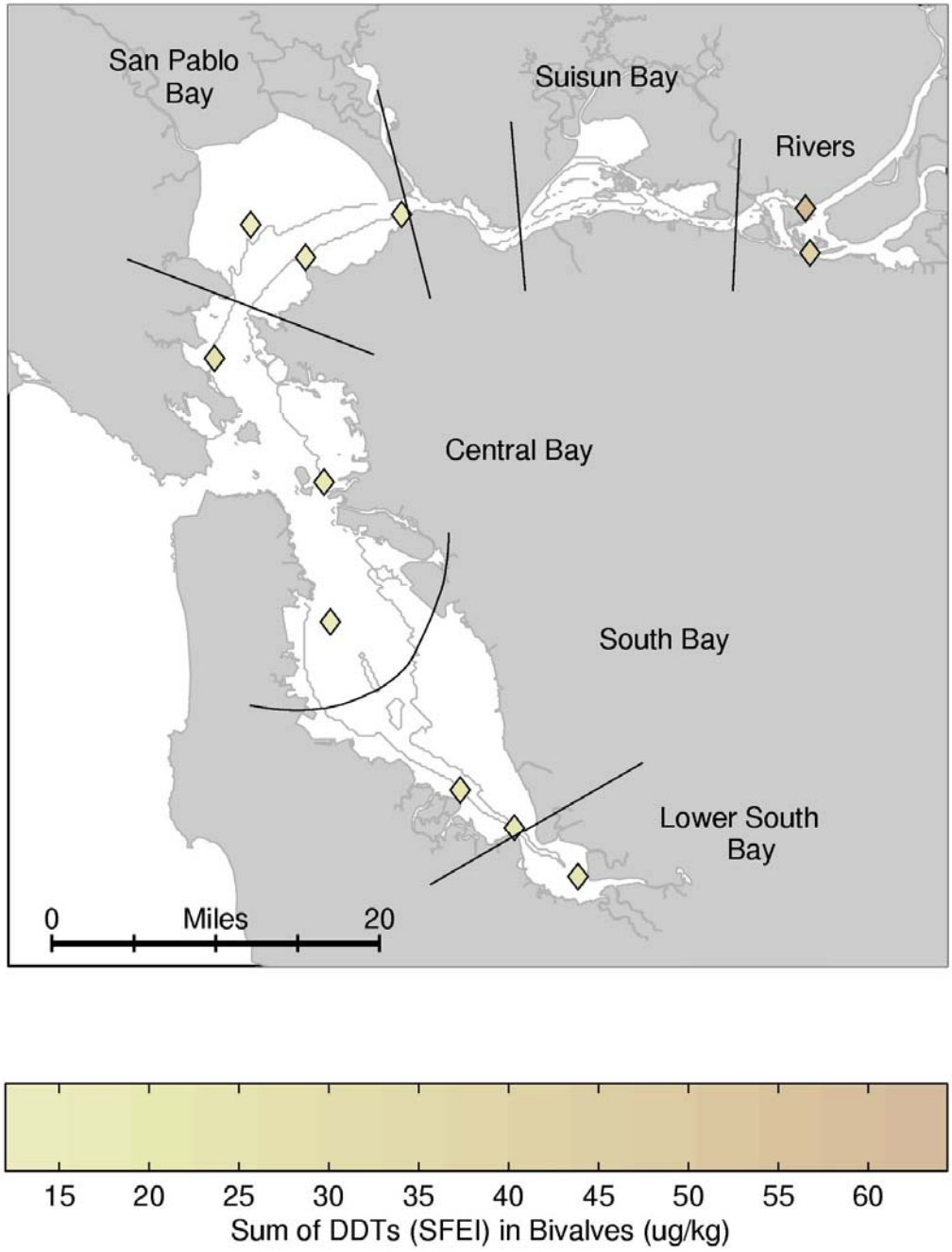


Figure 4.3 Bivalve tissue concentrations for Total DDTs at 11 sites sampled in the San Francisco Estuary in 2005. All concentrations were below the screening value (700 ng/g).

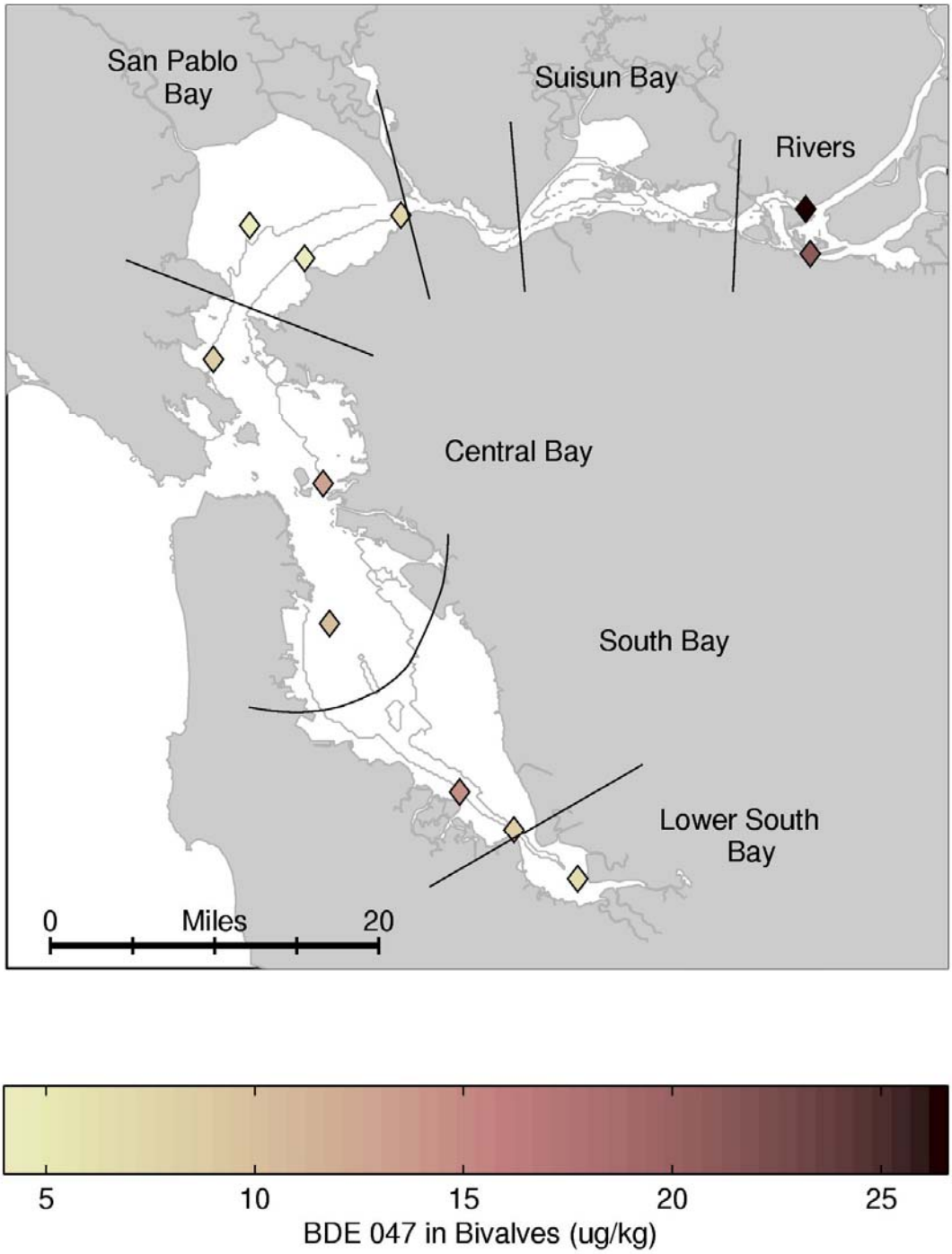


Figure 4.4 Bivalve tissue concentrations for BDE-47 at 11 sites sampled in the San Francisco Estuary in 2005. There is no screening value for PBDEs. Note that the graphic denotes only concentrations of one PBDE congener and not the sum of PBDE congeners.

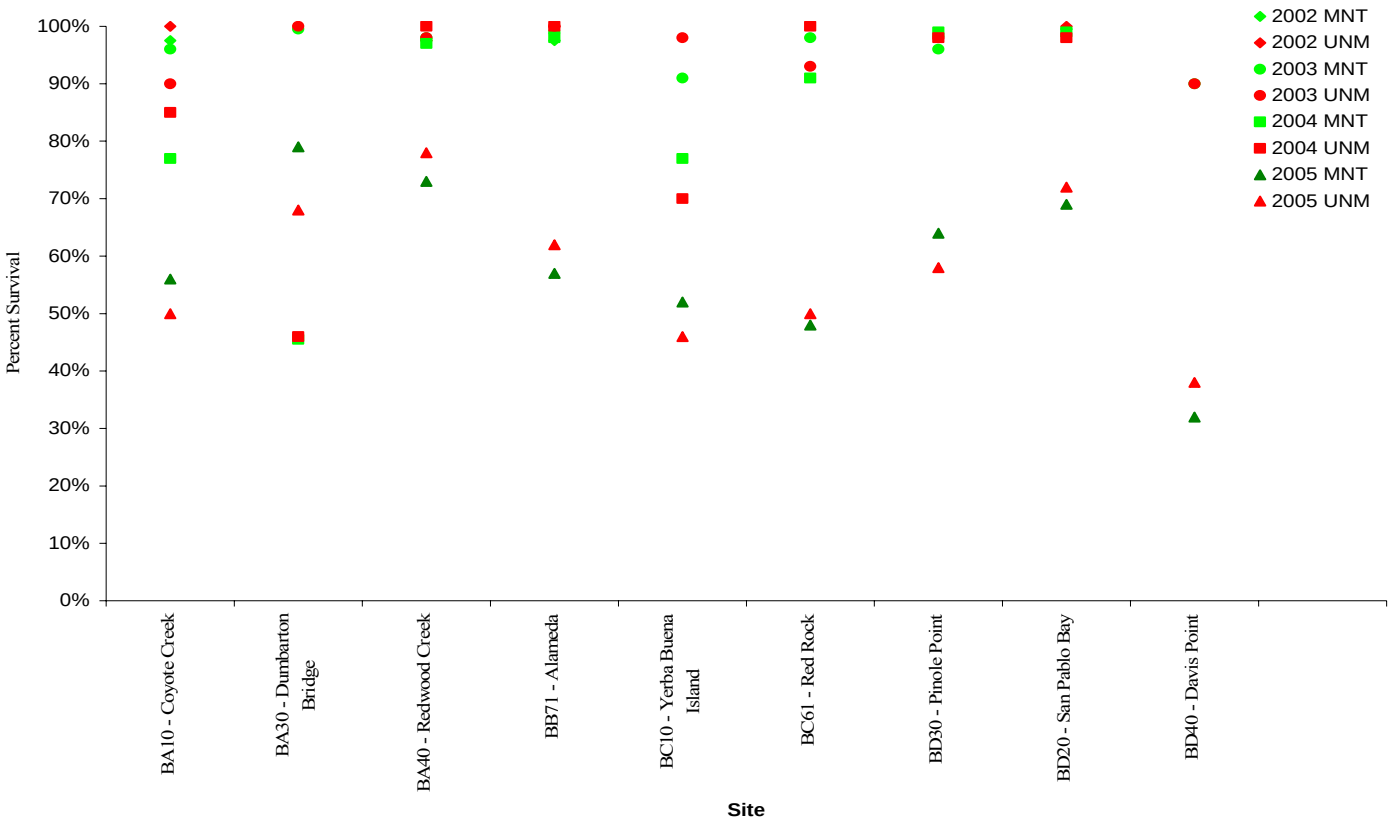
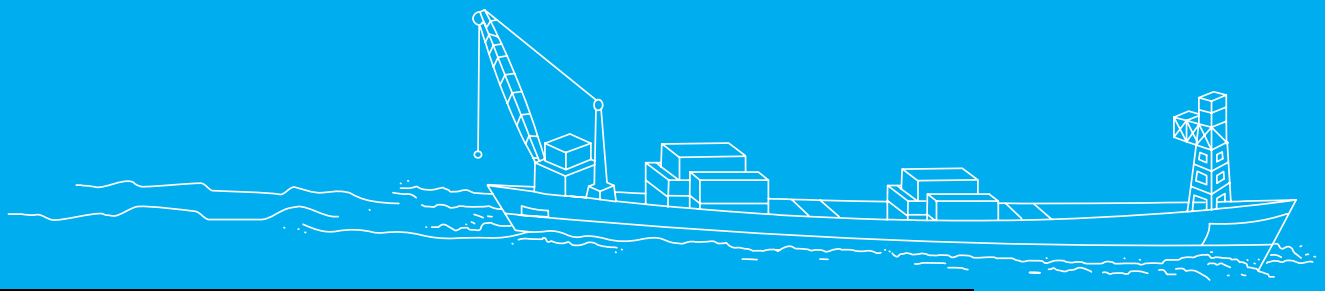


Figure 4.5 Bivalve survival at 11 sites sampled in the San Francisco Estuary in 2004-2005. MNT designates bivalve cages that were cleaned during deployment; UNM designates bivalve cages that were not cleaned during deployment.

Chapter 5



Description of Methods

5.0 DESCRIPTION OF METHODS

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

The purpose of this chapter is to provide brief descriptions of the sample collection and analytical methods used in the Status and Trends Monitoring component of the Regional Monitoring Program for Water Quality in the San Francisco Estuary (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 Meg Sedlak at meg@sfei.org.

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. Please Contact Don Yee (donald@sfei.org) for more information.

5.1 Field Sampling Methods

Logistical planning and field sampling for the RMP was implemented by Applied Marine Sciences Inc. who have systematically improved the field sampling logistics and sampling methods each year since the inception of the program in 1993.

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

Background

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. 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 acid by volume 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 2003, 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, and the Technical Review Committee will determine a new sampling frequency at the end of 2006.

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/Deionized (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 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 mmHg 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 mmHg concentrations. These factors include light, temperature and atmosphere. As there is usually only one mmHg 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 (30 mL) 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 alive 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 alive (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 Bivavles

Bioaccumulation was evaluated by collecting mussels (*Mytilus californianus*) from uncontaminated "background" sites of known chemistry and deploying these bivalves at 12 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 15 ppt (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 conducted by certified SCUBA divers.

Maintenance of Transplanted Bivalves

The deployed samples were checked approximately 50 days after deployment to ensure consistent exposure. Moorings and enclosures were checked for damage and repaired if necessary, and fouling organisms were removed. The comparison between maintained cages and unmaintained cages continued in 2004 and 2005 to evaluate whether results regarding survival rates were significantly different and to determine whether the maintenance work could be discontinued. The TRC reviewed the results of survival rates and recommended that the maintenance cruise be eliminated starting in 2006.

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 contaminants.

5.2 Laboratory Methods

For a list of analytes measured in 2004 and 2005 please refer to the Table 1.5 in the *Introduction*. SFEI maintains SOPs for all laboratory analyses. Please contact the RMP QA/QC manager Dr. Donald Yee (donald@sfei.org) for more details.

5.2.1 Water and Sediment Quality

No significant changes were made to the analytical methods in 2004 and 2005 for water or sediment quality.

Water Quality Parameters

In 2004 and 2005 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). 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^{TM} pH probe directly into the sediment sample to approximately 3 cm 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 oxidation reduction potential (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 1 cm and 6 cm 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 2004 and 2005.
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 2004 and 2005 RMP Monitoring Results, SFEI maintains these data in a database. Data are available upon request. Please contact the data manager Cristina Grosso (cristina@sfei.org).

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 2004 and 2005 as the RMP Redesign Workgroup decided to reduce analyses to every five years.

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 2004 and 2005. 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 same methods as in the past were employed. Samples were analyzed by Hydride Generation Atomic Absorption (HGAA, Brooks Rand SOP BR-0020, a modified EPA Method 1632). Samples were digested with nitric acid and hydrochloric acid and heating following U.S. EPA Method 200.2. The Brooks Rand method uses sample aliquots digested using an 80:20 HNO_3:$HClO_4$ acid mixture with heating. 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 2004 and 2005, 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 2004 and 2005, 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. No 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. Aresenic samples were analyzed by Stabilized Temperature Platform Graphite Furnace Atomic Spectrometry (STP-GFAA) (equivalent to EPA Method 200.9). 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 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 2005 trace metals in tissue were not analyzed. The next trace metal monitoring will be conducted 2006. 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 2004 and 2005, 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 glass fiber 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 quantification standards, with filters extracted by sonication in solvent, and XAD-2 Soxhlet extracted. 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. 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.

Analytical methods for diazinon and chlorpyrifos were not available from CDFG at the time of publication.

Analysis of Sediment Samples

In 2004 and 2005, 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 2002 and 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 and 2005 organics.

Sediment Extraction (all organic analytes): Samples were homogenized, then extracted using a Dionex Accelerated Solvent Extraction, ASE (U.S. EPA Method 3545). The sample extracts were then 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 2004 and 2005 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, 3rd Edition 1994, Chapter 3, Multi-residue Methods, Section 303-C1.

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 reported in the Annual Results. These samples will be considered for re-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 2004 and 2005 sediment toxicity was conducted 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 alive 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 alive 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. The 2004 and 2005 survival results include survival of both maintained and un-maintained bivalve cages.

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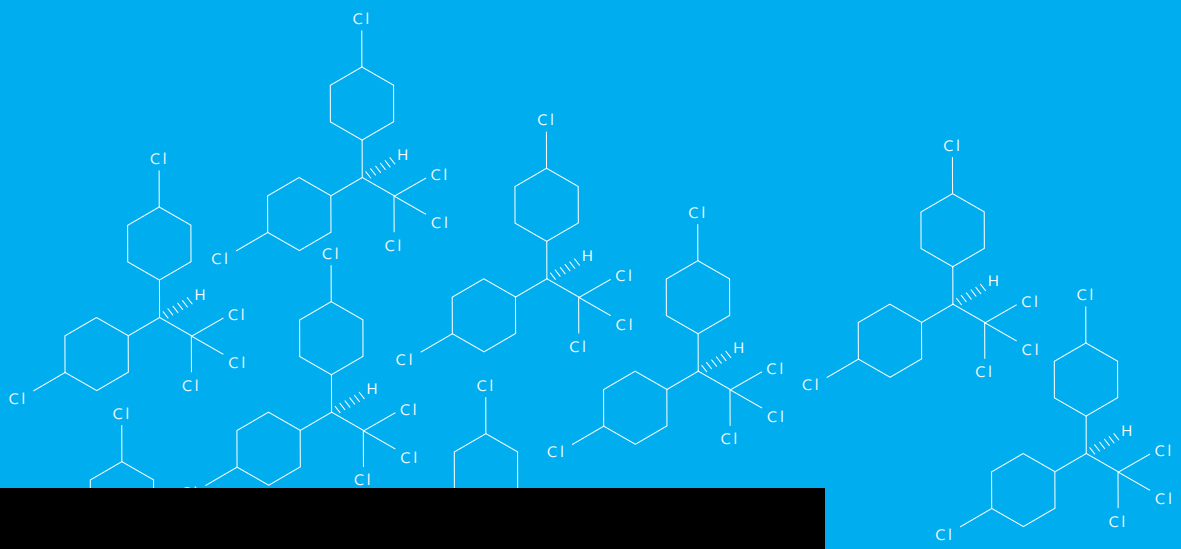
Chapter 6



DDTs in San Francisco Bay Sediments

6.0 DDTs in San Francisco Bay Sediments

John R.M. Ross and Daniel R. Oros

The aim of this work was to determine if DDT and its metabolites have decreased in San Francisco Bay sediments. DDT is a broad spectrum insecticide that was used from 1939 to 1972 on agricultural crops for pest control, and for mosquito abatement. The percent composition of the Technical DDT mixture is the following: p,p'-DDT (77%), o,p'-DDT (15%), and p,p'-DDE (4%). In the environment, under aerobic conditions DDT is converted to DDE, while under anaerobic conditions DDT is converted to DDD. DDTs are neurotoxins and classified by the US EPA as probable human carcinogens. They are persistent in the environment, lipophilic, and subject to biomagnification in aquatic food webs. The approach included using statistical evaluation to determine temporal trends in DDTs at 26 sediment sampling stations, the majority of which have been routinely monitored by the Regional Monitoring Program for Water Quality (RMP) since 1993.

6.1 Methods

Censored data are measurements whose values are known only to fall either above or below a certain threshold. Censored data are a key part of the social, economic, medical, and industrial sciences and methods developed in these fields allow the incorporation of censored data into statistical analyses. These methods, however, have rarely been used in environmental studies where censored data, "non-detects", are commonly encountered as values below a detection limit. Substitution or assignment of an arbitrary value such as one-half the detection limit is a widely used approach but it has no theoretical basis, and the values substituted do not bear any relation to the true value in the sample. Instead, they depend on the conditions, which determined the detection limit, such as lab precision or sample matrix interference. Substitution fails even more miserably when there are multiple detection limits, in these situations, either maximum likelihood estimation (MLE), or nonparametric methods will outperform substitution methods (Helsel, 2005).

MLE uses information about the numerical values above detection limits, the proportion of data below each detection limit, and the mathematical formula for an assumed distribution in order to perform computations. The most important assumption for MLE is how well the data fit the assumed distribution. For environmental data a lognormal distribution is usually assumed. MLE methods are the method of choice for large data sets of at least 50 observations, and where either the percent censoring is small or the distribution can be assumed from knowledge outside the data set (Helsel 2005). For small datasets there is often insufficient information to determine whether the assumed distribution is correct, or to reliably estimate statistical parameters. Indeed, MLE has been shown to perform poorly for data sets with less than 25 to 50 observations (Gleit, 1985; Shumway *et al*., 2002), therefore, when the data size is small or the proportion of censored data is high nonparametric or distribution-free methods are preferred.

A method commonly used to improve the comparison of contaminant concentrations in sediments is to normalize them to a sediment component unaffected by anthropogenic activities (Luoma, 1990; Hanson, 1993; Daskalakis and O'Connor, 1995). Site-specific relationships between the individual sediment DDT concentrations and total organic carbon (TOC) were

evaluated using Kendall's tau-b correlation coefficients, which are most applicable to the correlation of censored data with multiple method detection limits (Helsel, 2005); a significant positive correlation ($p<0.05$) indicating a relationship where normalization is appropriate (Hebert & Keenleyside, 1995). This analysis reveals little convincing evidence that normalization of the sediment DDT concentrations to TOC is appropriate (Table 6.1).

Temporal trends were estimated for 6 DDTs (o,p-DDD, o,p-DDE, o,p-DDT, p,p-DDD, p,p-DDE, and p,p-DDT) at 19 stations between 1993-2002, and at 7 stations between 1993-2005 (2003 DDT data not available). First order kinetic processes are natural log (ln) - linear with respect to time (Sericano *et al*., 1996). Therefore, temporal trends at each station for individual DDT's with no censored values were evaluated by ordinary least squares (OLS) linear regression analysis using the natural log of the DDT concentration as the dependent variable, and sampling date as the independent variable. The presence of first-order autocorrelation was examined using the Durbin-Watson test, but no conclusive evidence of first-order autocorrelation was found in the data. Normality of the residuals was evaluated using the Anderson-Darling test, and when sufficient evidence was observed to reject the null hypothesis of normality, a robust regression analysis was conducted using an *M*-estimation robust regression technique called iteratively reweighted least squares (Chatterjee and Machler, 1997). This procedure handles potential outlier and heteroskedasticity problems by down weighting influential residuals.

Due to the small sample sizes, less than 20 observations, and the generally high proportion of censoring, two nonparametric or distribution-free statistical methods were used to investigate temporal trends in the censored data. The Theil-Sen nonparametric regression, and an extension of this to censored data called the Akritas-Theil-Sen (ATS) method. The Theil-Sen line and slope estimator is commonly used in the trend analysis of environmental data (Helsel and Hirsch, 2002). The Theil-Sen slope is computed as the median of all possible slopes between observations, and is significantly different from zero when the Kendall's tau correlation coefficient is significantly different from zero. Because the Theil-Sen line is a "linear median" it is not strongly influenced by outliers. The Akritas-Sen-Theil method is an extension of the Theil-Sen slope to censored data that calculates the slope that, when subtracted from the dependent variable, would produce an approximately zero value for Kendall's tau correlation coefficient (Akritas *et al*., 1995). The Akritas-Theil-Sen slope has been shown to have a substantial advantage in bias and precision over the most commonly used nonparametric regression method for censored data, Buckley-James regression (Wilcox, 1998).

The Theil-Sen and Akritas-Sen-Theil methods were conducted using the rescaled natural log of the DDT concentration as the dependent variable, and sampling date as the independent variable. Adding a constant, in this case 10, rescaled the natural log of the

DDT concentrations in order to ensure all values were positive. For both nonparametric regressions, a significant positive slope ($p<0.05$) was assumed to indicate an increase in the concentration of the contaminant at the station over time. Similarly, a significant negative slope assumes a decrease over time, while a lack of significance indicates no change in sediment concentration. Analyses were conducted using packages developed by Helsel (2005) for Minitab Release 14 statistical software.

6.2 Results and Discussion

p,p'-DDT

Concentrations of p,p'-DDT showed a highly significant decrease at 1 of the 26 sediment sampling stations, Sunnyvale (C-1-3; robust regression, $p = 0.0002$, $adj\text{-}r^2 = 0.964$, $n = 5$) (Table 6.2), however, this result should be interpreted with caution because of the small sample size.

The p,p'-DDT concentrations increased significantly at 1 of the 26 sediment sampling stations, Dumbarton Bridge (BA30; Theil-Sen and ATS, $p = 0.014$, $n = 14$)) (Figure 6.1).

No temporal trends were found at 24 of the 26 stations, which suggest there was no significant change in sediment concentrations over the sampling period.

p,p'-DDD

Concentrations of p,p'-DDD decreased significantly at 1 of the 26 sediment sampling stations; Horseshoe Bay (BC21; Theil-Sen and ATS, $p = 0.049$, $n = 16$).

Temporal trends were not found at 25 of the 26 stations, which suggest there was no significant change in sediment concentrations over the sampling period.

p,p'-DDE

Concentrations of p,p'-DDE showed a significant decrease at Standish Dam (BW10; linear regression, $p = 0.011$, $adj\text{-}r^2 = 0.519$, $n = 10$). Whereas, p,p'-DDE concentrations increased significantly at Pacheco Creek (BF10; Theil-Sen and ATS, $p = 0.038$, $n = 16$) (Figure 6.2).

No temporal trends were found at any of the other stations, suggesting there was no significant change in sediment concentrations over the sampling period.

o,p-DDT

No temporal trends were found at any of the 26 stations, which suggest there was no significant change in sediment concentrations over the sampling period.

o,p-DDD

Concentrations of o,p-DDD significantly decreased at 3 of the 26 sediment sampling stations, including Alameda (BB70; Theil-Sen and ATS, $p = 0.037$, $n = 14$), Standish Dam (BW10; Theil-Sen and ATS, $p = 0.005$, $n = 10$), and Guadalupe River (BW15; Theil-Sen and ATS, $p = 0.027$, $n = 8$).

Temporal trends were not found at 23 of the 26 stations, which suggest there was no significant change in sediment concentrations over the sampling period.

o,p-DDE

No temporal trends were found at any of the 26 stations, which suggest there was no significant change in sediment concentrations over the sampling period.

Discussion

The principal component in the DDT Technical mixture, p,p'-DDT, showed a significant increase at 1 out of 26 San Francisco Bay sediment stations. This result was largely unexpected since DDT was banned from all but public health emergency uses in 1972.

For DDT and its metabolites, very few increasing or decreasing temporal trends were found, which suggests there was no significant change in sediment concentrations for these chemicals over the sampling period.

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Table 6.1. Kendall's tau-b correlation coefficients for relationship between station sediment DDT concentrations and total organic carbon (TOC) content.

	Station Code	BA10	BA21	BA30	BA41	BB15	BB30	BB70	BC11	BC21	BC32	BC41	BC60	BD15
o,p'-DDD	tau-b	-0.040	0.240	0.027	-0.208	-0.185	0.315	0.190	0.007	0.465	-0.194	0.109	NA	-0.047
	p	0.915	0.488	1.000	0.450	0.665	0.321	0.510	1.000	**0.047**	0.443	0.674	NA	0.950
	n	15	16	16	19	14	16	14	19	16	16	15	10	14
o,p'-DDE	tau-b	NA	NA	NA	0.255	NA	-0.346	NA	-0.120	NA	NA	NA	NA	0.196
	p	NA	NA	NA	0.613	NA	0.507	NA	0.787	NA	NA	NA	NA	0.749
	n	15	16	16	19	14	16	13	19	16	16	16	10	14
o,p'-DDT	tau-b	0.195	-0.154	0.031	NA	NA	0.232	-0.023	0.000	0.099	NA	0.000	NA	NA
	p	0.547	0.827	1.000	NA	NA	0.543	1.000	1.000	0.784	NA	1.000	NA	NA
	n	14	14	15	17	14	15	14	18	15	15	15	10	14
p,p'-DDD	tau-b	0.437	0.057	-0.078	-0.006	0.080	0.361	0.147	-0.071	0.474	0.185	-0.043	0.523	0.467
	p	**0.029**	0.875	0.782	1.000	0.774	0.074	0.508	0.699	**0.019**	0.343	0.855	0.110	**0.036**
	n	15	16	16	19	14	16	14	19	16	16	16	10	14
p,p'-DDE	tau-b	0.425	0.374	-0.047	0.006	-0.214	0.108	0.203	-0.012	0.143	0.319	0.122	0.405	0.509
	p	**0.033**	0.135	0.890	1.000	0.389	0.614	0.348	0.972	0.492	0.095	0.554	0.142	**0.021**
	n	15	16	16	19	14	16	14	19	16	16	16	9	14
p,p'-DDT	tau-b	-0.100	-0.061	0.322	0.136	0.279	0.175	0.017	0.306	0.264	0.314	0.323	0.194	-0.093
	p	0.724	0.914	0.239	0.571	0.369	0.553	1.000	0.161	0.257	0.174	0.145	0.619	0.771
	n	12	14	14	16	12	14	12	16	14	14	14	8	12

	Station Code	BD22	BD31	BD41	BD50	BF10	BF21	BF40	BG20	BG30	BW10	BW15	C-1-3	C-3-0
o,p'-DDD	tau-b	0.431	0.277	NA	-0.283	-0.055	-0.041	-0.286	0.153	0.393	-0.493	0.620	-0.472	-0.259
	p	0.100	0.199	NA	0.383	0.920	0.882	0.461	0.673	0.282	0.090	0.106	0.259	0.538
	n	18	19	17	18	16	19	14	18	18	9	7	7	10
o,p'-DDE	tau-b	NA	0.133	NA	NA	NA	0.159	0.304	-0.138	0.045	NA	-0.356	0.085	-0.239
	p	NA	0.937	NA	NA	NA	0.726	0.572	0.937	1.000	NA	0.580	1.000	0.544
	n	18	19	17	18	16	19	14	18	18	9	7	7	10
o,p'-DDT	tau-b	0.364	-0.216	NA	NA	0.182	0.202	0.322	NA	NA	-0.426	0.724	0.089	0.209
	p	0.238	0.673	NA	NA	0.621	0.642	0.531	NA	NA	0.161	0.080	0.893	0.520
	n	17	18	16	17	15	18	14	17	16	9	7	7	9
p,p'-DDD	tau-b	0.080	0.018	0.266	0.351	0.106	0.396	0.663	0.247	0.212	-0.278	-0.195	0.357	-0.068
	p	0.675	0.944	0.207	0.074	0.642	**0.022**	**0.001**	0.196	0.397	0.348	0.649	0.266	0.857
	n	18	19	17	18	16	19	14	18	17	9	7	7	10
p,p'-DDE	tau-b	0.067	-0.059	0.266	0.426	0.203	0.322	0.420	0.376	0.117	-0.556	0.429	0.143	0.159
	p	0.732	0.753	0.190	**0.020**	0.298	0.062	**0.042**	**0.034**	0.582	**0.048**	0.230	0.711	0.589
	n	18	19	16	18	16	19	14	18	16	9	7	7	10
p,p'-DDT	tau-b	-0.129	-0.223	0.207	0.593	0.175	0.062	-0.176	-0.152	0.206	-0.429	0.200	0.000	0.036
	p	0.549	0.272	0.492	**0.010**	0.554	0.783	0.486	0.690	0.516	0.230	0.806	1.000	1.000
	n	16	16	15	16	14	16	12	15	14	7	5	4	8

Table 6.2. Temporal trend analysis results.

	Temporal Trend (total sampling stations = 26)		
Analyte	**Increasing Trend**	**Decreasing Trend**	**No Trend**
p,p'-DDT (77% in tech mix)	Dumbarton Bridge	Sunnyvale	24/26
p,p'-DDD		Horseshoe Bay	25/26
p,p'-DDE (4% in tech mix)	Pacheco Creek	Standish Dam	24/26
o,p-DDT (15% in tech mix)			26/26
o,p-DDD		Alameda Standish Dam Guadalupe River	23/26
o,p-DDE			26/26

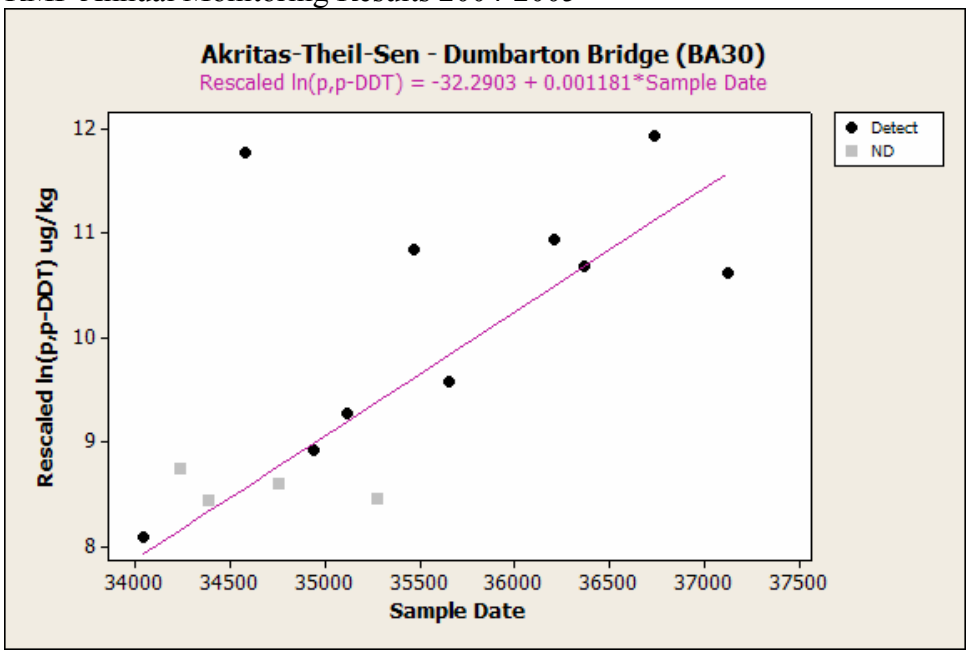

Figure 6.1. Akritas-Theil-Sen nonparametric regression analysis on censored p,p-DDT data from Dumbarton Bridge (BA30).

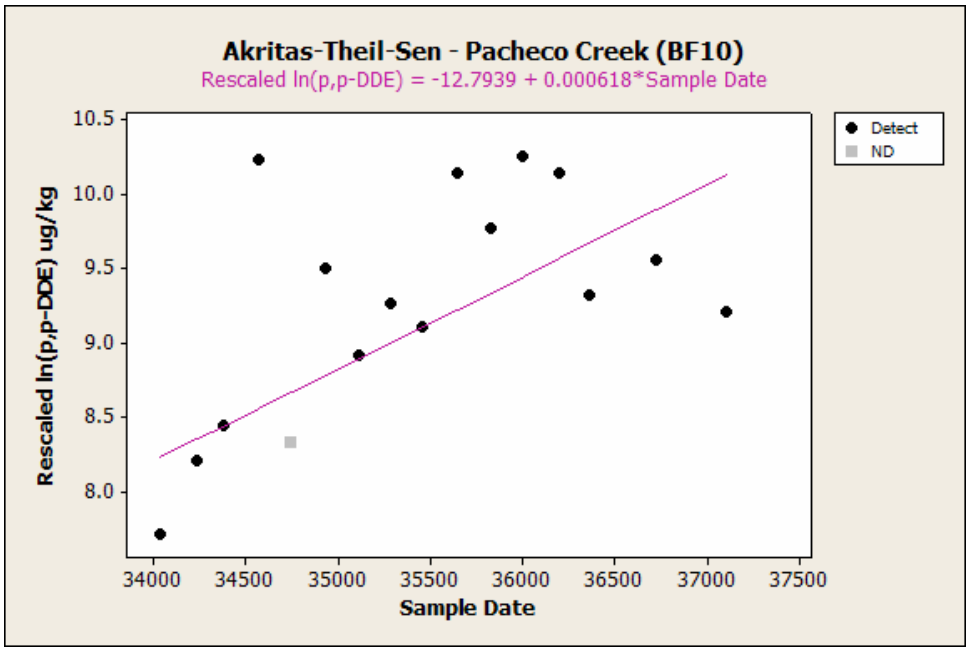

Figure 6.2. Akritas-Theil-Sen nonparametric regression analysis on censored p,p-DDE data from Pacheco Creek (BF10).

Chapter 7

Patterns of Temperature, Salinity, and Suspended Particulate Material in San Francisco Estuary: Water Year 2005 in the Context of Previous Water Years

Patterns of Temperature, Salinity, and Suspended Particulate Material in San Francisco Estuary: Water Year 2005 in the Context of Previous Water Years

A supplemental chapter to the RMP's Annual Monitoring Results

John J. Oram

San Francisco Estuary Institute
7770 Pardee Lane
Oakland, CA 94621
joram@sfei.org
(510) 746-7366

Introduction

San Francisco Estuary is the largest urbanized estuary on the west coast of the U.S. It is a shallow, productive estuary through which water draining approximately 40% of the land area of California enters the Pacific Ocean (McKee et al., 2002a). Geographically, and hydrodynamically, the Estuary can be divided into two reaches (Figure 1). The northern reach receives significant freshwater flows (~95% of total freshwater flows) from the Sacramento and San Joaquin river systems (the Delta) and consists of Suisun and San Pablo bays. The southern reach (commonly referred to as South Bay and composed of South and Lower South Bays) receives considerably less freshwater (<5% of total freshwater flows; McKee et al., 2002b) sourced from local watersheds. The two reaches join in the Central Bay near the Golden Gate, where they connect with the Pacific Ocean.

The millions of people in the cities surrounding San Francisco Estuary depend in one way or another on the water in the Estuary. Because the area immediately surrounding the Estuary is highly populated (6.8 million, U.S. Census Bureau, 2000) and urbanized, it is subject to chemical, and biological, contamination from a variety of sources and pathways. The overall water quality of the Estuary is a function of the relative rates at which human and natural processes add materials to or remove materials from the Estuary.

The Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP) has monitored the water quality of San Francisco Estuary since 1994. Since 2002, a stratified random sampling design for water and sediment has been used to annually estimate contaminant levels in each of the five Bay segments. However, very little has been done to report results of contaminant monitoring in the context of classical physical oceanographic and hydrologic parameters. Given that contaminant levels are a function of these parameters, it is difficult to view the results of a given year of contaminant monitoring relative to other years. Though RMP summer sampling is timed to minimize the effects of wet season flow events summarized here, several processes in the Estuary

are changing in ways we do not fully understand (Cloern *et al*, 2006). This chapter attempts to incorporate an analysis of oceanographic and hydrologic variables into the annual reporting of contaminant levels in an effort to characterize interannual variability of water circulation. Analyses of temperature, salinity, and suspended particulate material (SPM) are performed over the long-term (water years 1993-2005) and individually for water year 2005. Similar analyses will be performed in future years so that we may begin to view contaminant monitoring results in light of environmental change.

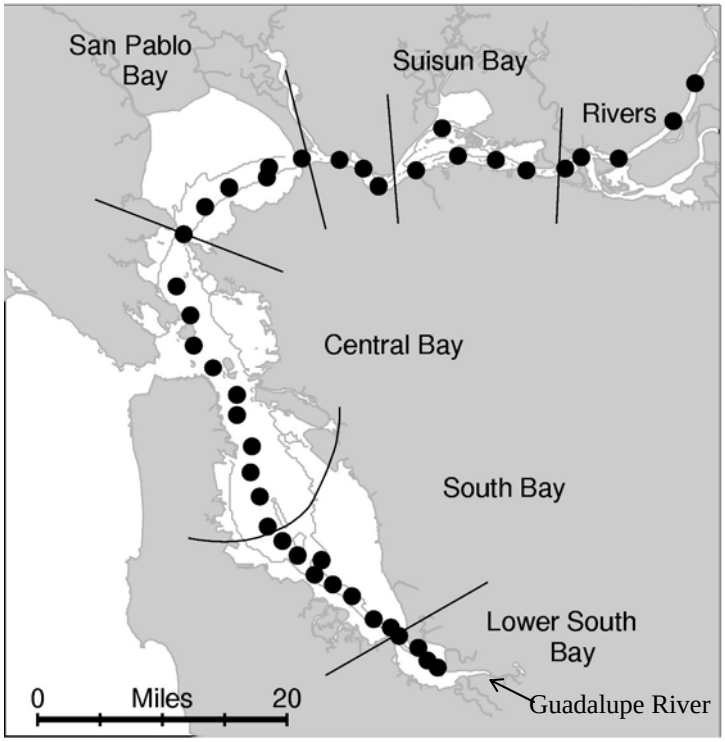

Figure 1: Map of San Francisco Estuary. The 5-meter depth contour is shown in light gray. The black dots indicate the locations of the USGS monthly sampling stations.

Temperature, Salinity, and Suspended Particulate Material

Estuary waters are a mixture of ocean, river, and waste waters The relative fractions of these mixtures in the Estuary are highly variable, changing rapidly in space and time in response to changes in precipitation, runoff, circulation and mixing (Conomos, 1979). In addition, the Estuary frequently receives substantial input from anthropogenic sources including municipal and industrial waste water, cooling waters, and urban runoff.

Long-Term Patterns

Fresh water flowing in through the Delta has a long-term mean salinity less than one part per thousand (ppt; Figure 2a), a long-term mean temperature of approximately 16 deg C (Figure 3a), and a long-term mean suspended particulate material (SPM) concentration of approximately 40 mg/L (Figure 4a). Salinity increases and temperature decreases downstream towards Central Bay, where the long-term mean salinity is approximately 30 ppt (Figure 2a) and the long-term mean temperature is approximately 14.5 deg C (Figure 3a). SPM initially increases downstream, reaching its long-term maximum in San Pablo Bay (approximately 65 mg/L), then decreases again towards Central Bay, where the long-term mean SPM is 10-20 mg/L (Figure 4a). Waters in the southern reach (South and Lower South Bays) are comparably saltier (22 ppt) and warmer (16.5 deg C) over the long-term than the northern reach (San Pablo and Suisun Bays). The waters exhibit SPM concentrations similar to northern waters.

Patterns of long-term variability in salinity, temperature, and SPM, expressed as coefficients of variation (COV), are illustrated in Figures 2b, 3b, and 4b respectively. Salinity is most variable in the northern reach of the Estuary where fluctuations in freshwater flow from the Delta dominate local salinity. Temperature is likewise highly variable in the northern reach. Variability of both salinity and temperature decrease downstream from the Delta towards Central Bay. SPM variability is largest at depth in the shallows of San Pablo Bay.

The long-term variability of salinity, temperature, and SPM is lowest in Central Bay. Because of tidal exchange, water properties of Central Bay are usually very near those of the coastal ocean. Conomos (1979) noted that water properties of the coastal ocean are relatively constant, with salinity varying by only 3 ppt over the long-term. Long-term salinity variations in Central Bay presented in Figure 2 exhibit the same magnitude of variability (Central Bay COV x Central Bay mean salinity $\approx$ 3 ppt).

The southern reach of the Estuary is more variable in temperature than Central Bay and less variable in both salinity and temperature than the northern reach. Variations in the salinity and temperature of southern waters are determined by exchange with the northern reach and the ocean, by direct wastewater inflow, and by solar heating, the relative contributions of which change seasonally (Conomos, 1979). Over the long-term, salinity variations in the southern reach are very similar to those in Central Bay (Figure 2b). Temperature variations are notably greater in the south than in Central Bay, owing to seasonal heating of the vast shallow margins in the southern reach. Deeper waters and ocean-Bay exchange limit the effects of solar heating on Central Bay waters. SPM variability in the southern reach is similar to that of San Pablo Bay; variability is greatest near the sediment bed in shallow regions where wind and tidal energy rework bedded sediments.

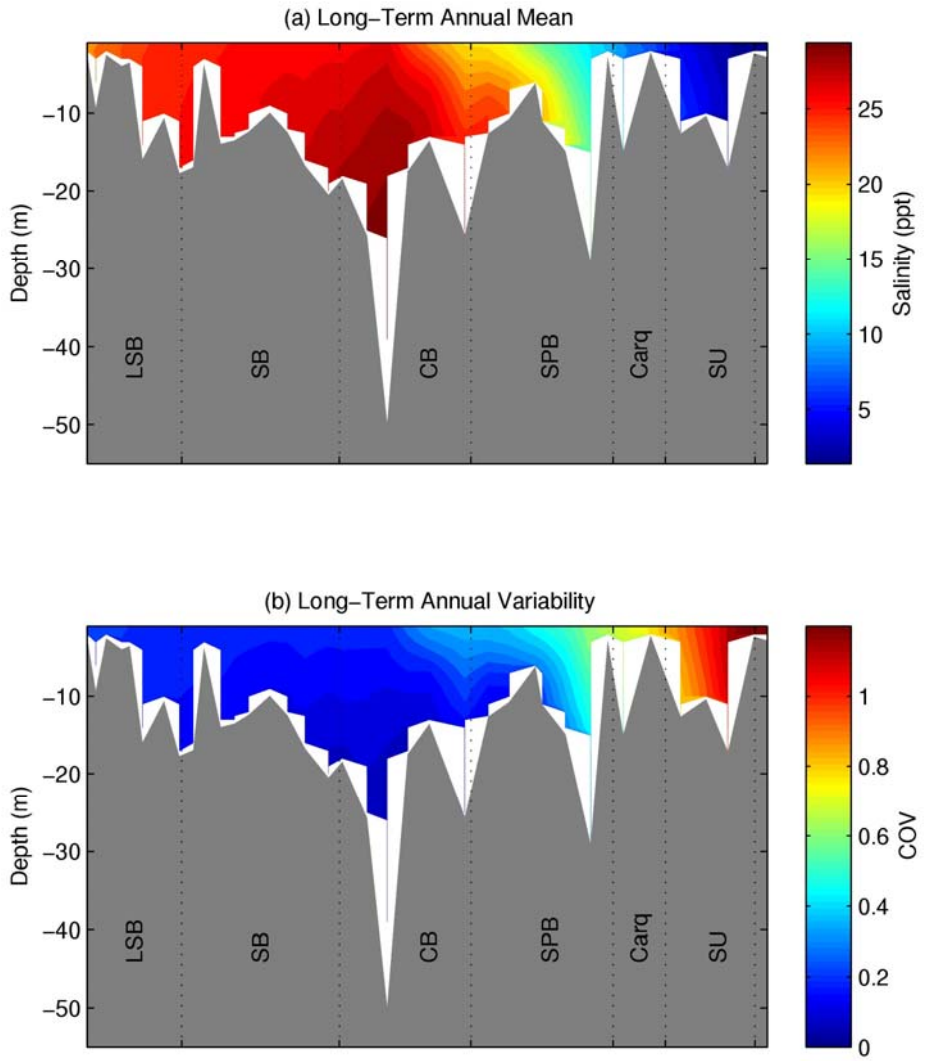

Figure 2: Long-term annual salinity (ppt) patterns in the San Francisco Estuary. Data are from USGS (2006a). Data from water years 1993-2005 were used to calculate long-term values.

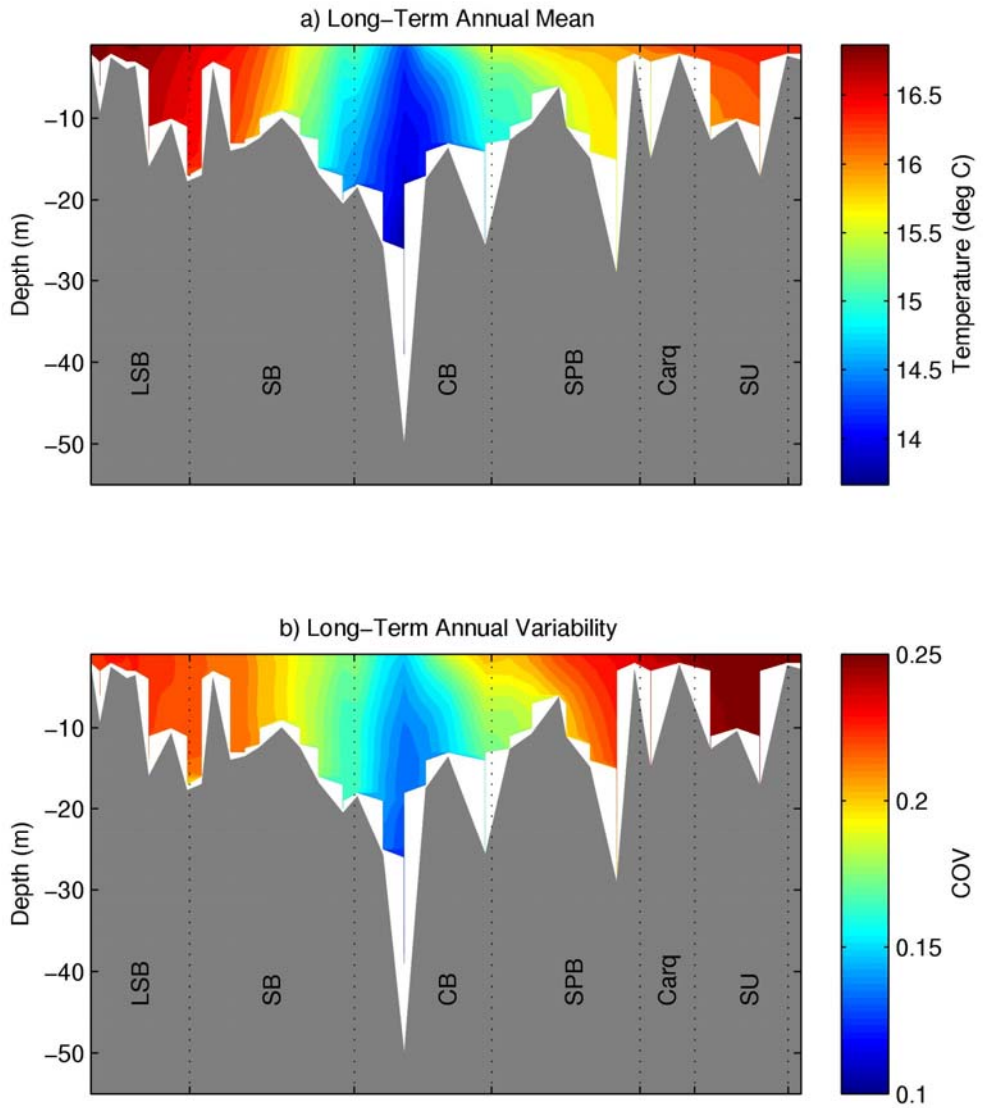

Figure 3: Long-term annual temperature (deg C) patterns in San Francisco Estuary. Data are from USGS (2006a). Data from water years 1993-2005 were used to calculate long-term values.

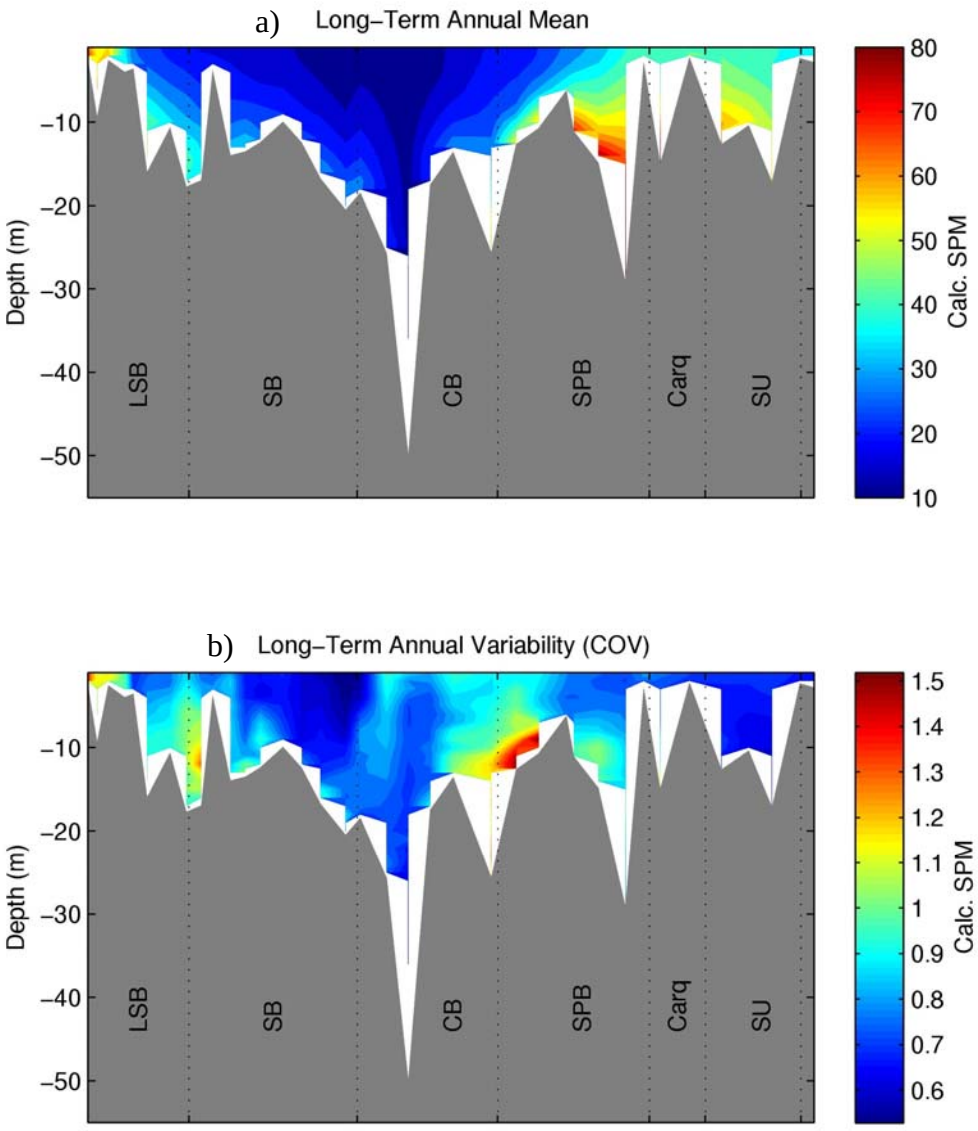

Figure 4: Long-term annual suspended particulate material concentration (calculated; mg/L) patterns in San Francisco Estuary. Data are from USGS (2006a). Data from water years 1993-2005 were used to calculate long-term values.

Water Year 2005

Salinity, temperature, and SPM anomalies for water year 2005 are plotted in Figures 5, 6, and 7 respectively. Anomalies represent the deviation of water year 2005 from the long-term annual means shown in Figures 2a - 4a. Water year 2005 was saltier and warmer than the long-term average in Central Bay, possibly a result of a strong upwelling season of the coast of Central California (Cloern et al, 2006). The northern reach was generally fresher and colder than the long-term average, except for the Carquinez Straits, which appear to have been saltier. Lower South and South Bays both exhibited a relatively cold year. However, Lower South Bay was fresher while South Bay was saltier. SPM anomalies for water year 2005 indicate that the Lower South and South Bays were slightly more turbid than the long-term average. The shallow regions of San Pablo and Central bay were considerably more turbid at depth.

Since the water properties of the Estuary are a function of freshwater inputs, the anomalies presented in Figures 5 and 6 should be examined the context of freshwater flows for water year 2005. Inputs from the Delta (Delta Outflow) and the Guadalupe River (in Lower South Bay) are shown in Figures 8 and 9 respectively. Water year 2005 flows (black lines) are overlaid on cumulative distributions of water years 1993-2005. By plotting the data in this way, one can make a quick assessment regarding the relative magnitude of a given flow. For example, a Delta Outflow greater than 2000 m3/s was observed in late May (Figure 8). This flow was greater than 99% of flows during late May for water years 1993-2005.

Water year 2005 was average in terms of total Delta Outflow. Daily flows fall with the 50th percentile of historic flows for most of the year (Figure 8). However, anomalously high flows (>98th percentile) occurred in late October 2004 and late May 2005. These flows, combined with large base flows from June - August (~80th percentile) resulted in the relatively fresh and cool conditions seen in the northern reach of the Estuary in Figures 5 and 6. In general, these average flows did not mobilize much sediment. As a result, mean SPM concentrations were slightly below the long-term average in the northern region of the Estuary (Figure 7). The high SPM concentrations near the Estuary floor (approximately 5-10 m depth) in San Pablo Bay are an exception. This region of the Estuary experiences high wind and tidal energy over vast shallow regions. Local sediment resuspension is therefore a likely cause of the elevated SPM concentrations observed in San Pablo Bay in water year 2005.

Freshwater flows from the Guadalupe River during water year 2005 were characterized by a number of large events during the October – May wet season followed by a period of high base flows during the May – September dry season. In fact, these base flows were the largest on record for most of the dry season. As a result, the waters in Lower South Bay were, on average, fresher and cooler in water year 2005 than the long-term mean (Figure 5 and 6). Mean SPM concentrations in the southern Estuary for water year 2005 were generally higher than the long term average (Figure 7). Sediment loads from Guadalupe River were reported by McKee et al. (2006) for water years 2003-2005. The load for water year 2005 (4,918 tonnes) was significantly less than the loads for water

years 2003 (10,805 tonnes) and 2004 (8,578 tonnes). The relatively elevated SPM concentration observed in the southern Estuary, therefore, must be due to either resuspension of bedded sediments or advection of particulate material from other regions of the Estuary.

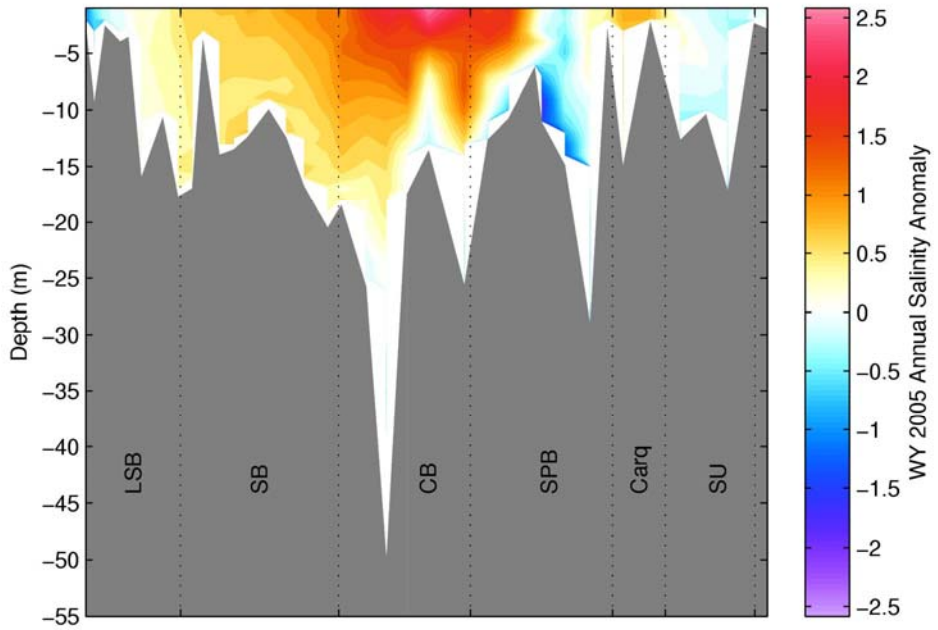

Figure 5: Water year 2005 salinity anomaly (ppt). Data are from USGS (2006a). Anomalies were computed by subtracting the long-term mean values (Figure 2a) from water year 2005.

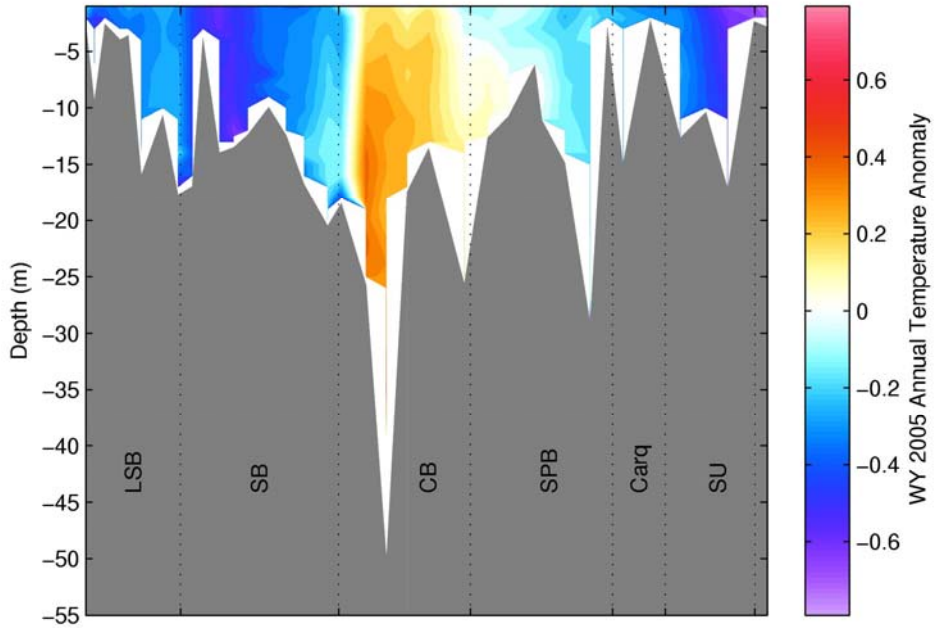

Figure 6: Water year 2005 temperature anomaly (deg C). Data are from USGS (2006a). Anomalies were computed by subtracting the long-term mean values (Figure 3a) from water year 2005.

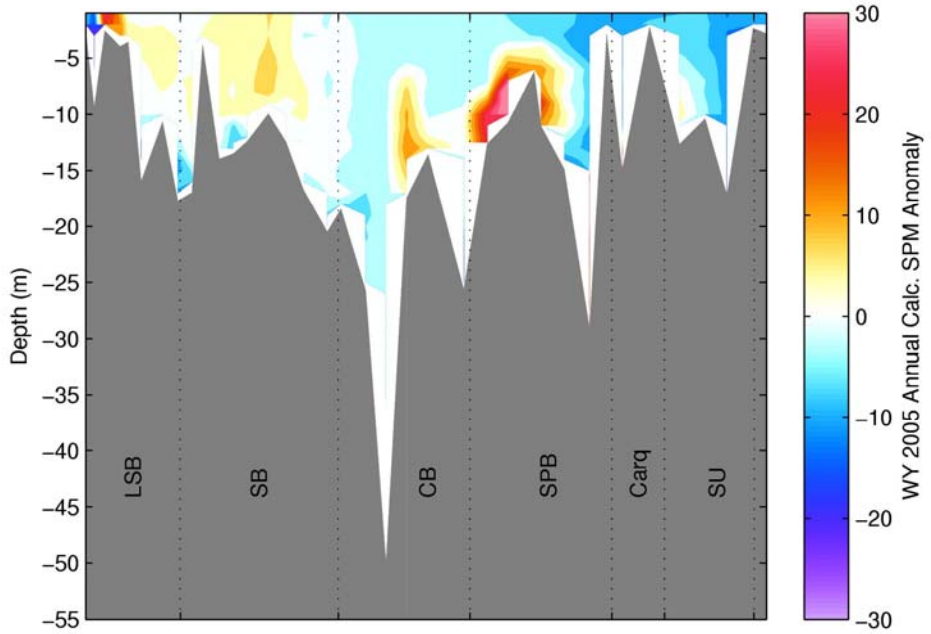

Figure 7: Water year 2005 suspended particulate material anomaly (mg/L). Data are from USGS (2006a). Anomalies were computed by subtracting the long-term mean values (Figure 4a) from water year 2005.

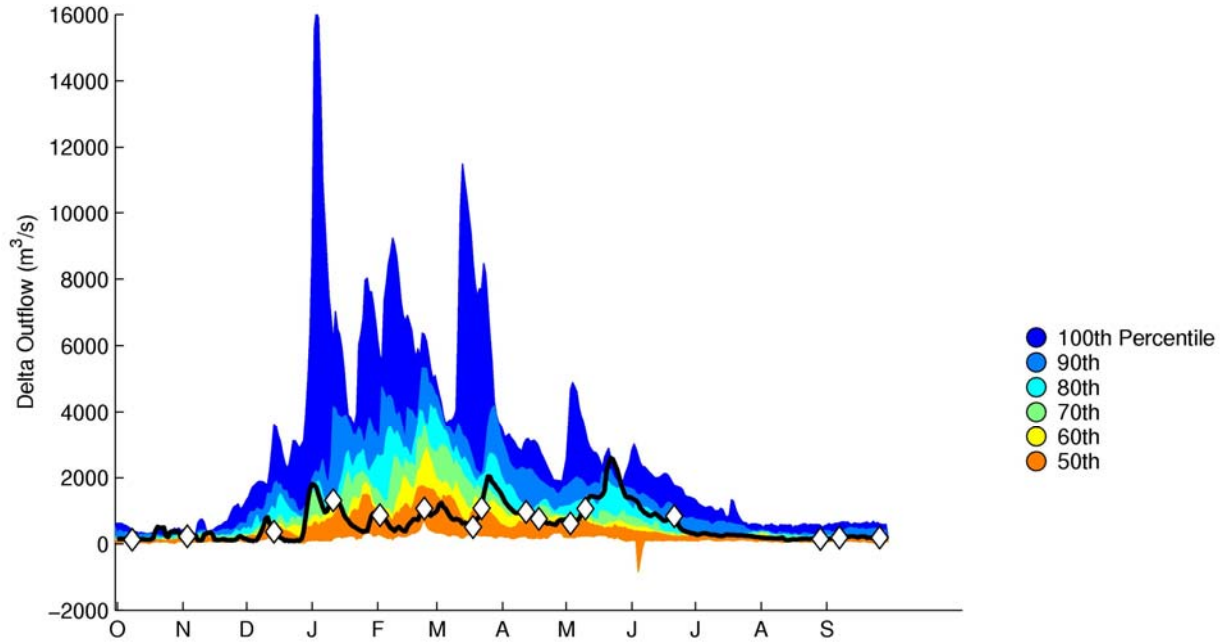

Figure 8: Delta Outflow (m3/s) for water year 2005 (black line) compared to historical data (water years 1993 – 2005). Delta Outflow data are from IEP (2006). The white diamonds indicate USGS water year 2005 Estuary sampling dates.

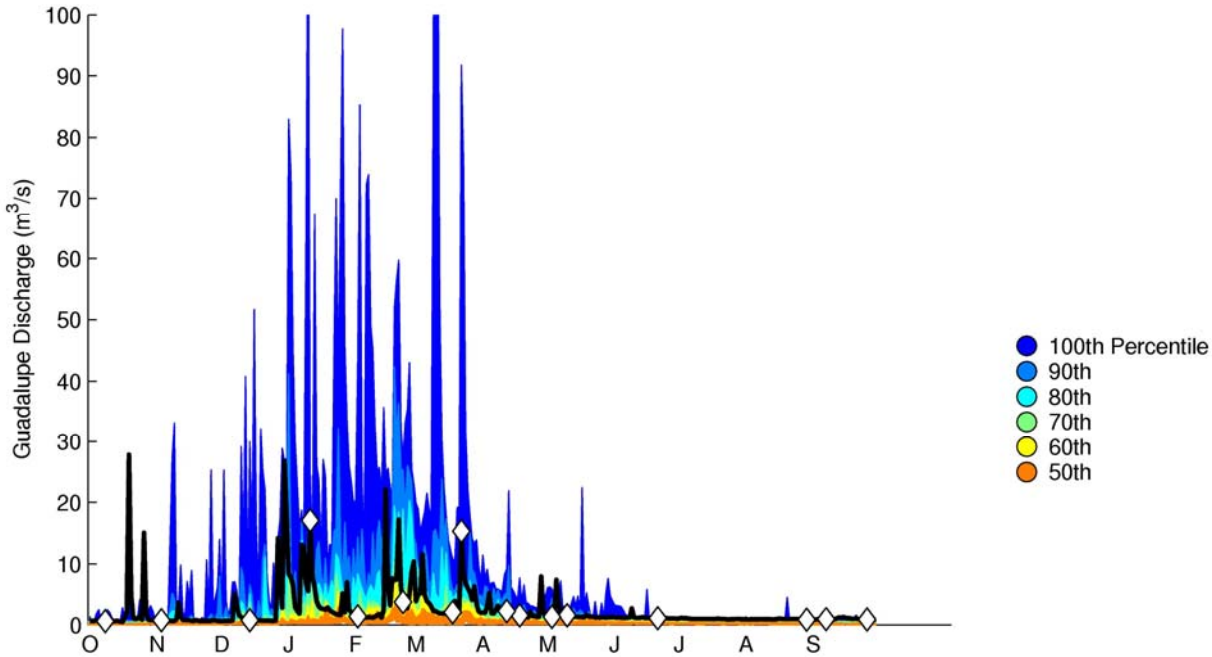

Figure 9: Guadalupe River discharge (m3/s) for water year 2005 (black line) compared to historical data (water years 1993-2005). Guadalupe discharge data are from CDEC (2006). The white diamonds indicate USGS water year 2005 Estuary sampling dates.

Effects of Delta Outflow on the Temperature-Salinity Field of the Southern Estuary

The significant role freshwater flows from the Delta have in determining the salinity field throughout San Francisco Estuary is well documented (e.g., Peterson and Carlson, 1968; McCulloch et al 1970; McCulloch, 1972; Imberger et al., 1977, Conomos, 1979). In general (from Imberger et al, 1977 as summarized by Conomos, 1979):

1) Typical winter Delta Outflows affect the salinity of the southern Estuary within a few days after the start of the winter flow.
2) Flows as low as 1,100 m^3/s significantly affect the salinity structure throughout the southern Estuary.
3) Changes in the salinity field of the southern Estuary are more dependent on the magnitude of the peak Delta Outflow and the history of previous flood events than on the total outflow volume during a given period.
4) The recovery of the salinity field of the southern Estuary is accomplished by tidal and wind mixing at a rate of 2ppt per month.

Figure 10 attempts to identify these processes by examining surface temperature – salinity patterns in relation to Delta Outflow and Guadalupe River discharge. From left to right in Figure 10 are Delta Outflow, Guadalupe River discharge, and temperature-salinity diagrams of surface (depth <= 5 meters) samples taken during water year 2005. Temperature – salinity diagrams are commonly used by physical oceanographers to

identify different water masses. Water masses tend to separate into clusters in T-S space. Points that fall on the line connecting the individual end members indicate mixing of water masses. For example, the samples taken in November 2004 are plotted as a temperature-salinity diagram in Figure 11. Three distinct three distinct waters (end members) can be identified: 1) Carquinez Straits, 2) Central Bay, and 3) Lower South Bay. The Carquinez and Central Bay end members are connected by San Pablo Bay waters, indicating that San Pablo Bay waters represent a mixture of Carquinez and Central Bay waters. Similarly, South Bay waters represent a mixture of Central Bay and Lower South Bay waters.

The first large Delta Outflow occurred in mid-December 2004 (arrow 1 in Figure 10, peak flow < 1,000 m3/s) and resulted in significantly reduced surface temperatures throughout the Estuary. The salinity field of the northern Estuary did not change noticeably. The southern Estuary, however, did exhibit a measurable drop in salinity (~3-4ppt). Guadalupe discharge was nominal during this period, pointing to Delta Outflow as the driver of the reduced salinity in the southern Estuary.

The second large Delta Outflow event occurred in mid-January (arrow 2, peak flow ~1,800 m3/s) and coincided with the large discharge from the Guadalupe River. Combined, these freshwater inflows produced a significant decrease in temperature and salinity throughout the entire Estuary. Additionally, the Lower South Bay end member observed in Figure 11 is no longer evident in the January-March temperature-salinity diagram of Figure 10. There are two possible explanations for this occurrence: 1) the salinity Lower South Bay end-member is decreased due to large freshwater inputs from local sources (highly probable considering the large Guadalupe discharge during this period), or 2) north-south exchange has replaced southern waters with northern waters. It is difficult to determine which scenario is dominant from these data alone. A salt budget of the southern Estuary is currently being developed to aid this investigation.

The salinity field did not change noticeably over the next few events (arrows 3 and 4), though surface temperatures did increase measurably, likely due to increased solar heating as the year progresses into Spring. The period from late-March through early-April saw significant flows from both the Delta and the Guadalupe River. Salinity samples taken in mid-April were the lowest of the water year (arrow 5). Surface temperature continued to increase from the winter minimum. The salinity field of each segment then recovered slowly back to summer conditions of high salinities. South Bay (medium blue points) salinity increased from an average of ~22ppt in May to an average of ~28ppt in late-August, consistent with the recovery rate of 2ppt per month estimated by Imberger et al. (1977).

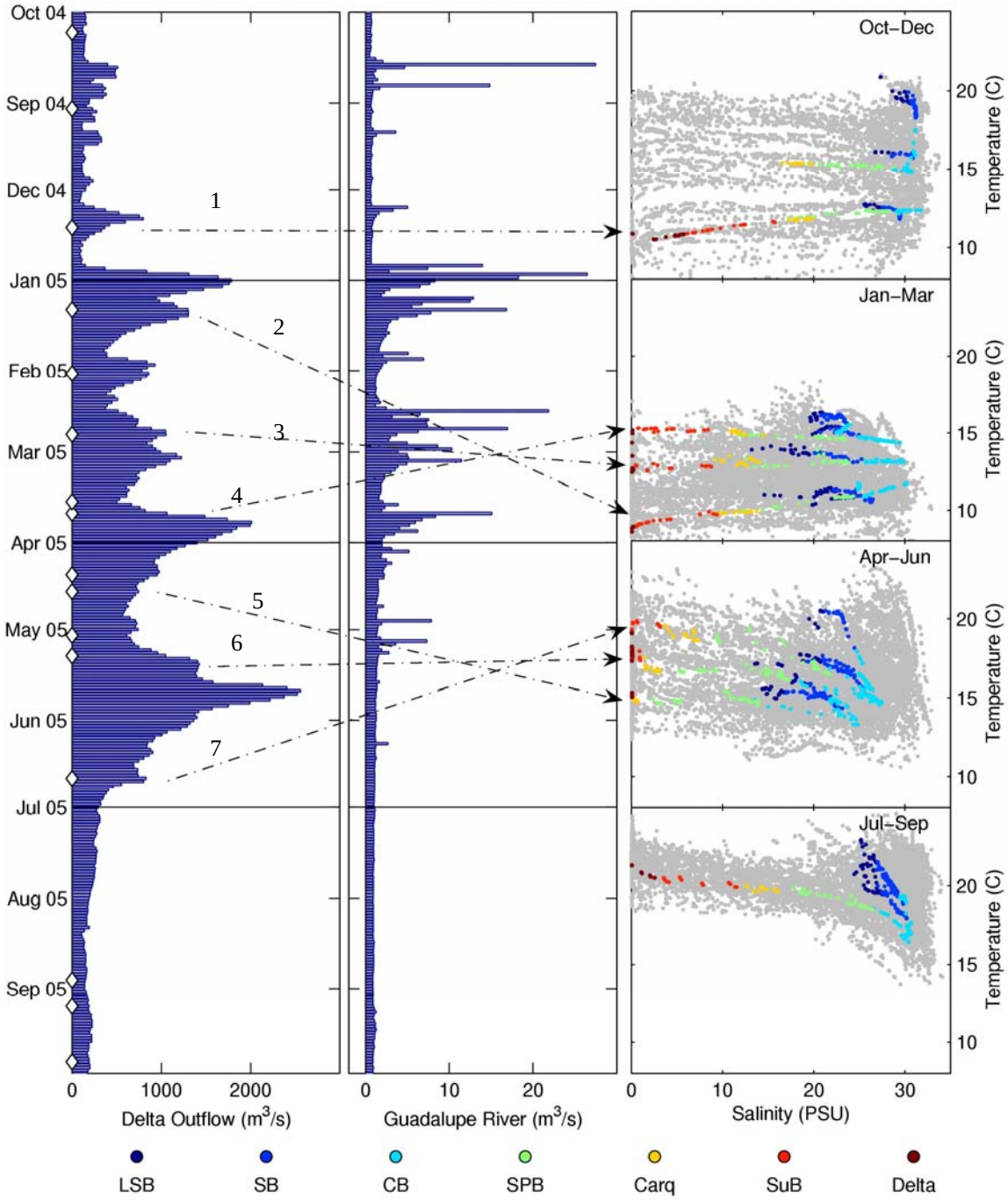

Figure 10: Effects of freshwater flows from the Delta and Guadalupe River on surface (depth<=5m) temperature and salinity patterns. Temperature and salinity data are from USGS (2006a), Guadalupe River flows are from CDEC (2006), and Delta Outflow is from IEP (2006). White diamonds indicate Estuary sampling dates. Light gray scatter points in the temperature-salinity plots represent values from water years 1993-2004. Colored scatter points indicate temperature-salinity values for water year 2005.

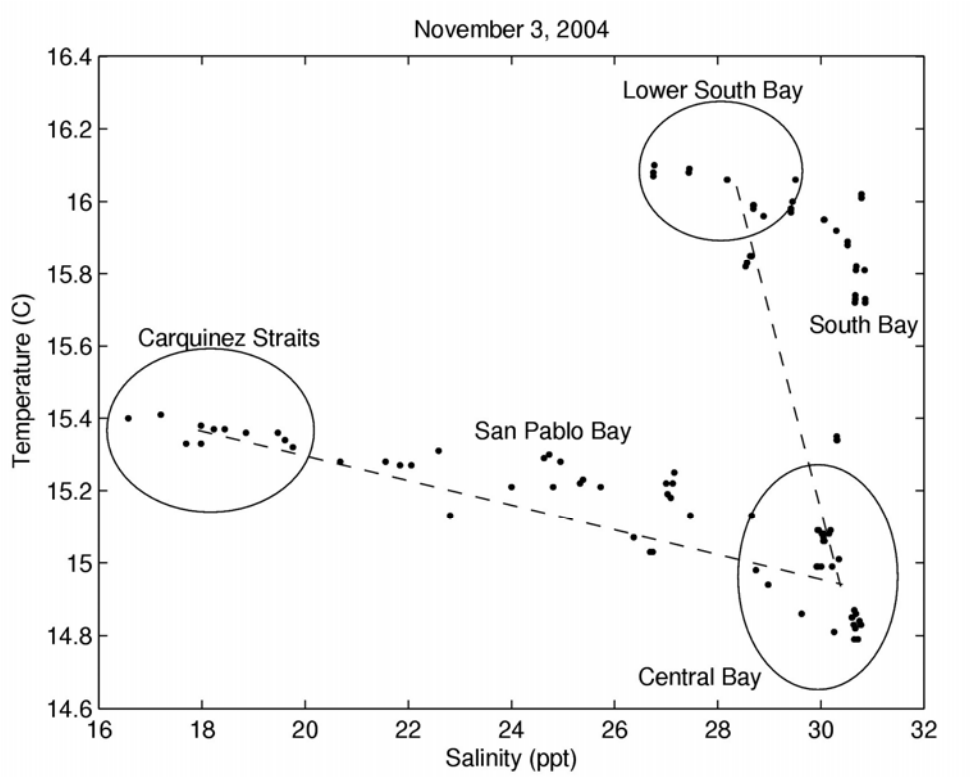

Figure 11: Temperature-salinity diagram of USGS water samples taken November 2004. Three end members are observed, representing Carquinez Straits, Central Bay, and Lower South Bay. San Pablo Bay waters represent a mixture of Central Bay and Carquinez waters. South Bay waters are a mixture of Lower South Bay and Central Bay waters. Data are from USGS (2006a)

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