1996 Annual Report: San Francisco Estuary Regional Monitoring Program for Trace Substances
San Francisco Estuary Institute
December 1997

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1996 Annual Report

San Francisco Estuary
Regional Monitoring Program for Trace Substances

RMP

Regional Monitoring Program for Trace Substances

1996 Annual Report

A Cooperative Program Managed and Administered by the San Francisco Estuary Institute

1996 Regional Monitoring Program Participants

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

Industrial Dischargers:
C & H Sugar
Chevron, USA
Dow Chemical Company
Exxon Company, USA
General Chemical
Pacific Refining Company
Rhone-Poulenc
Shell Martinez Refining
TOSCO Refining Company
UNOCAL-San Francisco Refinery
USS-POSCO

Cooling Water:
Pacific Gas & Electric

Stormwater:
Alameda Countywide Clean Water Program
CALTRANS
Contra Costa Clean Water Program
Fairfield-Suisun Sewer District
Marin County Stormwater Pollution Prevention Program
City and County of San Francisco
San Mateo County Stormwater Pollution Prevention Program
Santa Clara Valley Nonpoint Source Pollution Control Program
Vallejo Sanitation and Flood Control District

Dredgers:
Benicia Terminal Industries
Chevron, USA
Exxon Company, USA
Golden Gate Highway & Transportation District
Port of Oakland
Port of Richmond
Port of San Francisco
US Army Corps of Engineers
US Navy, Western Division

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Executive Summary

This report describes the results from the 1996 Regional Monitoring Program for Trace Substances (RMP). It is the fourth Annual Report from the RMP which began in 1993 and attempts to synthesize the most obvious data patterns from the last four years. This report includes data from Base Program monitoring activities, as well as results of Pilot and Special Studies conducted or completed in 1996. Additionally, several articles contributed by RMP investigators and others, are included. These articles provide perspective and insight on important contaminant issues identified by the RMP. This summary addresses which kinds of pollutants measured by the RMP appear to be at levels that warrant concern, what kinds of trends may be discerned, and which stations have consistently shown elevated contaminant levels.

The goals or general objectives of the RMP are:

1. To obtain high quality baseline data describing the concentrations of toxic and potentially toxic trace elements and organic contaminants in the water and sediment of the San Francisco Estuary.
2. To determine seasonal and annual trends in chemical and biological water quality in the San Francisco Estuary.
3. To continue to develop a data set that can be used to determine long-term trends in the concentrations of toxic and potentially toxic trace elements and organic contaminants in the water and sediments of the San Francisco Estuary.
4. To determine whether water quality and sediment quality in the Estuary at large are in compliance with objectives established by the Basin Plan (the regulatory planning document used by the Regional Water Quality Control Board).
5. To provide a database on water and sediment quality in the Estuary which is compatible with data being developed in other ongoing studies, including wasteload allocation studies and model development, sediment quality objectives development, in-bay studies of dredged material disposal, Interagency Ecological Program (IEP) water quality studies, primary productivity studies, local effects biomonitoring programs, and state and federal mussel watch programs.

Question: How contaminated is the Estuary, overall?

Answer: Almost all pollutants measured by the RMP are considerably higher in the Estuary than just outside the Golden Gate—some by as much as 50 times. Guidelines for water, sediment, and tissue quality are frequently exceeded for a number of trace elements and synthetic organic compounds. Toxicity in water and sediment at certain locations within the Estuary have been frequently observed during the last five years, although organisms living in sediment generally indicate unimpacted conditions. Long-term downward trends are apparent for a number of contaminants after data from the State Mussel Watch Program and the RMP were combined: Silver contamination in mussels has decreased by over ten times over the last decade and a half, and downward trends are also apparent for chlordane, mercury, and lead.

Question: What places measured by the RMP have the highest levels of contamination?

Answer: Most of the South Bay stations, especially the San Jose and Sunnyvale sites, have higher contamination levels than the more well-flushed Central Bay. In the northern reach of the Estuary, notably at the mouth of the Petaluma River and often at the San Pablo Bay station, some contaminant concentrations are also unusually high. The Sacramento and San Joaquin River stations exhibit the highest incidents of water toxicity to mysids.

The kinds of contaminants monitored and sites sampled remained essentially the same in 1996 as in the previous years.

Five types of samples were collected in the 1996 Base Program:

1. Conventional water quality and chemistry
2. Aquatic bioassays (toxicity tests)
3. Sediment quality and chemistry
4. Sediment bioassays (toxicity tests)
5. Transplanted bivalve bioaccumulation, survival, and condition

In collaboration with the RMP, the United States Geological Survey (USGS) monitors water quality and suspended sediments much more frequently to measure changes in the Estuary that occur on shorter time scales than what can be captured by RMP measurements three times per year. The RMP also conducted three Pilot Studies in 1996: the Benthic Pilot Study, the Watershed Pilot Study, and the Tidal Wetlands Pilot Study. Two Special Studies, sediment contamination indicators and a review of bivalve monitoring in the San Francisco Estuary, are also presented.

1996 Findings

Water

The 1996 monitoring year was considered a “wet” year, with Delta outflow during the February sampling period the highest measured since the inception of the RMP. However, 1996 findings generally showed patterns in pollutant concentrations and distributions similar to those of previous years. For example, the southern and northern ends of the Estuary exhibit the highest concentrations of many trace element and trace organic contaminants. Again, PCBs in water exceeded water quality criteria by a substantial amount at most stations. Several other classes of trace organic compounds also had concentrations above water quality guidelines, including polycyclic aromatic hydrocarbons (PAHs), primarily derived from car exhaust, and certain chlorinated pesticides which are still present in the Estuary long after the banning of their use. Of the ten trace elements measured, concentrations of chromium, copper, mercury, and nickel were higher than water quality guidelines on one or more occasions. Copper concentrations were most frequently above both guidelines for dissolved and total concentrations. Mercury, nickel, and chromium concentrations were also above guidelines in numerous instances.

Clear indications of aquatic toxicity were observed in bioassays with shrimp-like *Mysidopsis* in February at the

Sacramento and San Joaquin Rivers, Grizzly Bay, and Napa River stations. Survival was sharply depressed at three of these stations, and only in water from Grizzly Bay did more than 8% of the test organisms survive. Toxicity was also observed in July samples from the Sacramento and San Joaquin Rivers, and Grizzly Bay stations. The timing and geographical location of this toxicity suggest that organophosphate pesticides carried by agricultural runoff from the Central Valley, and possibly Napa Valley may have had a role in causing the toxicity.

Sediment

Nickel in sediments exceeded sediment quality guidelines developed by the National Oceanic and Atmospheric Administration at all sites, although the nickel guidelines are considered to be imprecise. Chromium, arsenic, mercury, total DDTs, and dieldrin also frequently exceeded the level where adverse effects are possible.

Bivalves

Contaminant bioaccumulation by bivalves in 1996 reflected the unusually high Delta outflows during the wet season. More metals showed appreciable bioaccumulation in 1996 than in 1995. No generally acceptable tissue guidelines for both trace elements and trace organics are available for the bivalve bioaccumulation data. However, maximum tissue residue levels (MTRLs), which are relatively recent, science-based guidelines, can be used as a relative "yard-stick". As in previous years, most major classes of trace organic contaminants in bivalve tissues were above the MTRLs in 1996. PCBs and PAHs were above MTRLs in all 1996 tissue samples.

Although the 1996 monitoring year did not yield any surprising new results, with the possible exception of unusually high trace organic contaminant concentrations at the San Jose monitoring station, some patterns, trends, and associations are beginning to emerge from RMP data after four years of data collection (six years counting the Pilot Studies). In addition to the RMP Base Program results, knowledge from several Pilot and Special Studies, as well as some non-RMP studies together contribute to our growing understanding of contaminants and their potential effects in the Estuary.

Question: Is the Estuary getting better or worse in terms of contamination?

Answer: So far, the data suggest that it is getting better, albeit slowly. Sediments, still significantly enriched with pollutants that have accumulated since the industrialization and urbanization of the Estuary's shores, appear to be a continuing source of many contaminants to the overlying water, thus preventing rapid recovery. Information to determine trends over time from various sources of contamination has not been fully evaluated.

Since the manufacturing of PCBs has been banned and their use restricted for more than two decades, their appearance in water is believed to derive primarily from reservoirs of historically deposited PCBs in sediments of the Estuary, contaminated soils of the Estuary's watershed, or accidental releases from a variety of dispersed sources.

Contaminants and Sites of Concern

The identification of contaminants and sites of concern using RMP data can be made in two ways:

1. Based on the frequency of measurements that exceed appropriate guidelines for water, sediment, and tissue by each contaminant measured. Such an evaluation assumes that the guidelines have been set at levels protective of aquatic life and/or human health and that exceedances indicate an increased potential for adverse effects attributable to contaminants.
2. Based on RMP water and sediment bioassays (toxicity tests).

Contaminants of Concern

It is important to note that the RMP measures a select suite of contaminants that is by no means exhaustive. The RMP parameter list includes several persistent synthetic organic chemicals that are known to impact wildlife and humans, but whose use is now banned, while other trace organic contaminants currently in use are not measured for a variety of reasons.

In water, PCBs and copper concentrations exceeded guidelines most frequently. Since 1993, total PCBs in water have exceeded the EPA criterion in nearly all samples collected. PCBs were also the contaminant group most frequently elevated in fish tissue samples collected in the early 1990s. Because the manufacturing of PCBs has been banned and their use restricted for more than two decades, their appearance in water is believed to derive primarily from reservoirs of historically deposited PCBs in sediments of the Estuary, contaminated soils of the Estuary's watershed, or accidental releases from a variety of dispersed sources.

The pesticides diazinon and chlorpyrifos are considered to be contaminants of concern by their apparent association with aquatic toxicity. Although those pesticides had relatively low frequencies of exceedances in 1996, seasonal pulses of these pesticides from the Central Valley and in the Guadalupe River may have been responsible for observed aquatic toxicity.

Certain contaminants in sediments have exhibited consistently elevated levels in sediment over the past four years. Chromium, arsenic, mercury, DDT compounds, and dieldrin frequently exceeded the level where adverse effects are possible. Nickel concentrations have been above sediment quality guidelines at all stations since the inception of the RMP in 1993, but it should be noted that

soils in the immediate Bay Area watersheds are naturally high in nickel, and guidelines for nickel are known to be quite imprecise. Based on an analysis of relationships between sediment toxicity test results and sediment contamination, the additive influence of numerous sediment contaminants was highly associated with toxicity to sediment-dwelling invertebrate species. At several sites elevated chlordane concentrations were associated with toxicity, as were low- and high-molecular weight PAHs at other sites. Dissolved trace metals from sediment at the River stations and Grizzly Bay were associated with bivalve larval toxicity through tests known as toxicity identification evaluations (TIEs) conducted at the Rivers confluence and Grizzly Bay sites.

Concentrations of silver, mercury, lead, and chlordane were shown to be decreasing in tissues over long time periods. In fish, PCB, dioxin, mercury, dieldrin, DDT, and chlordane concentrations have been shown to exceed EPA screening values for human consumption. Except for dioxins (not measured in RMP), those are the same organic contaminants that exceed the MTRLs in bivalve tissues measured by the RMP.

In other studies, the USGS has shown that bioaccumulation of cadmium by the Asian clam *Potamocorbula* was related to decreased biological condition and reproductive function. Bioaccumulation of selenium by *Potamocorbula* is believed to be related to increases in selenium in sturgeon tissues, approaching concentrations of concern. Mercury is another trace element with high bioaccumulation potential (although not reflected in bivalve tissue), as evidenced by concentrations found in fish tissue that exceed levels of concern to human health.

It is reasonable to consider the contaminants of highest concern to be those actually shown to be related to bioaccumulation or adverse effects. Of the contaminants measured in the RMP these include:

- diazinon and chlorpyrifos in water,
- DDTs, chlordanes, and PAHs in sediments, and
- PCBs, cadmium, mercury, selenium, PAHs, chlordanes, dieldrin, and DDTs in bivalve and fish tissue.

Although copper and nickel are of current regulatory interest, there is no conclusive evidence of biological effects from exposures to those contaminants in the Estuary. Several other trace elements (arsenic, silver, lead and zinc) are usually below guidelines and/or have shown no evi-

The sites at opposite ends of the Estuary, those at the mouth of Coyote Creek in the South Bay, and sites at the Rivers confluence and Suisun Bay in the Northern Estuary, are more impacted by contaminants than other RMP sites. Those locations are at the bayward ends of major tributaries where contamination might be expected to accumulate.

dence of bioaccumulation or association with biological effects in the Estuary. However, as suggested for sediments, a mixture of contaminants, such as that found in the Estuary, may have a greater cumulative effect than any of those contaminants considered alone.

Sites of Concern

Comparisons of exceedances of guidelines and incidences of toxicity among sites are difficult since not all measurements are made at all sites. Using the information available, a general picture can be seen: sites in the far South Bay and Southern Sloughs (BA10, C-3-0, C-1-3) had more exceedances of water and sediment guidelines than other locations in the Bay, and concentration gradients of many contaminants from South to Central Bay were apparent. The San Jose monitoring station (C-3-0) had the highest number of water quality exceedances and the highest measure of sediment contamination of any site sampled. Additionally, the Watershed Pilot Study samples from Standish Dam (head of tide) in Coyote Creek often had higher concentrations of some trace organic contaminant groups than any of the RMP Base Program sites.

Although there have been no indications of aquatic toxicity in the South Bay since monitoring began in 1993, Pilot Studies of episodic aquatic toxicity reported some toxicity associated with runoff in Guadalupe Slough. Redwood Creek (BA40) had the highest incidence of sediment toxicity to amphipods over the past six years (90% of tests) of any site in the Estuary.

These results underscore the importance of several non-RMP activities currently being conducted in the South Bay. The City of San Jose will be developing estimates of Total Maximum Daily Loads (TMDL) for copper and nickel that will attempt to model and calculate contributions of those elements from various sources in the South Bay. That exercise should help us to understand contributions of other contaminants as well. The Regional Board and South Bay stakeholders are collaborating on a Watershed Management Initiative in the South Bay that is examining new ways to manage contaminant inputs and restore impaired biological resources.

In the Northern Estuary, the Petaluma River (BD15) had numerous exceedances of water guidelines. San Pablo Bay (BD20) had the largest number of sediment contaminants above levels where effects are possible in August, largely due to elevated concentrations of several individual PAH compounds. Sites at San Joaquin River (BG30), Davis Point (BD40), and San Pablo (BD20) had the highest

number of tissue organics that exceeded the MTRL guidelines.

Sediment samples from wetland channels in China Camp State Park and Petaluma Marsh generally were more contaminated than samples from the adjacent San Pablo Bay. Using sediment-dwelling organisms as an indicator suggested some degree of contamination in the marsh sediments from China Camp.

The Sacramento and San Joaquin Rivers (BG20, BG30) and Grizzly Bay (BF20) sites had the highest incidences of water toxicity to mysid shrimp (39% of tests) between 1994–1996. As noted above, because of the timing and location of those "hits", the cause of that toxicity is believed to be the pesticides diazinon and chlorpyrifos, but further investigation is needed. However, there has been no toxicity of water samples to bivalve larvae at those sites. Interestingly, the same sites have shown the highest incidence of toxicity from sediment contaminants to bivalve larvae (100% of tests). As noted above, preliminary toxicity identification evaluations have suggested that dissolved trace elements in sediments may be the cause of toxicity. Those same sites also had the greatest degree of trace organics bioaccumulation. Toxicity of sediments to *Eohaustorius* amphipods (a sediment-dwelling invertebrate species) occurred in about half the tests conducted since 1991 at the Napa River and Grizzly Bay stations, and in only about 10–20 % of tests at the Sacramento and San Joaquin River sites.

Because RMP station locations were not randomly chosen, the RMP results are not necessarily representative of conditions in the Estuary as a whole. Other locations in the Bay that are not sampled by the RMP, particularly areas along the Estuary margins near some of the major harbors, closed military bases, Superfund sites, or other locations may be quite contaminated, while still other locations may be less contaminated than what the RMP database may indicate.

Generally, the Central Bay has the fewest exceedances of guidelines and the lowest incidence of toxicity of all Bay sites, probably due to the regular tidal flushing and greater water depths resulting in lower suspended sediment concentrations.

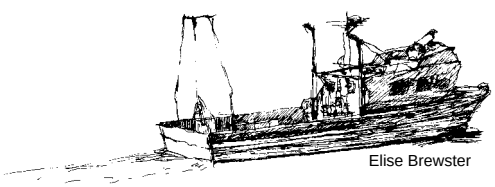
Trends in Contamination

Trends over time and site-specific patterns over time have been noted in this report for water, sediment, and tissue monitored by the RMP. In water, examination of dissolved contaminant data revealed strong gradients of contamination in the Estuary, with as much as a 50-fold difference between the stations with the highest and lowest concentrations. Station gradients have been consistently observed over the course of the RMP for most contaminants. Clear, consistent seasonal variation has also been evident for dissolved concentrations of many contaminants. These

patterns are apparent in the dissolved data because concentrations in the dissolved fraction are relatively independent of other water quality variables whose fluctuations might obscure the patterns. In sediment, spatial gradients and longer-term changes between 1991–1996 were indicated, but consistent seasonal variation has not been observed. In bivalves, the utility of the data for detecting station gradients is limited by the widely varying salinities of the Estuary and the restricted salinity tolerance of the three species employed, but some seasonal and long-term temporal trends have been observed.

A qualitative comparison of the trends observed in the three data sets (dissolved water, sediment, and bivalve) reveals little consistency. The strong station gradients in water were generally not mirrored by sediment concentrations. The exceptions to this were concentrations of PCB, DDT, and chlordane, which had similar composition of compounds in each pollutant group in water and sediment, dominated by relatively high concentrations at San Jose (C-3-0). These data clearly indicate source(s) of these compounds in that portion of the Estuary. Only two trace elements (nickel and silver) showed spatial variation that was roughly similar in water and sediment. Seasonal trends were obvious in the water data, and in one case (silver), the bivalve data indicated a similar increase in the dry season as observed in water. Long-term trends were indicated by an analysis of bivalve data collected from 1980–1996 under the State Mussel Watch Program and the RMP and from graphical analysis of the sediment data. In one case (chlordane) long-term declines in bivalves in sediment were consistent with declines noted since 1994.

The Program, as currently designed, does not attempt to determine contaminant source categories, inputs, or contaminant transport and fate. However, in 1997, the RMP underwent a thorough external review that recommended, among many other items, to modify the current program objectives to include determinations of contaminant sources and inputs. In addition, the information accumulated so far lends itself to a more thorough analysis to be used to re-design the monitoring program.



Elise Brewster

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CHAPTER ONE

Introduction

Introduction

This report describes the results from the 1996 Regional Monitoring Program for Trace Substances (RMP). It is the fourth Annual Report from the RMP which began in 1993. This report includes data, interpretation, and synthesis from Base Program monitoring, as well as results of Pilot and Special Studies conducted or completed in 1996. Additionally, several articles contributed by some of the RMP investigators, and others, are included. These articles provide perspective and insight on important contaminant issues identified by the RMP. Background information about the RMP, included in previous Annual Reports, is not repeated in this report. Instead, the reader is referred to those reports where appropriate. A full description of the RMP is also included in the *RMP Program Plan* available from the San Francisco Estuary Institute (SFEI), or on the World Wide Web: http://www.sfei.org.

In 1996, the list of Program Participants was expanded to sixty-five federal, state, and local agencies and companies. Together with the San Francisco Bay Regional Water Quality Control Board (Regional Board), they participated in the RMP as funders, service providers, and directing the Program through input or participation on the Steering and Technical Review Committees. The RMP Participants are listed on the inside of the front cover.

RMP Objectives

The Program objectives listed below were developed by staff at the Regional Board, representatives of RMP participating agencies, and SFEI staff.

1) To obtain high quality baseline data describing the concentrations of toxic and potentially toxic trace elements and organic contaminants in the water and sediment of the San Francisco Estuary.
2) To determine seasonal and annual trends in chemical and biological water quality in the San Francisco Estuary.
3) To continue to develop a data set that can be used to determine long-term trends in the concentrations of toxic and potentially toxic trace elements and organic contaminants in the water and sediments of the San Francisco Estuary.
4) To determine whether water quality and sediment quality in the Estuary at large are in compliance with objectives established by the Basin Plan.
5) To provide a data base on water and sediment quality in the Estuary which is compatible with data being developed in other ongoing studies in the system, including, but not limited to, wasteload allocation studies and model development, sediment quality objectives development, in-bay studies of dredged material disposal, Interagency Ecological Program (IEP) water quality studies, primary productivity studies, local effects biomonitoring programs, and state and federal mussel watch programs.

Monitoring Design

The RMP sampling design was based on the Bay Protection and Toxic Cleanup Program (BPTCP) Pilot Studies developed by the Regional Board (Flegal *et al*., 1994). The reasoning behind the original design, with stations located along the "spine" of the Estuary, was to include stations that, in a long-term monitoring program, would indicate spatial and temporal trends in toxicity and chemistry, determine background concentrations for different reaches of the Estuary, and assess whether there were high levels of contaminants or toxicity. Several new stations were added in 1994 to fill spatial gaps and to begin monitoring near major tributaries (SFEI, 1995). Additionally, two stations were added in the southern-most end of the Estuary in cooperation with the Cities of San Jose (station C-3-0) and Sunnyvale (station C-1-3) and the Regional Board as part of their National Pollutant Discharge Elimination System (NPDES) monitoring.

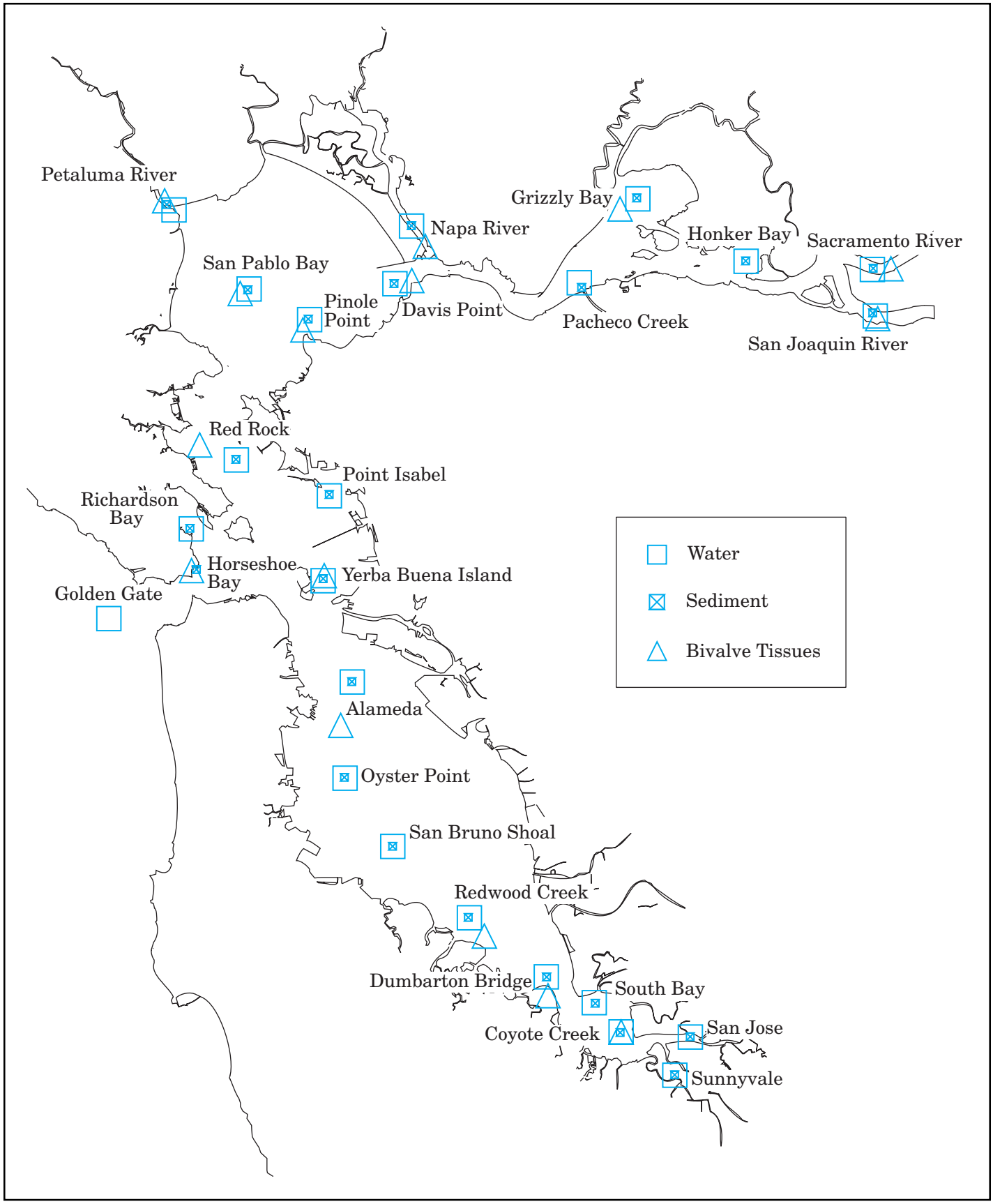

Figure 1. Location of the 1996 Regional Monitoring Program stations.

Table 1. Summary of RMP 1996 sampling stations and activities.

Station Name	Station Code	Type of Sample	Measurements Made	Dates Sampled			Latitude			Longitude		
							deg	min	sec	deg	min	sec
Coyote Creek	BA10	water	Q,M,O,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	28	11	122	3	50
	BA10	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	37	28	12	122	3	36
	BA10	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	37	28	11	122	3	50
South Bay	BA20	water	Q,M	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	29	41	122	5	20
	BA21	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	37	29	38	122	5	15
Dumbarton Bridge	BA30	water	Q,M,O	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	30	54	122	8	7
	BA30	sediment	Q,M,O	2/15 – 2/22		7/31 – 8/6	37	30	54	122	8	7
	BA30	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	37	30	54	122	8	7
Redwood Creek	BA40	water	Q,M,O,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	33	40	122	12	34
	BA40	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	37	32	49	122	11	42
	BA41	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	37	33	40	122	12	37
San Bruno Shoal	BB15	water	Q,M	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	37	1	122	17	0
	BB15	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	37	37	1	122	17	0
Oyster Point	BB30	water	Q,M	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	40	12	122	19	45
	BB30	sediment	Q,M,O	2/15 – 2/22		7/31 – 8/6	37	40	12	122	19	45
Alameda	BB70	water	Q,M,O,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	44	50	122	19	24
	BB70	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	37	44	50	122	19	24
	BB71	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	37	41	44	122	20	23
Yerba Buena Island	BC10	water	Q,M,O,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	49	22	122	20	58
	BC10	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	37	49	22	122	20	58
	BC11	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	37	49	26	122	20	56
Golden Gate	BC20*	water	Q,M,O	2/5 – 2/14			37	44	49	122	32	9
		water	Q,M,O		4/22 – 4/29		37	46	12	122	32	24
		water	Q,M,O			7/22 – 7/30	37	47	44	122	29	17
Horseshoe Bay	BC21	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	37	49	59	122	28	26
	BC21	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	37	49	59	122	28	26
Richardson Bay	BC30	water	Q,M	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	51	49	122	28	40
	BC32	sediment	Q,M,O	2/15 – 2/22		7/31 – 8/6	37	51	49	122	28	43
Point Isabel	BC41	water	Q,M	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	53	2	122	20	33
	BC41	sediment	Q,M,O	2/15 – 2/22		7/31 – 8/6	37	53	2	122	20	33
Red Rock	BC60	water	Q,M,O,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	55	0	122	26	0
	BC60	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	37	55	0	122	26	0
	BC61	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	37	55	42	122	28	8
Petaluma River	BD15	water	Q,M,O,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	38	6	37	122	29	13
	BD15	sediment	Q,M,O	2/15 – 2/22		7/31 – 8/6	38	6	47	122	30	4
	BD15	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	38	6	37	122	29	13
San Pablo Bay	BD20	water	Q,M,O	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	38	2	55	122	25	11
	BD20	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	38	2	55	122	25	43
	BD22	sediment	Q,M,O	2/15 – 2/22		7/31 – 8/6	38	2	52	122	25	14
Pinole Point	BD30	water	Q,M,O,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	38	1	29	122	21	39
	BD30	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	38	1	0	122	22	3
	BD31	sediment	Q,M,O	2/15 – 2/22		7/31 – 8/6	38	1	29	122	21	43
Davis Point	BD40	water	Q,M,O	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	38	3	7	122	16	37
	BD40	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	38	3	16	122	15	38
	BD41	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	38	3	7	122	16	39
Napa River	BD50	water	Q,M,O,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	38	5	47	122	15	37
	BD50	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	38	5	47	122	15	37
	BD50	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	38	5	47	122	15	37
Pacheco Creek	BF10	water	Q,M	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	38	3	5	122	5	48
	BF10	sediment	Q,M,O	2/15 – 2/22		7/31 – 8/6	38	3	5	122	5	48
Grizzly Bay	BF20	water	Q,M,O,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	38	6	58	122	2	19
	BF20	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	38	6	29	122	3	22
	BF21	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	38	6	58	122	2	21
Honker Bay	BF40	water	Q,M	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	38	4	2	121	55	56
	BF40	sediment	Q,M,O	2/15 – 2/22		7/31 – 8/6	38	4	2	121	55	56
Sacramento River	BG20	water	Q,M,O,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	38	3	34	121	48	35
	BG20	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	38	3	34	121	48	35
	BG20	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	38	3	34	121	48	35
San Joaquin River	BG30	water	Q,M,O,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	38	1	24	121	48	27
	BG30	sediment	Q,M,O,T	2/15 – 2/22		7/31 – 8/6	38	1	24	121	48	27
	BG30	bioaccumulation	M,O,C	4/30 – 5/2		9/10 – 9/12	38	1	24	121	48	27
San Jose	C-3-0	water	Q,M,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	27	43	121	58	32
	C-3-0	sediment	Q,M	2/15 – 2/22		7/31 – 8/6	37	27	43	121	58	32
Sunnyvale	C-1-3	water	Q,M,T	2/5 – 2/14	4/22 – 4/29	7/22 – 7/30	37	26	8	122	0	40
	C-1-3	sediment	Q,M	2/15 – 2/22		7/31 – 8/6	37	26	8	122	0	40

* location dependent on salinity
T = toxicity (only for Cruises 7 and 9)
C = bivalve condition index
Q = water and/or sediment quality
M = trace metals
O = trace organics

RMP station locations were not randomly chosen. Therefore, RMP results provide site-specific information, but should not be interpreted as providing information about the spatial extent of conditions in the Estuary. As a result of the RMP Program Review conducted in 1997, better rationale and justification will be made for the RMP monitoring design in the near future. Additionally, the monitoring design may be modified, although the level of those changes is not yet clear.

Five types of samples collected in the 1996 Base Program included:

1) Conventional water quality and chemistry.
2) Aquatic bioassays.
3) Sediment quality and chemistry.
4) Sediment bioassays.
5) Transplanted, bagged bivalve bioaccumulation, survival, and condition.

The locations of the 22 RMP and two Southern Slough (C-3-0, C-1-3) sampling stations are shown in Figure 1; Table 1 lists the station names, codes, locations, and sampling dates for all 1996 stations. Water, sediment, or bioaccumulation sampling sites with the same station name may have different station codes as they are situated at slightly different locations (latitude, longitude) due to practical considerations such as sediment type or ability to deploy bivalves, For example, at the South Bay site, BA20 is the water station code, and BA21 is the sediment station code.

Table 2. 1996 RMP contractors and principal investigators.

Prime Contractors	Dr. Bob Spies and Dr. Andy Gunther Applied Marine Sciences, Livermore, CA
Trace Element Chemistry	Dr. Russ Flegal, UC Santa Cruz, CA Dr. Eric Prestbo, Brooks-Rand, Seattle, WA
Trace Organic Chemistry	Dr. Bob Risebrough, Bodega Bay Institute, CA Dr. Terry Wade, Texas A&M University, TX Dr. Walter Jarman, UC Santa Cruz, CA
Water Toxicity Testing	Dr. Scott Ogle Pacific Eco-Risk Laboratories, Martinez CA
Sediment Toxicity Testing	Mr. John Hunt and Mr. Brian Anderson Marine Pollution Lab, Granite Canyon, CA
Bagged Bivalve Sampling	Mr. Dane Hardin, Applied Marine Sciences, Livermore, CA
USGS Water Quality	Dr. James Cloern, USGS, Menlo Park, CA
USGS Sediment Transport	Dr. David Schoellhamer, USGS, Sacramento, CA
Pilot Study on Benthic Macrofauna	Dr. Bruce Thompson San Francisco Estuary Institute, Richmond, CA Ms. Heather Peterson Dept. of Water Resources, Sacramento, CA
Pilot Study on Tidal Wetlands	Dr. Josh Collins San Francisco Estuary Institute, Richmond, CA
Watershed Pilot Study	Dr. Rainer Hoenicke San Francisco Estuary Institute, Richmond, CA Mr. Dane Hardin Applied Marine Sciences, Livermore, CA

Sampling occurred during three periods in 1996: during the wet season (February), a period of declining Delta outflow (late April), and during the dry season (July–August). Delta outflow during the RMP sampling periods is shown in the article by Cloern *et al.* in *Chapter Two: Water Monitoring*. Exact sampling dates are listed in Table 1. Logistic and scheduling constraints of this large, Estuary-wide program precluded sampling at consistent monthly or daily tidal cycles.

Not all parameters were measured at all RMP stations each sampling period. Sampling activities at each station are listed in Table 1. Water samples were collected at all stations during all three sampling periods. However, trace organic contaminants in water were only measured at 15 stations where bioaccumulation measurements were made and at San Jose (C-3-0). Aquatic bioassays were conducted at 13 stations during the wet- and dry-season sampling periods.

Sediment sampling was conducted during the wet- and dry-season sampling periods only. Sediment samples were collected from all RMP stations with the exception of the Golden Gate station (BC20). Sediment toxicity was measured at 13 of those stations during the wet- and dry-sampling periods. Measurements of ammonia and sulfides in sediment were also conducted in 1996.

Bivalve bioaccumulation, survival, and condition were measured at 15 stations during the wet- and dry-season sampling periods.

The water and sediment samples were collected from aboard the R/V DAVID JOHNSTON chartered through the University of California, Santa Cruz. During each sampling period or cruise, water sampling was conducted first at all RMP stations. Sediment sampling followed, making a separate run though the Estuary. Each sampling run required 3 to 5 days for completion. The bivalve monitoring consisted of three parts: deployment of transplants from reference sites, maintenance, and retrieval. This work was conducted using primarily the R/V RINCON POINT, owned by the City of San Francisco, in cooperation with the Bureau of Water Pollution Control. Additionally, the California Department of Water Resources provided back-up services for bivalve cruises. Details of sample collection are included in *Appendix A*.

As in past years, sampling and analysis were coordinated by the RMP Prime Contractor, Applied Marine Sciences in Livermore, CA. In addition, a very dedicated group of Principal Investigators also participated in the RMP (Table 2).

Complete listings of all parameters measured in 1996 are included in Table 3. Methods of collection and analysis are detailed in *Appendix A*. All RMP data included in this report are available through SFEI or on the World Wide Web: http://www.sfei.org.

References

Flegal, A.R., R.W. Risebrough, B. Anderson, J. Hunt, S. Anderson, J. Oliver, M. Stephenson, and R.Packard. 1994. San Francisco Estuary Pilot Regional Monitoring Program: Sediment Studies. San Francisco Bay Regional Water Quality Control Board, State Water Resources Control Board.

SFEI. 1995. 1994 Annual Report: San Francisco Estuary Regional Monitoring Program for Trace Substances. Prepared by the San Francisco Estuary Institute, Richmond, CA. 339 p.

Table 3. Parameters analyzed in water, sediment, and bivalve tissues during the 1996 RMP sampling of the San Francisco Estuary.

A. Conventional Water Quality Parameters

Conductivity
Dissolved Organic Carbon
Dissolved Oxygen (DO)
Hardness (when salinity is <5 ‰)
pH (acidity)
Phaeophytin (a chlorophyll degradation product)
Salinity
Temperature
Total Chlorophyll-*a*
Total Suspended Solids
Dissolved Phosphates
Dissolved Silicates
Dissolved Nitrate
Dissolved Nitrite
Dissolved Ammonia

B. Sediment Quality Parameters

% Clay (<4 µm)
% Silt (4 µm–62 µm)
% Sand (63 µm–2 mm)
% Gravel (>2 mm)
% Solids
pH
Total Ammonia
Total Organic Carbon
Total Sulfide

C. Bivalve Tissue Parameters

% Moisture
Bivalve % Survival
Total Volume
Shell Volume
Dry Flesh Weight
Biological Condition Index

D. Trace Elements

	Water	Sediment	Tissue
Aluminum*		•	
Arsenic	•	•	•
Cadmium*	•	•	•
Chromium	•	•	•
Copper*	•	•	•
Iron*		•	
Lead*	•	•	•
Manganese*		•	
Mercury	•	•	•
Nickel*	•	•	•
Selenium	•	•	•
Silver*	•	•	•
Zinc*	•	•	•
Dibutyltin (DBT)			•
Monobutyltin (MBT)			•
Tributyltin (TBT)			•
Tetrabutyltin (TTBT)			•

* Near-total rather than total concentrations 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.

Table 3 (continued). Parameters analyzed.

E. Polycyclic Aromatic Hydrocarbons (PAHs)	Water	Sediment	Tissue
2 rings			
1-Methylnaphthalene	•	•	•
2, 3, 5-Trimethylnaphthalene	•	•	•
2, 6-Dimethylnaphthalene	•	•	•
2-Methylnaphthalene	•	•	•
Biphenyl	•	•	•
Naphthalene	•	•	•
3 rings			
1-Methylphenanthrene	•	•	•
Acenaphthene	•	•	•
Acenaphthylene	•	•	•
Anthracene	•	•	•
Dibenzothiophene	•	•	•
Fluorene	•	•	•
Phenanthrene	•	•	•
4 rings			
Benz(a)anthracene	•	•	•
Chrysene	•	•	•
Fluoranthene	•	•	•
Pyrene	•	•	•
5 rings			
Benzo(a)pyrene	•	•	•
Benzo(b)fluoranthene	•	•	•
Benzo(e)pyrene	•	•	•
Benzo(k)fluoranthene	•	•	•
Dibenz(a,h)anthracene	•	•	•
Perylene	•	•	•
6 rings			
Benzo(ghi)perylene	•	•	•
Indeno(1, 2, 3-cd)pyrene	•	•	•
Alkylated PAHs			
C1-Chrysenes		•	•
C2-Chrysenes		•	•
C3-Chrysenes		•	•
C4-Chrysenes		•	•
C1-Dibenzothiophenes		•	•
C2-Dibenzothiophenes		•	•
C3-Dibenzothiophenes		•	•
C1-Fluoranthenes/Pyrenes		•	•
C1-Fluorenes		•	•
C2-Fluorenes		•	•
C2-Fluorenes		•	•
C1-Naphthalenes		•	•
C2-Naphthalenes		•	•
C3-Naphthalenes		•	•
C4-Naphthalenes		•	•

E. PAHs (continued)	Water	Sediment	Tissue
C1-Phenanthrenes/Anthracenes		•	•
C2-Phenanthrenes/Anthracenes		•	•
C3-Phenanthrenes/Anthracenes		•	•
C4-Phenanthrenes/Anthracenes		•	•

F. Synthetic Biocides	Water	Sediment	Tissue
Cyclopentadienes			
Aldrin		•	•
Dieldrin	•	•	•
Endrin	•	•	•
Chlordanes			
alpha-Chlordane	•	•	•
cis-Nonachlor	•	•	•
gamma-Chlordane	•	•	•
Heptachlor	•	•	•
Heptachlor Epoxide	•	•	•
Oxychlordane	•	•	•
trans-Nonachlor	•	•	•
DDTs			
o, p'-DDD	•	•	•
o, p'-DDE	•	•	•
o, p'-DDT	•	•	•
p, p'-DDD	•	•	•
p, p'-DDE	•	•	•
p, p'-DDT	•	•	•
HCHs			
alpha-HCH	•	•	•
beta-HCH	•	•	•
delta-HCH	•	•	•
gamma-HCH	•	•	•
Other			
Dacthal	•		
Diazinon	•		
Endosulfan I	•		
Endosulfan II	•		
Endosulfan Sulfate	•		
Mirex	•	•	•
Oxadiazon	•		
Chlorpyrifos	•		

Table 3 (continued). Parameters analyzed.

G. PCBs and Related Compounds

	Water	Sediment	Tissue		Water	Sediment	Tissue
Hexachlorobenzene	•	•	•	PCB 114		•	•
PCB 001		•	•	PCB 118	•	•	•
PCB 003		•	•	PCB 119		•	•
PCB 004		•	•	PCB 128	•	•	•
PCB 006		•	•	PCB 132	•	•	•
PCB 008	•	•	•	PCB 137		•	•
PCB 015		•	•	PCB 138	•	•	•
PCB 018	•	•	•	PCB 141	•	•	•
PCB 027		•	•	PCB 149	•	•	•
PCB 028	•	•	•	PCB 151	•	•	•
PCB 029		•	•	PCB 153	•	•	•
PCB 031	•	•	•	PCB 156	•	•	•
PCB 033	•	•	•	PCB 157		•	•
PCB 044	•	•	•	PCB 158	•	•	•
PCB 049	•	•	•	PCB 167		•	•
PCB 052	•	•	•	PCB 170	•	•	•
PCB 056		•	•	PCB 174	•	•	•
PCB 060	•	•	•	PCB 177	•	•	•
PCB 066	•	•	•	PCB 180	•	•	•
PCB 070	•	•	•	PCB 183	•	•	•
PCB 074	•	•	•	PCB 187	•	•	•
PCB 085		•	•	PCB 189		•	•
PCB 087	•	•	•	PCB 194	•	•	•
PCB 095	•	•	•	PCB 195	•	•	•
PCB 097	•	•	•	PCB 201	•	•	•
PCB 099	•	•	•	PCB 203	•	•	•
PCB 101	•	•	•	PCB 206		•	•
PCB 105	•	•	•	PCB 207		•	•
PCB 110	•	•	•				

CHAPTER TWO

Water Monitoring

Background

This chapter presents a graphical and narrative summary of RMP water monitoring results for 1996. This chapter also includes four articles contributed by RMP investigators that provide interpretive summaries of specific water monitoring activities.

Water quality was monitored at 22 RMP Base Program stations. Parameters measured included conventional water quality parameters (salinity, temperature, total suspended solids, and others), trace elements, trace organic contaminants, and toxicity. Water was also sampled at two stations in the southern end of the Estuary in cooperation with the SFBRWQCB and the cities of San Jose (station C-3-0) and Sunnyvale (station C-1-3). Water quality was also monitored by the US Geological Survey at shorter time scales to complement RMP monitoring activities.

Station locations are shown in Figure 1 in *Chapter One: Introduction*. Water samples were collected in February, April, and July. Sampling dates and parameters measured at each station are shown in Table 1 in *Chapter One: Introduction*. For trace elements, dissolved (0.45 µm filtered) and total (arsenic, chromium, mercury, selenium) or near-total (cadmium, copper, lead, nickel, silver, and zinc) concentrations are presented. Dissolved (1 µm filtered) and total concentrations of trace organic contaminants are also presented. Detailed methods of collection and analysis are included in *Appendix A*.

In order to compare water monitoring results among the major reaches of the Estuary, the RMP stations are separated into five groups based on similarities in geography, water chemistry, and hydrodynamics: the Southern Sloughs (C-1-3 and C-3-0), South Bay (seven stations, BA10 through BB70), Central Bay (five stations, BC10 through BC60), Northern Estuary (eight stations, BD15 through BF40), and the Rivers (BG20 and BG30).

Water Quality Objectives and Criteria

In this report, comparisons to water quality objectives and criteria are made to provide a context for evaluating the condition of the Estuary in terms of contamination, and not for any regulatory purpose. Water quality objectives and criteria used for these comparisons (Table 7) were selected based on guidance from the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB; Kim Taylor, personal communication). Most of the criteria used were taken from US Environmental Protection Agency's proposed California Toxics Rule (US EPA, 1997; CTR). US EPA is scheduled to issue a final rule formalizing

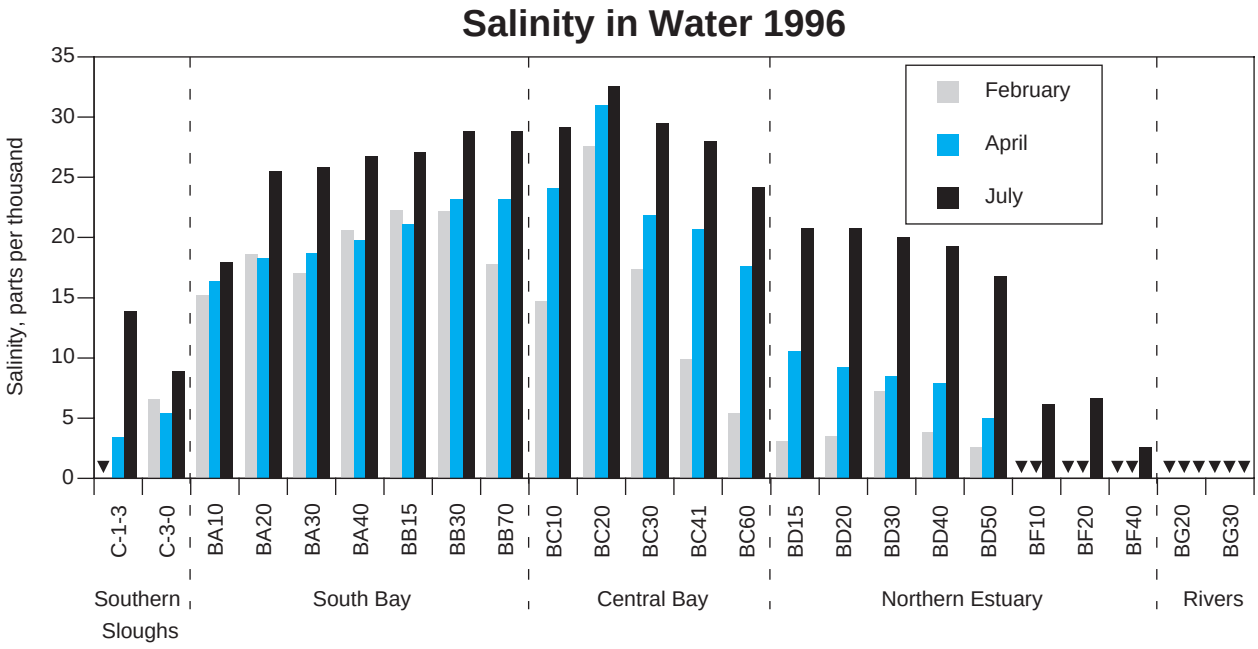

Figure 1. Salinity in parts per thousand (‰) at each RMP water station in February, April, and July 1996. ▼ = below detection limit. Samples were collected at approximately 1 m below the surface. Salinities ranged from below detection (1‰) to 33‰. The highest salinity was detected at Golden Gate (BC20) in July. Salinities were lowest in February as expected in the wet season. Salinities below 5‰ are considered freshwater for application of water quality standards.

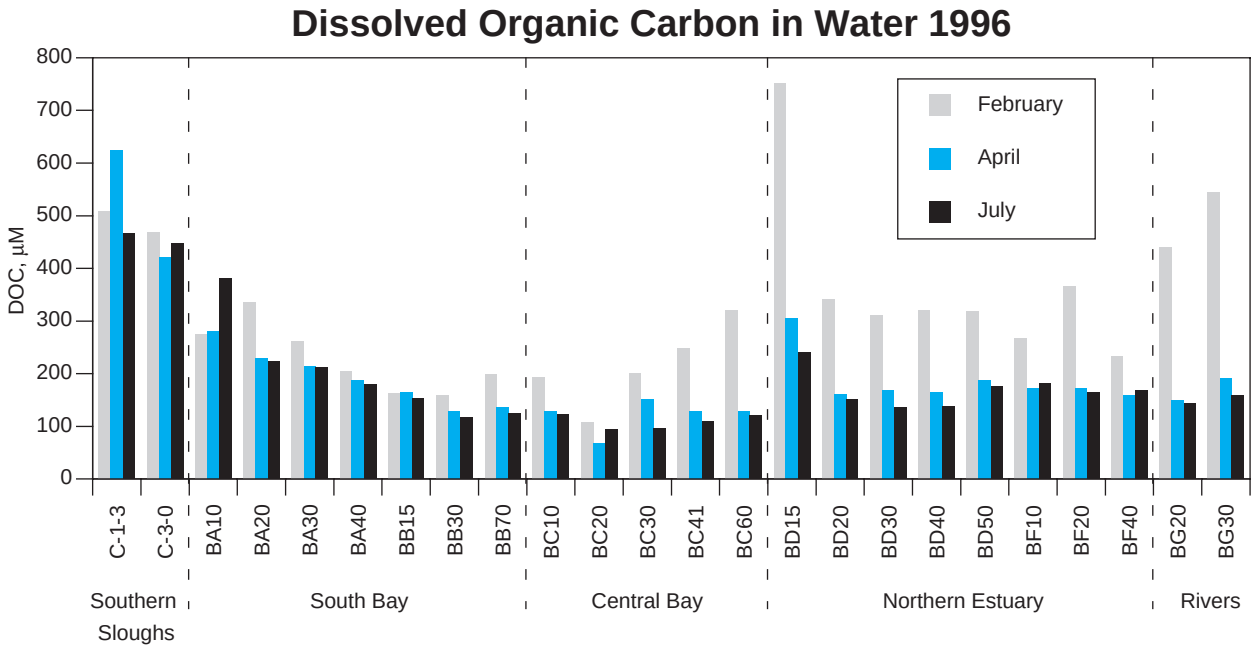

Figure 2. Dissolved organic carbon (DOC) in micromoles per liter (µM) at each water station in February, April, and July of 1996. 1 µM of dissolved organic carbon is equal to 12 mg/L. DOC ranged from 68 µM to 751 µM. The highest concentration was sampled at Petaluma River (BD15) in February and the lowest concentration was sampled at Golden Gate (BC20) in April.

these California Toxics Rule criteria in the near future. Objectives for mercury were obtained from the San Francisco Bay Basin Plan (SFBRWQCB, 1995). Selenium criteria are region-specific criteria for total recoverable selenium that apply to the entire Estuary (National Toxics Rule, US EPA, 1992). Criteria for chlorpyrifos and mirex are not included in the proposed CTR, but US EPA criteria for these chemicals were obtained from the SFBRWQCB. For diazinon, hazard assessment criteria developed by the California Department of Fish and Game (Menconi and Cox, 1994) are used in this report to evaluate the degree of contamination in the Estuary.

Different objectives and criteria apply to saltwater, estuarine, and freshwater portions of the Estuary (Table 7). As defined by the Basin Plan (SFBRWQCB, 1995), Estuary locations are 1) freshwater when their salinity is below 5 parts per thousand (ppt) more than 75% of the time; 2) saltwater when their salinity is greater than 5 ppt more than 75% of the time; and 3) estuarine if salinity is intermediate or if estuarine organisms are present for significant periods.

For estuarine locations, the Basin Plan specifies that the lower of the freshwater and saltwater objectives apply. For this report RMP stations were classified as freshwater, estuarine, or saltwater based on an evaluation by the SFBRWQCB (Kim Taylor, personal communication) of long-term data at RMP stations, and the characteristic benthic assemblages observed in the RMP Benthic Pilot Study (Thompson *et al.*, this report). For estuarine locations, the lower of the freshwater and saltwater criteria apply. The following stations are classified as estuarine in this report: Sunnyvale (C-1-3), San Jose (C-3-0), South Bay (BA20), Petaluma River (BD15), Davis Point (BD40), Napa River (BD50), Pacheco Creek (BF10), Grizzly Bay (BF20), and Honker Bay (BF40).

For some contaminants multiple criteria exist that apply to different target organisms (aquatic life or humans) or different lengths or routes of exposure (e.g., 1 hour or 4 days). For this report, RMP contaminant data are compared to the lowest criterion for each contaminant. In general, trace element concentrations were compared to 4-day average criteria for aquatic life, which are lower than 1-hour average criteria, and trace organic contaminant concentrations were compared to human health criteria based on consumption of organisms only, since RMP stations are all seaward of drinking water intakes in the Delta.

Water quality criteria for five elements measured at freshwater stations are related to water hardness. In the RMP, hardness data are only collected at stations where the salinity is less than 5‰. Freshwater criteria for these elements at estuarine stations were therefore calculated assuming a hardness of 100 µg/L.

Aquatic Bioassays

Laboratory bioassays using Estuary water were conducted at 11 RMP stations (Figure 36) during the wet-season sampling (February) and again in the dry-season sampling (July). Two laboratory bioassays were conducted. Mysids (*Mysidopsis bahia*) were exposed to Estuary water for seven days where percent survival was the endpoint. Larval mussels (*Mytilus* sp.) were exposed to Estuary water for 48 hours where percent normal development was the endpoint. Detailed methods are included in Appendix A. Significant toxicity was determined by statistical comparison (t-tests) of field samples with controls.

In the July *Mytilus* tests, controls for nine stations had less than 70% normal development (the quality control guideline). In spite of this problem with controls, these tests indicated an absence of toxicity at the nine affected stations (Scott Ogle, personal communication). At each of the nine stations, survival in the sample water was as high as in the controls. Concurrent reference toxicant test results, when normalized to the control response, were well within the acceptable range. Results for the *Mytilus* tests at these nine stations were therefore consistent with the absence of toxicity observed at all other stations in this test in both February and July.

References

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SFBRWQCB. 1995. 1995 Basin Plan. San Francisco Bay Regional Water Quality Control Board. Oakland, CA.

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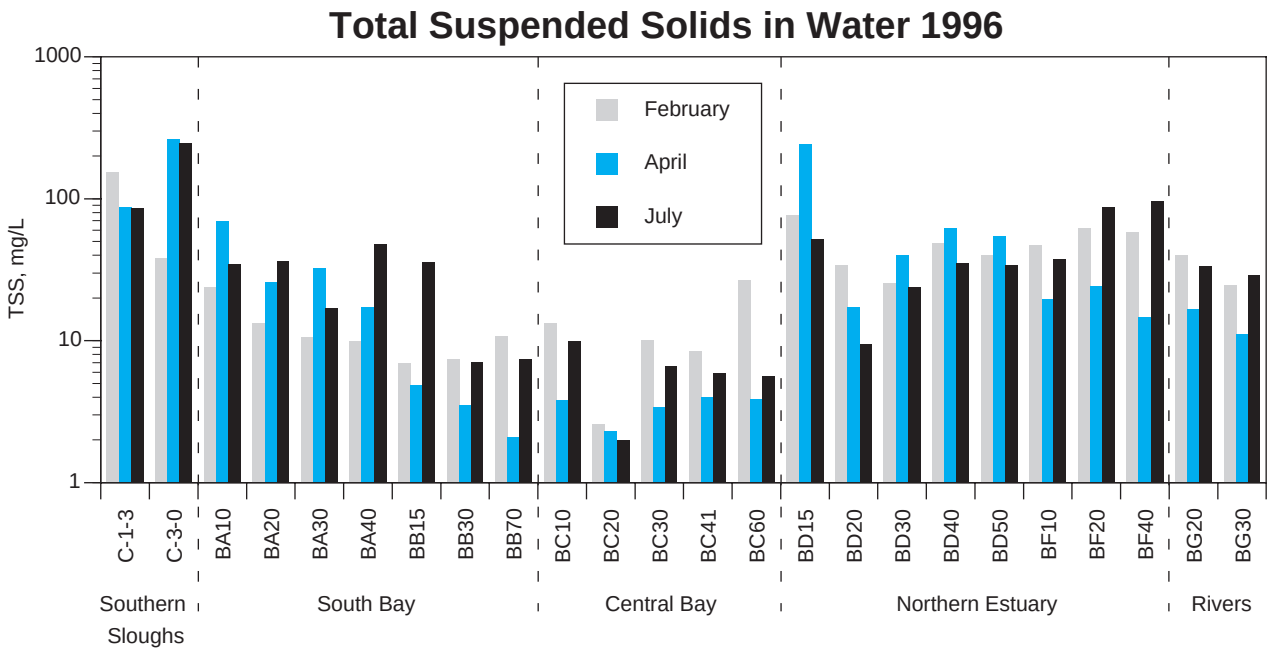

Figure 3. Total suspended solids (TSS) in milligrams per liter (mg/L) at each RMP water station in February, April, and July of 1996. Note logarithmic scale. TSS concentrations ranged from 2.0 mg/L to 264 mg/L. The highest concentration was sampled at San Jose (C-3-0) in April and the lowest at Golden Gate (BC20) in July. Average TSS concentrations were higher in the Southern Slough stations than other Estuary reaches.

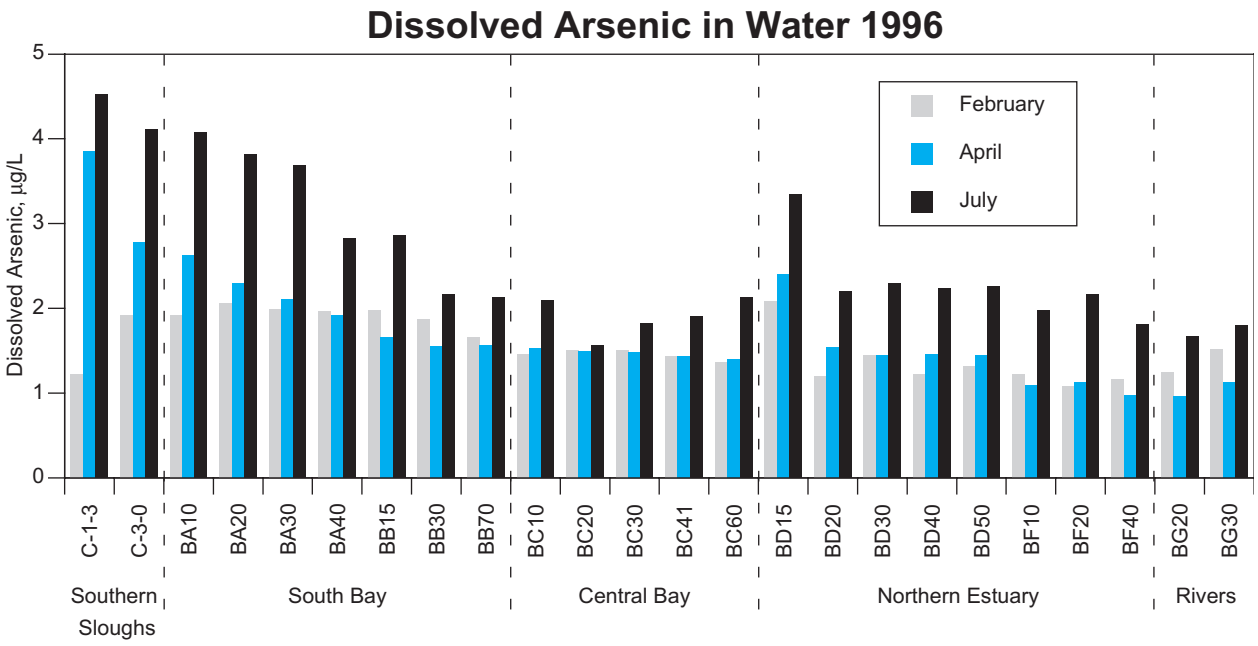

Figure 4. Dissolved arsenic (As) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Dissolved arsenic concentrations ranged from 0.96 to 4.52 ppb. The highest concentration was sampled at Sunnyvale (C-1-3) in July and the lowest at Sacramento River (BG20) in April. Average concentrations were highest in the Southern Sloughs in July (4.32 ppb) and lowest the Rivers in April (1.04 ppb). In general, concentrations were highest in July. All samples were below the 4-day average water quality criteria (WQC) for dissolved arsenic (saltwater 36 ppb, freshwater 150 ppb).

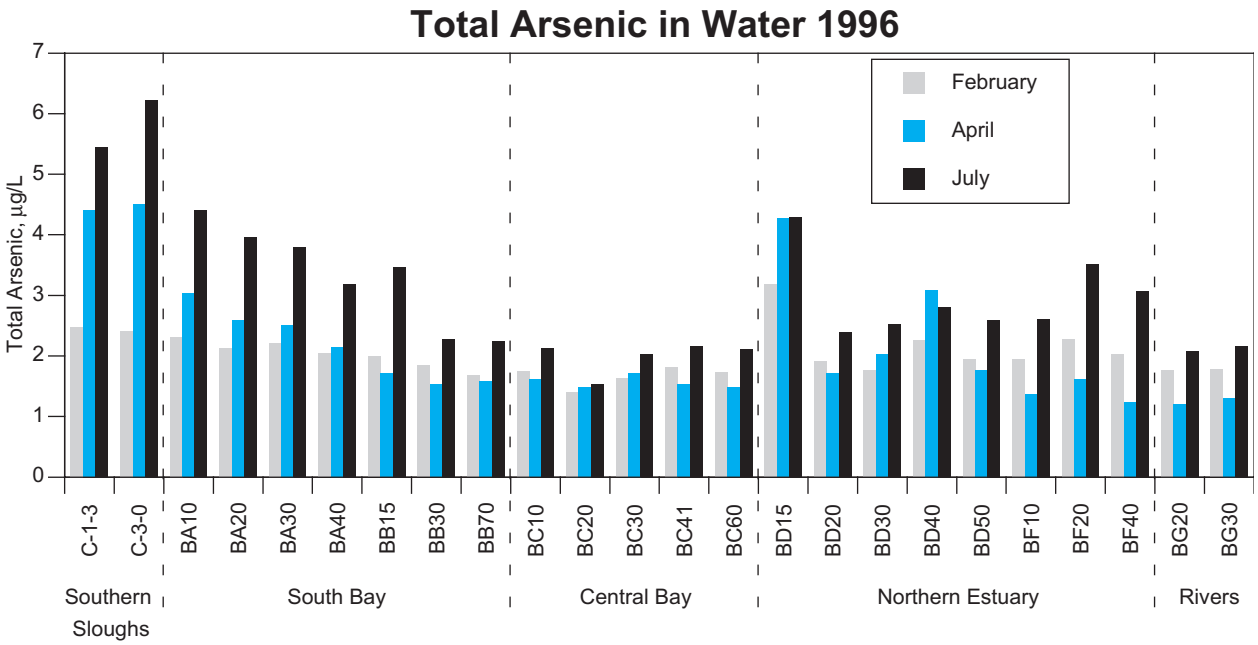

Figure 5. Total arsenic (As) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Total arsenic concentrations ranged from 1.21 to 6.22 ppb. The highest concentration was sampled at San Jose (C-3-0) in July, and the lowest at Sacramento River (BG20) in April. Average concentrations were highest in the Southern Sloughs in July (5.83 ppb) and lowest in the Rivers in April (1.26 ppb). In general concentrations were highest in July. All samples were below the 4-day average WQC for total arsenic (saltwater 36 ppb, freshwater 150 ppb).

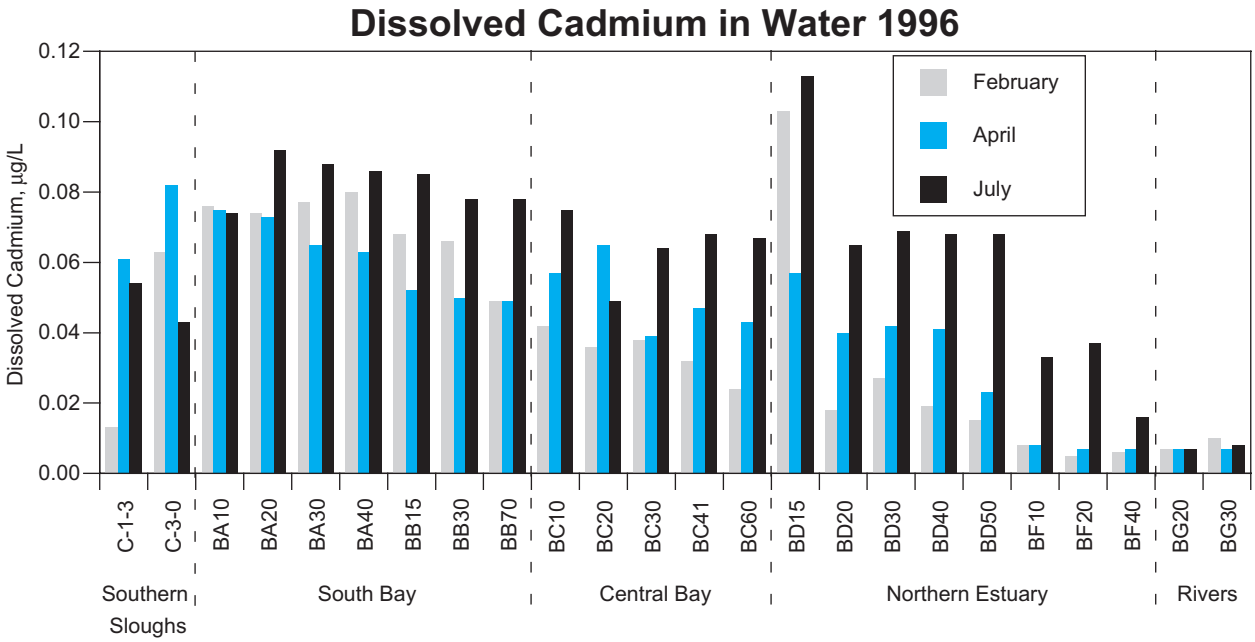

Figure 6. Dissolved cadmium (Cd) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Dissolved cadmium concentrations ranged from 0.005 to 0.113 ppb. The highest concentration was sampled at Petaluma River (BD15) in July and the lowest value at Grizzly Bay (BF20) in February. Average concentrations were highest in the South Bay in July (0.083 ppb) and lowest in the Rivers in April (0.007 ppb). In general, concentrations were highest in July. All samples were below the 4-day average WQC for dissolved cadmium (saltwater 9.3 ppb, freshwater—hardness dependent).

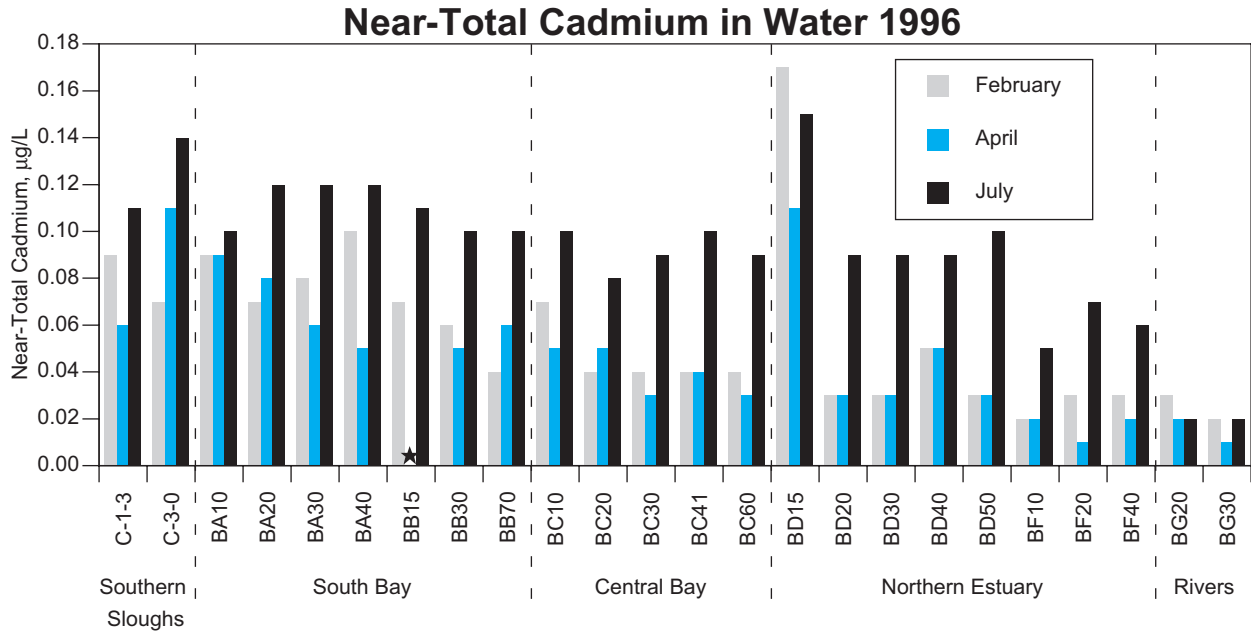

Figure 7. Near-total cadmium (Cd) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. ★ = not analyzed. Near-total cadmium concentrations ranged from 0.010 to 0.17 ppb. The highest concentration was sampled at Petaluma River (BD15) in February, and the lowest at Grizzly Bay (BF20) in April. Average concentrations were highest in the Southern Sloughs in July (0.125 ppb) and lowest in the Rivers in April (0.015 ppb). In general, concentrations were highest in July. All samples were below the 4-day average WQC for total cadmium (saltwater 9.4 ppb, freshwater—hardness dependent).

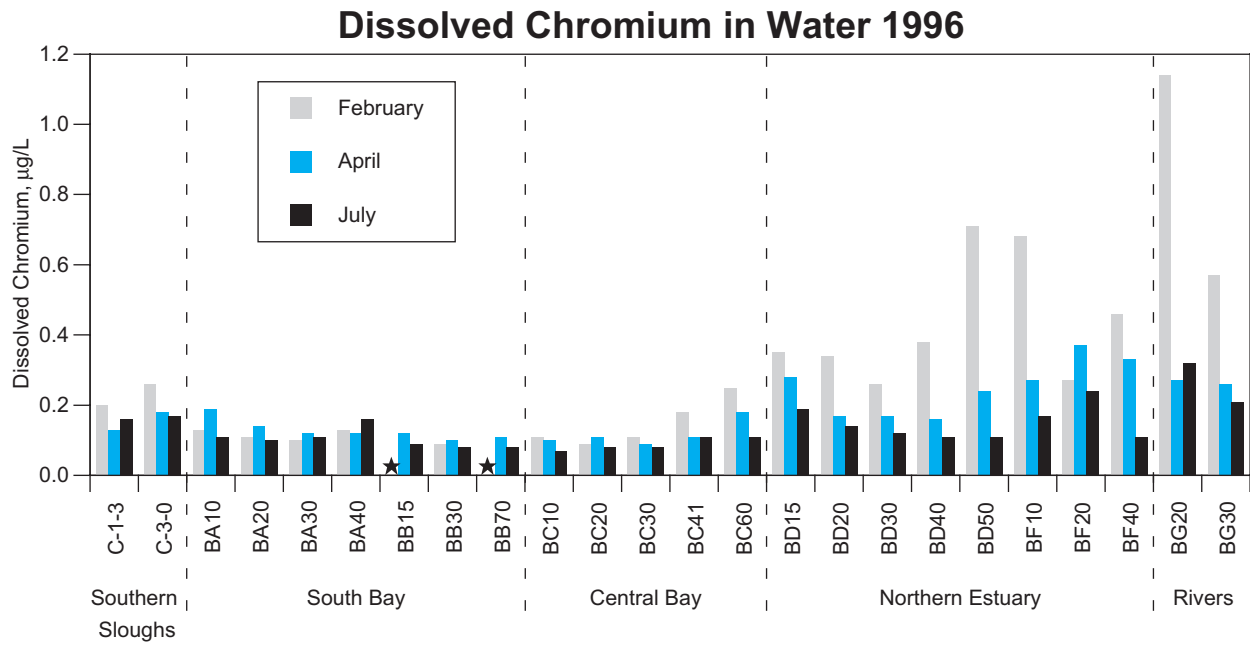

Figure 8. Dissolved chromium (Cr) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. ★ = not analyzed. Dissolved chromium concentrations ranged from 0.07 ppb to 1.14 ppb. The highest concentration was sampled at Sacramento River (BG20) in February and the lowest at Yerba Buena Island (BC10) in July. Average concentrations were highest at the River Stations in February (0.86 ppb) and lowest in the Central Bay in July (0.09 ppb). In general, concentrations were highest in February. All samples were below the 4-day average WQC for dissolved chromium VI (saltwater 50 ppb, freshwater 11 ppb).

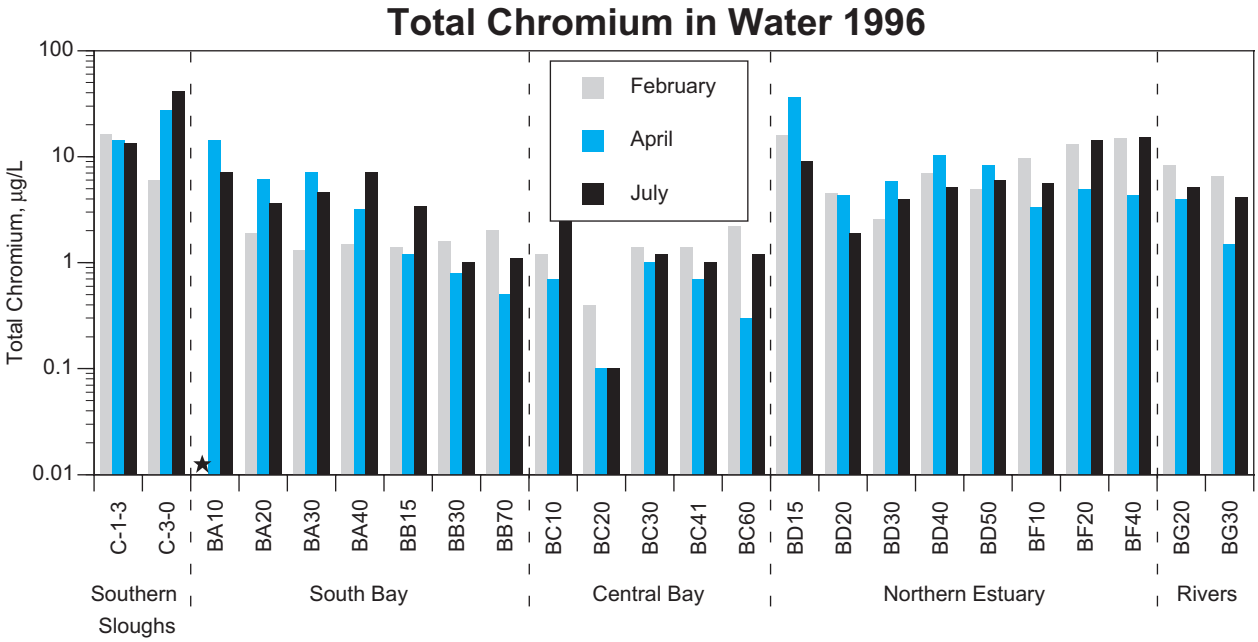

Figure 9. Total chromium (Cr) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Note logarithmic scale. ★ = not analyzed. Total chromium concentrations ranged from 0.10 ppb to 41.00 ppb. The highest concentration was sampled at San Jose (C-3-0) in July and the lowest at Golden Gate (BC20) in April and July. Average concentrations were highest in the Southern Sloughs in July (27.15 ppb) and lowest in the Central Bay in April (0.56 ppb). In general, concentrations were highest in April and lowest in July. Six samples were above the 4-day average WQC for total chromium VI (saltwater 50 ppb, freshwater 11 ppb).

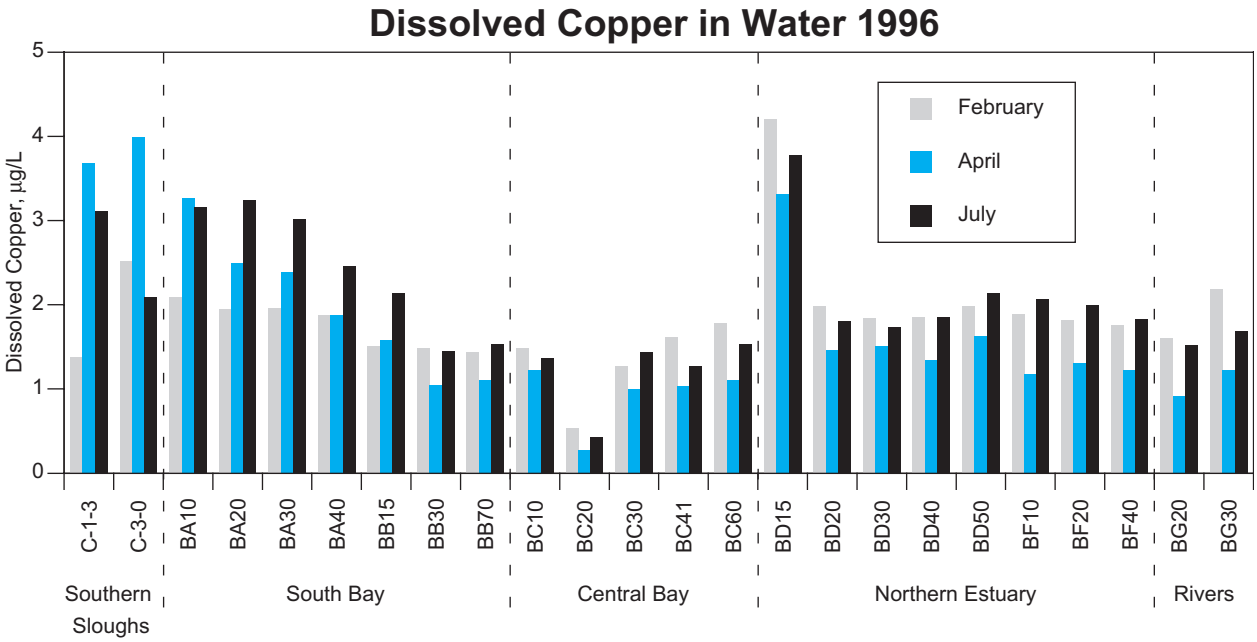

Figure 10. Dissolved copper (Cu) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Dissolved copper concentrations ranged from 0.27 to 4.20 ppb. The highest concentration was sampled at Petaluma River (BD15) in February and the lowest at Golden Gate (BC20) in April. Average concentrations were highest in the Southern Sloughs in April (3.84 ppb) and lowest in the Central Bay in April (0.93 ppb). Nine samples were above the 4-day average WQC for dissolved copper (saltwater 3.1, freshwater—hardness dependent).

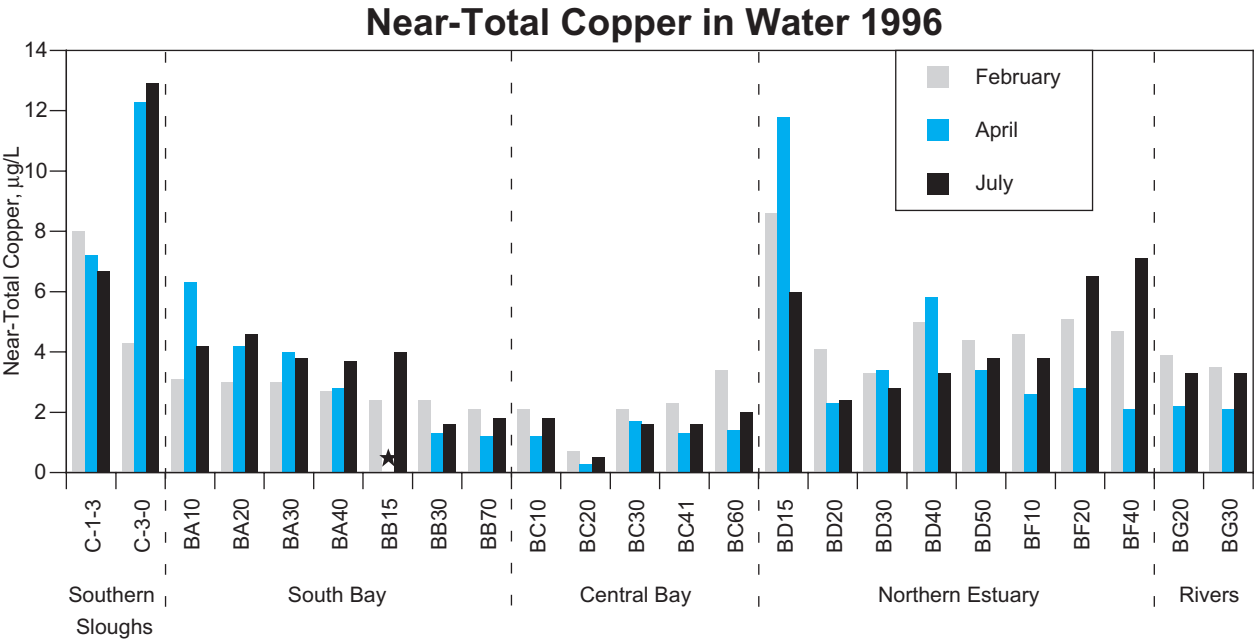

Figure 11. Near-total copper (Cu) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. ★ = not analyzed. Near-total copper concentrations ranged from 0.3 to 12.9 ppb. The highest concentration was sampled at San Jose (C-3-0) in July and the lowest at Golden Gate (BC20) in April. Average concentrations were highest in the Southern Sloughs (9.80 ppb) in July, and lowest in the Central Bay in April (1.18 ppb). Twenty six samples were above the WQC for total copper (saltwater 3.7 ppb, freshwater—hardness dependent).

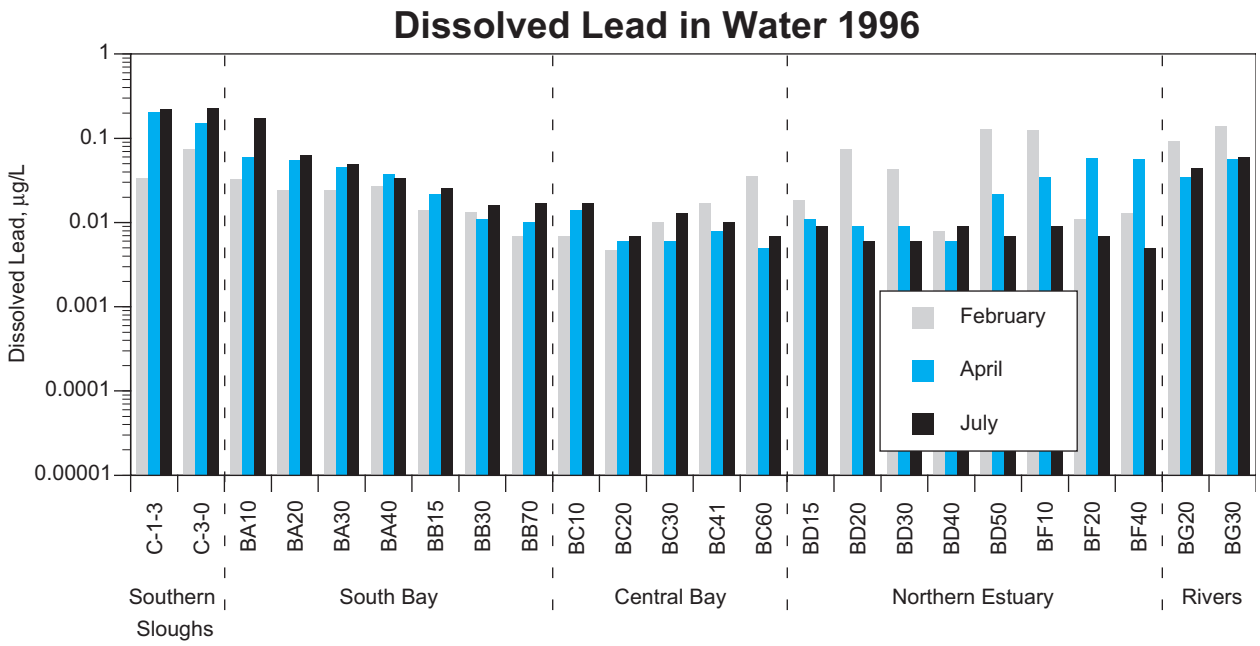

Figure 12. Dissolved lead (Pb) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Note logarithmic scale. Dissolved lead concentrations ranged from 0.005 to 0.225 ppb. The highest concentration was sampled at San Jose (C-3-0) in July and the lowest was sampled at Red Rock (BC60) in April. Average concentrations were highest in the Southern Sloughs in July (0.225 ppb) and lowest in the Northern Estuary in July (0.007 ppb). All samples were below the 4-day average WQC for dissolved lead (saltwater 8.1 ppb, freshwater—hardness dependent).

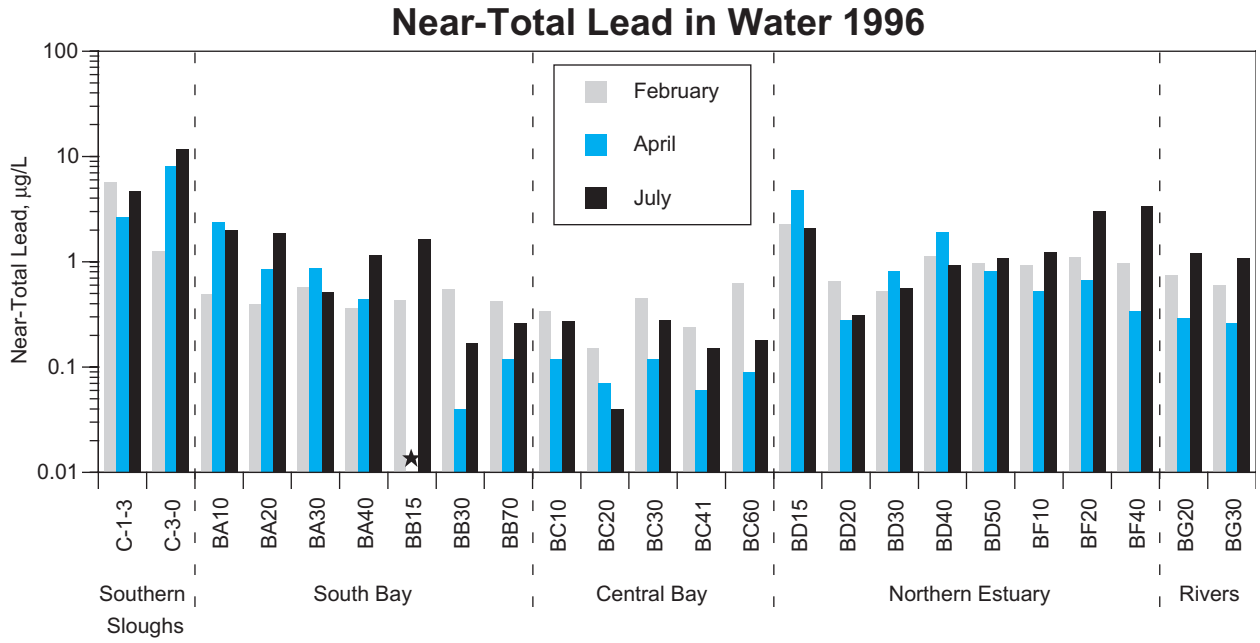

Figure 13. Near-total lead (Pb) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Note logarithmic scale. ★ = not analyzed. Near-total lead concentrations ranged from 0.04 to 11.77 ppb. The highest concentration was sampled at San Jose (C-3-0) in July and the lowest at Golden Gate (BC20) in July and and Oyster Point (BB30) in April. Average concentrations were highest in the Southern Sloughs in July (8.23 ppb) and lowest in the Central Bay in April (0.09 ppb). Four samples were above the 4-day average WQC for total lead (saltwater 8.5 ppb, freshwater—hardness dependent).

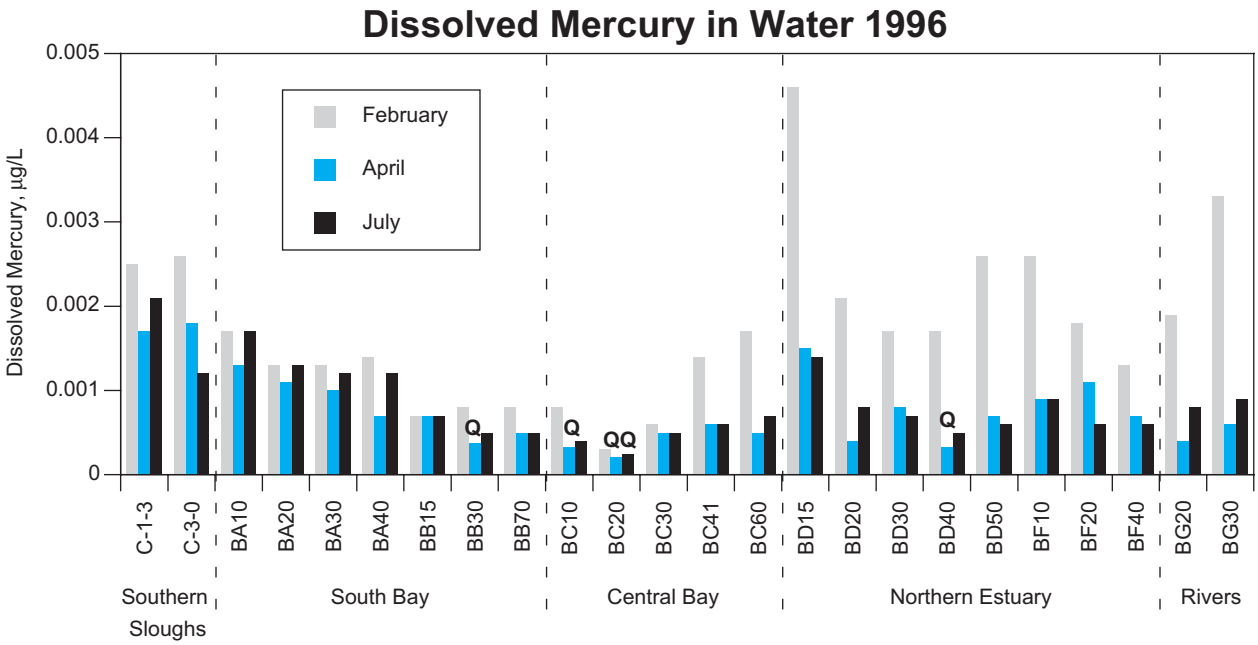

Figure 14. Dissolved mercury (Hg) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Q = less than limit of quantitation. Dissolved mercury concentrations ranged from Q to 0.0046 ppb. The highest concentration was at Petaluma River (BD15) in February and the lowest at Golden Gate (BC20) in February. Average concentrations were highest in the Rivers in February (0.00261 ppb) and lowest in the Northern Estuary in July (0.00021 ppb). In general, concentrations were highest in February and lowest in April and July. Mercury is compared to WQC on a total basis (see below).

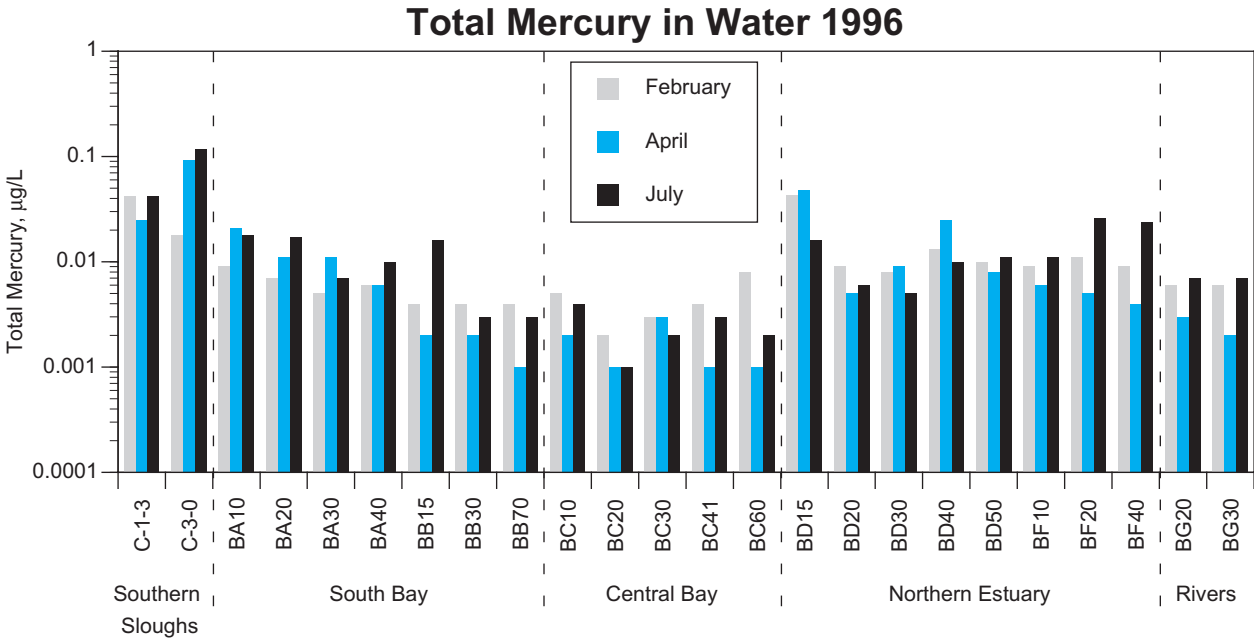

Figure 15. Total mercury (Hg) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Note logarithmic scale. Total mercury concentrations ranged from 0.001 ppb to 0.118 ppb. The highest concentration was at San Jose (C-3-0) in July and the lowest at Golden Gate (BC20) in April and July. Average concentrations were highest in the Southern Sloughs in July (0.080 ppb) and lowest in the Central Bay in April (0.0015 ppb). Fourteen samples were above the 4-day average WQC for total mercury (saltwater 0.025 ppb, freshwater 0.012 ppb).

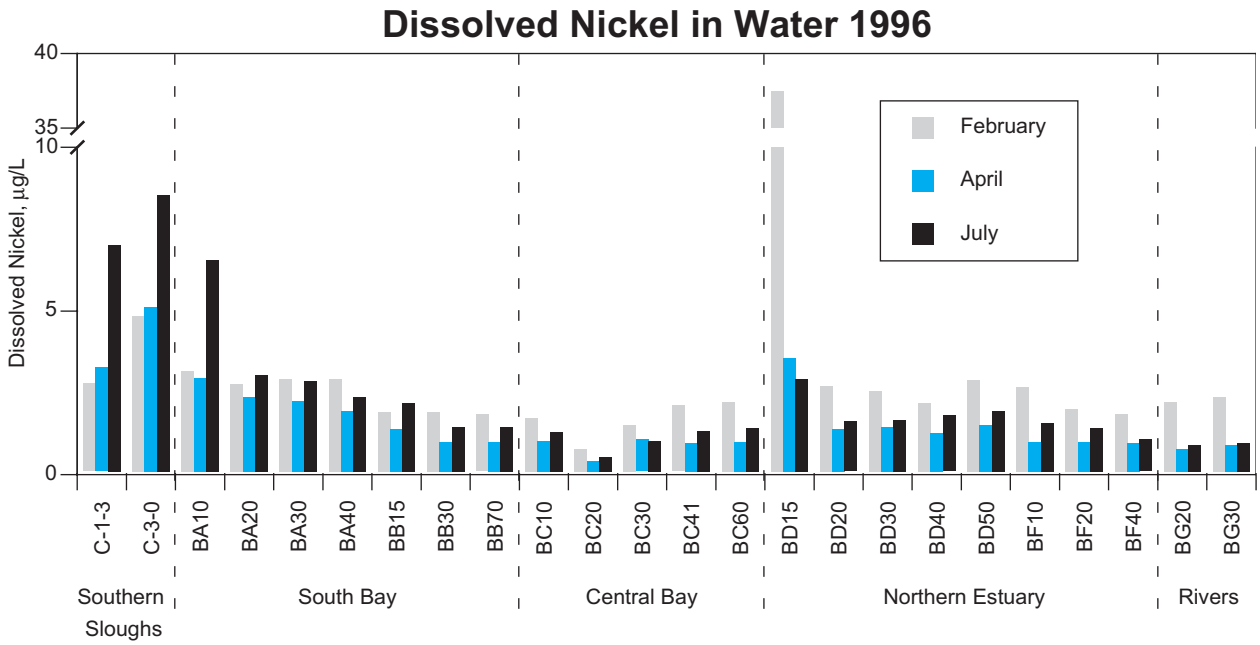

Figure 16. Dissolved nickel (Ni) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Dissolved nickel concentrations ranged from 0.43 to 37.41 ppb. The highest concentration was sampled at Petaluma River (BD15) in February and the lowest at Golden Gate (BC20) in April. Average concentrations were highest in the Southern Sloughs in July (7.79 ppb) and lowest in the Rivers in April (0.84 ppb). In general, concentrations were highest in April and lowest in July. Two samples were above the 4-day average WQC for dissolved nickel (saltwater 8.2, freshwater—hardness dependent).

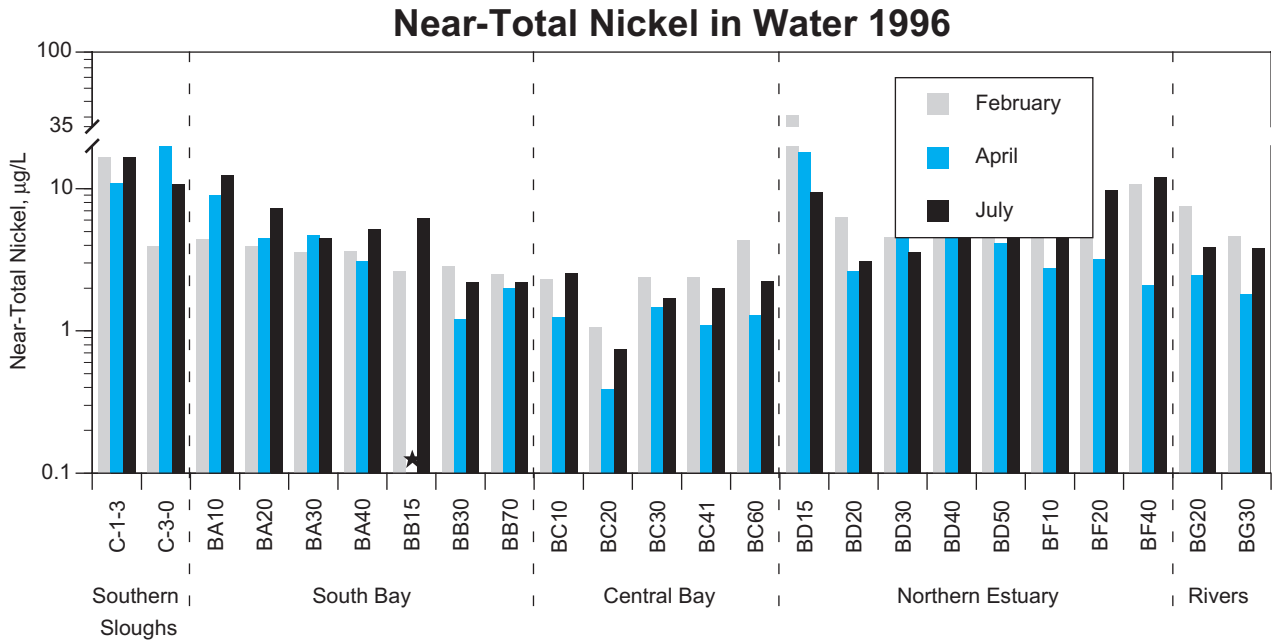

Figure 17. Near-total nickel (Ni) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Note logarithmic scale. ★ = not analyzed. Near-total nickel concentrations ranged from 0.39 to 41.30 ppb. The highest concentration was sampled at Petaluma River (BD15) in February and the lowest at Golden Gate (BC20) in April. Average concentrations were highest in the Southern Sloughs in April (16.29 ppb) and lowest in the Central Bay in April (1.09 ppb). Concentrations were generally lowest in July. Sixteen samples were above the 4-day average WQC for total nickel (saltwater 8.3 ppb, freshwater—hardness dependent).

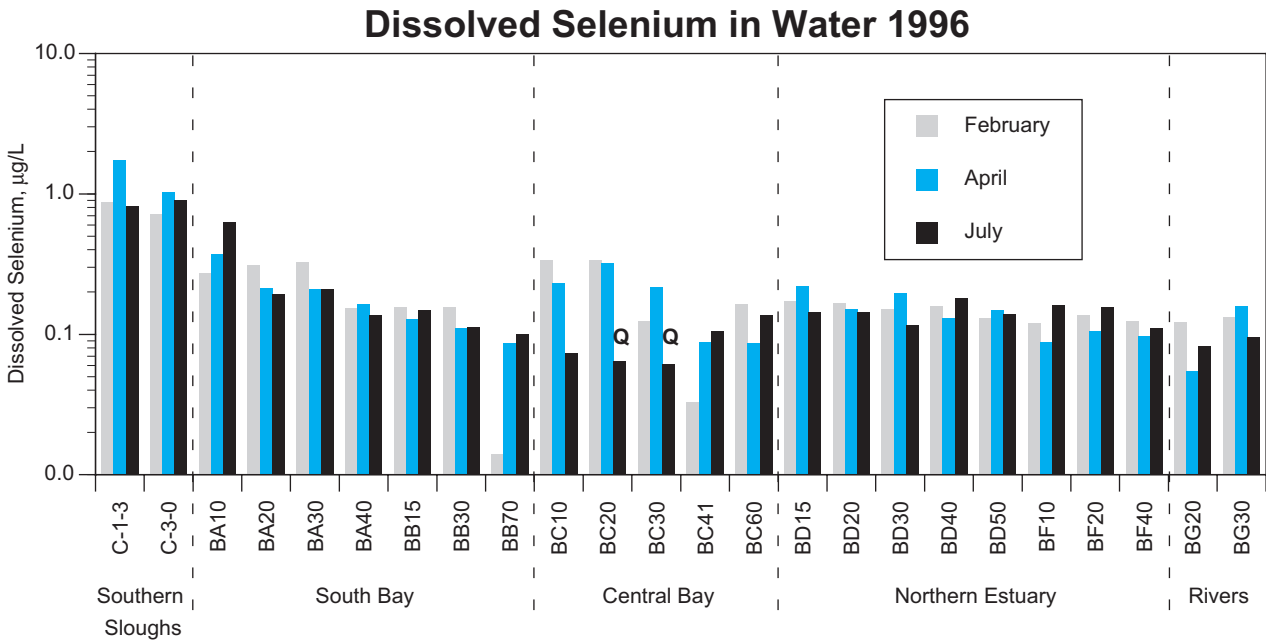

Figure 18. Dissolved selenium (Se) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Note logarithmic scale. Q = less than limit of quantitation. Dissolved selenium concentrations ranged from Q to 1.75 ppb. The highest concentration was sampled at Sunnyvale (C-1-3) in April, and the lowest was sampled at Alameda (BB70) in February. Average concentrations were highest in the Southern Sloughs in April (1.39 ppb) and lowest in the Rivers in July (0.088 ppb). Selenium is compared to WQC on a total basis (see below).

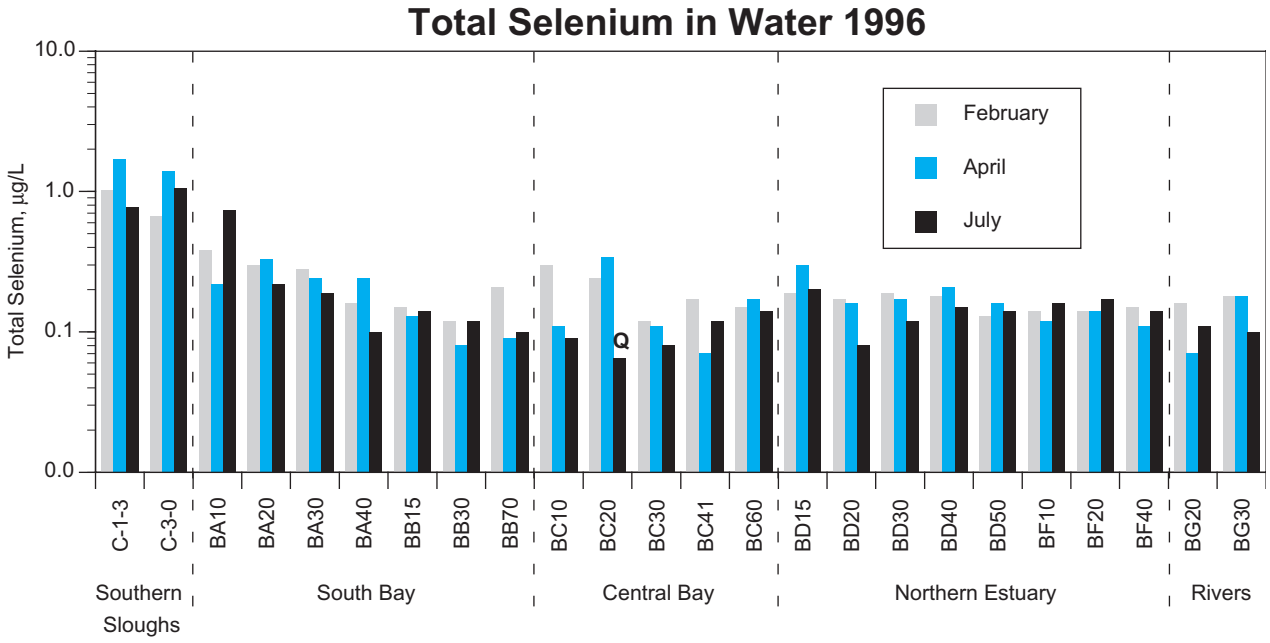

Figure 19. Total selenium (Se) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Note logarithmic scale. Q = less than limit of quantitation. Total selenium concentrations ranged from 0.07 ppb to 1.70 ppb. The highest concentration was sampled at Sunnyvale (C-1-3) in April, and the lowest at Point Isabel (BC41) in April. Average concentrations were highest in the Southern Sloughs in April (1.55 ppb) and lowest in the Rivers in July (0.10 ppb). All samples were below the WQC for total selenium (5 ppb for the entire San Francisco Estuary).

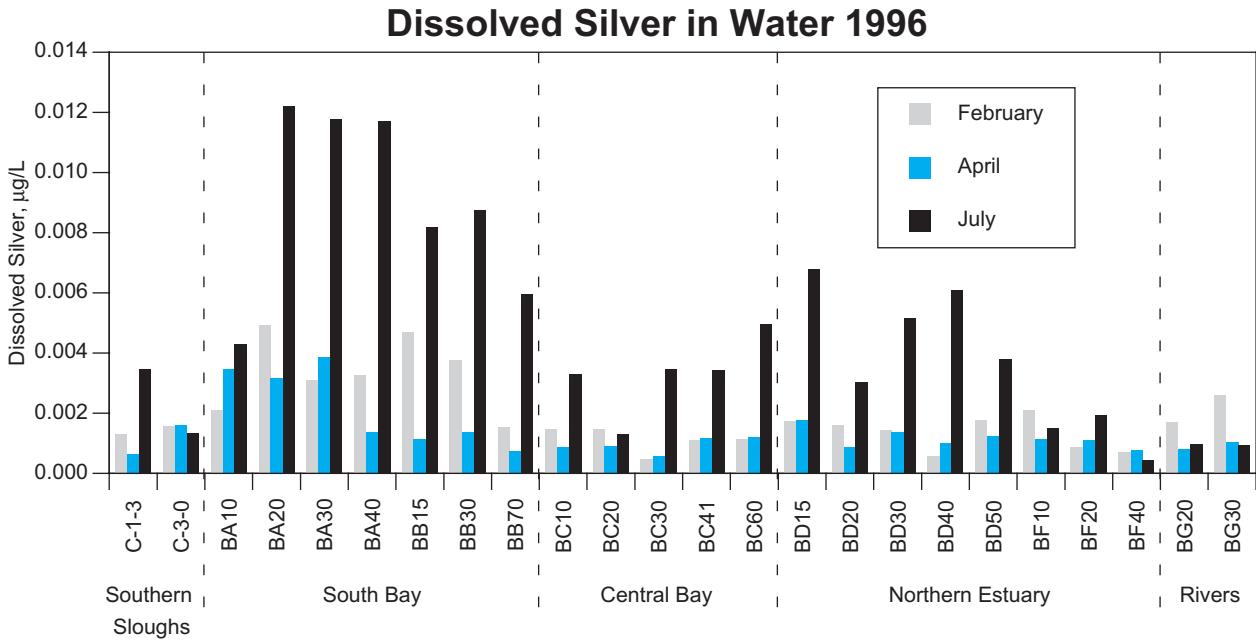

Figure 20. Dissolved silver (Ag) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Dissolved silver concentrations ranged from 0.0004 to 0.0122 ppb. The highest concentration was sampled at South Bay (BA20) in July, and the lowest at Honker Bay (BF40) in July. Average concentrations were highest in the South Bay in July (0.009 ppb) and lowest in the Rivers in February (0.0009 ppb). In general, concentrations were highest in July. All samples were below the 1-hour maximum WQC for dissolved silver (saltwater 1.9 ppb, freshwater—hardness dependent).

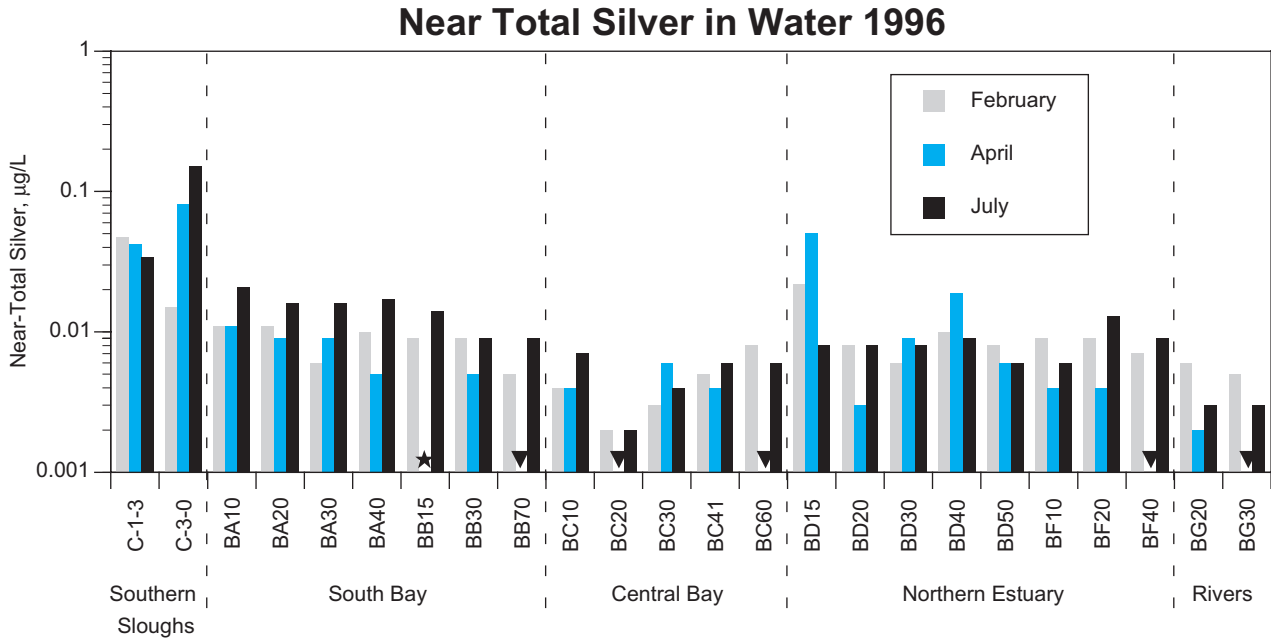

Figure 21. Near-total silver (Ag) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. ★ = not analyzed. ▼ = below detection limit. Near-total silver concentrations ranged from below detection limit to 0.152 ppb. The highest concentration was sampled at San Jose (C-3-0) in July. Average concentrations were highest in the Southern Sloughs in July (0.093 ppb) and lowest in the Rivers in April (0.002 ppb). No consistent seasonal variation was observed. All samples were below the 1-hour maximum WQC for total silver (saltwater 2.2 ppb, freshwater—hardness dependent).

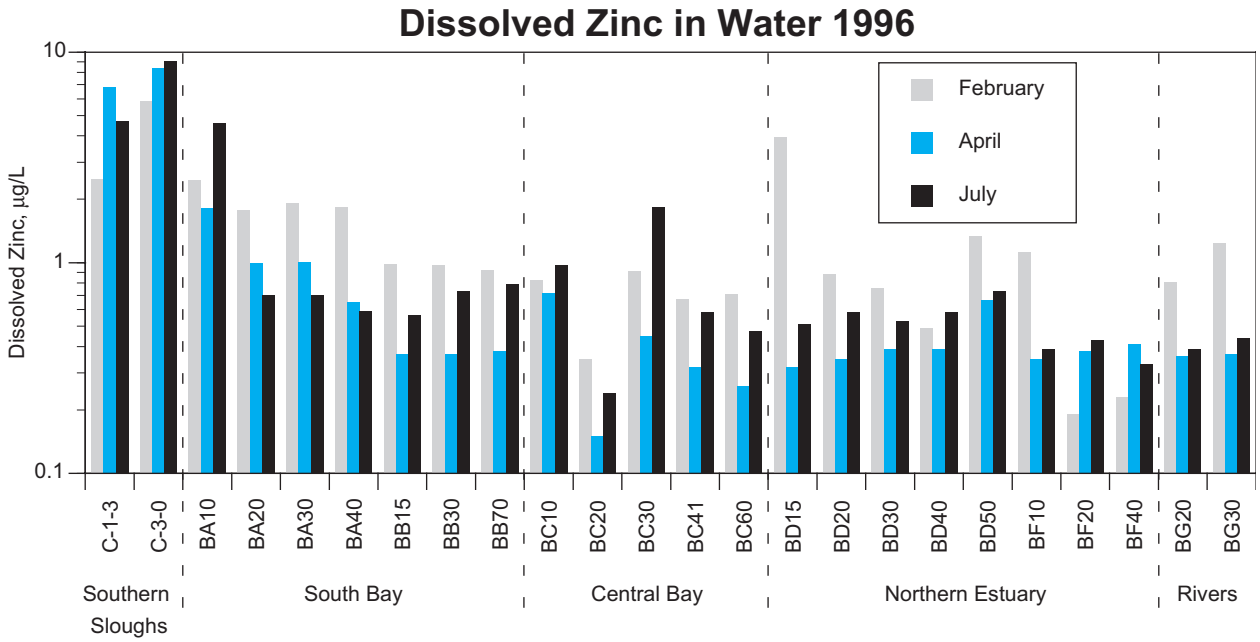

Figure 22. Dissolved zinc (Zn) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. Note logarithmic scale. Dissolved zinc concentrations ranged from 0.15 to 9.03 ppb. The highest concentration was sampled at San Jose (C-3-0) in July and the lowest at Golden Gate (BC20) in April. Average concentrations were highest in the Southern Sloughs in April (7.63 ppb) and lowest in the Rivers in April (0.37 ppb). In general concentrations were highest in February. All samples were below the 4-day average WQC for dissolved zinc (saltwater 81 ppb, freshwater—hardness dependent).

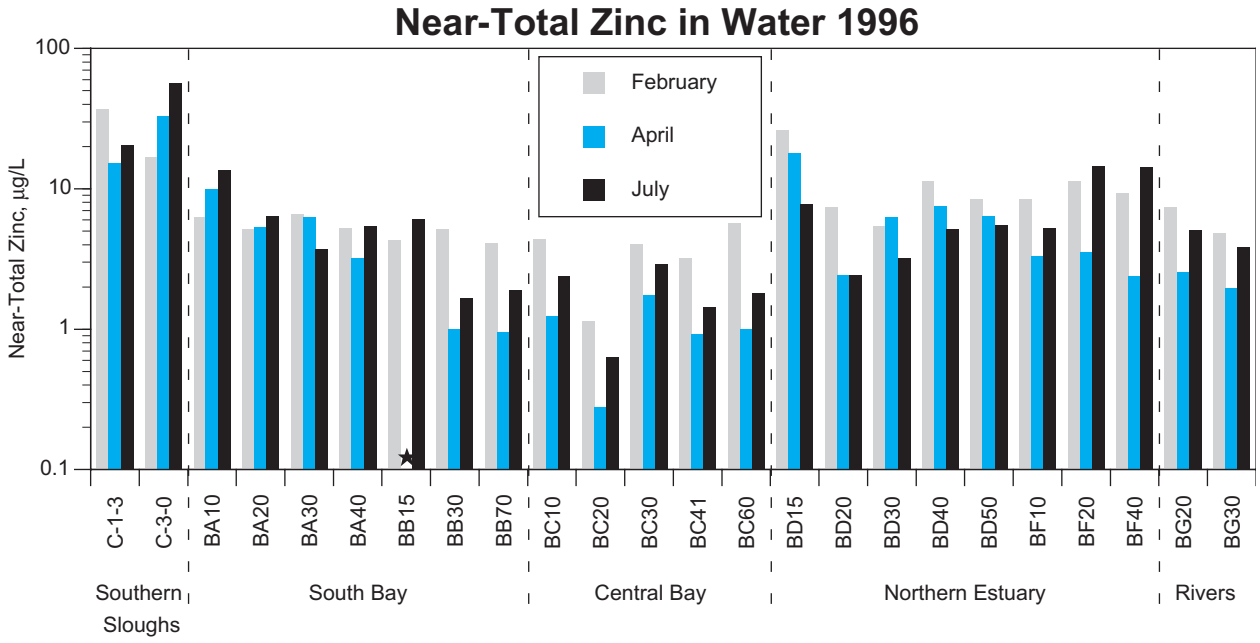

Figure 23. Near-total zinc (Zn) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and July of 1996. ★ = not analyzed. Note logarithmic scale. Near-total zinc concentrations ranged from 0.28 to 56.64 ppb. The highest concentration was sampled at San Jose (C-3-0) in July and the lowest at Golden Gate (BC20) in April. Average concentrations were highest in the Southern Sloughs in July (38.54 ppb) and lowest in the Central Bay in April (1.04 ppb). All samples were below the 4-day average WQC for total zinc (saltwater 86 ppb, freshwater—hardness dependent).

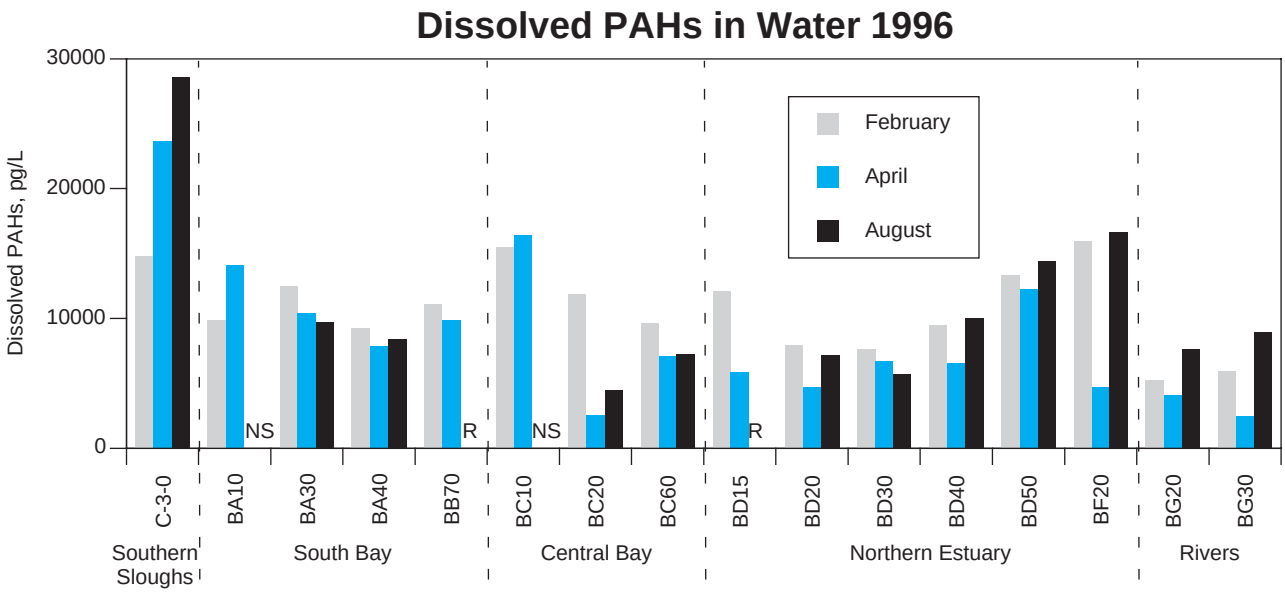

Figure 24. Dissolved PAH concentrations in water (ppq) at 16 RMP stations sampled in February, April, and August 1996. NS = not sampled, R = unacceptably low surrogate recoveries. Dissolved PAH concentrations ranged from 2,503 to 28,627 ppq (see Appendix B for MDLs). The highest concentration was sampled at San Jose (C-3-0) in August, and the lowest at San Joaquin River (BG20) in April. Average concentrations were highest in the Central Bay in February (12,342 ppq) and lowest in the Rivers in April (3,295 ppq).

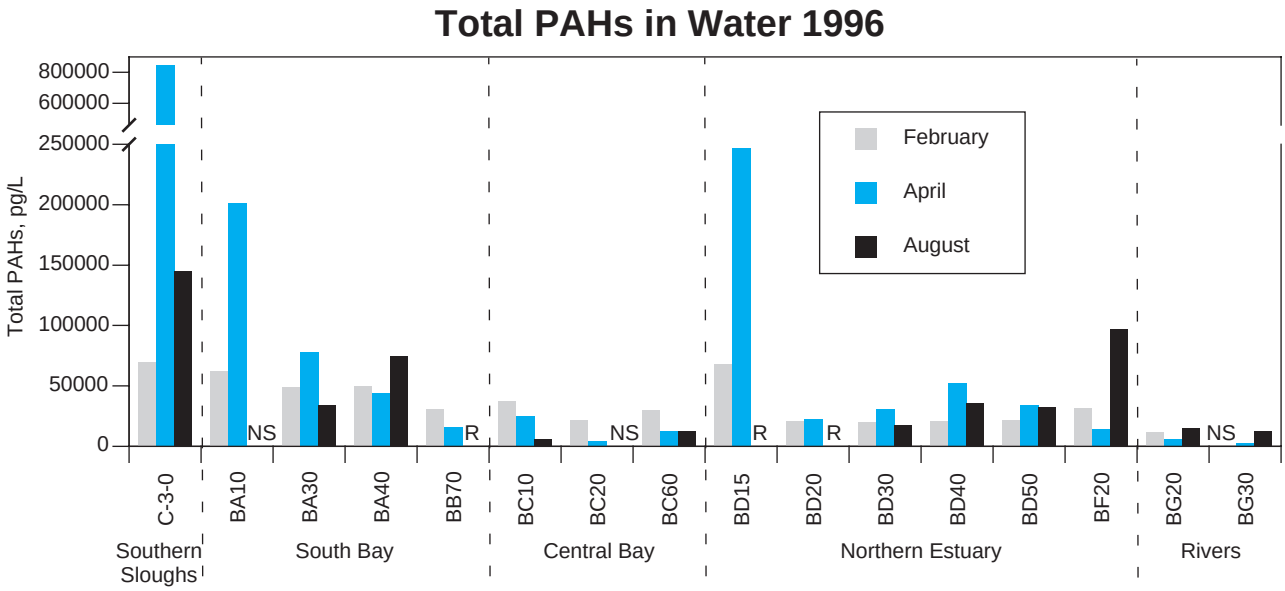

Figure 25. Total PAH concentrations in water (ppq) at 16 RMP stations sampled in February, April, and August 1996. NS = not sampled, R = unacceptably low surrogate recoveries. Total PAH concentrations ranged from 3,830 to 847,025 ppq (see Appendix B for MDLs). The highest concentration was sampled at San Jose (C-3-0) in April, and the lowest at Golden Gate (BC20) in April. Average concentrations were highest in the South Bay in April (84,582 ppq) and lowest in the Rivers in April (4,420 ppq). Three samples were above individual PAH criteria from the proposed California Toxics Rule (CTR; see Table 7, this chapter), however, there are no CTR criteria for total PAHs. Twenty-one samples were above the water quality criterion for total PAHs from the US EPA National Toxics Rule (US EPA, 1992) of 31,000 ppq.

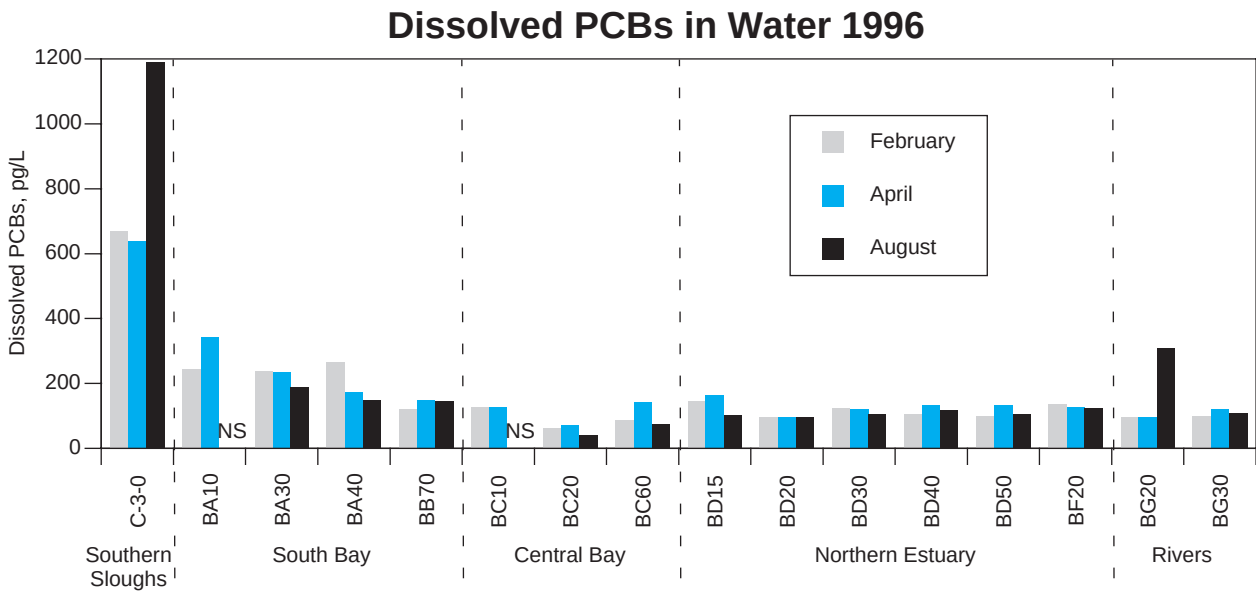

Figure 26. Dissolved PCB concentrations in water (ppq) at 16 RMP stations sampled in February, April, and August 1996. NS = not sampled. Dissolved PCB concentrations ranged from 41 to 1,190 ppq (see Appendix B for MDLs). The highest concentration was sampled at San Jose (C-3-0), and the lowest at Golden Gate (BC20), both in August. Average concentrations were highest in the South Bay in April (224 ppq) and lowest in the Central Bay in August (58 ppq).

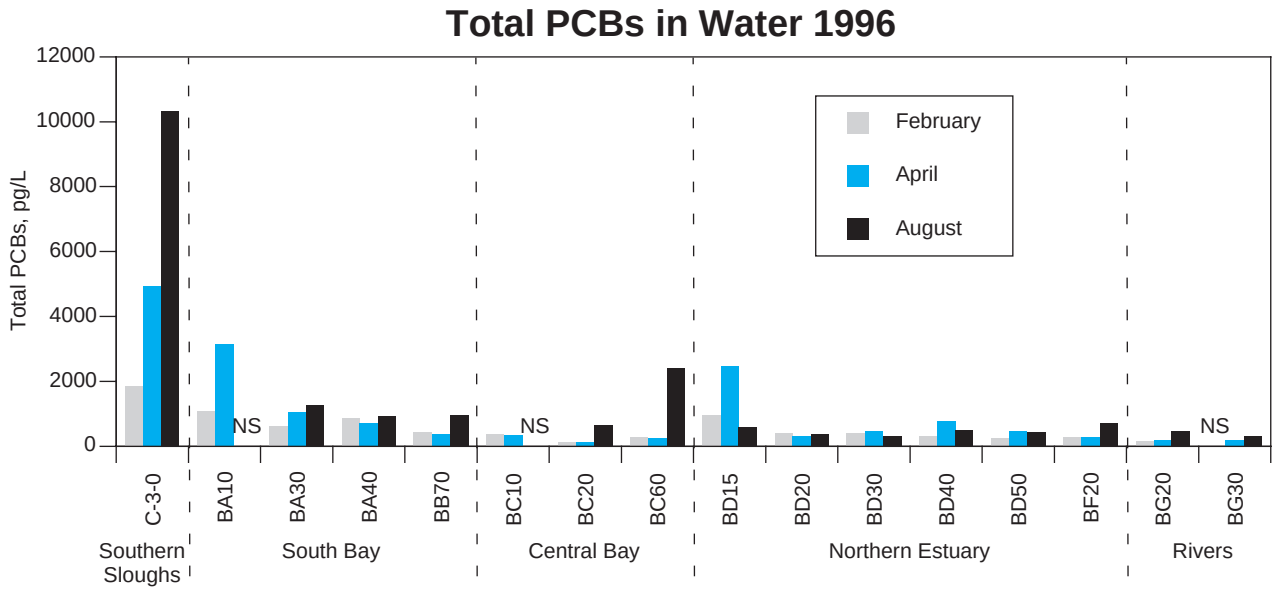

Figure 27. Total PCB concentrations in water (ppq) at 16 RMP stations sampled in February, April, and August 1996. NS = not sampled. Total PCB concentrations ranged from 125 to 10,313 ppq (see Appendix B for MDLs). The highest concentration was sampled at San Jose (C-3-0) in August, and the lowest at Golden Gate (BC20) in April. Average concentrations were highest in the Central Bay in August (1,526 ppq) and lowest in the Rivers in February (165 ppq). All but three samples were above the human health WQC for total PCB of 170 ppq.

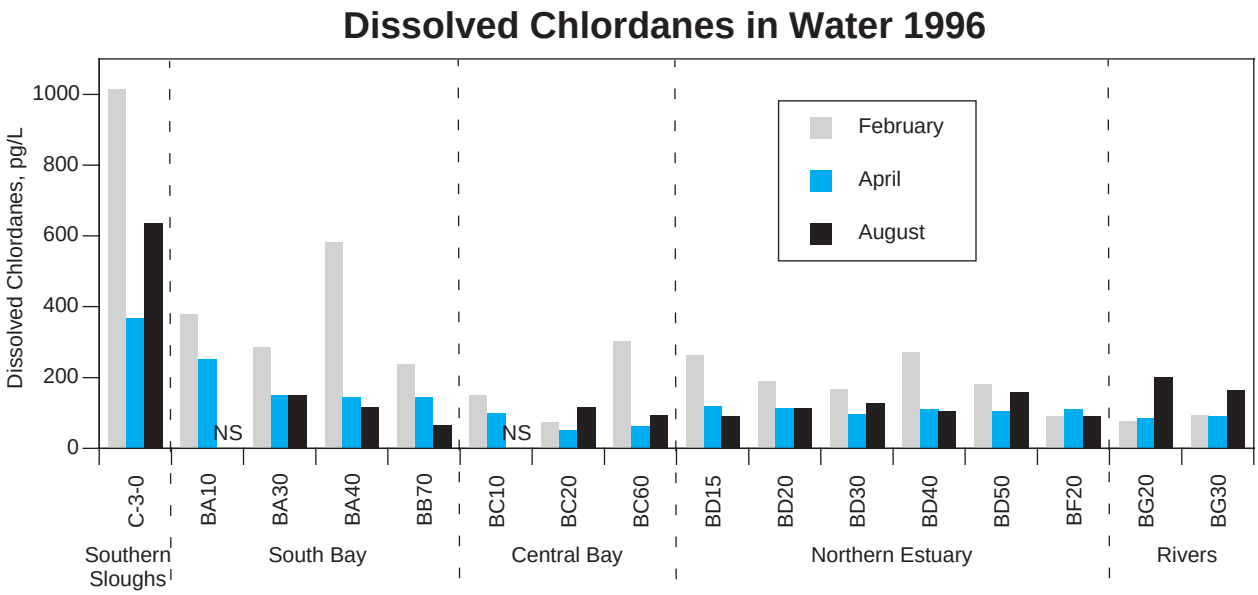

Figure 28. Dissolved chlordane concentrations in water (ppq) at 16 RMP stations sampled in February, April, and August 1996. NS = not sampled. Dissolved chlordane concentrations ranged from 52 to 1,014 ppq (see Appendix B for MDLs). The highest concentration was sampled at San Jose (C-3-0) in February, and the lowest at Golden Gate (BC20) in April. Average concentrations were highest in the South Bay in February (371 ppq) and lowest in the Central Bay in April (72 ppq).

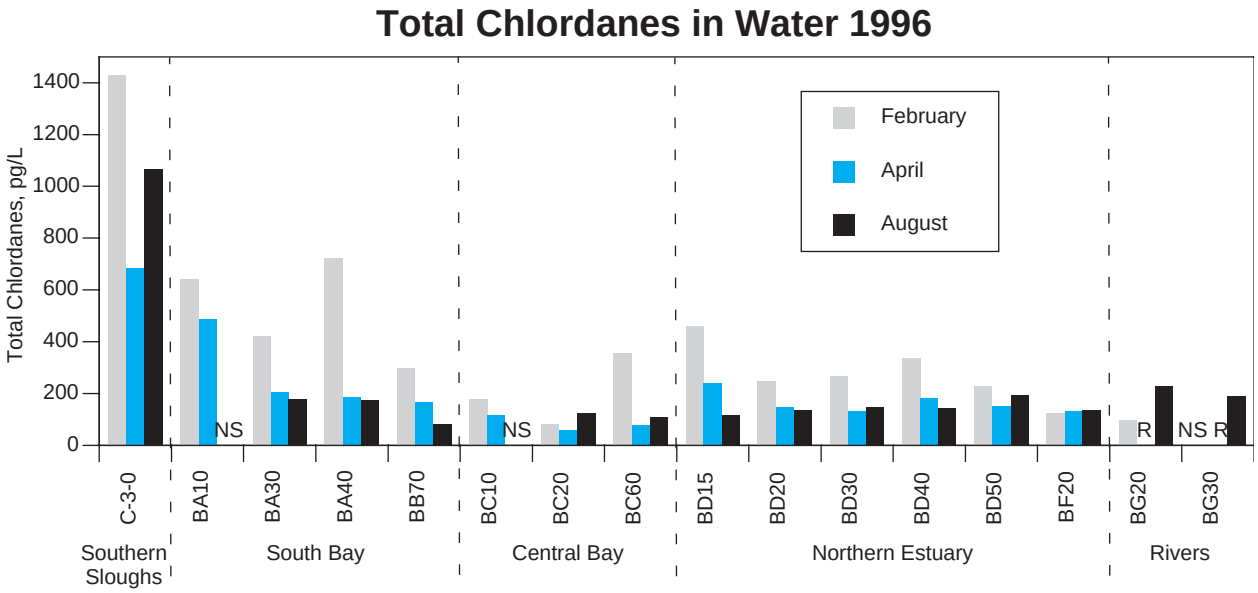

Figure 29. Total chlordane concentrations in water (ppq) at 16 RMP stations sampled in February, April, and August 1996. NS = not sampled, R = unacceptably low surrogate recoveries. Total chlordane concentrations ranged from 59 to 1,429 ppq (see Appendix B for MDLs). The highest concentration was sampled at San Jose (C-3-0) in February, and the lowest at Golden Gate (BC20) in April. Average concentrations were highest in the South Bay in February (522 ppq) and lowest in the Central Bay in April (84 ppq). Five samples were above the WQC for total chlordane of 590 ppq. Two individual chlordane compounds are listed in the proposed California Toxics Rule (Table 7, this chapter). Nine samples were above the heptachlor epoxide WQC of 110 ppq.

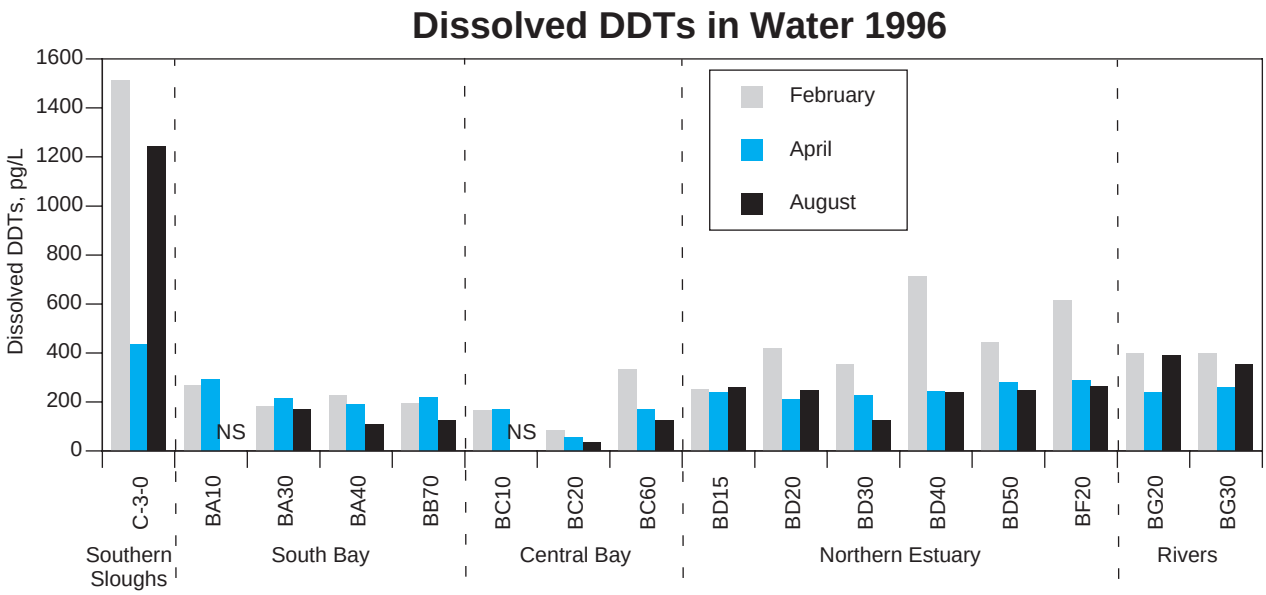

Figure 30. Dissolved DDT concentrations in water (ppq) at 16 RMP stations sampled in February, April, and August 1996. NS = not sampled. Dissolved DDT concentrations ranged from 35 to 1,512 ppq (see Appendix B for MDLs). The highest concentration was sampled at San Jose (C-3-0) in February, and the lowest at Golden Gate (BC20) in August. Average concentrations were highest in the Northern Estuary in February (465 ppq) and lowest in the Central Bay in August (80 ppq).

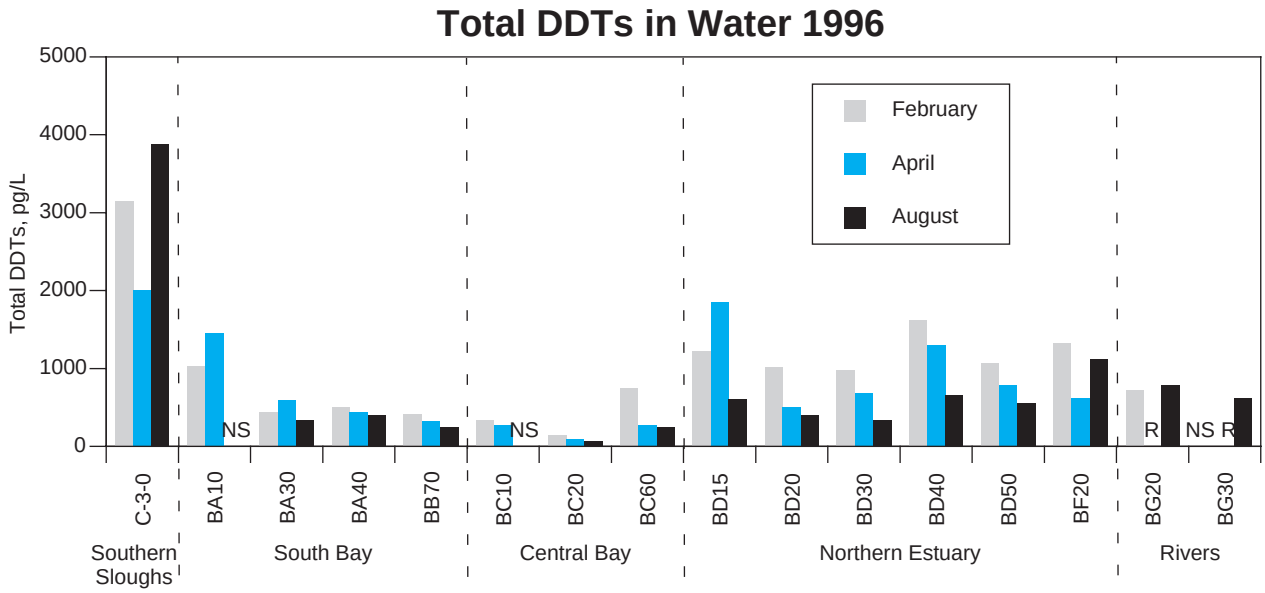

Figure 31. Total DDT concentrations in water (ppq) at 16 RMP stations sampled in February, April, and August, 1996. NS = not sampled, R = unacceptably low surrogate recoveries. Total DDT concentrations ranged from 64 to 3,875 ppq (see Appendix B for MDLs). The highest concentration was sampled at San Jose (C-3-0), and the lowest at Golden Gate (BC20), both in August. Average concentrations were highest in the Northern Estuary in February (1,203 ppq) and lowest in the Central Bay in August (156 ppq). Water quality criteria do not exist for total DDTs although individual compounds have criteria. Ten samples were above the WQC for individual DDT compounds (see Table 9, this chapter).

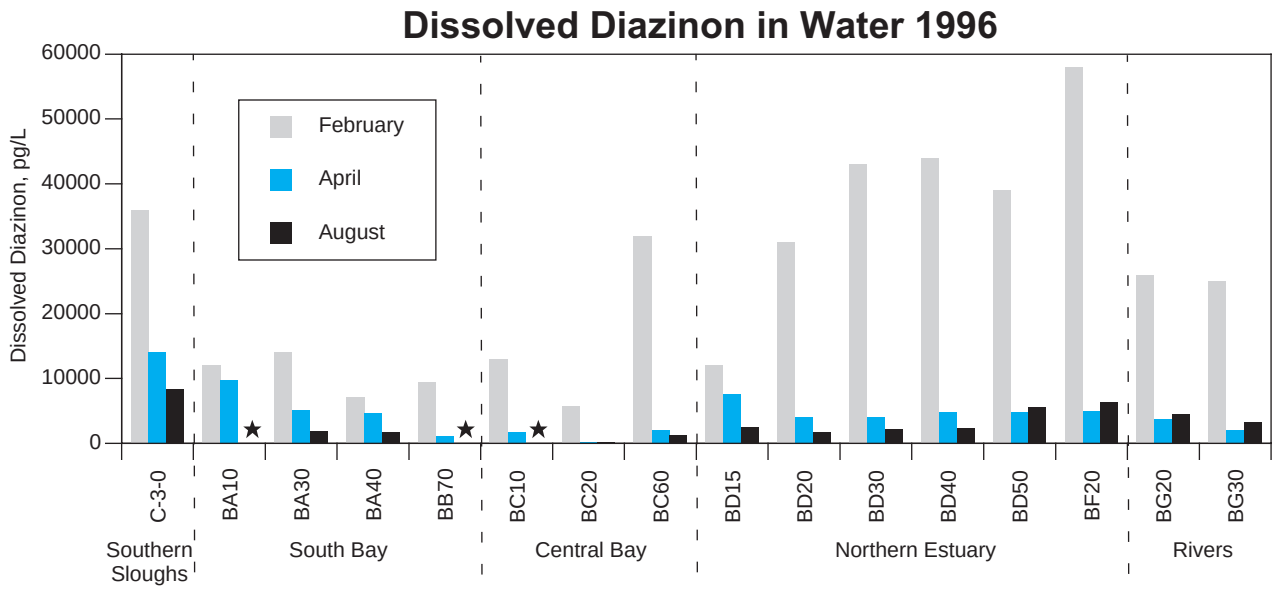

Figure 32. Dissolved diazinon concentrations in water (ppq) at 16 RMP stations sampled in February, April, and August 1996. ★ = not analyzed. Dissolved diazinon concentrations ranged from 190 to 58,000 ppq (see Appendix B for MDLs). The highest concentration was sampled at Grizzly Bay (BF20) in February, and the lowest at Golden Gate (BC20) in August. Average concentrations were highest in the South Bay in February (37,833 ppq) and lowest in the Central Bay in August (745 ppq).

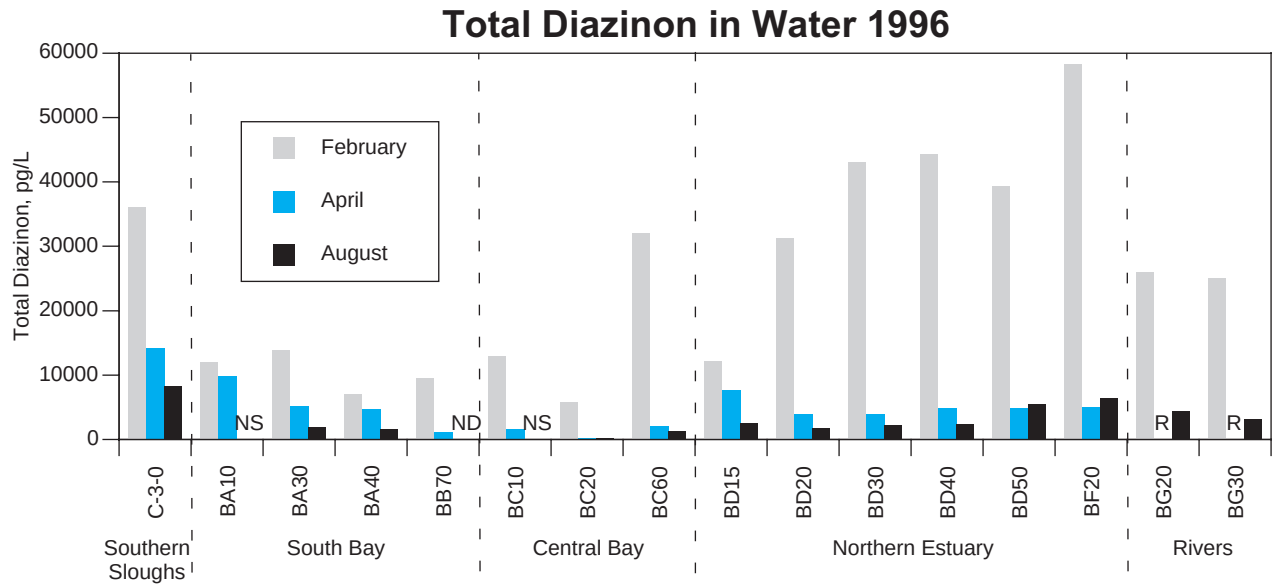

Figure 33. Total diazinon concentrations in water (ppq) at 16 RMP stations sampled in February, April, and August 1996. NS = not sampled, ND = not detected, R = unacceptably low surrogate recoveries. Total diazinon concentrations ranged from 190 to 58,350 ppq (see Appendix B for MDLs). The highest concentration was sampled at Grizzly Bay (BF20) in February, and the lowest at Golden Gate (BC20) in August. Average concentrations were highest in the Northern Estuary in February (38,072 ppq) and lowest in the Central Bay in August (745 ppq). Three samples were above the Department of Fish and Game guideline of 40,000 ppq.

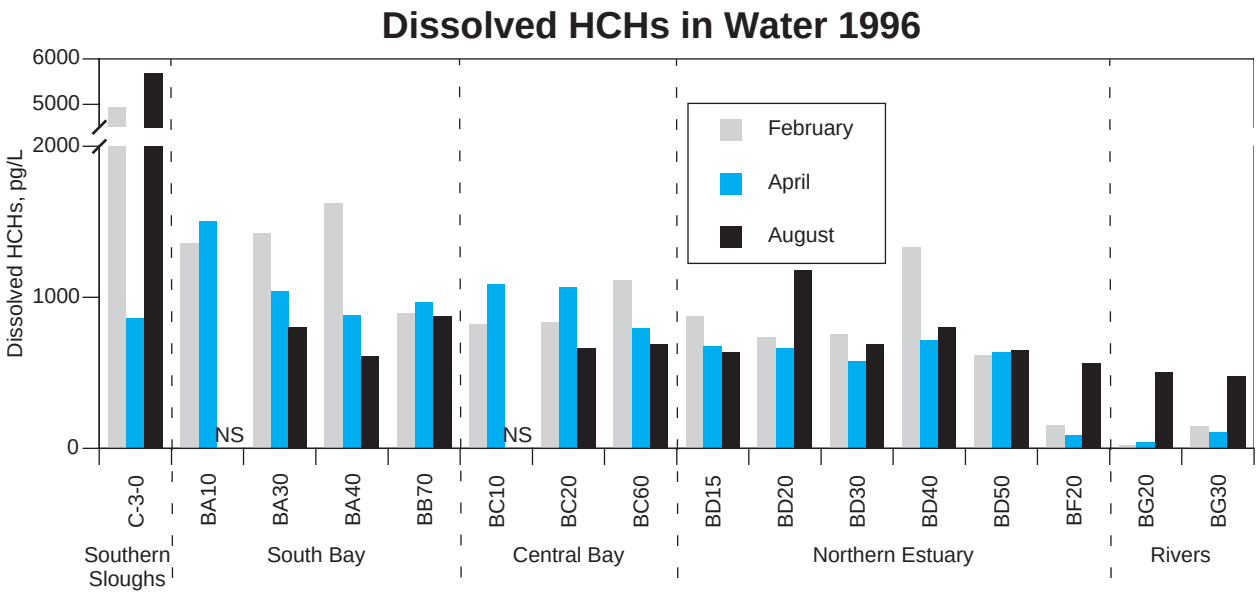

Figure 34. Dissolved HCH concentrations in water (ppq) at 16 RMP stations sampled in February, April, and August 1996. NS = not sampled. Dissolved HCH concentrations ranged from 24 to 5,689 ppq (see Appendix B for MDLs). The highest concentration was sampled at San Jose (C-3-0) in August, and the lowest at Sacramento River (BG20) in February. Average concentrations were highest in the the South Bay in February (1,326 ppq) and lowest in the Rivers in April (74 ppq).

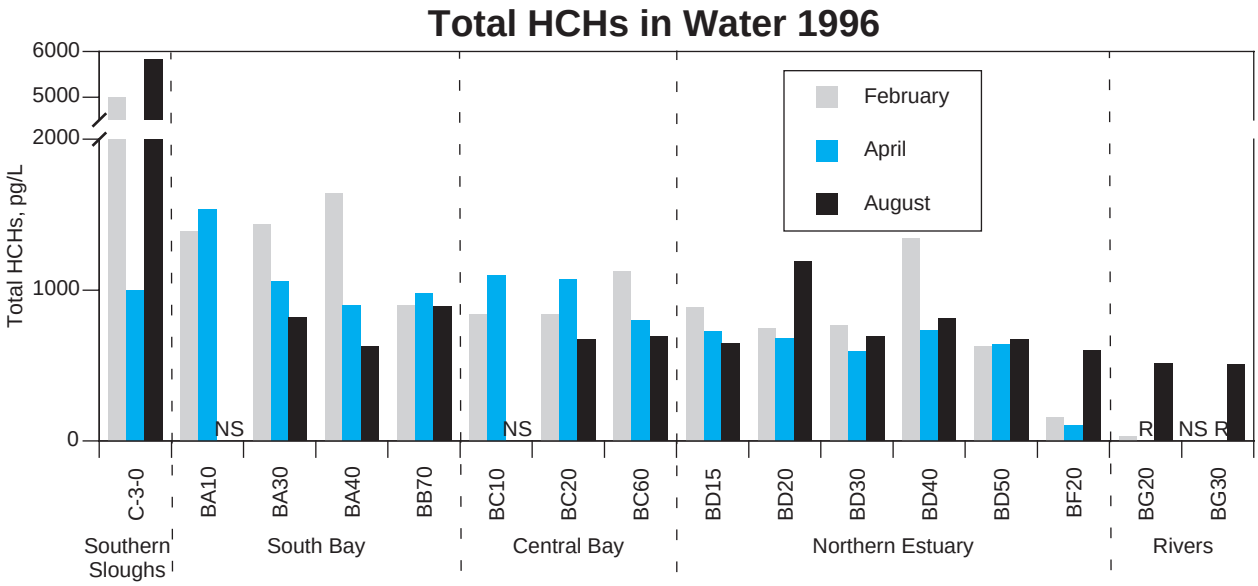

Figure 35. Total HCH concentrations in water (ppq) at 16 RMP stations sampled in February, April, and August 1996. NS = not sampled, R = unacceptably low surrogate recoveries. Total HCH concentrations ranged from 30 to 5,829 ppq (see Appendix B for MDLs). The highest concentration was sampled at San Jose (C-3-0) in August, and the lowest at Sacramento River (BG20) in February. Average concentrations were highest in the South Bay in February (1340 ppq) and lowest in the Rivers in February (30 ppq). Water quality criteria do not exist for total HCHs although individual compounds have criteria. None of the samples were above individual criteria.

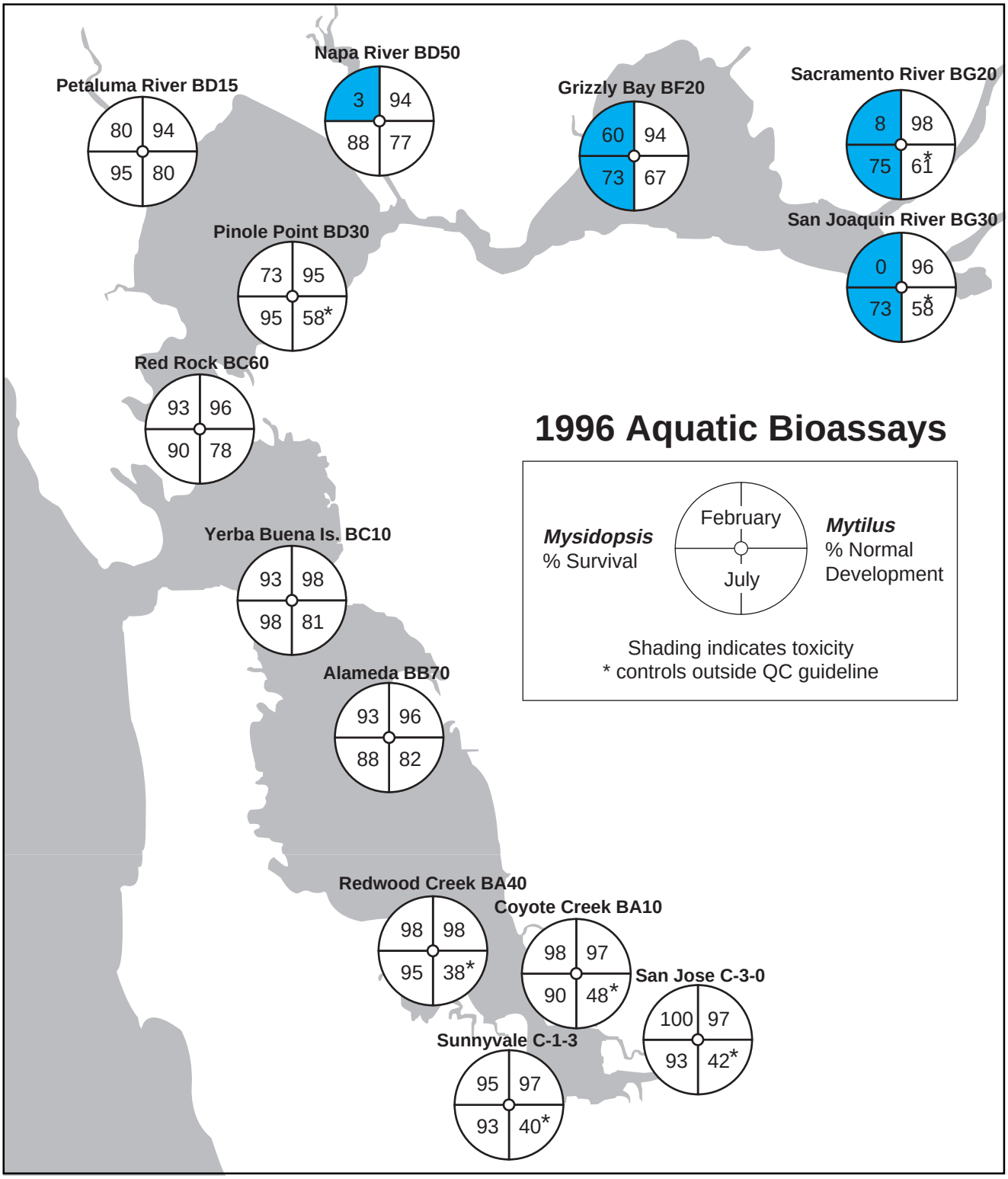

Figure 36. Aquatic bioassay results for 1996. Clean artificial seawater was used for control samples. See *Appendix A* for a description of the methods used. Toxicity was determined by statistical comparison to controls. Toxicity in the seven-day *Mysidopsis* test was observed in both February and July at Grizzly Bay (BF20), Sacramento River (BG20), and San Joaquin River (BG30). Mysid toxicity was also observed at Napa River (BD50) in February. None of the 48-hour tests using *Mytilus* larvae indicated toxicity in either February or July. In the July *Mytilus* tests, controls for nine stations (denoted by *) had less than 70% normal development, which is the quality control guideline (see text for discussion).

Water Monitoring Trends

Trace Elements

Long-term Trends

Long-term trends in total trace element concentrations were examined in detail the *1995 Annual Report* (Jassby, 1996). Increasing or decreasing trends were essentially nonexistent in the data collected from April 1989 to April 1995. Data for 1996 can now be included in long-term trend plots (Figure 37). In general the 1996 data are consistent with previous data and do not alter last year's conclusions.

With data from four years, however, seasonal patterns are becoming apparent and can be seen in the long-term trend plots (Figure 37). For example, cadmium concentrations have shown a consistent pattern of seasonal variation in the four years of RMP sampling. The pattern is clearest in the Central Bay. Cadmium concentrations are relatively low in winter and spring and high in late summer. The seasonal increase during the summer appears to be due to a combination of varying oceanic influence and seasonal variation in cadmium sources within or upstream of the Bay. Arsenic has shown a similar pattern to cadmium in the Northern Estuary and South Bay, but not the Central Bay, suggesting that seasonal variation in in-Bay or upstream sources (and not oceanic influence) causes the pattern seen in the Bay.

Another pattern is becoming clear in nickel concentrations in the Northern Estuary. Near-total nickel concentrations at the Petaluma River (BD15) are consistently high in the winter and spring sampling. While this is partially due to high total suspended solids (TSS) concentrations at this station, dissolved nickel concentrations are also consistently high. The unusually high concentration of near-total nickel in February 1996 actually consisted of 90% dissolved nickel. Sampling began at the Petaluma River station (BD15) in 1994 and dissolved nickel has been consistently high at this station, especially in February and April. These data strongly suggest the presence of a source of nickel in the Petaluma River watershed. This source is especially evident when salinity at this station is low, indicating that the nickel is transported during periods of freshwater runoff.

Several trace elements exhibit a seasonal pattern in total concentrations in the Northern Estuary (chromium, copper, lead, mercury, silver, and zinc) but this is largely driven by seasonal variation in TSS. This pattern was weak in 1996 due to relatively little seasonal variation in TSS in the Northern Estuary.

Trace Organic Contaminants

Long-term Trends

Long-term trend plots for total trace organic concentrations are provided in Figure 38. As for many trace elements, total concentrations of many trace organics are highly correlated with concentrations of TSS and this obscures real trends in the long-term dataset. In general, increasing or decreasing trends are not apparent in the data. Long-term seasonality is evident in the plot for diazinon, with high concentrations in February sampling for the past three years.Diazinon concentrations in February 1996 included the highest RMP values yet recorded for the Northern Estuary and Central Bay.

References

Jassby, A.D 1996. Methods for analysis of spatial and temporal patterns: Summary and conclusions. *In:* 1995 Annual Report: San Francisco Estuary Regional Monitoring Program for Trace Substances. Prepared by the San Francisco Estuary Institute, Richmond, CA. pp. 44–52.

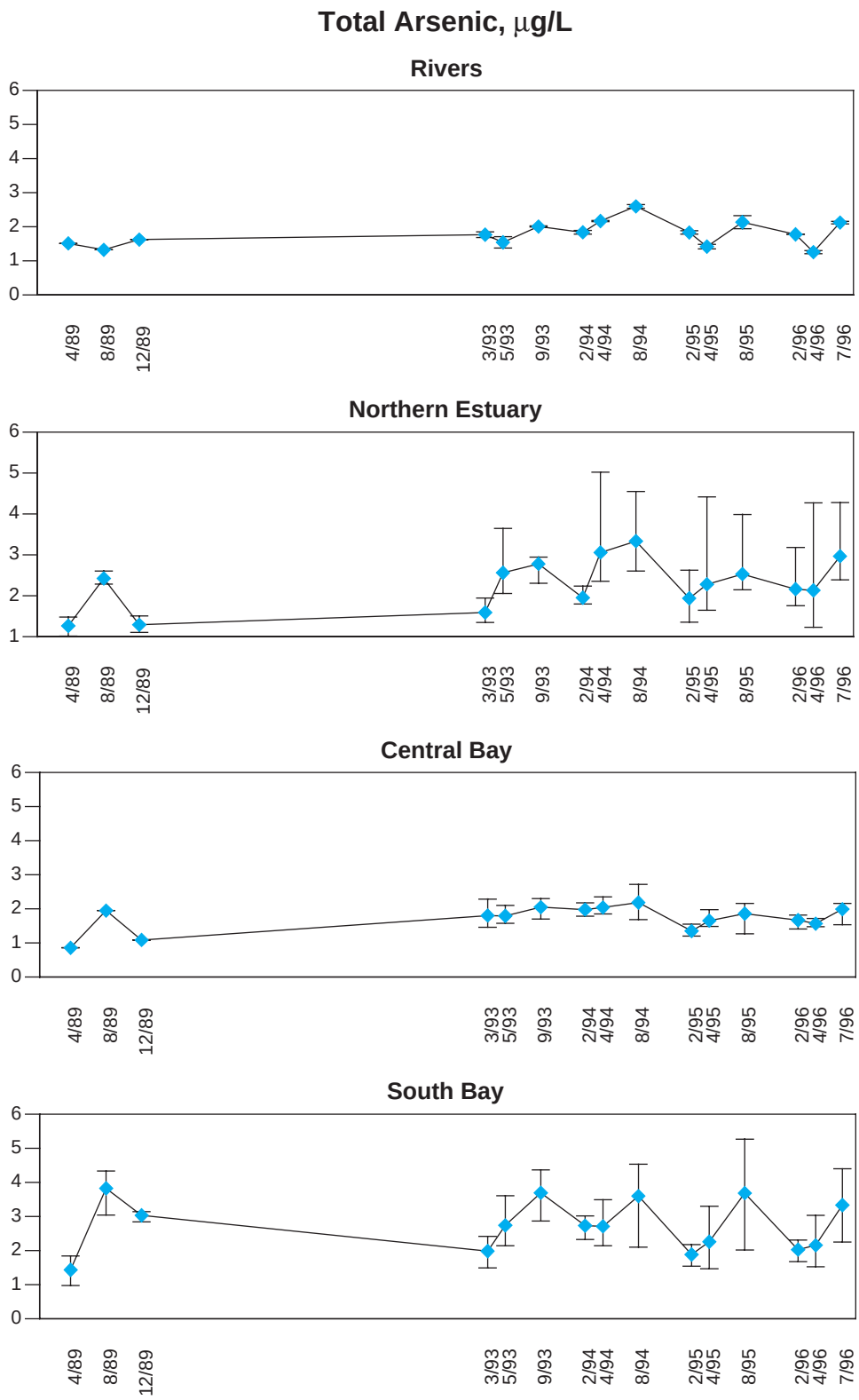

Figure 37. Plots of average trace element concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1996. The vertical bars represent ranges of values. Sample sizes are as follows: South Bay 1989–1993 n=4, 1994–1996 n=7; Central Bay 1989–1990 n=1, 1991 n=3, 1992–1993 n=4, 1994–1996 n=5; Northern Estuary 1989–1990 n=4, 1991–1992 n=7, 1993 n=6, 1994–1996 n=8; Rivers 1989–1990 n=1, 1991–1996 n=2.

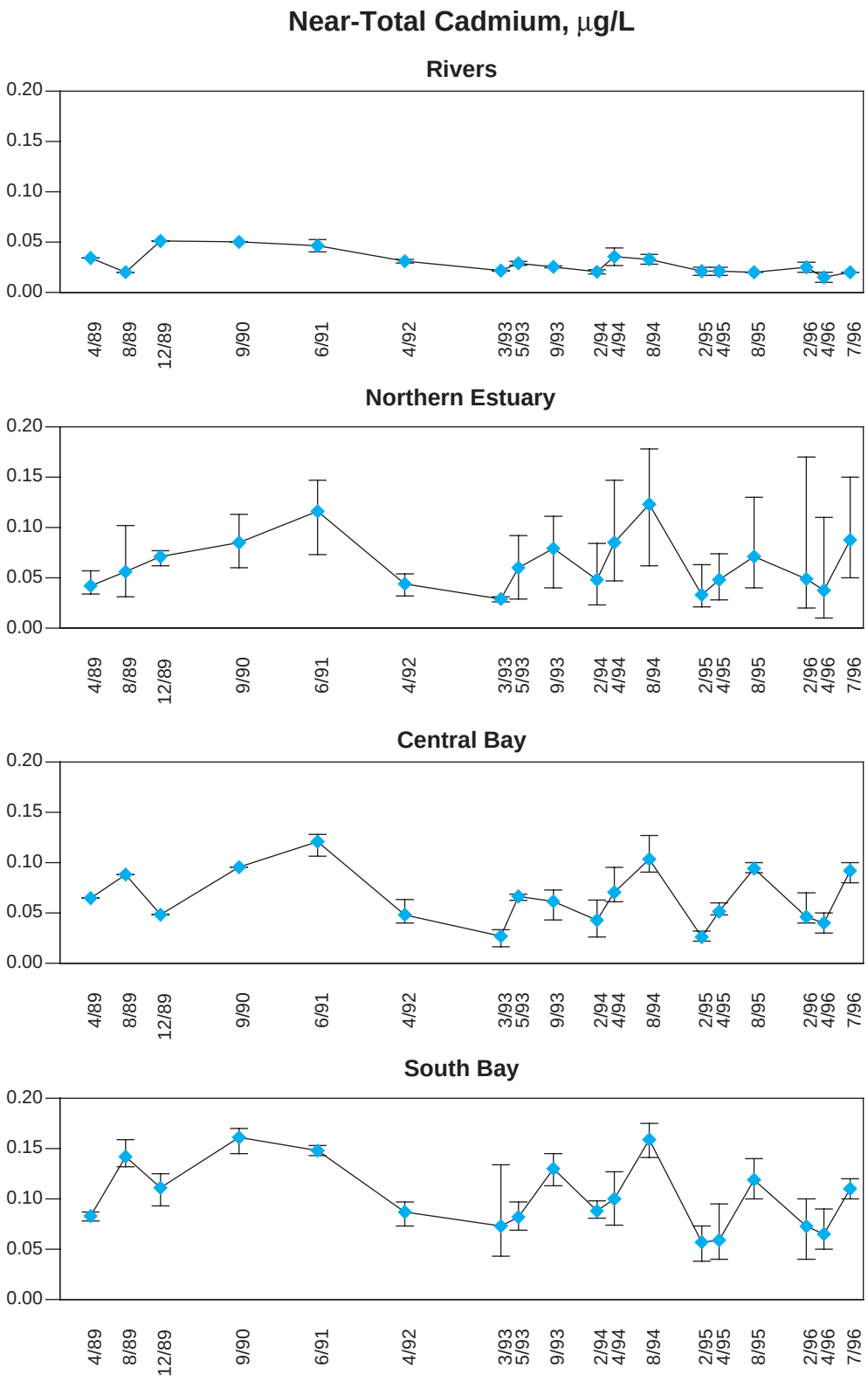

Figure 37 (continued). Plots of average trace element concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1996.

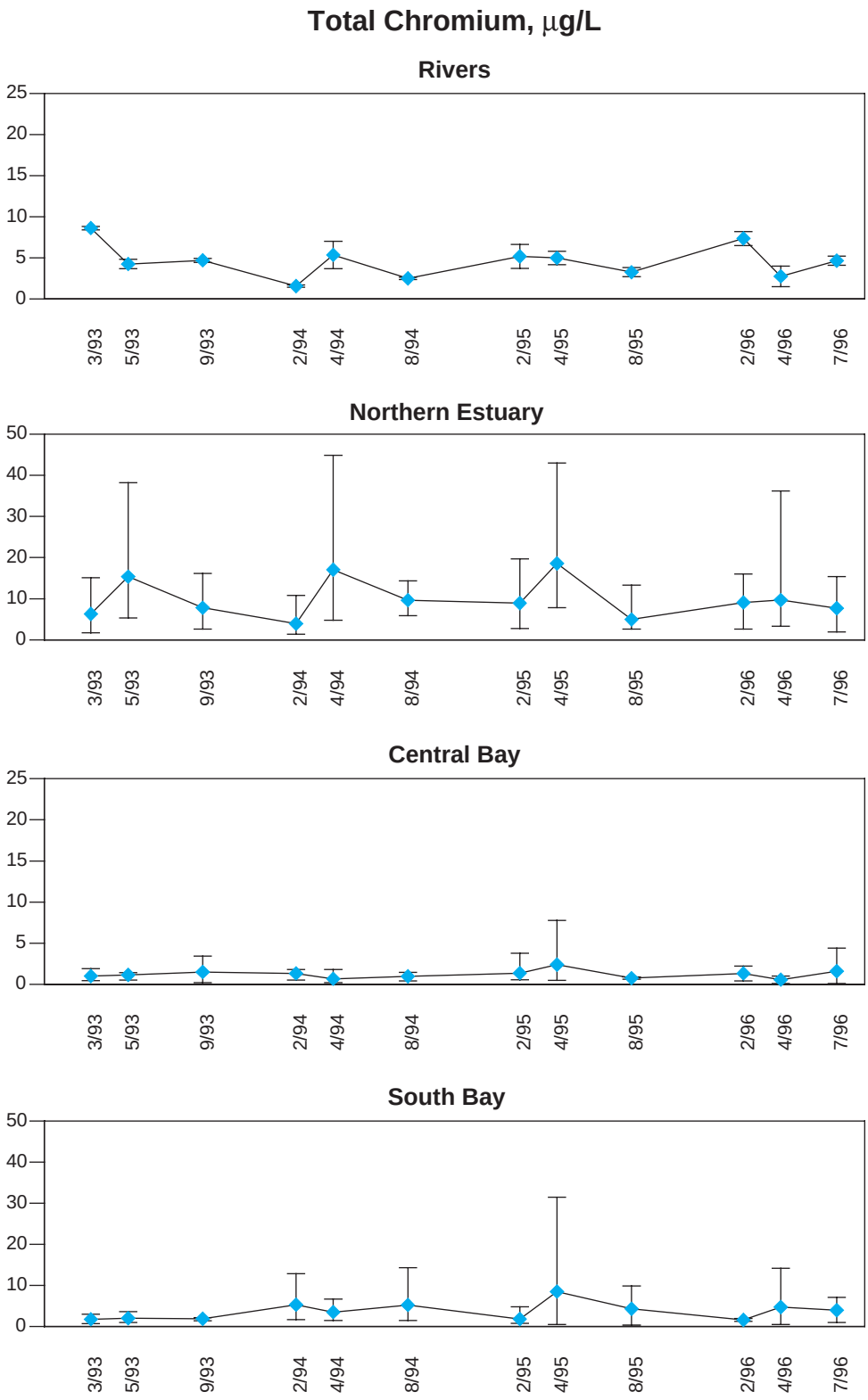

Figure 37 (continued). Plots of average trace element concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1996.

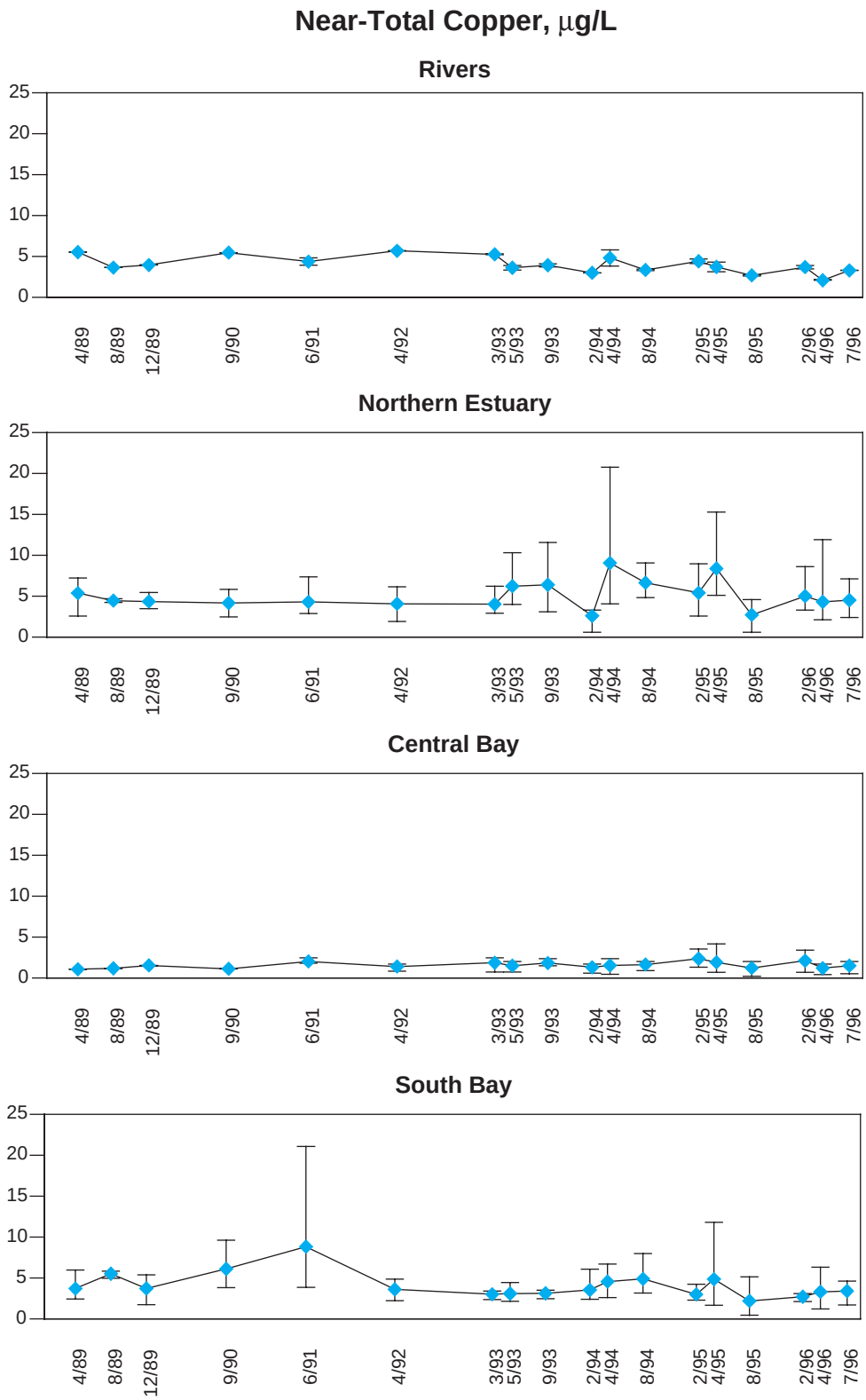

Figure 37 (continued). Plots of average trace element concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1996.

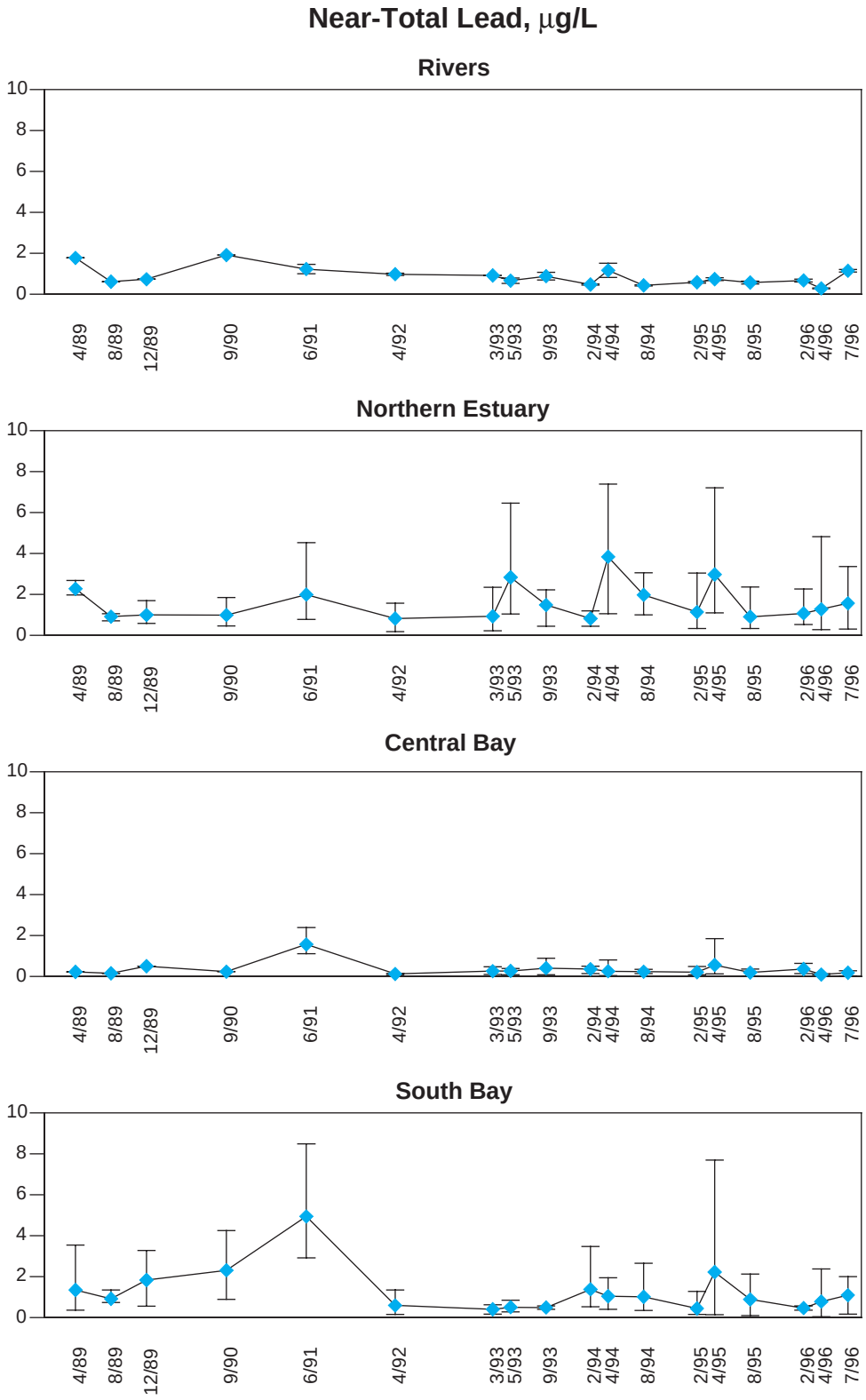

Figure 37 (continued). Plots of average trace element concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1996.

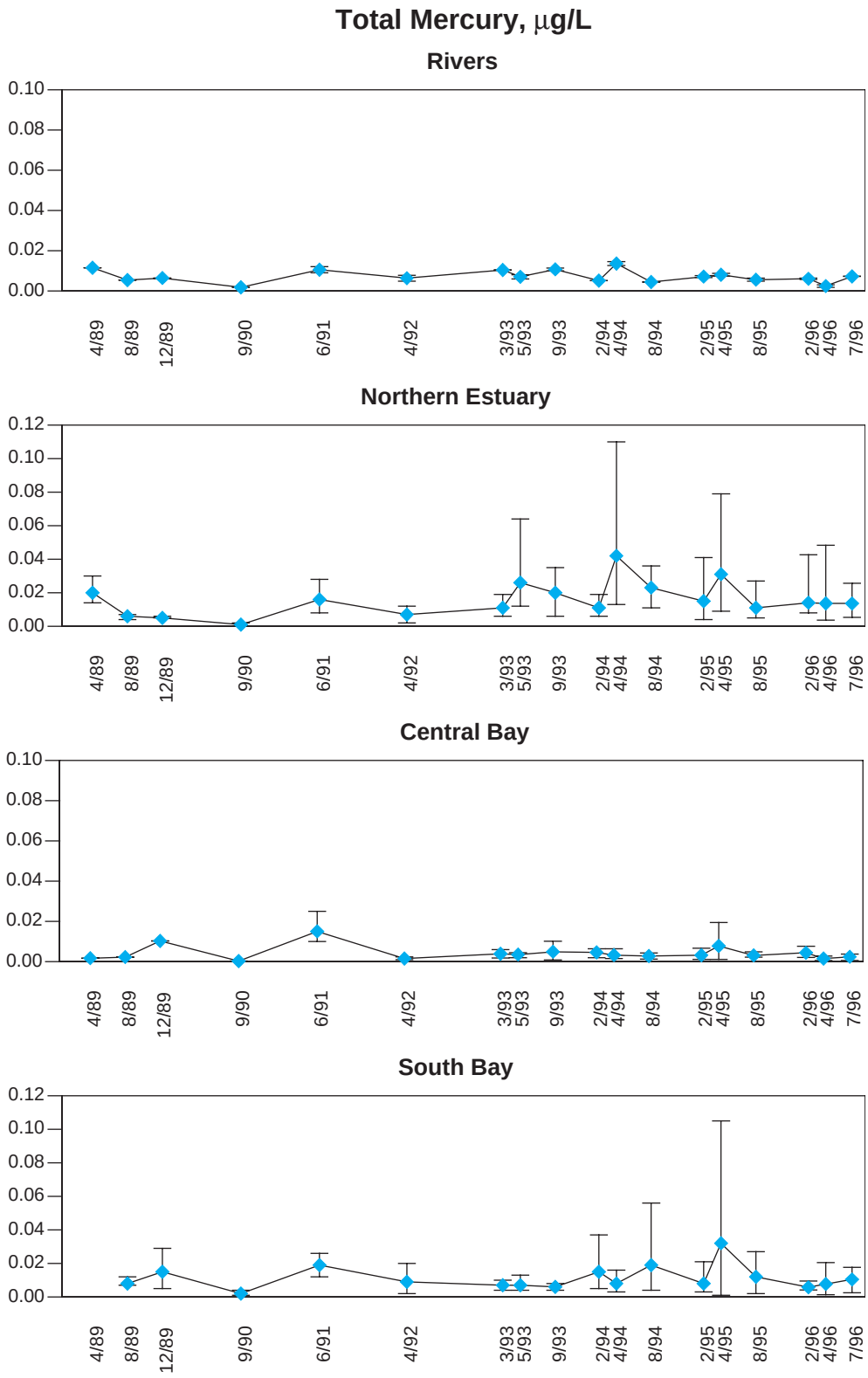

Figure 37 (continued). Plots of average trace element concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1996.

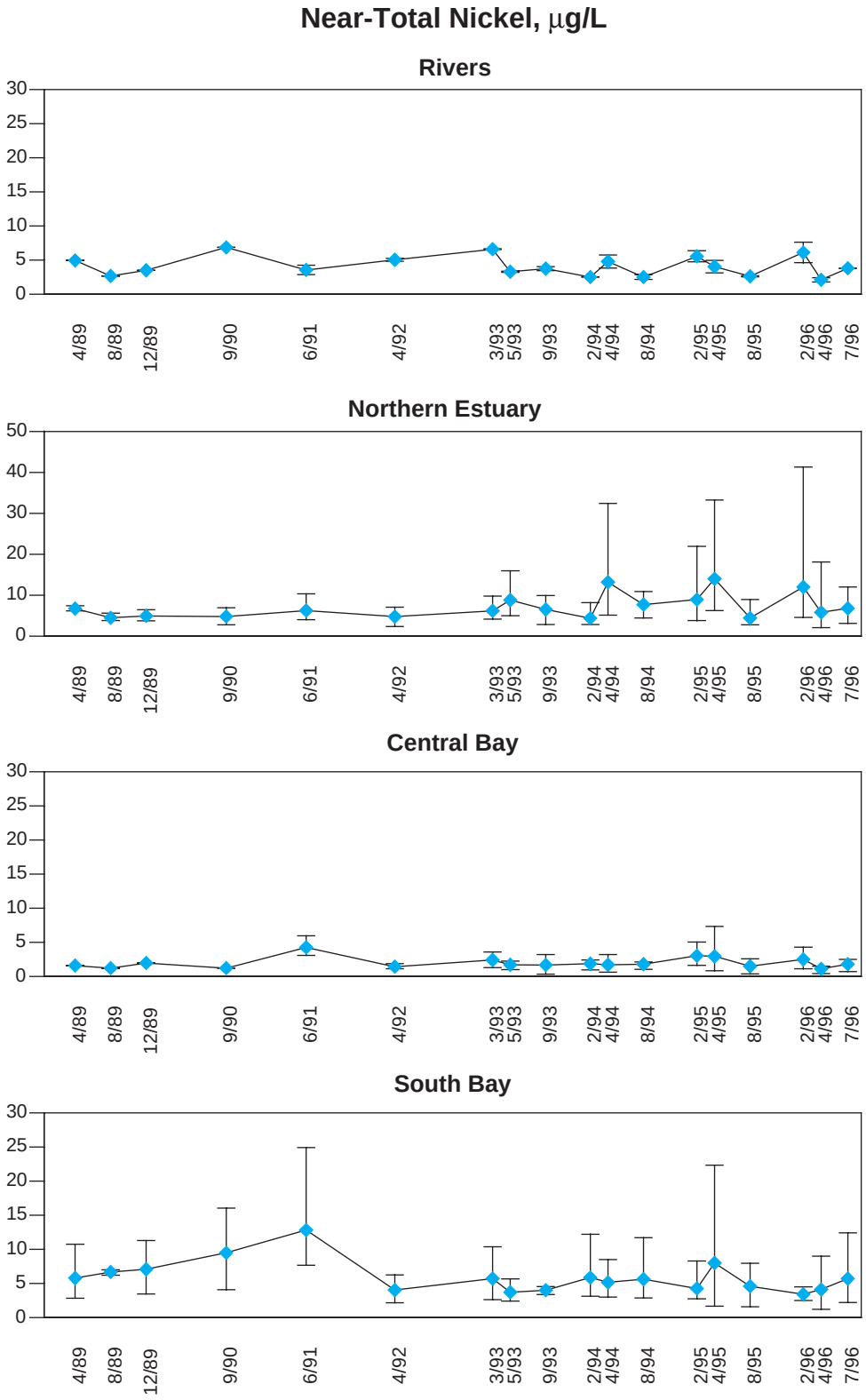

Figure 37 (continued). Plots of average trace element concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1996.

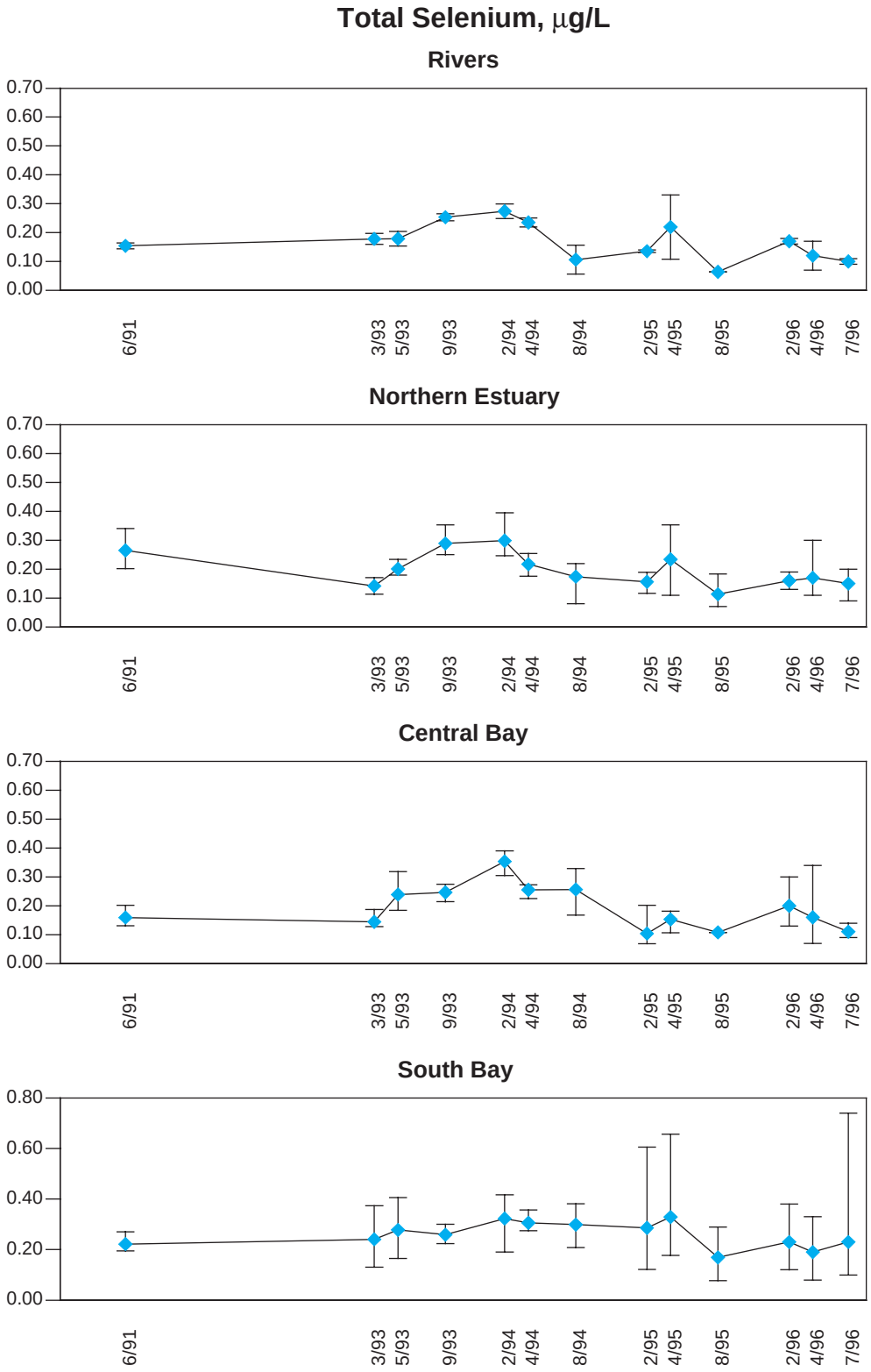

Figure 37 (continued). Plots of average trace element concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1996.

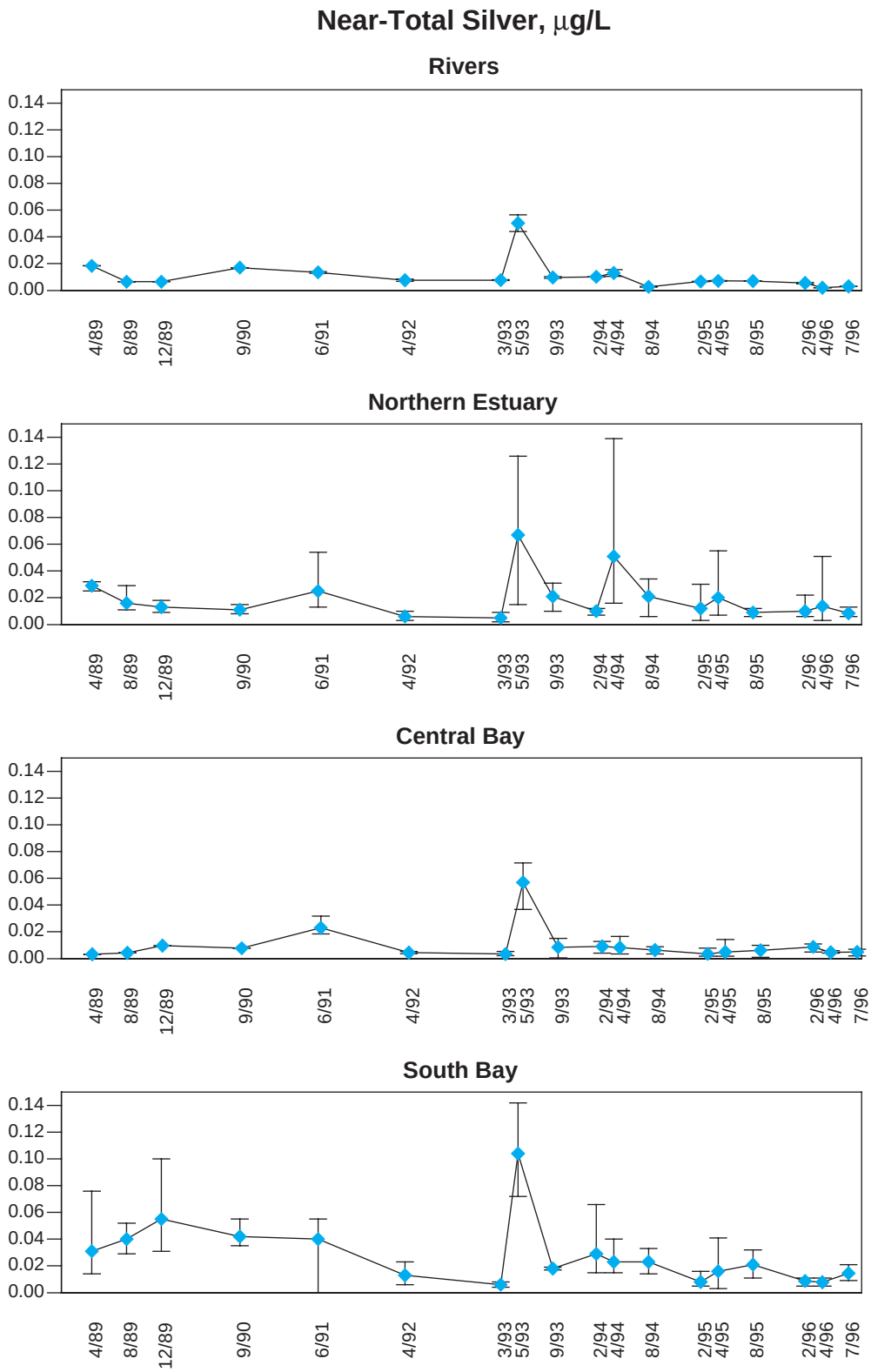

Figure 37 (continued). Plots of average trace element concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1996.

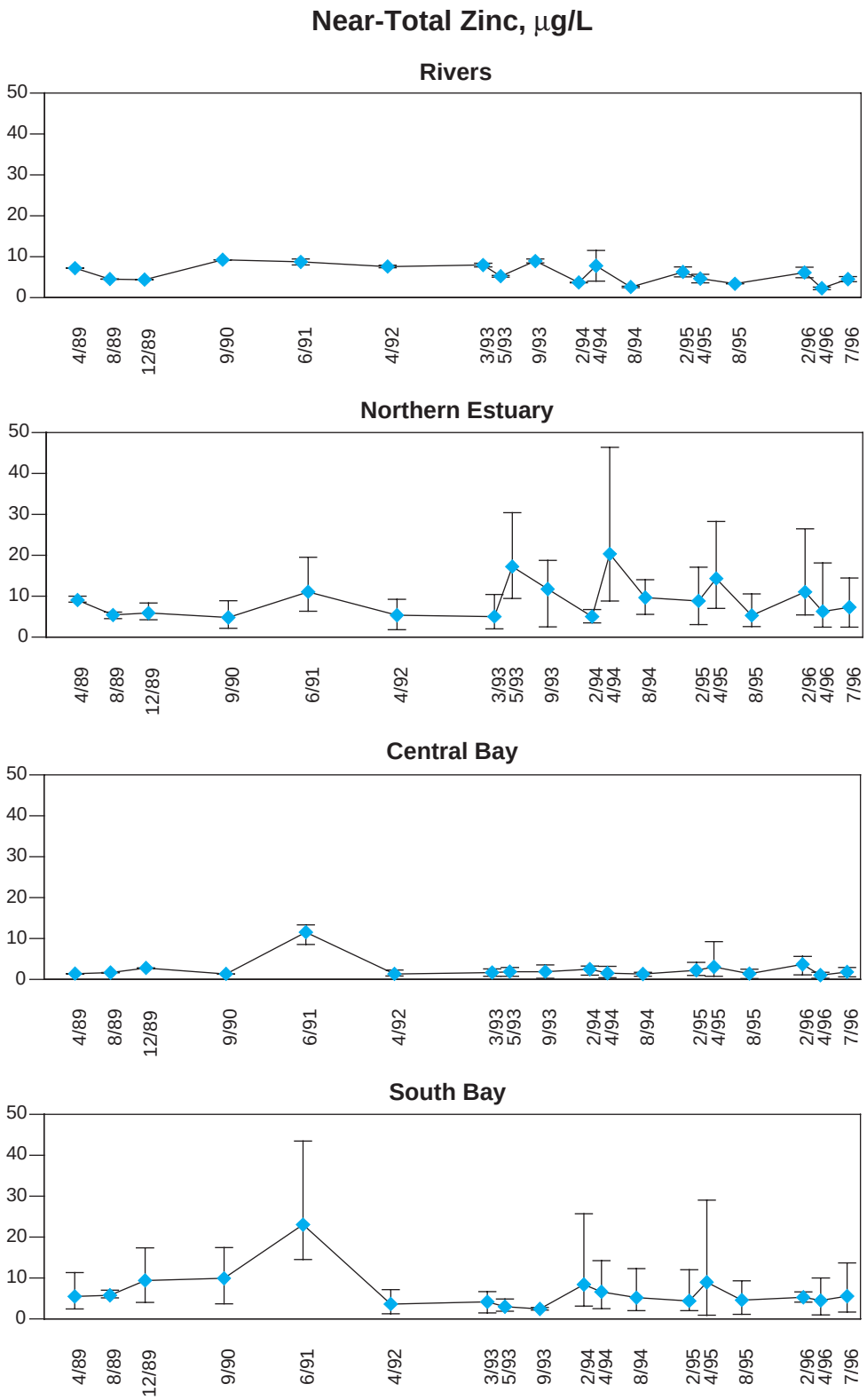

Figure 37 (continued). Plots of average trace element concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1996.

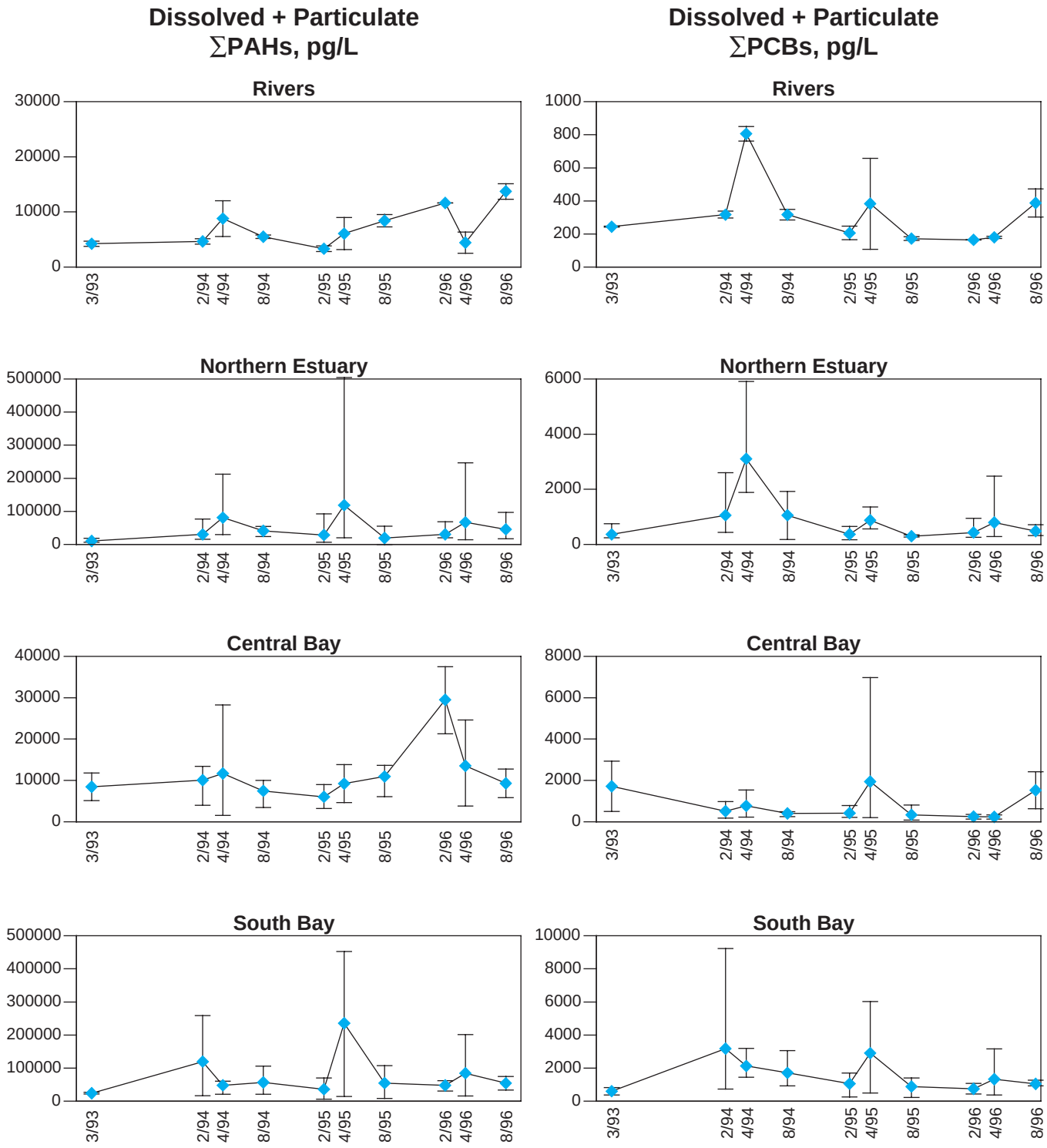

Figure 38. Plots of average dissolved + particulate organic concentrations (parts per quadrillion, ppq) in water for each Estuary reach from 1993–1996. The vertical bars represent the range of values. Sample sizes are as follows: South Bay 1993 n=2, 1994–1996 n=4; Central Bay 1993 n=2, 1994–1996 n=3; Northern Estuary 1993 n=5, 1994–1996 n=6; Rivers 1993–1996 n=2. Please note that in 1996 several samples had laboratory QA problems and the data from these samples are not available.

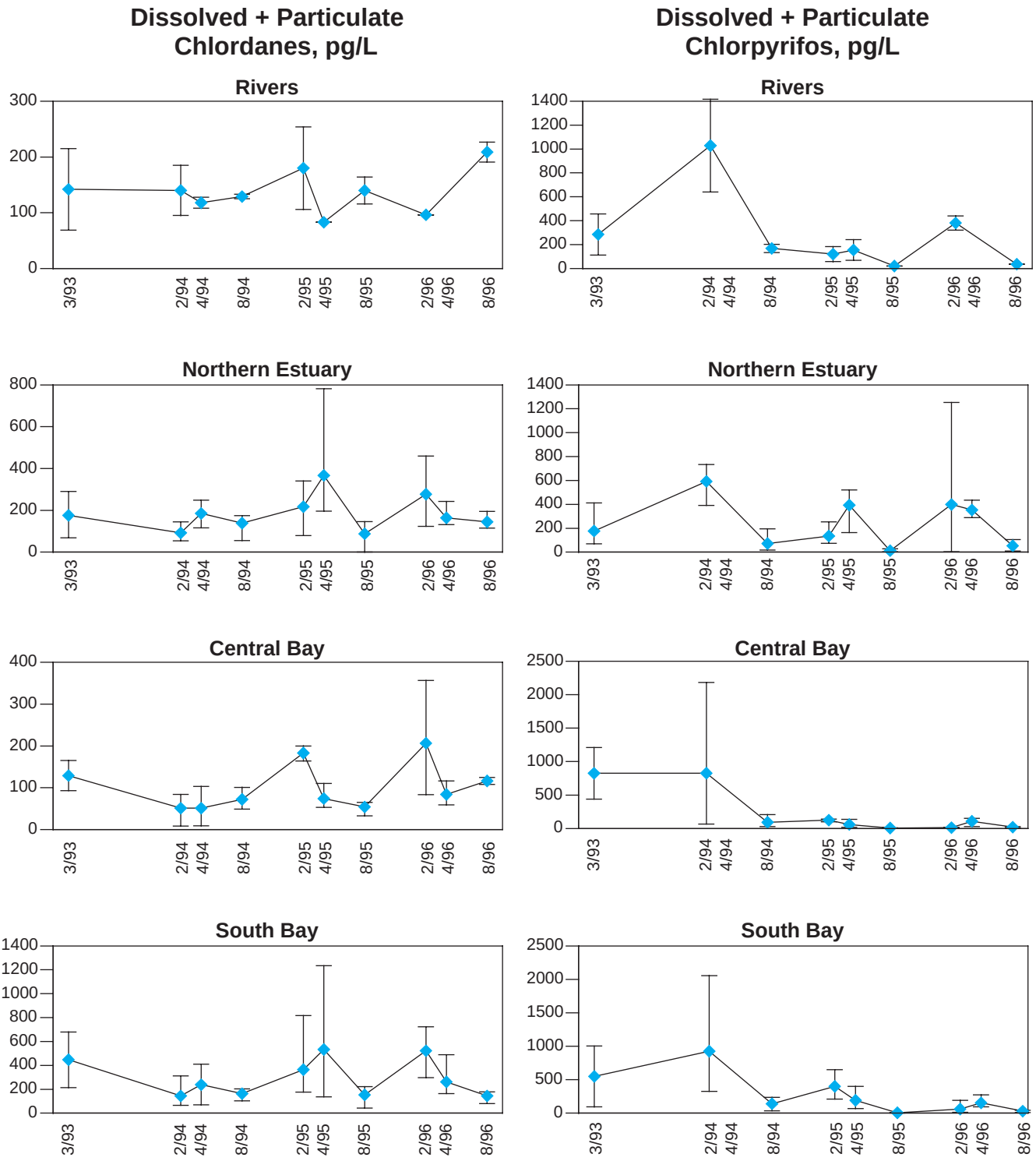

Figure 38 (continued). Plots of average dissolved + particulate organic concentrations (parts per quadrillion, ppq) in water for each Estuary reach from 1993–1996.

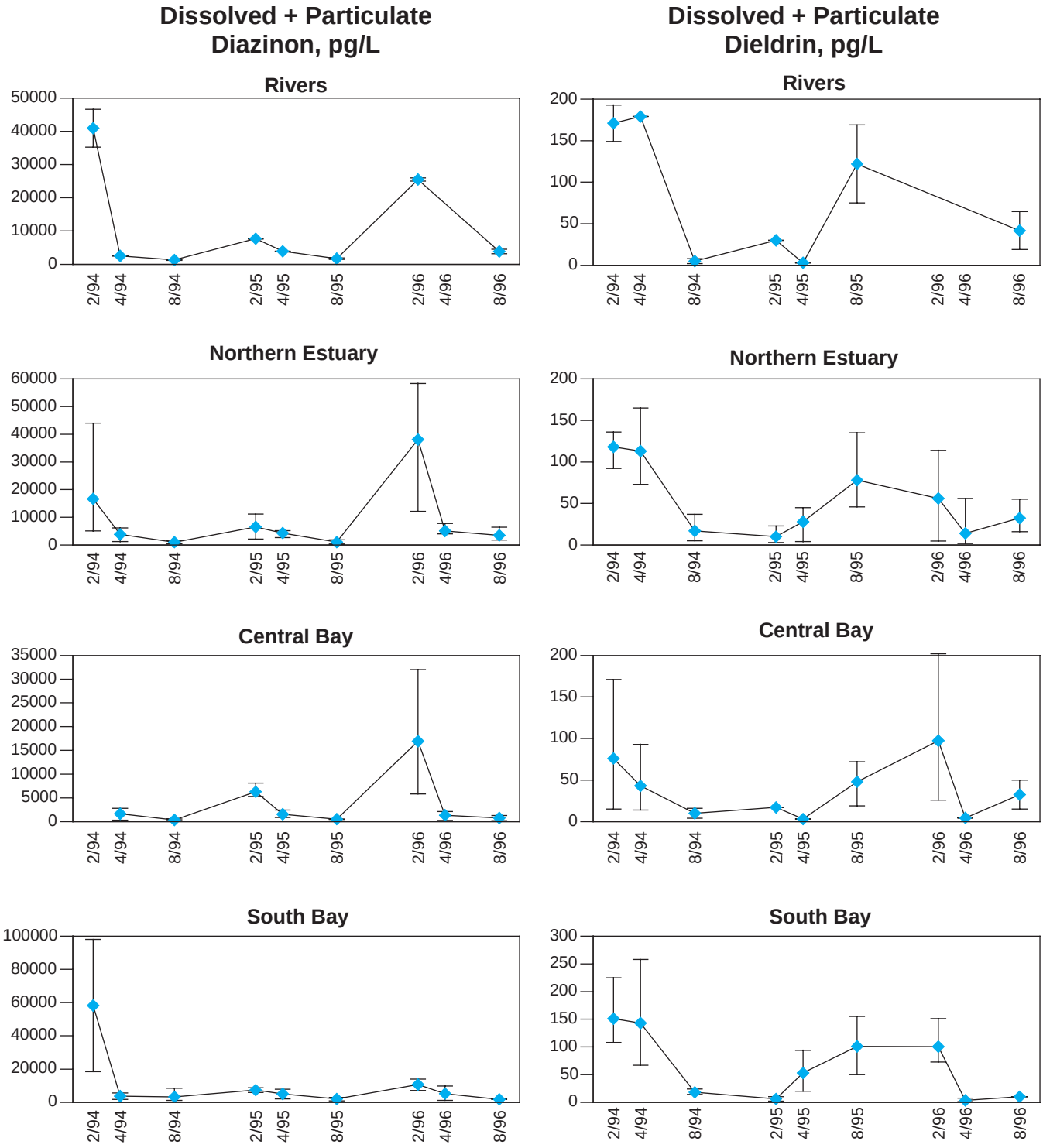

Figure 38 (continued). Plots of average dissolved + particulate organic concentrations (parts per quadrillion, ppq) in water for each Estuary reach from 1993–1996.

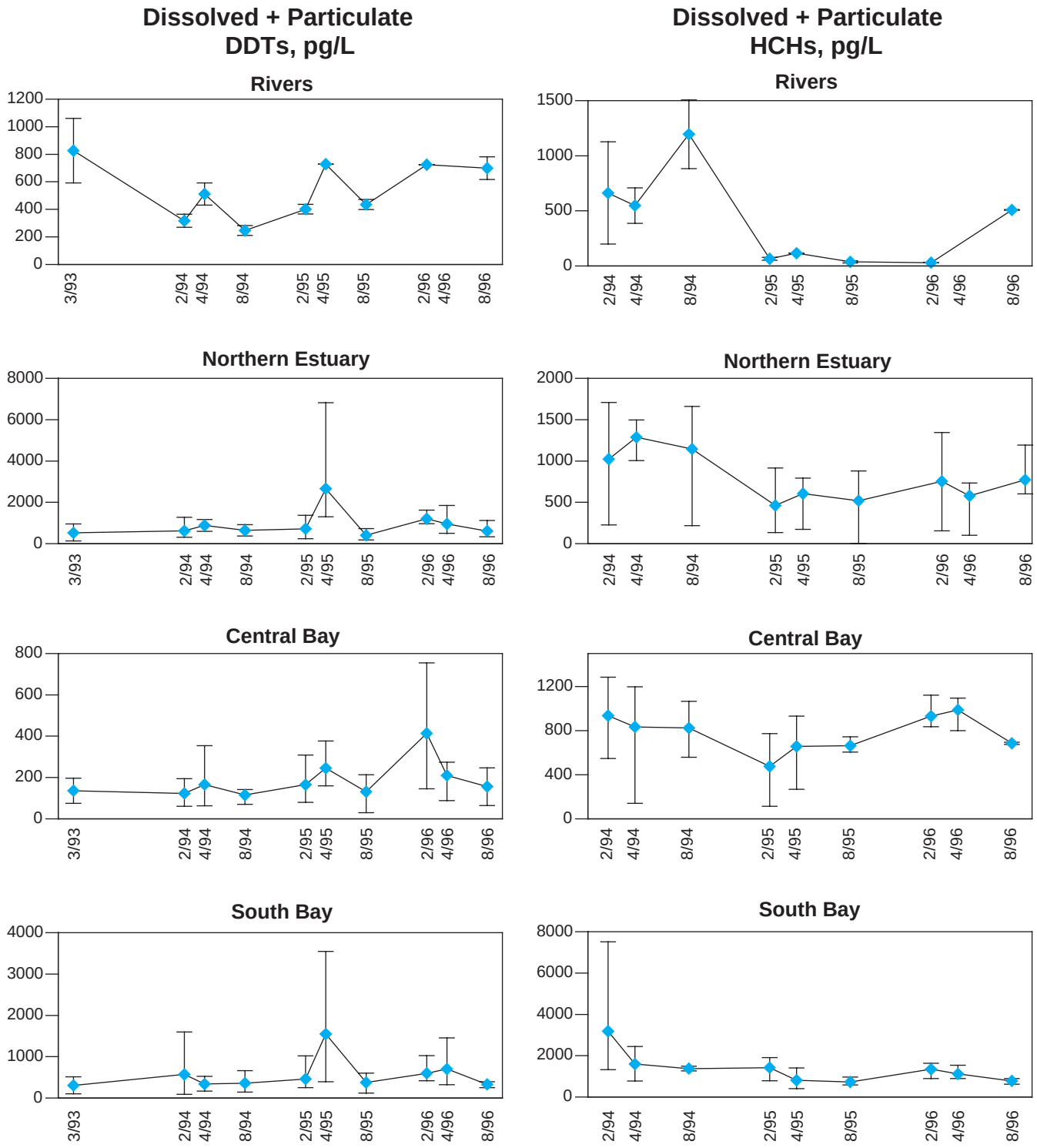

Figure 38 (continued). Plots of average dissolved + particulate organic concentrations (parts per quadrillion, ppq) in water for each Estuary reach from 1993–1996.

Water Quality Variability in San Francisco Bay, Some General Lessons from 1996 Sampling

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Introduction

A primary objective of the Regional Monitoring Program (RMP) is to identify the seasonal and annual patterns of variability in the chemical and biological condition of San Francisco Bay. One element of the RMP is a program of regular water quality measurements conducted by the US Geological Survey (USGS) to supplement the RMP monitoring done three times each year. This element is designed to describe the changing spatial patterns of water quality variability from the lower Sacramento River to the southern limit of the South Bay. Five water quality parameters are measured as basic descriptors of the chemical-biological status of the Estuary, and as indicators of the key processes that control the concentration, chemical form, or biological availability of toxic contaminants.

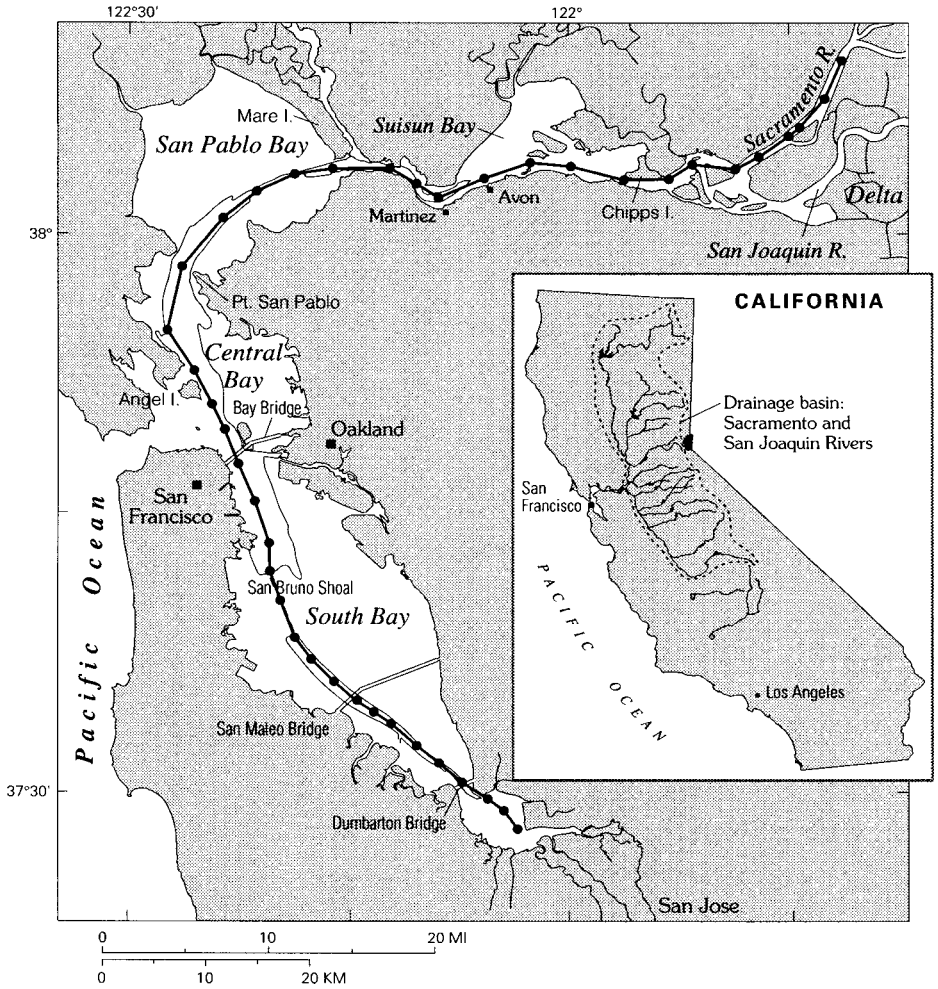

Figure 39. Map showing locations of USGS sampling stations along the axial transect of the San Francisco Bay-Delta, from the lower Sacramento River to the southern South Bay. Distances along the transect are referenced as positive values for the North Bay and negative values for the South Bay (see Figures 40–44), starting at station 18, south of Angel Island.

Another primary objective of the RMP is to identify trends of change in the concentrations of contaminants in San Francisco Bay. This objective poses a difficult challenge because estuaries have large natural variability that acts as noise around any signals of water quality improvement or degradation over time. Progress toward this objective will require innovative approaches for characterizing the natural variability of biological and chemical conditions in the Estuary, and then separating these natural fluctuations from any trends of change. In this chapter we summarize results of the USGS measurement program for 1996, and then use these results to illustrate four general lessons about natural variability in the San Francisco Bay-Delta ecosystem. Each of these lessons has direct relevance to the primary goals of the RMP.

The Measurement Program

Design

This element of the RMP characterizes water quality in the deep channel of the Bay-Delta system. It includes measurements at a series of fixed stations spaced every 3–6 km, from Rio Vista (lower Sacramento River; Figure 39), through Suisun Bay, Carquinez Strait, San Pablo Bay, the Central Bay, and South Bay to the mouth of Coyote Creek. Vertical profiles are taken at each station, so this measurement program provides two-dimensional (longitudinal-vertical) descriptions of spatial structure. Sampling along the 145-km transect requires 12–15 hours, so measurements are taken at varying phases of the semidiurnal tide cycle. Although it is logistically difficult to synchronize sampling to a constant tidal phase, we minimized the effects of intratidal variability by sampling near the periods of monthly minimum tidal energy when possible. Therefore, this sampling program is biased toward neap-tide conditions, and it is confounded by intratidal variability during the course of sampling (e.g., Cloern *et al.,* 1989). Sampling is confined to the central channel, so it does not measure directly the transverse component of water quality variability across the broad shoals (e.g., Powell *et al.,* 1989). However, sampling along the axial transect does describe variability along the estuarine salinity gradient, and it provides an integrative picture of all the "processes occurring upstream, in adjacent marshes and lateral shoals, due to point source discharges, and within the local water column" (Jassby *et al.,* 1997). Sampling was done once each month along the entire North Bay-South Bay transect. More frequent sampling was done in the South Bay to follow the dynamic water quality changes caused by the spring phytoplankton bloom (Cloern, 1996). Sampling dates for 1996 are listed in Table 1.

Table 1. Dates of USGS water quality sampling in the San Francisco Bay-Delta in 1996. Listed for each date are the range of station numbers, and a description of the spatial sampling. SB = South Bay only, NBSB = North Bay and South Bay.

Date, 1996	Station Range	Coverage
11 January	32–657	NBSB
1 February	36–21	SB
6 February	33–657	NBSB
13 February	36–21	SB
21 February	36–21	SB
1 March	36–21	SB
6 March	36–657	NBSB
14 March	36–21	SB
26 March	36–21	SB
3 April	36–657	NBSB
18 April	36–21	SB
23 April	36–21	SB
1 May	34–657	NBSB
9 May	36–21	SB
12 June	34–657	NBSB
17 July	36–657	NBSB
13 August	36–657	NBSB
11 September	34–657	NBSB
16 October	36–657	NBSB
13 November	33–657	NBSB
17 December	36–2	NBSB

Water Quality Parameters

This element of the RMP measures five water quality parameters, each reflecting a different set of processes that cause estuarine variability. Salinity measures the relative proportion of freshwater and seawater, and the salinity distribution reflects the changing importance of river flow as a source of dissolved materials carried into the Bay-Delta from runoff produced in the Estuary's watersheds. Water temperature is an independent indicator of mixing, and an important control on biological transformations of reactive trace substances. The concentration of suspended particles (as total suspended solids, TSS) changes in response to the alternating tidal cycles of sediment deposition and resuspension, episodic wind-driven resuspension, and riverine inputs of new sediments during periods of high flow. These processes are relevant to the RMP because many trace substances are reactive with particle surfaces, so the pathways of transport, retention, and incorporation of these contaminants into the food web are influenced by the transport of sediments. The USGS measurement program provides information about the large-scale changes in the spatial distribution of TSS associated with river inputs. Variability at shorter time scales is characterized by the continuous measurements of TSS by moored instruments at fixed locations (Schoellhamer, 1996).

The phytoplankton community represents the single largest component of living biomass in San Francisco Bay, and we measure the distribution of chlorophyll *a* as an index of this biomass. Unlike salinity and TSS, chlorophyll *a* is a nonconservative quantity that changes in response to processes of production and consumption as well as inputs and transports. The production of phytoplankton biomass involves the uptake of inorganic forms of elements (including C, N, P, and some trace metals) dissolved in the water, and then transformation of these inorganic raw materials into new organic matter packaged as algal cells. The partitioning of reactive elements between dissolved and particulate forms can be highly influenced by the phytoplankton community in San Francisco Bay (Cloern, 1996), and chlorophyll *a* concentration is a simple indicator of the potential for these biotransformations.

We measure dissolved oxygen (DO) concentration as an indicator of the net trophic status of the Estuary. When the oxygen content of water is undersaturated (less than that at equilibrium with atmospheric oxygen), this indicates that oxygen is being consumed by the biota faster than it is produced by photosynthesis (community respiration exceeds primary production). Supersaturation of oxygen occurs when the photosynthetic production of oxygen within the Estuary is faster than all the processes of consumption. Therefore, DO concentration is an index of the balance between production and oxygen consumption, a key descriptor of the status of the ecosystem. Episodes of DO supersaturation occur during periods of rapid phytoplankton primary production when the inorganic forms of elements (C, N, P, Si, Cd, etc.) are rapidly removed from solution and converted into particulate form. Therefore, DO provides a useful indicator of the rate of phytoplankton-mediated transformations of reactive elements in the water column. It also can be a very useful indicator of the origin of different water masses within the Estuary (see below).

Methods

Data for this RMP element were collected with an instrument package that includes sensors for measuring: sampling depth, conductivity, temperature, salinity (calculated from conductivity and temperature), TSS (optical backscatter sensor), chlorophyll (fluorometer), and DO (oxygen electrode). The instrument package is lowered through the water column, making measurements about every 4 cm. Here, we report only the measurements made in the upper meter of the water column, calculated as the mean of all measurements made between 0.5 and 1.5 m. The complete data set, including measurements made at all depths, is available as a data report (Baylosis *et al.*, 1997) or over

the Internet at the USGS website that archives and displays results of the water quality program: URL = http://sfbay.wr.usgs.gov/access/wqdata/.

The conductivity and temperature sensors were calibrated by Sea-Bird Electronics prior to the first sampling in January 1996. The optical backscatter sensor, fluorometer, and oxygen electrodes were calibrated each sampling date with analyses of water samples. Surface samples were collected by pump, and bottom samples were collected with a Niskin bottle. Aliquots were analyzed for: TSS (gravimetric method of Hager, 1993); chlorophyll *a* (spectrophotometric method of Lorenzen, 1967; using the equations of Riemann, 1978); and dissolved oxygen (automated Winkler titration, following Granéli and Granéli, 1991). Values reported here are calculated quantities based on daily calibrations of the optical backscatter, fluorescence, and oxygen sensors from linear regressions of measured concentrations versus voltage output of each instrument.

1996 Results

Hydrologic Variability

The 1996 water year was classified as a wet year in California, with statewide runoff 125% of average (Roos, 1997). Precipitation from December 1995 through February 1996 was well above normal, and flows into San Francisco Bay from the Delta were above average in January and February, reaching a peak Delta Outflow Index (DOI) of 5,983 m^3/s on February 23 (see Figure 40). Delta outflow then progressively declined until mid May, when a large Pacific storm carried heavy rainfall to northern and central California. This storm prompted flood-control releases from upstream reservoirs, overflow through the Yolo Bypass (Roos, 1997) and a Delta outflow spike of 2,873 m^3/s on May 20. Delta outflow was less than 400 m^3/s from July through September, and the dry season ended with a period of above-average precipitation and runoff in December 1996. Delta outflow peaked again at 3,621 m^3/s in mid December. The 1996 RMP samplings for trace substances were done in early February, late April, and late July, representing distinctly different hydrologic conditions.

Water Quality Variability

Results of the water quality sampling are summarized in Table 2, which gives the baywide mean and range of each constituent from the USGS samplings that coincided with the 1996 RMP water monitoring. Also included are measurements during the three prior years of RMP monitoring. These summary statistics give a general picture of the changing condition of the surface waters of the Estuary during the twelve events of RMP water monitoring since inception. Of these first four years, three (1993, 1995, 1996) were classified as wet or very wet, so the early results of RMP monitoring are biased toward conditions of heavy precipitation and runoff. Notable features of water quality variability during RMP monitoring of 1996 include:

- The mean DOI during the February 1996 sampling was 3,490 m^3/s, the highest outflow among all 12 RMP sampling periods (Table 2). Mean surface salinity in February was only 8.5 psu (practical salinity units), indicating that surface waters of the Bay were, on average, about 75% freshwater (salinity usually increases with depth, so the freshwater fraction decreases with depth). Chlorophyll and DO concentrations were both low, indicating small phytoplankton biomass and low primary productivity during this winter sampling.
- The April RMP sampling occurred during the period of declining flows, when mean DOI was 1,060 m^3/s and mean surface salinity increased to 14.8 psu. Mean TSS concentration was small and chlorophyll concentration was relatively high, indicating that the biogenic (phytoplankton) component of the suspended particles was relatively high in April. The maxi-

Table 2. Summary of hydrographic/water quality conditions in the San Francisco Bay Estuary around the periods of RMP water sampling, 1993–1996. Columns 2 and 3 show dates of RMP sampling and the corresponding dates of USGS sampling. Delta outflow is the mean Delta Outflow Index (from California Department of Water Resources) for the period of RMP sampling. Valuesfor salinity, temperature, concentration of suspended solids (TSS), chlorophyll *a*, and dissolved oxygen are mean values of near-surface (1-m) measurements at all USGS stations along the transect from Rio Vista to Coyote Creek (see Figure 39). Values in parentheses showthe range of measurements along the transect.

RMP Sample Number	RMP Sample Dates	USGS Sample Date	Mean Delta Outflow (m^3/s)	Salinity (psu)	Temperature (°C)	TSS (mg/l)	Chlorophyll *a* (mg/m^3)	Dissolved Oxygen (% saturation)
1	2–12 March 1993	24 Feb. 1993	995	10.8 (0.07–22.4)	10.9 (9.3–11.9)	67 (11–170)	1.8 (1.3–3.0)	93 (79–96)
2	24–27 May 1993	12 May 1993	762	12.9 (0.06–25.8)	17.0 (13.8–18.1)	25 (1–103)	2.2 (1.5–4.9)	89 (83–94)
3	13–16 Sept. 1993	8 Sept. 1993	123	22.2 (0.09–29.7)	20.9 (18.1–22.8)	9 (5–27)	2.9 (0.7–11.8)	94 (71–110)
4	31 Jan.–9 Feb. 1994	16–17 Feb. 1994	402	16.8 (0.1–28.1)	11.1 (9.8–11.8)	19 (7–36)	2.0 (1.1–4.1)	98 (92–104)
5	19–27 April 1994	19 April 1994	273	18.0 (0.1–28.6)	17.2 (14.9–18.6)	25 (5–76)	3.7 (1.6–9.1)	96 (82–102)
6	15–23 Aug. 1994	30–31 Aug. 1994	110	23.2 (0.09–32.2)	20.4 (16.5–21.7)	10 (5–24)	3.1 (1.7–6.2)	95 (85-102)
7	6–15 Feb. 1995	7 Feb. 1995	2,490	6.5 (0.07–16.3)	12.2 (10.9–13.6)	49 (6–100)	1.3 (0.7–2.5)	88 (82–93)
8	18–27 Apr. 1995	18–19 Apr. 1995	2,276	8.3 (0.07–17.4)	13.6 (12.4–14.3)	49 (10–239)	8.2 (3.0–18.0)	
9	16–23 Aug. 1995	16 Aug. 1995	314	15.5 (0.25–27.6)	21.2 (18.5–23.0)	19 (8–48)	3.7 (1.2–6.5)	91 (79–102)
10	5–14 Feb. 1996	6 Feb. 1996	3,490	8.5 (0.07–22.4)	11.8 (10.6–14.0)	41 (11–89)	1.2 (0.3–2.5)	85 (80–100)
11	22–29 Apr. 1996	1 May 1996	1,060	14.8 (0.08–29.8)	17.5 (12.4–21.8)	19 (4–77)	5.9 (3.0–21.5)	95 (68–117)
12	22–30 July 1996	17 July 1996	231	16.9 (0.06-29.2)	20.0 (16.9–21.6)	44 (9–122)	1.9 (0.6–5.7)	94 (76–100)

mum DO concentration was 117% saturation, indicating high primary productivity in some regions of the Bay.

- Mean DOI during the July RMP sampling was 231 m^3/s, and mean surface salinity was 16.9 psu (equivalent to about 50% freshwater baywide), considerably smaller than the mean surface salinities measured during the low-flow RMP samplings of September 1993 and August 1994 (Table 2). These differences in mean salinity show how the mean water chemistry depends on the month in which the annual low-flow sampling is conducted. The RMP samplings in 1993 and 1994 were more representative of estuarine conditions during sustained periods of low river flow than the July 1996 sampling.

Results from all the USGS measurements are depicted in Figures 40–44, which show the spatial-temporal patterns of water quality variability as gray scale shadings. The upper panel of each figure shows the daily record of the Delta Outflow Index. The bottom panels show the patterns of variability as shaded contour images, where shading intensity is proportional to the concentration of a particular constituent. The vertical axis represents the longitudinal transect from the lower Sacramento River (top of image, at kilometer 92), to the Central Bay at Angel Island (kilometer 0), and then to the lower South Bay at the mouth of Coyote Creek (kilometer -52.7). The horizontal axis represents monthly variability during 1996. Each shaded image is based on interpolations of the 499 surface measurements made during the 21 USGS sampling cruises in 1996. We can use these images to illustrate some general lessons of water quality variability in the San Francisco Bay-Delta Estuary.

Lesson #1: The Bay is Influenced by Processes in its Watershed

Perhaps the single most important principle of Bay-Delta variability is that all aspects of the Estuary, including physical processes, transports, water chemistry, turbidity, and the biota, respond to changing inputs of freshwater, sediments, and the dissolved constituents carried by river runoff—especially runoff through the Delta. This principle was illustrated with results from USGS sampling in 1993–1995 (Cloern *et al.,* 1996), and it is clearly evident from the changing distributions of salinity in the Bay-Delta during 1996 (Figure 40). Here, dark shading indicates high salinity and light shading indicates low salinity. The thick solid line shows the changing position of the surface salinity of 2 psu (an index of the location of X2, where bottom salinity = 2). This image shows that 1996 began with near-marine salinities in the South Bay, and a landward position of X2 near Suisun Bay. The salinity distribution changed dramatically in February and March (days 30–90), in response to the large input of freshwater from the Delta, as well as inputs from local streams. During peak flows of February–March, surface salinity in eastern San Pablo Bay was only 2 psu (nearly freshwater). As flows receded during the dry season, the salinity gradient progressively migrated upstream, and surface salinity of 2 psu was found far upstream, in the lower Sacramento River. The December 1996 floods displaced the salinity gradient seaward (a precursor to the radical changes following the New Year's Flood of 1997). This image also shows the response of the South Bay to inputs from its urban watershed, when surface salinities became diluted by local runoff in March (between days 60 and 90, lower region of Figure 40). The complex shading patterns in February–March show how the salinity (and therefore chemistry) of the South Bay changes in response to freshwater input from both the Delta and local streams. This figure also shows that salinities of the North Bay and South Bay do not necessarily change together, because local and Delta-derived flow events are not always synchronized.

The small diamonds on Figure 40 show the locations of USGS samples at the time of the three RMP monitoring periods. They show that the first RMP monitoring of 1996 occurred after

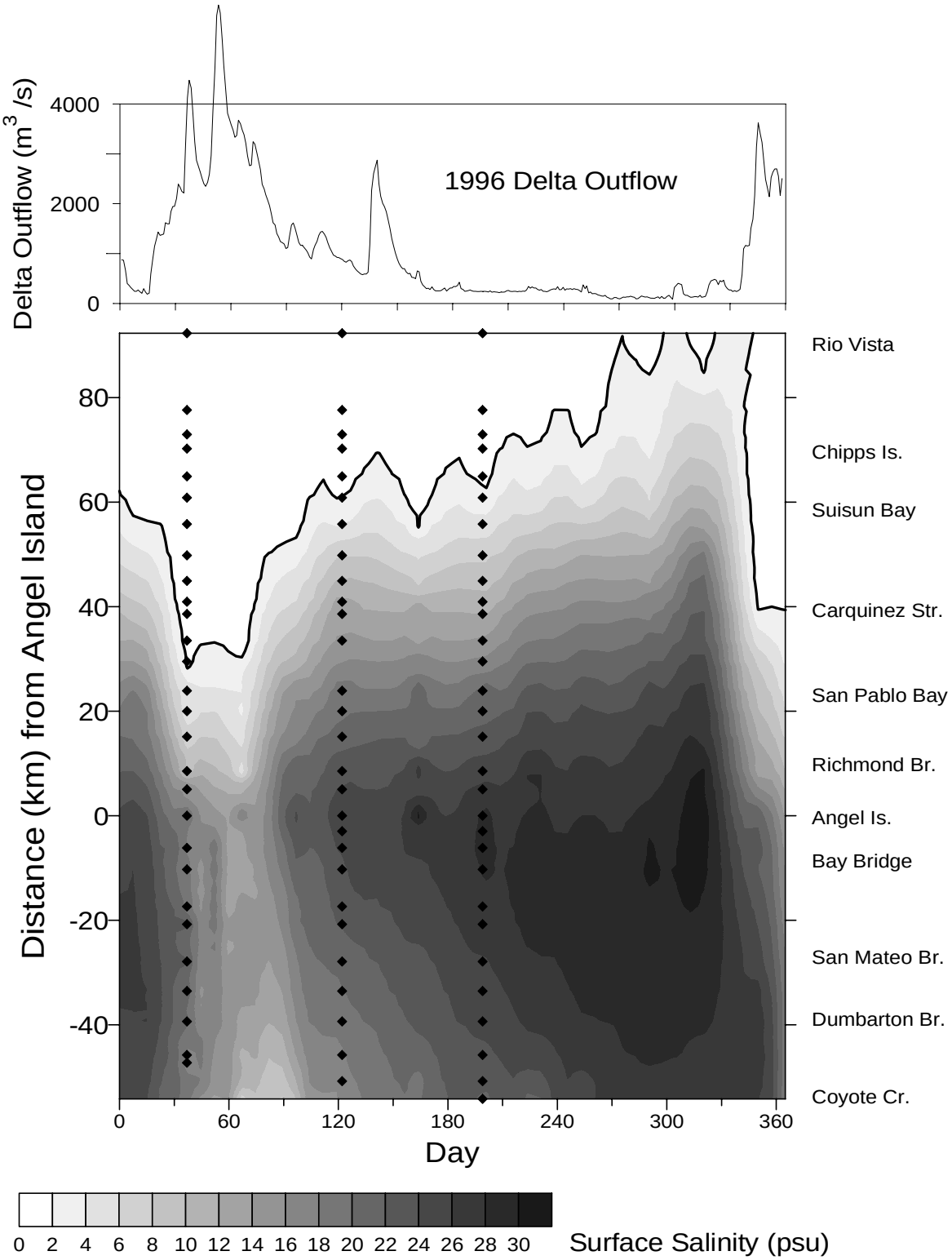

Figure 40. Upper panel shows the daily Delta Outflow Index (from California Department of Water Resources) for 1996. Lower panel shows the changing distribution of surface salinity along the USGS transect (Figure 39). Intensity of shading is proportional to salinity, with darker shadings indicating higher salinities. The vertical axis represents variability in space, from the lower Sacramento River (top of figure) to Central Bay (at kilometer 0) and then to the lower South Bay (bottom of vertical axis). The horizontal axis represents variability in time, matched to the flow-variability above. The thick solid line shows the changing position of the location where surface salinity was 2 psu. Small diamonds show the locations of USGS measurements that coincided with the three RMP samplings.

the North Bay salinity gradient had been displaced seaward by high Delta outflow, but before South Bay salinities were diluted by inputs from the local watershed. The second (April) RMP sampling occurred when the salinity distribution of North Bay and South Bay were recovering from the previous months of high flow. The July RMP sampling was done just at the beginning of the summer-autumn low-flow season. The distribution of the triangles on Figure 40 shows that RMP monitoring in 1996 did not capture changes associated with the peak local inputs of urban runoff to South Bay in March, the anomalous May flood, the period of minimum inflow and maximum salinity in October–November, or the large floods that began in December. Therefore, some features of the Bay-Delta response to watershed inputs were sampled by the RMP monitoring in 1996; other features were not sampled.

Lesson #2: The Bay is Influenced by Processes in the Pacific Ocean

San Francisco Bay is connected to the coastal Pacific Ocean (Gulf of the Farallones) by tidal- and wind-driven currents that drive transport and mixing of water masses through the Golden Gate. Just as the Bay is influenced by events in the watershed, it also is influenced by events in the coastal ocean that propagate into the Bay by these transport mechanisms. The temperature record for 1996 illustrates this lesson. The shading in Figure 41 shows the annual temperature distribution in the Bay-Delta, based on the 499 surface measurements made within the USGS element of the RMP. Dark shading indicates warm water, and the overriding pattern here is the seasonal fluctuation of temperature from about 10 °C (light shading) in winter to a maximum of about 23 °C (darkest shading) in summer. Within this regular seasonal pattern is a prominent anomaly in Central Bay around day 150. This anomaly shows a core of cold surface water at Angel Island which was measured both on May 1 and June 12. This temperature anomaly is a clear signal of coastal upwelling, which brings salty, cold, deep oceanic waters to the surface, where they can be transported into San Francisco Bay.

Deep oceanic water has very different chemistry from surface water, so the transport of deep Pacific water into San Francisco Bay after upwelling events can directly change the chemistry of Bay waters. One example of chemical change is illustrated in Figure 42, which shows the patterns of variability in dissolved oxygen (DO). Here, low DO is indicated with dark shading and high DO with light shading. This image shows the dynamic, complex character of the oxygen content of Bay waters. One obvious feature is the dark patch near Angel Island measured around day 150. In May and June 1996, DO in Central Bay was only about 67% of saturation, comparable to the low oxygen content of deep Pacific waters. This DO anomaly confirms the impact of coastal upwelling on San Francisco Bay, including changes in water chemistry in the Central Bay. These episodes of coastal influence have importance for the RMP because of large differences in the concentrations of trace substances between ocean and Bay waters. For many trace substances, exchange with coastal waters can act to dilute contaminants in the Central Bay. However for some elements, coastal upwelling can be a source to the Bay. Deep oceanic water is enriched in elements such as cadmium, silicon, and phosphorus. During episodes of upwelling, the dissolved cadmium concentration in coastal waters adjacent to San Francisco Bay can increase from 0.2 to 0.8 nanomoles/liter (van Geen *et al.*, 1992). Therefore, the potential existed for a fourfold increase in dissolved cadmium concentrations in Central Bay during the May and June upwelling events recorded by the USGS sampling component of the RMP.

Lesson #3: The Bay is Influenced by Internal Processes within the Estuary

In addition to the input of materials across the ocean-Estuary and Estuary-land boundaries, internal processes of geochemical and biological transformation cause change in the water quality of San Francisco Bay. One of the

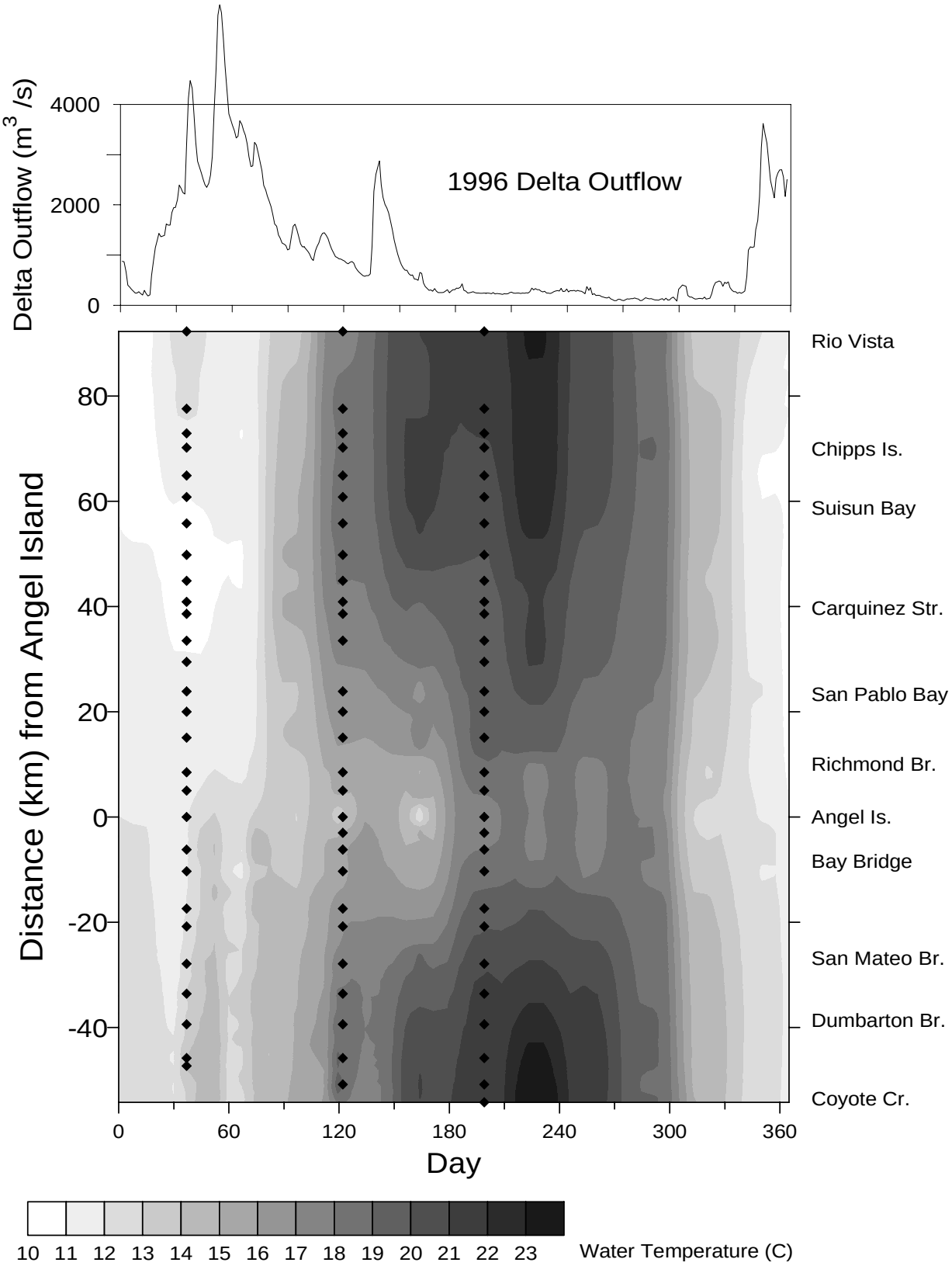

Figure 41. Delta Outflow Index (top panel) and surface water temperatures (lower panel) along the USGS transect for 1996 (see Figure 39). Intensity of shading is proportional to temperature, with darker shadings indicating higher temperatures.

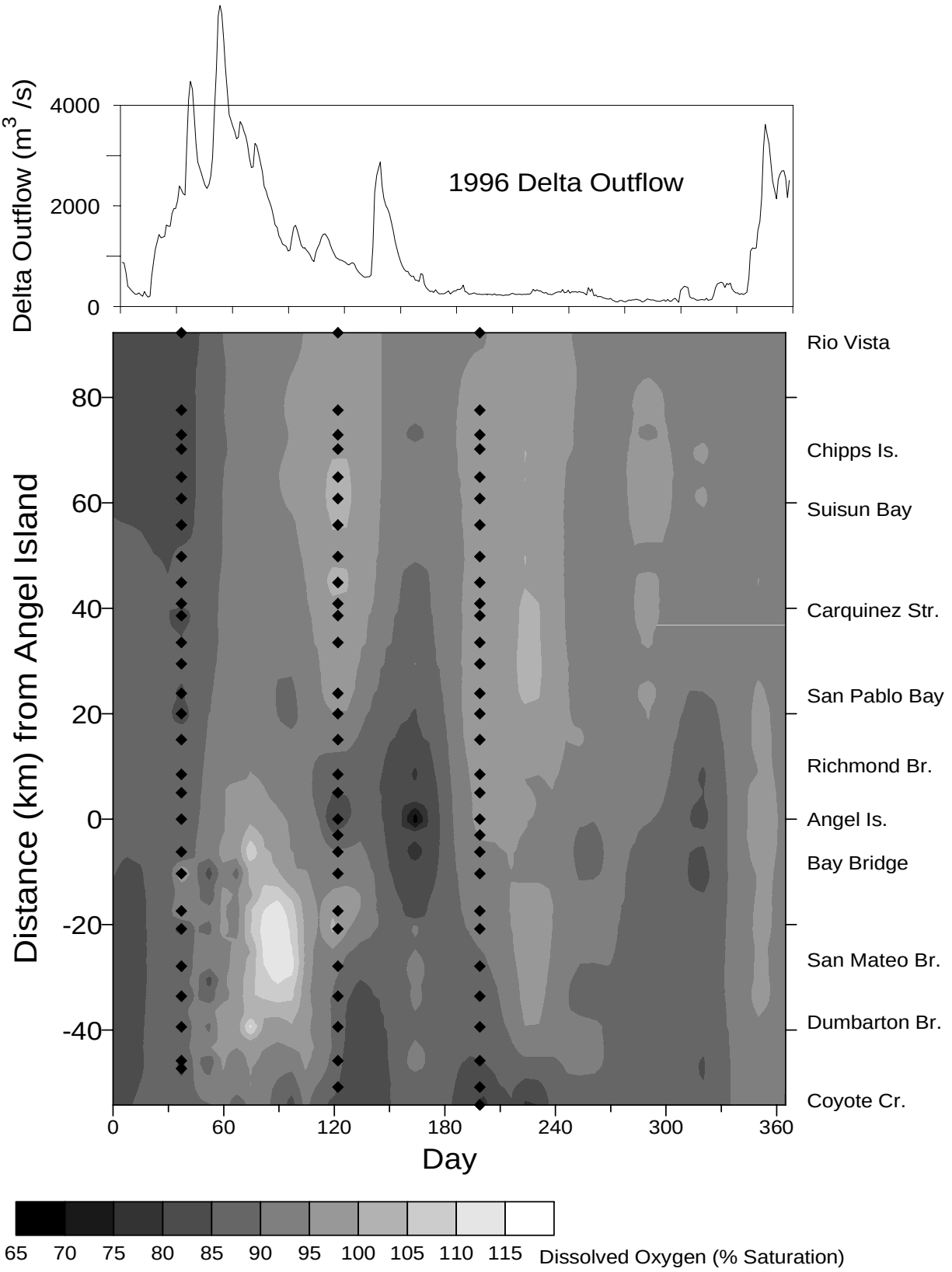

Figure 42. Delta Outflow Index (top panel) and concentrations of dissolved oxygen (lower panel) along the USGS transect for 1996 (see Figure 39). Intensity of shading is proportional to DO in the surface waters, with lighter shadings indicating higher concentrations.

most important internal processes is phytoplankton primary production, which acts to transform dissolved substances (nitrogen, carbon, phosphorus, trace elements, organic contaminants) into organic particles in the form of algal cells (Cloern, 1996). The most striking manifestation of this internal process is the spring phytoplankton bloom, a recurring event that leads to large chemical changes in the South Bay every year. The changing abundance of phytoplankton in 1996 is depicted in Figure 43, which shows the chlorophyll *a* concentration in surface waters of the Bay-Delta. Three different patterns of variability are evident: (1) the intense spring bloom between the Bay Bridge and Dumbarton Bridge, which began in March and persisted until late April (peak around day 90); (2) a sequence of localized episodes of high chlorophyll concentration below the Dumbarton Bridge in spring and summer; and (3) a smaller chlorophyll increase in the North Bay around May 1 (day 120).

The South Bay spring bloom occurred between the February and April RMP water monitoring (shown as diamonds), so the effects of this large biological event might not be evident in the measurements of trace contaminants. A clear signal of the chemical changes caused by the spring bloom is seen in the DO measurements (Figure 42), which show the greatest oxygen supersaturation (highest primary productivity) in South Bay from late March to early April. The April RMP sampling did coincide with the period of smaller phytoplankton population growth in North Bay, and the chemical consequences of this event may be evident in the other RMP results. For example, this small biomass increase was associated with DO increases, especially in Suisun Bay where slight DO supersaturation was measured. Similar increases in DO were measured in the North Bay in mid-August (Figure 42), again indicating a period of enhanced phytoplankton production and biotransformation.

These indicators of phytoplankton abundance and activity have direct relevance to the RMP because phytoplankton primary production is a potent force that transforms reactive elements from dissolved into particulate forms that can be transferred to consumer animals through their feeding. This pathway of bioconcentration is especially important for elements such as selenium, nickel, cadmium, and zinc. For example, observations during the 1994 spring bloom suggest that over half the total annual point-source loadings of cadmium, nickel, and zinc to the South Bay are assimilated by the phytoplankton (Luoma *et al.*, 1997). Progress toward full understanding of the trends of change in trace substances will require consideration of the biogeochemical transformations that take place within the Estuary, including those associated with phytoplankton production.

Lesson #4: The Bay is Composed of Geographic Subregions

The final lesson of estuarine variability can be illustrated with measurements of suspended solid concentrations in the Bay-Delta. Figure 44 shows high TSS concentrations with dark shading, and low concentrations with light shading. Within the North Bay, two patterns of variability were evident in 1996: (1) high TSS concentrations in the upper Estuary during periods of high Delta outflow, reflecting the large riverine input of sediments during floods (e.g., February and December); and (2) the formation of the turbidity maximum in Suisun Bay during summer (most evident around day 180). The highest surface concentrations of suspended solids were measured in the southernmost South Bay, during a sequence of events in spring and summer (Figure 44). These features show very sharp spatial gradients, with the highest TSS concentrations (and turbidity) confined below the Dumbarton Bridge. This highly patchy distribution of suspended solids suggests that the region of the Bay below the Dumbarton Bridge is a distinct subregion which can acquire its own particular water quality characteristics. Distributions of other constituents, such as salinity (Figure 40), dissolved oxygen (Figure 42), and chlorophyll (Figure 43), support this notion. The patchy

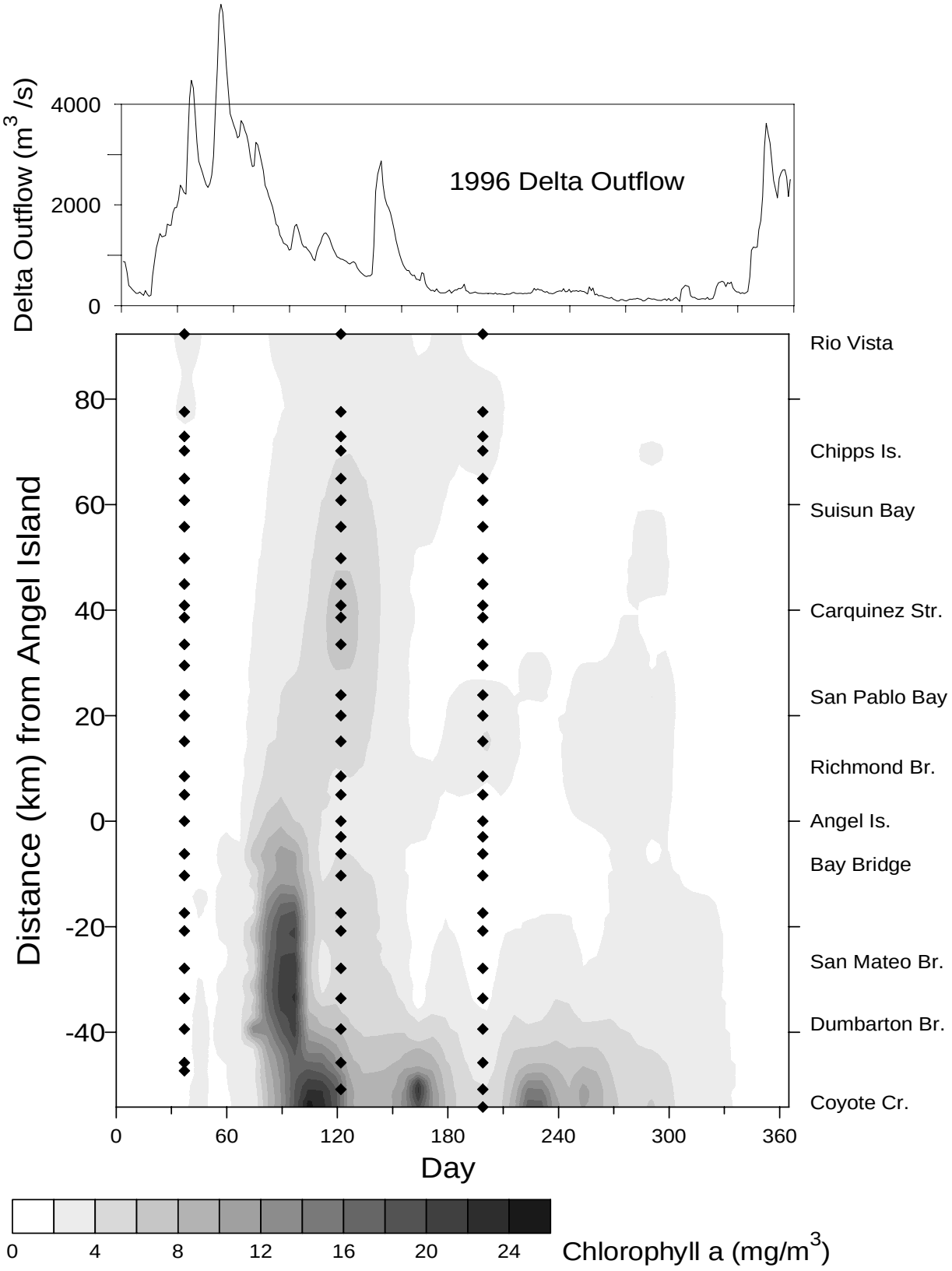

Figure 43. Delta Outflow Index (top panel) and concentrations of chlorophyll *a* (lower panel) along the USGS transect for 1996 (see Figure 39). Intensity of shading is proportional to chlorophyll *a*, with darker shadings indicating higher concentrations.

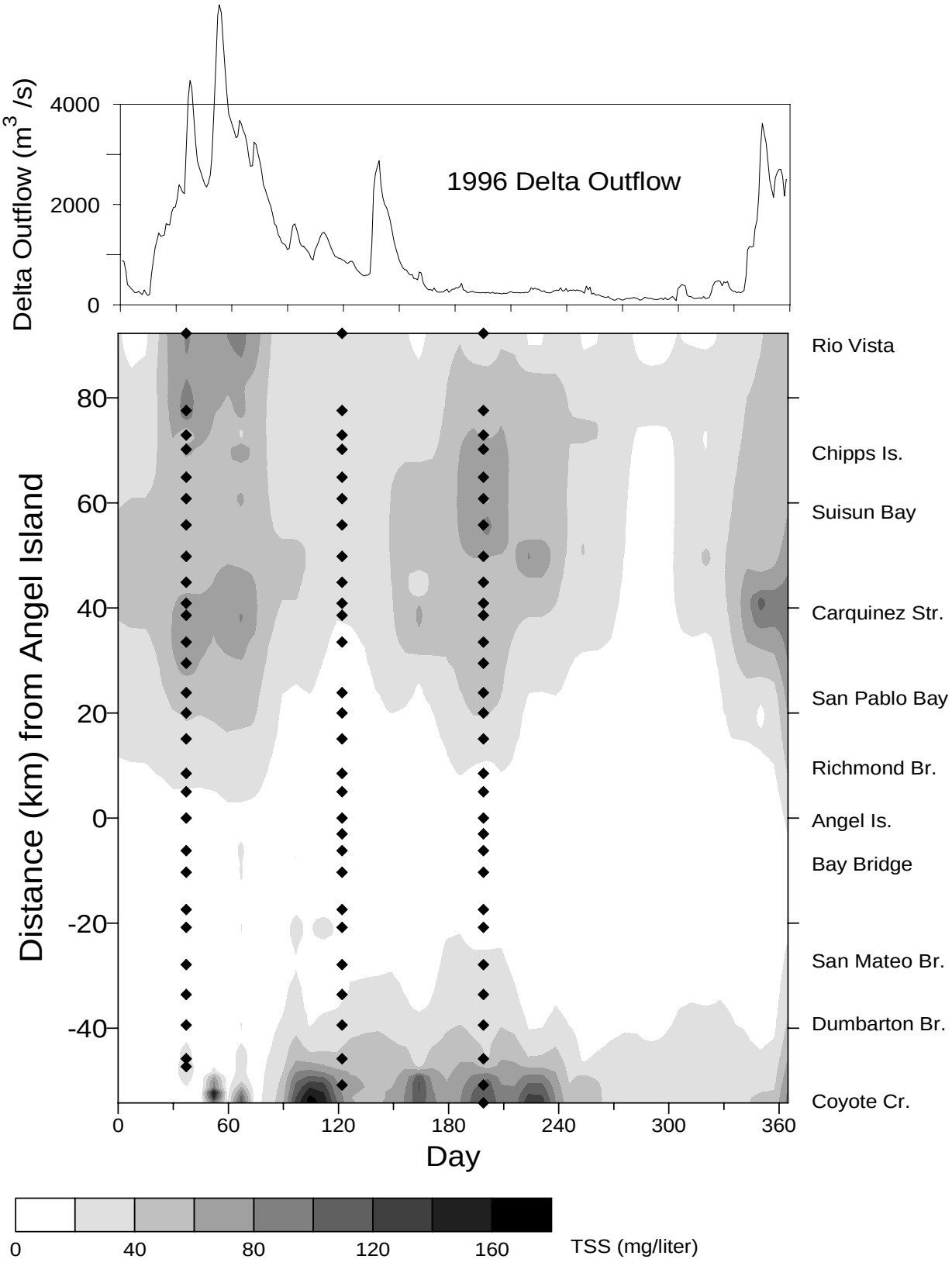

Figure 44. Delta Outflow Index (top panel) and concentrations of total suspended solids (lower panel) along the USGS transect for 1996 (see Figure 39). Intensity of shading is proportional to TSS, with darker shadings indicating higher concentrations of suspended solids.

distribution of TSS illustrates the importance of spatial variability, which can arise from many different processes and is unusually large in estuaries. The partitioning of the Bay-Delta system into geographic subregions is a consequence of the topographic and bathymetric features which shape the patterns of water circulation, mixing, and transport (Powell *et al.*, 1986). In this particular case, locally-high concentrations of TSS could be the result of intense resuspension in the shallow domain below the Dumbarton Bridge, coupled with the very narrow constriction that acts to slow horizontal mixing between this lower region and the main body of the South Bay. Other topographic controls on mixing and spatial variability include the San Bruno Shoal, Pinole Shoal, and Carquinez Strait.

This lesson, too, has relevance to the RMP and its design. Since large spatial variability is an inherent property of estuarine water quality, baywide monitoring should include identification of, and sampling within, all the important subregions. Recent analysis of high-resolution transects of salinity, chlorophyll, and TSS in San Francisco Bay (Jassby *et al.*, 1997) give general guidelines about how to allocate spatial sampling in complex estuarine ecosystems, and particular guidelines for efficient spatial sampling in San Francisco Bay.

Summary

In this chapter we use results from twenty-one USGS sampling cruises to describe some key features of water quality variability in San Francisco Bay during 1996. The patterns of variability are displayed as shaded images showing the annual cycle and the spatial gradients of water quality, from the Sacramento River to the southern South Bay. The five water quality parameters described here were chosen as indicators of different processes of estuarine variability, so results from this program element can be used as a starting place for interpreting the more complex patterns of variability in trace contaminants and their effects. We use results from 1996 to illustrate some general lessons of estuarine variability that are clearly evident in the easily-measured quantities: salinity, temperature, TSS, chlorophyll, and DO. These same lessons apply to trace substances, and we hope these lessons will be useful guides for identifying the patterns and causes of variability in trace substances, which are also influenced by watershed inputs, oceanic inputs, internal transformations, and physical features of the Bay-Delta that control circulation and mixing.

Acknowledgments

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Episodic Toxicity in the San Francisco Bay System

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Background and Objectives

The Regional Monitoring Program for Trace Substances in the San Francisco Estuary (RMP) has been assessing aquatic toxicity of estuarine waters two or three times annually since 1993. It is known that variations in contaminant concentrations occur on smaller time scales due to events such as urban runoff following rainstorms or from similar surface runoff following application of pesticides in agricultural areas. RMP sampling in the winter of 1995 coincided for the first time with stormwater inflows to the Estuary, and significant toxicity to mysid shrimp was detected in water samples from Grizzly Bay (BF20) and the Sacramento (BG20) and San Joaquin (BG30) Rivers. Sensitive life-stages of various organisms are present in this portion of the Estuary during winter and spring. It is therefore possible that episodic pollution events with important ecological consequences are occurring on time scales that the RMP would not systematically detect.

The goal of the episodic toxicity pilot study is to determine if short-term episodes of significant toxicity are occurring in the Estuary. If toxicity is detected, temporal correlations between these observations and the presence of sensitive Bay organisms would indicate species at risk.

Study Approach

Following is a brief summary of the methods used in this project; more detail can be found in the Sampling Plan that was completed and delivered to the San Francisco Estuary Institute in December 1996. The technical approach of the study is to use event-directed observations of water chemistry (using ELISA analysis) and aquatic toxicity at several sites. These observations were made at times when toxicity might be expected (high Delta outflow following pesticide applications, for example), using the sensitive crustacean species *Mysidopsis bahia* with representative sites in the extreme South Bay, and in the northern reach near Chipps Island.

The goal in the South Bay was to sample runoff that has begun to mix with estuarine water (as evidenced by elevated salinity) in Guadalupe Slough and Alviso Slough (Guadalupe River). We were provided with online access to real-time precipitation and runoff data by the Santa Clara Valley Water District, and these data were used to decide when sampling should occur. Sampling in the South Bay was accomplished using a 12-foot inflatable vessel that was launched in Guadalupe Slough. Sampling was timed to coincide with high tide when possible in order to facilitate boat access.

Table 3. Summary of RMP episodic toxicity testing pilot project, 1996–1997.

	Napa River	Guadalupe Slough & River	Mallard Island (USGS[a])	Mallard Island (Runoff[b])
Number of Tests	2	16	8	4
Tests with Significant Toxicity to Mysid Shrimp	0	3	0	0

[a] Sampling was conducted in conjunction with the USGS Honker Bay Project.

[b] Sampling was conducted independently, in response to rainstorm events.

The other sampling location was at the head of the Estuary near Chipps Island. The Department of Water Resources (DWR) provided access to their sampling station at Mallard Slough on the south side of the San Joaquin River near Chipps Island. This was an ideal location for sampling, as it represents the mixture of upstream waters (from the Sacramento and San Joaquin watersheds) that flow into the northern Estuary, and is located near the toxicity-testing laboratory in Martinez. Water was pumped directly into sampling containers using the pumping equipment at the site. In addition, the US Geological Survey (USGS) offered to provide GCMS analysis of the water collected at Mallard Slough in conjunction with their Honker Bay Project, which was an extraordinary opportunity for the project.

Progress to Date

The rainfall pattern in 1996–97 was quite unusual, and this influenced the progress of the project. The results of the toxicity tests are summarized in Table 3.

Heavy rains occurred early in the winter, with major flooding occurring on the Sacramento and San Joaquin Rivers. The scale of this flooding completely disrupted the USGS Honker Bay Project, which was put on hold after sampling in early January. The eight ambient water samples taken in conjunction with USGS were collected as part of our informal agreement with USGS, and we did not expect to see toxicity in these samples as they were collected prior to the period of heavy pesticide use in the watershed.

We conserved our testing resources during the winter to sample spring storms, as there is

Table 4. Summary of South Bay RMP episodic toxicity pilot study testing results (1996–97).

Site	Sample Collection Date	% Mysid Survival		ELISA Analyses	
		Control	Site Water	Diazinon (ng/L)	Chlorpyrifos (ng/L)
Guadalupe Slough (2 ppt salinity)	**10-29-96**	**97.5**	**0***	**392**	**145**
Guadalupe Slough (4 ppt salinity)	10-29-96	97.5	92.5	b.d.	b.d.
Guadalupe Slough	11-17-96	100	90	n.m.	n.m.
Guadalupe River	11-17-96	100	97.5	n.m.	n.m.
Guadalupe Slough	12-10-96	100	95	176	b.d.
Guadalupe River	12-10-96	100	95	515	67
Guadalupe Slough	1-2-97	100	95	b.d.	b.d.
Guadalupe River	1-2-97	100	95	b.d.	b.d.
Guadalupe Slough	3-17-97	97.5	95	b.d.	b.d.
Alviso Slough	3-17-97	97.5	90	b.d.	b.d.
Guadalupe Slough	**4-19-97**	**95**	**0 ***	**b.d.**	**78**
Guadalupe River	4-19-97	95	82.5	b.d.	67
Guadalupe Slough	**5-23-97**	**97.5**	**47.5 ***	**b.d.**	**70**
Guadalupe River	5-23-97	97.5	82.5	b.d.	63
Guadalupe Slough	6-4-97	95	100	54	*
Guadalupe River	6-4-97	95	100	74	*

n.m. = not measured.

b.d. = below detection limits.

* inconsistent results for chlorpyrifos analyses.

Table 5. Metal concentrations (μg/L) measured in stormwater runoff in South Bay.

Site	Date	Cd	Cu	Pb	Ni	Ag	Zn	As	Hg	Se
Guadalupe River	11/20/96	0.048	9.05	5.91	16.6	0.026	38.6	2.35	0.0366	0.7
Guadalupe River	12/17/96	0.814	71.61	76.3	171.69	0.332	364	16.4	0.971	1.98
Guadalupe Slough	11/20/96	0.027	5.31	3.11	8.47	0.013	20.2	2.09	0.0153	0.27
Guadalupe Slough	12/17/96	0.522	58.93	49.3	132.87	0.105	271	15.2	0.585	1.17
South Bay	11/7/96	0.088	10.1	4.99	13.42	0.0003	62.8	3.57	0.0202	1.33

more pesticide use in the watershed in late winter and early spring. Previous work suggested that runoff from spring storms might introduce episodic toxicity into the watershed. Unfortunately, there were no large spring storms after the early January flooding, with no opportunity to collect samples between January 12 and March 17. The storms sampled in March, April, May, and June were quite small, and did not generate large volumes of runoff. None of these samples were toxic.

In the extreme South Bay, toxicity was observed during three storm events, apparently associated with chlorpyrifos concentrations in the range of 70 ng/L or greater (Table 4); chemical analyses of these waters indicated that metals were below toxic concentrations (Table 5). Additional ELISA samples taken in conjunction with the toxicity tests indicated that pesticide concentrations varied on a very small spatial scale. It thus appears likely that the toxicity samples, although timed to coincide with episodes of runoff, probably did not coincide with "peak" pesticide concentrations. Characterizing the spatial and temporal extent of such toxicity as it enters the Bay should be a focus of further investigation.

Episodic Toxicity Monitoring Planned for 1997–1998

The planned Episodic Toxicity monitoring for 1987–1998 will be performed with the following objectives:

- document the frequency and duration of toxic episodes;
- expand the spatial extent of monitoring in the Bay system.

1. Episodic Toxicity Monitoring in the Northern Bay

Water samples will be collected from the Mallard Slough sampling station twice each week for six months, beginning in November (or the first major rainfall). The toxicity of these samples will be evaluated using the estuarine shrimp *Mysidopsis bahia*. The data from this sampling program will be plotted graphically over time to provide information regarding the frequency and duration of significant ambient water toxicity, which in turn will be used to:

1) confirm whether pulses of toxicity that move down the rivers are still toxic upon reaching the Estuary;
2) determine the magnitude of toxicity in the Estuary;
3) further test the working hypothesis that observable toxicity is caused by pesticide application and runoff.

Given that the RMP Baseline toxicity testing has detected ambient water toxicity in summer months as well, it may be desirable to extend such monitoring and toxicity testing throughout the year. Furthermore, as the observation of ambient water toxicity in summer is not explained by our current working hypothesis of ambient water toxicity due to seasonal runoff of pesticides, it would also be desirable to further investigate the causes of such toxicity through the application of Toxicity Identification Evaluation (TIE) methods. Additional extramural funding is currently being sought to provide additional monitoring and testing of ambient waters in the northern reach of the Bay.

2. Episodic Toxicity Monitoring in South Bay

At Guadalupe Slough, the focus will be on toxicity due to runoff. ELISA analysis of runoff waters collected last season clearly demonstrated that the practice of "grab" samples is 'hit or miss' with respect to catching the peak pesticide concentrations. Therefore, we are proposing to collect composite samples using an autosampler. Using on-line access to the runoff monitoring system of the Santa Clara Valley Water District to determine when significant runoff occurs, we will activate the autosampler to collect a composite sample over a 24 hour period. These water samples will be transported to the testing laboratory in Martinez, where diazinon and chlorpyrifos levels will be determined using ELISA, and toxicity evaluated using *Mysidopsis bahia*. Current funding will allow for the collection and evaluation of 12 runoff samples.

We will tentatively expand the spatial extent of the monitoring to include one other site where runoff enters the Estuary. There are many candidate sites, including the Napa River, Walnut Creek, Alameda Creek, San Lorenzo Creek, and Sonoma Creek. Discussion is currently underway between the RMP, the Regional Board, and the Bay Area Stormwater Management Agencies Association regarding these candidate sites. Samples entering the Bay at the selected site will be sampled and evaluated as at Guadalupe Slough.

Time Series Of Suspended-Solids Concentration, Salinity, Temperature, and Total Mercury Concentration in San Francisco Bay During Water Year 1996

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Many physical processes affect how constituents within San Francisco Bay vary. Processes and their associated time scales include turbulence (seconds), semidiurnal and diurnal tides (hours), the spring-neap tidal cycle (days), freshwater flow (weeks), seasonal winds (months), ecological and climatic changes (years), and geologic changes (thousands of years). The effect and relative importance of physical processes on the Bay can be determined from continuous time series of suspended-solids concentration (SSC), salinity, and water temperature. SSC time series and Regional Monitoring Program (RMP) water-quality data can be used to calculate time series of some trace-element concentrations (Schoellhamer, 1997). The purpose of this chapter is to qualitatively describe time series of SSC, salinity, water temperature, and mercury during water year 1996 (October 1995 through September 1996). In addition, a calculated time series of mercury will be used to evaluate the accuracy of using instantaneous water samples to evaluate a 4-day average water-quality objective.

Salinity, temperature, and sediment are important components of the San Francisco Bay estuarine system. Salinity and temperature affect the hydrodynamics (Monismith *et al.,* 1996), geochemistry (Kuwabara *et al.,* 1989), and ecology (Cloern, 1984; Nichols *et al.,* 1986; Jassby *et al.,* 1995) of the Bay. Suspended sediments limit light availability in the Bay, which, in turn, limits primary production (Cloern, 1987; Cole and Cloern, 1987), and thus food for higher trophic levels. Sediments deposit in ports and shipping channels, which must be dredged to maintain navigation (U.S. Environmental Protection Agency, 1992). Potentially toxic substances, such as metals and pesticides, adsorb to sediment particles (Kuwabara *et al.,* 1989; Domagalski and Kuivila, 1993; Schoellhamer, 1997).

The transport and fate of suspended sediments are important factors in determining the transport and fate of constituents adsorbed on the sediments. For example, the concentration of suspended particulate chromium in the Bay appears to be controlled primarily by sediment resuspension (Abu-Saba and Flegal, 1995). Concentrations of dissolved trace elements are greater in South Bay than elsewhere in San Francisco Bay, and bottom sediments are believed to be a significant source (Flegal *et al.,* 1991). The sediments on the Bay bottom provide the habitat for benthic communities that can ingest these substances and introduce them into the food web (Luoma *et al.,* 1985; Brown and Luoma, 1995). Bottom sediments also are a reservoir of nutrients that contribute to the maintenance of estuarine productivity (Hammond *et al.,* 1985).

Time Series Data

The US Geological Survey (USGS) operates several continuous salinity, temperature, and SSC monitoring sites in San Francisco Bay (Figure 45; Buchanan and Schoellhamer, 1996; Freeman *et al.,* 1997). At most sites, electrical conductance, temperature, and/or optical backscatterance (OBS) sensors are positioned at mid-depth and near the bottom. A measurement is taken every 15 minutes by a data recorder by averaging the output of each sensor for 1 minute. Electrical conductance and temperature are converted to salinity using the methods of Miller *et al.* (1988). The OBS sensors optically measure the amount of sus-

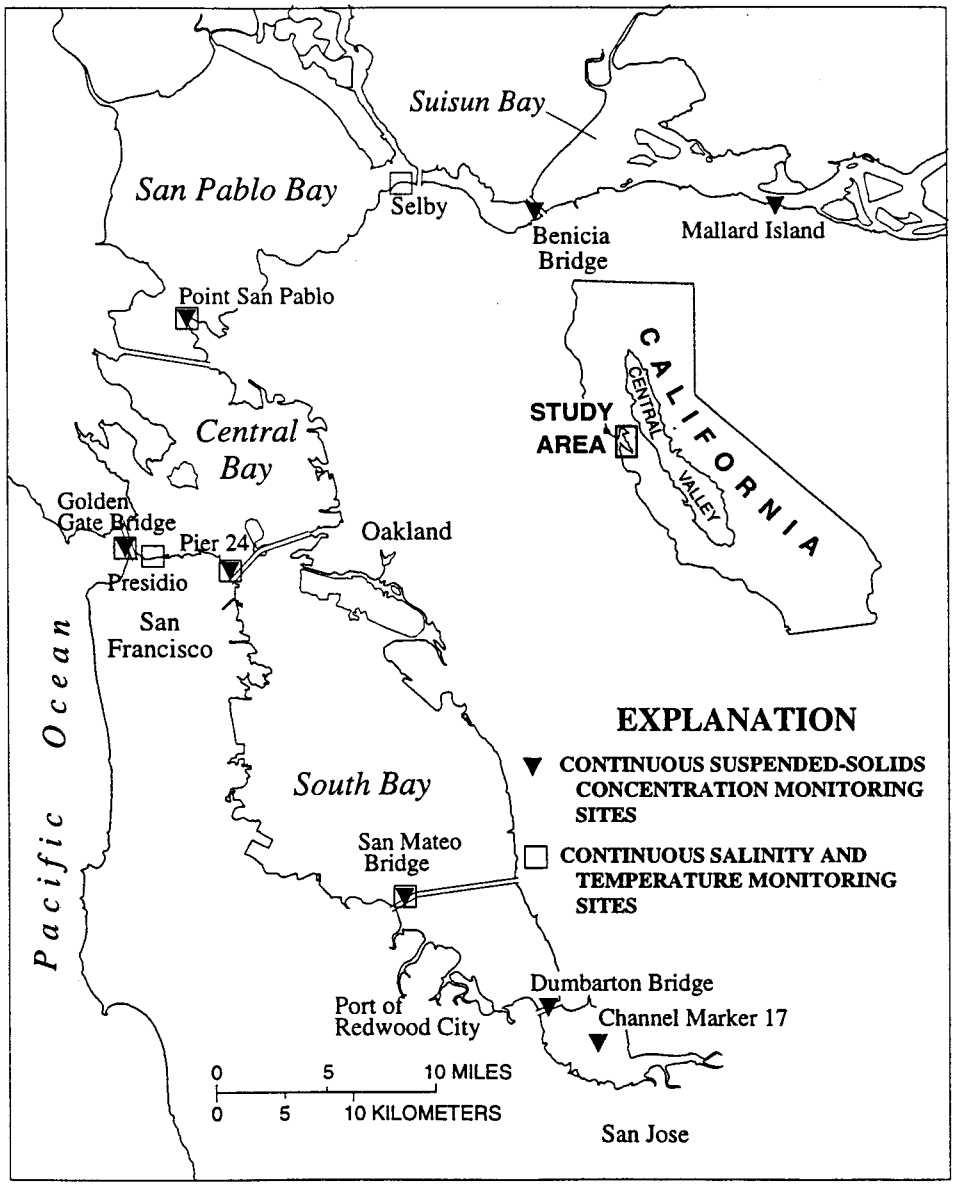

Figure 45. San Francisco Bay study area and USGS continuous monitoring sites.

pended material in the water, and the output of the sensors is converted to SSC with calibration curves developed from analysis of water samples. The sites are serviced every one to five weeks to clean the sensors, which are susceptible to biological fouling, and to collect water samples for sensor calibration. Biological growth fouls the sensors and invalidates sensor output. Equipment malfunctions also were responsible for some lost data.

This summary includes time series data on some processes that affect salinity and SSC. Estimates of discharge from the Sacramento-San Joaquin River Delta were obtained from the California Department of Water Resources (1986). Tidal currents are strongest during full and new moons, called spring tides, and weakest during half moons, called neap tides. The strength of the spring-neap cycle was quantified by calculating the low-pass root-mean-squared (RMS) water level by squaring water level measured at Point San Pablo, low-pass filtering, and taking the square root (Schoellhamer, 1996). Meteorological data, including insolation (solar energy) and wind speed and direction, were measured at the Port of Redwood City by Schemel (1995). Wind data were used to estimate the daily mean shear stress (force per unit area) on the water surface along the axis of South Bay from San Francisco toward San Jose (Pond and Pickard, 1983).

Salinity

Salinity decreased throughout the Bay during the winter wet season in 1996. The largest freshwater discharges from the Central Valley into San Francisco Bay for the water year occurred during the winter, and the lowest

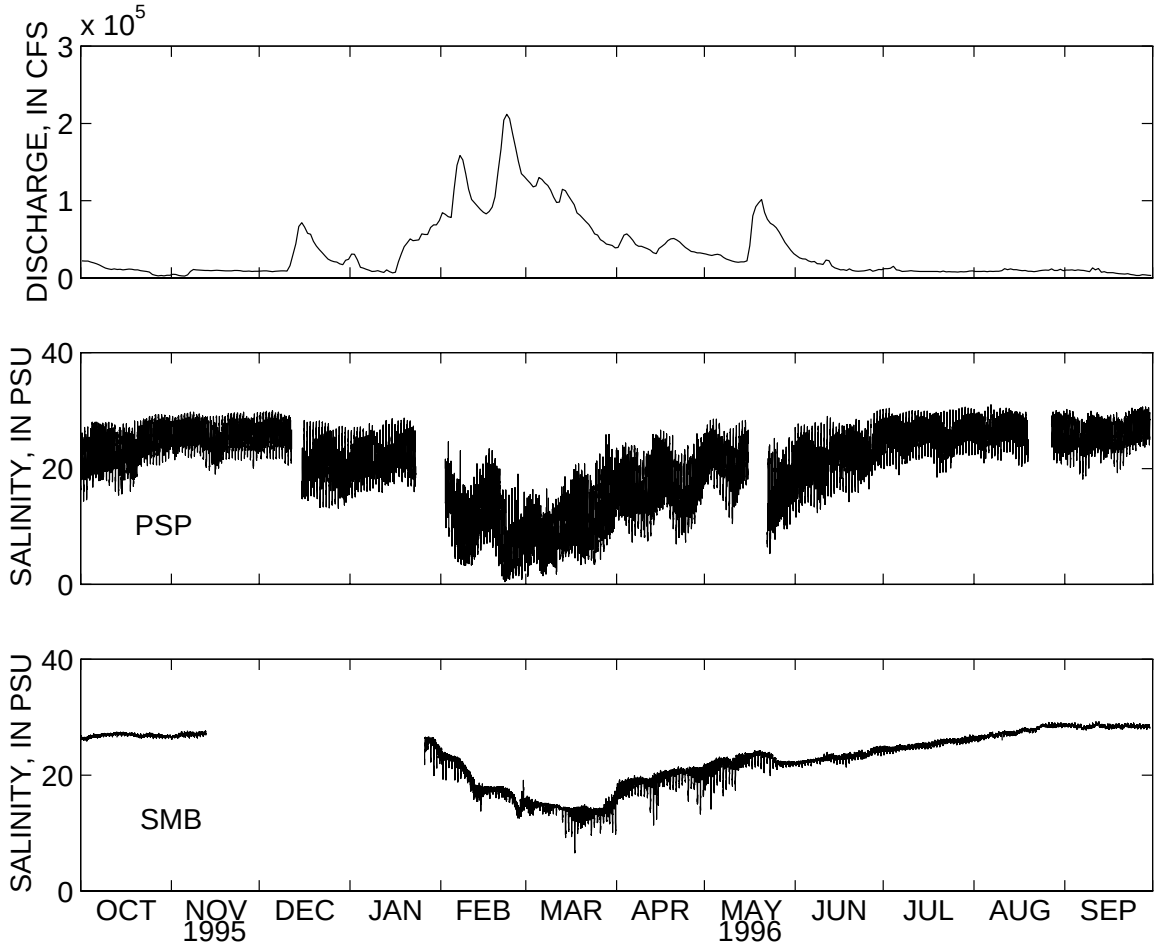

Figure 46. Time series of Delta discharge (California Department of Water Resources, 1986) and salinity at Point San Pablo (PSP) and the San Mateo Bridge (SMB), water year 1996.

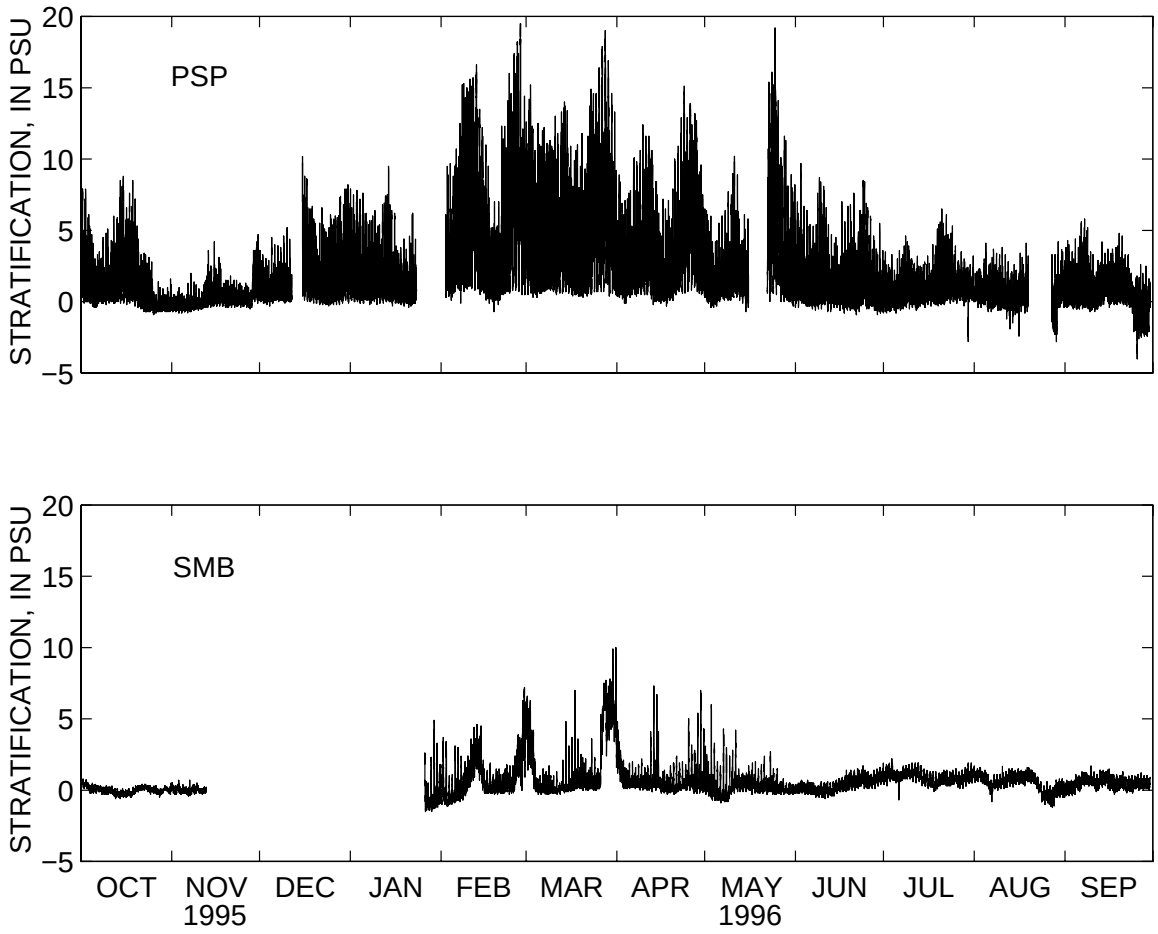

Figure 47. Time series of salinity stratification (bottom salinity minus mid-depth salinity) at Point San Pablo (PSP) and San Mateo Bridge (SMB), water year 1996.

salinity at mid-depth at Point San Pablo occurred at the end of February (Figure 46). In South Bay at the San Mateo Bridge, minimum salinities occurred during March. This delay in response in South Bay was because of the longer time required for mixing of oceanic water and freshwater in South Bay than in Central Bay. During summer and autumn, salinity was relatively high and gradually increased at both sites because freshwater discharge was relatively low.

Tidal variations of salinity, as indicated by the range of salinity on a given day, were much greater at Point San Pablo than at the San Mateo Bridge (Figure 46). Point San Pablo is closer to the Sacramento River, the primary source of freshwater to the Bay, and to the Pacific Ocean, the source of saltwater. Tidal currents also are greater at Point San Pablo than at the San Mateo Bridge. Thus, the change in salinity over a tidal cycle at Point San Pablo is greater than at the San Mateo Bridge.

The spring-neap cycle had a small, but noticeable, effect on salinity at Point San Pablo during the winter and spring. After the first discharge peak in mid-December, the envelope of tidal cycle salinity variations, which appears as a thick black band on Figure 46, oscillated with a 14-day period. Peaks in the envelope in late December, early January, and mid-January occurred during spring tides. Valleys in the envelope occurred during neap tides. Energetic spring tides pushed high salinity water farther up into the Estuary, and weak neap tides allowed low salinity water to move down into the Estuary. During late March, April, and early May, the salinity envelope increased and

oscillated slightly with a period of 14 to 28 days that was similarly correlated with the spring-neap cycle.

Vertical salinity differences that stratify the water column result when denser, more saline water lies below lighter, fresher water. Stratification at Point San Pablo was greatest during the wet season when delta discharge was large (Figure 47). Throughout the water year, the greatest stratification occurred during neap tides, which were too weak to vertically mix the water column. Stratification was much smaller during spring tides, which vertically mixed the water column. Because South Bay had less freshwater inflow, there was less stratification than in other parts of San Francisco Bay. Stratification was observed at the San Mateo Bridge only during the neap tides of February, March, and April (Figure 47). The annual phytoplankton bloom in South Bay occurs during periods of salinity stratification (Cloern, 1984). In 1996, the phytoplankton bloom peaked during late March and early April after a period of significant stratification (B.E. Cole, U.S. Geological Survey, written commun., 1996).

Temperature

Time series of solar radiation (insolation) and water temperature had a strong seasonality. Maximum temperatures occurred during summer and minimum temperatures during winter at both Point San Pablo and the San Mateo Bridge (Figure 48). Because of the seasonal dependence of temperature on insola-

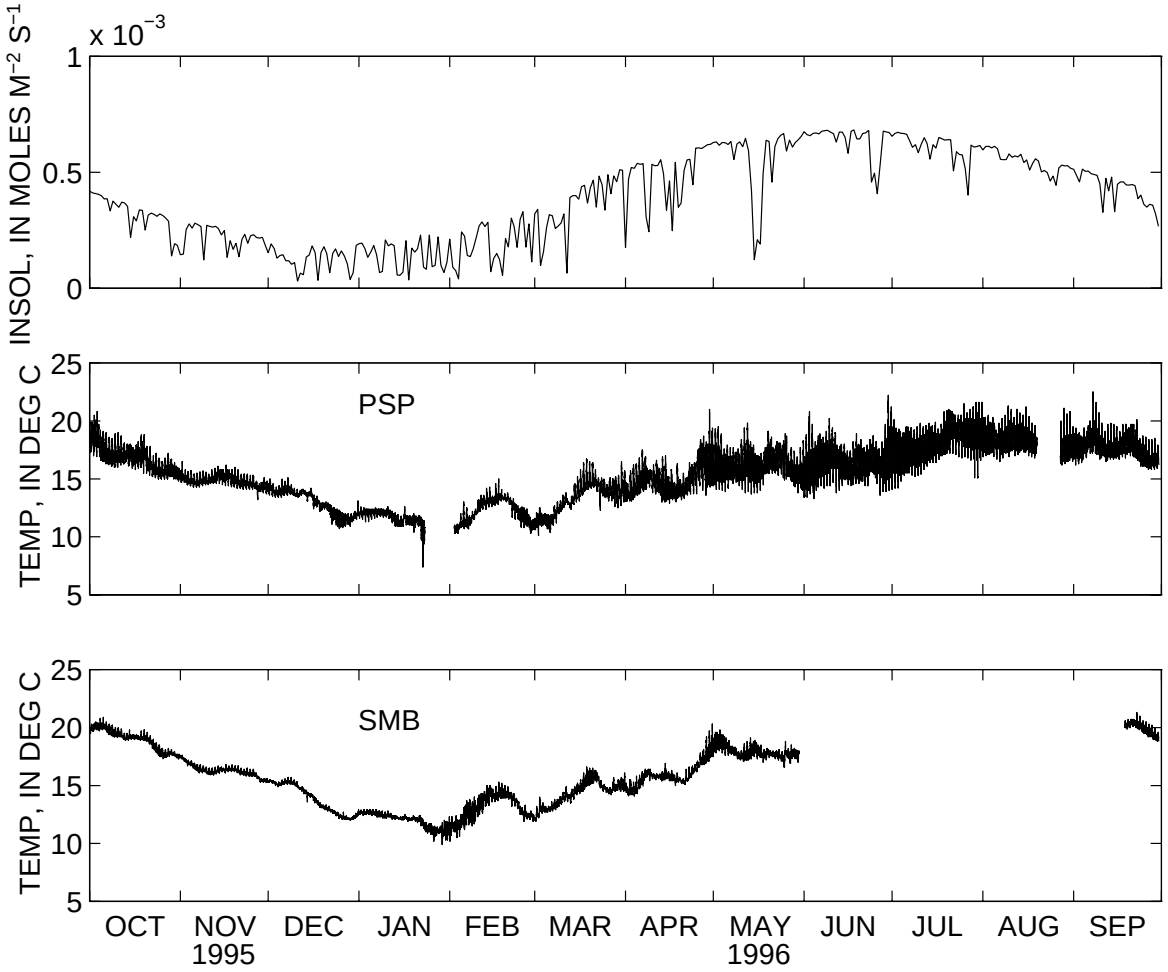

Figure 48. Time series of daily mean insolation at the Port of Redwood City (Schemel, 1995) and mid-depth water temperature at Point San Pablo (PSP) and the San Mateo Bridge (SMB), water year 1996.

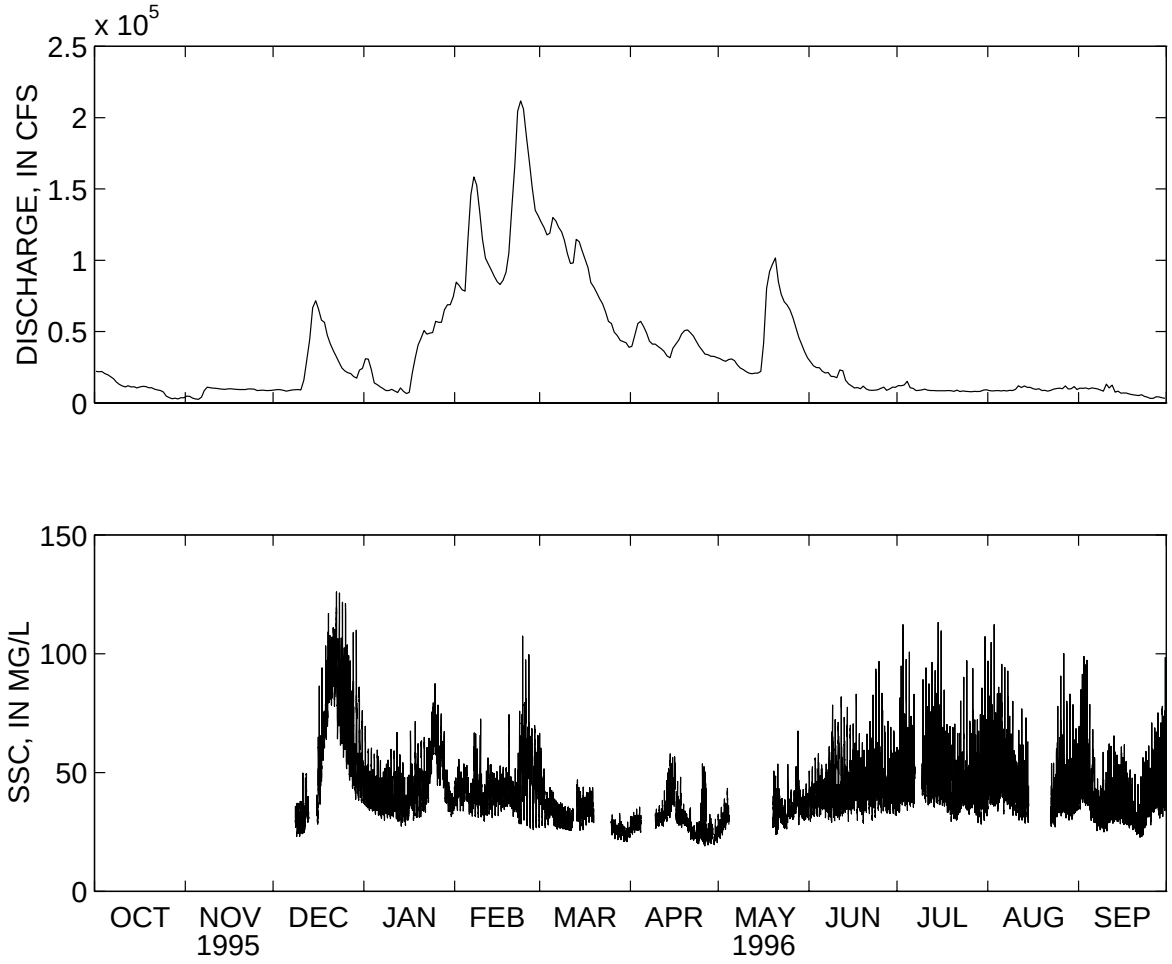

Figure 49. Time series of Delta discharge (California Department of Water Resources, 1986) and suspended-solids concentration (SSC) at Mallard Island, water year 1996.

tion, the general trend of water temperature at the two sites was very similar. The seasonal variation of water temperature lagged the seasonal variation of insolation by about 1 month. Tidal cycle variations in temperature were usually greatest at Point San Pablo because there is more exchange with the cooler Pacific Ocean. During winter, however, the differences in temperature over a tidal cycle at the two sites were small because water temperatures in the Bay and the ocean were more uniform. Instruments at both sites are located in deep channels adjacent to shallow waters, which are conducive to warming during the summer.

Suspended Solids Concentration

SSC in the northern part of San Francisco Bay varied in response to freshwater discharge from the Central Valley during water year 1996. In mid-December 1995, delta discharge peaked at 72,000 ft^3/s during the first large runoff event of the wet season (Figure 49). In response, SSC at Mallard Island, at the boundary between the Bay and the Delta, increased to more than 100 mg/L (Figure 49). This "first-flush" of the Central Valley watershed lasted about 2 weeks and produced the greatest SSC measured at Mallard Island during the water year. Larger peaks in Delta discharge that occurred after December produced smaller peaks in SSC, similar to the observations by Goodwin and Denton (1991). For example, the maximum daily mean discharge during the water year was 212,000 ft^3/s in late February, almost three times the December flow peak, but the response of SSC was much smaller.

During March and April 1996, discharge varied from 32,000 to 130,000 ft^3/s, and SSC at Mallard Island was relatively small. The

variation in SSC as a result of tides also was small. SSC during late winter and early spring is often relatively small because of releases of reservoir water with low SSC and periods of relatively low wind (discussed later).

Delta discharge did not have as much effect on SSC farther seaward in the Bay, but the tidal variation of SSC, especially the spring-neap tidal cycle, was more important. Throughout the water year, SSC varied with the spring-neap cycle at Point San Pablo (Figure 50), with greater SSC during spring tides and smaller SSC during neap tides. Previous analyses indicate that about one-half the variance in SSC is caused by the spring-neap cycle and that SSC lags the spring-neap cycle by about 2 days (Schoellhamer, 1994; 1996). The first-flush in December and discharge peaks in February increased SSC at Point San Pablo, but this effect was less than that observed at Mallard Island.

Winds in the Bay Area are strongest during summer, and these winds generate waves on the Bay that resuspend bottom sediments in shallow water (Schoellhamer, 1996). Wind-wave resuspension in the shallow waters of Suisun Bay and subsequent transport increased SSC at Mallard Island during the summer (Figure 49). During water year 1996, the estimated daily mean wind shear along the axis of South Bay from San Francisco toward San Jose decreased from autumn to winter, was large during winter only during storms, increased during spring, and was sustained at a relatively large value through the summer (Figure 51). SSC at channel marker 17 in South Bay was relatively low during winter, increased during spring as the seabreeze increased, and diminished slowly

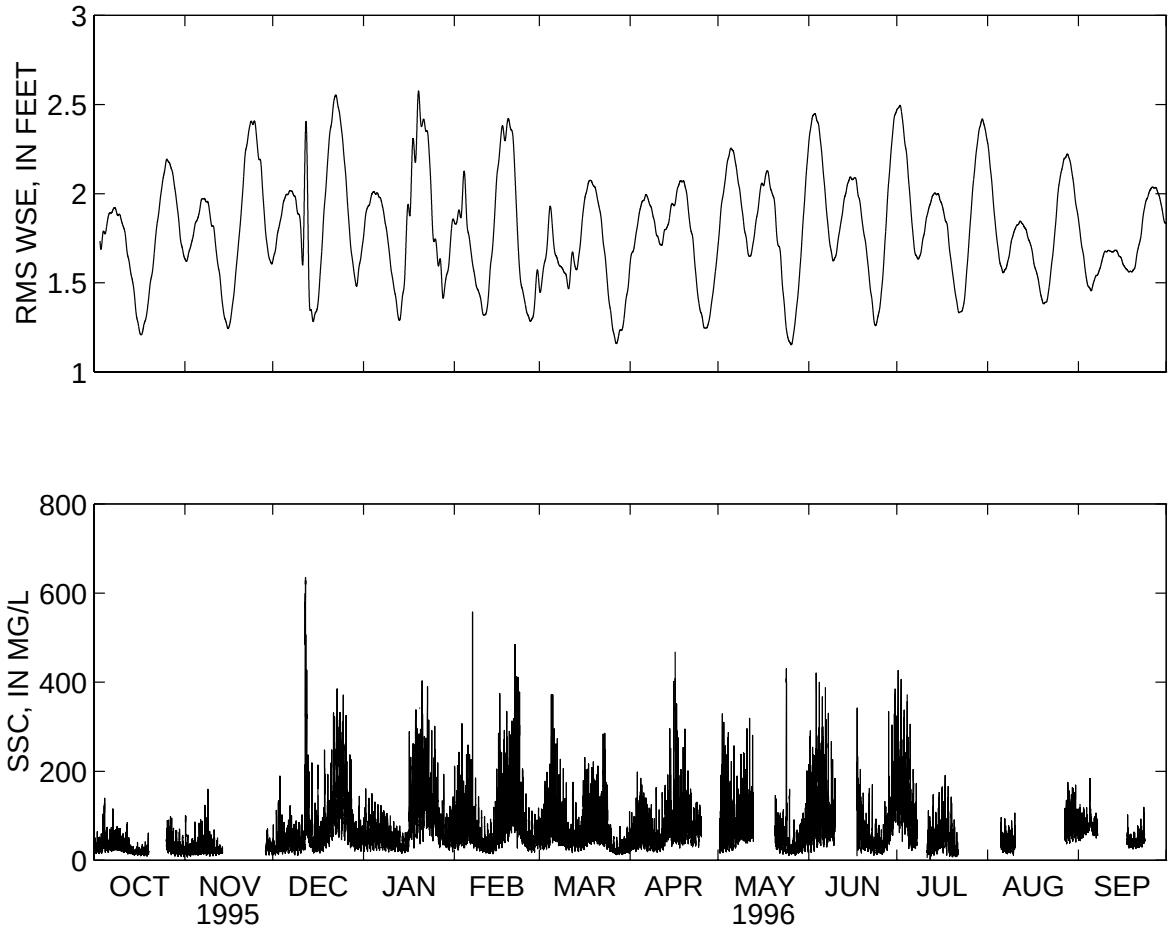

Figure 50. Root-mean-squared (RMS) water-surface elevation (WSE) and suspended-solids concentration (SSC) at Point San Pablo, water year 1996. Maxima in the RMS water-surface elevation indicate spring tides, and minima indicate weaker neap tides.

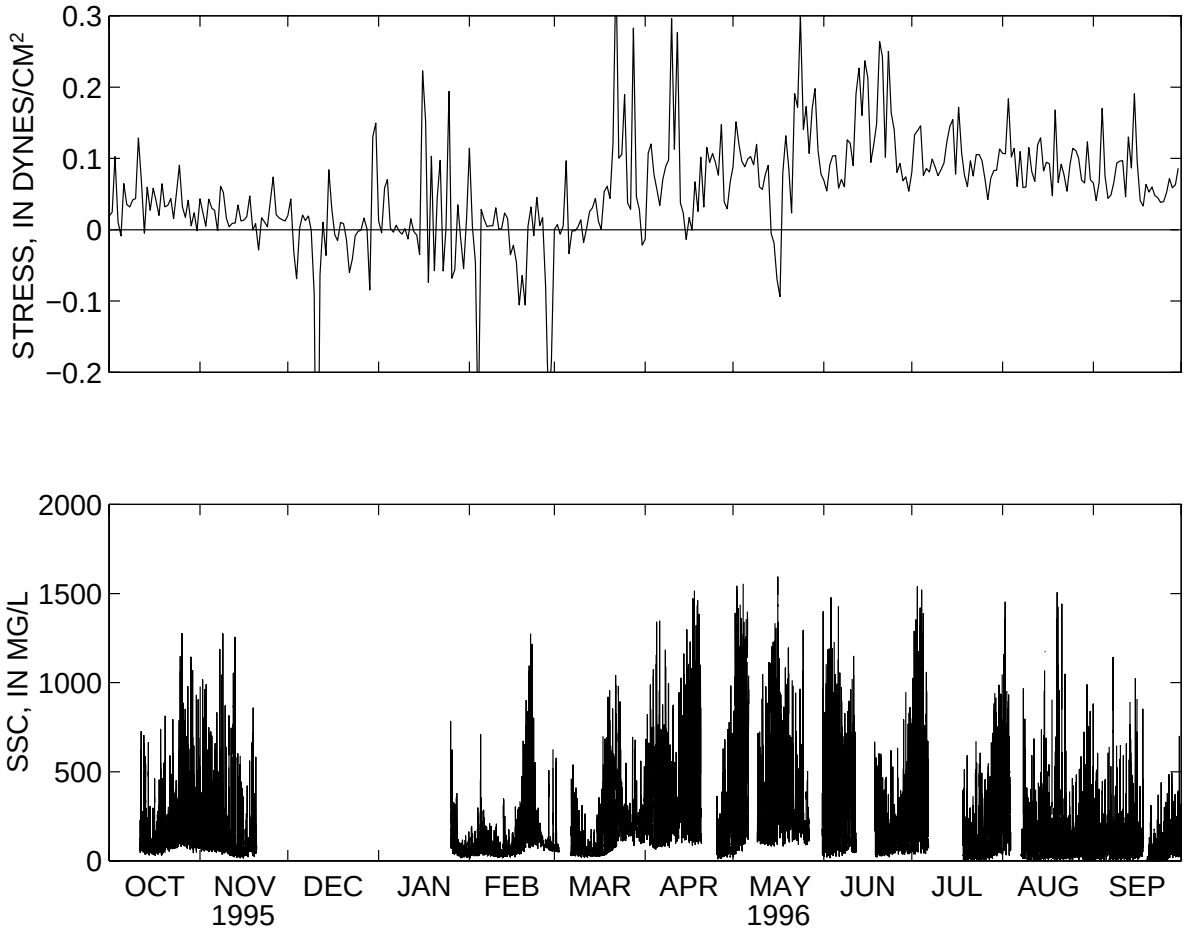

Figure 51. Estimated wind-shear stress along the landward axis of South Bay and suspended-solids concentration (SSC) at channel marker 17, water year 1996. Positive stress indicates wind blowing from San Francisco toward San Jose.

during the summer. The supply of finer, erodible sediment in shallow water is greatest during early spring and diminishes during the summer because wind-waves winnow fine sediment (Nichols and Thompson, 1985). Thus, SSC is greater in late spring and early summer compared to late summer, even though the wind-shear stress is about the same. The fortnightly spring-neap cycle also affects SSC at channel marker 17, with peaks in SSC corresponding to spring tides and valleys corresponding to neap tides. It is interesting to note that the variability in SSC at channel marker 17 is greater than at Point San Pablo (Figure 50) or at Mallard Island (Figure 49).

Strong southerly winds caused by winter storms increase SSC only for a length of time about equal to the duration of strong winds. On December 11 and 12, 1995, the strongest southerly winds of the water year blew in the Bay Area (Figure 51). The daily mean landward wind shear stress in South Bay was -0.54 dynes/cm^2 on December 11. Water levels measured at Point San Pablo were elevated 1 to 2 ft by the wind, which appears as a spike in the RMS water-surface elevation in Figure 50. SSC at Point San Pablo increased to over 600 mg/L early on December 12 and returned to prestorm levels of about 50 mg/L by mid-day on December 13 (Figure 50). Sediment resuspended by wind waves in San Pablo Bay and carried by tidal currents to Point San Pablo were the likely cause of the observed increase in SSC. Sediment resuspended by wind waves settled a few hours after the wind decreased. The fetch for southerly winds was smaller in Suisun Bay, and, therefore, SSC at Mallard Island increased only slightly to almost 50 mg/L (Figure 49).

Total Mercury Concentration

In the 1995 RMP annual report, RMP data from 1993 and 1994 were used to show that total concentrations of seven trace elements were well correlated with SSC (Schoellhamer, 1997). RMP mercury and SSC data from 1995 were added to the 1993 and 1994 data to update the relation between mercury and SSC shown in Figure 52. Some RMP sampling sites are located in tributary channels to the Bay. RMP data from tributaries sometimes had either low or high mercury compared to the predicted values based on SSC ('x' symbols in Figure 52). These data probably reflect the influent waters, not Bay waters and, therefore, were discarded (Schoellhamer, 1997). The slope is 0.32 ng/mg, the intercept is 2.8 ng/L, the squared correlation coefficient is 0.83, the significance level is less than 0.001, and the root-mean-squared error is 6.0 ng/L for 180 data points. These statistical properties are similar to those calculated using only the 1993 and 1994 data. These linear correlation results and SSC time series can be used to estimate time series of total mercury concentration. Example time series for SSC and mercury at mid-depth at Point San Pablo are shown in Figure 53.

The strong correlation between total mercury concentration and SSC indicates that the physical processes that affect SSC also affect total mercury concentration. These processes include semidiurnal and diurnal tides, the spring-neap tidal cycle, freshwater discharge, and seasonal winds. As with SSC, about one-half the variance of total mercury

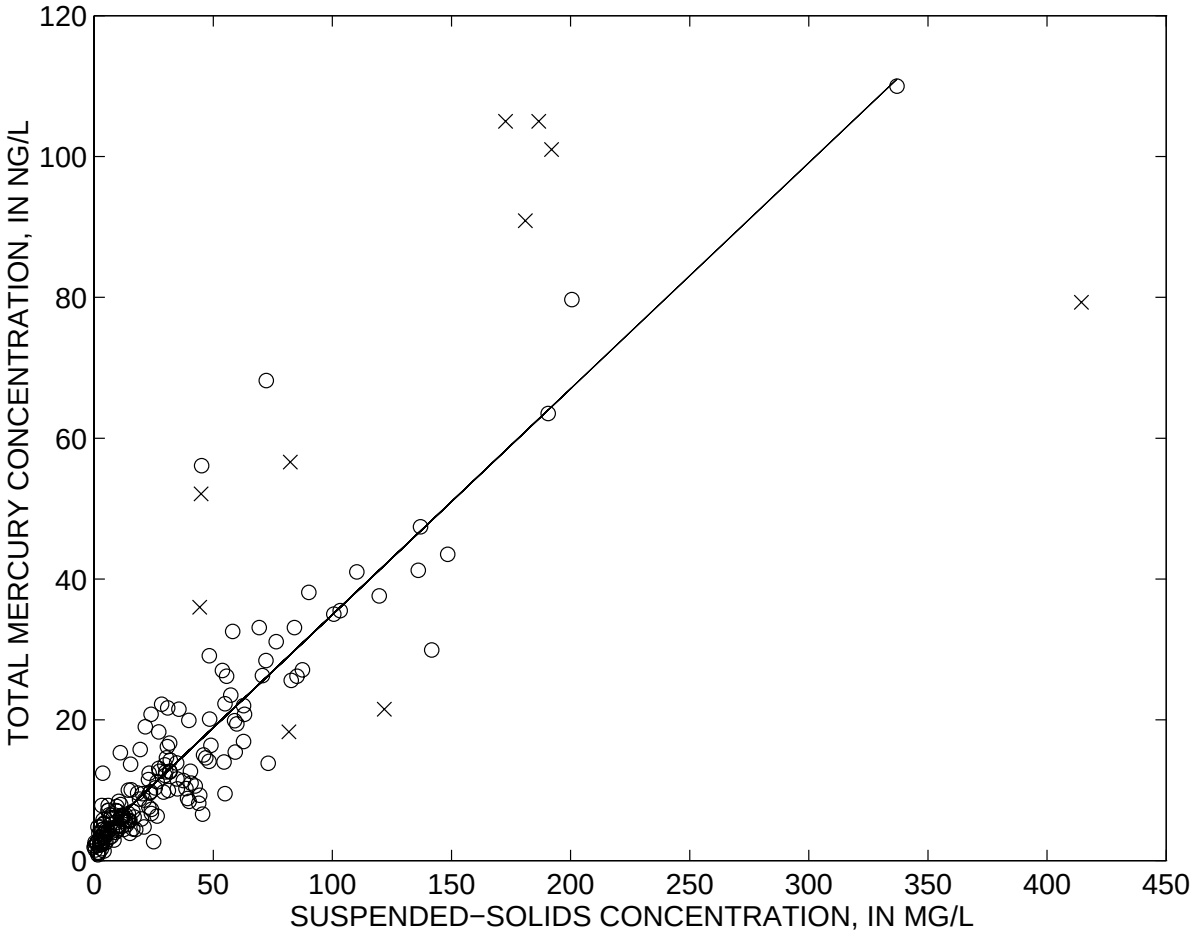

Figure 52. Correlation of suspended-solids concentration (SSC) and total mercury concentration. Outliers from samples taken from influent waters are indicated with an 'x'.

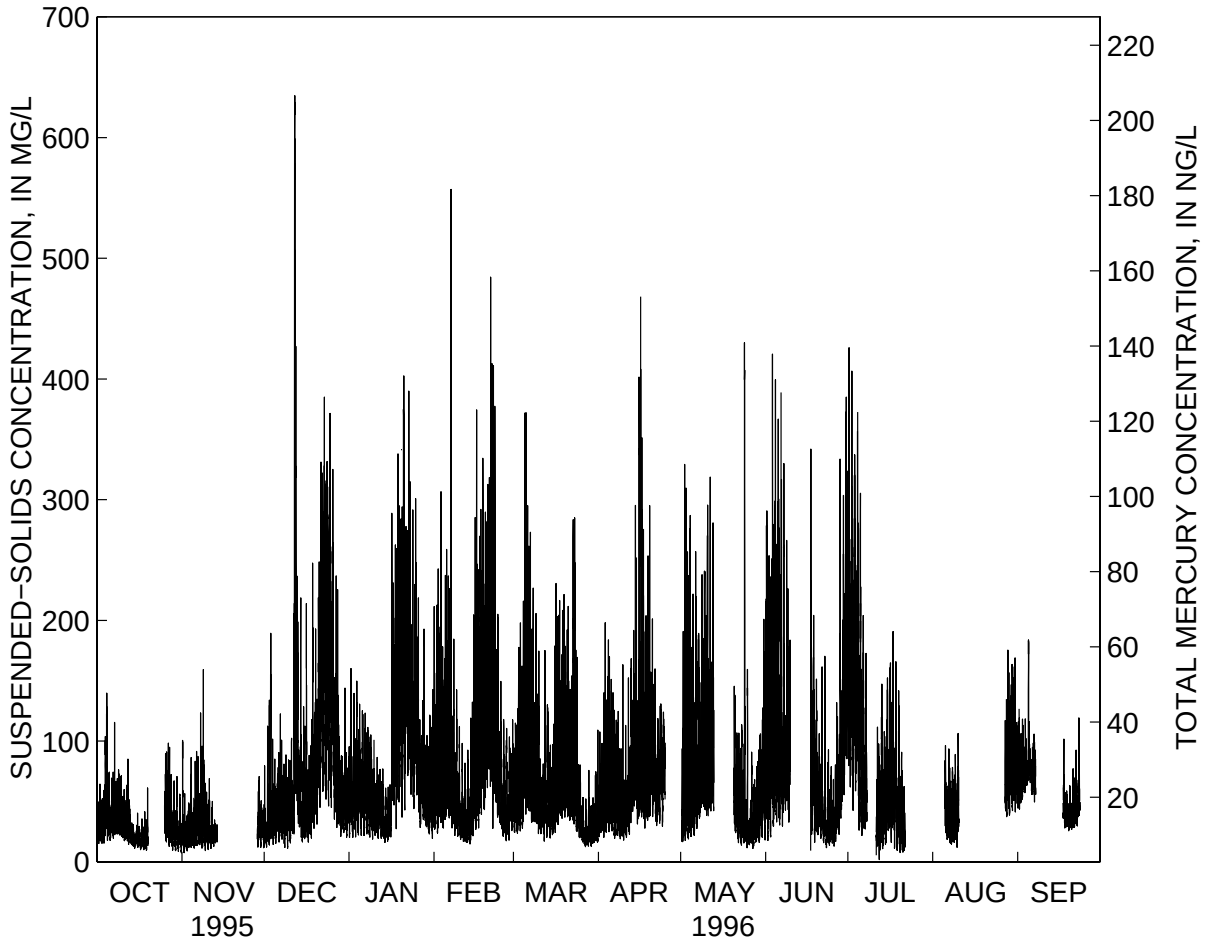

Figure 53. Time series of mid-depth suspended-solids concentration (SSC, measured) and total mercury concentration (calculated) at Point San Pablo, water year 1996.

concentration is the result of the spring-neap cycle.

The time series of total mercury concentration can be used to calculate the 4-day average concentration. The water quality objective currently in effect for mercury in the San Francisco Bay Estuary is a 4-day average total concentration of less than 25 ng/L (San Francisco Bay Regional Water Quality Control Board, 1995; Figure 15 of this chapter). This objective is based on laboratory experiments that expose organisms to constant contaminant levels, but the variability shown in Figure 53 reminds us that the Bay is a much more complex system. Discrete water samples provide an instantaneous value for total mercury concentration, not a 4-day average. The time series from a fixed point used here provides a Eulerian estimate of the 4-day average concentration. Individual parcels of water may experience a different 4-day average concentration because they are moving within the Estuary (a Lagrangian reference frame) and are not static at a fixed point. The 4-day centered running median of total mercury concentration at mid-depth at Point San Pablo is shown in Figure 54.

The 4-day averaging window removes the influence of diurnal and semidiurnal tides, primarily leaving a signal from the spring-neap cycle. Thus, for the present geochemical condition of the Estuary, the spring-neap cycle is the primary factor that determines whether the water-quality objective is satisfied at any given time.

The accuracy of using instantaneous water samples to evaluate a 4-day average water quality objective can be evaluated by comparing the time series averaged over 1 minute (Figure

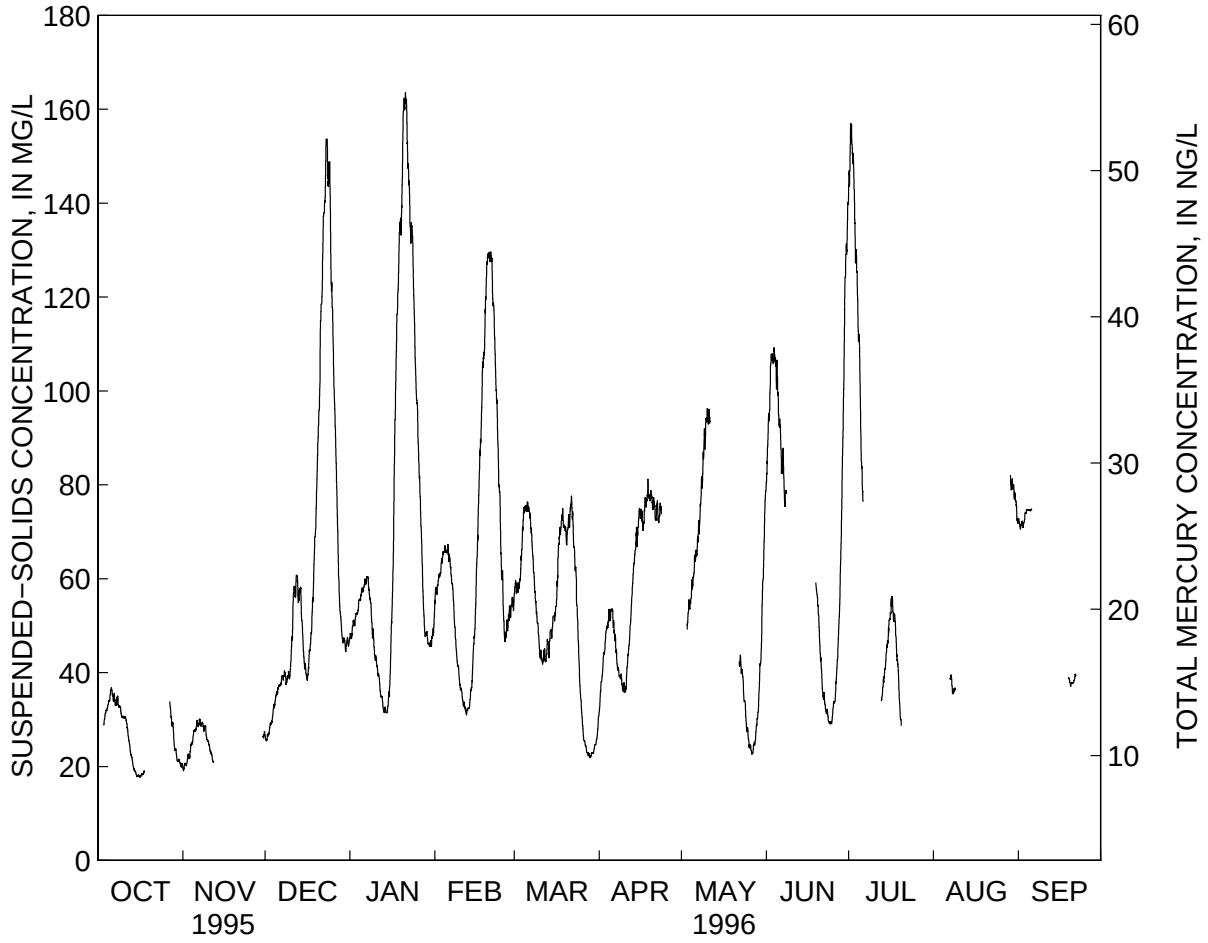

Figure 54. Four-day centered running median of suspended-solids concentration (SSC, measured) and total mercury concentration (calculated) at mid-depth at Point San Pablo, water year 1996. A median value was computed if more than 90 percent of the data within the 4-day averaging window were valid.

53) and averaged over 4 days (Figure 54). Instantaneous grab samples that are analyzed for total mercury concentration and 1-minute averaged OBS measurements that are converted to SSC and then to total mercury concentration are assumed to be equivalent for purposes of this analysis. The percent occurrence of the four possible combinations of the two averaging windows being less than or greater than the threshold concentration (25 ng/L) are presented in Table 6. Twenty percent of the time, a 1-minute average concentration gave an incorrect evaluation of the water-quality objective. When the 1-minute average was less than the threshold, 12 percent of the 4-day averages actually exceeded the threshold, and the water-quality objective was not satisfied. When the 1-minute average was greater than the threshold, 35 percent of the 4-day averages were actually less than the threshold, and the water quality objective was satisfied. Thus, the averaging periods for water quality objectives and sampling should be as similar as possible to evaluate water quality objectives accurately.

Conclusions

Time series data collected during water year 1996 reveal the influence of physical processes that are typically observed in San Francisco Bay. Freshwater discharge from the Central Valley during the winter and spring, seasonal wind, insolation, the spring-neap tidal cycle, and diurnal and semidiurnal tides affected salinity, temperature, suspended solids concentration, and total mercury concentration.

Table 6. Comparison of 1-minute and 4-day average concentrations for evaluating a 4-day average water quality objective using calculated total mercury concentration time series at mid-depth at Point San Pablo, water year 1996.

Averaged concentration compared to threshold concentration			Percent occurrence for all data	Percent occurrence when 1-minute	
1-minute average		4-day average		average is less than the threshold	average is greater than the threshold
Less	Less	58	88	—	
	Less	Greater	8	12	—
	Greater	Less	12	—	35
	Greater	Greater	22	—	65

Calculated time series of total mercury concentration, and other time series of trace element concentrations that are linearly correlated with SSC, can be used to evaluate water quality objectives that are based on averaging periods much longer than the time required to sample. Large differences between the averaging periods of water-quality objectives and sample collection can result in an inaccurate evaluation of water quality objectives from water samples (Table 6).

Acknowledgments

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Levels And Patterns of Polychlorinated Biphenyls in Water Collected from the San Francisco Bay and Estuary, 1993–95

Abstract[1]

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Levels of polychlorinated biphenyls (PCB) were measured in water (particulate and dissolved fractions) from various locations in the San Francisco Estuary over the years 1993–1995 during six cruises. Geometric mean levels of ∑PCBs (sum of 58 congeners) in the combined dissolved and particulate fractions for the six cruises ranged from 342 ng/L to 1,600 ng/L. Comparing this data to previous data from 1975 and 1980 do not reveal any significant temporal trends. The partitioning of PCBs into the dissolved/particulate fraction were correlated with total suspended solids. Using the novel chemometric technique of polytopic vector analysis (PVA) on the data from cruise 8 (April 1995), five separate PCB congener fingerprints were identified in the data. Fingerprint 1 (or end-member 1) represents a slightly degraded source of Aroclor® 1260 in the northern part of the South Bay; the end-member (EM) 2 fingerprint is related to a predominantly Aroclor® 1260 source that has been moderately-severely degraded present in the highest proportions in the Pacific Ocean sample; EM-3 is interpreted as a slightly degraded Aroclor® 1242:1254:1260 mixture in southern San Pablo Bay; EM-4 is interpreted as a moderately degraded source of multiple Aroclors® and is present in the River samples; EM-5 is interpreted as a slightly degraded Aroclor® 1254/1260 mixture present in northern San Pablo Bay and the South Bay.

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Water Monitoring Discussion

Introduction

With data now available from four years of RMP sampling, clear seasonal and spatial patterns in contaminant concentrations in the waters of the Estuary are beginning to emerge. It is also becoming clear that RMP contractors are producing very precise data that allow detection of these patterns, which are in some cases subtle but have persisted year after year.

These patterns are most apparent in the dissolved water data. As discussed in the *1995 Annual Report* (SFEI, 1996), spatial and temporal patterns in total (dissolved + particulate) concentrations of many contaminants are strongly influenced by fluctuations in total suspended solid (TSS) concentrations, which vary due to tidal movements, winds, algal growth, and freshwater inflows. Consequently, trends in total concentrations generally mirror those of TSS. The influence of TSS on total concentrations can be evaluated and removed statistically, but these procedures produce results that are not intuitively obvious. Data from the dissolved fractions of water samples, however, are relatively independent of the influence of TSS, and therefore provide a more direct, intuitively obvious, measure of contaminant dynamics in the Estuary.

The gradients and trends discussed in this section are based upon examination of plots of the raw data from 1996 (Figures 4–35) and from previous Annual Reports (SFEI, 1994; 1995; 1996). Long-term trends in total concentrations are also presented (Figures 37 and 38), and long-term patterns that are evident in these plots are also discussed. This discussion focuses on spatial gradients and seasonal trends that have persisted over the four years of the RMP. The strength of spatial gradients is expressed by comparing the magnitude of the highest concentrations with the lowest, which usually are measured in oceanic waters at the Golden Gate station.

High concentrations are interpreted in the following discussion as indications of sources of contamination. The term sources is used in a general sense that could include point sources, non-point sources, or processes that cause remobilization of historically deposited masses of contaminants. While the data probably hold clues as to the nature of the sources, that subject is not addressed in this discussion.

In evaluating inter-annual patterns in contaminant concentrations, it is important to keep in mind the large seasonal and annual hydrological variation that are characteristic of this Estuary. As described by Cloern *et al.* (see *Water Quality Variability in San Francisco Bay,* this chapter), 1996 was a wet year. At the time that February water samples were being collected, Delta outflow was higher than during any other RMP water sampling period. Salinities were correspondingly low, with salinities of 2 psu as far seaward as San Pablo Bay. At this time Bay surface waters were comprised of approximately 75% freshwater. Salinities during the second round of water sampling in April and July were higher. In July, Bay surface waters were comprised of approximately 50% freshwater. July 1996 salinities were similar to August 1995 (summer sampling period) salinities, but much lower than salinities during summer sampling in 1993 and 1994. Relative to other years in which RMP sampling was conducted, the hydrology in 1996 was similar to 1995 and 1993, two other years with significant Delta outflow, and dissimilar to 1994, when freshwater inflow was low and salinity was high.

Determination of long-term trends in the chemical quality of Bay waters is one of the primary objectives of the RMP. Long-term trends in total trace element concentrations were examined in detail by Jassby in the *1995 Annual Report* (SFEI, 1996). Increasing or decreasing trends were essentially nonexistent in the total concentrations measured from April 1989 to April 1995. In general the 1996 data

are consistent with previous data and do not alter last year's conclusions. More detailed analyses (e.g., of long-term data on dissolved concentrations or statistically filtered total concentrations) might reveal trends that are not apparent in the raw data for total concentrations, but these analyses have not yet been performed.

Spatial and seasonal trends

Trace elements

Dissolved arsenic concentrations have exhibited a consistent pattern in all four years of the RMP. A spatial gradient that varies seasonally exists in the southern end of the Estuary. In winter (February) samples, the gradient is weak with peak concentrations in the lower South Bay, but concentrations in the Southern Sloughs and lower South Bay increase progressively in spring and summer. The summer gradient is strongest, with concentrations in 1996 at Sunnyvale (C-1-3) approximately 3 times the concentration at Golden Gate (BC20). In the northern end of the Estuary, Petaluma River (BD15) consistently had the highest concentrations of dissolved arsenic. The same seasonal progression of concentrations seen in the south was evident at most northern stations. Concentrations at the Rivers were comparable to those at Golden Gate (BC20). The dissolved arsenic data therefore point to sources at the Southern Sloughs in April and July and at Petaluma River (BD15) in all three sampling periods.

Dissolved cadmium concentrations have a distinct spatial pattern, with higher concentrations at Golden Gate (BC20) than at the Rivers and landward portion of the Northern Estuary. A weak spatial gradient in the south was clearest in February and August, with concentrations approximately double those at Golden Gate (BC20) and eight times higher than at the Rivers. At the Golden Gate (BC20), spring concentrations have been higher than winter and summer in three of four years, and are high relative to spring measurements Bay-wide. Upwelling of waters with relatively high cadmium concentrations occurs along the coast in the spring, and is the likely cause of this pattern (Flegal *et al.*, 1991). Cloern *et al.* (see *Water Quality Variability in San Francisco Bay,* this chapter) showed the effect of upwelling on temperature and dissolved oxygen profiles in 1996 in the Central Bay. The influence of oceanic circulation on cadmium concentrations in the Bay therefore appears to be strong in the spring sampling period. In the summer sampling period concentrations are often higher than winter or spring at many stations when in-Bay sources of cadmium appear to become more influential than oceanic processes. The dissolved cadmium data indicate that sources of cadmium exist in the lower South Bay and at Petaluma River (BD15). The plot of long term trends in total cadmium (which is mostly comprised of dissolved cadmium) (Figure 37) shows the seasonal increase in summer concentrations that occurs at most stations.

The Sacramento and San Joaquin Rivers are clear sources of chromium, especially in winter sampling. Abu-Saba and Flegal (1995) and Abu-Saba *et al.* (1997) have described point and non-point sources of chromium in this region of the Estuary. February concentrations at the Sacramento River station (BG20) were 13 times higher than at the Golden Gate station (BC20). The gradient between these stations was weaker in April and August. A weak gradient exists in the southern end of the Estuary, with a maximum elevation at San Jose (C-3-0) in February of three-fold relative to Golden Gate (BC20).

Sources of copper exist in the southern end of the Estuary and at the Petaluma River. Dissolved copper concentrations in the south were up to 13 times higher (at San Jose [C-3-0] in April) than at Golden Gate (BC20). Concentrations in the northern portion of the Estuary were relatively low and constant, with the exception of Petaluma River (BD15) which was consistently about 10 times higher than Golden Gate (BC20). Spatial gradients in dissolved copper concentrations showed little seasonal variation. Previous studies have indicated that wastewater discharges are the principal source

of dissolved copper in the South Bay (Flegal *et al.,* 1991).

Steep spatial gradients in dissolved lead concentrations have been measured, with high concentrations at both the southern and northern ends of the Estuary. Concentrations at the Southern Sloughs have been consistently high, up to 34 times higher at Sunnyvale (C-1-3) than at Golden Gate (BC20). Concentrations in the Northern Estuary in February were quite variable. Concentrations at the Rivers stations were consistently high, with the highest values measured in February. In February, dissolved lead at the San Joaquin River station (BG30) was 9 times higher than at the Golden Gate station (BC20). Rivera-Duarte and Flegal (1994) present data suggesting that remobilization from contaminated Bay sediments is a primary source of dissolved lead in the Estuary.

Mercury sources are evident at both ends of the Estuary and at Petaluma River (BD15). Concentrations in the southern end are consistently elevated relative to Golden Gate (BC20), with a maximum 9-fold difference at San Jose (C-3-0) in February. Significant seasonal variation has been observed in the northern reach. Concentrations in February were higher than in other months, and were particularly high at Petaluma River (BD15, 15 times higher than Golden Gate, BC20) and San Joaquin River (BG30, 11 times higher than Golden Gate, BC20). Concentrations at Petaluma River were the highest in the northern reach in all sampling periods.

Sharp gradients in dissolved nickel concentrations have been detected, indicating nickel sources near the Southern Sloughs and Petaluma River (BD15). The gradient toward the southern reach was steepest in August, when the concentration at San Jose (C-3-0) was 17 times higher than at Golden Gate (BC20). Concentrations at Petaluma River (BD15) in winter have been high every year, with the highest concentration measured in February 1996 which was 47 times higher than at Golden Gate (BC20). Concentrations were also high at Petaluma River (BD15) in April and July, but the magnitude of the elevation was lower. The February concentration of total nickel at Petaluma River (BD15) was the highest yet recorded at an RMP base station, and the dissolved fraction accounted for 90% of total. Dissolved nickel concentrations in the rest of the northern reach were relatively low. Wastewater discharges are considered a primary source of nickel in South Bay (Flegal *et al.,* 1991).

Dissolved selenium concentrations in the Estuary have been very consistent seasonally. A spatial gradient has persisted in the southern reach. Concentrations in 1996 were consistently about 12 times higher than at Golden Gate (BC20). The highest concentration at an RMP base station was observed at Coyote Creek (BA10) in July. Some relatively high concentrations were recorded at two Central Bay stations (Yerba Buena Island [BC10] and Golden Gate [BC20]) in February and April. Concentrations in the northern reach have been relatively low and constant.

Dissolved silver concentrations have displayed a consistent seasonal pattern in which concentrations increase considerably in summer sampling. A spatial gradient in the South Bay was present in all sampling periods, but strongest in July when the concentration at South Bay (BA20) was 9 times higher than at Golden Gate (BC20). Increased remobilization of silver from contaminated sediments is thought to play a large role in the seasonal increase in dissolved silver concentrations in the South Bay (Smith and Flegal, 1993). Dissolved silver concentrations were also elevated relative to Golden Gate (BC20) in the Northern Estuary, especially in July, with a maximum of a 5-fold elevation at Petaluma River (BD15) in July.

Dissolved zinc concentrations have exhibited very distinct spatial gradients. Concentrations at the Southern Sloughs were up to 56 times higher than at Golden Gate (San Jose [C-3-0] in April). Concentrations in the northern reach were relatively low and constant, with the exception of one high value at Petaluma

River (BD15) in February which was 11 times higher than at Golden Gate (BC20).

Trace organics

Diazinon occurs in the Estuary almost entirely in dissolved form. Diazinon concentrations vary tremendously on a seasonal basis. In winter the Estuary is awash in diazinon. The lowest concentration in February was 5,800 pg/L, measured at Golden Gate (BC20). This concentration was 30 times higher than the Golden Gate (BC20) concentration in August (190 pg/L). Spatial gradients were observed in both the southern and northern reaches in all seasons. Concentrations were highest in February, but the difference between landward stations and the Golden Gate station (BC20) were strongest in April and August. In February the concentration at San Jose (C-3-0) was 6 times higher than Golden Gate (BC20), in July it was 56 times higher, and in August it was 44 times higher. In the north, the highest concentrations were at Grizzly Bay (BF20) in February (10 times higher than at Golden Gate, BC20), Petaluma (BD15) in April (30 times higher), and Grizzly Bay (BF20) again in August (34 times higher).

Water organics were measured at San Jose (C-3-0) for the first time in 1996, and concentrations of many trace organics were relatively high at this station. Dissolved PAHs at San Jose (C-3-0) were relatively high in all three sampling periods, up to 9 times higher than at Golden Gate (BC20). Concentrations at Yerba Buena Island (BC10) were higher than at other South Bay and Central Bay stations, as they have been in past RMP sampling. Concentrations were consistently elevated at Napa River (BD50) in the northern reach, up to 5 times higher than at Golden Gate (BC20).

Dissolved PCBs were also relatively high at San Jose (C-3-0, 9 times higher than Golden Gate, BC20, in April), with a distinct drop in concentrations between this station and the adjacent Coyote Creek (BA10) station (5 times higher than Golden Gate, BC20, in April). In August the southern gradient was even steeper, with a concentration at San Jose (C-3-0) 29 times higher than Golden Gate. No spatial gradient was evident in the northern reach, but one relatively high value was observed at Sacramento River (BG20) in August (8 times higher than Golden Gate, BC20).

Dissolved DDT data suggest sources at both the southern and northern ends of the Estuary. Concentrations were very high at San Jose (C-3-0), up to 35 times higher than Golden Gate (BC20). As with other trace organics, concentrations were significantly lower at the adjacent Coyote Creek (BA10) station, which was a maximum of 5 times higher than Golden Gate (BC20). Relatively strong spatial gradients were also observed in the northern reach, with high concentrations at Davis Point (BD40) in February (9 times Golden Gate) and at Sacramento River (BG20) in August (11 times Golden Gate).

Dissolved chlordane concentrations suggest a source near the San Jose (C-3-0) station, which had concentrations in February that were 14 times higher than the Golden Gate (BC20). In all years of the RMP a spatial gradient has consistently been observed in the southern reach with concentrations increasing toward the south end. Concentrations in the northern reach have been relatively constant and low.

Summary of spatial and seasonal trends

In summary, concentrations of many contaminants have shown consistent patterns of spatial and seasonal variation in RMP sampling. Spatial gradients in contamination have been consistently observed for most contaminants. Spatial variation has been especially strong in concentrations of lead, nickel, zinc, diazinon, and DDT. Concentrations of every contaminant discussed in this section were elevated in the southern reach. The Petaluma River (BD15) also appears to be a source of many contaminants, including many trace elements and diazinon. High concentrations of several contaminants were also observed at the Sacramento and San Joaquin Rivers (BG20 and BG30), including chromium, lead, mercury, diazinon, and DDT.

Table 7. Water quality objectives and criteria used for evaluation of 1996 RMP water results. Proposed California Toxics Rule water quality criteria (US EPA, 1997) are listed except where noted. Dissolved trace element criteria are listed (except for mercury and selenium). Total trace element criteria (not shown) were also calculated using the procedures specified in the proposed California Toxics Rule (except for mercury and selenium). Organic compounds are listed on a total (dissolved + particulate) basis. Units are ug/L. Bold and italicized values are hardness-dependent criteria and are calculated for this table using a hardness value of 100 mg/L.

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	36	.	.
Cd	***4.3***	***2.2***	42	9.3	.	.
Cr VI	16	11	1100	50	.	.
Cu	***13***	***9.0***	4.8	3.1	1300	.
Hg [A]	2.4	0.012	2.1	0.025	0.05	0.051
Ni	***468***	***52***	74	8.2	610	4600
Pb	***65***	***2.5***	210	8.1	.	.
Se [B]	20	5.0	20	5.0	.	.
Zn	***120***	***120***	90	81	.	.
Alpha-HCH	.	.	.	.	0.0039	0.013
Beta-HCH	.	.	.	.	0.014	0.046
Gamma-HCH	0.095	0.08	0.16	.	0.019	0.063
Total Chlordane	2.4	0.0043	0.09	0.004	0.00057	0.00059
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
Chlorpyrifos [C]	0.083	0.041	0.011	0.0056	.	.
Diazinon [E]	0.08	0.04	0.08	0.04	.	.
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
Dieldrin	0.24	0.056	0.71	0.0019	0.00014	0.00014
Endosulfan I	0.22	0.056	0.034	0.0087	110	240
Endosulfan II	0.22	0.056	0.034	0.0087	110	240
Endosulfan Sulfate	.	.	.	.	110	240
Endrin	0.086	0.036	0.037	0.0023	0.76	0.81
Mirex [C]	.	0.001	.	0.001	.	.
Hexachlorobenzene	.	.	.	.	0.00075	0.00077
Total PCBs [D]	.	0.014	.	0.03	0.00017	0.00017
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
Chrysene	.	.	.	.	0.0044	0.049
Dibenz(a,h)anthracene	.	.	.	.	0.0044	0.049
Fluoranthene	.	.	.	.	300	370
Fluorene	.	.	.	.	1300	14000
Indeno(1,2,3-cd)pyrene	.	.	.	.	0.0044	0.049
Pyrene	.	.	.	.	960	11000

[A] Mercury criteria are from the Basin Plan (SFBRWQCB, 1995), and are for total mercury.

[B] Selenium criteria are specific for the Bay region as outlined in the National Toxics Rule (US EPA, 1992). Criteria are for total selenium and freshwater criteria apply to the whole Estuary.

[C] Chlorpyrifos and mirex are not included in the proposed California Toxics Rule, but US EPA criteria for these chemicals were provided by the SFBRWQCB.

[D] Criteria apply to sums of congeners.

[E] Diazinon criteria are not included in the California Toxics Rule. Values are from the California Department of Fish and Game (Menconi and Cox, 1994).

Clear seasonal variation was evident for many contaminants, including arsenic, cadmium, chromium, mercury, nickel, silver, and diazinon. The large masses of fresh water that entered the Estuary in February were apparently relatively enriched in chromium, mercury, nickel, zinc, and diazinon and responsible for a clear increase in concentrations of these contaminants in the northern reach. Concentrations of arsenic, cadmium, and silver were higher during the low-flow months of summer; these increases may have been due to the increasing relative influence of remobilization from Bay sediments or upstream sources that receive less dilution in low-flow periods.

Comparison to Water Quality Guidelines

This section provides a brief overview of how 1996 data compare to relevant water quality guidelines (Table 7). Of the ten trace elements measured, concentrations of chromium, copper, mercury, nickel, and lead were higher than guidelines on one or more occasions (Table 8). Copper concentrations were most frequently above guidelines: total copper was above the guideline in 26 samples and dissolved copper was above the guideline in 9 samples. Nickel, mercury, and chromium concentrations were also above guidelines in numerous instances. Several trace organics also had concentrations above guidelines, including PCBs, DDTs, heptachlor epoxide, several PAHs, chlorpyrifos, and diazinon (Table 9). The sum of 39 PCB congeners were well above the congener-based ∑PCBs criteria of 170 pg/L in all but three RMP samples. Trace organic concentrations were generally highest at the San Jose (C-3-0) station, and this station accounted for many of the instances in which trace organics were above guidelines.

Effects of Water Contamination

Clear statistically and biologically significant toxicity was observed in the *Mysidopsis* test in February 1996 at Sacramento River (BG20), San Joaquin River (BG30), Grizzly Bay (BF20), and Napa River (BD50) stations. Survival was sharply depressed at three of these stations; only Grizzly Bay (BF20) showed survival greater than 8%. Statistically significant, but less distinct, toxicity was also observed in July samples at Sacramento River (BG20), San Joaquin River (BG30), and Grizzly Bay (BF20), with percent survival ranging from 73% to 75%. The timing and geographical location of this toxicity suggest that organophosphate pesticides carried by agricultural runoff from the Central Valley and Napa Valley had a role in causing the toxicity.

None of the 48-hour tests using *Mytilus* larvae indicated toxicity in either February or July.

The presence of some contaminants in waters of the Estuary, such as the organophosphate insecticides, is known to be episodic, with high concentrations entering the Estuary during periods of heavy use and/or high runoff. With just three sampling events in the RMP base program that are not targeted at specific contaminants, the likelihood is low that short-duration contamination events would be detected. In a special study begun in late 1996, a more targeted approach is being taken, with toxicity testing of water samples collected during storm events. Ogle and Gunther (see *Episodic Toxicity in the San Francisco Bay System*, this chapter) provide a detailed description of this study.

Table 8. Summary of trace elements that were above water quality objectives and criteria (WQC) for 1996 RMP water samples. WQC used in this comparison are found in Table 7. Of the 10 RMP trace element compounds that have WQC, only compounds that were above guidelines are listed. Designated estuarine sites were compared to the lower of the saltwater or freshwater criteria. ● = above guideline, - = data not available.

			Dissolved						Total															
			Cu			Ni			Cr			Cu			Hg			Ni			Pb		
	Code	Station	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug
Southern Sloughs	C-1-3	Sunnyvale		●	●				●	●	●	●	●	●	●	●	●	●	●	●			●
	C-3-0	San Jose		●				●		●	●	●	●	●	●	●	●		●	●		●	●
South Bay	BA10	Coyote Creek		●	●				-				●	●					●	●			
	BA20	South Bay			●								●	●			●						
	BA30	Dumbarton Bridge											●	●									
	BA40	Redwood Creek																					
	BB15	San Bruno Shoal											-	●					-			-	
	BB30	Oyster Point																					
	BB70	Alameda																					
Central Bay	BC10	Yerba Buena Island																					
	BC20	Golden Gate																					
	BC30	Richardson Bay																					
	BC41	Point Isabel																					
	BC60	Red Rock																					
Northern Estuary	BD15	Petaluma River	●	●	●	●			●	●		●	●	●	●	●	●	●	●	●		●	
	BD20	San Pablo Bay																					
	BD30	Pinole Point																					
	BD40	Davis Point										●	●		●	●		●	●				
	BD50	Napa River										●		●									
	BF10	Pacheco Creek										●		●									
	BF20	Grizzly Bay							●		●	●		●			●	●		●			
	BF40	Honker Bay							●		●	●		●			●	●		●			
Rivers	BG20	Sacramento River																					
	BG30	San Joaquin River																					

Table 9. Summary of organic contaminants that were above water quality objectives and criteria (WQC) for 1996 RMP water samples. WQC used in this comparison are from Table 7. Of the 30 RMP organic compounds that have WQC, only 10 had concentrations that were above guidelines. ● = above guideline, - = data not available

			Benz(a)anthracene			Benzo(b)fluoranthene			Dieldrin			Heptachlor Epoxide			Indeno(1,2,3-cd)pyrene			p,p'-DDD			p,p'-DDE			p,p'-DDT			Total Chlordanes			Total PCBs		
		WQC (ppb):	0.049			0.049			0.00014			0.00011			0.049			0.00084			0.00059			0.00059			0.00059			0.00017		
	Code	Station	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug	Feb	Apr	Aug
Southern Sloughs	C-3-0	San Jose		●			●				●	●	●	●		●		●		●	●	●	●	●			●	●	●	●	●	●
South Bay	BA10	Coyote Creek			-			-			-	●		-			-			-		●	-			-	●		-	●	●	-
	BA30	Dumbarton Bridge										●																		●	●	●
	BA40	Redwood Creek							●		-	●															●			●	●	●
	BB70	Alameda			-			-		-	-	●				-	-													●	●	●
Central Bay	BC10	Yerba Buena Island			-			-			-			-			-			-			-			-			-	●	●	-
	BC20	Golden Gate			-					-						-	-															●
	BC60	Red Rock							●	-		●				-	-													●	●	●
Northern Estuary	BD15	Petaluma River			-			-				●					-					●								●	●	●
	BD20	San Pablo Bay			-			-			-						-													●	●	●
	BD30	Pinole Point																												●	●	●
	BD40	Davis Point																			●									●	●	●
	BD50	Napa River																												●	●	●
	BF20	Grizzly Bay																			●									●	●	●
Rivers	BG20	Sacramento River							-	-			-						-			-			-			-			●	●
	BG30	San Joaquin River	-			-	-		-	-		-	-		-	-		-	-		-	-		-	-		-	-		-	●	●

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CHAPTER THREE

Sediment Monitoring

Background

Sediments are monitored because they are an important component of the Bay and Estuary ecosystem. Most contaminants accumulate in sediments to concentrations that are orders of magnitude above those in water, creating the potential for exposures to increased contamination.

Information about sediment contamination is used in making decisions related to many important management issues: the identification of sediment "toxic hot spots" is currently a priority for the State and Regional Boards, the clean-up of numerous military bases in the region requires information about background contaminant levels, and the continuous dredging of the Estuary requires testing and comparisons to some reference or background concentrations. Information gathered in those studies will use comparable information from the RMP as ambient or background levels.

However, the geochemistry of sediments is complex, and in order to interpret contaminant concentrations measured in sediments it is necessary to understand how hydrology and other non-contaminant sediment properties may affect contaminant concentrations. A description of those interactions is included in the *Sediment Monitoring Discussion* at the end of this chapter.

The RMP monitors sediment quality (grain-size, organic carbon, ammonia, and sulfides), trace elements, and trace organic contaminants at 22 RMP Base Program stations. Sediments were also monitored at two stations in the southern end of the Estuary in cooperation with the Regional Board and the Cities of San Jose (station C-3-0) and Sunnyvale (station C-1-3). CTD (conductivity, temperature, depth) profiles of the water column were collected at all RMP sediment stations, but those data are not presented.

Station locations are shown on Figure 1 in *Chapter One: Introduction*. Sediment samples were collected during the wet season (February) and dry season (August). Sampling dates are

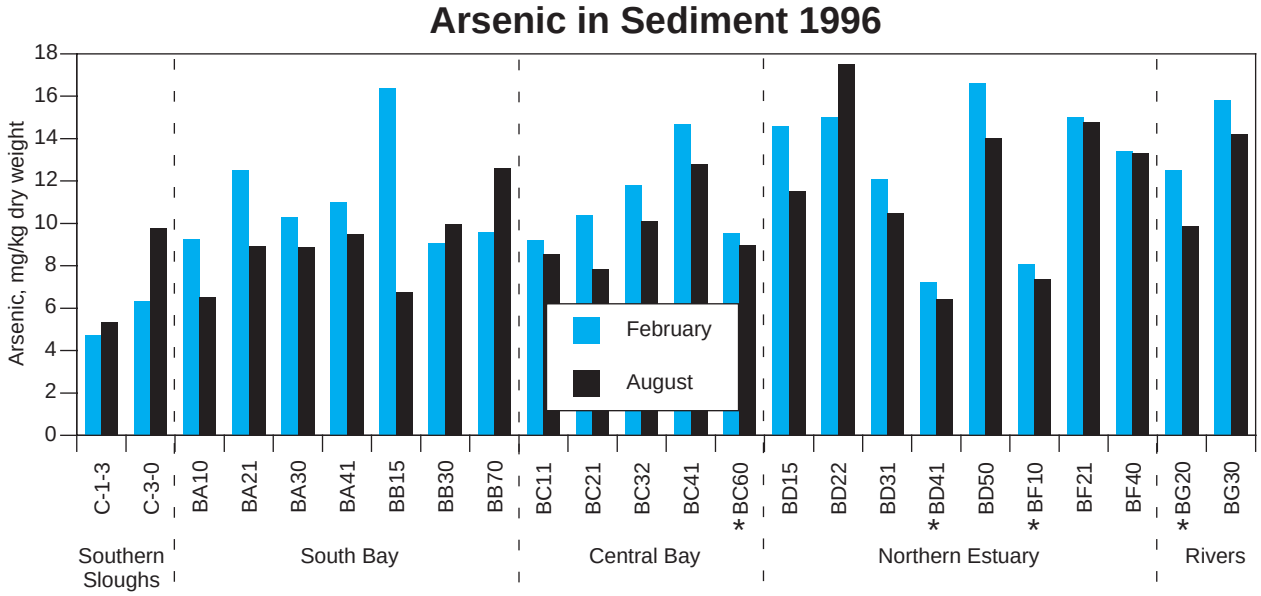

Figure 1. Arsenic (As) concentrations in sediment in parts per million, dry weight (ppm) at 24 stations sampled in February and August of 1996. * indicates coarse sediment stations. Arsenic concentrations ranged from 4.7 to 17.5 ppm. The highest concentration was sampled at San Pablo Bay (BD22) in August and the lowest at Sunnyvale (C-1-3) in February. Average concentrations were highest in the Northern Estuary in August (14.2 ppm). No consistent seasonal trend was observed in the Estuary although the February concentrations were usually higher except in the Southern Sloughs. As concentrations were below the ERM of 70 ppm at all stations. However, concentrations were above the ERL of 8.2 ppm at twenty stations in February and eighteen stations in August.

shown on Table 1 in *Chapter One: Introduction*. Detailed methods of collection and analysis are included in *Appendix A,* and a listing of the measurements made on sediment samples are in Table 3 in *Chapter One: Introduction*.

This section contains descriptive data for sediment trace elements, selected trace organic contaminants, and sediment bioassays (Figures 1–16). The selected trace organic contaminants are presented as total concentrations of detectable compounds. For example, total DDTs is the sum of the detectable concentrations of six isomers, total PAHs are the sum of 25 compounds, total PCBs are the sum of 49 congeners, chlordanes are the sum of seven compounds. Sediment quality parameters including station depths, and all contaminant concentrations are tabulated in *Appendix C*.

In order to compare sediment monitoring results among the major areas or reaches of the Estuary, the RMP stations are separated into six groups of stations in five Estuary reaches based subjectively on geography, similarities in sediment types, and patterns of trace contaminant concentrations. Five Estuary reaches include all stations with fine sediments: the Southern Sloughs (C-1-3 and C-3-0), South Bay (six stations, BA10 through BB70), Central Bay (five stations, BC11 through BC60), Northern Estuary (eight stations, BD15, through BF40), and Rivers (BG20 and BG30). Stations with coarse sediments (>60% sand: BC60, BD41, BF10, and BG20) generally have considerably lower contaminant concentrations and were grouped separately for analytical comparisons.

Results from an RMP Special Study on the development of sediment indicators are presented in articles by Thompson, Anderson *et al.,* Phillips *et al.,* and Weston. A progress report on the Benthic Pilot Study is also presented.

Sediment Quality Guidelines

There are currently no Basin Plan objectives or other regulatory criteria for sediment contaminant concentrations in the Estuary. The US EPA has produced draft objectives for five trace contaminants: three PAHs—acenapthene, fluoranthene, and phenanthrene—and two

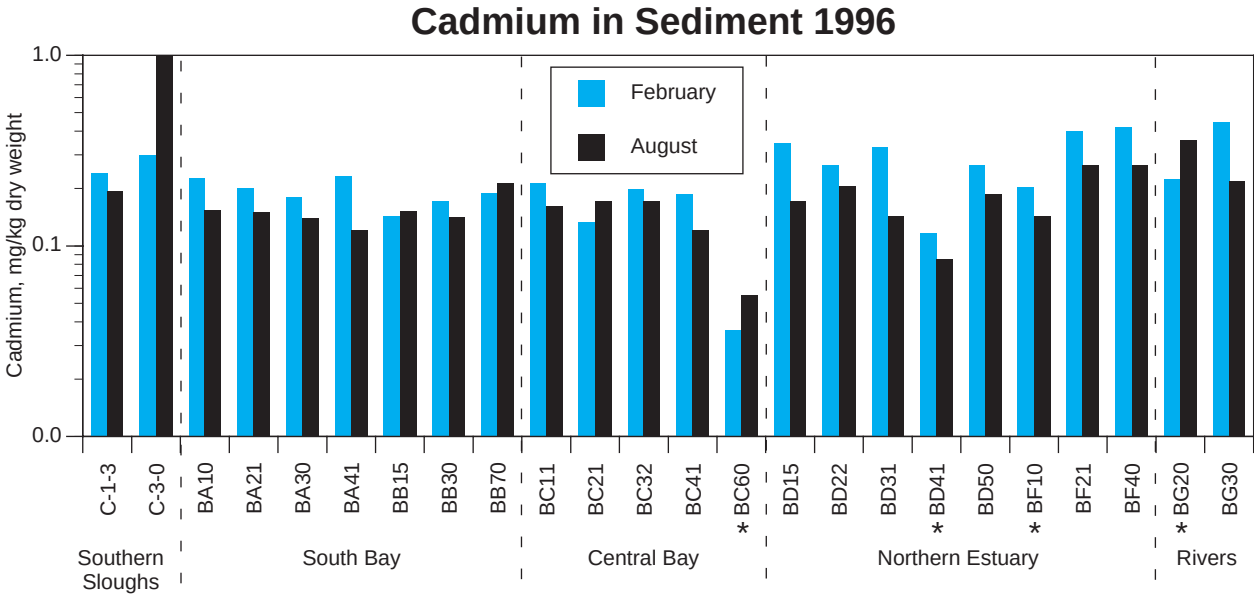

Figure 2. Cadmium (Cd) concentrations in sediment in parts per million, dry weight (ppm) at 24 stations sampled in February and August of 1996. Note logarithmic scale. * indicates coarse sediment stations. Cadmium concentrations ranged from 0.04 to 1.00 ppm. The highest concentration was sampled at San Jose (C-3-0) in August and lowest at Red Rock (BC60) in February. Average concentrations were highest in the Southern Sloughs in August (0.60 ppm). No consistent seasonal trend was observed in the Estuary although Cd concentrations were higher in the Northern Estuary in February. Cd concentrations were all below the ERM of 9.6 ppm and the ERL of 1.2 ppm.

pesticides—dieldrin and endrin (EPA, 1991). Those draft objectives, along with NOAA's Sediment Quality Guidelines (Long and Morgan, 1990; Long *et al.*, 1995) are used in this report as guidelines for the interpretation and assessment of sediment contaminant concentrations in the Estuary. These values are intended to be used as informal screening tools and hold no regulatory status. Several other sets of sediment guidelines are tabulated in the discussion of this chapter for comparison.

NOAA's Sediment Quality Guidelines (SQGs) are based on data compiled from numerous studies in the United States 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) is the concentration at which 10% of the studies showed effects, and the Effects Range-Median (ERM) is the concentration at which 50% of the studies showed effects. 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 (Long *et al.*, 1995). Effects range values for mercury, nickel, total PCBs, and total DDTs have low levels of confidence associated with them. The SQGs used for chlordanes and dieldrin are from Long and Morgan (1990). There are no SQGs for selenium, but the Regional Board has suggested guidelines of 1.4 ppm (Wolfenden and Carlin, 1992), and 1.5 ppm (Taylor *et al.*, 1992).

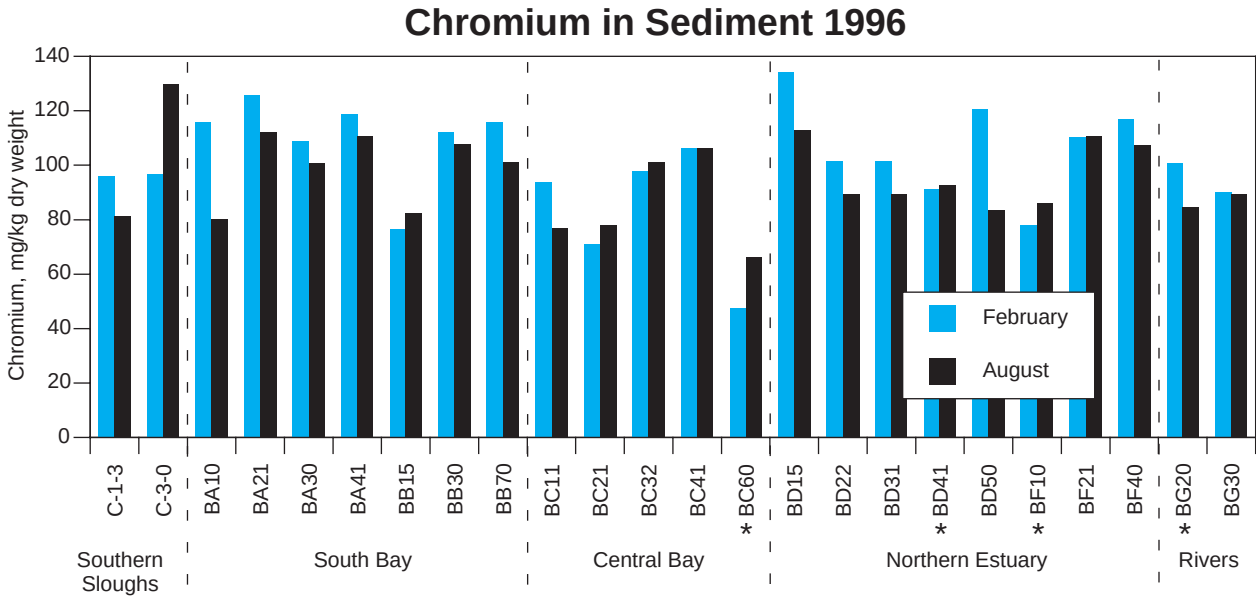

Figure 3. Chromium (Cr) concentrations in sediment in parts per million, dry weight (ppm) at 24 stations sampled in February and August of 1996. * indicates coarse sediment stations. Chromium concentrations ranged from 47.6 to 134.3 ppm. The highest concentration was sampled at Petaluma River (BD15) in February and the lowest concentration was at Red Rock (BC60) in February. Average concentrations were highest in the South Bay in February (110.5 ppm). No consistent seasonal trend was observed in the Estuary. Cr concentrations were below the ERM value of 370 ppm at all stations. However, concentrations were above the ERL value of 81 ppm at twenty stations in February and twenty stations in August.

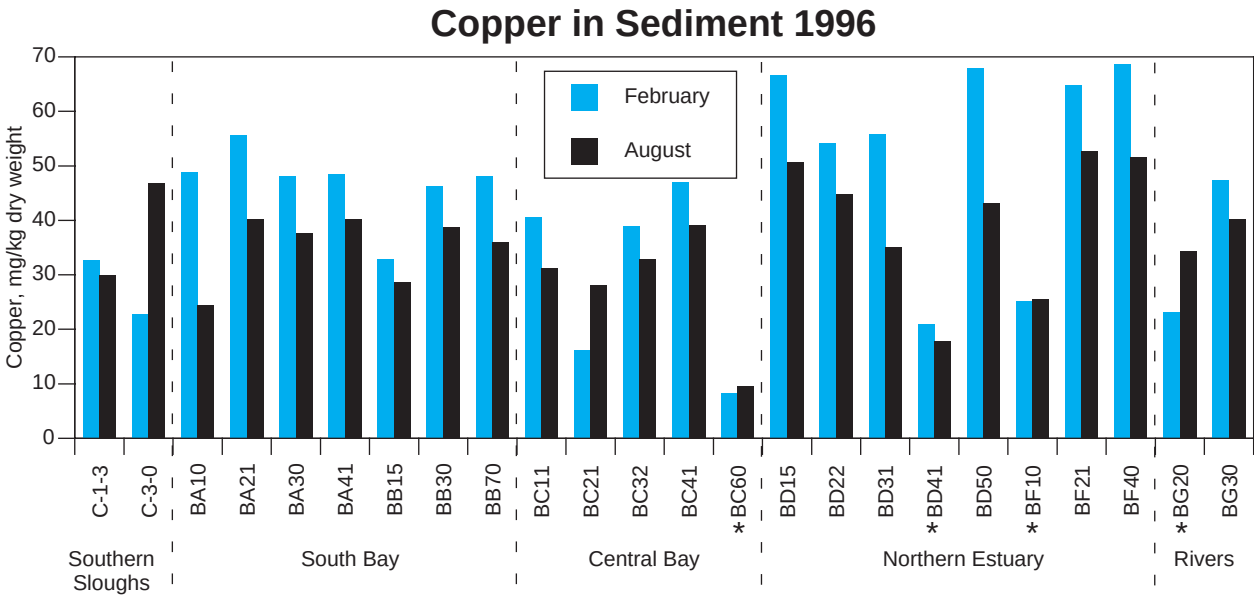

Figure 4. Copper (Cu) concentrations in sediment in parts per million, dry weight (ppm) at 24 stations sampled in February and August of 1996. * indicates coarse sediment stations. Copper concentrations ranged from 8.3 to 68.6 ppm. The highest concentration was sampled at Honker Bay (BF40) in February and the lowest at Red Rock (BC60) in February. Average concentrations were highest in the Northern Estuary in February (53.0 ppm). Concentrations were generally higher in February than August. Cu concentrations were below the ERM value of 270 ppm at all stations. However, concentrations were above the ERL value of 34 ppm at sixteen stations in February and fifteen stations in August.

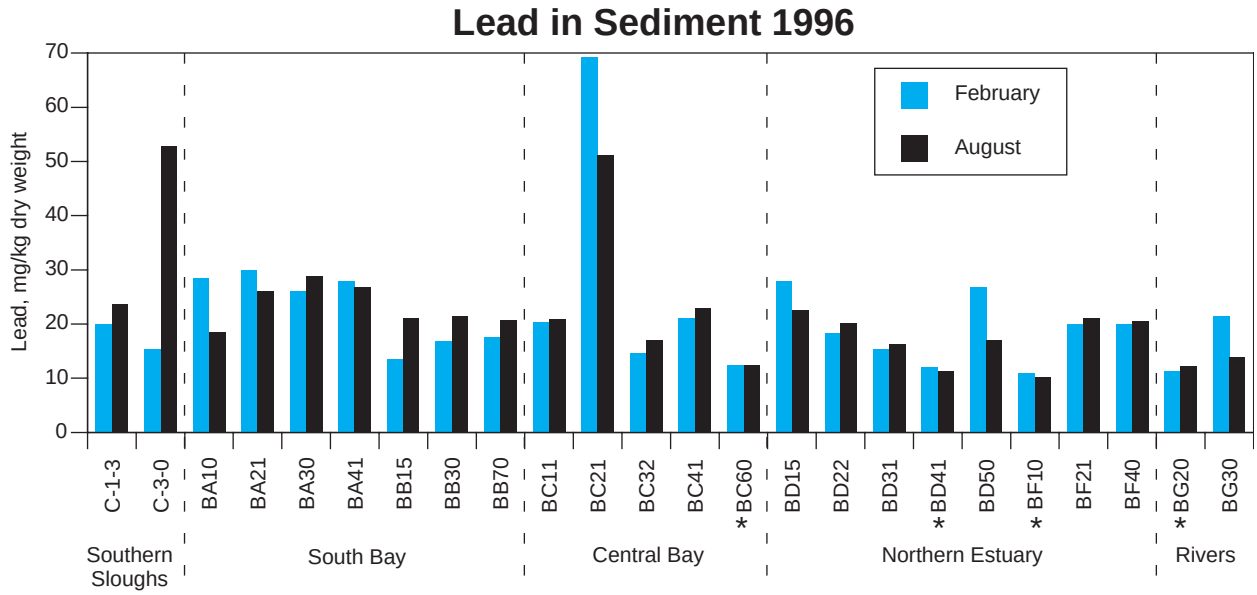

Figure 5. Lead (Pb) concentrations in sediment in parts per million, dry weight (ppm) at 24 stations sampled in February and August of 1996. * indicates coarse sediment stations. Lead concentrations ranged from 10.3 to 69.3 ppm. The highest concentration was sampled at Horseshoe Bay (BC21) in February and the lowest concentration at Pacheco Creek (BF10) in August. Average concentrations were highest in the Southern Sloughs in August (38.3 ppm). No consistent seasonal trend was observed in the Estuary. Pb concentrations were below the ERM value of 218 ppm at all stations. However, concentrations were above the ERL value of 46.7 ppm at Horseshoe Bay (BC21) during both sampling periods and at San Jose (C-3-0) in August.

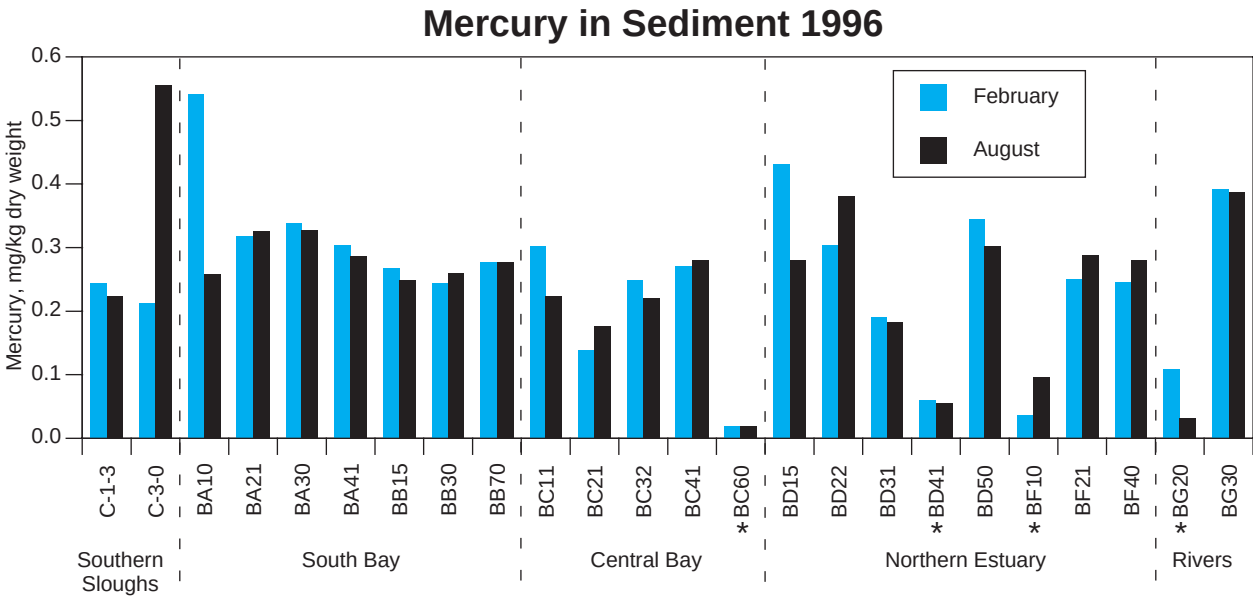

Figure 6. Mercury (Hg) concentrations in sediment in parts per million, dry weight (ppm) at 24 stations sampled in February and August of 1996. * indicates coarse sediment stations. Mercury concentrations ranged from 0.02 to 0.56 ppm. The highest concentration was sampled at San Jose (C-3-0) in August and the lowest at Red Rock (BC60) during both sampling periods. Average concentrations were highest in the Southern Sloughs in August (0.39 ppm). No consistent seasonal trend was observed in the Estuary. Hg concentrations were below the ERM value of 0.71 ppm at all stations. However, concentrations were above the ERL value of 0.15 ppm at nineteen stations in February and twenty stations in August.

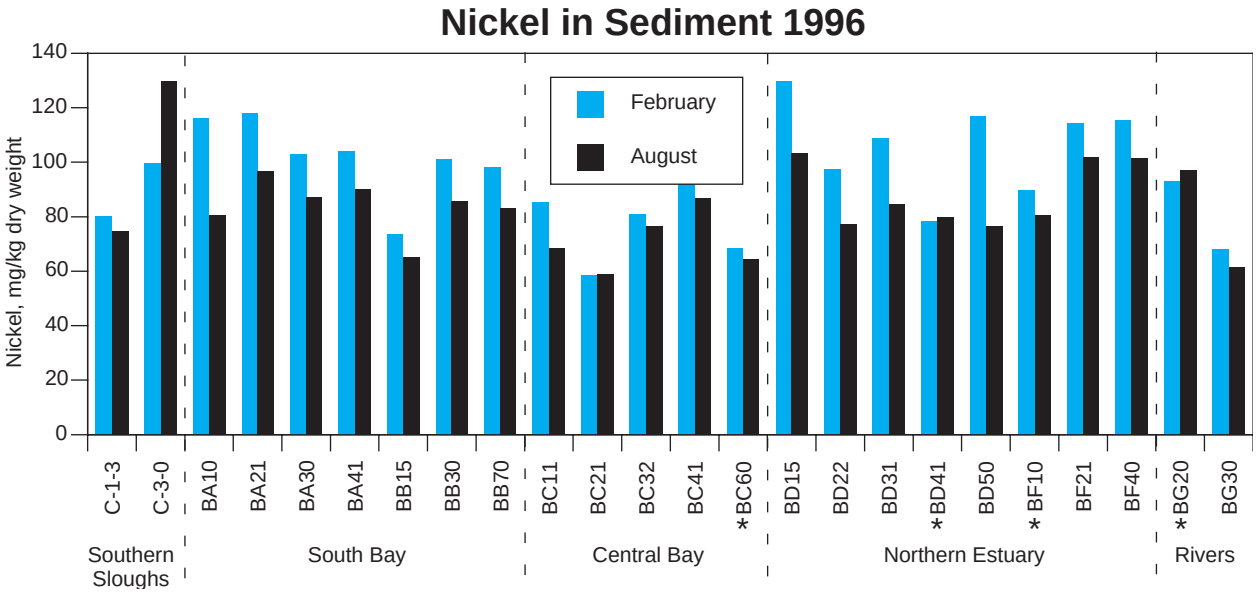

Figure 7. Nickel (Ni) concentrations in sediment in parts per million, dry weight (ppm) at 24 stations sampled in February and August of 1996. * indicates coarse sediment stations. Nickel concentrations ranged from 58.3 to 129.8 ppm. The highest concentration was sampled at San Jose (C-3-0) in August and the lowest at Horseshoe Bay (BC21) in February. Average concentrations were highest in the Northern Estuary in February (106.3 ppm). In general, concentrations were higher in February than in August. Ni concentrations were above the ERM value of 51.6 ppm and the ERL value of 20.9 ppm at all stations for both sampling periods.

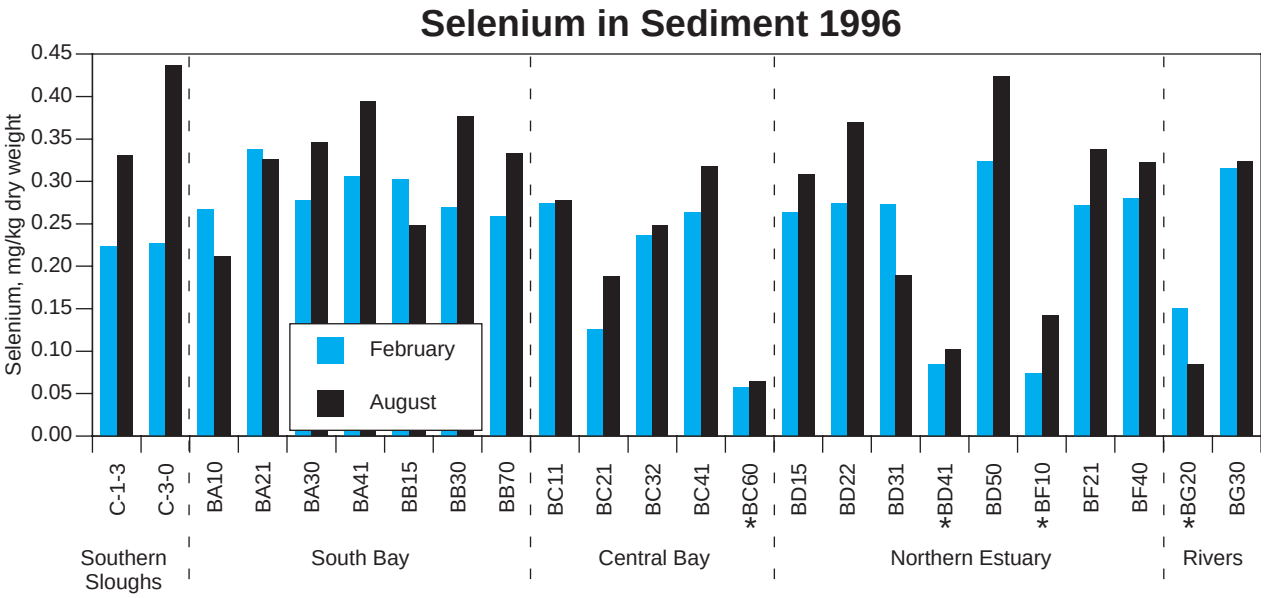

Figure 8. Selenium (Se) concentrations in sediment in parts per million, dry weight (ppm) at 24 stations sampled in February and August of 1996. * indicates coarse sediment stations. Selenium concentrations ranged from 0.06 to 0.44 ppm. The highest concentration was sampled at San Jose (C-3-0) in August and the lowest concentration was at Red Rock (BC60) in both sampling periods. Average concentrations were highest in the Southern Sloughs in August (0.38 ppm). Concentrations were slightly higher in August than in February at most stations. There are no ERM and ERL values for selenium and concentrations were always below Regional Board guidelines of 1.4–1.5 ppm.

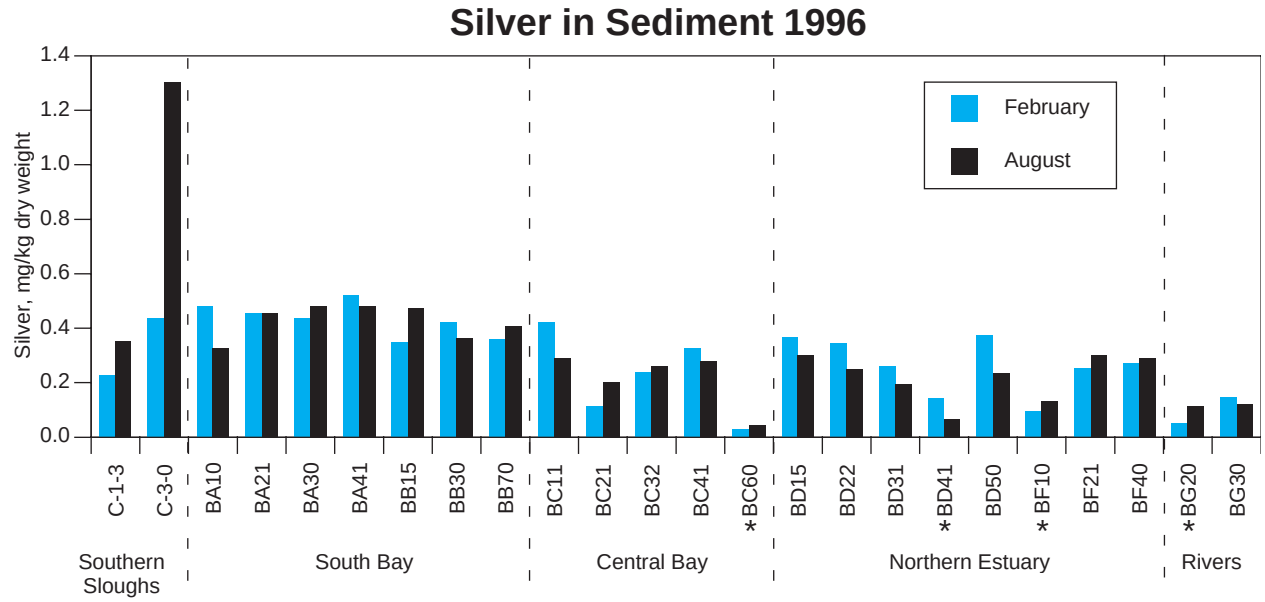

Figure 9. Silver (Ag) concentrations in sediment in parts per million, dry weight (ppm) at 24 stations sampled in February and August of 1996. * indicates coarse sediment stations. Silver concentrations ranged from 0.03 to 1.30 ppm. The highest concentration was sampled at San Jose (C-3-0) in August and the lowest concentration at Red Rock (BC60) in February. Average concentrations were highest in the Southern Sloughs in August (0.83 ppm). No consistent seasonal trend was observed throughout the Estuary. Ag concentrations were below the ERM of 3.7 ppm at all stations. However, The concentration was above the ERL value of 1 ppm at San Jose (C-3-0) in August.

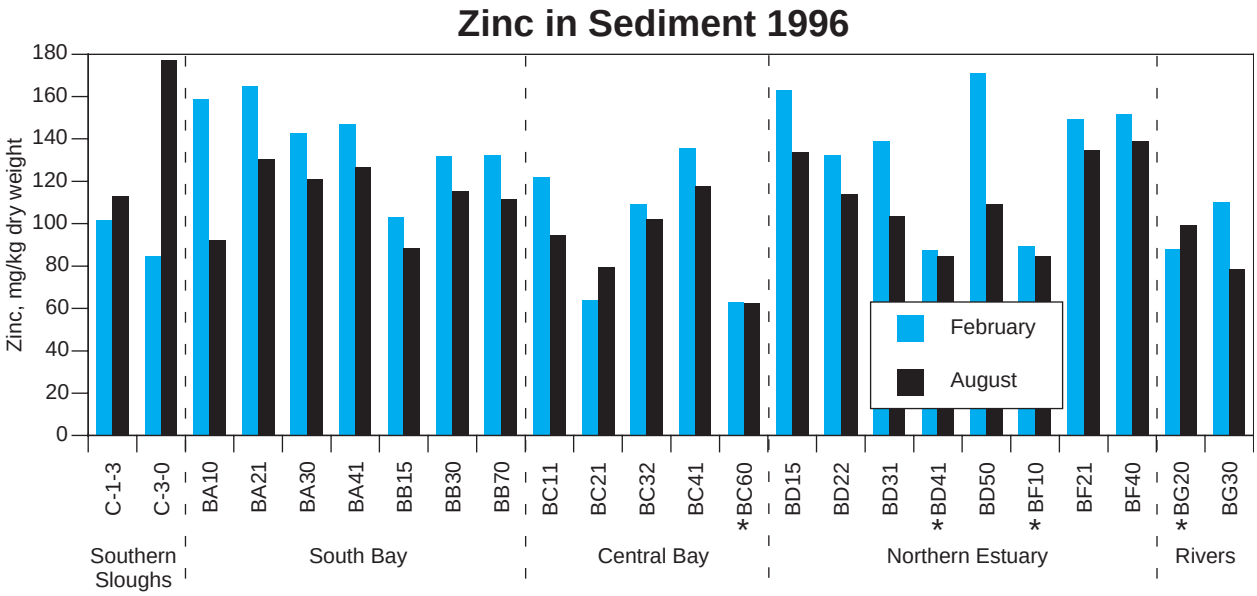

Figure 10. Zinc (Zn) concentrations in sediment in parts per million, dry weight (ppm) at 24 stations sampled in February and August of 1996. * indicates coarse sediment stations. Zinc concentrations ranged from 62 to 177 ppm. The highest concentration was sampled at San Jose (C-3-0) in August and the lowest concentration was at Red Rock (BC60) in August. Average concentrations were highest in the South Bay in February (140.0 ppm). Concentrations were higher in February than in August at most stations. Zn concentrations were below the ERM value of 410 ppm. However, concentrations were above the ERL value of 150 ppm at five stations in February and one station in August.

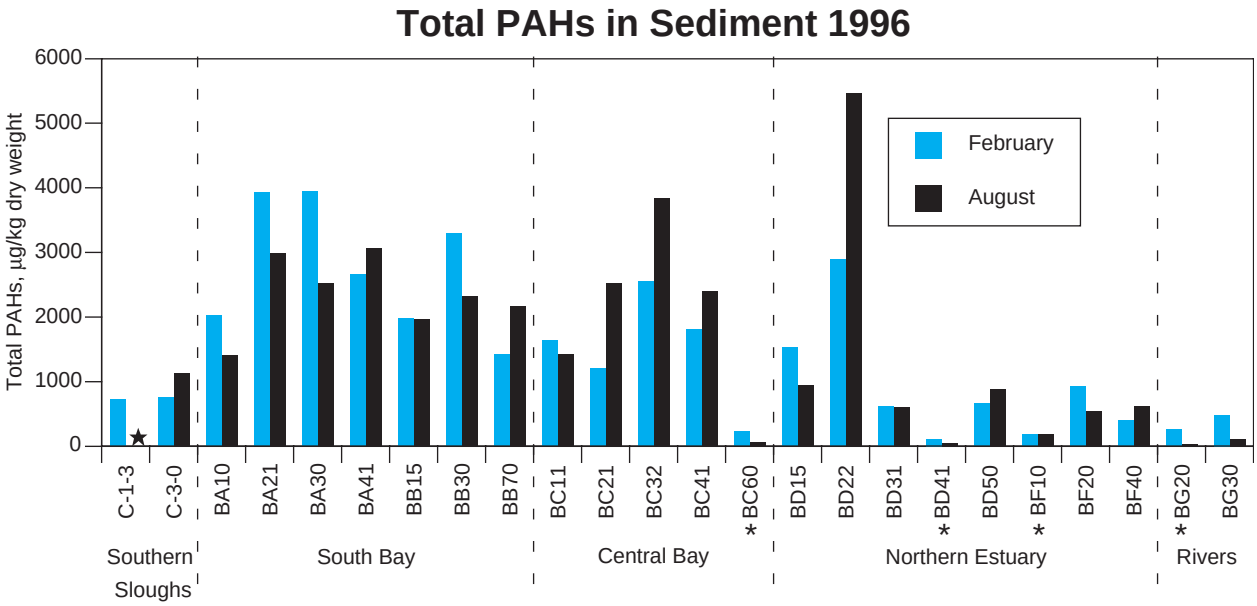

Figure 11. Total PAH concentrations in sediment in parts per billion (ppb), dry weight at 24 stations sampled in February and August of 1996. * indicates coarse sediment stations. ★ = not analyzed. Total PAH concentrations ranged between 32 and 5,464 ppb. The highest concentration was sampled at San Pablo Bay (BD22) in August and the lowest concentration was measured at Sacramento River (BG20) in August. Average concentrations were highest at the South Bay stations. Total PAH concentrations were below the ERM of 44,792 ppb and only San Pablo Bay (BD22) was above the ERL of 4,022 ppb in August.

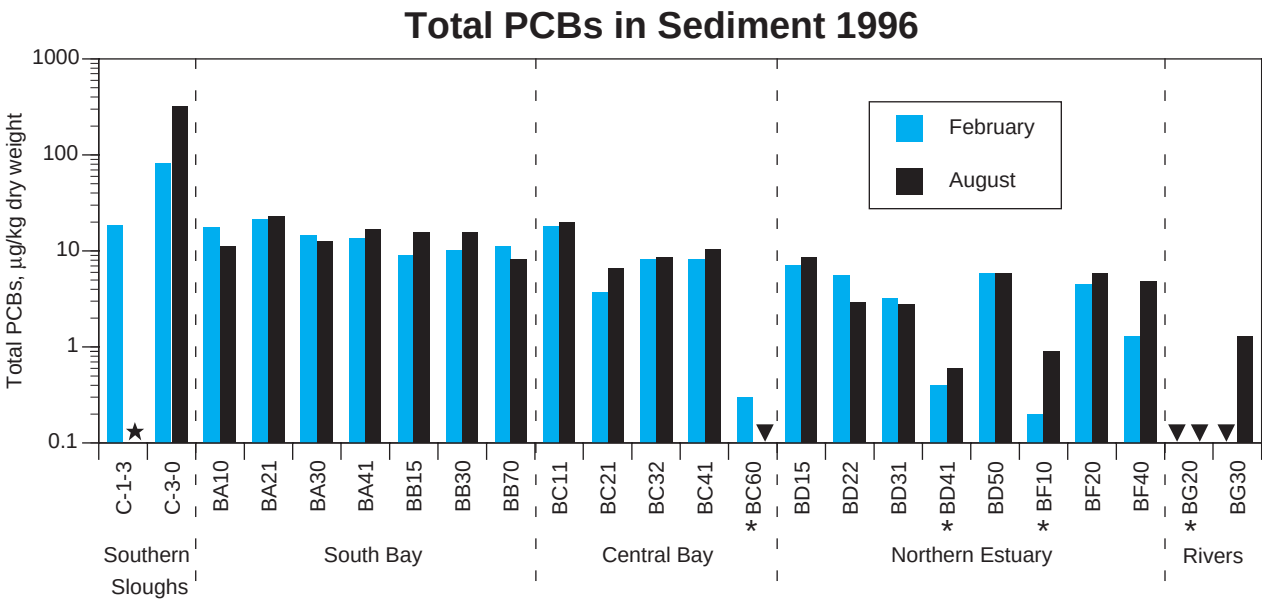

Figure 12. Total PCB concentrations in sediment in parts per billion (ppb), dry weight at 24 stations sampled in Febuary and August 1996. Note logarithmic scale. * indicates coarse sediment stations. ★ = not analyzed. ▼ = below detection limit. Total PCB concentrations ranged between not detected (▼) and 320 ppb (see *Appendix A* for MDLs). The highest concentration was sampled at San Jose (C-3-0) in August and concentrations were below the detection limit at several stations. Average concentrations were highest in the Southern Sloughs. Total PCB concentrations were below the ERM of 180 ppb at all stations except San Jose (C-3-0) in August, and the ERL of 23 ppb at all stations except San Jose (C-3-0) in February and August, and at South Bay (BA21) in

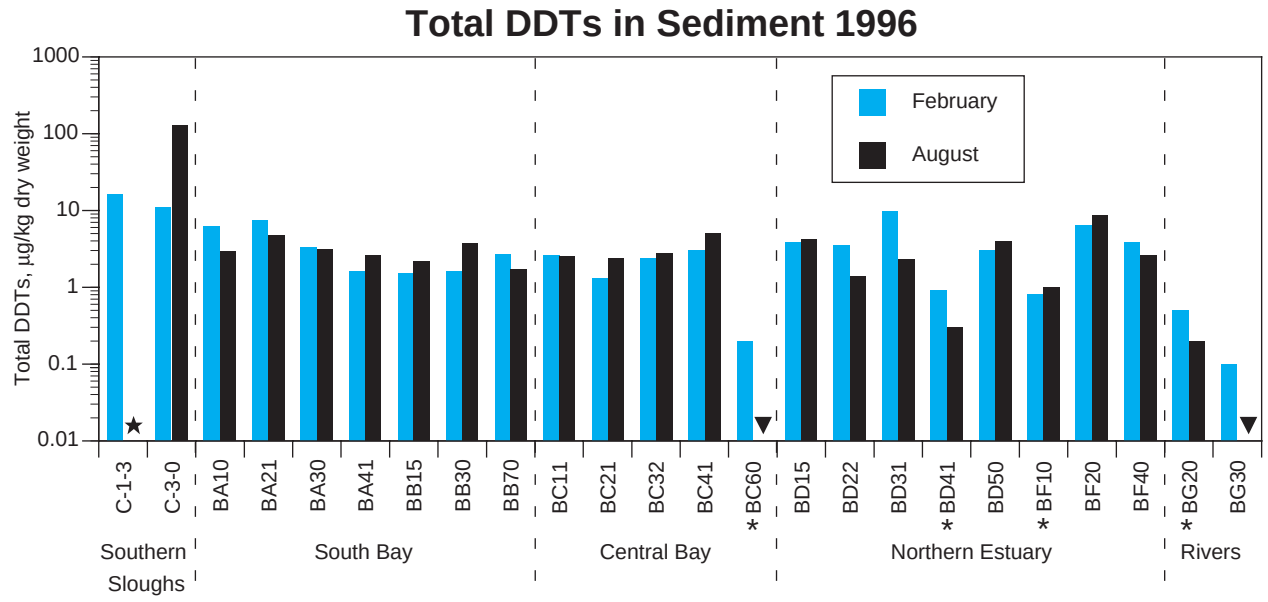

Figure 13. Total DDT concentrations in sediment in parts per billion (ppb), dry weight at 24 stations sampled in Febuary and August 1996. Note logarithmic scale. * indicates coarse sediment stations. ★ = not analyzed. ▼ = below detection limit. DDT concentrations ranged between not detected (▼) and 127 ppb (see *Appendix A* for MDLs). The highest concentration was sampled at San Jose (C-3-0) in August. Average concentrations were highest in the Southern Sloughs. Total DDT concentrations were below the ERM of 46 ppb at all stations except San Jose (C-3-0) in August. However, concentrations were above the ERL of 1.58 ppb at seventeen stations in February and August.

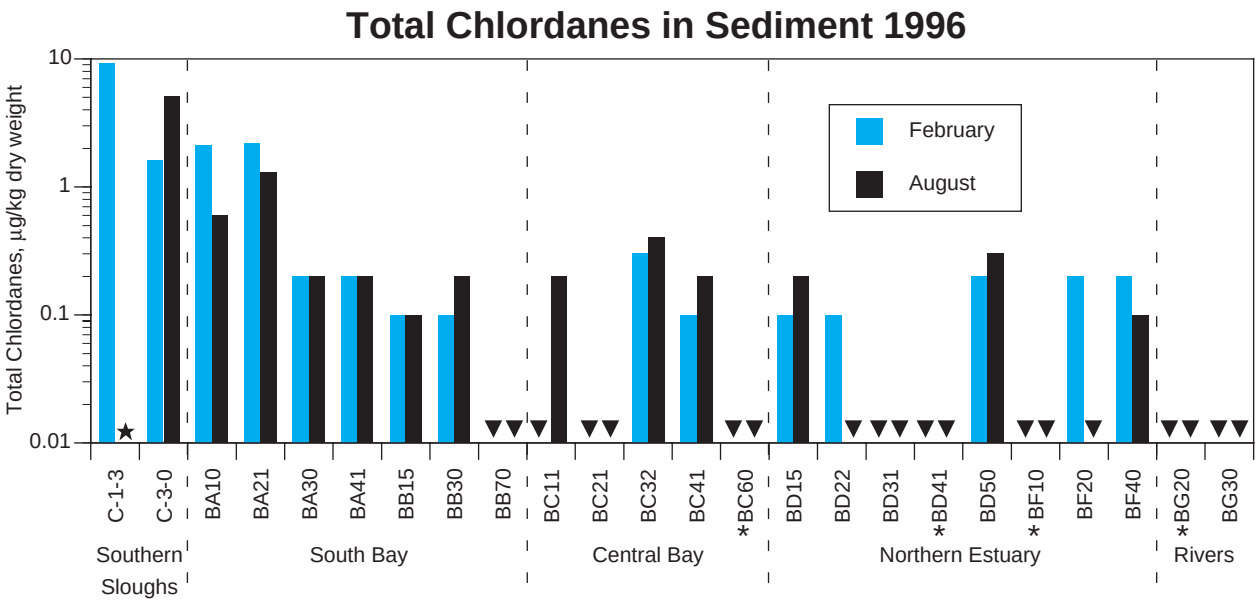

Figure 14. Total chlordane concentrations in sediment in parts per billion (ppb), dry weight at 24 stations sampled in Febuary and August 1996. Note logarithmic scale. * indicates coarse sediment stations. ★ = not analyzed. ▼ = below detection limit. Chlordane concentrations ranged between not detected (▼) and 9.2 ppb (see *Appendix A* for MDLs). The highest concentration was sampled at Sunnyvale (C-1-3) in February. Average concentrations were highest in the Southern Sloughs. Total chlordane concentrations were below the 1990 ERM of 6 ppb at all stations except Sunnyvale in February. However, concentrations were above the 1990 ERL of 0.5 ppb at four stations in February and three stations in August.

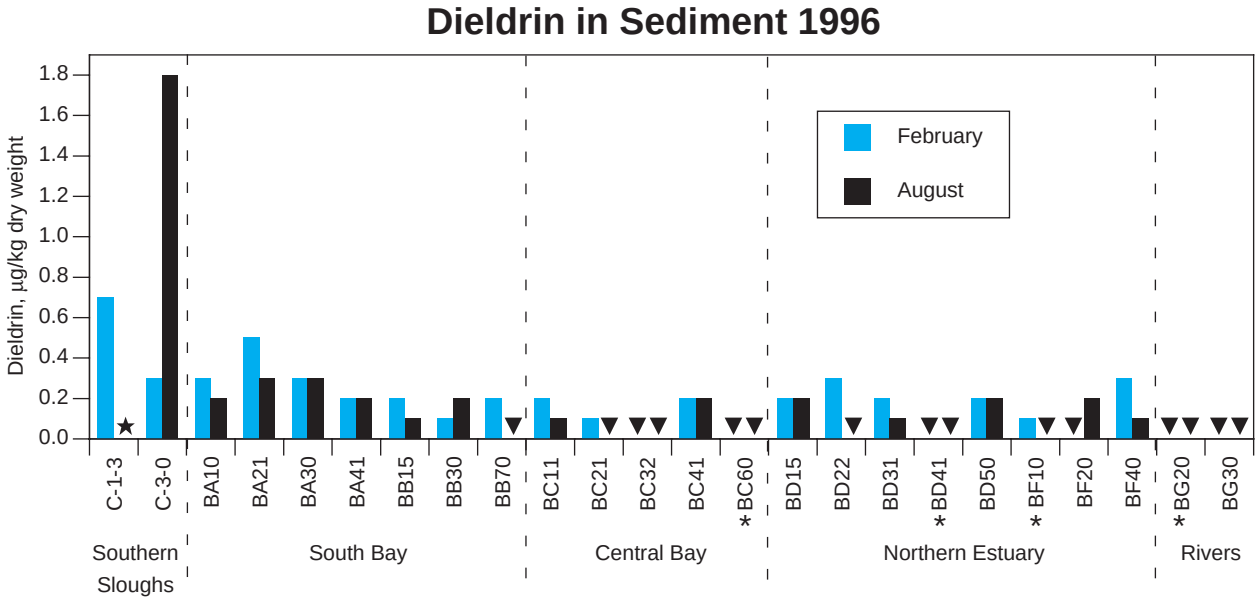

Figure 15. Dieldrin concentrations in sediment in parts per billion (ppb), dry weight at 24 stations sampled in Febuary and August 1996. * indicates coarse sediment stations. ★ = not analyzed. ▼ = below detection limit. Dieldrin concentrations ranged between not detected (▼) and 1.8 ppb (see *Appendix A* for MDLs). The highest concentration was sampled at San Jose (C-3-0) in August. Average concentrations were highest in the Southern Sloughs. Dieldrin concentrations were below the 1990 ERM of 8 ppb at all stations. However, concentrations were above the 1990 ERL of 0.02 ppb at nineteen stations in February and fourteen stations in August.

Sediment Bioassays

Sediment bioassays are conducted to determine the potential for biological effects from exposure to sediment contamination. Although the bioassays are conducted in the laboratory, standard, well developed protocols are used (detailed in *Appendix A*). When a sample is found to be toxic, it is interpreted as an indication of the potential for biological effects. However, since sediments are mixtures of numerous contaminants, it is difficult to determine which contaminant(s) may have caused any toxicity observed. The results of two RMP Special Studies are reported in this chapter which begin to investigate the question of what causes sediment toxicity.

Two sediment bioassays were conducted at 12 of the RMP stations (Figure 16) in February and again in August of 1996. Sampling dates are listed in Table 1 in *Chapter One: Introduction*. Amphipods (*Eohaustorius estuarius*) were exposed to whole sediment for ten days with percent survival as the endpoint. Larval mussels (*Mytilus sp.*) were exposed to sediment elutriates (water-soluble fraction) for 48 hours with percent normal development as the endpoint. Detailed methods of collection and testing are described in *Appendix A*, and quality assurance information is included in *Appendix B*.

A sample was considered toxic if:

1) there was a significant difference between the laboratory control and test replicates using a t-test, and
2) the difference between the mean endpoint value in the control and the mean endpoint value in the test sample was greater than the 90th percentile minimum significant difference (MSD).

The MSD is a statistic that indicates the difference between the two means that will be considered statistically significant given the observed level of between-replicate variation and the alpha level chosen for the comparison. The 90th percentile MSD value is the difference that 90% of the t-tests will be able to detect as statistically significant. Use of the 90th percentile MSD is similar to establishing statistical power at a level of 0.90, and is a way to insure that statistical significance is determined based on large differences between means, rather than small variation among replicates. MSDs were established by analysis of numerous bioassay results for San Francisco Bay (Anderson and Hunt, unpubl.; Hunt *et al.* 1996). Based on those analyses, the 90th percentile MSD for *Eohaustorius* was 18.8% and for the bivalve larvae test 21%. For the 1996 sediment bioassays, an amphipod bioassay was toxic if it had below 79.2% survival in either season tested. A larval bivalve bioassay was toxic it if had below 56% or 60% normal development in February or August, respectively.

Some of the samples used in the February bioassays were held in the laboratory beyond the recommended 14 days. Sediment samples from Grizzly Bay, Sacramento, and San Joaquin River were held for 18 days, and samples from Napa River and Davis Point were held for 19 days. Exceeding sample holding times by a few days is not considered to be a serious problem. Results from those samples were consistent with results from previous samples at those sites.

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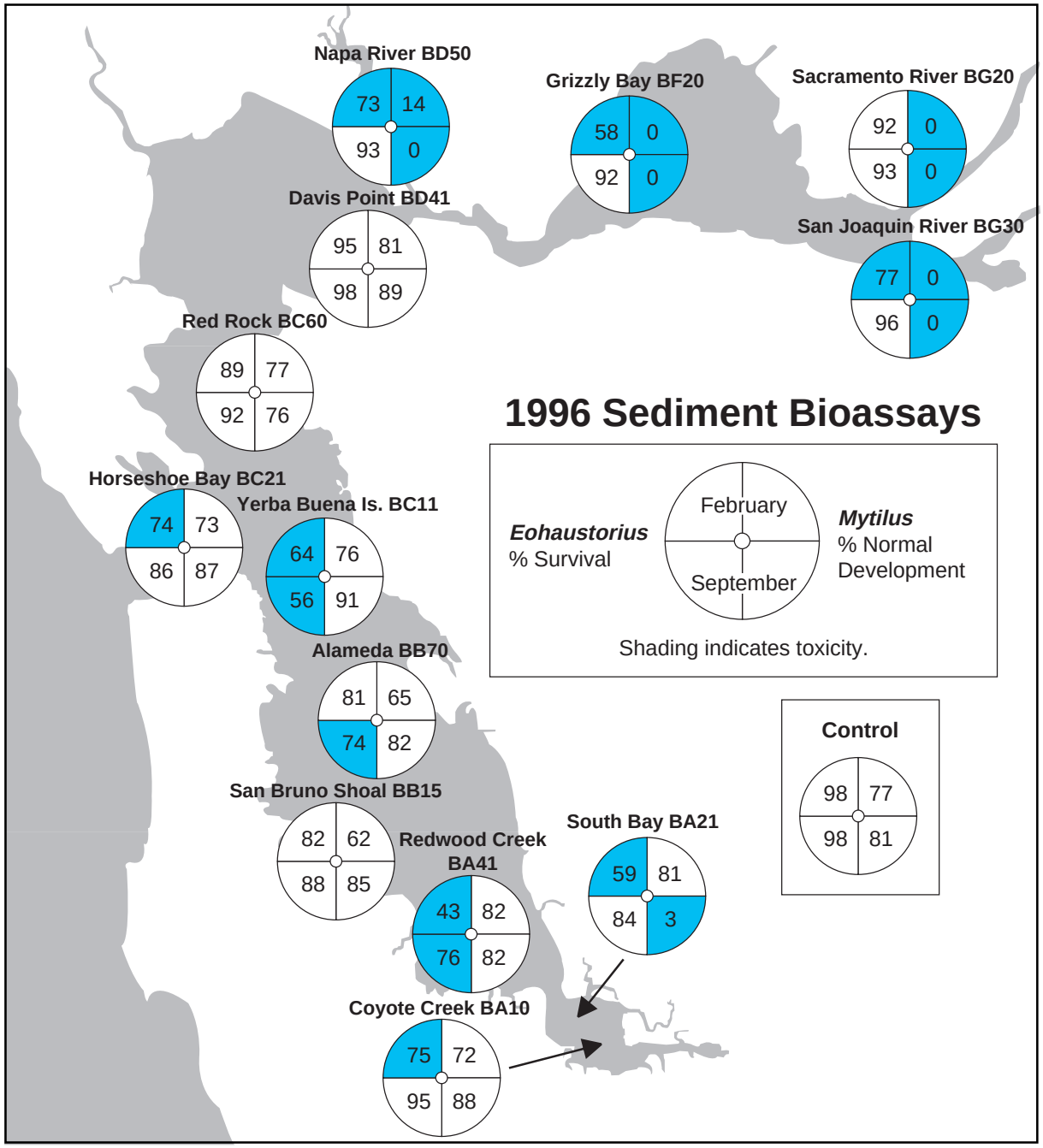

Figure 16. Sediment bioassay results for 1996. The control sediment used in the *Eohaustorius* test was "home" sediment from Yaquina Bay, Oregon where the amphipods were collected. The control used for the *Mytilus* (mussel) test was clean seawater from Granite Canyon, California. See *Appendix A* for a description of the tests used. Toxicity was determined as described in the text.

Sediments were toxic to either the amphipods or bivalve larvae at all stations, except Red Rock (BC60), San Bruno Shoal (BB15), and Davis Point (BD41), during at least one sampling period in 1996. Those stations have very sandy sediments with generally low levels of contamination. Amphipod toxicity occurred in both sampling periods at Redwood Creek (BA41) and Yerba Buena Island (BC11). Sediments were not toxic to amphipods at Red Rock, Davis Point, San Bruno Shoal, or Sacramento River (BG20). Sediment elutriates were toxic to larval mussels during both sampling periods at the Sacramento and San Joaquin Rivers (BG20, BG30), Grizzly Bay (BF20), and Napa River (BD50), and were only toxic at South Bay (BA21) in September. Sediments were not toxic to larval mussels at the remaing stations.

Sediment Monitoring Trends

Sediment contaminant concentrations have been measured at most of the RMP sites since 1991. Samples were collected by the State's Bay Protection and Toxic Clean-up Program (BPTCP) in 1991 and 1992, and by the RMP since 1993. Combining data from these two programs provides a time-series of ten sampling periods over six years. Average and ranges of concentrations for several trace element and trace organic contaminants are shown for each major Estuary reach (Figures 17 and 18).

Except for the Rivers, plots for the various Estuary reaches represent only muddy sediments (<60% sand). At the River stations, one or both stations had coarse sediments in each sampling period. A separate plot is presented for stations with coarse (>60% sand) sediments, including the Rivers. Most coarse sediment stations are from the Northern Estuary, but all samples from Red Rock, and one sample from Horseshoe Bay (August 1995) are also included.

In general, differences between the average concentrations and the ranges were small. There did not appear to be any seasonal or water-year-type variations in concentrations.

Trace element concentrations were mostly stable and constant between 1993 and 1996, and there were few obvious increasing or decreasing trends. Only arsenic and chromium at the River stations appear to have increased in concentration since 1991. However, since arsenic and mercury were systematically lower in most reaches in 1991–1992 than in 1993–1996, and the analyses in 1991–1992 were conducted by different laboratories than in 1993–1996, differences in measurement methods between laboratories are suspected rather than real increases in concentrations beginning in 1993. The remaining trace elements were all analyzed by the same laboratory. Selenium was not measured in 1991–1992. Silver in the Northern Estuary was higher in 1991 and 1992 than in most subsequent years. Lead at the Rivers was higher in August 1994 than in the other samples. Selenium was higher in most reaches, especially at the Rivers and Northern Estuary, in September 1993 than in the other samples. The sources of those two trace elements that may have caused those elevated measurements are not known. Mercury at the Rivers and Central Bay had the widest range of concentrations, and the coarse sediment stations generally had the lowest range of variation.

The trace organic contaminants exhibited wider ranges of concentrations within each reach, and more variation over time than trace elements. Chlorinated hydrocarbons (PCBs, DDT, chlordanes, dieldrin) at the River stations appeared to decrease in concentrations since 1991 (Figure 18). Average PAHs and dieldrin concentrations were higher in several reaches in February 1994, but the causes of those increases are not known. Average chlordanes appear to have decreased in most reaches since about 1994.

In considering the trends in these plots, it is important to recognize that concentrations may be influenced by physical sediment factors as well as proximity to sources. In general, sediments with more silt and clay (percent fines) and higher total organic carbon (TOC) have higher concentrations than sediments with sandy sediments and low TOC (see *Sediment Monitoring Discussion* for more details). Therefore, some of the variation represented in the plots could be attributable to spatial and temporal variations in sediment type rather than in changes in concentrations *per se*. Additionally, rigorous time-series analysis generally requires more than the eight to ten samples available. Further study of the relationships between concentrations and other sediment factors, and over time are good candidates for future RMP Special Studies.

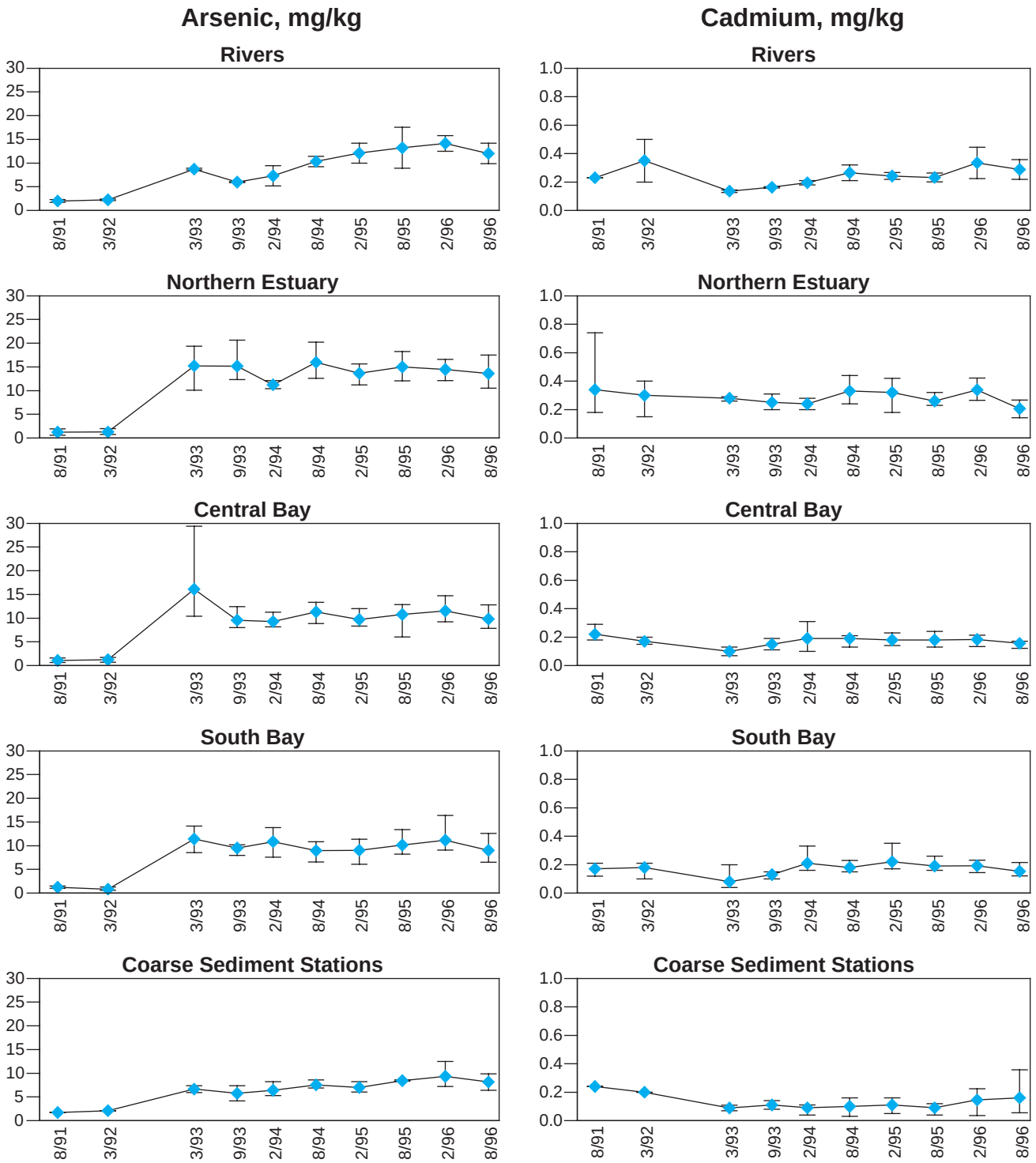

Figure 17. Plots of average trace element concentrations in sediment for each Estuary reach from 1991–1996. Units are in parts per million, ppm. The vertical bars represent the range of all values within a reach. Sample sizes are as follows: South Bay: 1991–1992 n=4, 1993 n=4, 1994 n=6, 1995–1996 n=7; Central Bay: 1991-1992 n=3, 1993–1995 n=4, 1996 n=5; Northern Estuary: 1991 n=5, 1992 n=5, 1993 n=4, 1994 n=5, 1995 n=6, 1996 n=8; Coarse Sediment Stations: 1991–1992 n=1, 1993 n=2, 1994–1995 n=3, 1996 n=4; Rivers: 1991–1996 n=2.

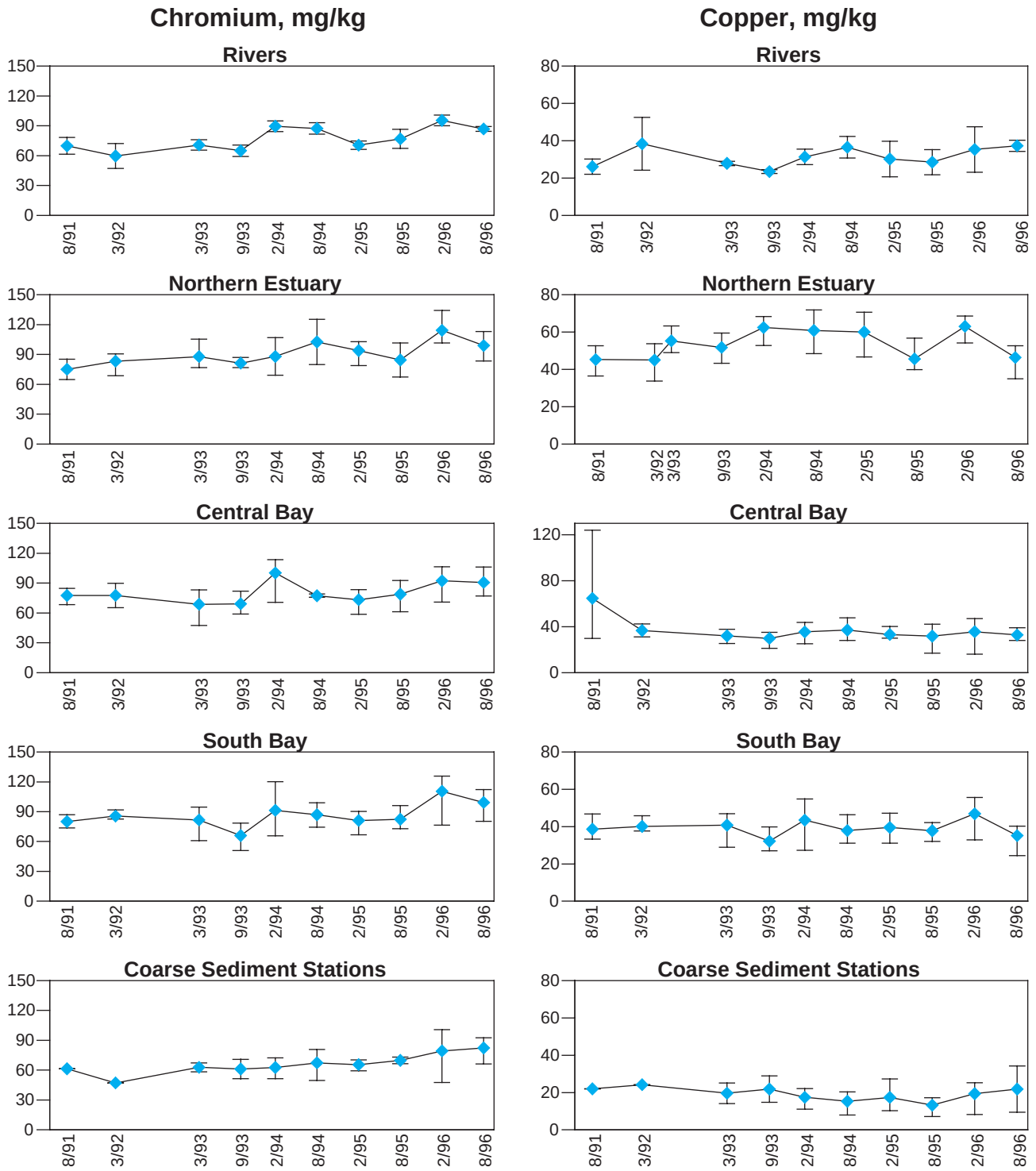

Figure 17 (continued). Plots of trace element concentrations in sediment for each Estuary reach from 1991–1996.

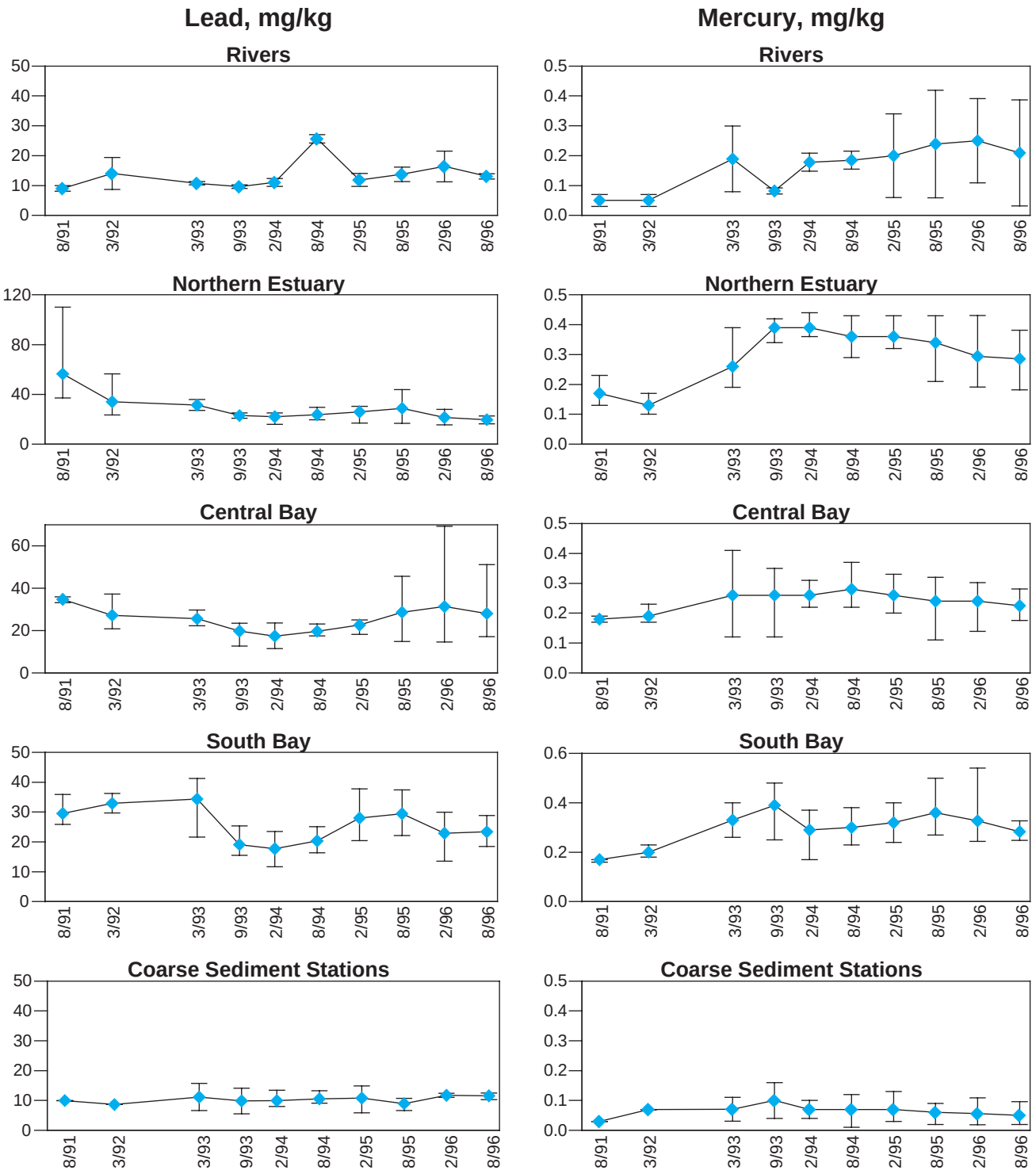

Figure 17 (continued). Plots of trace element concentrations in sediment for each Estuary reach from 1991–1996.

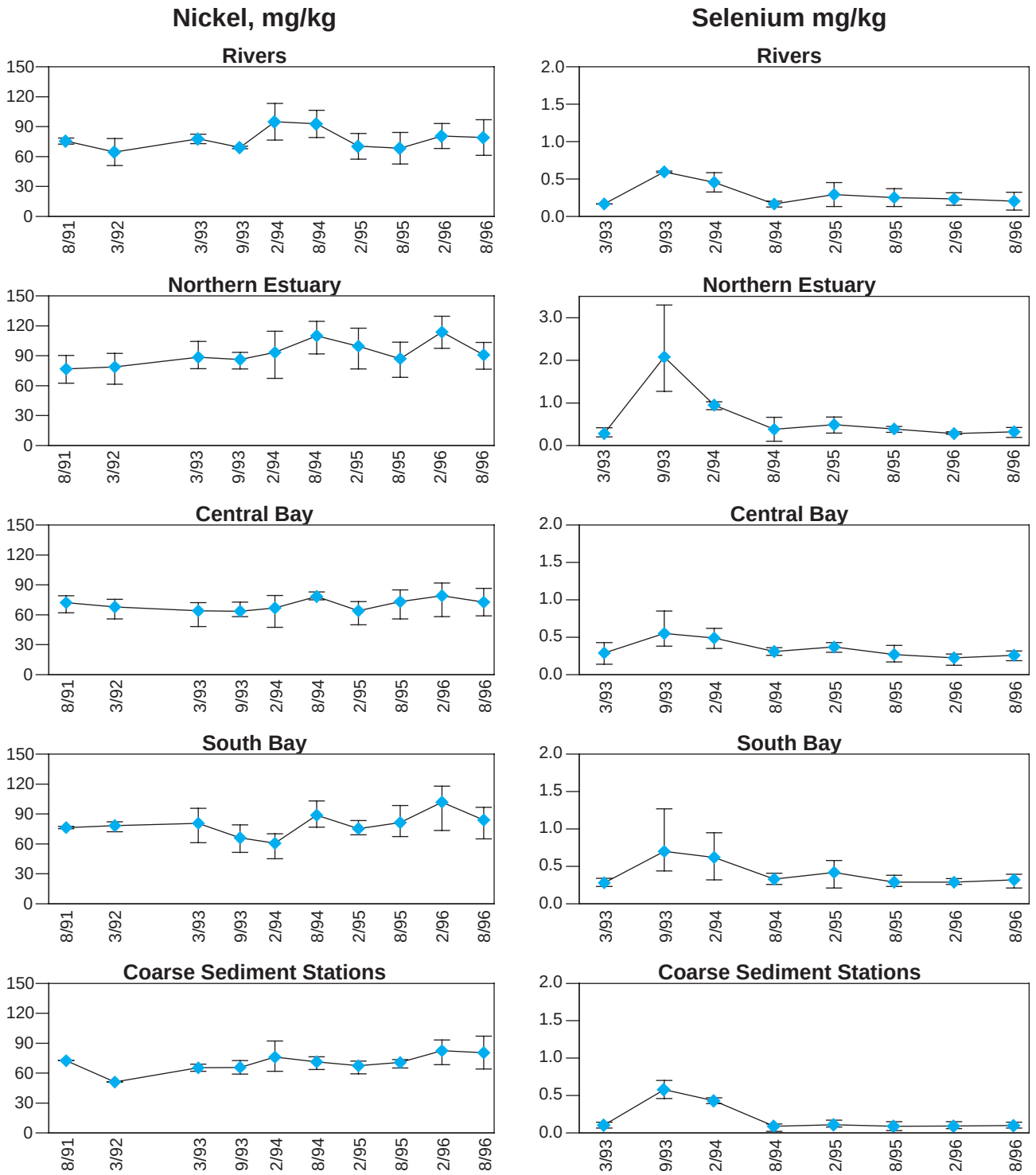

Figure 17 (continued). Plots of trace element concentrations in sediment for each Estuary reach from 1991–1996.

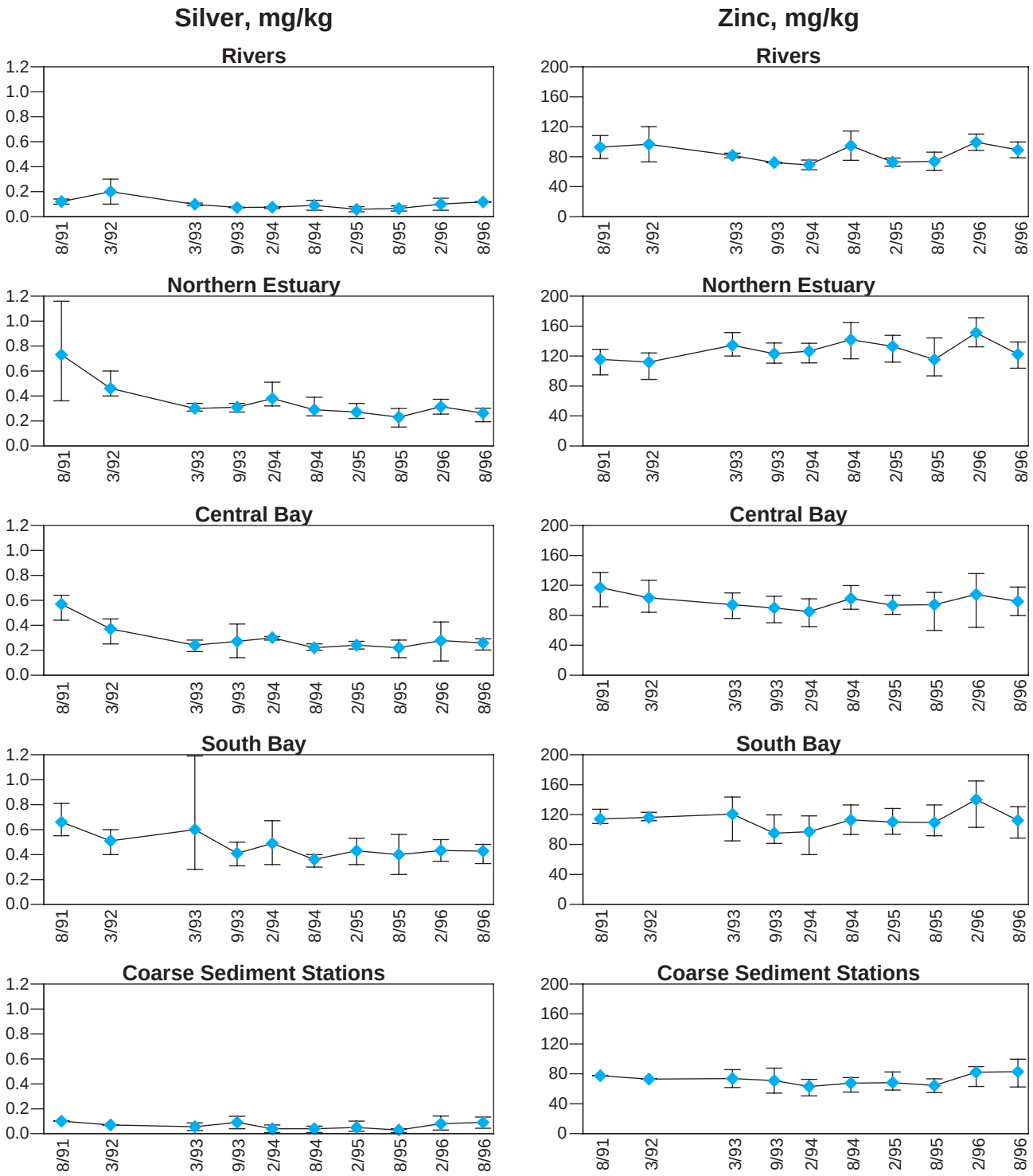

Figure 17 (continued). Plots of trace element concentrations in sediment for each Estuary reach from 1991–1996.

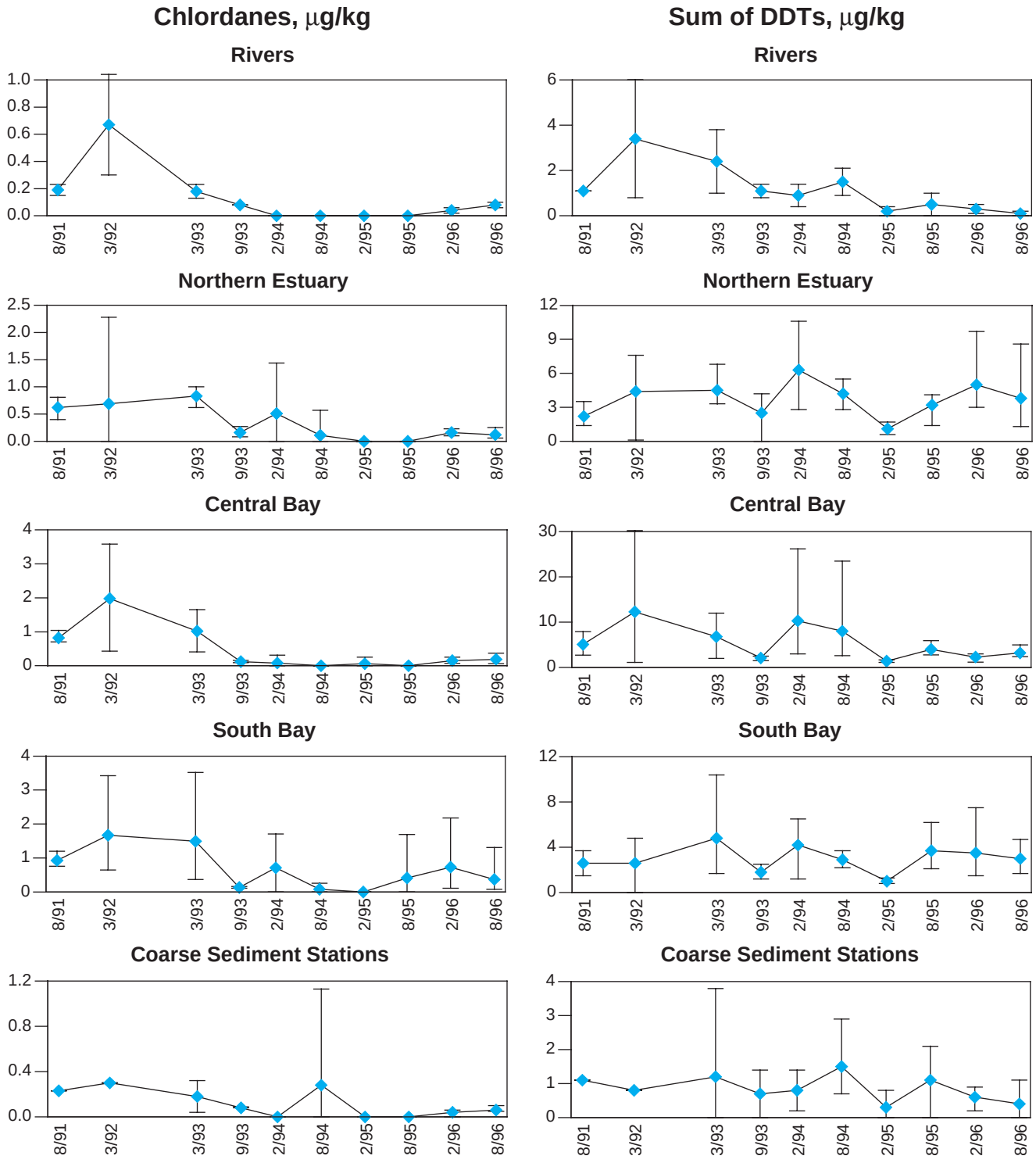

Figure 18. Plots of average trace organic concentrations in sediment for each Estuary reach from 1991–1996. Units are in parts per billion, ppb. The verticle bars represent the range of all values within a reach. Chlordane sample sizes are as follows: Rivers 1991–1996 n=2; Northern Estuary 1991 n=6, 1992 n=5, 3/93 n=4, 9/93 n=5, 1994 n=5, 1995 n=6, 1996 n=6; Central Bay 1991 n=3, 1992 n=3, 1993 n=4, 1994 n=4, 2/95 n=4, 8/95 n=3, 1996 n=4; South Bay 1991 n=4, 1992 n=4, 1993 n=4, 1994 n=6, 1995 n=7, 1996 n=7; Coarse Sediment Stations 1991 n=1, 1992 n=1, 3/93 n=4, 9/93 n=3, 1994 n=4, 2/95 n=4, 8/95 n=5, 1996 n=4. DDT sample sizes are as follows: Rivers 1991–1996 n=2; Northern Estuary 1991 n=6, 1992 n=5, 3/93 n=4, 9/93 n=5, 1994 n=5, 1995 n=6, 1996 n=6; Central Bay 1991 n=3, 1992 n=3, 1993 n=4, 1994 n=4, 2/95 n=4, 8/95 n=3, 1996 n=4; South Bay 1991 n=4, 1992 n=4, 1993 n=4, 1994 n=6, 1995 n=7, 1996 n=7; Coarse Sediment Stations 1991 n=1, 1992 n=1, 3/93 n=4, 9/93 n=3, 2/94 n=4, 8/94 n=3, 2/95 n=4, 8/95 n=5, 1996 n=4.

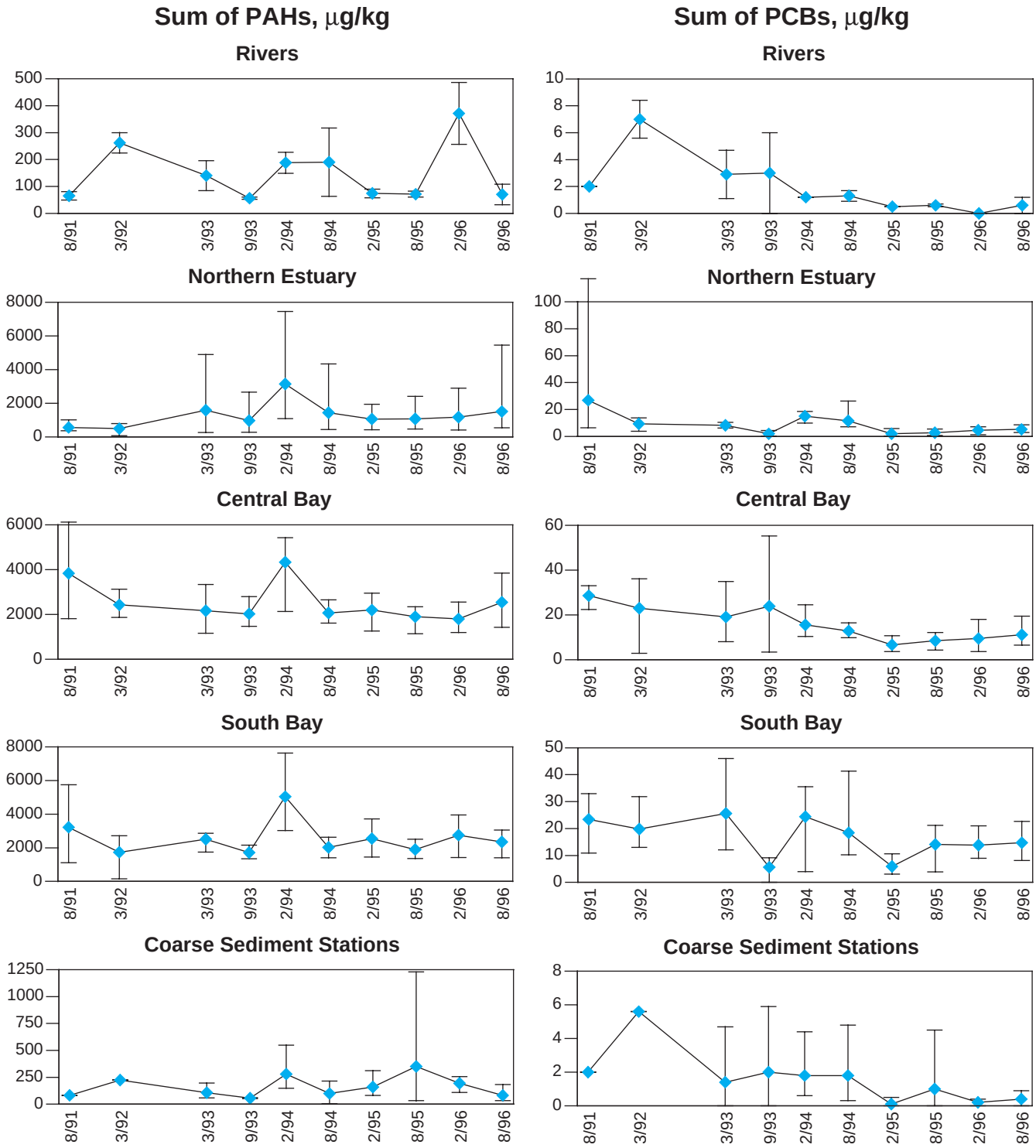

Figure 18 (continued). Plots of average trace organic concentrations in sediment for each Estuary reach from 1991–1996. PAH sample sizes are as follows: Rivers 1991–1996 n=2; Northern Estuary 1991 n=6, 1992 n=5, 1993 n=4, 1994 n=4, 1995 n=6, 1996 n=6; Central Bay 1991 n=3, 1992 n=3, 1993 n=4, 1994 n=4, 2/95 n=4, 8/95 n=3, 1996 n=4; South Bay 1991 n=4, 1992 n=4, 1993 n=4, 1994 n=4, 1995 n=7, 1996 n=7; Coarse Sediment Stations 1991 n=1, 1992 n=1, 3/93 n=4, 9/93 n=2, 1994 n=4, 2/95 n=4, 8/95 n=5, 1996 n=4. PCB sample sizes are as follows: Rivers 1991–1996 n=2; Northern Estuary 1991 n=6, 1992 n=5, 3/93 n=4, 9/93 n=5, 1994 n=5, 1995 n=6, 1996 n=6; Central Bay 1991 n=3, 1992 n=3, 1993 n=4, 1994 n=4, 2/95 n=4, 8/95 n=3, 1996 n=4; South Bay 1991 n=4, 1992 n=4, 1993 n=4, 1994 n=6, 1995 n=7, 1996 n=7; Coarse Sediment Stations 1991 n=1, 1992 n=1, 3/93 n=4, 9/93 n=3, 1994 n=4, 2/95 n=4, 8/95 n=5, 1996 n=4.

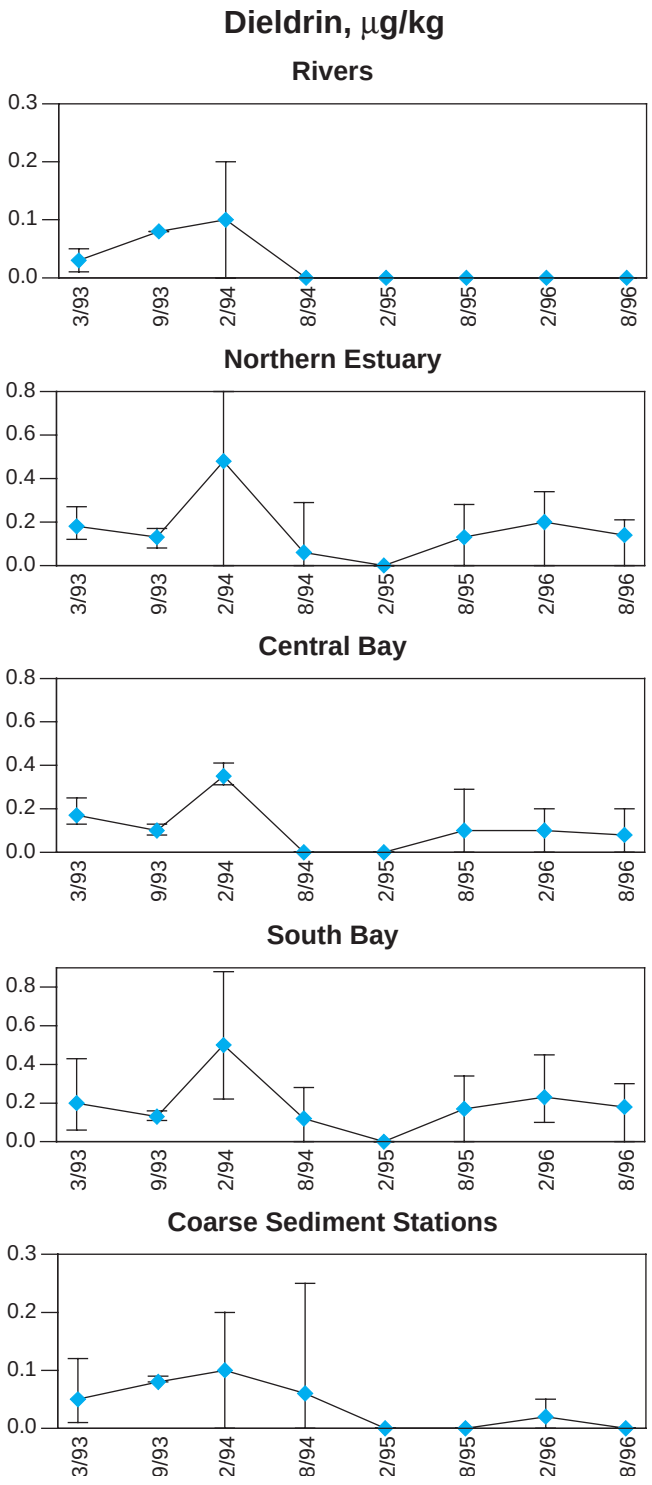

Figure 18 (continued). Plots of average trace organic concentrations in sediment for each Estuary reach from 1993–1996. Dieldrin sample sizes are as follows: Rivers 1993–1996 n=2; Northern Estuary 3/93 n=4, 9/93 n=5, 1994 n=5, 1995 n=6, 1996 n=6; Central Bay 1993 n=4, 1994 n=4, 2/95 n=4, 8/95 n=3, 1996 n=4; South Bay 1993 n=4, 1994 n=6, 1995 n=7, 1996 n=7; Coarse Sediment Stations 3/93 n=4, 9/93 n=3, 1994 n=4, 2/95 n=4, 8/95 n=5, 1996 n=4.

Relationships Between Sediment Toxicity and Contamination in San Francisco Bay, Summary and Conclusions[1]

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Introduction

Sediments sampled in monitoring programs are usually mixtures of numerous potential toxicants; therefore, the exact sediment component(s) that may have caused any observed toxicity in bioassays are difficult to identify. This is mainly because relationships between sediment bioassays and measurements of sediment contamination are correlational and it is not possible to attribute toxicity to a specific contaminant. However, rigorous numerical analysis of relationships between toxicity and contamination may identify significant associations, priority chemicals, or locations that can be used to form testable hypotheses for further intensive experiments that could determine the actual causes of toxicity.

The purpose of this study was to examine the relationships between sediment toxicity and sediment contamination in San Francisco Bay in order to identify the contaminant(s) that were statistically associated with the observed toxicity. While the results presented do not demonstrate the cause of sediment toxicity, they have facilitated the articulation of testable hypotheses about possible causes. These analyses are an important step in developing an understanding about which sediment components may be causing toxicity in the Bay. Environmental management requires such information in order to target source control or remedial action.

Methods

Data were analyzed from 14 sites sampled from 1991 to 1995 (Figure 19) under the Regional Monitoring Program (RMP) and the Bay Protection Toxic Cleanup Program (BPTCP). At Castro Cove, a spatial gradient of four sites extending from an old oil refinery discharge was sampled in May 1992. At the other sites, seven sites were sampled during eight sampling periods and six sites were sampled four or five times. Sampling occurred during wet (February–April) and dry (August–September) months in the region. Sampling methods used in the RMP and BPTCP were similar.

NOAA's Effects Range guidelines (ERLs, ERMs; Long *et al.*, 1995; Long and Morgan, 1990) were used to evaluate whether sediment concentrations were within ranges that have been associated with biological effects. Those guidelines were from a large national database and are currently the most widely used and accepted sediment effects guidelines available. Interpretation of these guidelines is explained in the introduction to the *Sediment Monitoring* chapter.

Effects Range Median (ERM) values were also used to calculate a mean ERM quotient (mERMq). The concentration of each contaminant was divided by its ERM to produce a quotient, or proportion of the ERM. The quotients calculated for all contaminants in each sample were summed, then divided by the number of contaminants whose ERMs were used to calculate each sum. The last step is useful since the number of contaminants measured at each site changed over time. Mean ERM quotient values were used to evaluate the cumulative contribution of many sediment contaminants at each site to toxicity. Similar

[1] This summary contains excerpts from a more extensive RMP Technical Report available from SFEI.

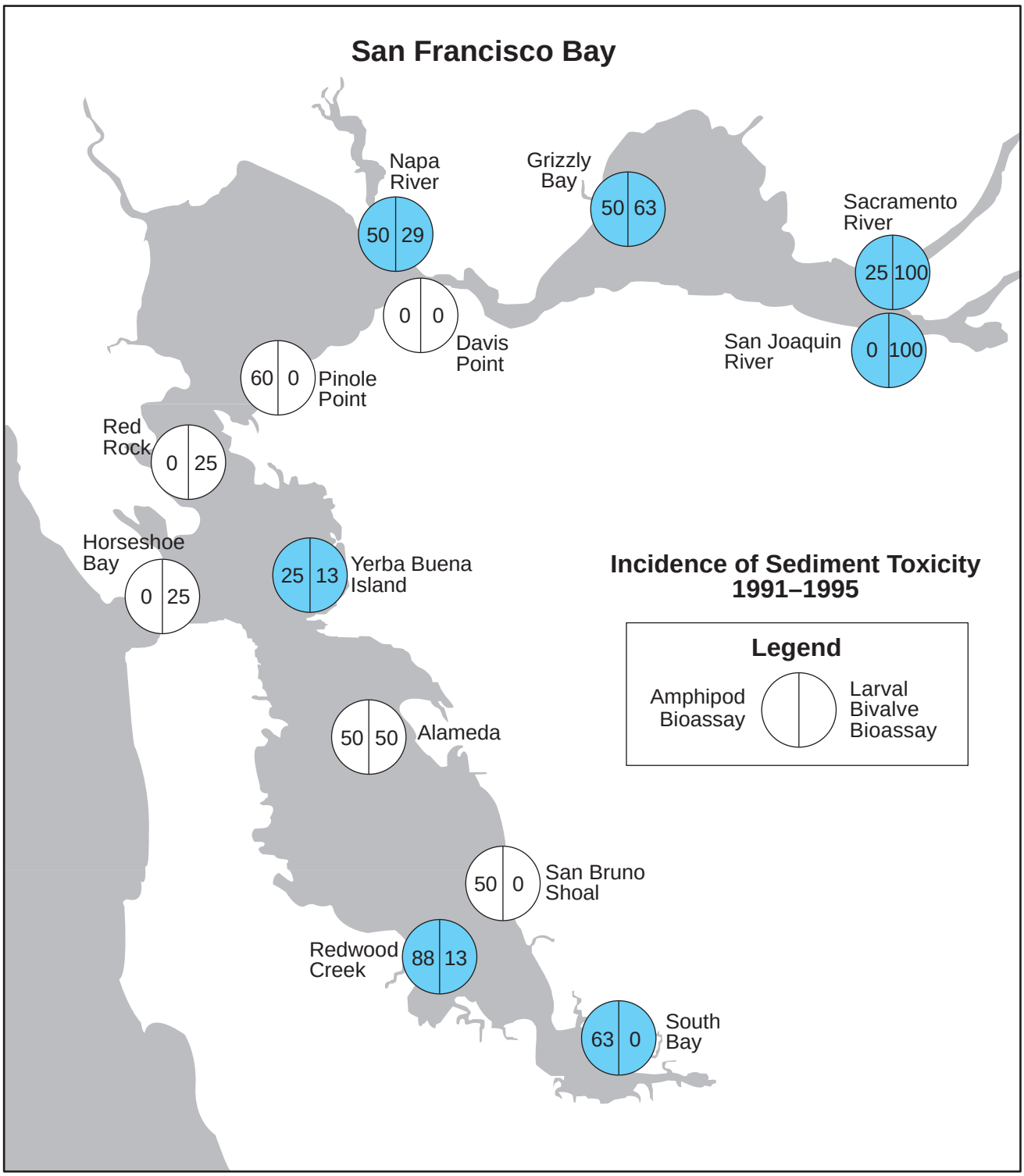

Figure 19. Percentages of sediment bioassays that were toxic at each site, 1991–1995. n=7 or 8 samples (shaded circles), n=4 or 5 (unshaded circles). Castro Cove site shown on Figure 28.

approaches have been used by Carr *et al*. (1996) and Canfield *et al*. (1996).

Multivariate analyses (principal components analysis, PCA and multiple regression) of relationships between sediment contaminant concentrations and toxicity test endpoints were conducted in several steps using Statistical Analysis System (1995) software (see Technical Report for more details).

Results

Patterns in Sediment Contamination

Nickel was the only contaminant that was above the ERM of 51.6 ppm at nearly all sites. Arsenic, Cr, Cu, Hg, Ni, DDTs, and chlordanes frequently exceeded ERLs.

There were obvious long-term changes in some contaminants in some areas (e.g., chlordanes in the Northern Estuary, see *Sediment Monitoring Trends* in this chapter), as well as seasonal changes in some contaminants at some sites, such as PAHs at Alameda. Those trends and patterns in sediment contamination may be reflected by trends in sediment toxicity.

Patterns in Sediment Toxicity

Sediments were toxic to amphipods most frequently (88% of the tests) at Redwood Creek (Figure 19). The incidence of toxicity decreased, and mean percent survival increased with distance from that site, suggesting a possible local source of contamination. Sediments from Horseshoe Bay, Red Rock, Davis Point, and San Joaquin River were never toxic to amphipods, probably due to the relatively uncontaminated coarse sediments at most of those sites.

There was temporal variability in the results of the amphipod tests at most sites between 1991 and 1995. Percent survival increased significantly over time at Grizzly Bay, Napa River, and South Bay. There were also seasonal (wet, dry) differences in amphipod toxicity. Overall, percent survival during the wet periods was significantly lower than during the dry periods (Wilcoxon 2- sample test, p=0.003). Seasonal differences in percent survival were obvious at San Joaquin River, Grizzly Bay, Alameda, and San Bruno Shoal.

Sediments elutriates were always extremely toxic to larval bivalves at the Sacramento and San Joaquin River sites. Fewer than 2.5% of larvae developed normally in samples from the Sacramento River, and fewer than 4.6% developed normally at San Joaquin River. The incidence of larval bivalve toxicity decreased, and mean percent normal development increased with distance from those sites. Toxicity also occurred in half the tests at Alameda. No larval bivalve toxicity was observed at Pinole Point, Davis Point, San Bruno Shoal, or South Bay (Figure 19).

Relationships Between Sediment Toxicity and Sediment Quality Guidelines

Percent survival of *Eohaustorius* was significantly inversely correlated with the mean ERM quotient (mERMq; Figure 20). This relationship suggests that many contaminants present in relatively low concentrations in sediments together may influence amphipod toxicity. That plot also provides values that reflect the potential for sediment samples from the Bay to be toxic: values below 0.105 were never toxic, values up to 0.182 were toxic in about half the tests, values above 0.185 were toxic in 89.2% of the tests, and values above 0.2195 were always toxic.

No meaningful relationship between mERMq and larval bivalve development was observed (Figure 20). Instead, normal development increased with increasing mERMq, whereas an inverse relationship should be expected. The lack of a meaningful relationship with the bivalve test is probably because mERMq values were calculated from measurements of contaminants in bulk sediment, whereas sediment elutriates were used in the larval bivalve bioassays.

Site Specific Relationships Between Sediment Concentrations and Bioassay Endpoints

Sediment contaminant patterns at each site were different from each other, and changed over time. Therefore, all samples collected at each site over time were analyzed together

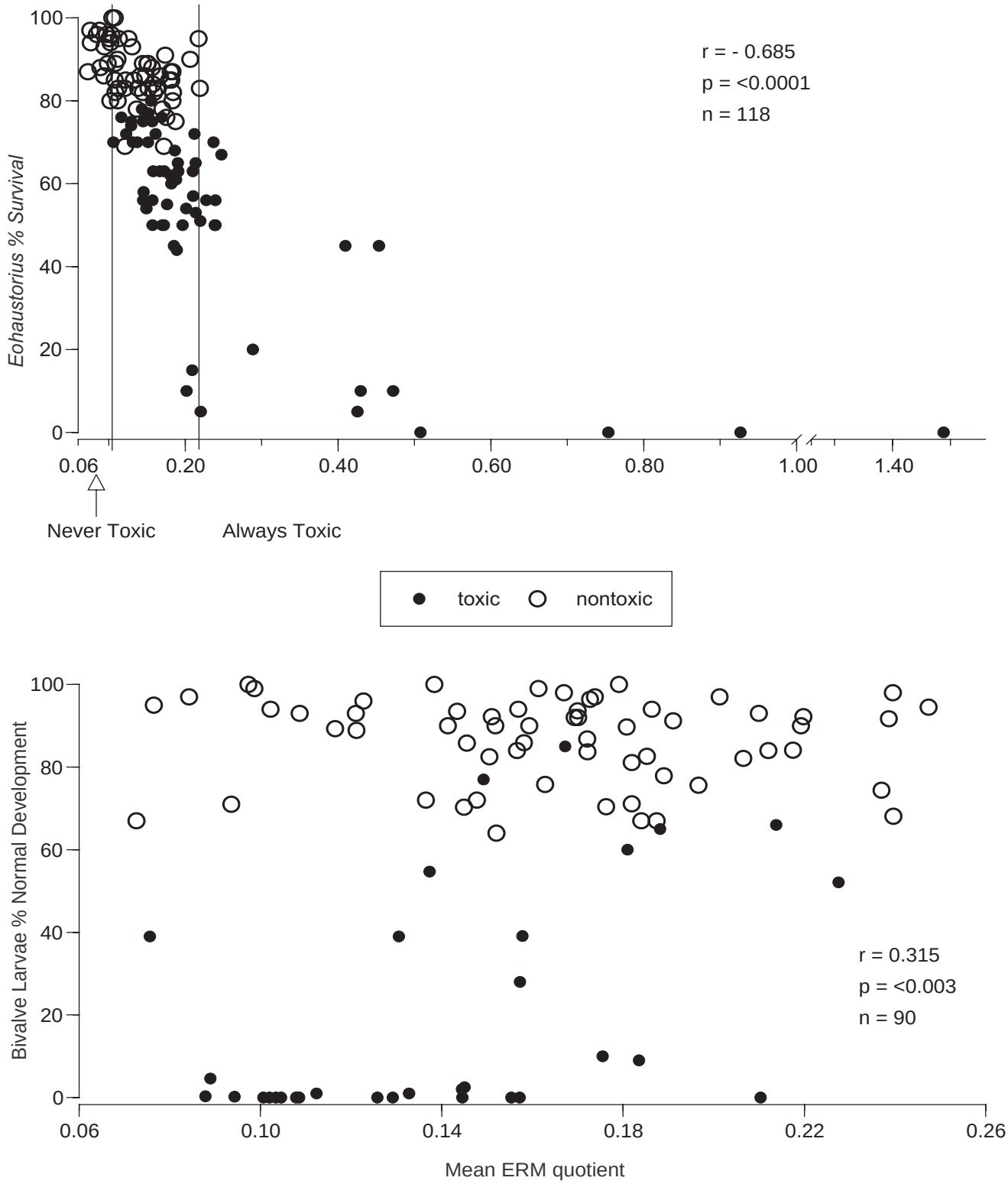

Figure 20. Plots of *Eohaustorius* percent survival (top) and bivalve larvae percent normal development (bottom) and the mean ERM quotient (mERMq) at each site sampled, 1991–1995.

Table 1. Summary of multivariate analyses of amphipod bioassays at each site. This table lists the contaminants identified by principal components analysis (PCA) that were most closely associated with amphipod survival by multiple regression analysis. Underscore indicates concentrations were usually above the ERL. * indicates a significant inverse correlation between individual contaminant and amphipod percent survival. R^2 is the proportion of variation in amphipod survival accounted for by the PCA factor(s) listed. Positively correlated contaminants listed are unlikely to have influenced toxicity at each site as inverse correlations are expected if there is a concentration-response relationship.

Site (n)	PCA Factor(s) most highly Associated with Amphipod Survival	No. of Factors incl.	R^2	Positively Correlated with Amphipod Survival
Sacramento River (8)	Ag*, chlordanes*, Fines*, DDTs* Cu*, TOC*, Zn, Cd, PCBs	1	.68	As, Cr, Hg, Se, HCHs
Grizzly Bay (8)	TOC*, chlordanes*, Ag*, Cd	1	.61	As, Hg, Se, HCHs, LPAH, HPAH
Napa River (8)	Pb*, Ag, PCBs, Cd, chlordanes DDTs,	2	.90	As, Cr, Cu, Hg, Ni, Se, Zn HCHs LPAHs, HPAHs
Pinole Pt. (5)	chlordanes*, TOC, Pb	1	.74	Ni, Se, DDTs
Castro Cove (25)	Ni*, Zn*, Ag*, Pb*, TOC*, Cr*, fines, Cd*, Cu*	1	.83	none
Yerba Buena Is. (8)	TOC, Ni, , DDTs, Cr, Cu, Fines, Zn	2	.68	Ag, Cd, Hg, Pb, Se CPDs, LPAHs, HPAHs, PCBs
Alameda (4)	LPAHs*, Se*, HPAHs, Cu,	1	.83	As, Hg, Ni, Zn chlordanes, DDTs, PCBs
San Bruno Shoal (4)	LPAHs, Cr, HPAHs	1	.75	Ag, Cu, Hg, Ni, Pb, Zn, chlordanes, DDTs, HCHs, PCBs, CPDs
Redwood Creek (8)	chlordanes*, fines, Ag, Pb, PCBs, TOC	2	.70	As, Cd, Hg, Se, HCHs, LPAHs
South Bay (8)	Ag	1	.47	As, Cr, Hg, Ni, Se, Zn

providing a site-specific evaluation. Analyses were only conducted at sites where toxicity occurred more than once. Analyses using total organic carbon (TOC) normalized trace organic concentrations produced the same results as using dry-weight concentrations except at three sites. Therefore, dry-weight concentrations are reported (TOC normalized exceptions are noted in the full Technical Report).

The results of this analysis for the amphipod bioassays at each station are summarized on Table 1 which shows the suites of contaminants determined by principal components analysis (PCA) that were most closely associated with amphipod percent survival using multiple regression. Also shown are contaminants that were directly correlated with survival, thus probably not important factors, although all contaminants could contribute cumulatively.

Significant regression models were obtained at half of the site, and more than 60% of the variation in amphipod survival was explained by those group of contaminants at all but at South Bay. The groups of contaminants identified are those that are most likely to have contributed the most to the toxicity observed at each site. Further evaluation of the contaminants within each group revealed several strong relationships with percent survival.

Total chlordanes were related to toxicity at the Sacramento River, Grizzly Bay, Napa River, Pinole Point, and Redwood Creek, and were significantly inversely correlated with amphipod survival at all but Napa River. Combining the data from those five sites showed that chlordane concentrations above 0.28 ng/g were always toxic (Figure 21). That concentration is very near the ERL of 0.5 ng/g, and the concentration of 0.3 ng/g predicted by equilibrium

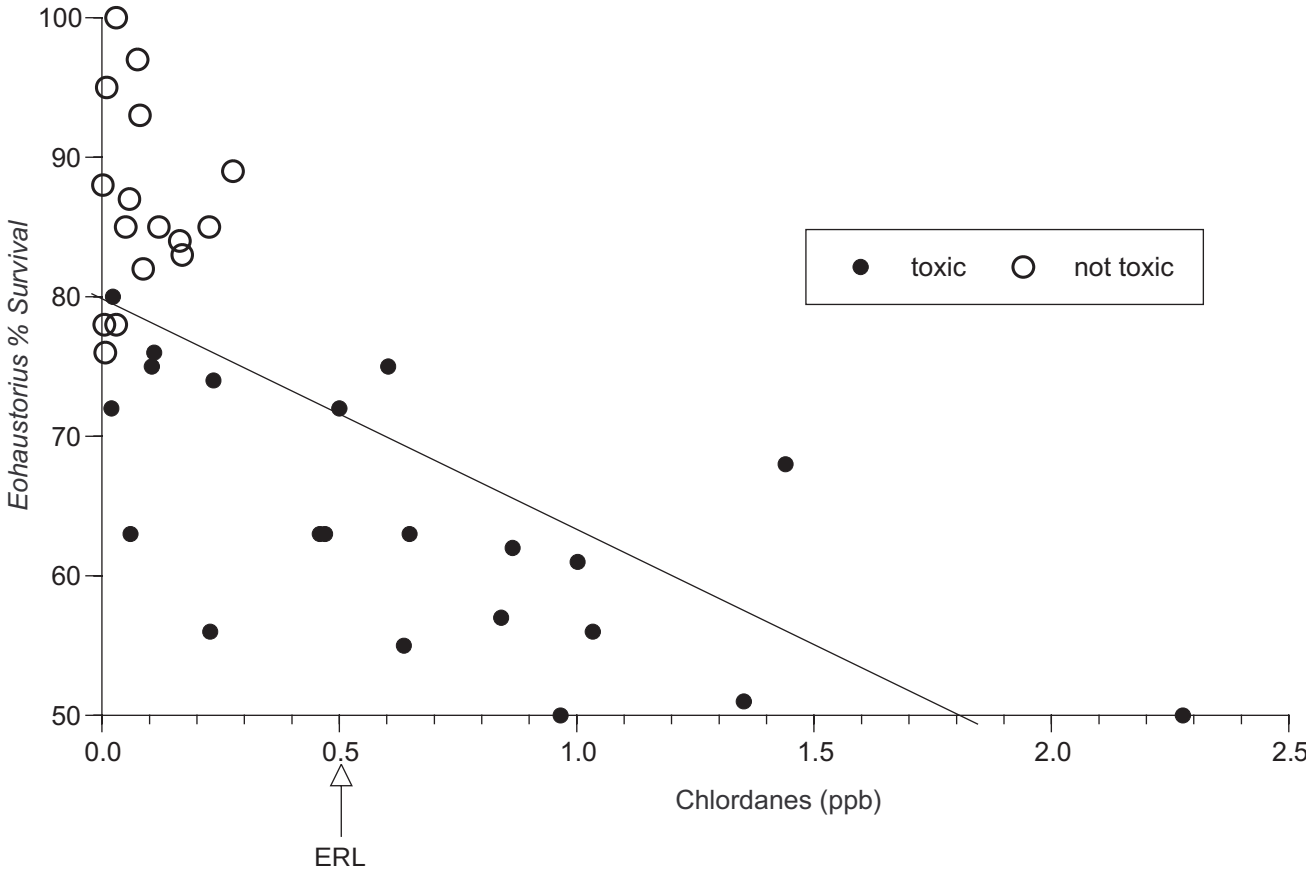

Figure 21. Plot of *Eohaustorius* percent survival and chlordanes in sediments at the Sacramento River, Grizzly Bay, Pinole Point, Napa River, and Redwood Creek sites combined, as identified by multivariate analysis.

partitioning for chronic effects (Pavlou *et al.*, 1987). There is no sediment LC_{50} for chlordane effects on *Eohaustorius* for comparison.

LPAHs and HPAHs were associated with toxicity at Alameda and San Bruno Shoal. Although the sample sizes at each station were small (n=4), the correspondence between toxicity and seasonal patterns of LPAHs suggested that wet weather runoff may be the source of PAHs that were associated with toxicity. Combining the data from those two sites showed that LPAH concentrations above 474 ng/g were always toxic and HPAH concentrations above 1,983 ng/g were always toxic (Figure 22). Both concentrations are very near their respective ERL values (552 and 1,700 ng/g).

For the bivalve bioassay, only weak relationships between percent normal development and concentrations were obtained (results not included in this summary).

Discussion and Conclusions

This study showed that either mixtures of contaminants (as mERMq) or individual contaminants in sediments could account for toxicity to *Eohaustorius* in all samples (Table 1). Overall, cumulative concentrations of contaminants in sediments (mERMq) were significantly associated with percent survival. That relationship was refined for each site using multivariate analysis which identified groups of contaminants that were most highly associated with toxicity (Table 1).

Individual contaminants identified by multivariate analysis that were significantly inversely correlated with percent survival, *and* with concentrations above ERLs were probably more important determinants of amphipod toxicity than the cumulative effects of multiple contaminants at most sites. However, since mERMq was significantly inversely correlated with percent survival at Sacramento River and Castro Cove, mixtures may have been more important at those sites.

In contrast to the results for the amphipod bioassay, a statistically significant relationship between contaminants and reduced larval bivalve development was observed only at the San Joaquin River where several metals were implicated. Metals in sediments formed the most consistent, yet weak, pattern related to larval bivalve toxicity in the Northern Estuary. The weak relationships between sediment contamination and reduced bivalve development was probably the result of comparing concentrations obtained from analysis of bulk sediments with bioassays using sediment elutriates. Metals were independently implicated based on toxicity identification evaluations (TIEs) conducted at some of the sites (see *Investigating Classes of Compounds Associated with Sediment Toxicity at Regional Monitoring Program River Stations* in this chapter).

The sites analyzed in this paper were monitored to provide information on background, or ambient Bay conditions, and do not provide a comprehensive assessment of all Bay sediments. However, many other locations in San Francisco Bay not sampled by the RMP have also been shown to be toxic. In particular, areas near some of the major harbors, closed military bases, and superfund sites have very toxic sediments (Hoffman *et al.*, 1994; Long and Markel, 1992; Chapman *et al.*, 1987; Risebrough, 1994; Swartz *et al.*, 1994).

The results presented in this study represent an important intermediate step in the determination of causes of sediment toxicity in San Francisco Bay sediments. The associations between individual sediment contaminants and amphipod survival provide information that can be used to pose hypotheses about the causes of toxicity in Bay. One hypothesis is that total chlordane concentrations in sediments above 0.28 ng/g causes significant mortality to *Eohaustorius*. Another hypothesis is that HPAHs above 1,983 ng/g, and LPAHs above 474 ng/g cause significant mortality. Other hypotheses about the toxicity of mixtures of those contaminants identified by multivariate analysis could also be tested. Further research needs to be conducted on elutriate or pore water chemistry and trace metals bioavailability at the San Joaquin and Sacramento Rivers to determine whether metals could be causing acute toxicity to bivalve larvae. Determination

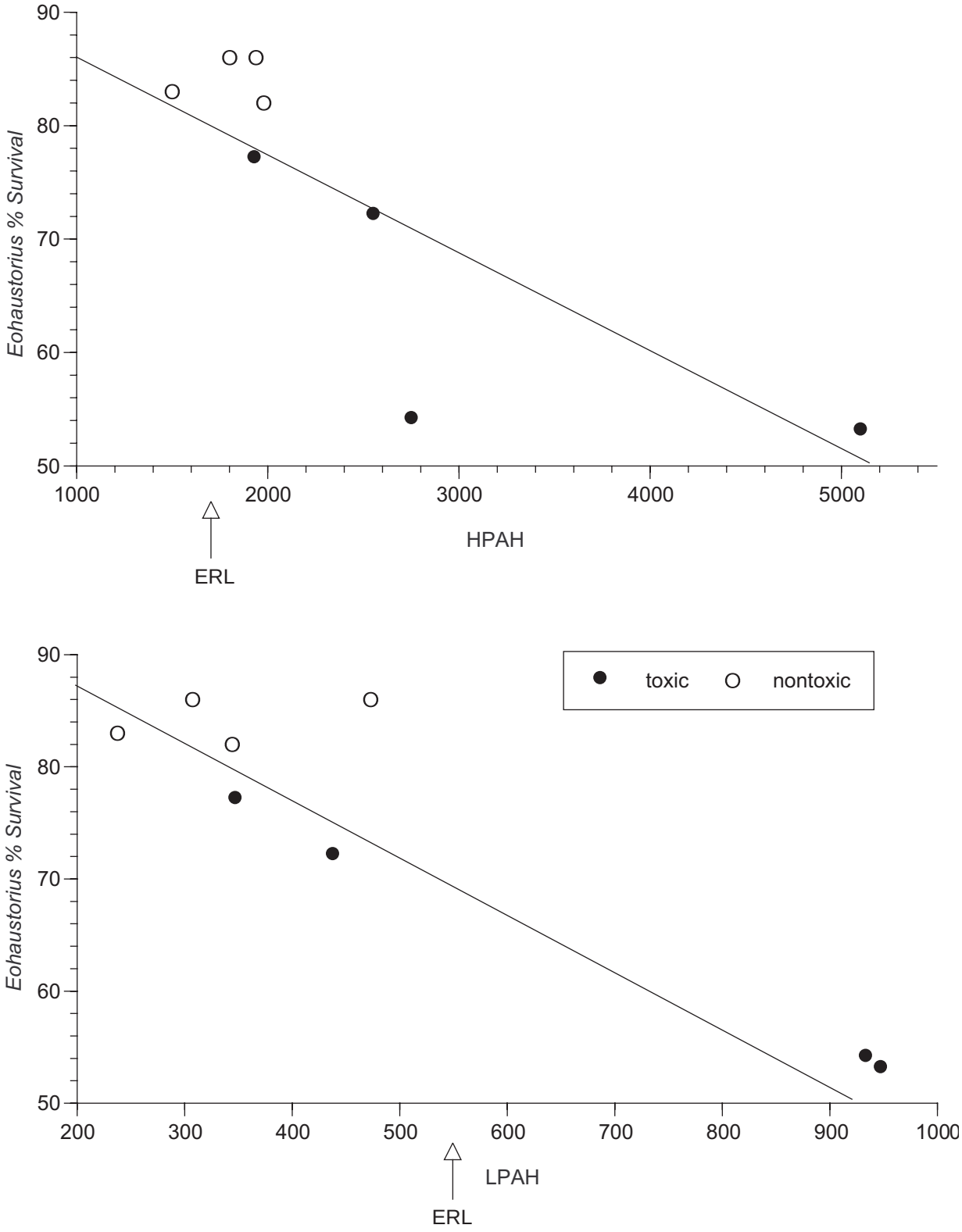

Figure 22. Plot of *Eohaustorius* percent survival and high molecular weight PAHs (HPAH) and low molecular weight PAHs (LPAH) in sediments at the Alameda and San Bruno Shoal sites combined, as identified by multivariate analysis.

of the causes of sediment toxicity observed in monitoring will ultimately require evidence from numerical analysis of monitoring data and manipulative experiments. Such experiments could include TIEs, laboratory and/or *in situ* sediment spiking and dose-response tests at concentrations shown to be associated with toxicity in this paper.

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Investigating Classes of Compounds Associated with Sediment Toxicity at Regional Monitoring Program River Stations

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Introduction

Since Regional Monitoring Program (RMP) sampling began in the winter of 1993, three stations have exhibited consistent toxicity to bivalves, and intermittent toxicity to amphipods. Significant toxicity to bivalves has been detected in all but one of the sediment elutriate samples from the Grizzly Bay, Sacramento River, and San Joaquin River stations (see Thompson *et al.,* this chapter). The cause(s) of this toxicity are not obvious. Because these sediments contain complex mixtures of several contaminants, it is difficult to associate measured contaminants with toxicity using traditional statistical correlations. Although elevated pesticide and metal concentrations have been detected in some of the water column samples at these sites, sediment concentrations of organic chemicals and metals have not exceeded published sediment quality guidelines (e.g., ERMs) for any of the contaminants measured. In addition, unionized ammonia and hydrogen sulfide measured during the toxicity tests did not exceed known bivalve effect concentrations for these sediment constituents.

The three stations mentioned above are essentially freshwater stations, although there is some tidal influence in Grizzly Bay. Because RMP samples have been tested with marine/estuarine species, sediment elutriates are prepared by mixing the sediments with water at the test salinity of 28‰. It is not clear what effect elution of freshwater sediment with higher saline water has on toxicant bioavailability or sediment toxicity.

To better characterize the causes of toxicity, we conducted Phase I Toxicity Identification Evaluation (TIE) manipulations on sediment elutriates from Grizzly Bay, Sacramento River, and San Joaquin River. Combining TIE data with measurements of trace metals and organics in sediment elutriates provided evidence leading toward the identification of chemical compounds associated with sediment toxicity.

In addition to the amphipod solid-phase tests and bivalve elutriate tests, we also exposed bivalve larvae to solid-phase sediment from the three river sites using a Sediment-Water Interface exposure system (Figure 23, Anderson *et al.,* 1996). This exposure system mimics situations that may occur in nature when negatively buoyant bivalve embryos contact sediment before hatching. For this test, intact (unhomogenized) sediment cores were taken directly from the grab sampler. Intact cores were used rather than sediment homogenates in order to minimize artifacts caused by sediment mixing. Freshwater sediment samples were tested with bivalve larvae (*Mytilus* sp.) at 28‰ overlying water salinity. This system allows for a more ecologically relevant exposure of epibenthic species, and comparison of test results allows evaluation of possible effects related to the elutriate preparation process.

In addition to TIE manipulations and Sediment-Water Interface (SWI) exposures conducted in August 1996, we also conducted a TIE manipulation of the overlying water in SWI exposures in February and August 1997. Based on results of the Phase I TIE manipulations of elutriate samples, EDTA was added to the overlying water to chelate and reduce the toxicity of divalent cations such as some trace metals potentially fluxing from the sediment.

In order to examine the possible effects of eluting freshwater samples in water near marine salinity, we also conducted freshwater elutriate tests using the cladoceran, *Ceriodaphnia dubia*.

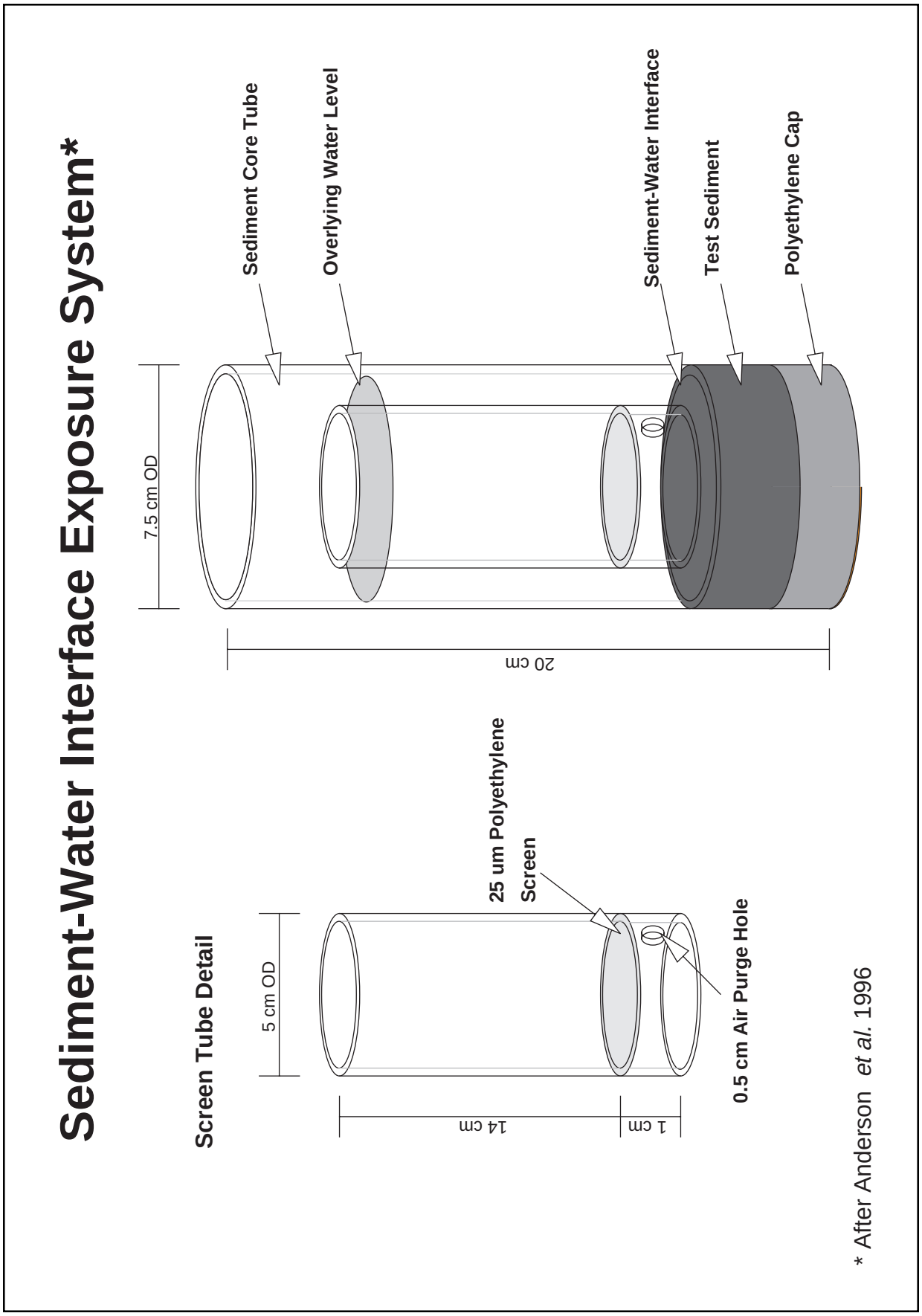

Figure 23. Sediment-Water Interface (SWI) Exposure System: 7.5 cm polycarbonate sample core with 5 cm screen tube.

Methods

Phase I Toxicity Identification Evaluations

Elutriate Preparation

All toxicity testing and sample manipulations were conducted at the Marine Pollution Studies Laboratory at Granite Canyon. Elutriate solutions were prepared by adding 200 grams of sediment to 800 mL of Granite Canyon seawater (adjusted to 28‰ with distilled water) in each of 4 clean 1-liter borosilicate glass jars with Teflon®-lined lids (1:4 volume to volume ratio; US EPA/ACOE, 1991). These mixtures were shaken vigorously for 10 seconds, then allowed to settle for 24 hours (Tetra Tech, 1986). The resulting supernatant was siphoned off for use in toxicity testing, TIE manipulations, and chemical analyses.

Chemical Analysis

Elutriate metals extraction was conducted by Mike Gordon at the Moss Landing Marine Laboratories, and analysis was conducted by Jon Goetzl at the Department of Fish and Game Trace Metals Analytical Facility. The liquid-liquid extraction method using APDC-DDDC-chloroform followed the procedure described by Bruland *et al*. (1979). Chemistry of both filtered and unfiltered samples was analyzed for metals. Samples were filtered using a 0.45 µm Teflon filter. Trace organics analysis was conducted by Walter Jarman at the University of California, Santa Cruz, using standard RMP trace organics methods (Appendix A). Bulk phase and elutriate chemical concentrations were compared to sediment quality guideline values proposed by NOAA. These were the Effects Range Low (ERL) and Effects Range Median (ERM) developed by Long *et al*. (1995).

Toxicity Testing

Prior to subjecting the samples to TIE manipulations, initial rangefinder tests were conducted to determine levels of sample toxicity. Initial elutriate tests were conducted at 25, 50, and 100% concentrations. At the termination of the initial tests, three concentrations that bracketed the EC_{50} of the initial test were chosen to use in the TIE. Grizzly Bay and Sacramento River samples were tested at 25, 50, and 100%, and the San Joaquin River sample was tested at 10, 25, and 100% elutriate. Bracketing the EC_{50} value with three concentrations increased the chance of detecting differences in toxicity using the various TIE manipulations.

Phase I TIE manipulations followed methods described by US EPA (1996). A brief description of the treatments follows. C18 solid-phase extraction columns remove non-polar organic compounds. Subsequent elution of the column with methanol will remove stripped organics that can be added back to clean dilution water for testing. Graduated pH adjustments (7.9, 8.1, and 8.4) assess toxicity of ionic constituents such as ammonia. Sample aeration (one hour) assesses volatile constituents such as sulfide. EDTA addition tests for toxicity from divalent cations. The addition of piperonyl butoxide (PBO) tests for the presence of metabolically activated pesticides such as diazinon. Each manipulation was conducted on three concentrations of elutriate and a control. Controls consisted of Granite Canyon seawater diluted to 28‰ with distilled water, and served as blanks for TIE treatments.

Because of limited data on the effects of pH on bivalve larvae, and because previous bivalve elutriate tests conducted for the RMP demonstrated toxicity in samples with low pH, we conducted rangefinder tests to determine the toxicity of graduated pH treatments. Three separate bivalve larval development tests were conducted on pH treatments ranging from seven to nine in quarter pH unit increments. pH was maintained in 20 mL test containers by filling the container completely, leaving no head space. Initial and final pH readings were within 0.1 pH unit of target.

TIE results were compared using Analysis of Variance between treatments within each elutriate concentration. Results were also compared by converting each treatment's dose/response into toxic units (1 TU = $100/EC_{50}$).

Toxic units from each treatment were compared qualitatively for differences.

Sediment-Water Interface Exposures

Intact sediment cores were sampled directly from a modified van Veen grab sampler during routine sediment sampling for the RMP. Cores were brought back to the laboratory and prepared for testing by adding 300 mL of 28‰ overlying water, and were allowed to equilibrate overnight with slow aeration. Before test initiation, 25 µm mesh screen tubes were inserted into the core tubes containing the sediment, so that the screen was positioned about 1 cm above the sediment. Approximately 200 mussel embryos were pipetted into the screen tubes and exposed for 48 hours. Tests were terminated by removing the screen tube and rinsing larvae into vials to be fixed with 5% formalin. All resulting 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 normal prodisoconch larvae at the end of the test by the mean number of live embryos inoculated at the beginning of the test. Sediment-Water Interface exposures were conducted concurrently with Phase I TIE manipulations.

Sediment-Water Interface TIEs

Results of Phase I TIEs conducted on elutriates in August 1996 indicated that removal of divalent cations reduced sample toxicity. To see if cation chelation would mitigate toxicity in SWI exposures, EDTA was added to overlying water in intact sediment cores from Grizzly Bay in February 1997. A second set of cores served as a baseline test. Cores of clean sand were also tested, with and without EDTA, as controls. As a follow-up to this test, a similar test was performed on intact cores and homogenized cores from all three sites in August 1997. Overlying water chemistry was not measured in these samples.

Ceriodaphnia Elutriate Exposure

To investigate whether changes of sample salinity in the preparation of elutriates was affecting toxicity, we conducted freshwater elutriate tests using the cladoceran

Table 2. Results of TIE Initial Test, SWI, and definitive TIE manipulations for Grizzly Bay (BF20) sampled August 1996. * indicates significantly reduced toxicity compared to Baseline treatment (ANOVA, p = 0.05). ** indicates significantly increased toxicity compared to Baseline treatment. *** indicates no significant difference from Eluate blank. IS indicates insufficient sample was available to conduct tests for these treatments. pH, ammonia and sulfide were measured in 100% sample.

Percent Normal Development	Elutriate Concentration Control	25%	50%	100%	Toxic Units	pH	Unionized Ammonia (mg/L)	Hydrogen Sulfide (mg/L)
Initial	81%	64	1	0	2.9	7.45	0.004	0.074
SWI	72			65		8.05	ND	0.023
Baseline	95	83	0	0	2.8	7.85	0.054	0.037
EDTA	65**	68	51*	0	1.5	7.94	0.017	
Aeration	84	80	0	0	2.7	8.11	0.025	
Filtration	95	82	0	0	2.8	7.92	0.015	
Column	84	91	0	0	2.7	7.95	0.012	
Eluate	89	85***	90***	88***		7.96	0.002	
pH 7.9	83	IS	0	IS		7.92	IS	
pH 8.1	76**	IS	0	IS		8.15	IS	
pH 8.4	79	IS	0	IS		8.43	IS	
PBO	85	83	0	0	2.7	7.77	0.007	

Ceriodaphnia dubia. Forty-eight-hour acute toxicity tests with *Ceriodaphnia* were conducted in August 1997 using neonates that were less than 24 hours old (US EPA, 1993). Elutriate samples were prepared as described above, but used moderately hard dilution water rather than 28‰ seawater (US EPA, 1993).

Results

Initial Elutriate Tests and SWI

All three concentrations of Grizzly Bay elutriate were significantly toxic (Table 2). Sixty-five percent of exposed larvae developed normally in the SWI test, which was not significantly different from the response in the SWI control (72%). Sacramento River elutriate was significantly toxic at 50 and 100% concentrations (Table 3). The SWI test produced 15% normal larvae, which was significantly different from the SWI control. Sediment elutriates from the San Joaquin River were significantly toxic at all concentrations (Table 4). The SWI exposure resulted in 46% normal larvae, which was significantly different from the control response.

pH Rangefinder. In studies of pH-adjusted clean Granite Canyon seawater, sample pH beyond the range of 7.75 to 8.75 resulted in significantly decreased rates of normal bivalve larval development (Figure 24). Based on previous experience with larval TIEs, we chose more conservative limits for actual TIE manipulations (7.9–8.4).

Sediment and Elutriate Chemistry

As of this writing, sediment chemistry had not yet been analyzed for the 1996 and 1997 samples, but a survey of chemistry from 1993–1995 indicates that there were exceedances of Effects Range Low (ERL) values for As, Cr, Cu and Hg, but no exceedances of Effects Range Median (ERM) values for the River sites, with the exception of nickel. Nickel concentrations exceeded the ERM on every sampling occasion. It should be noted that there is low confidence in the current nickel guideline (Long *et al.* 1995). There were no exceedances of either ERL or ERM values for PAHs and PCBs, but p,p'-DDE and dieldrin exceeded ERL values on several occasions. Chlorpyrifos and diazinon were below detection limits in bulk sediment at all three sites. Although analysis of selected

Table 3. Results of TIE Initial Test, SWI, and definitive TIE manipulations for Sacramento River (BG20) sample August 1996. * indicates significantly reduced toxicity compared to Baseline treatment (ANOVA, p = 0.05). ** indicates significantly increased toxicity compared to Baseline treatment. *** indicates no significant difference from Eluate blank. pH, ammonia and sulfide were measured in 100% sample.

Percent Normal Development	Elutriate Concentration Control	25%	50%	100%	Toxic Units	pH	Unionized Ammonia (mg/L)	Hydrogen Sulfide (mg/L)
Initial	81%	78	42	0	1.7	7.5	0.001	0.065
SWI	72			15		8.0	ND	0.019
Baseline	94	83	34	0	2.3	7.79	0.001	0.036
EDTA	75**	71	27	0	2.3	7.8	0.001	
Aeration	82	80	38	0	2.1	8.05	0.002	
Filtration	99	81	28	0	2.5	7.83	0.002	
Column	88	92	48*	0	1.9	7.83	0.002	
Eluate	88	87***	87***	91***		7.95	0.002	
pH 7.9	78	67**	39	0	2	7.92	0.003	
pH 8.1	67**	77	32	0	2.1	8.16	0.004	
pH 8.4	69**	57**	32	0	2.1	8.39	0.006	
PBO	87	81	34	0	2.2	7.95	0.002	

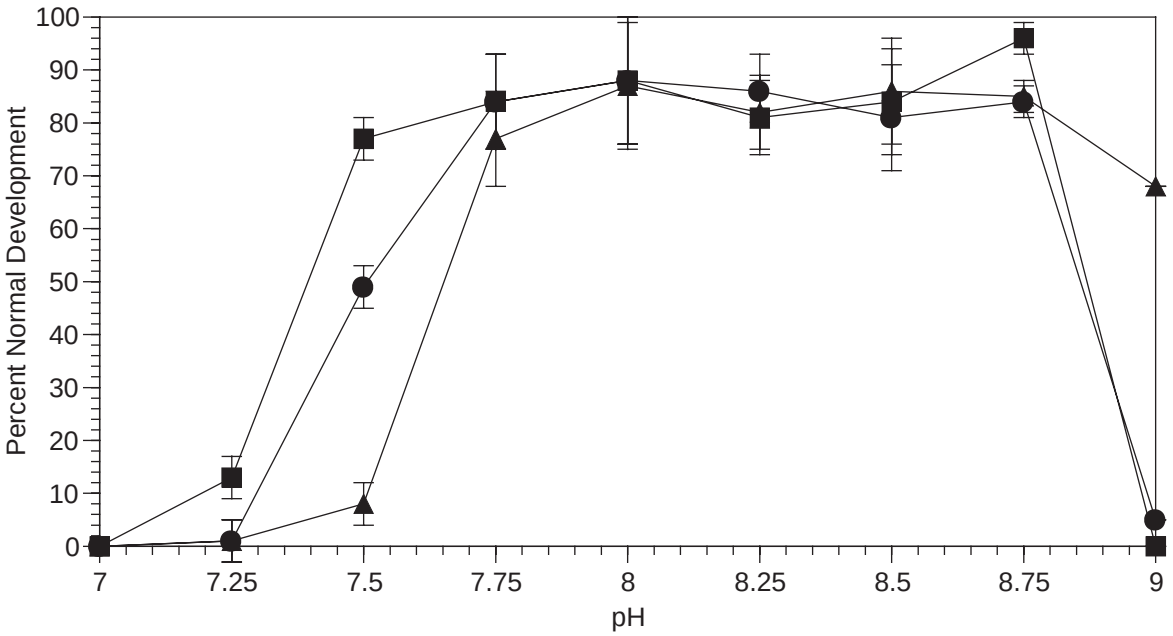

Figure 24. pH tolerance limits for *Mytilus* spp. Error bars indicate one SD.

Table 4. Results of TIE Initial Test, SWI, and definitive TIE manipulations for San Joaquin River (BG30) sampled August 1996. * indicates significantly reduced toxicity compared to Baseline treatment (ANOVA, p = 0.05). ** indicates significantly increased toxicity compared to Baseline treatment. ** indicates no significant difference from Eluate blank. pH, ammonia and sulfide were measured in 100% sample.

Percent Normal Development	Elutriate Concentration				Toxic Units	pH	Unionized Ammonia (mg/L)	Hydrogen Sulfide (mg/L)
	Control	25%	50%	100%				
Initial	81%	0	0	0	8	6.48	0.002	0.274
SWI	82			46		8.00	0.002	0.023
Baseline	92	48	3	0	5.6	6.76	0.004	0.201
EDTA	75	65	0	0	6.1	6.74	0.004	
Aeration	96	63	3	0	7.3	6.62	0.006	
Filtration	88	1**	0	0	19.8	6.62	0.003	
Column	94	68	0	0	6.8	6.68	0.004	
Eluate	94	97***	88***	92***		7.95	0.002	
pH 7.9	85	15**	0	0	16.5	7.88	0.006	
pH 8.1	81	26**	0	0	13.6	8.1	0.012	
pH 8.4	83	26**	0	0	13.7	8.44	0.012	
PBO	86	46	0	0	9.1	6.58	0.002	

Table 5. Results of metals analysis for filtered and unfiltered elutriate samples and control water. [a]Martin *et al.,* 1981, [b]MPSL unpublished data.

Station Name	Elutriate Matrix	Ag µg/L	Cd µg/L	Cu µg/L	Zn µg/L
Grizzly Bay (BF20)	Filtered	0.0015	0.385	0.377	4.900
	Unfiltered	0.0131	0.398	2.520	6.350
Sacramento River (BG20)	Filtered	0.0030	1.59	0.889	5.510
	Unfiltered	0.0052	1.52	2.100	7.210
San Joaquin River (BG30)	Filtered	0.0026	0.172	0.170	3.930
	Unfiltered	0.0030	0.135	0.390	2.850
Granite Canyon Water	Filtered	0.0029	0.067	0.042	2.030
	Unfiltered	0.0009	0.188	0.133	0.716
Mytilus EC_{50}		14[a]	3530 [b]	5.8 [a]	175 [a]

metals in sample elutriates showed concentrations well below the effect limits for Ag, Cd, and Zn, the Cu concentration approached the EC_{50} value of 5.8 (Table 5, Martin *et al.,* 1981). Pesticides, PCBs, and PAHs in the elutriates were below known effects thresholds for bivalves, but total chlordane in the elutriate did exceed the ERL at Grizzly Bay (Table 6).

Grizzly Bay (BF20) TIE

Addition of EDTA significantly reduced toxicity of the 50% dilution of this elutriate sample (Table 2). This treatment was significantly less toxic than the Baseline treatment. The EDTA treatment produced 1.5 toxic units compared to 2.8 in the Baseline test and 2.9 in the Initial test. These results suggest that divalent cations contributed to toxicity in this sample. It should be noted that the EDTA control was significantly more toxic than the Baseline control. Though this suggests EDTA toxicity in the full strength sample, in the 50% sample EDTA probably was not toxic due to dilution.

The elute treatments were not significantly more toxic than the elute blank. This result corroborates the result from the C18 Column treatment: non-polar organic chemicals were probably not a cause of toxicity, since their potential removal from the sample by the column did not affect sample toxicity, and no toxic compounds could be eluted back off the column. Unionized ammonia was below effects threshold, and pH levels were within the acceptable range. However, baseline concentrations of hydrogen sulfide were above the effects limits for *Mytilus* (0.0053 mg/L, Knezovich *et al.,* 1997). There was no mitigation of toxicity in the aeration or graduated pH manipulations, which would be expected if sulfide were the sole cause of toxicity. Similar concentrations of sulfide were found in the SWI exposure, which produced results that were not significantly different from the controls.

Sacramento River (BG20) TIE

Toxicity was significantly mitigated in the 50% concentration by the C18 Column treatment (Table 3). Although the column removed some toxicity, no compounds were eluted off the column in toxic concentrations. Toxicity did not occur in the eluate treatment probably because the eluate concentrations were tested at 25% of the original elutriate strength in order to minimize toxicity associated with the methanol used to elute the column. The Column treatment produced 1.9 toxic units. This was lower than the Baseline treatment (2.3), but higher than the Initial test (1.7). Reduced toxicity in the Column treatment suggests that non-polar organic compounds might be the cause of some of the observed toxicity in the Baseline test.

Table 6. Results of selected pesticide, PCB, and PAH analyses for elutriate samples and control water.

Station Name	Total PAH ng/L	Total PCB ng/L	Total DDT ng/L	Total Chlordane ng/L
Grizzly Bay (BF20)	79.6	4.09	1.36	0.78
Sacramento River (BG20)	5.5	3.29	0.80	0.40
San Joaquin River (BG30)	4.1	10.60	0.46	0.40
Granite Canyon Water	2.3	1.17	0.92	0
NOAA ERL	4022.0	22.70	1.58	0.50

Increased toxicity was noted in the 25% concentration of the pH 7.9 and pH 8.4 treatments. The cause for this is unknown.

Unionized ammonia and pH were within acceptable limits, but hydrogen sulfide exceeded the effects limit for *Mytilus*. A similar concentration of hydrogen sulfide was found in the SWI exposure, which had significant toxicity. Toxicity was not significantly reduced in the aeration or graduated pH treatments, which indicates that hydrogen sulfide was not the principal cause of toxicity.

San Joaquin River (BG30) TIE

Toxicity was not significantly mitigated in any of the TIE manipulations performed on this sample (Table 4). The Baseline hydrogen sulfide concentration (0.201 mg/L) was above the effects limit, and may have played a role in the toxicity of the elutriate tests. Again, lack of mitigation of toxicity in the aeration or graduated pH manipulations suggests other causes of toxicity. The ambient pH of the elutriate sample was well below the acceptable limit for *Mytilus*. Graduated pH treatments did not mitigate toxicity, and toxicity also occurred in the SWI exposure where pH was within acceptable limits. It appears that other factors must be involved. There was slight but statistically insignificant mitigation of toxicity in the EDTA, Aeration and C18 Column treatments, perhaps indicating a combination of toxic contaminants.

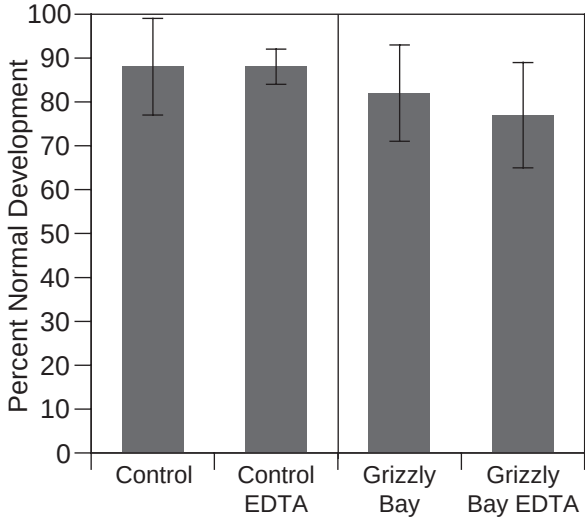

Figure 25. Results of EDTA treatments on overlying water of Sediment-Water Interface exposures from Grizzly Bay.

Sediment-Water Interface TIE Manipulations

SWI exposures conducted in February 1997 produced no toxic response, therefore no mitigation is noted in the EDTA samples (Figure 25). This test demonstrated that the concentration of EDTA used in the overlying water would not be toxic in this exposure system.

SWI exposures conducted in August 1997 produced significantly toxic responses in intact cores from Sacramento River and San Joaquin River (Figure 26). Less EDTA was added to overlying water in this test, and no mitigation of toxicity was seen, therefore only the SWI data are presented. We prepared an additional SWI exposure with homogenate of the same sediment sample, creating a SWI exposure with homogenized instead of intact cores. All three sites were significantly toxic to bivalve larvae,

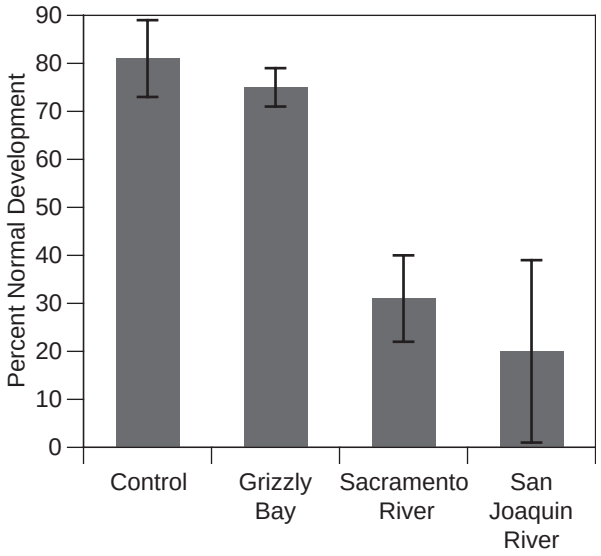

Figure 26. Results of Sediment-Water Interface exposures conducted on intact cores.

with Grizzly Bay the most toxic at 19% normal development (Figure 27). This is in contrast to the exposure with intact cores, where Grizzly Bay was not significantly toxic.

The addition of EDTA mitigated toxicity in homogenized cores from Grizzly Bay and San Joaquin River (Figure 25). Toxicity in the Grizzly Bay and San Joaquin River exposures was reduced by 57% and 32% respectively. Overlying water metals concentrations were not measured in either the intact or homogenized cores, but mitigation with EDTA suggests divalent cations were associated with sample toxicity.

Intact core samples have generally been more toxic than homogenized samples in previous SWI tests (Anderson *et al.*, 1995). In this study, however, the Grizzly Bay homogenate was more toxic than its intact core counterpart (Figure 25 versus Table 2).

Ceriodaphnia Elutriate Exposure

There were no mortalities in any of the freshwater elutriates tested. Survival in the control treatment was also 100%. A concurrent *Ceriodaphnia* reference toxicant test with copper produced an acceptable dose response curve, with an LC_{50} of 14.87 µg/L, indicating normal sensitivity of the test organisms.

Discussion

Elutriates (seawater extracts) of all samples were significantly toxic. Corresponding SWI exposures were significantly toxic in two of the three samples (Sacramento River and San Joaquin River). In Toxicity Identification Evaluations (TIEs), EDTA chelation treatments significantly reduced toxicity in the Grizzly Bay sample, indicating divalent cations such as some trace metals may have been responsible. Carbon column filtration significantly reduced toxicity in the Sacramento River sample, indicating nonpolar organics may have contributed to toxicity. Although some toxicity was mitigated by the C18 column in the Sacramento River TIE (Table 3), past bulk phase chemistry data for RMP Sacramento River sediment samples show low levels of measured organic contaminants. The pH value of San Joaquin River elutriate samples were low enough to cause the observed toxicity at this site, but pH manipulations did not mitigate toxicity, and toxicity was observed in the corresponding SWI test, where pH was within acceptable limits. Follow-up TIE manipulations utilizing EDTA in the overlying water of SWI exposures suggest divalent cations were responsible for toxicity in Grizzly Bay SWI samples and, to a lesser extent, in San Joaquin River SWI samples.

Divalent cations appear to have contributed to the toxicity of some River samples at different times during the past year. Although none of the metals measured in this elutriate study had concentrations above effects limits, copper did approach the *Mytilus* EC_{50} for this metal in Grizzly Bay elutriate (Table 5). Silver, cadmium, copper, and zinc were the only metals measured, and might have contributed to toxicity. Combinations of certain metals have been shown to be additive in their toxicity. Masnado *et al.* (1995) found that combinations of metals including cadmium, chromium, copper, nickel, and zinc with concentrations below NPDES water quality permit limits were toxic to *Ceriodaphnia dubia*. If metals additivity was a factor, Grizzly Bay exhibited the highest overall metals concentrations measured for the August 1996 TIE manipulations.

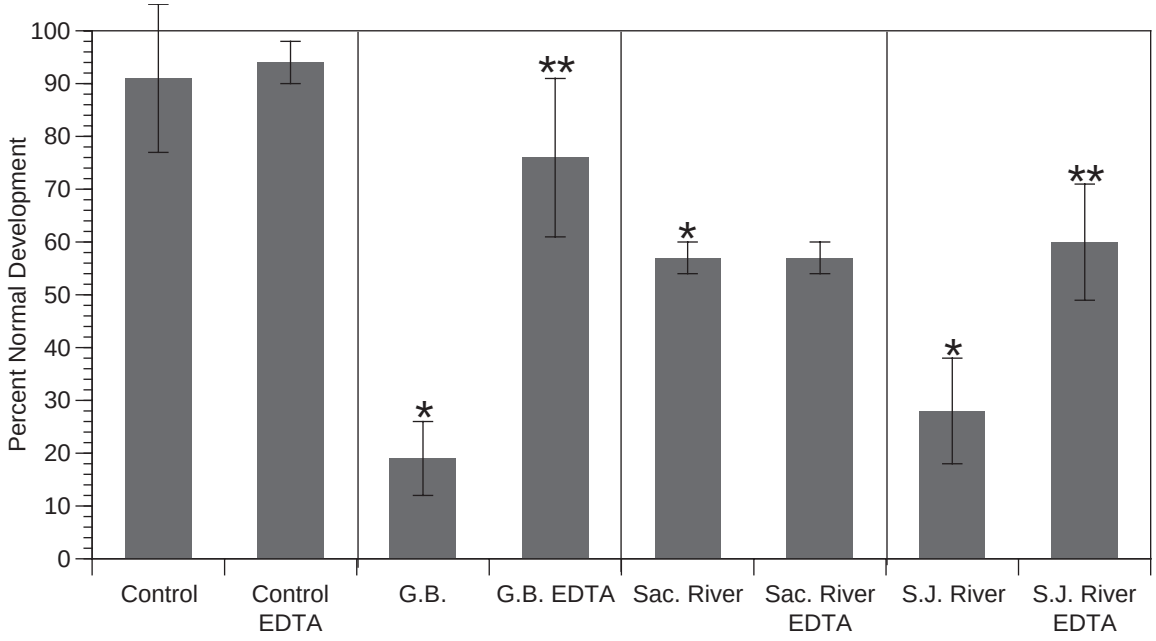

Figure 27. Results of EDTA treatments on overlying water from homogenized Sediment-Water Interface tests. G.B. = Grizzly Bay, S.J. = San Joaquin. Error bars indicate one standard deviation. *indicates significant difference from control. ** indicates significant differenct from non-EDTA treatment.

Preliminary experiments with TIE manipulations of the overlying water in SWI exposures suggest divalent cations as a possible cause of toxicity in Grizzly Bay and San Joaquin River. Toxicity was significantly reduced in overlying water when treated with an adequate concentration of EDTA. These results agree with Phase I TIE results on Grizzly Bay elutriates, suggesting metals are a possible cause of toxicity at the site. Although the San Joaquin River elutriate TIE was inconclusive, toxicity in SWI exposures, and the removal of toxicity with EDTA, indicates metals toxicity. The low pH levels found in the tests with San Joaquin River, may have contributed to toxicity at that site because the toxicity of metals such as copper and lead tend to increase as pH decreases (Schubauer-Berigan *et al.,* 1993). Therefore, low pH, coupled with moderate concentrations of metals may have caused greater relative concentrations of bioavailable metal ions.

Elutriate exposures with *Ceriodaphnia* showed no mortalities. In-house (MPSL—Granite Canyon) reference toxicant testing with *Ceriodaphnia* has produced a mean 48 hour LC_{50} value of 22.2 µg/L Cu. This value is four times higher than the *Mytilus* EC_{50} of 5.8 µg/L (Martin *et al.,* 1981). Although *Ceriodaphnia* are known to be less sensitive than *Mytilus* larvae, they are one of the most sensitive freshwater species that can be tested using the elutriate matrix. Bivalve toxicity might be affected by elutriate preparation with seawater or there might be some natural factor in freshwater sediments that is toxic to marine bivalves. Potential metals toxicity in these samples might be occurring at levels below the sensitivity of *Ceriodaphnia* acute tests. Chronic tests with *Ceriodaphnia* might provide better resolution of metals toxicity.

Conclusions

Results of TIE manipulations, SWI exposures, and SWI/EDTA exposures suggest some possible causes of toxicity in Grizzly Bay, Sacramento River, and San Joaquin River samples. Mitigation of toxicity in Grizzly Bay samples by EDTA manipulations in the TIE and in the SWI/EDTA exposure indicate diva-

lent cations are the likely cause of toxicity. SWI/EDTA exposures for the San Joaquin River also suggest divalent cations. Although toxicity occurred in Sacramento River elutriate and SWI exposures, TIE results were inconclusive. *Ceriodaphnia* test results indicate either that bivalves are more sensitive to toxicants in these samples or that elutriate preparation with seawater is changing the bioavailability of contaminants. Further work is needed to isolate the exact causes of toxicity at the River sites. We suggest an extension of Phase I TIE manipulations, including use of a cation exchange column that will enable us to add back metals after their removal from the sample. We would also like to propose experiments on metals additivity and the implementation of Phase II TIE manipulations. In the case of the Grizzly Bay and San Joaquin River stations, it would be instructive to measure divalent ion concentrations of specific metals and compare these concentrations to effects concentrations measured in laboratory dose-response experiments.

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Progress Report on the Benthic Pilot Study

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Introduction

The RMP Benthic Pilot Study was started in 1994 because it was important for the Program to include some measurement of the condition of resident biota in order to evaluate whether or not ecological effects from contamination actually occur in the Estuary. Benthic macrofauna are monitored in all major national and regional monitoring programs in the United States (EMAP, NOAA Status and Trends, Chesapeake Bay, and Puget Sound). Benthos are monitored because they inhabit sediments where they may be exposed to elevated contaminant concentrations. Since they are generally not very motile, benthic organisms can be reliable indicators of sediment conditions within a local area. Additionally, benthos may accumulate and transfer contaminants from sediments into the estuarine food web as benthos provide food for bottom feeding fish and birds. They also facilitate other important sediment functions, such as nutrient and carbon flux, by their burrowing and feeding activities.

The objective of this Pilot Study is to evaluate the use of benthic information for determining environmental conditions in the Estuary. While the focus for the RMP is contaminant effects on the benthos, there is also a need to understand natural variations of the benthos in space and time as influenced by freshwater flows, salinity, sediment-type, and invasions of other species.

This report summarizes progress made on the Benthic Pilot Study in 1996 which has focused on refining descriptions of benthic assemblages in the Estuary and on the determination of benthic "reference" sites.

Methods

The Benthic Pilot Study is a collaborative project. It includes samples collected at RMP stations, the Regional Board's proposed reference sites, Bay Area Discharger's Association's (BADA) Local Effects Monitoring (LEM) sites near some of the major Publicly Owned Treatment Works (POTW) outfalls in the Estuary, and the California Department of Water Resources' (DWR) compliance monitoring stations in the Northern Estuary and Delta (Figure 28). All samples have been combined to provide an Estuary-wide evaluation of benthic assemblages over the past three years, which were rather different water-year types.

Sampling and analysis have been described in the *1994* and *1995 Annual Reports*. Several modifications or additions were made in 1996. DWR added several new sampling sites in the Delta, and dropped several others (Figure 28). Single samples were collected at four RMP Wetland Pilot Study sites in China Camp in March 1996. Overall, 424 benthic samples collected from 44 sites were included in the analysis.

In attempting to relate benthic species composition and abundances to sediment contamination, one of the biggest problems encountered was that sediment chemistry was not sampled at all sites. In particular, DWR does not sample sediment contaminants. Fortunately, three of their sites are within a mile and are of similar sediment type as RMP sites where sediment contamination is monitored. Therefore, at Sacramento River, Grizzly Bay, and Pinole Point, RMP sediment data is used along with DWR benthos sampled in the same month.

Ordination and classification analyses were used to group sites based on similarities in

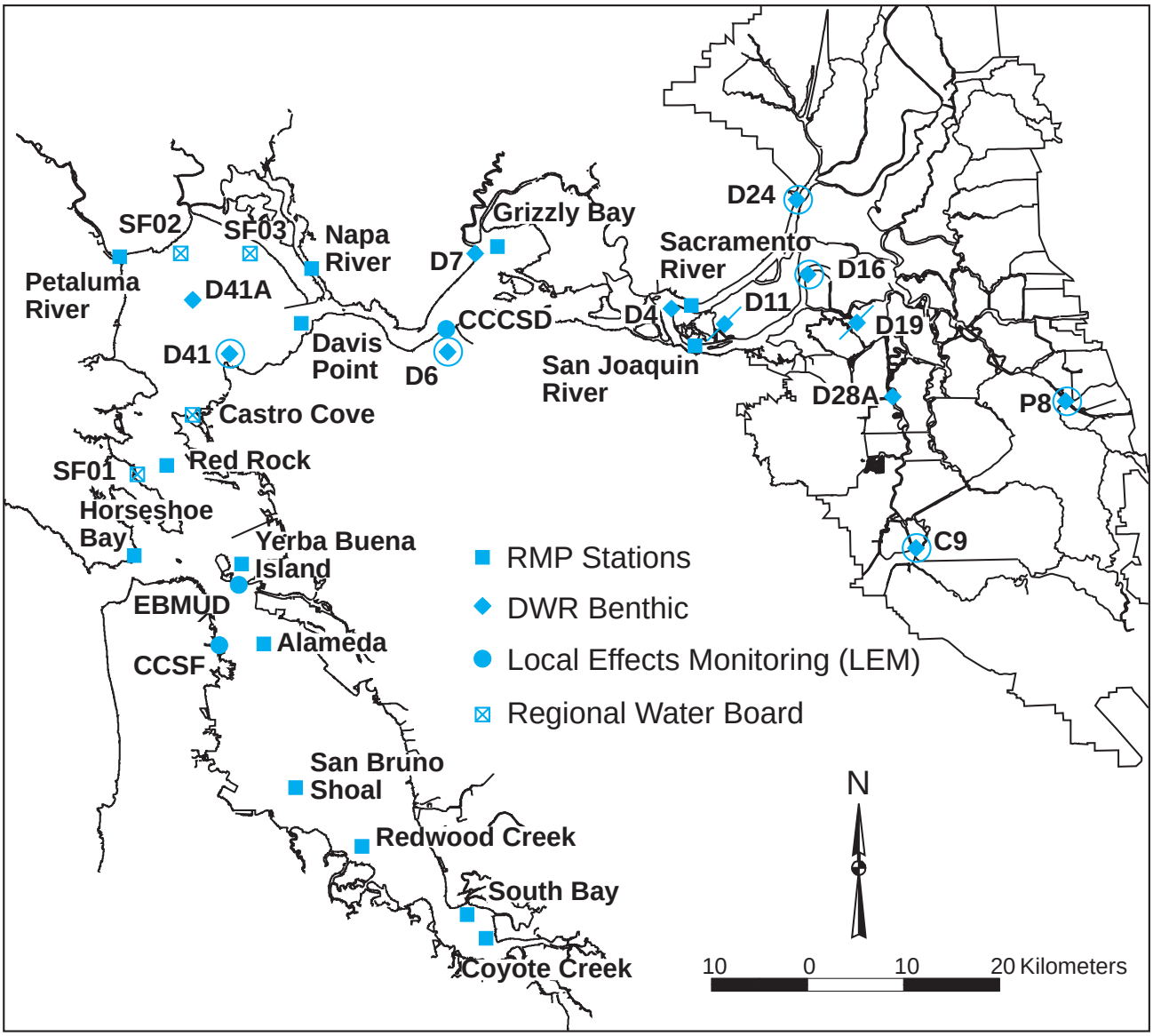

Figure 28. Benthic sediment sampling sites. Circled DWR sites were added, slashed DWR sites were dropped in 1996. For the location of the China Camp wetland site, see the Wetland Pilot Study article in *Chapter Six: Pilot and Special Studies.*

species composition and abundances at each site (Smith *et al.* 1988).

Results

Defining a "reference", "normal", or unimpacted benthic assemblage requires a clear understanding of the biological and physical characteristics of the various benthic assemblages in the Estuary, and their natural variation. An assemblage is a term used to describe the association of benthic species that inhabit a location; assemblages may be thought of as communities. The geographic scale of an assemblage may vary depending on responses of the organisms to physical factors such as salinity or sediment type (e.g., sand, silt, etc.), and biological factors such as competition or predation. However, it is important to recognize that an assemblage is a manifestation of responses by individual organisms to physical gradients and biological interactions.

Benthic Assemblages of San Francisco Estuary

Three major benthic assemblages, each with sub-assemblages, have been identified through ordination and classification analyses (Figure 29). The sites that were included in each assemblage are shown in Table 7. These assemblages may be slightly different from those described in previous Annual Reports as each year the analyses includes another year of data. The most common and abundant species collected in each assemblage are listed on Table 8.

All of the DWR sites from the Delta and Rivers, where water is fresh or brackish, were grouped together because they had similar species composition and abundances. Sites with muddy or sandy sediment types were each inhabited by similar species, but were characterized by shifts in numerical dominance (Table 8). Some of the sites sampled at different times were variously classified in different sub-assemblages (Table 7), and sites in Suisun Bay appear to represent the transition from brackish water to estuarine conditions and included species characteristic of both the Fresh / Brackish, and Estuarine assemblages. Those results

Table 7. Benthic monitoring sites included in each benthic assemblage.

Assemblage sub assemblage	Sites Name (Code)	
Fresh and Brackish (oligohaline)		
Muddy sediments	Franks Tract (D19)	Buckley Cove (P8)
	Old River (D28A)	Clifton Court (C8)
	Sherman Is. (D11)	Rio Vista (D24)
	Twitchell Is. (D16)	Collinsville (D4)
Sandy sediments	Rio Vista (D24)	Twitchell Is. (D16)
	Collinsville (D4)	
Estuarine transition	Grizzly Bay (D7)	Pacheco Creek (D6)
	CCCSD	Collinsville (D4)
Estuarine (euryhaline)		
Muddy sediments	Pacheco Creek (D6)	Davis Point (BD41)
	Petaluma R. (BD15)	Pinole Point (D41)
	Petaluma R. (D41A)	Grizzly Bay (D7)
	South Bay (BA21)	SFO3
	SFO2	CCCSD
Contaminated seds	Castro Cove	China Camp
Central Bay (stenohaline)		
Muddy sediments	SFO1	Horseshoe Bay (BC21)
	Alameda (BB70)	Yerba Buena Is. (BC11)
	EBMUD	San Bruno Sh. (BB15)
	Redwood Ck. (BA41)	CCSF
Sandy sediments	Red Rock (BC60)	

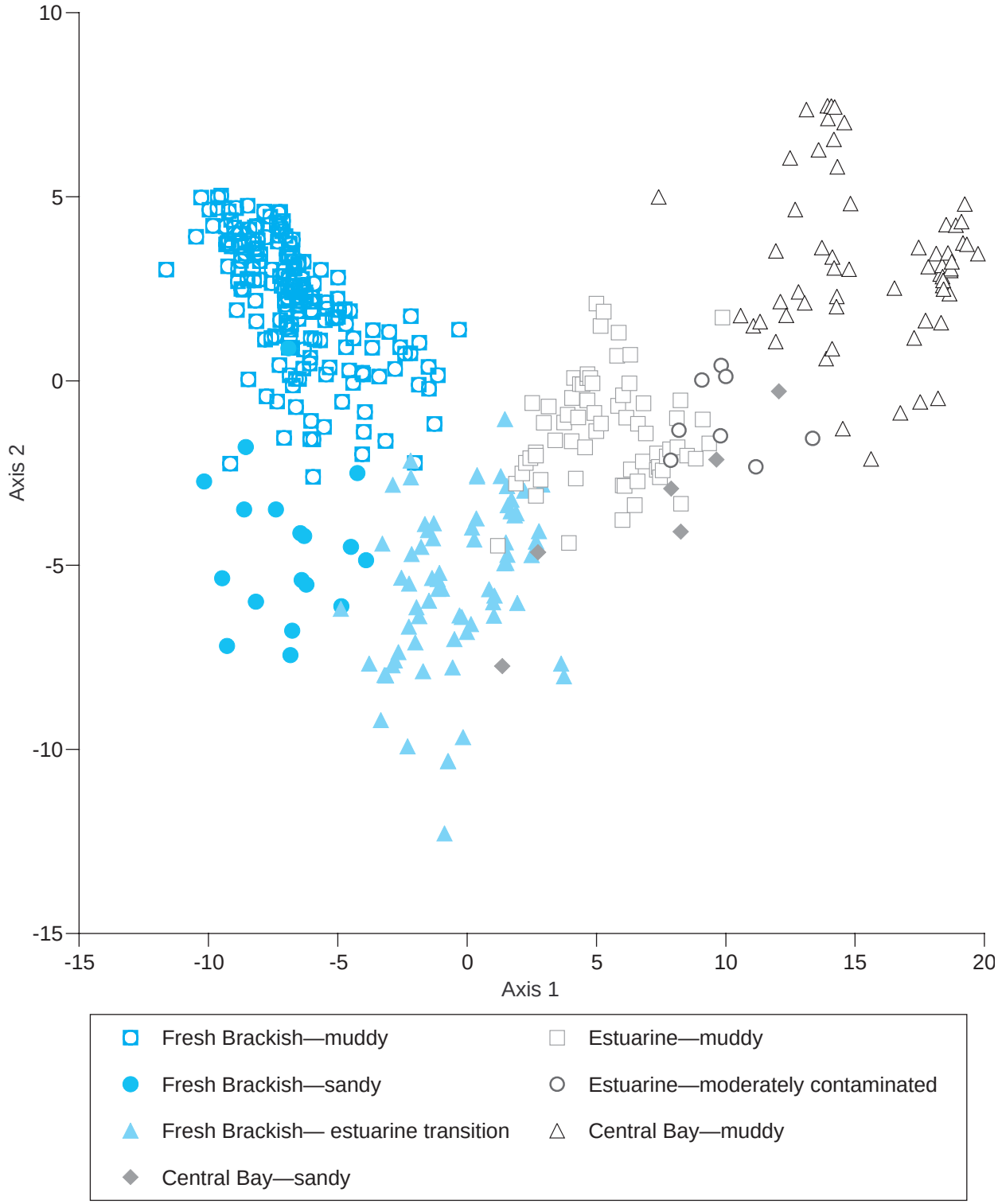

Figure 29. Benthic sampling sites in the San Francisco Bay Estuary plotted on the first two principal coordinate axes.

Table 8. Most common and abundant species in each benthic assemblage.

	Num. of Occurrences	Average Abundance (per grab)
Fresh Brackish—muddy sediments (n = 192)		
Manayunkia speciosa (P)	103	117
Corophium stimpsoni (A)	162	56
Corbicula fluminea (B)	191	49
Limnodrilus hoffmeisteri (O)	180	36
Gammarus daiberi (A)	172	36
Varichaetadrilus angustipenis (O)	188	29
Corophium spinicorne (A)	120	19
Cyprideis sp. A (C)	27	15
Aulodrilus limnobius (O)	97	13
Dorylaimus sp. A (N)	106	13
Fresh Brackish—sandy sediments (n = 19)		
Corbicula fluminea (B)	19	18
Paratendipes sp. A (C)	9	5
Gammarus daiberi (A)	15	3
Corophium stimpsoni (A)	12	1
Marenzelleria viridis (P)	11	1
Chaetogaster limnaei (O)	2	1
Varichaetadrilus angustipenis (O)	12	1
Corophium spinicorne (A)	3	0.4
Potamocorbula amurensis (B)	5	0.2
Limnodrilus hoffmeisteri (O)	5	0.1
Fresh Brackish—estuarine transition (n = 72)		
Potamocorbula amurensis (B)	67	28
Corophium alienense (A)	33	26
Marenzelleria viridis (P)	57	19
Corophium stimpsoni (A)	19	3
Gammarus daiberi (A)	32	3
Nippoleucon hinumensis (Ar)	26	2
Tubificoides heterochaetus (O)	27	2
Limnodrilus hoffmeisteri (O)	10	1
Corophium heteroceratum (A)	7	1
Tubificoides fraseri (O)	8	0.4
Estuarine—muddy sediments (n = 68)		
Potamocorbula amurensis (B)	67	162
Ampelisca abdita (A)	52	135
Nippoleucon hinumensis (Ar)	49	21
Corophium heteroceratum (A)	42	9
Corophium alienense (A)	9	4
Grandidierella japonica (A)	29	4
Balanus improvisus (Ar)	28	3
Tubificidae (O)	13	2
Neanthes succinea (P)	54	2
Streblospio benedicti (P)	37	2
Estuarine—moderately contaminated (n = 8)		
Tubificidae (O)	4	404
Nippoleucon hinumensis (Ar)	8	144
Streblospio benedicti (P)	8	116
Corophium spp. (A)	5	92
Gemma gemma (B)	4	70
Ampelisca abdita (A)	4	54
Grandidierella japonica (A)	6	46
Nematoda (N)	4	37
Eusarsiella zostericola (C)	4	36
Pseudopolydora kempi (P)	4	35
Central Bay—muddy sediments (n = 60)		
Corophium acherusicum (A)	34	745
Ampelisca abdita (A)	56	697
Corophium heteroceratum (A)	55	133
Euchone limnicola (P)	26	57
Corophium spp. (A)	23	52
Leptochelia dubia (C)	37	50
Corophium insidiosum (A)	14	50
Photis spp. (A)	28	42
Mediomastus spp. (P)	52	36
Exogone lourei (P)	41	26
Central Bay—sandy sediments (n = 6)		
Heteropodarke heteromorpha (P)	4	18
Nematoda (N)	3	8
Grandifoxus grandis (A)	2	3
Hesionura coineaui difficilis (Ar)	3	2
Glycera tenuis (P)	4	2
Tellina bodegensis (B)	2	1
Tubificidae (O)	3	1
Glycera americana (P)	2	1
Glycera spp. (P)	1	1
Mediomastus spp. (P)	1	0.3

Oligochaeta = (O), Arthropoda = (Ar), Polychaeta = (P), Amphipoda = (A), Bivalvia = (B), Nematoda = (N), Crustacea = (C)

reflect responses of the organisms to seasonal changes in flow, salinity, or sediment type. Thus, the Fresh / Brackish Assemblages are dynamic; a site may alternately be inhabited by different species with varying abundances in response to changes in the physical environment.

Sites from the Northern Estuary and South Bay were grouped together in an Estuarine Assemblage dominated by the clam *Potamocorbula amurensis*. In contrast to other major assemblages, estuarine assemblage sites with muddy and sandy sediments were grouped together as they apparently had similar species and abundances. That assemblage included the RMP South Bay site, approximately equidistant to the Golden Gate as the Northern Estuary sites, thus similar salinities. Sites in Castro Cove and in the wetland channels at China Camp formed a related but distinct assemblage which, as will be shown, appears to be moderately impacted by contamination.

The RMP and LEM Central Bay sites were grouped together. Sub-assemblages with muddy or sandy sediments (only one site) were identified. The muddy sediment assemblage included the sites near the East Bay Municipal Utility District (EBMUD) and City and County of San Francisco (CCSF) outfalls which apparently were similar to the other Central Bay sites. The Central Bay assemblages were dominated by several species of amphipods (Table 8).

Factors that Influence Assemblages

While it appears obvious that the assemblages (defined above) obtained were related to the estuarine salinity gradient, no salinity data was included in the ordination and classification analyses. Those analyses only included species and abundances at each site. In order to help understand which physical factors may influence the distribution of the benthos, ordination and physical measurements were analyzed together.

The distribution of the benthic sites along the first two ordination axes is shown on Figure 29. Each point is a site, and sites in each benthic assemblage are identified by a different symbol. The sites are arranged along two multivariate dimensions (axes) that optimize the variation in species composition and abundances among the sites. It is assumed that the axes represent environmental gradients that influence the variation among the sites. Since the Delta sites are on the left end, and the Central Bay sites on the right end of Axis 1, a salinity gradient is suggested. Correlation analysis substantiated that observation.

Salinity was the abiotic variable most highly correlated with the Axis 1 ordination scores (Table 9). However, several other variables were also significantly correlated with Axis 1 scores, indicating that salinity was not the only influence along Axis 1, or that other variables covaried with salinity. Total suspended solids (TSS) was also significantly correlated with Axis 1, but the number of sites where TSS was measured was restricted. There were few strong correlations with Axis 2 scores. Besides TSS again, Total organic carbon (TOC) was most highly correlated with Axis 2. Axis 3 (not shown) was associated with sediment type. Percent sand, fines, and depth were each significantly correlated with Axis 3 scores. Delta outflow, near-bottom water temperature and dissolved oxygen (DO) were not significantly correlated with any of the axes.

Table 9. Rank correlation coefficients for several abiotic variables and ordination axis scores. * significant at α=0.05; ** significant at α=0.01.

Abiotic Variable	n	Axis 1	Axis 2	Axis 3
Salinity	336	.808**	-.123*	-.072
Temperature	306	-.113*	.061	.074
Depth	284	.176**	.164	-.544**
% Sand	422	-.062	-.121*	-.558**
% Fines	422	.047	.122*	.555**
% Gravel	422	.306**	.002	-.151**
TOC	419	-.496**	.346**	.390**
TSS	52	-.572**	-.538**	.550**
mERMq	113	.431**	.297*	.266**
Dflow	394	-.009	-.031	-.081
O_2	58	.112	-.126	-.145

Table 10. Mean (range) of key physical variables for the benthic assemblages in San Francisco Estuary.

Assemblage	Salinity	Silt-Clay (%)	TOC (%)
Fresh and Brackish (oligohaline)			
Muddy sediments	0.68 (0–5.1)	71.8 (1–100)	3.86 (.3–21.7)
Sandy sediments	0.08 (0–.1)	15.3 (0–100)	.74 (.20–2.5)
Estuarine transition	4.9 (0–15.9)	50.9 (0–100)	2.05 (.10–3.9)
Estuarine (euryhaline)			
Muddy sediment	16.1 (.1–30.7)	88.2 (13–100)	2.63 (.10–5.1)
Contaminated	22.8 (22–24)	91.8 (67.2–99)	2.0 (1.1–3.3)
Central Bay (stenohaline)			
Muddy sediments	27.5 (16.3–33.3)	73.9 (30–97)	1.00 (.33–2.22)
Sandy sediments	26.6 (15.6–31.9)	4.7 (2–7)	.40 (<.01–.96)

Based on the above analysis, the assemblages may be defined by the ranges of their physical variables. Averages and ranges of salinity, sediment type, and TOC for each benthic assemblage is shown on Table 10. The ranges of salinity for the three major assemblages are very near those reported for other estuaries (Boesch, 1977).

Defining "Reference" Benthic Assemblages

How do we know if the benthic assemblages that have been defined are impacted or unimpacted by sediment contamination? From RMP data on sediment contamination and toxicity we know that sediments at some sites may be moderately contaminated and that toxicity occurs frequently. Some of the benthic assemblages included sites located near outfalls or other sources of contamination. However, it should not be assumed that because sediments at a site are contaminated, or toxic in laboratory tests, that the benthos that inhabit the site are impacted by contaminants. Preliminary assessments of benthic condition should be made independent of knowledge about sediment contamination and toxicity and should rely solely on the benthic species that inhabit each site.

A working definition of a "normal" or unimpacted benthic assemblage was included in last years Annual Report article (Thompson *et al.*, 1996). Paraphrased, that definition stated that...*an unimpacted benthic assemblage is characterized by the presence of species known to be sensitive to contamination and the absence of species known to be tolerant of contamination.* However, a rigorous definition of how many unimpacted versus impacted indicator species there should be for a site to be considered unimpacted has not been developed. Therefore, such a designation will initially need to rely on professional judgment.

The first step of the process being developed is to use the scientific literature, or other reports, to guide the selection of benthic indicator species. Based on the authors conclusions about whether a species is an impacted or unimpacted indicator, 104 species, about a third of the benthic species identified in the Bay, were categorized (Table 11). Since the species listed on Table 11 do not include all species collected, any estimates of the numbers (or proportions) of impacted and unimpacted indicator species at a site will probably be underestimates. In addition to individual species, several higher taxa have been used as indicators. Overall, a dozen potential benthic

Table 11. List of potential benthic indicator species. Compiled from Dauer, 1993; BPTCP, 1996; Chapman *et al.*, 1987; Swartz *et al.*, 1994; Canfield *et al.*, 1994; 1996; Word, 1977; Thompson, 1982; Pearson and Rosenberg, 1978; Filice, 1954; Tetra Tech, 1990.

Estuarine Impacted Indicator Species		Fresh and Brackish Impacted Indicator Species	
Polychaeta	**Polychaeta (continued)**	**Oligochaeta**	**Chironomidae**
Armandia brevis	*Nephtys caecoides*	*Aulodrilus limnobius*	*Chironomus attenuatus*
Capitella "capitata"	*Notomastus tenuis*	*Dero digitata*	*Cryptochironomus* sp. A
Dorvilleidae	*Paraprionospio pinnata*	*Ilyodrilus templetoni*	*Cryptochironomus* sp. B
Dorvilleidae sp. A	*Polydora ligni*	*Limnodrilus claparedianus*	*Procladius* sp. A
Dorylaimus sp. A	*Prionospio cirrifera*	*Limnodrilus hoffmeisteri*	*Tanytarsus* sp. A
Eteone lighti	*Pseudopolydora kempi*	*Limnodrilus udekemianus*	
Eteone spilotus	*Streblospio benedicti*	*Ophidonais serpentina*	
Glycinde armigera	**Mollusca**	*Tubificoides brownae*	
Heteromastus filiformis	*Mysella tumida*	*Tubificoides fraseri*	
Neanthes succinea		*Tubificoides heterochaetus*	
		Tubificoides wasselli	

Estuarine Unimpacted Indicator Species		Fresh and Brackish Unimpacted Indicator Species
Phoronida	**Amphipoda (continued)**	**Amphipoda**
Phoronis spp.	*Corophium spinicorne*	*Corophium alienense*
Echinodermata	*Corophium* spp.	*Corophium insidiosum*
Amphiodia digitata	*Corophium stimpsoni*	*Corophium spinicorne*
Amphiodia spp.	*Dulichia monocantha*	*Corophium stimpsoni*
Amphipholis spp.	*Elasmopus antennatus*	*Crangonyx* sp. A
Amphiurid sp. A	*Ericthonius brasiliensis*	*Gammarus daiberi*
Ophiodromus pugettensis	*Ericthonius hunteri*	*Hyalella azteca*
Ophionereis eurybrachyplax	*Ericthonius* spp.	
Ophionereis eurybrachyplax	*Gammarus daiberi*	
Ophiuroidea	*Gnathopleustes pugettensis*	
Ophiuroidea C	*Grandifoxus grandis*	
Mollusca	*Hyalella azteca*	
Mactridae	*Ischyrocerus* sp.	
Tellina bodegensis	*Jassa marmorata*	
Tellina modesta	*Listriella goleta*	
Amphipoda	*Melita dentata*	
Ampelisca abdita	*Metacaprella anomala*	
Ampelisca macrocephala	*Microdeutopus schmitti*	
Ampelisca spp.	*Monoculodes spinipes*	
Ampithoe spp.	*Monoculodes spinipes*	
Ampithoe valida	*Orchestoidea columbiana*	
Aoridae	*Paradexamine* spp.	
Caprella californica	*Paraphoxus milleri*	
Caprella equilibra	*Photis brevipes*	
Caprella mendax	*Photis* spp.	
Caprella natalensis	*Podoceridae*	
Caprella spp.	*Podocerus spongicolus*	
Caprellidea	*Protomedeia penates*	
Corophium acherusicum	*Rhepoxynius tridentatus*	
Corophium alienense	*Stenothoe* spp.	
Corophium heteroceratum	*Synchelidium shoemakeri*	
Corophium insidiosum		
Corophium oaklandense		

indicators were identified for evaluation. Both counts and proportions of each indicator listed are being evaluated:

- impacted sediment indicator species
- impacted sediment indicator individuals
- nonimpacted sediment indicator species
- nonimpacted sediment indicator individuals
- amphipod species
- amhipods individuals
- echinoderm species
- echinoderm individuals
- oligochaete species
- oligochaete individuals
- chironomid species
- chironomid individuals

Amphipods have been shown to decrease in abundance in contaminated sediments (Sanders *et al*., 1980; Long and Chapman, 1985; Swartz *et al.,* 1994). Echinoderms are known to avoid contaminated sediments in marine and the more saline areas of the Estuary (Word *et al.,* 1977, Swartz *et al.,* 1986). Increased proportions of oligochaetes and chironomids have been used as indicators of impacts in fresh and brackish waters (Canfield *et al*., 1994; 1996).

Table 12. Significant relationships (p < .05) between potential benthic indicators and sediment contamination, as mERMq. All other potential indicators listed in the text were not significantly correlated with mERMq, or the correlation was of the wrong sign.

Site / Assemblages analyzed	R^2	p
All sites (with chemistry, n=113)		
No. of impacted indicator species	.045	.024
No. amphipod individ.	.071	.004
Proportion of amphipod individ.	.051	.017
No. oligochaete species	.048	.019
All fine sediment sites (<60% sand, with chemistry, n=85)		
No. unimpacted indicator species	.130	.0007
No. species	.144	.0003
No. amphipod species	.095	.004
No. echinoderm species	.132	.0006
No. echinoderm individ.	.085	.007

Numbers (or proportions) of species and individuals are also frequently used as indicators. Very low numbers of species are expected in severely impacted habitats. However, there is currently no way to decide *a priori* if a given species count or number of individuals is indicative of impacted or unimpacted sediments. Those indicators will be evaluated in a subsequent step of the process being developed (described below).

One criterion for good indicators of impacted or unimpacted sediments is that the indicator responds to gradients in contamination. To determine if each proposed indicator responds to contamination in the Estuary, correlations between each indicators and a general measure of contamination were examined. The mean ERM quotient, mERMq, is a cumulative quotient of ERM values for all contaminants measured at each site. It is described in more detail in *Relationships Between Sediment Toxicity and Contamination in San Francisco Bay* in this chapter).

Only a few of the potential indicators were significantly correlated with contamination (mERMq; Table 12), but the fit of the regressions (R^2) were uniformly low. In general, counts correlated better with mERMq than proportions. Numbers (or proportions) of impacted and unimpacted indicator species, amphipods, echinoderms, and oligochaetes were all significantly related to contamination when data from all sites, or only fine sediment sites were used. Those results confirm that those indicators may be used to evaluate sediment contamination in the Estuary. However, further testing should be done to see if different sets of indicators should be used for each assemblage, or for specific sediment, or salinity regimes.

Using several of the indicators that were shown to respond to contamination, an example of how the they may be used to screen each site is shown on Table 13. For each

Table 13. Average proportions of several potential benthic indicators at each site sampled, 1994–1996. + indicates presence, 0 indicates absence, - indicates not expected at that station, * indicates that the site may occasionally have sandy sediments.

			Average Proportions			
	Site	Impacted Sp.	UnImpacted Sp.	Amphip.	Echino.	Oligo.	Chiron.
RMP Sites							
	BA21	0.31	0.11	0.02	-	0.04	-
	BA41	0.09	0.15	0.33	+	0.04	-
	BB15	0.17	0.15	0.23	+	0.18	-
	BB70	0.07	0.19	0.87	+	0.00	-
	BC11	0.08	0.18	0.31	+	0.00	-
	BC21	0.12	0.11	0.27	+	0.02	-
	BC60*	0.11	0.15	0.12	+	0.04	-
	BD15	0.20	0.05	<.01	-	0.01	-
	BD41*	0.22	0.07	<.01	-	0.00	-
DWR Sites							
	D11	0.12	0.18	0.47	-	0.16	0
	D16*	0.08	0.32	0.36	-	0.10	0.10
	D19	0.17	0.13	0.20	-	0.23	<.01
	D24*	0.13	0.16	0.15	-	0.13	0.13
	D28AL*	0.15	0.14	0.18	-	0.25	<.01
	D28AR	0.20	0.10	0.06	-	0.18	<.01
	D41	0.31	0.18	0.10	-	0.03	0
	D41A	0.29	0.22	0.54	-	0.00	0
	D4C*	0.03	0.25	0.20	-	0.07	0
	D4L*	0.12	0.18	0.34	-	0.24	<.01
	D4R*	0.19	0.13	0.07	-	0.58	<.01
	D6*	0.04	0.32	0.07	-	0.00	0
	D7	0.20	0.30	0.40	-	0.05	0
	C9*	0.18	0.17	0.14	-	0.52	<.01
	P8*	0.22	0.12	0.14	-	0.54	0.03
Regional Board Reference Sites							
	SF01	0.10	0.19	0.42	0	0.00	-
	SF02	0.22	0.11	0.11	-	0.02	-
	SF03	0.36	0.09	0.03	-	0.02	-
Outfall Sites							
	CCCSD04*	0.24	0.21	0.15	-	0.05	0
	CCCSD05*	0.14	0.19	0.13	-	0.01	0
	CCCSD06*	0.04	0.18	0.18	-	0.01	0
	CCSF04	0.10	0.14	0.52	+	0.02	-
	CCSF05	0.10	0.20	0.59	+	0.02	-
	CCSF06	0.12	0.14	0.58	+	0.03	-
	EBMUD04	0.11	0.18	0.62	+	0.00	-
	EBMUD05	0.11	0.19	0.67	+	0.00	-
	EBMUD06	0.11	0.17	0.55	+	0.02	-
Castro Cove Sites							
	CC2	0.29	0.18	0.37	-	0.01	-
	CC4	0.21	0.14	0.21	-	0.01	-
	EVS4	0.27	0.27	0.54	-	0.00	-
	Pt. Pinole	0.33	0.24	0.36	-	0.02	-
China Camp Sites							
	WBCC2A	0.27	0.18	0.09	-	0.76	0
	WBCC2B	0.24	0.19	0.04	-	0.54	0
	WBCC3A	0.30	0.10	0.02	-	0.54	0
	WBCC3B	0.33	0.13	0.03	-	0.80	0

site, the question, "are the benthos more characteristic of impacted or unimpacted assemblages?", was considered.

At the South Bay site (BA21), an average of 31% of the species were indicators of impacted sediments and 11% were indicators of unimpacted sediments, 2% of the organisms were amphipods, and 4% were oligochaetes. Echinoderms and chironomids were not expected at that estuarine site where they would not naturally occur. Based on the comparative proportions of impacted versus unimpacted indicator species and reduced proportions of amphipods, that site would be considered to be moderately impacted. In contrast, the remaining RMP sites had low to moderate proportions of impacted compared to unimpacted indicator species, moderate proportions of amphipods, with echinoderms present, and would be considered to be characteristic of unimpacted sites.

Two DWR sites in San Pablo Bay (D41, D41A) had more that 25% impacted indicator species. Most DWR sites had more than 6% oligochaetes and some sites had more than 12% chironomids, reported to be indicators for impacted benthos in fresh water (Canfield *et al.,* 1994). Those proportions suggest slightly impacted benthos.

The Regional Board Reference Site near Tubbs Island in San Pablo Bay had elevated proportions of impacted indicators and low proportions of amphipods. Most of the outfall sites had low to moderate proportions of impact indicator species compared to unimpacted indicator species, and moderate to high proportions of amphipods. That the outfall sites were classified with other Central Bay sites also suggests no obvious differences in species composition and abundances.

Most of the Castro Cove and wetland sites had more than 25% impacted indicators compared to nonimpacted species, very low proportions of amphipods, and high proportions of oligochaetes suggesting impacts. Those sites were classified separately from the adjacent San Pablo Bay Estuarine sites, which also indicated that they had different benthos.

The initial screening demonstrated above was largely subjective and more objective methods based on numerical limits for each indicator are needed to rigorously define unimpacted benthos. The next step, which has not been conducted, would be to calculate statistical tolerance, or confidence limits for selected indicators, such as number of species, individuals, amphipods, etc. based on data from only the sites considered to be characteristic of unimpacted conditions. Additionally, it would be prudent that sites selected to represent unimpacted conditions be located away from sources of contamination. Thus, sites near outfalls or other sources of contamination would be eliminated from statistical calculations. A numerical definition of unimpacted, or reference benthic assemblage may then be used in statistical comparisons to sites suspected of being impacted.

Discussion

To date, the Benthic Pilot Study has provided information about the distribution, species composition and abundances, variation, and limits of physical factors on the benthos of the Estuary. That information may be used to rigorously define benthic assemblages in the Estuary. Continued sampling will refine that knowledge, especially for varying water years.

Firm conclusions about the condition of the benthos of the Estuary related to sediment contamination cannot be made at this time. The development of methods for screening and assessing contaminant impacts will continue. More references are being checked to expand the list of potential indicator species. Testing will be conducted to evaluate temporal differences in the potential benthic indicators rather than simply using averages, and calculation of statistical tolerance limits will be conducted.

Similar approaches to defining "reference" conditions have been used by BPTCP in describing reference envelopes for sediment toxicity (Taberski and Hunt, 1996), and sediment contamination (Regional Board, Draft Report). Additionally, several studies where a benthic index (e.g., EPA, 1990), or other benthic

assessment methods (e.g., Reynoldson *et al*., 1997) have been reported will be considered for use in the San Francisco Estuary.

Formal benthic assessments are not part of the RMP. However, the development of a scientific approach for evaluating benthic conditions is an good role for the RMP, especially since the RMP is not currently monitoring any other estuarine ecological component. Benthic assessments are being used in a variety of situations in the management of the Estuary including the clean-up of military bases and toxic hot spots, dredging assessments, and habitat restorations. Thus, the RMP Pilot Study may eventually provide a methodology for monitoring the general condition of the benthos that includes a definition of "reference" conditions that may also be used in formal regulatory benthic assessments.

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Population Dynamics of *Ampelisca abdita* in San Francisco Bay

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Introduction

The amphipod *Ampelisca abdita* is a prominent member of the benthic community in many subtidal areas of San Francisco Bay. In the central and southern portions of the Bay its tubes may carpet the sediment surface, with populations attaining a density up to 80,000 individuals m^{-2} (KLI, 1983). This study was intended to quantify temporal fluctuations in the abundance of a resident population of *A. abdita*, and to examine the size structure of the population throughout the year.

This study was conducted for two reasons. First, work in San Francisco Bay (Weston, 1995; 1996) and elsewhere (Scott and Redmond, 1989; Redmond *et al*., 1994) have shown that the growth rate of *A. abdita* holds promise as an indicator of chronic sediment toxicity. Approximately a 30–60% increase in body length is attainable in a 17-day period under laboratory conditions (Weston, 1996). Growth rates are rapid in a wide variety of relatively uncontaminated San Francisco Bay sediments, but are depressed upon exposure to toxicants such as cadmium, DDT, and crude oil (Weston, 1995; 1996). Use of a growth endpoint for toxicity testing, however, obviously requires the availability of individuals having some potential for growth. Attempts to culture *A. abdita* in the laboratory in order to provide juveniles for toxicity testing have not been consistently successful (Redmond *et al*., 1994). Until culturing procedures are perfected, a growth-based toxicity test will require the collection of animals from field populations. Thus, it is necessary to establish if juveniles are available throughout the year, and if not, those months in which an adequate supply is available.

Secondly, the San Francisco Estuary Regional Monitoring Program (RMP) regularly monitors benthic invertebrate community structure at many Bay locations with the intent of using shifts in population density and species composition as indicators of anthropogenic disturbance. *A. abdita* is represented in the benthic community at many of the RMP stations and is numerically dominant at some stations (e.g., Yerba Buena, Alameda). The presence and abundance of this one species alone has a strong influence on community structure parameters (e.g., total number of individuals) and numerical classification results. Thus, information on temporal fluctuations of *A. abdita* density will be of value in interpreting the benthic monitoring data, and helping to differentiate between "natural" population changes and those attributable to human impacts.

Methods

All samples were collected at the RMP Alameda station (BB70) located approximately midway across the Bay between Alameda and Hunters Point. This site is at least 3 km from any pollution point source. Sampling was conducted approximately every other month for a year and a half from November 1995 through March 1996. At each sampling time, three replicate benthic samples were collected using a 0.025 m^2 Ponar grab. The contents of each grab were washed on stacked sieves with screen sizes of 2 mm, 1 mm, 0.5 mm, and 0.25 mm. The material retained on each sieve was preserved in 10% formalin and transferred to 70% ethanol within a few days.

All specimens of *A. abdita* were removed from the samples by sorting under a dissecting microscope. Individuals from each sample, segregated by sieve size, were enumerated. Body length in *A. abdita* was measured along the dorsum from the insertion point of the first

Table 14. Sampling dates and concurrent hydrographic conditions during the investigation

Sampling date	Sediment temperature (°C)	Bottom water salinity (‰)
November 20, 1995	15	32
January 22, 1996	12	29
March 19, 1996	no data	no data
June 5, 1996	17	25*
August 5, 1996	no data	no data
October 8, 1996	18	33*
January 7, 1997	13	10
March 21, 1997	13	28

*Surface water salinities. Bottom water likely to be comparable or slightly more saline.

antennae to the base of the telson, using a drawing tube to trace the dorsal outline and a map-measuring device to obtain a length from the drawing. If a sample contained fewer than 100 individuals (sum of all sieve sizes), then all animals from that sample were measured. If more than 100 individuals were collected, then 100 were randomly selected and measured. Size frequency distributions were determined by compositing individuals from all three replicates at a station (i.e., maximum possible n of about 300).

Data on amphipod sizes are available only for samples collected during this investigation (November 1995–March 1996), however temporal coverage of abundance data was extended by inclusion of RMP data from the Alameda site as generated during the routine spring and fall sampling cruises. Data are available from February and August 1994 and February and August 1995. RMP sampling differed from that of our investigation in the following respects:

1) a 0.5 m^2 van Veen grab was used;
2) 0.5 mm and 1.0 screens were used, but these are inadequate to retain juveniles of *A. abdita*; and
3) only one replicate sample was collected during some sampling events.

Results and Discussion

A. abdita densities at the Alameda site were characterized by dramatic seasonal fluctuations spanning two orders-of-magnitude (Figure 30A). The total population (all size classes included) varied from a minimum of 280 indiv. m^{-2} in March 1996 up to 34,480 indiv. m^{-2} in June 1996. Although extended temporal coverage would be desirable, available data suggests that density minima occur in the winter months (January to March of both 1996 and 1997). Both minima are coincident with colder temperatures, but appear unrelated to salinity fluctuations (Table 14).

Extension of observations into 1994 and 1995 is possible by inclusion of the regular RMP monitoring data, however this program utilizes a 0.5 mm screen sieve, and thus would fail to quantitatively capture juvenile *A. abdita*. Thus in order to make our data comparable with that of the RMP, in Figure 30B we have excluded those individuals that were retained on a 0.25 mm screen, but which had passed through a 0.5 mm screen. This adjustment had the greatest impact on June 1996 data, reducing density estimates by about 50%, but was of minimal effect in other months. From the temporally-extended data set, it is evident that the peak densities of the summer of 1996 (approximately 17,000 indiv. m^{-2}) were actually

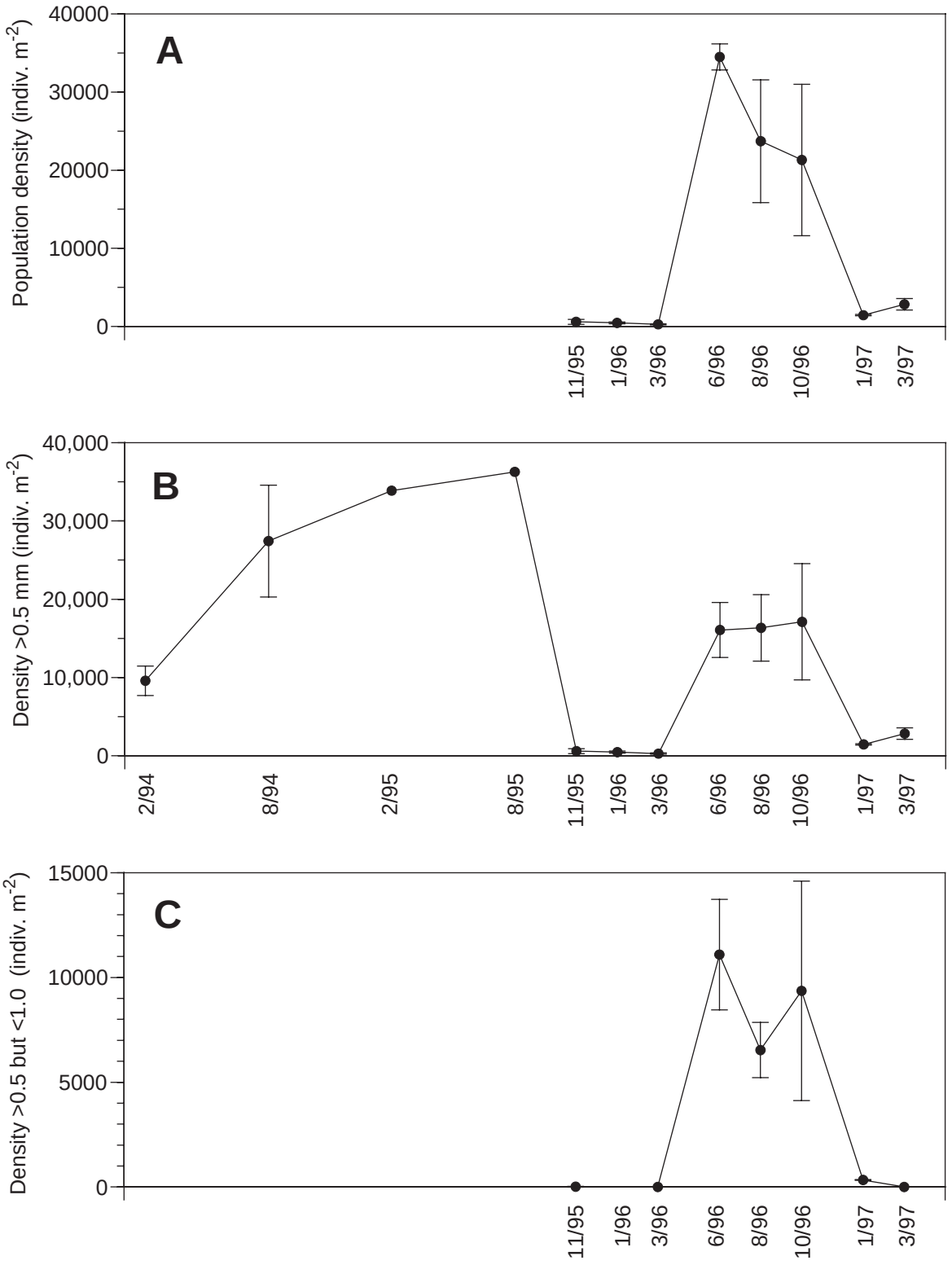

Figure 30. Fluctuations in abundance of *A. abdita* at the RMP Alameda site over time. Panel A = Total population density including all individuals; Panel B = Density of individuals retained on a 0.5 mm screen sieve, shown to achieve consistency with standard RMP practices; Panel C = Density of individuals passing through a 1.0 mm screen but retained on a 0.5 mm screen, representing the size class typically used for growth-based toxicity testing.

low by historical standards. For two years prior to that time densities had been about twice as great (approximately 25,000–35,000 indiv. m^{-2}). Winter density minima were evident in 1994, 1996, and 1997, but not in 1995.

These results are generally consistent with historical data from *A. abdita* populations 7 km south of the Alameda site (KLI, 1983). In sampling from the fall of 1979 to the fall of 1981, population densities were typically lowest in February to April, and peaked at about 80,000 indiv m^{-2} in the late summer and fall (including the individuals retained on a 0.25 mm screen).

Use of *A. abdita* for toxicity testing using a growth endpoint obviously requires the availability of animals having some potential for growth. It has been the practice to exclude large individuals as are retained on a 1.0 mm screen (Weston, 1996). Very small juveniles as are retained on a 0.25 mm screen provide excellent growth potential, but are difficult to count reliably and to separate from debris in the sediment. Therefore, efforts to develop a growth-based bioassay have relied on those individuals passing through a 1.0 mm screen, but retained on a 0.5 mm screen (Weston, 1995; 1996). Adjusting the abundance data to include only this size class (Figure 30C) indicates that appropriately-sized individuals were readily available in the summer and early fall, but were either absent or present in densities too low to make growth-based toxicity testing feasible in the late fall and winter months.

Size-frequency data (Figure 31) are useful to investigate individual growth and recruitment patterns in *A. abdita*. When emerging from the egg, juveniles have a body length of about 1.2 mm, as indicated by the smallest individuals in the size-frequency distributions and confirmed by our laboratory observations of emerging animals. A maximum body length of about 8 mm was observed in March 1997, although this is unusually large. A maximum size of 6–7 mm is more typical (KLI, 1983; our 1996 data). Sexual maturity in females, as indicated by the brooding of embryos, occurs in animals 3 to 6 mm in length (KLI, 1983).

Interpretation of our size-frequency data is best done in light of the description of San Francisco Bay *A. abdita* population dynamics provided in a study by Kinnetic Laboratories (KLI, 1983). This work indicated the presence of two generations per year. Recruitment in July through October produces a cohort which overwinters. The overwintering cohort then gives rise to a summer cohort produced in April through June. The summer generation matures rapidly, producing another overwintering cohort in late summer.

The overwintering cohort was evident in our data from November 1995 and January–March 1996 (Figure 31). During these months densities were low (indicated by the n value of the figures) and the population was comprised of animals about 4 to 6 mm in length. Juveniles less than 3 mm were nearly absent. Growth was negligible in the winter months, as indicated by the similarity of the frequency distributions over this five month period.

By June of 1996 only a few individuals of the overwintering generation remained, and the population was dominated by new recruits of the summer generation, ranging in length from about 1.5 to 4 mm. It is likely that the peak period of recruitment occurred in April and May, prior to the June sampling, as indicated by:

1) a modal size of 2.0 mm relative to the 1.2 mm length representative of newly-emerged individuals; and
2) the skewed nature of the distribution with the cohort including animals up to about 4 mm.

In the summer of 1996 animals of the summer generation grew rapidly, with the modal size of the cohort increasing from 2.0 in June, to 4.2 mm in August, and 4.6 mm in October. By January of 1997 the summer cohort could not be differentiated in the data, and past studies by KLI (1983) suggest all representatives of the cohort would have died in October or November.

A filial cohort, representing the next overwintering generation, probably appeared in

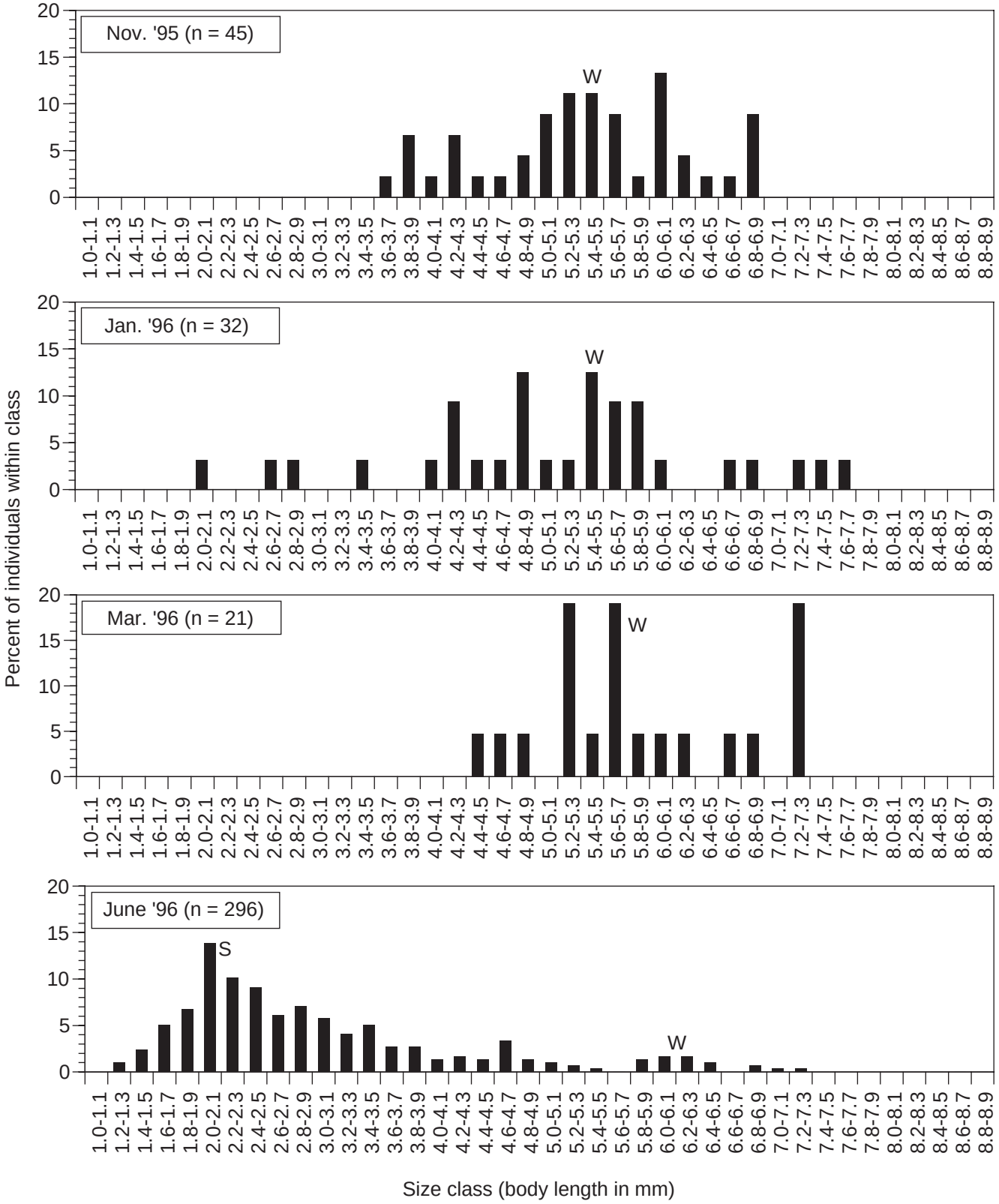

Figure 31. Size-frequency distribution of body lengths in the *A. abdita* population at the Alameda site. The n value represents the total number of individuals collected in the three replicate samples, and serves as the basis for the percent composition histograms. W and S denote the approximate modal size of the winter and summer cohorts, respectively, as described in the text. Figure 31 continued on following page.

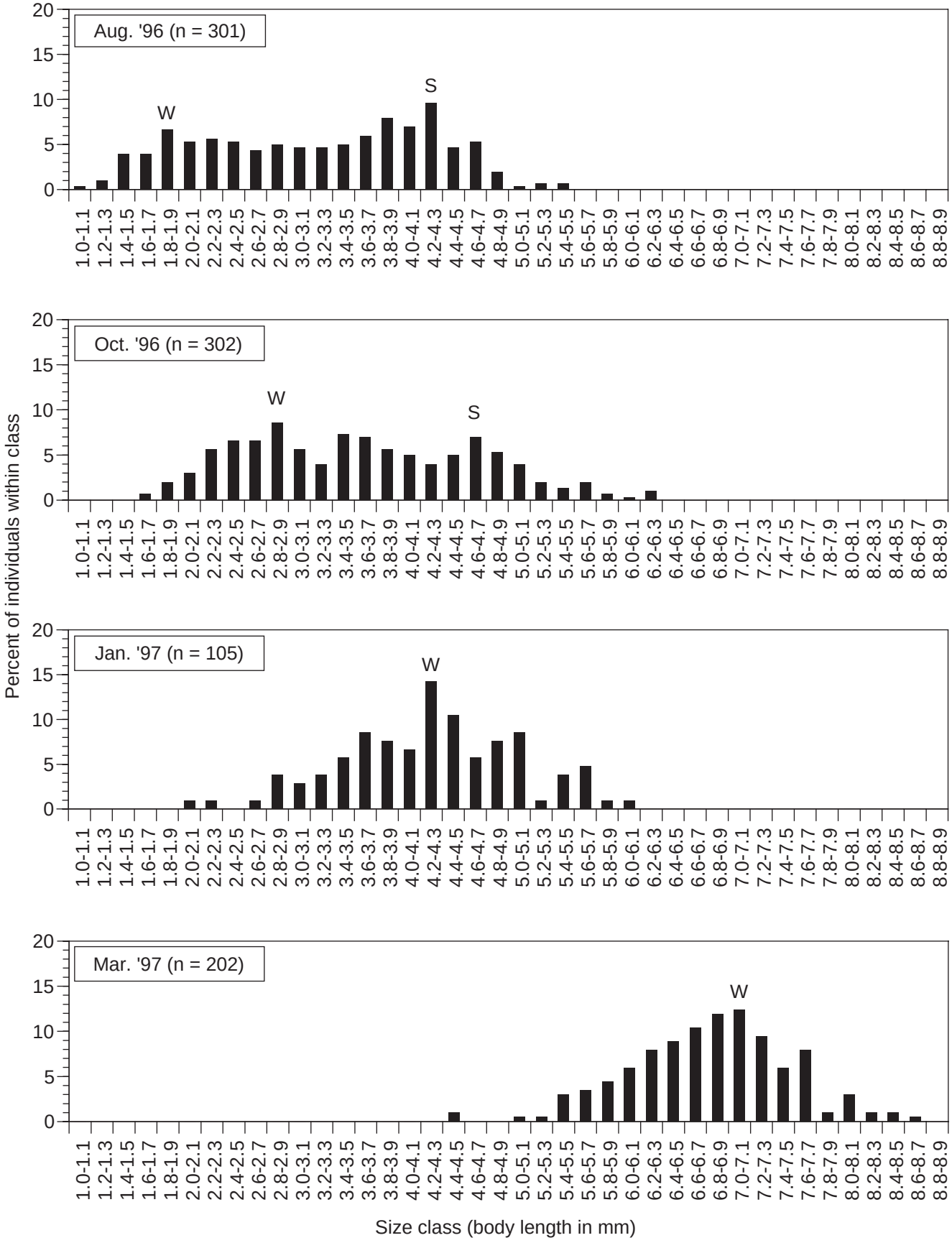

Figure 31 (continued).

July, and is represented in the August 1996 data with a modal size of 1.8 mm. The modal size increased to about 2.8 mm in October and 4.2 mm in January 1997. A striking period of growth occurred from January to March 1997. Data from the winters of 1980, 1981, and 1996 (KLI, 1983; this study) all indicate an increase of less than a 1 mm during these months. In contrast, during January to March of 1997, the modal size of the overwintering cohort increased by 2.8 mm (from 4.2 to 7.0 mm). This growth rate is faster than growth rates noted at any other time during the study. These results indicate atypical conditions in factors such as food availability during the winter of 1997, and also demonstrate remarkable growth potential under appropriate conditions even in relatively large individuals.

From the perspective of growth-based toxicity testing, the individuals previously considered useful for such testing (passing through a 1.0 mm screen, but retained on 0.5 mm) are typically about 2.8 to 4.5 mm in length. Individuals within this size range are available through the spring and summer from either the summer generation (May through August) or the overwintering generation (August through October). Fecund females are found in the population throughout the summer months (KLI, 1983), thus insuring a good supply of juveniles. Collection of individuals in the 2.8–4.5 size class through the fall and winter (roughly November to April) is likely to be difficult or impossible in most years. Larger animals (>4.5 mm) are generally available, however, and the growth observed in resident individuals in the winter of 1997 suggests these individuals may have more than adequate growth potential for toxicity testing purposes if the proper conditions are provided.

Conclusions

Resident populations of *A. abdita* in San Francisco Bay are a suitable source of animals for sediment toxicity testing. If doing acute tests in which growth is not a consideration, animals would typically be available year around. The collection effort required would vary considerably however, with the greatest effort required in the winter months when densities are orders-of-magnitude below their summer peaks. In the fall/winter of 1995/1996 densities were so low as to make collection impractical, but data over four winters indicates this situation was atypical.

For toxicity testing based on a growth rate endpoint, availability of juveniles is a significant seasonal constraint. A recruitment period in the spring provides abundant juveniles from May through August, and continued recruitment throughout the summer extends availability through about October. Sufficient numbers of small individuals (<4.5 mm) is likely to be difficult to obtain for toxicity testing during November through April if dependent upon resident populations as a source of test animals. Laboratory culturing and manipulation of reproductive cycles would be necessary to insure a reliable supply of small animals during the fall and winter months. However, monitoring of the resident populations have shown remarkable growth potential in animals previously considered too large (>4.5 mm) for growth-based toxicity testing. These larger individuals may be useful in extending the time period suitable for growth-based testing into months when juveniles are unavailable. If appropriate conditions for growth of these large individuals can be found, testing may be possible in all months except March and early April when nearly all individuals are at their maximum body size.

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Sediment Monitoring Discussion

Variability in sediment contaminant concentrations in the San Francisco Estuary observed since 1991 reflect the complexity of estuarine biogeochemical cycles and the varied sources of contamination.

Contamination in sediments may derive from two primary sources:

1) contaminants in dissolved forms that enter the Estuary may adsorb onto the surfaces of mineral particles or absorb into the organic matrix of particulate organic material (of various origins), or
2) contaminant laden sediment particles may be directly transported into the Estuary from its tributary watersheds.

As runoff from local rivers and streams bring new mineral particles into the Estuary, they undergo chemical changes that facilitate adsorption of dissolved contaminants (Stumm and Morgan, 1981). These particles may then be deposited in the sediment. This mechanism may explain the generally higher trace contaminant concentrations observed at the Southern Slough stations and near the turbidity maximum (Entrapment Zone) in the northern Estuary. However, few studies have been conducted to demonstrate this phenomenon. Once in the Estuary, sediments are transported by currents and tides, deposited, and resuspended. Plankton may assimilate contaminants in water in dissolved or particulate forms, and facilitate their deposition into the sediments in their feces or their corpses. Organisms that live in the sediments may mix the deeper layers with the newly deposited material. Animals that ingest particles may remove some of that material, then re-deposit the sediment where it may then re-adsorb more contaminants.

All of the mechanisms described above may affect what is measured by the RMP. Monitoring measurements alone can only provide information on the status of sediments at the time collected. Understanding the variability among the stations, Estuary reaches, and between the sampling periods, or over the long-term will require understanding more of the details of the mechanisms summarized above. Such understanding must come from focused special studies.

It is difficult to attribute elevated sediment contamination to a particular source. Concentrations of contaminants measured in sediments reflect areas where contaminants associated with particulate material are deposited. Sediment deposition and resuspension is known to be very dynamic in the San Francisco Estuary (Krone, 1992), often removing or depositing large volumes of sediment within short time-periods. Such dynamic resuspension, transportation, and deposition in sediments may result in sediment measurements that do not necessarily reflect proximity to the contaminant sources.

Patterns in Sediment Contamination in 1996

Sediment concentrations of Ag, Cd, Hg, Ni, Se, Zn, PCBs, DDTs, chlordanes, and dieldrin were higher at San Jose (C-3-0) in August than at the other sites sampled. PAHs and As were highest in San Pablo Bay (BD22) in August. Concentrations at Red Rock (BC60) were usually lower than all other sites, probably due to tidal flushing and the sandy sediment at that site.

On the average, Ag, Hg, Pb, Cd, Se, and most trace organics had the highest concentrations in the Southern Slough stations, PAHs were highest in the South Bay, and As, Cu, and Ni were highest in the Northern Estuary. Sediment concentrations were generally lowest at the sandy sediment sites.

Although As, Cd, Cu, Ni, and Zn were usually higher during the wet-sampling period in February than in August, and Se and PCBs were usually highest in August of 1996, plots of long-term trends for those metals did not reveal any seasonality over the past several years (Figure 17). Plots of trends in sediment con-

tamination between 1991–1996 suggested that there have been increases in As, Cd, and Cr concentrations at the Sacramento and San Joaquin River sites since 1993, but decreases in most trace organics (except PAHs) at those sites (Figure 18). Chlordanes have decreased throughout the Estuary since about 1994. No seasonal or water-year trends were apparent in the trends to date. However, further analyses needs to be conducted to account for variation in concentrations over time due to differences in sediment type, organic content, and depositional characteristics in the Estuary. One of the major recommendations by the RMP Program Review conducted in 1997 was to rationalize the RMP sediment contaminant sampling design in light of sediment dynamics.

Comparisons to Sediment Quality Guidelines

Although there are no formal regulatory sediment quality criteria or objectives, informal guidelines have been developed by several programs. Table 15 lists several of the more commonly used sediment quality guidelines available. The RMP uses primarily NOAA's Effects Range guidelines to evaluate sediment contaminant concentrations (see explanation in the introduction of this chapter).

Sediment contaminants that were above the ERM and ERLs in 1996 are tabulated in Table 16. As in past years, Ni was above the ERM (51.6 ppm) at all sites. 1996 was the first year that trace organics were measured at the Southern Slough sites, and those results showed that total PCBs, p,p'-DDE, and total DDTs were above ERMs at San Jose in August. Arsenic, Cr, Cu, Hg, Ni, and DDTs were above the ERLs at most sites. Additionally, Ag, Pb, Zn, HPAHs, PCBs, DDTs, and several individual PAH compounds were above ERLs at some sites.

An ERL for chlordane (0.5 ppb) was proposed by Long and Morgan (1990), but was not included in Long *et al*. (1995) due to lack of data. However, since chlordanes were shown to be associated with sediment toxicity at concentrations below the old ERL at several sites (see *Relationships Between Sediment Toxicity and Contamination in San Francisco Bay,* this chapter) comparisons to the old ERL are made, with the qualification that the Effects Ranges for chlordane are questionable. Sediment chlordane concentrations were above the ERM of 6 ppb at Standish Dam and Sunnyvale and above the ERL in 15 other samples including all Wetland Pilot Study sites in 1996 (*Appendix C,* Table 15).

Effects of Sediment Contamination

New information was produced this year by RMP investigators about the possible effects of sediment contamination in the Estuary. Analysis of the relationships between sediment contamination and toxicity between 1991 and 1995 showed that in general, amphipod toxicity was associated with cumulative effects of many contaminants, and at several sites, toxicity was associated with specific contaminants (see *Relationships Between Sediment Toxicity and Contamination in San Francisco Bay,* this chapter). Hypotheses about threshold toxic concentrations of chlordanes (0.28 ppb), LPAHs (474 ppb), and HPAHs (1,983 ppb) were proposed. Further studies are needed to test these hypotheses using *in situ* or laboratory dose-response experiments. No significant relationships between normal bivalve larvae development and sediment concentrations were observed because the bivalves were exposed to only the water soluble fraction of the sediments.

The persistent toxicity to bivalve larvae exposed to sediment elutriates from the Sacramento and San Joaquin Rivers and Grizzly Bay was investigated (see *Investigation Classes of Compounds Associated with Sediment Toxicity at Regional Monitoring Program River Stations,* this chapter). Toxicity Identification Evaluations (TIEs) conducted on the elutriates in August 1996 indicated that trace metals may have influenced toxicity at San Joaquin River and Grizzly Bay, and that non-polar organics could have influenced toxicity at the Sacra-

Table 15. Commonly used sediment quality guidelines.

Parameter	unit	EPA*[1]	ERL[2]	ERM[2]	Puget Sound Amphipod AET[3]	Puget Sound Bivalve AET[3]	Background Concentrations (Bay-wide ranges)[4] Total
Arsenic	mg/kg		8.2	70	.	.	.
Cadmium	mg/kg		1.2	9.6	6.7	9.6	.
Chromium	mg/kg		81	370	270	.	110–170
Copper	mg/kg		34	270	1300	390	20–55
Mercury	mg/kg		0.15	0.71	2.1	0.59	.
Nickel	mg/kg		20.9	51.6	.	.	70–100
Lead	mg/kg		46.7	218	660	660	20–40
Silver	mg/kg		1	3.7	5.9	0.56	0.1–0.1
Zinc	mg/kg		150	410	960	1600	60–70
high mol wt PAHs	µg/kg		1700	9600	69000	17000	
Fluoranthene	µg/kg	300	600	5100	30000	2500	
Pyrene	µg/kg		665	2600	16000	3300	
Benzo(a)anthracene	µg/kg		261	1600	5100	1600	
Chrysene	µg/kg		384	2800	9200	2800	
Benzo(b,k)fluoranthene	µg/kg		.	.	7800	3600	
Benzo(a)pyrene	µg/kg		430	1600	3000	1600	
Dibenz(a,h)anthracene	µg/kg		63.4	260	540	230	
Benzo(g,h,i)perylene	µg/kg		.	.	1400	720	
Indeno(1,2,3-c,d)pyrene	µg/kg		.	.	1800	690	
low mol wt PAHs	µg/kg		552	3160	24000	5200	
2-Methylnaphthalene	µg/kg		70	670	.	.	
Naphthalene	µg/kg		160	2100	2400	2100	
Acenaphthylene	µg/kg		44	640	1300	.	
Acenaphthene	µg/kg	230	16	500	2000	500	
Fluorene	µg/kg		19	540	3600	540	
Phenanthrene	µg/kg	240	240	1500	6900	1500	
Anthracene	µg/kg		85.3	1100	13000	960	
TOTAL PAHs	µg/kg		4022	44792	.	.	
DDE	µg/kg		.	.	15	.	
DDD	µg/kg		.	.	43	.	
DDT	µg/kg		.	.	.	.	
TOTAL DDTs	µg/kg		1.58	46.1	.	.	
Dieldrin	µg/kg	20	.	.	.	.	
Endrin	µg/kg	0.76	.	.	.	.	
TOTAL PCBs	µg/kg		22.7	180	3000	1100	

* Expressed as µg/g organic carbon.

[1] **EPA—Federal Sediment Guidelines**
From: EPA, 1991

[2] **ERL & ERM—Effects Range Low (ERL) and Effects Range Median (ERM)**
From: Long *et al.,* 1995.

[3] **AET—Puget Sound Apparent Effects Threshhold (AET) values**
From: Barrick, R. *et al.,* 1988.
AETs are values above which statistically significant (p<= 0.05) biological effects are always observed in data used to generate the AET.

[4] **Background sediment concentrations for selected trace elements in SF Bay sediment cores.**
From: Hornberger *et al.* (unpublished)

Table 16a. Summary of sediment trace element concentrations that were above ERL guidelines during the wet- and dry-sampling periods in 1996. There are nine ERL guidelines for trace elements. Eight trace element compounds had sample results above the guidelines. ● = above ERL, ◆ = above both the ERL and the ERM. The ERM for nickel is 51.6 ppm.

			Ag		As		Cr		Cu		Hg		Ni		Pb		Zn	
		ERL (ppm) =	1		8.2		81		34		0.15		20.9		46.7		150	
	code	station	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
Southern Sloughs	C-1-3	Sunnyvale					●	●			●	●	◆	◆				
	C-3-0	San Jose		●		●	●	●		●	●	●	◆	◆		●		●
South Bay	BA10	Coyote Creek			●		●		●		●	●	◆	◆			●	
	BA21	South Bay			●	●	●	●	●	●	●	●	◆	◆			●	
	BA30	Dumbarton			●	●	●	●	●	●	●	●	◆	◆				
	BA41	Redwood Creek			●	●	●	●	●	●	●	●	◆	◆				
	BB15	San Bruno			●			●			●	●	◆	◆				
	BB30	Oyster Point			●	●	●	●	●	●	●	●	◆	◆				
	BB70	Alameda			●	●	●	●	●	●	●	●	◆	◆				
Central Bay	BC11	Yerba Buena Island			●	●	●		●		●	●	◆	◆				
	BC21	Horseshoe Bay			●							●	◆	◆	●	●		
	BC32	Richardson Bay			●	●	●	●	●		●	●	◆	◆				
	BC41	Point Isabel			●	●	●	●	●	●	●	●	◆	◆				
	BC60	Red Rock			●	●							◆	◆				
Northern Estuary	BD15	Petaluma River			●	●	●	●	●	●	●	●	◆	◆			●	
	BD22	San Pablo Bay			●	●	●	●	●	●	●	●	◆	◆				
	BD31	Pinole Point			●	●	●	●	●	●	●	●	◆	◆				
	BD41	Davis Point					●	●					◆	◆				
	BD50	Napa River			●	●	●	●	●	●	●	●	◆	◆			●	
	BF10	Pacheco Creek						●					◆	◆				
	BF20	Grizzly Bay			●	●	●	●	●	●	●	●	◆	◆				
	BF40	Honker Bay			●	●	●	●	●	●	●	●	◆	◆			●	
Rivers	BG20	Sacramento River			●	●	●	●		●			◆	◆				
	BG30	San Joaquin River			●	●	●	●	●	●	●	●	◆	◆				

Table 16b. Summary of sediment trace organic concentrations that were above ERL guidelines during the wet- and dry-sampling periods in 1996. There are nineteen ERL guidelines for trace organic compounds (including the low and high molecular weight PAHs). Fourteen trace organic compounds had sample results above the guidelines. ● = above ERL, ◆ = above both the ERL and the ERM. The ERM for PCBs = 180, p,p'-DDE = 27, Sum DDTs = 46 ppb. - = data not available.

			Sum of PCBs		p,p'-DDE		Sum of DDTs		Acenaphthene		Anthracene		Benzo(a)anthracene		Benzo(a)pyrene		Fluoranthene		Fluorene		Phenanthrene		Pyrene		Sum of HPAHs		Sum of LPAHs		Sum of PAHs	
		ERL (ppb) =	22.7		2.2		1.58		16		85.3		261		430		600		19		240		665		1700		552		4022	
	code	station	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
Southern Sloughs	C-1-3	Sunnyvale		-	●	-	●	-		-		-		-		-		-		-		-		-		-		-		-		-
	C-3-0	San Jose	●	◆	●	◆	●	◆																								
South Bay	BA10	Coyote Creek			●		●	●																	●							
	BA21	South Bay		●	●		●	●											●						●	●						
	BA30	Dumbarton					●	●																	●	●						
	BA41	Redwood Creek					●	●																	●	●						
	BB15	San Bruno						●																	●	●						
	BB30	Oyster Point					●	●	●										●						●	●						
	BB70	Alameda					●	●																		●						
Central Bay	BC11	Yerba Buena Island					●	●																								
	BC21	Horseshoe Bay						●		●										●						●						
	BC32	Richardson Bay					●	●										●						●	●	●						
	BC41	Point Isabel					●	●																		●						
	BC60	Red Rock		-				-																								
Northern Estuary	BD15	Petaluma River					●	●																								
	BD22	San Pablo Bay					●			●		●		●		●		●		●		●		●	●	●		●		●		●
	BD31	Pinole Point					●	●																								
	BD41	Davis Point																														
	BD50	Napa River					●	●																								
	BF10	Pacheco Creek																														
	BF20	Grizzly Bay			●		●	●																								
	BF40	Honker Bay					●	●																								
Rivers	BG20	Sacramento River	-	-																												
	BG30	San Joaquin River	-					-																								

mento River. Further study is needed to verify these preliminary findings.

The Benthic Pilot Study showed that, in general, benthic assemblages at most sites sampled did not appear to be severely impacted by contaminants (see *Progress Report on the Benthic Pilot Study,* this chapter). However, the benthos at Castro Cove (1992), and at China Camp may be moderately impacted, and benthos at several other sites may be slightly impacted. Further analysis is necessary before firm conclusions can be made about the condition of the benthos.

The amphipod *Ampelisca abdita* is the dominant benthic species at several sites. It is also a commonly used species in laboratory sediment bioassays. Dr. Weston's article focused on the population dynamics of *A. abdita* in order evaluate their availability for laboratory work and to begin to link information obtained in laboratory sediment tests with information from benthic sampling (see *Population Dynamics of Ampelisca Abdita* in San Francisco Bay, this chapter). Populations of this species in the Central Bay exhibit large natural fluctuations in abundances and growth rates in response to dynamic environmental factors. Such variations complicate interpretation of benthic and toxicity test information. Since Dr. Weston's work on the development of *A. abdita* as a sediment indicator is complete, decisions may now be made about incorporating its use into the RMP.

Sediment Conditions in the Estuary

Sediment assessments are being conducted throughout the world using information about sediment contamination, toxicity, and benthos—the sediment quality triad. The RMP monitors all of those components and can begin to use that information to evaluate the health of estuarine sediments. In a recent workshop about using the Triad (Chapman *et al.* 1997), it was recommended that each "leg" of the triad be considered an independent piece of information about the condition of the sediments. Used together, along with any other pertinent information (e.g., bioaccumulation), the measurements provide a "weight-of-evidence" about the condition of sediments in the Estuary.

For sediments, the mean ERM quotient (mERMq) reflects increasing contaminant concentrations in sediments from many contaminants and appears to provide a useful way to express the degree of overall sediment contamination (see *Relationships Between Sediment Toxicity and Contamination in San Francisco Bay,* this chapter for more details). The mERMq was shown to be highly significantly correlated with amphipod survival such that at mERMq values below 0.105 toxicity should not occur, and between 0.105 and 0.185 there is about an even chance for toxicity. Toxicity probably occurs above 0.185 and above 0.220 toxicity will certainly occur. Using those predictions, mERMq was calculated for the 1996 data and compared with the sediment toxicity results to test those predictions (Table 17). Toxicity at the RMP monitoring sites was accurately predicted at nine of the thirteen sites. Toxicity did not occur at the South Bay site in August despite an elevated mERMq, but did occur at Horseshoe Bay in February despite a low mERMq. At the latter sites, chlordanes, which are not included in the mERMq calculation, were 0.3 ppb near concentration hypothesized to be toxic.

At sites where sediment toxicity was not measured, mERMq values suggest that San Jose and Sunnyvale in August would have been toxic; Dumbarton Bridge, Oyster Point, Petaluma River, San Pablo in February would probably have been toxic; and Pacheco Creek in August would not have been toxic. Further development of the use of mERMq as a sediment contamination "index" needs to be conducted.

Samples collected from the four sites in China Camp for the Wetland Pilot Study (see article in *Chapter Six: Pilot and Special Studies*) included sediment contamination and benthos, but did not include sediment toxicity. The mERMqs calculated for those samples (0.183 to 0.205) suggest that those sites would probably have been toxic. Furthermore, the

Table 17. mERMq values for 1996 sediment samples.
* RMP sediment toxicity site. + Toxicity predicted to probably occur. ++ Toxicity predicted to occur. - No toxicity predicted. (see *Relationships Between Sediment Toxicity and Contamination in San Francisco Bay* in this chapter).

			mERMq	
	code	station	wet	dry
Southern	C-1-3	Sunnyvale	0.144	0.296++
Sloughs	C-3-0	San Jose	0.167	0.417++
	BA10	Coyote Creek*	0.215+	0.137
	BA21	South Bay*	0.235++	0.193+
South	BA30	Dumbarton	0.212+	0.175
Bay	BA41	Redwood Creek*	0.195+	0.185+
	BB15	San Bruno*	0.147	0.136
	BB30	Oyster Point	0.195+	0.167
	BB70	Alameda*	0.169	0.163
	BC11	Yerba Buena Island*	0.160	0.129
Central	BC21	Horseshoe Bay*	0.112	0.141
Bay	BC32	Richardson Bay	0.163	0.172
	BC41	Point Isabel	0.171	0.173
	BC60	Red Rock*	0.082-	0.078-
	BD15	Petaluma River	0.217+	0.167
	BD22	San Pablo Bay	0.193+	0.208+
	BD31	Pinole Point	0.166	0.128
Northern	BD41	Davis Point*	0.100-	0.098-
Estuary	BD50	Napa River*	0.189+	0.138
	BF10	Pacheco Creek	0.110	0.105-
	BF20	Grizzly Bay*	0.181	0.167
	BF40	Honker Bay	0.172	0.160
Rivers	BG20	Sacramento River*	0.125	0.122
	BG30	San Joaquin River*	0.135	0.116

very reduced amphipod populations at those sites correspond to elevated pesticide concentrations. Since amphipods are important food for wetland fish and birds, further studies of wetland sediment contamination and its food chain consequences are needed.

The Benthic Pilot Study was summarized above. With further development, the benthic information may be used along with sediment contamination and toxicity information in sediment evaluations for the region.

The RMP sites are monitored to provide information on background or ambient Bay condition, and do not provide comprehensive information about all Bay sediments. However, other locations are being sampled by private contractors working on military base closures, the BPTCP, and for dredged material testing. A synthesis of knowledge gained by those studies is a good candidate for future RMP Special Studies.

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CHAPTER FOUR

Bivalve Monitoring

Background

It has long been known that bivalves will accumulate contaminants in concentrations much greater than those found in ambient water (Vinogradov, 1959). This phenomenon results from the limited ability of bivalves to regulate the concentrations of most contaminants in their tissues. This method of active bio-monitoring has been widely applied by the California State Mussel Watch Program (Phillips, 1988; Rasmussen, 1994) and others (Young *et al.,* 1976; Wu and Levings, 1980; Hummel *et al.,* 1990; Martincic *et al.,* 1992). For many contaminants, bivalves are good integrators of contaminant exposure over time and indicators of contaminant transfer from water into the food web.

Bivalves were collected from sites thought to be uncontaminated and transplanted to 15 stations in the Estuary during the wet season (April through May) and the dry season (September; Figure 1 in *Chapter One: Introduction*). Sampling dates are listed in Table 1 in *Chapter One: Introduction*. Contaminant concentrations in tissues, survival, and biological condition were measured before deployment (referred to as time zero (T-0) or background) and at the end of the 90–100 day deployment period. Because of the variability between each individual bivalve organism, composite samples of tissue were made from T-0 organisms, and from surviving organisms from each deployment site (up to 45 individuals) for analyses of trace contaminants. The *Corbicula* reference site had to be changed from Lake Isabella to Putah Creek and a pond at UC Davis, due to a population crash at Lake Isabella.

The effects of high short-term flows of freshwater on the transplanted bivalves west of Carquinez Strait were minimized by deploying the bivalves near the bottom where density gradients tend to maintain higher salinities. All bivalves were kept on ice after collection and deployed within 72 hours. Multiple species were deployed at several stations due to uncertain salinity regimes and tolerances. Detailed methods are included in *Appendix A*. Data are tabulated in *Appendix C*.

Overall, the bivalve bioaccumulation and condition study objectives for 1996 were met, with successful deployments at each of the fifteen sites for both the wet- and dry-season deployments. One exception to this was the loss of the mooring (and thus the bivalves) at the San Pablo Bay site (BD20) during the dry-season deployment.

Accumulation Factors

In addition to using the absolute tissue concentrations at the end of each deployment period and comparing them to initial tissue concentrations prior to transplanting the bivalves to the Estuary (T-0), this report uses accumulation factors (AFs) to indicate accumulation during the 90–100 day deployment period or depuration (loss of constituents from bivalve tissue). The AF is calculated by dividing the contaminant concentration in transplants by the initial bivalve concentration at T-0. For example, an AF of 1.0 indicates that the concentration of a specific contaminant remained the same during the deployment period compared to the initial contaminant level prior to transplanting the bivalve sample to the Estuary. An AF less than 1 indicates that the bivalves decreased in contaminant concentration during the deployment period, while an AF above 1 indicates accumulation.

Guidelines

In the following figures, tissue concentrations of various trace contaminants are compared to the guidelines for Maximum Tissue Residue Levels (MTRLs), as used to evaluate data from the California State Mussel Watch Program (Rasmussen, 1994). However, it should be kept in mind that there are a number of more or less meaningful or science-based yard sticks upon which comparisons can be based. These are detailed in the discussion section at the end of this chapter. MTRLs were developed by the State Water Resources Control Board and are used as alert levels indicating water bodies with potential human health

concerns. MTRLs are only an assessment tool and are not used as compliance or enforcement criteria. Since no direct regulatory tissue standards for trace metal and organic contaminants exist in the United States (although tissue "standards" are embedded in EPA water quality criteria), comparisons to these guidelines serve only as a relative yard stick in comparisons. A comprehensive summary of applicable tissue concentrations guidelines is tabulated in Table 6 in the Discussion section of this chapter for the reader to evaluate a variety of "yardsticks" that indicate how contaminants in the Estuary compare with what is considered "acceptable" or "undesirable" by public health and regulatory agencies.

Tissue guidelines are expressed in ppm wet weight, while the RMP tissue data are presented as ppm dry weight. A wet-to-dry weight conversion factor of 7, based on an average of 85% moisture content in bivalves, was applied for comparisons.

Biological Condition and Survival

The biological condition (expressed as the ratio of dry tissue weight to shell cavity volume) and survival rates of transplanted bivalves following exposure to Estuary water is evidence that the animals were healthy and capable of bioaccumulation at most sites (Figures 17 and 18). However, for a detailed discussion of condition measurements, see *Bivalve Monitoring Discussion* (pp. 201–207) and *An Evaluation of Bioaccumulation Monitoring with Transplanted Bivalves in the RMP* (pp. 187–200).

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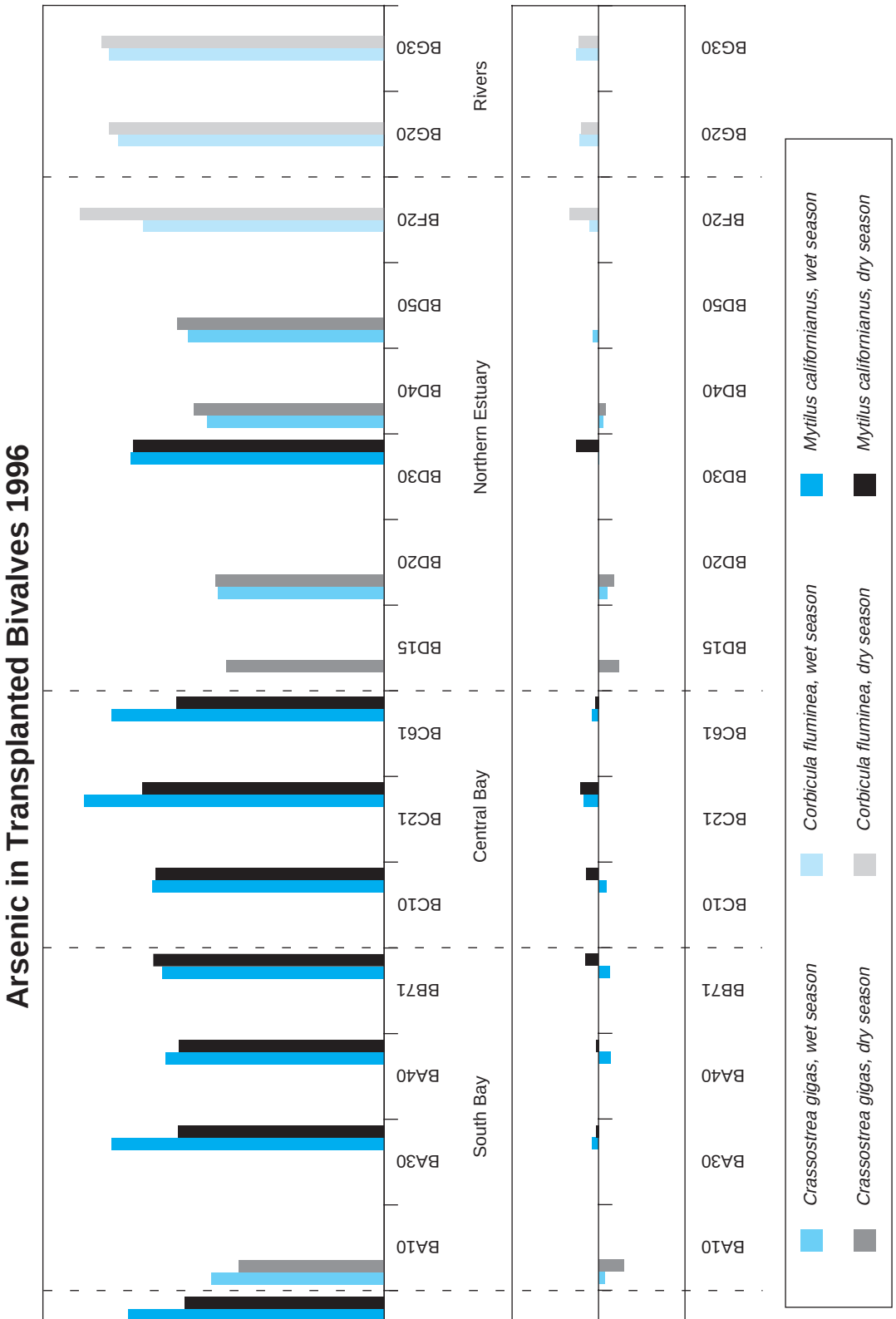

Figure 1. Arsenic concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. T-0 (time zero) indicates the initial concentrations of arsenic measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary.Accumulation factors at all stations were below 2. Accumulation factors ranged from 0.7, indicating depuration, to 1.3, and averaged highestin the Rivers. Clams consistently accumulated higher arsenic concentrations than mussels or oysters. All stations for which freshwater Maximum Tissue Residue Levels (MTRLs) are applicable (*C. flumínea*) were higher than the guideline of 1.4 mg/kg (including the T-0 samples). Due to 0% survival, *C. gigas* was not analyzed in the wet season at Petaluma River (BD15).

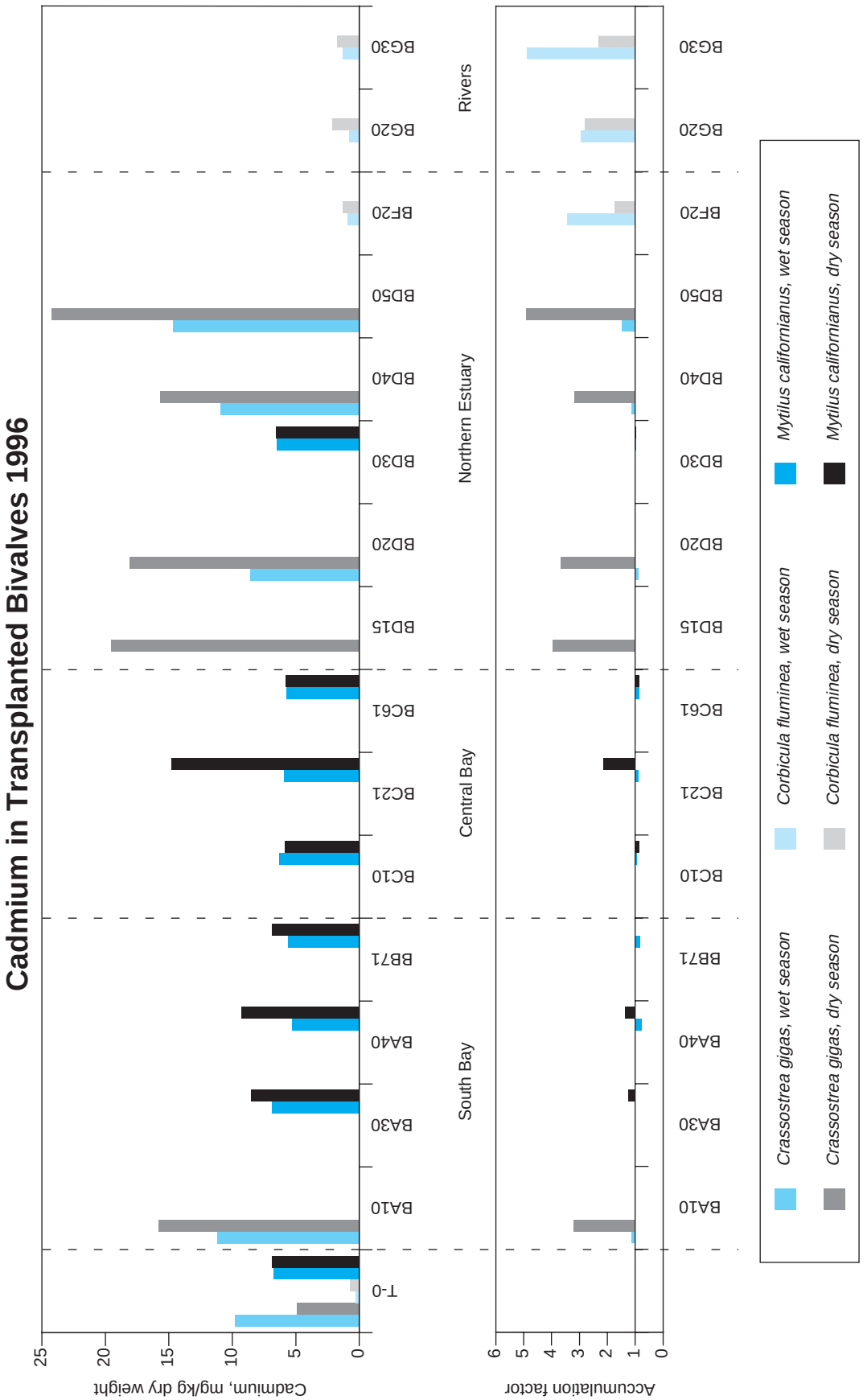

Figure 2. Cadmium concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. T-0 (time zero) indicates the initial concentrations of cadmium measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary.Accumulation factors were > 2 at the Northern Estuary stations during the dry season where *C. gigas* were deployed and at the Rivers stations for both the wet and dry seasons where *C. fluminea* were deployed. Accumulation factors ranged from 0.8, indicating depuration, to 4.9. The highest concentrations of cadmium were found in oysters in the dry season. All freshwater stations had tissue concentrations much lowerthan the applicable Maximum Tissue Residue Level (MTRL) guideline of 4.48 mg/kg. Due to 0% survival, *C. gigas* was not analyzed in the wet season at Petaluma River (BD15).

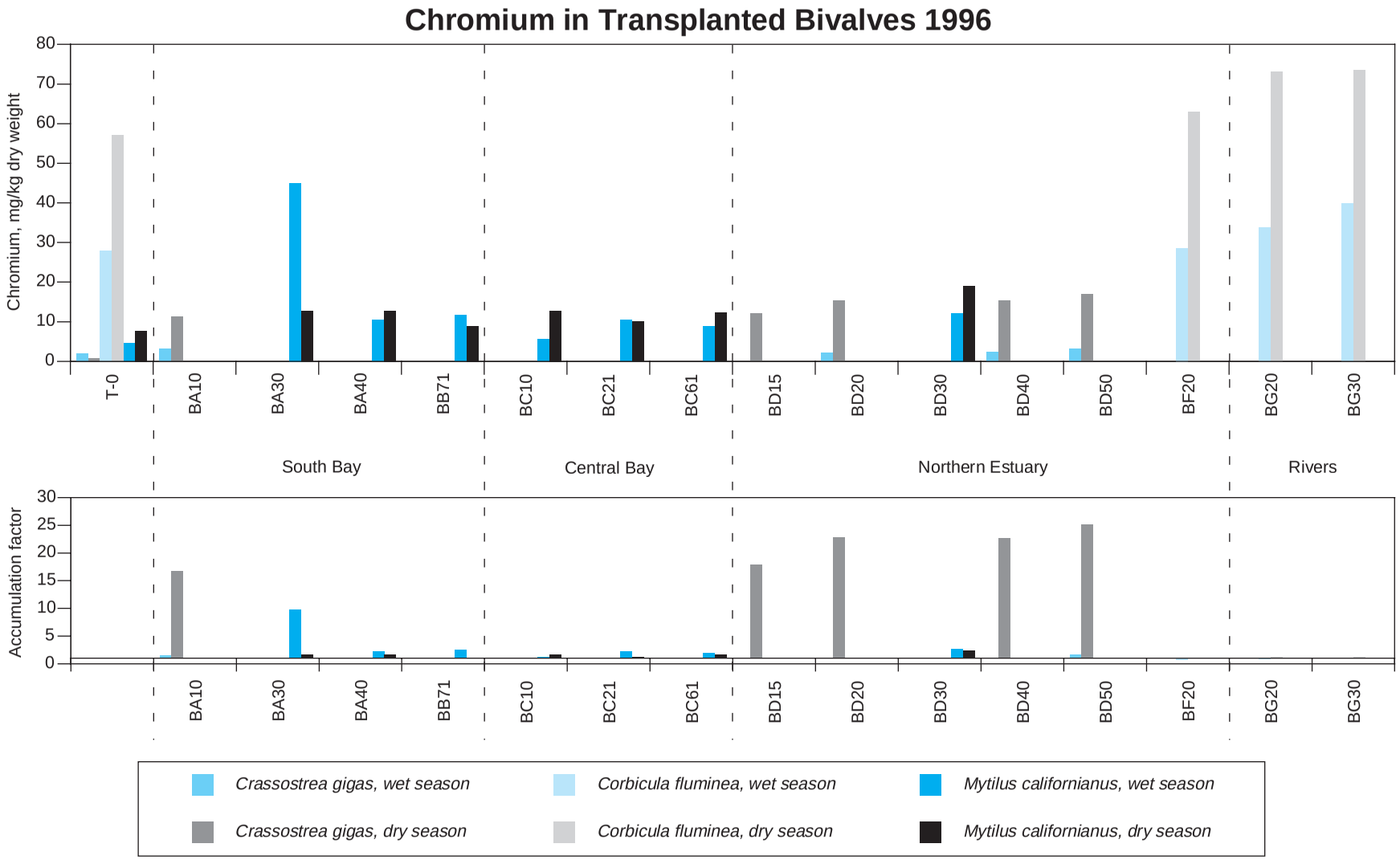

Figure 3. Chromium concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. T-0 (time zero) indicates the initial concentrations of chromium measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary Accumulation factors were > 2 at all stations during the dry season where *C. gigas* were deployed (South Bay and Northern Estuary) and at most stations where *M. californianus* were deployed during the wet season. Accumulation factors ranged from 0.7, indicating depuration, to 25. The highest tissue concentrations of chromium were found in *C. fluminea* during the dry season. However, the highest accumulation factors were found in *C. gigas* during the dry season. There are no Maximum Tissue Residue Level (MTRL) guidelines for this compound. Due to 0% survival, *C. gigas* was not analyzed in the wet season at Petaluma River (BD15).

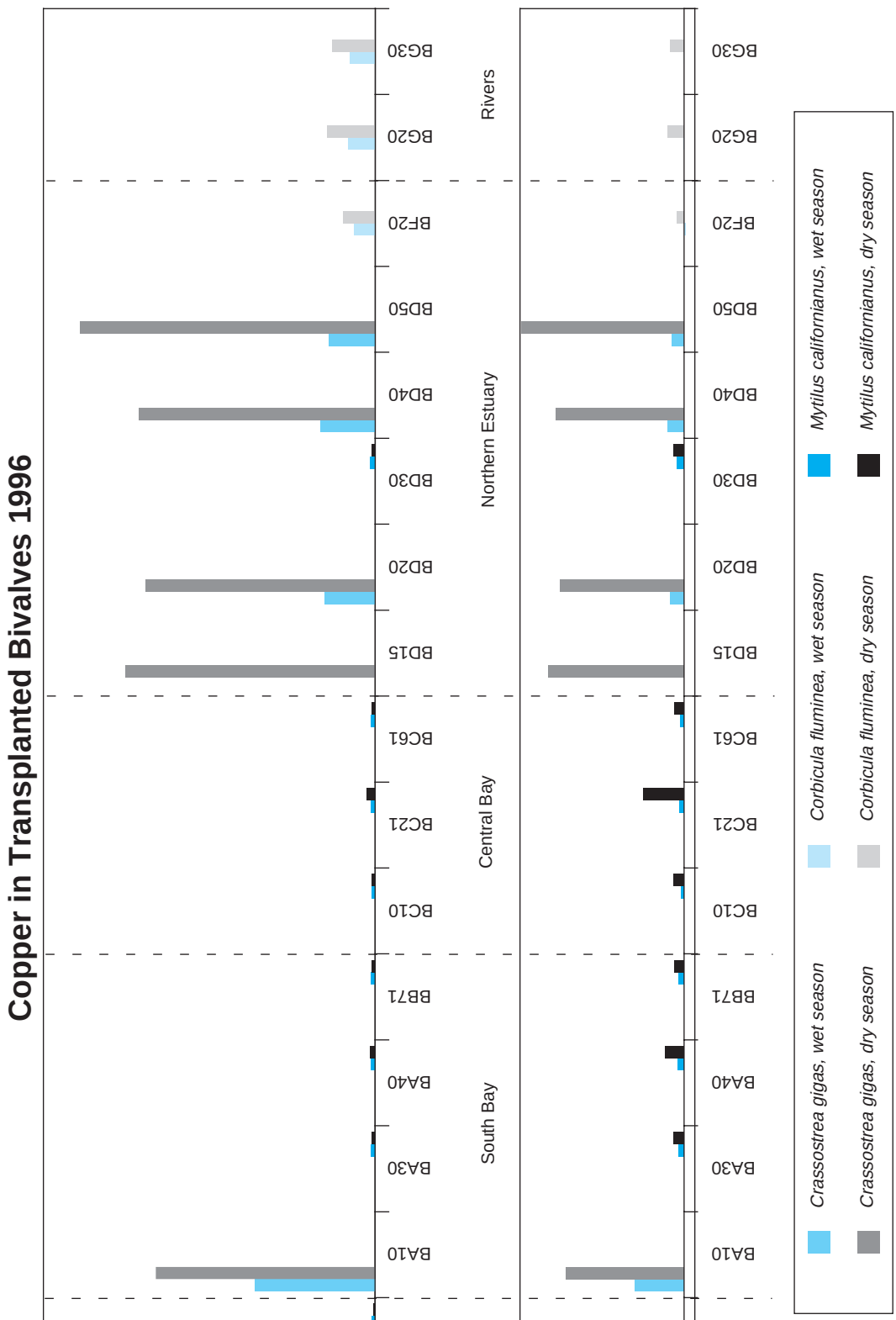

Figure 4. Copper concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. T-0 (time zero) indicates the initial concentrations of copper measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary.Accumulation factors were > 2 at all stations where *C. gigas* were deployed during both seasons, and at two stations during the dry season for both *M.californianus* and *C. fluminea*. Accumulation factors ranged from 0.8, indicating depuration, to 15.9. *C. gigas* had substantially higher accumulation factors and tissue concentrations than *M.californianus*. Accumulation factors in *C. gigas* were consistently high in the dry season. There are no Maximum Tissue Residue Level (MTRL) guidelines for this compound. Due to 0% survival, *C. gigas* was not analyzed in the wet season at Petaluma River (BD15).

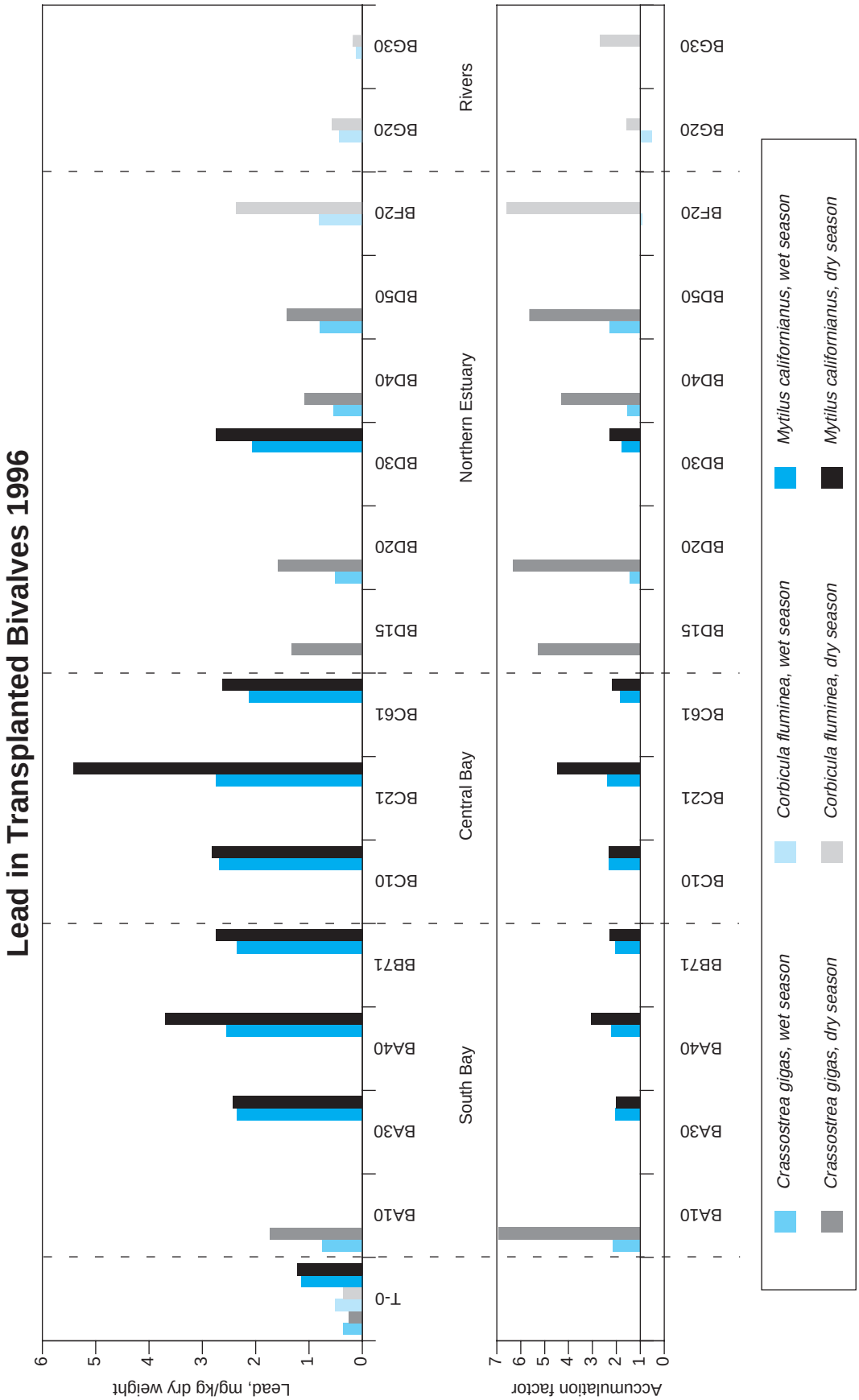

Figure 5. Lead concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. T-0 (time zero) indicates the initial concentrations of lead measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Accumulation factors were > 2 at most stations where *C. gigas* and *M. californianus* were deployed (most notably during the dry season). Accumulation factors ranged from 0.5, indicating depuration, to 6.9. There are no Maximum Tissue Residue Level (MTRL) guidelines for this compound. Due to 0% survival, *C. gigas* was not analyzed in the wet season at Petaluma River (BD15).

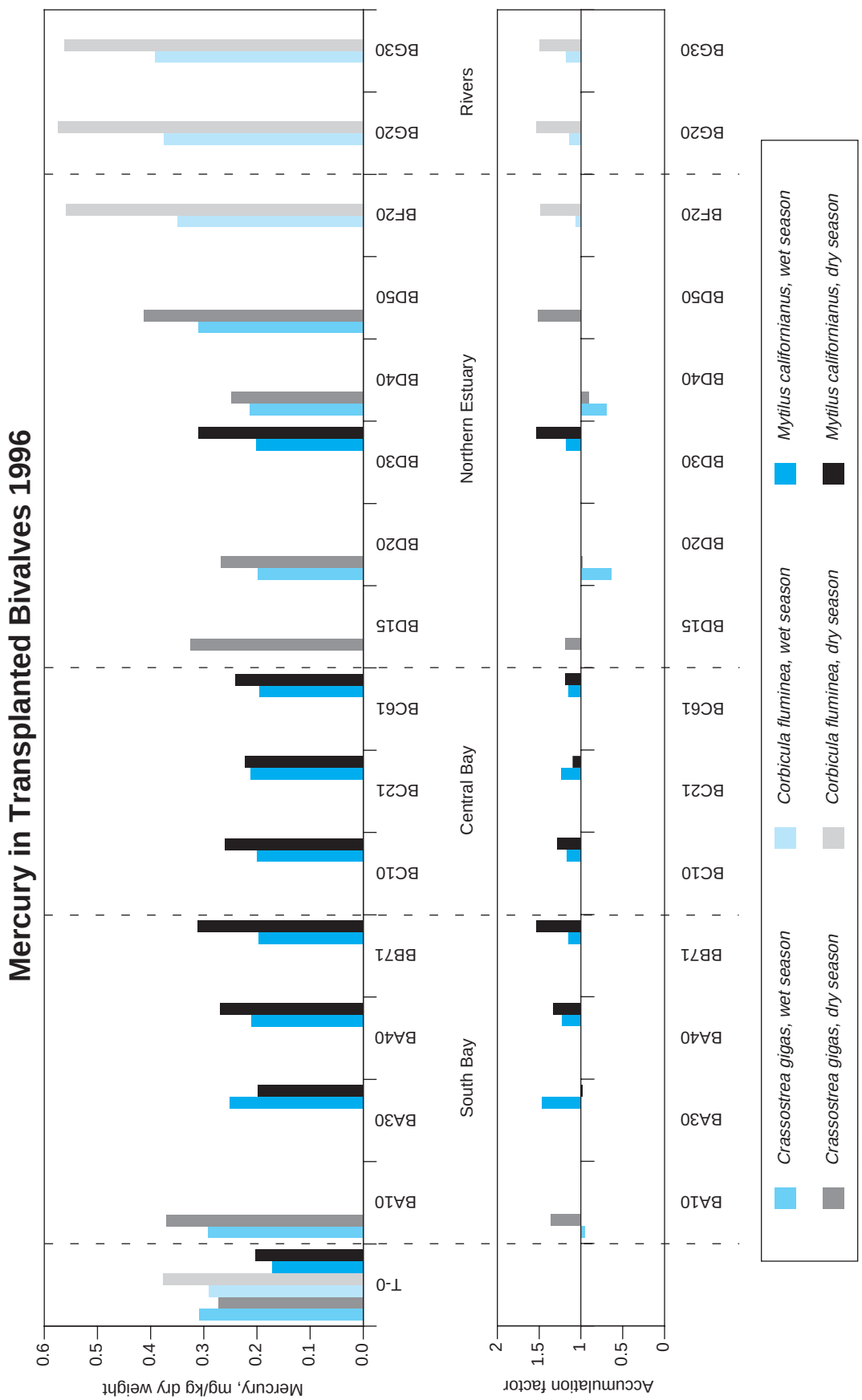

Figure 6. Mercury concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. T-0 (time zero) indicates the initial concentrations of mercury measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary.Accumulation factors at all stations were below 2 with the highest tissue concentrations found in *C. fluminea* during the dry season. Accumulation factors ranged from 0.6, indicating depuration, to 1.5. All stations had tissue concentrations much lower than the Maximum Tissue Residue Level (MRTL) of 7 ppm dry weight during both seasons. Due to 0% survival, *C. gigas* was not analyzed in the wet season at Petaluma River (BD15).

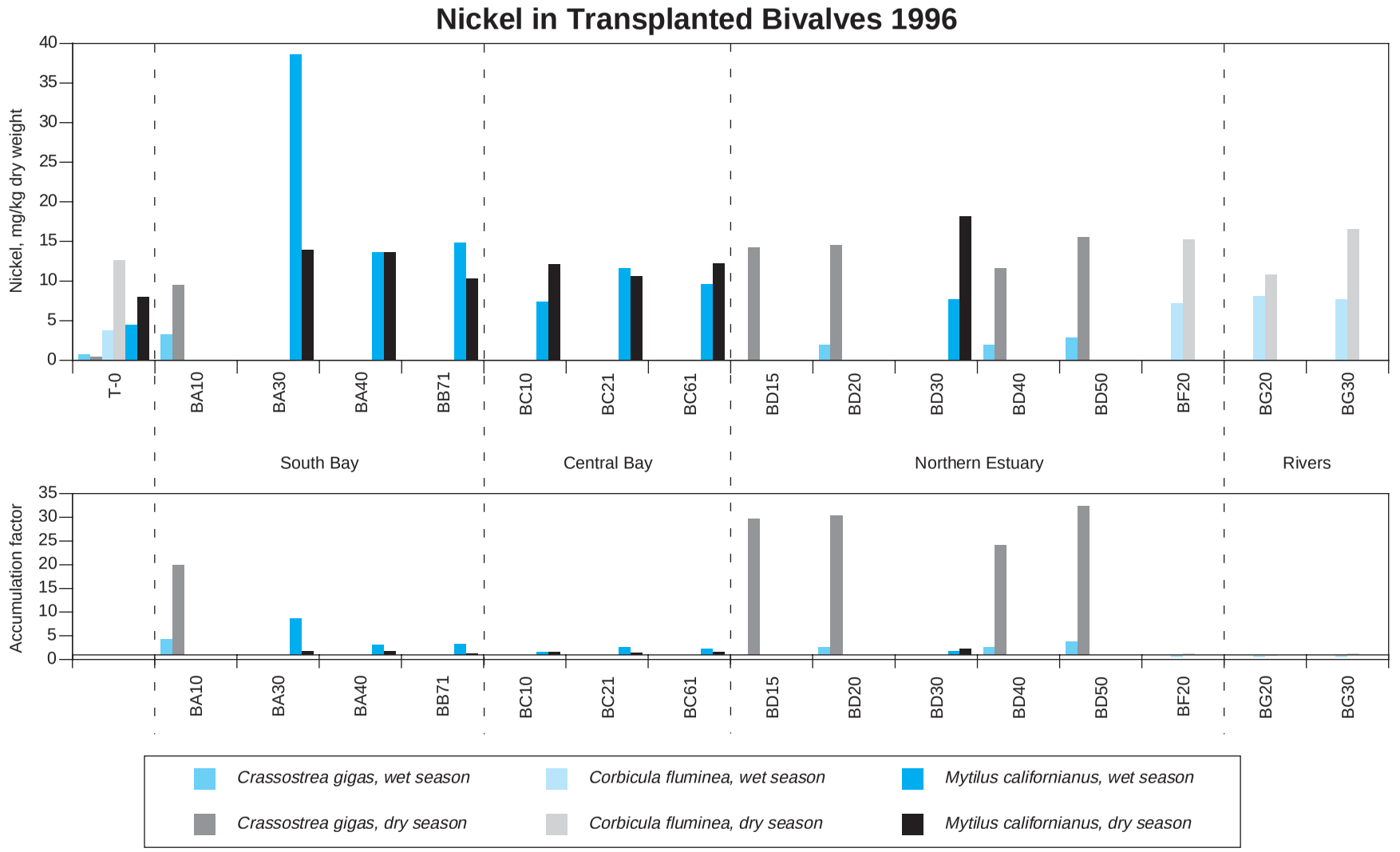

Figure 7. Nickel concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. T-0 (time zero) indicates the initial concentrations of nickel measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary.Accumulation factors were > 2 at all station where *C. gigas* were deployed during both seasons, and at most stations where *M. californianus* were deployed during the wet season. Accumulation factors ranged from 0.5, indicating depuration, to 32. All stations showed tissue concentrations much lower than the Maximum Tissue Residue Level (MTRL) of 1,540 ppm dry weight (196 ppm dry weight for *C. fluminea*) during both seasons. Due to 0% survival, *C. gigas* was not analyzed in the wet season at Petaluma River (BD15).

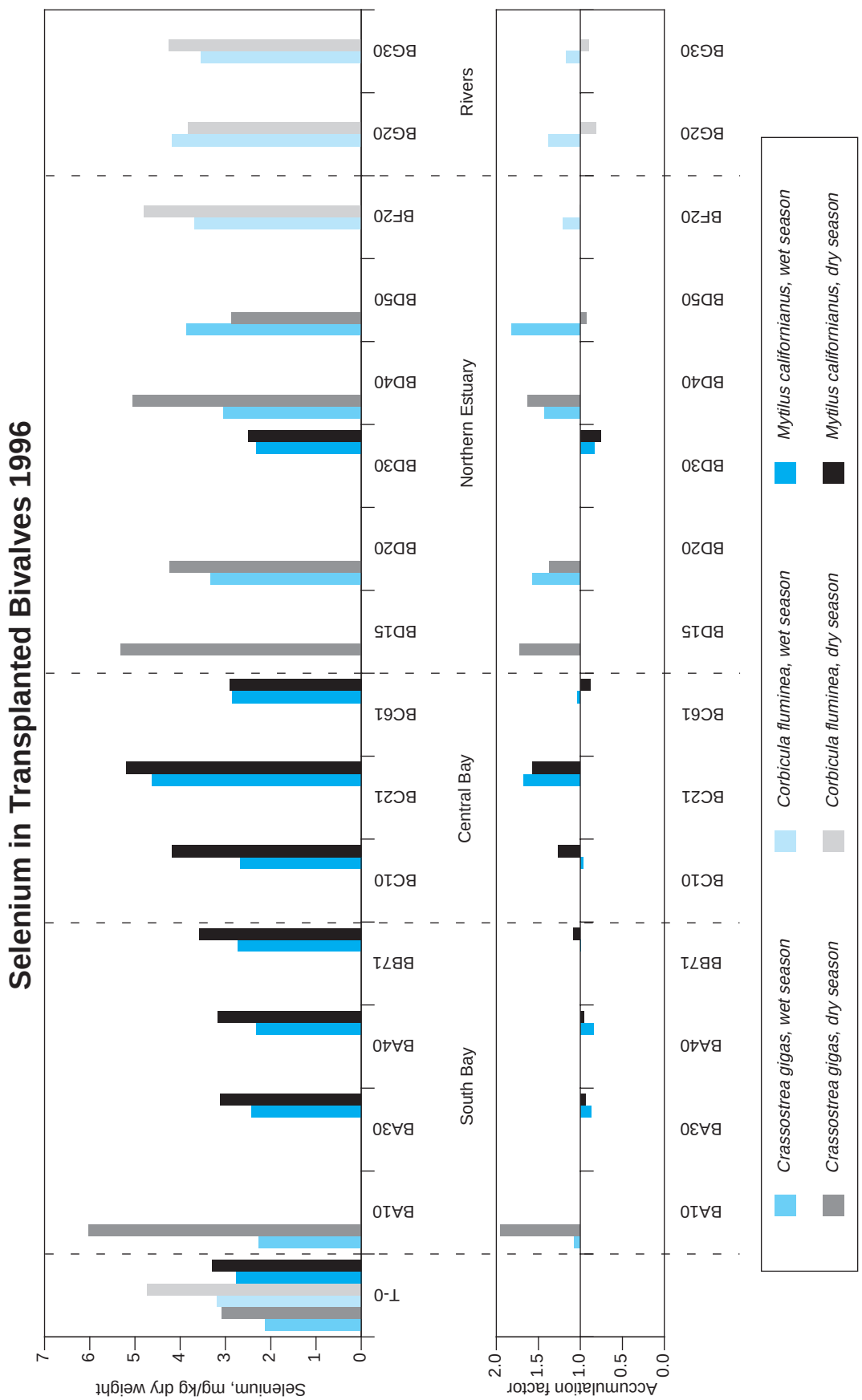

Figure 8. Selenium concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. T-0 (time zero) indicates the initial concentrations of selenium measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Accumulation factors at all stations were below 2 with the highest tissue concentrations found in *C. gigas* during the dry season. Accumulation factors ranged from 0.8, indicating depuration, to 1.9. There are no Maximum Tissue Residue Level (MTRL) guidelines for selenium. Due to 0% survival, *C. gigas* was not analyzed in the wet season at Petaluma River (BD15).

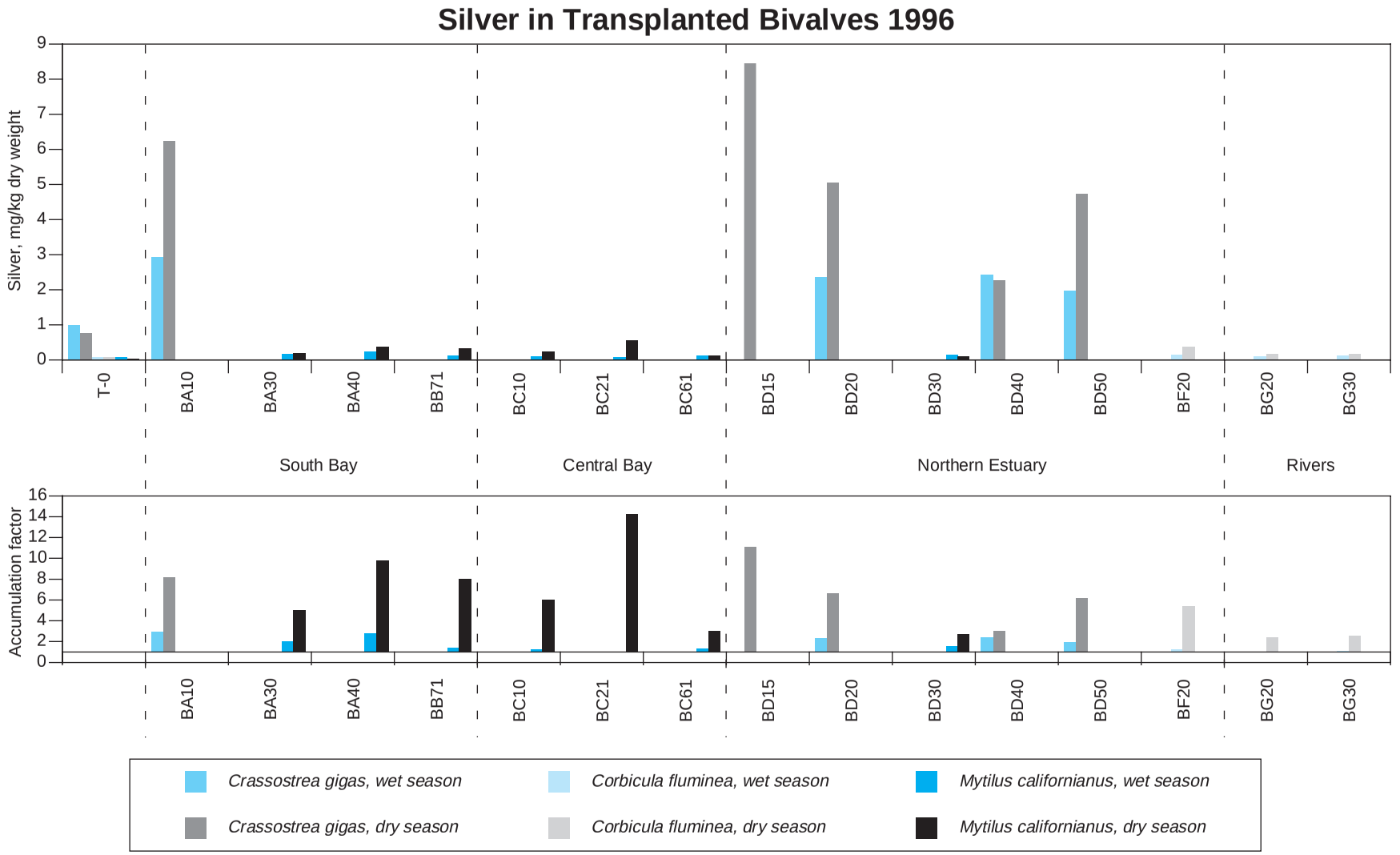

Figure 9. Silver concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. T-0 (time zero) indicates the initial concentrations of silver measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Accumulation factors were > 2 at all stations during the dry season, and at five stations during the wet season. Accumulation factors ranged from 1.0, indicating depuration, to 14.3. Silver concentrations in *C. gigas* were considerably higher than in *M. californianus* or *C. fluminea*. On average, all bivalves accumulated roughly three times more silver during the dry season than during the wet. There are no Maximum Tissue Residue Level (MTRL) guidelines for this compound. Due to 0% survival, *C. gigas* was not analyzed in the wet season at Petaluma River (BD15).

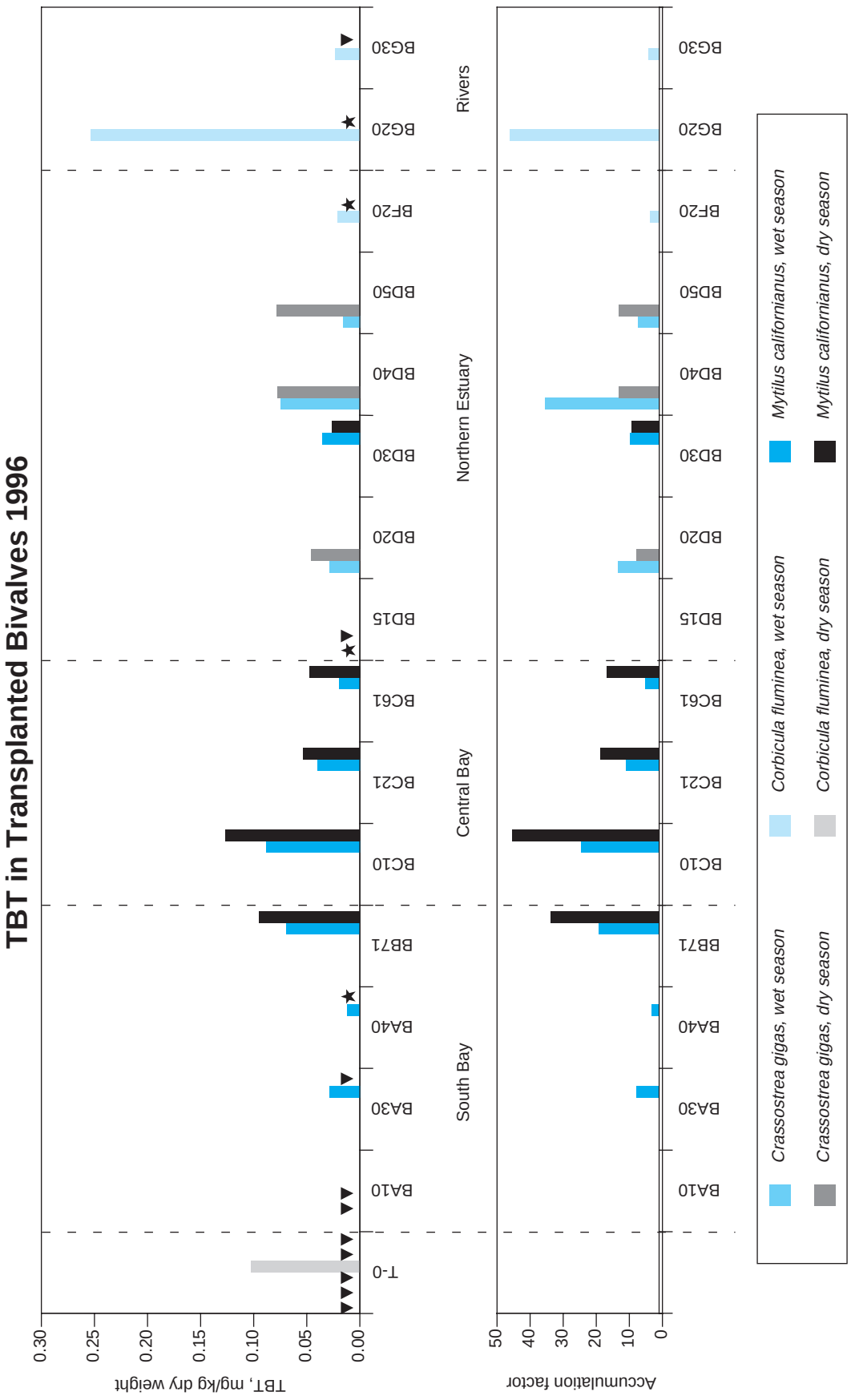

Figure 10. Tributyltin concentrations, expressed in terms of total tin (ppm dry weight), in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. T-0 (time zero) indicates the initial concentrations of tributyltin measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. ▼ indicates not detected and ★ indicates that the compound was not analyzed for at that station. There are no Maximum Tissue Level (MTRL) guidelines for this compound. Accumulation factors were calculated using half the method detection limit (MDL) for thosestations where the T-0 concentration was below detection. The MDLs for *C. gigas* for the wet and dry season were 0.004 and 0.01 ppm respectivly. *C. fluminea* wet season MDL was 0.01 ppm and *M. californianus* wet and dry season MDLs were 0.007 and 0.006 ppm respectively.

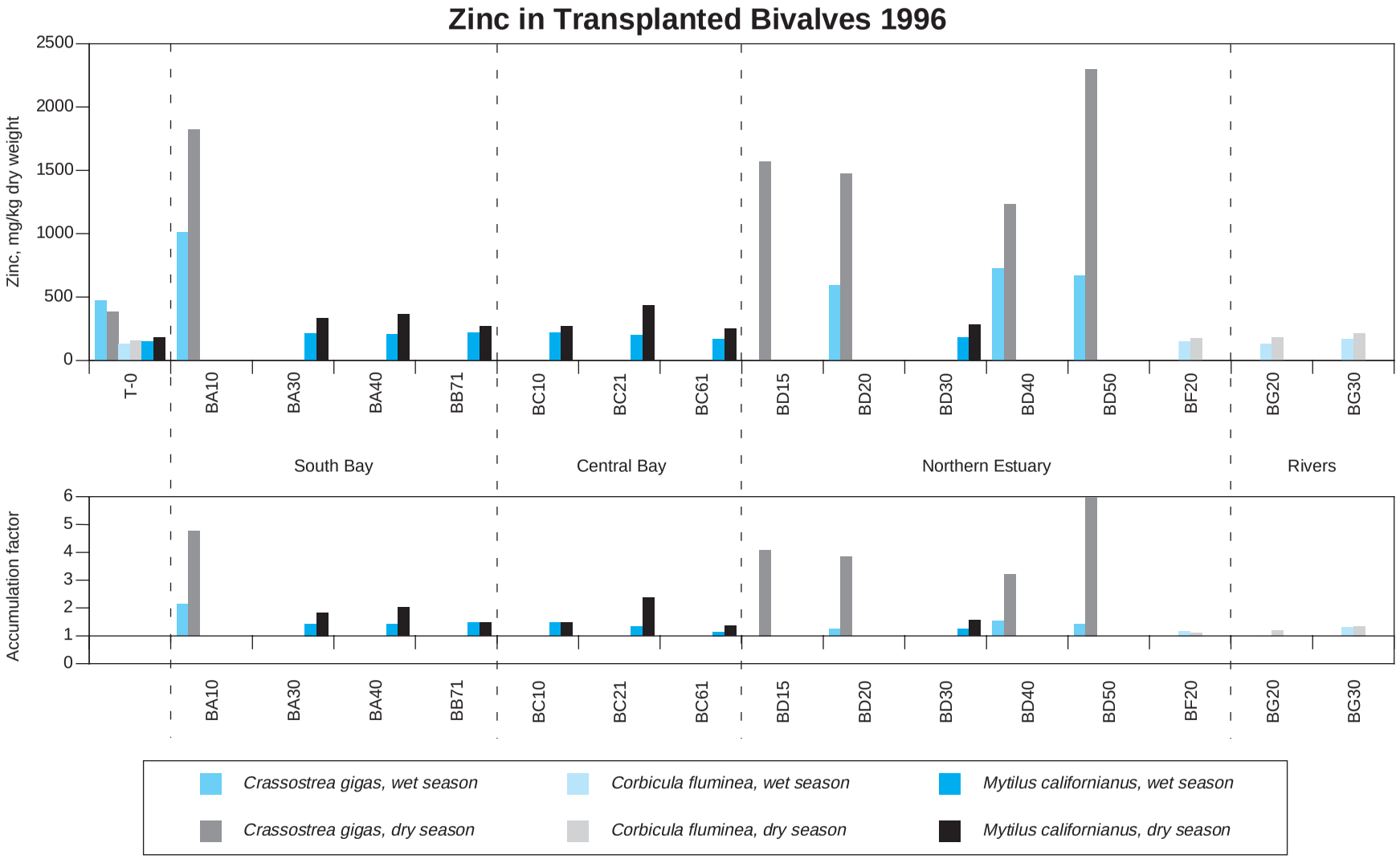

Figure 11. Zinc concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. T-0 (time zero) indicates the initial concentrations of zinc measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Accumulation factors were > 2 at all stations where *C. gigas* were deployed during the dry season. Accumulation factors ranged from 1 to 6. *C. gigas* had the highest accumulation factors as well as tissue concentrations among the three species. The highest concentrations were observed in *C. gigas* at Napa River (BD50) and Coyote Creek (BA10) during the dry season. There are no Maximum Tissue Residue Level (MTRL) guidelines for this compound. Due to 0% survival, *C. gigas* was not analyzed in the wet season at Petaluma River (BD15).

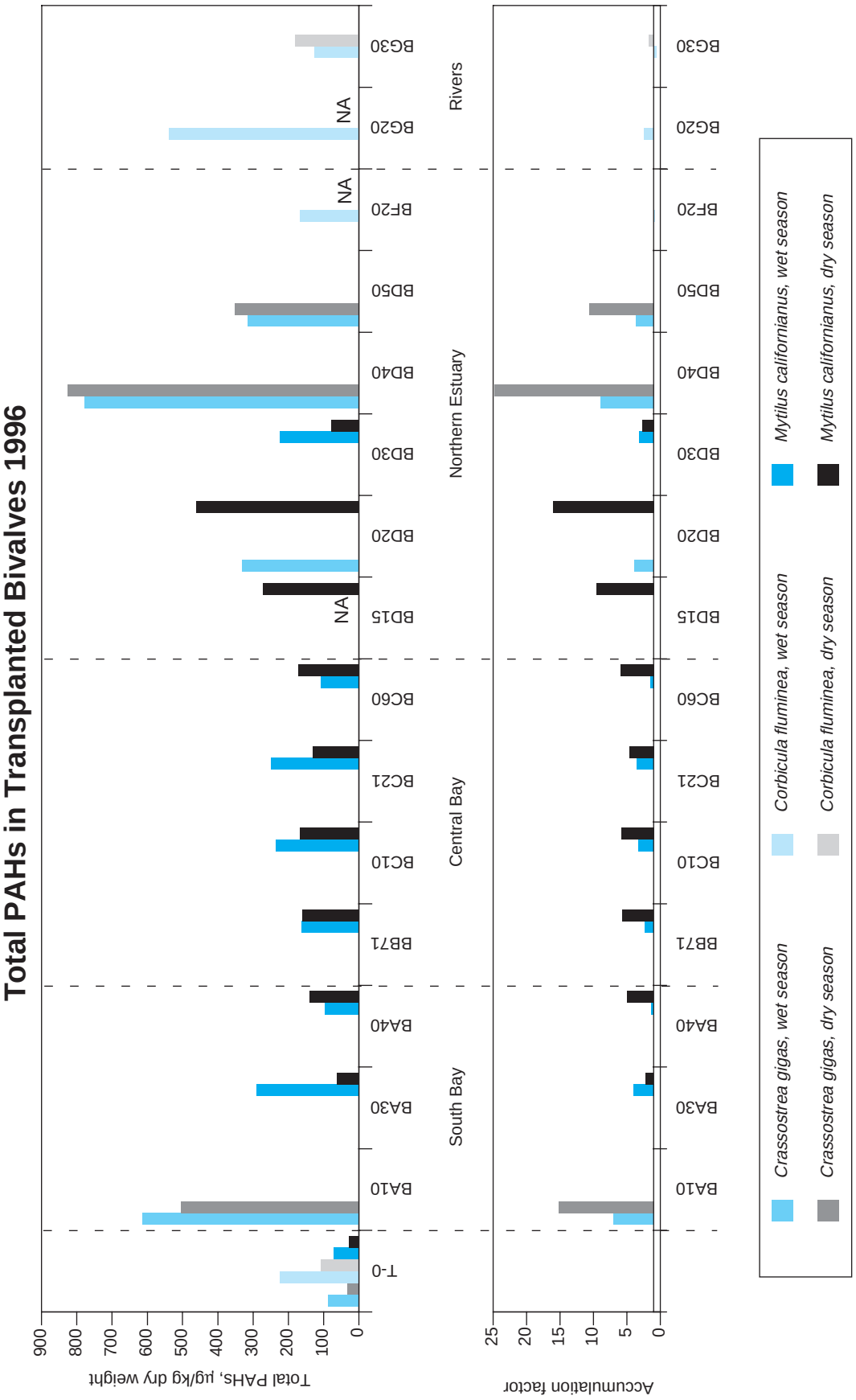

Figure 12. Total PAH concentrations in parts per billion dry weight (ppb) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. There were no wet-season samples for Petaluma River (BD15) due to zero percent bivalve survival, and no dry-season samples for Grizzly Bay (BF20) and Sacramento River (BG20)due to sample contamination. T-0 (time zero) indicates the initial concentrations of total PAHs measured on a subsample of each species takenfrom the reference locations at the time of deployment in the Estuary. Oysters had the highest median concentrations, clams were intermediate, andmussels were lowest. The highest concentration was measured in oysters at Davis Point (BD40) in the dry season. Accumulation factors rangedfrom 0.6, indicating depuration, to 24.8. All but five stations had accumulation factors > 2. All stations, including the reference stations, had total PAH concentrations that were higher than the Maximum Tissue Residue Level (MTRL) of 6.5 ppb dry weight (0.56 for *C. fluminea)* during both seasons.

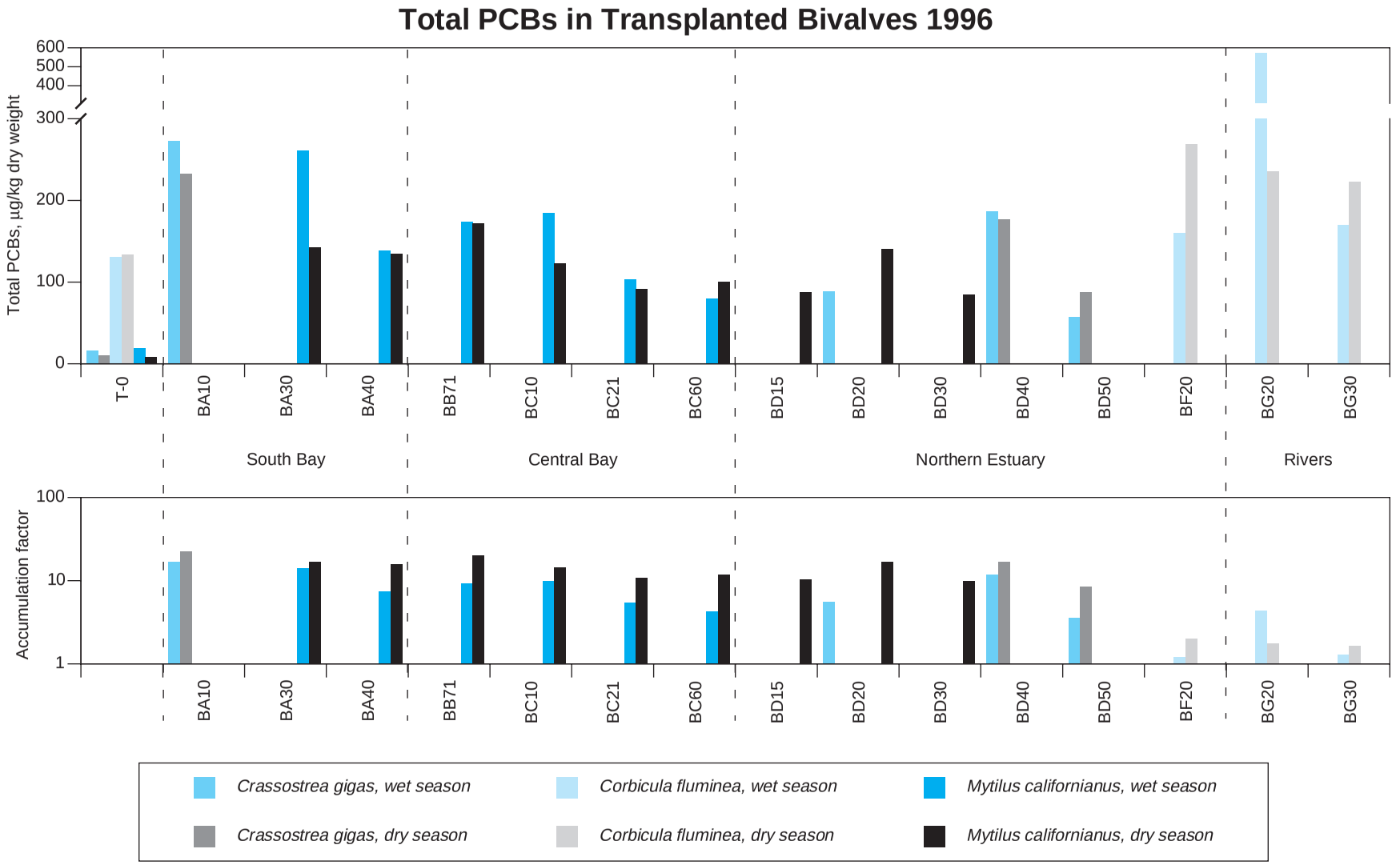

Figure 13. Total PCB concentrations in parts per billion dry weight (ppb) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. There were no wet-season samples for Petaluma River (BD15) due to zero percent bivalve survival, and no dry-season samples for Grizzly Bay (BF20) and Sacramento River (BG20) due to sample contamination. T-0 (time zero) indicates the initial concentrations of total PCBs measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Clams had the highest median concentrations, oysters were intermediate, and mussels were lowest. The highest concentration was measured in clams in the Sacramento River (BG20) in the wet season. Accumulation factors ranged from 1.2 to 22.5. All but five stations had accumulation factors > 2. All stations, including four of the six reference samples, had total PCB concentrations that were higher than the Maximum Tissue Residue Level (MTRL) of 15.4 ppb dry weight during both seasons.

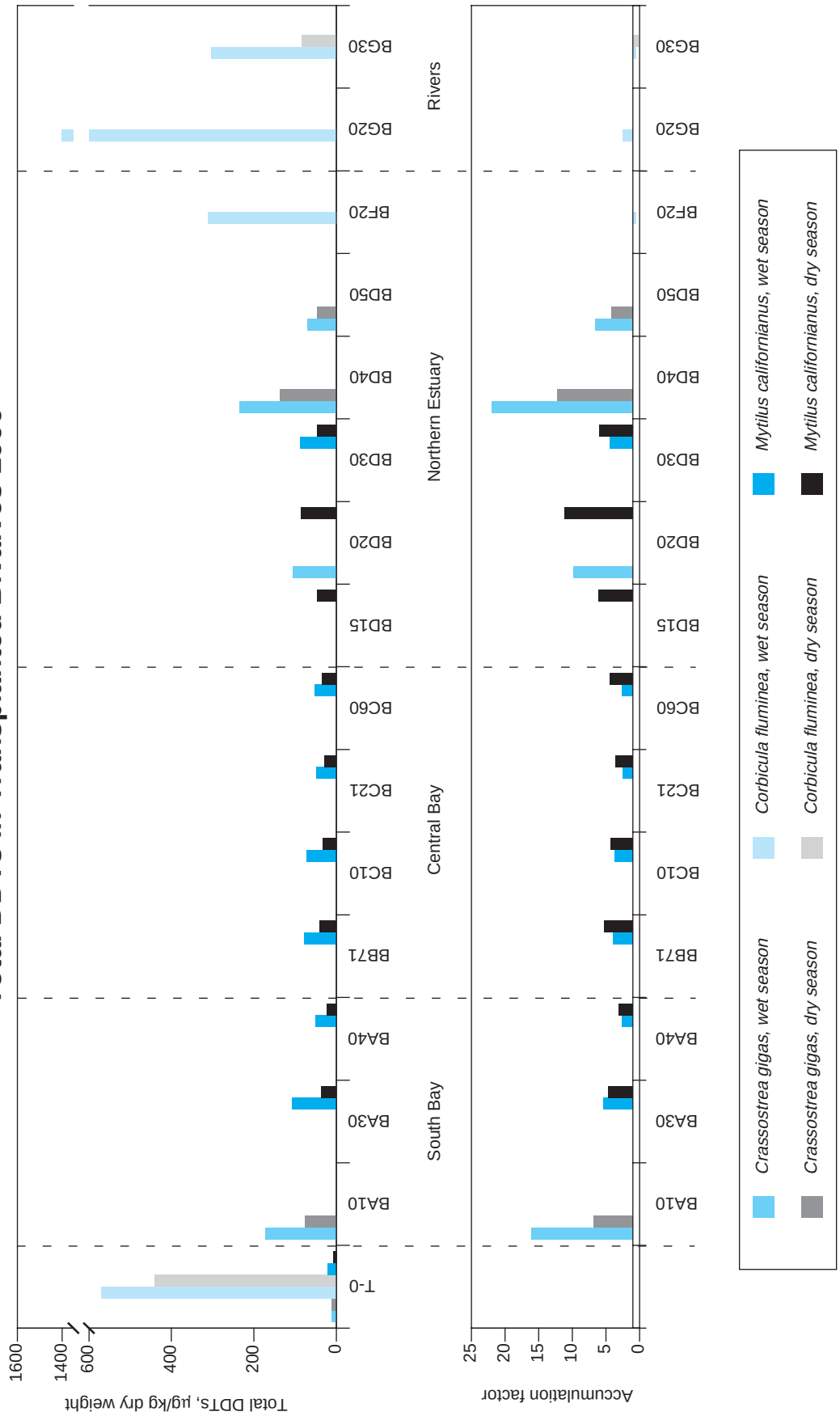

Figure 14. Total DDT concentrations in parts per billion dry weight (ppb) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. There were no wet-season samples for Petaluma River (BD15) due to zero percent bivalve survival, and no dry-season samples for Grizzly Bay (BF20) and Sacramento River (BG20) due to sample contamination. T-0 (time zero) indicates the initial concentrations of total DDTs measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Clams had the highest median concentrations, oysters were intermediate, and mussels were lowest. Accumulation factors were low for clams due to high concentrations at the control site, but were > 2 at all other sites. Five stations had total DDT concentrations that were higher than the Maximum Tissue Residue Level (MTRL) for DDTs of 224 ppb dry weight during the wet season. Only one station had a total DDT concentration higher than the MTRL during the dry season.

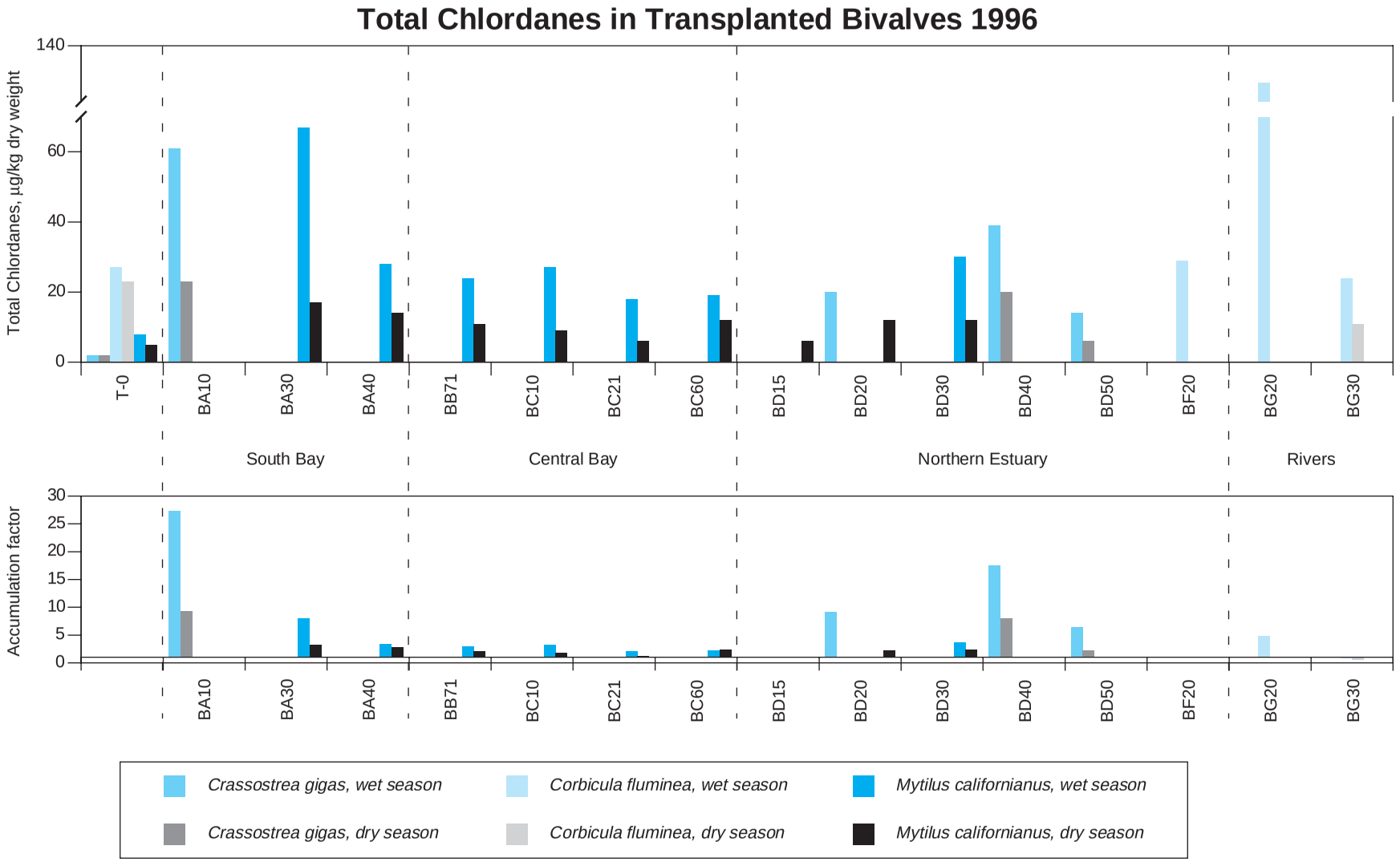

Figure 15. Total chlordane concentrations in parts per billion dry weight (ppb) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. There were no wet-season samples for Petaluma River (BD15) due to zero percent bivalve survival, and no dry-season samples for Grizzly Bay (BF20) and Sacramento River (BG20) due to sample contamination. T-0 (time zero) indicates the initial concentrations of chlordane measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Accumulation factors were > 2 at all but three *C. fluminea* stations. The highest concentration by far was measured in clams at Sacramento River (BG20) in the wet season. There are no MTRL values for total chlordanes.

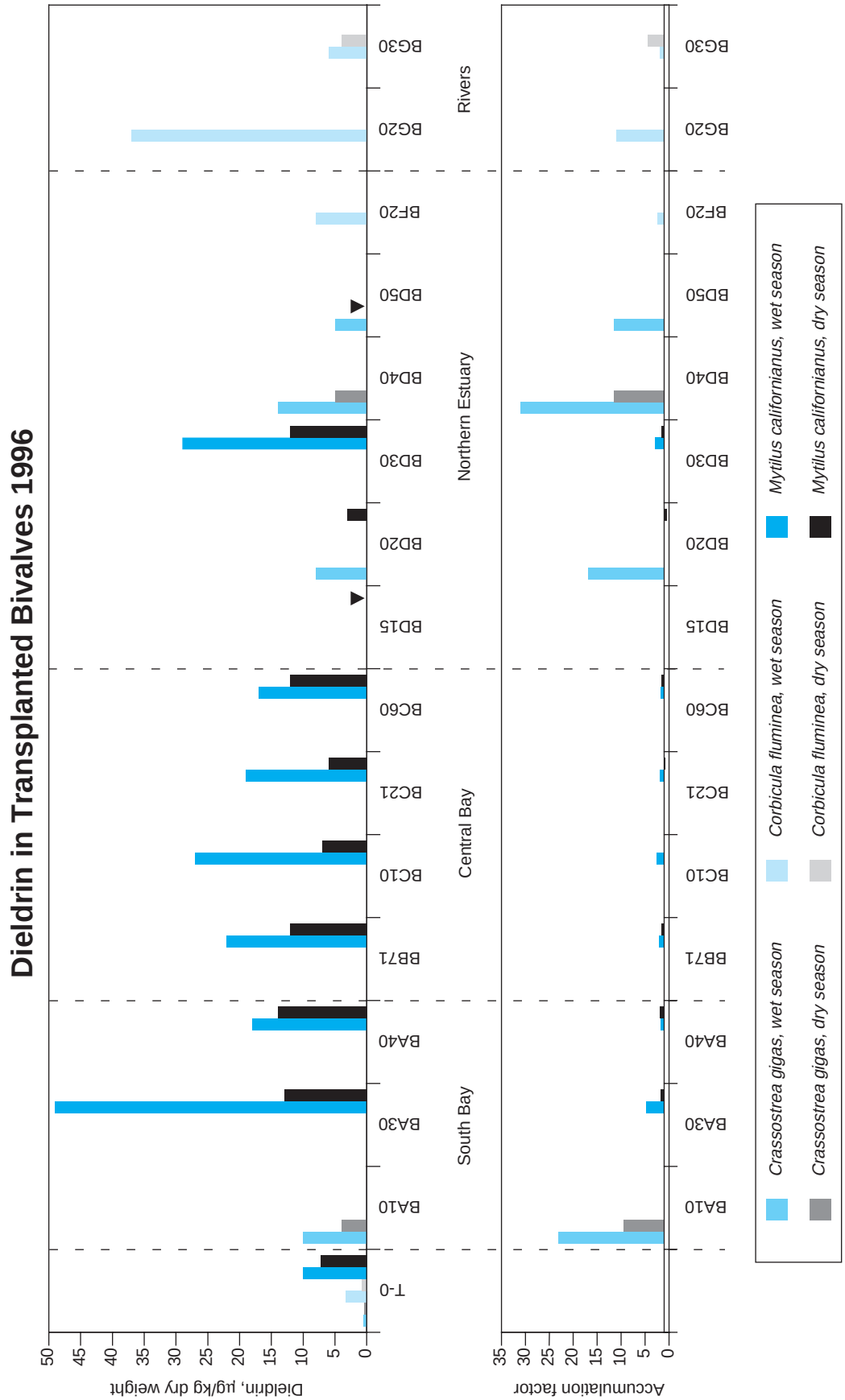

Figure 16. Total dieldrin concentrations in parts per billion dry weight (ppb) in three species of transplanted bivalves at 15 RMP stations during the wet- (April–May) and dry- (September) season sampling periods. There were no wet-season samples for Petaluma River (BD15) due to zero percent bivalve survival, and no dry-season samples for Grizzly Bay (BF20) and Sacramento River (BG20) due to sample contamination. T-0 (time zero) indicates the initial concentrations of chlordane measured on a subsample of each speciestaken from the reference locations at the time of deployment in the Estuary. ▼ indicates not detected. Mussels had the highest concentrations. Accumulation factors were higher for clams than for mussels and oysters, but the control site for mussels was relatively contaminated. Accumulation factors are calculated for *C. gigas* (both sample periods) and *C. fluminea* (dry season) using one half of the method detection limit, as initial T-0 concentrations were below the detection limit. In all species wet season concentrations were consistently higher than dry season concentrations. Please note that the T-0 concentrations for *M. californianus* were above the Maximum Tissue Residue Level (MTRL) guideline for both the wet and dry season. During the wet season, all RMP stations had concentrations that were higher than the MTRL of 4.9 ppb dry weight All seven *M. californianus* stations were above the MTRL guideline for dieldrin during the dry season.

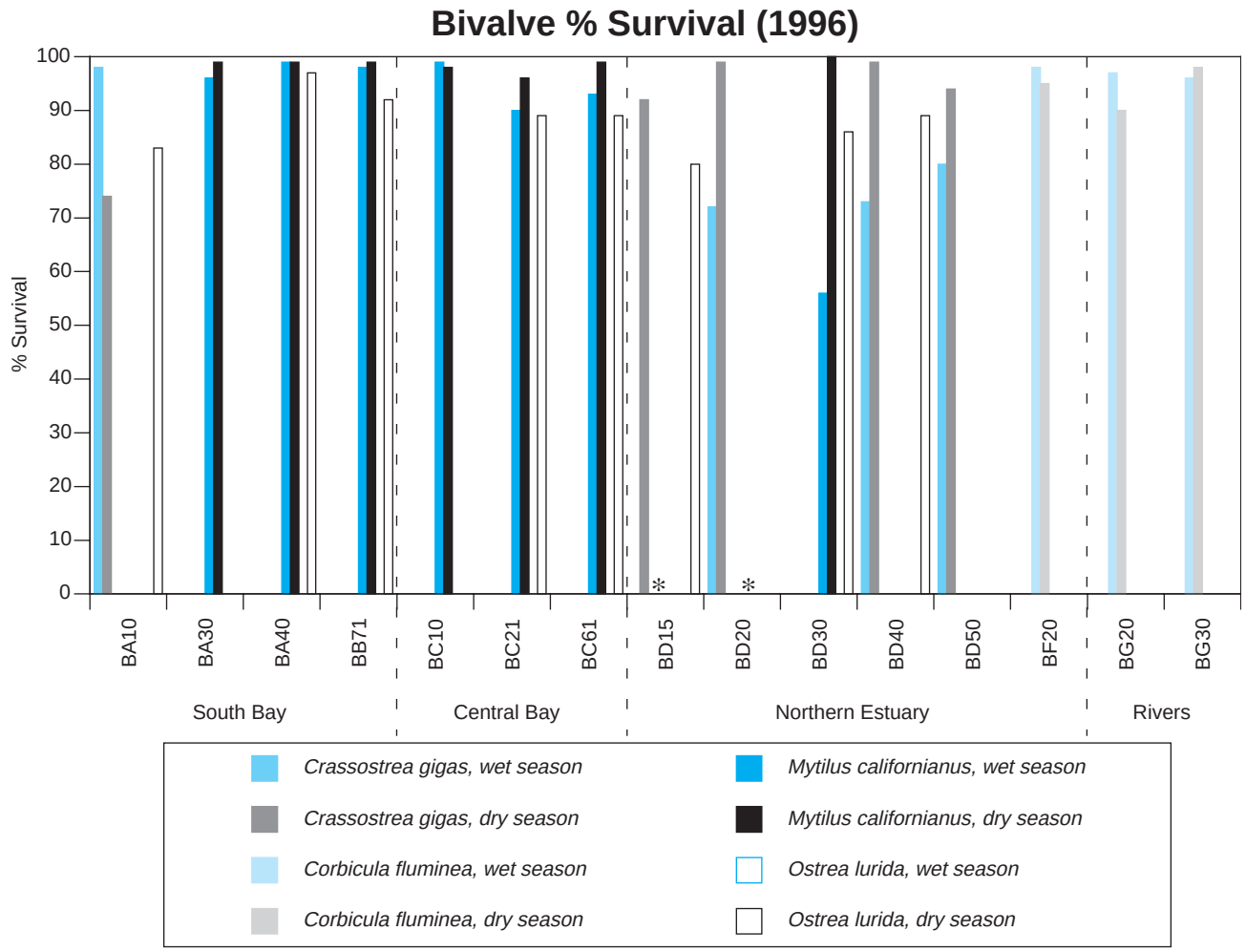

Figure 17. Percent survival of four species of transplanted bivalves following exposure to Estuary conditions during the wet (April–May) and dry season (September) of 1996.
* indicates 0% survival. *Ostrea lurida* was not deployed during the wet season.

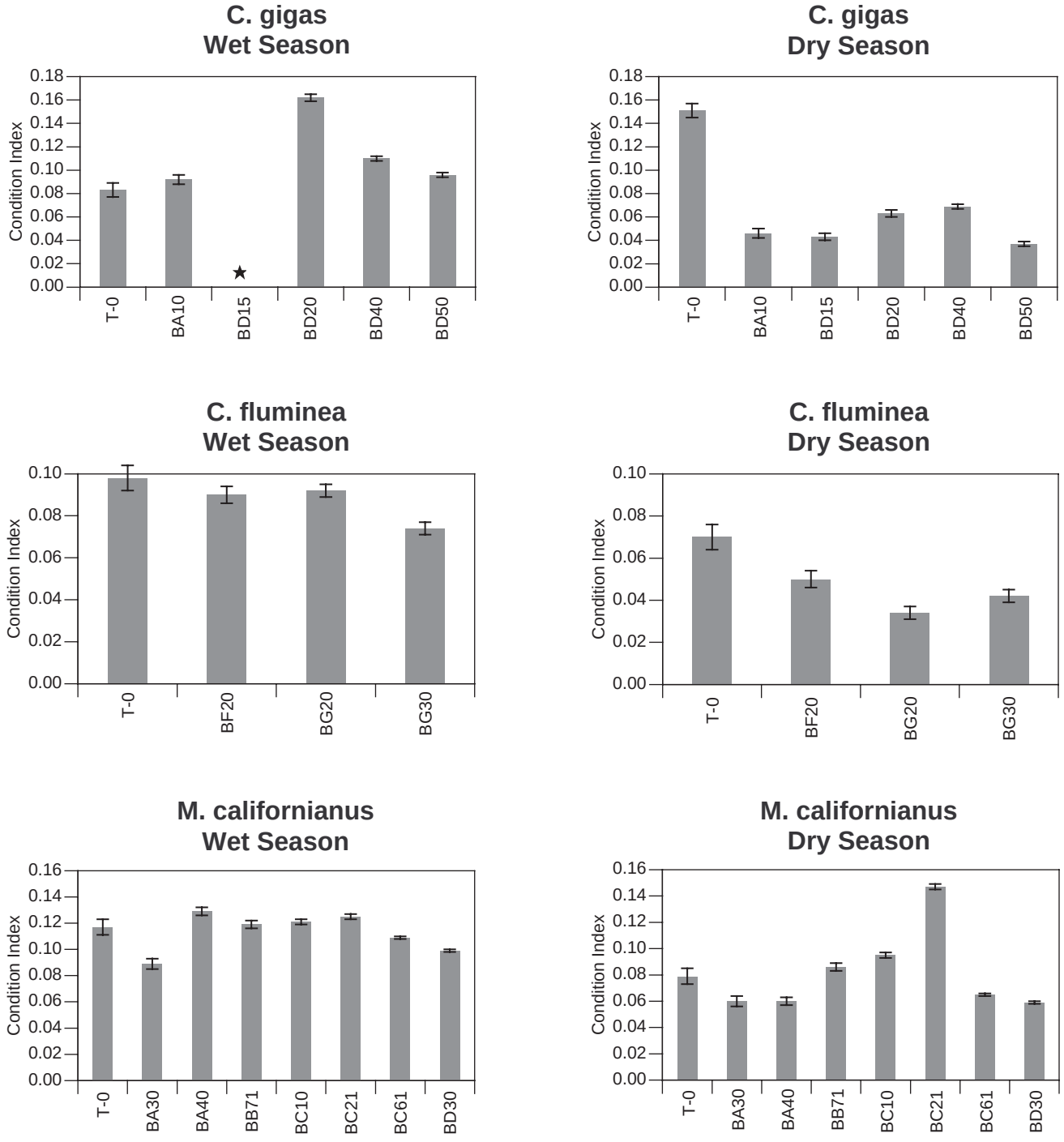

Figure 18. Condition Indices of three species of bivalves at their original "reference" locations, prior to deployment (T-0), and at the end of their exposure to San Francisco Estuary waters (various locations) during the wet and dry seasons of 1996. Bivalves deployed at the Petaluma River station (BD15) during the wet season did not survive (indicated by ★).

Bivalve Monitoring Trends

Transplanted bivalves are valuable in the assessment of long-term trends because they provide an integrated measure of contamination over a three-month period. This interval is more appropriate for assessment of interannual trends than the one-hour interval represented by RMP water samples or the approximate 20-year interval represented by RMP sediment samples. Long-term trends in contaminant concentrations in bivalves as measured in the California State Mussel Watch and the RMP are discussed in detail in the article by Gunther and Davis (this chapter).

This section presents plots of RMP bivalve bioaccumulation data from 1993 to 1996 (Figures 19 and 20). Concentrations in these plots are expressed as net bioaccumulation or depuration during the deployment period (initial concentrations prior to deployment have been subtracted from final concentrations measured after deployment). Presented in this manner, the plots are capable of showing the presence or absence of both trends and accumulation during deployment. In many cases (e.g., arsenic) there was either little accumulation or even net depuration during deployment. Mercury in clams has exhibited a consistent seasonal pattern, with higher concentrations in summer samples in all four years and perhaps an increasing trend over the period of record. Organics in clams showed depressed net accumulation in 1996 due to high concentrations present prior to deployment (T_{zero} concentrations). Clams at the Sacramento River in May 1996 had the highest concentrations of total PCBs and total DDTs observed in RMP clam deployments to date—these concentrations were far above even the high T_{zero} concentrations for that sampling period.

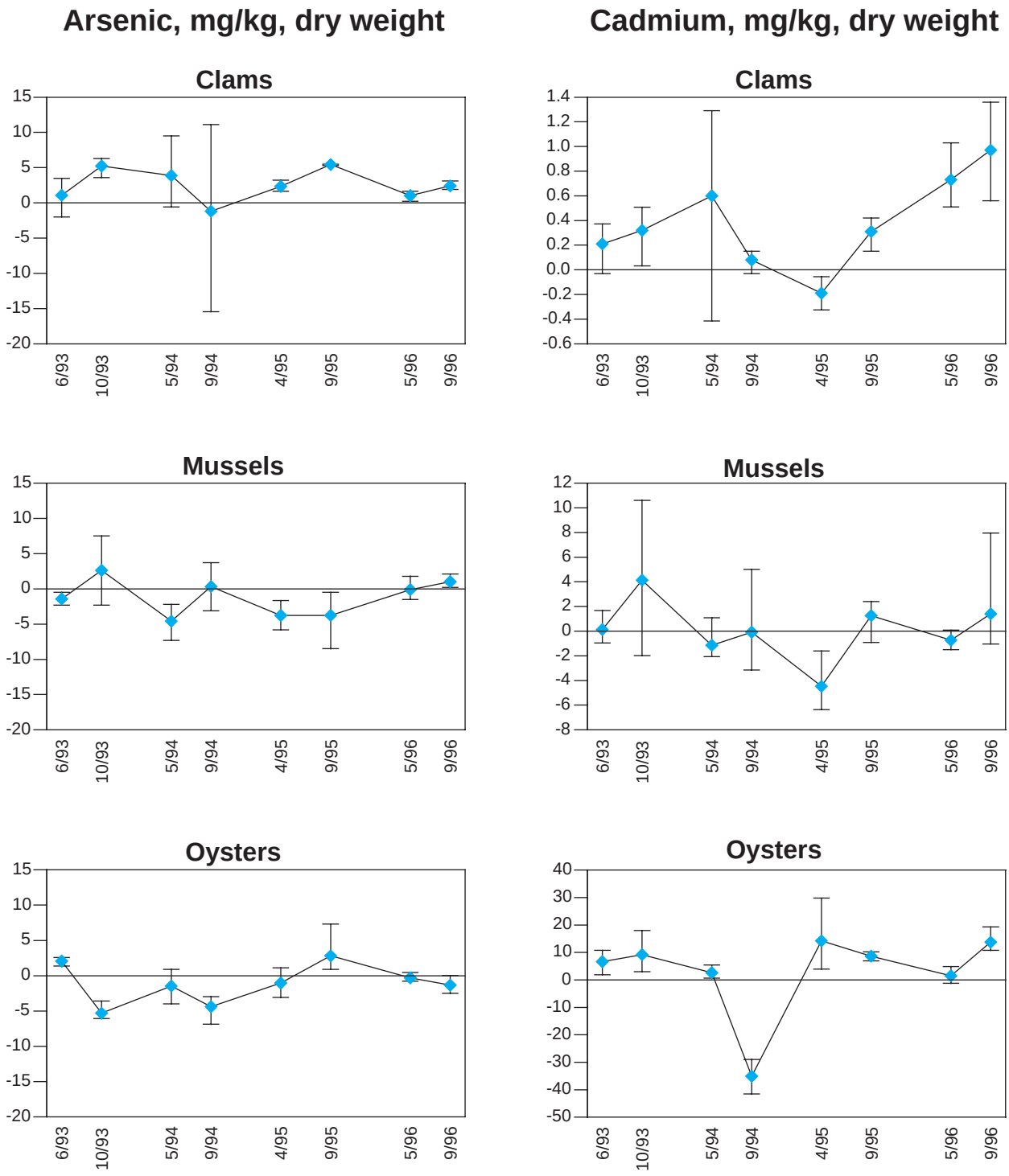

Figure 19. Trace element accumulation or depuration in parts per million, dry weight, (ppm) in three species of transplanted bivalves for eight sampling periods from 1993–1996. Initial (T-0) concentrations are subtracted from tissue concentrations after retrieval to give concentrations accumulated or depurated (negative value) during deployment in the Estuary. Bars indicate the range of values of all stations where species were deployed. Note different y-axis scales.

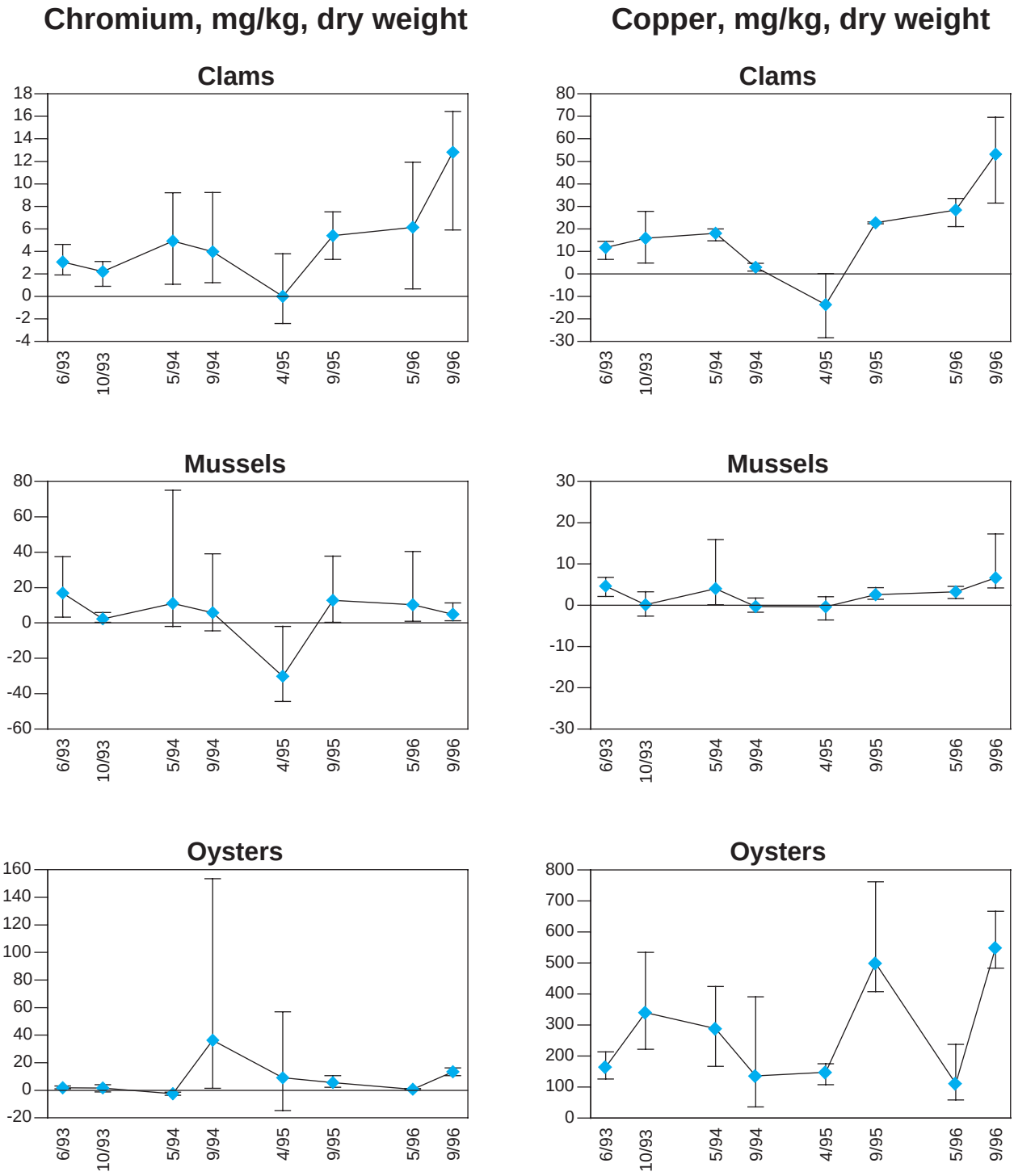

Figure 19 (continued). Trace element accumulation or depuration in parts per million, dry weight, (ppm) in three species of transplanted bivalves for eight sampling periods from 1993–1996.

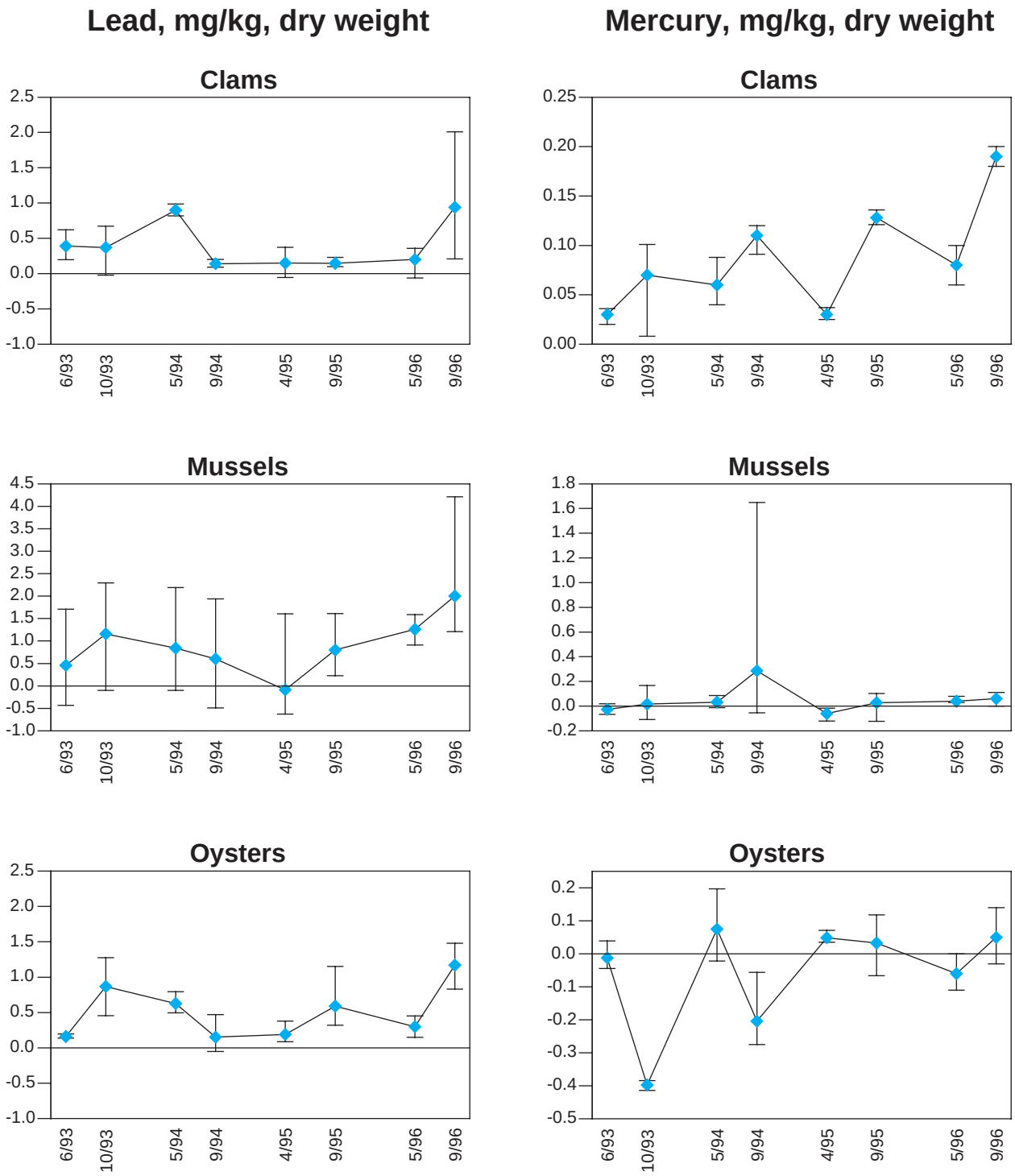

Figure 19 (continued). Trace element accumulation or depuration in parts per million, dry weight, (ppm) in three species of transplanted bivalves for eight sampling periods from 1993–1996.

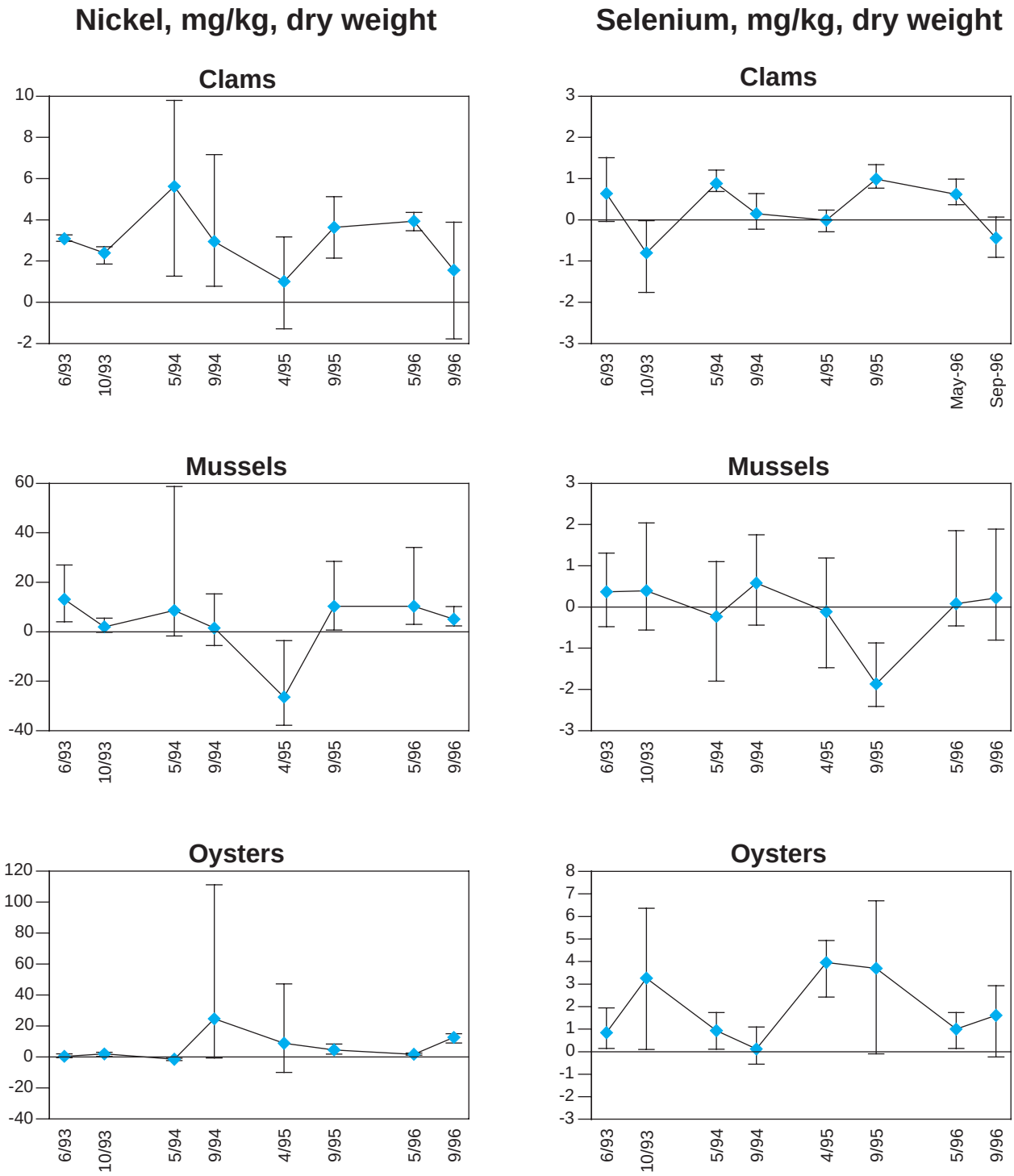

Figure 19 (continued). Trace element accumulation or depuration in parts per million, dry weight, (ppm) in three species of transplanted bivalves for eight sampling periods from 1993–1996.

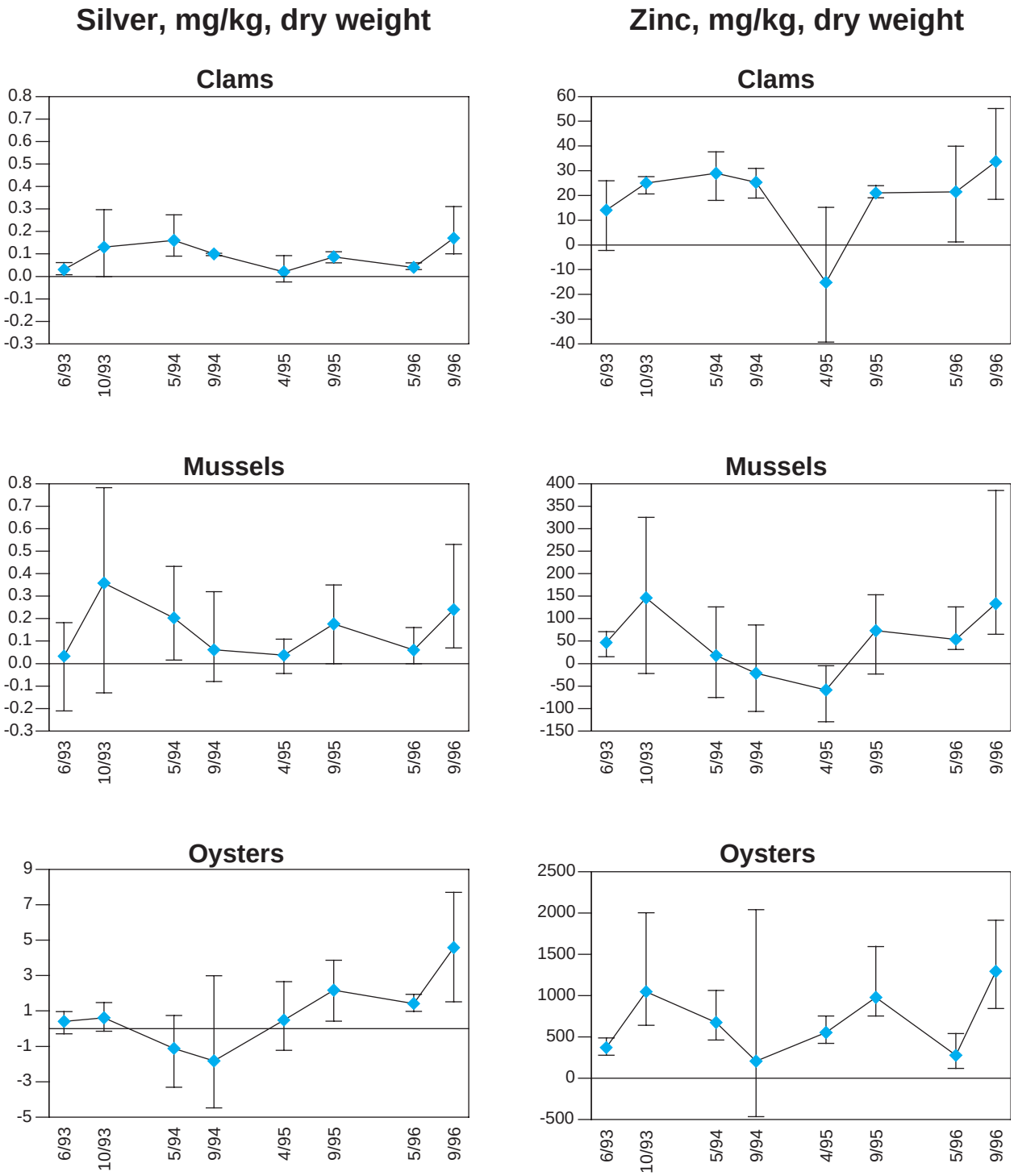

Figure 19 (continued). Trace element accumulation or depuration in parts per million, dry weight, (ppm) in three species of transplanted bivalves for eight sampling periods from 1993–1996.

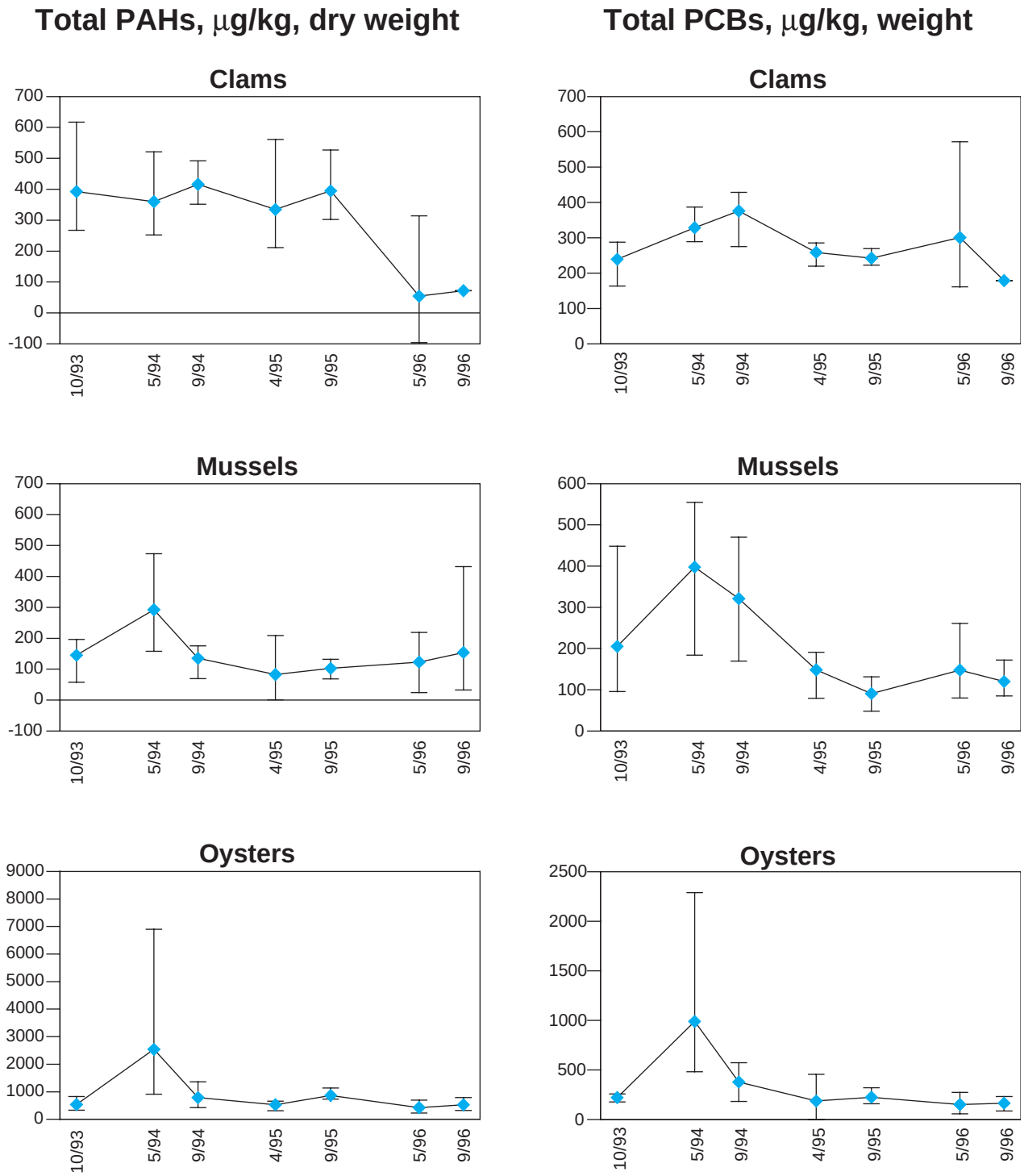

Figure 20. Trace organic accumulation or depuration in parts per billion, dry weight, (ppb) in three species of transplanted bivalves for eight sampling periods from 1993–1996. Initial (T-0) concentrations are subtracted from tissue concentrations after retrieval to give concentrations accumulated or depurated (negative value) during deployment in the Estuary. Bars indicate the range of values of all stations where species were deployed. Note different y-axis scales.

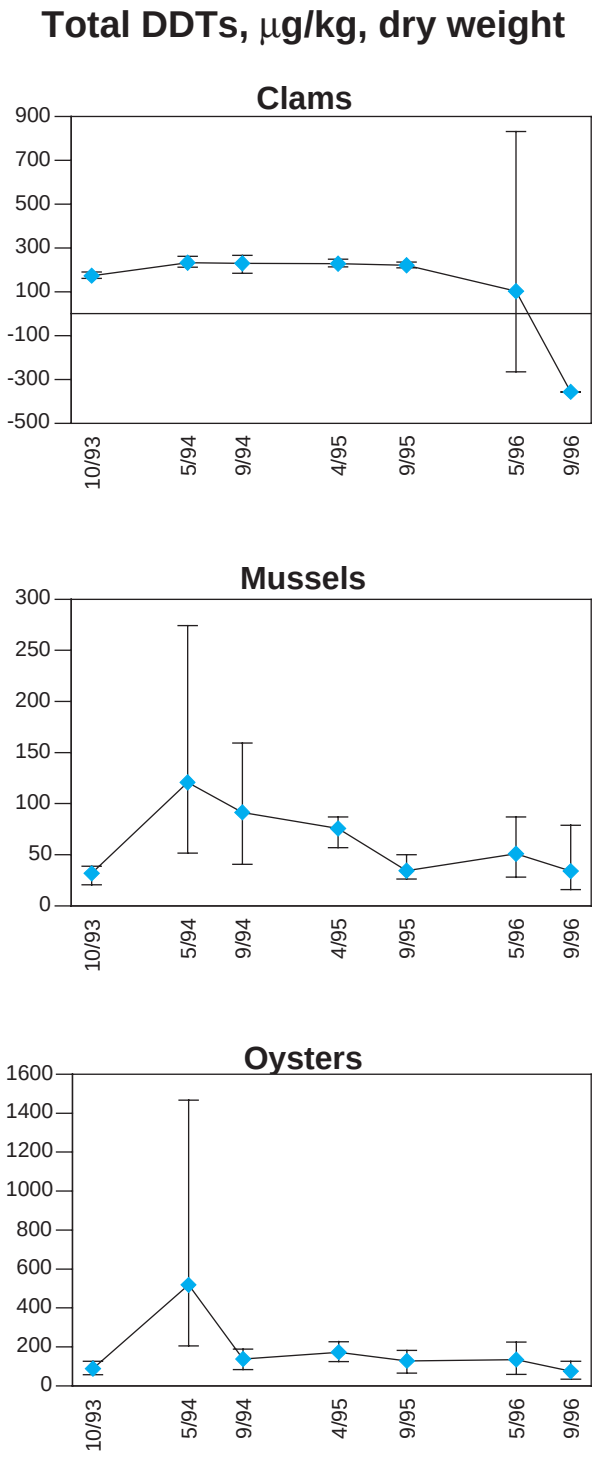

Figure 20 (continued). Trace organic accumulation or depuration in parts per billion, dry weight, (ppb) in three species of transplanted bivalves for eight sampling periods from 1993–1996.

An Evaluation of Bioaccumulation Monitoring with Transplanted Bivalves in the RMP

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Introduction

Contamination of estuarine waters by toxic substances is a problem throughout the United States (OTA, 1987; Kennish, 1992). In the San Francisco Estuary, water quality standards have been established for a variety of substances, and a large number of management programs have been implemented to reduce the discharge of toxic substances to the Estuary (SFBRWQCB, 1995). Monitoring the abundance and distribution of regulated contaminants in the Estuary is an essential step in determining the effectiveness of control efforts, identifying new contamination problems, and tracking natural processes that control contaminant abundance and distribution in the long term. The temporal and spatial variability of contaminant concentrations in water and sediment makes intensive sampling necessary to identify temporal trends, which is often too expensive for management agencies to undertake.

One long-recognized solution to this predicament is to utilize bivalves as biomonitors in what has often been called the "mussel watch" approach (Goldberg *et al.*, 1978; Phillips, 1980; Burns and Smith, 1981; Martin, 1985; De Kock and Kramer, 1994). Transplanted or resident bivalves can provide an indication of temporally and spatially averaged concentrations of bioavailable contaminants in aquatic ecosystems, thereby providing an integrated picture of the success of source reduction efforts in a watershed.

Practical advantages of the mussel watch approach include the ability of bivalves to:

1) accumulate contaminants to much higher concentrations than in water,
2) be easily transplanted and maintained,
3) tolerate contaminated environments,
4) not metabolize contaminants appreciably, and
5) provide an indication of contaminant bioavailability in an important estuarine and marine species (Martin and Richardson, 1991; Dame, 1996).

Disadvantages include:

1) uptake of contaminants will vary with environmental conditions such as salinity, turbidity, and food availability,
2) uptake kinetics may be too slow to equilibrate with the environment,
3) bioaccumulation can be affected by physiological status, especially reproduction, and
4) not all contaminants in the environment are readily accumulated by bivalves (Luoma and Linville, 1995).

Bioaccumulation sampling can be conducted using resident organisms ("passive" biomonitoring), or by transplanting organisms from relatively clean environments to locations of interest ("active" biomonitoring) (De Kock and Kramer, 1994). The latter technique has several advantages, including:

1) organisms can be placed at desired locations,
2) bioaccumulation occurs over a known time interval,
3) statistically similar groups of organisms (source population, size, age, exposure history) can be placed at each station, and
4) in San Francisco Bay, the State Mussel Watch program provides a historical database for comparison.

The disadvantages of transplants include:

1) spatial coverage of any one species is limited in an estuary,
2) changes in behavior after transplantation are possible, including reduced feeding due to physiological stress or other causes,
3) "clean" sites that are sources of transplants may become contaminated,
4) contaminants may not reach equilibrium

during the deployment period, and
5) the method is relatively expensive and complicated compared to using resident organisms.

In this paper we report on the results of biomonitoring for 15 years at two locations in the San Francisco Estuary via transplantation of the mussel *Mytilus californianus* under the State Mussel Watch and RMP, and on results using the oyster *Crassostrea gigas* and the clam *Corbicula fluminea* in the four years of the RMP. Temporal trends are examined to draw conclusions about changes in the water quality over time, including the detection of a major influx of chromium to the Estuary.

Methods

The methods used for collection, deployment, and analysis are summarized in previous publications. The trace element methods used by State Mussel Watch (SMW) are described by Stephenson and Leonard (1994), and organic chemistry methods are found in Stephenson *et al*. (1995). The methods used by the Regional Monitoring Program (RMP) are found in the *Quality Assurance Program Plan* (Lowe and Hoenicke, 1996) and *Appendix A*.

The RMP biomonitoring program was modeled after the SMW program in order to make best use of the long-term data set developed by the SMW for San Francisco Bay. Due to the participation of different laboratories, limitations of funds, and logistical considerations, the methods of the two programs have deviated slightly. These differences must be considered when comparing the results from the RMP and SMW, and are discussed below as appropriate.

Evaluation of the Utility of Monitoring with Transplanted Bivalves

Survival and Condition of Transplants

Despite the hardiness of bivalves, including their tolerance to pollution, their utility as biomonitors is compromised if they are severely stressed (or, obviously, if they do not survive). The RMP has monitored survival and the change of body condition of the transplanted animals to indicate physiological stress. Body condition is defined as the ratio of dry weight to shell volume (Pridmore *et al*., 1990), and this measurement is made for individuals from each station and compared to condition in individuals in the waters that serve as sources for the transplanted bivalves.

Survival

Survival data for the three species are summarized in Table 1. The California mussel (*Mytilus californianus)* is a native species on the west coast in wave-exposed intertidal settings (McDonald and Koehn, 1988), and has a salinity tolerance of approximately 50%–150% natural seawater (Morris *et al*., 1980). This species has been deployed primarily in the most saline portions of the Bay, between the Dumbarton Bridge (BA30) and Pinole Point (BD30) stations. *Mytilus* transplants have had higher survival rates when prevailing salinities were high (Table 1). Consistently high survival has been observed at the most saline stations (Alameda [BB70], Yerba Buena Island [BC10], and Horseshoe Bay [BC21]). Survival at the other lower salinity mussel stations was more variable, and was low in the winter of 1995 when high freshwater flows led to low salinities in most of the Estuary. Survival has always been low in winter deployments at Pinole Point except for the dry winter of 1994. Survival in summer mussel transplants has been consistently high at all stations.

The oyster *Crassostrea gigas* is a native of Japan, with a salinity tolerance of 2–35‰ (Phillips, 1988). Oysters have been deployed at RMP stations with intermediate salinities. Oyster survival was best at San Pablo Bay (Table 1), with only one cruise yielding a survival of less than 90% (72% in winter 1996). Survival was moderately good at Coyote Creek (BA10) and Davis Point (BD40). At both Petaluma River (BD15) and Napa River (BD50) survival was poor in three of the eight cruises. No clear seasonal pattern in oyster survival was evident.

Table 1. Survival (%) of transplanted bivalves at RMP stations from 1993–1996.

MYTILUS

	Dumbarton Bridge	Redwood Creek	Alameda	Yerba Buena Island	Horseshoe Bay	Red Rock	Petaluma River	Pinole Point	Davis Point	Napa River
Winter 93	88	96		94	98			63		
Summer 93	98	99		98	95		98	97	97	16
Winter 94	96	99	99	99	97	96	33	99		
Summer 94	98	98	98	94	95	96	80	95		
Winter 95	18	18	93	92	98	37		0		
Summer 95	89	96	99	97	98	99		99		
Winter 96	96	99	98	99	90	93		56		
Summer 96	99	99	99	98	96	99		100		
Winter Average	*74*	*78*	*97*	*96*	*95*	*75*	*33*	*54*		
Summer Average	*96*	*98*	*99*	*97*	*96*	*98*	*89*	*98*	*97*	*16*
Overall Average	*85*	*88*	*98*	*96*	*96*	*86*	*70*	*76*	*97*	*16*

CRASSOSTREA

	Coyote Creek	Dumbarton Bridge	Petaluma River	San Pablo Bay	Davis Point	Napa River	Grizzly Bay
Winter 93				100	95	18	
Summer 93		37	61		46	32	
Winter 94	73		96	97	97	97	
Summer 94	69		75	91	91	91	23
Winter 95	97		0	92	77	83	0
Summer 95	60		25		64	33	
Winter 96	98		0	72	73	80	
Summer 96	74		92	99	99	94	
Winter Average	*89*		*32*	*90*	*85*	*70*	*0*
Summer Average	*68*	*37*	*63*	*95*	*75*	*63*	*23*
Overall Average	*78*	*37*	*50*	*92*	*80*	*66*	*12*

CORBICULA

	Petaluma River	Grizzly Bay	Sacramento River	San Joaquin River
Winter 93		96	96	85
Summer 93		84	53	69
Winter 94		72	93	86
Summer 94		45	94	95
Winter 95	65	89	62	71
Summer 95	2	96	90	76
Winter 96		98	97	96
Summer 96		95	90	98
Winter Average	*65*	*89*	*87*	*84*
Summer Average	*2*	*80*	*82*	*84*
Overall Average	*34*	*84*	*84*	*84*

Table 2. Condition factors for transplanted bivalves at RMP stations from 1993–1996. Condition factor is the ratio of the condition index at the transplant site to the condition index of animals at the source location after the deployment period.

MYTILUS

	Dumbarton Bridge	Redwood Creek	Alameda	Yerba Buena Island	Horseshoe Bay	Red Rock	Pinole Point
Winter 94	1.38	1.65	1.00	1.56	1.66	0.75	0.88
Summer 94	0.72	0.66	0.70	1.40	1.54	0.83	0.67
Winter 95	1.16	1.53	1.22	1.27	1.17	0.87	
Summer 95	0.56	0.56	0.78	0.80	1.27	0.68	0.63
Winter Average	*1.27*	*1.59*	*1.11*	*1.42*	*1.42*	*0.81*	*0.88*
Summer Average	*0.64*	*0.61*	*0.74*	*1.10*	*1.41*	*0.76*	*0.65*
Overall Average	*0.95*	*1.10*	*0.93*	*1.26*	*1.41*	*0.78*	*0.73*

CRASSOSTREA

	Coyote Creek	Petaluma River	San Pablo Bay	Davis Point	Napa River
Winter 94	0.80	0.66	0.83	0.64	0.35
Summer 94	0.24	0.22	0.40	0.55	0.35
Winter 95	0.82		0.69	0.56	0.31
Summer 95	0.27	0.40		0.74	0.40
Winter Average	*0.81*	*0.66*	*0.76*	*0.60*	*0.33*
Summer Average	*0.25*	*0.31*	*0.40*	*0.64*	*0.38*
Overall Average	*0.53*	*0.43*	*0.64*	*0.62*	*0.35*

CORBICULA

	Petaluma River	Grizzly Bay	Sacramento River	San Joaquin River
Winter 94		0.64	0.67	0.67
Summer 94		1.25	1.16	1.07
Winter 95	0.88	0.82	0.71	0.75
Summer 95		0.72	0.62	0.66
Winter Average	*0.88*	*0.73*	*0.69*	*0.71*
Summer Average		*0.99*	*0.89*	*0.86*
Overall Average	*0.88*	*0.86*	*0.79*	*0.79*

The Asiatic clam, *Corbicula fluminea,* is native to China and has a salinity tolerance of 0–3‰, and possibly as high as 10‰ (Phillips, 1988). Clams have been deployed at freshwater RMP sites near the Delta. Clam survival was moderately good at all sites, averaging 84% at the three sites with consistent deployments. Low survival rates were observed at Grizzly Bay (BF20) in summer 1994 and at Sacramento River (BG20) in summer of 1993. No clear seasonal pattern in clam survival was evident.

Condition

Condition data for the three species are summarized in Table 2. The data are expressed as a ratio of the condition index at each station to the condition measured in animals at the source location at the end of the deployment period ("condition factor"). This condition factor provides an indication of whether transplanted bivalves experienced gains or losses in body mass during deployment while taking into account the normal body mass variation that might occur in undisturbed animals due to reproductive cycles or other seasonal physiological variation. A condition factor of less than one indicates that the animals lost body mass relative to undisturbed animals during the deployment period. On the other hand, a condition factor greater than one indicates that the transplants gained body mass relative to undisturbed animals. A condition factor significantly lower than one suggests that the animals were not feeding or were under physiological stress during deployment. Suppressed feeding might occur due to several causes (e.g., osmotic stress, low food availability, or toxic effects of contaminants), but, whatever the cause, observation of low condition factors in transplants raises doubts about the effective functioning of the bivalves as indicators of trophic transfer of contaminants in the estuarine food web.

Condition in animals at the source locations at the end of the deployment period (referred to as "T1 condition" in previous Annual Reports) was only measured in 1994 and 1995.

Condition factors in mussels were consistently greater than one at the most saline sites, Horseshoe Bay (BC21) and Yerba Buena Island (BC10), with only one instance of a ratio less than one (BC10 in summer 1995). Condition factors at Dumbarton Bridge (BA30), Redwood Creek (BA40), and Alameda (BB70) were always greater than one in winter deployments, and always well below one in summer deployments. At Red Rock (BC61) and Pinole Point (BD30) condition factors were always less than one. Pinole Point (BD30) had the lowest average condition factor (0.73) of any of the mussel stations.

In oysters, condition factors were always less than one. At three stations, Coyote Creek (BA10), Petaluma River (BD15), and San Pablo Bay (BD20), average condition factors in winter were much higher than in summer. Condition factors in oysters at Napa River (BD50) were consistently very low, averaging 0.35.

Condition factors in clams were generally less than 1 (Table 2). In summer of 1994, however, condition factors greater than 1 were obtained at all three stations where clams were deployed. Condition factors in clams did not show consistent seasonal variation.

Summary of Survival and Condition Data

Two prerequisites of the mussel watch approach are that the transplanted bivalves survive and are not subject to undue physiological stress at transplant sites. Certain of the RMP transplants did not appear to meet these requirements. Clear and somewhat paradoxical seasonality was observed in mussels, with higher survival but lower condition during summer. In oysters, survival did not show a consistent seasonal pattern, but condition was worse at several stations in summer. In clams, neither survival nor condition displayed consistent seasonal variation.

One hypothesis that could explain the paradoxical seasonal variation in mussels is that salinity, which is higher and more tolerable in summer, results in higher summer rates of survival, while contaminant exposure, which is higher in summer due to reduced dilution

and increased remobilization of contaminants from sediment, results in reduced summer condition. Reduced food availability in summer after the spring phytoplankton bloom is another possible explanation for low summer condition.

Sites where condition factors consistently indicated limited stress and where survival was consistently good included only winter deployments of mussels at Yerba Buena Island (BC10), Horseshoe Bay (BC21), Dumbarton Bridge (BA30), Redwood Creek (BA40), and Alameda (BB70). In only one period did clam deployment yield good survival and condition (summer 1994 at Sacramento River [BG20] and San Joaquin River [BG30]). Only one oyster deployment yielded reasonably good survival and condition (Coyote Creek [BA10] in winter 1995).

Contaminant Bioaccumulation

In addition to demonstrating growth and survival, transplanted bivalves must accumulate contaminants of interest to concentrations above those at the time of deployment. Similar to condition factors, accumulation factors (AFs) can be calculated as the ratio of the concentration of a contaminant in transplanted bivalves to the concentration prior to deployment. AFs therefore indicate the degree to which the transplants accumulated contaminants from the Estuary (or "signal strength") during the deployment period. AFs above one indicate that transplants accumulated contaminants above the concentrations in the animals prior to deployment. AFs less than or equal to one indicate that concentrations in transplants did not increase during deployment. Such a lack of accumulation could be due to several causes, including relatively low levels of contamination in the Estuary (e.g., depuration of initial body burdens), relatively high levels of contamination in the locations that served as sources for the transplanted bivalves, or limited capacity of the bivalves for accumulation. Without accumulation, it is difficult to ascertain whether contaminant concentrations in tissue were the result of exposure prior to deployment, or if there were no bioavailable contaminants present at the site of deployment. It is thus essential that contaminant concentrations in animals to be transplanted be as low as possible.

Table 3 lists median accumulation factors (AFs) derived from the RMP deployments during the period 1993–1996. The data show a significant variation among species and contaminant classes, which are a function of both differences

Table 3. Median accumulation factors derived from RMP deployments during 1993–1996. Accumulation factors were calculated for each sample as the concentration in the sample after deployment divided by the concentration in the animals prior to deployment.

PARAMETER	*Mytilus*	*Crassostrea*	*Corbicula*
Ag	1.7	1.5	2.2
As	0.9	0.9	1.2
Cd	0.9	2.0	1.7
Cr	1.7	2.4	1.5
Cu	1.4	2.6	1.5
Hg	1.1	0.9	1.3
Ni	1.6	2.6	2.1
Pb	1.8	3.2	2.2
Se	1.0	1.4	1.1
Zn	1.3	2.0	1.3
Total DDT	4.6	9.1	2.4
p,p'-DDD	8.7	15.7	4.0
p,p'-DDE	3.0	8.2	2.0
Total Chlordane	2.9	4.6	2.5
alpha-Chlordane	1.6	4.6	2.2
gamma-Chlordane	3.5	4.3	3.0
trans-Nonachlor	3.8	3.4	2.3
Dieldrin	1.8	2.9	8.9
Total PCB	10.0	7.8	3.1
Naphthalene	1.2	1.0	0.7
Anthracene	2.9	2.7	2.3
Phenanthrene	2.2	2.1	0.9
Fluoranthene	6.1	3.6	2.9
Pyrene	5.2	5.0	8.4

in accumulation potential and differences in spatial distribution of contamination in the Estuary. For certain contaminants in some years, high contamination at the sites where the animals are collected results in low AFs (e.g., *Corbicula* collected from Putah Creek in 1996).

The bioaccumulation signal for metals, as evidenced by the accumulation factors, is generally weak. For mercury, which is a main parameter driving advisories over consumption of Bay fish, the low accumulation factor indicates that bivalve transplants are not an effective monitoring tool for mercury in the Estuary. Low bioaccumulation by bivalves, which was also noted by (Luoma and Linville, 1995) for *Potamocorbula amurensis* and *Macoma balthica*, does not predict the higher trophic level problem known to exist. Table 3 indicates a similar result was also found for selenium and arsenic.

Accumulation factors for metals appeared lowest in the mussels (*Mytilus californianus*), with all values less than two (Table 3). The oyster *Crassostrea gigas* was the best accumulator of metals, particularly for chromium, copper, lead, and zinc. The clam *Corbicula fluminea* was the best accumulator of silver, and a relatively good accumulator of nickel and lead.

Accumulation factors for organic contaminants of concern were generally high, indicating that transplanted bivalves are capable of detecting a distinct signal of organic contamination in the Estuary. Mussels were particularly strong accumulators of p,p'-DDD (a relatively abundant anaerobic breakdown product of p,p'-DDT in the Bay), PCBs (which reach high concentrations at South Bay where mussels are deployed), and high-molecular weight PAHs such as fluoranthene and pyrene. Oysters readily accumulated DDTs, chlordanes, PCBs, and high-molecular weight PAHs. Clams had lower AFs overall than mussels and oysters, but still showed clear net accumulation of everything but low-molecular weight PAHs, and strong accumulation of dieldrin and pyrene. Low-molecular weight PAHs, such as naphthalene, had relatively low AFs in all species.

In summary, oysters showed the strongest overall net accumulation of trace elements and trace organics. Mussels and clams accumulated significant masses of organic contaminants during deployment, but generally exhibited little net accumulation of trace elements.

Long-term Trends

The most important reason for establishing the bioaccumulation monitoring program as part of the RMP was to investigate long-term trends with a spatially and temporally averaged measurement of bioavailable contaminants in the Estuary. The four-year database available from the RMP is not yet adequate to detect such trends. However, the fact that the RMP took over deployment of bivalves from the SMW at certain sites in the Estuary provides the opportunity to examine a much larger database, dating back to 1980 or 1981. Using such a long-term database provides an extraordinary opportunity to examine the status of contamination in the Estuary over the last two decades.

The RMP and SMW data sets are not, however, strictly comparable for several reasons. Some slight differences in analytical methods exist due to the fact that different laboratories using different analytical methods (e.g., packed column versus capillary column gas chromatography) have been responsible for chemical analyses. Conventions for estimating total PCBs have also changed over time, and certain analytes, such as chlorpyrifos and diazinon, were not included in the earlier analyses. In addition, the time of deployment differs between SMW (fall) and RMP (winter and summer), which can bias bioaccumulation data (De Kock and Kramer, 1994; O'Connor, 1996).

While such comparability problems require consideration when assessing trend data, they do not eliminate the value of this long-term data set. The vast majority of methods utilized by RMP in bivalve collection, maintenance, retrieval, and analysis were modeled after

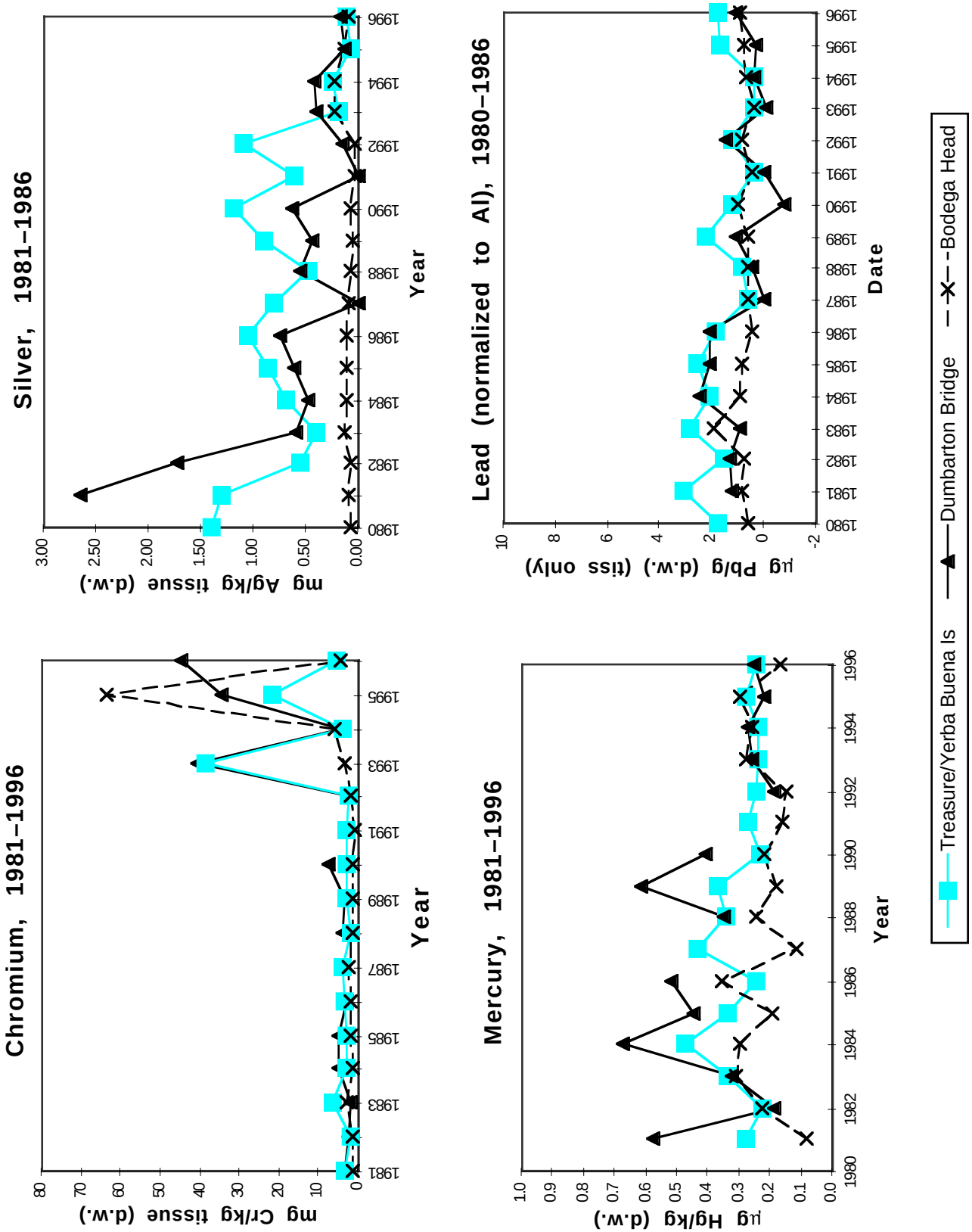

Figure 21. Long-term bioaccumulation of trace elements in transplanted bivalves.

SMW methods (Lowe and Hoenicke, 1996). Some of the trends noted below are significant enough that they are unlikely to be the result of methodological differences, and some of the large changes noted do not correspond to changes in program methods. Even with qualifications, this discussion documents the value of long-term bioaccumulation monitoring by indicating the nature of the perspective this method brings to assessment of the health of the Estuary.

The assessment of long-term trends is presented for the Central Bay using the RMP Yerba Buena Island station and the SMW Treasure Island station, and in South Bay for metals using the Dumbarton Bridge station (the SMW data set for organics at the Dumbarton Bridge station is incomplete). Statistical significance of trends are examined (Table 4) using Spearman's ranked correlation (Ferguson, 1971; O'Connor, 1996). The trend data are displayed graphically in Figures 21 and 22. In general, the data indicate significant declines for contaminants where use has been outlawed or restricted, less significant declines for other contaminants, and no trends for others.

Trace Elements

For trace elements, a significant decline (Table 4) is indicated for silver in both the Central and South Bays, with concentrations decreasing over an order of magnitude (Figure 21). This suggests wastewater treatment programs have successfully reduced the abundance of silver in the Estuary. A similar trend for silver is noted by (Luoma *et al*., 1996) from their monthly monitoring of resident clams (*Macoma balthica)* in South San Francisco Bay. The continued presence of bioaccumulated silver in the South Bay is expected due to remobilization of silver from sediments (Rivera-Duarte and Flegal, 1997a).

Declines for mercury and lead are also indicated by the data, although the relatively low accumulation of these metals, as evidenced by the data from the Bodega Bay collection site (Figure 21), makes the importance of these trends less clear those identified for silver. The data for lead have been normalized to aluminum (Hoenicke *et al*., 1996) to correct for sediment in the gut of the bivalves as they were not depurated. (In certain instances, this required estimating aluminum concentrations in the bivalves from adjacent year's data. The uncertainty in this technique is indicated by a value less than zero for 1990 at the Dumbarton Bridge).

The declines in silver, lead, and mercury are in marked contrast to a significantly increasing trend for chromium (Table 4). Figure 21 clearly indicates that since 1993 the abundance of bioavailable chromium in the Estuary has been much higher than in the past, although fluctuating in both time and space. In both 1993 and 1995, chromium concentrations are higher, although in 1995 high concentrations at Bodega Head make interpretation of the transplant data difficult, as it is not known if the concentrations after deployment represent accumulated contamination or incomplete depuration of the initial body burden. In 1996, the concentrations at Treasure Island and Dumbarton Bridge diverge after tracking closely in 1981–95, suggesting differing pro-

Table 4. Long-term trends in the concentration of bioavailable contaminants in the San Francisco Estuary, 1980–1996. Significance of trends tested with Spearman's rank correlation. ⇓ = very significant decrease ($p<.01$) ↓ = significant decrease ($p<.05$), ↓* = decreasing trend ($p<0.1$) ↓ = decreasing trend ($p < 0.2$), ↑ = significant increase ($p<.05$). INC = incomplete data base for analysis.

site (N)	cis-chlordane	PCB	DDE	dieldrin	Ag	Hg	Cr	Pb (Al cor)
Dumbarton (14)	INC	INC	INC	INC	↓	↓	↑	↓*
Treasure Island (17)	⇓	⇓	⇓	⇓	↓	↓	↑	↓

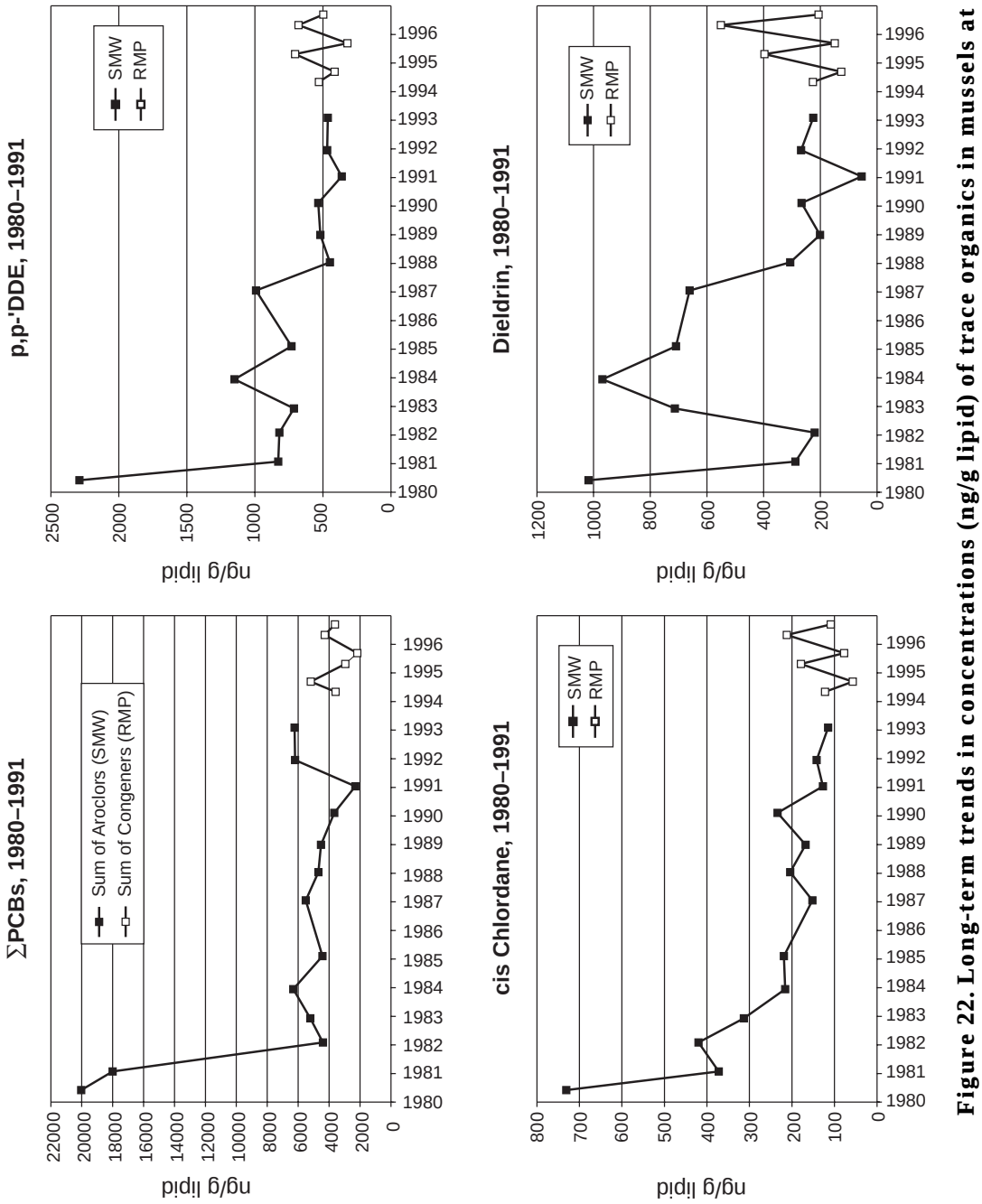

Figure 22. Long-term trends in concentrations (ng/g lipid) of trace organics in mussels at Yerba Buena Island as measured in the State Mussel Watch Program and the RMP.
SMW = State Mussel Watch, RMP = Regional Monitoring Program

cesses affecting chromium availability in these two locations.

The bioaccumulation monitoring data for chromium strongly suggest that a large influx of chromium to the Estuary occurred in 1993 and 1995. The source of this chromium appears to be the flushing of the Yolo Bypass, as indicated by intensive sampling of the water column for chemical species of chromium (Abu-Saba and Flegal, 1997). Floodwaters sitting in lowlands such as the Yolo Bypass apparently leach chromium from the soils/sediments, and this chromium is carried into the Estuary during later storm events. The flux of chromium to the Estuary via these high flow events exceeds direct anthropogenic inputs by almost two orders of magnitude (Abu-Saba and Flegal, 1997). (While this mechanism should also have been documented during the heavy rains of 1982–83, the SMW deployment occurred in the fall, and so the biomonitoring data does not reflect the period of high flows in the winter.)

The diagenic remobilization of chromium from the sediments in the South Bay might explain higher concentrations found at the Dumbarton Bridge site during the winter/spring periods of 1995 and 1996. Abu-Saba and Flegal (1997) indicate that the principal source of dissolved chromium to the South Bay is remobilization of chromium from sediments. This process is likely to exert a significant influence on measurements of bioaccumulation by bivalves.

For copper and zinc, two other contaminants of concern in the San Francisco Estuary, the long-term data indicate no trend. For copper, this is in direct contrast to the long term data from resident clams in the South Bay, that show a significant decrease in bioavailable copper (Luoma *et al*., 1996). The sampling site of Luoma *et al*. is very close to the outfall of the Palo Alto Sewage Treatment Plant, and the declines at this site may reflect the important influence of that local source. As with chromium, copper, and zinc concentrations in the water column of South Bay are likely influenced by benthic fluxes, especially zinc (Rivera-Duarte and Flegal, 1997b). The lack of a trend at the central channel Dumbarton Bridge site, despite efforts to reduce anthropogenic inputs of these trace elements, may reflect the importance of sediment-water interactions in controlling the temporally and spatially averaged bioavailable concentrations as represented by the transplanted bivalves. In addition, there is also some evidence of regulation of zinc body burdens (and to a lesser extent, copper) by mussels, although the effect of this metabolic activity is not thought to interfere with larger changes of zinc bioavailability in the environment (Rainbow, 1995).

Trace Organic Contaminants

The most extensive long-term data for organic contaminants from the SMW Program were collected at Treasure Island and Point Pinole. These stations are close to Yerba Buena Island (BC10) and Pinole Point (BD30) stations from the RMP, and are directly compared to these stations in this discussion. RMP data indicate that mussels at Yerba Buena Island/Treasure Island have had consistently high survival and good condition, while Pinole Point transplants appear to lose body mass during deployment (Tables 1 and 2). This raises the concern that these animals are beyond the range of their physiological tolerance, and for this reason the discussion of long-term trends will focus on data from Yerba Buena Island/Treasure Island.

Long-term trends in selected trace organics at Yerba Buena Island are depicted in Figure 22. The data are expressed on a lipid weight basis because of correlations of contaminant concentrations with lipid for SMW data at this station and for RMP data in general, and because lipid normalization reduced the variance around the long-term trend lines and between SMW and RMP data. Overall, these data generally show statistically significant declines ($p<.01$, Table 4) in organic contaminant concentrations since 1980. The trajectory of the declines, however, varies from contaminant to contaminant.

PCB concentrations were high in 1980 and 1981, then dropped considerably in 1982 and have remained essentially constant ever since. It should be noted that PCB concentrations at other SMW stations showed the same pattern in the early 1980s, with high concentrations in 1980 and 1981 and a major reduction by 1982. RMP data for total PCBs are expressed as the sum of individual PCB congeners, in contrast to the SMW which used the older convention of the sum of Aroclors. In wildlife tissues, sums of Aroclors are approximately double the sums of congeners in the same sample (Turle *et al.,* 1991). Given this consideration, RMP PCB data appear to be in good agreement with SMW data from the early 1990s.

p,p'-DDE is usually the most abundant DDT compound in samples from the Estuary. Concentrations of p,p'-DDE were high in 1980, dropped sharply in 1981, and appeared to decline at a low rate after 1981. Concentrations since 1988 have been essentially constant, with close agreement between SMW and RMP data.

cis-Chlordane was one of the most abundant chlordane compounds in the technical chlordane mixtures and is also relatively abundant in RMP samples. Like PCBs and p,p'-DDE, concentrations of cis-chlordane were highest in 1980. Unlike PCBs and p,p'-DDE, however, cis-chlordane showed a more gradual, continuing decline from 1981 to 1991. Concentrations since 1991 have been relatively constant. Dieldrin concentrations have been relatively variable, but were also generally high in the early 1980s, with the highest concentrations observed in 1980 and 1984. Concentrations have been constant since 1989.

Uses of all of the organic chemicals discussed have been restricted for long periods of time. Restrictions on PCB production and use began in the early 1970s and commercial PCB production ceased in 1977 (Brinkman and de Kok, 1980). The use of DDT for almost all purposes was banned in California in 1970 and in the US in 1971 (Phillips, 1987). Restrictions on chlordane use began in 1975 and domestic sales and production ceased in 1988 (Shigenaka, 1990). Dieldrin use has been restricted since 1974 (Harte *et al.,* 1991) and ceased in 1987 (SFBRWQCB, 1995). Declines in concentrations of these contaminants in the Bay have occurred in the period covered by SMW and RMP as would be expected. It is important and somewhat surprising, however, that concentrations of these contaminants have not continued to decline in the 1990s. Concentrations of these contaminants remain high enough for concern over human health, as evidenced by current fish consumption advisories (SFBRWQCB, 1995), and for concern over effects on wildlife (Davis, 1997; Kopec and Harvey, 1995). The most recent long-term trend data suggest that these concerns are not likely to diminish in the near future.

Recommendations for Continued Monitoring with Transplants

It is anticipated that in 1998 the RMP will be reviewing the biomonitoring program. As a contribution to this process, the following recommendations based on the preceding analysis are offered for consideration.

1) The biomonitoring program of the RMP should be continued, as the long-term data on the spatially and temporally averaged abundance and distribution of contaminants provided by this effort are of extraordinary value in assessing the health of the Estuary. While interpretation of the trends presented in this paper must recognize certain problems of comparability between the SMW and RMP data sets, if the RMP continues in a consistent manner into the future, an internally consistent long-term data set will be established.
2) The RMP currently deploys three species of bivalves at 15 sites in the Estuary. The data on survival and condition of the transplants indicates that certain sites are generating physiological stress in the animals at certain times, which interferes with their usefulness as biomonitors. The possible causes of reduced condition in transplants should be investigated. At sites where reduced condition is associated with physiological changes that interfere with

contaminant bioaccumulation, monitoring with transplanted bivalves should not be continued.

3) Certain elements are not accumulated significantly by bivalves, suggesting that these substances are of limited bioavailability in the Estuary or that bivalves are not good biomonitors for these substances. Thus, the bivalves do not adequately document the ongoing problem of bioaccumulation of mercury in the Estuary. It consequently may make sense to eliminate certain substances from the analyte list. The recent data on bioavailable chromium, however, suggests that elimination of potentially bioavailable substances should be done with great caution, as it is possible to confound no bioaccumulation and limited ability to bioaccumulate. If pre-1993 data were assessed, one might conclude that chromium is not accumulated by the bivalves and should be dropped from the RMP analyte list.
4) A growing body of evidence suggests that many sources of contamination to the Estuary are episodic in nature, and it is likely that these pulses of contaminant input can greatly influence the abundance and distribution of contaminants. The data from biomonitoring will be a valuable tool to prioritize efforts at pollution control in the face of episodic inputs detected in the future.

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Bivalve Monitoring Discussion

The primary purpose for the bivalve bioaccumulation component of the RMP is to measure the bioavailable portion of contaminants in the water column and thus the potential for entry into the food web. Unlike the "snapshot" picture of water column contamination obtained from water sampling during three periods each year, the bioaccumulation component provides an integrative measure of water contamination, since bivalves are exposed to a variety of concentrations during the three-month deployment period that are reflected in their tissues. The RMP bioaccumulation component is also used to discern trends over time and as a comparison tool with other areas throughout California. However, it is not used as a screening process for determining pollution hot spots.

Time series of bivalve concentrations for the last eight sampling events starting in 1993 are depicted in Figures 19 and 20 in *Bivalve Monitoring Trends*. As is the case with water and sediment concentration "trends", exogenous variables probably exert strong influences on bivalve concentrations as well. The raw data essentially show no trends for most of the contaminants, and quantitative relationships of bivalve concentrations with key environmental factors should be established so that the non-contaminant factors can be removed statistically. Gunther and Davis (this chapter) evaluated the combined databases of the RMP and the State Mussel Watch Program, covering fifteen years and found statistically significant declines in silver in both Central and South Bay reaches, and less pronounced declines in mercury and lead concentrations. The much shorter RMP monitoring period would lead to different conclusions and points out how short-term "blips" can easily lead to premature conclusions, as in the case of cadmium, copper, and mercury, for which four years of RMP monitoring show hints of slight upward "trends" at stations where clams were deployed.

Trace Element Contaminants

Tissue trace element concentrations in the Estuary as a whole were generally comparable during the four years of RMP sampling. Almost all contaminants varied within a range of plus or minus two times the mean concentration for all years combined, and usually much less than that. Species differences in bioaccumulation potential remained consistent, not only within the RMP database, but also when compared to the National Status and Trends Program and the State Mussel Watch Program (Table 5; O'Connor, 1992; Stephenson, 1992).

In 1996 different trace element bioaccumulation patterns were evident than in previous years (see Figures 1–11). Copper, lead, nickel, and silver accumulated in tissues of mussels and oysters between two and thirty-two times above background concentrations at the majority of stations. Copper and silver bioaccumulated at all Estuary stations during at least one of the two deployment periods, lead and nickel at all but one. As in 1995, arsenic and mercury showed no appreciable differences in pre-and post-deployment tissue concentrations, and, in 1996, selenium was not bioaccumulated appreciably above background. Cadmium, chromium, and zinc increased over reference concentrations between two and twenty-five times at one or more stations, but primarily in the South Bay and the Northern Estuary. Arsenic is the only trace element that has not shown bioaccumulation in any of the three species at any station since the inception of the RMP.

Trace Organic Contaminants

Bivalves accumulate many trace organic contaminants to a much larger degree than trace elements, particularly the lipophilic compounds. For some organic compounds, accumulation can be on the order of hundreds of times above initial tissue concentrations measured at control sites. Thus, contaminants

that occur in minute quantities in the water column or in sediments are quite easily detected and quantified. This results in more pronounced year-to-year variations for trace organics than trace elements.

Consistent with the findings from the previous three years, chlorinated compounds and PAHs clearly bioaccumulate, with water representing the main exposure route. All trace organic contaminants were roughly comparable to 1995 concentrations, with the exception of total PCBs and DDT compounds at the Sacramento River station which exhibited concentrations up to four and six times higher during the wet season than any 1995 samples for each respective contaminant group (Figures 12–16). This may be partially due to the fact that the 1996 values at stations where *C. fluminea* were deployed were heavily influenced by high initial concentrations (T-0) of animals from the source location in Putah Creek. This was especially pronounced for DDT compounds, and to a lesser extent for other trace organic contaminants. As detailed in Appendix A: Methods, the reference population of clams in Lake Isabella crashed and could no longer supply adequate numbers to transplant in the Estuary. Putah Creek was chosen as an interim "reference" site.

Seasonal differences in PCB accumulation were much more pronounced than in 1995. Dry-season accumulation factors were up to an order of magnitude higher that those of the wet season. Unlike in previous years, bivalve concentrations of chlorinated hydrocarbons in the South Bay were not as dramatically different from other Estuary reaches during the wet season, and a less consistent wet-to-dry season pattern could be discerned with pesticides. PAH tissue concentrations were consistently variable between seasons, without any consistent patterns.

Spatial patterns, such as those observed in 1994 for PCBs, did not recur in 1996 and did not hold for even the historically most contaminated South Bay station (BA10). The Petaluma River also had greater similarity to the rest of the bivalve deployment sites than in previous years. The mixture of PAH isomers, although not individual concentrations, was again fairly uniform throughout the Estuary, suggesting multiple inputs via urban runoff or direct aerial deposition.

Comparison with Guidelines

An extensive summary of tissue concentration guidelines is included in this chapter, so the reader can evaluate a variety of "yardsticks" that indicate how some of the Estuary data compare to what is considered "acceptable" or "undesirable" by public health and regulatory agencies. Table 6 summarizes threshold concentrations for human consumption of fish and shellfish tissue and the assumptions behind each. It should be kept in mind that these guidelines were developed for a variety of purposes and either do not have any regulatory implications or are only used indirectly in the assessment of beneficial use attainment. The SFBRWQCB Pilot Study values for fish tissue are not necessarily applicable to shellfish, but they are included because they identify potential chemicals of concern and are based on fairly recent toxicological and exposure information. These fish values were designed for use in screening data and have received extensive public and scientific review. Similarly, the Great Lakes Draft Sport Fish Consumption Advisory of 1993 does not apply to shellfish, but is based on recent scientific information. Since human exposure to toxic chemicals, and, therefore, the health risk, depends on the consumption rate and the body weight of the individual eating the contaminated tissue, both of these threshold levels are calculated using certain consumption values and a standard weight of 70 kg (the weight of an average male adult). The EPA screening values used in the Fish Contamination Pilot Study were calculated based on consumption of 30 g per day and the Great Lakes level based on consumption of 7.4 g per day. Only rarely does the consumption rate of shellfish approach the same levels as that for fish.

A column listing implicit maximum tissue residues as proposed in the California Toxics rule was added to Table 6 because water

Table 5. Average and range of metal concentrations in bivalve tissue statewide and in the RMP transplanted bivalves, 1991–1996. State Mussel Watch data are the average of all samples, statewide. Trace element units are mg/kg and trace organics units are µg/kg. n = number of samples.

Corbicula fluminea

	RMP Pilot 1991	RMP 1993	RMP 1994	RMP 1995	RMP 1996	State Mussel Watch (87–93)
	Average (n = 26)	Average (n = 6)	Average (n = 6)	Average (n = 7)	Average (n = 7)	Average (n = 64)
Ag	**0.4** (0.15–0.6)	**0.1** (0.051–0.348)	**0.2** (0.13–0.37)	**0.1** (0.052–0.2)	**0.2** (0.11–0.38)	**0.2** (0.03–0.774)
Al	**3920** (790–7050)	.	**543.2** (79–983.87)	**333.7** (103.6–534.2)	.	**1423.5** (37.78–8000)
As	**9** (6–12)	**15.6** (10.6–18.6)	**23.4** (6.83–33.36)	**21** (18.312–23.8)	**11.2** (9.88–12.5)	**8.6** (4.8–15.75)
Cd	**2.7** (2.4–2.9)	**0.6** (0.12–1.041)	**0.8** (0.18–1.88)	**0.7** (0.32–1.04)	**1.4** (0.8–2.12)	**6.4** (0.4–110)
Cr	**19.6** (8.2–31)	**5.7** (1.42–10.16)	**5.8** (1.69–11.53)	**6.7** (4.56–8.78)	**52** (28.6–73.46)	**12.5** (0.4–61)
Cu	**65** (45–85)	**39** (29.11–55.46)	**42.8** (27.8–58.136)	**43.7** (17.1–60.05)	**79.5** (52.49–115.58)	**78** (27.45–250)
Hg	**0.3** (0.18–0.4)	**0.2** (0.196–0.289)	**0.2** (0.22093–0.276)	**0.2** (0.146023–0.30348)	**0.5** (0.35–0.575)	**0.3** (0.07–1.8)
Ni	**68.5** (41–96)	**5.2** (2.33–7.75)	**5.2** (1.29–11.12)	**6** (3.19–9.16)	**10.9** (7.2–16.54)	**8.7** (1.44–26)
Pb	**1.5** (0.65–2.4)	**0.7** (0.36–1.054)	**0.7** (0.19–1.17)	**0.3** (0.067–0.495)	**1** (0.44–2.37)	**1.2** (0.13–7.06)
Se	**3.1** (3–3.1)	**3** (1.7–4.21)	**2.2** (1.36–2.99)	**2** (1.354–2.89)	**4** (3.55–4.8)	**4.3** (2.1–9.6)
Zn	**160** (120–200)	**101.2** (61.95–126.56)	**84.6** (57–114.56)	**70.3** (29.1–96)	**169.4** (129.59–210.36)	**160** (74–470)

Crassostrea gigas

	RMP Pilot 1991	RMP 1993	RMP 1994	RMP 1995	RMP 1996	State Mussel Watch (87–93)
	Average (n = 24)	Average (n = 7)	Average (n = 11)	Average (n = 8)	Average (n = 10)	NO DATA AVAILABLE
Ag	**6.8** (4.3–8.3)	**1.8** (0.718–2.98)	**5.1** (0.73–9.13)	**4** (2.16–6.25)	**4** (1.97–8.45)	
Al	**635** (390–950)	.	**259.2** (90–483.96)	**442.2** (262–870.8)	.	
As	**6.8** (5.5–9)	**8.1** (6.15–10.7)	**8.9** (5.01–13)	**9.8** (5.628–16.4)	**7.2** (5.98–8.49)	
Cd	**8** (6.1–9.8)	**13.7** (5.128–25.337)	**13** (7.9–20.46)	**18.3** (10.6–36.5)	**15.4** (8.57–24.26)	
Cr	**3.6** (1.1–6)	**3.5** (1.22–6.41)	**21.9** (1.7–154.8)	**8.8** (5.32–13.86)	**9** (2.2–16.85)	
Cu	**286.6** (180–420)	**334.6** (154.9–634.19)	**406** (188–683.648)	**431.2** (218–867.12)	**403** (111.36–711.95)	
Hg	**0.2** (0.12–0.25)	**0.3** (0.19–0.334)	**0.3** (0.1375–0.592)	**0.2** (0.137826–0.34859)	**0.3** (0.199–0.413)	
Ni	**71.4** (49–95)	**2.7** (0.76–4.45)	**15.7** (1.25–113)	**15.5** (4.28–62.2)	**8.4** (1.99–15.56)	
Pb	**0.8** (0.52–1.6)	**0.7** (0.202–1.496)	**0.6** (0.18–0.97)	**0.5** (0.226–1.32)	**1.1** (0.5–1.73)	
Se	**3.5** (2.7–4.3)	**5** (1.99–8.25)	**3.4** (1.91–5.19)	**6.8** (4.011–11)	**4** (2.26–6.02)	
Zn	**3687.8** (900–21002)	**1244.4** (554.57–2646.54)	**1428.9** (764–3268)	**1422.6** (1207–2050)	**1265.3** (590.78–2296.08)	

Mytilus californianus

	RMP Pilot 1991	RMP 1993	RMP 1994	RMP 1995	RMP 1996	State Mussel Watch (87–93)
	Average (n = 30)	Average (n = 12)	Average (n = 6)	Average (n = 13)	Average (n = 14)	Average (n = 432)
Ag	**0.2** (0.09–0.49)	**0.5** (0.014–1.111)	**0.4** (0.19–0.67)	**0.2** (0.086–0.44)	**0.2** (0.09–0.57)	**0.3** (0.003–2.885)
Al	**1530.6** (640–2000)	.	**433.1** (103–1199.09)	**538.7** (250–1042.3)	.	**611.2** (15–3200)
As	**8.5** (7.7–10)	**11.6** (7.19–18.6)	**12.1** (7.91–15.2)	**13.2** (9.085–18.3)	**9.8** (8.42–12.3)	**9.5** (4.3–14)
Cd	**9.1** (7–12)	**8.6** (1.357–19.499)	**5.9** (1.77–9.95)	**5.5** (2.1–7.86)	**7.1** (5.27–14.8)	**7.6** (1.3–24)
Cr	**8** (2.2–19)	**11.1** (2.55–40.91)	**14.7** (2.14–80.93)	**17.2** (4.77–42.21)	**13.8** (5.57–44.99)	**4.3** (0.5–170)
Cu	**10.7** (7–13)	**5.9** (2.66–8.59)	**7.5** (3.433–22.022)	**8.7** (6.54–12.2)	**10.9** (8.77–21.86)	**26.1** (4.44–303.69)
Hg	**0.3** (0.18–0.32)	**0.3** (0.215–0.503)	**0.4** (0.23515–1.93578)	**0.3** (0.16471–0.38989)	**0.2** (0.196–0.311)	**0.2** (0.04–1.48)
Ni	**29.7** (20–54)	**9.3** (2.98–28.85)	**11.4** (1.34–64.41)	**20.4** (4.45–50.7)	**13.9** (7.46–38.56)	**2.4** (0.7–6.2)
Pb	**2.6** (1.8–3.9)	**2.2** (0.02–4.174)	**1.8** (0.61–3.31)	**1.5** (0.267–2.87)	**2.8** (2.06–5.42)	**5** (0.1–47.54)
Se	**2.4** (1.2–3.4)	**2.3** (0.79–4.2)	**3.3** (1.58–4.68)	**3.3** (1.884–4.543)	**3.2** (2.31–5.19)	**4** (1.1–44.29)
g/d of fish	**220** (170–260)	**308.4** (135.77–588.09)	**234.5** (122.33–369.52)	**184.5** (68.8–303)	**258.6** (170.81–433.65)	**261.4** (32.21–1147.74)

Values based on consumption of 7.4 g/d of fish (one meal per month) for a 70 kg adult.

Table 6. Commonly used tissue guidelines. When necessary, values are converted to dry weight using a multiplication factor of 7. Trace element units are mg/kg and trace organics units are µg/kg.

	MTRL[1] (fish, shellfish & drinking water)	Great Lakes[2] (fish)	SFBRWQCB[3] Pilot Study (fish)	NAS[4] (freshwater shellfish)	FDA[5] (fresh & marine shellfish)	MIS[6] (shellfish)	EPA CA[7] Toxics Rule (fish)
Arsenic	1.4*	.	.	.	.	9.8	0.0062
Cadmium	4.48*	.	2.33	.	.	7	2.33
Chromium	.	.	.	.	.	7	.
Copper	.	.	.	.	.	140	.
Lead	.	.	.	.	.	14	.
Mercury	7	.	0.14	.	7	3.5	1
Nickel	1540 / 196*	.	.	.	.	.	215.4
Selenium	.	.	11.67	.	.	2.1	.
Zinc	.	.	.	.	.	490	.
Aldrin	2.31 / 0.35*	.	.	.	2100	.	6.54
Alpha-HCH	11.9 / 3.5*	.	.	.	.	.	1.7
Beta-HCH	42 / 12.6*	.	.	.	.	.	6
Acenaphthene	.	.	.	.	.	.	646200
Anthracene	.	.	.	.	.	.	3230800
Benz(a)anthracene	.	.	.	.	.	.	1.47
Benzo(a)pyrene	.	.	.	.	.	.	1.47
Benzo(b)fluoranthene	.	.	.	.	.	.	1.47
Benzo(k)fluoranthene	.	.	.	.	.	.	1.47
Chrysene	.	.	.	.	.	.	1.47
Dibenz(a,h)anthracene	.	.	.	.	.	.	1.47
Fluoranthene	.	.	.	.	.	.	430800
Fluorene	.	.	.	.	.	.	430800
Indeno(1,2,3-cd)pyrene	.	.	.	.	.	.	1.47
Pyrene	.	.	.	.	.	.	323000
Dieldrin	4.9 / 4.55*	.	10.5	.	2100	.	0.67
Endrin	22400 / 21000*	.	4900	.	2100	.	3230
Gamma-HCH	56.7 / 17.5*	.	.	.	.	.	8.1
Heptachlor	13.3 / 12.6*	.	.	.	2100	.	2.4
Heptachlor Epoxide	5.6	.	18.2	.	2100	.	1.2
Hexachlorobenzene	42	.	102.2	.	.	.	6.73
Chlordane	.	.	125.3	.	.	.	8.3
p,p'-DDD	.	.	.	.	.	.	44.9
p,p'-DDE	.	.	.	.	.	.	31.6
p,p'-DDT	.	.	.	.	.	.	31.6
Sum DDTs	224	.	480.2	7000	.	.	.
Total Endosulfan	3500 / 1750*	.	24500	.	.	.	.
Total PAHs	6.51 / 0.56*	.	.	.	.	.	.
Total PCBs (aroclors)	15.4	1470-7000	21	3500	14000	.	0.0014

* Values are MTRLs for inland surface waters (freshwater).

[1] MTRL from: State Mussel Watch Program 1987–93 Data Report. Maximum Tissue Residue Levels (MTRLs) in Enclosed Bays and Estuaries

[2] Great Lakes from: Contaminant Levels in Fish Tissue from San Francisco Bay, Final Draft Report; Great Lakes Sport Fish Advisory Task Force Draft—June 1993. Values based on consumption of 7.4 g/d of fish (one meal per month) for a 70 kg adult.

[3] SFBRWQCB Pilot Study from: Contaminant Levels in Fish Tissue from San Francisco Bay, Final Draft Report. Values based on consumption of 30 g/d of fish (one meal per week) for a 70 kg adult.

[4] NAS from: State Mussel Watch Program 1987–93 Data Report. NAS Recomended Guidelines and FDA Action Levels for Toxic Chemicals in Shellfish.

[5] FDA from: State Mussel Watch Program 1987–93 Data Report. NAS Guidelines and FDA Action Levels for Toxic Chemicals in Shellfish.

[6] MIS from: State Mussel Watch Program 1987–93 Data Report. Median International Standards for Trace Elements (edible portion).

[7] Proposed CA Toxics Rule from: Implicit Maximum Fish Tissue Residue as proposed in the California Toxics Rule (1997). EPA TSC195 Criteria Chart, Jan. 1995 EPA Region IV. (Updated 304(a) Criteria as per SFBRWQCB)

quality standards will be derived from these most recent threshold values.

Median International Standards (MIS), on the other hand, while applicable to shellfish, are not based on rigorous scientific information, and individual countries' contaminant residue standards were influenced by international trade negotiations. MIS were compiled by the United Nations based on a survey of health protection criteria used by member nations (Nauen, 1983). The MIS do not apply within the United States, but they indicate what other nations consider to be elevated concentrations of trace elements in shellfish.

The United States Food and Drug Administration (USFDA) has set action levels at or above which it will take legal action to remove contaminated food from the market. These values contain economic and other assumptions that are not based on health risk. The FDA numbers are traceable to "acceptable" residue levels in meat and poultry as calculated by pesticide manufacturers when their products were applied to fields as per label directions. They began to be applied to fish tissue in the 1970s. Both FDA and MIS guidelines have a limited degree of toxicological and exposure information associated with them, and are generally considered of low value to health risk managers.

Maximum Tissue Residue Levels (MTRLs) were developed by staff at the State Water Resources Control Board from human health water quality objectives that protect against consumption of fish, shellfish, and drinking water containing substances at levels which could result in significant human health problems. MTRLs are only an assessment tool and will likely be revised once the new water quality criteria in the California Toxics Rule become effective.

National Academy of Science (NAS) guidelines were developed to protect both the organisms containing the toxic substance and any animals that prey on the contaminated species. These guidelines are quite outdated (NAS, 1973) and are primarily applicable to marine fish. Only two guidelines apply to freshwater clams.

Because MTRLs are the most recent guidelines directly applicable to seafood in general, the 1996 report uses these criteria only to compare bioaccumulation results with those of the previous years. Arsenic, cadmium (freshwater only), mercury, and nickel are the only trace elements for which MTRLs apply. With the exception of arsenic, bivalve tissue concentrations were far below the threshold level for each of these elements, although bivalves may not be the best indicators for bioaccumulation potential of these kinds of pollutants. Most of the trace organic compounds analyzed by the RMP for which MTRL guidelines exists were higher than their respective threshold levels and frequently exceeded MTRLs even at the reference sites. Table 7 summarizes where RMP tissue samples were above MTRL guidelines for the three bivalve species. Dieldrin and chlordane levels were above guidelines at all Estuary stations during the wet season. DDT compounds were above MTRL guidelines only at the River stations, Grizzly Bay, and Davis Point during the wet season, and for clams collected at Putah Creek (the pseudo-reference site) during both deployment periods. PCB and PAH tissue levels were consistently far above MTRLs throughout the Estuary at all times.

Bivalve Condition and Survival

The condition and survival data primarily serve to reduce confounding factors in bioaccumulation measurements and to determine if the animals were healthy. The causes for poor bivalve condition and low survival can be numerous, but are probably most strongly related to the varying seasonal and year-to-year salinity regimes (see Gunther and Davis, this chapter). High survival and good condition are not necessarily related, which may indicate that different factors influence each to varying degrees.

Dry season condition indices were almost always lower than wet season condition indices for all species that had high survival rates at their respective stations (see Figure 18 in this

Table 7. Summary of 1996 tissue contaminant concentrations that were above the MTRL guidelines in 1996. Of the eighteen MTRL guidelines for which there are data, only four compounds had tissue concentrations that were above the guideline. ● = above guideline., - = data not available.

				Sum of PAHs		Total PCBs		Total DDTs		Dieldrin		Total Chlordanes	
		MTRL (µg/kg):		6.51		15.4		224		4.9		8.4	
	Code	Station name	Species	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
South Bay	BA10	Coyote Creek	CGIG	●	●	●	●			●		●	●
	BA30	Dumbarton Bridge	MCAL	●	●	●	●			●	●	●	●
	BA40	Redwood Creek	MCAL	●	●	●	●			●	●	●	●
	BB71	Alameda	MCAL	●	●	●	●			●	●	●	●
Central Bay	BC10	Yerba Buena Island	MCAL	●	●	●	●			●	●	●	●
	BC21	Horseshoe Bay	MCAL	●	●	●	●			●	●	●	
	BC61	Red Rock	MCAL	●	●	●	●			●	●	●	●
Northern Estuary	BD15	Petaluma River	CGIG	-	●	-	●	-		-		-	
	BD20	San Pablo Bay	CGIG	●	●	●	●			●		●	●
	BD30	Pinole Point	MCAL	●	●	●	●			●	●	●	●
	BD40	Davis Point	CGIG	●	●	●	●	●		●		●	●
	BD50	Napa River	CGIG	●	●	●	●			●		●	
	BF20	Grizzly Bay	CFLU	●	-	●	-	●	-	●	-	●	-
Rivers	BG20	Sacramento River	CFLU	●	-	●	-	●	-	●	-	●	-
	BG30	San Joaquin River	CFLU	●	●	●	●	●		●		●	●
	T-0	Bodega Head	MCAL	●	●	●				●	●		
	T-0	Putah Creek	CFLU	●	●	●	●	●	●		●	●	●
	T-0	Tomales Bay	CGIG	●	●	●							

CFLU = *Corbicula fluminea,* CGIG = *Crassostra gigas,* MCAL = *Mytilus californianus*

chapter). Condition measurements at the reference sites at the end of each deployment period in the Estuary were suspended in 1996. Thus, the influence of the reproductive cycle on loss or gain of biomass can no longer be estimated. It is thus more difficult, if not altogether impossible, to interpret changes in condition at the Estuary deployment sites, and bivalve condition now only serves as a rough indication of a potential correlation between loss of biomass and reduced potential of contaminant uptake.

Unlike the previous year, oyster condition during the wet season deployment increased at all deployment sites in the Estuary over initial condition at the Tomales Bay control site, while consistent and dramatic decreases are evident during the dry-season deployment. This decrease was most pronounced at the Napa River site.

Clam condition decreased very slightly during the wet season, while animals lost significant biomass during the dry-season deployment.

Compared to controls, mussels slightly improved their condition at four of seven stations during the wet season and slightly lost biomass at Dumbarton Bridge (BA30), Red Rock (BC61), and Davis Point (BD30). During the dry season, mussels lost biomass at four sites and gained biomass at three sites.

It should be noted that condition and survival alone are not indicators of pollution effects, especially since bivalves are known to tolerate and survive contaminant levels far in excess of those observed in the Estuary (see Gunther and Davis, this chapter). However, with appropriate ancillary measurements, the usefulness of bivalve condition as a possible contaminant influence indicator should be investigated.

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CHAPTER FIVE

Quality Assurance and Quality Control Review

Review of Quality Assurance and Quality Control Procedures for RMP Water, Sediment, and Bivalve Monitoring

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Background

Between late 1995 and mid 1997, the San Francisco Estuary Institute (SFEI) conducted a comprehensive internal review of the Regional Monitoring Program's (RMP) Quality Assurance and Control (QA/QC) Program. Because of the involvement of academic institutions and commercial laboratories with extensive records of method development and validation, portions of the QA/QC program were based on these laboratories' procedures that had been developed in other research efforts and published over the last decade in the peer-reviewed scientific or the "gray" literature. This review article is intended to bring together the pertinent documentation from many dispersed sources in one comprehensive summary that describes the steps taken in the field and laboratory to minimize, control, and account for potential measurement errors.

The purpose of quality assurance measurements is to ascertain that the data truly represent conditions in the environment with negligible artifacts due to sample collection and processing. In conjunction with methods and procedural test results from the literature that form the foundation for the way RMP samples are collected and handled in field and laboratory, QA sample results generated for each 1996 RMP cruise are used below to demonstrate how accurately and reproducibly analyte levels, bioassay results, and benthic community assessments are reflected in the database and how the annual QA data evaluation is causing continuous improvement of the analytical system. In addition, field and QA data documentation, transfer and verification steps and procedures are summarized in this article.

The level and intensity of quality assurance procedures depends on the intended uses of the data. The potential consequences of ignoring this important link are outlined for the interested reader in a paper by Hoenicke *et al.* (1991). The less intense the quality assurance and control procedures are, the more variable and uncertain the resulting data will be and the fewer specific inferences can be drawn from the data. For example, if the level of certainty in mercury concentrations is ±100% (i.e., a reported value of 2 mg/kg dry weight in sediment means that it could be 0 mg/kg or 4 mg/kg), the data set is unsuitable to determine if mercury concentrations in sediment have decreased by more than 20%, or 0.4 mg/kg, over a five-year time period as a result of mercury control measures.

The RMP has in place one of the most rigorous quality assurance and control systems of any large-scale monitoring program, despite the fact that at this time, the data users have not yet defined the necessary level of specificity and the range of questions for which they would like to have answers. The quality assurance and control system was designed to accommodate evolving information needs by the data users within the inherent constraints of the best available sampling and analytical methodologies. The acceptable or unavoidable variability that is introduced through the sampling and measurement system, as well as the desired detection levels that allow quantitative comparisons to receiving water quality objectives, are reflected in the RMP data quality objectives (DQOs) expressed in terms of accuracy, precision, completeness, and method detection limit requirements. The DQOs for the RMP were established based on instrument

manufacturers' specifications, scientific experience, and historical data. Individual contract laboratories are given the greatest degree of flexibility in their analytical procedures, as long as they can demonstrate that DQOs are being met and that data comparability between laboratories and analytical matrices are documented.

In 1997, an outside review of the overall monitoring program was conducted. The quality assurance and data management systems were evaluated, along with other RMP components. Several recommendations were made that will lead to further improvements of the QA program. These recommendations include the development of a computer-assisted approach to data quality checking, implementation of a specific list of PCB congeners for all matrices that allows for a standardized definition of "total PCBs", and a more thorough documentation of the derivation of accuracy and precision estimates, as well as method detection limits. As much as possible, these recommendations were incorporated into the 1996 Annual Report and this particular article.

Summary of Field QC

Types of Field QA/QC Samples and Their Purpose

Various monitoring programs use a variety of field performance measurements that are frequently included in the sampling protocol. Some of these performance measurements only need to be taken whenever an established procedure is changed; others need to be taken at various intervals throughout the sampling process. It should be noted that the QA nomenclature is not standardized and that a variety of terms exist for the same type of QA sample. Therefore, definitions are given below to facilitate comparisons of QA procedures with other programs.

- *Source Solution Blanks* account for any pre-existing contamination in the water or preservatives used to prepare the sample containers as well as the field or travel blanks.
- *Bottle Blanks* account for contamination in sampling containers, in addition to any contamination due to the source solution.
- *Travel Blanks* account for contaminants introduced during the transport process between the laboratory and field site, in addition to any contamination from the source solution and container.
- *Equipment Blanks* account for contamination introduced by the field sampling equipment.
- *Field Blanks* account for all of the above sources of contamination that might be introduced to a sample (source solution, sample container, transport and handling) as well as that which would be due to the sampling equipment and the immediate field environment. Field blanks are generated under actual field conditions and are subjected to the same aspects of sample collection, field processing, preservation, transport, and laboratory handling as the environmental samples. Field blanks for sediment analyses generally consist of ultra-pure sand. True field blanks for biological tissue samples do not exist.
- *Field Duplicate Samples* allow evaluation of sampling precision, or reproducibility, and are used to determine if data from different samples taken as closely together in space and time as possible are significantly different. These samples assess sample variation due to changing sample qualities within short periods of time and space and also incorporate differences due to both analytical and sampling imprecision.

Field QA/QC Samples Used by the RMP

Trace Elements in Water, Sediment, and Tissue

Routine preparation, collection and analysis of all six of the field QA samples would be redundant and an inefficient use of time, labor, and materials. Trace metals in environmental water samples are orders of magnitude lower than in sediments or tissues, therefore, the

field QA/QC measures are much more rigorous for water samples. Consequently, each type of field QA sample, with the exception of the travel blank, has been performed at some time during the program for the water samples.

Source solution blanks are made with Milli-Q or Nanopure water (free of trace organic and trace element contaminants), and trace-metal grade acids are used in all aspects of trace metal cleaning, storage, and analysis. The sample bottles are both cleaned and stored filled (water sample containers only) with acid solutions. Contamination of these source solutions is routinely checked, and corrective steps are taken whenever contamination of source solutions is indicated.

Bottle blanks generated early in the monitoring program demonstrated that the "trace-metal clean" polyethylene and Teflon® bottles used for the RMP water, sediment, and tissue samples are not a source of trace element contamination. Certified trace-metal-free borosilicate glass containers have recently been used for sediment samples and measurements of bottle blanks are conducted for each lot. Routine analysis of the extraction and instrument blanks continue to show trace-metal clean status. Additionally, time series analyses of acidified stored water samples show that metals are not released from, nor adsorbed to, the bottle walls over time.

Travel blanks are not routinely used for any of the three matrices, and the possibility of contamination during the transport process between the laboratory and field site is mitigated by the measures taken to keep the sample bottles in an enclosed micro-environment. All trace element water sample bottles are quadruple-bagged and kept inside a tightly closed plastic bucket. They are filled with a weak acid solution, so any metals leached from the container are kept in solution. The "storage solution" is discarded immediately prior to sampling, followed by five rinses with the sample. The sample bottles are removed from the plastic bags only in a class 100 clean laboratory, except during active sampling. The bottles are always handled with polyethylene-gloved "clean hands".

Equipment blanks for water samples are collected periodically in the laboratory by pumping Milli-Q water through the sample tubing connected to a filter cartridge. Contamination levels are always non-detectable. The sampling equipment consists of a dual-head peristaltic pump which pumps water up through the inlet length of Teflon® tubing (attached to a telescopic aluminum pole) connecting to C-flex tubing (passing through the pump heads), and finally to the outlet length of Teflon® tubing (held by plastic clamps to an aluminum rod support; EPA Method 1669). The Teflon® and C-flex tubing are connected via polypropylene "Y" connector fittings. Filtered samples additionally pass through a 0.45 micrometer polycarbonate filter cartridge attached to the outlet end. The sample is exposed to the interior of the Teflon® and C-flex tubing, the Y fittings, and the filter cartridge, all of which have been rigorously cleaned with ultra-pure reagents. Sediments are collected with a van Veen grab sampler. However, equipment blanks are not taken. The sediment sampling protocol is discussed thoroughly in the Field Blanks section. Bivalves are "hand-collected", and, therefore, equipment blanks are not relevant for tissue samples.

Field duplicates are routinely collected for water samples only. Water is filtered in duplicate so that evaluation of the sampling system precision includes the filter cartridge. Short-term environmental variability, most notably due to swift currents and non-homogeneous suspended sediment load will affect the sampling precision. The oceanic end-member station (Golden Gate—BC20) probably has the least variability, and is, therefore, usually included as a field duplicate. Two or three additional stations at different locations of the Bay are also collected in duplicate. As an example of sampling precision, Table 1 shows concentrations of duplicates taken at the Golden Gate station for total copper.

Sediment concentrations in the Estuary are variable in space and time, and a field duplicate

Table 1. Field duplicate results for total copper at Golden Gate station (BC20). Units are µg/L.

Replicate	Feb 96	Apr 96	Aug 96
1	0.582	0.268	0.420
2	0.470	0.271	0.384
RPD	21.2%	1.1%	8.8%

would be unable to separate natural variability from that introduced by the sampling and analysis system. In 1994, triplicate samples were taken at three RMP stations (Horseshoe Bay—BC21, Alameda—BB70, and Davis Point—BD41) to assess within-station field variability. As Table 2 shows, variability was parameter-specific for trace elements, with certain metals exhibiting less than 3% variation between triplicates, while triplicate samples of others were up to 40% different from each other.

Field duplicate tissue samples are not collected *per se*. Approximately 40–100 bivalves are deployed at each site. They are hand-collected and are later homogenized as a single sample. Two sub-samples of fewer animals each, would assess variability in the animals rather than precision in technique or environmental variability.

Field blanks for water are generated under actual field conditions and are treated in the exact same manner as the environmental field samples in both the field and laboratory. However, true field blanks are logistically difficult to obtain, because assessment of the monitoring vessel's aura of contamination at the time of sampling is not straight-forward. Indeed, true field blanks are not routinely collected by any worker in this field and are not routinely reported in the literature. Collection of a field blank by pumping the "source solution" (Milli-Q water) through the system on deck does not adequately address the issue of potential contamination of the water sample by the monitoring vessel. Metals are ubiquitous on boats (e.g., in diesel exhaust fumes, copper-based anti-fouling paint, and brass and nickel-plated fittings). A field blank therefore merely measures contamination of the sampling equipment (already accounted for) and perhaps aerosol contamination, but it cannot sort out vessel contamination from water contamination present without the vessel sitting in the source water. Mitigation steps for this potential problem are taken. To avoid aerosol contamination, the sample tubing inlet and outlet are kept veiled until the engines are turned off, and the engines remain off until sampling is completed and the tubing inlet and outlet are covered again. To avoid possible contamination of the sample by the boat, the 15–20-foot sampling pole is extended over the windward side, oriented up-current from the vessel and upwind from the equipment and personnel.

To get around the inability to collect a true field blank, the metal concentrations of environmental water samples are considered accurate (i.e., not influenced by vessel contamination) if they are oceanographically consistent (Boyle *et al.,* 1981) and comparable values are obtained by intercalibration studies (Patterson and Settle, 1976). These mitigation methods have been adopted by many workers in the field following extensive experience (Bruland, 1980; Bewers and Windom, 1981; Boyle *et al.,* 1981; Schaule and Patterson, 1981; Berman *et al.,* 1983; Bruland, 1983; Bruland *et al.,* 1985; Flegal and Stukas, 1987; Landing *et al.,* 1995; Yeats *et al.,* 1995). The concept of "oceanographic consistency" (Boyle, 1977) was borne from the mid-1970s trace metal research revolution when advances in analytical chemistry and instrumentation, along with the evolution of "trace-metal clean" techniques (Patterson and Settle, 1976) reduced metal concentrations by up to three orders of magnitude and revealed profiles consistent with known biological, physical, and geochemical processes. In a 1983 review, Bruland provides a comprehensive description of oceanic trace metal profiles, whereas, in an earlier review by Brewer (1975), few definitive conclusions could be drawn. Subsequently, much of the pre-1975 published data are considered suspect.

Table 2. Data from triplicate samples collected at three RMP stations to assess within-station variability for trace elements in sediments.

	Site Name	Code		Rep 1	Rep 2	Rep 3	Mean	STD	MDL
Ag	Alameda	BB70	Feb.	0.443	0.442	0.473	0.453	0.0175	0.00005
			Aug.	0.403	0.384	0.408	0.399	0.0129	0.00008
	Horseshoe Bay	BC21	Feb.	0.283	0.319	0.318	0.307	0.0209	0.00004
			Aug.	0.178	0.216	0.201	0.198	0.0190	0.00008
	Davis Point	BD41	Feb.	0.061	0.076	0.070	0.069	0.0072	0.00005
			Aug.	0.059	0.038	0.049	0.049	0.0106	0.00009
Al	Alameda	BB70	Feb.	47732	46429	42160	45440	2915	1331
			Aug.	24732	30928	25333	26998	3417	169
	Horseshoe Bay	BC21	Feb.	26847	35595	30526	30989	4392	1257
			Aug.	18803	21533	20706	20347	1400	179
	Davis Point	BD41	Feb.	22381	23492	24205	23359	919	1364
			Aug.	15118	14450	18266	15945	2038	201
As	Alameda	BB70	Feb.	11.8	12.8	11.5	12.0	0.7	0.001
			Aug.	9.4	10.3	10.1	9.9	0.5	0.002
	Horseshoe Bay	BC21	Feb.	9.6	11.5	12.7	11.3	1.6	0.001
			Aug.	12.7	12.9	14.3	13.3	0.9	0.002
	Davis Point	BD41	Feb.	5.7	5.6	6.0	5.7	0.2	0.001
			Aug.	5.9	7.1	7.7	6.9	0.9	0.002
Cd	Alameda	BB70	Feb.	0.163	0.154	0.154	0.157	0.005	0.00001
			Aug.	0.220	0.232	0.240	0.231	0.010	0.00005
	Horseshoe Bay	BC21	Feb.	0.160	0.167	0.174	0.167	0.007	0.00001
			Aug.	0.186	0.257	0.190	0.211	0.040	0.00005
	Davis Point	BD41	Feb.	0.105	0.119	0.104	0.109	0.008	0.00001
			Aug.	0.122	0.080	0.109	0.103	0.021	0.00006
Cr	Alameda	BB70	Feb.	93	85	94	91	5	24
			Aug.	93	97	95	95	2	1
	Horseshoe Bay	BC21	Feb.	108	121	111	113	7	23
			Aug.	78	73	76	76	3	1
	Davis Point	BD41	Feb.	65	77	75	72	7	25
			Aug.	75	82	85	81	5	1
Cu	Alameda	BB70	Feb.	46	43	43	44	2	9.5
			Aug.	38	41	38	39	2	0.1
	Horseshoe Bay	BC21	Feb.	35	43	38	38	4	9.0
			Aug.	29	28	26	28	2	0.1
	Davis Point	BD41	Feb.	21	23	23	22	1	9.8
			Aug.	21	13	19	18	4	0.1
Fe	Alameda	BB70	Feb.	46777	46321	43146	45415	1978	3394
			Aug.	34605	38754	32315	35225	3264	169
	Horseshoe Bay	BC21	Feb.	39169	45765	44380	43105	3478	3206
			Aug.	29135	30399	30442	29992	742	179
	Davis Point	BD41	Feb.	36830	38287	38944	38020	1082	3477
			Aug.	30701	29189	31261	30384	1072	201
Hg	Alameda	BB70	Feb.	305	298	314	306	8	0.003
			Aug.	388	295	314	332	49	0.360
	Horseshoe Bay	BC21	Feb.	197	239	235	224	23	0.003
			Aug.	206	194	249	216	29	0.360
	Davis Point	BD41	Feb.	93	93	109	98	9	0.003
			Aug.	89	52	86	76	20	0.360
Mn	Alameda	BB70	Feb.	538	449	397	461	71	8
			Aug.	280	293	299	291	10	7
	Horseshoe Bay	BC21	Feb.	346	438	380	388	47	8
			Aug.	311	283	268	287	22	7
	Davis Point	BD41	Feb.	407	423	449	426	21	8
			Aug.	368	322	359	350	24	8
Ni	Alameda	BB70	Feb.	66.7	61.8	63.4	64.0	2.5	16.0
			Aug.	88.5	94.9	86.6	90.0	4.3	1.6
	Horseshoe Bay	BC21	Feb.	74.3	76.9	74.5	75.2	1.4	15.1
			Aug.	79.1	79.7	79.5	79.4	0.3	1.7
	Davis Point	BD41	Feb.	61.0	63.5	61.2	61.9	1.3	16.4
			Aug.	72.7	70.6	77.5	73.6	3.5	1.9
Pb	Alameda	BB70	Feb.	19.5	18.6	19.5	19.2	0.5	0.0011
			Aug.	25.2	21.9	28.2	25.1	3.1	0.0005
	Horseshoe Bay	BC21	Feb.	20.5	28.1	22.0	23.5	4.0	0.0011
			Aug.	19.2	16.5	33.7	23.1	9.2	0.0005
	Davis Point	BD41	Feb.	11.6	12.4	16.2	13.4	2.5	0.0011
			Aug.	14.3	13.3	12.2	13.2	1.1	0.0006
Se	Alameda	BB70	Feb.	0.590	0.526	0.549	0.555	0.032	0.001
			Aug.	0.249	0.238	0.306	0.264	0.037	0.048
	Horseshoe Bay	BC21	Feb.	0.435	0.460	0.455	0.450	0.013	0.001
			Aug.	0.263	0.249	0.283	0.265	0.017	0.048
	Davis Point	BD41	Feb.	0.394	0.406	0.361	0.387	0.023	0.002
			Aug.	0.122	0.074	0.179	0.125	0.053	0.048
Zn	Alameda	BB70	Feb.	105	102	101	103	2	19
			Aug.	113	118	119	117	3	1
	Horseshoe Bay	BC21	Feb.	85	95	88	89	5	18
			Aug.	92	87	85	88	4	1
	Davis Point	BD41	Feb.	68	77	72	73	4	20
			Aug.	77	70	78	75	4	1

Flegal and Stukas (1987) successfully intercalibrated lead measurements with samples collected with a vacuum-intercept polyethylene pumping system similar to the one used by the RMP and a Teflon®-coated General Oceanic Go-Flo sampler with those collected by hand from a raft and with the Caltech protected deep water sampler. By extension, the RMP sampling equipment and technique is in accordance with what is acceptable for trace metal research and currently serves as a model for the EPA trace metal sampling protocol (EPA Method 1669, 1995).

Samples approaching field blanks have been obtained for the RMP by collecting relatively pristine oceanic water well beyond coastal influences, using the same research vessel and sampling equipment as during a normal sampling cruise. The field blank is not collected during the cruise, because of the extra time required to motor the boat beyond coastal influences. Routine collection of these oceanic "blanks" is not conducted due to the costs involved.

Collection of true sediment field blanks is logistically difficult and has been deemed unnecessary due to precautions taken that minimize contamination of the samples. Sediment samples are collected with a van Veen grab sampler based on the NOAA Status and Trends, Benthic Surveillance Project methods (Lauenstein and Young, 1986) and modified as described in *Appendix A*. All surfaces of sediment sampling and processing instruments coming in contact with the sample are made of inert material, such as Teflon®, or stainless steel coated with Dykon® and are thoroughly cleaned prior to field use. Equipment is also cleaned with Alkonox® detergent between stations and rinsed with hydrochloric acid, followed by methanol in order to avoid any carryover contamination from one station to the next. Sampling, compositing, and homogenization is conducted on board ship with gloved hands, and the homogenate is placed into precleaned certified glass jars with Teflon®-lined lids for trace organic analyses, and into precleaned polyethylene or Teflon® containers for trace element analyses. The homogenization bucket is always covered with aluminum foil during the collection of the sediment samples to avoid sample contamination via aerial deposition.

Comparisons of samples collected with the van Veen grab and a non-coated, stainless steel Ponar grab with rubber lids normally used for the collection of benthic invertebrates showed very similar results that were within the station variability of replicate composite samples taken at three RMP stations in 1994 to determine within- and between-station variability. It appears that all precautions taken during sediment sampling are sufficient to minimize artifacts.

Bivalves are handled in the field according to established protocols of the California State Mussel Watch Program designed to minimize sample contamination. Bivalves destined for trace element analysis are placed in polyethylene ziploc bags, placed on dry ice, and kept frozen until homogenization and analysis. Bivalves used for trace organic analysis are wrapped in aluminum foil.

Trace Organic Contaminants in Water, Sediment, and Tissue

Most quality assurance and control steps taken to minimize trace element sampling artifacts are also applicable for the collection of trace organic samples. The considerations associated with a field blank apply also to the sampling of trace organic contaminants. However, similar precautions as for trace element sampling are taken for the collection of samples destined for trace organic analysis. For example, containers are routinely checked for contamination, and plastic material for storage, transport, and protection of samples is avoided. Only ultra-pure solvents are used in the preparation of the XAD resin and filters that capture the particulate and "dissolved" fraction (particles or colloidal material <1 micrometer in size pass through the filter) of the water samples. The XAD resin and filters through which approximately 100 liters of water are pumped remain enclosed and inaccessible to

aerial contamination. Tests on travel blanks of XAD columns and of a solvent-extracted glass fiber filter showed either no measurable levels of analytes or levels one to two orders of magnitude lower than field concentrations (Jarman, in prep.)

The precautions taken during sediment and bivalve sampling for trace elements also apply to the sub-sample used for trace organic analyses, except that the sediment homogenate is placed into pre-cleaned, certified (trace-organics-clean) glass jars with Teflon®-lined lids, and the bivalves are wrapped in aluminum foil.

Field duplicates can theoretically be sampled and evaluated for water samples if a second sampler of identical design were employed, filtering the same water mass as the first. Given the time involved in filtering the large amount of water through the resin and glass fiber filters, back-to-back samples would not represent the same water mass and do not constitute true duplicates.

In 1996, field duplicate measurements, in a sense, were taken as part of an intercomparison of the new RMP Axis sampler (see *Appendix A*) with the polyurethane foam plug sampler used in previous years (de Lappe *et al.*, 1980). Because foam-plug sampler results of side-by-side tests are not yet available, field precision could not be evaluated at this time. However, potential sampler bias was evaluated based on data from previous cruises. Three stations were chosen for the intercomparison: two that have had relatively high levels of trace organic contaminants in the past (Redwood Creek and Coyote Creek—BA30 and BA10); and one that has had very low levels of contaminants—the Golden Gate station (BC20). Results of these comparisons will be presented in a separate report. A detailed description of the sampler intercomparison data available to date is contained in a draft report by Jarman *et al.* (in prep.).

Because of the transition from the foam-plug water sampler to the resin sampler, the 1997 Annual Report will contain a detailed description of procedures and test used to determine the magnitude of potential errors associated with the sampling equipment, such as break-through of certain compounds and differential adsorption of different contaminant categories to the resin.

Summary of Laboratory QC

Types of Laboratory QA/QC Samples and Their Purpose

Laboratory performance measurements are used to assess the random and systematic errors introduced as part of the analysis. An unacceptable error is indicated when the standard QA/QC limit from a laboratory or a specific procedure has been exceeded. The appropriate corrective action is then immediately taken. As with field QA terms, the laboratory QA nomenclature varies between laboratories, and terms commonly used are defined below.

- *Laboratory, Method, or Procedural Blanks* account for all possible contamination sources introduced during sample processing and analyses.
- *Instrument Blanks* account for all sources of contamination introduced by the analytical instrument.
- *(Blind) Laboratory or Procedural Replicate Samples* are used to measure precision by evaluating analytical differences between splits of the same sample.
- *(Blind) Matrix Spike Samples* are field samples to which a known amount of contaminant is added. The percent recovery of the added analyte determines the degree of accuracy a laboratory measurement has and measures the magnitude of potential interferences in the field sample. The method of standard additions will also account for sample matrix effects.
- *Standard Reference Materials* determine analytical accuracy by comparing the recovery of an analyte with the certified or "consensus" value for that material. A standard reference material with a

similar matrix and concentration range as the sample of interest is usually chosen.

Laboratory blank samples, laboratory replicates, matrix spikes (or standard additions methods), and standard reference material are all incorporated into the RMP at a minimum frequency of 10% per sample batch.

Laboratory Intercomparisons

Starting in 1994, split samples were collected in the field and sent blind to external laboratories in order to validate RMP results. By 1995, split sediment and tissue sample analysis became part of the regular RMP quality assurance program. In addition, most RMP laboratories participate in the intercomparison exercises sponsored by the National Oceanic and Atmospheric Administration. Results of both RMP and international laboratory intercomparisons are detailed in *Summary of the 1996 Regional Monitoring Program Inter-laboratory Comparisons* in this chapter). Split sample results from previous years are contained in the Quality Assurance Appendices of each applicable Annual Report.

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Summary of the 1996 Regional Monitoring Program Inter-laboratory Comparisons

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During 1995 and 1996, Bay Area Dischargers Association (BADA) laboratories interested in participating in the analyses of Regional Monitoring Program (RMP) samples and existing RMP contract laboratories participated in several intercomparison exercises. Sediment and tissue reference material from the San Francisco Estuary were used in two intercomparisons, and many laboratories participated in the international NIST/NOAA intercomparison exercises of 1995 and 1996. Additionally, sediment samples from three RMP sediment stations were split and sent to participants during the 1996 February and August sampling cruises as part of an ongoing effort to compare analytical results of participating RMP laboratories (see Table 3 for a summary of participants).

Laboratory performance was evaluated using the NIST/NOAA evaluation criteria employed in the 1996 inter-laboratory comparison exercises for contaminants in the marine environment. Laboratory precision and accuracy were evaluated using the 95% confidence interval around the mean (for the RMP reference materials and the NIST/NOAA blind samples) or the certified standard reference material (SRM) value. Precision is a measure of replicate sample variability. Accuracy determines how close to a "true" concentration (a certified value) the sample result is. Charts used in summarizing laboratory results below will be included in the complete 1996 RMP Inter-Laboratory Comparison Technical Report (in prep.) and will be available through SFEI. Data quality objectives (DQOs) outlined in the 1996 Quality Assurance Project Plan for the Regional Monitoring Program for Trace Substances (Lowe and Hoenicke, 1996; QAPP) were not used to assess laboratory performance at this time.

Laboratories were asked to analyze five sub-samples (replicates) in order to determine laboratory precision. Laboratory accuracy was evaluated for those compounds that had certified values for the standard reference material (SRM). Each laboratory's method detection limits (MDL) for analytes of interest were evaluated in terms of being able to detect background estuarine concentrations with confidence (values being at least ten times the MDL).

Because the laboratories submitted varying numbers of replicates and did not always submit results for all the analytes of interest, it is difficult to generalize about inter-laboratory performance and to compare existing contract laboratories with new participants. With the limited amount of data for tissue, only a cursory performance evaluation is possible at this time for tissue trace elements. However, there are enough sediment data to begin to evaluate which compounds were problematic for most laboratories and which were problematic for any particular laboratory.

Evaluation of Sediment MDLs

The MDL represents a quantitative estimate of the low-level response detected at the maximum sensitivity of a method. At this time the RMP does not prescribe to participating laboratories how the MDL is assessed, but requires documentation of each laboratory's determination. This practice is currently under review.

Reported MDLs for the 1996 sediment intercomparison data are presented in Tables 4–7 along with the range of RMP field sample concentrations. Average field sample results, from the intercomparison stations, were compared with the MDLs for most laboratories to determine if estuarine concentrations of compounds of interest are detectable at concentra-

Table 3. List of laboratories that participated in the 1995 and 1996 inter-laboratory comparisons.

	BRL	EBMUD	CCCSD	CCSF	SJWTP	USD	NOAA/NIST	UCSCLABS[1]	GERG	BRL	EBMUD	CCCSD	CCSF	SJWTP	USD	NOAA/NIST	UCSCLABS[1]	GERG
	1995									1996								
Sediment Trace Elements:																		
NOAA Unknown		•		•	•		•	•			•		•	•		•	•	
NOAA SRM		•		•	•		•	•			•		•	•		•	•	
SED SPLIT 96 (spring)										•	•	•	•	•	•		•	
SED SPLIT 96 (fall)										•	•		•	•			•	
SFERM-S95	•	•	•	•	•		•	•										
Sediment Organics:																		
NIST Unknown											•	•						•
NIST SRM											•	•						•
SED SPLIT 96 (spring)											•	•						•
SED SPLIT 96 (fall)											•			•				•
SFERM-S95		•	•					•	•									
Tissue Trace Elements:																		
NOAA Unknown			•	•	•	•	•				•		•	•		•	•	
NOAA SRM				•	•	•	•				•		•	•		•	•	
SFERM-T96													•	•		•		
Tissue Organics:																		
NIST Unknown			•				•	•	•									
NIST SRM			•				•	•	•									
SFERM-T96											•	•		•			•[2]	•

[1] UCSCDET = trace elements, USCSOL= trace organics, UCSCMPL= SFERM-S95 trace organics.

[2] DFG analyzed this sample for trace elements.

KEY:

BRL	Brooks Rand, Ltd.
CCCSD	Contra Costa Central Sanitary District
CCSF	City and County of San Francisco
DFG	Department of Fish and Game (Moss Landing)
EBMUD	East Bay Municipal Utility District
GERG	Texas A&M University, Geochemical and Environmental Research Group
NIST	National Institute of Standards and Technology
NRC	National Research Council Canada
SJWTP	San Jose Wastewater Treatment Plant
UCSCDET	UCSC Environmental Toxicology
UCSCOL	UCSC Organics Laboratory
USD	Union Sanitary District

Table 4. Average laboratory MDL values for the sediment trace elements, 1996.

LAB:	BRL		CCCSD	CCSF		CCSJ		EBMUD		UCSCDET		USD	SF Estuary
	spring	fall	spring	spring	fall	spring	fall	spring	fall	spring	fall	spring	[field sample][1]
Trace Elements													
Ag	.	.	0.01	.	0.01	0.05	0.10	1.19	0.84	0.03	0.06	0.04	0.03–1.3
Al	.	.	.	1.00	1.00	.	.	9.87	25.17	52.77	7506.00	.	14805–56179
As	0.01	0.02	0.09	1.20	1.20	0.05	0.10	0.13	1.00	.	.	.	4.73–31.7
Cd	.	.	0.001	0.10	0.10	0.03	0.05	0.83	0.83	0.03	0.05	0.04	0.0363–1
Cr	.	.	4.78	0.10	0.10	2.50	5.00	2.49	2.57	6.27	11.90	.	47.6–141.8
Cu	.	.	0.20	0.30	0.30	5.00	5.00	0.83	1.30	0.50	2.20	1.67	8.2–76.3
Fe	.	.	.	0.30	0.30	.	.	3.30	4.17	36.07	3480.00	.	19303–64927
Hg	0.16	0.18	0.001	20.00	20.00	0.01	0.01	0.01	0.10	.	.	.	0.018–0.563
Mn	.	.	.	0.10	0.10	.	.	0.82	0.37	5.86	24.50	.	259.5–3554.8
Ni	.	.	0.88	0.30	0.30	5.00	10.00	2.77	3.33	3.86	5.90	18.93	58.286–158.52
Pb	.	.	0.90	1.00	1.00	0.05	5.00	8.31	12.57	0.01	3.30	8.68	10.3–69
Se	0.01	0.01	0.02	0.02	0.02	0.03	0.10	0.06	0.48	.	.	.	0.06–0.65
Zn	.	.	0.48	0.10	0.10	5.00	5.00	8.31	25.17	3.55	24.20	6.35	62–184

Units are in mg/kg (ppm)

[1] Field sample concentration range includes the uncensored, reported results.

Table 5. Average laboratory MDL values for the sediment PAHs, 1996.

LAB:	CCCSD	CCSJ	EBMUD		GERG		SF Estuary
	spring	fall	spring	fall	spring	fall	[field sample][1]
PAHs							
1-Methylnaphthalene	1.55	.	2.08	2.67	.	.	.
1-Methylphenanthrene	1.55	.	1.30	1.63	.	.	0.4–32.6
2,3,5-Trimethylnaphthalene	1.55	.	3.98	5.10	.	.	.
2,6-Dimethylnaphthalene	1.55	.	1.27	1.63	.	.	.
2-Methylnaphthalene	1.55	.	2.06	2.67	.	.	.
Acenaphthene	1.55	2.00	1.28	1.63	.	.	0.8–27.1
Acenaphthylene	1.55	2.00	1.19	1.53	.	.	0.5–36.8
Anthracene	1.93	2.00	1.24	1.53	7.13	.	0.9–95.3
Benz(a)anthracene	1.93	2.00	0.40	0.48	3.49	.	0.9–310.4
Benzo(a)pyrene	1.93	2.00	0.90	1.10	8.70	.	2.1–667.3
Benzo(b)fluoranthene	1.93	2.00	0.67	0.83	18.01	.	2.5–585.4
Benzo(e)pyrene	1.93	.	0.67	0.83	8.07	.	2–398.8
Benzo(ghi)perylene	1.93	2.00	1.51	1.88	19.06	.	2–496.8
Benzo(k)fluoranthene	1.93	2.00	1.21	1.48	6.76	.	0.8–170.9
Biphenyl	1.55	.	2.46	3.17	.	.	0.7–13.1
Chrysene	1.93	2.00	1.48	1.80	9.75	.	1.6–323.3
Dibenz(a,h)anthracene	1.93	2.00	1.43	1.75	7.84	.	1–54.2
Fluoranthene	1.93	2.00	1.13	1.40	14.67	.	2.9–661.8
Fluorene	1.93	2.00	1.84	2.28	6.96	.	0.8–22.7
Indeno(1,2,3-cd)pyrene	1.93	2.00	1.50	1.85	3.99	.	1.5–415.9
Naphthalene	1.93	2.00	0.99	1.23	31.47	.	3.2–44.6
Perylene	1.93	.	0.74	0.90	8.02	.	1.2–135.1
Phenanthrene	1.93	2.00	0.87	1.08	11.57	.	1.5–261.6
Pyrene	1.93	2.00	1.38	1.70	15.19	.	3.5–764.1

Units are in µg/kg (ppb)

[1] Field sample concentration range includes the uncensored, reported results.

Table 6. Average laboratory MDL values for the sediment PCBs, 1996.

LAB:	CCCSD	EBMUD		GERG		SF Estuary
	spring	spring	fall	spring	fall	[field sample][1]
PCBs						
PCB 008	.	0.67	1.20	.	.	.
PCB 018	0.30	0.67	0.35	.	.	.
PCB 028	.	0.67	.	.	.	0.13–7.17
PCB 028/31	0.30	.	0.63	.	.	.
PCB 031	.	0.67	.	.	.	.
PCB 044	0.37	0.59	1.60	1.43	.	0.16–8.1
PCB 049	.	.	.	2.14	.	0.2–2.39
PCB 052	0.37	0.59	0.51	5.99	.	0.87–11.09
PCB 060	.	.	.	.	.	.
PCB 066	0.37	0.59	0.33	1.00	.	0.13–5.39
PCB 087	.	0.59	0.24	0.71	.	.
PCB 095	.	.	.	2.14	.	0.19–13.1
PCB 099	0.37	0.59	0.22	2.14	.	0.18–9.7
PCB 101	.	0.59	0.68	2.14	.	0.24–22.2
PCB 105	0.37	0.59	0.34	0.86	.	0.1–2.69
PCB 110	.	.	.	2.14	.	0.28–18.7
PCB 118	0.37	0.59	0.61	.	.	0.16–14.15
PCB 128	0.37	0.54	0.45	2.00	.	0.16–2.98
PCB 138	.	0.59	0.19	1.00	.	0.08–16.9
PCB 138/160	0.30	.	.	.	.	.
PCB 149	.	.	.	2.14	.	0.28–14.97
PCB 153	.	0.59	0.33	1.14	.	0.08–39.1
PCB 170	.	0.59	0.47	2.42	.	0.29–7.99
PCB 170/190	0.30	.	.	.	.	.
PCB 180	0.37	0.59	0.33	1.64	.	0.08–19.46
PCB 194	0.37	0.59	0.29	2.14	.	0.23–5
PCB 195	.	0.67	0.34	.	.	.
PCB 195/208	0.30	.	.	.	.	.
PCB 196/203	0.30	.	.	.	.	.
PCB 201	0.30	.	.	.	.	.
PCB 206	0.37	0.59	0.58	0.71	.	0.08–2.72
PCB 207	.	.	1.00	.	.	.
PCB 209	0.37	0.59	0.39	.	.	.

Units are in µg/kg (ppb)

[1] Field sample concentration range includes the uncensored, reported results.

Table 7. Average laboratory MDL values for the sediment pesticides, 1996.

LAB:	CCSJ	EBMUD		GERG		SF Estuary
	fall	spring	fall	spring	fall	[field sample][1]
Pesticides						
Aldrin	1.00	0.67	0.59			.
Alpha-Chlordane	1.00	0.59	0.19	1.14		0.27–3.49
Alpha-HCH	1.00					.
Beta-HCH	1.00					.
Delta-HCH	1.00					.
Dieldrin	1.00	0.59	0.23	0.81		0.04–2.15
Endrin	1.00					.
gamma-Chlordane	1.00					.
Gamma-HCH	1.00	0.67	0.31			.
Heptachlor	1.00	0.67	0.13			.
Heptachlor Epoxide	1.00	0.67	1.30			.
Hexachlorobenzene		0.59	0.35	3.14		0.2–0.33
Mirex		0.67	0.31			.
o,p'-DDD	1.00	0.67	0.68			.
o,p'-DDE	1.00	0.59	0.65	1.14		0.11–5.09
o,p'-DDT	1.00	0.67	0.20			.
Oxychlordane				1.00		0.14–1.14
p,p'-DDD		0.59	0.36	1.00		0.12–49.1
p,p'-DDE		0.59	0.16	0.86		0.06–68.6
p,p'-DDT		0.59	2.70	1.28		0.09–10.35
trans-Nonachlor		0.59	0.30	1.43		0.16–3.15

Units are in µg/kg (ppb)

[1] Field sample concentration range includes the uncensored, reported results.

tions greater than ten times the MDL. Estuarine silver and cadmium results were below ten times the MDL for most laboratories (except Central Contra Costa Sanitary District for cadmium). Lead concentrations in the Estuary were above ten times the MDL for half of the participating laboratories: Central Contra Costa Sanitary District (CCCSD), City and County of San Francisco (CCSF), and University of Santa Cruz Department of Environmental Toxicology (UCSCDET). For the remaining trace elements of interest, values were above ten times the MDL for most laboratories.

The estuarine concentrations at the intercomparison stations of most of the PCB/pesticide compounds of interest were below detection for most laboratories. PAH concentrations in the estuarine samples showed most laboratory results for benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(e)pyrene, benzo(ghi)perylene, benzo(k)fluoranthene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, perylene, phenanthrene, and pyrene above the ten times the MDL criterion. 1-methylnaphthalene, 1-methylphenanthrene, 2,3,5-trimethylnaphthalene, 2,6-dimethylnaphthalene, 2-methylnaphthalene, acenaphthene, acenaphthylene, fluorene field sample results were below ten times the MDL for most laboratories. The remaining compounds showed mixed results.

Evaluation of Precision and Accuracy

In evaluating performance with the unknown NIST/NOAA samples, San Francisco Estuary field samples, and the SRMs in these studies, it has become evident that SRM intercomparisons, while valuable in assessing accuracy, do not necessarily reflect the accuracy obtained for an unknown or field sample containing a different matrix and different concentrations of the compounds of interest. It has also become evident that because of the "normal" intra-laboratory variability between analyses of SRM samples, more samples are necessary in order to evaluate laboratory tendencies. It would be valuable to have a large enough SRM sample size to evaluate any laboratory trends and tendencies.

Below is a summary of each laboratory's performance based on the NIST/NOAA evaluation criteria. Tables 8 and 9 are tabular summaries of the laboratory average value and range for certified and consensus analytes of sediment SRM BCSS-1 and sediment SRM 1941a. While evaluating the results of the 1995 and 1996 intercomparison exercises, it is important to keep in mind which laboratory analyzed the 1997 RMP samples and which laboratory has been the RMP contract laboratory in the past.

Sediment Trace Elements

Laboratories participated in the NOAA-95 and NOAA-96 intercomparison exercises analyzing both an unknown and a standard reference material (BCSS-1). In 1995, interlaboratory comparisons were also performed on the local reference material (SFERM-S95) from the RMP's Napa River sediment station. In 1996, six RMP sediment samples were split and analyzed by participating laboratories. Participating laboratories were: the BADA laboratories (East Bay Municipal Utility District (EBMUD), CCSF, San Jose Wastewater Treatment Plant (SJWTP), CCCSD, Union Sanitary District (USD)), and the RMP contract laboratories (UCSCDET and Brooks-Rand Laboratory (BRL)). Most laboratories submitted results (in replicate) for all these studies with the exception of BRL which did not participate in the NOAA intercomparison exercises and did not submit any SRM results. CCCSD and USD did not participate in the 1996 NOAA intercomparison or the fall RMP split sample trace element analyses, as they are not directly involved with the analyses of the RMP samples for trace elements. EBMUD analyzed all but arsenic, mercury, and selenium in 1997. BRL analyzed arsenic, mercury, and selenium in 1997.

Table 8. Average sediment SRM (BCSS-1) results for participating laboratories. (Refer to Table 3 for the key to laboratory names.) Shading indicates that the results were outside the 95% confidence limits.

		Certified value	95% conf. interval	CCCSD	CCSF	EBMUD	SJWTP	UCSCDET	USD
	n =			2	1–10	1–5	10	11–25	5–8
Ag	Ave.	0.11	0.03	0.09	2.00	2.00	0.10	0.11	0.09
	MAX			0.09	2.00	2.60	0.13	0.14	0.11
	MIN			0.09	2.00	1.70	0.06	0.07	0.07
Al (%)	Ave.	6.26	0.41	.	2.61	1.98	.	1.84	.
	MAX			.	2.98	2.08	.	2.63	.
	MIN			.	2.14	1.87	.	1.42	.
As	Ave.	11.1	1.4	9.55	11.33	10.10	10.72	.	.
	MAX			9.69	13.10	10.20	15.30	.	.
	MIN			9.41	9.00	10.00	7.60	.	.
Cd	Ave.	0.25	0.04	0.24	0.31	0.40	0.24	0.26	0.29
	MAX			0.24	0.40	0.40	0.28	0.31	0.32
	MIN			0.24	0.20	0.40	0.18	0.21	0.26
Cr	Ave.	123	14	56.10	59.13	.	90.61	51.76	.
	MAX			56.20	73.60	.	122.00	70.36	.
	MIN			56.00	52.30	.	66.20	40.00	.
Cu	Ave.	18.5	2.7	14.50	15.74	14.66	17.53	14.03	14.78
	MAX			14.60	16.60	16.30	18.00	20.79	18.00
	MIN			14.40	15.00	13.80	16.60	12.00	11.40
Fe (%)	Ave.	3.28	0.14	.	3.20	2.99	.	2.91	.
	MAX			.	3.27	3.06	.	3.32	.
	MIN			.	3.10	2.84	.	2.62	.
Hg	Ave.	0.176	0.023	.	0.19	0.19	0.16	.	.
	MAX			.	0.21	0.19	0.18	.	.
	MIN			.	0.16	0.19	0.13	.	.
Mn	Ave.	229	15	.	192.01	202.20	220.75	231.30	.
	MAX			.	198.00	208.00	243.00	626.16	.
	MIN			.	187.30	193.00	207.00	152.43	.
Ni	Ave.	55.3	3.6	45.10	49.66	57.00	53.53	51.39	55.58
	MAX			45.30	55.30	59.20	61.70	59.85	61.40
	MIN			44.90	47.80	54.10	48.80	43.56	50.70
Pb	Ave.	22.7	3.4	17.60	20.06	21.80	20.20	20.40	21.74
	MAX			17.90	21.90	22.40	24.40	24.88	23.40
	MIN			17.30	18.40	21.10	16.90	16.23	19.70
Se	Ave.	0.43	0.06	0.025	1.07	0.56	.	.	.
	MAX			0.03	4.00	0.65	.	.	.
	MIN			0.02	0.31	0.48	.	.	.
Zn	Ave.	119	12	95.05	105.92	105.00	114.33	103.29	101.80
	MAX			95.20	108.90	107.00	124.00	123.49	104.00
	MIN			94.90	102.00	102.00	106.00	89.58	99.60

Units are in mg/kg unless otherwise specified.

Table 9. Average sediment SRM (1941a) results for participating laboratories. (Refer to Table 3 for the key to laboratory names.) Shading indicates that the results were outside the 95% confidence limits.

		Certified value	95% conf. interval	CCCSD	EBMUD	GERG
	n =			4	3	21
1-Methylphenanthrene	Ave.	101	27	102	53.1	81.9
	MIN			65.7	0.70	76.5
	MAX			128	158	87.9
Acenaphthene	Ave.	41	10	42.5	39.3	35.1
	MIN			35.3	23	30.7
	MAX			49.5	56	36.9
Acenaphthylene	Ave.	37	14	69.1	68.0	65
	MIN			60.2	37	57.8
	MAX			81.9	119	70.3
alpha-Chlordane	Ave.	2.33	0.56		6.17	2.05
	MIN				0.35	1.66
	MAX				21.5	2.52
Anthracene	Ave.	184	14	145	164	167
	MIN			122	98	157
	MAX			189	184	182
Benz(a)anthracene	Ave.	427	25	389	389	332
	MIN			312	110	286
	MAX			428	470	366
Benzo(a)pyrene	Ave.	628	52	460	548	468
	MIN			422	131	427
	MAX			505	820	504
Benzo(b)fluoranthene	Ave.	740	0	1064	928	966
	MIN			1064	243	947
	MAX			1064	1800	985
Benzo(e)pyrene	Ave.	553	59	526	542	437
	MIN			490	139	351
	MAX			616	770	482
Benzo(ghi)perylene	Ave.	525	67	573	337	439
	MIN			497	0.916	390
	MAX			720	690	507
Benzo(k)fluoranthene	Ave.	361	0	102	354	262
	MIN			102	152	251
	MAX			102	550	273
Biphenyl	Ave.	175	18	94.7	68.7	79.5
	MIN			86.8	15	72.1
	MAX			101	175	90.2
Chrysene	Ave.	380	24	648	460	462
	MIN			550	171	404
	MAX			765	650	483
Dibenz(a,h)anthracene	Ave.	73.9	6.8	121	130	99.3
	MIN			115	0.866	91.7
	MAX			127	257	105
Dieldrin	Ave.	1.26	0.37		0.612	2.30
	MIN				0.23	1.45
	MAX				1.26	4.14
Endosulfan I	Ave.	0.73	0			
	MIN					
	MAX					
Fluoranthene	Ave.	981	78	932	801	773
	MIN			815	75	695
	MAX			1090	1110	919
Fluorene	Ave.	97.3	8.6	89.225	71.8	68.2
	MIN			76.9	61	64.5
	MAX			111	97.3	72

Units are in µg/kg.

Table 9 (continued). Average sediment SRM (1941a) results for participating laboratories.

		Certified value	95% conf. interval	CCCSD	EBMUD	GERG
	n =			4	3	21
Hexachlorobenzene	Ave.	70	25		33.4	49.6
	MIN				0.347	0.48
	MAX				70	67.4
Indeno(1,2,3-cd)pyrene	Ave.	501	72	532.5	359	454
	MIN			511	0.906	386
	MAX			553	780	537
Naphthalene	Ave.	1010	140	810	364	705
	MIN			810	9	664
	MAX			810	1010	746
o,p'-DDE	Ave.	0.73	0.11		0.576	1.40
	MIN				0.347	0.53
	MAX				0.73	3.27
Oxychlordane	Ave.	2.59	0.19			1.65
	MIN					0.64
	MAX					3.58
p,p'-DDD	Ave.	5.06	0.58		22.0	6.50
	MIN				3.4	3.88
	MAX				67.2	10.32
p,p'-DDE	Ave.	6.59	0.56		4.56	5.95
	MIN				0.347	4.83
	MAX				10.6	6.77
p,p'-DDT	Ave.	1.25	0.1		2.60	1.39
	MIN				1.25	0.69
	MAX				3.24	2.14
PCB 018	Ave.	1.15	0.16	4.08	0.616	4.12
	MIN			3.66	0.347	2.68
	MAX			4.42	1.15	5.83
PCB 028	Ave.	9.8	3.7	12.9	3.61	7.79
	MIN			12.5	3.6	6.34
	MAX			13.3	3.61	9.49
PCB 044	Ave.	4.8	0.62	6.61	12.0	8.41
	MIN			6.2	2.2	5.39
	MAX			6.93	45.8	12.8
PCB 049	Ave.	9.5	2.1			8.27
	MIN					6.35
	MAX					11.26
PCB 052	Ave.	6.89	0.56	8.96	4.86	12.9
	MIN			7.69	0.51	9.13
	MAX			9.78	6.89	19.3
PCB 066	Ave.	6.8	1.4	7.6	4.58	8.47
	MIN			7.6	0.33	6.13
	MAX			7.6	6.8	10.8
PCB 087	Ave.	6.7	0.37		3.47	2.86
	MIN				0.24	2.68
	MAX				6.7	3.03
PCB 095	Ave.	7.5	1.1			9.11
	MIN					7.78
	MAX					10.9
PCB 099	Ave.	4.17	0.51	5.6	20.5	7.12
	MIN			5.6	3	6.14
	MAX			5.6	71.9	8.32

Units are in µg/kg.

Table 9 (continued). Average sediment SRM (1941a) results for participating laboratories.

		Certified value	95% conf. interval	CCCSD	EBMUD	GERG
	n =			4	3	21
PCB 101	**Ave.**	11	1.6		24.3	15.1
	MIN				4.92	12.4
	MAX				53	18.6
PCB 105	**Ave.**	3.65	0.27	3.37	13.8	4.11
	MIN			2.95	2	2.49
	MAX			3.8	54.8	9.11
PCB 110	**Ave.**	9.47	0.85			16.6
	MIN					15.4
	MAX					18.6
PCB 118	**Ave.**	10	1.1	9.2	13.3	7.98
	MIN			8.68	0.347	6.76
	MAX			9.44	39	9.95
PCB 128	**Ave.**	1.87	0.32	1.61	11.5	2.52
	MIN			1.55	0.29	1.04
	MAX			1.7	64.2	3.84
PCB 138	**Ave.**	13.38	0.97		19.5	11.7
	MIN				6.1	10.2
	MAX				45.6	13.0
PCB 149	**Ave.**	9.2	1.1			9.72
	MIN					8.76
	MAX					11.4
PCB 153	**Ave.**	17.6	1.9	16.2	14.5	15.3
	MIN			15.8	6.3	13.8
	MAX			16.4	35.8	17
PCB 170	**Ave.**	3	0.46		24.4	12.3
	MIN				1.8	7.6
	MAX				90	20.4
PCB 180	**Ave.**	5.83	0.58	9.94	21.3	4.66
	MIN			9.65	4.9	0.79
	MAX			10.2	84	8.79
PCB 194	**Ave.**	1.78	0.23	2.9	29.3	22.1
	MIN			2.9	1	2.36
	MAX			2.9	112	29.6
PCB 206	**Ave.**	3.67	0.87	3.56	32.7	4.49
	MIN			3.4	0.347	2.43
	MAX			3.64	101	5.76
PCB 209	**Ave.**	8.34	0.49	10.0	29.8	7.74
	MIN			9.6	5.3	7.21
	MAX			10.4	120	8.22
Perylene	**Ave.**	452	58	271	378	294
	MIN			259	119	277
	MAX			299	540	323
Phenanthrene	**Ave.**	489	23	524	387	408
	MIN			463	96	388
	MAX			606	489	454
Pyrene	**Ave.**	811	24	781	759	631
	MIN			690	105	567
	MAX			924	1030	786
trans-Nonachlor	**Ave.**	1.26	0.13		12.5	1.21
	MIN				0.347	0.94
	MAX				47.6	1.54

Units are in µg/kg.

Evaluation of Sediment Trace Element Results. Laboratory performance evaluation was based on precision and accuracy using the 95% confidence interval around the mean or target value.

Ag	EBMUD had trouble with concentrations lower than 0.4 ppm. SJWTP had good precision and accuracy. UCSCDET had good precision and accuracy. They tend to be slightly higher than the other labs.
As	EBMUD had good precision and accuracy. BRL had few data, but they are comparable to EBMUD. CCSF seems to come up a slightly, and had some problem with precision.
Cd	Cd values seem to be reached with good precision and accuracy by all labs. UCSCDET seems slightly higher than other labs.
Cr	Cr values seem to be reached with good precision by all labs. However, due to the use of the *aqua regia* extraction method employed by the labs, accuracy for the SRMs were well below the 95% confidence limits.
Cu	Cu values seem to be reached with good precision and accuracy by all labs in 1996. In 1995 all laboratories had trouble with precision. UCSCDET tends to be slightly higher than the other labs in 1996. EBMUD's SRM analysis showed improved accuracy in 1996.
Fe	Fe values seem to be reached with good precision and accuracy by all labs with the exception of EBMUD. EBMUD came in slightly low for the NOAA-95 and 96 comparison of SRM BCSS-1. However, SED-10 results were fine except at station BF10 when comparing the difference with UCSCDET (EBMUD was about 10,000 ppm lower).
Hg	Hg values seemed to be reached with good precision and accuracy. EBMUD and SJWTP had difficulty with accuracy in 1995 but greatly improved in 1996. CCSF MESS-2 SRM results were higher than the confidence interval. CCSF 96 split field sample results were consistently higher than BRL.
Ni	Ni values seemed to be reached with good precision and accuracy.
Pb	SRM values were within DQOs for both years and had good accuracy and precision. Pb values seemed to be variable between labs, with split sample analyses values sometimes outside the 95% confidence limits.
Se	Se values varied considerably between labs. CCSF results were within the 95% confidence limits while EBMUD were just outside.
Zn	Zn values were reached with good precision and accuracy. UCSCDET values were generally higher than the other labs, and outside the confidence limits for the split samples taken during the winter 1996 cruise.

In summary, sediment analyses of cadmium, copper, iron, nickel, zinc, and lead have consistently comparable results between all laboratories. Silver poses a problem for EBMUD at low concentrations (comparable to the RMP field samples), although other laboratories showed consistently high precision and accuracy. EBMUD and BRL seem to be comparable in the arsenic analyses (although we do not have BRL SRM results for comparison). Mercury analyses were within confidence limits for all laboratories in 1996 (EBMUD and SJWTP improved from 1995). Selenium analyses showed variable results.

Tissue Trace Elements

Laboratories participated in the NOAA-95 and NOAA-96 intercomparison exercise analyzing both an unknown and a standard reference material (1566a). In 1996 an inter-laboratory comparison was performed on the local reference material (SFERM-T96) from oysters transplanted from Tomales Bay and exposed for approximately one hundred days to San Francisco Estuary conditions in the Alameda Channel. Participating laboratories were: the BADA laboratories (EBMUD, CCSF, SJWTP), and UCSCDET. Most laboratories submitted results (in replicate) for all these studies. Results from the local reference material SFERM-T96 are not included in this evaluation at this time because data from the RMP contract laboratories are not available. CCSF analyzed all but arsenic, mercury, and selenium in 1997. BRL analyzed arsenic, mercury, and selenium in 1997.

Evaluation of Tissue Trace Element Results. Laboratory performance evaluation was based on precision and accuracy using the 95% confidence interval around the mean or target value.

Ag	Ag values varied with regard to precision and accuracy between labs. CCSF had poor precision and accuracy for the unknown sample, but was within confidence limits for the SRM in 1995. CCSF did not analyze the unknown in 1996, but they showed improved precision for the SRM, although it was well below the 95% confidence limit. UCSCDET showed variable precision for the unknown and SRM and was below the 95% confidence limit for the SRM.
As	CCSF analysis of SRM 1566a had good precision and accuracy for 1995 and 1996 while the unknown tissues analyzed had poor precision and accuracy in 1995 with improvement in precision in 1996. No BRL data are available for comparison.
Cd	Cd values had good precision and accuracy for all labs for both years with the exception that UCSCDET had poor accuracy for the SRM 1566a in 1996, and CCSF had poor precision and accuracy for the NOAA unknown (Tiss-Z) in 1996.
Cr	Cr accuracy and precision were within DQOs for all labs. CCSF values were, although accurate, consistently lower than other laboratories for both years in the SRM and within precision and accuracy limits for the unknown samples. UCSCDET was within limits for both precision and accuracy for both samples in 1996. There are no 1995 data available for UCSCDET.
Cu	Cu values were mostly within limits for all samples for all labs. Both CCSF and UCSCDET values were comparable in 1996.
Fe	Fe values were within limits for all samples for all labs.
Hg	Hg values were within limits for all samples for all labs. SJWTP showed the best precision and accuracy for this compound, although CCSF performed well on three out of four samples. No BRL data are available for comparison.
Ni	Ni values were within limits for all samples for most labs. UCSCDET results were variable and went outside limits for the SRM in 1996. CCSF showed good accuracy and precision for three out of four samples .
Pb	Pb accuracy and precision seems to be variable for most labs. The SRM analyses were more variable for CCSF than the unknown samples. SJWTP had consistently good precision and accuracy. UCSCDET had good precision for both samples in 1996 but were below the 95% confidence limit on the SRM.
Se	Se accuracy and precision seems to be variable for most labs. CCSF accuracy improved slightly between years. SJWTP had good precision and accuracy in 1995 but showed some problems in 1996. No BRL data are available for comparison.
Zn	Zn values were within limits for all samples for most labs. UCSCDET showed a wider spread of results that extended outside the confidence limits for both 1996 samples.

In summary, chromium, copper, iron, and nickel tissue results seem to be comparable between participating laboratories. Arsenic, selenium, and mercury results show that the BADA laboratories are improving for arsenic analysis, are capable of meeting DQOs for mercury, but are having difficulties with selenium. Unfortunately, we do not have results from the current RMP contract laboratory (BRL) in order to compare these results. BADA laboratories, as a whole, had good results for cadmium and zinc, while the previous RMP contract laboratory (UCSCDET) showed mixed results. Silver and lead analyses were challenging to all laboratories.

Sediment Organics

Laboratories participated in the 1996 NIST Intercomparison Exercise where an unknown sample and a certified reference material (SRM 1941a) were analyzed in replicate. In 1995, the RMP initiated the inter-laboratory analyses of a local reference material from the RMP's Napa River sediment station (BD50). Organics results from this sample indicated that concentrations of compounds of interest were generally below the limits of detection and, therefore,

are not part of this evaluation. In 1996, six sediment stations were selected as split sample stations to be analyzed by both the RMP contract laboratory and the BADA laboratories. Although analyses were to be submitted by each laboratory as three replicates, many laboratories only submitted single sample results. Therefore, laboratory precision cannot be evaluated from the split sample results. Some laboratories only submitted a portion of the NIST organics analyses. For example, in 1996 EBMUD provided NIST sediment organics results in triplicate for the unknown NIST sample and only one SRM sample result. Therefore, for EBMUD precision can not be evaluated for the NIST SRM analysis.

Please note that not all of the analytes of interest were analyzed by all laboratories, and this evaluation only focuses on those compounds for which certified SRM values are available. EBMUD organics data for the 1995 and 1996 intercomparisons were generated using methods that were under development. They have since changed their analytical procedures so the results of this evaluation will not reflect EBMUD's analytical performance for the 1997 RMP sediment organics analyses.

Evaluation of Sediment Trace Organics Results (PAHs). Laboratory performance evaluation was based on precision and accuracy using the 95% confidence interval around the mean or target value.

PAHs:	
Anthracene	
NIST-96 unknown	All labs fell within confidence limits with the exception that EBMUD reported a non-detect for one of three replicates.
SRM 1941a	CCCSD had difficulty with precision. EBMUD and GERG showed good precision and accuracy.
Benz(a)anthracene	
NIST-96 unknown	GERG had good precision and accuracy while CCCSD and EBMUD were within accuracy limits but had variable precision.
SRM 1941a	All labs showed some difficulty meeting the SRM target range, although CCCSD had two of three samples within confidence limits.
Benzo(a)pyrene	
NIST-96 unknown	GERG and CCCSD had good precision and accuracy, while EBMUD fell outside confidence limits for both.
SRM 1941a	Both GERG and CCCSD had good precision, but fell below confidence limits. EBMUD was within range.
Benzo(e)pyrene	
NIST-96 unknown	GERG and CCCSD had good precision and accuracy while EBMUD fell outside confidence limits.
SRM 1941a	Both GERG and CCSD had good precision. GERG fell below confidence limits. CCCSD showed good accuracy and EBMUD fell on the upper and lower confidence lines for two out of two SRM samples.
Benzo(ghi)perylene	
NIST-96 unknown	GERG and CCCSD had good precision and accuracy while EBMUD fell outside confidence limits.
SRM 1941a	GERG fell below confidence limits while CCCSD showed good accuracy and precision for one study and fell outside range on the SED-96 SRM. EBMUD had difficulty detecting this compound in the SRM, even though their reported MDL was 0.9 ppb.
Benzo(k)fluoranthene	
NIST-96 unknown	Not evaluated, as NIST-96 did not report this compound.
SRM 1941a	SED-96 SRM values varied widely between labs.
Chrysene	
NIST-96 unknown	GERG showed good accuracy and precision. CCCSD results were above the confidence limits, and EBMUD ranged from ND to just inside the lower limit.
SRM 1941a	GERG fell just above confidence limits in both studies. CCCSD and EBMUD values were well above confidence limits.
Dibenz(a,h)anthracene	
NIST-96 unknown	All labs showed fair precision and accuracy, although GERG values extended outside the upper confidence limit.
SRM 1941a	While precision was good, all labs had difficulty meeting accuracy targets.

Fluoranthene

NIST-96 unknown	All labs fell within confidence limits.
SRM 1941a	CCCSD fell within range for one study while they were slightly low for the SED-96 SRM. GERG and EBMUD fell just outside of confidence limits.

Fluorene

NIST-96 unknown	All labs fell within confidence limits.
SRM 1941a	All labs had trouble with reaching target range with the exception of CCCSD whose results fell around the lower confidence level.

Indeno(1,2,3-cd)pyrene

NIST-96 unknown	GERG and CCCSD showed good precision and accuracy, while EBMUD did not.
SRM 1941a	GERG (although they extended slightly below the lower confidence limit in one study) showed good precision and accuracy, while EBMUD did not. CCCSD showed good precision and accuracy.

Naphthalene

NIST-96 unknown	Not evaluated, as NIST-96 did not report this compound
SRM 1941a	All labs fell below confidence limits.

Perylene

NIST-96 unknown	GERG fell below confidence limits. CCCSD was within range though extended slightly below the lower confidence limit. EBMUD was within confidence limits.
SRM 1941a	All labs fell below confidence limits with the exception that EBMUD samples spanned the target range to the upper and lower limits.

Phenanthrene

NIST-96 unknown	GERG showed good accuracy and precision while CCCSD and EBMUD had good precision but fell just above confidence limits.
SRM 1941a	All labs fell just outside of target range in both studies.

Pyrene

NIST-96 unknown	GERG fell within confidence limits but extended below the lower confidence limit. CCCSD showed good accuracy and precision. EBMUD did not meet targets.
SRM 1941a	All labs fell outside confidence limits for this compound.

Evaluation of Sediment Trace Organics Results (PCBs)

NOTE: Only SRM 1941a sample results are evaluated for the PCBs as EBMUD and CCCSD reported non-detect values for most parameters of the split field samples.

PCB 044
NIST-96 results showed labs having good precision but poor accuracy for this compound.
SED-96 SRM also showed that the labs had trouble with accuracy.

PCB 052
NIST-96 results showed GERG and CCSD having good precision but poor accuracy for this compound. EBMUD had poor precision. Results spanned the confidence interval for the unknown sample.
SED-96 SRM also showed that the labs had trouble with accuracy.

PCB 066
NIST-96 results had PCB 095 coeluting. Results showed GERG and CCSD having good precision but poor accuracy for the unknown sample. All three labs were within confidence limits for the SRM. EBMUD had poor precision for the unknown sample.
SED-96 SRM also showed that CCCSD had good accuracy, while EBMUD reported below detection and GERG results were above the 95% confidence limit.

PCB 087
NIST-96 No certified value exists for this congener.
SED-96 SRM also showed that EBMUD reported below detection and GERG was below the 95% confidence limit.

PCB 095
NIST-96 reported this compound as coeluting with PCB 066.
SED-96 SRM also showed that CCCSD had good accuracy while EBMUD reported below detection and GERG was above the 95% confidence limit.

PCB 099
NIST-96 No certified value exists for this congener.

PCB 101
NIST-96 reported this as coeluting with PCB 090. Results from the unknown sample showed labs having good precision and OK accuracy for this compound.
CCCSD showed good precision and accuracy for the SRM while GERG was slightly high and EBMUD was well below confidence limits.
SED-96 SRM showed that the labs had trouble with accuracy, although precision was fairlygood for this compound.
SED-96 SRM showed CCCSD having good accuracy (no replicate data for precision comparison) while GERG and EBMUD had variable results with precision spanning the confidence range.

PCB 110
NIST-96 No certified value exists for this congener.

	SED-96 SRM GERG was the only lab to report this compound, showing good precision but poor accuracy.
PCB 118	NIST-96 results from the unknown and SRM samples showed labs having moderately good precision and poor accuracy for this compound, with CCCSD coming in closest to target range and EBMUD below detection. SED-96 SRM showed CCCSD having good accuracy, EBMUD ND or below confidence range, and GERG did not report this compound.
PCB 128	NIST-96 results from the unknown and SRM samples showed labs having good precision and accuracy for this compound with the exception of GERG which showed precision problems and EBMUD that had low recovery for the SRM. SED-96 SRM showed CCCSD again having good accuracy while EBMUD fell short and GERG came in slightly high (both labs had fairly tight precision).
PCB 138	NIST-96 reported this as coeluting with PCBs 163 and 164. Results from the unknown sample showed labs having good precision and only GERG had good accuracy for this compound. The NIST-96 SRM showed both GERG and EBMUD to be within limits though GERG had poor precision. SED-96 SRM showed both EBMUD and GERG below confidence limits with GERG falling only slightly outside the lower confidence limit.
PCB 149	NIST-96 No certified value exists for this congener. SED-96 SRM GERG was the only lab to report this compound, showing good precision but poor accuracy.
PCB 153	NIST-96 No certified value exists for this congener. SED-96 SRM both labs showed good precision but poor accuracy.
PCB 170	NIST-96 reported this as coeluting with PCB 190. Results from the unknown sample showed CCCSD and EBMUD having good precision while GERG had widely variable replicate results. CCCSD showed good accuracy for the unknown sample though all labs were outside confidence limits for the SRM. SED-96 SRM showed EBMUD having good precision (though outside confidence limits) and GERG varying widely and well outside confidence limits.
PCB 180	NIST-96 results from the unknown and SRM samples showed labs having good precision but outside confidence limits for this compound with the exception of EBMUD who fell within range two out of three times for the SRM 1941a sample (including SED-96 sample).
PCB 194	NIST-96 No certified value exists for this congener. SED-96 SRM CCCSD and EBMUD showed good accuracy while GERG showed poor precision and accuracy for this compound.
PCB 206	NIST-96 results from the unknown samples showed labs having good precision but GERG fell outside confidence limits for this compound. NIST-96 SRM results also showed good precision for GERG and CCCSD but values fell outside target range. SED-96 SRM CCCSD showed good accuracy while GERG and EBMUD showed poor precision and accuracy for this compound.
PCB 209	NIST-96 results from the unknown samples showed labs having good precision and accuracy with the exception of GERG which fell just above confidence limits for this compound. NIST-96 SRM results also showed good precision for GERG and CCCSD but values fell outside target range. SED-96 SRM all labs fell outside target range. (GERG did not report this compound.)

Evaluation of Sediment Trace Organics Results (Pesticides)

NOTE: Only SRM 1941a sample results are evaluated for the pesticides as EBMUD reported non-detect values for most parameters of the split field samples. CCCSD did not analyze for pesticides.

Alpha-Chlordane	NIST-96 results showed precision and accuracy for both the unknown and the SRM for GERG to be within confidence limits. SED-96 SRM results showed both labs reporting either ND or variable results.
Dieldrin	Dieldrin SRM values were below detection for both labs (EBMUD and GERG) NIST-96 unknown sample was too low a concentration to be detected by EBMUD while GERG showed good precision, but fell slightly above the 95% confidence limit.
Hexachlorobenzene	NIST-96 exercise results showed GERG with good precision and accuracy while EBMUD had poor precision and trouble with detection. SED-96 SRM results showed EBMUD still having detection problems and GERG falling within confidence limits two out of three times.
Oxychlordane	Oxychlordane was not analyzed by EBMUD. GERG had poor precision for the NIST-96 exercise and had trouble with detection of the SRM in the SED-96 SRM sample.
The DDT compounds:	In general GERG showed OK precision and accuracy for the NIST-96 exercise samples while having trouble with the SED-96 SRM DDTs. EBMUD showed trouble with the DDTs with poor precision and accuracy in the NIST-96 exercise and poor accuracy in the SED-96 SRM results.
o,p'-DDE	NIST-96 exercise results showed GERG with good precision and accuracy for the unknown sample while the SRM replicate results varied widely. NIST-96 exercise results showed EBMUD outside the unknown sample confidence limits (very high) and unable to detect o,p'-DDE in the SRM. SED-96 SRM results showed both labs below detection.
p,p'-DDD	NIST-96 exercise results showed EBMUD well above the confidence range for the SRM and having trouble with precision with the unknown. NIST-96 exercise results showed GERG just below the confidence range for the SRM but with good precision, and having good precision and accuracy with the unknown. SED-96 SRM results showed both outside confidence range.
p,p'-DDE	NIST-96 exercise results showed EBMUD well below the confidence range for the Unknown sample and below detection for the SRM. NIST-96 exercise results showed GERG just below the confidence range for the SRM but with OK precision, and having good precision and accuracy with the unknown. SED-96 SRM results were below detection for EBMUD and outside confidence range for GERG.
p,p'-DDT	NIST-96 exercise results showed both labs having precision and accuracy trouble for both the unknown and SRM. SED-96 SRM results were variable for both labs.
trans-Nonachlor	NIST-96 exercise results showed both labs having precision and accuracy trouble with the SRM while falling barely within the confidence limits for the unknown sample (GERG high and EBMUD low). SED-96 SRM value was difficult to detect for both labs.

In summary, the PAH results of the NIST-96 unknown sample showed that EBMUD had trouble with one replicate which biased their results. Excluding this sample, EBMUD, CCCSD, and GERG showed comparable results for most compounds evaluated. SRM results revealed that most laboratories had trouble meeting the target range for many compounds. SRM results submitted as part of the 1996 field sample analyses showed that although CCCSD and GERG were outside the 95% confidence intervals for most compounds, they had comparable results. However, RMP split field sample results showed CCCSD (three samples only) and GERG having variable results, while EBMUD showed detection limit problems. Both EBMUD and CCCSD had trouble detecting most PCBs in the RMP split field samples, therefore, they were not included in this evaluation. NIST-96 results showed all laboratories having difficulty meeting target range for both the unknown and the SRM samples. The RMP split sample SRM results submitted also showed precision and accuracy variability.

CCCSD did not analyze sediment pesticides in the NIST-96 intercomparison. RMP split field sample results from EBMUD were mostly below detection could not be compared to GERG results. They were not included in this evaluation. EBMUD did not detect most pesticides in the quality control SRM sample from both the RMP split field sample analyses and the NIST-96 exercise. NIST-96 results showed both EBMUD and GERG having difficulty meeting target ranges for both the unknown and the SRM samples. The RMP split sample SRM results also showed precision and accuracy variability among laboratories.

Conclusion

Some trace contaminants of interest are present in the San Francisco Estuary at concentrations that are below ten times the method detection limits for most laboratories. This is an important point to keep in mind when evaluating the RMP data, as it impacts the amount of confidence one has in the individual results. RMP trace element concentrations in sediment are generally detected with a high degree of confidence with the exception of silver and to a lesser degree, cadmium, and selenium. Detection of trace organic compounds poses a more difficult problem, as analytical detection limits generally are not much lower than observed laboratory results.

In the spring of 1997, SFEI provided participating laboratories with Data Reporting Expectations for the RMP. This document outlines key quality assurance information required to accompany each data submittal to SFEI (starting in 1997) so that high level QA summaries can be generated and used for inter- and intra-laboratory evaluations. Although the QA/QC responsibilities outlined in the 1996 RMP QAPP remain with the individual laboratories, the requested cover letters and QA/QC summary data will allow SFEI to efficiently document and evaluate overall performance. This information is essential if the RMP database is to remain a solid, scientifically defensible resource.

Other improvements that are being considered are:

1) Consistent program-wide determination of method detection limits.
2) Identification and minimization of factors influencing inter-laboratory variability in trace organic analyses.
3) Increased field QA for the new RMP trace organic water sampling unit.

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PCB Intercalibration Exercise with Regional Monitoring Program Water Sample Extracts

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Introduction

The Regional Monitoring Program for Trace Substances in the San Francisco Estuary (RMP) analyzes concentrations of polychlorinated biphenyls (PCBs) in water, sediment, bivalves, and fish from the Estuary. PCBs are a group of 209 individual chemicals (known as "congeners") based on substitution of the biphenyl molecule with varying numbers and arrangements of chlorine atoms. PCBs were produced and sold as complex mixtures of individual PCB congeners. These mixtures were known as Aroclors in the United States and by other names in other parts of the world (Brinkman and de Kok, 1980). Each Aroclor contained a mixture of a number of individual PCB congeners. Aroclor 1242, for example, was the most heavily used Aroclor in the US (Brinkman and de Kok, 1980), and 77 congeners have been identified in this mixture (Schulz *et al.*, 1989).

Until the early 1980s the principal analytical methodology used to measure PCBs in environmental samples was packed-column gas chromatography. This type of chromatography yields chromatograms with resolution that is not sufficient to distinguish and quantify individual congeners, but does allow a general comparison with patterns obtained from Aroclor mixtures and estimation of "Aroclor equivalents". PCB water quality regulations for the Bay are still based on packed-column measurements of Aroclor equivalents, although these rarely provide an accurate description of PCBs in environmental samples.

Capillary (or high resolution) chromatography began to grow in popularity in the 1980s with the advent of fused silica capillary columns (Erickson, 1992). With capillary columns, resolution of many individual PCB congeners, or "congener-specific analysis" became readily achievable. Congener-specific data obtained from high resolution gas chromatography offer many advantages over Aroclor equivalents obtained from packed column gas chromatography. Among these are:

- it is easier to detect and discard results biased by interference due to chemicals that coelute with PCBs (such chemicals are common in RMP samples);
- quantitation of individual congeners is more objective than estimation of Aroclor equivalents;
- the congeners that yield the cleanest chromatography and lowest analytical error can be used for statistical analyses and modeling;
- weathering, degradation, and metabolism can be measured and do not pose a problem for quantitation;
- Aroclor concentrations can be estimated with confidence using congener concentrations (Draper *et al.*, 1991, Newman submitted), but congener concentrations cannot be estimated with confidence using Aroclor concentrations; and
- the toxic potency of PCBs is congener-specific and extremely variable from congener to congener.

On the other hand, the advantages of the packed-column method are the clear connection with environmental regulations, less data reduction, higher permissible sample loading on chromatographic columns, lower cost per sample, and general ease of use. The RMP has opted for congener-specific analysis primarily

because of the higher quality and the higher information content of congener-specific data.

While congener-specific analysis can provide higher quality data, this method demands greater effort at data reduction and quality assurance. Long lists of congeners are analyzed to obtain the higher information content of congener data (40 PCB congeners are analyzed in the RMP), and longer analyte lists take more effort to process. PCBs are analyzed in complex matrices and are often present at concentrations that are low relative to detection limits. Electron capture detection is typically used in order to provide low limits of detection, but the specificity of this detection method and the complexity of the sample matrices are such that the analysis of samples on two separate GC columns ("dual column chromatography") significantly improves the reliability of the data. Even with dual column chromatography, careful review of the data is required to ensure that the data are free of interferences or transcriptional errors. A problematic area in congener analysis is the comparability of data among different laboratories, which typically have different coelution patterns and analyze different lists of congeners, in addition to the usual sources of inter-laboratory variability. A strong quality assurance program is essential to obtaining reliable PCB congener data.

In the past few years the RMP has implemented several measures to specifically improve the quality and comparability of PCB congener data from all RMP contract laboratories. The data are carefully screened by SFEI for unusual congener ratios, and questionable results are then re-checked by the contract laboratories against the original chromatograms and data tables. In 1996, the RMP required that all contract laboratories use dual column chromatography for PCB analysis. For 1997, a standard list of 40 congeners to be analyzed in all RMP samples (including water, sediment, bivalve tissue, and fish tissue) was adopted. This list was developed using data from longer lists of congeners analyzed in 1995 and 1996.

The most recent effort to evaluate and improve the quality and comparability of RMP congener data was an intercalibration exercise in which one set of extracts from RMP water samples was analyzed by three laboratories for PCB congeners. The objectives of this exercise were to:

- develop a means of consistently reporting congener data from different laboratories;
- detect inconsistencies in peak identification; and
- detect inconsistencies in quantitation.

This exercise did detect substantial differences among the laboratories and was a good first step toward the goal of obtaining comparable congener data from different RMP contractors. This type of intercalibration will continue in the future to resolve the problems identified in PCB analysis and to investigate whether similar problems exist for other analytes, including pesticides and PAHs. This chapter provides a summary of the results obtained to date from the water extract intercalibration.

Methods

Three laboratories participated in this intercalibration exercise:

1. Dr. Jarman's laboratory at the University of Utah (UU; formerly at UC Santa Cruz), which has analyzed water extracts for trace organics since 1994, currently collects, processes and analyzes water samples for trace organics;
2. Dr. Risebrough's laboratory at the Bodega Bay Institute (BBI), which has collected, processed and analyzed water samples for trace organics since 1993; and
3. Dr. Sericano's laboratory at the Geochemical and Environmental Research Group (GERG) at Texas A&M University, which has analyzed trace organics in sediment and bivalves for the RMP since 1993.

Each laboratory analyzed a set of four extracts prepared from RMP water samples collected in February 1996. The samples were

the dissolved and particulate fractions collected at Red Rock (BC60) and Alameda (BB70). Methods for the collection, extraction, and fractionation of the samples are described in *Appendix A*. The F1 fraction from the Florisil cleanup was analyzed by the three laboratories.

Details of the chromatographic methods employed by each laboratory are presented in Table 10. Each laboratory used a DB-5 capillary column with an electron capture detector. UU additionally used a DB-17 column, and was the only laboratory reporting dual column chromatography in this exercise. Reported results were corrected for surrogate recoveries measured by each laboratory.

Results and Discussion

Detailed comparative evaluation of the chromatograms generated by the laboratories and of the concentrations reported by each laboratory has been performed. This chapter provides a brief overview of the major results and conclusions. For the sake of simplicity the discussion focuses on the ten most abundant congeners. The sum of the concentrations of these ten congeners accounted for about half of the sums of all congeners reported by each laboratory.

Table 11 presents a summary of a qualitative comparison of the results from each laboratory. The last column of Table 11 indicates how many laboratories obtained peaks free of coelution and with consistent heights relative to other major peaks. For only three of the ten congeners (PCBs 110, 118, and 187) were consistent and directly comparable results obtained by all three laboratories. Coelution (either with other PCBs or unknown interferents) or poor separation was observed for many of the most abundant congeners (including PCBs 153, 138, 180, 149, 170, 52 and 101).

Table 12 presents a quantitative comparison of the results obtained from each laboratory. The data are provided both as reported in pg/L and as a ratio relative to PCB 110. The relative concentrations provide a means of comparing results free of the influence of gross differences in recoveries among the laboratories. PCB 110 was used because clean chromatography and consistent results were obtained for this congener by all of the laboratories. The table only includes data for the two particulate samples. As seen in the qualitative comparison, results that were consistent for all three laboratories were observed for three congeners (PCBs 110, 118, and 187). Relative concentrations of PCB 153 were also comparable for the two laboratories that separated PCB 153. Relative concentrations of the remaining six congeners were variable from laboratory to laboratory. For PCBs 138, 52, and perhaps 180 coelution with unknown interferents seems a probable cause of the inter-laboratory variability. Results for PCB 52 from UU are noteworthy, where interference from an unknown is apparent on both GC columns.

Sums obtained for the three most consistent congeners (PCBs 110, 118, and 187) were closely comparable (Table 13). For the two particulate samples BBI and GERG results averaged 1.14 and 1.36 times larger than the UU results, respectively. The observed difference between GERG and the other laboratories may be related to lower recoveries reported and used by GERG than by the other two laboratories.

When the sums of all congeners are considered, greater differences among the laboratories are seen, with BBI and GERG averaging 1.50 and 1.85 times higher than the UU results, respectively. The use of dual columns by UU and the practice of selecting the lower value obtained from the two columns (and the reduced influence of interferences that results from this practice) probably account for some of the difference in sums of all congeners.

Conclusions

Coelution of analytes is a major impediment to the analysis of PCB congeners in environmental samples. Coelution is common both with other PCB congeners and with unknown interferents. Data for specific congeners and sums of congeners obtained by different laboratories using only one column will

Table 10. Details of chromatographic methods used in analysis of the water extracts.

	UU	GERG	BBI
Extract volume when shot	**100 ul**		**45–90 ul**
Volume shot	2 ul	2 ul	1 ul
GC Column(s) used	DB-5 (60 m, .25 i.d. and .25 film thickness) DB-17ht (60m, .25 i.d., and .25 film thickness)	DB-5 (30 m, 0.25 mm i.d., 0.25 um film thickness)	DB-5 (30 m, 0.25 mm i.d., 0.25 um film thickness)
Carrier gas	Helium at constant flow of 2.0 ml/min	Helium at 1.2 ml/min	Helium at 2.0 ml/min
Makeup gas	argon/methane (95:5)	argon/methane (95:5) at 40-42 ml/min	Purified nitrogen about 20 ml/min
Injection	Splitless	Splitless	Direct injection into Varian programmable injection system
Injection port temperature	250 deg C	275 deg C	100 deg C, programmed to 280 deg C at 300 deg/min, hold at 280 for 5 min
Temperature program	50 deg for 1 min, 30 deg/min up to 190 deg and hold for 1 min, 1.1 deg/min up to 250 deg and hold for 1 min, 15 deg/min up to 300 deg and hold for 30 min	100 deg for 1 min, 5 deg/min up to 140 and hold for 1 min, 1.5 deg/min up to 250 deg and hold for 1 min, 10 deg/min to 300 deg and hold for 5 min.	100 deg for 2 min, 10 deg/min to 140 deg, 4 deg/min to 280 deg, hold for 19 min for clean samples, up to 49 min for dirtier samples
Total run time	95 min	94 min	60 min or more
Source of response factors	Standards for each congener shot with each sample	Authentic standards for most congeners, others using representative for each homolog	Authentic standards
Source for retention time information	Standards for each congener	Standards and Aroclor mixtures for congeners not present in standard mixtures	Authentic standards
Correction for non-linear responses	Linear range is from 2 - 500 pg/ul, dilute if necessary		Fitting of area response of DDE over range of 2–1000 pg to a parabolic function in the form pg=a(area)exp b; application of relative response factors
Surrogate used for correction	PCB 207	PCB 103	Average of recoveries of PCB 103 and PCB 207

Table 11. Qualitative comparison of chromatography obtained on each column with RMP water sample extracts. Congeners are listed in descending order of abundance. indicates number of laboratories yielding comparable data.

	UU		BBI	GERG	
Congener	**DB-5**	**DB-17**	**DB-5**	**DB-5**	**Overall**
153	Coelutes with 132	Very well separated	Well separated	Coelutes with 132	
138	Just separated from major unknown	Well separated	Coeluting unknown	Coeluting unknown	
180	Well separated	Well separated	Possible coeluting unknown	Well separated	
187	Well separated	Well separated	Well separated	Well separated	
110	Well separated	Coelutes with 151	Well separated	Well separated	
118	Well separated	Well separated	Barely separated	Barely separated	
149	Well separated	Well separated	Barely separated. Height of peak relative to 118 different from others.	Barely separated	
170	Possible coelution with 190	Coelutes with 196	Coelutes with 190	Coelutes with 190	
52	Coeluting unknown	Coeluting unknown	Coeluting unknown	Well separated?	
101	Well separated	Just separated from unknown	Base obscured	Well separated	

Table 12. Quantitative comparison of results obtained on each column. Concentrations are presented as reported ("raw data") and expressed as ratio relative to PCB 110. indicates number of laboratories yielding consistent data. See text for further explanation.

RED ROCK PARTICULATE								
RAW DATA (PG/L)				**RELATIVE TO 110**				
CONGENER	**BBI**	**UU**	**GERG**	**CONGENER**	**BBI**	**UU**	**GERG**	**OVERALL**
153	23.2	16		153	1.61	1.33		
138	25.2	10	29.7	138	1.75	0.83	1.84	
180	16.1	11	15.3	180	1.12	0.92	0.95	
187	12.3	9.6	12.3	187	0.85	0.8	0.76	
110	14.4	12	16.1	110	1	1	1	
118	13.4	11	17	118	0.93	0.92	1.06	
149	19	10	16.4	149	1.32	0.83	1.02	
170	8.6	5.2	12.3	170	0.6	0.43	0.76	
52	16.2	14	8.4	52	1.13	1.17	0.52	
101	15.8	7.1	14.1	101	1.1	0.59	0.88	

ALAMEDA PARTICULATE								
RAW DATA (PG/L)				**RELATIVE TO 110**				
CONGENER	**BBI**	**UU**	**GERG**	**CONGENER**	**BBI**	**UU**	**GERG**	**OVERALL**
153	33.4	31		153	1.79	1.94		
138	38.3	22	46.3	138	2.05	1.38	1.96	
180	30	20	25.6	180	1.6	1.25	1.08	
187	16.1	15	17.3	187	0.86	0.94	0.73	
110	18.7	16	23.6	110	1	1	1	
118	18.4	19	25.9	118	0.98	1.19	1.1	
149	26.7	19	23.9	149	1.43	1.19	1.01	
170	12.5	11	22.5	170	0.67	0.69	0.95	
52		19	10.3	52		1.19	0.44	
101	20.1	14	22.3	101	1.07	0.88	0.94	

Table 13. Comparison of sums of the three congeners with the most consistent results (PCBs 110, 118, and 187) and the sum of all congeners reported by each laboratory for the particulate samples from Red Rock and Alameda. Data in pg/L.

		UU	BBI	GERG
RED ROCK	SUM OF ALL	196	326	390
	SUM OF 3	33	40	45
ALAMEDA	SUM OF ALL	343	452	588
	SUM OF 3	50	53	67

often not be comparable due to inter-laboratory variation in chromatography. Established lists of congeners used to calculate sums (e.g., the NOAA list of 18) should not be used without consideration of the coelution of PCB congeners under the chromatographic conditions employed in analysis.

In this exercise a DB17 column yielded good separation of PCB congeners, including many of the most important congeners. The use of dual column chromatography greatly increases the ability to screen out interferents and to avoid coelution of PCB congeners, and greatly increases the reliability of PCB congener data.

A strong QA program is also essential to obtaining reliable and comparable PCB congener data from methods employing electron capture detection (ECD). Congener data generated by single column GC-ECD should be cautiously interpreted, because interfering compounds are abundant in environmental matrices and frequently will produce spurious results. Even with painstaking sample cleanup and dual column chromatography, interferences can produce spurious results for some congeners. Inter-laboratory comparison exercises such as that discussed in this chapter should be part of the QA program, as they are fundamental to evaluating the comparability of results reported by different laboratories. Under the RMP, efforts will continue to understand and resolve the inter-laboratory variation observed in this exercise and to assess and improve the comparability of data for other analytes.

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CHAPTER FIVE

Pilot Studies and Special Studies

Watershed Pilot Study

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Introduction

"Why do we see exceedances of water quality objectives in the Estuary?" was one of the questions posed as early as the second year of the Regional Monitoring Program (RMP), after the first year's data had been evaluated. Other questions were: "What can environmental managers do to reduce pollutant inputs into the Estuary? How are they best controlled?" Many Program Participants came to the realization that the Estuary represents a mixing bowl whose pollutant profile is reflected by inflow of the two large rivers, local runoff contributions, wastewater discharges, complex sediment resuspension and distribution processes, and atmospheric deposition. To take the next step from describing the pollutant profile in the Estuary to drawing conclusions about general source categories, and getting from there to pollutant control actions, Pilot Studies would have to be undertaken.

The Watershed Pilot Study is the first one of these studies with the general goal of describing how the pollutant spectrum in surface runoff attenuates and influences that of nearby RMP stations in the main channel of the South Bay. In addition to any sampling effort, it was decided that more specific assessment questions should be selected which could then guide a targeted review of existing information[1] that could serve, together with new data at the watershed-Estuary interface, to better interpret pollutant data and identify knowledge gaps. One station (Standish Dam) at the watershed-Estuary interface was selected for water and sediment sampling in 1996. Together, the City of San Jose and the Santa Clara Valley Nonpoint Source Pollution Control Program made available half of the necessary funds to conduct this Pilot Study, while the RMP provided the other half. At the same time, the City of San Jose also decided to expand the monitoring parameter list at their Local Effects Monitoring (LEM) station to include trace organic contaminants in water and sediment for comparison purposes.

Objectives

The goals of the Watershed Pilot Study were to:

- Link pollutant patterns found in the Estuary with those in an adjacent watershed to test if runoff and sediment taken at the lower end of Coyote Creek differs from water and sediment in the South Bay, including the LEM stations maintained by the San Jose-Santa Clara Wastewater Treatment Plant and the Sunnyvale Treatment Plant.
- Explore what kinds of ancillary water quality parameters and watershed characteristics should be measured or described to explain some of the patterns found, improve sampling design, and fine-tune testing methodology.

Specific questions to be explored by sampling this watershed-Estuary interface station were:

1) Is the pollutant profile in water and sediment deposited in the lower reaches of Coyote Creek different from that at nearby Estuary stations (i.e., can a distinct watershed signal can discerned?)
2) Are there differences in the pollutant profile at the sampling station between high- and low-flow periods, corresponding with the wet- and dry-season sampling events in the Estuary?
3) Which factors may influence the findings?

This article describes a very limited data set and should not be interpreted as a definitive assessment of Coyote Creek watershed contri-

[1] *RMP Watershed Pilot Study: An Information Review with Emphasis on Contaminant Loadings, Sources, and Effects* is available from SFEI.

butions to the Estuary. The findings of this Pilot Study are also compared to the database accumulated by the Santa Clara Valley Nonpoint Source Pollution Control Program (the Program) upstream (south) of the Highway 237 overpass between the late 1980s and 1995. The Program discontinued monitoring at the Coyote Creek waterway monitoring station due to flood management construction activities, but general and preliminary comparisons of the two data sets can be made.

Sampling Plan

In 1996, a sampling station was selected on Coyote Creek, very close to Dixon Landing Road and Highway 880 where the city boundaries of Fremont, Milpitas, and San Jose converge (Figure 1). This location is within the tidal prism of the creek, just downstream from the site of a seasonal dam (hence the name *Standish Dam*) designed to maintain a small freshwater wetland and a newly established riparian habitat during the dry season when creek flows may not be high enough to prevent saltwater intrusion. The site was selected for its accessibility, location in the brackish transitional zone, and the fact that sediment deposition and accumulation was likely to occur. During the winter of 1996, the reservoir in the upper reach of Coyote Creek was filled to capacity by the end of February, and creek flows in the lower reaches exceeded 5,000 cfs

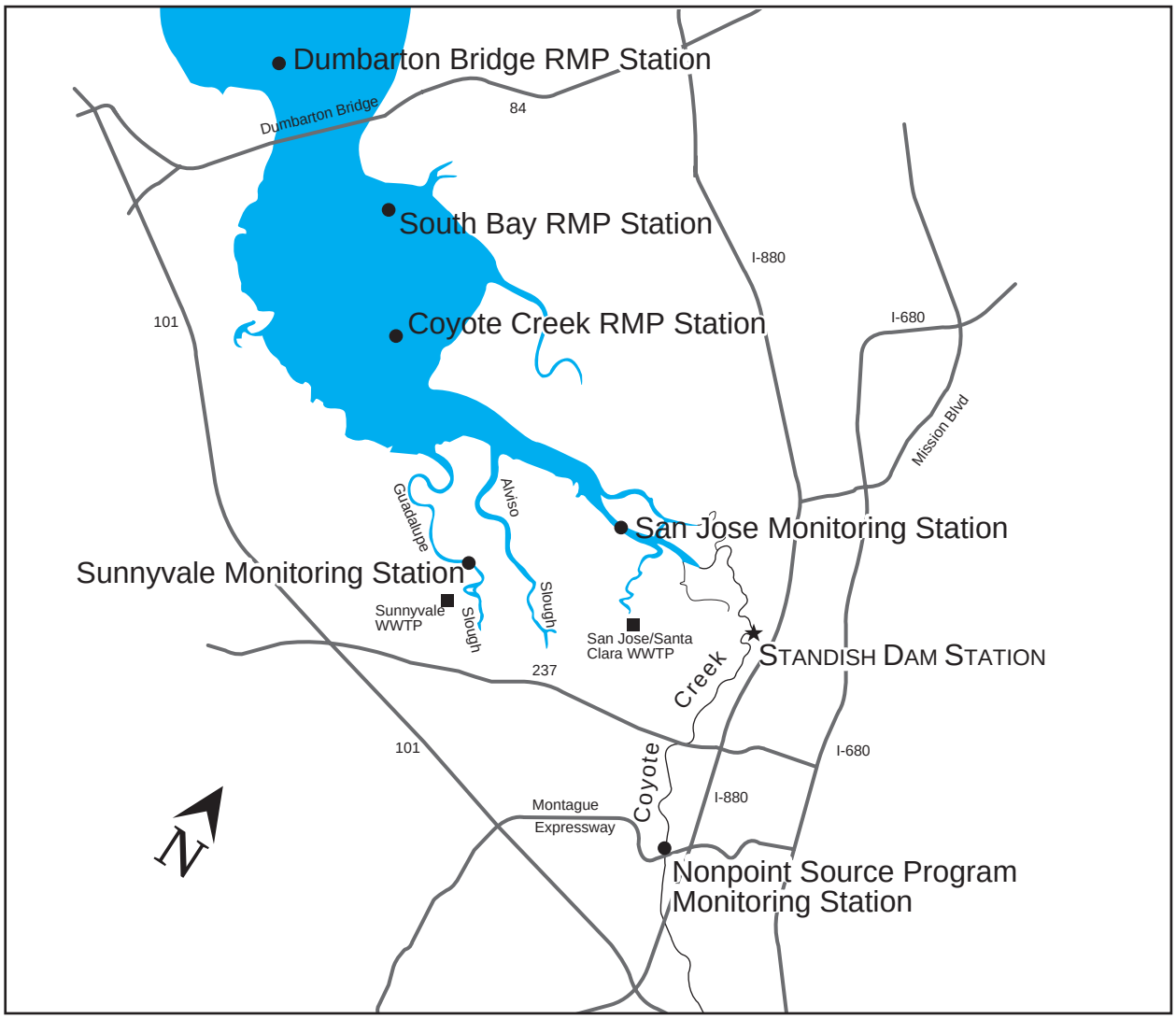

Figure 1. Monitoring station locations. The Sunnyvale and San Jose LEM stations are together referred to as the Southern Slough stations. WWTP = wastewater treatment plant.

during the wet-season sampling event due to rainfall events prior and during sampling (John Shay, pers. communication). For the purpose of this study "wet-season" connotes creek flows high enough to generate complete freshwater conditions at the sampling location even at high tide, while "dry season" connotes brackish conditions. During the winter wet-season sampling event on an incoming tide, the salinity was zero from the water surface to the bottom of the creek, indicating that the station was exclusively influenced by the creek, while during the dry-season sampling, salinity approximately 1 m below the surface was between 2.7 and 3 ppt, indicating a mix of creek and Estuary water. Although no flow measurements were taken, dry-season flow in Coyote Creek was estimated to be two to three orders of magnitude lower than at the time of winter sampling. The same parameters in water and sediment were measured here as in the Estuary at approximately the same times (late February/early March, late April, and early August). The sampling methodology for water was similar to that employed by the RMP. Sediment was sampled from the creek bank at low tide using a Dykon®-coated scoop (see *Appendix A*). Any surface diatom layer was removed before collecting the top five centimeters of an area approximately the same size as the van Veen grab used at the Estuary stations. The sample was then homogenized. The homogenate was divided into aliquots for analysis of trace elements, conventional sediment parameters, for trace organic analyses, and for archiving.

Results

The dry-season sediment concentrations of most trace metals are not yet available. They will be included in the *1997 Annual Report*. All available data from this Pilot Study have been included in the data tables (see *Appendix C*).

Water Elements

Figures 2–7 show concentrations of all measured trace elements in water. Arsenic and cadmium concentrations (both dissolved and total) were consistently lower at Standish Dam than at adjacent RMP and LEM stations for all three sampling events, while selenium (both dissolved and total) showed pronounced elevated signals compared to the South Bay stations at the spring and summer sampling events. Total mercury at Standish Dam was slightly higher than at the South Bay stations for all three sampling events. Total nickel was appreciably higher at the Standish Dam site during the wet season than in the South Bay, suggesting transport of nickel out of the watershed. Total copper, lead, silver, and zinc concentrations were comparable at the Standish Dam site and in South Bay water.

Pronounced seasonal differences between the watershed site at Standish Dam and the RMP South Bay stations were not recognizable, with the exception of total/near-total selenium and nickel. Wet-season concentrations of near-total copper were slightly higher than dry-season concentrations. Near-total copper concentrations showed only a hint of being higher at Standish Dam during the wet season relative to South Bay RMP stations.

Water Organics

Figures 8–11 show concentrations of selected trace organic contaminants. Seasonal differences between the watershed station, the closest LEM station (San Jose, C-3-0), and the closest Estuary station (Coyote Creek, BA10) are very apparent for most chlorinated hydrocarbons. Although data points from one year are not necessarily representative, it appears as though during high runoff periods, contaminant concentrations at the watershed station are distinctly different from the South Bay RMP sites for the following compounds:

- dissolved PCBs (truly dissolved and PCBs associated with colloidal material and particles <1μm in size) and total PCBs (dissolved and particulate fractions). The particulate fraction also showed a clear influence of higher chlorinated Aroclors (e.g., Aroclor 1260) for the winter and spring sampling periods—different from the Estuary;

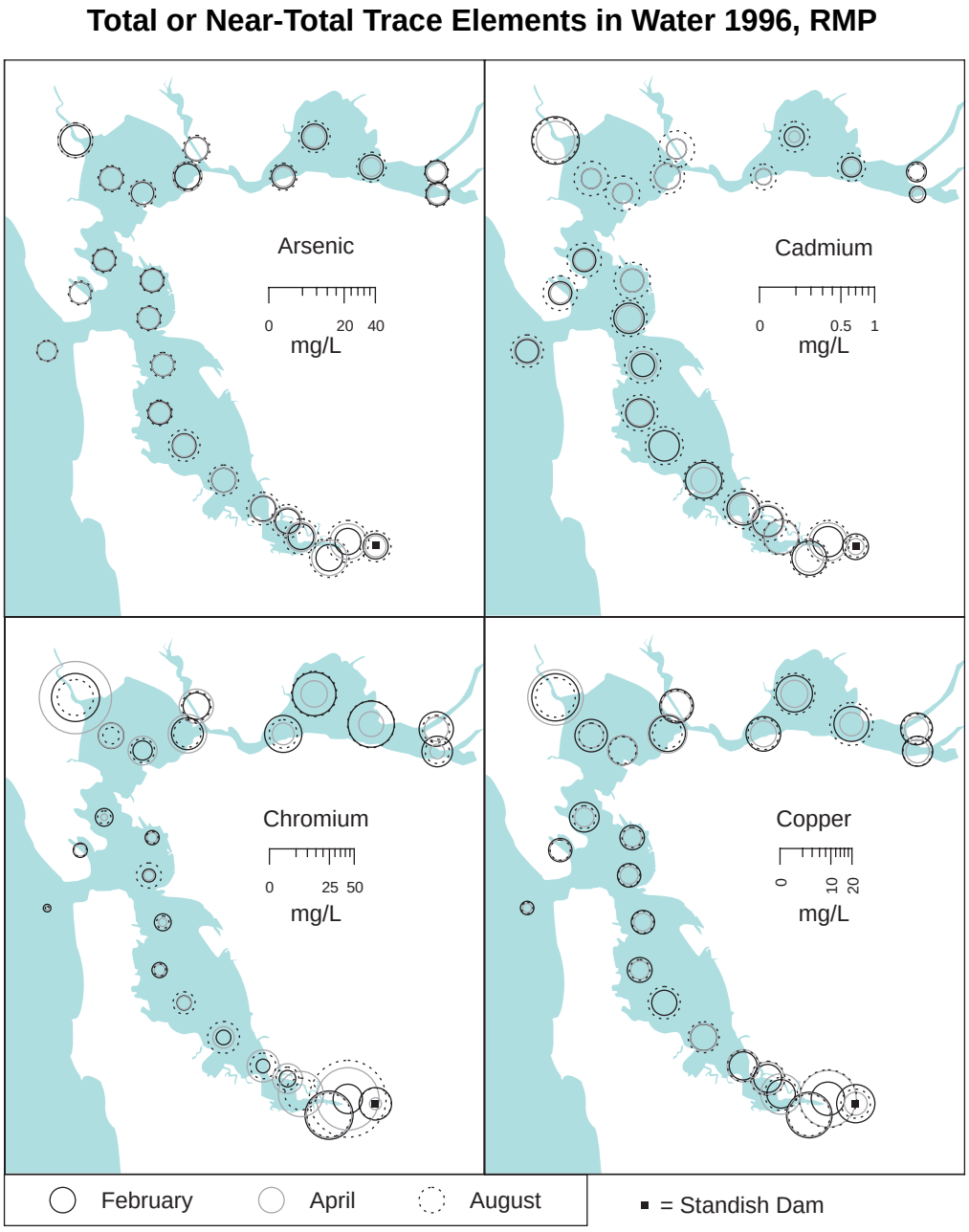

Figure 2. Total or near-total trace elements in water at 24 RMP stations and the Standish Dam pilot station in 1996. The area of each circle is proportional to concentration. Circle area standardized to median value. Missing circles are either missing data or not detected.

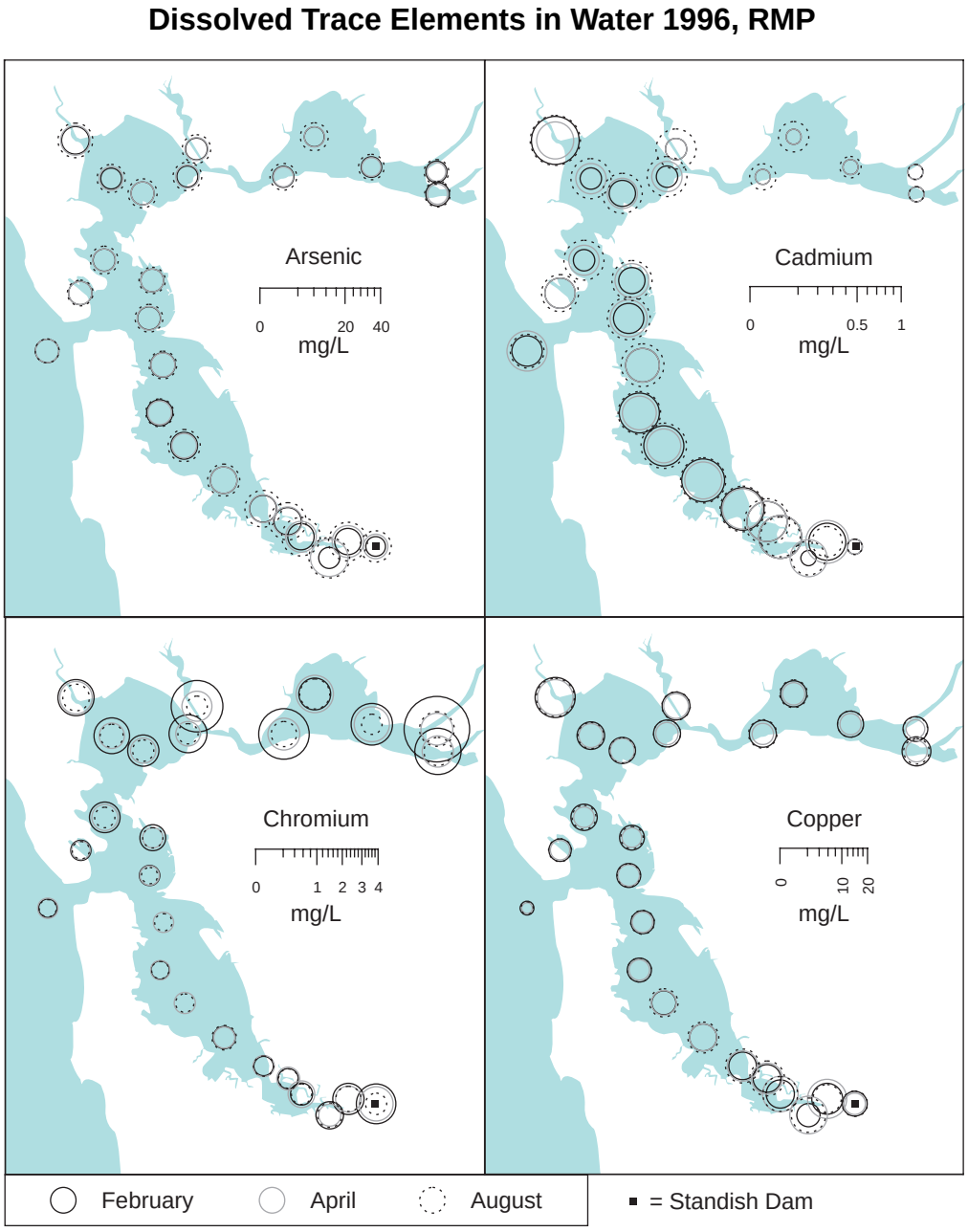

Figure 3. Dissolved trace elements in water at 24 RMP stations and the Standish Dam pilot station in 1996. The area of each circle is proportional to concentration. Circle area standardized to median value. Missing circles are either missing data or not detected.

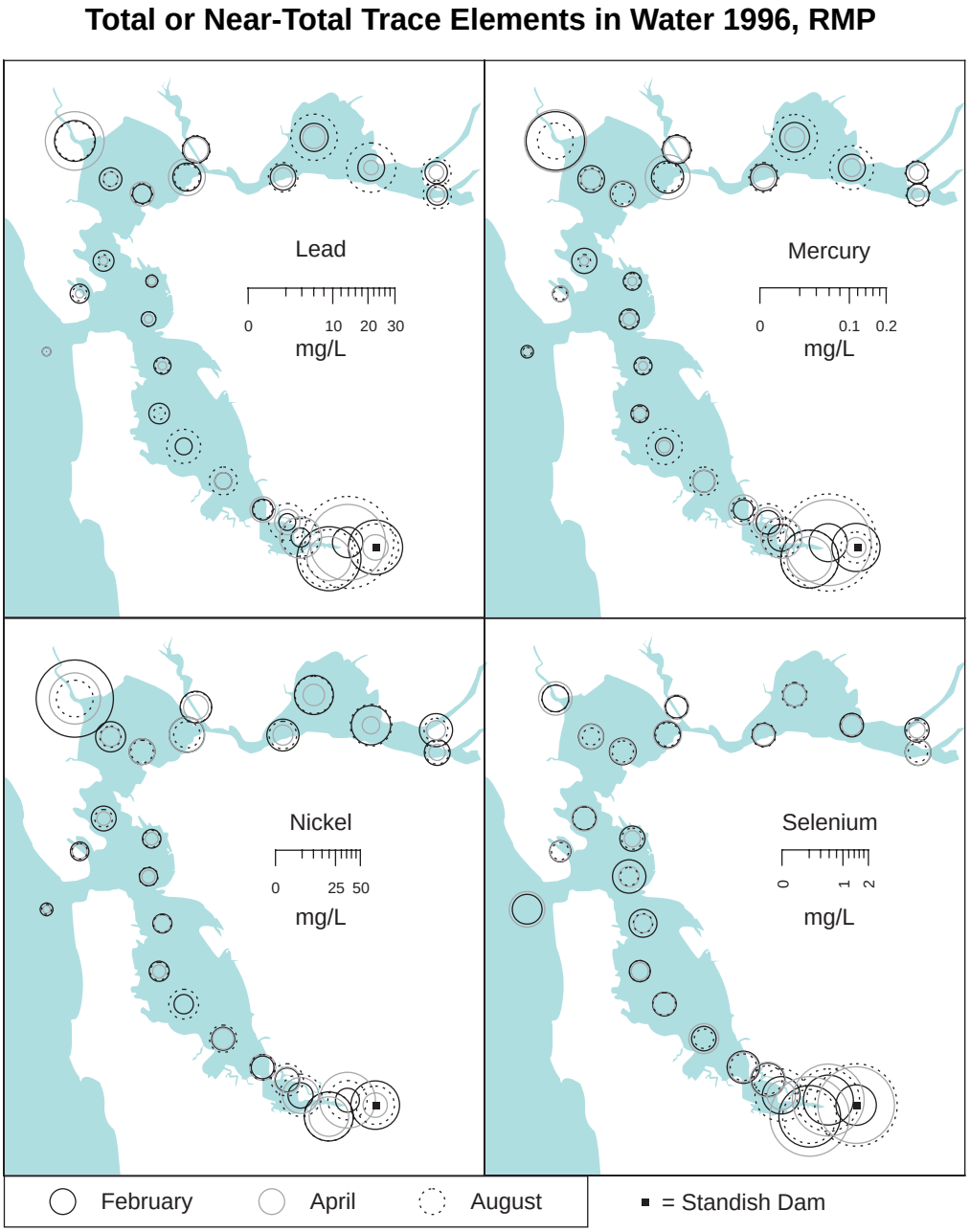

Figure 4. Total or near-total trace elements in water at 24 RMP stations and the Standish Dam pilot station in 1996. The area of each circle is proportional to concentration. Circle area standardized to median value. Missing circles are either missing data or not detected.

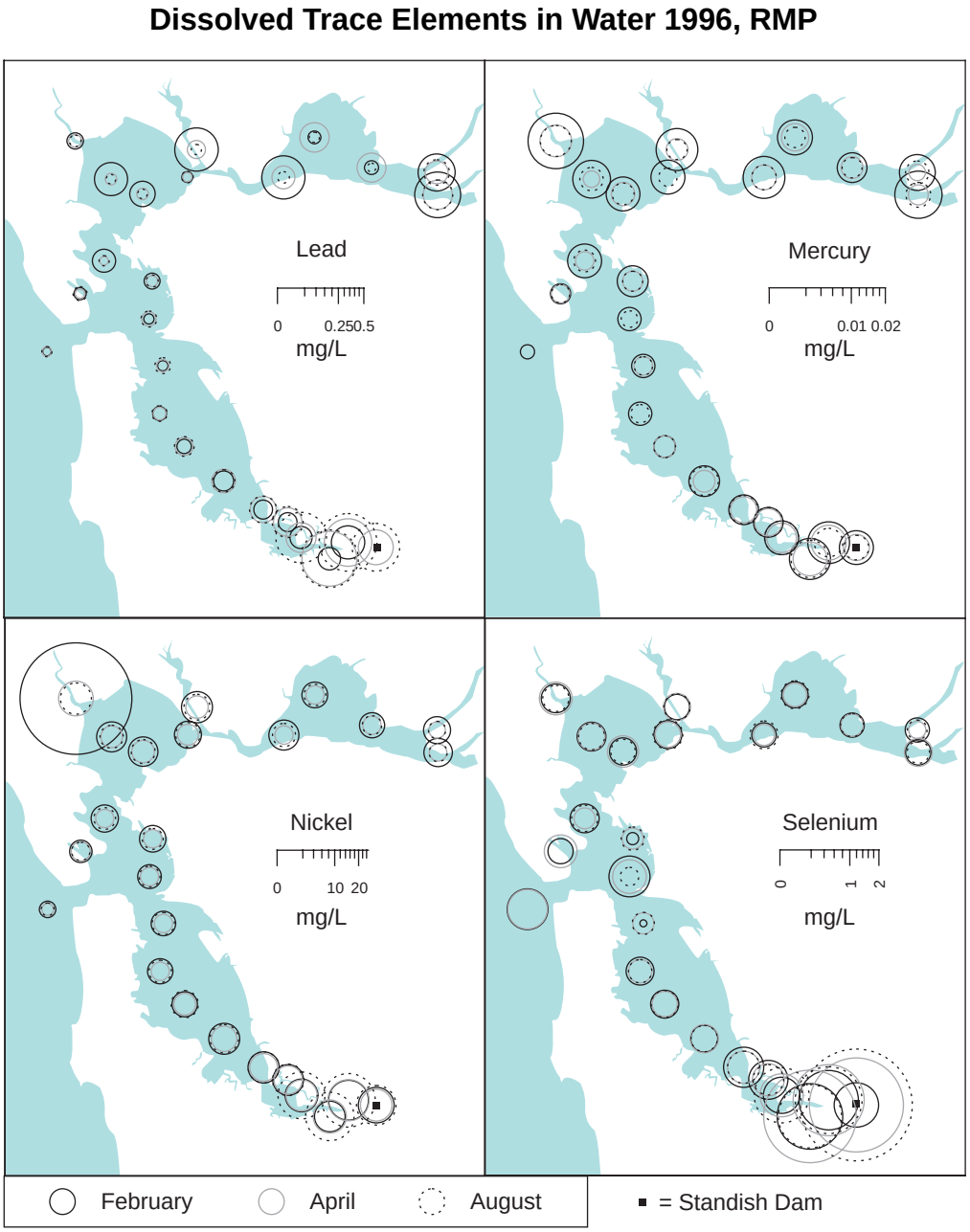

Figure 5. Dissolved trace elements in water at 24 RMP stations and the Standish Dam pilot station in 1996. The area of each circle is proportional to concentration. Circle area standardized to median value. Missing circles are either missing data or not detected.

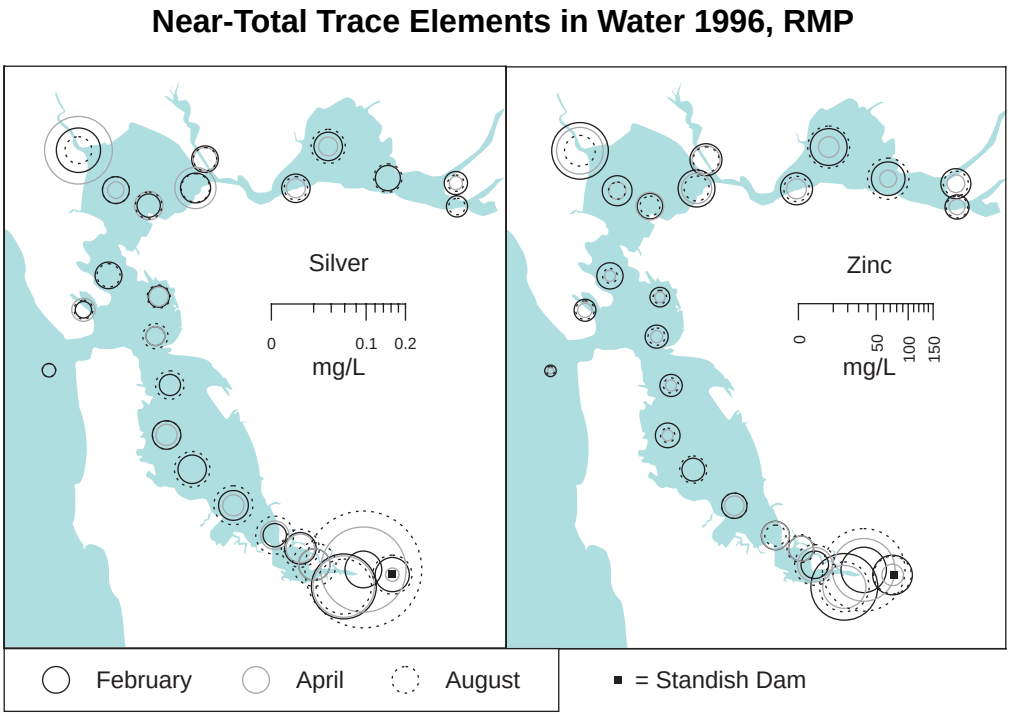

Figure 6. Near-total trace elements in water at 24 RMP stations and the Standish Dam pilot station in 1996. The area of each circle is proportional to concentration. Circle area standardized to median value. Missing circles are either missing data or not detected.

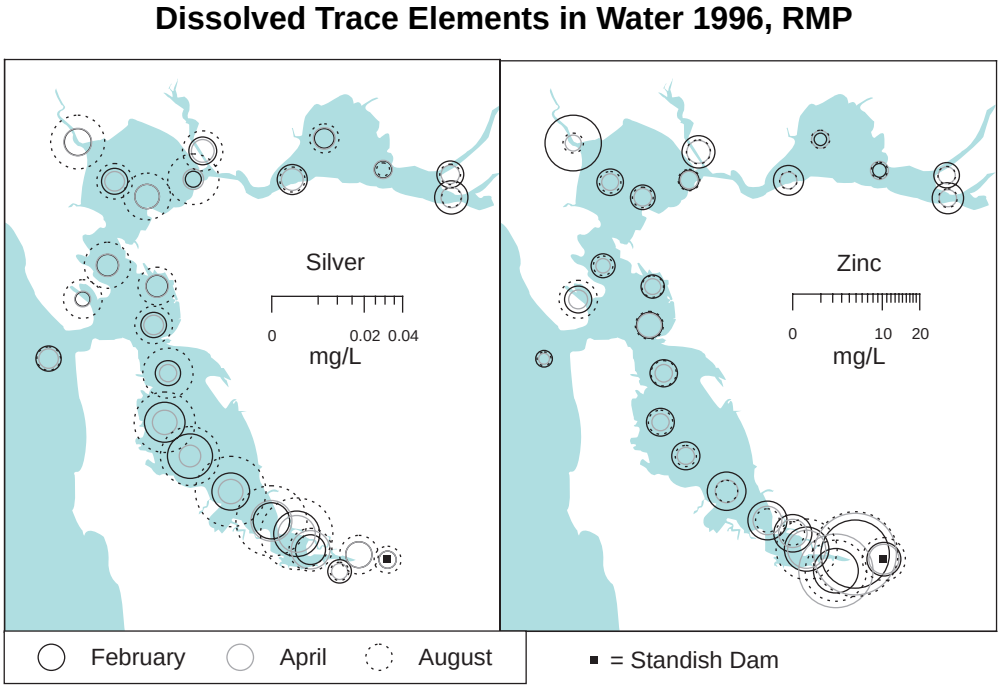

Figure 7. Dissolved trace elements in water at 24 RMP stations and the Standish Dam pilot station in 1996. The area of each circle is proportional to concentration. Circle area standardized to median value. Missing circles are either missing data or not detected.

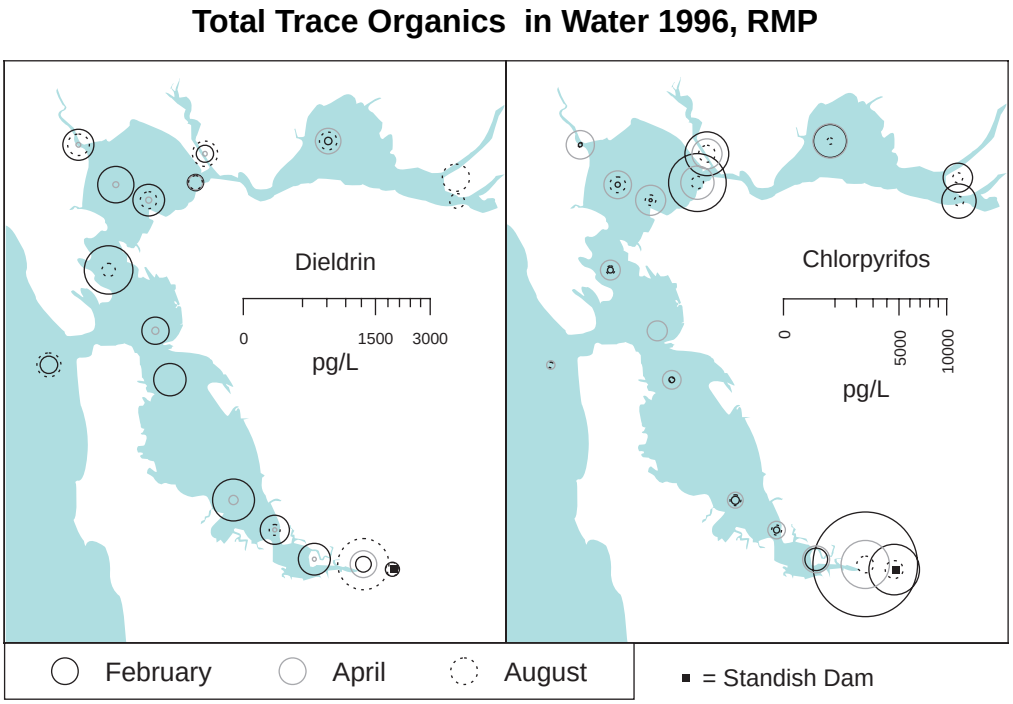

Figure 8. Total trace organics in water at 24 RMP stations and the Standish Dam pilot station in 1996. The area of each circle is proportional to concentration. Circle area standardized to median value. Missing circles are either missing data or not detected.

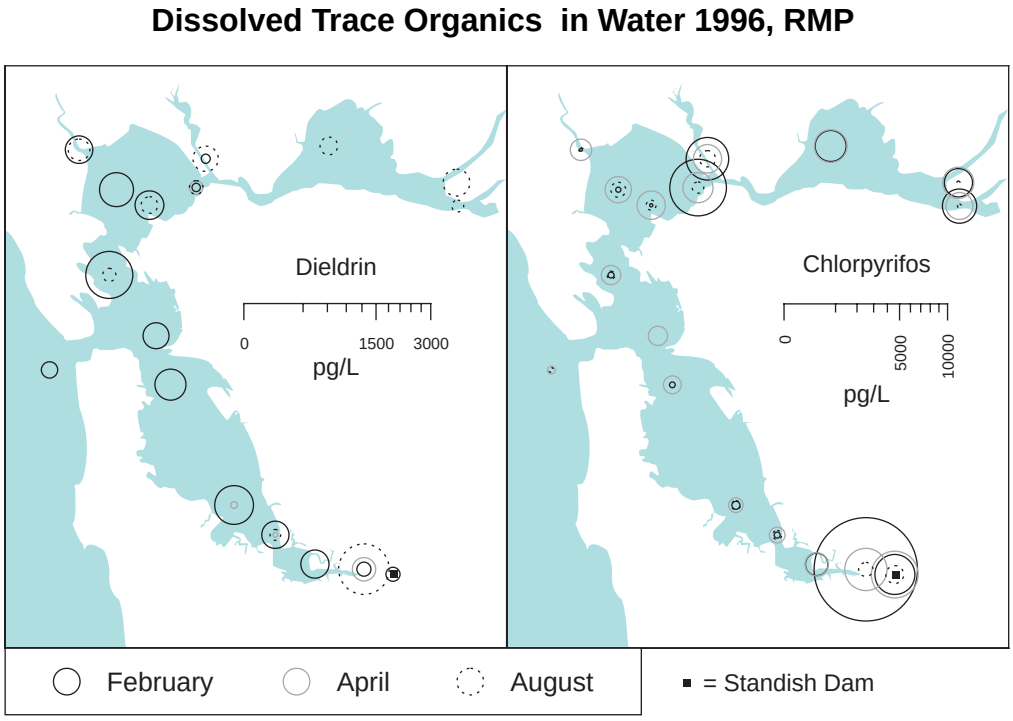

Figure 9. Dissolved trace organics in water at 24 RMP stations and the Standish Dam pilot station in 1996. The area of each circle is proportional to concentration. Circle area standardized to median value. Missing circles are either missing data or not detected.

Figure 10. Total trace organics in water at 24 RMP stations and the Standish Dam pilot station in 1996. The area of each circle is proportional to concentration. Circle area standardized to median value. Missing circles are either missing data or not detected.

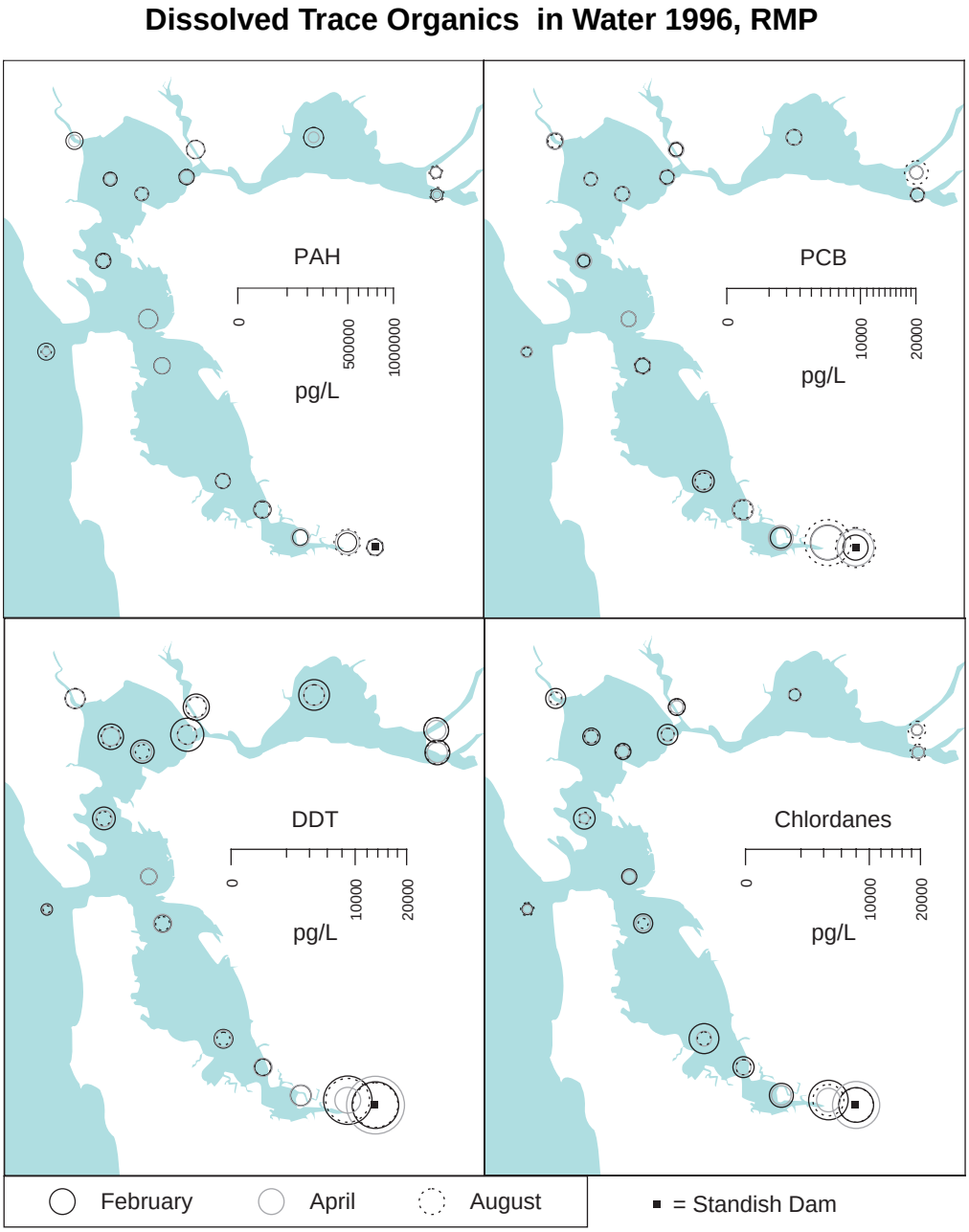

Figure 11. Dissolved trace organics in water at 24 RMP stations and the Standish Dam pilot station in 1996. The area of each circle is proportional to concentration. Circle area standardized to median value. Missing circles are either missing data or not detected.

- dissolved and total DDT compounds; and
- dissolved and total chlordanes.

During the early March and late April sampling events, the organophosphate pesticide chlorpyrifos was considerably higher at Standish Dam than at all South Bay stations, and comparable to concentrations observed in the Northern Estuary (Figures 8 and 9). The San Jose LEM station exhibited the highest chlorpyrifos concentrations. Only hexachlorocyclohexanes and dieldrin were higher in the Estuary than at Standish Dam (all sampling periods). Total PAHs at Standish Dam were indistinguishable from most other Estuary stations, including compound profiles. The highest total PAH concentrations in water were found at the San Jose monitoring station.

Sediment Trace Elements

This data set is, as of yet, incomplete for silver, cadmium, chromium, copper, lead, nickel, and zinc measurements in the dry season. The Standish Dam station is depicted together with concentration averages of the Southern Slough (LEM), South Bay, Central Bay, Northern Estuary, and River Station reaches. However, some general observations can be made. The watershed-Estuary interface site had comparable metal concentrations to the nearest South Bay RMP site, and, with the exception of silver, it is also similar to the two LEM sites (Figure 12). In fact, only selenium concentrations in the dry season were appreciably higher at Standish Dam than at any other station. These preliminary metals data show that contaminant concentrations in sediment carried down the watershed and deposited where the creek meets the Bay may not be very different from what we find in the Bay itself. In contrast, the Santa Clara Valley and the Alameda County urban runoff programs have found in their sampling studies that stream sediments were higher in lead, copper, zinc, cadmium, nickel, and chromium than Bay sediments, although nickel and chromium are likely from erosion of localized soils than from human inputs. Possibly because the sediments sampled at Standish Dam represent a mixture of Bay and creek sediments, the urban runoff program findings were not corroborated. It should also be noted that prior to sampling, several major storms caused high runoff events with associated creek-bed scouring. In fact, water in Anderson Reservoir, located in the upper reaches of Coyote Creek, had reached the spillway elevation in February (John Shay, personal communication). Based on the predominance of coarse grain sizes in the sediment sample collected in the wet season, it is fair to assume that much of the previous year's accumulated sediment at the site had been washed away. If contaminant concentrations were normalized to grain size, Standish Dam data would likely be higher than Bay sediment concentrations, since smaller particles can adsorb more pollutants than large ones due to their greater surface area per unit mass of sediment.

Sediment Trace Organics

As with water samples, spatial differences appear to be quite pronounced for trace organic contaminants (Figure 13), with the Standish Dam site having the highest DDT and chlordane concentrations during the wet season when high flows mobilize sediment in the watershed and carry down particle-associated pollutants with them. The Santa Clara Valley was prime agricultural land during the time these pesticides were still in use, and residual pesticides seem to get mobilized during the rainy season and washed down the creek.

Surprisingly, San Jose's LEM station had the highest sediment concentrations of DDT compounds in the dry season (Figure 13). The South Bay stations were consistently low relative to the San Jose and Standish Dam sites.

PCBs showed pronounced seasonal and spatial differences: they were highest near the San Jose LEM station, intermediate at Standish Dam, and lowest in the Bay. However, it is quite striking that PCB concentrations at Standish Dam, although not as high as at the San Jose LEM station, were considerably

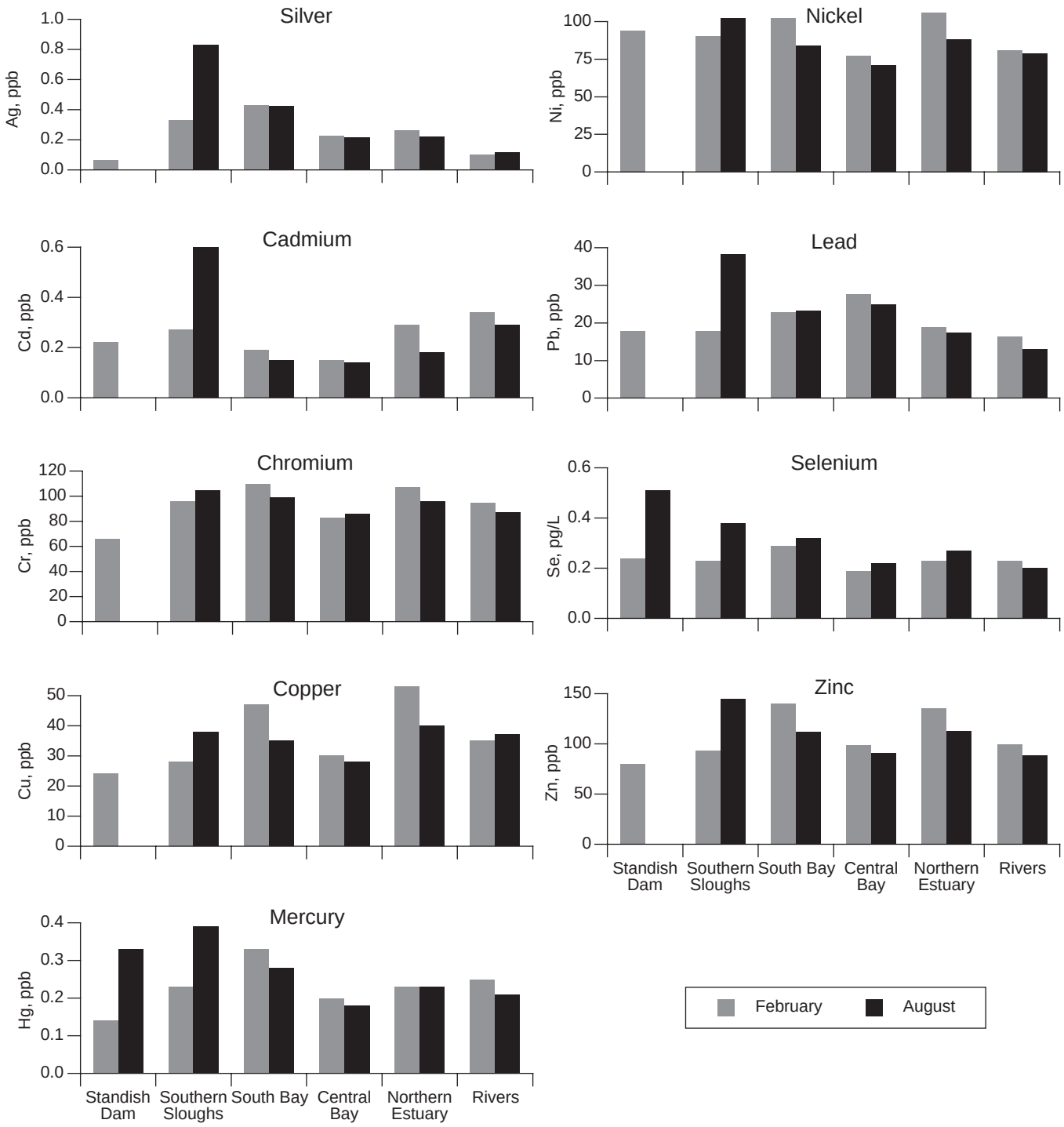

Figure 12. Concentrations of trace elements in sediments at the Standish Dam site compared with RMP stations averaged by Bay reach, 1996. Data for some Standish Dam August cruise trace elements are not yet available.

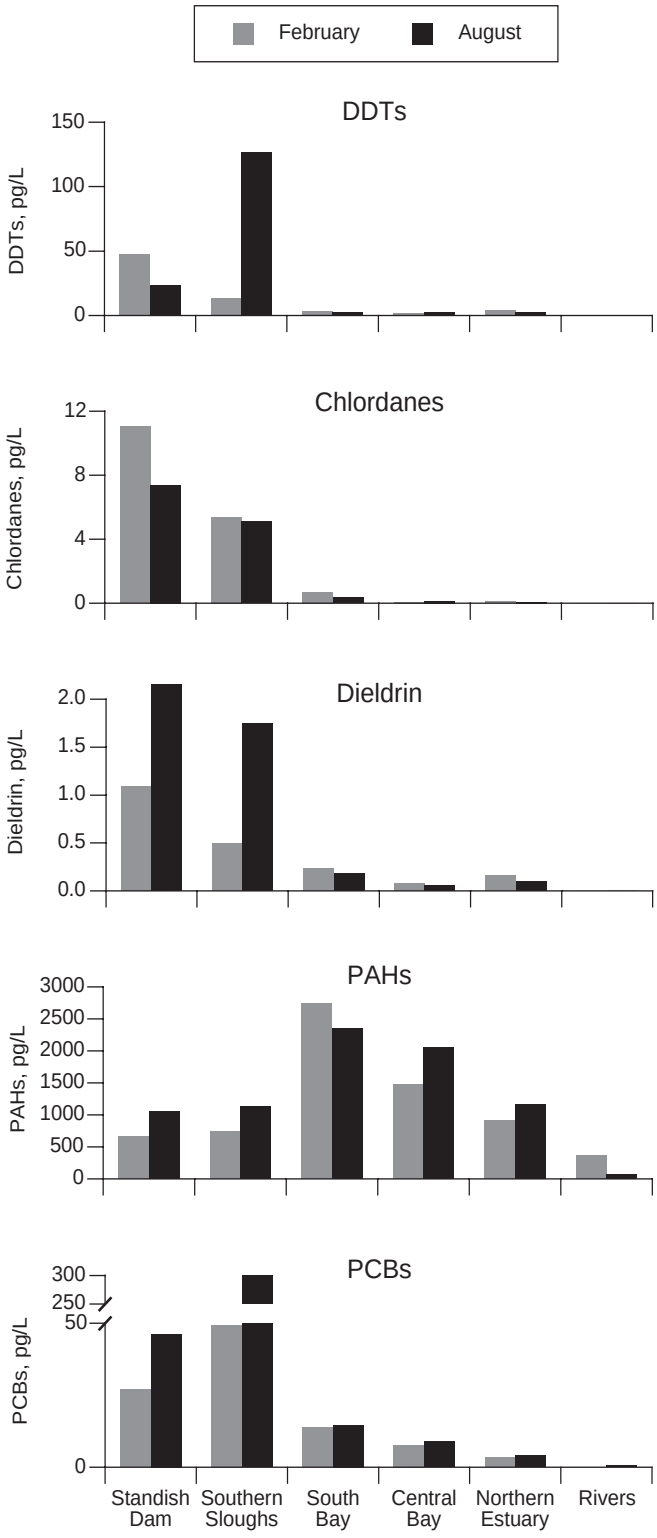

Figure 13. Concentrations of trace organics in sediments at the Standish Dam site compared with RMP stations averaged by Bay reach, 1996.

higher than anywhere in the Estuary itself. Sediment PAH concentrations, on the other hand, were lower at Standish Dam than most stations in the Estuary (Figure 13)

Many of the observed contaminant patterns in water and sediment are influenced by the specific conditions at the time of sampling. For example, sediment contaminant concentrations are directly related to sediment particle size. Silt and clay can adsorb much more contaminant mass than an equal mass of sand particles. Sand predominated in wet-season sediment samples at Standish Dam, while clay dominated in the dry season. Flow rates, runoff conditions prior to sampling, sediment transport, erosion and land-slide events, tidal elevations, and many other factors were not established as part of this Pilot Study. Quantitative relationships of contaminant concentrations with key environmental factors should be established so that the degree of contamination can be accurately assessed. The collection of many of these other environmental factors is outside the scope of the RMP and would have to be conducted through other means. For example, the determination of erosional and depositional reaches of Coyote Creek would assist in identifying temporary pollutant storage sites that under certain hydrologic conditions could release contaminants and thus affect observed concentrations at the terminus of the watershed. Partnerships between RMP participants, flood management agencies, volunteer monitoring organizations, and resource agencies, such as the Natural Resource Conservation Service and the Resource Conservation Districts, might be able to generate a more complete picture of watershed processes influencing observed pollutant patterns. Such partnerships are gradually emerging under the umbrella of the Regional Board's Watershed Management Initiative.

Comparisons with Urban Runoff Monitoring Data

An attempt was made to conduct a preliminary comparison between Standish Dam data for total or near-total concentrations of trace elements in water and the Santa Clara Valley Nonpoint Source Pollution Control Program data set collected at the Montague Expressway waterway station. The Nonpoint Source Program began characterizing urban runoff in 1987 and initially included wet-weather monitoring at seven stations draining different land use areas, and wet-and dry-weather monitoring at four waterway stations—Coyote Creek being among the latter (BASMAA, 1996). Monitoring at the Coyote Creek waterway station, located approximately three miles upstream of the Standish Dam site, continued until 1995 and included continued operation of automatic flow-weighted composite sampling.

Several factors made comparisons between the two data sets difficult, if not altogether impossible: The RMP collected water samples in 1996 using the routine RMP sampling methodology, which approximates grab samples more closely than flow-weighted composites. Additionally, water samples at Standish Dam were taken after several major storm systems had moved through the area. Measurable precipitation was noted the day prior and during the wet-season sampling event. Sampling design and methodology, analytical techniques, and geographic location also hampered direct comparisons.

For example, with the exception of arsenic and selenium concentrations, trace element results at Montague Expressway (means of all sampling events) were considerably higher (up to an order of magnitude for cadmium, lead, silver, and zinc) than those found at Standish Dam in 1996. Arsenic concentrations were very similar between the two data sets, while both total and dissolved selenium concentrations were approximately three times higher at the Standish Dam site than for the Montague Expressway data set. It should be noted that the urban runoff data set at Montague Expressway is comprised of many more data points than the Pilot Study data set, and that it has fewer uncertainties associated with it.

Future Steps

In 1997, another Watershed Pilot station at the interface of the Guadalupe River and the South Bay in Alviso was added to determine if the same or similar patterns can be observed in an adjacent watershed. These Pilot station results will be closely linked to the watershed management planning process currently taking place in the Santa Clara Valley and evaluated for their applicability throughout the region.

The growing database accumulated through this Pilot Study promises to address questions that are relevant throughout the Bay Area. It also points out numerous fundamental gaps that need to be addressed, probably outside the framework of the RMP. Multiple factors influence the observed pollutant data, for which in some cases data exist that can be integrated into a more thorough analysis. In other cases, data have not been collected to evaluate observed pollutant patterns— especially those of long-banned chlorinated hydrocarbons. For example, it is not clear where sediment and sediment-associated pollutant sources are located within the watershed, or how the physical characteristics of the watershed influence pollutant transport, thus revealing possible control mechanisms.

Acknowledgments

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Contamination of Tidal Wetlands

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Introduction

Wetlands provide a broad range of ecological services, from the support of endangered species and the filtration of local pollutants to the stabilization of coasts and the regulation of air quality (e.g., Sather and Smith, 1984; Mitsch and Gosselink, 1986; Bay Institute, 1987; ABAG, 1991). For the protection of these services, wetlands are intensively managed and regulated, especially in the United States (Kusler, 1983). The management of wetlands has involved regional and national inventories of the existing conditions and historical changes in wetlands, with numerous methodologies for classifying wetlands and assessing their ecological health (e.g., Cowardin *et al.*, 1979; FWS, 1989; Brinson, 1993; Ferren *et al.*, 1996).

In the San Francisco Bay Area, the concern about wetlands has grown for decades into larger and more integrated plans for wetlands protection, with the expectation for a coordinated regional wetlands monitoring program (SF NERR, 1992; SFEP, 1993; RMG, 1995; Shaefer, 1995; CALFED, 1996). It is hoped that this wetlands pilot study of the RMP will advance the discussion of coordinated regional wetlands research and monitoring.

Given all this interest in wetlands, the risk of having uncoordinated approaches to wetlands monitoring and assessment seems slight. The assumption is, of course, false. Coordination among different wetlands studies that are based in different disciplines is an ongoing challenge, even when the investigators agree to be coordinated. The difficulties reflect institutionalized differences in scientific terminology, procedure, and interpretation. They are not unreasonable or insurmountable differences, and it is generally expected that they will be resolved as wetlands science becomes more integrative among its many component disciplines, as necessary to understand wetland ecosystems.

The challenge for coordination of wetlands assessment and management is well illustrated by the various ways that tidal marshes in the Bay Area have been stratified for the study of either contamination, geomorphology, or ecology. It may be important to note that there has been very little linkage among studies of these different basic aspects of tidal marsh condition, either through the scientists involved or their institutions. It should also be noted that the use of different sampling strata for different aspects of wetlands assessment prevents any examination of the correlations among the different aspects and thus inhibits the formulation of testable, integrative hypotheses.

This isn't to say that the separate studies have not been justified or useful, but that they do not inform each other as well as they could, or perhaps should. For example, the few previous studies of tidal marsh contamination have identified tidal marshland as a single stratum, with no differentiation between old or young marsh, youthful or mature marsh, high or low marsh, or areas near or away from tidal marsh channels and shorelines. In contrast, local and regional studies of tidal marsh hydro-geomorphology and ecology regard the natural physiographic structure of tidal marshland as a detailed sampling template. For geomorphic studies, the tidal channels of different order (i.e., natural size class), the levees, pannes, and vegetated plains are commonly regarded as major strata for sampling the tides, edaphic conditions, and sedimentation. Further stratification is common for ecological studies, where living resources are enumerated among numerous stations or transects arrayed along gradients of elevation and tidal water supply. In general, there is more opportunity to study the

correlation among geomorphic and ecological data than among either of these kinds of data and contamination, since the contamination studies have not recognized any of the sampling strata used for geomorphic or ecological studies. This means that assessments of wildlife hazards and restoration success are less likely to use contaminant data because they are not related to specific habitats. As habitat contamination becomes more broadly recognized as a stressor for wildlife support functions of tidal marshland, the agreement between stratification schemes for contamination studies and other kinds of studies will probably increase. The use of comparable sampling strata will be necessary to understand the linkages among tidal marsh contamination, hydro-geomorphology, and ecological function, and such understanding is require to protect the ecological services of tidal marshlands.

The time is right to build a foundation for coordinated investigations of tidal marsh condition, including contamination. We are in an early stage in the study of tidal marsh contamination in the Bay Area. Data sets are not large and the sampling record is short. This means that an approach to contaminant studies in tidal marshland can be developed in coordination with related ecological and hydro-geomorphic studies. Recent reviews of local and regional pollutant studies (e.g., Chan *et al.,* 1981; CBE, 1983; Phillips, 1987; SFEI, 1991; 1992; ACURCWP, 1994; CH2M HILL, 1994), indicate that the amount of data about the contaminants of our open bays, major rivers, local streams, and constructed wetlands far exceeds what is available for our tidal marshes. There is scant information about tidal marsh contamination compared to the information about hydrology (e.g., Leopold *et al.,* 1993), geomorphology (e.g., Collins *et al.,* 1987; Haltiner and Williams, 1987; Siegel, 1993; Grossinger, 1995), plants (e.g., Atwater and Hedel, 1976; Balling and Resh, 1983; Wayne, 1995; Larsson, 1996), or animals (e.g., Collins and Resh, 1985; Barnby *et al.,* 1985; Foerester *et al.,* 1990; Evens *et al.,* 1991; Lonzarich *et al.,* 1992; Garcia, 1995). The existing regional description of tidal marsh contamination (e.g., Anderson *et al.,* 1990; Flegal *et al.,* 1994; Hoffman *et al.,* 1994) is an excellent start, but is very general and lacks linkage to tidal marsh form or ecological function.

Objectives

The following objectives were set to assure that the first stage of the wetlands pilot can help to establish a Regional Monitoring Program for Trace Substances that yields data about tidal marshlands as ecological systems as well as physical systems.

- Develop equipment and train personnel to sample tidal marsh sediments for contaminant analysis. It is desirable to have a methodology that can be used by supervised personnel with little or no previous experience in contaminant monitoring, such that many people, including those of us more familiar with ecological or hydro-geomorphic work, might be available to conduct the contaminant studies in many places throughout the region. It is also desirable to have a methodology that can yield results that are comparable to other results of the Regional Monitoring Program for Trace Substances (RMP), and that are consistent with other scientific efforts to understand tidal marshes as wildlife habitats. Given that the necessary methodology was developed, then it became a secondary objective of this study to compare the tidal marsh study sites with nearby, in-bay stations of the RMP.
- Gain insight about the usefulness of natural tidal marsh physiography, including especially the network of natural channels and the marsh plain, as a spatial template for sampling sediment contaminants, since such physiography comprises the sampling template for most hydro-geomorphic and ecological studies of tidal marshland. Given that the necessary insight was gained, then it

became a secondary objective to compare tidal marsh channels and marsh plains within and among the study sites.

Sampling Plan

Study Sites

The RMP wetlands pilot was conducted in tidal marshlands at China Camp State Park in Marin County, and Petaluma Marsh in Sonoma County (Figure 14). These marshlands were selected for the following reasons:

1) they are among the best understood tidal marshlands in the region, based upon past and continuing ecological and geomorphic studies;
2) they are sites of the proposed San Francisco Bay National Estuarine Research Reserve (NERR), and therefore future sampling in these marshlands may be supported through funding or in-kind services and coordination through the NERR;
3) there is easy access, such that this new sampling effort is not complicated by logistical problems;
4) there are areas within these tidal marshlands that do not receive any direct fluvial inputs of sediment or water, and that are, therefore, indicative of the pattern of sediment contamination affected by the tides; and
5) they are located adjacent to existing RMP stations for San Pablo Bay and the entrance to the Petaluma River, and, therefore, they might yield results that are comparable to the existing data for the RMP for trace substances.

Temporal and Spatial Considerations

The sampling effort was designed to determine whether the natural physiography of tidal marshlands is a useful spatial template to sample sediments for contaminant analysis.

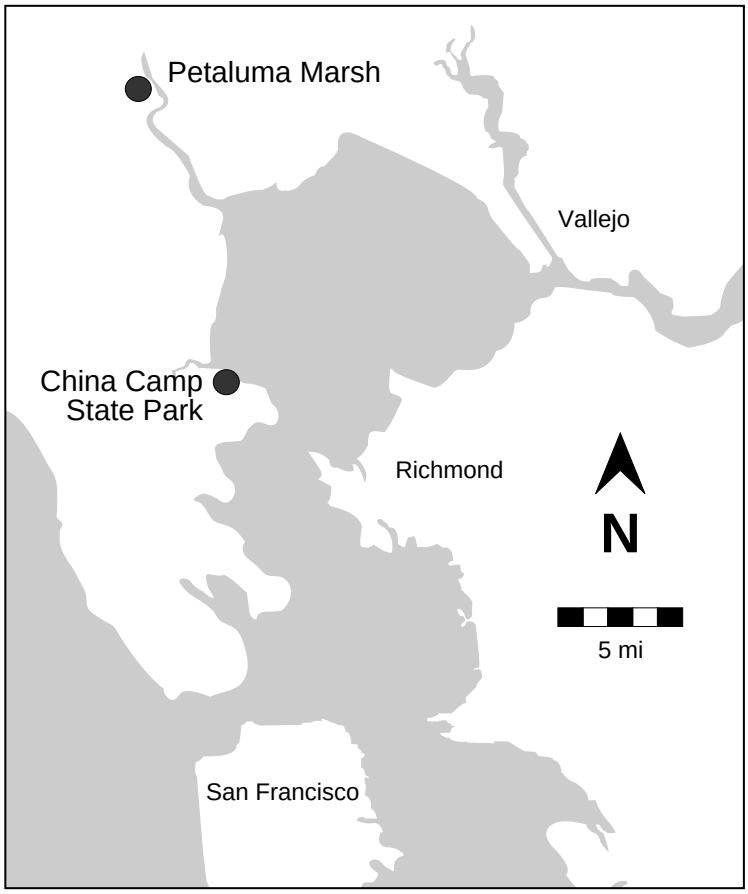

Figure 14. Location of RMP wetland sampling sites.

The physiography of the marsh controls the distribution and abundance of tidal water and the sediment that it carries. It can be assumed, therefore, that the spatial patterns of contaminant concentrations in a tidal marsh sediments are related to its physiography.

The most obvious elements of tidal marsh physiography are the channel network, vegetated plain, and natural pannes (Collins *et al.*, 1987). The channel network is dendritic in plan view. The pattern of branching upstream of the tidal source, or entrance into the channel network, is remarkably regular, and can be described by the Strahler system of stream classification (Strahler, 1957). That is, channels with no tributaries are termed first-order; two or more first-order channels coming together form a second-order channel; two or more second-order channels coming together form a third-order channel, and so forth (Figure 15). Channels of different order have distinct profiles in cross section or longitudinal view. Depth, width, and area of cross section can be predicted based upon upstream tidal prism or marsh surface area (Leopold *et al.,* 1993). The vegetated plain is defined as the area of marshland surrounded by channels or bordered in part by adjacent uplands. The natural levees, tension cracks to the side of channel banks, and the natural pannes are not considered part of the vegetated plain. The pannes tend to form on the vegetated plain at places equidistant from any channels.

The frequency and duration of tidal inundation, and the rate of suspended sediment supply, generally decrease with distance upstream, or away from the tidal sources, from high- to low-order tidal channels, and with distance across the vegetated plain away from channel banks. The efficiency of drainage and the frequency of tidal exchange also decrease with distance upstream or away from the tidal source. Furthermore, there are rather abrupt steps in bed elevation from a channel of one order into a confluent channel of a higher or lower order, such that there are predictable

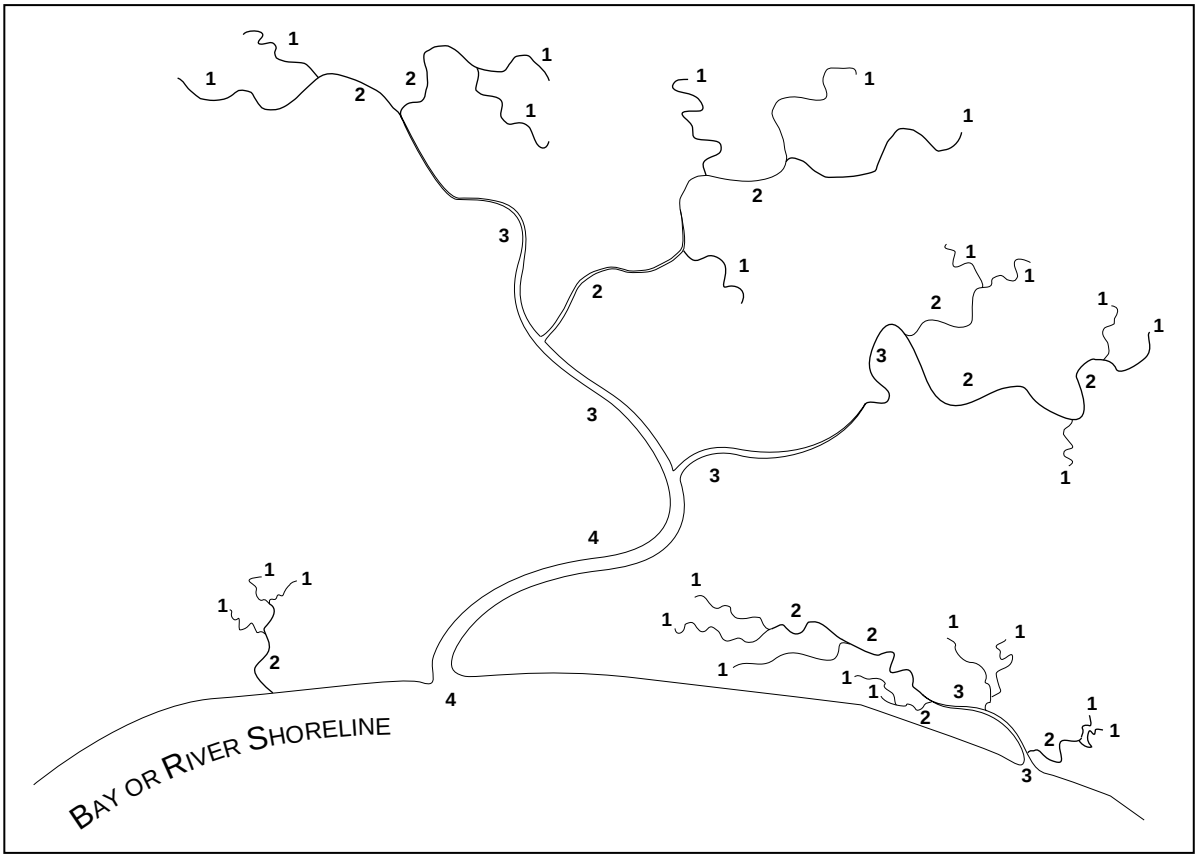

Figure 15. Wetland channel order classification.

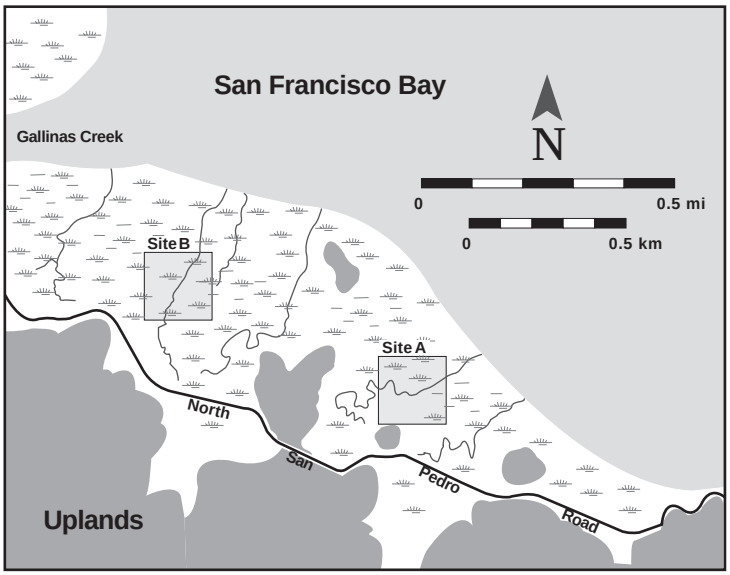

Figure 16. Sampling sites at China Camp marsh. Shaded squares show regions where sub-sampling was performed (see text.) Smaller channels not shown.

breaks in tidal regime and sediment supply among channels of different order, and between the channel network and the vegetated plain. Funding for this project was sufficient to explore the notion that such phenomena affect the spatial distribution of sediment contaminants.

The orders of the tidal channels of China Camp and Petaluma Marsh were determined from recent low-elevation aerial photography and ground-truthing. At these locations, the most common drainage networks with independent tidal sources are third-order. In other words, most of the drainage networks are connected to the bayshore through a third-order channel. Two typical third-order drainage networks were selected at each location, China Camp and Petaluma (Figures 16 and 17). Three sampling stations were established in each of the four selected networks as follows: one station near a panne on the drainage divide of the vegetated plain, one station at the downstream reach of a second-order channel, and one station at the downstream reach of the third-order channel.

Each drainage divide station involved an area of about 200 m^2, at least 10 meters from any channel or ditch, and at least 5 meters from the upland edge of the tidal marsh. The stations were therefore outside of the drawdown curves of nearby channels (Howland, 1976; Balling and Resh, 1983).

Each channel station was a reach of channel about 20 m long. Based upon this array of stations, the variability within and between channels large and small and whole drainage networks could be investigated.

To further assure that data for the bays and tidal marsh channels were comparable, the marsh channel stations were stratified into substrate types, and only sediments similar to the nearby Bay stations of the RMP were sampled. The chosen substrate stratum was unconsolidated fine-grain sediments of recent deposition. The stratum lacked a diatom felt and was very easily penetrated. This substrate is common on the surface of recent slump blocks and the surface of actively accreting point bars on the inside of meander bends (Figure 18).

A sample was defined as 10 sub-samples taken at random from one station during one sample period. A sub-sample was defined as about 100 cm^3 of sediment collected as a single sediment core from the surface of the sediment to a depth of 5 cm. The volume of a sample was therefore about 1000 cm^3, which is comparable to the volume of an RMP subaqeuous in-bay sediment sample. For channel stations, the maximum sample depth of 5 cm did not extend into the black, obviously anoxic sediments below the zone of recent deposition. For drainage divide stations, the maximum sample depth of 5 cm is well within the active root zone and, therefore, does not extend into the anoxic sediments.

During 1995, samples were taken from the two replicate drainage divides and two replicate third-order channel networks at China Camp during the regular fall and winter RMP sampling periods. These early results suggested that, for most chemical species analyzed, the stations for second- and third-order channels

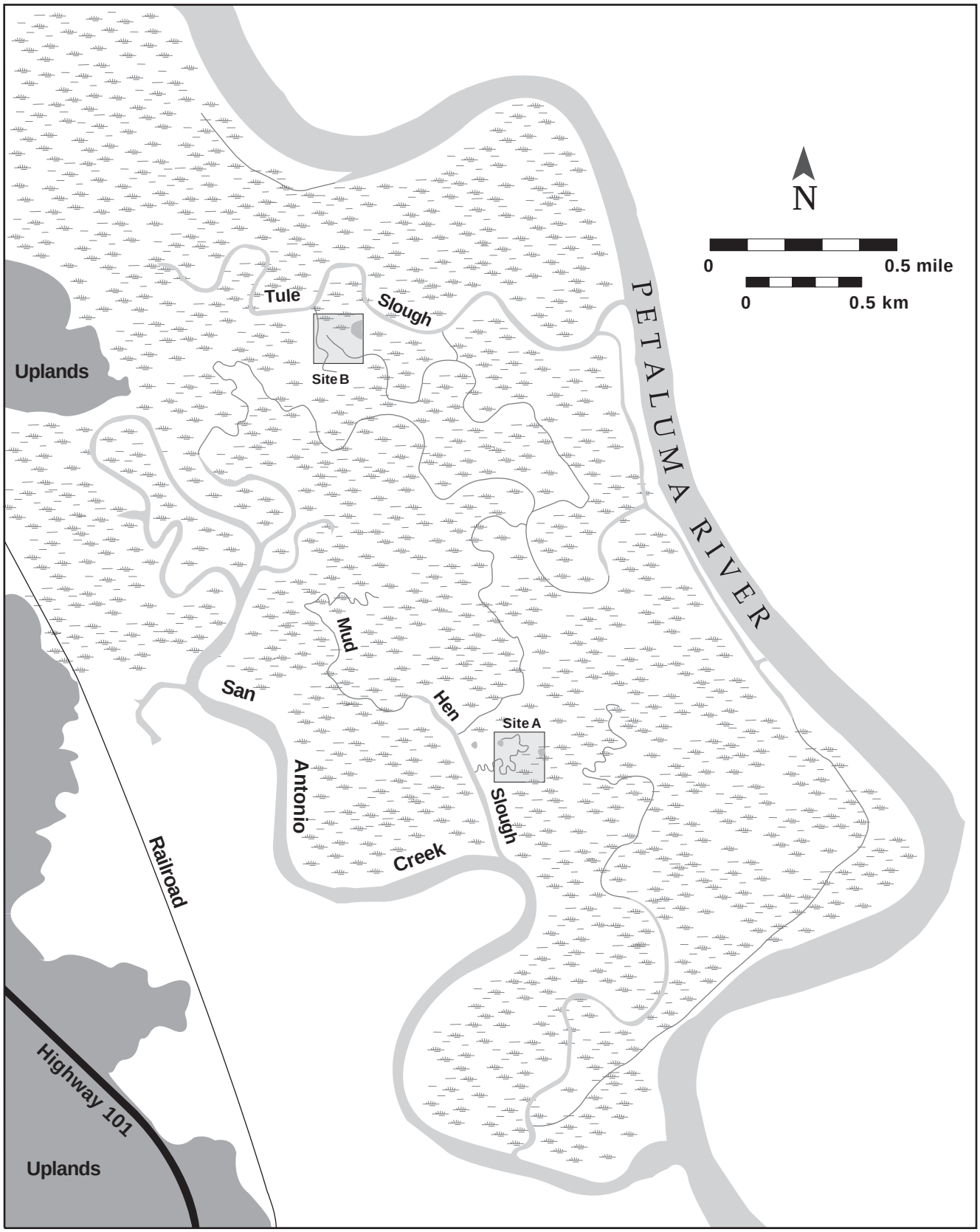

Figure 17. Sampling sites at Petaluma marsh. Shaded squares show regions where subsampling was performed (see text.) Smaller channels not shown.

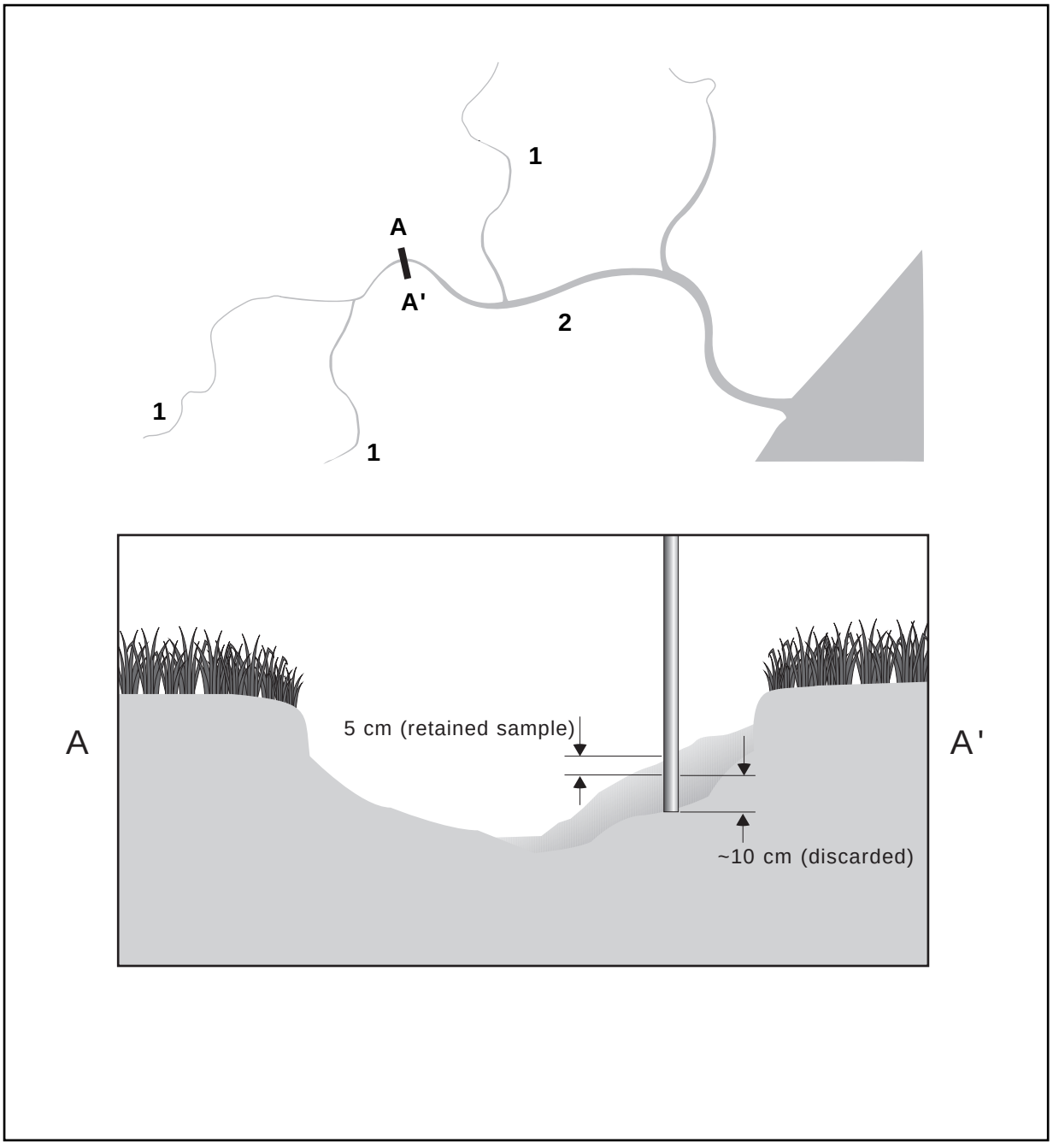

Figure 18. Idealized channel, showing typical sampling of unconsolidated sediment at the inside of a channel meander bend. Only the top 5cm of core material was retained from each core.

were the same within and among the replicate channel networks, and the replicate drainage divides were also the same. Therefore, during the fall and winter periods of 1996, the sampling effort at China Camp was decreased to one second-order channel station and one adjacent drainage divide station. This decrease in sampling effort at China Camp provided resources to extend the Pilot Project into two replicate channel networks and two replicate drainage divides at Petaluma Marsh. The early results for Petaluma Marsh suggested that the replicate drainage networks and the replicate drainage divides are similar in most regards, which prompted a decrease in sampling effort to one drainage divide station and one second-order channel station at Petaluma Marsh during the fall 1996 RMP sampling period. The final design therefore consisted of a single drainage divide station and a single second-order channel station at each of the two study sites, China Camp and Petaluma Marsh.

Sampling Gear and Procedure

The following procedure was followed for all samples of tidal marsh sediment:

1) One week prior to sampling, all equipment was thoroughly cleaned with Alconox® detergent. The Teflon®-coated sampling scoops were soaked in the detergent for two days, then rinsed three times with deionized water, soaked three days with 10% HCL, and finally rinsed with petroleum ether. The cleaned scoops were stored in sealed Ziploc® bags until used in the field. Following the detergent wash, the glass coring tubes and Teflon®-coated bucket were rinsed with tap water, followed by three rinses with deionized water, a rinse with 10% HCL, and a final rinse with petroleum ether. The ends of the glass coring tubes and the top of the bucket were sealed with plastic wrap.
2) All samples were taken with a thick-walled, 2 m long glass tube, having an inside diameter of 5 cm.
3) For channel stations, sub-samples were randomly selected in unconsolidated fine-grain sediment below the exposed root zone of the bank vegetation and above the bed of the channel. For drainage divide stations, sub-samples were randomly selected at least 10 m from any channel or ditch, and at least 5 m from the upland edge of the tidal marsh.
4) The tube was inserted to a depth of firm resistance from stiff, consolidated sediments (typically about 15 cm). If the depth to resistance was less than 5 cm, then another place for sub-sampling was randomly selected within the station. As the glass tube was inserted, its top end was kept uncovered, to prevent back pressure that could inhibit the sediment from entering the bottom of the tube.
5) The tube was extracted from the substrate by turning the tube in a twisting motion to break the connection between the substrate and the sediment in the core. Before the tube was pulled from the substrate, some of the air within the tube was removed by inhalation. As the tube was being extracted, its top end was firmly capped with one hand. The plug of stiff sediment at the base of tube and the partial vacuum in the tube helped the tube hold the core.
6) The total length of the core in the tube was measured to the nearest 0.5 cm. The outside of the tube was wiped clean with a dry cloth to clearly view the core.
7) The core was slowly extruded from the tube by blowing on the top end of the tube until only the top 5 cm of the core remain inside. The clean scoop was used to cut the extruded portion of the core flush with the bottom of the tube. The extruded portion (representing conditions below the five centimeter depth) was discarded.
8) The remaining portion of the core was extruded into the Teflon©-coated bucket. This procedure required one person to blow into the top end of the tube and a

second person to measure, cut, and otherwise direct extrusion of the core.

9) After all ten subsamples from a station had been combined in the bucket, then the clean scoop was used to thoroughly stir the combined sediment into one homogenous mixture.
10) Using the same clean scoop, about one liter of the homogenous mixture was placed into a clean glass jar, sealed and labeled, and the jar was placed on ice for short-term storage. Space was left at the top of the sample jar to allow for expansion of the sediment due to freezing.
11) To avoid cross-contamination between stations, all utensils, buckets, and the glass core tubes were rinsed between stations with tide water, then scrubbed thoroughly with Alconox®, followed successively by one rinse with deionized water, one rinse with 1% HCL, and one rinse with methanol. Spent chemicals were bottled separately and disposed of properly.

Results

Figures 19–36 show the concentrations of trace elements and trace organics, respectively, for drainage divides and second-order channels in China Camp and Petaluma Marsh for winter (February) and fall (September) 1995 and 1996. In each graph, concentrations at the marsh stations are compared to the appropriate Effects Range Low (ERL) and/or Effects Range Medium (ERM), and to the range of concentrations observed at the nearest RMP Bay station (BD22) for the 18 month period between the 1995 winter and 1996 fall sample periods. On dates when data from replicate drainage systems were obtained, the data was averaged, and "error" bars indicate the range.

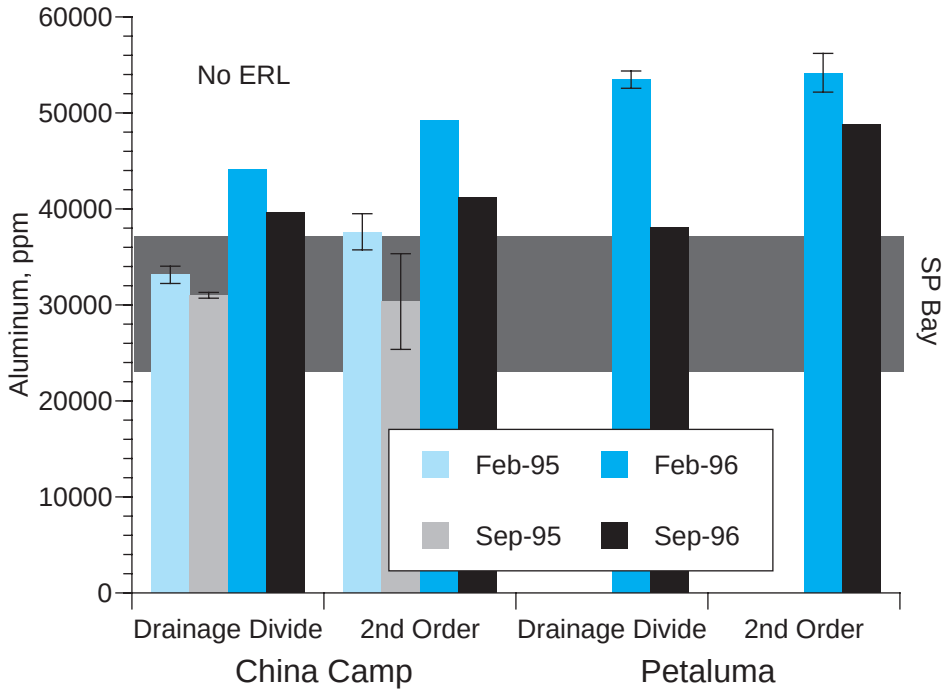

Figure 19. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

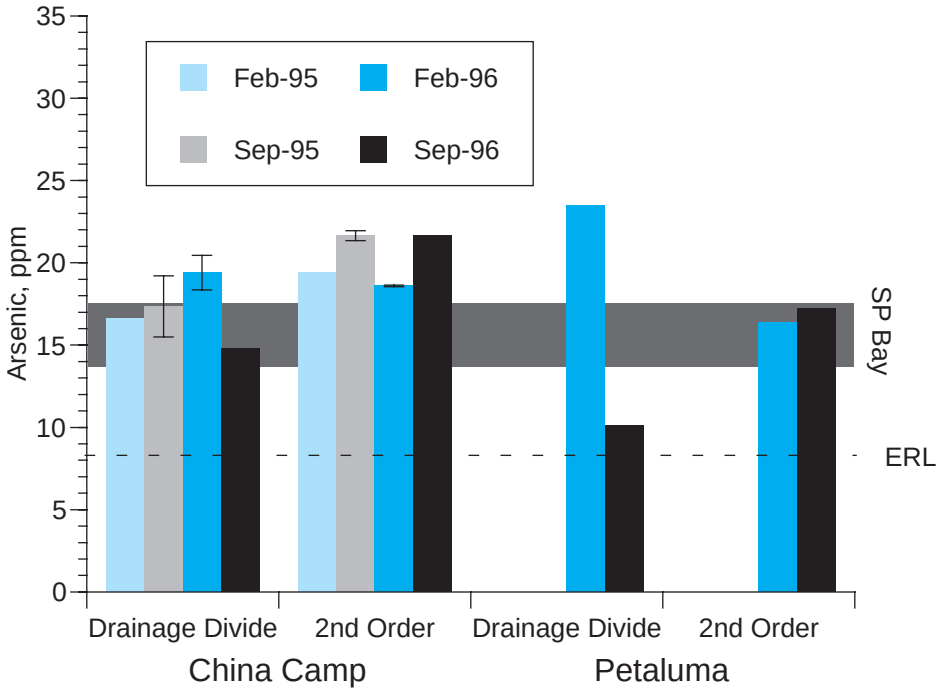

Figure 20. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

Discussion

Development of Field Methods and Training

A practical field method was developed and successfully implemented with novice personnel to describe patterns of contaminant concentration in sediments associated with medium-sized tidal channels and the vegetated plain or drainage divides of tidal marshlands. With no undo supervision, changes in field personnel had no effect on field procedures or technique. The method needs to be refined, perhaps following some of the suggestions provided below, but it is generally applicable at reasonable costs throughout the tidal marshlands of the Bay Area.

Sample Analysis

All samples were processed according to established RMP protocols through the same laboratories that process all other RMP data for concentrations of trace substances. Consequently, data for the RMP bay stations and for the wetlands pilot should be comparable, differences in data collection technique notwithstanding.

Sample Site Stratification Scheme

In general, the preliminary results suggest that concentrations of trace substances were similar among replicate stations within a location and sampling period (absolute value of range was less than 25% of median value). For example, within any sample period, concentrations tended to be similar for the two drainage divide stations at China Camp for all trace metals except cadmium, chromium, and lead. Concentrations were also similar for the replicate stations among second-order channels. These results support the decision to reduce the number of replicate drainage networks samples, based upon the use of drainage divides and second-order channels as sampling strata.

The stratification scheme used in this project is unusually specific for contaminant studies, but may yet be too general to characterize tidal marshlands as habitat for plant and wildlife. For example, the drainage divide stations as defined in this Pilot Project may not be adequate to characterize the effect of elevation (i.e., tidal regime) on the sediment chemistry of mature, high-elevation tidal marsh plains. Each drainage divide sample represents 10 sub-samples taken randomly within a station that included perhaps 200 m^2 of tidal marshland. While this may seem like a large station, two or three stations of this size together represent less than 1% of the area served by a typical third-order channel network. Given that the surface elevation of mature marshland corresponds to the upper limits of the tide, then slight topographic relief of the marsh surface can have substantial influence on the frequency and duration of tidal inundation. Given also that the tidal regime may be a controlling factor for contaminant concentration, either through delivery or removal, then having small sampling stations relative to the area of the marsh plain could produce a false picture of uniformity. The stratification used to select stations on drainage divides may have yielded data that only pertain to these highest parts of the marsh plain. A more representative sample of the plain might have been produced by sampling within a number of elevational strata. Since the sub-samples were pooled, there was no opportunity to collect covariate data on tidal elevation. But it is possible that the observed similarity among drainage divide samples from different sites resulted from pooling data across a number of high elevation contours.

It should also be noted that none of the sampling involved the high-order channels (i.e., fourth- and fifth-order) which serve as tidal sources to the largest existing drainage networks in Bay Area tidal marshlands. It is possible that, while contaminant concentrations are similar among second- and third-order

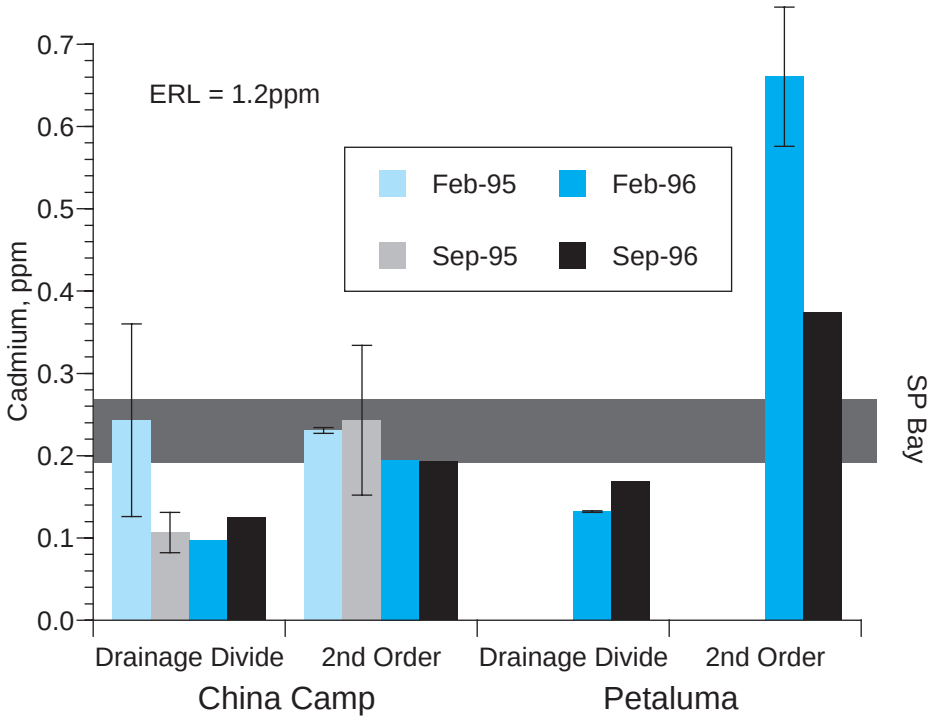

Figure 21. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

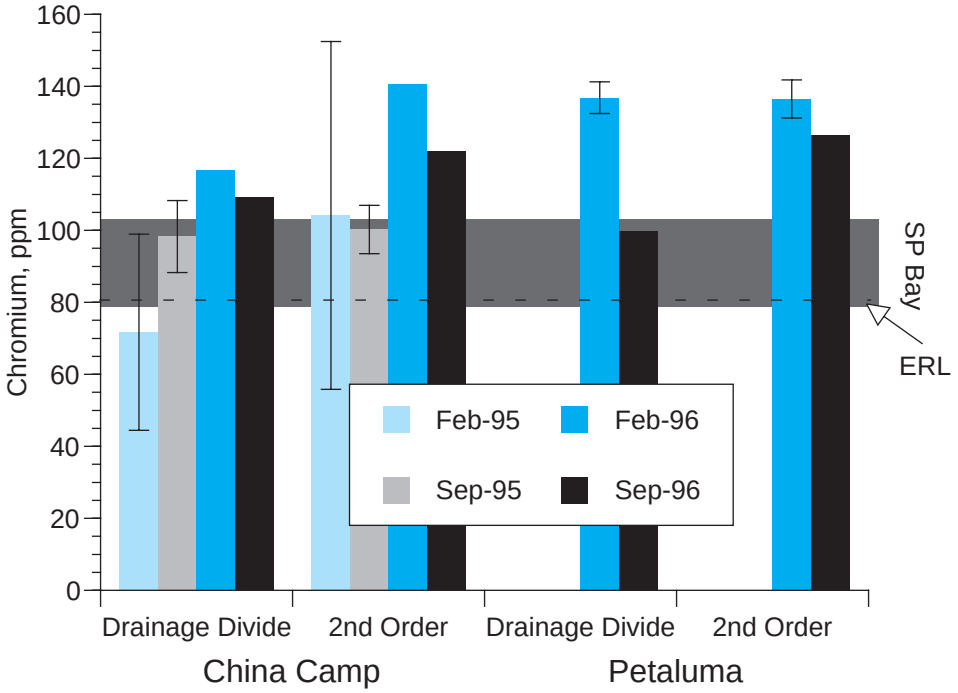

Figure 22. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

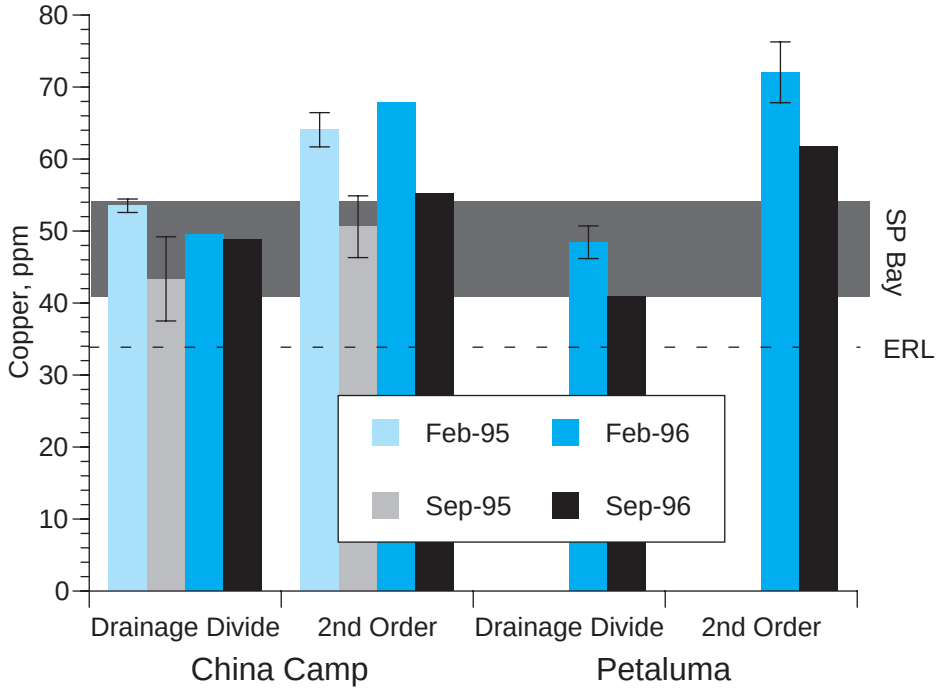

Figure 23. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

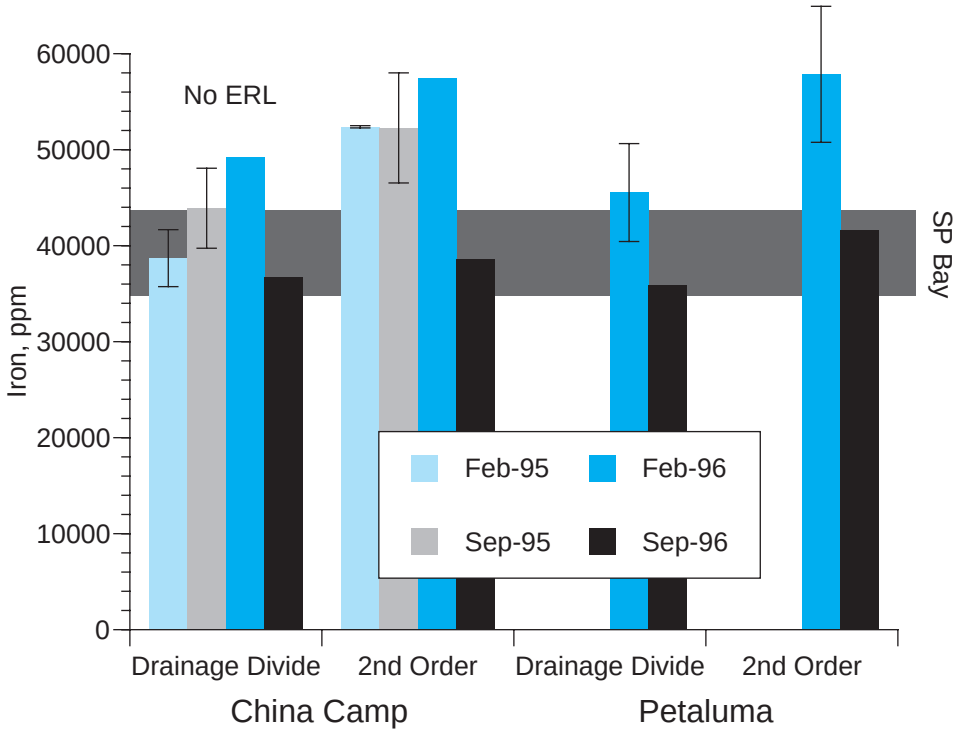

Figure 24. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

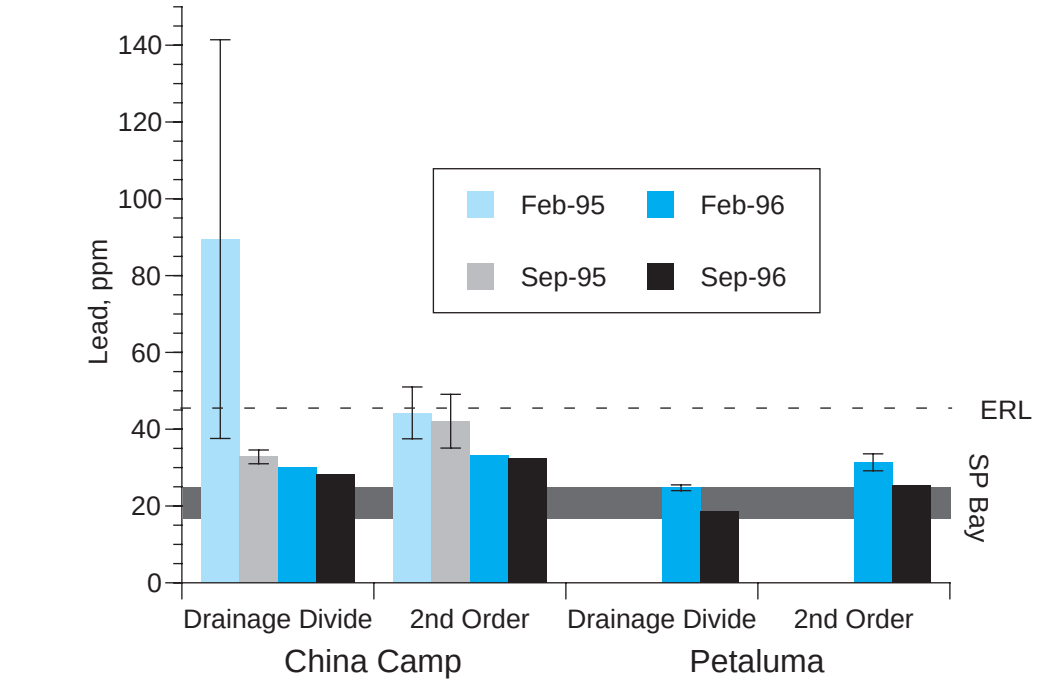

Figure 25. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

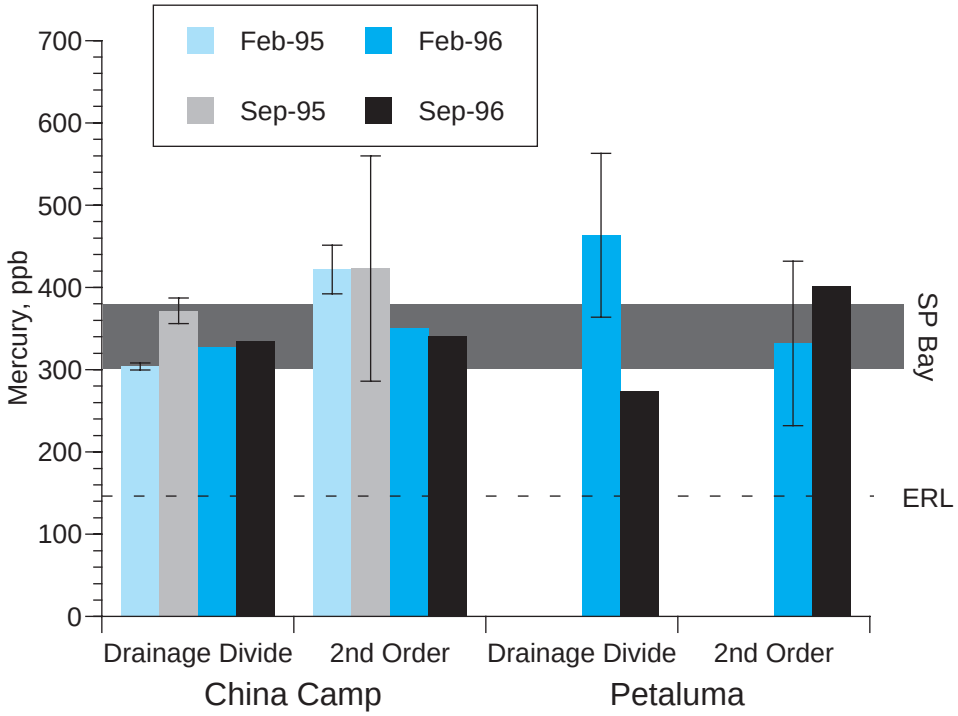

Figure 26. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

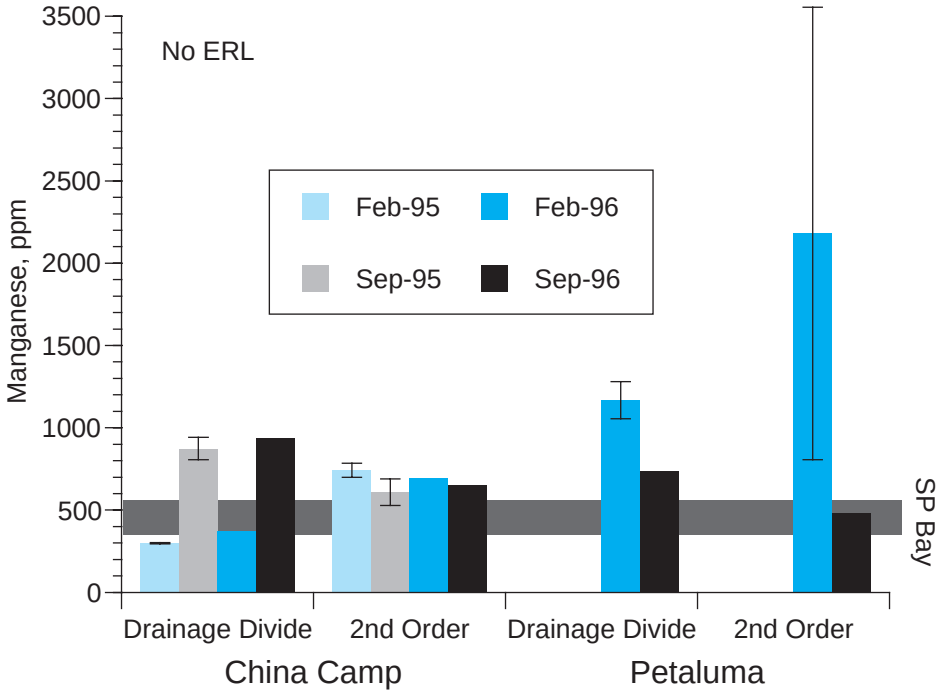

Figure 27. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

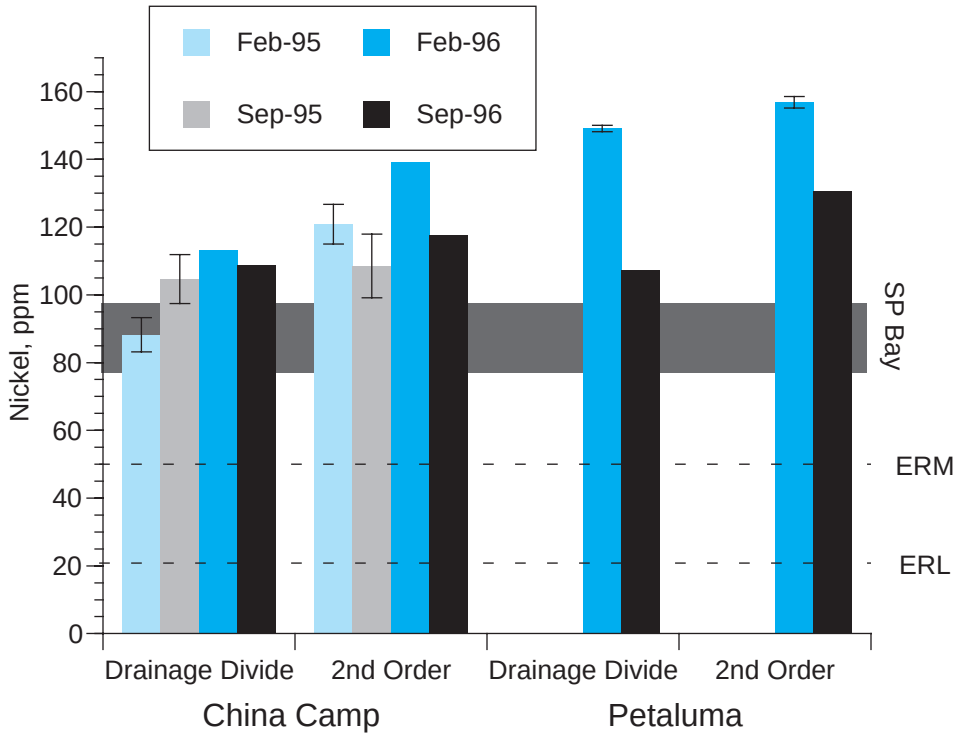

Figure 28. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

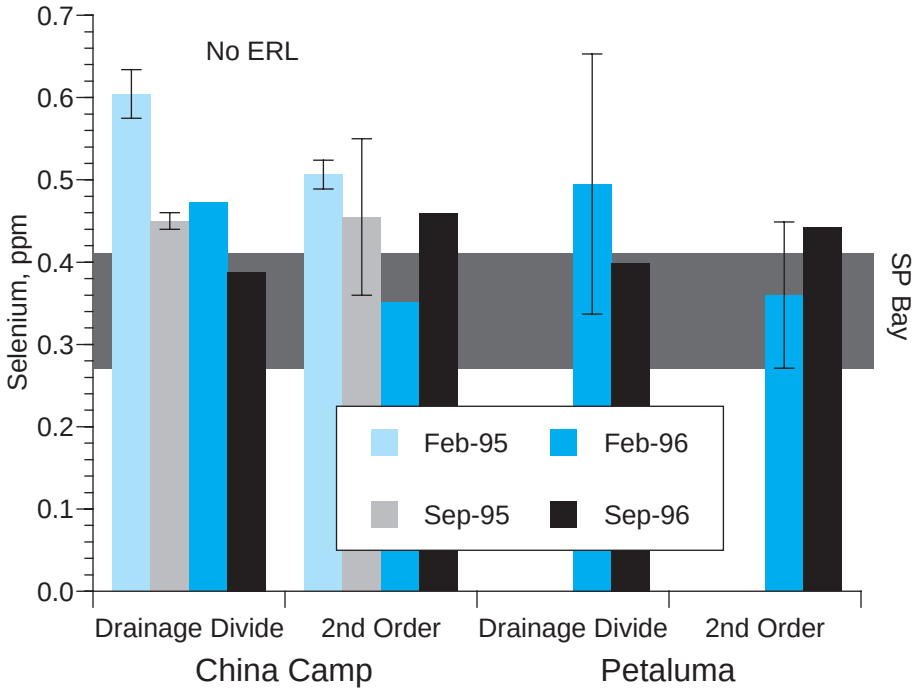

Figure 29. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

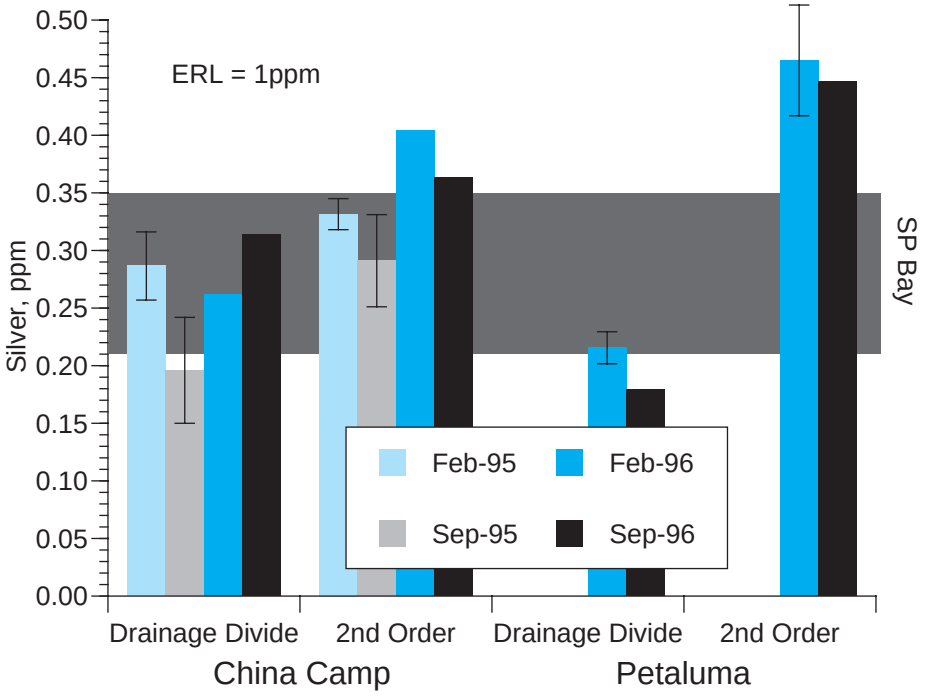

Figure 30. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

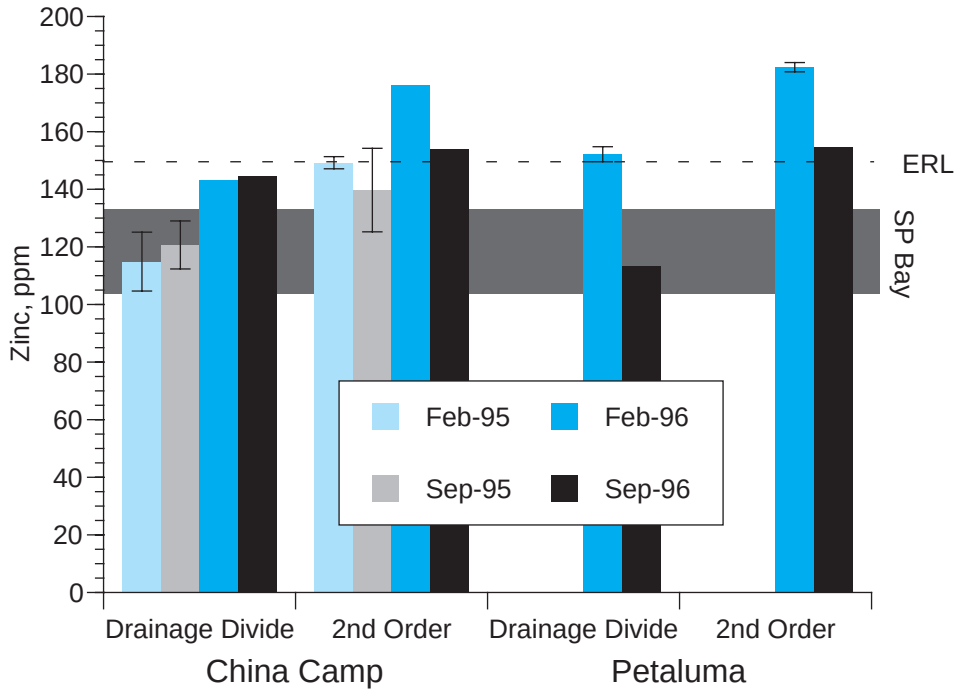

Figure 31. RMP wetlands trace element results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

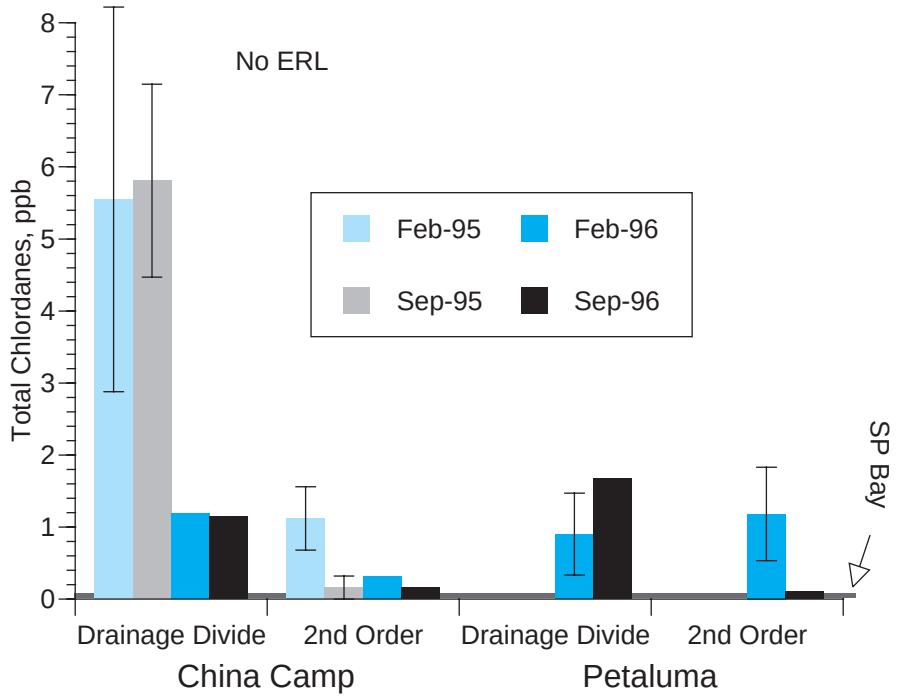

Figure 32. RMP wetlands trace organic results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

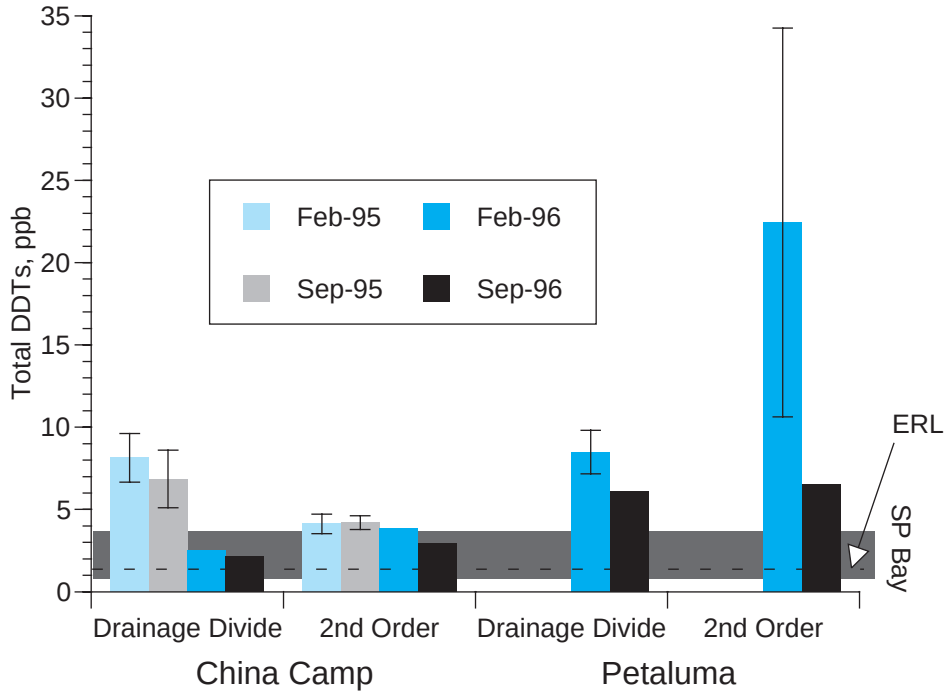

Figure 33. RMP wetlands trace organic results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

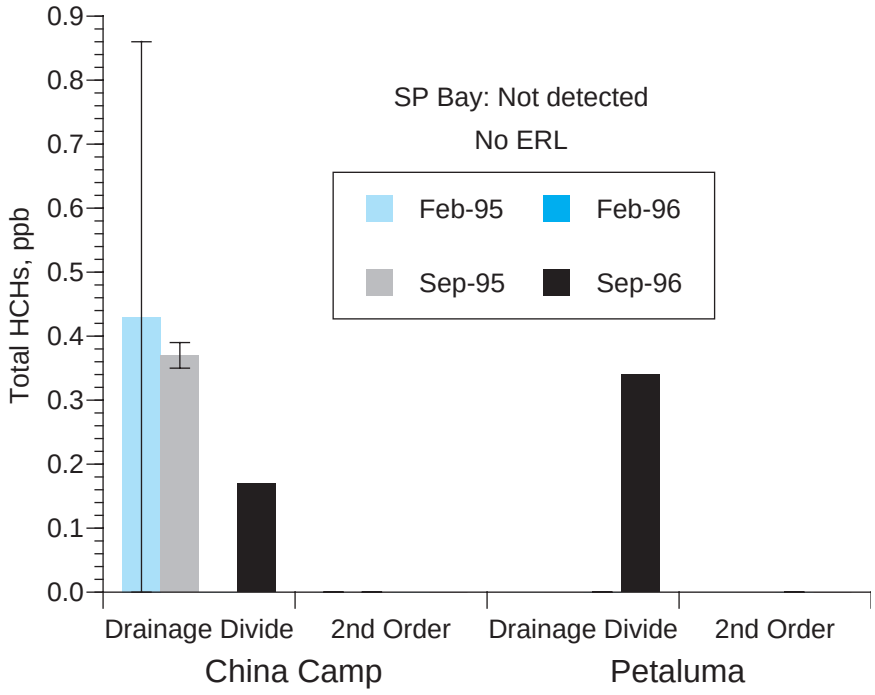

Figure 34. RMP wetlands trace organic results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

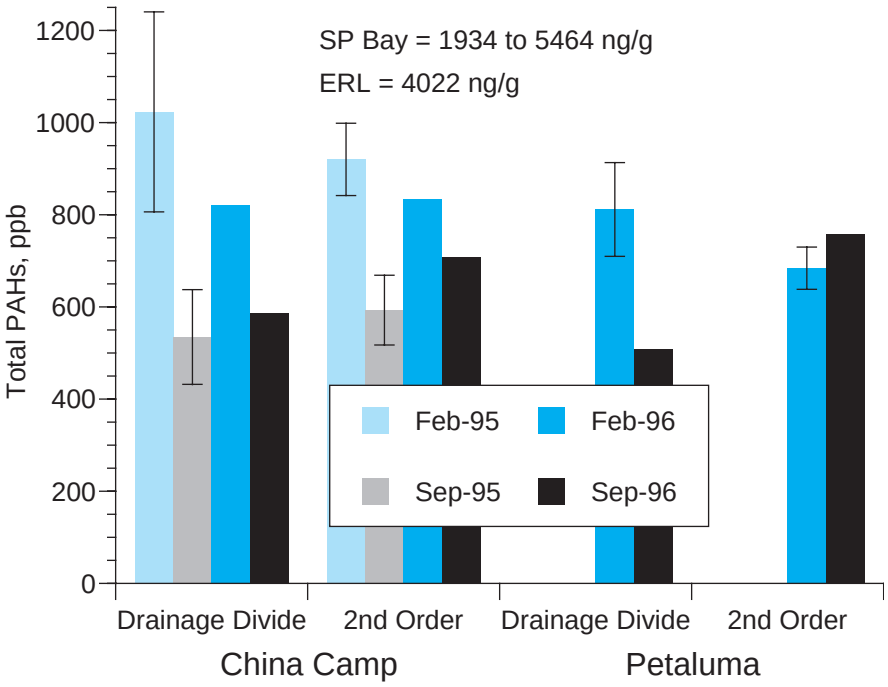

Figure 35. RMP wetlands trace organic results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

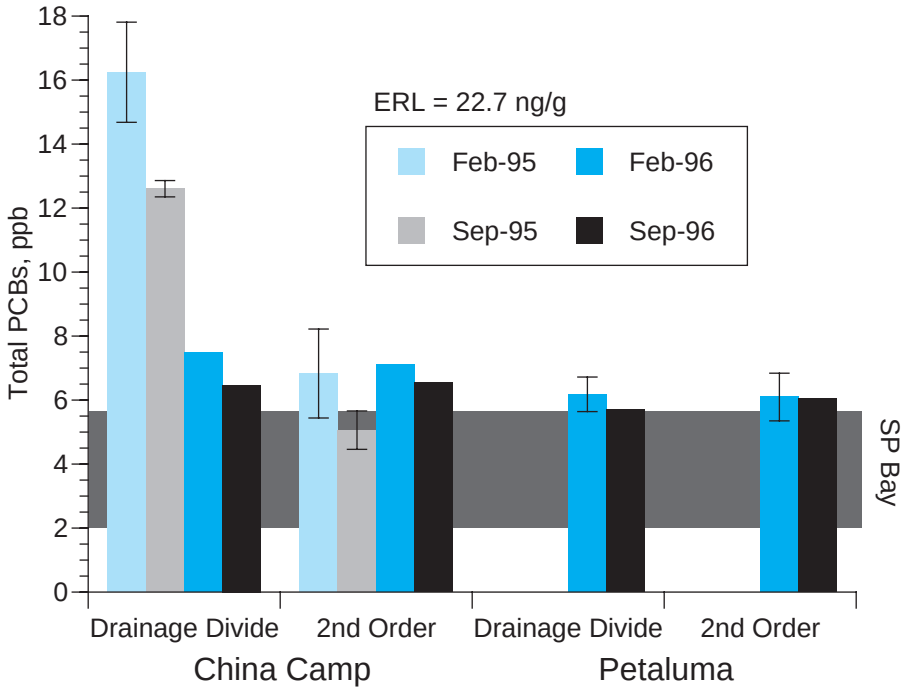

Figure 36. RMP wetlands trace organic results. Data pooled among two drainage systems. "Error" bars indicate range. Horizontal gray bar indicates range of nearby San Pablo Bay sediment station BD22. ERL = effects range low (see *Chapter Two: Sediment Monitoring* for an explanation.)

channels, there may be dissimilar concentrations between these channels and the larger channels. The level of contamination in the larger channels is perhaps less important now then it will be in the future, since there are few channels of this large size in existing marshes, but future expansion of tidal marshlands through restoration efforts could increase the number and extent of large channels. Further funding is required to investigate the variation in contaminant concentration among narrow elevational strata on the marsh plain, and among the fourth- and fifth-order tidal channels of the largest drainage networks.

By randomly selecting subsamples within a relatively large sample station, the impacts of field work on the fragile plant cover of the tidal marshlands was minimized. Photographic accounts of the sampling effort revealed no residual visual impacts that lasted between sample periods.

The analyses of temporal and spatial patterns are complicated because it is not known what period of time is represented by the samples. For example, it is possible that concentrations within the root zone on the drainage divides or in the channels vary between neap and spring tides, between seasons, and at rates that depend upon plant community composition. And it is possible that concentrations vary more rapidly within channels, due to more efficient drainage and more frequent tidal exchange. Samples from drainage divides might therefore represent more depositional time, then samples in channels. If it is assumed that the data represent either instantaneous values, or average value for the time period between samples, then the data can be used to compare sample stations and sites. Further funding is required to define the depositional periods for channels and drainage divides.

Temporal and Spatial Patterns for Trace Elements

No consistent temporal pattern was observed for any trace elements except aluminum,

Table 1. Spatial and temporal patterns in trace element concentrations.

	Al	Ag	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Zn
Most samples exceed maxima for BD22	•		•		•	•	•	•	•	•	•	•	•
Most samples exceed ERL	na		•		•	•	na	•	na	•		na	
Consistently higher winter maxima	•	•				•					•		
Consistently higher fall maxima													
Consistently higher maxima in channels	•	•	•	•	•	•	•	•		•	•		•
Consistently higher maxima on drainage divides													
Higher maxima in Petaluma Marsh	•			•		•			•	•			
Higher maxima in China Camp											•		

na means not applicable

silver, lead, and copper, which tended to be higher in winter (Table 1). The lack of a temporal pattern probably indicates the need for longer term studies that can partition the temporal variability among local and regional influences.

Concentrations of trace elements tended to be higher in the channels than on the drainage divides for all trace elements except manganese and selenium. This is a striking pattern that deserves to be explored further. A possible explanation for the pattern is that most of the metals are strongly associated with inorganic sediments, such as clays and silts, which dominate the sediments of the channels, whereas the sediments of the drainage divides are mostly peat, with a small inorganic faction.

Concentrations tended to be higher in Petaluma Marsh than at China Camp. It is not known if the higher concentrations upstream along the Petaluma River represent runoff from the Petaluma watershed, increased residence time of tidal water upstream from the Bay (and hence more opportunity for filtration by the upstream marshlands), or differences in local sources. Sewage treatment outfalls exist upstream of both of these locations, but Petaluma Marsh also borders an active sanitary landfill.

For all trace elements except silver and cadmium, maximum concentrations tended to be higher in the marshlands than at the nearby RMP Bay station in San Pablo Bay. The obvious suggestion is that the tidal marsh sediments are more contaminated than the Bay sediments. This suggestion alone may be reason enough to extent the wetlands sampling program to other marshes in the region. Concentrations also exceeded the ERL for more than half of the trace elements for which an ERL has been established.

Temporal and Spatial Patterns for Trace Organics

No consistent seasonal pattern was observed for any trace organics except PAHs and

DDTs, which tended to be higher in winter (Table 2). As in the case for trace elements, the lack of temporal pattern probably indicates the need for longer term studies that can partition the temporal variability among local and regional influences. Further funding is needed for continue monitoring to characterize temporal variability.

Concentrations of trace organics tended to be higher or similar on the drainage divides compared to marsh channels. This pattern is in contrast to what was suggested by the data for trace metals. Atmospheric deposition and absorption by peaty sediments may be part of the explanation for the high concentrations of the trace organics on the drainage divides. A preliminary examination of the raw data suggestions an abundance of DDT degradation products, and the spikes in HCHs and PAHs apparently relate to combustion products rather than petroleum. Further funding is required to measure the relative contribution of the tides and atmospheric deposition to the contamination of drainage divides.

No overall difference was apparent between trace organic concentrations at Petaluma Marsh and China Camp. The data for trace organics was generally more variable than the data for trace elements.

For all compounds except PAHs, maximum concentrations tended to be higher in the marshlands than at the nearby RMP Bay station in San Pablo Bay. Again, the obvious suggestion is that the tidal marsh sediments are more contaminated than the Bay sediments, as expected given the filtration function of tidal marshlands. Concentrations also exceeded the ERL for DDT's.

Conclusions

The RMP Wetlands Pilot Project, although of short duration and limited scope, produced a methodology for sampling tidal marsh sediments yielding data on contaminants that are

Table 2. Spatial and temporal patterns in trace organic concentrations.

	Total HCHs	Total PAHs	Total Chlordanes	Total DDTs
Most samples exceed maxima for BD22	•		•	•
Most samples exceed ERL	na		na	•
Consistently higher winter maxima		•		•
Consistently higher fall maxima				
Consistently higher maxima in channels				
Consistently higher maxima on drainage divides	•		•	
Higher maxima in Petaluma Marsh				•
Higher maxima in China Camp				

na means not applicable

comparable to other RMP data. The project has demonstrated that novice field personnel can be trained to test and conduct technical sampling procedures for sediment sampling consistent with existing RMP protocols.

The Wetlands Pilot clearly demonstrated that the natural physiography of the tidal marsh is a useful template for a stratified sediment sampling plan. Using medium-sized channels and drainage divides as major sampling strata, and substrate types within channels as minor strata, new patterns of contaminant concentration were revealed. To the extent that these sampling strata correspond to habitats for plants and wildlife, then sampling scheme presented here may serve to begin to integrate ecological, hydrogeomorphic, and contamination studies of tidal marshlands. Although the data are rather scant, the patterns of higher concentrations of trace organic compounds on drainage divides, and higher concentrations of trace elements in channels seem especially persistent within and among locations and sample periods. The suggestion of an upstream increase in contamination along the Petaluma River also deserves further examination.

The evidence that tidal marshland sediments are more contaminated than the sediments of the open Bay is not surprising, given that the marshlands are retentive filters washed twice daily by the tides.

Additional research and a more focused monitoring program seems warranted to characterize the basic temporal and spatial patterns of contaminant concentration in tidal marshlands. Based upon this Pilot Project, the following research questions are suggested. The answers to these questions would lead to testable hypotheses about the causes of the patterns observed. But basic, descriptive work is yet required.

- What are the patterns of concentration of trace organic and trace element contaminants along gradients of elevation and distance from channel bank across drainage divides.
- What are the temporal scales of variability within a year for concentrations of trace organic and trace element contaminants within tidal marsh channels large and small and on drainage divides.
- What is the variability for concentrations of trace organic and trace element contaminants from year to year.
- What are the patterns of concentration of trace organic and trace element contaminants within fourth- and fifth-order tidal marsh channels.
- What are the relative contributions of the tides and atmospheric deposition to the contamination of tidal marsh drainage divides.

In addition to these basic research questions, there seems to be a need to begin to build linkages between studies of tidal marsh contamination and studies of tidal marsh ecology. It might be useful, for example, to review the existing data on tidal marsh contamination, and the research topics suggested above, to identify which conditions of contamination and which research topics relate to which ecological services, and of these, which are of the greatest concern to wetlands managers. It would be helpful to use the ecological services of greatest concern, whether they refer to organisms, populations, communities, or ecosystem ecology, as focal for tidal marsh contaminant monitoring and research.

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CHAPTER SEVEN

Other Monitoring Activities

Sacramento River Watershed Program Phase 1 Monitoring Plan

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Background

The Sacramento River Watershed Program (SRWP) is an association of stakeholders in the Sacramento River watershed. These stakeholders include representatives of local municipalities and districts, state and federal agencies, agriculture, industry, landowners, environmental organizations, universities, technical consultants, watershed conservancies, and the general public. The SRWP was formed in 1996 through a series of stakeholder meetings.

Formation of the SRWP was facilitated by the Sacramento River Toxic Pollutant Control Program (SRTPCP), a locally initiated effort led by Sacramento County and the Sacramento Regional County Sanitation District (SRCSD). The SRTPCP is a watershed-based approach to the management of toxic pollutants in surface waters of the Sacramento Valley. An element of the SRTPCP is assistance in the formation of the broader watershed program.

The federal government provides a major portion of the direct funding for the SRTPCP to SRCSD. For the first three years of the program, federal funding of $2.4 million has been awarded. The federal funds are administered by the United States Environmental Protection Agency (US EPA), Region IX. SRCSD is providing 5 percent matching funding and additional in-kind services through staff support of program activities. Additionally, significant public and private support of the program is being provided through the active participation of numerous representatives on the SRWP subcommittees.

The goal statement for the SRWP that was developed by the participating stakeholders is as follows:

To ensure that current and potential uses of the watershed's resources are sustained, restored and, where possible, enhanced while promoting the long-term social and economic vitality of the region.

One of the primary tasks of the SRTPCP and the SRWP is the design and implementation of a monitoring program for the watershed. In early stakeholder meetings, a Monitoring Subcommittee was formed to lead the development of the monitoring program.

The Monitoring Subcommittee has established the following long-term goal for the SRWP monitoring program:

In coordination with other subcommittees and the larger stakeholder group, develop a cost-efficient and well-coordinated long term monitoring program within the watershed to identify the causes, effects and extent of constituents of concern that affect the beneficial uses of water and to measure progress as control strategies are implemented.

The SRWP monitoring program is envisioned by the subcommittee to be a long-term (i.e., 20 year) effort that will provide information to promote the understanding of conditions in the watershed and to assess the health of the watershed. The monitoring program will be a dynamic activity that will change over time as information is accumulated and new information needs are identified.

The Monitoring Subcommittee has set the following goal for the first year of the monitoring program:

To assess conditions in the main stem of the Sacramento River through the collection of baseline information, with an emphasis on examining the degree to which beneficial uses are attained or potentially impaired.

Description of Program

The proposed first year SRWP monitoring program includes chemical, physical, biological, and toxicological monitoring elements. The proposed program will augment and coordinate with a number of other monitoring efforts that are ongoing in the watershed, including the United States Geological Survey's National Water Quality Assessment program (USGS NWQA), the Sacramento Coordinated Water Quality Monitoring Program, and monitoring efforts by the Central Valley Regional Water Quality Control Board, Department of Water Resources (DWR), Department of Pesticide Regulation, US Bureau of Reclamation, City of Sacramento, and City of Redding.

The following environmental monitoring is included in the proposed program:

A) Mercury, PCBs, and chlorinated pesticides in fish tissue
B) Trace metals in water (arsenic, cadmium, copper, chromium, lead, mercury, nickel, selenium, silver, and zinc)
C) Aquatic life toxicity in water and sediment
D) Pathogens in water (*Cryptosporidium*, *Giardia*, coliforms)
E) Organic carbon in water
F) General constituents (minerals, nutrients, solids, turbidity, hardness) in water
G) Benthic invertebrates
H) Algae (attached and planktonic)
I) Physical habitat assessment

The purpose for monitoring these parameters is provided below.

Fish Tissue Monitoring

Mercury and certain organic constituents (including DDT, chlordane, and PCBs) readily accumulate in the food web, resulting in concentrations in fish tissue which may be of concern to humans and wildlife. Monitoring the levels of these constituents in fish is an effective way to assess whether human health is potentially at risk in the Sacramento River system due to environmental levels of these constituents. Fish accumulate these constituents throughout their life span and their habitat; fish tissue measurements therefore provide an indication of average conditions over space and time. Fish tissue data can also be useful in the determination of long-term trends in levels of bioaccumulative constituents (such as mercury, DDT, and PCBs) in the watershed. These long-term data can potentially be used to measure the effectiveness of activities to control these constituents.

Trace Metals in Water

Low levels of trace metals in water can affect the growth, reproduction, and/or survival of sensitive aquatic species. Trace metals of potential concern to aquatic life in the Sacramento River system include copper, cadmium, zinc, lead, chromium, selenium, silver, nickel, and arsenic. Mercury and arsenic are of potential concern to human health. Mercury is also of concern due to its accumulation in the food chain and potential adverse effects on fish-eating birds and other predators. Several programs are currently underway in the Sacramento River watershed to monitor trace metal levels at various locations, including the Sacramento Coordinated Water Quality Monitoring Program, the USGS NWQA for the Sacramento River, and seasonal monitoring by the US Bureau of Reclamation and the US EPA near Keswick. The proposed SRWP trace metal monitoring would supplement the existing data with information for two additional locations (Sacramento River at Keswick and Cache Slough near Rio Vista). Data obtained will be used to quantify ambient levels of metals in the Sacramento River watershed and to assess whether these levels are potentially affecting beneficial uses.

Aquatic Life Toxicity in Water and Sediment

Ambient samples of water and sediment can be tested in the laboratory for aquatic life toxicity to provide an indication of the conditions that exist in the natural environment. Standard test species and test procedures are used to provide reliable results. Toxicity is

deemed to occur when test species are adversely affected by exposure to ambient water or sediment. Adverse effects may include impaired growth or reproduction, abnormalities, and/or death of test species. Effects may occur rapidly (acute toxicity) or may occur over a longer period (chronic toxicity). For the SRWP monitoring program, the results of toxicity testing will be used to trigger further investigations to determine the cause of observed laboratory toxicity. These investigations include the consideration of a number of factors, including contributing watershed characteristics, chemical characteristics, biological characteristics, and additional toxicity test results. In addition, toxicity identification evaluations will be performed on acutely toxic samples. Information from these investigations is useful in identifying potential water quality problems in the watershed through an integrated, weight-of-evidence evaluation of multiple factors. Toxicity testing in water is proposed at fifteen locations in the watershed. Sediment toxicity testing is proposed at nine locations in the watershed.

Pathogens in Water

Pathogens are disease-producing organisms (protozoans, bacteria, viruses) which adversely affect the quality of drinking water and may pose health risks for water contact recreation. Two pathogens are of particular concern, *Cryptosporidium* and *Giardia,* due to their ineffective removal through conventional water treatment technologies. In general, data on the levels of these pathogens is lacking in the Sacramento River system. Limited datasets exist for the Sacramento River near Redding and in the Sacramento River below Sacramento. Monitoring efforts have recently been initiated in the lower end of the watershed near Sacramento to assess levels of *Cryptosporidium*, *Giardia*, and coliform organisms (common indicators of fecal contamination) by DWR, Metropolitan Water District of Southern California, and the City of Sacramento. The proposed SRWP pathogen monitoring extends monitoring for these specific parameters to seven additional locations in the Sacramento River watershed. Data will be used to determine the magnitude and extent of levels of these pathogens in the main stem of the River below major dams.

Organic Carbon in Water

Organic content (as measured by organic carbon) is a parameter important to drinking water suppliers. High levels of organic carbon in source waters leads to the production of disinfection by-products as a result of conventional water treatment. These by-products pose human health problems at relatively low concentrations. Baseline data on typical organic carbon levels and seasonal variability of those levels in the Sacramento River system are important to the assessment of drinking water uses. The proposed SRWP monitoring for organic carbon at seven sites will augment fairly extensive monitoring already being performed by the USGS NWQA program, the City of Sacramento and DWR.

General Constituents (Suspended and Dissolved Solids, Hardness, Turbidity, Minerals, and Nutrients) in Water

These “conventional” water quality parameters affect a variety of uses, including drinking water supply, recreation, aesthetics, aquatic habitat, and agricultural supply. Data on these parameters are available from a number of other programs, including USGS NWQA, the Sacramento Coordinating Monitoring Program and DWR. Proposed SRWP monitoring will augment these ongoing data collection efforts for some of these constituents at 12 sites. SRWP monitoring for minerals and nutrients is only proposed at one site each.

Benthic Invertebrates

Benthic invertebrates are the aquatic insects and other organisms that live along the bottom of water bodies. Procedures have recently been developed to standardize the assessment of biological habitat and benthic communities for use as a monitoring tool. Information collected at specific sites is com-

pared against expected (or reference stream) conditions to evaluate the relative health of the biological community at that location. This information is used in combination with chemical characteristics and aquatic life toxicity information to assess ecosystem conditions at various locations. Different procedures are used depending on the characteristics of the stream (i.e., wadable versus non-wadable). This monitoring tool can be effectively used by citizen monitoring groups in smaller tributary watersheds. DWR and Department of Fish and Game are working actively with a number of tributary watershed groups to provide education and training regarding the assessment methods. Data from the proposed SRWP monitoring program will be used to supplement and integrate results from projected tributary efforts.

Algae

Algae exist in aquatic systems in a variety of locations: suspended in the water column (planktonic); attached to submerged tree limbs and surface debris; and attached to rocky bottom material (benthic). Methods exist to sample and quantify algal characteristics in these locations. Levels of algae in surface waters are used to evaluate the overall health of an ecosystem. Community analysis of algae species is used in a similar fashion to the benthic invertebrate data. Species diversity, number of species, presence of sensitive species and other measures are used in the evaluation. Elevated algae levels indicate a biologically productive, organically enriched aquatic environment. Detrimental effects of elevated algae levels may include poor water clarity, aesthetic impairment, reduced dissolved oxygen levels, and degraded drinking water quality. Data on algae levels will be used to assess these beneficial use issues and to establish a baseline for future trend monitoring.

Sampling Locations

The proposed program includes monitoring at 53 locations in the Sacramento River watershed. Eight of these sites are located on the main stem of the Sacramento River, ranging from the Upper Sacramento River above Shasta to the Sacramento River below Freeport at River mile 44. The other proposed sites in the first year program are located on tributaries to the Sacramento River. The proposed sites cover over 300 miles of the Sacramento River system and capture a drainage area of over 23,000 square miles. The following is a listing of the proposed first year monitoring sites:

1) Pit River above Lake Shasta
2) McCloud River above Lake Shasta
3) Sacramento River above Lake Shasta
4) Spring Creek Powerplant discharge to Keswick Reservoir
5) Sacramento River below Keswick Reservoir
6) Sacramento River at Bend Bridge near Red Bluff
7) Mill Creek (6 sites)
8) Deer Creek (10 sites)
9) Big Chico Creek (12 sites)
10) Sacramento River at Colusa
11) Butte Creek (6 sites)
12) Sacramento Slough at the mouth
13) Colusa Basin Drain at the mouth
14) Yuba River at Marysville
15) Feather River near Nicolaus
16) Sacramento River at Verona
17) Sacramento River at Alamar (Veteran's Bridge)
18) Arcade Creek near mouth
19) American River at J Street
20) American River at Discovery Park
21) Sacramento River at Freeport
22) Sacramento River at River Mile 44
23) Cache Slough near Ryer Island Ferry

Semi-intensive monitoring (either monthly or semi-monthly) is proposed at 16 of the above sites, including 7 of the main stem sites and 9 of the tributary sites. Monitoring at the other sites will consist of either:

1) one-time biological monitoring events (34 sites),
2) a mix of biological monitoring and sediment toxicity (2 sites), or
3) sediment toxicity testing (one site).

The program will also include water quality monitoring in three tributary watersheds, Deer Creek, Big Chico Creek, and Mill Creek. The monitoring in these tributaries will be similar to the program in the main stem.

Sediment toxicity will be monitored at nine NWQA sites where sediment sampling is being performed by USGS.

Quality Assurance/Quality Control

Data quality integrity is a primary focus of the SRWP monitoring program. Quality control samples will be collected and analyzed to ensure the development of accurate and precise environmental data which can be trusted for use in long-term trend analysis and to ensure that analytical results are not compromised by contamination in the field or the laboratory.

Details of the Quality Assurance/Quality Control (QA/QC) program for the SRWP monitoring program are described in the Quality Assurance Project Plan (QAPP). The QAPP has been submitted to US EPA for approval prior to the commencement of the SRWP monitoring effort.

Coordination with Other Programs

As described earlier, the proposed SRWP monitoring program will augment and coordinate with several ongoing monitoring programs. Sampling sites and analyses are coordinated with USGS Sacramento River NWQA, Sacramento CMP, Regional Water Quality Control Board, DWR, Department of Pesticide Regulation, City of Sacramento, City of Redding, US Bureau of Reclamation, US EPA, and the San Francisco Estuary Regional Monitoring Program.

The design of the proposed SRWP monitoring program depends on the collection of key information by these other programs. For example, monitoring by the USGS NWQA program for pesticides is being counted on to fill important information needs which are not covered by proposed SRWP monitoring. The NWQA program is collecting monthly organophosphate and carbamate pesticide data at four main stem Sacramento River sites, Colusa Basin Drain, Sacramento Slough, Feather River, Yuba River, American River, Arcade Creek, and Cache Creek.

Schedule

It is anticipated that the full monitoring program will begin in December 1997 or January 1998. Fish collection for the fish tissue study was completed in September. Other elements of the monitoring program will begin after approval of the QAPP and execution of the appropriate subcontracts.

For information on the Sacramento River Watershed Program, contact Val Connor at (916) 255–3111 or by e-mail at: connorv@gwgate.swrcb.ca.gov.

For information on the SRWP Monitoring Program, contact Tom Grovhoug at (916) 753–6400 or by e-mail at: lwa@davis.com or TomG@lwadavis.com.

Sacramento Coordinated Water Quality Monitoring Program

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Introduction

The Sacramento Coordinated Water Quality Monitoring Program (CMP) is a cooperative voluntary program initiated and implemented by the Sacramento Regional County Sanitation District (SRCSD), the City of Sacramento (City), and the County of Sacramento—Water Resources Division (County). These three public agencies are responsible for the management of all municipal wastewater and most stormwater in the Sacramento urban area within Sacramento County. The CMP was established in July 1991 through a Memorandum of Understanding between these entities

The purpose of the CMP is to coordinate monitoring activities to produce a scientifically defensible database of water quality information on the Sacramento River and American River in the Sacramento metropolitan area.

The Ambient Monitoring Program is the primary water quality monitoring element of the CMP. Sampling under the Ambient Program began in December 1992 and continues at present on a monthly basis. Additionally, episodic storm events are sampled in coordination with the Sacramento Stormwater Monitoring Program.

Five river sites are now monitored under the Ambient Program, three on the Sacramento River (at Veteran's Bridge near Alamar Marina, at Freeport Bridge, and at River Mile 44 downstream of the Sacramento metropolitan area) and two on the American River (at Nimbus Dam and at Discovery Park near the confluence with the Sacramento) (See Figure 1). The monitoring sites have been selected to provide water quality data upstream and downstream of the influence of urban inputs from the Sacramento community.

The primary emphasis of the Ambient Program has been on trace metals monitoring—both total recoverable and dissolved—using clean techniques and low detection limits. Other parameters monitored under the Ambient Program include total and fecal coliforms, total organic carbon, dissolved organic carbon, pH, temperature, dissolved oxygen, hardness, total suspended solids, and electrical conductivity.

Annual reports have been produced each year of the CMP. The latest (1996) Annual Report for the Sacramento CMP presented the

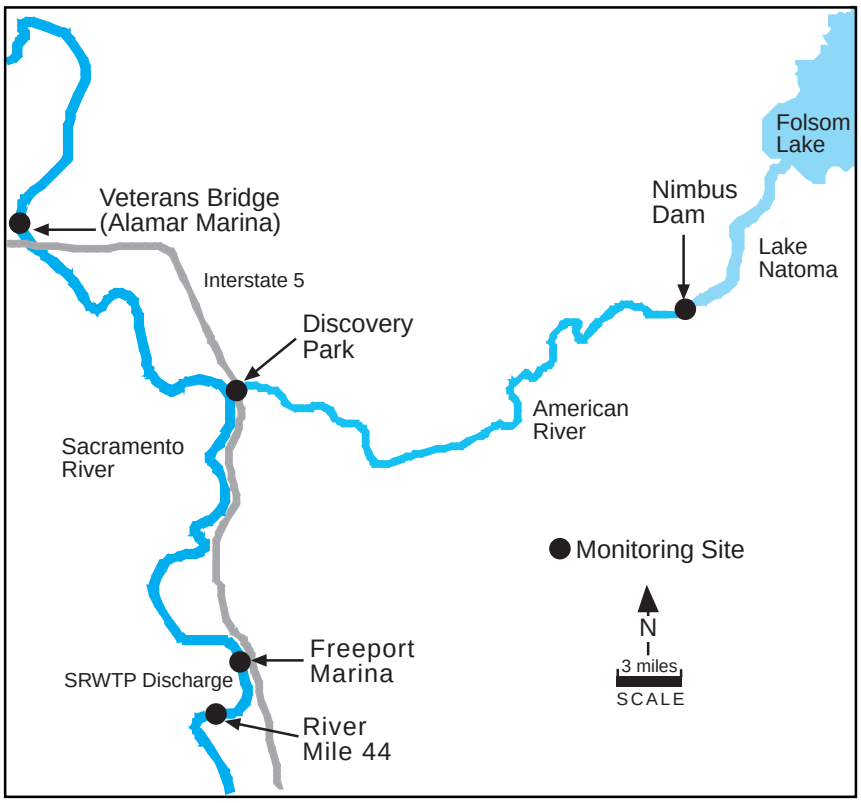

Figure 1. Ambient Program monitoring stations.

results of Ambient Program monitoring completed through July 1996. The next Annual Report will cover data collected through December 1997 and is scheduled for release in spring 1998.

Coordination with the Sacramento River Watershed Program

The Sacramento CMP and the Sacramento River Watershed Program (SRWP) are being coordinated at several levels. The SRWP monitoring program (which will start in the fall of 1997) has been developed to incorporate a number of ongoing monitoring efforts, including the CMP Ambient Monitoring Program. The CMP sampling team will take samples for analysis by the SRWP at a number of locations. The analytical results produced by the CMP will be used to augment other data collected under the SRWP. The CMP will also participate in inter-laboratory quality control testing for trace metals analyses.

The CMP and SRWP have also cooperated in the joint sponsorship of the State of the Watershed 1997 conference held in October 1997 in Sacramento. This second annual conference featured speakers from the Sacramento River watershed and was highlighted by awards given to local organizations which distinguished themselves in a variety of categories.

Results Of CMP Monitoring

Important information collected to date under the Ambient Program has indicated the following:

- Trace metal levels in the Sacramento and American Rivers near Sacramento comply with the proposed water quality standards contained in the California Toxics Rule issued by the US EPA on August 5, 1997.
- A correlation exists between river flows, suspended solid levels, and total recoverable metal concentrations in the Sacramento River, with higher concentrations occurring during the wet season (November through April) when river flow and suspended solid levels are highest. This finding supports the hypothesis that episodic high river flows are a primary mechanism of both sediment and trace element transport in the Sacramento River system
- Water quality in the American River, as measured by suspended solid concentrations, temperature, hardness, organic carbon, and trace metal levels, is typically better than in the Sacramento River.
- An analysis of trace element concentration changes in the Sacramento River indicate relatively minor increases in concentrations of specific trace elements downstream of the Sacramento metropolitan area.

Future Direction

The CMP Steering Committee annually reviews the program to examine the program direction and to make appropriate adjustments. The Steering Committee may increase the number and diversity of parameters monitored under the Ambient Program in the Sacramento and American Rivers in the future. The program may also be modified to include special river studies to examine water quality issues of particular local interest. Public outreach and education efforts will continue at the local level. The CMP monitoring effort will continue to be coordinated closely with the activities of the Sacramento River Watershed Program.

CHAPTER EIGHT

Conclusions

Conclusions

After four years of data collection (six years counting the BPTCP Pilot Studies) some patterns, trends, and associations are beginning to emerge from RMP data. In addition to the RMP Base Program results, knowledge from several Pilot and Special Studies, as well as some non-RMP studies together contribute to our understanding of contaminants and their potential effects in the Estuary. The discussions in the *Water, Sediment,* and *Bivalve Monitoring* chapters of this report summarize much of that information. This discussion uses the information in those chapters to make conclusions about contaminants and sites of concern, concordance in contaminant trends in water, sediment, and tissues, and, finally, it summarizes some of the recommendations from the RMP Program Review conducted in 1997 and their implications for data interpretation.

Contaminants and Sites of Concern

The identification of contaminants and sites of concern may be facilitated by evaluating RMP data in two ways:

1) Based on the frequency of exceedances of appropriate guidelines for water, sediment, and tissues by each contaminant measured. Such an evaluation assumes that the guidelines are protective of aquatic life and/or human health and that exceedances indicate an increased potential for effects.
2) Evidence from RMP aquatic and sediment bioassays. That assessment is based on knowledge synthesized to date from RMP analyses (see articles by Ogle and Gunther in *Chapter Two: Water Monitoring,* Thompson, Anderson *et al.* and Phillips *et al.* in *Chapter Three: Sediment Monitoring*).

Table 1. Percentages of 1996 samples of water, sediment, and bivalve tissues that exceeded appropriate guidelines. Data compiled from Table 8 in Chapter Two, Table 15 in Chapter Three, and Table 7 in Chapter Four. - = no consistent guidelines.

	Water		Sediment	Bivalve Tissue
	Dissolved	Total		
As	0	0	79	-
Ag	0	0	2	-
Cd	0	0	0	-
Cr	0	15	83	-
Cu	13	37	65	-
Hg	0	19	81	0
Ni	3	22	100	0
Pb	0	6	6	-
Se	0	0	0[3]	-
Zn		0	13	-
∑PCBs		93	6	100*
∑PAHs		0	38[2]	100*
Chlordanes		12	31[1]	89*
Dieldrin		8	68	78*
P,P'-DDE		16	71	15
Chlorpyrifos		4	-	-
Diazinon		16[4]	-	-

[1] Long & Morgan, 1990
[2] as HPAHs
[3] Taylor *et al.,* 1992
[4] NAS guideline = 9,000 ng/L
* Some of the T-0 samples were also above the MTRL.

Contaminants of Concern

In water, total PCBs and dissolved and near-total Cu had the greatest number of exceedances of guidelines (Table 1). Since 1993, total PCBs in water have exceeded the EPA criterion in nearly all samples collected. PCB was also the contaminant most frequently elevated in fish tissue samples collected in 1994 (SFBRWQCB, 1995). PCBs in water are believed to be derived primarily from reservoirs of historically deposited PCBs in sediments of the Estuary and soils of the Estuary's watershed.

The organophosphate pesticides, diazinon and chlorpyrifos, are considered to be contaminants of concern by their association with aquatic toxicity (e.g. Kuivila and Foe, 1995). Although those pesticides had relatively low frequencies of exceedances in 1996 (Table 1), seasonal pulses from the Central Valley, and in the Guadalupe River may have been responsible for the aquatic toxicity observed (Figure 36 in *Chapter Two: Water Monitoring;* see article by Ogle and Gunther).

Nickel in sediments exceeded NOAA's sediment quality guidelines (ERM, see Sediment Quality Guidelines in *Chapter Three: Sediment Monitoring*) at all sites. Chromium, As, Hg, total DDTs, and dieldrin also frequently exceeded the ERLs (Table 1). Based on an analysis of relationships between sediment toxicity test results and sediment chemistry, the additive influence of numerous sediment contaminants was highly associated with amphipod toxicity in the Bay. At several sites elevated chlordane concentrations were associated with toxicity, as were low, and high molecular weight PAHs at other sites (see article by Thompson, Anderson *et al.* in *Chapter Three: Sediment Monitoring*) Dissolved trace metals in sediment elutriates at the River stations and Grizzly Bay were associated with bivalve larval toxicity through toxicity identification evaluations (TIEs) conducted at the Rivers confluence and Grizzly Bay sites (see article by Phillips *et al* . in *Chapter Three: Sediment Monitoring*).

No scientifically based tissue guidelines covering both trace elements and trace organics are available for the bivalve bioaccumulation data (see *Bivalve Monitoring Discussion*). However, most major classes of trace organic contaminants in bivalve tissues were above the maximum tissue residue levels (MTRLs); PCBs and PAHs were above MTRLs in all 1996 tissue samples (Table 7 in *Chapter Four: Bivalve Monitoring*). Concentrations of Ag, Hg, Pb, and chlordane were shown to be decreasing in tissues over long time periods (see article by Gunther and Davis in *Chapter Four: Bivalve Monitoring*).

In fish, PCB, dioxin, Hg, dieldrin, DDT, and chlordane concentrations have been shown to exceed EPA screening values for human consumption (SFBRWQCB, 1995). Except for dioxins (not measured in RMP), those are the same organic contaminants that exceed the MTRL guidelines in bivalve tissues measured by the RMP.

In related studies, the USGS has shown that bioaccumulation of cadmium by the Asian clam *Potamocorbula* was related to decreased biological condition and asynchronous spawning (J. Thompson *et al.*, 1996). Bioaccumulation of Se by *Potamocorbula* is believed to be related to increases in Se in sturgeon tissues, approaching concentrations of concern (S. Luoma, pers. comm.). DDTs caused severe sediment toxicity and altered the benthos at the superfund site in Richmond Harbor (Swartz *et al.*, 1994).

It is reasonable to consider the contaminants of most concern to be those actually shown to be related to bioaccumulation or effects. Those contaminants include diazinon and chlorpyrifos in water, DDTs, chlordanes, and PAHs in sediments, and PCBs, Cd, Hg, Se, PAHs, chlordanes, dieldrin, and DDTs in bivalve and fish tissue. Although Cu and Ni are of current regulatory interest, there is no conclusive evidence of biological effects from exposures to those contaminants in the Estuary. Several other trace metals (As, Ag, Pb, Zn) are usually below guidelines and/or have shown no evidence of bioaccumulation or association with biological effects in the Estuary. However, as suggested for sediments, all contaminants may contribute to effects cumulatively.

Sites of Concern

Comparisons of exceedances of guidelines and incidences of toxicity among sites are difficult since not all measurements are made at all sites. Using the information available, in general, sites in the far South Bay and Southern Sloughs (BA10, C-3-0, C-1-3) had more exceedances of water and sediment guidelines than other locations in the Bay. Concentration gradients of many contaminants were apparent

in this report (see Figures 4–35 in *Chapter Two: Water Monitoring,* and Figures 1–15 in *Chapter Three: Sediment Monitoring*). San Jose (C-3-0) had the highest number of water quality exceedances and the highest mean ERM quotient (see *Sediment Monitoring Discussion*) of any site sampled. Additionally, the Watershed Pilot Study samples from Standish Dam (head of tide) in Coyote Creek often had higher concentrations than any of the RMP Base Program sites (see article by Hoenicke and Daum in *Chapter Six: Pilot and Special Studies*).

Although there have been no indications of aquatic toxicity in the South Bay since monitoring began in 1993, Pilot Studies of episodic aquatic toxicity reported some toxicity associated with runoff in Guadalupe Slough (see article by Ogle and Gunther in *Chapter Two: Water Monitoring*). Redwood Creek (BA40) had the highest incidence of sediment toxicity to amphipods over the past 6 years (90% of tests) of any site in the Estuary.

These results underscore the importance of several non-RMP activities currently being conducted in the South Bay. The City of San Jose will be developing estimates of Total Maximum Daily Loads (TMDL) for copper and nickel that will attempt to model and calculate contributions of those elements from various sources in the South Bay. That exercise should help us to understand contributions of other contaminants as well. The Regional Board and South Bay stakeholders are collaborating on a Watershed Management Initiative in the South Bay that is examining new ways to manage contaminant inputs and restore impaired biological resources.

In the Northern Estuary, the Petaluma River (BD15) had numerous exceedances of water guidelines (Tables 8 and 9 in *Chapter Two: Water Monitoring*). San Pablo Bay (BD20) had the largest number of sediment contaminants above ERLs in August, largely due to elevated concentrations of several individual PAH compounds (Table 15 in *Chapter Three: Sediment Monitoring*). Sites at San Joaquin River (BG30), Davis Point (BD40), and San Pablo (BD20) had the highest number of tissue organics that exceeded the MTRL guidelines (Table 7 in *Chapter Four: Bivalve Monitoring*).

Sediment samples from wetland channels in China Camp State Park and Petaluma Marsh generally were more contaminated than samples from the adjacent San Pablo Bay (see article by Collins and May in *Chapter Six: Pilot and Special Studies*). Benthic indicators from the China Camp samples suggested some degree of degradation of the benthos in the marsh.

The Sacramento and San Joaquin River (BG20, BG30) and Grizzly Bay (BF20) sites had the highest incidences of water toxicity to mysids (39% of tests) between 1994–1996. As noted above, because of the timing and location of those "hits", the cause of that toxicity is believed to be the pesticides diazinon and chlorpyrifos, but further investigation is needed. However, there has been no toxicity of water samples to bivalve larvae at those sites. Interestingly, the same sites have shown the highest incidence of toxicity from sediment elutriates to bivalve larvae (100% of tests). As noted above, preliminary TIEs conducted on the elutriates have suggested that dissolved metals in the sediments may be the cause of toxicity. Those same sites also had the greatest degree of trace organics bioaccumulation. Toxicity of bulk sediments to *Eohaustorius* amphipods occurred in about half the tests conducted since 1991 at Napa River and Grizzly Bay, and in only about 10–20 % of tests at the Sacramento and San Joaquin River sites.

The above summary suggests that the sites at opposite ends of the Estuary, those at the mouth of Coyote Creek in the South Bay, and sites at the Rivers confluence and Suisun Bay in the Northern Estuary, are more impacted by contaminants than the other RMP sites. Both locations are at the bayward ends of major tributaries where contamination might be expected to accumulate. Generally, the Central Bay has the fewest exceedances of guidelines and the lowest incidence of toxicity of all Bay sites, probably due to the regular tidal flushing

and greater water depths resulting in lower suspended sediment contaminants.

The sites monitored by the RMP are intended to provide information on background, or ambient Bay conditions, not a comprehensive assessment of entire Bay. Other locations in the Bay that are not sampled by the RMP, particularly areas along the Estuary margins near some of the major harbors, closed military bases, and Superfund sites may be quite contaminated.

Trends in Contamination

Spatial and temporal trends have been noted in this report for each of the media sampled by the RMP. In water, examination of dissolved contaminant data revealed strong spatial gradients of contamination in the Estuary, with as much as a 50-fold difference between the stations with the highest and lowest concentrations. Spatial gradients have been consistently observed over the course of the RMP for most contaminants. Clear, consistent seasonal variation has also been evident for dissolved concentrations of many contaminants. These patterns are apparent in the dissolved data because concentrations in the dissolved fraction are relatively independent of other exogenous variables whose fluctuations might obscure the patterns. In sediment, spatial gradients and longer-term changes between 1991–1996 were indicated by the raw data, but consistent seasonal variation has not been observed. In bivalves, the utility of the data for detecting spatial gradients is limited by the widely varying salinities of the Estuary and the restricted salinity tolerance of the three species employed, but some seasonal and long-term temporal trends have been observed.

A qualitative comparison of the trends observed in the three datasets (dissolved water, sediment, and bivalve) reveals little consistency among the three media. The strong spatial gradients in water were generally not mirrored by spatial variation in sediment concentrations. The exceptions to this were concentrations of PCB, DDT, and chlordane, which had similar profiles in water and sediment, dominated by relatively high concentrations at San Jose (C-3-0). These data clearly indicate a source or sources of these compounds in this portion of the Estuary. Only two trace elements (nickel and silver) showed spatial variation that was roughly similar in both water and sediment.

Seasonal trends were obvious in the water data, and in one case (silver) the bivalve data indicated a similar increase in the dry season as observed in water. Long-term trends were indicated by an analysis of bivalve data collected from 1980–1996 under the State Mussel Watch Program and the RMP (Gunther and Davis, this report) and from graphical analysis of the sediment data. In one case (chlordane) long-term declines in bivalves are consistent with declines noted since 1994 in sediment.

More consistency in the spatial and temporal trends observed in each matrix would probably be revealed by a more thorough analysis in which the influence of important exogenous variables is accounted for and filtered out statistically. In sediment, the measured concentrations are a function of sediment grain size, organic content, and depositional characteristics. In bivalves, lipid content is a critical factor controlling accumulation of organic contaminants. An accurate assessment of trends in contamination in the Estuary must take these influential exogenous variables into consideration. Characterizing their influence would not only aid trend analysis and comparison of different sampling matrices, but would also provide information that would lead to a better understanding of the mechanisms by which contaminants cycle through the water, sediment, and biota of the Estuary.

RMP Program Review

Although, this report has primarily described the findings from monitoring in 1996, at the time of printing (December 1997), the RMP has completed its fifth year. At this time, the RMP Steering Committee, Regional Board staff, and SFEI staff are deliberating how to implement the recommendations of the Program Review, many of which will have strong

bearing on how data will be presented, interpreted, and used. Key examples of recommendations affecting data interpretation and information integration are:

- Refine and focus the list of current objectives and management questions.
- Document the aims of the RMP.
- Apply a greater degree of interpretation to the data being collected, as well as a more thorough integration into the RMP of the results from other monitoring and research programs in the Bay Area, both past and present.
- Assess source categories and develop a mass balance inventory for the Estuary.

Up to this point, RMP results have been presented mostly in descriptive form, reflective of the current, fairly non-specific objective statements (see *Chapter One: Introduction*). The growing database is making it easier to draw inferences and conduct focused descriptive analyses that could reveal or suggest patterns obscured by simple compilation and description of unsummarized data. In addition, the Steering Committee is in the process of developing clearly defined, specific questions that will improve the way "...monitoring and other scientific data can direct, set limits on, or otherwise inform management decision-making" (Boesch *et al.*, 1997). This report marks the transition between simple, descriptive data summaries and providing the synthesis and context that make the data more useful for water quality managers. Where inferences and data summaries were appropriate, they were included, such as in the review of bioaccumulation data by Gunther and Davis in *Chapter Four: Bivalve Monitoring* and the relationship between sediment contamination and toxicity by Thompson *et al.* in *Chapter Three: Sediment Monitoring*. These report articles integrate RMP data from different program components as well as from data derived from other monitoring efforts and scientific studies. In the *Watershed Pilot Study (Chapter Six: Pilot and Special Studies)* an alternative data display was explored using geographically-based presentation of contaminant concentrations and data summaries by Estuary reach. This is an example of the attempt to facilitate recognition of patterns and to enhance the usefulness of the report. The RMP Steering Committee discussions about data interpretation are not yet final. Although the Steering Committee has not decided which recommendations to implement and in what time frame at this time, it has agreed that the re-evaluation of the RMP objectives and development and prioritization of specific management questions based on those objectives is a high priority. Once this re-evaluation is completed, the planning phase for each monitoring year will contain the development of a data interpretation plan that will closely link monitoring data to management questions. The interpretation plan will also identify information audiences an appropriate display tools for each in order to enhance the users' ability to comprehend and effectively utilize RMP results.

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REGIONAL MONITORING PROGRAM

Statement of Income and Expense
for Twelve-Month Period Ending December 31, 1996

Income:

Participant Fees:		
Municipal Dischargers	$ 1,007,600.00	
Industrial Dischargers	$ 251,900.00	
Cooling Water Dischargers	$ 91,600.00	
Stormwater Dischargers	$ 538,150.00	
Dredged Material Dischargers	$ 150,950.00	
Additional Sampling Assistance	$ 62,787.00	
Matching Funds	$ 33,378.00	
In-Kind Fees	$ 332,600.00	
Interest	$ 83,140.00	
	Total Income	**$ 2,552,105.00**

Expense:

Program Management	$ 186,108.00	
Quality Assurance/Quality Control	$ 73,155.00	
Public Information	$ 38,714.00	
Data Management	$ 134,674.00	
Annual Report	$ 202,568.00	
Five Year Review Preparation	$ 9,977.00	
Monitoring Program	$ 1,545,778.00	
Pilot Studies	$ 131,179.00	
Special Studies	$ 98,667.00	
US Navy Cash Deficit	$ 27,600.00	
	Total Expense	**$ 2,448,420.00**
Net Gain (Loss)		**$ 103,685.00**

Notes: This statement is unaudited and approximate. SFEI's audited financial statement is available upon request. SFEI has a July 1–June 30 fiscal year, therefore, amounts in the official audit will not correspond directly to the amounts shown here. Much of SFEI's work on the Annual Report was done during the 1997 calendar year, therefore, the final cost of the Annual Report is not reflected in these figures.

Appendices

Table of Contents

Appendix A
Description of Methods

Water Sampling

One of the objectives of the RMP is to evaluate if water quality objectives are met at the sampled stations. Therefore, the sampling and analysis methods have to be able to detect substances below these levels. In order to attain the low detection levels used in the RMP (see *Appendix B*), ultra-clean sampling methods were used in all sampling procedures (Flegal and Stukas, 1987; EPA Method 1669, 1995).

Water samples were collected approximately one meter below the water surface using peristaltic pumps. The sampling ports for both the organic chemistry 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. Total (or near-total) and dissolved fractions of Estuary water were measured for trace elements. Particulate and dissolved fractions were measured for trace organics, and totals were calculated.

The RMP used the 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 began to phase in a new, modified, commercially available XAD resin extraction sampler in 1996, beginning with side-by-side comparisons of both sampling systems. Results for 1996 trace organic contaminants in water are still based on the foam-plug sampler, whose operation is described in the Methods sections of previous Annual Reports (SFEI, 1994; 1995; 1996).

XAD resins have been used throughout the world to measure synthetic organic contaminants in both water and air (Infante *et al.,* 1993). The custom-manufactured AXYS system (AXYS Environmental Systems, Ltd., Sidney, B.C.) consists of a constant-flow, gear-driven positive displacement pump, $^1/_2$ inch Teflon® tubing, 1 µm glass fiber particulate filter enclosed in a cartridge, and two parallel Teflon® columns filled with XAD-2 resin with a particle size range of 300–900 µm. The flow rate was approximately 1.5 liters per minute. The intercomparison results between the foam-plug and resin samplers will be described in detail in the *1997 Annual Report*.

For trace metals, water samples were collected using a peristaltic pump system equipped with C-Flex tubing in the pump head. Sample aliquoting was conducted on deck on the windward side of the ship to minimize contamination from shipboard sources (Flegal and Stukas, 1987). Filtered 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. Unfiltered water samples were pumped directly into acid-cleaned containers. Prior to collecting water, several liters of water were pumped through the system, and sample bottles were rinsed five times 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 laboratory, except for chromium samples, which were acidified and extracted within an hour of collection.

Samples for conventional water quality parameters were collected using the same apparatus as for trace metals; however, containers were only rinsed three times, and the "clean hands" procedure was not necessary.

Water samples were collected for toxicity tests using the same pumping apparatus as for the collection of the trace organic samples, but were not filtered. Five gallons of water were collected and placed in ice chests for transfer at the end of each cruise day to the testing labora-

tory. Two field blanks were collected each cruise by filtering (0.45 μm) water from the Bodega Marine Laboratory known to be non-toxic.

Sediment Sampling

Sediment sampling was conducted using a 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 achieve chemical inertness. All scoops, buckets, and stirrers used to collect and homogenize sediments were also constructed of Teflon® or stainless steel coated with Dykon®. Sediment sampling equipment was thoroughly cleaned prior to each sampling event.

A sub-core of sediment was removed for measurement of porewater ammonia. Then, the top 5 cm of sediment were scooped from each of two replicate grabs and mixed in a bucket to provide a single composite sample for each station. Aliquots were split on board for each analytical laboratory, for archive samples and for sediment toxicity tests. The quality of grab samples was ensured by requiring each sample to satisfy criteria concerning depth of penetration and disturbance of the sediment within the grab (see the *1996 Quality Assurance Project Plan* available from SFEI).

Bivalve Bioaccumulation Sampling

Bivalves were collected from uncontaminated sites and transplanted to fifteen stations in the Estuary during the wet season (February through May) and the dry season (June through September). Contaminant concentrations in the animals' tissues and the animals' biological condition (expressed as the ratio of dry weight and shell cavity volume) were measured before deployment (referred to as time zero or background samples) and at the end of the 90–100 day deployment period. Since the RMP sites encompass a range of salinities, three species of bivalves were used, according to the expected salinities in each area and the known tolerances of the organisms. The mussel *Mytilus californianus* was collected from Bodega Head and stored in running seawater at the Bodega Marine Laboratory until deployment at the stations west of Carquinez Strait, which were expected to have the highest salinities. *Mytilus californianus* will survive exposure to salinities as low as 5 ppt (Bayne, 1976). Oysters (*Crassostrea gigas*) were obtained from Tomales Bay Oyster Company (Marshall, California) and deployed at moderate-salinity sites closest to Carquinez Strait and in the extreme South Bay. *Crassostrea gigas* tolerates salinities as low as 2 ppt. The freshwater clam *Corbicula fluminea* was collected from Putah Creek, moved to UC Davis for depuration, and deployed at sites with the lowest salinities. *Corbicula fluminea* tolerates salinities from 0 ppt to perhaps 10 ppt (Foe and Knight, 1986). The effects of high, short-term flows of freshwater on the transplanted bivalves west of Carquinez Strait were minimized by deploying the bivalves near the bottom where density gradients tend to maintain higher salinities. All bivalves were kept on ice after collection and deployed within 24–48 hours.

Because of the unavailability of clams at Lake Isabella, the RMP's traditional reference site, clams were collected from Putah Creek, conditioned at a pond and fed by Davis well water. Survival during deployment was also measured. Composites of tissue were made from 40–60 individual bivalves from each site before and after deployment for analyses of trace contaminants.

Within each species, animals of approximately the same size were used. Mussels were between 49–81 mm shell length, oysters were between 71–149 mm, and clams were 25–36 mm. One hundred and fifty oysters and 160 mussels and clams were randomly allocated for deployment at the appropriate sites, with the same number being used as travel blank (time zero) samples for analysis of tissue and condition before deployment. At each site, oysters were divided among five nylon mesh bags, and mussels and clams were divided among four nylon mesh bags.

Moorings were associated with pilings or other permanent structures. Mooring installation, bivalve deployment, maintenance, and retrieval were all accomplished by SCUBA divers. The deployed samples were checked approximately half-way through the 90-day deployment period to ensure consistent exposure. Moorings and nylon bags were checked for damage and repaired, and fouling organisms were removed.

Upon retrieval, the bags of bivalves were placed into polyethylene bags and taken to the surface. On the vessel, the number of dead organisms was noted, with 20 percent of the live organisms being allocated for condition measurement, and the remainder being 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, gonads were removed, and remaining tissue was rinsed with ultrapure water and placed in an acid cleaned, plastic-coated, glass jar. 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 gonads were removed from organisms for trace metal analyses. Stephenson (1992) found that, with the exception of lead and selenium, no significant differences were found 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 contaminant concentration.

Analytical Methods

Conventional Water Quality Parameters

Samples for dissolved nutrients were analyzed using the Lachat QuikChem 800 System Nutrient Autoanalyzer (Ranger and Diamond, Lachat Instruments, 1994). The QuickChem methods used were: 31-114-27-1 for silicates, 31-107-06-1 for ammonia, 31-107-04-1 for nitrate/nitrite, and 31-115-01-3 for phosphate. 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 multifunctional 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) was determined using method 2540D in Standard Methods for the Examination of Water and Wastewater (Greenberg *et al.,* 1992)

A Sea-Bird SBE19 Conductivity, Temperature, and Depth probe (CTD) was used to measure water quality parameters at depths throughout the water column. CTD casts were taken at each site during water and sediment sampling. 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. The CTD was then lowered to the bottom at approximately 0.15 meters per second, and raised. Only data from the down-cast were kept. Data were downloaded onboard the ship, and processed in the laboratory using software supplied by Sea-Bird.

The CTD measures temperature, conductivity, pressure, dissolved oxygen, and backscatter at a sampling rate of two scans per second. These data were edited and averaged into 0.25 m depth bins during processing. Also during processing, salinity (based on conductivity measurements), oxygen, time, and depth (based on pressure) were calculated. Although the CTD data are not detailed in this report, SFEI maintains these data in its database.

Trace Elements

In water, total and dissolved (0.45 µm filtered) concentrations of mercury, arsenic, selenium, chromium, copper, nickel, lead, silver, and zinc were measured. Mercury, arsenic, and selenium samples were obtained from the same field sample. The mercury sub-samples were photo-oxidated with the addition of bromium chloride, and quantified using a cold-vapor atomic fluorescence technique. Arsenic and selenium were analyzed by hydride-generation atomic absorption with cryogenic trap preconcentration based on a method described in Liang *et al.* (1994) and Cercelius *et al.* (1986).

The chromium samples were collected separately. The suspended particulates underwent hydrofluoric acid digestion, and the dissolved chromium was co-preciptated with a ferrous hydroxide scavenger (Cranston and Murray, 1978). Chromium was quantified by graphite furnace atomic absorption spectrometry (GFAAS).

The remaining trace elements in water were measured using the APDC/DDDC organic extraction and preconcentration method (Bruland *et al.,* 1985; Flegal *et al.,* 1991) and then quantified by GFAAS.

Results for cadmium, chromium, copper, nickel, lead, silver, and zinc were reported by the laboratory in weight/weight units (µg/kg). For use in this report, those values are reported as µg/L, without taking account of the difference in density between Estuary water and distilled water. This difference was not taken into account because it was much less than the precision of the data, which was on the order of 10%. In some instances, dissolved metal concentrations are reported as higher than total (dissolved + particulate) metal concentrations. This is due to expected analytical variation in the methods of analysis, particularly at concentrations near the detection limits. Such results should be interpreted as no difference between dissolved and total concentrations, or that the total fraction of metals is in the dissolved phase.

Sediments were digested with *aqua regia* to obtain "near-total" concentrations of aluminum, silver, cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc (Flegal *et al.,* 1981). The metals were quantified by inductively coupled plasma atomic emission spectrometry (ICP-AES) or by inductively coupled plasma mass spectrometry (ICP-MS). The method chosen for RMP sediment analysis is comparable to standard EPA procedures (Tetra Tech, 1986) but does not decompose the silicate matrix of the sediment. Because of this, any element tightly bound as a naturally occurring silicate may not be fully recovered.

Bivalve tissue samples were digested with *aqua regia* to obtain near-total concentrations of trace elements similar to techniques used in the California State Mussel Watch Program (e.g., Flegal *et al.,* 1981; Smith *et al.,* 1986) and consistent with the RMP Pilot Program (Stephenson, 1992). The trace metals were quantified on ICP-AES or ICP-MS. Hydride generation coupled with atomic absorption spectroscopy was used to quantify arsenic. Mercury was quantified using a cold-vapor atomic fluorescence technique, and selenium was quantified using the methods of Cutter (1986). Butyltins were measured following NOAA Status and Trends Mussel Watch Project methods described in NOAA Technical Memorandum NOS/ORCA/CMBAD71 vol. IV. This technique involves extracting the sample with hexane and the chelating agent tropolone and measuring the butyltin residues by capillary gas chromatography. Concentrations are expressed in total tin per gram of tissue dry weight.

Trace Organics

For water samples, the foam plugs and filters containing the particulate fraction were spiked with extraction surrogates. ECD surrogates consisted of PCB 103 and PCB 207 for the first fraction, and Pentachloronitorobenzene for Fractions 2 and 3. The MSD surrogate consisted of deutereated acenaphthalene. The foam plugs were eluted using the methods described in previous Annual Reports. The XAD columns

used in the intercomparison tests were eluted in reverse with methanol and methylene chloride in a method similar to the filter cartridges. The separate extracts were then combined and separated into three fractions. Extraction methods were based upon standard EPA and AXYS extraction protocols.

The extracts were subjected to Florisil column chromatography resulting in three fractions, a PCB/aliphatic, a pesticide/aromatic fraction, and a polar third fraction, which contains diazinon and other polar pesticides. Chlorinated hydrocarbons (CH) were analyzed on a Hewlett Packard 6890 capillary gas chromatograph utilizing electron capture detectors (GC/ECD). The quantitation internal standards utilized for the CH analysis were dibromo-octafluorobiphenyl (DOB) for Fractions 1 and 3, and DOB or PCB 209 for Fraction 2. Analyte concentrations were corrected for surrogate losses prior to reporting. PAHs were quantified in the F-2 fraction by analysis on a Hewlett-Packard 6890 capillary gas chromatograph equipped with a 5971A mass spectral detector (GC/MS). A 2 μL splitless injection was chromatographed on a DB-5 column and analyzed in a single ion monitoring (SIM) mode. The quantitation internal standard utilized for the PAH analysis when samples were at 100 μL was hexamethyl benzene (HMB). DOB was used as an internal standard for diazinon.

Sediment samples were analyzed based on the methods followed by NOAA's Status and Trends Program. Samples were freeze-dried, mixed with kiln-fired sodium sulfate, and soxhlet-extracted with methylene chloride. Surrogate standards were added prior to extraction to account for methodological analyte losses. ECD surrogates consisted of PCB 103 and PCB 198. The extract was concentrated and purified using EPA Method 3611 alumina column purification to remove matrix interferences. Tissue samples were homogenized and macerated, and the eluate was dried with sodium sulfate, concentrated, and purified using a combination of EPA Method 3611 alumina column purification and EPA Method 3630 silica gel purification to remove matrix interferences. PAHs and their alkylated homologues in both sediment and tissue extracts were quantified by gas chromatography mass spectrometry (GC/MS) in the selected ion monitoring mode (SIM) with a temperature-programmable gas chromatograph with a 30-m long 0.32-mm internal diameter fused silica capillary column with DB-5MS bonded phase. Surrogates for PAHs consisted of naphthalene-d8, acenaphthene-d10, phenanthrene-d10, chrysene-d12, and perylene-d12. Chlorinated hydrocarbons are quantified in both sediment and tissue extracts via high-resolution capillary gas chromoatorgraphy using electron-capture detection (GC/ECD). For the first time in 1996, dual-column confirmation on 30-m long, 0.25-mm internal diameter fused silica capillary columns with DB-5 and DB-17 bonded phase, was conducted. Data from the two columns were combined by SFEI to generate the values listed in the Annual Report. Some analytes included in the 1996 analyte list coeluted on both columns and could not be reported as single congeners.

Aquatic Bioassays

Water column toxicity was evaluated using a 48-hour bivalve embryo development test and a seven-day growth test using the estuarine mysid *Mysidopsis bahia.* The bivalve embryo development test was performed according to ASTM standard method E 724-89 (ASTM, 1991). The mysid test was based on EPA test method 1007. Larval *Mytilus* sp. were used in both sampling periods. The mysid growth and survival test consisted of an exposure of 7-day old *Mysidopsis bahia* juveniles to different concentrations of Estuary water in a static system during the period of egg development and was used during both sampling periods. Appropriate salinity adjustments were made for Estuary water from sampling stations with salinities below the test species' optimal ranges. Reference toxicant tests with copper chloride and potassium dichromate were

performed for the bivalve and mysid tests, respectively. These tests were used to determine if the responses of the test organisms were relatively consistent over time.

The salinities of the ambient samples and the control/diluent (Evian spring water) were adjusted to 5 ppt using artificial sea-salts (Tropic Marin). The test concentrations were 100%, 50%, and control, each with eight replicates, and with 20 larvae per replicate. Waste, dead larvae, excess food, and 80% of the test water were siphoned from the test chambers daily, and general water chemistry parameters of dissolved oxygen, pH, and salinity were recorded before and after each water change.

Sediment Quality Characteristics

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 Coulometrics CM 150 Analyzer made by UIC, Inc. This method involves measurements of transmitted light through a cell. The amount of transmitted light is related to the amount of carbon dioxide evolved from a combusted sample. Spectrophotometric analyses of sulfides in sediment porewater were performed using a method adapted from Fonselius (1985) with variations from Standard Methods (APHA, 1985).

Sediment Bioassays

Two sediment bioassays were used: a ten-day acute mortality test using the estuarine amphipod *Eohaustorius estuarius* exposed to whole sediment using American Society for Testing and Materials (ASTM) method E 1367 (ASTM, 1992), and a sediment elutriate test where larval bivalves were exposed to the material dissolved from whole sediment in a water extract using ASTM method E 724-89 (ASTM, 1991). Elutriate solutions were prepared by adding 100 g of sediment to 400 ml of Granite Canyon seawater, shaken for 10 seconds, allowed to settle for 24 hours, and carefully decanted (EPA and COE, 1977; Tetra Tech, 1986). Larval mussels (*Mytilus* sp.) were used in both sampling periods, where percent normally developed larvae was measured.

Bivalve Condition and Survival

The condition of bivalves is a measure of their general health following exposure to Estuary water for 90–100 days. Measurements were made on subsamples of specimens before deployment and on the deployed specimens following exposure. Dry weight (without the shell) and the volume of the shell cavity of each bivalve was measured. Bivalve tissue was removed from the specimens and dried at 60° C in an oven for 48 hours before weighing. Shell cavity volume was calculated by subtracting shell volume of water displaced by a whole live bivalve less the volume of water displaced by the shell alone. The condition index is calculated by taking the ratio of tissue dry weight and the shell cavity volume.

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Appendix B
Quality Assurance Tables

The following section contains summaries of quality assurance (QA) information for the 1996 Regional Monitoring Program (RMP). In addition to the QA review in Chapter Five of this report, a description of the RMP's quality assurance program can be found in the *1996 Quality Assurance Program Plan* available from the San Francisco Estuary Institute.

Table 1. Quality assurance and control summary for laboratory analyses of water.
Cruise 10: February 96, Cruise 11: April 96, and Cruise 12: August 96

Analysis type: water trace elements, dissolved

Cruise #	Parameter	Units	MDL Target	MDL Measured	Precision Target (+/- %)	Precision Measured (rsd)[1]	Accuracy Target (+/- %)	Accuracy Measured (+/- %)	No. Blanks/Batch
10	Ag	µg/L	0.0003	0.0001	15	7	25	NA[2]	12/24
10	As	µg/L	0.002	0.054	25	2	25	10	2/20
10	Cd	µg/L	0.0003	0.0000	15	2	25	5	12/24
10	Cr	µg/L	0.0250	0.0361	15	7	25	21	8/24
10	Cu	µg/L	0.0058	0.0021	15	3	25	7	12/24
10	Hg	µg/L	0.0001	0.0001	25	8	25	8	2/20
10	Ni	µg/L	0.0054	0.0016	15	2	25	1	12/24
10	Pb	µg/L	0.0028	0.0004	15	5	25	30	10/24
10	Se	µg/L	0.005	0.005	35	9	35	7	2/20
10	Zn	µg/L	0.0008	0.0014	15	5	25	9	12/24
11	Ag	µg/L	0.0003	0.0002	15	4	25	NA[2]	12/24
11	As	µg/L	0.002	0.059	25	5	25	8	2/20
11	Cd	µg/L	0.0003	0.0000	15	4	25	7	12/24
11	Cr	µg/L	0.0250	0.0100	15	9	40	1	7/24
11	Cu	µg/L	0.0054	0.0025	15	3	25	6	12/24
11	Hg	µg/L	0.0001	0.0001	25	7	25	8	2/20
11	Ni	µg/L	0.0000	0.0012	15	1	25	3	12/24
11	Pb	µg/L	0.0028	0.0001	15	4	25	25	12/24
11	Se	µg/L	0.005	0.012	35	8	35	8	2/20
11	Zn	µg/L	0.0008	0.0011	15	4	25	19	12/24
12	Ag	µg/L	0.0003	0.0003	15	4	25	NA[2]	12/24
12	As	µg/L	0.002	0.100	25	7	25	9	2/20
12	Cd	µg/L	0.0003	0.0001	15	2	25	9	12/24
12	Cr	µg/L	0.0250	0.0200	15	8	40	21	4/24
12	Cu	µg/L	0.0058	0.0022	15	3	25	1	12/24
12	Hg	µg/L	0.0001	0.0001	25	6	25	5	2/20
12	Ni	µg/L	0.0054	0.0045	15	3	25	6	12/24
12	Pb	µg/L	0.0028	0.0001	15	2	25	3	12/24
12	Se	µg/L	0.005	0.019	35	14	35	6	2/20
12	Zn	µg/L	0.0008	0.0030	15	8	25	9	12/24

[1] relative standard deviation

[2] There are no SRM certified values for silver.

Table 1 (continued).

Analysis type: water trace elements, total									
Cruise #	Parameter	Units	MDL Target	MDL Measured	Precision Target (+/- %)	Precision Measured (rsd)[1]	Accuracy Target (+/- %)	Accuracy Measured (+/- %)	No. Blanks/Batch
10	Ag	µg/L	0.0016	0.0003	15	17	25	NA[2]	24/24
10	As	µg/L	0.0020	0.0540	25	2	25	10	2/20
10	Cd	µg/L	0.0004	0.0004	15	11	25	2	24/24
10	Cr	µg/L	0.3530	0.1070	15	4	40	41	7/24
10	Cu	µg/L	0.0066	0.0270	15	5	25	8	24/24
10	Hg	µg/L	0.0001	0.0001	25	8	25	8	2/20
10	Ni	µg/L	0.0095	0.0199	15	4	25	0	24/24
10	Pb	µg/L	0.0050	0.0034	15	19	25	4	24/24
10	Se	µg/L	0.0050	0.0050	35	9	35	7	2/20
10	Zn	µg/L	0.0074	0.0050	15	9	25	17	23/24
11	Ag	µg/L	0.0012	0.0021	15	34	25	NA[2]	24/24
11	As	µg/L	0.0020	0.0590	25	5	25	8	2/20
11	Cd	µg/L	0.0004	0.0023	15	10	25	2	24/24
11	Cr	µg/L	0.3530	0.0100	15	14	40	21	4/24
11	Cu	µg/L	0.0066	0.0079	15	5	25	4	24/24
11	Hg	µg/L	0.0001	0.0001	25	7	25	8	2/20
11	Ni	µg/L	0.0095	0.0132	15	4	25	7	24/24
11	Pb	µg/L	0.0050	0.0013	15	34	33	1	8/24
11	Se	µg/L	0.0050	0.0190	35	8	35	8	2/20
11	Zn	µg/L	0.0074	0.0164	15	7	25	2	24/24
12	Ag	µg/L	0.0012	0.0004	15	12	25	NA[2]	22/24
12	As	µg/L	0.0020	0.1000	25	7	25	9	2/20
12	Cd	µg/L	0.0004	0.0001	15	4	25	8	24/24
12	Cr	µg/L	0.3530	0.1100	15	10	40	26	2/20
12	Cu	µg/L	0.0066	0.0170	15	2	25	3	24/24
12	Hg	µg/L	0.0001	0.0001	25	6	25	5	2/20
12	Ni	µg/L	0.0095	0.0078	15	11	25	17	24/24
12	Pb	µg/L	0.0050	0.0051	15	8	25	3	24/24
12	Se	µg/L	0.0050	0.0010	35	30	33	3	24/24
12	Zn	µg/L	0.0074	0.0075	15	4	25	10	24/24

[1] relative standard deviation

[2] There are no SRM certified values for silver.

Table 2. Quality assurance and control summary for laboratory analyses of water. Cruise 10: February 96, Cruise 11: April 96, and Cruise 12: August 96

Analysis type: water trace organics, dissolved & particulate (Total values are calculated as the sum of dissolved and particulate data.)							
Cruise #	Parameter	Units	MDL Target	MDL Measured Dissolved and Particulate	Precision Target (+/- %)	Precision Measured (rsd)[1]	Accuracy Measured[2] (% recovery)
10	PAHs	pg/L	50	20	20	< 30	NA
10	PCBs	pg/L	50	1	20	< 30	NA
10	Chlorpyrifos	pg/L	50	1	20	< 30	NA
10	Diazinon	pg/L	50	180	20	< 30	NA
10	Other Pesticides	pg/L	50	1	20	< 30	NA
11	PAHs	pg/L	50	250	20	< 30	NA
11	PCBs	pg/L	50	1	20	< 30	NA
11	Chlorpyrifos	pg/L	50	1	20	< 30	NA
11	Diazinon	pg/L	50	180	20	< 30	NA
11	Other Pesticides	pg/L	50	1	20	< 30	NA
12	PAHs	pg/L	50	125	20	< 30	NA
12	PCBs	pg/L	50	1	20	< 30	NA
12	Chlorpyrifos	pg/L	50	1	20	< 30	NA
12	Diazinon	pg/L	50	180	20	< 30	NA
12	Other Pesticides	pg/L	50	1	20	< 30	NA

[1] relative standard deviation

[2] Not analyzed, because no standard reference available and matrix spikes not feasible.

Table 3. Quality assurance and control summary for laboratory analyses of sediment.
Cruise 10: February 96 and Cruise 12: August 96

Analysis type: sediment trace elements

Cruise #	Parameter	Units	MDL Target	MDL Measured	Precision Target (+/- %)	Precision Measured (rsd)[1]	Accuracy Target (+/- %)	Accuracy Measured (+/- %)	No. Blanks/Batch
10	Ag	mg/kg	0.0012	0.0300	15	5	25	18	2/24
10	Al	mg/kg	70	53	15	5	25	62	2/24
10	As	mg/kg	1.6	0.012	25	9	25	5	2/20
10	Cd	mg/kg	0.00002	0.0300	15	3	25	20	2/24
10	Cr	mg/kg	9.44	6.27	15	4	40	50	2/24
10	Cu	mg/kg	4.57	0.50	15	7	25	11	2/24
10	Fe	mg/kg	140	36	15	3	25	0	2/24
10	Hg	mg/kg	5	0.16	35	13	25	7	2/20
10	Mn	mg/kg	27	6	15	3	25	15	2/24
10	Ni	mg/kg	4.26	3.86	15	4	25	3	2/24
10	Pb	mg/kg	0.1	0.01	15	12	25	11	2/24
10	Se	mg/kg	2.2	0.008	35	10	35	6	2/20
10	Zn	mg/kg	18.9	3.55	15	3	25	4	2/24
12	Ag	mg/kg	0.0012	0.06	15	9	25	NA[2]	2/24
12	Al	mg/kg	70	135	25	10	25	68	2/24
12	As	mg/kg	1.6	0.02	25	14	25	7	2/20
12	Cd	mg/kg	0.00002	0.049	15	11	25	11	2/24
12	Cr	mg/kg	9.4	11.9	15	7	40	55	2/24
12	Cu	mg/kg	4.57	2.16	15	8	25	29	2/24
12	Fe	mg/kg	140	3480	15	5	25	86	2/24
12	Hg	mg/kg	5	0.14	35	3	25	4	2/20
12	Mn	mg/kg	27	24.5	15	5	25	24	2/24
12	Ni	mg/kg	4.26	5.91	15	4	25	10	2/24
12	Pb	mg/kg	0.01	3.25	15	6	25	15	2/24
12	Se	mg/kg	2.2	0.01	35	5	35	8	2/20
12	Zn	mg/kg	18.9	24.2	15	5	25	13	2/24

Analysis type: sediment trace organics

Cruise #	Parameter	Units	QA batch#	MDL Target	MDL Measured	Precision Target (+/- %)	Precision Measured (rsd)[1]	Accuracy Target (+/- %)	Accuracy Measured (+/- %)	Blank Frequency
10	PAHs	µg/kg	M2484	5	0.25–9.8	20	2	20	20	5% min.
10	PCBs	µg/kg	M2484	1	0.1	20	14	20	17	5% min.
10	Pesticides	µg/kg	M2484	1	0.1	20	6	20	17	5% min.
12	PAHs	µg/kg	M2528	5	0.3–8.9	20	5	20	9	5% min.
12	PCBs	µg/kg	M2528	1	0.1–6.2	20	5	20	10	5% min.
12	Pesticides	µg/kg	M2528	1	0.1–5.5	20	4	20	16	5% min.

[1] relative standard deviation
[2] There are no SRM certified values for silver.

Table 4. Quality assurance and control summary for laboratory analyses of bivalve tissue.
Cruise 10: February 96, and Cruise 12: August 96

Analysis type: tissue trace elements

Cruise #	Parameter	Units	MDL Target	MDL Measured	Precision Target (+/- %)	Precision Measured (rsd)[1]	Accuracy Target (+/- %)	Accuracy Measured (+/- %)	No. Blanks/Batch
10	Ag	mg/kg	0.0012	0.007	30	5.9–10.6	35	41	3/24
10	As	mg/kg	1.6	0.01	25	12	25	3	2/20
10	Cd	mg/kg	0.00002	0.006	30	2.0–6.2	25	2	3/24
10	Cr	mg/kg	9.44	0.012	30	9.4–10.3	25	18	3/24
10	Cu	mg/kg	4.57	0.025	30	10.7–13.4	25	17	3/24
10	Hg	mg/kg	1	0.27	35	4	25	4	2/20
10	Ni	mg/kg	4.26	0.02	30	5.5–5.8	25	12	3/24
10	Pb	mg/kg	0.1	0.014	30	7.0–11.7	25	22	3/24
10	Se	mg/kg	2.2	0.013	35	9	35	3	2/20
10	Zn	mg/kg	18.9	0.106	30	0.1–5.9	25	15	3/24
12	Ag	mg/kg	0.0012	0.004	25	8.2–10.0	30	22	3/24
12	As	mg/kg	1.6	0.01	25	4	25	4	2/20
12	Cd	mg/kg	0.00002	0.007	25	3.2–4.7	30	11	3/24
12	Cr	mg/kg	9.4	0.047	25	5.5–6.8	60	1	3/24
12	Cu	mg/kg	4.57	0.052	25	4.3–11.8	30	5	3/24
12	Hg	mg/kg	1	0.14	35	20	25	3	2/20
12	Ni	mg/kg	4.26	0.013	25	3.7–5.5	30	8	3/24
12	Pb	mg/kg	0.01	0.012	25	2.6–5.7	30	0	3/24
12	Se	mg/kg	2.2	0.008	35	3	35	11	2/20
12	Zn	mg/kg	18.9	0.25	25	2.6–4.1	30	2	3/24

Analysis type: tisssue trace organics

Cruise #	Parameter	Units	QA batch#	MDL Target	MDL Measured	Precision Target (+/- %)	Precision Measured (rsd)[1]	Accuracy Target (+/- %)	Accuracy Measured (+/- %)	Blank Frequency
10	PAHs	µg/kg	M1693	5	0.2–1.2	±20	6	±20	8	5% min.
10	PCBs	µg/kg	M1693	1	0.5–3.7	±20	6	±20	8	5% min.
10	Pesticides	µg/kg	M1693	1	0.3–1.7	±20	6	±20	8	5% min.
12	PAHs	µg/kg	M1772	5	0.2–2.2	±20	26	±20	2	5% min.
12	PCBs	µg/kg	M1772	1	0.1–6.6	±20	26	±20	2	5% min.
12	Pesticides	µg/kg	M1772	1	0.25–3.0	±20	26	±20	2	5% min.

[1] relative standard deviation

Table 5. Reference toxicant and QA information for the aquatic bioassays.

	Salinity (‰)	EC50*	EC25**	QA Notes:
February				
Mytilus edulis	30	9.6	8.7	
coefficient of variation:		5.0	10.9	
Mysidopsis bahia	25	5.9	4.4	
coefficient of variation:		7.2	14.2	
August				
Mytilus edulis	30	9.4		The following sites failed to achieve the acceptability criteria for % normal embryo development (70%) in several instances: Pt. Pinole, Napa River, Grizzly Bay, Sacramento River, San Joaquin River. However, they still lend themselves to academic evaluation of ambient toxicity, and all indicate no toxicity.
coefficient of variation:		18.9		
Mysidopsis bahia	30	5.7		
coefficient of variation:		13.1		

*Concentration of reference toxicant at which 50% of the organisms show effects.
**Concentration of reference toxicant at which 25% of the organisms show effects.

Table 6. Physical/chemical measurements of test solutions and QA information for the sediment bioassays.
n.d. means measurement below the detection limit of 0.01 mg/L.

	EC50[1] ($CdCl_2$) mg/L	Salinity (‰)	Unionized Ammonia mg/L	Hydrogen Sulfide[2] mg/L	QA Notes
February					
Eohaustorius estuarius	1.52–2.68	19–22	n.d.–0.068	nd	Amphipod survival in all control samples was 98 ±3%, indicating test organisms were healthy and not affected by test conditions.
Mytilus edulis **embryos**	2.48–2.63	26–29	n.d.–0.006	nd	Mean % normal development of test controls was 77 ±5%, above protocol miniumum of 70%.
August					
Eohaustorius estuarius	5.58–8.78	18–23	nd–0.227	na	Amphipod survival in all control samples was 98 ±4% indicating test organisms were healthy and not affected by test conditions.
Mytilus edulis **embryos**	6.52–6.79	26–28	n.d.–0.047	nd	Mean % normal development of test controls was 81 ±7%, above protocol miniumum of 70%.

[1] Effects concentration of reference toxicant at which 50% of the organisms exhibit effects.
[2] From the overlying water

Appendix C
Data Tables

Table 1. Conventional water quality parameters, 1996. For conversion of µM to µg/L, use the following atomic weight multipliers: P = 31; C = 12; N = 14; Si = 28. . = no data, NA = not analyzed, ND = not detected, Q = outside the QA limit.

Station Code	Station	Date	Cruise	Ammonia	Chlorophyll-a	Conductivity	DO	DOC	Hardness	Nitrate	Nitrite	pH	Phaeophytin	Phosphate	Salinity	Silicates	Temperature	TSS
				µM	mg/m³	µmho	mg/L	µM	mg/L	µM	µM	pH	mg/m³	µM	‰	µM	°C	mg/L
BG20	Sacramento River	2/14/96	10	3.6	1.1	110	8.7	439	210	19.0	0.9	6.4	0.6	2.0	ND	189	12.5	40.1
BG30	San Joaquin River	2/14/96	10	8.2	0.6	140	9.0	544	170	44.6	1.5	6.3	0.6	3.6	ND	212	12.5	24.6
BF40	Honker Bay	2/14/96	10	4.5	1.1	120	8.7	233	200	22.0	1.0	6.5	0.8	2.1	ND	239	13.0	58.1
BF20	Grizzly Bay	2/13/96	10	2.3	1.4	0	8.4	366	210	18.5	0.7	6.6	0.8	2.1	ND	80	13.0	61.6
BF10	Pacheco Creek	2/13/96	10	4.4	0.7	400	8.8	267	250	26.7	0.8	6.0	0.7	2.1	ND	204	13.0	47.3
BD50	Napa River	2/13/96	10	4.5	0.3	3000	8.4	319	560	18.7	0.9	7.4	0.9	2.1	2.6	236	12.2	40.2
BD40	Davis Point	2/12/96	10	3.9	0.5	5500	9.2	321	780	26.1	0.7	7.4	0.9	2.1	3.8	224	14.0	48.5
BD30	Pinole Point	2/12/96	10	5.0	0.7	9500	9.0	311	.	22.9	0.9	7.6	0.5	2.4	7.2	218	13.2	25.4
BD20	San Pablo Bay	2/12/96	10	4.6	0.7	4800	9.5	342	720	24.1	0.8	7.5	0.7	2.2	3.5	224	13.0	34.2
BD15	Petaluma River	2/12/96	10	15.4	3.0	5000	8.6	751	730	61.0	2.4	7.4	2.2	9.0	3.1	267	15.0	76.1
BC60	Red Rock	2/7/96	10	4.8	0.6	8000	9.0	321	.	29.0	0.7	7.7	0.6	2.4	5.4	170	11.4	26.7
BC41	Point Isabel	2/7/96	10	5.6	0.8	20500	7.1	249	.	26.4	0.8	7.8	0.4	2.3	9.9	190	12.0	8.4
BC30	Richardson Bay	2/7/96	10	5.0	0.4	20000	9.1	200	.	27.5	0.8	7.7	0.5	2.6	17.4	147	12.5	10.0
BC20	Golden Gate	2/7/96	10	1.4	0.8	32200	9.8	107	.	16.3	0.8	7.8	0.4	1.7	27.6	65	12.2	2.6
BC10	Yerba Buena Island	2/7/96	10	5.0	0.7	18500	9.3	192	.	25.2	0.9	7.8	0.7	2.6	14.7	155	12.7	13.4
BB70	Alameda	2/7/96	10	6.3	1.0	24000	7.7	199	.	30.5	0.9	7.8	0.6	2.9	17.8	145	12.8	10.7
BB30	Oyster Point	2/5/96	10	9.6	1.1	26200	9.0	159	.	33.8	1.7	7.8	0.8	4.7	22.2	198	12.3	7.4
BB15	San Bruno Shoal	2/5/96	10	8.9	1.2	22000	9.4	163	.	32.8	1.7	7.9	0.7	18.2	22.3	118	12.5	7.0
BA40	Redwood Creek	2/6/96	10	9.7	2.0	24800	8.3	205	.	39.0	1.8	7.8	1.0	5.9	20.6	126	13.4	9.9
BA30	Dumbarton Bridge	2/5/96	10	9.8	1.1	26200	9.2	262	.	42.4	2.2	7.9	0.5	7.6	17.0	133	13.5	10.6
BA20	South Bay	2/5/96	10	10.3	0.6	25500	8.2	335	.	71.3	2.4	7.8	0.4	7.4	18.6	117	13.2	13.2
BA10	Coyote Creek	2/6/96	10	11.1	1.1	20200	8.0	275	.	118.4	2.6	7.8	0.8	9.4	15.2	113	14.1	23.8
C-3-0	San Jose	2/6/96	10	15.6	1.6	12500	7.5	468	.	238.0	4.9	7.7	1.3	18.5	6.6	176	16.2	38.3
C-1-3	Sunnyvale	2/6/96	10	12.0	5.8	870	7.7	508	350	164.1	3.7	7.8	5.3	14.1	ND	253	15.3	153.6
BW10	Standish Dam	3/4/96	10	8.4	2.5	2500	9.3	454	.	Q	0.7	8.1	2.1	1.0	ND	193	13.6	88.1
BG20	Sacramento River	4/23/96	11	3.7	1.6	110	9.9	150	68	11.9	0.4	7.7	1.1	0.9	ND	239	13.6	16.6
BG30	San Joaquin River	4/23/96	11	1.9	2.1	147	9.9	191	96	18.2	0.5	7.8	0.6	1.4	ND	217	16.1	11.1
BF40	Honker Bay	4/24/96	11	2.2	2.2	125	9.9	158	52	15.2	0.4	7.7	1.0	1.1	ND	239	15.0	14.6
BF20	Grizzly Bay	4/24/96	11	1.5	2.9	163	10.0	173	110	17.7	0.5	7.9	1.1	1.3	ND	245	16.0	24.3
BF10	Pacheco Creek	4/24/96	11	2.6	2.6	600	9.8	173	220	16.3	0.5	7.8	0.9	1.3	ND	244	15.8	19.5
BD50	Napa River	4/23/96	11	5.0	4.0	6300	9.1	188	1000	14.4	0.8	7.6	2.6	2.1	5.0	219	15.2	54.1
BD40	Davis Point	4/22/96	11	3.1	3.2	10500	8.5	165	.	13.0	0.8	7.8	1.8	1.2	7.9	182	14.7	61.6
BD30	Pinole Point	4/22/96	11	4.0	11.7	10500	8.9	168	.	13.0	0.8	7.8	2.3	2.0	8.5	191	15.9	40.1
BD20	San Pablo Bay	4/22/96	11	1.6	11.5	12500	10.3	160	.	17.5	0.8	8.0	6.7	2.0	9.2	171	16.0	17.4
BD15	Petaluma River	4/22/96	11	4.2	13.4	15500	9.3	305	.	10.3	0.8	7.9	4.8	5.1	10.6	101	22.5	244.0
BC60	Red Rock	4/29/96	11	1.8	2.9	20000	8.8	129	.	11.5	0.5	8.0	0.7	1.3	17.6	86	16.0	3.9
BC41	Point Isabel	4/29/96	11	0.8	4.2	21200	9.4	129	.	14.4	0.4	7.7	1.1	1.2	20.7	69	15.7	4.0
BC30	Richardson Bay	4/29/96	11	ND	3.2	26800	9.0	152	.	1.7	0.2	8.1	1.7	1.1	21.9	68	21.0	3.4
BC20	Golden Gate	4/29/96	11	1.6	0.7	31000	7.7	68	.	16.0	0.4	7.9	0.5	1.5	31.0	34	12.8	2.3
BC10	Yerba Buena Island	4/30/96	11	3.7	2.8	27000	9.0	128	.	9.1	0.5	8.0	1.1	1.9	24.1	63	17.0	3.8
BB70	Alameda	4/30/96	11	2.0	3.1	26500	8.2	135	.	8.9	0.5	8.0	1.0	1.7	23.2	77	17.2	2.1
BB30	Oyster Point	4/30/96	11	1.8	4.3	24500	8.8	128	.	17.7	0.6	7.9	1.3	1.7	23.2	70	16.5	3.5
BB15	San Bruno Shoal	4/30/96	11	ND	1.9	25000	8.8	165	.	8.5	0.7	8.0	0.9	2.1	21.1	60	18.5	4.9
BA40	Redwood Creek	5/2/96	11	4.7	5.5	24000	7.9	188	.	22.0	1.1	7.8	1.2	4.4	19.8	69	20.0	17.2
BA30	Dumbarton Bridge	5/2/96	11	5.0	4.5	24500	6.6	215	.	31.7	1.3	7.9	2.0	5.9	18.7	32	22.3	32.5
BA20	South Bay	5/2/96	11	5.1	7.1	21800	6.9	229	.	39.8	1.9	7.8	2.0	6.6	18.3	41	21.8	25.8
BA10	Coyote Creek	5/1/96	11	6.3	9.9	21800	7.5	281	.	80.8	3.8	7.9	3.2	9.9	16.4	41	22.9	69.0
C-3-0	San Jose	5/1/96	11	18.7	23.5	7700	6.6	421	1200	505.0	13.0	8.0	16.8	26.4	5.4	168	23.0	264.0
C-1-3	Sunnyvale	5/1/96	11	52.9	19.3	5500	5.2	625	880	685.0	34.2	8.0	17.9	62.1	3.4	212	23.7	87.6
BW10	Standish Dam	4/16/96	11	2.8	6.8	1030	8.4	484	370	Q	2.9	8.2	2.8	1.5	ND	262	17.8	6.1
BG20	Sacramento River	7/22/96	12	3.1	1.6	415	7.6	144	84	13.9	1.4	7.8	1.1	1.7	ND	119	21.9	33.4
BG30	San Joaquin River	7/22/96	12	2.6	2.1	NA	8.3	159	84	14.9	0.9	7.8	0.6	1.9	ND	116	22.7	29.0
BF40	Honker Bay	7/22/96	12	NA	2.2	3890	8.3	168	470	22.7	0.9	7.7	1.0	.	2.6	140	21.4	96.5
BF20	Grizzly Bay	7/23/96	12	3.4	2.9	8700	8.1	165	1200	28.1	0.9	7.9	1.1	2.8	6.7	255	20.5	87.7
BF10	Pacheco Creek	7/22/96	12	3.6	2.6	570	8.4	182	1200	24.8	0.8	7.8	0.9	2.7	6.2	108	22.2	37.7
BD50	Napa River	7/24/96	12	9.8	4.0	20200	7.3	175	.	26.6	1.1	7.6	2.6	3.2	16.8	171	20.1	33.9
BD40	Davis Point	7/23/96	12	3.1	3.2	21500	8.4	139	.	24.7	1.0	7.9	1.8	3.1	19.3	141	20.3	35.2
BD30	Pinole Point	7/23/96	12	1.8	11.7	23900	8.1	136	.	22.9	1.0	8.0	2.3	2.9	20.0	134	20.7	23.9
BD20	San Pablo Bay	7/24/96	12	0.3	11.5	25300	7.9	151	.	22.0	1.0	7.8	6.7	2.8	20.8	150	21.0	9.4
BD15	Petaluma River	7/24/96	12	0.6	13.4	24700	7.3	240	.	20.1	0.7	7.8	4.8	5.2	20.8	123	20.4	52.2
BC60	Red Rock	7/24/96	12	0.9	2.9	28300	7.9	122	.	19.8	1.1	7.8	0.7	2.7	24.2	124	19.6	5.6
BC41	Point Isabel	7/25/96	12	0.2	4.2	298	9.5	110	.	15.7	1.1	8.1	1.1	2.3	28.0	64	18.2	5.9
BC30	Richardson Bay	7/25/96	12	2.4	3.2	31200	7.4	96	.	17.1	1.1	7.9	1.7	2.3	29.5	79	17.3	6.6
BC20	Golden Gate	7/25/96	12	NA	0.7	30200	8.9	95	.	12.2	0.9	8.0	0.5	2.1	32.6	37	14.1	2.0
BC10	Yerba Buena Island	7/26/96	12	9.6	2.8	30900	7.2	123	.	17.8	1.3	7.9	1.1	3.4	29.2	83	18.3	9.9
BB70	Alameda	7/26/96	12	5.6	3.1	30800	6.9	125	.	23.3	1.6	7.9	1.0	3.8	28.8	104	19.2	7.4
BB30	Oyster Point	7/26/96	12	5.1	4.3	30300	6.8	116	.	24.6	1.6	7.8	1.3	3.6	28.8	96	18.9	7.1
BB15	San Bruno Shoal	7/29/96	12	3.6	1.9	29000	6.8	153	.	27.4	1.4	8.0	0.9	6.5	27.1	130	21.3	35.7
BA40	Redwood Creek	7/29/96	12	3.4	5.5	32000	6.7	180	.	26.8	1.4	7.9	1.2	7.0	26.8	128	19.2	47.6
BA30	Dumbarton Bridge	7/29/96	12	1.9	4.5	31000	6.7	212	.	33.2	1.7	8.0	2.0	9.8	25.8	171	24.4	16.9
BA20	South Bay	7/29/96	12	2.2	7.1	31000	6.4	223	.	33.4	1.7	8.0	2.0	9.9	25.5	179	21.1	36.2
BA10	Coyote Creek	7/30/96	12	4.5	9.9	23500	4.9	381	.	210.2	8.6	7.8	3.2	21.4	18.0	267	23.5	34.6
C-3-0	San Jose	7/30/96	12	20.4	23.5	13000	3.4	448	.	399.6	14.0	7.7	16.8	30.3	8.9	356	24.9	247.6
C-1-3	Sunnyvale	7/30/96	12	10.9	19.3	20800	4.0	467	.	257.9	9.0	7.8	17.9	25.6	13.9	280	23.4	85.9
BW10	Standish Dam	8/16/96	12	15.5	6.8	7800	8.6	352	.	55.2	13.6	8.4	2.8	10.9	3.1	345	25.5	32.9

Table 2. Dissolved concentrations of trace elements in water, 1996. NA = not analyzed, Q = outside the QA limit. For method detection limits refer to Table 1 in *Appendix B*.

Station Code	Station	Date	Cruise	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
				µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
BG20	Sacramento River	2/14/96	10	0.0017	1.25	0.01	1.14	1.6	0.0019	2.2	0.092	0.12	0.81
BG30	San Joaquin River	2/14/96	10	0.0026	1.52	0.01	0.57	2.2	0.0033	2.4	0.141	0.13	1.23
BF40	Honker Bay	2/14/96	10	0.0007	1.16	0.01	0.46	1.8	0.0013	1.9	0.013	0.12	0.23
BF20	Grizzly Bay	2/13/96	10	0.0009	1.08	0.01	0.27	1.8	0.0018	2.0	0.011	0.14	0.19
BF10	Pacheco Creek	2/13/96	10	0.0021	1.22	0.01	0.68	1.9	0.0026	2.7	0.125	0.12	1.12
BD50	Napa River	2/13/96	10	0.0018	1.32	0.02	0.71	2.0	0.0026	2.9	0.127	0.13	1.33
BD40	Davis Point	2/12/96	10	0.0006	1.22	0.02	0.38	1.9	0.0017	2.2	0.008	0.16	0.49
BD30	Pinole Point	2/12/96	10	0.0014	1.45	0.03	0.26	1.8	0.0017	2.6	0.043	0.15	0.76
BD20	San Pablo Bay	2/12/96	10	0.0016	1.20	0.02	0.34	2.0	0.0021	2.7	0.074	0.17	0.88
BD15	Petaluma River	2/12/96	10	0.0017	2.08	0.10	0.35	4.2	0.0046	37.4	0.018	0.17	3.94
BC60	Red Rock	2/7/96	10	0.0011	1.36	0.02	0.25	1.8	0.0017	2.2	0.036	0.17	0.71
BC41	Point Isabel	2/7/96	10	0.0011	1.44	0.03	0.18	1.6	0.0014	2.1	0.017	0.03	0.67
BC30	Richardson Bay	2/7/96	10	0.0005	1.50	0.04	0.11	1.3	0.0006	1.5	0.010	0.13	0.91
BC20	Golden Gate	2/7/96	10	0.0015	1.51	0.04	0.09	0.5	0.0003	0.8	0.005	0.34	0.35
BC10	Yerba Buena Island	2/7/96	10	0.0015	1.46	0.04	0.11	1.5	0.0008	1.7	0.007	0.34	0.83
BB70	Alameda	2/7/96	10	0.0015	1.66	0.05	NA	1.4	0.0008	1.8	0.007	0.01	0.92
BB30	Oyster Point	2/5/96	10	0.0038	1.87	0.07	0.09	1.5	0.0008	1.9	0.013	0.16	0.97
BB15	San Bruno Shoal	2/5/96	10	0.0047	1.98	0.07	NA	1.5	0.0007	1.9	0.014	0.16	0.99
BA40	Redwood Creek	2/6/96	10	0.0033	1.96	0.08	0.13	1.9	0.0014	2.9	0.027	0.15	1.84
BA30	Dumbarton Bridge	2/5/96	10	0.0031	1.99	0.08	0.10	2.0	0.0013	2.9	0.024	0.33	1.91
BA20	South Bay	2/5/96	10	0.0049	2.06	0.07	0.11	2.0	0.0013	2.8	0.024	0.31	1.78
BA10	Coyote Creek	2/6/96	10	0.0021	1.92	0.08	0.13	2.1	0.0017	3.2	0.033	0.27	2.46
C-3-0	San Jose	2/6/96	10	0.0016	1.92	0.06	0.26	2.5	0.0026	4.8	0.074	0.72	5.85
C-1-3	Sunnyvale	2/6/96	10	0.0013	1.22	0.01	0.20	1.4	0.0025	2.8	0.034	0.88	2.50
BW10	Standish Dam	3/4/96	10	0.0007	1.07	0.01	0.42	1.6	0.0017	3.8	0.000	0.40	1.43
BG20	Sacramento River	4/23/96	11	0.0008	0.96	0.01	0.27	0.9	0.0004	0.8	0.035	0.06	0.36
BG30	San Joaquin River	4/23/96	11	0.0010	1.12	0.01	0.26	1.2	0.0006	0.9	0.057	0.16	0.37
BF40	Honker Bay	4/24/96	11	0.0008	0.97	0.01	0.33	1.2	0.0007	1.0	0.056	0.10	0.41
BF20	Grizzly Bay	4/24/96	11	0.0011	1.13	0.01	0.37	1.3	0.0011	1.0	0.058	0.11	0.38
BF10	Pacheco Creek	4/24/96	11	0.0011	1.09	0.01	0.27	1.2	0.0009	1.0	0.035	0.09	0.35
BD50	Napa River	4/23/96	11	0.0012	1.45	0.02	0.24	1.6	0.0007	1.5	0.022	0.15	0.66
BD40	Davis Point	4/22/96	11	0.0010	1.46	0.04	0.16	1.3	Q	1.3	0.006	0.13	0.39
BD30	Pinole Point	4/22/96	11	0.0014	1.45	0.04	0.17	1.5	0.0008	1.5	0.009	0.20	0.39
BD20	San Pablo Bay	4/22/96	11	0.0009	1.54	0.04	0.17	1.5	0.0004	1.4	0.009	0.15	0.35
BD15	Petaluma River	4/22/96	11	0.0018	2.40	0.06	0.28	3.3	0.0015	3.6	0.011	0.22	0.32
BC60	Red Rock	4/29/96	11	0.0012	1.40	0.04	0.18	1.1	0.0005	1.0	0.005	0.09	0.26
BC41	Point Isabel	4/29/96	11	0.0012	1.43	0.05	0.11	1.0	0.0006	1.0	0.008	0.09	0.32
BC30	Richardson Bay	4/29/96	11	0.0006	1.48	0.04	0.09	1.0	0.0005	1.1	0.006	0.22	0.45
BC20	Golden Gate	4/29/96	11	0.0009	1.49	0.07	0.11	0.3	Q	0.4	0.006	0.32	0.15
BC10	Yerba Buena Island	4/30/96	11	0.0009	1.53	0.06	0.10	1.2	Q	1.0	0.014	0.23	0.72
BB70	Alameda	4/30/96	11	0.0007	1.56	0.05	0.11	1.1	0.0005	1.0	0.010	0.09	0.38
BB30	Oyster Point	4/30/96	11	0.0014	1.55	0.05	0.10	1.1	Q	1.0	0.011	0.11	0.37
BB15	San Bruno Shoal	4/30/96	11	0.0011	1.66	0.05	0.12	1.6	0.0007	1.4	0.022	0.13	0.37
BA40	Redwood Creek	5/2/96	11	0.0014	1.92	0.06	0.12	1.9	0.0007	1.9	0.037	0.16	0.65
BA30	Dumbarton Bridge	5/2/96	11	0.0039	2.11	0.07	0.12	2.4	0.0010	2.3	0.046	0.21	1.01
BA20	South Bay	5/2/96	11	0.0032	2.29	0.07	0.14	2.5	0.0011	2.4	0.055	0.21	1.00
BA10	Coyote Creek	5/1/96	11	0.0035	2.62	0.08	0.19	3.3	0.0013	2.9	0.060	0.38	1.82
C-3-0	San Jose	5/1/96	11	0.0016	2.78	0.08	0.18	4.0	0.0018	5.1	0.152	1.03	8.42
C-1-3	Sunnyvale	5/1/96	11	0.0006	3.85	0.06	0.13	3.7	0.0017	3.3	0.203	1.75	6.83
BW10	Standish Dam	4/16/96	11	0.0007	1.63	0.01	0.31	1.2	0.0010	3.0	0.081	1.80	1.13
BG20	Sacramento River	7/22/96	12	0.0010	1.67	0.01	0.32	1.5	0.0008	0.9	0.044	0.08	0.39
BG30	San Joaquin River	7/22/96	12	0.0009	1.80	0.01	0.21	1.7	0.0009	1.0	0.060	0.10	0.44
BF40	Honker Bay	7/22/96	12	0.0004	1.81	0.02	0.11	1.8	0.0006	1.1	0.005	0.11	0.33
BF20	Grizzly Bay	7/23/96	12	0.0020	2.16	0.04	0.24	2.0	0.0006	1.4	0.007	0.16	0.43
BF10	Pacheco Creek	7/22/96	12	0.0015	1.98	0.03	0.17	2.1	0.0009	1.6	0.009	0.16	0.39
BD50	Napa River	7/24/96	12	0.0038	2.26	0.07	0.11	2.1	0.0006	2.0	0.007	0.14	0.73
BD40	Davis Point	7/23/96	12	0.0061	2.24	0.07	0.11	1.9	0.0005	1.8	0.009	0.18	0.58
BD30	Pinole Point	7/23/96	12	0.0052	2.29	0.07	0.12	1.7	0.0007	1.7	0.006	0.12	0.53
BD20	San Pablo Bay	7/24/96	12	0.0030	2.20	0.07	0.14	1.8	0.0008	1.6	0.006	0.14	0.58
BD15	Petaluma River	7/24/96	12	0.0068	3.34	0.11	0.19	3.8	0.0014	2.9	0.009	0.14	0.51
BC60	Red Rock	7/24/96	12	0.0050	2.13	0.07	0.11	1.5	0.0007	1.4	0.007	0.14	0.47
BC41	Point Isabel	7/25/96	12	0.0034	1.91	0.07	0.11	1.3	0.0006	1.3	0.010	0.11	0.58
BC30	Richardson Bay	7/25/96	12	0.0035	1.82	0.06	0.08	1.4	0.0005	1.0	0.013	Q	1.83
BC20	Golden Gate	7/25/96	12	0.0013	1.56	0.05	0.08	0.4	Q	0.5	0.007	Q	0.24
BC10	Yerba Buena Island	7/26/96	12	0.0033	2.10	0.08	0.07	1.4	0.0004	1.3	0.017	0.07	0.97
BB70	Alameda	7/26/96	12	0.0059	2.13	0.08	0.08	1.5	0.0005	1.5	0.017	0.10	0.79
BB30	Oyster Point	7/26/96	12	0.0087	2.16	0.08	0.08	1.5	0.0005	1.5	0.016	0.11	0.73
BB15	San Bruno Shoal	7/29/96	12	0.0082	2.86	0.09	0.09	2.1	0.0007	2.2	0.026	0.15	0.56
BA40	Redwood Creek	7/29/96	12	0.0117	2.83	0.09	0.16	2.5	0.0012	2.4	0.034	0.14	0.59
BA30	Dumbarton Bridge	7/29/96	12	0.0118	3.69	0.09	0.11	3.0	0.0012	2.9	0.049	0.21	0.70
BA20	South Bay	7/29/96	12	0.0122	3.82	0.09	0.10	3.2	0.0013	3.0	0.064	0.19	0.70
BA10	Coyote Creek	7/30/96	12	0.0043	4.08	0.07	0.11	3.2	0.0017	6.6	0.172	0.62	4.61
C-3-0	San Jose	7/30/96	12	0.0014	4.11	0.04	0.17	2.1	0.0012	8.6	0.225	0.91	9.03
C-1-3	Sunnyvale	7/30/96	12	0.0035	4.52	0.05	0.16	3.1	0.0021	7.0	0.224	0.82	4.69
BW10	Standish Dam	8/16/96	12	0.0008	2.73	0.01	0.12	1.7	0.0009	4.7	0.152	2.55	2.31

Table 3. Total or near total* concentrations of trace elements in water, 1996.. = no data, ND = not detected, Q = outside the QA limit, NA = not analyzed. For method detection limits refer to Table 1 in *Appendix B*.

Station Code	Station	Date	Cruise	Ag*	As	Cd*	Cr	Cu*	Hg	Ni*	Pb*	Se	Zn*
				µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
BG20	Sacramento River	2/14/96	10	0.006	1.77	0.03	8.20	3.9	0.006	7.6	0.7	0.16	7.4
BG30	San Joaquin River	2/14/96	10	0.005	1.78	0.02	6.50	3.5	0.006	4.6	0.6	0.18	4.8
BF40	Honker Bay	2/14/96	10	0.007	2.03	0.03	14.80	4.7	0.009	10.7	1.0	0.15	9.4
BF20	Grizzly Bay	2/13/96	10	0.009	2.28	0.03	13.20	5.1	0.011	10.6	1.1	0.14	11.3
BF10	Pacheco Creek	2/13/96	10	0.009	1.95	0.02	9.60	4.6	0.009	7.1	0.9	0.14	8.4
BD50	Napa River	2/13/96	10	0.008	1.95	0.03	4.90	4.4	0.010	6.9	1.0	0.13	8.5
BD40	Davis Point	2/12/96	10	0.010	2.26	0.05	7.00	5.0	0.013	8.6	1.1	0.18	11.3
BD30	Pinole Point	2/12/96	10	0.006	1.76	0.03	2.60	3.3	0.008	4.6	0.5	0.19	5.4
BD20	San Pablo Bay	2/12/96	10	0.008	1.91	0.03	4.50	4.1	0.009	6.3	0.7	0.17	7.4
BD15	Petaluma River	2/12/96	10	0.022	3.18	0.17	16.00	8.6	0.043	41.3	2.3	0.19	26.4
BC60	Red Rock	2/7/96	10	0.008	1.73	0.04	2.20	3.4	0.008	4.3	0.6	0.15	5.7
BC41	Point Isabel	2/7/96	10	0.005	1.82	0.04	1.40	2.3	0.004	2.4	0.2	0.17	3.2
BC30	Richardson Bay	2/7/96	10	0.003	1.63	0.04	1.40	2.1	0.003	2.4	0.5	0.12	4.0
BC20	Golden Gate	2/7/96	10	0.002	1.41	0.04	0.40	0.7	0.002	1.1	0.1	0.24	1.1
BC10	Yerba Buena Island	2/7/96	10	0.004	1.75	0.07	1.20	2.1	0.005	2.3	0.3	0.30	4.4
BB70	Alameda	2/7/96	10	0.005	1.68	0.04	2.00	2.1	0.004	2.5	0.4	0.21	4.1
BB30	Oyster Point	2/5/96	10	0.009	1.84	0.06	1.60	2.4	0.004	2.8	0.6	0.12	5.1
BB15	San Bruno Shoal	2/5/96	10	0.009	1.99	0.07	1.40	2.4	0.004	2.6	0.4	0.15	4.3
BA40	Redwood Creek	2/6/96	10	0.010	2.04	0.10	1.50	2.7	0.006	3.6	0.4	0.16	5.3
BA30	Dumbarton Bridge	2/5/96	10	0.006	2.21	0.08	1.30	3.0	0.005	3.6	0.6	0.28	6.6
BA20	South Bay	2/5/96	10	0.011	2.13	0.07	1.90	3.0	0.007	4.0	0.4	0.30	5.2
BA10	Coyote Creek	2/6/96	10	0.011	2.31	0.09	.	3.1	0.009	4.4	0.5	0.38	6.3
C-3-0	San Jose	2/6/96	10	0.015	2.41	0.07	6.00	4.3	0.018	4.0	1.3	0.67	16.9
C-1-3	Sunnyvale	2/6/96	10	0.047	2.48	0.09	16.10	8.0	0.042	16.7	5.7	1.02	37.0
BW10	Standish Dam	3/4/96	10	0.013	2.26	0.05	7.30	5.6	0.029	16.4	4.1	0.44	13.0
BG20	Sacramento River	4/23/96	11	0.002	1.21	0.02	4.00	2.2	0.003	2.5	0.3	0.07	2.6
BG30	San Joaquin River	4/23/96	11	ND	1.30	0.01	1.50	2.1	0.002	1.8	0.3	0.18	2.0
BF40	Honker Bay	4/24/96	11	ND	1.23	0.02	4.30	2.1	0.004	2.1	0.3	0.11	2.4
BF20	Grizzly Bay	4/24/96	11	0.004	1.62	0.01	4.90	2.8	0.005	3.2	0.7	0.14	3.5
BF10	Pacheco Creek	4/24/96	11	0.004	1.37	0.02	3.30	2.6	0.006	2.8	0.5	0.12	3.3
BD50	Napa River	4/23/96	11	0.006	1.77	0.03	8.20	3.4	0.008	4.2	0.8	0.16	6.4
BD40	Davis Point	4/22/96	11	0.019	3.09	0.05	10.30	5.8	0.025	8.8	1.9	0.21	7.5
BD30	Pinole Point	4/22/96	11	0.009	2.02	0.03	5.80	3.4	0.009	4.6	0.8	0.17	6.3
BD20	San Pablo Bay	4/22/96	11	0.003	1.71	0.03	4.30	2.3	0.005	2.6	0.3	0.16	2.5
BD15	Petaluma River	4/22/96	11	0.051	4.27	0.11	36.20	11.8	0.048	18.1	4.8	0.30	18.1
BC60	Red Rock	4/29/96	11	ND	1.48	0.03	0.30	1.4	0.001	1.3	0.1	0.17	1.0
BC41	Point Isabel	4/29/96	11	0.004	1.53	0.04	0.70	1.3	0.001	1.1	0.1	0.07	0.9
BC30	Richardson Bay	4/29/96	11	0.006	1.72	0.03	1.00	1.7	0.003	1.5	0.1	0.11	1.7
BC20	Golden Gate	4/29/96	11	ND	1.49	0.05	0.10	0.3	0.001	0.4	0.1	0.34	0.3
BC10	Yerba Buena Island	4/30/96	11	0.004	1.61	0.05	0.70	1.2	0.002	1.2	0.1	0.11	1.2
BB70	Alameda	4/30/96	11	ND	1.58	0.06	0.50	1.2	0.001	2.0	0.1	0.09	1.0
BB30	Oyster Point	4/30/96	11	0.005	1.53	0.05	0.80	1.3	0.002	1.2	0.0	0.08	1.0
BB15	San Bruno Shoal	4/30/96	11	NA	1.71	NA	1.20	NA	0.002	NA	NA	0.13	NA
BA40	Redwood Creek	5/2/96	11	0.005	2.15	0.05	3.20	2.8	0.006	3.1	0.4	0.24	3.2
BA30	Dumbarton Bridge	5/2/96	11	0.009	2.51	0.06	7.10	4.0	0.011	4.7	0.9	0.24	6.3
BA20	South Bay	5/2/96	11	0.009	2.58	0.08	6.20	4.2	0.011	4.5	0.9	0.33	5.3
BA10	Coyote Creek	5/1/96	11	0.011	3.03	0.09	14.20	6.3	0.021	9.0	2.4	0.22	10.0
C-3-0	San Jose	5/1/96	11	0.081	4.51	0.11	27.10	12.3	0.092	21.7	8.0	1.39	32.8
C-1-3	Sunnyvale	5/1/96	11	0.042	4.40	0.06	14.20	7.2	0.025	10.8	2.7	1.70	15.4
BW10	Standish Dam	4/16/96	11	0.002	1.58	0.02	1.00	2.0	0.005	4.1	0.9	1.58	3.8
BG20	Sacramento River	7/22/96	12	0.003	2.08	0.02	5.20	3.3	0.007	3.9	1.2	0.11	5.1
BG30	San Joaquin River	7/22/96	12	0.003	2.16	0.02	4.10	3.3	0.007	3.8	1.1	0.10	3.9
BF40	Honker Bay	7/22/96	12	0.009	3.06	0.06	15.40	7.1	0.024	12.0	3.4	0.14	14.2
BF20	Grizzly Bay	7/23/96	12	0.013	3.51	0.07	14.30	6.5	0.026	9.8	3.0	0.17	14.5
BF10	Pacheco Creek	7/22/96	12	0.006	2.61	0.05	5.60	3.8	0.011	5.3	1.2	0.16	5.3
BD50	Napa River	7/24/96	12	0.006	2.59	0.10	6.00	3.8	0.011	6.6	1.1	0.14	5.5
BD40	Davis Point	7/23/96	12	0.009	2.80	0.09	5.20	3.3	0.010	4.9	0.9	0.15	5.2
BD30	Pinole Point	7/23/96	12	0.008	2.52	0.09	4.00	2.8	0.005	3.5	0.6	0.12	3.2
BD20	San Pablo Bay	7/24/96	12	0.008	2.39	0.09	1.90	2.4	0.006	3.1	0.3	0.08	2.4
BD15	Petaluma River	7/24/96	12	0.008	4.28	0.15	9.00	6.0	0.016	9.4	2.1	0.20	7.8
BC60	Red Rock	7/24/96	12	0.006	2.11	0.09	1.20	2.0	0.002	2.2	0.2	0.14	1.8
BC41	Point Isabel	7/25/96	12	0.006	2.16	0.10	1.00	1.6	0.003	2.0	0.2	0.12	1.5
BC30	Richardson Bay	7/25/96	12	0.004	2.02	0.09	1.20	1.6	0.002	1.7	0.3	0.08	2.9
BC20	Golden Gate	7/25/96	12	0.002	1.54	0.08	0.10	0.5	0.001	0.7	0.0	Q	0.6
BC10	Yerba Buena Island	7/26/96	12	0.007	2.13	0.10	4.40	1.8	0.004	2.5	0.3	0.09	2.4
BB70	Alameda	7/26/96	12	0.009	2.25	0.10	1.10	1.8	0.003	2.2	0.3	0.10	1.9
BB30	Oyster Point	7/26/96	12	0.009	2.28	0.10	1.00	1.6	0.003	2.2	0.2	0.12	1.7
BB15	San Bruno Shoal	7/29/96	12	0.014	3.47	0.11	3.40	4.0	0.016	6.2	1.6	0.14	6.1
BA40	Redwood Creek	7/29/96	12	0.017	3.19	0.12	7.10	3.7	0.010	5.2	1.1	0.10	5.4
BA30	Dumbarton Bridge	7/29/96	12	0.016	3.79	0.12	4.60	3.8	0.007	4.5	0.5	0.19	3.7
BA20	South Bay	7/29/96	12	0.016	3.96	0.12	3.60	4.6	0.017	7.2	1.9	0.22	6.4
BA10	Coyote Creek	7/30/96	12	0.021	4.40	0.10	7.10	4.2	0.018	12.4	2.0	0.74	13.7
C-3-0	San Jose	7/30/96	12	0.152	6.22	0.14	41.00	12.9	0.118	10.7	11.8	1.05	56.6
C-1-3	Sunnyvale	7/30/96	12	0.034	5.44	0.11	13.30	6.7	0.042	16.7	4.7	0.78	20.4
BW10	Standish Dam	8/16/96	12	0.012	3.37	0.04	5.40	3.0	0.012	10.6	2.4	1.83	11.7

Table 4. Dissolved PAH concentrations in water samples, 1996. . = no data, ND = not detected, DEG = analyte degraded in standard: could not get accurate value, QS = outlier value qualified by SFEI, R = unacceptably low surrogate recovery, CE = coelution, LPAH = low molecular weight PAHs, * = not available at the time of report production**.** For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PAHs (SFEI)	Sum of L PAHs (SFEI)	Biphenyl	Naphthalene	1-Methylnaphthalene	2-Methylnaphthalene	2,6-Dimethylnaphthalene	2,3,5-Trimethylnaphthalene	Acenaphthene	Acenaphthylene	Anthracene	Dibenzothiophene	Fluorene	Phenanthrene	1-Methylphenanthrene
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	5222	4106	610	310	410	1400	120	62	QS	QS	33	32	320	720	89
BG30	San Joaquin River	2/14/96	10	5904	4502	190	370	320	1100	94	98	QS	130	230	110	1000	690	170
BF20	Grizzly Bay	2/13/96	10	15954	14200	760	200	810	2700	1200	1200	QS	2700	270	140	1800	2200	220
BD50	Napa River	2/13/96	10	13319	10602	410	410	1100	3200	260	150	1500	640	74	78	1100	1500	180
BD40	Davis Point	2/12/96	10	9505	7443	440	310	750	2000	310	160	880	300	54	79	860	1100	200
BD30	Pinole Point	2/12/96	10	7660	5939	340	1100	520	1300	150	110	380	210	27	43	570	1100	89
BD20	San Pablo Bay	2/12/96	10	7985	6433	320	1200	690	1700	190	140	390	290	22	51	570	760	110
BD15	Petaluma River	2/12/96	10	12131	8653	150	2500	980	2400	130	91	380	290	41	51	430	670	540
BC60	Red Rock	2/7/96	10	9652	7633	330	1500	670	1700	220	160	560	290	18	85	650	1100	350
BC20	Golden Gate	2/7/96	10	11870	9115	610	1500	530	1600	320	120	390	100	ND	95	850	2400	600
BC10	Yerba Buena Island	2/7/96	10	15504	10948	500	1600	730	2000	200	180	620	360	38	140	1300	2600	680
BB70	Alameda	2/7/96	10	11074	7957	310	730	400	1100	160	120	780	210	47	110	880	2400	710
BA40	Redwood Creek	2/6/96	10	9228	6039	250	770	490	1400	180	130	390	190	38	71	480	1200	450
BA30	Dumbarton Bridge	2/5/96	10	12518	9145	370	1700	870	2100	160	140	570	230	55	120	750	1600	480
BA10	Coyote Creek	2/6/96	10	9888	6373	270	990	660	1300	210	180	470	220	34	79	610	910	440
C-3-0	San Jose	2/6/96	10	14822	11197	580	860	1300	2500	440	360	890	400	87	150	1300	2000	330
BW10	Standish Dam	3/4/96	10	10178	7010	360	200	710	1600	210	270	QS	320	220	170	960	1600	390
BG20	Sacramento River	4/23/96	11	4086	3013	200	510	870	DEG	210	150	QS	100	24	26	390	460	73
BG30	San Joaquin River	4/23/96	11	2503	1799	96	660	360	DEG	120	86	CE	22	ND	ND	200	220	35
BF20	Grizzly Bay	4/24/96	11	4678	2775	220	370	630	DEG	340	170	QS	43	32	44	320	520	86
BD50	Napa River	4/23/96	11	12266	6372	280	970	700	DEG	240	180	1000	83	72	87	880	1700	180
BD40	Davis Point	4/22/96	11	6525	3887	190	890	370	DEG	83	79	530	64	32	59	510	980	100
BD30	Pinole Point	4/22/96	11	6724	3804	200	640	460	DEG	160	120	420	76	26	62	520	1000	120
BD20	San Pablo Bay	4/22/96	11	4714	2815	170	220	380	DEG	160	100	340	65	17	26	440	810	87
BD15	Petaluma River	4/22/96	11	5834	2806	170	170	490	DEG	180	130	210	97	48	32	360	820	99
BC60	Red Rock	4/29/96	11	7078	4748	240	66	320	DEG	140	100	300	77	ND	55	1000	2300	150
BC20	Golden Gate	4/29/96	11	2571	2166	260	160	440	DEG	150	64	98	46	ND	19	280	610	39
BC10	Yerba Buena Island	4/30/96	11	16432	11138	560	990	1200	DEG	310	190	1300	180	ND	88	2000	4100	220
BB70	Alameda	4/30/96	11	9851	7164	320	800	950	DEG	260	140	620	180	ND	44	1300	2400	150
BA40	Redwood Creek	5/2/96	11	7879	4219	180	110	340	DEG	180	110	530	120	ND	89	730	1700	130
BA30	Dumbarton Bridge	5/2/96	11	10435	5620	220	160	360	DEG	150	120	680	130	ND	130	1000	2500	170
BA10	Coyote Creek	5/1/96	11	14106	7371	300	230	480	DEG	300	180	1100	160	81	120	1300	2900	220
C-3-0	San Jose	5/1/96	11	23645	11510	530	530	950	DEG	390	370	1500	250	180	210	1800	4400	400
BW10	Standish Dam	4/16/96	11	12247	4874	290	280	650	DEG	390	270	ND	140	120	64	710	1500	460
BG20	Sacramento River	7/22/96	12	7654	5227	300	2100	700	DEG	170	110	270	83	19	38	460	880	97
BG30	San Joaquin River	7/22/96	12	8925	5712	250	1500	720	DEG	250	200	760	100	60	32	700	990	150
BF20	Grizzly Bay	7/23/96	12	16693	7472	260	1300	340	DEG	140	160	290	92	ND	130	1200	3200	360
BD50	Napa River	7/24/96	12	14404	6008	120	790	360	DEG	170	150	550	79	79	140	970	2300	300
BD40	Davis Point	7/23/96	12	10047	6201	290	1100	570	DEG	280	190	500	100	ND	91	1100	1800	180
BD30	Pinole Point	7/23/96	12	5729	4089	190	720	370	DEG	180	120	650	83	ND	51	840	810	75
BD20	San Pablo Bay	7/24/96	12	7136	4401	190	710	340	DEG	190	140	350	75	ND	56	810	1400	140
BD15	Petaluma River	7/24/96	12	.	.	R	R	R	R	R	R	R	R	R	R	R	R	R
BC60	Red Rock	7/24/96	12	7248	4941	210	1000	410	DEG	190	120	310	96	ND	55	910	1500	140
BC20	Golden Gate	7/25/96	12	4464	3568	160	960	350	DEG	140	100	380	46	ND	42	460	880	50
BC10	Yerba Buena Island	7/26/96	12	.	.	*	*	*	*	*	*	*	*	*	*	*	*	*
BB70	Alameda	7/26/96	12	.	.	R	R	R	R	R	R	R	R	R	R	R	R	R
BA40	Redwood Creek	7/29/96	12	8428	5121	220	1000	540	DEG	210	120	180	140	QS	61	720	1800	130
BA30	Dumbarton Bridge	7/29/96	12	9706	5927	240	980	460	DEG	210	150	580	89	18	110	870	2100	120
BA10	Coyote Creek	7/30/96	12	.	.	*	*	*	*	*	*	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	28627	12420	310	1500	630	DEG	300	390	1100	160	120	410	2100	4900	500
BW10	Standish Dam	8/16/96	12	12288	7230	330	260	880	DEG	180	220	760	170	130	110	1300	2600	290

Table 4. Dissolved PAH concentrations in water samples, 1996 (continued). . = no data, ND = not detected, R = unacceptably low surrogate recovery, HPAH = high molecular weight PAHs, * = not available at the time of report production. For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PAHs (SFEI)	Sum of H PAHs (SFEI)	Benz(a)anthracene	Chrysene	Pyrene	Benzo(a)pyrene	Benzo(e)pyrene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Dibenz(a,h)anthracene	Perylene	Benzo(ghi)perylene	Fluoranthene	Indeno(1,2,3-cd)pyrene
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	5222	1116	34	38	600	ND	92	ND	48	ND	ND	34	270	ND
BG30	San Joaquin River	2/14/96	10	5904	1402	23	ND	720	ND	120	ND	130	ND	44	83	260	22
BF20	Grizzly Bay	2/13/96	10	15954	1754	ND	ND	780	27	130	26	140	ND	53	140	430	28
BD50	Napa River	2/13/96	10	13319	2717	95	66	1200	36	130	ND	230	ND	ND	ND	960	ND
BD40	Davis Point	2/12/96	10	9505	2062	83	69	950	20	100	ND	110	ND	ND	ND	730	ND
BD30	Pinole Point	2/12/96	10	7660	1721	56	26	720	ND	130	ND	79	ND	ND	ND	710	ND
BD20	San Pablo Bay	2/12/96	10	7985	1552	64	33	730	ND	110	ND	55	ND	ND	ND	560	ND
BD15	Petaluma River	2/12/96	10	12131	3478	230	250	1600	ND	160	92	150	21	ND	ND	940	35
BC60	Red Rock	2/7/96	10	9652	2019	120	130	860	ND	110	ND	89	ND	ND	ND	710	ND
BC20	Golden Gate	2/7/96	10	11870	2755	240	260	920	ND	180	45	120	ND	ND	ND	990	ND
BC10	Yerba Buena Island	2/7/96	10	15504	4556	240	280	1600	ND	200	56	180	ND	ND	ND	2000	ND
BB70	Alameda	2/7/96	10	11074	3117	310	320	1900	ND	170	67	170	ND	ND	ND	180	ND
BA40	Redwood Creek	2/6/96	10	9228	3189	200	200	1300	ND	150	60	79	ND	ND	ND	1200	ND
BA30	Dumbarton Bridge	2/5/96	10	12518	3373	180	190	1400	ND	150	43	210	ND	ND	ND	1200	ND
BA10	Coyote Creek	2/6/96	10	9888	3515	200	210	1600	ND	160	59	86	ND	ND	ND	1200	ND
C-3-0	San Jose	2/6/96	10	14822	3625	110	140	1600	ND	120	39	84	ND	ND	32	1500	ND
BW10	Standish Dam	3/4/96	10	10178	3168	110	160	1500	ND	110	48	120	ND	ND	95	1000	25
BG20	Sacramento River	4/23/96	11	4086	1073	42	51	540	ND	ND	ND	ND	ND	ND	ND	440	ND
BG30	San Joaquin River	4/23/96	11	2503	704	34	ND	510	ND	ND	ND	QS	ND	ND	ND	160	ND
BF20	Grizzly Bay	4/24/96	11	4678	1903	58	220	870	ND	54	28	ND	ND	ND	110	440	27
BD50	Napa River	4/23/96	11	12266	5894	240	180	2800	ND	95	60	42	ND	ND	ND	2400	21
BD40	Davis Point	4/22/96	11	6525	2638	120	93	1100	ND	58	49	23	ND	ND	ND	1100	23
BD30	Pinole Point	4/22/96	11	6724	2920	110	58	1300	ND	70	49	23	ND	ND	ND	1200	27
BD20	San Pablo Bay	4/22/96	11	4714	1899	59	71	670	ND	40	43	36	ND	ND	ND	980	ND
BD15	Petaluma River	4/22/96	11	5834	3028	130	130	1200	ND	100	110	58	ND	ND	ND	1300	ND
BC60	Red Rock	4/29/96	11	7078	2330	25	100	350	ND	23	ND	32	ND	ND	ND	1800	ND
BC20	Golden Gate	4/29/96	11	2571	405	ND	21	34	ND	ND	ND	ND	ND	ND	ND	350	ND
BC10	Yerba Buena Island	4/30/96	11	16432	5294	41	150	380	ND	30	44	49	ND	ND	ND	4600	ND
BB70	Alameda	4/30/96	11	9851	2687	ND	57	130	ND	ND	ND	ND	ND	ND	ND	2500	ND
BA40	Redwood Creek	5/2/96	11	7879	3660	85	160	1000	ND	90	82	43	ND	ND	ND	2200	ND
BA30	Dumbarton Bridge	5/2/96	11	10435	4815	110	210	1500	ND	120	110	65	ND	ND	ND	2700	ND
BA10	Coyote Creek	5/1/96	11	14106	6735	270	200	2800	ND	140	150	75	ND	ND	ND	3100	ND
C-3-0	San Jose	5/1/96	11	23645	12135	480	460	5200	ND	400	350	220	21	ND	25	4900	79
BW10	Standish Dam	4/16/96	11	12247	7373	850	350	3600	29	180	150	77	ND	ND	170	1900	ND
BG20	Sacramento River	7/22/96	12	7654	2427	110	190	820	40	150	88	65	ND	ND	ND	900	64
BG30	San Joaquin River	7/22/96	12	8925	3213	96	130	1500	ND	36	22	29	ND	ND	ND	1400	ND
BF20	Grizzly Bay	7/23/96	12	16693	9221	220	420	3100	23	110	76	72	ND	ND	ND	5200	ND
BD50	Napa River	7/24/96	12	14404	8396	260	280	3300	28	130	88	110	ND	ND	ND	4200	ND
BD40	Davis Point	7/23/96	12	10047	3846	85	110	1200	ND	47	51	53	ND	ND	ND	2300	ND
BD30	Pinole Point	7/23/96	12	5729	1640	59	35	600	ND	36	ND	ND	ND	ND	ND	910	ND
BD20	San Pablo Bay	7/24/96	12	7136	2735	29	110	470	ND	33	42	51	ND	ND	ND	2000	ND
BD15	Petaluma River	7/24/96	12	.	R	R	R	R	R	R	R	R	R	R	R	R	R
BC60	Red Rock	7/24/96	12	7248	2307	30	110	100	ND	30	ND	37	ND	ND	ND	2000	ND
BC20	Golden Gate	7/25/96	12	4464	896	ND	26	160	ND	ND	ND	ND	ND	ND	ND	710	ND
BC10	Yerba Buena Island	7/26/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*
BB70	Alameda	7/26/96	12	.	R	R	R	R	R	R	R	R	R	R	R	R	R
BA40	Redwood Creek	7/29/96	12	8428	3307	47	200	780	ND	77	93	110	ND	ND	ND	2000	ND
BA30	Dumbarton Bridge	7/29/96	12	9706	3779	97	220	1300	ND	110	89	63	ND	ND	ND	1900	ND
BA10	Coyote Creek	7/30/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	28627	16207	820	770	6700	120	490	340	220	ND	ND	ND	6700	47
BW10	Standish Dam	8/16/96	12	12288	5058	220	270	2100	ND	160	150	72	ND	ND	50	2000	36

Table 5. Total (dissolved + particulate) PAH concentrations in water samples, 1996.. = no data, NA = not analyzed, ND = not detected, DEG = analyte degraded in standard: could not get accurate value, QS = outlier value qualified by SFEI, R = unacceptably low surrogate recovery, CE = coelution, LPAH = low molecular weight PAHs, * = not available at the time of report production. For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PAHs (SFEI)	Sum of L PAHs (SFEI)	Biphenyl	Naphthalene	1-Methylnaphthalene	2-Methylnaphthalene	2,6-Dimethylnaphthalene	2,3,5-Trimethylnaphthalene	Acenaphthene	Acenaphthylene	Anthracene	Dibenzothiophene	Fluorene	Phenanthrene	1-Methylphenanthrene
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	11632	7138	1300	345	540	1890	205	123	QS	QS	85	56	720	1480	249
BG30	San Joaquin River	2/14/96	10	.	.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BF20	Grizzly Bay	2/13/96	10	31639	21090	1640	330	1160	3700	1390	1320	QS	2870	353	239	2790	4600	610
BD50	Napa River	2/13/96	10	21565	13385	790	479	1230	3630	337	199	1556	706	113	115	1450	2410	370
BD40	Davis Point	2/12/96	10	20961	10481	860	372	850	2380	360	204	942	368	103	122	1250	2300	370
BD30	Pinole Point	2/12/96	10	20117	9596	900	1610	670	1770	280	168	424	301	58	86	890	2200	239
BD20	San Pablo Bay	2/12/96	10	20484	10150	930	1590	820	2120	320	201	436	382	63	98	900	1960	330
BD15	Petaluma River	2/12/96	10	68182	14963	740	3210	1230	3090	280	231	590	590	371	201	1150	2170	1110
BC60	Red Rock	2/7/96	10	29721	14432	1140	2170	920	2530	480	248	660	420	62	162	1250	3600	790
BC20	Golden Gate	2/7/96	10	21279	12735	1300	1940	595	1860	394	150	478	161	19	138	1070	3700	930
BC10	Yerba Buena Island	2/7/96	10	37490	17079	1350	2290	880	2560	263	240	689	530	87	220	1750	5100	1120
BB70	Alameda	2/7/96	10	30706	10706	353	730	400	1100	160	152	827	248	109	167	1120	4300	1040
BA40	Redwood Creek	2/6/96	10	50001	12387	870	1440	610	1810	340	184	510	520	117	126	960	4100	800
BA30	Dumbarton Bridge	2/5/96	10	48646	14818	1070	2350	1010	2600	257	210	649	540	155	207	1280	3600	890
BA10	Coyote Creek	2/6/96	10	62020	12533	910	1780	870	1970	370	300	630	560	254	189	1240	2610	850
C-3-0	San Jose	2/6/96	10	69636	18137	1240	1030	1520	3250	600	470	1100	640	397	330	2070	4700	790
BW10	Standish Dam	3/4/96	10	55782	20085	990	235	940	2540	420	480	QS	670	600	510	1920	8800	1790
BG20	Sacramento River	4/23/96	11	6336	3746	234	680	953	DEG	210	172	QS	100	24	26	472	760	115
BG30	San Joaquin River	4/23/96	11	2503	1799	96	660	360	DEG	120	86	CE	22	ND	ND	200	220	35
BF20	Grizzly Bay	4/24/96	11	14253	4450	315	600	770	DEG	407	224	QS	85	32	68	470	1250	206
BD50	Napa River	4/23/96	11	34058	9304	480	1460	930	DEG	339	251	1069	164	160	141	1140	2800	370
BD40	Davis Point	4/22/96	11	51725	9297	530	1460	710	DEG	283	209	690	224	362	199	980	3180	470
BD30	Pinole Point	4/22/96	11	31016	7396	510	1110	690	DEG	280	202	485	176	146	137	800	2500	360
BD20	San Pablo Bay	4/22/96	11	22294	4925	330	315	500	DEG	246	142	381	150	45	69	610	1910	227
BD15	Petaluma River	4/22/96	11	2E+05	23546	1570	510	1590	DEG	930	510	890	1017	2248	702	1960	10020	1599
BC60	Red Rock	4/29/96	11	12124	5476	296	115	362	DEG	194	100	300	109	ND	55	1057	2690	198
BC20	Golden Gate	4/29/96	11	3830	2467	302	203	476	DEG	150	64	98	46	ND	19	280	790	39
BC10	Yerba Buena Island	4/30/96	11	24624	12140	633	1065	1243	DEG	386	190	1300	223	ND	88	2078	4650	284
BB70	Alameda	4/30/96	11	15406	7966	386	894	996	DEG	287	140	620	218	ND	44	1363	2820	198
BA40	Redwood Creek	5/2/96	11	43580	7250	420	194	470	DEG	273	156	606	300	76	165	950	3300	340
BA30	Dumbarton Bridge	5/2/96	11	77865	10350	560	290	560	DEG	300	200	810	380	250	260	1330	4900	510
BA10	Coyote Creek	5/1/96	11	2E+05	22041	1300	510	1100	DEG	770	430	1550	1010	1381	500	2400	9900	1190
C-3-0	San Jose	5/1/96	11	8E+05	44290	2330	870	2050	DEG	1590	860	2350	3150	3880	1210	3900	19400	2700
BW10	Standish Dam	4/16/96	11	19461	5811	376	313	723	DEG	428	307	ND	140	147	64	773	1970	570
BG20	Sacramento River	7/22/96	12	15124	7073	370	2810	800	DEG	230	138	293	111	35	38	560	1500	188
BG30	San Joaquin River	7/22/96	12	12321	7061	328	1920	860	DEG	301	233	798	129	78	51	850	1330	183
BF20	Grizzly Bay	7/23/96	12	96817	16652	590	1900	650	DEG	400	330	470	302	640	370	1860	7900	1240
BD50	Napa River	7/24/96	12	32505	9060	280	1210	540	DEG	270	203	623	158	229	217	1210	3600	520
BD40	Davis Point	7/23/96	12	35907	10851	590	2000	920	DEG	510	286	591	240	150	184	1450	3500	430
BD30	Pinole Point	7/23/96	12	17032	6382	320	1400	560	DEG	278	158	672	139	28	92	990	1560	185
BD20	San Pablo Bay	7/24/96	12	.	.	R	R	R	R	R	R	R	R	R	R	R	R	R
BD15	Petaluma River	7/24/96	12	.	.	R	R	R	R	R	R	R	R	R	R	R	R	R
BC60	Red Rock	7/24/96	12	12731	6259	281	1390	508	DEG	244	159	310	135	ND	75	990	1970	197
BC20	Golden Gate	7/25/96	12	5848	4188	192	1260	423	DEG	164	100	380	46	ND	42	491	1040	50
BC10	Yerba Buena Island	7/26/96	12	.	.	*	*	*	*	*	*	*	*	*	*	*	*	*
BB70	Alameda	7/26/96	12	.	.	R	R	R	R	R	R	R	R	R	R	R	R	R
BA40	Redwood Creek	7/29/96	12	74676	12119	600	1840	790	DEG	420	208	350	510	QS	171	1120	5100	600
BA30	Dumbarton Bridge	7/29/96	12	33750	8571	440	1330	610	DEG	269	191	618	259	75	159	1040	3300	280
BA10	Coyote Creek	7/30/96	12	.	.	*	*	*	*	*	*	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	1E+05	45910	3110	7700	2730	DEG	1700	1020	2300	2360	2020	970	4700	15900	1400
BW10	Standish Dam	8/16/96	12	55516	11659	630	560	1110	DEG	279	311	840	330	250	149	1650	4900	650

Table 5. Total (dissolved + particulate) PAH concentrations in water samples, 1996 (continued). . = no data, NA = not analyzed, ND = not detected, QS = outlier value qualified by SFEI, R = unacceptably low surrogate recovery, HPAH = high molecular weight PAHs, * = not available at the time of report production. For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PAHs (SFEI)	Sum of HPAHs (SFEI)	Benz(a)anthracene	Chrysene	Pyrene	Benzo(a)pyrene	Benzo(e)pyrene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Dibenz(a,h)anthracene	Perylene	Benzo(ghi)perylene	Fluoranthene	Indeno(1,2,3-cd)pyrene
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	11632	4494	144	228	1030	30	402	330	928	ND	18	34	1180	170
BG30	San Joaquin River	2/14/96	10	.	.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BF20	Grizzly Bay	2/13/96	10	31639	10549	280	500	1880	187	940	1026	2740	280	115	163	1930	508
BD50	Napa River	2/13/96	10	21565	8180	405	516	2120	71	770	820	1090	100	18	ND	1860	410
BD40	Davis Point	2/12/96	10	20961	10480	543	719	2350	81	1060	1300	1310	160	37	ND	1930	990
BD30	Pinole Point	2/12/96	10	20117	10521	566	666	2220	20	1330	1400	889	220	ND	ND	2210	1000
BD20	San Pablo Bay	2/12/96	10	20484	10334	554	693	2230	32	1310	1200	1005	250	ND	ND	1960	1100
BD15	Petaluma River	2/12/96	10	68182	53219	2630	2850	8400	94	5660	6592	4050	1221	47	7500	5640	8535
BC60	Red Rock	2/7/96	10	29721	15289	890	1100	3160	30	1810	2000	1489	300	ND	ND	2810	1700
BC20	Golden Gate	2/7/96	10	21279	8544	580	740	1920	ND	1070	995	730	79	ND	ND	2190	240
BC10	Yerba Buena Island	2/7/96	10	37490	20411	1120	1480	4100	35	2500	1856	1480	640	ND	ND	4700	2500
BB70	Alameda	2/7/96	10	30706	20000	1240	1520	4600	23	2370	2567	1370	630	ND	ND	2880	2800
BA40	Redwood Creek	2/6/96	10	50001	37614	1900	2400	6500	25	5050	4660	2479	1400	ND	ND	5800	7400
BA30	Dumbarton Bridge	2/5/96	10	48646	33828	1680	2190	5900	26	4450	4643	2510	1200	ND	29	5200	6000
BA10	Coyote Creek	2/6/96	10	62020	49487	2300	2910	8500	54	5460	6559	2986	1200	18	5700	6200	7600
C-3-0	San Jose	2/6/96	10	69636	51499	1910	2740	7300	3900	4720	7039	3384	1100	74	6632	5900	6800
BW10	Standish Dam	3/4/96	10	55782	35697	690	4860	7900	580	720	1548	8920	1900	880	194	6700	805
BG20	Sacramento River	4/23/96	11	6336	2590	162	221	820	ND	150	220	83	17	ND	ND	890	27
BG30	San Joaquin River	4/23/96	11	2503	704	34	ND	510	ND	ND	ND	QS	ND	ND	ND	160	ND
BF20	Grizzly Bay	4/24/96	11	14253	9803	948	900	2270	ND	914	1328	420	130	ND	110	1840	847
BD50	Napa River	4/23/96	11	34058	24754	2940	1480	5800	ND	2095	3160	962	440	ND	ND	5000	2821
BD40	Davis Point	4/22/96	11	51725	42428	5320	2393	7300	ND	3658	5849	1923	790	ND	4400	5900	4823
BD30	Pinole Point	4/22/96	11	31016	23620	2910	1458	4700	ND	2370	3549	1123	400	ND	ND	4200	2827
BD20	San Pablo Bay	4/22/96	11	22294	17369	2159	1271	3170	ND	2240	3143	986	400	ND	ND	1100	2900
BD15	Petaluma River	4/22/96	11	246744	223198	27130	11130	40200	26000	19100	33110	9858	3900	170	24000	5600	23000
BC60	Red Rock	4/29/96	11	12124	6648	385	520	970	ND	713	920	362	58	ND	ND	2720	ND
BC20	Golden Gate	4/29/96	11	3830	1363	44	141	99	ND	150	230	89	ND	ND	ND	610	ND
BC10	Yerba Buena Island	4/30/96	11	24624	12484	791	720	1300	ND	970	1444	519	140	ND	ND	6000	600
BB70	Alameda	4/30/96	11	15406	7440	380	537	610	ND	720	1100	400	93	ND	ND	3600	ND
BA40	Redwood Creek	5/2/96	11	43580	36330	3785	2160	5700	ND	3890	5582	1743	670	ND	1500	6100	5200
BA30	Dumbarton Bridge	5/2/96	11	77865	67515	6510	3310	10000	ND	6520	9810	3065	1300	ND	8700	9100	9200
BA10	Coyote Creek	5/1/96	11	201476	179435	19270	9600	29800	19000	16140	26150	8975	3000	ND	21000	5500	21000
C-3-0	San Jose	5/1/96	11	847025	802735	100480	37460	94200	6600	85400	170350	37220	16021	46000	98025	15900	95079
BW10	Standish Dam	4/16/96	11	19461	13650	1340	830	4700	116	860	1070	387	140	ND	810	2770	560
BG20	Sacramento River	7/22/96	12	15124	8051	740	770	2020	89	600	688	225	95	ND	ND	2200	624
BG30	San Joaquin River	7/22/96	12	12321	5260	446	260	1960	ND	216	302	72	ND	ND	90	1820	94
BF20	Grizzly Bay	7/23/96	12	96817	80165	8120	5020	14100	5923	5910	7776	1272	1200	44	5200	16200	9400
BD50	Napa River	7/24/96	12	32505	23445	1960	1380	6500	117	1330	1788	280	290	ND	ND	7200	2600
BD40	Davis Point	7/23/96	12	35907	25056	2785	1610	4900	170	2347	3151	413	480	ND	ND	5400	3800
BD30	Pinole Point	7/23/96	12	17032	10650	1259	905	2000	140	1236	1500	110	190	ND	ND	2110	1200
BD20	San Pablo Bay	7/24/96	12	.	.	R	R	R	R	R	R	R	R	R	R	R	R
BD15	Petaluma River	7/24/96	12	.	.	R	R	R	R	R	R	R	R	R	R	R	R
BC60	Red Rock	7/24/96	12	12731	6472	400	660	680	ND	810	750	247	85	ND	ND	2840	ND
BC20	Golden Gate	7/25/96	12	5848	1660	ND	176	200	28	110	99	87	ND	ND	ND	960	ND
BC10	Yerba Buena Island	7/26/96	12	.	.	*	*	*	*	*	*	*	*	*	*	*	*
BB70	Alameda	7/26/96	12	.	.	R	R	R	R	R	R	R	R	R	R	R	R
BA40	Redwood Creek	7/29/96	12	74676	62557	6547	3600	9980	650	5277	7593	1310	1100	ND	8100	9000	9400
BA30	Dumbarton Bridge	7/29/96	12	33750	25179	2497	1820	4300	200	2710	3689	553	510	ND	ND	4400	4500
BA10	Coyote Creek	7/30/96	12	.	.	*	*	*	*	*	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	144487	98577	8620	3870	27700	6120	5490	11340	2020	870	ND	7100	18700	6747
BW10	Standish Dam	8/16/96	12	55516	43857	3820	2870	7600	310	4660	6750	2872	880	19	5550	2390	6136

Table 6. Dissolved PCB concentrations in water samples, 1996. . = no data, ND = not detected, CE = coelution, * = not available at the time of report production, « = originally reported as PCB 005/8. For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 008	PCB 018	PCB 028	PCB 031	PCB 033	PCB 044	PCB 049	PCB 052	PCB 060	PCB 066	PCB 070	PCB 074	PCB 087
					pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	96	4.9	8.0	6.4	8.5	.	3.9	2.9	CE	2.1	6.7	4.5	1.1	1.7
BG30	San Joaquin River	2/14/96	10	99	ND	7.2	5.6	9.0	.	4.1	3.2	CE	1.7	6.4	3.7	1.1	1.6
BF20	Grizzly Bay	2/13/96	10	135	6.7	9.6	6.9	11.0	.	4.3	4.4	CE	2.3	8.5	5.4	2.0	1.8
BD50	Napa River	2/13/96	10	99	ND	7.0	4.7	7.5	.	3.7	3.8	CE	2.4	7.4	4.0	ND	2.1
BD40	Davis Point	2/12/96	10	107	ND	8.4	5.2	8.4	.	3.4	4.9	CE	1.9	7.3	3.7	ND	2.1
BD30	Pinole Point	2/12/96	10	123	5.0	8.9	6.1	7.4	.	4.1	6.3	CE	1.9	7.8	3.9	ND	2.4
BD20	San Pablo Bay	2/12/96	10	98	ND	9.4	5.5	7.2	.	2.8	4.3	CE	1.1	6.7	3.4	ND	2.0
BD15	Petaluma River	2/12/96	10	144	ND	13.0	5.0	5.4	.	4.5	4.9	CE	2.4	9.5	4.0	1.5	2.5
BC60	Red Rock	2/7/96	10	86	ND	7.6	5.0	6.6	.	3.4	3.3	CE	ND	7.1	3.4	1.3	1.6
BC20	Golden Gate	2/7/96	10	63	ND	3.9	3.4	4.1	.	2.2	2.6	CE	1.6	3.5	2.7	1.2	1.4
BC10	Yerba Buena Island	2/7/96	10	127	6.9	14.0	5.9	8.5	.	5.3	5.8	CE	2.3	7.6	4.1	1.6	2.5
BB70	Alameda	2/7/96	10	119	2.9	11.0	6.1	7.9	.	5.0	6.4	CE	2.5	4.3	5.1	1.9	2.3
BA40	Redwood Creek	2/6/96	10	265	13.0	35.0	15.0	26.0	.	10.0	7.0	CE	3.7	16.0	7.2	2.8	3.9
BA30	Dumbarton Bridge	2/5/96	10	239	12.0	20.0	15.0	22.0	.	9.4	5.8	CE	4.9	15.0	9.4	3.6	5.6
BA10	Coyote Creek	2/6/96	10	243	11.0	21.0	11.0	23.0	.	9.5	6.0	CE	4.2	18.0	8.3	2.9	4.6
C-3-0	San Jose	2/6/96	10	670	35.0	86.0	36.0	72.0	.	29.0	14.0	CE	8.1	47.0	20.0	6.2	12.0
BW10	Standish Dam	3/4/96	10	351	8.0	20.0	15.0	17.0	.	11.0	8.3	CE	3.4	25.0	8.8	2.3	5.7
BG20	Sacramento River	4/23/96	11	97	1.2 «	5.3	6.1	6.4	.	5.0	3.6	CE	5.3	9.4	4.6	2.1	1.9
BG30	San Joaquin River	4/23/96	11	122	1.4 «	5.9	5.4	7.4	.	6.4	6.9	CE	10.0	11.0	5.9	3.2	2.6
BF20	Grizzly Bay	4/24/96	11	127	1.7 «	6.5	6.3	8.5	.	6.5	4.5	CE	5.8	11.0	5.7	3.0	3.2
BD50	Napa River	4/23/96	11	134	1.5 «	7.0	6.4	7.0	.	5.9	4.3	CE	4.3	12.0	6.8	3.5	2.5
BD40	Davis Point	4/22/96	11	132	2.4 «	5.9	5.1	9.5	.	6.3	9.3	CE	1.5	11.0	7.0	3.9	2.0
BD30	Pinole Point	4/22/96	11	121	3.2 «	5.7	2.3	6.3	.	5.8	7.9	CE	4.2	9.7	7.5	1.4	1.8
BD20	San Pablo Bay	4/22/96	11	98	1.3 «	3.4	4.7	5.1	.	4.9	4.8	CE	2.7	7.2	4.4	1.7	2.3
BD15	Petaluma River	4/22/96	11	163	1.7 «	5.4	5.8	6.5	.	6.4	5.7	CE	4.1	9.8	5.8	2.4	3.0
BC60	Red Rock	4/29/96	11	141	2.5 «	5.5	7.2	8.4	.	6.6	4.9	CE	1.7	10.0	7.3	3.3	3.2
BC20	Golden Gate	4/29/96	11	73	1.2 «	4.0	4.6	5.9	.	4.4	2.9	CE	3.8	6.0	4.5	1.5	1.8
BC10	Yerba Buena Island	4/30/96	11	128	2.4 «	5.2	7.4	7.8	.	7.3	5.9	CE	4.3	8.2	6.2	2.7	2.9
BB70	Alameda	4/30/96	11	149	2.3 «	6.7	9.3	8.9	.	8.4	6.5	CE	5.3	10.0	8.1	3.0	2.1
BA40	Redwood Creek	5/2/96	11	173	2.5 «	CE	10.0	12.0	.	8.5	6.6	CE	2.0	12.0	8.8	3.0	3.9
BA30	Dumbarton Bridge	5/2/96	11	234	4.5 «	7.4	8.2	11.0	.	10.0	5.8	CE	9.2	16.0	12.0	4.8	5.4
BA10	Coyote Creek	5/1/96	11	341	15.0 «	13.0	16.0	22.0	.	16.0	14.0	CE	11.0	20.0	12.0	5.2	7.4
C-3-0	San Jose	5/1/96	11	640	28.0 «	53.0	35.0	48.0	.	36.0	27.0	CE	17.0	30.0	24.0	9.7	12.0
BW10	Standish Dam	4/16/96	11	751	19.0 «	46.0	42.0	42.0	.	37.0	21.0	CE	24.0	66.0	25.0	12.0	12.0
BG20	Sacramento River	7/22/96	12	309	10.0 «	39.0	22.0	19.0	.	11.0	8.3	CE	6.7	17.0	17.0	8.0	7.2
BG30	San Joaquin River	7/22/96	12	108	2.3 «	7.1	6.0	7.0	.	5.9	4.9	CE	2.6	6.3	5.0	2.2	2.3
BF20	Grizzly Bay	7/23/96	12	124	2.0 «	5.6	4.8	5.4	.	4.7	3.8	CE	3.2	6.3	5.3	2.3	2.8
BD50	Napa River	7/24/96	12	105	1.9 «	4.6	3.8	5.1	.	4.9	4.4	CE	3.2	6.5	4.4	1.7	2.6
BD40	Davis Point	7/23/96	12	116	3.4 «	5.3	4.3	5.0	.	5.7	6.0	CE	3.8	5.3	4.5	1.9	2.8
BD30	Pinole Point	7/23/96	12	107	3.3 «	5.2	3.9	4.8	.	5.2	6.5	CE	3.9	5.1	4.1	1.7	2.5
BD20	San Pablo Bay	7/24/96	12	95	2.9 «	4.9	3.4	4.0	.	4.7	3.8	CE	2.9	4.1	3.9	1.7	2.2
BD15	Petaluma River	7/24/96	12	104	1.5 «	2.8	2.8	3.0	.	3.6	3.6	CE	2.5	4.2	3.5	1.7	2.6
BC60	Red Rock	7/24/96	12	75	2.4 «	4.3	3.2	3.5	.	3.7	4.1	CE	ND	3.7	3.3	1.4	1.8
BC20	Golden Gate	7/25/96	12	41	2.0 «	2.4	2.6	1.6	.	1.3	4.7	CE	1.5	3.2	2.2	1.5	1.1
BC10	Yerba Buena Island	7/26/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*
BB70	Alameda	7/26/96	12	145	5.1 «	6.6	6.2	6.8	.	6.5	6.0	CE	4.9	6.2	6.4	3.0	3.0
BA40	Redwood Creek	7/29/96	12	149	3.2 «	5.1	5.0	5.9	.	6.0	5.3	CE	5.6	5.6	5.4	2.5	3.1
BA30	Dumbarton Bridge	7/29/96	12	189	3.9 «	6.2	6.7	8.1	.	7.1	8.1	CE	4.7	7.8	5.8	3.4	4.1
BA10	Coyote Creek	7/30/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	1190	33.0 «	140.0	77.0	87.0	.	85.0	71.0	CE	25.0	41.0	47.0	20.0	24.0
BW10	Standish Dam	8/16/96	12	896	45.0 «	68.0	49.0	64.0	.	49.0	31.0	CE	8.4	58.0	38.0	16.0	18.0

Table 6. Dissolved PCB concentrations in water samples, 1996 (continued). . = no data, ND = not detected, * = not available at the time of report production. For method detection limits refer to Table 2 in *Appendix B.*

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 095	PCB 097	PCB 099	PCB 101	PCB 105	PCB 110	PCB 118	PCB 128	PCB 132	PCB 138	PCB 141	PCB 149	PCB 151
					pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	96	4.8	1.3	1.4	2.9	ND	5.8	1.9	ND	2.7	3.6	ND	5.6	2.2
BG30	San Joaquin River	2/14/96	10	99	5.3	1.2	1.8	4.7	ND	5.7	2.6	ND	3.1	4.0	1.1	6.7	3.5
BF20	Grizzly Bay	2/13/96	10	135	7.3	1.9	1.5	4.3	1.3	7.5	3.9	1.1	3.3	5.2	1.6	7.7	5.9
BD50	Napa River	2/13/96	10	99	7.0	1.3	2.0	4.9	ND	6.9	3.6	ND	3.2	4.3	ND	6.0	3.3
BD40	Davis Point	2/12/96	10	107	6.9	1.6	2.1	4.0	1.1	6.7	3.8	ND	3.4	4.5	ND	6.7	3.5
BD30	Pinole Point	2/12/96	10	123	8.7	1.7	3.4	4.6	ND	7.3	2.6	ND	3.5	5.3	ND	8.6	4.2
BD20	San Pablo Bay	2/12/96	10	98	6.3	1.5	2.1	4.7	ND	6.7	1.8	ND	2.8	4.0	ND	6.6	3.1
BD15	Petaluma River	2/12/96	10	144	11.0	2.6	4.5	7.3	1.1	9.9	5.7	1.3	3.9	5.9	1.2	8.8	3.6
BC60	Red Rock	2/7/96	10	86	7.8	1.3	2.9	3.5	ND	5.9	3.0	ND	2.2	3.1	ND	5.6	2.3
BC20	Golden Gate	2/7/96	10	63	3.7	1.3	2.0	3.7	ND	4.4	2.3	ND	2.2	3.0	ND	4.2	1.3
BC10	Yerba Buena Island	2/7/96	10	127	10.0	1.9	3.7	6.4	ND	7.2	4.2	ND	3.0	4.0	ND	6.5	2.7
BB70	Alameda	2/7/96	10	119	4.5	2.1	3.8	6.7	ND	8.0	4.7	ND	3.7	4.7	ND	7.5	2.3
BA40	Redwood Creek	2/6/96	10	265	21.0	4.0	8.0	13.0	1.1	12.0	7.1	1.2	5.1	8.1	1.7	12.0	4.4
BA30	Dumbarton Bridge	2/5/96	10	239	18.0	4.4	6.1	9.4	2.0	14.0	7.3	1.2	4.7	7.8	1.4	9.8	3.5
BA10	Coyote Creek	2/6/96	10	243	22.0	2.9	5.9	12.0	1.9	15.0	8.8	1.4	4.6	6.9	1.5	11.0	4.2
C-3-0	San Jose	2/6/96	10	670	65.0	9.1	15.0	29.0	4.1	34.0	15.0	2.5	11.0	17.0	4.0	27.0	11.0
BW10	Standish Dam	3/4/96	10	351	37.0	4.5	5.2	15.0	1.4	20.0	7.3	1.9	11.0	14.0	4.4	29.0	13.0
BG20	Sacramento River	4/23/96	11	97	3.8	1.5	ND	3.7	1.7	6.3	5.3	ND	1.5	3.5	1.0	5.5	2.1
BG30	San Joaquin River	4/23/96	11	122	3.6	1.4	1.2	4.3	1.1	7.6	7.0	ND	ND	5.2	ND	7.7	3.8
BF20	Grizzly Bay	4/24/96	11	127	4.9	2.2	2.7	4.9	1.6	7.6	6.4	ND	1.4	4.3	1.2	7.1	4.0
BD50	Napa River	4/23/96	11	134	8.8	3.0	4.1	6.2	1.2	7.7	6.8	ND	1.3	5.2	1.1	7.7	3.3
BD40	Davis Point	4/22/96	11	132	2.0	3.1	2.1	6.6	1.3	7.9	7.7	ND	ND	5.9	1.4	7.2	2.9
BD30	Pinole Point	4/22/96	11	121	2.1	2.6	2.1	5.9	1.7	7.3	5.3	ND	1.1	4.1	1.1	6.2	2.6
BD20	San Pablo Bay	4/22/96	11	98	7.1	2.1	2.6	5.3	1.4	6.7	3.8	ND	1.8	3.8	ND	6.3	2.5
BD15	Petaluma River	4/22/96	11	163	13.0	3.2	5.5	8.4	1.9	11.0	7.3	1.1	ND	7.0	1.1	12.0	3.9
BC60	Red Rock	4/29/96	11	141	9.4	2.9	3.4	5.4	1.5	8.5	7.4	ND	ND	5.6	1.5	8.3	5.1
BC20	Golden Gate	4/29/96	11	73	3.9	1.4	1.1	2.7	ND	3.5	3.9	ND	ND	2.1	ND	3.4	1.9
BC10	Yerba Buena Island	4/30/96	11	128	10.0	3.0	3.7	7.5	1.4	8.1	6.7	ND	ND	4.3	ND	7.6	2.6
BB70	Alameda	4/30/96	11	149	14.0	3.2	4.3	8.0	1.7	7.2	7.1	ND	1.5	5.5	1.2	7.3	2.6
BA40	Redwood Creek	5/2/96	11	173	12.0	4.0	6.2	9.7	2.1	10.0	9.8	1.2	ND	7.8	1.1	13.0	3.8
BA30	Dumbarton Bridge	5/2/96	11	234	13.0	5.5	9.3	13.0	2.9	15.0	13.0	1.5	ND	11.0	1.2	16.0	5.7
BA10	Coyote Creek	5/1/96	11	341	22.0	7.3	11.0	18.0	3.9	21.0	16.0	2.1	4.1	13.0	1.8	19.0	7.5
C-3-0	San Jose	5/1/96	11	640	42.0	14.0	17.0	35.0	6.3	35.0	22.0	3.6	9.3	21.0	2.8	29.0	12.0
BW10	Standish Dam	4/16/96	11	751	43.0	8.8	9.5	32.0	7.6	38.0	27.0	2.6	11.0	28.0	8.4	51.0	27.0
BG20	Sacramento River	7/22/96	12	309	13.0	4.2	6.3	16.0	3.6	14.0	15.0	1.0	3.6	10.0	2.5	11.0	8.5
BG30	San Joaquin River	7/22/96	12	108	7.6	1.6	2.4	6.0	ND	6.0	4.2	ND	1.7	4.3	ND	5.8	4.8
BF20	Grizzly Bay	7/23/96	12	124	8.5	2.6	3.1	7.8	ND	7.8	5.6	ND	2.3	5.9	1.2	8.2	4.7
BD50	Napa River	7/24/96	12	105	8.5	2.4	3.3	8.2	ND	7.6	4.5	ND	2.5	4.7	ND	5.0	3.0
BD40	Davis Point	7/23/96	12	116	8.6	2.7	3.7	8.2	ND	7.9	5.1	ND	1.9	5.0	ND	7.0	4.0
BD30	Pinole Point	7/23/96	12	107	7.9	2.5	3.3	7.0	ND	6.8	4.7	ND	1.9	4.4	ND	6.3	3.4
BD20	San Pablo Bay	7/24/96	12	95	8.4	2.3	3.3	6.8	ND	6.6	3.5	ND	1.7	4.1	ND	5.8	3.3
BD15	Petaluma River	7/24/96	12	104	7.8	2.7	3.8	7.7	1.1	7.6	4.8	ND	1.7	5.5	ND	7.2	3.4
BC60	Red Rock	7/24/96	12	75	6.2	1.6	2.2	5.6	ND	5.7	3.2	ND	1.4	3.1	ND	4.6	2.4
BC20	Golden Gate	7/25/96	12	41	2.5	ND	ND	3.1	ND	2.4	1.8	ND	ND	1.5	ND	2.1	1.6
BC10	Yerba Buena Island	7/26/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*
BB70	Alameda	7/26/96	12	145	12.0	3.1	4.8	11.0	1.1	8.7	6.4	ND	2.2	5.6	1.1	8.3	3.9
BA40	Redwood Creek	7/29/96	12	149	12.0	3.4	6.0	11.0	1.2	9.9	6.8	1.0	2.6	6.9	ND	9.5	4.5
BA30	Dumbarton Bridge	7/29/96	12	189	14.0	3.8	6.9	14.0	1.9	12.0	8.4	1.2	3.1	8.5	ND	11.0	5.1
BA10	Coyote Creek	7/30/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	1190	100.0	23.0	31.0	74.0	6.6	54.0	32.0	4.0	15.0	30.0	5.6	49.0	19.0
BW10	Standish Dam	8/16/96	12	896	54.0	16.0	18.0	42.0	12.0	45.0	43.0	4.6	11.0	29.0	6.7	44.0	24.0

Table 6. Dissolved PCB concentrations in water samples, 1996 (continued).. = no data, ND = not detected, * = not available at the time of report production. For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 153	PCB 156	PCB 158	PCB 170	PCB 174	PCB 177	PCB 180	PCB 183	PCB 187	PCB 194	PCB 195	PCB 201	PCB 203	Hexachlorobenzene
					pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	96	7.8	ND	ND	ND	1.3	ND	2.0	ND	2.1	ND	ND	.	ND	8.9
BG30	San Joaquin River	2/14/96	10	99	6.8	ND	1.1	ND	1.4	ND	2.2	1.0	3.2	ND	ND	.	ND	13.2
BF20	Grizzly Bay	2/13/96	10	135	8.0	ND	ND	1.1	1.8	1.0	2.7	1.5	3.7	ND	ND	.	ND	17.0
BD50	Napa River	2/13/96	10	99	6.7	ND	ND	ND	1.3	ND	1.9	1.0	2.5	ND	ND	.	ND	9.5
BD40	Davis Point	2/12/96	10	107	8.5	ND	ND	1.1	1.5	ND	2.5	1.1	2.9	ND	ND	.	ND	11.5
BD30	Pinole Point	2/12/96	10	123	9.0	ND	ND	ND	1.6	1.0	2.5	1.2	3.6	ND	ND	.	ND	11.4
BD20	San Pablo Bay	2/12/96	10	98	8.0	ND	ND	ND	1.2	ND	2.3	1.2	2.8	ND	ND	.	ND	10.1
BD15	Petaluma River	2/12/96	10	144	11.0	ND	ND	1.2	1.4	1.4	3.4	1.3	4.3	ND	ND	.	0.4	9.3
BC60	Red Rock	2/7/96	10	86	6.0	ND	ND	ND	ND	ND	1.1	ND	2.0	ND	ND	.	ND	10.8
BC20	Golden Gate	2/7/96	10	63	4.7	ND	ND	ND	ND	ND	1.2	ND	1.9	ND	ND	.	ND	4.0
BC10	Yerba Buena Island	2/7/96	10	127	7.0	ND	ND	ND	1.1	ND	2.0	ND	2.6	ND	ND	.	ND	8.5
BB70	Alameda	2/7/96	10	119	8.4	ND	ND	ND	1.3	ND	2.2	1.0	2.7	ND	ND	.	ND	5.8
BA40	Redwood Creek	2/6/96	10	265	13.0	ND	ND	1.3	1.8	1.4	3.4	1.4	4.7	ND	ND	.	ND	8.0
BA30	Dumbarton Bridge	2/5/96	10	239	13.0	ND	1.1	1.1	1.4	1.2	3.2	1.2	4.0	ND	ND	.	ND	9.6
BA10	Coyote Creek	2/6/96	10	243	12.0	ND	ND	1.4	1.7	1.4	3.3	1.4	4.5	ND	ND	.	ND	12.1
C-3-0	San Jose	2/6/96	10	670	27.0	2.0	1.7	2.7	4.1	2.6	7.5	3.0	8.1	1.3	ND	.	1.1	53.0
BW10	Standish Dam	3/4/96	10	351	25.0	ND	1.8	4.2	6.0	3.2	9.4	2.6	8.8	1.6	ND	.	ND	8.9
BG20	Sacramento River	4/23/96	11	97	5.3	ND	ND	ND	1.1	ND	1.9	ND	2.0	ND	ND	.	ND	8.1
BG30	San Joaquin River	4/23/96	11	122	7.0	ND	ND	ND	1.2	ND	2.0	ND	2.3	ND	ND	.	ND	16.0
BF20	Grizzly Bay	4/24/96	11	127	7.3	ND	ND	ND	1.4	ND	2.9	1.1	2.9	ND	ND	.	ND	12.0
BD50	Napa River	4/23/96	11	134	8.7	ND	ND	ND	1.2	ND	2.6	1.2	3.1	ND	ND	.	ND	6.5
BD40	Davis Point	4/22/96	11	132	9.1	ND	ND	1.1	1.2	ND	2.8	1.4	2.6	2.0	ND	.	ND	10.0
BD30	Pinole Point	4/22/96	11	121	7.7	ND	ND	ND	1.0	1.1	2.4	1.5	2.9	6.7	ND	.	ND	10.0
BD20	San Pablo Bay	4/22/96	11	98	6.5	ND	ND	ND	1.0	ND	2.1	ND	2.4	ND	ND	.	ND	7.8
BD15	Petaluma River	4/22/96	11	163	12.0	ND	ND	1.3	1.8	1.3	4.5	2.5	4.8	1.7	ND	.	1.4	18.0
BC60	Red Rock	4/29/96	11	141	9.8	ND	ND	1.8	1.6	ND	3.1	1.6	3.2	ND	ND	.	ND	5.9
BC20	Golden Gate	4/29/96	11	73	4.0	ND	ND	1.1	ND	ND	1.6	ND	1.5	ND	ND	.	ND	6.0
BC10	Yerba Buena Island	4/30/96	11	128	7.2	ND	ND	ND	1.0	ND	1.9	ND	2.2	ND	ND	.	ND	3.4
BB70	Alameda	4/30/96	11	149	7.5	ND	ND	ND	1.3	ND	2.1	1.1	2.6	ND	ND	.	ND	8.9
BA40	Redwood Creek	5/2/96	11	173	13.0	ND	ND	ND	1.1	1.1	2.3	1.9	3.5	ND	ND	.	ND	1.4
BA30	Dumbarton Bridge	5/2/96	11	234	17.0	ND	1.3	1.3	1.3	1.5	3.2	2.3	4.9	ND	ND	.	ND	1.7
BA10	Coyote Creek	5/1/96	11	341	20.0	1.0	1.4	1.6	1.9	1.9	4.3	3.4	6.8	ND	ND	.	ND	29.0
C-3-0	San Jose	5/1/96	11	640	31.0	1.4	2.1	3.6	3.9	3.5	8.5	4.8	11.0	1.3	ND	.	ND	49.0
BW10	Standish Dam	4/16/96	11	751	40.0	1.1	3.0	7.5	9.3	4.9	20.0	5.0	14.0	3.0	1.2	.	2.0	32.0
BG20	Sacramento River	7/22/96	12	309	16.0	ND	1.2	1.4	2.3	1.6	5.8	1.9	4.6	ND	ND	.	ND	27.0
BG30	San Joaquin River	7/22/96	12	108	6.5	ND	ND	ND	1.1	ND	2.0	ND	2.5	ND	ND	.	ND	30.4
BF20	Grizzly Bay	7/23/96	12	124	9.0	ND	ND	ND	1.3	1.1	3.5	1.4	3.3	ND	ND	.	ND	5.7
BD50	Napa River	7/24/96	12	105	7.2	ND	ND	ND	ND	ND	1.8	1.1	2.4	ND	ND	.	ND	4.2
BD40	Davis Point	7/23/96	12	116	7.7	ND	ND	ND	ND	ND	2.3	1.1	2.6	ND	ND	.	ND	5.2
BD30	Pinole Point	7/23/96	12	107	6.6	ND	ND	ND	ND	ND	2.0	1.2	2.6	ND	ND	.	ND	4.2
BD20	San Pablo Bay	7/24/96	12	95	6.5	ND	ND	ND	ND	ND	1.6	ND	2.2	ND	ND	.	ND	3.4
BD15	Petaluma River	7/24/96	12	104	8.9	ND	ND	ND	1.0	1.2	2.3	1.9	3.3	ND	ND	.	ND	2.7
BC60	Red Rock	7/24/96	12	75	4.8	ND	ND	ND	ND	ND	1.4	ND	1.6	ND	ND	.	ND	ND
BC20	Golden Gate	7/25/96	12	41	2.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.	ND	5.3
BC10	Yerba Buena Island	7/26/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*	*
BB70	Alameda	7/26/96	12	145	8.4	ND	ND	ND	1.2	ND	2.5	1.3	2.9	ND	ND	.	ND	4.5
BA40	Redwood Creek	7/29/96	12	149	11.0	ND	ND	ND	1.0	1.3	2.4	1.6	3.9	ND	ND	.	ND	3.5
BA30	Dumbarton Bridge	7/29/96	12	189	13.0	ND	1.1	1.1	1.3	1.7	3.3	2.2	4.9	ND	ND	.	4.4	3.1
BA10	Coyote Creek	7/30/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	1190	44.0	1.7	3.0	4.9	5.8	5.1	11.0	5.6	14.0	1.2	ND	.	ND	14.5
BW10	Standish Dam	8/16/96	12	896	43.0	ND	2.6	7.6	7.5	4.4	15.0	5.2	13.0	2.5	ND	.	1.7	34.0

Table 7. Total (dissolved + particulate) PCB concentrations in water samples, 1996.. = no data, ND = not detected, CE = coelution, NA = not anaylzed, * = not available at the time of report production, « = originally reported as PCB 005/8. For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 008	PCB 018	PCB 028	PCB 031	PCB 033	PCB 044	PCB 049	PCB 052	PCB 060	PCB 066	PCB 070	PCB 074	PCB 087
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	165	6.3	10.5	8.1	10.3	.	4.9	2.9	14.0	2.1	8.0	6.1	1.1	3.0
BG30	San Joaquin River	2/14/96	10	NA	NA	NA	NA	NA	.	NA	NA	NA	NA	NA	NA	NA	NA
BF20	Grizzly Bay	2/13/96	10	282	6.7	11.7	10.5	14.6	.	6.9	6.6	26.0	23.3	11.3	8.1	2.0	4.1
BD50	Napa River	2/13/96	10	262	ND	8.4	8.7	10.9	.	5.9	6.4	20.0	4.3	11.6	7.9	ND	6.3
BD40	Davis Point	2/12/96	10	298	ND	8.4	9.6	12.1	.	5.4	7.2	22.0	3.7	13.0	8.8	ND	8.8
BD30	Pinole Point	2/12/96	10	399	5.0	8.9	10.6	11.1	.	6.8	11.1	30.0	4.7	14.7	9.6	1.6	8.3
BD20	San Pablo Bay	2/12/96	10	397	ND	11.5	9.7	11.1	.	7.3	8.5	34.0	4.1	12.9	10.5	1.1	11.0
BD15	Petaluma River	2/12/96	10	949	1.7	13.0	18.0	17.4	.	12.3	4.9	41.0	10.0	37.5	24.0	6.7	14.5
BC60	Red Rock	2/7/96	10	268	ND	7.6	8.2	9.5	.	6.5	6.2	14.0	2.2	11.9	6.9	2.5	5.3
BC20	Golden Gate	2/7/96	10	126	ND	3.9	4.5	4.1	.	2.2	3.7	15.0	1.6	5.1	3.8	1.2	1.4
BC10	Yerba Buena Island	2/7/96	10	360	8.5	15.5	10.5	12.5	.	7.9	9.8	17.0	6.1	13.9	9.4	3.7	6.8
BB70	Alameda	2/7/96	10	436	2.9	12.8	10.7	11.6	.	8.4	11.2	19.0	7.0	11.3	11.5	4.3	7.8
BA40	Redwood Creek	2/6/96	10	855	13.0	35.0	24.2	32.9	.	14.9	14.7	27.0	7.4	30.0	18.2	7.3	12.8
BA30	Dumbarton Bridge	2/5/96	10	608	14.0	21.7	21.4	26.7	.	13.4	10.8	18.0	9.2	25.0	17.2	6.8	11.3
BA10	Coyote Creek	2/6/96	10	1081	15.4	26.6	24.0	36.0	.	19.1	15.9	37.0	11.6	44.0	27.3	8.6	18.6
C-3-0	San Jose	2/6/96	10	1855	44.5	103.0	55.0	95.0	.	48.0	20.2	45.0	18.0	85.0	45.0	14.8	34.0
BW10	Standish Dam	3/4/96	10	5319	20.0	42.0	42.0	50.0	.	42.0	29.3	72.0	3.4	83.0	38.8	10.7	49.7
BG20	Sacramento River	4/23/96	11	172	7.4 «	6.5	6.1	12.7	.	7.9	3.6	CE	14.1	12.4	8.2	2.1	3.7
BG30	San Joaquin River	4/23/96	11	187	1.4 «	5.9	7.2	9.5	.	8.2	7.9	CE	15.2	13.5	7.5	3.2	3.6
BF20	Grizzly Bay	4/24/96	11	286	1.7 «	7.9	8.7	14.1	.	10.2	10.0	CE	18.8	17.2	10.1	5.2	7.0
BD50	Napa River	4/23/96	11	446	1.5 «	8.7	13.2	13.5	.	10.0	7.6	CE	13.7	23.0	14.6	6.5	7.0
BD40	Davis Point	4/22/96	11	773	5.3 «	8.9	13.7	25.5	.	15.5	26.3	CE	10.0	36.0	26.0	10.0	13.0
BD30	Pinole Point	4/22/96	11	460	3.2 «	7.7	10.0	14.1	.	11.6	10.4	CE	11.5	21.7	17.0	5.6	7.1
BD20	San Pablo Bay	4/22/96	11	325	1.3 «	4.4	7.8	9.2	.	4.9	12.4	CE	11.0	18.2	10.5	4.9	6.6
BD15	Petaluma River	4/22/96	11	2475	29.7 «	20.4	47.8	52.5	.	37.4	34.7	CE	63.1	89.8	66.8	26.4	43.0
BC60	Red Rock	4/29/96	11	249	2.5 «	5.5	8.8	9.8	.	8.7	7.0	CE	4.2	12.8	9.9	4.4	5.4
BC20	Golden Gate	4/29/96	11	125	3.3 «	4.0	4.6	5.9	.	5.7	6.5	CE	6.0	9.1	7.8	3.6	3.8
BC10	Yerba Buena Island	4/30/96	11	331	2.4 «	6.4	9.9	7.8	.	10.8	9.6	CE	6.5	14.8	11.5	2.7	6.4
BB70	Alameda	4/30/96	11	378	2.3 «	6.7	14.0	11.8	.	11.4	8.8	CE	10.9	16.1	13.3	5.4	5.6
BA40	Redwood Creek	5/2/96	11	720	2.5 «	1.9	17.5	18.7	.	14.4	12.6	CE	13.0	29.0	20.8	9.2	12.4
BA30	Dumbarton Bridge	5/2/96	11	1061	6.4 «	10.3	23.2	24.0	.	19.7	12.2	CE	25.2	42.0	32.0	14.2	17.4
BA10	Coyote Creek	5/1/96	11	3155	38.0 «	28.0	71.0	77.0	.	59.0	47.0	CE	73.0	130.0	94.0	42.2	60.4
C-3-0	San Jose	5/1/96	11	4947	62.0 «	77.0	98.0	109.0	.	83.0	60.0	CE	73.0	150.0	122.0	48.7	69.0
BW10	Standish Dam	4/16/96	11	2413	20.8 «	52.0	53.0	55.0	.	54.0	26.9	CE	76.0	92.0	41.0	15.3	30.0
BG20	Sacramento River	7/22/96	12	473	10.0 «	41.6	26.2	23.1	.	15.4	12.6	CE	27.7	24.4	24.5	11.5	10.0
BG30	San Joaquin River	7/22/96	12	302	2.3 «	9.8	10.6	11.4	.	10.6	7.7	CE	30.6	13.8	12.5	5.8	5.3
BF20	Grizzly Bay	7/23/96	12	715	4.7 «	10.0	17.8	15.1	.	15.7	12.0	CE	14.2	27.3	24.3	10.6	13.8
BD50	Napa River	7/24/96	12	416	3.1 «	6.9	9.8	10.0	.	10.5	10.2	CE	5.4	20.5	15.4	6.8	8.8
BD40	Davis Point	7/23/96	12	493	4.9 «	7.7	11.6	10.5	.	13.4	14.5	CE	6.2	20.3	17.5	8.0	9.5
BD30	Pinole Point	7/23/96	12	323	3.3 «	6.8	7.7	7.8	.	9.0	10.1	CE	9.7	12.5	10.5	4.9	6.8
BD20	San Pablo Bay	7/24/96	12	358	2.9 «	9.3	10.2	10.9	.	12.8	9.5	CE	7.9	21.1	20.9	9.5	8.1
BD15	Petaluma River	7/24/96	12	591	2.8 «	4.9	11.1	8.7	.	11.3	12.5	CE	13.5	22.2	17.5	7.9	10.7
BC60	Red Rock	7/24/96	12	2417	34.4 «	154.3	203.2	203.5	.	173.7	102.1	CE	150.0	243.7	243.3	131.4	47.8
BC20	Golden Gate	7/25/96	12	635	7.3 «	37.4	50.6	48.6	.	42.3	29.7	CE	35.5	71.2	64.2	33.5	13.1
BC10	Yerba Buena Island	7/26/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*
BB70	Alameda	7/26/96	12	942	9.5 «	33.6	42.2	44.8	.	54.5	32.0	CE	49.9	80.2	81.4	38.0	20.0
BA40	Redwood Creek	7/29/96	12	920	6.3 «	10.2	20.0	17.9	.	21.0	17.3	CE	13.0	38.6	34.4	15.5	17.1
BA30	Dumbarton Bridge	7/29/96	12	1263	11.6 «	38.2	54.7	56.1	.	63.1	35.1	CE	55.7	107.8	92.8	46.4	26.1
BA10	Coyote Creek	7/30/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	10313	93.0 «	270.0	367.0	317.0	.	285.0	261.0	CE	225.0	361.0	357.0	150.0	204.0
BW10	Standish Dam	8/16/96	12	2993	53.5 «	95.0	100.0	132.0	.	99.0	64.0	CE	40.4	152.0	104.0	43.0	77.0

Table 7. Total (dissolved + particulate) PCB concentrations in water samples, 1996 (continued). . = no data, ND = not detected, NA = not anaylzed, * = not available at the time of report production. For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 095	PCB 097	PCB 099	PCB 101	PCB 105	PCB 110	PCB 118	PCB 128	PCB 132	PCB 138	PCB 141	PCB 149	PCB 151
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	165	6.7	6.3	1.4	4.4	1.2	9.2	4.6	ND	5.1	6.7	ND	8.7	3.8
BG30	San Joaquin River	2/14/96	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BF20	Grizzly Bay	2/13/96	10	282	11.5	3.5	3.4	7.3	1.3	15.0	9.6	2.2	7.1	11.0	3.0	13.9	9.3
BD50	Napa River	2/13/96	10	262	11.3	3.4	4.6	10.4	2.6	15.2	11.1	1.8	9.0	13.7	2.1	15.5	7.2
BD40	Davis Point	2/12/96	10	298	12.5	4.1	5.8	11.9	2.7	17.7	12.3	2.0	10.1	17.5	1.5	17.7	8.7
BD30	Pinole Point	2/12/96	10	399	17.5	5.6	9.7	16.6	5.0	23.3	17.6	3.4	12.7	22.3	2.5	23.6	10.7
BD20	San Pablo Bay	2/12/96	10	397	19.3	7.2	9.0	20.7	5.4	26.7	20.8	3.6	12.6	22.0	2.6	22.6	9.4
BD15	Petaluma River	2/12/96	10	949	41.0	13.6	25.5	36.3	17.1	52.9	57.7	12.3	29.9	61.9	8.6	54.8	21.6
BC60	Red Rock	2/7/96	10	268	12.7	3.9	7.0	10.6	3.9	17.9	14.0	2.2	8.4	13.1	1.7	15.6	6.5
BC20	Golden Gate	2/7/96	10	126	5.3	1.3	3.7	6.1	ND	7.7	6.8	ND	4.6	7.5	ND	8.3	2.6
BC10	Yerba Buena Island	2/7/96	10	360	17.1	5.0	9.2	15.4	4.0	19.2	18.2	3.1	10.7	18.0	1.8	23.5	7.6
BB70	Alameda	2/7/96	10	436	14.5	6.8	11.8	20.7	4.9	24.0	23.7	4.3	14.7	26.7	2.9	26.5	9.3
BA40	Redwood Creek	2/6/96	10	855	36.0	11.2	22.0	37.0	11.1	42.0	43.1	9.0	26.1	49.1	8.5	50.0	18.4
BA30	Dumbarton Bridge	2/5/96	10	608	29.0	9.6	15.3	26.4	9.2	34.0	33.3	6.3	16.7	32.8	4.9	31.8	11.8
BA10	Coyote Creek	2/6/96	10	1081	53.0	14.9	26.9	48.0	16.9	58.0	58.8	12.4	31.6	64.9	9.9	60.0	22.2
C-3-0	San Jose	2/6/96	10	1855	115.0	28.1	38.0	76.0	25.1	95.0	80.0	15.5	50.0	96.0	19.0	100.0	40.0
BW10	Standish Dam	3/4/96	10	5319	277.0	32.5	53.2	145.0	27.4	150.0	81.3	43.9	241.0	364.0	104.4	479.0	193.0
BG20	Sacramento River	4/23/96	11	172	5.7	1.5	1.0	10.4	1.7	9.3	10.2	ND	1.5	7.7	2.2	10.1	2.1
BG30	San Joaquin River	4/23/96	11	187	5.1	2.6	2.7	7.3	2.2	10.5	11.4	ND	1.9	8.6	ND	11.3	5.6
BF20	Grizzly Bay	4/24/96	11	286	4.9	5.2	5.6	13.1	5.1	16.5	18.4	2.1	3.1	13.9	2.4	15.5	8.4
BD50	Napa River	4/23/96	11	446	18.3	8.2	11.6	23.2	6.9	27.7	29.8	4.3	6.7	26.2	4.0	27.7	11.0
BD40	Davis Point	4/22/96	11	773	16.0	15.1	17.1	42.6	16.3	43.9	59.7	8.8	12.0	49.9	6.4	46.2	13.9
BD30	Pinole Point	4/22/96	11	460	14.1	8.5	11.4	23.9	8.2	27.3	33.3	4.5	8.1	28.1	4.3	28.2	10.6
BD20	San Pablo Bay	4/22/96	11	325	11.1	6.7	8.2	18.3	5.5	19.7	21.8	3.6	4.5	14.8	2.6	21.3	8.6
BD15	Petaluma River	4/22/96	11	2475	97.0	38.2	74.5	99.4	59.9	131.0	167.3	39.1	8.9	187.0	24.1	182.0	47.9
BC60	Red Rock	4/29/96	11	249	13.4	6.2	7.3	10.9	3.1	16.4	15.0	1.8	1.8	8.9	2.7	15.9	8.4
BC20	Golden Gate	4/29/96	11	125	7.0	2.7	2.8	6.2	ND	5.8	7.0	ND	ND	5.8	ND	6.0	4.3
BC10	Yerba Buena Island	4/30/96	11	331	19.4	7.2	10.9	19.5	4.7	20.1	19.7	2.7	2.1	18.3	2.4	22.6	8.3
BB70	Alameda	4/30/96	11	378	25.0	8.4	12.4	22.0	5.7	21.2	21.1	2.7	4.2	18.5	3.8	24.3	9.6
BA40	Redwood Creek	5/2/96	11	720	30.0	13.6	22.2	35.7	15.1	43.0	51.8	9.7	16.0	41.8	5.9	50.0	18.8
BA30	Dumbarton Bridge	5/2/96	11	1061	38.0	19.5	34.3	54.0	25.9	60.0	82.0	15.5	20.0	63.0	8.0	68.0	24.7
BA10	Coyote Creek	5/1/96	11	3155	122.0	63.3	85.0	148.0	78.9	191.0	216.0	50.1	25.1	153.0	28.8	209.0	56.5
C-3-0	San Jose	5/1/96	11	4947	162.0	74.0	105.0	195.0	116.3	225.0	292.0	82.6	37.3	391.0	44.8	319.0	91.0
BW10	Standish Dam	4/16/96	11	2413	101.0	25.8	28.5	77.0	19.6	90.0	74.0	20.6	38.0	138.0	41.4	191.0	83.0
BG20	Sacramento River	7/22/96	12	473	17.1	5.9	9.5	34.0	6.9	21.7	23.3	2.9	6.3	17.7	3.6	17.2	11.2
BG30	San Joaquin River	7/22/96	12	302	13.2	3.7	5.8	30.0	3.6	14.2	13.2	2.0	4.5	12.8	1.1	13.6	9.0
BF20	Grizzly Bay	7/23/96	12	715	28.5	12.4	20.1	35.8	12.0	41.8	45.6	8.3	15.3	48.9	3.8	44.2	18.7
BD50	Napa River	7/24/96	12	416	19.5	8.2	13.1	24.2	6.3	25.6	26.5	4.3	9.5	25.7	2.8	24.0	9.8
BD40	Davis Point	7/23/96	12	493	22.6	10.0	15.7	27.2	8.4	30.9	30.1	5.6	10.2	30.0	3.5	30.0	12.5
BD30	Pinole Point	7/23/96	12	323	17.1	7.0	10.0	19.0	4.4	19.8	19.7	3.3	7.0	19.4	1.5	20.3	8.9
BD20	San Pablo Bay	7/24/96	12	358	17.9	8.2	9.8	18.8	6.6	21.6	19.5	3.3	7.2	19.1	1.4	19.8	9.4
BD15	Petaluma River	7/24/96	12	591	26.8	11.2	19.8	33.7	9.5	33.6	35.8	5.7	12.7	39.5	3.8	41.2	14.4
BC60	Red Rock	7/24/96	12	2417	65.2	40.6	35.2	82.6	40.0	90.7	94.2	13.0	21.4	53.1	9.7	39.6	19.4
BC20	Golden Gate	7/25/96	12	635	16.5	11.0	8.5	22.1	12.0	25.4	23.8	3.5	5.4	15.5	2.6	11.7	6.4
BC10	Yerba Buena Island	7/26/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*
BB70	Alameda	7/26/96	12	942	35.0	19.1	19.8	43.0	20.1	45.7	39.4	7.8	13.2	34.6	6.2	32.3	15.9
BA40	Redwood Creek	7/29/96	12	920	38.0	17.4	28.0	49.0	18.2	50.9	59.8	13.0	18.6	63.9	1.3	53.5	21.5
BA30	Dumbarton Bridge	7/29/96	12	1263	44.0	23.8	28.9	56.0	27.9	63.0	69.4	13.2	18.1	54.5	5.6	46.0	22.1
BA10	Coyote Creek	7/30/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	10313	600.0	183.0	291.0	644.0	156.6	604.0	642.0	100.0	325.0	290.0	101.6	679.0	239.0
BW10	Standish Dam	8/16/96	12	2993	184.0	66.0	42.0	77.0	57.0	215.0	193.0	38.6	86.0	229.0	18.7	184.0	61.0

Table 7. Total (dissolved + particulate) PCB concentrations in water samples, 1996 (continued). . = no data, ND = not detected, NA = not anaylzed, * = not available at the time of report production. For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 153	PCB 156	PCB 158	PCB 170	PCB 174	PCB 177	PCB 180	PCB 183	PCB 187	PCB 194	PCB 195	PCB 201	PCB 203	Hexachlorobenzene
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	165	12.3	ND	ND	1.9	2.6	ND	5.4	1.2	4.7	1.0	ND	.	ND	12
BG30	San Joaquin River	2/14/96	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	.	NA	NA
BF20	Grizzly Bay	2/13/96	10	282	17.9	ND	ND	4.8	4.3	2.5	8.9	3.2	8.6	1.8	ND	.	ND	24
BD50	Napa River	2/13/96	10	262	18.7	ND	1.2	4.8	5.6	2.7	11.0	3.8	10.7	2.8	1.1	.	1.6	15
BD40	Davis Point	2/12/96	10	298	25.5	ND	1.5	7.4	5.3	2.9	12.5	4.5	11.9	3.0	ND	.	ND	18
BD30	Pinole Point	2/12/96	10	399	33.0	1.5	2.3	8.5	6.6	5.9	17.5	5.2	16.6	4.4	1.4	.	2.7	17
BD20	San Pablo Bay	2/12/96	10	397	32.0	1.2	2.5	7.7	6.1	3.7	16.3	4.6	12.8	3.6	1.2	.	1.9	16
BD15	Petaluma River	2/12/96	10	949	99.0	5.5	6.1	26.2	16.4	18.4	53.4	13.3	49.3	14.0	5.0	.	8.6	25
BC60	Red Rock	2/7/96	10	268	22.0	1.7	1.1	5.2	4.0	3.6	12.1	2.7	11.6	3.1	1.1	.	1.7	15
BC20	Golden Gate	2/7/96	10	126	10.9	ND	ND	2.1	1.5	1.2	4.9	ND	5.2	ND	ND	.	ND	6
BC10	Yerba Buena Island	2/7/96	10	360	28.0	1.2	1.7	6.7	5.8	4.5	15.0	3.5	12.6	3.8	1.3	.	1.9	12
BB70	Alameda	2/7/96	10	436	39.4	2.2	2.5	11.0	8.2	6.9	22.2	5.8	17.7	5.5	2.1	.	3.0	8
BA40	Redwood Creek	2/6/96	10	855	74.0	4.6	4.6	22.3	15.8	16.4	43.4	11.4	38.7	12.0	4.5	.	6.8	11
BA30	Dumbarton Bridge	2/5/96	10	608	49.0	1.8	3.2	12.1	8.2	9.8	25.2	6.6	24.0	6.6	1.9	.	3.2	12
BA10	Coyote Creek	2/6/96	10	1081	97.0	4.8	4.8	29.4	18.7	19.4	55.3	14.4	47.5	15.0	5.1	.	8.2	19
C-3-0	San Jose	2/6/96	10	1855	126.0	22.0	9.4	42.7	32.1	26.6	86.5	21.0	58.1	23.3	7.8	.	14.1	62
BW10	Standish Dam	3/4/96	10	5319	555.0	55.0	31.8	254.2	256.0	143.2	569.4	122.6	348.8	141.6	57.0	.	110.0	37
BG20	Sacramento River	4/23/96	11	172	10.9	1.3	ND	2.3	2.8	ND	6.5	2.2	4.4	ND	ND	.	ND	R
BG30	San Joaquin River	4/23/96	11	187	12.1	ND	ND	1.9	3.1	1.1	6.6	1.4	5.9	1.3	ND	.	1.3	R
BF20	Grizzly Bay	4/24/96	11	286	20.3	ND	1.5	4.1	4.5	2.4	11.5	3.8	8.3	2.5	ND	.	2.3	27
BD50	Napa River	4/23/96	11	446	39.7	1.7	2.6	9.5	6.9	5.7	20.6	6.5	18.1	5.1	1.5	.	3.3	16
BD40	Davis Point	4/22/96	11	773	69.1	5.9	5.1	21.1	13.2	12.0	42.8	12.4	31.6	13.0	3.9	.	7.6	24
BD30	Pinole Point	4/22/96	11	460	40.7	ND	2.5	10.0	6.7	7.0	21.4	7.0	17.9	12.0	1.6	.	3.2	19
BD20	San Pablo Bay	4/22/96	11	325	28.5	1.3	1.9	6.6	5.3	4.0	15.1	4.1	12.4	3.4	1.2	.	3.2	12
BD15	Petaluma River	4/22/96	11	2475	262.0	23.0	22.0	83.3	42.8	47.3	134.5	39.5	114.8	47.7	16.0	.	2.6	55
BC60	Red Rock	4/29/96	11	249	21.8	ND	1.2	4.6	3.7	2.0	9.5	3.3	8.7	1.8	ND	.	1.3	7
BC20	Golden Gate	4/29/96	11	125	7.7	ND	ND	2.2	ND	ND	3.7	ND	3.3	ND	ND	.	2.1	6
BC10	Yerba Buena Island	4/30/96	11	331	31.2	1.6	1.9	5.3	5.2	3.6	13.9	3.7	12.2	2.9	ND	.	2.3	5
BB70	Alameda	4/30/96	11	378	34.5	3.8	1.9	5.3	5.3	3.7	14.1	4.9	14.6	2.7	ND	.	1.6	9
BA40	Redwood Creek	5/2/96	11	720	75.0	4.7	4.6	15.0	9.7	12.1	31.3	10.9	36.5	8.0	2.4	.	4.0	3
BA30	Dumbarton Bridge	5/2/96	11	1061	106.0	7.0	6.2	28.3	14.3	19.5	50.2	16.3	49.9	16.0	4.2	.	5.9	5
BA10	Coyote Creek	5/1/96	11	3155	350.0	17.0	23.4	92.6	47.9	57.9	144.3	47.4	156.8	49.0	16.0	.	29.0	42
C-3-0	San Jose	5/1/96	11	4947	531.0	45.4	29.1	213.6	103.9	113.5	308.5	87.8	241.0	121.3	40.0	.	59.0	83
BW10	Standish Dam	4/16/96	11	2413	200.0	15.1	15.0	104.5	90.3	51.9	200.0	49.0	124.0	58.0	22.2	.	41.0	R
BG20	Sacramento River	7/22/96	12	473	24.8	1.0	2.3	5.2	4.6	3.7	12.1	3.2	9.2	1.6	ND	.	1.3	41
BG30	San Joaquin River	7/22/96	12	302	18.5	ND	ND	4.4	4.0	2.8	9.9	2.4	8.9	2.3	ND	.	1.8	49
BF20	Grizzly Bay	7/23/96	12	715	63.0	2.7	5.6	18.0	11.3	15.1	38.5	12.4	31.3	10.0	2.6	.	5.9	23
BD50	Napa River	7/24/96	12	416	35.2	2.9	2.0	8.8	5.2	6.5	18.8	6.3	16.4	4.5	1.2	.	2.3	10
BD40	Davis Point	7/23/96	12	493	41.7	3.5	3.6	11.0	6.4	7.9	23.3	7.1	19.6	5.8	1.6	.	2.3	14
BD30	Pinole Point	7/23/96	12	323	26.6	1.6	1.4	5.7	3.5	4.1	13.0	3.9	12.2	2.7	ND	.	1.3	8
BD20	San Pablo Bay	7/24/96	12	358	25.5	1.8	1.2	5.5	3.9	3.8	12.6	3.5	11.3	2.3	ND	.	1.3	6
BD15	Petaluma River	7/24/96	12	591	56.9	4.2	2.9	14.0	9.2	12.2	29.3	10.0	28.3	7.5	2.4	.	4.1	9
BC60	Red Rock	7/24/96	12	2417	48.8	12.0	7.8	17.0	8.6	6.8	25.4	5.8	14.6	5.4	1.9	.	2.4	2
BC20	Golden Gate	7/25/96	12	635	15.1	3.0	2.6	4.8	2.5	1.7	7.5	1.2	3.6	ND	ND	.	ND	5
BC10	Yerba Buena Island	7/26/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*	*
BB70	Alameda	7/26/96	12	942	40.4	3.9	3.0	12.0	8.3	6.2	22.5	6.4	16.9	4.9	1.2	.	2.4	7
BA40	Redwood Creek	7/29/96	12	920	87.0	6.8	5.1	22.0	13.0	21.3	44.4	14.6	42.9	12.0	4.1	.	5.7	8
BA30	Dumbarton Bridge	7/29/96	12	1263	68.0	7.3	7.0	17.1	9.7	12.7	31.3	10.8	29.9	7.5	2.1	.	7.5	5
BA10	Coyote Creek	7/30/96	12	.	*	*	*	*	*	*	*	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	10313	864.0	41.7	29.0	234.9	175.8	5.1	501.0	135.6	404.0	121.2	42.0	.	73.0	35
BW10	Standish Dam	8/16/96	12	2993	94.0	14.0	25.6	127.6	74.5	71.4	62.0	17.2	46.0	16.5	21.0	.	20.7	48

Table 8. Dissolved pesticide concentrations in water samples, 1996. . = no data, ND = not detected, CE = coelution, QS = outlier value qualified by SFEI, * = not available at the time of report production. For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Chlorpyrifos	Diazinon	Sum of DDTs (SFEI)	o,p'-DDD	o,p'-DDE	o,p'-DDT	p,p'-DDD	p,p'-DDE	p,p'-DDT	Sum of Chlordanes (SFEI)	alpha-Chlordane	gamma-Chlordane	cis-Nonachlor	trans-Nonachlor	Heptachlor	Heptachlor Epoxide	Oxychlordane
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	300	26000	399	25	8	QS	180	170	16	78	21	17	4	19	ND	14	2
BG30	San Joaquin River	2/14/96	10	440	25000	398	29	9	QS	160	200	ND	95	23	14	10	30	ND	11	7
BF20	Grizzly Bay	2/13/96	10	360	58000	615	110	17	QS	180	290	18	91	37	13	3	28	ND	9	ND
BD50	Napa River	2/13/96	10	680	39000	443	46	5	QS	190	140	62	183	53	35	7	26	ND	58	4
BD40	Davis Point	2/12/96	10	1200	44000	711	93	8	QS	340	150	120	271	86	57	11	32	ND	67	18
BD30	Pinole Point	2/12/96	10	4	43000	352	44	7	QS	130	130	41	166	43	28	9	27	ND	54	6
BD20	San Pablo Bay	2/12/96	10	10	31000	420	50	7	QS	170	140	53	190	52	34	7	25	ND	67	5
BD15	Petaluma River	2/12/96	10	3	12000	250	36	4	QS	120	71	19	262	53	30	10	32	3	130	5
BC60	Red Rock	2/7/96	10	13	32000	335	37	4	QS	170	70	54	302	73	62	10	38	ND	110	10
BC20	Golden Gate	2/7/96	10	ND	5800	83	8	2	QS	41	23	10	73	17	10	3	9	ND	32	2
BC10	Yerba Buena Island	2/7/96	10	ND	13000	167	19	3	QS	77	49	19	150	40	22	6	22	ND	56	4
BB70	Alameda	2/7/96	10	12	9500	195	25	2	QS	100	41	27	238	55	38	9	21	ND	110	5
BA40	Redwood Creek	2/6/96	10	24	7100	226	33	2	QS	110	47	34	581	140	94	24	51	ND	260	12
BA30	Dumbarton Bridge	2/5/96	10	13	14000	182	20	2	QS	73	58	29	285	68	43	11	35	ND	120	8
BA10	Coyote Creek	2/6/96	10	190	12000	270	33	3	QS	110	85	39	379	100	62	16	54	ND	140	7
C-3-0	San Jose	2/6/96	10	4000	36000	1512	130	12	QS	880	310	180	1014	290	250	45	120	ND	260	49
BW10	Standish Dam	3/4/96	10	600	9300	1411	220	19	QS	780	350	42	788	240	190	12	100	ND	230	16
BG20	Sacramento River	4/23/96	11	360	3700	240	31	5	QS	88	99	17	84	22	23	5	17	ND	12	5
BG30	San Joaquin River	4/23/96	11	270	2100	262	32	10	QS	92	110	18	92	27	22	5	21	ND	13	4
BF20	Grizzly Bay	4/24/96	11	400	5000	287	31	6	QS	120	110	20	110	30	21	7	15	5	12	20
BD50	Napa River	4/23/96	11	300	4800	281	36	8	QS	140	67	30	106	27	25	12	21	3	14	4
BD40	Davis Point	4/22/96	11	340	4800	243	28	5	QS	120	64	26	111	25	22	9	20	6	25	4
BD30	Pinole Point	4/22/96	11	300	4000	225	28	8	QS	110	53	26	96	22	19	9	17	6	20	3
BD20	San Pablo Bay	4/22/96	11	260	4000	211	26	7	QS	120	39	19	113	20	18	9	17	4	42	4
BD15	Petaluma River	4/22/96	11	170	7600	241	40	7	QS	120	58	16	119	34	20	12	17	8	22	7
BC60	Red Rock	4/29/96	11	140	2100	172	18	6	QS	80	56	12	63	18	17	CE	8	6	12	2
BC20	Golden Gate	4/29/96	11	23	250	55	6	7	QS	22	14	6	52	7	8	CE	2	2	31	2
BC10	Yerba Buena Island	4/30/96	11	140	1700	171	26	12	QS	79	40	14	100	24	20	CE	10	8	35	4
BB70	Alameda	4/30/96	11	120	1200	217	18	9	QS	71	100	19	145	24	27	CE	8	8	75	3
BA40	Redwood Creek	5/2/96	11	80	4700	190	26	9	QS	110	34	11	146	33	28	10	16	3	50	7
BA30	Dumbarton Bridge	5/2/96	11	93	5200	214	31	14	QS	110	42	17	150	39	32	6	18	3	46	6
BA10	Coyote Creek	5/1/96	11	200	9700	292	40	20	QS	150	64	18	251	58	51	9	30	3	95	5
C-3-0	San Jose	5/1/96	11	670	14000	434	49	34	QS	190	130	31	368	92	87	9	40	3	130	7
BW10	Standish Dam	4/16/96	11	820	7800	2170	420	81	QS	1200	430	39	1443	520	420	57	210	16	140	80
BG20	Sacramento River	7/22/96	12	4	4500	389	78	31	QS	160	99	21	200	45	37	20	28	ND	39	31
BG30	San Joaquin River	7/22/96	12	6	3200	354	66	5	QS	180	82	22	165	51	37	26	22	ND	18	11
BF20	Grizzly Bay	7/23/96	12	ND	6400	265	41	7	QS	150	54	13	91	30	15	9	18	ND	19	ND
BD50	Napa River	7/24/96	12	97	5600	248	38	9	QS	150	43	8	159	33	17	13	10	ND	86	ND
BD40	Davis Point	7/23/96	12	49	2400	241	41	9	QS	140	42	9	106	27	21	12	11	ND	31	4
BD30	Pinole Point	7/23/96	12	37	2200	124	31	10	QS	52	30	1	128	21	13	10	12	ND	72	ND
BD20	San Pablo Bay	7/24/96	12	84	1800	248	44	11	QS	160	27	6	115	31	22	12	16	ND	29	4
BD15	Petaluma River	7/24/96	12	7	2500	260	47	10	QS	160	34	9	91	19	14	10	8	ND	40	ND
BC60	Red Rock	7/24/96	12	24	1300	126	23	6	QS	76	16	5	93	18	8	4	5	ND	59	ND
BC20	Golden Gate	7/25/96	12	9	190	35	7	2	QS	20	5	1	117	5	3	16	3	ND	87	4
BC10	Yerba Buena Island	7/26/96	12	*	*	.	*	*	*	*	*	*	.	*	*	*	*	*	*	*
BB70	Alameda	7/26/96	12	ND	NA	125	20	6	QS	70	19	10	64	20	17	8	9	ND	10	ND
BA40	Redwood Creek	7/29/96	12	31	1700	108	13	9	QS	58	24	4	116	25	22	11	12	ND	43	3
BA30	Dumbarton Bridge	7/29/96	12	31	1900	171	27	6	QS	100	33	5	149	42	26	22	15	ND	38	6
BA10	Coyote Creek	7/30/96	12	*	*	.	*	*	*	*	*	*	.	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	75	8300	1245	130	51	QS	860	182	22	637	210	150	72	93	ND	112	ND
BW10	Standish Dam	8/16/96	12	120	14000	1308	200	48	QS	660	380	20	770	270	210	28	110	ND	110	42

Table 8. Dissolved pesticide concentrations in water samples, 1996 (continued).. = no data, NA = not analyzed, ND = not detected, QS = outlier value qualified by SFEI, * = not available at the time of report production. For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of HCHs (SFEI)	alpha-HCH	beta-HCH	delta-HCH	gamma-HCH	Dieldrin	Endrin	Dacthal	Endosulfan I	Endosulfan II	Endosulfan Sulfate	Oxadiazon	Mirex
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	24	4.3	5.2	8.0	6.8	QS	ND	QS	QS	ND	ND	QS	ND
BG30	San Joaquin River	2/14/96	10	147	61.0	23.0	8.7	54.0	ND	ND	6.6	18.0	ND	ND	29.0	ND
BF20	Grizzly Bay	2/13/96	10	150	20.0	35.0	13.0	82.0	ND	ND	4.9	34.0	ND	ND	ND	ND
BD50	Napa River	2/13/96	10	615	270.0	73.0	12.0	260.0	6.5	ND	390.0	ND	ND	33.0	72.0	ND
BD40	Davis Point	2/12/96	10	1335	610.0	130.0	25.0	570.0	6.0	ND	350.0	ND	ND	42.0	68.0	ND
BD30	Pinole Point	2/12/96	10	755	350.0	97.0	8.0	300.0	71.0	ND	300.0	ND	ND	ND	56.0	ND
BD20	San Pablo Bay	2/12/96	10	733	330.0	83.0	9.9	310.0	100.0	ND	500.0	ND	ND	ND	64.0	ND
BD15	Petaluma River	2/12/96	10	876	380.0	170.0	6.2	320.0	65.0	ND	210.0	19.0	ND	ND	2.7	ND
BC60	Red Rock	2/7/96	10	1118	390.0	160.0	7.5	560.0	190.0	ND	700.0	45.0	ND	ND	ND	ND
BC20	Golden Gate	2/7/96	10	832	400.0	240.0	2.0	190.0	23.0	ND	120.0	ND	ND	ND	1.7	ND
BC10	Yerba Buena Island	2/7/96	10	824	340.0	170.0	3.8	310.0	58.0	ND	160.0	ND	ND	ND	ND	ND
BB70	Alameda	2/7/96	10	892	300.0	300.0	2.0	290.0	83.0	ND	310.0	ND	ND	ND	ND	ND
BA40	Redwood Creek	2/6/96	10	1626	500.0	370.0	6.3	750.0	130.0	ND	480.0	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	2/5/96	10	1428	390.0	290.0	7.7	740.0	64.0	ND	240.0	ND	ND	ND	14.0	ND
BA10	Coyote Creek	2/6/96	10	1358	310.0	220.0	8.0	820.0	68.0	ND	340.0	ND	ND	ND	4.5	ND
C-3-0	San Jose	2/6/96	10	4936	550.0	650.0	36.0	3700.0	17.0	ND	12.0	ND	ND	6.5	17.0	ND
BW10	Standish Dam	3/4/96	10	47	7.8	12.0	5.8	21.0	17.0	ND	360.0	5.2	ND	ND	ND	ND
BG20	Sacramento River	4/23/96	11	43	8.3	25.0	2.1	7.2	ND	ND	900.0	ND	ND	ND	ND	ND
BG30	San Joaquin River	4/23/96	11	106	16.0	74.0	4.9	11.0	ND	ND	1200.0	ND	ND	ND	ND	ND
BF20	Grizzly Bay	4/24/96	11	88	4.4	57.0	21.0	5.5	ND	ND	1200.0	ND	ND	ND	72.0	0.2
BD50	Napa River	4/23/96	11	639	230.0	95.0	3.8	310.0	ND	ND	1100.0	ND	ND	ND	ND	0.2
BD40	Davis Point	4/22/96	11	716	300.0	110.0	6.3	300.0	16.0	ND	760.0	ND	ND	ND	ND	ND
BD30	Pinole Point	4/22/96	11	580	230.0	110.0	ND	240.0	ND	ND	680.0	ND	ND	ND	ND	ND
BD20	San Pablo Bay	4/22/96	11	662	280.0	120.0	2.0	260.0	ND	ND	750.0	ND	ND	ND	ND	ND
BD15	Petaluma River	4/22/96	11	677	300.0	150.0	6.8	220.0	ND	ND	650.0	ND	ND	ND	ND	0.1
BC60	Red Rock	4/29/96	11	798	340.0	200.0	7.9	250.0	ND	29.0	380.0	ND	ND	69.0	9.8	ND
BC20	Golden Gate	4/29/96	11	1066	550.0	350.0	5.5	160.0	ND	11.0	63.0	ND	ND	7.5	2.3	ND
BC10	Yerba Buena Island	4/30/96	11	1086	490.0	320.0	5.6	270.0	ND	16.0	170.0	31.0	69.0	ND	30.0	ND
BB70	Alameda	4/30/96	11	971	440.0	250.0	11.0	270.0	ND	140.0	130.0	14.0	97.0	59.0	ND	ND
BA40	Redwood Creek	5/2/96	11	882	300.0	200.0	22.0	360.0	3.5	ND	530.0	ND	ND	6.2	5.2	ND
BA30	Dumbarton Bridge	5/2/96	11	1038	310.0	220.0	7.8	500.0	1.5	22.0	520.0	ND	22.0	4.6	5.3	ND
BA10	Coyote Creek	5/1/96	11	1502	270.0	280.0	12.0	940.0	ND	29.0	940.0	ND	ND	12.0	ND	0.05
C-3-0	San Jose	5/1/96	11	862	24.0	590.0	28.0	220.0	47.0	190.0	130.0	42.0	190.0	ND	ND	0.2
BW10	Standish Dam	4/16/96	11	164	39.0	110.0	ND	15.0	ND	ND	2300.0	ND	ND	ND	64.0	0.2
BG20	Sacramento River	7/22/96	12	504	130.0	16.0	18.0	340.0	62.0	ND	310.0	1.8	ND	120.0	ND	ND
BG30	San Joaquin River	7/22/96	12	476	110.0	31.0	5.3	330.0	12.0	ND	38.0	ND	ND	13.0	ND	ND
BF20	Grizzly Bay	7/23/96	12	566	170.0	92.0	14.0	290.0	27.0	ND	150.0	ND	ND	11.0	ND	ND
BD50	Napa River	7/24/96	12	653	200.0	190.0	23.0	240.0	55.0	ND	130.0	ND	ND	ND	ND	ND
BD40	Davis Point	7/23/96	12	803	300.0	220.0	3.3	280.0	16.0	ND	130.0	ND	ND	22.0	ND	ND
BD30	Pinole Point	7/23/96	12	689	260.0	190.0	9.4	230.0	24.0	ND	100.0	8.7	ND	ND	30.0	ND
BD20	San Pablo Bay	7/24/96	12	1180	440.0	340.0	20.0	380.0	ND	ND	110.0	ND	ND	11.0	ND	ND
BD15	Petaluma River	7/24/96	12	637	180.0	240.0	6.7	210.0	40.0	ND	88.0	15.0	ND	ND	ND	ND
BC60	Red Rock	7/24/96	12	689	280.0	200.0	9.4	200.0	15.0	ND	59.0	ND	ND	6.7	ND	ND
BC20	Golden Gate	7/25/96	12	662	230.0	340.0	14.0	78.0	ND	ND	27.0	ND	ND	ND	ND	ND
BC10	Yerba Buena Island	7/26/96	12	.	.	*	*	*	*	*	*	*	*	*		
BB70	Alameda	7/26/96	12	875	350.0	290.0	4.6	230.0	NA	NA	NA	NA	NA	NA	NA	ND
BA40	Redwood Creek	7/29/96	12	608	190.0	180.0	18.0	220.0	ND	ND	73.0	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	7/29/96	12	803	210.0	240.0	3.3	350.0	10.0	ND	98.0	ND	ND	ND	1.1	ND
BA10	Coyote Creek	7/30/96	12	.	.	*	*	*	*	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	5689	260.0	810.0	19.0	4600.0	220.0	ND	410.0	30.0	ND	48.0	36.0	ND
BW10	Standish Dam	8/16/96	12	853	73.0	190.0	ND	590.0	ND	ND	330.0	ND	ND	ND	ND	0.2

Table 9. Total (dissolved + particulate) pesticide concentrations in water samples, 1996.. no data, NA = not anaylzed, ND = not detected, QS = outlier value qualified by SFEI, R = unacceptably low surrogate recovery, * = not available at the time of report production. For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Chlorpyrifos	Diazinon	Sum of DDTs (SFEI)	o,p'-DDD	o,p'-DDE	o,p'-DDT	p,p'-DDD	p,p'-DDE	p,p'-DDT	Sum of Chlordanes (SFEI)	alpha-Chlordane	gamma-Chlordane	cis-Nonachlor	trans-Nonachlor	Heptachlor	Heptachlor Epoxide	Oxychlordane
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	321	26000	724	34	22	QS	192	460	16	96	24	20	6	23	ND	22	2
BG30	San Joaquin River	2/14/96	10	440	25000	.	NA	NA	NA	NA	NA	NA	.	NA	NA	NA	NA	NA	NA	NA
BF20	Grizzly Bay	2/13/96	10	404	58350	1319	128	45	QS	228	900	18	124	43	19	5	34	ND	24	ND
BD50	Napa River	2/13/96	10	715	39300	1067	73	16	QS	276	460	242	229	62	44	9	35	ND	76	4
BD40	Davis Point	2/12/96	10	1253	44320	1617	123	24	QS	460	640	370	337	98	69	14	45	ND	94	18
BD30	Pinole Point	2/12/96	10	4	43140	973	76	16	QS	270	380	231	266	65	48	18	43	ND	84	8
BD20	San Pablo Bay	2/12/96	10	10	31190	1014	75	18	QS	258	460	203	248	62	45	11	37	ND	88	5
BD15	Petaluma River	2/12/96	10	6	12130	1227	101	16	QS	480	471	159	460	103	76	34	74	3	164	6
BC60	Red Rock	2/7/96	10	13	32000	754	56	10	QS	254	260	174	357	85	74	14	48	ND	127	10
BC20	Golden Gate	2/7/96	10	ND	5800	145	11	2	QS	61	45	26	83	20	11	3	10	ND	37	2
BC10	Yerba Buena Island	2/7/96	10	ND	13000	341	27	6	QS	126	127	55	180	46	27	10	29	2	63	4
BB70	Alameda	2/7/96	10	12	9537	419	42	6	QS	177	121	73	298	66	48	14	29	ND	136	5
BA40	Redwood Creek	2/6/96	10	24	7133	504	49	5	QS	202	132	116	722	175	127	39	74	2	293	12
BA30	Dumbarton Bridge	2/5/96	10	15	14000	446	33	6	QS	138	168	101	424	91	63	19	67	ND	174	10
BA10	Coyote Creek	2/6/96	10	191	12000	1029	75	10	QS	280	425	239	643	155	112	37	99	ND	232	8
C-3-0	San Jose	2/6/96	10	4110	36150	3149	207	32	QS	1110	1160	640	1429	377	332	76	198	5	390	51
BW10	Standish Dam	3/4/96	10	960	9450	6841	247	359	QS	900	5250	85	1501	279	247	23	390	ND	530	32
BG20	Sacramento River	4/23/96	11	R	R	.	R	R	R	R	R	R	.	R	R	R	R	R	R	R
BG30	San Joaquin River	4/23/96	11	R	R	.	R	R	R	R	R	R	.	R	R	R	R	R	R	R
BF20	Grizzly Bay	4/24/96	11	436	5000	619	54	19	QS	153	370	23	132	37	31	7	20	8	14	22
BD50	Napa River	4/23/96	11	338	4834	779	65	21	QS	280	307	106	151	38	38	20	34	4	16	6
BD40	Davis Point	4/22/96	11	416	4864	1302	93	29	QS	420	554	206	181	41	40	22	43	10	30	8
BD30	Pinole Point	4/22/96	11	338	4034	679	57	17	QS	240	263	102	132	31	30	16	27	8	22	5
BD20	San Pablo Bay	4/22/96	11	289	4026	497	45	19	QS	214	159	60	146	28	27	16	26	4	43	6
BD15	Petaluma River	4/22/96	11	300	7770	1849	210	65	QS	290	918	366	242	64	63	38	41	8	30	9
BC60	Red Rock	4/29/96	11	148	2107	268	24	8	QS	114	97	25	76	22	20	4	12	6	15	3
BC20	Golden Gate	4/29/96	11	27	250	89	7	9	QS	34	25	13	59	10	9	1	3	4	31	5
BC10	Yerba Buena Island	4/30/96	11	151	1700	273	33	16	QS	119	74	32	116	29	25	3	13	8	38	6
BB70	Alameda	4/30/96	11	132	1200	320	25	14	QS	109	140	32	165	29	33	4	13	8	81	4
BA40	Redwood Creek	5/2/96	11	94	4720	442	43	21	QS	207	130	41	187	45	39	13	30	4	51	11
BA30	Dumbarton Bridge	5/2/96	11	113	5237	590	57	31	QS	250	182	70	205	58	47	10	35	4	57	10
BA10	Coyote Creek	5/1/96	11	273	9850	1453	129	92	QS	260	764	208	489	131	113	42	100	7	101	18
C-3-0	San Jose	5/1/96	11	870	14230	2006	319	115	QS	500	980	92	686	202	187	30	127	18	146	93
BW10	Standish Dam	4/16/96	11	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
BG20	Sacramento River	7/22/96	12	38	4500	781	130	87	QS	234	303	27	227	57	53	20	37	ND	45	31
BG30	San Joaquin River	7/22/96	12	34	3200	617	86	49	QS	219	242	22	191	55	43	26	27	ND	36	11
BF20	Grizzly Bay	7/23/96	12	15	6400	1126	105	51	QS	410	407	153	134	42	29	20	30	ND	27	ND
BD50	Napa River	7/24/96	12	105	5600	556	64	24	QS	270	164	35	195	44	27	22	16	6	90	ND
BD40	Davis Point	7/23/96	12	57	2400	656	76	28	QS	310	182	61	142	40	34	22	19	ND	36	4
BD30	Pinole Point	7/23/96	12	41	2200	334	46	24	QS	135	104	25	147	28	20	15	17	ND	74	ND
BD20	San Pablo Bay	7/24/96	12	94	1800	401	58	23	QS	219	81	20	135	38	30	17	20	1	32	4
BD15	Petaluma River	7/24/96	12	9	2500	608	73	35	QS	270	185	46	115	26	24	18	14	ND	43	ND
BC60	Red Rock	7/24/96	12	28	1300	247	35	7	QS	129	58	18	108	24	21	8	6	ND	62	ND
BC20	Golden Gate	7/25/96	12	12	190	64	12	2	QS	30	18	4	125	9	8	19	3	ND	88	4
BC10	Yerba Buena Island	7/26/96	12	*	*	.	*	*	*	*	*	*	.	*	*	*	*	*	*	*
BB70	Alameda	7/26/96	12	8	ND	252	31	18	QS	128	53	22	81	28	29	14	12	ND	10	ND
BA40	Redwood Creek	7/29/96	12	44	1700	397	38	33	QS	178	113	35	173	46	40	30	22	ND	50	3
BA30	Dumbarton Bridge	7/29/96	12	38	1900	342	41	22	QS	166	94	20	179	52	40	32	22	ND	42	6
BA10	Coyote Creek	7/30/96	12	*	*	.	*	*	*	*	*	*	.	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	105	8300	3875	380	421	QS	933	2098	43	1065	360	310	172	222	2	159	ND
BW10	Standish Dam	8/16/96	12	120	14097	4456	470	126	QS	1590	2080	190	1396	470	410	74	290	ND	110	42

Table 9. Total (dissolved + particulate) pesticide concentrations in water samples, 1996 (continued). . = no data, NA = not anaylzed, ND = not detected, QS = outlier value qualified by SFEI, R = unacceptably low surrogate recovery, * = not available at the time of report production. For method detection limits refer to Table 2 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of HCHs (SFEI)	alpha-HCH	beta-HCH	delta-HCH	gamma-HCH	Dieldrin	Endrin	Dacthal	Endosulfan I	Endosulfan II	Endosulfan Sulfate	Oxadiazon	Mirex
					pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BG20	Sacramento River	2/14/96	10	30	6	6	8	9	QS	ND	QS	QS	ND	ND	QS	ND
BG30	San Joaquin River	2/14/96	10	.	NA	NA	NA	NA	ND	ND	12	21	ND	ND	NA	NA
BF20	Grizzly Bay	2/13/96	10	157	22	38	13	83	5	ND	54	34	ND	ND	59	ND
BD50	Napa River	2/13/96	10	625	274	78	12	261	26	ND	412	ND	ND	33	133	ND
BD40	Davis Point	2/12/96	10	1344	613	134	25	572	23	ND	382	ND	ND	42	128	ND
BD30	Pinole Point	2/12/96	10	769	354	105	8	302	86	ND	312	ND	ND	ND	127	ND
BD20	San Pablo Bay	2/12/96	10	744	332	90	10	312	114	ND	518	ND	ND	ND	110	ND
BD15	Petaluma River	2/12/96	10	886	381	176	6	323	83	ND	235	19	ND	ND	3	ND
BC60	Red Rock	2/7/96	10	1123	392	162	8	562	202	ND	700	50	ND	ND	ND	ND
BC20	Golden Gate	2/7/96	10	835	400	243	2	190	26	ND	123	6	ND	ND	2	ND
BC10	Yerba Buena Island	2/7/96	10	835	346	171	7	310	64	ND	165	ND	ND	ND	2	ND
BB70	Alameda	2/7/96	10	898	300	304	2	291	91	ND	317	ND	ND	ND	ND	ND
BA40	Redwood Creek	2/6/96	10	1637	502	376	6	753	151	ND	497	ND	ND	ND	3	ND
BA30	Dumbarton Bridge	2/5/96	10	1437	393	294	8	742	73	ND	253	ND	ND	ND	14	ND
BA10	Coyote Creek	2/6/96	10	1391	313	230	21	827	87	ND	363	ND	ND	ND	5	ND
C-3-0	San Jose	2/6/96	10	4997	578	672	36	3711	21	ND	53	ND	ND	7	70	2
BW10	Standish Dam	3/4/96	10	79	26	21	6	26	17	ND	370	5	ND	ND	ND	10
BG20	Sacramento River	4/23/96	11	.	R	R	R	R	R	R	R	R	R	R	R	R
BG30	San Joaquin River	4/23/96	11	.	R	R	R	R	R	R	R	R	R	R	R	R
BF20	Grizzly Bay	4/24/96	11	101	10	63	23	6	56	ND	1211	ND	ND	ND	97	0
BD50	Napa River	4/23/96	11	644	233	95	6	310	2	ND	1109	ND	ND	ND	ND	0
BD40	Davis Point	4/22/96	11	733	304	114	14	301	18	ND	775	ND	ND	ND	ND	0
BD30	Pinole Point	4/22/96	11	594	232	113	8	241	3	ND	695	ND	ND	ND	ND	ND
BD20	San Pablo Bay	4/22/96	11	679	283	131	5	260	3	ND	758	ND	ND	ND	12	ND
BD15	Petaluma River	4/22/96	11	723	313	169	21	220	2	ND	675	ND	ND	ND	ND	1
BC60	Red Rock	4/29/96	11	801	340	201	10	250	ND	29	380	ND	ND	79	14	ND
BC20	Golden Gate	4/29/96	11	1070	552	352	6	160	ND	11	66	ND	ND	8	5	ND
BC10	Yerba Buena Island	4/30/96	11	1095	496	322	7	270	4	16	172	31	69	11	50	ND
BB70	Alameda	4/30/96	11	978	443	252	13	270	ND	140	132	16	97	74	12	ND
BA40	Redwood Creek	5/2/96	11	895	304	205	27	360	7	ND	536	ND	ND	12	13	1
BA30	Dumbarton Bridge	5/2/96	11	1059	314	230	14	502	2	22	531	ND	22	14	11	1
BA10	Coyote Creek	5/1/96	11	1535	274	293	28	940	1	29	964	ND	ND	12	ND	3
C-3-0	San Jose	5/1/96	11	997	37	657	48	255	61	224	171	42	224	8	ND	4
BW10	Standish Dam	4/16/96	11	R	R	R	R	R	R	R	R	R	R	R	R	R
BG20	Sacramento River	7/22/96	12	511	137	16	18	340	65	ND	317	2	ND	120	ND	ND
BG30	San Joaquin River	7/22/96	12	505	119	36	12	339	19	ND	38	8	ND	13	ND	ND
BF20	Grizzly Bay	7/23/96	12	602	184	105	16	297	27	ND	150	ND	ND	15	ND	ND
BD50	Napa River	7/24/96	12	673	208	197	23	245	55	ND	131	ND	ND	ND	18	ND
BD40	Davis Point	7/23/96	12	815	303	223	5	283	16	ND	130	ND	ND	27	ND	ND
BD30	Pinole Point	7/23/96	12	697	263	192	11	232	24	ND	100	9	ND	8	30	ND
BD20	San Pablo Bay	7/24/96	12	1192	446	344	22	380	ND	ND	110	ND	ND	11	ND	ND
BD15	Petaluma River	7/24/96	12	648	183	246	8	211	40	ND	88	15	ND	ND	ND	ND
BC60	Red Rock	7/24/96	12	695	282	201	12	200	15	ND	59	ND	ND	7	ND	ND
BC20	Golden Gate	7/25/96	12	674	233	343	20	78	50	ND	27	ND	ND	ND	ND	ND
BC10	Yerba Buena Island	7/26/96	12	.	.	*	*	*	*	*	*	*	*	*		
BB70	Alameda	7/26/96	12	889	353	293	11	232	ND	ND	2	ND	ND	ND	ND	ND
BA40	Redwood Creek	7/29/96	12	624	194	186	20	224	ND	ND	74	ND	ND	ND	ND	1
BA30	Dumbarton Bridge	7/29/96	12	819	211	241	14	353	10	ND	98	ND	ND	ND	1	ND
BA10	Coyote Creek	7/30/96	12	.	.	*	*	*	*	*	*	*	*	*	*	*
C-3-0	San Jose	7/30/96	12	5829	281	840	44	4664	226	ND	420	30	ND	54	36	5
BW10	Standish Dam	8/16/96	12	866	73	197	3	593	15	ND	350	ND	ND	ND	21	1

Table 10. Aquatic bioassay data for 1996 RMP cruises. For reference toxicant and QA information refer to Table 5 in *Appendix B*.

Station Code	Station	Date	Cruise	% Normal Development Mean	% Normal Development (Control) Mean	Mean % Survival	Mean % Survival (Control)
				%	%	%	%
				MEDU	MEDU	MYSI	MYSI
BG20	Sacramento River	2/14/96	10	98	98	8*	88
BG30	San Joaquin River	2/14/96	10	96	98	0*	88
BF20	Grizzly Bay	2/13/96	10	94	95	60*	88
BD50	Napa River	2/13/96	10	94	96	3*	88
BD30	Pinole Point	2/12/96	10	95	95	73	85
BD15	Petaluma River	2/12/96	10	94	97	80	85
BC60	Red Rock	2/7/96	10	96	98	93	90
BC10	Yerba Buena Island	2/7/96	10	98	98	93	90
BB70	Alameda	2/7/96	10	96	98	93	90
BA40	Redwood Creek	2/6/96	10	98	99	98	100
BA10	Coyote Creek	2/6/96	10	97	98	98	100
C-3-0	San Jose	2/6/96	10	97	98	100	100
C-1-3	Sunnyvale	2/6/96	10	97	97	95	100
BG20	Sacramento River	7/21/96	12	61	60	75*	95
BG30	San Joaquin River	7/21/96	12	58	59	73*	95
BF20	Grizzly Bay	7/22/96	12	67	62	73*	95
BD50	Napa River	7/23/96	12	77	65	88	90
BD30	Pinole Point	7/22/96	12	58	59	95	95
BD15	Petaluma River	7/23/96	12	80	77	95	90
BC60	Red Rock	7/23/96	12	78	73	90	90
BC10	Yerba Buena Island	7/25/96	12	81	80	98	93
BB70	Alameda	7/25/96	12	82	79	88	93
BA40	Redwood Creek	7/28/96	12	38	38	95	98
BA10	Coyote Creek	7/29/96	12	48	40	90	98
C-3-0	San Jose	7/29/96	12	42	33	93	98
C-1-3	Sunnyvale	7/29/96	12	40	40	93	98

* Statistically significantly different from the control at the 0.05 level
MEDU *Mytilus edulis*
MYSI *Mysidopsis bahia*

Table 11. General characteristics of sediment samples, 1996. Wetlands pilot study data are included. . = no data, ND = not detected, NA = not analyzed, NS = not sampled.

Station Code	Station	Date	Cruise	% Clay (<4um)	% Gravel+Shell (>2mm)	% Sand (63um-2mm)	% Silt (4um-63um)	Depth	Ammonia	Hydrogen Sulfide	pH	TOC	Total Sulfide
				%	%	%	%	meters	mg/L	mg/L	pH	%	mg/L
BG20	Sacramento River	2/15/96	10	14	0	71	15	10	0.2	ND	7.2	0.3	ND
BG30	San Joaquin River	2/15/96	10	34	0	29	36	6	1.0	ND	5.9	1.2	ND
BF40	Honker Bay	2/15/96	10	51	0	4	44	3	1.3	ND	7.4	1.3	ND
BF20	Grizzly Bay	2/15/96	10	58	0	2	40	3	1.2	ND	7.5	1.4	ND
BF10	Pacheco Creek	2/15/96	10	6	1	89	4	5	0.2	ND	6.8	0.3	ND
BD50	Napa River	2/16/96	10	76	0	1	23	4	3.2	ND	6.5	1.6	ND
BD41	Davis Point	2/16/96	10	11	0	83	7	8	0.2	ND	8.1	0.2	ND
BD31	Pinole Point	2/16/96	10	45	0	28	27	8	1.6	ND	6.6	1.7	ND
BD22	San Pablo Bay	2/16/96	10	53	1	16	31	3	0.2	ND	7.3	1.2	ND
BD15	Petaluma River	2/16/96	10	62	0	3	35	3	1.3	ND	7.0	1.2	ND
BC60	Red Rock	2/20/96	10	3	6	90	2	9	0.1	ND	7.4	0.1	ND
BC41	Point Isabel	2/20/96	10	47	0	13	40	1	0.2	ND	7.3	1.0	ND
BC32	Richardson Bay	2/20/96	10	39	0	19	42	3	0.1	ND	7.8	0.8	ND
BC21	Horseshoe Bay	2/20/96	10	17	30	40	13	13	0.4	ND	6.7	0.8	ND
BC11	Yerba Buena Island	2/20/96	10	49	0	21	29	6	0.1	ND	7.4	1.1	ND
BB70	Alameda	2/21/96	10	51	0	20	29	10	0.3	ND	7.0	1.0	ND
BB30	Oyster Point	2/21/96	10	49	3	20	28	8	0.4	ND	6.9	1.0	ND
BB15	San Bruno Shoal	2/21/96	10	57	0	11	32	12	1.1	ND	6.8	1.2	ND
BA41	Redwood Creek	2/21/96	10	60	4	8	28	4	0.1	ND	7.4	1.2	ND
BA30	Dumbarton Bridge	2/22/96	10	61	0	6	32	7	0.2	ND	7.5	1.3	ND
BA21	South Bay	2/21/96	10	73	0	2	26	4	1.0	ND	7.5	1.5	ND
BA10	Coyote Creek	2/22/96	10	51	3	9	37	4	0.2	.	7.5	1.4	ND
C-3-0	San Jose	2/21/96	10	29	0	54	17	3	0.1	ND	7.8	0.8	ND
C-1-3	Sunnyvale	2/21/96	10	31	0	51	19	3	1.8	ND	7.2	1.0	ND
BW10	Standish Dam	3/8/96	10	17	0	NS	NS	.	NS	NS	NS	1.0	NS
WCCA0	China Camp Marsh A0	3/13/96	10	90	0	2	8	.	0.6	ND	6.6	5.9	ND
WCCA2	China Camp Marsh A2	3/13/96	10	84	0	1	15	.	0.8	ND	7.1	1.9	ND
WPMA0	Petaluma Marsh A0	3/14/96	10	85	0	2	13	.	0.2	ND	6.7	3.6	ND
WPMA2	Petaluma Marsh A2	3/14/96	10	83	0	0	16	.	0.6	ND	7.2	4.7	ND
WPMB0	Petaluma Marsh B0	3/14/96	10	76	0	1	23	.	0.2	ND	6.7	2.9	ND
WPMB2	Petaluma Marsh B2	3/14/96	10	81	0	2	18	.	2.1	ND	7.2	5.4	ND
BG20	Sacramento River	8/6/96	12	5	0	91	4	8	0.2	0.12	7.0	0.3	0.3
BG30	San Joaquin River	8/6/96	12	30	0	33	37	5	0.7	0.07	7.6	0.8	0.5
BF40	Honker Bay	8/6/96	12	51	0	10	39	3	1.0	0.06	7.1	1.6	0.2
BF20	Grizzly Bay	8/6/96	12	58	0	2	39	3	1.3	0.03	7.5	1.4	0.2
BF10	Pacheco Creek	8/6/96	12	16	0	76	8	4	0.1	0.35	7.0	0.7	0.8
BD50	Napa River	8/5/96	12	75	0	1	24	4	0.6	0.11	7.3	1.7	0.5
BD41	Davis Point	8/5/96	12	8	0	88	5	6.5	0.1	0.24	7.2	0.3	0.9
BD31	Pinole Point	8/5/96	12	28	1	50	20	6.5	0.0	0.14	7.2	0.9	0.5
BD22	San Pablo Bay	8/5/96	12	55	1	11	34	3	0.1	0.06	7.2	1.3	0.2
BD15	Petaluma River	8/5/96	12	66	0	1	33	4	0.2	0.04	7.4	1.5	0.2
BC60	Red Rock	8/2/96	12	3	2	93	1	11	2.5	0.02	7.3	NA	0.1
BC41	Point Isabel	8/2/96	12	56	0	10	34	1.5	5.7	0.12	7.4	1.2	0.6
BC32	Richardson Bay	8/2/96	12	35	0	21	43	1	3.2	0.09	6.9	0.9	0.2
BC21	Horseshoe Bay	8/2/96	12	21	0	59	20	12	1.1	0.07	7.0	0.7	0.2
BC11	Yerba Buena Island	8/1/96	12	42	10	29	19	6	0.1	0.03	7.4	1.0	0.2
BB70	Alameda	8/1/96	12	53	0	15	32	10	0.5	0.07	7.1	1.2	0.2
BB30	Oyster Point	8/1/96	12	57	0	14	28	9	0.7	0.11	7.1	1.3	0.3
BB15	San Bruno Shoal	8/1/96	12	36	4	42	18	12	2.2	0.08	7.2	0.8	0.3
BA41	Redwood Creek	8/1/96	12	65	1	5	28	2.5	0.6	0.05	7.6	1.2	0.4
BA30	Dumbarton Bridge	7/31/96	12	56	6	6	32	7	0.6	0.05	7.2	1.4	0.2
BA21	South Bay	8/1/96	12	69	2	1	28	5.5	11.6	0.13	7.4	1.4	0.6
BA10	Coyote Creek	7/31/96	12	28	14	46	12	5	0.9	0.05	7.1	0.8	0.2
C-3-0	San Jose	7/31/96	12	55	0	15	30	3	6.1	0.07	7.1	1.1	0.2
C-1-3	Sunnyvale	7/31/96	12	30	0	46	23	2.5	4.0	0.07	7.1	1.5	0.2
BW10	Standish Dam	8/6/96	12	58	0	11	31	.	.	.	.	.	.
WCCA0	China Camp Marsh A0	9/26/96	12	85	0	1	14	.	NS	NS	7.8	3.8	NS
WCCA2	China Camp Marsh A2	9/26/96	12	85	0	1	14	.	2.5	NS	7.5	2.3	NS
WPMA0	Petaluma Marsh A0	9/26/96	12	82	0	2	16	.	NS	NS	NS	5.9	NS
WPMA2	Petaluma Marsh A2	9/26/96	12	78	0	2	20	.	3.4	NS	8.3	2.0	NS

Table 12. Concentrations of trace elements for sediment samples, 1996. Wetlands pilot study data are included. NA = not analyzed. For method detection limits refer to Table 3 in *Appendix B*.

Station Code	Station	Date	Cruise	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Zn
				ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
BG20	Sacramento River	2/15/96	10	0.051	20983	12.5	0.23	101	23	34425	0.11	499	93	11.3	0.15	88.3
BG30	San Joaquin River	2/15/96	10	0.147	35741	15.8	0.45	90	47	35249	0.39	549	68	21.5	0.32	110.0
BF40	Honker Bay	2/15/96	10	0.272	41818	13.4	0.42	117	69	49199	0.25	975	115	20.0	0.28	151.9
BF20	Grizzly Bay	2/15/96	10	0.255	35841	15.0	0.40	110	65	48679	0.25	961	114	20.1	0.27	149.3
BF10	Pacheco Creek	2/15/96	10	0.097	23185	8.1	0.20	78	25	34909	0.04	705	90	11.0	0.07	89.6
BD50	Napa River	2/16/96	10	0.373	51604	16.6	0.27	121	68	47978	0.34	792	117	26.8	0.32	171.1
BD41	Davis Point	2/16/96	10	0.142	25896	7.2	0.12	91	21	35767	0.06	444	78	12.2	0.08	87.3
BD31	Pinole Point	2/16/96	10	0.262	43003	12.1	0.33	101	56	43711	0.19	666	109	15.5	0.27	139.1
BD22	San Pablo Bay	2/16/96	10	0.346	37473	15.0	0.27	102	54	43463	0.30	573	98	18.4	0.27	132.4
BD15	Petaluma River	2/16/96	10	0.368	51242	14.6	0.35	134	67	52159	0.43	686	130	28.0	0.26	163.0
BC60	Red Rock	2/20/96	10	0.029	16022	9.5	0.04	48	8	30446	0.02	397	68	12.5	0.06	63.2
BC41	Point Isabel	2/20/96	10	0.326	41065	14.7	0.19	106	47	40040	0.27	349	92	21.1	0.26	135.8
BC32	Richardson Bay	2/20/96	10	0.238	35399	11.8	0.20	98	39	37781	0.25	390	81	14.6	0.24	109.3
BC21	Horseshoe Bay	2/20/96	10	0.114	18471	10.4	0.13	71	16	28167	0.14	270	58	69.3	0.13	63.7
BC11	Yerba Buena Island	2/20/96	10	0.424	33521	9.2	0.21	94	41	36558	0.30	293	85	20.3	0.27	122.1
BB70	Alameda	2/21/96	10	0.360	40251	9.6	0.19	116	48	43556	0.28	344	98	17.5	0.26	132.3
BB30	Oyster Point	2/21/96	10	0.423	45277	9.1	0.17	112	46	44463	0.24	487	101	16.8	0.27	132.0
BB15	San Bruno Shoal	2/21/96	10	0.347	31787	16.4	0.14	77	33	25309	0.27	349	74	13.6	0.30	102.9
BA41	Redwood Creek	2/21/96	10	0.520	44055	11.0	0.23	119	48	43096	0.30	483	104	27.9	0.31	147.1
BA30	Dumbarton Bridge	2/22/96	10	0.437	34569	10.3	0.18	109	48	44527	0.34	870	103	26.1	0.28	142.8
BA21	South Bay	2/21/96	10	0.457	43138	12.5	0.20	126	56	49585	0.32	1037	118	29.9	0.34	165.0
BA10	Coyote Creek	2/22/96	10	0.481	45682	9.3	0.23	116	49	46368	0.54	1046	116	28.5	0.27	158.8
C-3-0	San Jose	2/21/96	10	0.436	19017	6.3	0.30	97	23	28293	0.21	695	99	15.5	0.23	84.8
C-1-3	Sunnyvale	2/21/96	10	0.228	25934	4.7	0.24	96	33	31910	0.24	591	80	20.1	0.22	101.5
BW10	Standish Dam	3/8/96	10	0.063	17533	8.5	0.22	66	24	26053	0.14	398	94	17.9	0.24	79.8
WCCA0	China Camp Marsh A0	3/13/96	10	0.262	44093	19.4	0.10	117	49	49268	0.33	373	113	30.1	0.47	143.4
WCCA2	China Camp Marsh A2	3/13/96	10	0.404	49254	18.6	0.20	141	68	57471	0.35	695	139	33.1	0.35	176.1
WPMA0	Petaluma Marsh A0	3/14/96	10	0.248	54363	31.7	0.13	141	51	50623	0.56	1055	148	25.5	0.65	149.6
WPMA2	Petaluma Marsh A2	3/14/96	10	0.513	56179	17.9	0.58	142	76	50776	0.43	806	155	33.6	0.45	180.8
WPMB0	Petaluma Marsh B0	3/14/96	10	0.183	52572	15.3	0.13	132	46	40431	0.36	1279	150	24.0	0.34	154.8
WPMB2	Petaluma Marsh B2	3/14/96	10	0.417	52165	14.8	0.75	131	68	64927	0.23	3555	159	29.2	0.27	184.1
BG20	Sacramento River	8/6/96	12	0.114	23586	9.9	0.36	85	34	31101	0.03	702	97	12.2	0.08	99.5
BG30	San Joaquin River	8/6/96	12	0.120	37251	14.2	0.22	89	40	36132	0.39	482	61	14.0	0.32	78.5
BF40	Honker Bay	8/6/96	12	0.289	37080	13.3	0.27	108	52	43258	0.28	695	102	20.5	0.32	138.8
BF20	Grizzly Bay	8/6/96	12	0.301	40031	14.8	0.27	111	53	44098	0.29	836	102	21.2	0.34	134.8
BF10	Pacheco Creek	8/6/96	12	0.134	25541	7.4	0.14	86	26	31509	0.10	414	81	10.3	0.14	84.6
BD50	Napa River	8/5/96	12	0.234	30093	14.0	0.19	84	43	19303	0.30	536	77	17.1	0.42	109.3
BD41	Davis Point	8/5/96	12	0.068	20750	6.4	0.09	93	18	32824	0.06	366	80	11.3	0.10	84.6
BD31	Pinole Point	8/5/96	12	0.194	29714	10.5	0.14	89	35	34589	0.18	462	85	16.4	0.19	103.6
BD22	San Pablo Bay	8/5/96	12	0.251	32109	17.5	0.21	89	45	34576	0.38	352	77	20.2	0.37	113.8
BD15	Petaluma River	8/5/96	12	0.302	37627	11.5	0.17	113	51	41744	0.28	773	103	22.6	0.31	133.8
BC60	Red Rock	8/2/96	12	0.043	14805	9.0	0.06	66	10	28260	0.02	493	64	12.5	0.06	62.4
BC41	Point Isabel	8/2/96	12	0.279	36143	12.8	0.12	106	39	38422	0.28	400	87	22.9	0.32	117.7
BC32	Richardson Bay	8/2/96	12	0.261	30825	10.1	0.17	101	33	31665	0.22	260	77	17.1	0.25	102.1
BC21	Horseshoe Bay	8/2/96	12	0.202	22032	7.8	0.17	78	28	28139	0.18	280	59	51.2	0.19	79.6
BC11	Yerba Buena Island	8/1/96	12	0.291	24083	8.5	0.16	77	31	30812	0.22	268	69	21.0	0.28	94.6
BB70	Alameda	8/1/96	12	0.408	33680	12.6	0.22	101	36	36807	0.28	460	83	20.8	0.33	111.5
BB30	Oyster Point	8/1/96	12	0.362	36527	10.0	0.14	108	39	37584	0.26	357	86	21.4	0.38	115.3
BB15	San Bruno Shoal	8/1/96	12	0.473	26947	6.7	0.15	82	29	27929	0.25	298	65	21.2	0.25	88.6
BA41	Redwood Creek	8/1/96	12	0.480	38788	9.5	0.12	111	40	38610	0.29	740	90	26.8	0.39	126.9
BA30	Dumbarton Bridge	7/31/96	12	0.482	31559	8.9	0.14	101	38	38868	0.33	747	87	28.8	0.35	120.9
BA21	South Bay	8/1/96	12	0.456	36926	8.9	0.15	112	40	38751	0.33	830	97	26.1	0.33	130.5
BA10	Coyote Creek	7/31/96	12	0.328	22755	6.5	0.15	80	25	30083	0.26	509	80	18.5	0.21	92.2
C-3-0	San Jose	7/31/96	12	1.304	31588	9.8	1.00	130	47	37397	0.56	570	130	52.9	0.44	177.2
C-1-3	Sunnyvale	7/31/96	12	0.351	23632	5.3	0.20	81	30	29982	0.22	536	75	23.7	0.33	113.0
BW10	Standish Dam	8/12/96	12	NA	NA	8.6	NA	NA	NA	NA	0.33	NA	NA	NA	0.51	NA
WCCA0	China Camp Marsh A0	9/26/96	12	0.314	39657	14.8	0.13	109	49	36762	0.33	939	109	28.2	0.39	144.5
WCCA2	China Camp Marsh A2	9/26/96	12	0.363	41221	21.7	0.19	122	55	38623	0.34	651	118	32.4	0.46	153.9
WPMA0	Petaluma Marsh A0	9/26/96	12	0.179	38026	10.1	0.17	100	41	35919	0.27	737	107	18.7	0.40	113.2
WPMA2	Petaluma Marsh A2	9/26/96	12	0.447	48807	17.2	0.37	126	62	41673	0.40	481	131	25.5	0.44	154.8

Table 13. PAH concentrations in sediment samples, 1996. Wetlands pilot study data are included. ND = not detected, LPAH = low molecular weight PAHs. For method detection limits refer to Table 3 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PAHs (SFEI)	Sum of LPAHs (SFEI)	Biphenyl	Naphthalene	1-Methylnaphthalene	2-Methylnaphthalene	2,6-Dimethylnaphthalene	2,3,5-Trimethylnaphthalene	Acenaphthene	Acenaphthylene	Anthracene	Dibenzothiophene	Fluorene	Phenanthrene	1-Methylphenanthrene
				µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	2/14/96	10	256	16	1	3	ND	ND	ND	ND	1	1	2	1	1	7	0
BG30	San Joaquin River	2/14/96	10	486	39	2	6	ND	ND	1	1	2	3	3	1	2	15	3
BF40	Honker Bay	2/14/96	10	405	56	2	7	3	5	3	2	1	2	5	2	2	18	3
BF20	Grizzly Bay	2/14/96	10	929	146	7	22	8	15	9	6	4	7	11	3	7	40	7
BF10	Pacheco Creek	2/14/96	10	188	62	1	4	2	2	2	1	4	1	4	2	5	32	3
BD50	Napa River	2/15/96	10	668	75	3	7	4	5	4	3	3	4	8	2	5	24	4
BD41	Davis Point	2/15/96	10	110	24	1	3	2	2	1	1	1	1	2	1	2	7	1
BD31	Pinole Point	2/15/96	10	624	86	3	11	4	7	5	2	3	3	8	2	5	27	4
BD22	San Pablo Bay	2/15/96	10	2899	383	8	26	8	10	8	7	13	23	61	10	18	166	25
BD15	Petaluma River	2/15/96	10	1524	176	6	21	6	9	5	3	6	9	22	5	8	67	10
BC60	Red Rock	2/19/96	10	221	68	2	8	4	5	3	7	2	3	7	2	3	16	6
BC41	Point Isabel	2/19/96	10	1807	257	6	16	6	7	9	5	11	15	41	6	11	110	14
BC32	Richardson Bay	2/19/96	10	2552	374	8	31	13	16	8	3	16	15	57	8	16	162	21
BC21	Horseshoe Bay	2/19/96	10	1196	162	3	13	4	6	4	7	7	6	22	4	6	72	8
BC11	Yerba Buena Island	2/19/96	10	1638	234	6	23	9	11	7	2	8	12	33	6	8	95	15
BB70	Alameda	2/20/96	10	1414	208	5	15	6	7	6	4	14	11	26	5	10	89	10
BB30	Oyster Point	2/20/96	10	3286	500	9	44	9	11	10	6	19	25	68	14	23	237	27
BB15	San Bruno Shoal	2/20/96	10	1977	245	7	20	5	7	6	5	9	17	35	7	12	101	15
BA41	Redwood Creek	2/20/96	10	2656	301	8	27	7	11	10	4	9	15	34	8	12	141	16
BA30	Dumbarton Bridge	2/21/96	10	3945	418	10	37	10	15	10	6	12	21	51	12	17	196	21
BA21	South Bay	2/20/96	10	3933	423	13	45	13	20	15	7	14	20	49	12	20	175	20
BA10	Coyote Creek	2/21/96	10	2026	224	8	26	8	15	9	5	5	10	22	6	10	89	11
C-3-0	San Jose	2/20/96	10	762	108	4	13	6	9	6	4	3	3	12	3	7	34	5
C-1-3	Sunnyvale	2/20/96	10	726	93	4	10	4	8	5	3	2	2	6	3	6	35	6
BW10	Standish Dam	3/8/96	10	663	98	3	9	5	11	5	4	2	1	5	3	3	43	6
WCCA0	China Camp Marsh A0	3/13/96	10	821	91	4	16	6	9	4	2	2	3	5	3	3	31	4
WCCA2	China Camp Marsh A2	3/13/96	10	833	104	5	14	5	9	6	3	3	4	10	3	5	34	5
WPMA0	Petaluma Marsh A0	3/14/96	10	710	75	3	11	4	6	3	2	2	3	5	2	3	27	4
WPMA2	Petaluma Marsh A2	3/14/96	10	913	101	4	13	6	9	5	4	2	4	10	3	5	33	5
WPMB0	Petaluma Marsh B0	3/14/96	10	638	70	3	10	4	6	3	2	2	3	5	2	3	25	3
WPMB2	Petaluma Marsh B2	3/14/96	10	730	72	3	11	4	7	4	2	2	3	5	2	4	22	4
BG20	Sacramento River	8/6/96	12	32	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1	2	ND
BG30	San Joaquin River	8/6/96	12	108	6	1	ND	ND	ND	ND	1	ND	1	ND	ND	1	2	1
BF40	Honker Bay	8/6/96	12	621	72	3	9	3	6	4	2	3	4	8	2	6	21	3
BF20	Grizzly Bay	8/6/96	12	543	69	4	10	3	5	3	2	2	3	7	2	5	20	3
BF10	Pacheco Creek	8/6/96	12	184	29	1	4	ND	ND	2	1	3	1	3	1	3	9	1
BD50	Napa River	8/5/96	12	878	126	6	16	7	11	6	4	4	5	11	4	8	37	6
BD41	Davis Point	8/5/96	12	50	11	1	4	ND	ND	1	ND	ND	1	1	ND	1	3	1
BD31	Pinole Point	8/5/96	12	601	78	3	10	3	5	3	2	3	4	8	3	5	26	5
BD22	San Pablo Bay	8/5/96	12	5464	564	11	42	7	10	8	7	18	37	95	18	20	262	31
BD15	Petaluma River	8/5/96	12	936	108	5	15	4	8	5	2	3	5	12	3	6	34	6
BC60	Red Rock	8/2/96	12	65	41	1	ND	ND	ND	2	1	ND	ND	2	2	2	21	10
BC41	Point Isabel	8/2/96	12	2393	304	8	20	6	9	9	5	12	17	50	9	15	127	17
BC32	Richardson Bay	8/2/96	12	3841	437	8	26	7	11	7	6	12	17	67	13	18	212	33
BC21	Horseshoe Bay	8/2/96	12	2524	446	8	23	8	10	7	2	27	29	62	13	23	213	22
BC11	Yerba Buena Island	8/1/96	12	1425	167	6	16	4	7	6	3	8	9	24	5	10	59	11
BB70	Alameda	8/1/96	12	2168	305	7	19	5	8	8	5	12	19	53	10	14	132	14
BB30	Oyster Point	8/1/96	12	2323	277	8	28	7	13	10	5	11	15	40	8	13	104	15
BB15	San Bruno Shoal	8/1/96	12	1961	209	6	22	5	7	5	3	9	16	28	6	10	83	10
BA41	Redwood Creek	8/1/96	12	3054	342	11	35	8	13	12	7	13	23	43	9	18	132	18
BA30	Dumbarton Bridge	7/31/96	12	2527	257	8	26	6	10	7	4	10	19	36	7	12	99	13
BA21	South Bay	8/1/96	12	2988	298	10	33	9	15	10	6	10	17	37	9	15	109	18
BA10	Coyote Creek	7/31/96	12	1412	142	5	18	4	6	5	2	4	9	18	5	7	53	7
C-3-0	San Jose	7/31/96	12	1134	230	8	21	8	17	22	21	4	7	22	8	18	54	20
BW10	Standish Dam	8/12/96	12	1058	131	5	15	6	9	14	5	3	5	10	5	7	40	7
WCCA0	China Camp Marsh A0	9/26/96	12	588	58	3	7	3	4	3	2	2	3	4	2	3	20	3
WCCA2	China Camp Marsh A2	9/26/96	12	708	86	4	12	5	7	5	3	3	4	7	3	5	25	4
WPMA0	Petaluma Marsh A0	9/26/96	12	508	55	3	7	2	4	3	1	2	3	4	2	3	18	3
WPMA2	Petaluma Marsh A2	9/26/96	12	759	83	4	11	4	6	4	3	3	4	8	3	5	25	4

Table 13. PAH concentrations in sediment samples, 1996 (continued). Wetlands pilot study data are included. ND = not detected, HPAH = high molecular weight PAHs. For method detection limits refer to Table 3 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PAHs (SFEI)	Sum of HPAHs (SFEI)	Benz(a)anthracene	Chrysene	Fluoranthene	Pyrene	Benzo(a)pyrene	Benzo(e)pyrene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Dibenz(a,h)anthracene	Perylene	Benzo(ghi)perylene	Indeno(1,2,3-cd)pyrene
				µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	2/14/96	10	256	240	8	12	29	44	25	18	22	6	2	20	31	25
BG30	San Joaquin River	2/14/96	10	486	446	17	24	55	74	42	30	40	11	4	61	49	41
BF40	Honker Bay	2/14/96	10	405	349	17	25	44	55	33	26	38	11	4	24	40	33
BF20	Grizzly Bay	2/14/96	10	929	782	43	60	91	115	84	59	92	23	9	46	87	75
BF10	Pacheco Creek	2/14/96	10	188	127	9	8	32	26	9	7	12	4	1	6	7	7
BD50	Napa River	2/15/96	10	668	594	30	35	72	91	61	45	71	14	7	42	69	57
BD41	Davis Point	2/15/96	10	110	86	4	6	14	15	8	6	9	3	1	5	9	7
BD31	Pinole Point	2/15/96	10	624	539	33	38	69	88	55	38	57	19	6	30	58	49
BD22	San Pablo Bay	2/15/96	10	2899	2517	165	176	345	446	301	175	290	47	29	73	251	217
BD15	Petaluma River	2/15/96	10	1524	1348	76	87	173	237	150	93	150	41	15	50	149	128
BC60	Red Rock	2/19/96	10	221	154	11	14	22	27	16	10	17	5	2	6	13	12
BC41	Point Isabel	2/19/96	10	1807	1550	98	117	223	276	176	102	163	53	18	46	143	137
BC32	Richardson Bay	2/19/96	10	2552	2178	137	167	328	407	238	140	222	75	24	62	195	184
BC21	Horseshoe Bay	2/19/96	10	1196	1034	52	61	162	213	111	66	102	9	12	29	116	101
BC11	Yerba Buena Island	2/19/96	10	1638	1404	83	98	206	261	152	90	141	50	15	48	141	121
BB70	Alameda	2/20/96	10	1414	1206	73	77	170	203	139	83	138	32	14	40	125	112
BB30	Oyster Point	2/20/96	10	3286	2786	145	172	414	559	299	178	276	52	36	68	312	277
BB15	San Bruno Shoal	2/20/96	10	1977	1732	107	127	234	301	197	114	188	58	20	51	176	159
BA41	Redwood Creek	2/20/96	10	2656	2355	111	120	322	428	252	163	239	53	30	64	308	264
BA30	Dumbarton Bridge	2/21/96	10	3945	3527	167	210	466	632	392	246	380	43	46	86	463	397
BA21	South Bay	2/20/96	10	3933	3511	149	200	423	596	392	250	359	88	47	95	497	416
BA10	Coyote Creek	2/21/96	10	2026	1802	71	102	230	313	186	128	199	37	25	50	253	208
C-3-0	San Jose	2/20/96	10	762	655	31	41	81	114	66	49	71	12	9	20	94	68
C-1-3	Sunnyvale	2/20/96	10	726	633	27	44	89	102	55	47	73	14	10	19	85	69
BW10	Standish Dam	3/8/96	10	663	564	28	52	85	88	43	43	70	9	12	13	68	55
WCCA0	China Camp Marsh A0	3/13/96	10	821	730	28	38	81	110	76	59	81	18	11	26	113	92
WCCA2	China Camp Marsh A2	3/13/96	10	833	729	27	39	83	116	75	53	82	14	10	39	104	88
WPMA0	Petaluma Marsh A0	3/14/96	10	710	636	22	34	72	99	65	49	69	18	8	24	96	80
WPMA2	Petaluma Marsh A2	3/14/96	10	913	812	29	43	89	128	83	62	91	18	11	41	119	99
WPMB0	Petaluma Marsh B0	3/14/96	10	638	568	21	29	66	91	55	45	62	15	8	23	86	71
WPMB2	Petaluma Marsh B2	3/14/96	10	730	658	23	36	65	93	72	57	81	12	9	28	102	80
BG20	Sacramento River	8/6/96	12	32	30	1	2	3	4	2	3	5	2	ND	2	4	3
BG30	San Joaquin River	8/6/96	12	108	102	3	2	4	5	6	3	6	2	ND	54	9	8
BF40	Honker Bay	8/6/96	12	621	549	28	32	64	82	59	42	69	11	6	42	63	50
BF20	Grizzly Bay	8/6/96	12	543	474	24	27	55	70	50	34	52	15	6	38	59	46
BF10	Pacheco Creek	8/6/96	12	184	155	8	10	21	28	15	11	17	5	1	13	14	11
BD50	Napa River	8/5/96	12	878	752	41	58	95	113	83	55	90	25	8	38	83	66
BD41	Davis Point	8/5/96	12	50	38	2	2	6	7	4	3	4	1	ND	3	4	3
BD31	Pinole Point	8/5/96	12	601	524	26	32	70	88	62	38	56	17	6	24	58	48
BD22	San Pablo Bay	8/5/96	12	5464	4899	310	323	662	764	667	399	585	171	54	135	436	392
BD15	Petaluma River	8/5/96	12	936	829	42	51	98	132	100	61	93	29	9	37	98	80
BC60	Red Rock	8/2/96	12	65	23	2	3	3	4	2	2	3	ND	ND	1	2	2
BC41	Point Isabel	8/2/96	12	2393	2090	126	134	292	363	259	143	225	70	24	63	208	184
BC32	Richardson Bay	8/2/96	12	3841	3404	205	239	660	683	360	202	350	103	31	80	253	241
BC21	Horseshoe Bay	8/2/96	12	2524	2079	145	133	331	442	228	115	208	62	23	47	178	166
BC11	Yerba Buena Island	8/1/96	12	1425	1258	58	65	162	201	130	75	153	144	12	36	122	100
BB70	Alameda	8/1/96	12	2168	1863	112	111	294	348	222	118	197	57	19	53	177	155
BB30	Oyster Point	8/1/96	12	2323	2045	108	111	266	348	250	145	248	41	22	67	242	199
BB15	San Bruno Shoal	8/1/96	12	1961	1752	98	95	217	290	225	121	192	60	20	47	213	175
BA41	Redwood Creek	8/1/96	12	3054	2712	152	158	361	477	335	190	323	71	29	84	286	247
BA30	Dumbarton Bridge	7/31/96	12	2527	2269	121	139	282	358	286	165	295	44	27	64	260	229
BA21	South Bay	8/1/96	12	2988	2690	134	155	316	424	334	201	298	98	32	83	339	276
BA10	Coyote Creek	7/31/96	12	1412	1271	61	72	142	194	156	97	166	29	15	39	164	137
C-3-0	San Jose	7/31/96	12	1134	904	56	72	129	168	83	65	96	19	14	37	99	67
BW10	Standish Dam	8/12/96	12	1058	928	46	69	102	121	95	77	133	30	13	30	122	90
WCCA0	China Camp Marsh A0	9/26/96	12	588	530	22	31	59	80	60	43	62	17	7	20	71	57
WCCA2	China Camp Marsh A2	9/26/96	12	708	623	27	34	65	91	71	49	77	18	8	34	84	65
WPMA0	Petaluma Marsh A0	9/26/96	12	508	453	17	27	49	66	48	38	59	12	5	19	64	50
WPMA2	Petaluma Marsh A2	9/26/96	12	759	676	31	36	70	101	80	54	77	23	8	34	91	71

Table 14. PCB concentrations in sediment samples, 1996. Wetlands pilot study data are included. ND = not detected, . = no data. For method detection limits refer to Table 3 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 001	PCB 003	PCB 004	PCB 006	PCB 008	PCB 015	PCB 017/18	PCB 027	PCB 028	PCB 031	PCB 033	PCB 044	PCB 049
				µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	2/14/96	10	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	2/14/96	10	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	2/14/96	10	1.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF20	Grizzly Bay	2/14/96	10	4.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF10	Pacheco Creek	2/14/96	10	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	2/15/96	10	5.9	ND	ND	ND	ND	ND	ND	ND	ND	0.2	ND	ND	ND	ND
BD41	Davis Point	2/15/96	10	0.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	2/15/96	10	3.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	2/15/96	10	5.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	2/15/96	10	7.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2	ND
BC60	Red Rock	2/19/96	10	0.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	2/19/96	10	8.2	ND	ND	ND	ND	ND	ND	ND	ND	0.2	ND	ND	0.2	ND
BC32	Richardson Bay	2/19/96	10	8.2	ND	ND	ND	ND	ND	ND	ND	ND	0.4	ND	ND	ND	ND
BC21	Horseshoe Bay	2/19/96	10	3.7	ND	ND	ND	ND	ND	ND	ND	ND	0.1	ND	ND	ND	ND
BC11	Yerba Buena Island	2/19/96	10	18.0	ND	ND	ND	ND	0.5	ND	ND	ND	0.5	ND	ND	0.3	ND
BB70	Alameda	2/20/96	10	11.2	ND	ND	ND	ND	ND	ND	0.2	ND	0.2	ND	ND	0.2	ND
BB30	Oyster Point	2/20/96	10	10.1	ND	ND	ND	ND	ND	ND	ND	ND	0.3	ND	ND	0.2	ND
BB15	San Bruno Shoal	2/20/96	10	8.9	ND	ND	ND	ND	0.3	ND	ND	ND	0.2	ND	ND	0.2	ND
BA41	Redwood Creek	2/20/96	10	13.4	ND	ND	ND	ND	0.3	ND	ND	ND	0.3	ND	ND	0.2	ND
BA30	Dumbarton Bridge	2/21/96	10	14.7	ND	ND	ND	ND	ND	ND	ND	ND	0.5	ND	ND	0.2	ND
BA21	South Bay	2/20/96	10	21.0	ND	ND	ND	ND	ND	ND	ND	ND	0.6	ND	ND	0.3	ND
BA10	Coyote Creek	2/21/96	10	17.5	ND	ND	ND	ND	ND	ND	ND	ND	0.5	ND	ND	0.3	ND
C-3-0	San Jose	2/20/96	10	80.5	ND	0.3	ND	ND	1.2	1.6	1.6	ND	7.2	ND	ND	2.8	1.6
C-1-3	Sunnyvale	2/20/96	10	18.3	ND	ND	0.3	ND	ND	0.2	ND	ND	0.4	ND	ND	0.5	0.2
BW10	Standish Dam	3/8/96	10	27.0	0.7	ND	ND	ND	0.4	0.3	ND	ND	0.5	ND	ND	ND	0.4
WCCA0	China Camp Marsh A0	3/13/96	10	7.5	ND	ND	ND	ND	ND	ND	ND	ND	0.3	ND	ND	ND	ND
WCCA2	China Camp Marsh A2	3/13/96	10	7.1	ND	ND	ND	ND	ND	ND	ND	ND	0.3	ND	ND	ND	ND
WPMA0	Petaluma Marsh A0	3/14/96	10	6.7	ND	ND	ND	ND	0.3	ND	ND	ND	0.3	ND	ND	0.2	ND
WPMA2	Petaluma Marsh A2	3/14/96	10	6.8	ND	ND	ND	ND	ND	ND	ND	ND	0.3	ND	ND	ND	ND
WPMB0	Petaluma Marsh B0	3/14/96	10	5.6	ND	ND	ND	ND	0.4	ND	ND	ND	ND	ND	ND	ND	ND
WPMB2	Petaluma Marsh B2	3/14/96	10	5.4	ND	ND	ND	ND	ND	ND	ND	ND	0.4	ND	ND	ND	ND
BG20	Sacramento River	8/6/96	12	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	8/6/96	12	1.3	0.3	ND	0.5	ND	0.3	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	8/6/96	12	4.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF20	Grizzly Bay	8/6/96	12	5.9	ND	ND	1.7	ND	ND	ND	ND	ND	ND	0.4	ND	ND	ND
BF10	Pacheco Creek	8/6/96	12	0.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	8/5/96	12	5.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.3	ND
BD41	Davis Point	8/5/96	12	0.6	ND	ND	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	8/5/96	12	2.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	8/5/96	12	2.9	ND	ND	ND	ND	ND	0.2	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	8/5/96	12	8.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC60	Red Rock	8/2/96	12	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	8/2/96	12	10.3	ND	ND	ND	ND	0.3	ND	ND	ND	ND	ND	ND	ND	ND
BC32	Richardson Bay	8/2/96	12	8.6	ND	ND	ND	ND	ND	0.3	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	8/2/96	12	6.6	ND	ND	0.7	ND	ND	ND	ND	ND	ND	0.3	ND	ND	ND
BC11	Yerba Buena Island	8/1/96	12	19.6	ND	ND	1.1	ND	ND	ND	ND	ND	0.2	0.5	ND	0.3	0.4
BB70	Alameda	8/1/96	12	8.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB30	Oyster Point	8/1/96	12	15.7	ND	ND	0.7	ND	ND	ND	ND	ND	ND	ND	ND	0.3	ND
BB15	San Bruno Shoal	8/1/96	12	15.7	ND	ND	0.8	ND	ND	ND	ND	ND	0.2	ND	ND	0.2	0.3
BA41	Redwood Creek	8/1/96	12	16.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	7/31/96	12	12.7	ND	ND	1.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA21	South Bay	8/1/96	12	22.7	ND	ND	2.4	ND	ND	ND	ND	ND	ND	0.6	ND	ND	ND
BA10	Coyote Creek	7/31/96	12	11.2	ND	ND	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-3-0	San Jose	7/31/96	12	320.4	0.4	ND	0.8	ND	1.4	2.5	2.5	ND	5.7	4.8	1.2	8.1	2.4
BW10	Standish Dam	8/12/96	12	46.4	ND	ND	1.3	ND	1.2	ND	ND	ND	2.1	2.1	ND	0.8	0.5
WCCA0	China Camp Marsh A0	9/26/96	12	6.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WCCA2	China Camp Marsh A2	9/26/96	12	6.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WPMA0	Petaluma Marsh A0	9/26/96	12	5.7	ND	ND	ND	ND	0.3	ND	ND	ND	0.4	ND	ND	ND	ND
WPMA2	Petaluma Marsh A2	9/26/96	12	6.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 14. PCB concentrations in sediment samples, 1996 (continued). Wetlands pilot study data are included. ND = not detected, . = no data. For method detection limits refer to Table 3 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 052	PCB 060	PCB 066	PCB 070	PCB 074	PCB 085	PCB 095	PCB 097	PCB 099	PCB 101	PCB 105	PCB 110	PCB 118
				µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	2/14/96	10	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	2/14/96	10	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	2/14/96	10	1.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2
BF20	Grizzly Bay	2/14/96	10	4.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.9	0.5
BF10	Pacheco Creek	2/14/96	10	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	2/15/96	10	5.9	ND	ND	ND	ND	ND	ND	0.3	ND	ND	0.3	0.1	0.6	0.4
BD41	Davis Point	2/15/96	10	0.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	2/15/96	10	3.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2	0.1	ND	0.2
BD22	San Pablo Bay	2/15/96	10	5.6	ND	ND	0.2	ND	ND	ND	0.3	ND	ND	0.4	0.2	ND	0.5
BD15	Petaluma River	2/15/96	10	7.1	ND	ND	ND	ND	ND	ND	0.4	ND	0.3	0.4	0.2	0.6	0.4
BC60	Red Rock	2/19/96	10	0.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	2/19/96	10	8.2	ND	ND	0.3	ND	ND	ND	0.4	ND	0.3	0.5	0.2	0.5	0.5
BC32	Richardson Bay	2/19/96	10	8.2	ND	ND	0.3	ND	ND	ND	0.4	ND	0.4	0.5	0.2	0.5	0.5
BC21	Horseshoe Bay	2/19/96	10	3.7	ND	ND	0.2	ND	ND	ND	0.2	ND	0.2	0.3	ND	0.3	0.2
BC11	Yerba Buena Island	2/19/96	10	18.0	ND	0.3	0.4	0.3	ND	ND	0.7	0.3	0.5	0.9	0.4	1.1	0.9
BB70	Alameda	2/20/96	10	11.2	ND	0.3	0.4	0.3	ND	ND	ND	0.2	0.4	0.6	0.2	0.8	0.8
BB30	Oyster Point	2/20/96	10	10.1	ND	ND	0.4	ND	ND	ND	0.5	ND	0.4	0.7	0.3	ND	0.7
BB15	San Bruno Shoal	2/20/96	10	8.9	ND	ND	0.3	ND	ND	ND	0.3	ND	0.3	0.5	0.2	ND	0.6
BA41	Redwood Creek	2/20/96	10	13.4	ND	ND	ND	0.3	ND	ND	0.8	ND	0.4	0.7	0.3	0.8	0.9
BA30	Dumbarton Bridge	2/21/96	10	14.7	ND	ND	ND	0.3	ND	ND	0.4	ND	0.4	0.8	0.3	0.9	1.1
BA21	South Bay	2/20/96	10	21.0	ND	ND	0.6	ND	ND	ND	0.8	ND	0.6	1.1	0.3	1.5	1.4
BA10	Coyote Creek	2/21/96	10	17.5	0.9	ND	ND	ND	ND	ND	1.0	ND	0.4	0.9	0.3	1.2	1.0
C-3-0	San Jose	2/20/96	10	80.5	4.2	2.1	4.1	6.6	1.6	0.4	3.2	1.3	2.5	4.3	0.9	4.9	3.8
C-1-3	Sunnyvale	2/20/96	10	18.3	2.8	0.4	ND	ND	0.3	ND	0.9	0.3	0.6	1.1	ND	0.9	0.9
BW10	Standish Dam	3/8/96	10	27.0	1.7	ND	ND	ND	0.2	ND	1.0	ND	0.3	ND	ND	1.3	0.8
WCCA0	China Camp Marsh A0	3/13/96	10	7.5	1.3	ND	ND	ND	ND	ND	0.6	ND	ND	ND	0.2	0.5	ND
WCCA2	China Camp Marsh A2	3/13/96	10	7.1	ND	ND	ND	ND	ND	ND	0.5	ND	ND	0.4	0.2	0.6	0.5
WPMA0	Petaluma Marsh A0	3/14/96	10	6.7	ND	ND	ND	ND	ND	ND	0.7	ND	ND	ND	0.2	0.4	0.4
WPMA2	Petaluma Marsh A2	3/14/96	10	6.8	ND	ND	ND	ND	ND	ND	0.4	ND	ND	0.5	0.1	0.7	0.5
WPMB0	Petaluma Marsh B0	3/14/96	10	5.6	ND	ND	ND	ND	ND	ND	0.3	ND	ND	ND	0.2	0.4	ND
WPMB2	Petaluma Marsh B2	3/14/96	10	5.4	ND	ND	ND	ND	ND	ND	0.4	ND	ND	0.4	ND	0.5	0.4
BG20	Sacramento River	8/6/96	12	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	8/6/96	12	1.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	8/6/96	12	4.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4	0.3
BF20	Grizzly Bay	8/6/96	12	5.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.3
BF10	Pacheco Creek	8/6/96	12	0.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	8/5/96	12	5.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4	ND	0.5	0.4
BD41	Davis Point	8/5/96	12	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	8/5/96	12	2.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.3	0.2
BD22	San Pablo Bay	8/5/96	12	2.9	ND	ND	0.2	ND	ND	ND	ND	ND	ND	ND	ND	0.4	0.2
BD15	Petaluma River	8/5/96	12	8.6	ND	ND	ND	ND	ND	ND	0.5	ND	ND	0.6	ND	0.7	0.5
BC60	Red Rock	8/2/96	12	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	8/2/96	12	10.3	ND	ND	ND	ND	ND	ND	0.4	ND	ND	0.7	0.2	0.8	0.7
BC32	Richardson Bay	8/2/96	12	8.6	ND	ND	0.2	0.4	0.4	ND	0.3	ND	ND	0.6	ND	0.8	0.4
BC21	Horseshoe Bay	8/2/96	12	6.6	ND	ND	0.1	ND	ND	ND	ND	ND	ND	0.4	ND	0.6	0.3
BC11	Yerba Buena Island	8/1/96	12	19.6	ND	0.3	0.2	0.4	ND	ND	1.0	0.6	0.7	1.4	ND	1.5	1.4
BB70	Alameda	8/1/96	12	8.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.5	ND	0.6	0.6
BB30	Oyster Point	8/1/96	12	15.7	ND	ND	0.2	ND	ND	ND	0.6	ND	0.6	0.9	0.2	1.1	1.0
BB15	San Bruno Shoal	8/1/96	12	15.7	ND	ND	0.3	0.4	0.3	ND	0.6	ND	0.7	0.9	0.2	1.1	0.9
BA41	Redwood Creek	8/1/96	12	16.8	ND	ND	0.4	ND	ND	ND	0.7	ND	ND	1.0	0.3	1.3	1.2
BA30	Dumbarton Bridge	7/31/96	12	12.7	ND	ND	0.3	ND	0.4	ND	0.4	ND	0.3	0.6	0.2	0.9	0.8
BA21	South Bay	8/1/96	12	22.7	ND	ND	0.4	0.6	ND	ND	0.6	ND	0.5	1.0	0.3	1.4	1.2
BA10	Coyote Creek	7/31/96	12	11.2	ND	ND	0.2	ND	ND	ND	0.4	ND	0.4	0.6	0.2	0.9	0.8
C-3-0	San Jose	7/31/96	12	320.4	11.1	ND	5.4	10.6	5.9	ND	13.1	5.0	9.7	22.2	2.7	18.7	14.2
BW10	Standish Dam	8/12/96	12	46.4	3.8	ND	0.4	1.2	0.6	ND	1.2	ND	0.5	1.8	0.6	2.2	1.8
WCCA0	China Camp Marsh A0	9/26/96	12	6.5	ND	0.3	ND	ND	0.2	ND	0.6	ND	0.3	0.3	0.1	0.4	0.4
WCCA2	China Camp Marsh A2	9/26/96	12	6.5	ND	ND	0.3	0.3	ND	ND	ND	ND	ND	0.4	0.1	0.7	0.6
WPMA0	Petaluma Marsh A0	9/26/96	12	5.7	ND	ND	ND	ND	0.5	ND	0.3	ND	0.3	ND	0.1	0.4	0.4
WPMA2	Petaluma Marsh A2	9/26/96	12	6.1	ND	ND	0.2	ND	ND	ND	ND	ND	0.3	0.4	ND	0.6	0.5

Table 14. PCB concentrations in sediment samples, 1996 (continued). Wetlands pilot study data are included. ND = not detected, . = no data. For method detection limits refer to Table 3 in *Appendix B*.

Station	Date	Cruise	Cruise	Sum of PCBs (SFEI)	PCB 119	PCB 128	PCB 132	PCB 138	PCB 141	PCB 149	PCB 151	PCB 153	PCB 158	PCB 167	PCB 170	PCB 174
				µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	2/14/96	10	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	2/14/96	10	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	2/14/96	10	1.3	ND	ND	ND	0.4	ND	ND	ND	0.4	ND	ND	ND	ND
BF20	Grizzly Bay	2/14/96	10	4.5	ND	ND	ND	0.9	ND	ND	ND	1.0	ND	ND	0.8	ND
BF10	Pacheco Creek	2/14/96	10	0.2	ND	ND	ND	0.1	ND	ND	ND	0.1	ND	ND	ND	ND
BD50	Napa River	2/15/96	10	5.9	ND	ND	0.4	0.7	ND	0.5	0.2	0.9	ND	ND	ND	ND
BD41	Davis Point	2/15/96	10	0.4	ND	ND	ND	0.1	ND	ND	ND	0.2	ND	ND	ND	ND
BD31	Pinole Point	2/15/96	10	3.2	ND	ND	ND	0.4	ND	0.3	ND	0.6	ND	ND	0.3	ND
BD22	San Pablo Bay	2/15/96	10	5.6	ND	ND	0.2	0.7	ND	0.5	ND	0.9	ND	ND	0.6	ND
BD15	Petaluma River	2/15/96	10	7.1	ND	ND	ND	0.7	ND	0.6	ND	1.0	ND	ND	0.7	ND
BC60	Red Rock	2/19/96	10	0.3	ND	ND	ND	ND	ND	ND	ND	0.2	ND	ND	ND	ND
BC41	Point Isabel	2/19/96	10	8.2	ND	ND	0.5	0.9	ND	0.5	ND	1.1	ND	ND	0.5	ND
BC32	Richardson Bay	2/19/96	10	8.2	ND	ND	0.8	0.8	ND	0.6	ND	0.9	ND	ND	0.6	ND
BC21	Horseshoe Bay	2/19/96	10	3.7	ND	ND	0.2	0.4	ND	0.3	ND	0.5	ND	ND	0.4	ND
BC11	Yerba Buena Island	2/19/96	10	18.0	ND	ND	0.7	1.4	0.3	1.0	ND	2.0	ND	ND	1.1	0.4
BB70	Alameda	2/20/96	10	11.2	ND	0.2	0.2	0.9	ND	0.6	ND	1.3	ND	ND	0.7	0.2
BB30	Oyster Point	2/20/96	10	10.1	ND	ND	0.6	1.0	ND	0.6	ND	1.3	ND	ND	0.9	ND
BB15	San Bruno Shoal	2/20/96	10	8.9	ND	ND	0.5	0.9	ND	0.6	ND	1.3	ND	ND	0.8	ND
BA41	Redwood Creek	2/20/96	10	13.4	ND	ND	0.4	1.4	ND	0.9	ND	1.7	ND	ND	0.8	0.3
BA30	Dumbarton Bridge	2/21/96	10	14.7	ND	ND	0.9	1.5	ND	1.0	ND	2.0	ND	ND	0.8	0.4
BA21	South Bay	2/20/96	10	21.0	ND	ND	1.3	2.1	ND	1.3	ND	2.8	ND	ND	1.1	0.5
BA10	Coyote Creek	2/21/96	10	17.5	0.3	ND	1.0	1.5	0.3	1.1	0.3	2.0	ND	ND	0.7	0.3
C-3-0	San Jose	2/20/96	10	80.5	ND	0.9	1.7	3.5	0.8	2.3	0.7	4.4	0.4	ND	1.4	0.9
C-1-3	Sunnyvale	2/20/96	10	18.3	ND	ND	0.0	1.0	0.2	0.8	0.3	1.6	ND	ND	0.9	0.4
BW10	Standish Dam	3/8/96	10	27.0	ND	0.3	0.7	1.7	0.6	1.6	0.5	2.5	0.2	ND	1.8	1.0
WCCA0	China Camp Marsh A0	3/13/96	10	7.5	0.4	ND	ND	1.3	ND	0.6	ND	0.9	ND	ND	ND	ND
WCCA2	China Camp Marsh A2	3/13/96	10	7.1	ND	ND	0.4	0.8	ND	0.5	ND	1.0	ND	ND	0.6	ND
WPMA0	Petaluma Marsh A0	3/14/96	10	6.7	ND	ND	ND	1.0	ND	0.6	ND	0.8	ND	ND	0.8	ND
WPMA2	Petaluma Marsh A2	3/14/96	10	6.8	ND	ND	ND	0.9	ND	0.6	ND	1.3	ND	ND	0.4	ND
WPMB0	Petaluma Marsh B0	3/14/96	10	5.6	ND	ND	ND	1.0	ND	0.6	ND	0.8	ND	ND	0.4	ND
WPMB2	Petaluma Marsh B2	3/14/96	10	5.4	ND	ND	ND	0.7	ND	0.4	ND	0.9	ND	ND	0.7	ND
BG20	Sacramento River	8/6/96	12	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	8/6/96	12	1.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.3	ND
BF40	Honker Bay	8/6/96	12	4.8	ND	ND	0.4	0.6	ND	0.4	ND	0.7	ND	ND	1.1	ND
BF20	Grizzly Bay	8/6/96	12	5.9	ND	ND	0.6	0.5	ND	ND	ND	0.7	ND	ND	0.9	ND
BF10	Pacheco Creek	8/6/96	12	0.9	ND	ND	ND	0.3	ND	ND	ND	0.3	ND	ND	ND	ND
BD50	Napa River	8/5/96	12	5.9	ND	ND	ND	0.8	ND	0.5	ND	1.0	ND	ND	1.3	ND
BD41	Davis Point	8/5/96	12	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	8/5/96	12	2.8	ND	ND	0.4	0.5	ND	ND	ND	0.5	ND	ND	0.5	ND
BD22	San Pablo Bay	8/5/96	12	2.9	ND	ND	ND	0.5	ND	ND	ND	0.6	ND	ND	ND	ND
BD15	Petaluma River	8/5/96	12	8.6	ND	ND	0.6	1.2	ND	0.8	ND	1.4	ND	ND	1.0	ND
BC60	Red Rock	8/2/96	12	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	8/2/96	12	10.3	ND	0.3	0.6	1.1	ND	0.7	ND	1.5	ND	ND	1.1	ND
BC32	Richardson Bay	8/2/96	12	8.6	ND	ND	0.5	0.7	ND	ND	ND	1.2	ND	ND	1.0	ND
BC21	Horseshoe Bay	8/2/96	12	6.6	ND	ND	0.6	0.6	ND	0.4	ND	0.9	ND	ND	0.5	ND
BC11	Yerba Buena Island	8/1/96	12	19.6	ND	0.5	0.9	1.8	0.4	1.1	ND	1.9	ND	ND	1.0	ND
BB70	Alameda	8/1/96	12	8.1	ND	ND	0.6	1.0	ND	0.6	ND	1.3	ND	ND	1.1	ND
BB30	Oyster Point	8/1/96	12	15.7	ND	0.4	0.8	1.5	ND	1.0	ND	1.9	ND	ND	1.3	ND
BB15	San Bruno Shoal	8/1/96	12	15.7	ND	0.3	0.7	1.3	ND	0.9	ND	1.9	ND	ND	0.7	0.3
BA41	Redwood Creek	8/1/96	12	16.8	ND	ND	1.0	1.9	ND	1.1	ND	2.6	ND	ND	1.9	ND
BA30	Dumbarton Bridge	7/31/96	12	12.7	ND	0.4	0.6	1.2	ND	0.7	ND	1.6	ND	ND	1.0	ND
BA21	South Bay	8/1/96	12	22.7	ND	0.6	1.5	1.8	ND	1.1	ND	2.8	ND	ND	2.0	ND
BA10	Coyote Creek	7/31/96	12	11.2	ND	ND	0.6	1.1	ND	0.7	ND	1.5	ND	ND	0.8	ND
C-3-0	San Jose	7/31/96	12	320.4	0.7	3.0	5.0	16.9	5.4	15.0	4.2	39.1	2.9	0.8	8.0	7.8
BW10	Standish Dam	8/12/96	12	46.4	ND	0.5	0.5	2.4	0.7	2.7	0.6	3.2	ND	ND	3.3	0.9
WCCA0	China Camp Marsh A0	9/26/96	12	6.5	ND	0.2	ND	0.7	ND	0.4	ND	0.6	0.4	ND	ND	ND
WCCA2	China Camp Marsh A2	9/26/96	12	6.5	ND	0.3	0.4	0.8	ND	0.4	ND	0.9	ND	ND	0.4	ND
WPMA0	Petaluma Marsh A0	9/26/96	12	5.7	ND	0.3	ND	0.5	ND	0.4	ND	0.7	ND	ND	ND	ND
WPMA2	Petaluma Marsh A2	9/26/96	12	6.1	ND	0.3	0.3	0.7	ND	0.5	ND	0.9	ND	ND	0.3	ND

Table 14. PCB concentrations in sediment samples, 1996 (continued). Wetlands pilot study data are included. ND = not detected, . = no data. For method detection limits refer to Table 3 in *Appendix B*.

Station	Date	Cruise	Cruise	Sum of PCBs (SFEI)	PCB 177	PCB 180	PCB 183	PCB 187	PCB 189	PCB 194	PCB 195	PCB 201	PCB 203	PCB 206	PCB 207	Hexachlorobenzene
				µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	2/14/96	10	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	2/14/96	10	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	2/14/96	10	1.3	ND	0.2	ND	0.2	ND	ND	ND	ND	ND	ND	ND	ND
BF20	Grizzly Bay	2/14/96	10	4.5	ND	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF10	Pacheco Creek	2/14/96	10	0.2	ND	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	2/15/96	10	5.9	0.4	0.6	ND	0.4	ND	ND	ND	ND	ND	ND	ND	ND
BD41	Davis Point	2/15/96	10	0.4	ND	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	2/15/96	10	3.2	0.3	0.5	ND	0.2	ND	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	2/15/96	10	5.6	0.4	0.5	ND	0.2	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	2/15/96	10	7.1	0.4	0.7	ND	0.4	ND	ND	ND	ND	ND	0.2	ND	ND
BC60	Red Rock	2/19/96	10	0.3	ND	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	2/19/96	10	8.2	0.4	0.7	ND	0.4	ND	ND	ND	0.2	ND	0.1	ND	ND
BC32	Richardson Bay	2/19/96	10	8.2	0.5	0.6	ND	0.3	ND	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	2/19/96	10	3.7	ND	0.3	ND	0.2	ND	ND	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	2/19/96	10	18.0	0.6	1.4	0.4	0.8	ND	0.3	ND	0.3	0.3	0.1	ND	ND
BB70	Alameda	2/20/96	10	11.2	0.4	0.9	0.2	0.5	ND	0.3	ND	0.3	0.2	ND	ND	ND
BB30	Oyster Point	2/20/96	10	10.1	0.4	0.9	ND	0.5	ND	ND	ND	0.3	ND	ND	ND	ND
BB15	San Bruno Shoal	2/20/96	10	8.9	0.4	0.8	ND	0.4	ND	ND	ND	0.3	ND	0.1	ND	ND
BA41	Redwood Creek	2/20/96	10	13.4	0.5	1.0	0.3	0.7	ND	ND	0.2	0.4	ND	0.1	ND	ND
BA30	Dumbarton Bridge	2/21/96	10	14.7	0.6	1.2	0.3	0.8	ND	ND	ND	0.4	ND	0.1	ND	ND
BA21	South Bay	2/20/96	10	21.0	0.8	1.8	0.4	1.0	ND	ND	ND	0.6	ND	0.2	ND	ND
BA10	Coyote Creek	2/21/96	10	17.5	0.6	1.2	0.3	0.8	ND	ND	ND	0.4	0.3	0.1	ND	ND
C-3-0	San Jose	2/20/96	10	80.5	0.8	2.0	0.7	1.4	ND	0.5	0.2	0.7	0.6	0.4	ND	ND
C-1-3	Sunnyvale	2/20/96	10	18.3	0.4	1.1	0.3	0.6	ND	0.2	ND	0.4	0.3	0.2	ND	ND
BW10	Standish Dam	3/8/96	10	27.0	0.7	2.6	0.7	1.4	ND	0.6	0.3	1.0	0.8	0.5	ND	ND
WCCA0	China Camp Marsh A0	3/13/96	10	7.5	0.5	0.8	ND	0.3	ND	ND	ND	ND	ND	ND	ND	ND
WCCA2	China Camp Marsh A2	3/13/96	10	7.1	0.3	0.7	ND	0.4	ND	ND	ND	ND	ND	0.1	ND	ND
WPMA0	Petaluma Marsh A0	3/14/96	10	6.7	ND	0.8	ND	0.3	ND	ND	ND	ND	ND	ND	ND	ND
WPMA2	Petaluma Marsh A2	3/14/96	10	6.8	ND	0.7	ND	0.4	ND	ND	ND	ND	ND	0.1	ND	ND
WPMB0	Petaluma Marsh B0	3/14/96	10	5.6	ND	1.2	ND	0.3	ND	ND	ND	ND	ND	0.1	ND	ND
WPMB2	Petaluma Marsh B2	3/14/96	10	5.4	ND	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	8/6/96	12	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	8/6/96	12	1.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	8/6/96	12	4.8	ND	0.6	ND	0.2	ND	ND	ND	ND	ND	0.2	ND	0.3
BF20	Grizzly Bay	8/6/96	12	5.9	ND	0.6	ND	0.3	ND	ND	ND	ND	ND	ND	ND	0.2
BF10	Pacheco Creek	8/6/96	12	0.9	ND	0.2	ND	ND	ND	ND	ND	ND	ND	0.1	ND	ND
BD50	Napa River	8/5/96	12	5.9	ND	0.5	ND	0.3	ND	ND	ND	ND	ND	ND	ND	ND
BD41	Davis Point	8/5/96	12	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	8/5/96	12	2.8	ND	0.3	ND	0.2	ND	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	8/5/96	12	2.9	ND	0.4	ND	ND	ND	0.4	ND	ND	ND	0.1	ND	ND
BD15	Petaluma River	8/5/96	12	8.6	ND	0.7	ND	0.6	ND	ND	ND	ND	ND	0.2	ND	ND
BC60	Red Rock	8/2/96	12	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	8/2/96	12	10.3	0.5	0.9	ND	0.5	ND	ND	ND	ND	ND	0.2	ND	ND
BC32	Richardson Bay	8/2/96	12	8.6	0.6	0.6	ND	0.3	ND	ND	ND	ND	ND	0.1	ND	ND
BC21	Horseshoe Bay	8/2/96	12	6.6	0.3	0.5	ND	0.3	ND	ND	ND	ND	ND	0.2	ND	ND
BC11	Yerba Buena Island	8/1/96	12	19.6	0.4	1.1	ND	0.6	ND	ND	ND	ND	ND	0.1	ND	ND
BB70	Alameda	8/1/96	12	8.1	0.5	0.9	ND	0.5	ND	ND	ND	ND	ND	0.1	ND	ND
BB30	Oyster Point	8/1/96	12	15.7	0.6	1.3	ND	0.8	ND	ND	ND	0.5	ND	0.2	ND	ND
BB15	San Bruno Shoal	8/1/96	12	15.7	0.6	0.9	ND	0.6	ND	0.3	ND	0.4	ND	0.1	ND	ND
BA41	Redwood Creek	8/1/96	12	16.8	0.9	1.5	ND	0.8	ND	ND	ND	ND	ND	0.2	ND	ND
BA30	Dumbarton Bridge	7/31/96	12	12.7	0.7	0.9	ND	0.6	ND	ND	ND	0.3	ND	ND	ND	ND
BA21	South Bay	8/1/96	12	22.7	1.0	1.6	ND	0.9	ND	ND	ND	ND	ND	0.4	ND	ND
BA10	Coyote Creek	7/31/96	12	11.2	0.4	0.8	ND	0.6	ND	ND	ND	ND	ND	0.1	ND	ND
C-3-0	San Jose	7/31/96	12	320.4	5.2	19.5	5.0	12.5	0.4	5.0	2.2	6.3	4.5	2.7	ND	ND
BW10	Standish Dam	8/12/96	12	46.4	1.5	2.9	0.7	1.8	ND	0.8	ND	1.0	0.7	0.4	ND	ND
WCCA0	China Camp Marsh A0	9/26/96	12	6.5	0.4	0.5	ND	0.4	ND	ND	ND	ND	ND	0.1	ND	0.1
WCCA2	China Camp Marsh A2	9/26/96	12	6.5	0.3	0.4	ND	0.3	ND	ND	ND	ND	ND	ND	ND	ND
WPMA0	Petaluma Marsh A0	9/26/96	12	5.7	0.3	0.5	ND	0.3	ND	ND	ND	ND	ND	ND	ND	ND
WPMA2	Petaluma Marsh A2	9/26/96	12	6.1	0.4	0.4	ND	0.3	ND	ND	ND	ND	ND	ND	ND	ND

Table 15. Pesticide concentrations in sediment samples, 1996. Wetlands pilot study data are included. ND = not detected, . = no data. For method detection limits refer to Table 3 in *Appendix B*.

Station Code	Station	Date	Cruise	Sum of DDTs (SFEI)	o,p'-DDD	o,p'-DDE	o,p'-DDT	p,p'-DDD	p,p'-DDE	p,p'-DDT	Sum of Chlordanes	alpha-Chlordane	gamma-Chlordane	cis-Nonachlor	trans-Nonachlor	Heptachlor	Heptachlor Epoxide	Oxychlordane
				µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	2/14/96	10	0.5	ND	ND	ND	0.2	0.3	ND	.	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	2/14/96	10	0.1	ND	ND	ND	ND	0.1	ND	.	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	2/14/96	10	3.8	0.5	ND	ND	0.8	2.0	0.4	0.2	ND	ND	ND	0.2	ND	ND	ND
BF20	Grizzly Bay	2/14/96	10	6.3	1.0	ND	ND	1.6	3.0	0.8	0.2	ND	ND	0.2	ND	ND	ND	ND
BF10	Pacheco Creek	2/14/96	10	0.8	0.2	ND	ND	0.2	0.3	0.1	0.0	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	2/15/96	10	3.0	0.6	ND	ND	0.9	1.5	ND	0.2	ND	0.2	ND	ND	ND	ND	ND
BD41	Davis Point	2/15/96	10	0.9	ND	ND	ND	0.3	0.5	0.1	.	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	2/15/96	10	9.8	0.7	ND	ND	1.9	2.0	5.2	.	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	2/15/96	10	3.5	ND	ND	ND	1.6	1.7	0.2	0.1	ND	ND	0.1	ND	ND	ND	ND
BD15	Petaluma River	2/15/96	10	3.8	0.6	ND	ND	1.3	1.8	0.2	0.1	ND	ND	0.1	ND	ND	ND	ND
BC60	Red Rock	2/19/96	10	0.2	ND	ND	ND	ND	0.2	ND	.	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	2/19/96	10	3.0	0.7	ND	ND	1.1	1.1	0.2	0.1	ND	ND	0.1	ND	ND	ND	ND
BC32	Richardson Bay	2/19/96	10	2.4	ND	ND	ND	0.9	1.2	0.4	0.3	ND	ND	0.1	ND	ND	ND	0.1
BC21	Horseshoe Bay	2/19/96	10	1.3	0.4	ND	ND	0.5	0.4	ND	.	ND	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	2/19/96	10	2.6	ND	ND	ND	1.1	1.3	0.3	.	ND	ND	ND	ND	ND	ND	ND
BB70	Alameda	2/20/96	10	2.7	0.4	0.1	ND	0.9	1.1	0.2	.	ND	ND	ND	ND	ND	ND	ND
BB30	Oyster Point	2/20/96	10	1.6	ND	ND	ND	0.9	0.7	ND	0.1	ND	ND	0.1	ND	ND	ND	ND
BB15	San Bruno Shoal	2/20/96	10	1.5	ND	ND	ND	0.6	0.8	ND	0.1	ND	ND	0.1	ND	ND	ND	ND
BA41	Redwood Creek	2/20/96	10	1.6	ND	ND	ND	0.7	0.9	ND	0.2	ND	ND	0.2	ND	ND	ND	ND
BA30	Dumbarton Bridge	2/21/96	10	3.3	ND	ND	ND	1.2	1.6	0.5	0.2	ND	ND	0.2	ND	ND	ND	ND
BA21	South Bay	2/20/96	10	7.5	1.4	ND	ND	2.0	3.3	0.9	2.2	0.6	0.7	0.3	0.6	ND	ND	ND
BA10	Coyote Creek	2/21/96	10	6.2	1.4	ND	ND	1.5	2.7	0.6	2.1	0.6	0.6	0.3	0.6	ND	ND	ND
C-3-0	San Jose	2/20/96	10	10.9	0.7	0.2	0.2	2.0	7.3	0.5	1.6	0.4	0.6	ND	0.3	ND	ND	0.3
C-1-3	Sunnyvale	2/20/96	10	16.1	1.3	0.2	0.5	3.4	7.8	2.9	9.2	2.9	3.2	ND	2.5	0.6	0.1	ND
BW10	Standish Dam	3/8/96	10	47.7	3.8	0.4	2.3	12.2	18.8	10.4	11.1	3.5	4.2	0.1	3.2	ND	0.1	ND
WCCA0	China Camp Marsh A0	3/13/96	10	2.5	0.6	ND	ND	0.5	1.4	ND	1.2	ND	ND	ND	0.8	0.4	ND	ND
WCCA2	China Camp Marsh A2	3/13/96	10	3.9	0.8	ND	ND	1.2	1.7	0.2	0.3	ND	ND	0.2	ND	0.2	ND	ND
WPMA0	Petaluma Marsh A0	3/14/96	10	7.2	0.9	ND	ND	1.7	4.6	ND	1.5	ND	0.4	ND	0.8	0.2	ND	ND
WPMA2	Petaluma Marsh A2	3/14/96	10	9.8	1.0	ND	ND	2.2	6.3	0.4	0.3	ND	ND	0.1	0.2	ND	ND	ND
WPMB0	Petaluma Marsh B0	3/14/96	10	10.6	0.9	ND	0.3	1.8	7.5	0.2	1.8	0.3	0.4	ND	0.9	0.2	ND	ND
WPMB2	Petaluma Marsh B2	3/14/96	10	34.3	1.6	0.4	0.2	3.5	28.0	0.7	0.5	ND	ND	0.3	0.3	ND	ND	ND
BG20	Sacramento River	8/6/96	12	0.2	ND	ND	ND	ND	0.2	ND	.	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	8/6/96	12	.	ND	ND	ND	ND	ND	ND	.	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	8/6/96	12	2.6	ND	ND	ND	1.2	1.3	ND	0.1	ND	ND	0.1	ND	ND	ND	ND
BF20	Grizzly Bay	8/6/96	12	8.6	ND	ND	ND	1.7	1.4	5.6	.	ND	ND	ND	ND	ND	ND	ND
BF10	Pacheco Creek	8/6/96	12	1.0	ND	ND	ND	0.4	0.5	0.2	.	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	8/5/96	12	3.9	ND	ND	ND	1.5	2.1	0.2	0.3	ND	ND	0.3	ND	ND	ND	ND
BD41	Davis Point	8/5/96	12	0.3	ND	ND	ND	0.1	0.1	ND	.	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	8/5/96	12	2.3	0.3	ND	ND	0.8	1.0	0.2	.	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	8/5/96	12	1.4	0.4	ND	ND	0.5	0.5	ND	.	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	8/5/96	12	4.2	0.4	ND	ND	1.7	2.2	ND	0.2	ND	ND	0.2	ND	ND	ND	ND
BC60	Red Rock	8/2/96	12	.	ND	ND	ND	ND	ND	ND	.	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	8/2/96	12	5.0	0.8	ND	ND	2.2	1.2	0.8	0.2	ND	ND	0.2	ND	ND	ND	ND
BC32	Richardson Bay	8/2/96	12	2.8	0.8	ND	ND	1.2	0.8	ND	0.4	ND	0.4	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	8/2/96	12	2.4	0.6	ND	ND	1.1	0.5	0.2	.	ND	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	8/1/96	12	2.5	0.5	ND	ND	1.2	0.9	ND	0.2	ND	ND	0.2	ND	ND	ND	ND
BB70	Alameda	8/1/96	12	1.7	ND	ND	ND	0.9	0.7	ND	.	ND	ND	ND	ND	ND	ND	ND
BB30	Oyster Point	8/1/96	12	3.7	0.8	ND	ND	1.7	1.2	ND	0.2	ND	ND	0.2	ND	ND	ND	ND
BB15	San Bruno Shoal	8/1/96	12	2.2	0.5	ND	ND	1.1	0.5	ND	0.1	ND	ND	0.1	ND	ND	ND	ND
BA41	Redwood Creek	8/1/96	12	2.6	ND	ND	ND	1.3	1.4	ND	0.2	ND	ND	0.2	ND	ND	ND	ND
BA30	Dumbarton Bridge	7/31/96	12	3.1	0.7	ND	ND	1.4	1.0	ND	0.2	ND	ND	0.2	ND	ND	ND	ND
BA21	South Bay	8/1/96	12	4.7	1.0	ND	ND	1.8	1.9	ND	1.3	ND	0.6	0.4	0.4	ND	ND	ND
BA10	Coyote Creek	7/31/96	12	2.9	0.5	ND	ND	1.1	1.3	ND	0.6	ND	0.4	0.2	ND	ND	ND	ND
C-3-0	San Jose	7/31/96	12	126.5	2.6	5.1	ND	49.1	68.6	1.2	5.1	1.0	2.5	ND	0.5	ND	ND	1.1
BW10	Standish Dam	8/12/96	12	23.5	2.2	0.3	0.6	6.3	12.4	1.7	7.4	2.2	2.9	0.4	2.0	ND	ND	ND
WCCA0	China Camp Marsh A0	9/26/96	12	2.2	0.4	ND	0.2	0.8	0.8	ND	1.1	ND	ND	ND	0.6	0.4	0.1	ND
WCCA2	China Camp Marsh A2	9/26/96	12	3.0	0.6	ND	ND	1.2	1.2	ND	0.2	ND	ND	ND	ND	ND	0.2	ND
WPMA0	Petaluma Marsh A0	9/26/96	12	6.1	0.6	ND	ND	1.9	3.6	ND	1.7	ND	0.3	ND	1.0	0.2	0.1	ND
WPMA2	Petaluma Marsh A2	9/26/96	12	6.5	0.8	ND	ND	2.1	3.4	0.2	0.1	ND	ND	0.1	ND	ND	ND	ND

Table 15. Pesticide concentrations in sediment samples, 1996 (continued). Wetlands pilot study data are included. ND = not detected. For method detection limits refer to Table 3 in *Appendix B*.

Station Code	Station	Date	Cruise	Aldrin	Dieldrin	Endrin	alpha-HCH	beta-HCH	delta-HCH	gamma-HCH	Mirex
				µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	2/14/96	10	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	2/14/96	10	ND	ND	0.2	ND	ND	ND	ND	ND
BF40	Honker Bay	2/14/96	10	ND	0.3	0.2	ND	ND	ND	ND	ND
BF20	Grizzly Bay	2/14/96	10	ND	ND	0.5	ND	ND	ND	ND	ND
BF10	Pacheco Creek	2/14/96	10	ND	0.1	0.1	ND	ND	ND	ND	ND
BD50	Napa River	2/15/96	10	ND	0.2	0.1	ND	ND	ND	ND	ND
BD41	Davis Point	2/15/96	10	ND	0.0	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	2/15/96	10	ND	0.2	0.1	ND	ND	ND	ND	ND
BD22	San Pablo Bay	2/15/96	10	ND	0.3	0.2	ND	ND	ND	ND	ND
BD15	Petaluma River	2/15/96	10	ND	0.2	0.2	ND	ND	ND	ND	ND
BC60	Red Rock	2/19/96	10	ND	ND	0.2	ND	ND	ND	ND	ND
BC41	Point Isabel	2/19/96	10	ND	0.2	0.1	ND	ND	ND	ND	ND
BC32	Richardson Bay	2/19/96	10	ND	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	2/19/96	10	ND	0.1	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	2/19/96	10	ND	0.2	ND	ND	ND	ND	ND	ND
BB70	Alameda	2/20/96	10	ND	0.2	ND	ND	ND	ND	ND	ND
BB30	Oyster Point	2/20/96	10	ND	0.1	ND	ND	ND	ND	ND	ND
BB15	San Bruno Shoal	2/20/96	10	ND	0.2	0.2	ND	ND	ND	ND	ND
BA41	Redwood Creek	2/20/96	10	ND	0.2	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	2/21/96	10	ND	0.3	ND	ND	ND	ND	0.2	ND
BA21	South Bay	2/20/96	10	ND	0.5	ND	ND	ND	ND	0.3	ND
BA10	Coyote Creek	2/21/96	10	ND	0.3	ND	ND	ND	ND	ND	ND
C-3-0	San Jose	2/20/96	10	ND	0.3	ND	ND	ND	ND	ND	ND
C-1-3	Sunnyvale	2/20/96	10	ND	0.7	ND	ND	ND	ND	0.1	ND
BW10	Standish Dam	3/8/96	10	ND	1.1	ND	ND	ND	ND	ND	ND
WCCA0	China Camp Marsh A0	3/13/96	10	ND	ND	ND	ND	ND	ND	ND	0.4
WCCA2	China Camp Marsh A2	3/13/96	10	ND	0.2	ND	ND	ND	ND	ND	ND
WPMA0	Petaluma Marsh A0	3/14/96	10	ND	0.3	ND	ND	ND	ND	ND	0.3
WPMA2	Petaluma Marsh A2	3/14/96	10	ND	0.1	ND	ND	ND	ND	ND	ND
WPMB0	Petaluma Marsh B0	3/14/96	10	ND	0.2	ND	ND	ND	ND	ND	0.4
WPMB2	Petaluma Marsh B2	3/14/96	10	ND	0.1	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	8/6/96	12	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	8/6/96	12	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	8/6/96	12	ND	0.1	ND	ND	ND	ND	ND	ND
BF20	Grizzly Bay	8/6/96	12	ND	0.2	ND	ND	ND	ND	ND	ND
BF10	Pacheco Creek	8/6/96	12	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	8/5/96	12	ND	0.2	ND	ND	ND	ND	ND	ND
BD41	Davis Point	8/5/96	12	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	8/5/96	12	ND	0.1	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	8/5/96	12	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	8/5/96	12	ND	0.2	ND	ND	ND	ND	ND	ND
BC60	Red Rock	8/2/96	12	ND	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	8/2/96	12	ND	0.2	ND	ND	ND	ND	0.2	ND
BC32	Richardson Bay	8/2/96	12	ND	ND	ND	ND	ND	ND	0.2	ND
BC21	Horseshoe Bay	8/2/96	12	ND	ND	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	8/1/96	12	ND	0.1	ND	ND	ND	ND	ND	ND
BB70	Alameda	8/1/96	12	ND	ND	ND	ND	ND	ND	ND	ND
BB30	Oyster Point	8/1/96	12	ND	0.2	ND	ND	ND	ND	ND	ND
BB15	San Bruno Shoal	8/1/96	12	ND	0.1	ND	ND	ND	ND	ND	ND
BA41	Redwood Creek	8/1/96	12	ND	0.2	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	7/31/96	12	ND	0.3	ND	ND	ND	ND	ND	ND
BA21	South Bay	8/1/96	12	ND	0.3	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	7/31/96	12	ND	0.2	ND	ND	ND	ND	ND	ND
C-3-0	San Jose	7/31/96	12	ND	1.8	ND	ND	ND	ND	ND	ND
BW10	Standish Dam	8/12/96	12	1.5	2.2	ND	ND	ND	ND	0.7	ND
WCCA0	China Camp Marsh A0	9/26/96	12	ND	0.2	ND	ND	ND	0.2	ND	ND
WCCA2	China Camp Marsh A2	9/26/96	12	ND	0.2	ND	ND	ND	ND	ND	ND
WPMA0	Petaluma Marsh A0	9/26/96	12	ND	ND	ND	ND	ND	0.3	ND	ND
WPMA2	Petaluma Marsh A2	9/26/96	12	ND	0.2	ND	ND	ND	ND	ND	ND

Table 16. Sediment bioassay data for 1996 RMP Cruises. For physical/chemical measurements of test solutions and QA information refer to Table 6 in *Appendix B*.

Station Code	Station	Date	Cruise	Mean † Normal Development	SD — % Normal Development	Mean % Survival	SD — % Survival
				% MEDU	% MEDU	% EOHA	% EOHA
BG20	Sacramento River	2/15/96	10	0 *†	0	92	8
BG30	San Joaquin River	2/15/96	10	0 *†	0	77	23
BF20	Grizzly Bay	2/15/96	10	0 *†	0	58 †	10
BD50	Napa River	2/16/96	10	14 *†	4	73 *†	8
BD41	Davis Point	2/16/96	10	81	3	95	4
BC60	Red Rock	2/20/96	10	77	5	89	8
BC21	Horseshoe Bay	2/20/96	10	73	9	74 *†	16
BC11	Yerba Buena Island	2/20/96	10	76	6	64 †	19
BB70	Alameda	2/21/96	10	65	12	81 *†	17
BB15	San Bruno Shoal	2/21/96	10	62	13	82 *†	9
BA41	Redwood Creek	2/21/96	10	82	9	43 †	24
BA21	South Bay	2/21/96	10	81	6	59 †	11
BA10	Coyote Creek	2/22/96	10	72	4	75 *†	8
	Control		10	98	3	77	5
BG20	Sacramento River	8/6/97	12	0 *†	0	93	6
BG30	San Joaquin River	8/6/97	12	0 *†	0	96	4
BF20	Grizzly Bay	8/6/97	12	0 *†	0	92	6
BD50	Napa River	8/5/96	12	0 *†	0	93	4
BD41	Davis Point	8/5/96	12	89	10	98	3
BC60	Red Rock	8/2/96	12	76	12	92	6
BC21	Horseshoe Bay	8/2/96	12	87	4	86	12
BC11	Yerba Buena Island	8/1/96	12	91	3	56 †	33
BB70	Alameda	8/1/96	12	82	8	74 *†	7
BB15	San Bruno Shoal	8/1/96	12	85	15	88	9
BA41	Redwood Creek	8/1/96	12	82	14	76 †	35
BA21	South Bay	8/1/96	12	3 *†	4	84 *	9
BA10	Coyote Creek	7/31/96	12	88	9	95	10
	Control		12	81	7	98	4

* Significantly different from laboratory controls based on separate-variance t-tests (1 tailed, alpha = 0.01).
† Sample mean was less than MSD, see text.
SD Standard deviation
MEDU *Mytilus edulis*
EOHA *Eohaustorius estuarius*

Table 17. Bivalve condition index and survival, 1996. . = no data, NS= not sampled.

Station Code	Station	Date	Cruise	Species	Condition Index Mean	Condition Index Standard Error	Survival Per Species
							%
BG20	Sacramento River	5/2/96	10	CFLU	0.092	0.003	97
BG30	San Joaquin River	5/2/96	10	CFLU	0.074	0.003	96
BF20	Grizzly Bay	5/2/96	10	CFLU	0.09	0.004	98
BD50	Napa River	5/1/96	10	CGIG	0.096	0.004	80
BD40	Davis Point	5/1/96	10	CGIG	0.11	0.004	73
BD30	Pinole Point	5/1/96	10	MCAL	0.099	0.007	56
BD20	San Pablo Bay	5/1/96	10	CGIG	0.162	0.005	72
BD15	Petaluma River	5/1/96	10	CGIG	NS	NS	0
BC61	Red Rock	5/1/96	10	MCAL	0.109	0.005	93
BC21	Horseshoe Bay	5/1/96	10	MCAL	0.125	0.003	90
BC10	Yerba Buena Island	4/30/96	10	MCAL	0.121	0.012	99
BB71	Alameda	4/30/96	10	MCAL	0.119	0.005	98
BA40	Redwood Creek	4/30/96	10	MCAL	0.129	0.008	99
BA30	Dumbarton Bridge	4/30/96	10	MCAL	0.089	0.003	96
BA10	Coyote Creek	4/30/96	10	CGIG	0.092	0.007	98
T-0	Bodega Head	1/17/96	10	MCAL	0.117	0.007	.
T-0	Tomales Bay	1/26/96	10	CGIG	0.083	0.007	.
T-0	Putah Creek	12/20/96	10	CFLU	0.098	0.006	.
BG20	Sacramento River	9/10/96	12	CFLU	0.034	0.001	90
BG30	San Joaquin River	9/10/96	12	CFLU	0.042	0.001	98
BF20	Grizzly Bay	9/10/96	12	CFLU	0.05	0.002	95
BD50	Napa River	9/10/96	12	CGIG	0.037	0.002	94
BD40	Davis Point	9/10/96	12	CGIG	0.069	0.004	99
BD40	Davis Point	9/10/96	12	OLUR	0.054	0.003	89
BD30	Pinole Point	9/11/96	12	MCAL	0.059	0.001	100
BD30	Pinole Point	9/11/96	12	OLUR	0.048	0.002	86
BD20	San Pablo Bay	9/11/96	12	CGIG	0.063	0.004	99
BD15	Petaluma River	9/11/96	12	CGIG	0.043	0.002	92
BD15	Petaluma River	9/11/96	12	OLUR	0.04	0.002	80
BC61	Red Rock	9/11/96	12	MCAL	0.065	0.002	99
BC61	Red Rock	9/11/96	12	OLUR	0.058	0.003	89
BC21	Horseshoe Bay	9/11/96	12	MCAL	0.147	0.004	96
BC21	Horseshoe Bay	9/11/96	12	OLUR	0.107	0.007	89
BC10	Yerba Buena Island	9/11/96	12	MCAL	0.095	0.003	98
BB71	Alameda	9/12/96	12	MCAL	0.086	0.002	99
BB71	Alameda	9/12/96	12	OLUR	0.071	0.004	92
BA40	Redwood Creek	9/12/96	12	MCAL	0.06	0.002	99
BA40	Redwood Creek	9/12/96	12	OLUR	0.058	0.002	97
BA30	Dumbarton Bridge	9/12/96	12	MCAL	0.06	0.002	99
BA10	Coyote Creek	9/12/96	12	CGIG	0.046	0.002	74
BA10	Coyote Creek	9/12/96	12	OLUR	0.047	0.003	83
T-0	Putah Creek	6/14/96	12	CFLU	0.07	0.002	.
T-0	Tomales Bay	6/14/96	12	CGIG	0.151	0.005	.
T-0	Bodega Head	6/14/96	12	MCAL	0.079	0.001	.
T-0	Tomales Bay	6/14/96	12	OLUR	0.11	0.007	.

CGIG—*Crassostrea gigas,* CFLU—*Corbicula fluminea,* MCAL—*Mytilus californianus,* OLUR—*Ostrea lurida*

Table 18. Trace element concentrations in bivalve tissues, 1996.. = no data, ND = not detected, NS = not sampled. Units expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading. For method detection limits refer to Table 4 in *Appendix B*.

Station Code	Station	Date	Cruise	Species	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	DBT	MBT	TBT	TTBT
					mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	µg/kg Sn*	µg/kg Sn*	µg/kg Sn*	µg/kg Sn*
BG20	Sacramento River	5/2/96	10	CFLU	0.1	10.9	0.8	33.7	65	0.376	8.1	0.4	4.2	130	ND	ND	254	ND
BG30	San Joaquin River	5/2/96	10	CFLU	0.1	11.3	1.3	39.9	62	0.392	7.7	0.9	3.6	168	ND	ND	23	ND
BF20	Grizzly Bay	5/2/96	10	CFLU	0.1	9.9	0.9	28.6	52	0.350	7.2	0.8	3.7	152	ND	ND	21	ND
BD50	Napa River	5/1/96	10	CGIG	2.0	8.1	14.7	3.2	111	0.310	2.9	0.8	3.9	667	ND	ND	16	ND
BD40	Davis Point	5/1/96	10	CGIG	2.4	7.3	11.0	2.3	133	0.213	2.0	0.5	3.0	725	ND	ND	74	ND
BD30	Pinole Point	5/1/96	10	MCAL	0.1	10.4	6.5	12.2	12	0.202	7.7	2.1	2.3	185	ND	ND	35	ND
BD20	San Pablo Bay	5/1/96	10	CGIG	2.4	6.8	8.6	2.2	122	0.199	2.0	0.5	3.3	591	ND	ND	29	ND
BD15	Petaluma River	5/1/96	10	CGIG	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BC61	Red Rock	5/1/96	10	MCAL	0.1	11.2	5.8	8.9	10	0.196	9.7	2.1	2.9	171	ND	ND	19	ND
BC21	Horseshoe Bay	5/1/96	10	MCAL	0.1	12.3	5.9	10.5	10	0.212	11.7	2.7	4.6	198	ND	ND	40	ND
BC10	Yerba Buena Island	4/30/96	10	MCAL	0.1	9.5	6.3	5.6	9	0.200	7.5	2.7	2.7	220	ND	ND	88	ND
BB71	Alameda	4/30/96	10	MCAL	0.1	9.1	5.6	11.6	11	0.197	14.8	2.4	2.7	220	5.7	ND	69	ND
BA40	Redwood Creek	4/30/96	10	MCAL	0.3	9.0	5.3	10.5	12	0.211	13.7	2.5	2.3	208	ND	ND	12	ND
BA30	Dumbarton Bridge	4/30/96	10	MCAL	0.2	11.2	6.9	45.0	11	0.251	38.6	2.4	2.4	212	ND	ND	29	ND
BA10	Coyote Creek	4/30/96	10	CGIG	2.9	7.1	11.2	3.1	291	0.293	3.3	0.8	2.3	1013	ND	ND	ND	ND
T-0	Bodega Head	1/17/96	10	MCAL	0.1	10.5	6.8	4.6	7	0.171	4.5	1.2	2.8	148	ND	ND	ND	ND
T-0	Tomales Bay	1/26/96	10	CGIG	1.0	7.6	9.8	2.0	53	0.309	0.8	0.4	2.1	471	ND	ND	ND	ND
T-0	Putah Creek—post depuration	12/20/95	10	CFLU	0.1	9.7	0.3	27.9	31	0.291	3.7	0.5	3.2	128	ND	ND	ND	ND
T-0	Putah Creek—pre depuration	12/20/95	10	CFLU	0.1	9.0	0.3	38.3	62	0.331	13.2	0.9	3.0	129	ND	ND	ND	ND
BG20	Sacramento River	9/10/96	12	CFLU	0.2	11.3	2.1	73.2	116	0.575	10.9	0.6	3.8	183	NS	NS	NS	NS
BG30	San Joaquin River	9/10/96	12	CFLU	0.2	11.6	1.8	73.5	104	0.562	16.5	1.0	4.3	210	ND	ND	ND	ND
BF20	Grizzly Bay	9/10/96	12	CFLU	0.4	12.5	1.3	63.0	77	0.559	15.2	2.4	4.8	174	NS	NS	NS	NS
BD50	Napa River	9/10/96	12	CGIG	4.7	8.5	24.3	16.9	712	0.413	15.6	1.4	2.9	2296	ND	ND	78	ND
BD40	Davis Point	9/10/96	12	CGIG	2.3	7.8	15.7	15.2	571	0.248	11.6	1.1	5.1	1230	ND	ND	78	ND
BD30	Pinole Point	9/11/96	12	MCAL	0.1	10.3	6.6	19.0	9	0.310	18.2	2.8	2.5	284	ND	ND	26	ND
BD20	San Pablo Bay	9/11/96	12	CGIG	5.0	6.9	18.1	15.3	555	0.268	14.6	1.6	4.2	1473	ND	ND	46	ND
BD15	Petaluma River	9/11/96	12	CGIG	8.5	6.5	19.6	12.0	603	0.326	14.3	1.3	5.3	1569	ND	ND	ND	ND
BC61	Red Rock	9/11/96	12	MCAL	0.1	8.5	5.8	12.3	9	0.241	12.3	2.6	2.9	250	ND	ND	48	ND
BC21	Horseshoe Bay	9/11/96	12	MCAL	0.6	9.9	14.8	10.1	22	0.223	10.6	5.4	5.2	434	ND	ND	53	ND
BC10	Yerba Buena Island	9/11/96	12	MCAL	0.2	9.4	5.9	12.7	9	0.260	12.2	2.8	4.2	268	ND	ND	127	ND
BB71	Alameda	9/12/96	12	MCAL	0.3	9.5	6.9	8.9	9	0.311	10.4	2.8	3.6	270	ND	ND	95	ND
BA40	Redwood Creek	9/12/96	12	MCAL	0.4	8.4	9.3	12.8	13	0.269	13.6	3.7	3.2	367	NA	NA	NA	NA
BA30	Dumbarton Bridge	9/12/96	12	MCAL	0.2	8.5	8.5	12.7	9	0.199	14.0	2.4	3.1	334	ND	ND	ND	ND
BA10	Coyote Creek	9/12/96	12	CGIG	6.2	6.0	15.8	11.2	529	0.371	9.5	1.7	6.0	1825	ND	ND	ND	ND
T-0	Putah Creek	6/5/96	12	CFLU	0.1	9.4	0.8	57.0	46	0.377	12.7	0.4	4.7	155	ND	ND	102	ND
T-0	Tomales Bay	6/5/96	12	CGIG	0.8	8.5	4.9	0.7	45	0.273	0.5	0.3	3.1	384	ND	ND	ND	ND
T-0	Bodega Head	6/5/96	12	MCAL	0.0	8.2	6.9	7.7	5	0.203	8.0	1.2	3.3	182	ND	ND	ND	ND

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus,* * Tins are reported in terms of total tin.

Table 19. PAH concentrations in bivalve tissues, 1996. . = no data, ND = not detected, NS = not sampled, LPAH = low molecular weight PAHs. Units expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading. For method detection limits refer to Table 4 in *Appendix B*.

Station Code	Station	Date	Cruise	Species	Sum of PAHs (SFEI)	Sum of LPAHs (SFEI)	Biphenyl	Naphthalene	1-Methylnaphthalene	2-Methylnaphthalene	2,6-Dimethylnaphthalene	2,3,5-Trimethylnaphthalene	Acenaphthene	Acenaphthylene	Anthracene	Dibenzothiophene	Fluorene	Phenanthrene	1-Methylphenanthrene
					µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	5/2/96	10	CFLU	538	198	ND	62	31	ND	ND	ND	ND	ND	21	ND	ND	48	36
BG30	San Joaquin River	5/2/96	10	CFLU	127	49	ND	18	9	7	ND	ND	ND	ND	7	ND	ND	8	ND
BF20	Grizzly Bay	5/2/96	10	CFLU	167	41	ND	12	ND	ND	ND	6	ND	ND	6	ND	5	13	ND
BD50	Napa River	5/1/96	10	CGIG	315	61	ND	7	4	4	5	ND	ND	ND	5	ND	5	24	6
BD40	Davis Point	5/1/96	10	CGIG	779	112	ND	16	ND	13	ND	ND	ND	ND	12	ND	16	55	ND
BD30	Pinole Point	5/1/96	10	MCAL	224	98	ND	32	9	20	ND	ND	ND	ND	11	ND	ND	26	ND
BD20	San Pablo Bay	5/1/96	10	CGIG	332	62	ND	7	4	4	ND	4	6	ND	6	ND	6	21	6
BC61	Red Rock	5/1/96	10	MCAL	107	52	ND	18	ND	9	ND	ND	ND	ND	6	ND	6	13	ND
BC21	Horseshoe Bay	5/1/96	10	MCAL	250	147	11	33	7	22	ND	ND	ND	ND	12	ND	11	50	ND
BC10	Yerba Buena Island	4/30/96	10	MCAL	236	97	ND	22	7	21	ND	ND	ND	ND	10	ND	9	28	ND
BB71	Alameda	4/30/96	10	MCAL	163	65	ND	17	ND	14	ND	ND	ND	ND	11	ND	11	13	ND
BA40	Redwood Creek	4/30/96	10	MCAL	96	28	ND	9	4	5	ND	ND	ND	ND	4	ND	ND	6	ND
BA30	Dumbarton Bridge	4/30/96	10	MCAL	291	137	ND	61	14	20	ND	ND	ND	ND	15	ND	ND	27	ND
BA10	Coyote Creek	4/30/96	10	CGIG	614	52	ND	13	ND	ND	ND	ND	ND	3	7	ND	7	22	ND
T-0	Putah Creek—pre depuration	12/20/95	10	CFLU	216	158	ND	32	14	14	ND	ND	ND	ND	9	ND	14	61	14
T-0	Putah Creek—post depuration	1/26/96	10	CFLU	224	188	13	29	17	30	21	ND	ND	ND	5	ND	11	51	11
T-0	Tomales Bay	1/26/96	10	CGIG	87	24	ND	7	4	ND	ND	ND	ND	ND	3	ND	ND	10	ND
T-0	Bodega Head	1/26/96	10	MCAL	72	72	ND	30	6	25	ND	ND	ND	ND	ND	ND	ND	12	ND
BG20	Sacramento River	9/10/96	12	CFLU	.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BG30	San Joaquin River	9/10/96	12	CFLU	180	58	ND	ND	ND	ND	ND	ND	ND	ND	15	43	ND	ND	ND
BF20	Grizzly Bay	9/10/96	12	CFLU	.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BD50	Napa River	9/10/96	12	CGIG	353	60	13	ND	ND	ND	ND	ND	ND	ND	10	32	ND	ND	6
BD40	Davis Point	9/10/96	12	CGIG	826	161	ND	ND	ND	ND	ND	ND	ND	ND	18	93	7	ND	33	10
BD30	Pinole Point	9/11/96	12	MCAL	78	51	ND	ND	ND	ND	ND	ND	ND	ND	14	37	ND	ND	ND	ND
BD20	San Pablo Bay	9/11/96	12	MCAL	461	72	8	ND	ND	ND	ND	ND	ND	ND	14	39	ND	10	ND	ND
BD15	Petaluma River	9/11/96	12	MCAL	273	31	10	ND	ND	ND	ND	ND	ND	ND	21	ND	ND	ND	ND
BC61	Red Rock	9/11/96	12	MCAL	171	86	ND	ND	ND	ND	ND	ND	ND	8	14	38	ND	12	15	ND
BC21	Horseshoe Bay	9/11/96	12	MCAL	132	88	3	14	ND	ND	ND	ND	ND	13	36	ND	7	14	2
BC10	Yerba Buena Island	9/11/96	12	MCAL	167	94	4	ND	ND	ND	ND	4	5	16	47	ND	6	12	ND
BB71	Alameda	9/12/96	12	MCAL	161	59	ND	ND	ND	ND	ND	ND	ND	8	24	ND	7	16	3
BA40	Redwood Creek	9/12/96	12	MCAL	140	81	ND	ND	ND	ND	12	6	11	7	16	ND	13	15	ND
BA30	Dumbarton Bridge	9/12/96	12	MCAL	62	56	9	ND	ND	ND	ND	11	ND	7	17	ND	ND	13	ND
BA10	Coyote Creek	9/12/96	12	CGIG	505	80	7	ND	ND	ND	ND	ND	ND	9	24	ND	15	25	ND
T-0	Putah Creek	6/14/96	12	CFLU	108	108	13	ND	ND	ND	23	8	ND	ND	10	ND	18	36	ND
T-0	Tomales Bay	6/14/96	12	CGIG	33	15	3	ND	ND	ND	ND	4	5	ND	4	ND	ND	ND	ND
T-0	Bodega Head	6/14/96	12	MCAL	29	29	3	ND	ND	ND	ND	4	8	4	6	ND	4	ND	ND

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus*

Table 19. PAH concentrations in bivalve tissues, 1996 (continued). . = no data, ND = not detected, NS = not sampled, HPAH = high molecular weight PAHs. Units expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading. For method detection limits refer to Table 4 in *Appendix B*.

Station Code	Station	Date	Cruise	Species	Sum of PAHs (SFEI)	Sum of HPAHs (SFEI)	Benz(a)anthracene	Chrysene	Fluoranthene	Pyrene	Benzo(a)pyrene	Benzo(e)pyrene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Dibenz(a,h)anthracene	Perylene	Benzo(ghi)perylene	Indeno(1,2,3-cd)pyrene
					µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	5/2/96	10	CFLU	538	340	17	62	127	135	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	5/2/96	10	CFLU	127	79	6	12	20	33	ND	4	ND	ND	ND	ND	4	ND
BF20	Grizzly Bay	5/2/96	10	CFLU	167	126	8	15	38	48	ND	7	6	ND	ND	ND	4	ND
BD50	Napa River	5/1/96	10	CGIG	315	254	15	22	75	84	7	14	16	5	ND	7	6	4
BD40	Davis Point	5/1/96	10	CGIG	779	668	41	73	179	184	21	50	54	18	ND	22	16	9
BD30	Pinole Point	5/1/96	10	MCAL	224	125	10	9	24	28	12	9	11	ND	ND	ND	12	10
BD20	San Pablo Bay	5/1/96	10	CGIG	332	270	12	29	73	82	10	21	20	6	ND	7	7	4
BC61	Red Rock	5/1/96	10	MCAL	107	54	4	ND	15	19	5	5	ND	ND	ND	ND	7	ND
BC21	Horseshoe Bay	5/1/96	10	MCAL	250	103	6	11	33	34	6	6	ND	ND	ND	ND	8	ND
BC10	Yerba Buena Island	4/30/96	10	MCAL	236	139	6	13	29	33	10	9	15	ND	ND	ND	15	9
BB71	Alameda	4/30/96	10	MCAL	163	98	5	8	18	23	8	7	10	5	ND	ND	10	6
BA40	Redwood Creek	4/30/96	10	MCAL	96	68	4	5	11	16	6	6	7	3	ND	ND	7	4
BA30	Dumbarton Bridge	4/30/96	10	MCAL	291	153	16	12	28	51	16	11	19	ND	ND	ND	ND	ND
BA10	Coyote Creek	4/30/96	10	CGIG	614	562	30	56	104	152	25	65	69	19	ND	9	23	10
T-0	Putah Creek—pre depuration	12/20/95	10	CFLU	216	58	ND	13	28	17	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Putah Creek—post depuration	1/26/96	10	CFLU	224	35	ND	ND	21	15	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Tomales Bay	1/26/96	10	CGIG	87	64	3	9	29	21	ND	3	ND	ND	ND	ND	ND	ND
T-0	Bodega Head	1/26/96	10	MCAL	72	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	9/10/96	12	CFLU	.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BG30	San Joaquin River	9/10/96	12	CFLU	180	123	13	25	31	55	ND	ND	ND	ND	ND	ND	ND	ND
BF20	Grizzly Bay	9/10/96	12	CFLU	.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BD50	Napa River	9/10/96	12	CGIG	353	292	23	31	53	61	18	31	39	ND	ND	23	ND	13
BD40	Davis Point	9/10/96	12	CGIG	826	665	41	70	186	158	29	52	64	23	ND	30	ND	12
BD30	Pinole Point	9/11/96	12	MCAL	78	28	8	ND	ND	15	ND	ND	ND	ND	ND	ND	ND	5
BD20	San Pablo Bay	9/11/96	12	MCAL	461	390	23	40	77	82	21	40	46	15	ND	18	18	11
BD15	Petaluma River	9/11/96	12	MCAL	273	243	14	21	43	52	20	25	29	11	ND	16	ND	10
BC61	Red Rock	9/11/96	12	MCAL	171	85	9	14	21	26	9	ND	ND	ND	ND	ND	ND	6
BC21	Horseshoe Bay	9/11/96	12	MCAL	132	44	4	6	14	14	4	ND	ND	ND	ND	ND	ND	3
BC10	Yerba Buena Island	9/11/96	12	MCAL	167	73	9	10	19	19	7	6	ND	ND	ND	ND	ND	4
BB71	Alameda	9/12/96	12	MCAL	161	102	9	18	23	29	14	ND	ND	ND	ND	ND	ND	9
BA40	Redwood Creek	9/12/96	12	MCAL	140	60	8	11	19	22	ND	ND	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	9/12/96	12	MCAL	62	5	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	9/12/96	12	CGIG	505	426	22	54	76	96	31	58	62	26	ND	ND	ND	ND
T-0	Putah Creek	6/14/96	12	CFLU	108	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Tomales Bay	6/14/96	12	CGIG	33	19	ND	ND	11	8	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Bodega Head	6/14/96	12	MCAL	29	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus*

Table 20. PCB concentrations in bivalve tissues, 1996.. = no data, ND = not detected, NS = not sampled, units expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading. For method detection limitsrefer to Table 4 in *Appendix B*.

Station Code	Station	Date	Cruise	Species	Sum of PCBs (SFEI)	PCB 001	PCB 003	PCB 004	PCB 006	PCB 008	PCB 015	PCB 017/18	PCB 027	PCB 028	PCB 029	PCB 031	PCB 033	PCB 044	PCB 049	PCB 052	PCB 060	PCB 066	PCB 070	PCB 074	PCB 085	PCB 095	PCB 097	PCB 099	PCB 101	PCB 105	PCB 110
					µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	5/2/96	10	CFLU	572	ND	ND	ND	ND	ND	11.5	18.5	ND	12.4	ND	12.4	ND	19.3	ND	40.1	8.2	ND	29.8	5.3	ND	25.6	24.1	18.4	33.5	19.1	26.3
BG30	San Joaquin River	5/2/96	10	CFLU	170	ND	1.8	ND	ND	ND	2.3	2.3	ND	ND	ND	2.8	ND	6.3	ND	6.9	3.3	ND	7.9	1.6	ND	8.4	5.5	6.6	8.9	3.2	7.6
BF20	Grizzly Bay	5/2/96	10	CFLU	160	ND	2.0	ND	ND	ND	1.1	2.9	ND	ND	ND	2.4	ND	4.7	2.5	6.9	1.1	ND	8.6	1.0	ND	7.4	5.4	5.3	8.9	3.3	7.9
BD50	Napa River	5/1/96	10	CGIG	57	0.7	0.9	ND	ND	ND	ND	0.5	ND	ND	ND	1.3	ND	1.2	1.0	2.3	0.9	ND	1.2	0.5	ND	3.1	ND	2.7	4.1	0.6	3.6
BD40	Davis Point	5/1/96	10	CGIG	187	ND	2.0	ND	ND	ND	ND	0.9	ND	ND	ND	1.1	ND	3.7	4.3	5.6	2.7	ND	3.6	1.3	ND	9.6	ND	9.0	13.9	ND	11.8
BD30	Pinole Point	5/1/96	10	MCAL	95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.8	ND	2.3	2.0	4.0	ND	0.8	1.4	ND	ND	4.2	ND	4.2	6.7	ND	6.0
BD20	San Pablo Bay	5/1/96	10	CGIG	89	ND	0.5	ND	ND	ND	ND	0.8	0.5	ND	0.4	1.2	ND	1.8	1.6	2.9	1.8	ND	1.7	0.8	ND	5.1	ND	4.9	6.7	ND	5.9
BC61	Red Rock	5/1/96	10	MCAL	80	0.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.4	ND	1.7	1.4	3.4	ND	ND	1.0	ND	ND	3.9	ND	3.7	5.8	1.0	4.7
BC21	Horseshoe Bay	5/1/96	10	MCAL	103	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.9	ND	1.9	1.8	4.2	ND	1.2	1.3	ND	ND	3.8	ND	5.0	7.2	1.3	4.9
BC10	Yerba Buena Island	4/30/96	10	MCAL	185	ND	1.3	ND	ND	ND	ND	1.3	ND	ND	ND	2.9	ND	3.1	2.6	5.5	2.1	ND	2.5	2.0	ND	8.1	ND	9.6	12.3	2.2	9.6
BB71	Alameda	4/30/96	10	MCAL	174	ND	ND	ND	ND	ND	ND	2.1	ND	ND	0.7	1.7	ND	2.8	1.7	5.1	2.0	ND	2.4	1.3	ND	8.3	4.9	9.3	12.4	ND	8.7
BA40	Redwood Creek	4/30/96	10	MCAL	139	ND	0.6	ND	ND	ND	ND	1.3	ND	0.9	ND	1.7	ND	2.3	1.4	3.8	1.6	1.5	2.5	1.6	ND	4.8	ND	6.7	9.8	1.5	7.2
BA30	Dumbarton Bridge	4/30/96	10	MCAL	261	2.0	ND	ND	ND	ND	ND	2.7	2.7	ND	1.7	4.5	ND	4.5	3.9	7.3	3.4	ND	3.8	2.8	ND	10.6	ND	12.6	17.9	ND	15.1
BA10	Coyote Creek	4/30/96	10	CGIG	273	ND	0.9	ND	ND	ND	ND	ND	ND	1.3	ND	2.7	ND	4.0	3.3	7.0	2.5	ND	5.3	2.4	ND	12.7	7.8	12.2	20.5	2.7	17.6
T-0	Putah Creek—pre depuration	12/20/95	10	CFLU	134	ND	ND	ND	ND	ND	ND	2.3	ND	ND	ND	5.0	ND	5.0	ND	16.7	ND	ND	7.5	ND	ND	5.5	ND	5.4	7.6	ND	7.4
T-0	Putah Creek—post depuration	1/26/96	10	CFLU	131	ND	ND	ND	ND	ND	2.5	3.8	ND	ND	ND	7.2	ND	4.2	1.8	14.6	ND	ND	8.4	1.2	ND	5.4	ND	4.9	6.7	ND	6.1
T-0	Tomales Bay	1/26/96	10	CGIG	16	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.5	ND	ND	ND	0.7	1.3	ND	ND	ND	ND	1.1	ND	0.8	1.1	ND	1.0
T-0	Bodega Head	1/26/96	10	MCAL	19	ND	ND	ND	ND	ND	ND	1.1	2.2	ND	ND	0.8	ND	ND	ND	1.4	ND	ND	ND	ND	ND	0.8	ND	ND	ND	ND	ND
BG20	Sacramento River	9/10/96	12	CFLU	.	NS	NS	NS	NS	NS	NS	NS	NS	NS	.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BG30	San Joaquin River	9/10/96	12	CFLU	179	ND	ND	ND	ND	ND	ND	2.2	ND	ND	.	ND	ND	6.4	ND	8.6	ND	0.9	3.6	ND	ND	5.3	3.4	4.2	4.6	ND	6.3
BF20	Grizzly Bay	9/10/96	12	CFLU	.	NS	NS	NS	NS	NS	NS	NS	NS	NS	.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BD50	Napa River	9/10/96	12	CGIG	88	3.9	ND	ND	ND	ND	ND	ND	ND	ND	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.5	2.2	2.5	5.8	ND	4.9
BD40	Davis Point	9/10/96	12	CGIG	177	ND	ND	ND	ND	ND	ND	ND	ND	1.1	.	1.5	ND	2.8	ND	5.2	0.8	1.7	3.2	1.7	ND	8.5	2.3	9.0	15.4	ND	14.2
BD30	Pinole Point	9/11/96	12	MCAL	85	ND	ND	2.5	ND	ND	ND	ND	ND	ND	.	0.8	ND	1.9	1.1	2.6	ND	ND	1.6	0.9	ND	3.4	ND	3.5	7.2	ND	5.2
BD20	San Pablo Bay	9/11/96	12	MCAL	141	0.9	ND	ND	ND	ND	ND	ND	ND	ND	.	1.5	ND	2.6	ND	3.6	ND	1.2	2.2	1.3	ND	6.4	1.0	7.4	12.1	ND	10.6
BD15	Petaluma River	9/11/96	12	MCAL	88	ND	ND	ND	ND	ND	ND	ND	ND	ND	.	ND	ND	ND	1.4	ND	ND	0.4	ND	ND	ND	3.1	2.4	2.5	6.3	ND	6.2
BC61	Red Rock	9/11/96	12	MCAL	100	0.8	ND	1.0	ND	1.0	ND	ND	ND	ND	.	ND	ND	1.5	1.3	2.7	ND	1.0	1.4	ND	ND	3.5	1.5	4.9	7.8	ND	6.5
BC21	Horseshoe Bay	9/11/96	12	MCAL	92	ND	ND	2.1	ND	0.5	ND	0.5	0.5	0.7	.	0.6	ND	1.3	ND	4.0	ND	1.7	2.2	1.0	0.7	3.5	ND	3.8	7.7	1.8	4.1
BC10	Yerba Buena Island	9/11/96	12	MCAL	123	ND	ND	ND	ND	ND	ND	ND	ND	0.7	.	1.0	ND	1.9	1.1	3.8	ND	1.7	2.3	1.3	1.0	4.4	1.6	6.6	10.2	ND	8.0
BB71	Alameda	9/12/96	12	MCAL	172	ND	ND	0.9	ND	ND	ND	ND	ND	0.9	.	1.0	ND	1.7	1.4	4.6	ND	2.0	2.9	1.5	ND	6.1	3.6	8.6	14.7	ND	11.0
BA40	Redwood Creek	9/12/96	12	MCAL	135	ND	ND	ND	ND	ND	ND	ND	ND	ND	.	1.1	ND	1.6	1.1	2.6	ND	1.4	2.0	1.5	ND	2.8	2.4	6.7	9.6	ND	7.2
BA30	Dumbarton Bridge	9/12/96	12	MCAL	143	1.2	ND	ND	ND	ND	ND	ND	ND	ND	.	1.2	ND	1.6	1.5	3.2	ND	1.8	2.2	1.7	ND	3.3	3.0	7.1	10.9	ND	8.5
BA10	Coyote Creek	9/12/96	12	CGIG	233	0.8	ND	ND	ND	ND	ND	ND	ND	ND	.	1.3	ND	4.4	3.7	6.7	ND	3.3	4.9	2.8	ND	9.3	5.8	11.6	19.5	ND	15.8
T-0	Putah Creek	6/14/96	12	CFLU	134	ND	ND	ND	ND	3.5	3.9	5.6	ND	1.3	.	3.2	1.6	7.1	1.7	6.4	4.1	1.4	7.8	1.0	ND	5.2	5.3	4.3	7.1	ND	4.3
T-0	Tomales Bay	6/14/96	12	CGIG	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	.	0.5	ND	ND	ND	0.7	ND	0.1	ND	ND	ND	ND	0.7	0.5	1.0	ND	0.8
T-0	Bodega Head	6/14/96	12	MCAL	8	1.0	ND	1.0	ND	ND	ND	ND	ND	ND	.	ND	ND	ND	ND	0.8	ND	ND	ND	ND	ND	ND	0.8	ND	0.5	ND	0.6

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus*

Table 20. PCB concentrations in bivalve tissues, 1996 (continued). . = no data, ND = not detected, NS = not sampled, units expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading. For method detection limits refer to Table 4 in *Appendix B*.

Station Code	Station	Date	Cruise	Species	Sum of PCBs (SFEI)	PCB 118	PCB 119	PCB 128	PCB 132	PCB 138	PCB 141	PCB 149	PCB 151	PCB 153	PCB 158	PCB 167	PCB 170	PCB 174	PCB 177	PCB 180	PCB 183	PCB 187	PCB 189	PCB 194	PCB 195	PCB 200	PCB 201	PCB 203	PCB 206	PCB 207	Hexachlorobenzene
					µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	5/2/96	10	CFLU	572	32.6	ND	ND	ND	47.1	4.0	27.7	7.2	75.4	ND	12.2	QS	3.5	7.9	ND	11.4	26.1	ND	6.4	5.7	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	5/2/96	10	CFLU	170	11.1	ND	ND	ND	13.3	ND	7.5	ND	23.7	ND	ND	QS	1.0	2.4	24.4	2.0	6.6	ND	1.6	1.2	ND	ND	ND	ND	ND	ND
BF20	Grizzly Bay	5/2/96	10	CFLU	160	9.2	ND	ND	.	12.3	ND	8.4	ND	22.8	ND	1.3	QS	0.7	2.6	18.0	2.7	8.1	ND	1.7	1.0	0.8	ND	ND	ND	ND	ND
BD50	Napa River	5/1/96	10	CGIG	57	3.3	ND	ND	0.4	3.8	ND	3.6	0.8	8.0	ND	ND	QS	ND	0.7	8.5	0.7	2.4	ND	0.5	ND	ND	ND	ND	ND	ND	ND
BD40	Davis Point	5/1/96	10	CGIG	187	9.8	QS	ND	1.8	14.1	ND	13.5	2.4	29.7	ND	ND	QS	ND	4.2	27.6	2.8	10.3	ND	1.3	ND	ND	ND	ND	ND	ND	ND
BD30	Pinole Point	5/1/96	10	MCAL	95	7.0	QS	ND	ND	10.1	ND	6.4	1.3	16.2	ND	ND	QS	ND	2.7	11.7	1.5	4.4	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD20	San Pablo Bay	5/1/96	10	CGIG	89	4.2	ND	ND	0.1	6.3	1.0	6.3	1.4	13.8	ND	ND	QS	ND	2.2	10.6	1.4	5.1	ND	0.4	ND	ND	ND	ND	ND	ND	ND
BC61	Red Rock	5/1/96	10	MCAL	80	4.0	QS	ND	1.8	8.3	ND	5.2	0.8	14.0	ND	ND	QS	ND	2.2	9.9	1.3	4.0	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	5/1/96	10	MCAL	103	5.1	QS	ND	3.2	10.7	ND	7.2	ND	18.9	1.2	ND	QS	ND	3.2	11.5	1.6	5.4	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC10	Yerba Buena Island	4/30/96	10	MCAL	185	11.5	QS	ND	4.9	17.6	ND	11.4	1.3	30.0	1.3	ND	QS	ND	5.3	24.2	2.5	8.7	ND	1.1	ND	ND	ND	ND	ND	ND	ND
BB71	Alameda	4/30/96	10	MCAL	174	9.8	QS	ND	4.5	17.0	ND	11.5	1.4	28.4	1.4	ND	QS	ND	5.1	20.6	2.5	8.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA40	Redwood Creek	4/30/96	10	MCAL	139	8.1	ND	ND	4.5	13.4	ND	9.3	1.0	24.7	1.0	ND	QS	ND	5.2	12.7	1.8	7.2	ND	0.5	ND	0.7	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	4/30/96	10	MCAL	261	13.6	QS	ND	8.0	27.7	ND	17.9	ND	46.2	2.5	ND	QS	ND	9.3	24.6	3.0	12.4	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	4/30/96	10	CGIG	273	17.9	ND	3.8	11.3	21.6	ND	19.3	2.6	43.7	1.9	ND	QS	ND	9.0	21.3	3.0	13.9	ND	0.6	ND	0.9	ND	ND	ND	ND	ND
T-0	Putah Creek—pre depuration	12/20/95	10	CFLU	134	10.6	ND	ND	.	14.0	ND	5.2	2.4	21.6	ND	ND	QS	ND	2.5	5.8	3.2	3.8	ND	ND	2.1	ND	ND	ND	ND	ND	ND
T-0	Putah Creek—post depuration	1/26/96	10	CFLU	131	10.6	ND	ND	.	10.9	ND	4.4	ND	17.1	ND	ND	QS	ND	3.0	7.9	3.5	3.1	ND	ND	2.3	1.6	ND	ND	ND	ND	0.5
T-0	Tomales Bay	1/26/96	10	CGIG	16	0.9	QS	ND	ND	1.5	ND	0.8	ND	3.1	ND	ND	QS	ND	ND	2.5	ND	0.7	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Bodega Head	1/26/96	10	MCAL	19	1.7	QS	ND	ND	3.6	ND	ND	ND	3.1	ND	ND	QS	ND	ND	3.3	ND	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	9/10/96	12	CFLU	.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	.	NS	NS	NS	NS	NS
BG30	San Joaquin River	9/10/96	12	CFLU	179	10.4	ND	ND	4.0	11.6	ND	9.8	ND	35.4	ND	1.8	7.0	ND	3.2	35.1	2.9	10.5	ND	ND	ND	.	ND	1.8	ND	ND	1.9
BF20	Grizzly Bay	9/10/96	12	CFLU	.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	.	NS	NS	NS	NS	NS
BD50	Napa River	9/10/96	12	CGIG	88	3.7	ND	ND	4.2	8.5	ND	7.6	ND	16.1	ND	ND	6.1	ND	2.2	9.4	ND	8.4	ND	ND	ND	.	ND	ND	ND	ND	ND
BD40	Davis Point	9/10/96	12	CGIG	177	9.6	QS	ND	5.6	11.8	ND	13.1	1.0	26.3	ND	ND	2.5	ND	4.2	18.9	3.0	13.2	ND	ND	ND	.	ND	ND	ND	ND	ND
BD30	Pinole Point	9/11/96	12	MCAL	85	5.3	ND	ND	1.9	8.5	ND	5.5	ND	10.9	ND	ND	6.5	ND	1.7	6.7	1.8	4.9	ND	ND	ND	.	ND	ND	ND	ND	ND
BD20	San Pablo Bay	9/11/96	12	MCAL	141	9.1	QS	ND	5.8	10.1	ND	11.5	1.6	22.6	ND	ND	2.7	ND	3.1	10.1	2.7	11.1	ND	ND	ND	.	ND	ND	ND	ND	ND
BD15	Petaluma River	9/11/96	12	MCAL	88	5.4	ND	ND	3.5	8.9	ND	8.3	ND	17.0	ND	ND	5.1	ND	2.4	4.8	1.7	8.5	ND	ND	ND	.	ND	ND	ND	ND	ND
BC61	Red Rock	9/11/96	12	MCAL	100	5.6	ND	ND	3.6	10.2	ND	6.7	ND	13.8	ND	ND	6.9	ND	1.9	7.5	2.6	6.1	ND	ND	ND	.	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	9/11/96	12	MCAL	92	6.4	QS	1.8	2.7	6.8	ND	4.7	0.7	11.7	ND	0.5	5.5	ND	1.5	6.7	1.9	4.7	ND	ND	ND	.	ND	ND	ND	ND	ND
BC10	Yerba Buena Island	9/11/96	12	MCAL	123	8.1	ND	ND	4.1	10.7	ND	7.4	0.9	16.8	ND	0.8	3.6	ND	2.1	13.9	2.8	6.7	ND	ND	ND	.	ND	ND	ND	ND	ND
BB71	Alameda	9/12/96	12	MCAL	172	9.7	ND	ND	6.4	16.5	ND	11.2	1.4	24.7	1.5	1.2	4.5	ND	3.5	15.7	4.3	10.8	ND	ND	ND	.	ND	ND	ND	ND	ND
BA40	Redwood Creek	9/12/96	12	MCAL	135	8.4	ND	ND	6.2	15.3	ND	8.1	ND	21.2	1.1	1.1	7.3	ND	3.1	10.3	3.1	9.7	ND	ND	ND	.	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	9/12/96	12	MCAL	143	10.7	ND	ND	5.2	16.2	ND	8.8	ND	21.5	1.2	1.2	4.9	ND	3.3	9.1	3.6	10.0	ND	ND	ND	.	ND	ND	ND	ND	ND
BA10	Coyote Creek	9/12/96	12	CGIG	233	14.6	QS	ND	11.0	17.1	ND	16.3	2.0	36.1	ND	1.5	7.5	ND	5.0	11.1	3.3	18.0	ND	ND	ND	.	ND	ND	ND	ND	ND
T-0	Putah Creek	6/14/96	12	CFLU	134	11.7	ND	ND	1.3	10.7	ND	3.6	1.3	14.7	ND	1.0	3.9	ND	ND	7.9	ND	3.0	ND	ND	ND	.	ND	ND	ND	ND	0.8
T-0	Tomales Bay	6/14/96	12	CGIG	10	0.7	ND	ND	0.2	1.0	ND	0.6	ND	1.8	ND	ND	1.1	ND	ND	0.4	ND	0.6	ND	ND	ND	.	ND	ND	ND	ND	ND
T-0	Bodega Head	6/14/96	12	MCAL	8	ND	ND	ND	0.3	1.9	ND	ND	ND	1.0	ND	ND	0.7	ND	ND	ND	ND	ND	ND	ND	ND	.	ND	ND	ND	ND	ND

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus*

Table 21. Pesticide concentrations in bivalve tissues, 1996. . = no data, ND = not detected, NS = not sampled, units expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading. For method detection limits refer to Table 4 in *Appendix B*.

Station Code	Station	Date	Cruise	Species	Sum of DDTs (SFEI)	o,p'-DDD	o,p'-DDE	o,p'-DDT	p,p'-DDD	p,p'-DDE	p,p'-DDT	Sum of Chlordanes (SFEI)	alpha-Chlordane	gamma-Chlordane	cis-Nonachlor	trans-Nonachlor	Heptachlor	Heptachlor Epoxide	Oxychlordane	Aldrin	Dieldrin	Endrin	alpha-HCH	beta-HCH	delta-HCH	gamma-HCH	Mirex
					µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BG20	Sacramento River	5/2/96	10	CFLU	1401	55.3	30.5	59.3	98.7	1062.0	95.1	130	30.5	34.1	19.4	45.9	ND	ND	ND	ND	36.6	ND	ND	ND	ND	26.8	ND
BG30	San Joaquin River	5/2/96	10	CFLU	303	10.3	5.7	10.8	23.3	225.0	28.4	24	6.1	6.1	1.8	9.6	ND	ND	ND	ND	6.1	ND	ND	ND	ND	ND	0.6
BF20	Grizzly Bay	5/2/96	10	CFLU	312	12.2	5.9	13.3	34.1	213.4	32.9	29	7.4	7.1	3.2	11.0	ND	ND	ND	ND	7.7	ND	ND	ND	ND	ND	ND
BD50	Napa River	5/1/96	10	CGIG	70	4.8	1.7	5.0	17.7	36.2	4.6	14	4.4	4.4	ND	4.7	ND	0.3	0.5	ND	5.1	ND	ND	ND	ND	0.1	ND
BD40	Davis Point	5/1/96	10	CGIG	235	18.3	5.2	14.1	52.5	125.6	19.4	39	12.3	11.5	0.7	14.5	ND	ND	ND	ND	13.8	ND	ND	ND	ND	1.9	ND
BD30	Pinole Point	5/1/96	10	MCAL	88	9.4	ND	5.0	26.2	42.4	5.2	30	11.4	8.9	ND	6.9	ND	2.0	1.1	ND	29.1	ND	ND	ND	ND	1.0	ND
BD20	San Pablo Bay	5/1/96	10	CGIG	105	9.0	2.3	6.0	24.5	56.4	6.6	20	6.1	5.6	1.5	6.4	ND	0.3	0.4	ND	7.5	ND	ND	0.4	ND	1.3	ND
BC61	Red Rock	5/1/96	10	MCAL	52	6.2	ND	3.7	13.4	26.2	2.1	19	7.9	5.3	ND	4.7	ND	1.2	ND	ND	17.2	ND	ND	ND	ND	1.1	ND
BC21	Horseshoe Bay	5/1/96	10	MCAL	48	5.5	ND	3.8	13.5	22.7	2.7	18	6.8	5.0	ND	3.9	ND	1.1	0.7	ND	19.4	ND	ND	0.9	ND	1.1	ND
BC21	Yerba Buena Island	4/30/96	10	MCAL	73	8.6	1.6	5.6	19.5	33.3	4.8	27	10.4	8.3	ND	6.1	ND	1.5	0.8	ND	27.2	ND	ND	ND	ND	1.3	ND
BB71	Alameda	4/30/96	10	MCAL	77	9.0	1.8	4.4	24.7	32.7	4.6	24	9.4	6.9	ND	5.7	ND	1.4	0.8	ND	21.7	ND	ND	0.9	ND	1.1	ND
BA40	Redwood Creek	4/30/96	10	MCAL	51	5.9	1.0	3.2	13.9	23.7	3.5	28	9.6	8.2	1.1	6.9	ND	1.6	0.9	ND	18.2	ND	ND	ND	ND	1.1	ND
BA30	Dumbarton Bridge	4/30/96	10	MCAL	107	14.1	ND	8.5	27.8	50.3	6.5	67	26.2	19.7	ND	14.3	ND	4.5	1.9	ND	49.1	ND	ND	ND	ND	0.7	ND
BA10	Coyote Creek	4/30/96	10	CGIG	172	14.8	3.0	14.1	33.8	91.9	14.7	61	20.3	16.6	ND	21.1	ND	1.2	1.5	ND	10.3	ND	ND	ND	ND	1.4	ND
T-0	Putah Creek—pre depuration	12/20/95	10	CFLU	642	12.5	11.8	15.9	27.9	515.9	57.7	32	6.9	6.8	6.2	11.5	ND	0.7	ND	ND	8.2	ND	ND	ND	ND	ND	ND
T-0	Putah Creek—post depuration	1/26/96	10	CFLU	569	9.9	9.5	16.9	23.3	468.3	41.0	27	5.6	6.0	5.3	9.7	ND	ND	ND	ND	3.3	ND	ND	ND	ND	ND	ND
T-0	Tomales Bay	1/26/96	10	CGIG	11	1.4	ND	0.7	1.4	7.2	ND	2	0.8	0.6	ND	0.9	ND	ND	ND	ND	ND	ND	ND	0.6	ND	ND	ND
T-0	Bodega Head	1/26/96	10	MCAL	20	2.0	ND	1.4	3.4	11.8	1.1	8	3.6	2.1	ND	1.5	ND	1.1	ND	ND	10.1	ND	4.0	3.0	ND	1.7	ND
BG20	Sacramento River	9/10/96	12	CFLU	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BG30	San Joaquin River	9/10/96	12	CFLU	84	6.8	ND	1.8	2.7	65.9	6.4	11	3.0	3.6	ND	4.6	ND	ND	ND	ND	3.8	ND	ND	ND	ND	ND	ND
BF20	Grizzly Bay	9/10/96	12	CFLU	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BD50	Napa River	9/10/96	12	CGIG	46	4.3	0.7	ND	11.6	29.7	ND	6	1.8	1.8	ND	2.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD40	Davis Point	9/10/96	12	CGIG	137	11.4	4.0	2.1	33.2	82.0	4.9	20	6.3	6.0	0.8	6.8	ND	ND	ND	ND	4.5	ND	ND	ND	ND	0.8	0.8
BD30	Pinole Point	9/11/96	12	MCAL	46	4.5	1.2	ND	12.9	26.5	1.4	12	4.8	3.8	ND	3.0	ND	0.5	ND	ND	12.0	ND	ND	ND	ND	ND	ND
BD20	San Pablo Bay	9/11/96	12	MCAL	86	6.2	2.5	1.8	20.6	52.1	3.1	12	4.0	3.5	ND	4.2	ND	ND	ND	ND	2.5	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	9/11/96	12	MCAL	47	4.0	0.8	ND	12.0	30.1	ND	6	1.9	1.6	ND	2.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC61	Red Rock	9/11/96	12	MCAL	34	0.9	1.2	ND	10.2	20.7	1.0	12	4.3	4.3	ND	2.8	ND	0.4	ND	ND	12.1	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	9/11/96	12	MCAL	28	2.0	1.0	0.9	8.6	15.3	ND	6	2.2	2.0	0.3	1.3	ND	0.3	ND	ND	5.7	ND	0.7	0.7	ND	0.5	ND
BC10	Yerba Buena Island	9/11/96	12	MCAL	33	3.2	0.8	1.5	9.5	16.9	1.3	9	3.7	3.3	ND	2.2	ND	0.2	ND	ND	7.5	ND	ND	ND	ND	ND	ND
BB71	Alameda	9/12/96	12	MCAL	41	4.2	ND	0.5	11.2	23.3	1.5	11	4.3	3.5	ND	2.7	ND	0.3	ND	ND	11.6	ND	ND	ND	ND	ND	ND
BA40	Redwood Creek	9/12/96	12	MCAL	24	2.5	ND	ND	5.2	16.1	ND	14	5.6	4.4	ND	3.4	ND	0.4	ND	ND	13.7	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	9/12/96	12	MCAL	36	3.3	0.8	ND	7.5	24.1	ND	17	6.1	5.5	ND	4.7	ND	0.5	ND	ND	13.0	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	9/12/96	12	CGIG	76	3.1	1.7	2.5	14.8	54.1	ND	23	7.3	6.5	0.9	8.3	ND	ND	ND	ND	3.8	ND	ND	ND	ND	ND	ND
T-0	Putah Creek	6/14/96	12	CFLU	441	3.2	5.9	12.2	10.8	359.1	49.7	23	6.0	5.1	1.5	10.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.1
T-0	Tomales Bay	6/14/96	12	CGIG	11	0.6	ND	0.3	1.3	9.0	ND	2	0.9	0.8	ND	0.8	ND	ND	ND	ND	ND	ND	0.7	0.7	ND	ND	ND
T-0	Bodega Head	6/14/96	12	MCAL	8	0.3	ND	ND	1.5	5.9	ND	5	2.3	1.6	ND	0.7	ND	0.4	ND	ND	7.2	ND	1.1	1.0	ND	ND	ND

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus*

Glossary

accumulation factor: The ratio of the concentration of a contaminant in transplanted bivalves at a sampling site to the concentration prior to deployment. *See also* transplanted bivalves.

acute effect: A toxic effect produced within a short period of time. *Compare with* chronic effect.

Ag: The chemical symbol for silver, a trace metal measured by the RMP.

Al: The chemical symbol for aluminum, a trace metal measured by the RMP.

As: The chemical symbol for arsenic, a trace element measured by the RMP.

aliquot: A subsample taken from a field sample (e.g., of sediment).

ambient: Refers to the overall conditions surrounding a place or thing. In the case of the RMP, **ambient monitoring** is done to determine existing pollutant levels in the San Francisco Bay-Delta Estuary.

amphipod: An order of small shrimp-like crustaceans such as sand fleas and related forms. Many live on the bottom of the Estuary (i.e., are benthic) and feed on algae and detritus.

anaerobic: In the absence of oxygen.

anthropogenic: Effects or processes that are derived *from human activities*, as opposed to natural effects or processes that occur in the environment without human influences.

axial transect: A line which follows the deep channel along the length or "axis" of the Estuary. Most RMP stations are on the axial transect of the Estuary. Also known as the "spine".

Base Program: Standard RMP monitoring, i.e., water, sediment, and tissue cruise sampling and analyses at the stations normally sampled, excluding Special Studies and Pilot Studies.

Basin Plan: California Regional Water Quality Control Board, San Francisco Bay Basin (Region 2), Water Quality Control Plan (June 21, 1995). The Basin Plan is a master policy document that contains descriptions of the legal, technical, and programmatic bases of water quality regulation in the San Francisco Bay Region.

benthic (bottom dwelling): Organisms that live in or at the sediment-water interface.

benthic assemblage: A group of benthic organisms.

benthos: The entire assemblage of plants and animals living in the benthic zone.

bioaccumulation: The buildup of contaminants in an organism's tissues (usually fatty tissue) through ingestion, contact with the skin, or respiratory tissue. Contaminants that bioaccumulate may also biomagnify up the foodchain, resulting in high tissue concentrations in predators relative to ambient environmental concentrations.

bioassay: A laboratory test using live organisms to measure biological effects of a substance, factor, or condition. The effect measured may be growth, reproduction or survival.

bioavailability: The extent to which a compound is available for intake by organisms. Bioavailable compounds have the potential to cause biological effects, such as increased mortality.

bivalves: Any mollusks, such as an oyster or clam, that has a shell with two hinged "valves" or shell halves.

brackish: Somewhat salty water that is less salty than seawater.

C: The chemical symbol for carbon, a trace element measured by the RMP in conventional water and sediment quality parameters.

Cd: The chemical symbol for cadmium, a trace metal measured by the RMP.

chlorinated hydrocarbons: A group of organic compounds which include PCBs, DDT, chlordanes, and dieldrin.

chlorophyll *a*: A key substance in the process of photosynthesis. Found with photosynthesizing organisms. Used in the RMP as a measure of abundance of photosynthetic organisms in the water column (phytoplankton).

chronic effect: A toxic effect produced after a contaminant exposure of long duration, often 1/10 or more of the test organisms life. *Compare with* acute effect.

cohort: A group of organisms of similar age.

Comprehensive Conservation and Management Plan (CCMP): Created by direction of the Federal Clean Water Act, the CCMP is a blueprint to protect and restore the chemical, physical, and biological integrity of the Estuary, while maintaining its beneficial uses.

condition factor: A ratio of the condition index at a sampling station to the condition index prior to deployment. *See also* condition index.

condition index: A measure of the biological condition of RMP transplanted bivalves, expressed as the ratio of tissue dry weight and shell cavity volume.

Cr: The chemical symbol for chromium, a trace metal measured by the RMP.

Cu: The chemical symbol for copper, a trace metal measured by the RMP.

DDE (dichloro diphenyl dichloroethylene): A degradation product of DDT.

DDT (dichloro diphenyl trichloroethane): A formally commonly used pesticide now banned in the United States.

delta: A broad area formed by riverine deposits of sand, silt, and mud at the mouth of a river.

depuration: The holding of clams, mussels, or oysters in clean water to flush pollutants from the gut.

diurnal tide: The tide cycle within a lunar day (24.84 hrs). *See also* semidiurnal.

dry-season sampling: RMP sampling carried out in August–September.

EC_{50}: The "effective concentration" of a contaminant that exhibits a sublethal effect for half the organisms in a bioassay.

echinoderm: The name of a taxonomic group of marine invertebrate. Members include starfish and sea urchins.

ERL (Effects Range Low): Part of the Effects Range sediment quality guidelines, developed by the National Oceanic and Atmospheric Administration, above which adverse biological effects are possible. Derived from a large number of sediment toxicity studies, ERL is the concentration at which 10% of the studies reported adverse effects. *See also* ERM.

ERM (Effects Range Median): Part of the Effects Range sediment quality guidelines, developed by the National Oceanic and Atmospheric Administration, above which adverse biological effects are probable. ERM is the concentration at which 50% of the studies reported adverse effects. *See also* ERL.

estuary: A body of water at the lower end of a river which is connected to the ocean and semi-enclosed by land. In an estuary, seawater is measurably diluted by freshwater from the land.

euryhaline: A body of water with wide variations in salinity.

Fe: The chemical symbol for iron, a trace metal measured by the RMP.

freshwater: Water with salinity below 5 parts per thousand.

GERG (Geochemical and Environmental Research Group): An interdisciplinary research group affiliated with Texas A & M University.

Hg: The chemical symbol for mercury, a trace metal measured by the RMP.

hydrocarbons: Organic compounds containing only carbon and hydrogen, including petroleum-based fuels.

hydrodynamics: The motion and action of water and other liquids.

kinetics: The study of the relationships between motion and the forces affecting motion.

LC_{50}: The concentration of a contaminant that is lethal to half the organisms in a bioassay.

levee: An embankment raised to prevent a river from flowing onto adjacent land; also known as a dike.

method detection limit (MDL): The MDL is the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero. It is determined from analysis of a sample in a given matrix containing the analyte.

MTRL (Maximum Tissue Residue Levels): MTRLs, developed by the State Water Resources Control Board, refer to concentrations of contaminants in transplanted bivalve tissue. They are used as alert levels indicating water bodies with potential human health concerns.

Mn: The chemical symbol for manganese, a trace metal measured by the RMP.

N: The chemical symbol for nitrogen, a trace element measured by the RMP in conventional water and sediment quality parameters.

neap tides: Tides with the smallest height difference between high tide and low tide, usually occurring during the moons quarters. *Compare with* spring tide.

near-total: Water or sediment concentrations resulting from a metal extraction process that does not digest a sample completely. Near-total concentrations underestimate total concentrations by an unknown amount.

Ni: The chemical symbol for nickel, a trace metal measured by the RMP.

NPDES (National Pollutant Discharge Elimination System): A provision of the Clean Water Act that prohibits discharge of pollutants into waters of the United States unless a special permit is issued by EPA, a state, or another delegated agency.

P: The chemical symbol for phosphorous, a trace element measured by the RMP in conventional water quality parameters.

Pb: The chemical symbol for lead, a trace metal measured by the RMP.

pathogen: An organism capable of causing disease.

phytoplankton: Microscopic photosynthesizing organisms that drift with the currents.

Pilot Study: Studies which employ methods that are under evaluation for potential incorporation into the RMP monitoring program.

POTWs (Publicly Owned Treatment Works): POTWs treat municipal sewage and wastewater before discharging it into the Estuary.

runoff: Water from rain, melted snow, or agricultural or landscape irrigation that flows over the land surface. Runoff can pick up contaminants from the land and transport them to a body of water.

salinity: the salt content of water, in the RMP expressed as ppt or ‰ (parts per thousand).

Se: The chemical symbol for selenium, a trace element measured by the RMP.

semidiurnal: Two high and two low tides per lunar day (24.84 hrs). In the San Francisco Bay-Delta, the cycle is known as mixed semidiurnal, where the two highs are of unequal height and the two lows are of unequal height.

shoals: Shallows or sandbars in a body of water.

Si: The chemical symbol for silicon, a trace element measured by the RMP in conventional water quality parameters.

Sn: The chemical symbol for tin, a trace element measured by the RMP. *See also* TBT.

Special Study: A study initiated by the RMP in order to help improve interpretation or collection of RMP data.

spring tides: Tides with the greatest range between highs and lows, usually occurring during the full or new moons.

stenohaline: Slight variations in salinity.

substrate: Material upon which something rests or is attached.

TBT: tributyltin, an anti-fouling agent used on boat hulls and dock pilings, containing the trace metal tin.

TTBT: tetrabutyltin, a degradation product of tin.

tidal prism: The volume of water that is moved in or out of an embayment or channel with each tide.

time zero (or T_{zero}, or T-0): The moment of deployment of transplanted bivalves. Concentrations are initial concentrations at the moment of deployment. They are measured in a subset of animals taken from the group that is being deployed.

toxicity: A measure of characteristics which are poisonous, carcinogenic or otherwise harmful to life.

trace element: One of a group of naturally occurring elements found in low ("trace") concentrations in the water, sediment, and tissue measured by the RMP.

trace organic: An organic compound found in low ("trace") concentrations in the water, sediment, and tissue measured by the RMP.

trace substance: An element, compound, or organic substance found in low or trace concentrations.

transplanted bivalves: Clams, mussels, or oysters brought in from elsewhere and placed ("deployed") in the Estuary for a fixed time period. The bivalves are then collected and contaminant levels in the tissues are measured as one indication of Estuary contamination.

TSS: Total suspended solids. Organic and inorganic particles of all sizes suspended in a measured volume of water.

uptake: *See* bioaccumulation

wet season sampling: RMP sampling carried out between February and April

X2: The location within the Estuary where near-bottom salinity is 2 parts per thousand (ppt), often located near Suisun Bay. Used as a salinity standard in the San Francisco Estuary.

Zn: The chemical symbol for zinc, a trace metal measured by the RMP.

Acronyms

AF	accumulation factor *see glossary entry*
APHA	American Public Health Association
ASTM	American Society for Testing and Materials
BADA	Bay Area Dischargers Association
BASMAA	Bay Area Stormwater Management Agencies Association
BBI	Bodega Bay Institute
BPTCP	Bay Protection and Toxic Cleanup Program
BRL	Brooks-Rand Ltd.
CCCSD	Central Contra Costa Sanitary District
CCSF	City and County of San Francisco
CMP	Sacramento Coordinated Water Quality Monitoring Program
CRM	certified reference materials
CTD	conductivity, temperature, depth
DDE	dichloro diphenyl dichloroethylene *see glossary entry*
DDT	dichloro-diphenyl-trichloroethane *see glossary entry*
DO	dissolved oxygen
DOC	dissolved organic carbon
DOI	Delta Outflow Index
DQO	data quality objectives
EBMUD	East Bay Municipal Utility District
ECD	electron capture detection
EDTA	ethylene diamine tetracetic acid
ELISA	enzyme-linked immunosorbent assay
EMAP	Environmental Monitoring and Assessment Program
ERL	Effects Range Low *see glossary entry*
ERM	Effects Range Median *see glossary entry*
GC/ECD	gas chromatograph with electron capture detector
GC/MS	gas chromatograph with mass spectral detector
GERG	Geochemical and Environmental Research Group *see glossary entry*
GFAAS	graphite furnace atomic absorption spectrometry
HCH	hexachlorocyclohexanes
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
ICP/AES	inductively coupled plasma atomic emission spectrometry
ICP/MS	inductively coupled plasma mass spectrometry
IEP	Interagency Ecological Program
LEM	Local Effects Monitoring
LPAH	low-molecular-weight polycyclic aromatic hydrocarbon
MDL	method detection limit *see glossary entry*
mERMq	mean Effects Range Median quotient
MSD	minimum significant difference
MTRL	Maximum Tissue Residue Level *see glossary entry*
NERR	National Estuarine Research Reserve
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System *see glossary entry*

OBS	optical backscatterance
PAH	polycyclic aromatic hydrocarbon
PCA	principal components analysis
PCB	polychlorinated biphenyl
POTW	public owned treatment works *see glossary entry*
PVA	polytopic vector analysis
QA	quality assurance
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RMP	Regional Monitoring Program for Trace Substances
RMS	root mean squared
RWQCB	Regional Water Quality Control Board
SFEI	San Francisco Estuary Institute
SJWTP	San Jose Wastewater Treatment Plant
SMW	California State Mussel Watch
SQG	sediment quality guidelines
SRCSD	Sacramento Regional County Sanitation District
SRM	standard reference material
SRTPCP	Sacramento River Toxic Pollutant Control Program
SRWP	Sacramento River Watershed Program
SSC	suspended solids concentration
SWI	Sediment-Water Interface
TIE	Toxicity Identification Evaluation
TMDL	Total Maximum Daily Load
TOC	total organic carbon
TSS	total suspended solids/sediments *see glossary entry*
UCD	University of California, Davis
UCSCDET	University of Santa Cruz Department of Environmental Toxicology
US EPA	United States Environmental Protection Agency
USD	Union Sanitary District
USGS	United States Geological Survey
UU	University of Utah
WQC	water quality criteria

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