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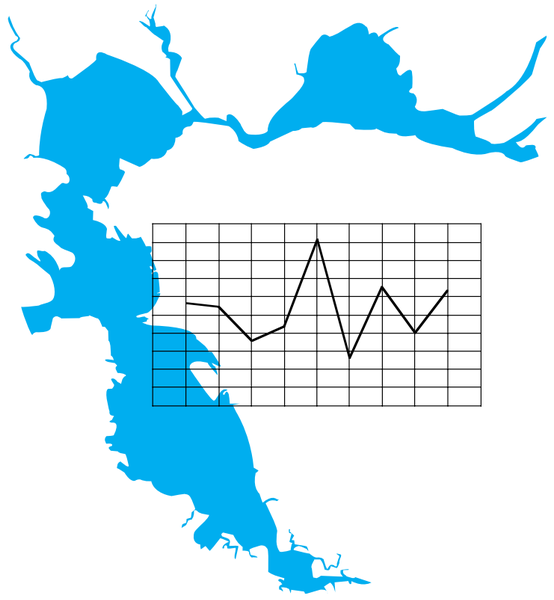
1995 Annual Report

San Francisco Estuary
Regional Monitoring Program for Trace Substances

RMP

Regional Monitoring Program for Trace Substances

1995 Annual Report



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

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
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

Storm Water
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
Port of Oakland
Port of Redwood City
Port of Richmond
Port of San Francisco
US Army Corps of Engineers
US Navy, Western Division

Executive Summary

The 1995 Regional Monitoring Program (RMP) Annual Report includes monitoring results from the Base Program, Pilot and Special Studies, and summary and perspective articles contributed by RMP investigators and other scientists.

The purpose of the RMP is to provide information on the status and trends of contamination in San Francisco Estuary water, sediment, and bivalve tissue, and to assess the potential for biological effects from exposure to those contaminants. The objectives, background, and rationale for the RMP are described in the Introduction (Chapter 1).

The 1995 RMP Base Program was essentially the same as in 1994. Water monitoring was conducted in February, April, and August at 24 stations throughout the Estuary. Aquatic bioassays were conducted in February and August at 13 of those stations. Sediment monitoring was conducted in February and August at all 24 stations, and sediment bioassays were conducted at 12 of those stations. Bioaccumulation of contaminants by transplanted bivalves was monitored at 15 stations during two 90 day sampling periods: January to April and July to September.

Pilot Studies on benthic fauna and tidal wetlands were conducted and Special Studies on trends in trace elements and development of sediment indicators were also included.

Water Monitoring

Water Quality

Monthly water quality monitoring was conducted by the US Geological Survey (USGS). This component of the RMP describes water quality (e.g., salinity, suspended sediments, dissolved oxygen, etc.) throughout the Estuary (Chapter 2). Their monthly samples provide supplementary information about water quality at the times between RMP Base Program sampling periods.

In general, the patterns of salinity in 1995 reflected the effects of river flow on the distribution of dissolved constituents. Salinity decreased from the Golden Gate into northern San Francisco Estuary during most of the year, whereas salinity in the South Bay was usually homogeneous. This reflects the role of Delta outflow as a continual source of freshwater into the North Bay. The North Bay salinity gradient changed rapidly in response to changing flows during the year. Salinity in the South Bay may be diluted by freshwater arriving from the northern connection to Delta-derived flows, as well as by runoff from the local watershed.

The patterns of total suspended sediments (TSS) showed that strong freshwater flows deliver new sediments to the Estuary. This is important because concentrations of TSS are directly related to concentrations of many contaminants. TSS was generally lowest in the Central Bay, far from the riverine supplies of sediments and far from the shallow habitats where wind-wave resuspension creates high turbidity.

Salinity patterns reflected the effects of river flow on dissolved constituent distributions.

The potential for biological transformations of dissolved chemicals in water into organic forms was monitored by measuring chlorophyll. Phytoplankton comprise one of the largest components of living biomass in San Francisco Bay. Phytoplankton biomass, as measured by chlorophyll, was usually low in the Bay-Delta. However, during spring blooms in the South Bay, biomass increased rapidly. During these blooms, dissolved inorganic carbon, nitrogen, phosphorus, and silicon, as well as some trace elements (cadmium, nickel, zinc) were removed from water and transformed into organic forms. As the 1995 RMP sampling in April occurred at the end of a two-month bloom, reduced concentrations of those dissolved trace elements were observed in the South Bay samples (pages 15, 20, and 23).

Contaminants in Water

Different contaminants exhibited different patterns of distribution in the Estuary. In 1995, overall, the South Bay had the highest concentrations of both trace elements and trace organic contaminants (Chapter 2). However, concentrations of dissolved copper and nickel were much higher at the Petaluma River suggesting the presence of a source of these elements near that station. The distribution of total (or near-total) concentrations of chromium, copper, lead, mercury, nickel, silver, and zinc reflected the distribution of TSS, with the highest concentrations in the Southern Sloughs and at the Petaluma River, intermediate concentrations at the Northern Estuary and River stations, and lowest concentrations in the Central Bay. Analysis by USGS showed that seven trace elements were well-correlated with TSS in the Estuary (page 53). Concentrations of trace organic contaminants that tend to be associated with particles, such as PAHs, PCBs, DDTs, and chlordanes, also displayed the same basic pattern as TSS; the highest concentrations occurred in the South Bay, lower concentrations in the Central Bay, higher concentrations in the Northern Estuary, and intermediate concentrations in the Rivers. Most dissolved trace organic contaminants, including PCBs, chlordanes, DDTs, HCHs (hexachlorocyclohexanes) and diazinon, were elevated in the South Bay relative to other reaches of the Estuary, with concentrations progressively decreasing from Coyote Creek to the Golden Gate. Diazinon concentrations were highest at nearly all stations in February, reflecting its seasonal usage.

Seasonal variation was also observed in many other contaminants. Total arsenic, near-total cadmium, and dissolved silver, arsenic, cadmium and PAHs were highest in August. Total concentrations of chromium, copper, lead, mercury, nickel, silver, PAHs, PCBs, chlordanes, and DDTs tend to be associated with particles and were often highest in April, coinciding with high concentrations of TSS.

Long-term trends in total trace element concentrations were examined in detail using data collected from April 1989 to April 1995 under the RMP and Pilot Studies that preceded the RMP (pages 78–84). There were no obvious increasing or decreasing trends in trace element concentrations. For certain persistent trace organics, the long-term rate of decline in concentrations appears to be very slow. Data for water organics from the mid-1970s and early 1980s compared to RMP data showed that concentrations of PCBs have generally not declined appreciably, although they have been been banned for decades. Neither have PAHs declined, as continuous sources still exist. DDTs and chlordanes appear to have declined since being banned in the 1970s.

In water, the South Bay had the highest concentrations of most trace elements and trace organic contaminants.

Comparisons to Water Quality Objectives and Criteria

Concentrations of many contaminants were above applicable water quality objectives or criteria. Of the 10 trace elements measured, concentrations of chromium, copper, lead, mercury, and nickel were above applicable water quality objectives or criteria on one or more occasions. Copper, mercury, and nickel were most frequently above objectives or criteria. PCBs were always above EPA criteria, PAHs were frequently above criteria, and DDTs, chlordanes, dieldrin, and diazinon were occasionally above water quality objectives or criteria. The stations with the largest number of concentrations above guidelines were Coyote Creek, the Dumbarton Bridge, and the Petaluma River. The overall pattern of exceedances was very similar in 1994 and 1995.

Copper, mercury, and nickel were most frequently above water quality objectives or criteria. PCBs were always above criteria, PAHs were frequently above criteria, and DDTs, chlordanes, dieldrin, and diazinon were occasionally above objectives or criteria.

Aquatic Bioassays

Aquatic toxicity was observed in only one water sample in 1995, in the *Mysidopsis* (mysid shrimp) test of San Joaquin River water collected in February. However, the presence of some contaminants, particularly organophosphate insecticides, is known to be episodic, with high concentrations entering the Estuary during periods of heavy use and/or high runoff. The lack of significant results in 1995, therefore, does not necessarily mean that the Estuary was free of ambient toxicity for the entire year. RMP sampling at fixed times may have missed elevated pesticides entering the Estuary at other times.

Aquatic toxicity was observed only in the February *Mysidopsis* test of San Joaquin River water.

Sediment Monitoring

Contaminants in Sediments

Despite the very wet year of 1995, the distributions and concentrations of sediment contaminants in the Estuary remained similar to those in previous years. There were two patterns of trace element concentrations in sediments: 1) average concentrations of arsenic, chromium, copper, nickel, and zinc were highest in the Northern Estuary. Chromium, copper, and nickel were highest at Pinole Point in February, and 2) average concentrations of silver, cadmium, lead, mercury, and selenium were highest in the South Bay and Southern Sloughs. Cadmium, lead, silver, and zinc were highest at San Jose in August. Concentrations of most elements (except arsenic and chromium) were lowest at the stations with the sandiest sediments, particularly at Red Rock, reflecting the influence of sediment-type on sediment contaminant concentrations. For trace organics, sediment concentrations were always higher south of the Golden Gate than in other parts of the Estuary. Concentrations of PCBs and DDTs were lowest at stations with the most sand in the sediments, but PAH concentrations were lowest at the Rivers confluence stations (Chapter 3).

The only consistent seasonal pattern for trace elements was that nearly all concentrations were highest in August at both Southern Slough stations. Seasonally, PAHs were generally highest in February in the South and Central Bays. PCBs were generally highest in August in the South Bay. DDTs were always higher in August than February throughout the Estuary.

Examination of sediment contaminants over the first three years of the RMP showed that trace element concentrations have generally remained constant in all locations since 1993 with no apparent increasing or decreasing trends (page 127–136). There were no observable increasing or decreasing trends in PAHs. However, PAH concentrations were elevated in the Northern Estuary, Central, and South Bays in February 1994. Average PCB concentrations appear to have decreased slightly in the Rivers, Northern Estuary, and Central Bay, and average DDTs appear to have decreased slightly in the Rivers. Average chlordanes have also decreased in most Estuary reaches.

Comparisons to Sediment Quality Guidelines

There are currently no Basin Plan objectives or other regulatory criteria for sediment contaminant concentrations in the Estuary. Effects Range concentrations developed by the National Oceanic and Atmospheric Administration were used by the RMP in the interpretation and assessment of sediment contaminant concentrations in the Estuary (pages 132–138), but hold no regulatory status. As in past years, nickel concentrations in nearly all samples were above the Effects Range-Median (ERM). Nickel is present naturally in serpentine soils abundant in the region. Concentrations in USGS sediment cores were generally constant for centuries. Also similar to past years, concentrations of arsenic, chromium, copper, mercury, nickel, and

In sediment, arsenic, chromium, copper, mercury, nickel, and total DDT concentrations were usually above the ERLs, and nickel was usually above the ERM.

Sediment bioassays indicated that sediments were toxic at many Estuary stations, but there was no indication of sediment toxicity at San Bruno Shoal, Horseshoe Bay, Davis Point, or Napa River.

total DDTs were usually above the Effects Range-Low (ERL). In 1995, concentrations of several PAH compounds were above ERLs at Alameda. Stations with the greatest number of contaminants above ERLs included Alameda where eight contaminants exceeded ERL concentrations in February, and Honker Bay had six exceedances in each sampling period. The stations with more sand in the sediments had only one or two ERL exceedances (Davis Point, Pacheco Creek, Red Rock, and Sunnyvale).

Sediment Bioassays

Results of the amphipod and larval mussel bioassays indicated that sediments were toxic at many Estuary stations (page 103), but there was no indication of sediment toxicity at San Bruno Shoal, Horseshoe Bay, Davis Point, or Napa River in 1995. Redwood Creek was toxic to amphipods in both sampling periods. Grizzly Bay and the Sacramento and San Joaquin Rivers were toxic to mussel larvae during both sampling periods, but none of the South Bay stations were toxic to larval mussels. Yerba Buena Island was toxic to both amphipods and bivalve larvae in August.

Bioassays conducted over the past six years in the San Francisco Estuary have indicated that toxicity in Estuary sediments was widespread in space and time. Overall, the highest incidence of toxicity occurred at Grizzly Bay where sediments were toxic in 60% of the tests conducted between 1991 and 1996. Toxicity occurred much less frequently in the Central Bay and sediments were never toxic at Davis Point probably due to the low contamination in sandy sediments. The incidence of amphipod toxicity has decreased at most stations since 1991, but bivalve larval toxicity has remained rather constant. The cause of the observed toxicity is not well understood. However, analyses presented show that when more than seven contaminants in sediments exceeded ERL values, toxicity to amphipods was usually observed, suggesting that several contaminants present in low concentrations may cause toxicity. However, the number of contaminants above ERLs was not a good predictor of larval bivalve toxicity (page 106).

The RMP Special Studies on the development of sediment bioassays using the resident amphipod *Ampelisca abdita* showed that they were equally or more sensitive to contamination as other amphipods commonly used in bioassays, but depended on which toxicants were used in the exposures (page 108–115). Since *A. abdita* is a resident of the Estuary, is numerically dominant at many RMP benthic stations, and can be used in controlled sediment bioassays, it could become a powerful indicator for the RMP in attempting to understand sediment contaminant effects.

Benthic Pilot Study

For 1995, this study focused on the identification of "normal" or reference benthic (animals that inhabit sediments) assemblages (communities). Based on monitoring in 1994 and 1995, four benthic assemblages were identified that appear to reflect differences in salinity or sediment types. This information may eventually be useful for comparisons to sites where the benthos is degraded due to contamination or other factors. However, those results are based on only two years of data and require verification through several years of varying environmental conditions. In general, benthic assemblages appeared mostly unimpacted, but indicators of contamination occurred at some sites in the Central Bay, Delta and Rivers suggesting slight impacts.

Bioaccumulation Monitoring

Contaminants in Bivalve Tissues

Bivalves are very useful for assessing the capacity of contaminants in water to accumulate in animal tissues. Lead and nickel were the only trace elements that accumulated substantially above background concentrations (between two and 33 times) in all three bivalve

species used in the RMP (Chapter 4). Lead bioaccumulated at all Estuary stations, and nickel at all but one. Cadmium, chromium, copper, selenium, silver, and zinc accumulated between two and nine times above reference levels at one or more stations, but primarily in the South Bay and the Northern Estuary. Arsenic and mercury showed no appreciable bioaccumulation. Arsenic is the only trace element that did not bioaccumulate in any of the three species at any station since the inception of the RMP.

Bivalves accumulate most trace organic contaminants to a much larger degree than trace elements, particularly certain highly fat-soluble compounds. For some compounds, accumulation can be on the order of hundreds of times above initial tissue concentrations measured at control sites. The ratios of the various PAH compounds in tissue was fairly uniform throughout the Estuary, suggesting consistent sources.

In bivalves, lead and nickel were the only trace elements that accumulated above background concentrations. However, nearly all trace organic compounds accumulated substantially.

Many of the chlorinated pesticides showed distinct seasonal differences in bioaccumulation. DDTs, chlordanes, and dieldrin concentrations were elevated at Coyote Creek during the wet sampling period, suggesting that runoff was a source, despite the fact that most chlorinated pesticides have long been banned. PAH concentrations in tissues were also variable between seasons, but without any consistent patterns.

Bivalve tissue concentrations monitored between 1993 and 1995 showed no obvious increasing or decreasing trends for any contaminants. The three-year RMP database suggests that the bioaccumulation potential for oysters is considerably higher than for the other two species in the case of copper, silver, selenium, and zinc, while mussels accumulate lead to a greater extent than the other two species.

Arsenic and most of the trace organic contaminants measured in bivalves were above the MTRL guidelines, but cadmium, nickel, and mercury were below the guidelines.

Comparisons to Tissue Guidelines

For the 1995 Annual Report, Maximum Tissue Residue Levels (MTRLs) were used as a relative yardstick to evaluate how much tissue levels deviate from guidelines (page 140). Arsenic, cadmium, nickel (freshwater only), and mercury are the only trace elements for which MTRLs apply, and as in 1993 and 1994, bivalve tissue concentrations were far below the threshold level for each of these elements, except arsenic. It should be noted, however, that the MTRL for arsenic was exceeded even at the uncontaminated control site. As in previous years, most of the trace organic contaminants measured were above the MTRL guidelines. At Coyote Creek during the wet season, and the Rivers during both wet and dry seasons, tissues were consistently above the MTRLs for most pesticides. PCB and PAH tissue levels were consistently well above MTRLs throughout the Estuary. These same patterns were observed in previous years.

Bivalve Condition and Survival

Survival and biological condition measurements were made to determine if animals were capable of bioaccumulation. However, changes in condition and survival may also reflect exposure to adverse conditions such as elevated salinities or lack of food. Bivalve condition in the dry season was almost always lower than in the wet season for all species (page 159). Mussels condition improved at all stations during the wet season (except Red Rock) but showed approximately 20–45% reductions in condition during the dry season. For the second year in a row, the two stations with the most elevated tissue contaminant concentrations (Napa River, Coyote Creek) also showed pronounced decreases in

condition in oysters. Clam condition decreased at all Estuary stations in both the wet and dry seasons. Bivalve condition indices of the last three years are remarkably similar among stations and between the seasons.

Bivalve survival was below 50% during the wet season at Dumbarton Bridge, Redwood Creek, Red Rock, and Pinole Point, and at the Petaluma and Napa Rivers in the dry season. The decreased salinities at many Estuary stations due to the unusually wet year may be partly responsible for those results.

Wetlands Monitoring Pilot Study

Tidal wetlands provide a broad range of ecological services including support of endangered species, filtration of contamination, stabilization of coasts, and regulation of air quality. The RMP Wetlands Pilot Study was initiated in 1995 to provide information about how and where to sample wetlands habitats in order to develop a monitoring program for wetlands that would complement the RMP (page 197).

Two locations believed to represent natural tidal marshes were sampled: China Camp State Park and Petaluma Marsh. These locations were sampled concurrently with the RMP Estuary samples. Contaminant concentrations were consistently higher in Petaluma Marsh than at China Camp. Concentrations of most contaminants were higher in the marshlands than at the adjacent RMP San Pablo Bay station. Contaminant concentrations may be higher in marshes because they are retentive filters washed twice daily by the tides. Concentrations of most trace elements tended to be higher in the channel stations than on the drainage divides, but concentrations of trace organics tended to be much higher on the drainage divides than in the marsh channels. Silver, copper, PAHs, and chlordane concentrations tended to be higher in winter.

The natural physiography of the tidal marsh was shown to be a useful template for a stratified sediment sampling plan. Potential effects of these elevated concentrations on the ecological functions of the tidal marshes remains to be assessed.

Conclusions

RMP results for 1995 indicated that concentrations of several contaminants were high enough to raise concern over possible effects on aquatic biota or human health. The contaminants of concern were generally different in water, sediment, and bivalve tissue. In water, PCBs and nickel were most often above water quality objectives or criteria. In sediments arsenic, chromium, copper, mercury, nickel, lead, and DDTs were above guidelines at most Estuary stations. In bivalve tissues, dieldrin, chlordanes, PAHs and PCBs were usually above the MTRLs at all stations.

The total number of contaminants above the various guidelines at each RMP station provides an indication of where contaminants may be the greatest problem and where they may be the least problem. For water, Coyote Creek and Petaluma River had the largest numbers of water quality exceedances and the Central Bay stations generally had the fewest. For sediments, Alameda and Honker Bay had the most ERL exceedances, and the stations with the coarsest sediments at Red Rock and Davis Point had the fewest ERL exceedances. For bivalve bioaccumulation, most stations had similar numbers of exceedances of MTRLs, but stations in San Pablo Bay had the fewest exceedances.

The potential for biological effects from contamination at each station was evaluated by summing the number of samples that were toxic in bioassays and that had reduced bivalve condition or survival. The Central Bay generally had the fewest indications of biological effects and the Sacramento and San Joaquin Rivers had the most indications of possible biological effects. The San Joaquin River station indicated possible biological effects in about 50% of the measurements made between 1993 and 1995. Grizzly Bay and Napa River indicated biological effects about 47% of the time. It is not yet known what may be causing these measured biological effects.

The Central Bay generally had the fewest indications of biological effects and the Sacramento and San Joaquin Rivers had the most.

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CHAPTER ONE

Introduction

Introduction

This report describes the results from the 1995 Regional Monitoring Program for Trace Substances (RMP). It includes data and discussions from the Base Monitoring Program, as well as results of Pilot Studies and Special Studies conducted in 1995. Additionally, this Annual Report includes several articles contributed by RMP investigators and others. These articles provide perspective and insight on important contaminant issues identified by the RMP. Some of those articles are summaries of more detailed RMP Technical Reports, noted where applicable.

Some 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 SFEI, or on the World Wide Web: www.sfei.org.

In 1995, sixty-three federal, state, and local agencies and companies, and the San Francisco Bay Regional Water Quality Control Board participated in the RMP which entered into its third year. RMP Participants are listed inside the front cover of this report.

RMP Objectives

The formal program objectives listed below are those with which the RMP began in 1993. They were developed by staff at the San Francisco Bay Regional Water Quality Control Board (Regional Board), representatives of RMP Participants, and San Francisco Estuary Institute (SFEI) staff.

- 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;
- To determine seasonal and annual trends in chemical and biological water quality in the San Francisco Estuary;
- 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;
- To determine whether water quality and sediment quality in the Estuary at large are in compliance with objectives established by the Basin Plan; and
- 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.

Sampling 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 (SFEI, 1995), as well as two stations in the southern-most end of the Estuary in cooperation with the cities of San Jose (C-3-0) and Sunnyvale (C-1-3) and the Regional Board as part of their National Pollutant Discharge Elimination System (NPDES) monitoring.

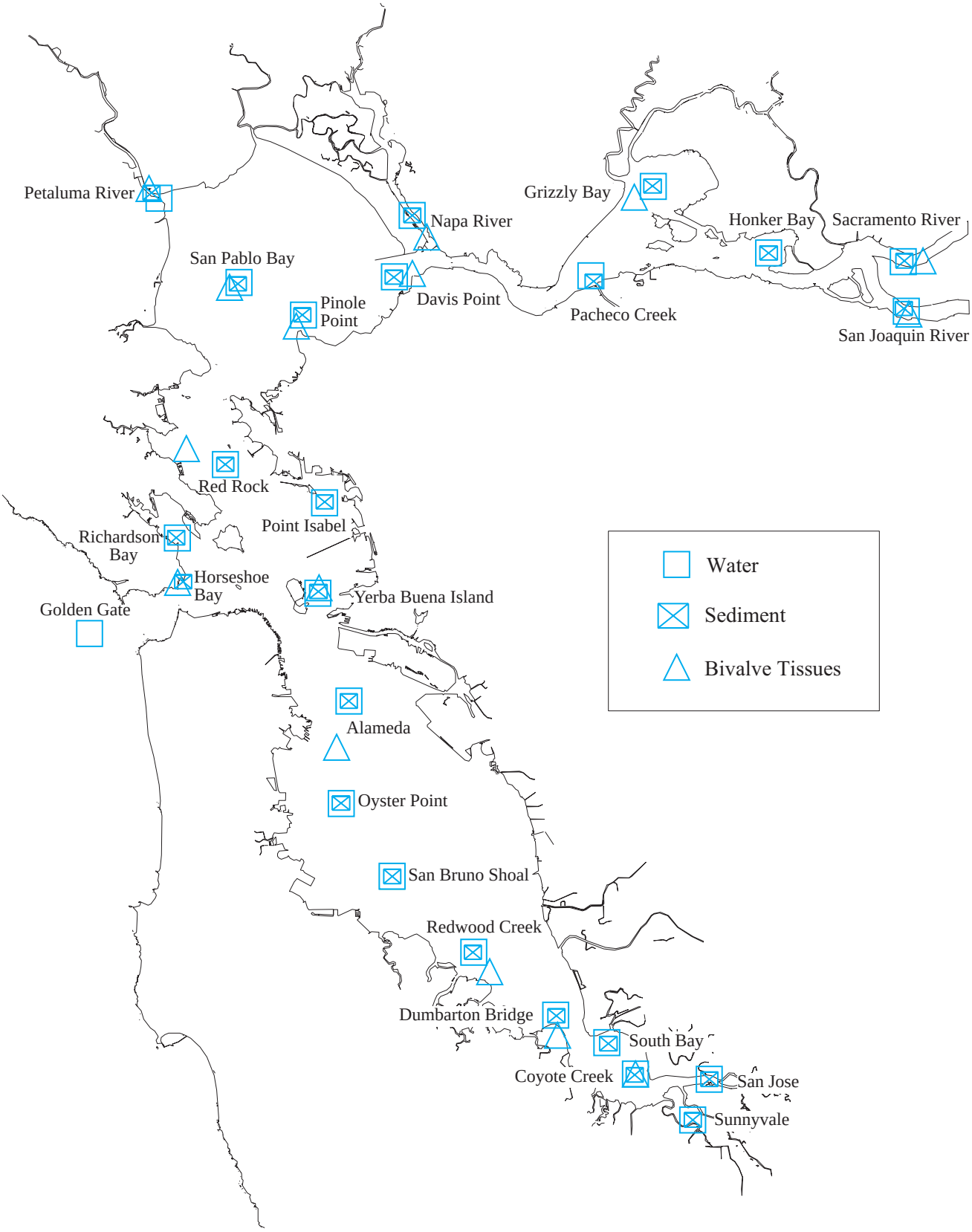

Figure 1. Location of 1995 Regional Monitoring Program stations.

Table 1. Summary of RMP 1995 sampling stations and activities.

Station Name	Station Code	Type of Sample	Measurement Made	Dates Sampled			Latitude			Longitude		
							deg	min	sec	deg	min	sec
Coyote Creek	BA10	water	Q,M,O,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	28	11	122	3	50
	BA10	sediment	Q,M,O	2/17 – 2/23		8/25 – 8/31	37	28	12	122	3	36
	BA10	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	37	28	11	122	3	50
South Bay	BA20	water	Q,M	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	29	41	122	5	20
	BA21	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	37	29	38	122	5	15
Dumbarton Bridge	BA30	water	Q,M,O	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	30	54	122	8	7
	BA30	sediment	Q,M,O	2/17 – 2/23		8/25 – 8/31	37	30	54	122	8	7
	BA30	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	37	30	54	122	8	7
Redwood Creek	BA40	water	Q,M,O,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	33	40	122	12	34
	BA40	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	37	32	49	122	11	42
	BA41	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	37	33	40	122	12	37
San Bruno Shoal	BB15	water	Q,M	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	37	1	122	17	0
	BB15	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	37	37	1	122	17	0
Oyster Point	BB30	water	Q,M	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	40	12	122	19	45
	BB30	sediment	Q,M,O	2/17 – 2/23		8/25 – 8/31	37	40	12	122	19	45
Alameda	BB70	water	Q,M,O,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	44	50	122	19	24
	BB70	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	37	44	50	122	19	24
	BB71	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	37	41	44	122	20	23
Yerba Buena Island	BC10	water	Q,M,O,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	49	22	122	20	58
	BC10	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	37	49	22	122	20	58
	BC11	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	37	49	26	122	20	56
Golden Gate	BC20*	water	Q,M,O	2/7 – 2/16			37	44	49	122	32	9
		water	Q,M,O		4/19 – 4/28		37	46	12	122	32	24
		water	Q,M,O			8/15 – 8/24	37	47	44	122	29	17
Horseshoe Bay	BC21	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	37	49	59	122	28	26
	BC21	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	37	49	59	122	28	26
Richardson Bay	BC30	water	Q,M	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	51	49	122	28	40
	BC32	sediment	Q,M,O	2/17 – 2/23		8/25 – 8/31	37	51	49	122	28	43
Point Isabel	BC41	water	Q,M	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	53	2	122	20	33
	BC41	sediment	Q,M,O	2/17 – 2/23		8/25 – 8/31	37	53	2	122	20	33
Red Rock	BC60	water	Q,M,O,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	55	0	122	26	0
	BC60	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	37	55	0	122	26	0
	BC61	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	37	55	42	122	28	8
Petaluma River	BD15	water	Q,M,O,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	38	6	37	122	29	13
	BD15	sediment	Q,M,O	2/17 – 2/23		8/25 – 8/31	38	6	47	122	30	4
	BD15	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	38	6	37	122	29	13
San Pablo Bay	BD20	water	Q,M,O	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	38	2	55	122	25	11
	BD20	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	38	2	55	122	25	43
	BD22	sediment	Q,M,O	2/17 – 2/23		8/25 – 8/31	38	2	52	122	25	14
Pinole Point	BD30	water	Q,M,O,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	38	1	29	122	21	39
	BD30	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	38	1	0	122	22	3
	BD31	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	38	1	29	122	21	43
Davis Point	BD40	water	Q,M,O	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	38	3	7	122	16	37
	BD40	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	38	3	16	122	15	38
	BD41	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	38	3	7	122	16	39
Napa River	BD50	water	Q,M,O,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	38	5	47	122	15	37
	BD50	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	38	5	47	122	15	37
	BD50	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	38	5	47	122	15	37
Pacheco Creek	BF10	water	Q,M	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	38	3	5	122	5	48
	BF10	sediment	Q,M,O	2/17 – 2/23		8/25 – 8/31	38	3	5	122	5	48
Grizzly Bay	BF20	water	Q,M,O,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	38	6	58	122	2	19
	BF20	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	38	6	29	122	3	22
	BF21	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	38	6	58	122	2	21
Honker Bay	BF40	water	Q,M	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	38	4	2	121	55	56
	BF40	sediment	Q,M,O	2/17 – 2/23		8/25 – 8/31	38	4	2	121	55	56
Sacramento River	BG20	water	Q,M,O,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	38	3	34	121	48	35
	BG20	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	38	3	34	121	48	35
	BG20	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	38	3	34	121	48	35
San Joaquin River	BG30	water	Q,M,O,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	38	1	24	121	48	27
	BG30	sediment	Q,M,O,T	2/17 – 2/23		8/25 – 8/31	38	1	24	121	48	27
	BG30	bioaccumulation	M,O,C	4/26 – 4/28		9/13 – 9/17	38	1	24	121	48	27
San Jose	C-3-0	water	Q,M,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	27	43	121	58	32
	C-3-0	sediment	Q,M	2/17 – 2/23		8/25 – 8/31	37	27	43	121	58	32
Sunnyvale	C-1-3	water	Q,M,T	2/7 – 2/16	4/19 – 4/28	8/15 – 8/24	37	26	8	122	0	40
	C-1-3	sediment	Q,M	2/17 – 2/23		8/25 – 8/31	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, and therefore estimates of the areal extent of water quality changes cannot be made. It was initially decided to locate sites as far as possible from the influence of major contaminant sources in order to be able to interpret temporal and spatial variability in the data without the confounding variable of contaminant inputs from nearby sources. However, several stations are located near the mouths of the major tributaries to the Estuary.

The five types of samples collected in the 1995 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 1995 stations. The coding system developed in the BPTCP Pilot program was adopted for use in the RMP. Water, bioaccumulation, or sediment sampling stations with the same station name (location) may have slightly different locations due to practical considerations such as sediment type or ability to deploy bivalves, and thus have different station codes. For example, at the South Bay station, BA20 is the water station code and BA21 is the sediment station code.

Sampling occurred during three periods in 1995: during the wet season (February), a period of declining Delta outflow (late April), and during the dry season (late August). 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 for each sampling period. Sampling activities at each station are listed on Table 1. Water samples were collected at all

Table 2. 1995 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 Dr. Allen Uhler, Battelle, Duxbury, MA
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 Bioassays	Dr. Stephen Hansen S.R. Hansen and Associates, Concord, CA
Sediment Bioassays	Mr. John Hunt and Mr. Brian Anderson Marine Pollution Lab, Granite Canyon, CA
Bagged Bivalve Sampling	Mr. Dane Hardin, Applied Marine Sciences.
USGS Water Quality	Dr. James Cloern, USGS, Menlo Park, CA Dr. Alan Jassby, UC Davis
USGS Sediment Transport	Dr. David Schoellhamer, USGS, Sacramento, CA
Pilot Study on Benthic Macrofauna	Dr. Bruce Thompson, SFEI, Richmond, CA Mr. Harlan Proctor, Dept. of Water Resources, Sacramento, CA
Pilot Study on Tidal Wetlands	Dr. Josh Collins, SFEI, Richmond, CA

stations during all three sampling periods. However, trace organics contaminants in water were only measured at 15 stations where bioaccumulation measurements were made. 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 periods only. Sediment samples were collected from all RMP stations with the addition of Coyote Creek (BA10) and Petaluma River (BD15) in 1995. Sediment toxicity was measured at 12 of those stations during the wet- and dry-sampling periods. Measurements of ammonia and sulfides in sediment were also added in 1995.

Bivalve bioaccumulation 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, water sampling was conducted first at all RMP stations. Sediment sampling followed, making a separate run though the Estuary. Each sampling run required three to five days for completion. The bivalve monitoring consisted of three parts: deployment of transplants from reference sites, maintenance, and retrieval. This work was conducted using the R/V RINCON POINT, owned by the City of San Francisco, in cooperation with the Bureau of Water Pollution Control.

As in past years, sampling and analysis were conducted by contract through Applied Marine Sciences in Livermore, CA. The principal investigators for the main components of the RMP are listed in Table 2.

Complete listings of all chemical parameters measured in 1995 are included in Table 3. Methods of collection and analysis are detailed in Appendix A. All RMP data included in this report is available through SFEI or on the World Wide Web: www.sfei.org.

Table 3. Parameters analyzed in water, sediment, and bivalve tissues during the 1995 RMP sampling of the San Francisco Estuary.

A. Conventional Water Quality Parameters

- Conductivity
- Dissolved Organic Carbon
- Dissolved Oxygen (DO)
- Hardness
- pH (acidity)
- Phaeophytin (a chlorophyll degradation product)
- Temperature
- Chlorophyll-*a*
- Total Suspended Sediments
- Dissolved Phosphates
- Dissolved Silicates
- Dissolved Nitrate
- Dissolved Nitrite
- Dissolved Ammonia

B. Sediment Quality Parameters

- % Clay (<4um)
- % Silt (4um–63um)
- % Sand (63um–2mm)
- % Gravel + Shell (>2mm)
- Ammonia
- Hydrogen Sulfide
- pH
- Total Organic Carbon
- Total Sulfide

C. Bivalve Tissue Parameters

- % Lipids
- % Moisture
- % Solids
- Dry Weight
- Species Survival
- Species Condition

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

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.

E. Hydrocarbons

	Water	Sediment	Tissue
Alkanes n-C11 to n-C32	•	•	
Alkanes C10, C33, C34		•	
Phytane	•	•	
Pristane	•	•	
Total Alkanes	•	•	

Table 3. Parameters analyzed (continued).

F. 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		•	•
C3-Fluorenes		•	•
C1-Naphthalenes		•	•
C2-Naphthalenes		•	•
C3-Naphthalenes		•	•
C4-Naphthalenes		•	•

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

G. 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	•		

Table 3. Parameters analyzed (continued).

H. PCBs and Related Compounds

	Water	Sediment	Tissue		Water	Sediment	Tissue
Hexachlorobenzene	•	•	•	PCB 114	•		
PCB 003/30	•			PCB 118	•	•	•
PCB 007/9		•	•	PCB 119	•		
PCB 008	•			PCB 128	•	•	•
PCB 008/5		•	•	PCB 129		•	•
PCB 015	•	•	•	PCB 132	•		
PCB 016/32		•	•	PCB 136		•	•
PCB 018	•	•	•	PCB 137	•		
PCB 022/51		•	•	PCB 137/176		•	•
PCB 024/27		•	•	PCB 138	•		
PCB 025		•	•	PCB 138/160		•	•
PCB 026			•	PCB 141	•		
PCB 027	•			PCB 141/179		•	•
PCB 028	•	•	•	PCB 146	•	•	•
PCB 029	•	•	•	PCB 149	•		
PCB 031	•	•	•	PCB 149/123		•	•
PCB 033/53/20		•	•	PCB 151	•	•	•
PCB 037/42/59		•	•	PCB 153	•		
PCB 040		•	•	PCB 153/132		•	•
PCB 041/64		•	•	PCB 156	•		
PCB 044	•	•	•	PCB 156/171		•	•
PCB 045		•	•	PCB 157	•		
PCB 046		•	•	PCB 158	•	•	•
PCB 047/48/75		•	•	PCB 167	•	•	•
PCB 049	•	•	•	PCB 170	•		
PCB 052	•	•	•	PCB 170/190		•	•
PCB 056/60		•	•	PCB 172		•	•
PCB 060	•			PCB 174	•	•	•
PCB 066	•	•	•	PCB 177	•	•	•
PCB 070	•	•	•	PCB 178	•	•	•
PCB 074	•	•	•	PCB 180	•	•	•
PCB 082		•	•	PCB 183	•	•	•
PCB 083		•	•	PCB 185		•	•
PCB 084		•	•	PCB 187	•		
PCB 085	•	•	•	PCB 187/182/159		•	•
PCB 087	•			PCB 189	•	•	•
PCB 087/115		•	•	PCB 191		•	•
PCB 088		•	•	PCB 194		•	•
PCB 089	•			PCB 195	•		
PCB 092		•	•	PCB 195/208		•	•
PCB 095	•			PCB 196/203		•	•
PCB 097	•	•	•	PCB 198	•		
PCB 099	•	•	•	PCB 200	•	•	•
PCB 100		•	•	PCB 201		•	•
PCB 101	•			PCB 203	•		
PCB 101/90		•	•	PCB 205		•	•
PCB 103	•			PCB 206	•	•	•
PCB 105	•	•	•	PCB 207	•		
PCB 107/108/144		•	•	PCB 209		•	•
PCB 110	•						
PCB 110/77		•	•				

CHAPTER TWO

Water Monitoring

Background

The water monitoring component of the RMP Base Program has two purposes. The most important purpose is to evaluate compliance with water quality objectives. Ancillary water quality measurements are also measured to appraise water quality in the Estuary and to provide supporting data for interpretation of contaminant concentrations which can be directly influenced by salinity, total suspended sediments (TSS), dissolved organic carbon (DOC), and other parameters.

Samples were collected approximately 1 m below the surface at 22 RMP stations, and at two stations in the southern end of the Estuary in cooperation with the Regional Board and the Cities of San Jose (C-3-0) and Sunnyvale (C-1-3) (Figure 1 in Chapter One: Introduction). Water sampling in the Sacramento and San Joaquin Rivers during peak flows, conducted in the first two years of the RMP, was suspended in 1995. Sampling was conducted during three sampling periods in 1995, the wet season (February), declining hydrograph (April), and the dry season (August). Detailed methods of sampling and analysis are included in Appendix A. Sampling dates and activities are listed in Table 1 in Chapter One: Introduction. Data are tabulated in Appendix C.

Conventional water quality parameters (Table 3 in Chapter One: Introduction) were measured at all sampling stations. Salinity, DOC, and TSS measurements are shown in Figures 1–3. Concentrations of ten trace elements were measured at all stations (Table 3 in Chapter One: Introduction). Dissolved (0.45 µm filtered) and total (arsenic, chromium, mercury, selenium) and near-total (cadmium, copper, lead, nickel, silver, and zinc) concentrations are presented in graphic form in Figures 4–23.

Dissolved (1 µm filtered) and total fractions of 135 trace organic compounds were measured at the 15 stations where bioaccumulation samples were also collected (Table 3 in Chapter One: Introduction). The organic contaminants represent four major groups of compounds: the PAHs, PCBs, alkanes, and pesticides. Selected representative compounds are presented in graphic form in Figures 24–35.

In order to make comparisons of trace contaminant concentration between different areas of the Estuary, stations were grouped subjectively into five Estuary reaches based on similarities in water quality, trace contamination, and geography. The reaches are: the Southern Sloughs (C-1-3, C-3-0), South Bay (seven stations: BA10–BB70), Central Bay (five stations: BC10–BC60), Northern Estuary (eight stations: BD15–BF40) and Rivers (BG20, BG30).

Water Quality Objectives and Criteria

In this report, comparisons to water quality objectives are made to evaluate the overall condition of the Estuary in terms of contamination, and not for any regulatory purpose. Water quality objectives currently in effect for the San Francisco Estuary are those of the San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan, SFBRWQCB, 1995a) and the US EPA (National Toxics Rule, US EPA, 1993c).

For this report, RMP trace element data are compared to the lower values from the 1995 Basin Plan objectives and the US EPA-NTR. Trace organics data are compared to US EPA-NTR human health criteria (at a 10^{-6} risk level) and chronic, 4-hour average, aquatic life criteria when available. Concentrations below these values should produce no adverse effects.

In some cases measurements made by the RMP differ from the way the criteria are expressed. For example, the water quality objective for total PAHs from the 1995 Basin Plan includes sums of the compounds listed in the EPA Method 610 while the RMP total PAHs include sums of a different suite of compounds.

Different standards exist for saltwater and freshwater (salinity below 5 ppt as defined in the Basin Plan). Eight RMP stations and both Southern Slough stations had salinities below 5 ppt in 1995 (Figure 1). Basin Plan water quality objectives for five of the ten metals measured at those stations are related to water hardness (expressed as mg/L calcium carbonate). Since the RMP measured water hardness at those stations (see Appendix C, Table 1), the exact criteria at each station were calculated.

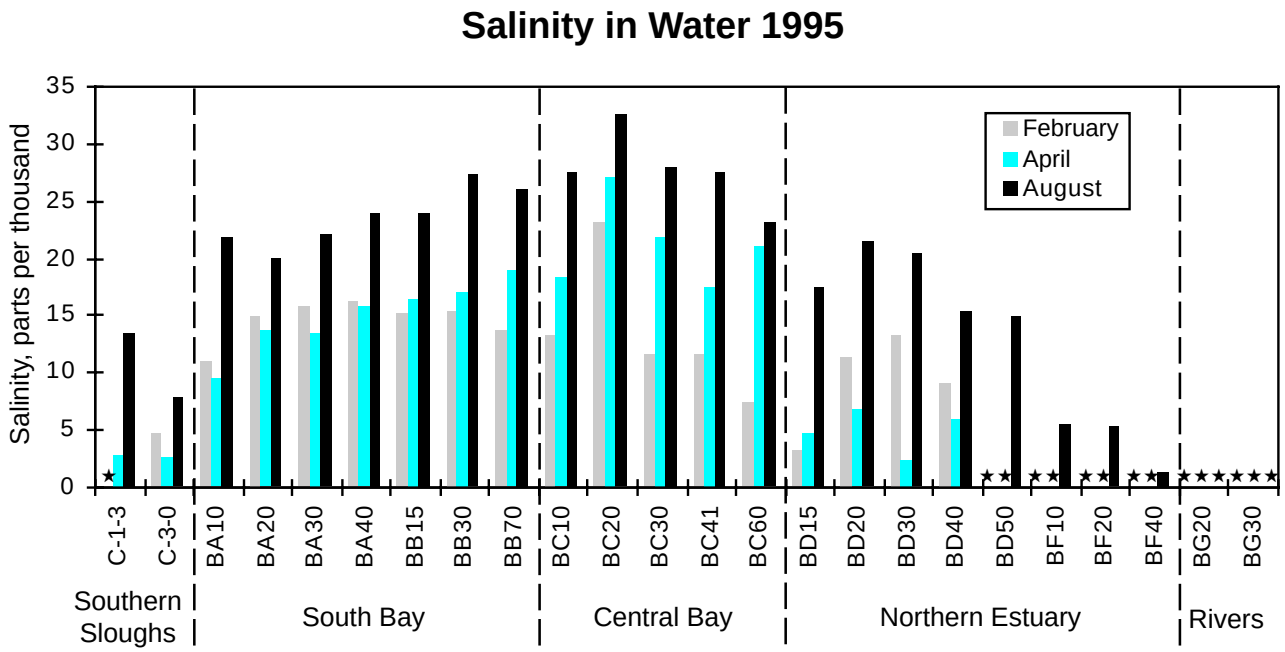

Figure 1. Salinity in parts per thousand (‰) at each RMP water station in February, April, and August 1995. ★ indicates salinity was < 1 ‰. Samples were collected at approximately 1 m below the surface. Salinities ranged from below detection (1 ‰) to 33 ‰. The highest concentration was detected at Golden Gate (BC20) in August. Salinities were lowest in February as expected in that very wet season. Salinities below 5 ‰ are considered freshwater for application of water quality standards.

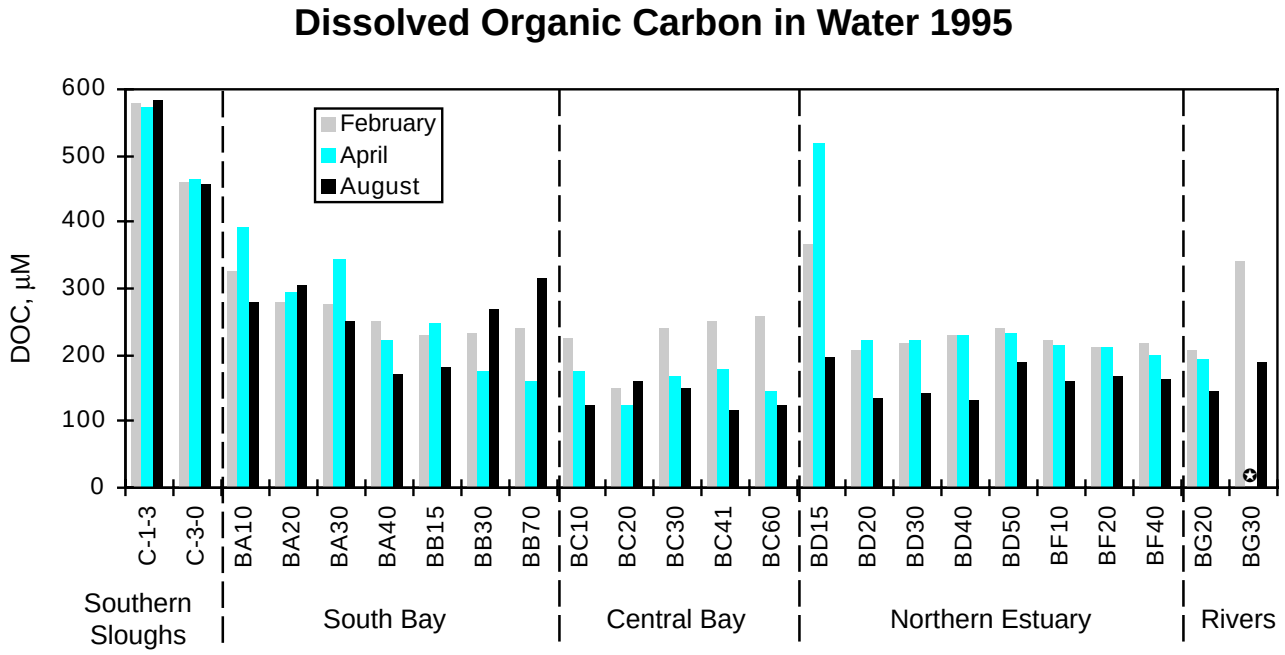

Figure 2. Dissolved organic carbon (DOC) in micromoles per liter (µM) at each water station in February, April, and August of 1995. 1 µM of dissolved organic carbon is equal to 12 µg/L. ✪ indicates not analyzed. DOC ranged from 116 µM to 581 µM. The highest concentration was sampled at Sunnyvale (C-1-3) in August and the lowest concentration was sampled in Point Isabel (BC41) in August. In general DOC concentrations were lowest in August, highest in February, and intermediate in April.

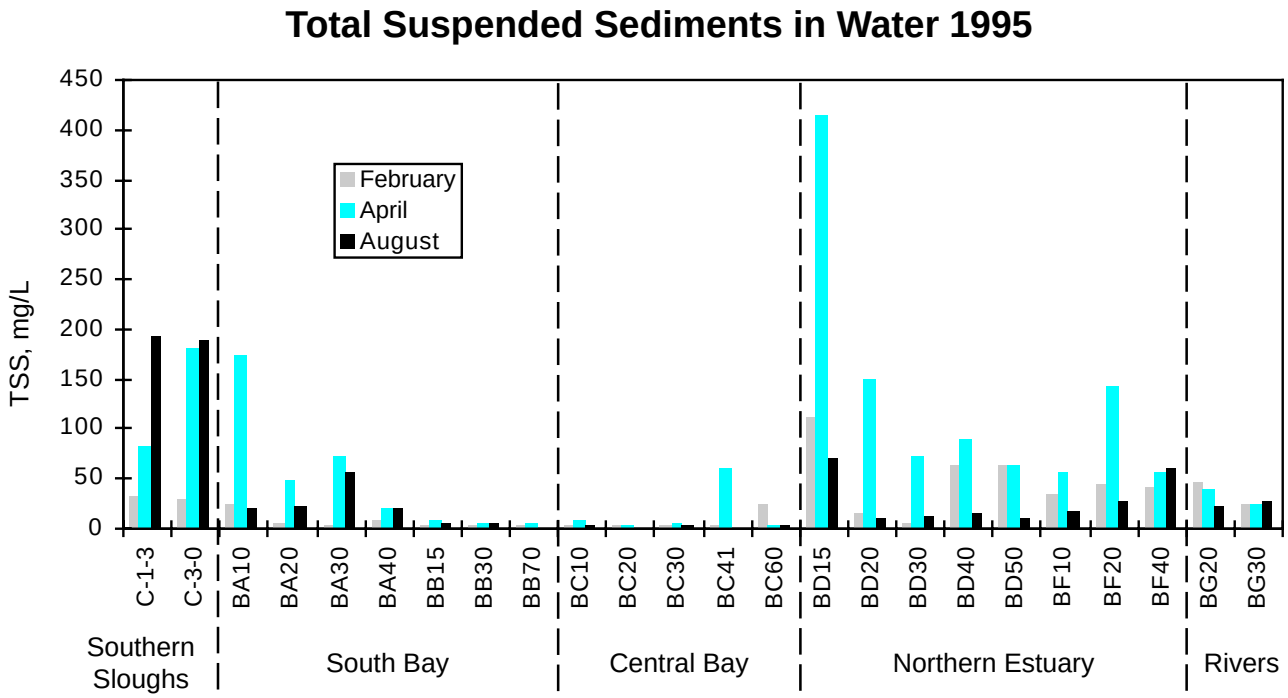

Figure 3. Total suspended sediments (TSS) in milligrams per liter (mg/L) at each RMP water station in February, April, and August of 1995. TSS concentrations ranged from 0.28 mg/L to 414 mg/L. The highest concentration was sampled at Petaluma River (BD15) in April and the lowest at Golden Gate (BC20) in August. Average TSS concentrations were higher in the Southern Slough stations than other Estuary reaches. Generally concentrations were highest in April in the Northern Estuary. Petaluma River (BD15) had a similar yet higher "spike" as in April of 1994.

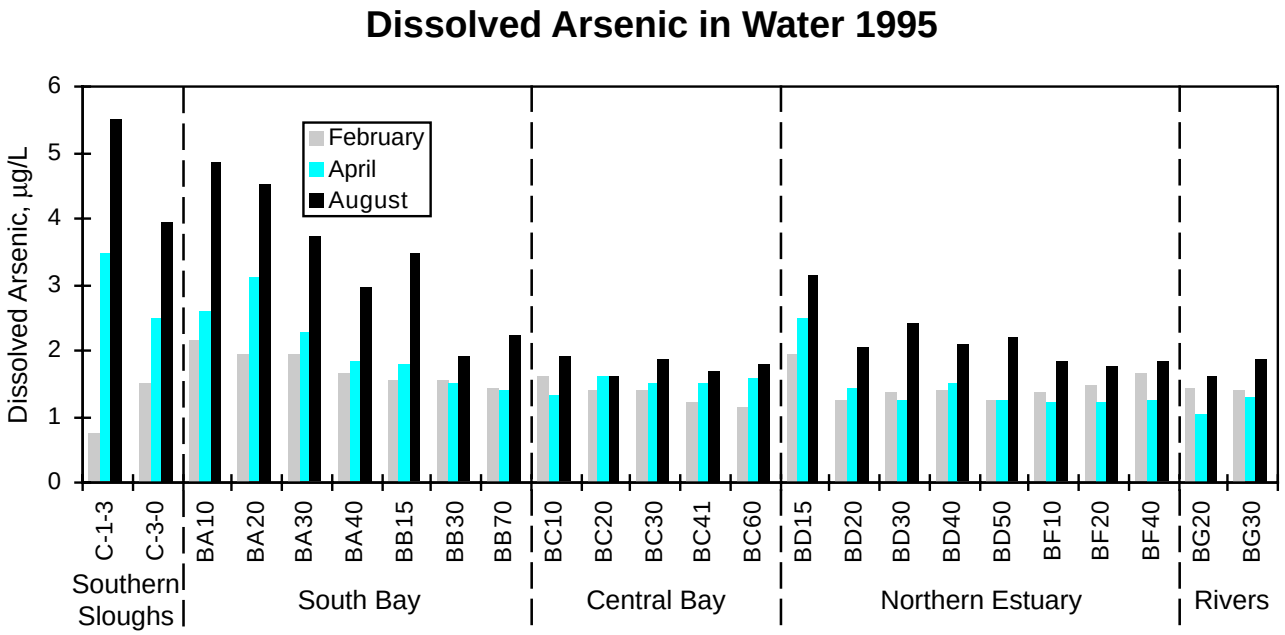

Figure 4. Dissolved arsenic (As) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Dissolved arsenic concentrations ranged from 0.74 to 5.49 ppb. The highest and lowest concentrations were sampled at Sunnyvale (C-1-3) in August and February respectively. Average concentrations were highest in the Southern Sloughs in August (4.70 ppb) and lowest there in February (1.12 ppb). In general, concentrations were highest in August, intermediate in April and lowest in February. All stations were below the 4-day average water quality objective for dissolved arsenic (saltwater 36 ppb, freshwater 190 ppb).

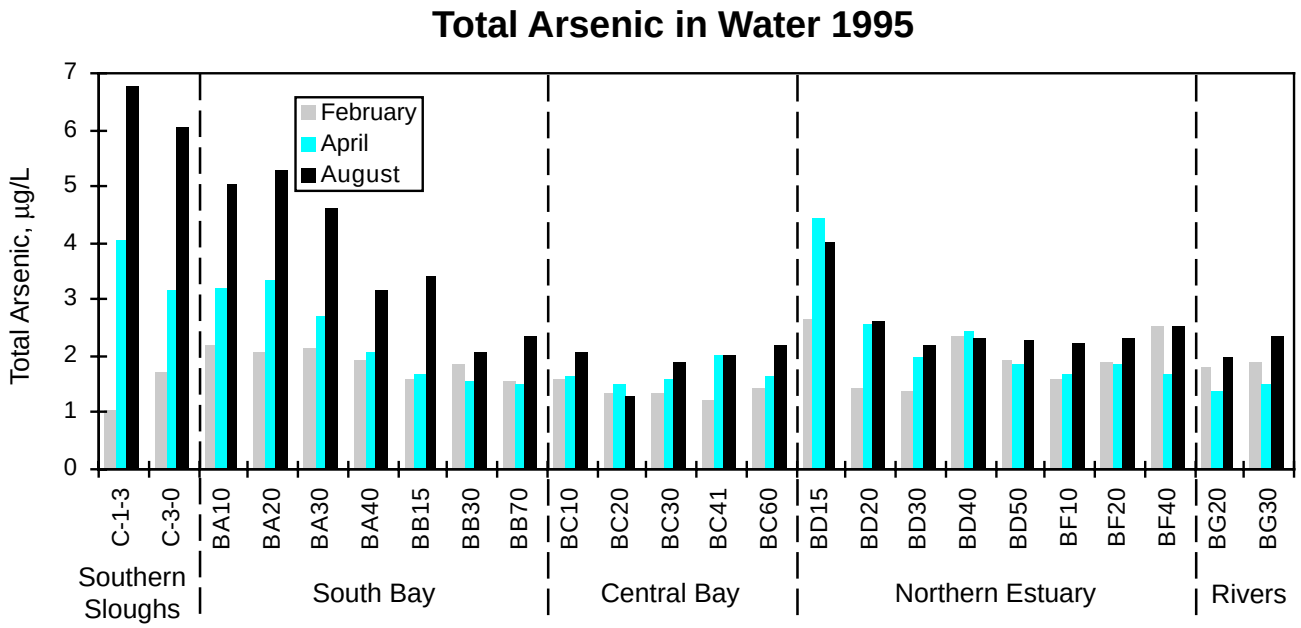

Figure 5. Total arsenic (As) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Total arsenic concentrations ranged from 1.00 to 6.74 ppb. The highest and lowest concentrations were sampled at Sunnyvale (C-1-3) in August and February, respectively. Average concentrations were highest in the Southern Sloughs in August (6.38 ppb) and lowest there and in the Central Bay in February (1.35 ppb). In general concentrations were highest in August, intermediate in April and lowest in February in the Southern Sloughs, South and Central Bay. In the Northern Estuary and Rivers seasonal trends were not as apparent but generally were highest in August. All stations were below the 4-day average water quality objective for total arsenic (saltwater 36 ppb, freshwater 190 ppb).

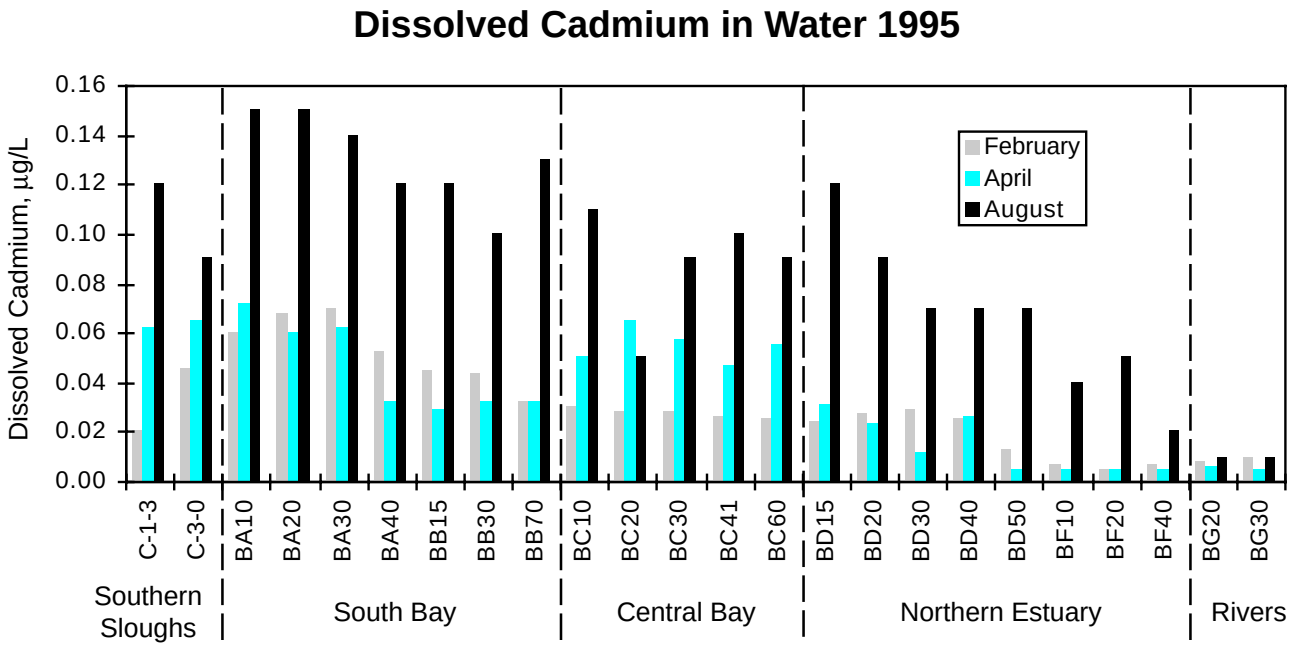

Figure 6. Dissolved cadmium (Cd) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Dissolved cadmium concentrations ranged from 0.005 to 0.150 ppb. The highest concentration was sampled at Coyote Creek (BA10) in August and the lowest value at the following stations: Napa River (BD50), Pacheco Creek (BF10), Grizzly Bay (BF20), Honker Bay (BF40), and San Joaquin River (BG30) in April and Grizzly Bay (BF20) in February. Average concentrations were highest in the South Bay in August (0.130 ppb) and lowest in the Rivers in February (0.009 ppb). In general, concentrations were highest in August and lowest in February and April. All stations were below the 4-day average water quality objective for dissolved cadmium (saltwater 9.2 ppb, freshwater-hardness dependent).

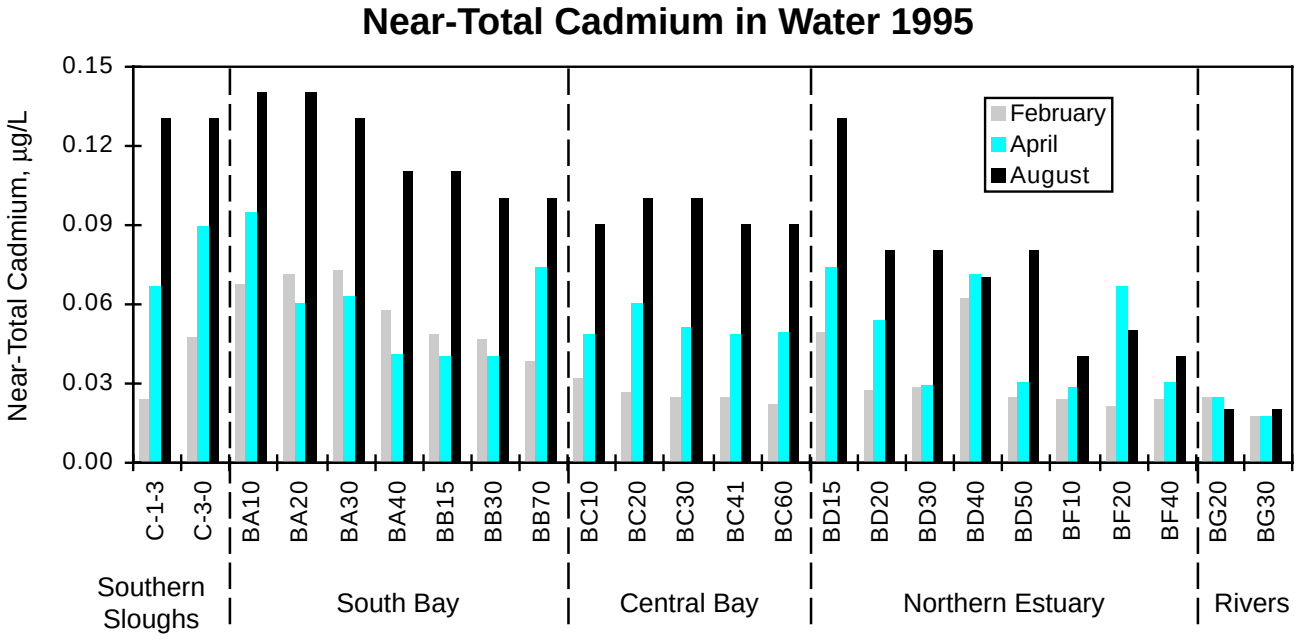

Figure 7. Near-total cadmium (Cd) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Near-total cadmium concentrations ranged from 0.017 to 0.140 ppb. The highest concentration was sampled at Coyote Creek (BA10) and the South Bay station (BA20) in August. The lowest concentration was sampled at San Joaquin River (BG30) in February and in April. Average concentrations were highest in the Southern Sloughs in August (0.130 ppb) and lowest in the Rivers in August (0.020 ppb). In general, concentrations were highest August and lowest in February. All stations were below the 4-day average water quality objective for total cadmium (saltwater 9.3 ppb, freshwater-hardness dependent).

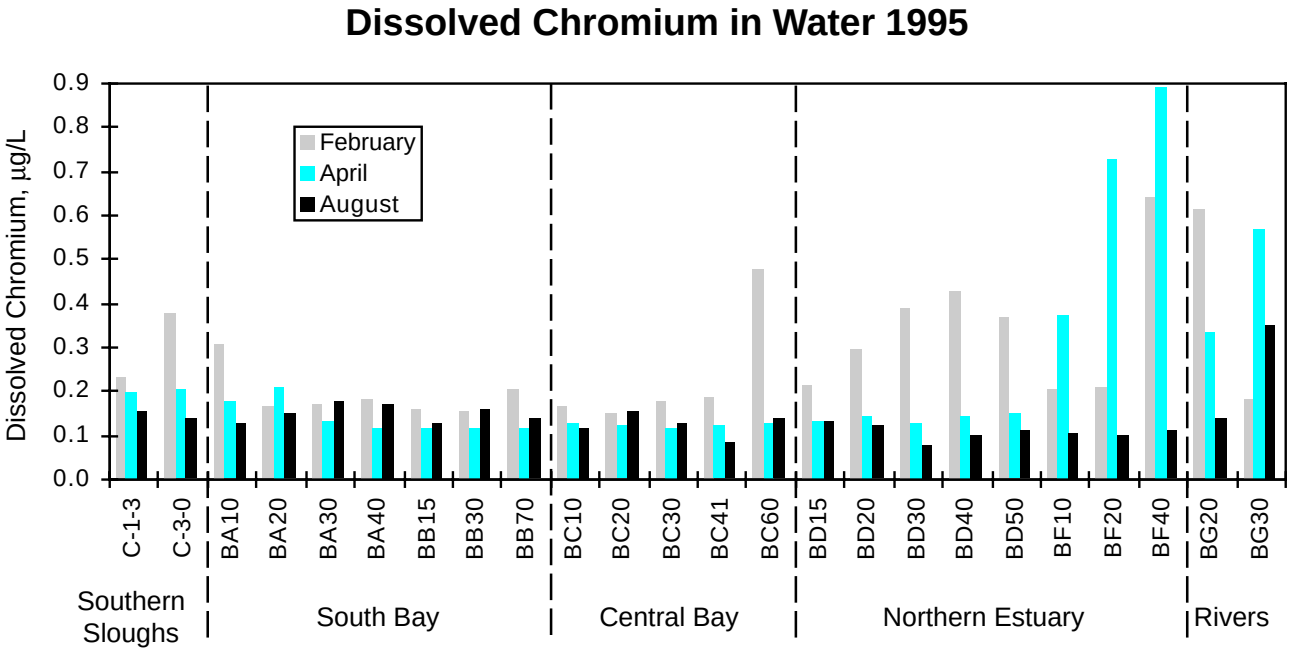

Figure 8. Dissolved chromium (Cr) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Dissolved chromium concentrations ranged from 0.10 ppb at Pacheco Creek (BF10) in August to 0.89 ppb at Honker Bay (BF40) in April. Average concentrations were highest at the River Stations in April (0.45 ppb) and lowest in the Northern Estuary in August (0.10 ppb). In general, concentrations were highest in February and lowest in August. All stations were below the 4-day average water quality objective for dissolved chromium (saltwater 50 ppb, freshwater 10.82 ppb).

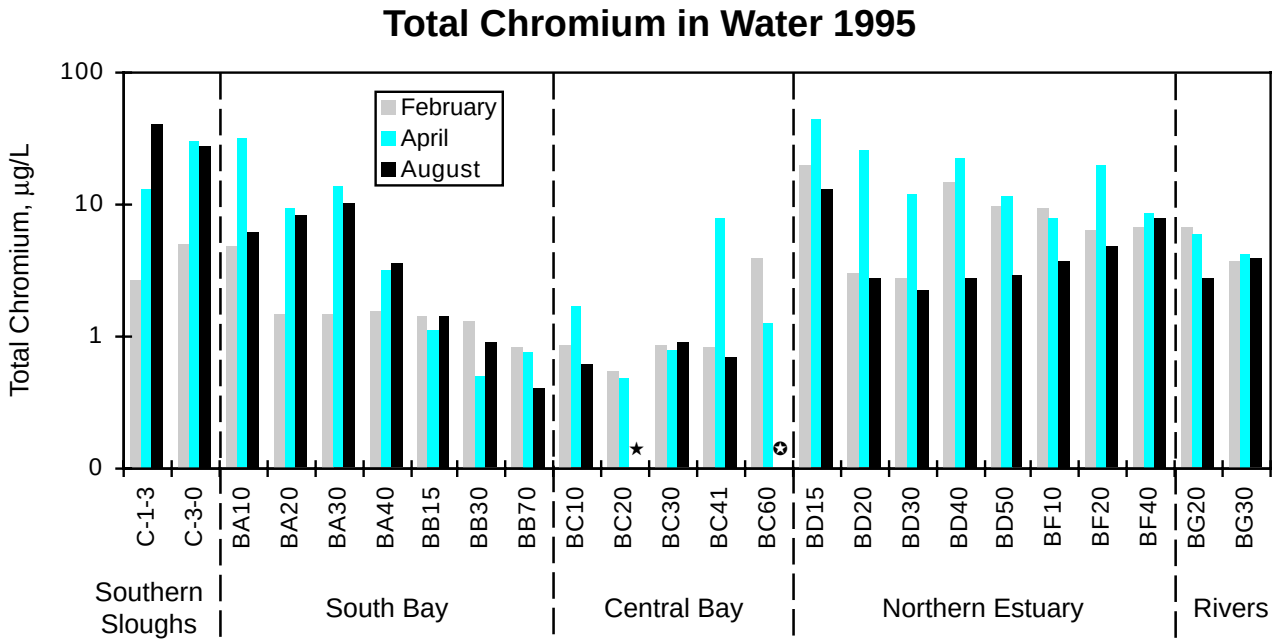

Figure 9. Total chromium (Cr) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Note logarithmic scale. ✪ indicates not analyzed. Total chromium concentrations ranged from below the detection limit of 0.07 ppb (★) to 42.980 ppb. The highest concentration was sampled at Petaluma River (BD15) in April. Average concentrations were highest in the Southern Sloughs in August (33.10 ppb) and lowest in the Central Bay in August (0.73 ppb). In general, concentrations were highest in April and lowest in August. All saltwater stations were below the saltwater, 4-day average water quality objective (WQO) for total chromium of 50 ppb. Six freshwater stations (Figure 1) were above the freshwater, 4-day average WQO of 11 ppb.

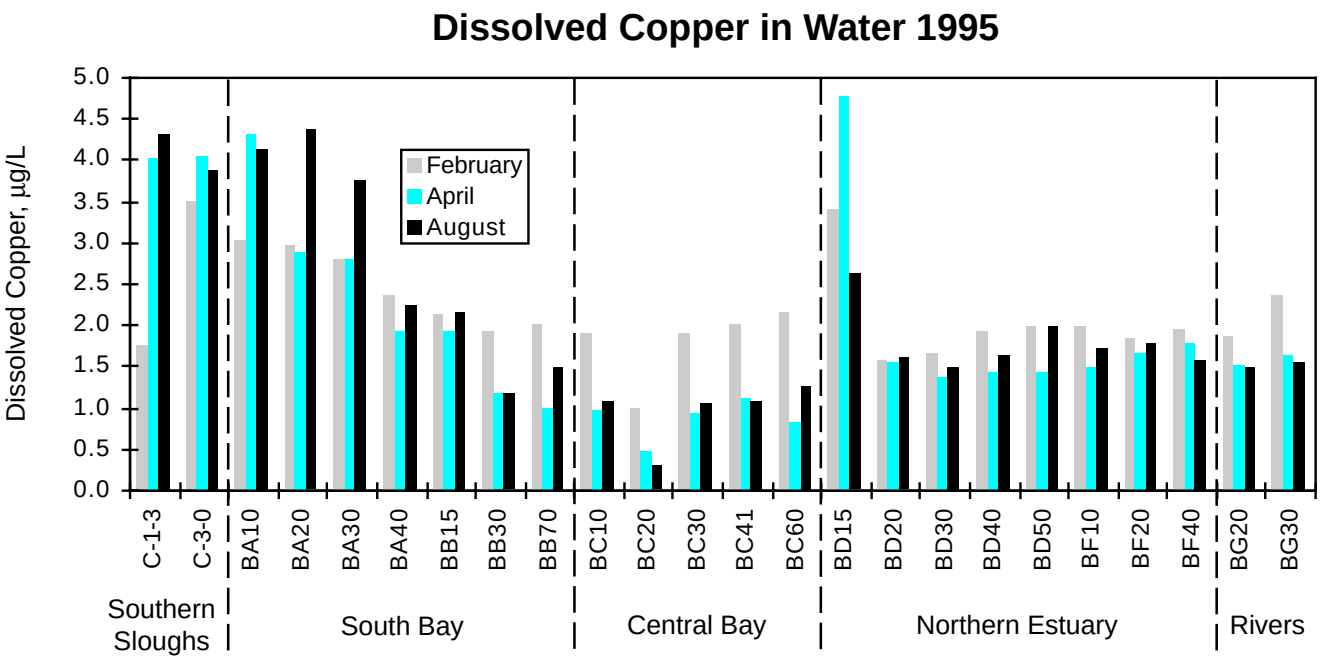

Figure 10. Dissolved copper (Cu) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Dissolved copper concentrations ranged from 0.280 to 4.77 ppb. The highest concentration was sampled at Petaluma River (BD15) in April and the lowest at Golden Gate (BC20) in August. Average concentrations were highest in the Southern Sloughs in August (4.08 ppb) and lowest in the Central Bay in April (0.85 ppb). Seasonal concentrations were highest in February from the the Central Bay to the north. Two stations were above the saltwater, 1-hour average, water quality objective (WQO) for dissolved copper of 4.1 ppb in April. None of the fresh water stations were above the freshwater WQOs which are hardness dependent. Eight stations were above the EPA-National Toxics Rule saltwater, 4-day average, water quality criterion for dissolved copper of 2.32 ppb.

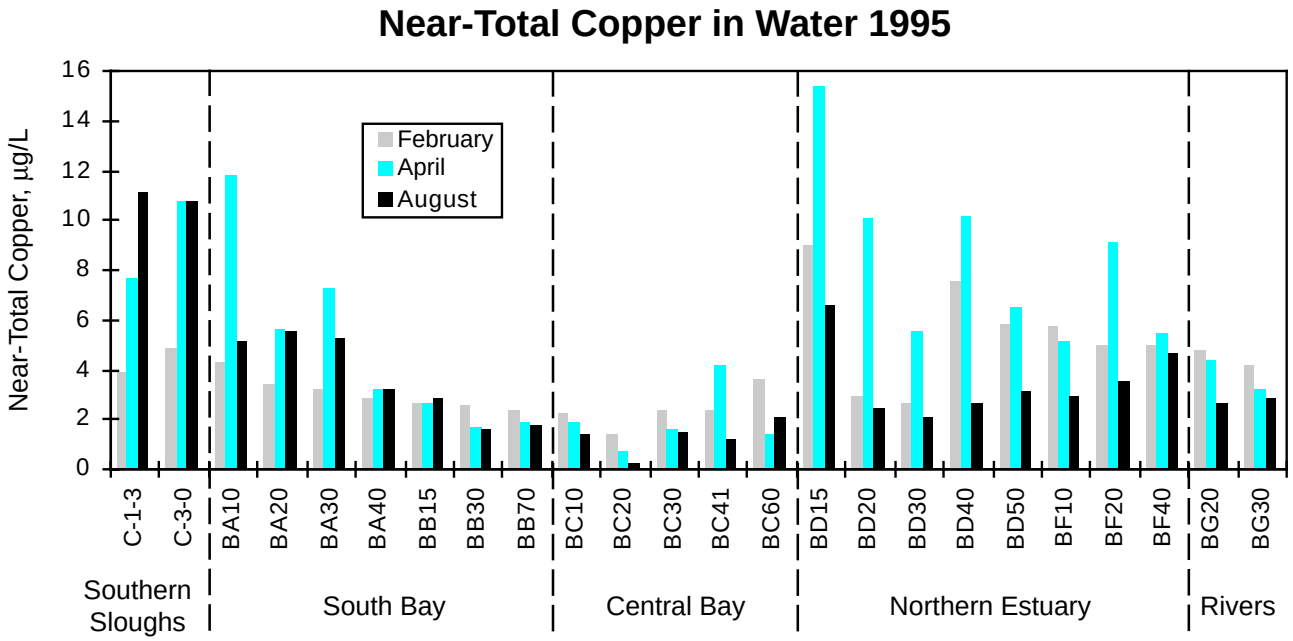

Figure 11. Near-total copper (Cu) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Near-total copper concentrations ranged from 0.19 to 15.28 ppb. The highest concentration was sampled at Petaluma River (BD15) in April and the lowest at Golden Gate (BC20) in August. Average concentrations were highest in the Southern Sloughs (9.17 ppb) and the Northern Estuary (8.37 ppb) in April, and lowest in the Southern Sloughs in August (0.97 ppb). In general, concentrations were highest in April and lowest in August. Five stations were above the saltwater, 1-hour average, water quality objective (WQO) for total copper of 4.9 ppb in February, eight stations in April, and one station in August. None of the fresh water stations were above the freshwater WQOs which are hardness dependent. Note that because BD15, BD30, BD40, C-1-3 and C-3-0 were freshwater stations during April, they were not above the freshwater WQOs. Twenty-seven stations were above the EPA-National Toxics Rule saltwater, 4-day average water quality criterion for total copper of 2.9 ppb.

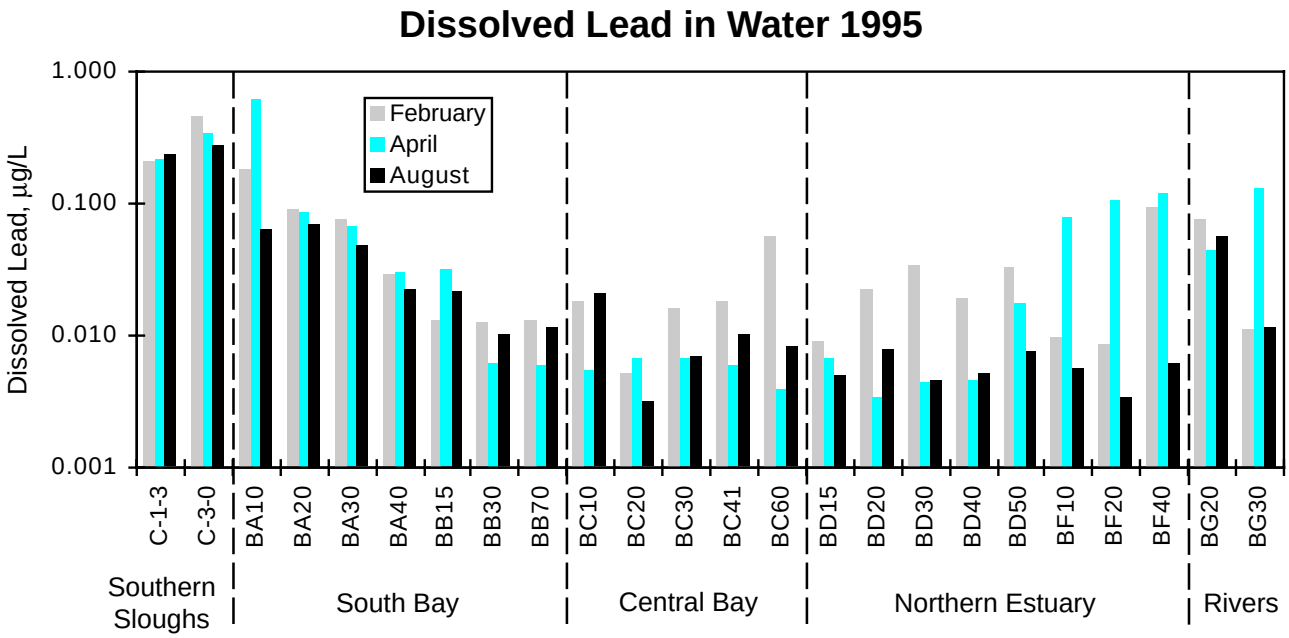

Figure 12. Dissolved lead (Pb) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Note logarithmic scale. Dissolved lead concentrations ranged from 0.003 to 0.612 ppb. The highest concentration was sampled at Coyote Creek (BA10) in April and the lowest was sampled at Golden Gate (BC20) in August. Average concentrations were highest in the Southern Sloughs in February (0.333 ppb) and lowest in the Central Bay in April (0.006 ppb). Seasonal concentrations were generally lowest in August. All stations were below the 4-day average water quality objective for dissolved lead (saltwater 5.3 ppb, freshwater-hardness dependent).

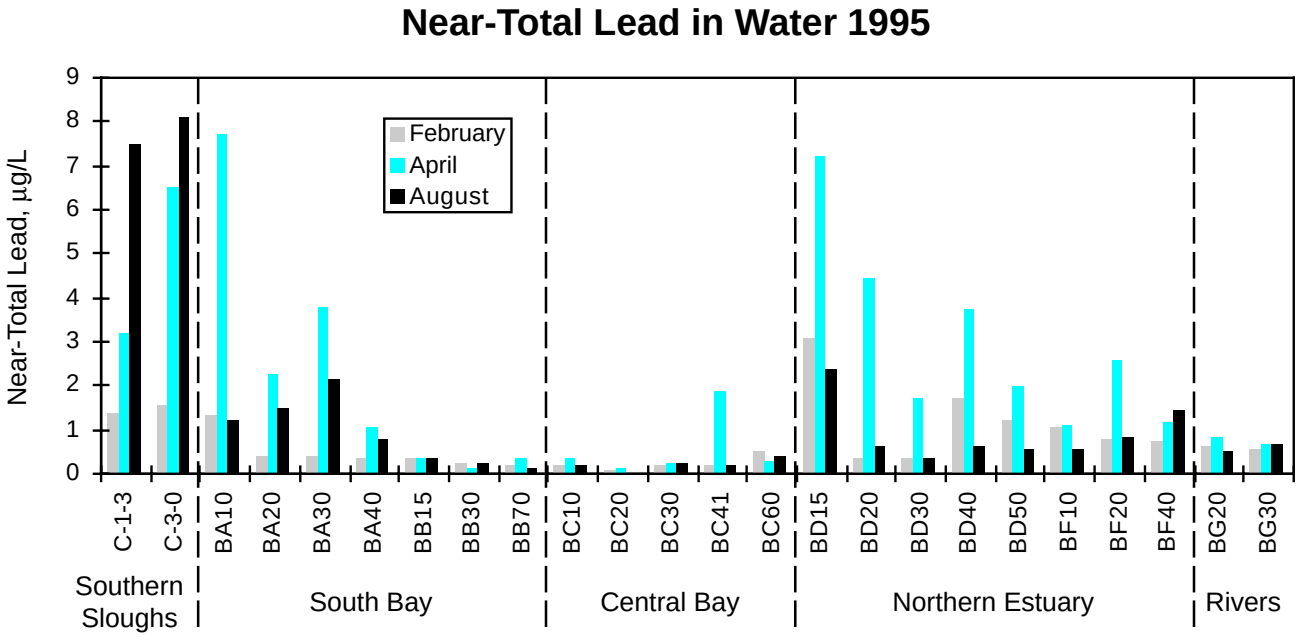

Figure 13. Near-total lead (Pb) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Near-total lead concentrations ranged from 0.010 to 8.08 ppb. The highest concentration was sampled at San Jose (C-3-0) and the lowest at Golden Gate (BC20). Average concentrations were highest in the Southern Sloughs in August (7.79 ppb) and lowest in the Central Bay in August (0.19 ppb). Concentrations were generally highest in April. Three stations were above the saltwater, 4-day average water quality objective (WQO) for total lead of 5.6 ppb, one in April, and two in August. Note that because BD15 and C-3-0 were freshwater stations in April, they were not above the freshwater WQOs. None of the fresh water stations were above the freshwater WQOs which are hardness dependent.

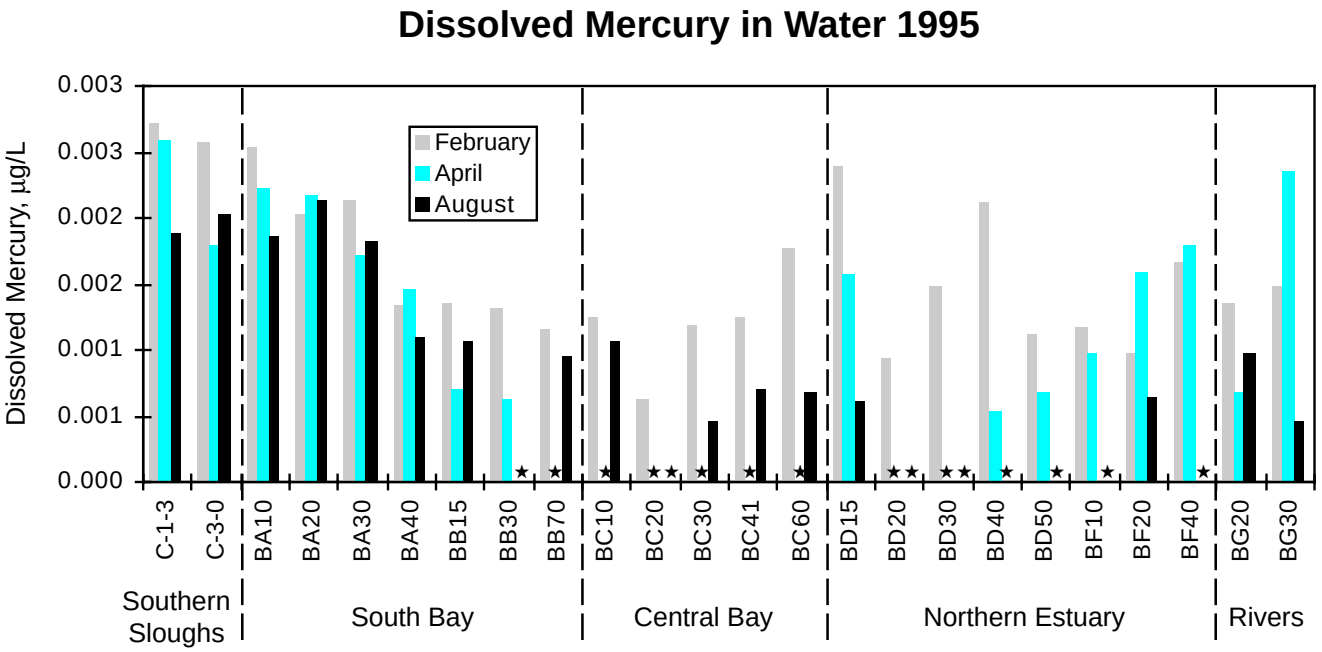

Figure 14. Dissolved mercury (Hg) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Dissolved mercury concentrations ranged from below the detection limit of 0.0001 ppb (★) to 0.00271 ppb. The highest concentration was at Sunnyvale (C-1-3) in February. Sixteen stations had concentrations below the MDL. Average concentrations were highest in the Southern Sloughs in February (0.00264 ppb) and lowest in the Northern Estuary in August (0.00021 ppb). In general, concentrations were higher in February and lowest in August. There are no water quality objectives for dissolved mercury.

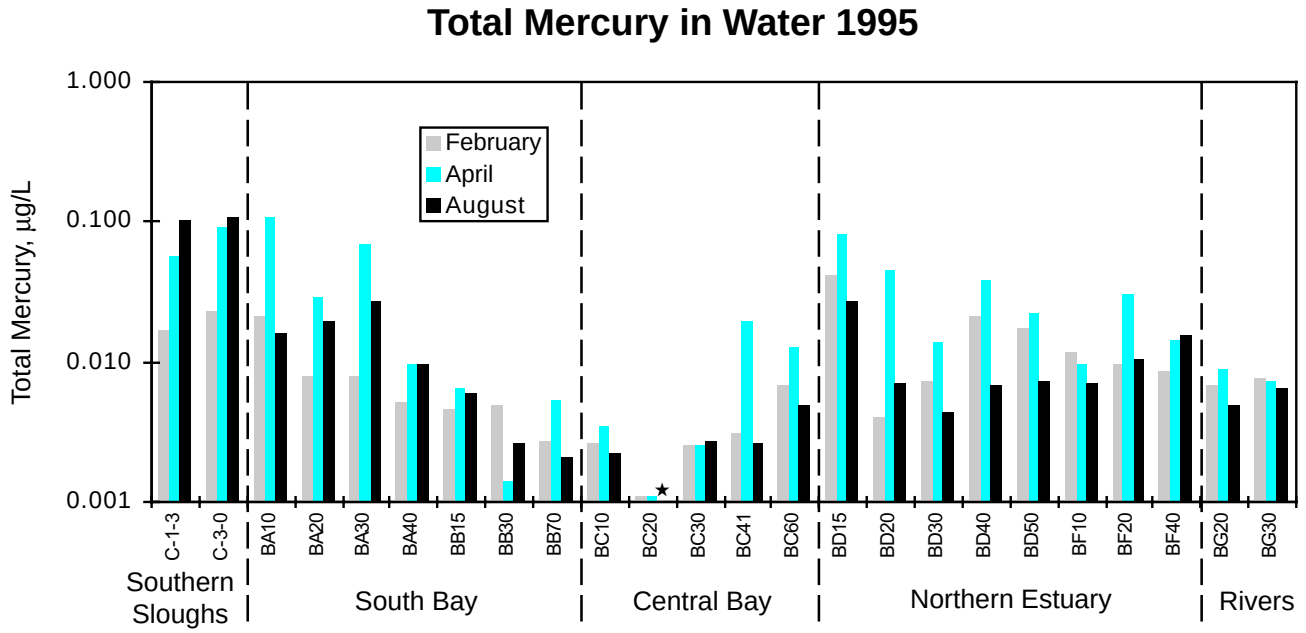

Figure15. Total mercury (Hg) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Note logarithmic scale. Total mercury concentrations ranged from below the detection limit of 0.0001 ppb (★) to 0.105 ppb. The highest concentrations were at San Jose (C-3-0) in August and Coyote Creek (BA10) in April and the lowest at Golden Gate (BC20) in August. Average concentrations were highest in the Southern Sloughs in August (0.103 ppb) and lowest in the Central Bay in August (0.00309 ppb). In general, concentrations were highest in April and lowest in August in the northern part of the Estuary but lowest in April in the southern part of the Estuary. Fifteen stations were above the 4-day average water quality objectives for total mercury (saltwater 0.025 ppb, freshwater 0.025 ppb).

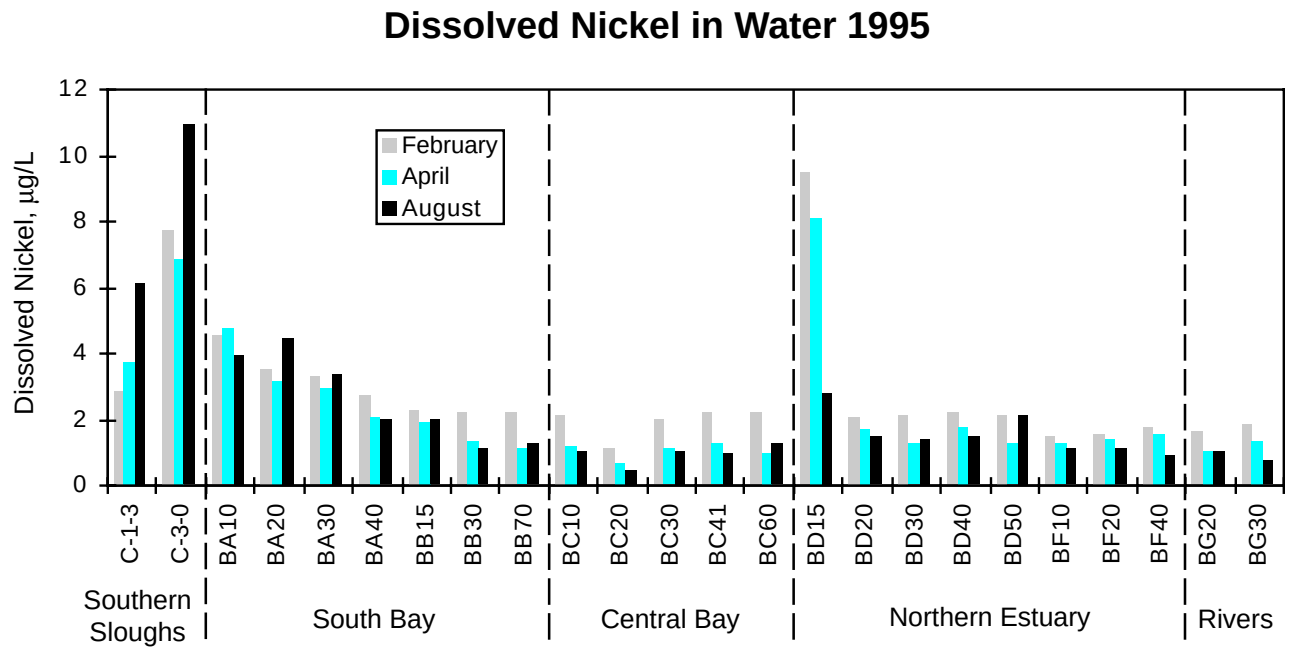

Figure 16. Dissolved nickel (Ni) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Dissolved nickel concentrations ranged from 0.47 to 10.94 ppb. The highest concentration was sampled at San Jose (C-3-0) and the lowest at Golden Gate (BC20). Average concentrations were highest in the Southern Sloughs in August (8.53 ppb) and lowest in the Rivers in August (0.85 ppb). In general, concentrations were highest in April and lowest in August. Only San Jose (C-3-0) in August was above the saltwater, 24-hour average water quality objective (WQO) for dissolved nickel of 7.0 ppb. None of the freshwater stations were above the freshwater WQOs which are hardness dependent. Note that because BD15 and C-3-0 were freshwater stations during February and April, they were not above the freshwater WQOs.

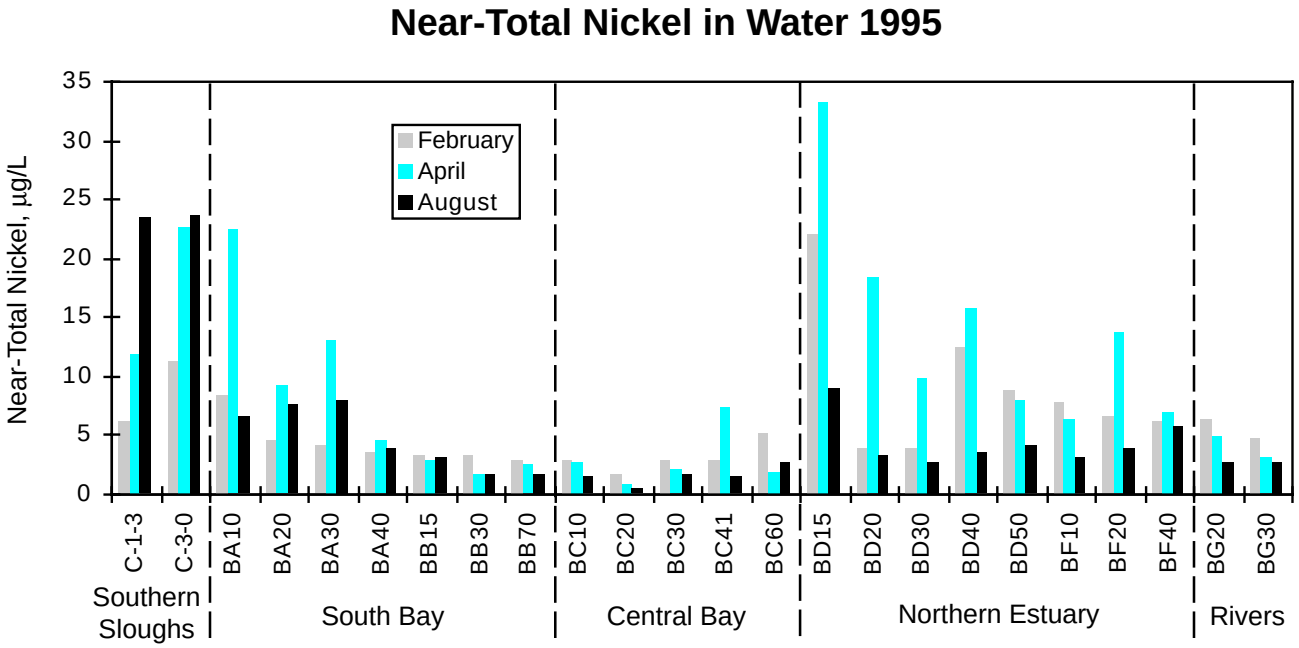

Figure 17. Near-total nickel (Ni) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Near-total nickel concentrations ranged from 0.35 to 33.23 ppb. The highest concentration was sampled at Petaluma River and the lowest at Golden Gate (BC20). Average concentrations were highest in the Southern Sloughs in August (23.59 ppb) and lowest in the Central Bay in August (1.49 ppb). Seasonal trends varied in February and April but concentrations were generally lowest in August except for the Southern Sloughs where concentrations were highest in August. Sixteen stations were above the saltwater, 24-hour average water quality objective (WQO) for total nickel of 7.1 ppb. None of the freshwater stations were above the freshwater WQOs which are hardness dependent. Ten stations were above the EPA-National Toxics Rule 4-day average water quality criterion for total nickel of 8.3 ppb.

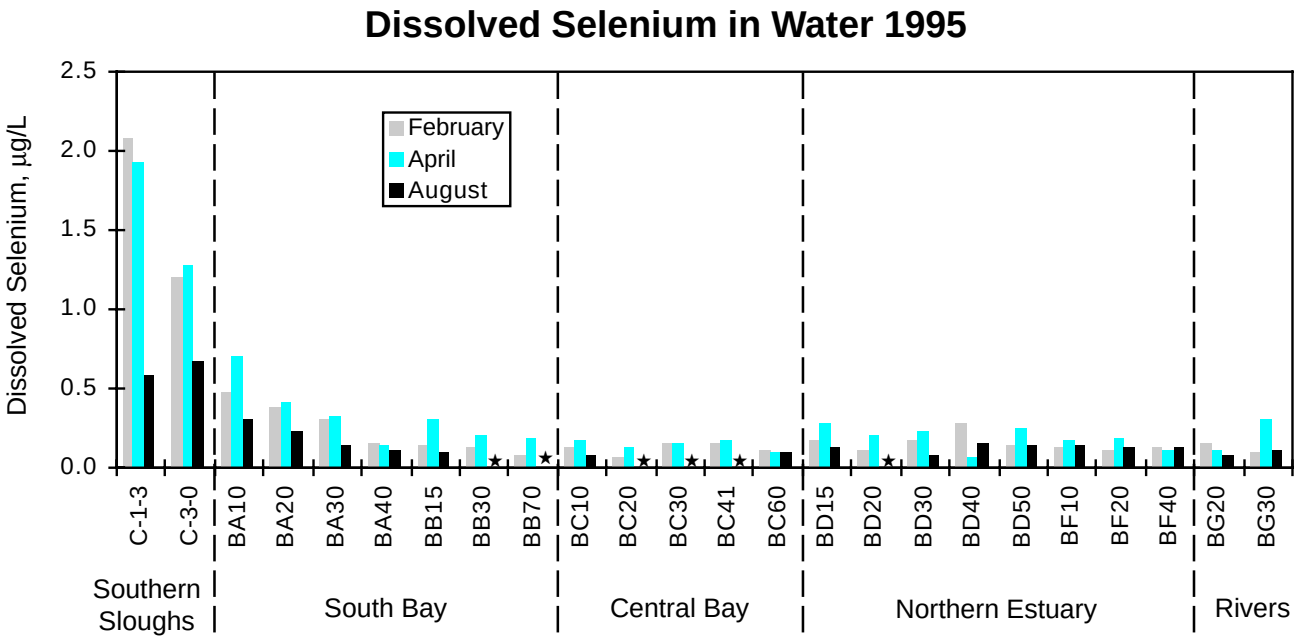

Figure 18. Dissolved selenium (Se) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Dissolved selenium concentrations ranged from below the detection limit of 0.019 ppb (★) to 2.08 ppb. The highest concentration was sampled at Sunnyvale (C-1-3) in February. Six stations were below the MDL. Average concentrations were highest in the Southern Sloughs in February (1.64 ppb) and lowest in the Central Bay in August (0.04 ppb). In general, concentrations were highest in April and lowest in August. There are no water quality objectives for dissolved selenium.

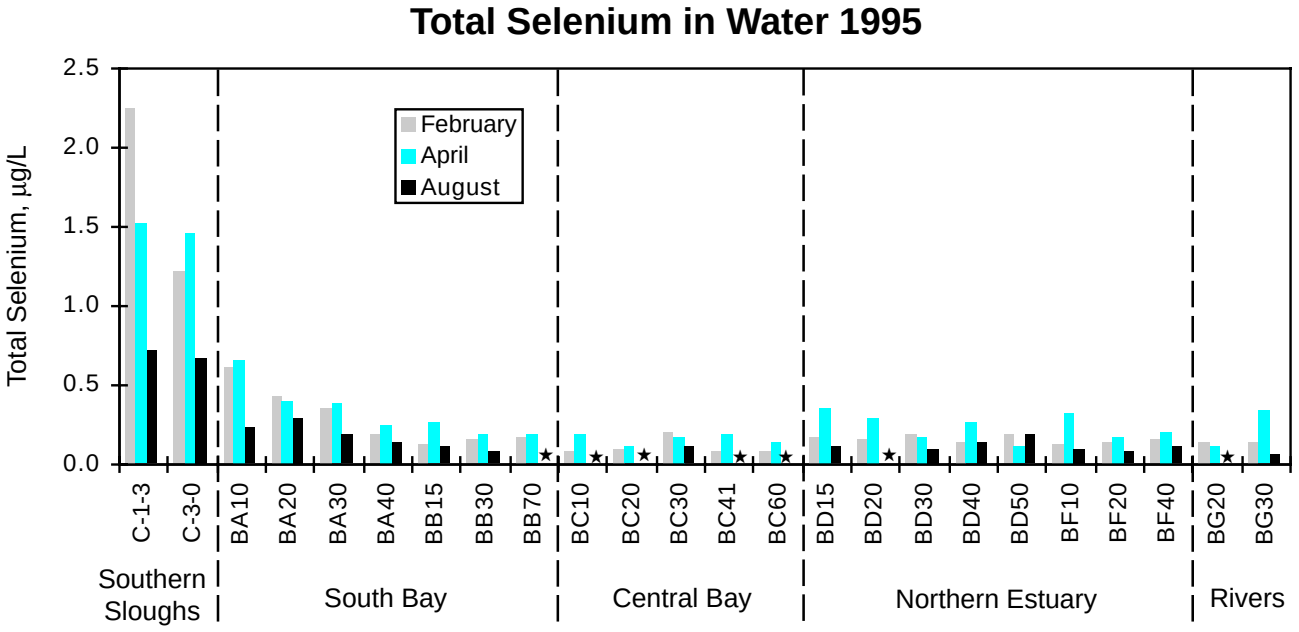

Figure 19. Total selenium (Se) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Total selenium concentrations ranged from below the detection limit of 0.019 ppb (★) to 2.24 ppb. The highest concentration was sampled at Sunnyvale (C-1-3) in February. Seven stations were below the MDL. Average concentrations were highest in the Southern Sloughs in February (1.73 ppb) and lowest in the Northern Estuary in August (0.10 ppb). In general, concentrations were highest in April and lowest in August. There are no Basin Plan water quality objectives for selenium. All stations were below the EPA-National Toxics Rule 4-day average water quality criteria for total selenium (saltwater 71 ppb and freshwater 5 ppb).

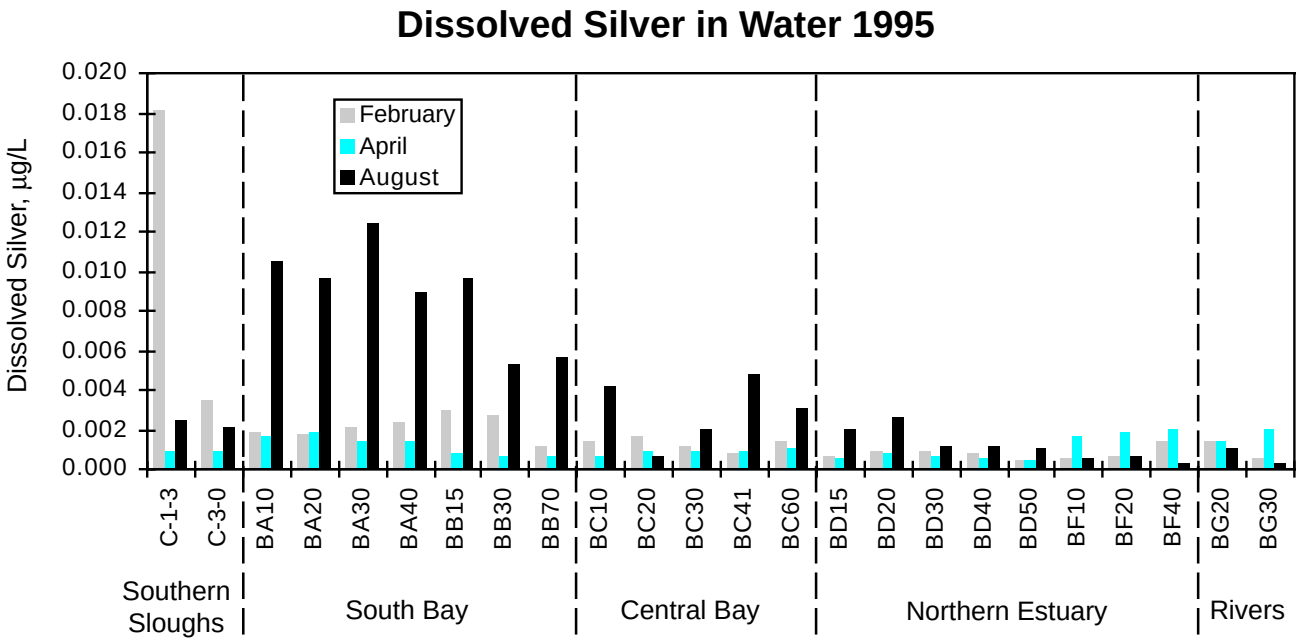

Figure 20. Dissolved silver (Ag) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Dissolved silver concentrations ranged from 0.00024 to 0.018 ppb. The highest concentration was sampled at Sunnyvale (C-1-3) in February, and the lowest at San Joaquin River (BG30) in August. Average concentrations, by reach, were highest in the Southern Sloughs in February (0.0107 ppb) and lowest in the Rivers in August (0.0006 ppb). In general, concentrations were highest in August and lowest in April. All stations were below the instantaneous maximum water quality objectives for dissolved silver (saltwater 2.0 ppb, freshwater 1.0 ppb).

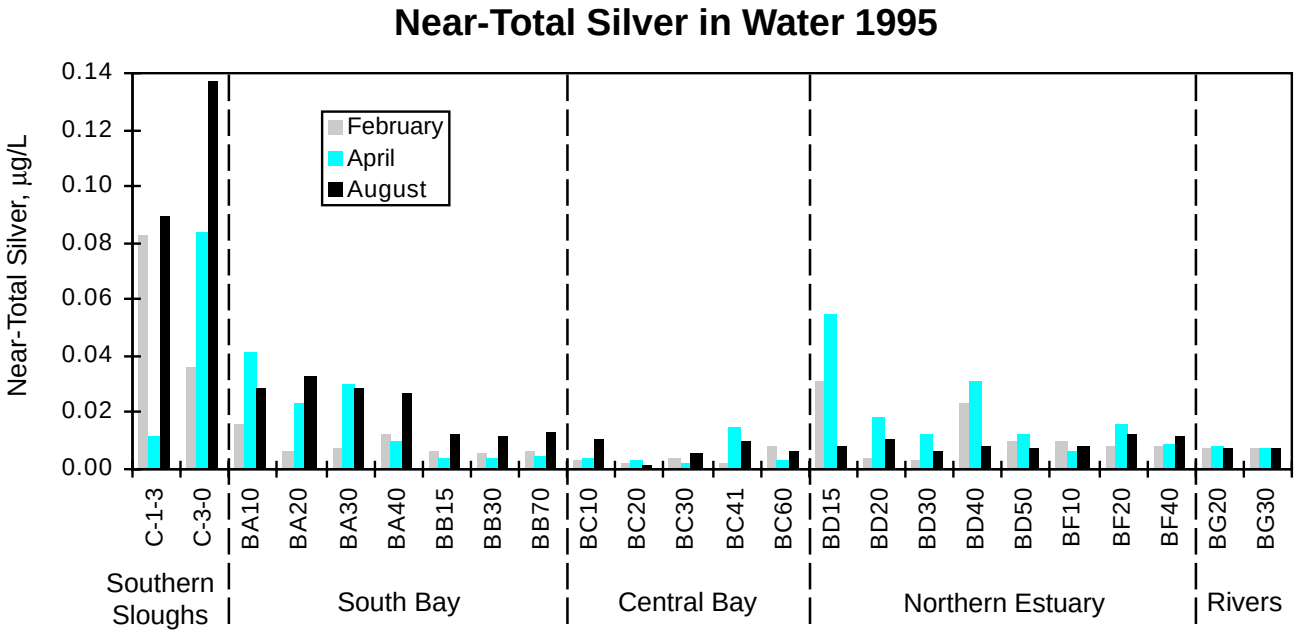

Figure 21. Near-total silver (Ag) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Near-total silver concentrations ranged from 0.002 to 0.113 ppb. The highest concentration was sampled at San Jose (C-3-0) in August, and Golden Gate (BC20) in August. Average concentrations were highest in the Southern Sloughs in August (0.113 ppb) and lowest in the Central Bay in February (0.003 ppb). No consistent seasonal variation was observed. All stations were below the instantaneous maximum water quality objectives for total silver (saltwater 2.3 ppb, freshwater 1.2 ppb).

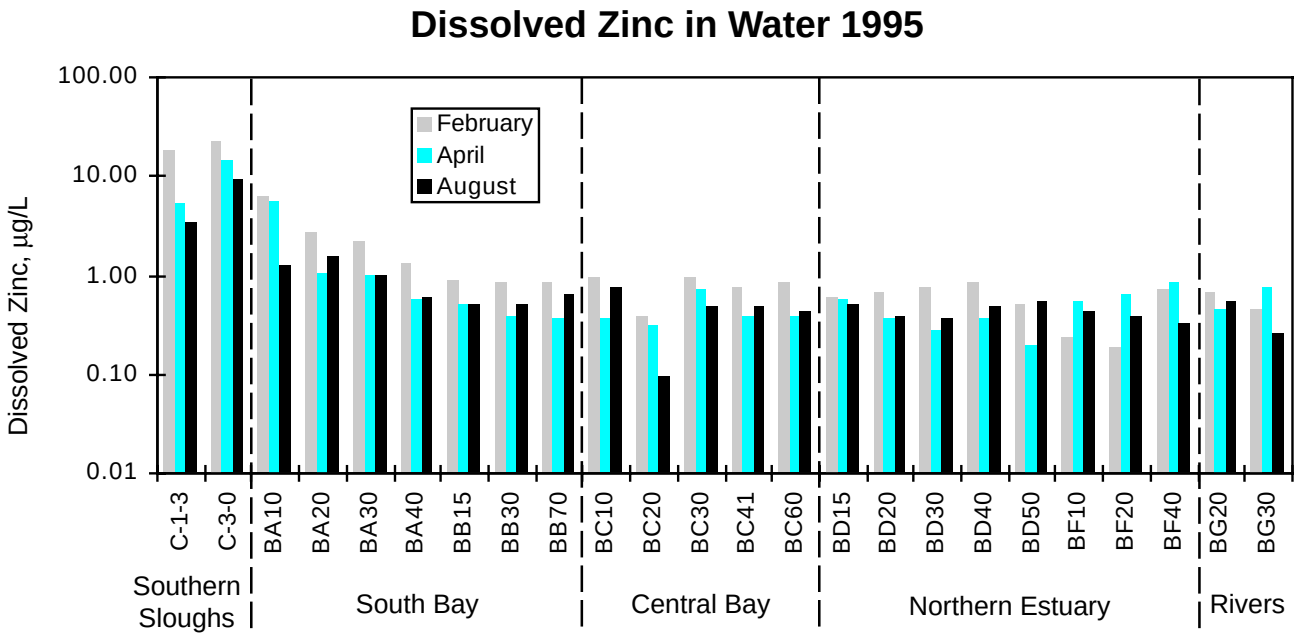

Figure 22. Dissolved zinc (Zn) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. Note logarithmic scale. Dissolved zinc concentrations ranged from 0.09 to 22.41 ppb. The highest concentration was sampled at San Jose (C-3-0) in February and the lowest at Golden Gate (BC20) in August. Average concentrations were highest in the Southern Sloughs in February (19.88 ppb) and lowest in the Rivers in August (0.38 ppb). In general concentrations were highest in February. All stations were below the 24-hour average water quality objectives for dissolved zinc (saltwater 55 ppb, freshwater-hardness dependent).

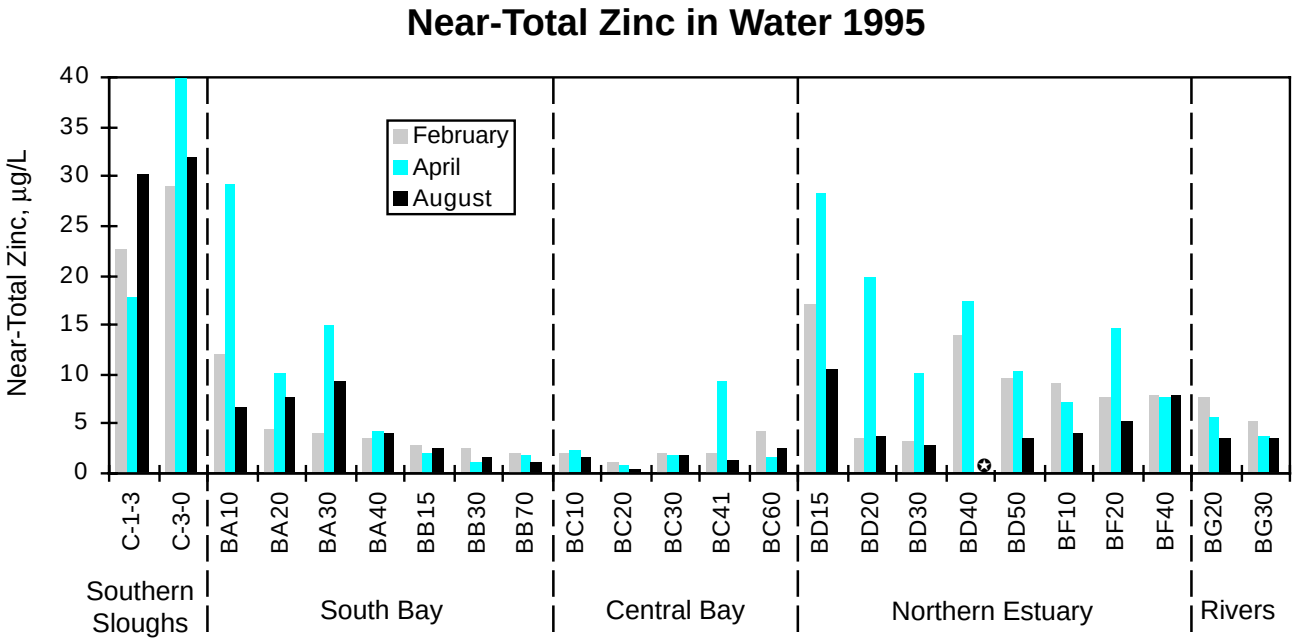

Figure 23. Near-total zinc (Zn) concentrations in water in parts per billion (ppb) at 24 RMP stations sampled in February, April, and August of 1995. ✪ indicates not analyzed. Near-total zinc concentrations ranged from 0.22 to 39.64 ppb. The highest concentration was sampled at San Jose in April and the lowest at Golden Gate (BC20) in August. Average concentrations were highest in the Southern Sloughs in August (30.83 ppb) and lowest in the Central Bay in August (1.42 ppb). In general, concentrations were lowest in August but varied in February and April. All stations were below the 24-hour average water quality objectives for total zinc (saltwater 58 ppb, freshwater-hardness dependent).

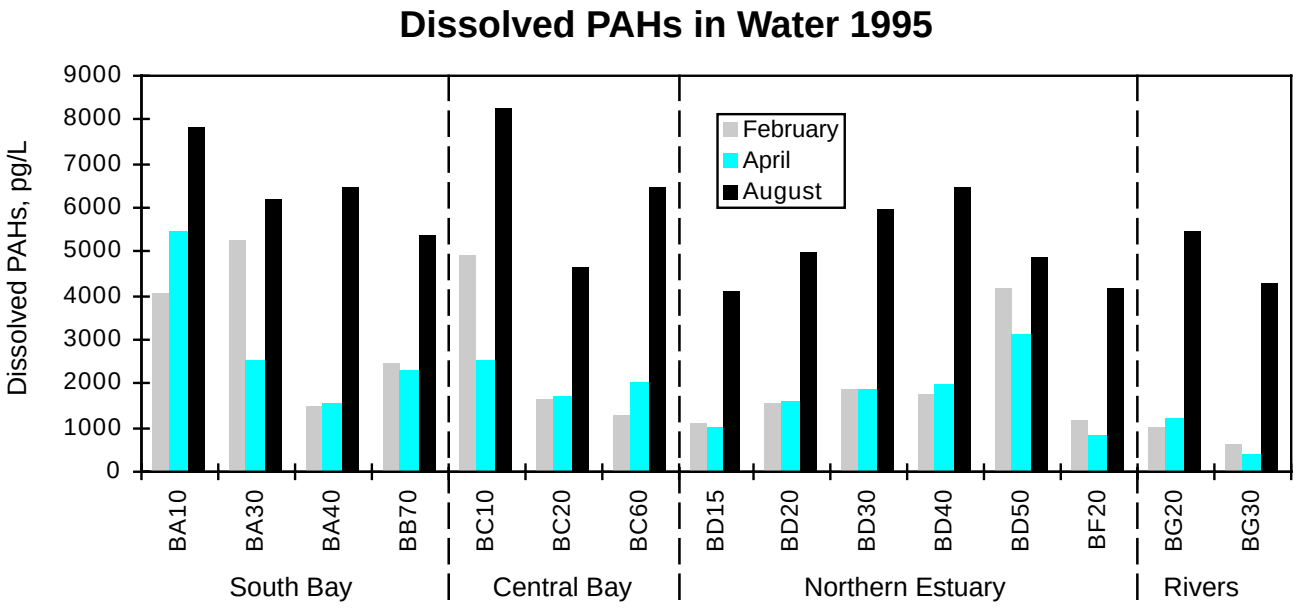

Figure 24. Dissolved PAH concentrations in water (ppq) at 15 RMP stations sampled in February, April, and August of 1995. Dissolved PAH concentrations ranged between 393 and 8,240 ppq. The highest concentration was sampled at Yerba Buena Island (BC10) in August and the lowest at San Joaquin River (BG30) in April. Average concentrations were highest in the South Bay in August (6,443 ppq) and lowest in the Rivers in February (805 ppq). In general, concentrations were highest in August and varied in February and April. There is no water quality guideline for dissolved PAHs.

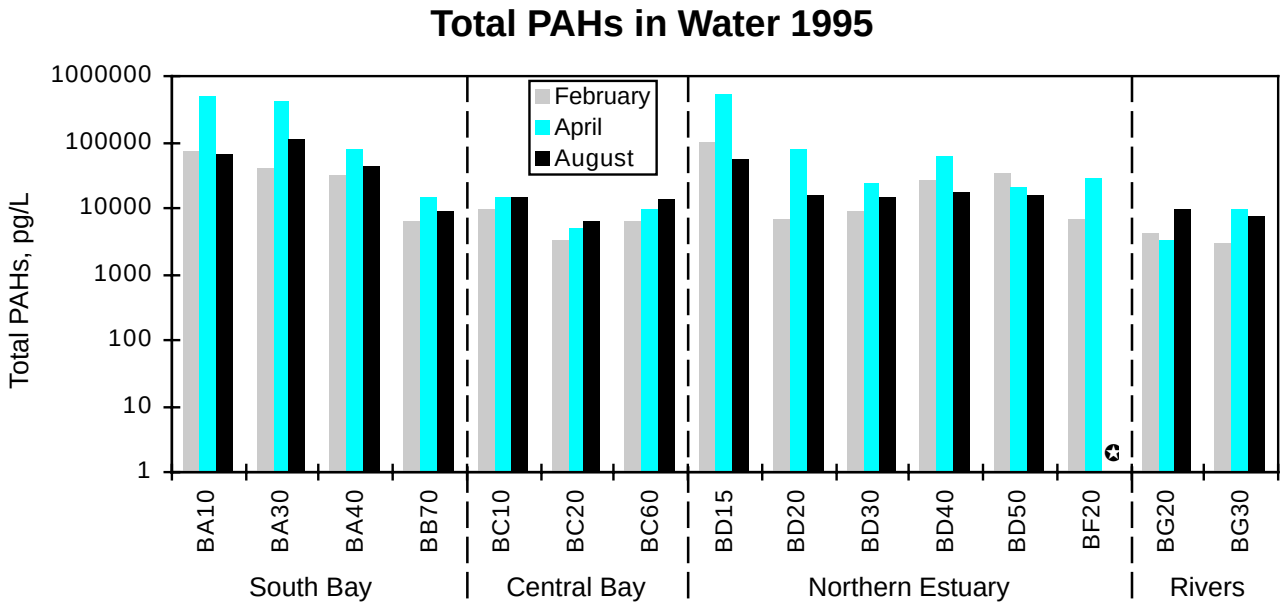

Figure 25. Total PAH concentrations in water in parts per quadrillion (ppq) at 15 RMP stations sampled in February, April, and August of 1995. ✪ indicates not analyzed. Total PAH concentrations ranged between 2,822 and 504,872 ppq. The highest concentration was sampled at Petaluma River (BD16) in April, and the lowest at San Joaquin River (BG30) in April. Average concentrations were highest in the South Bay in April (238,552 ppq) and lowest in the Rivers in February (3,434 ppq). In general, concentrations were highest in April and lowest in February. No stations were above the Basin plan water quality objective for total PAHs of 15,000,000 ppq. Four stations were above the water quality criterion for total PAHs from the US EPA National Toxics Rule of 31,000 ppq in February, six in April, and four in August.

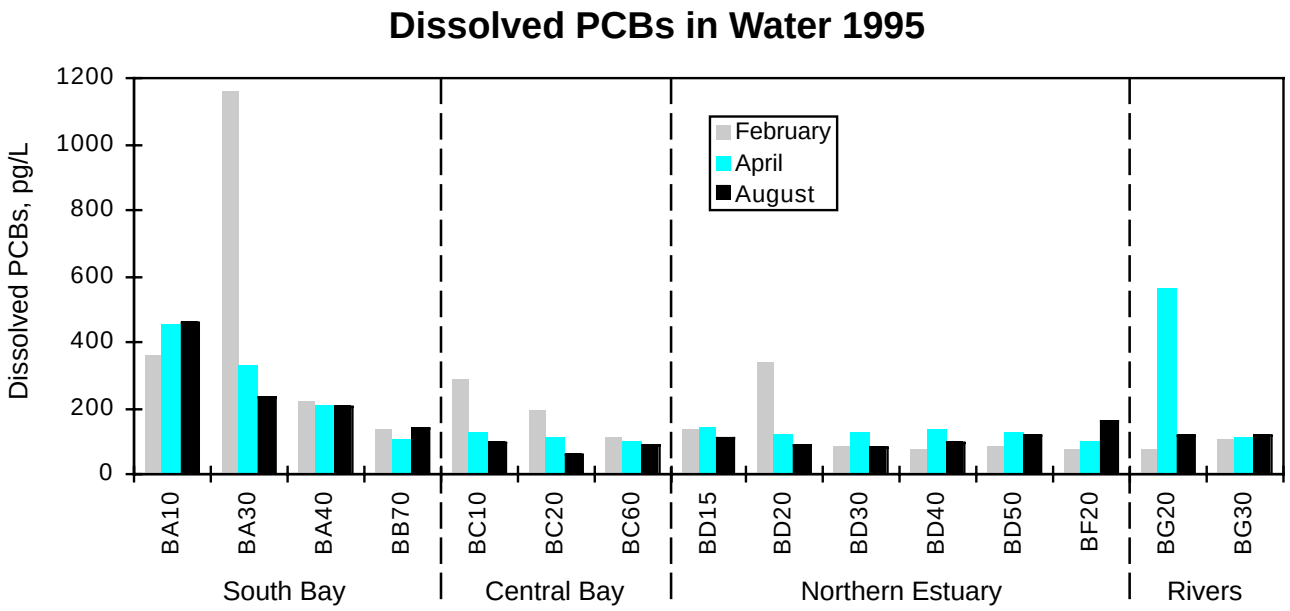

Figure 26. Dissolved PCB concentrations in water in parts per quadrillion (ppq) at 15 RMP stations sampled in February, April, and August of 1995. Dissolved PCB concentrations ranged from 55 to 1,156 ppq. The highest concentration was sampled at the Dumbarton Bridge (BA30) in February, and the lowest at Golden Gate (BC20) in August. Average concentrations were highest in the South Bay in February (502 ppq) and lowest in the Central Bay in August (79 ppq). There is no water quality guideline for dissolved PCBs.

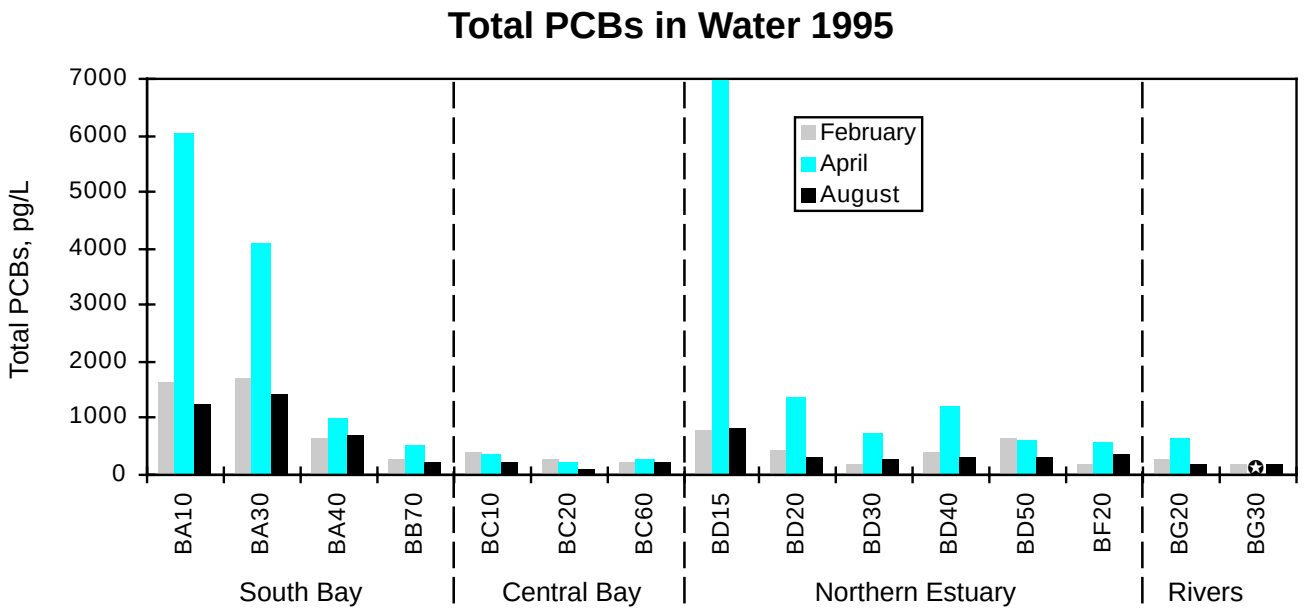

Figure 27. Total PCB concentrations in water in parts per quadrillion (ppq) at 15 RMP stations sampled in February, April, and August of 1995. ✪ indicates not analyzed. Total PCB concentrations ranged from 83 to 6,974 ppq. The highest concentration was sampled at Petaluma River (BD15) in April, and the lowest at the Golden Gate (BC20) in August. Average concentrations were highest in the South Bay in April (2,893 ppq) and lowest in the Rivers in August (171 ppq). In general, concentrations were highest in April, but no other seasonal trend was apparent. The Basin Plan does not have a water quality objective for total PCBs, but US EPA-NTR PCB (Aroclor-based) criteria are 14,000 ppq for freshwater aquatic life, 30,000 ppq for saltwater aquatic life, and 45 ppq for human health (consumption of organisms only). All stations were above the human health criterion during all sampling periods.

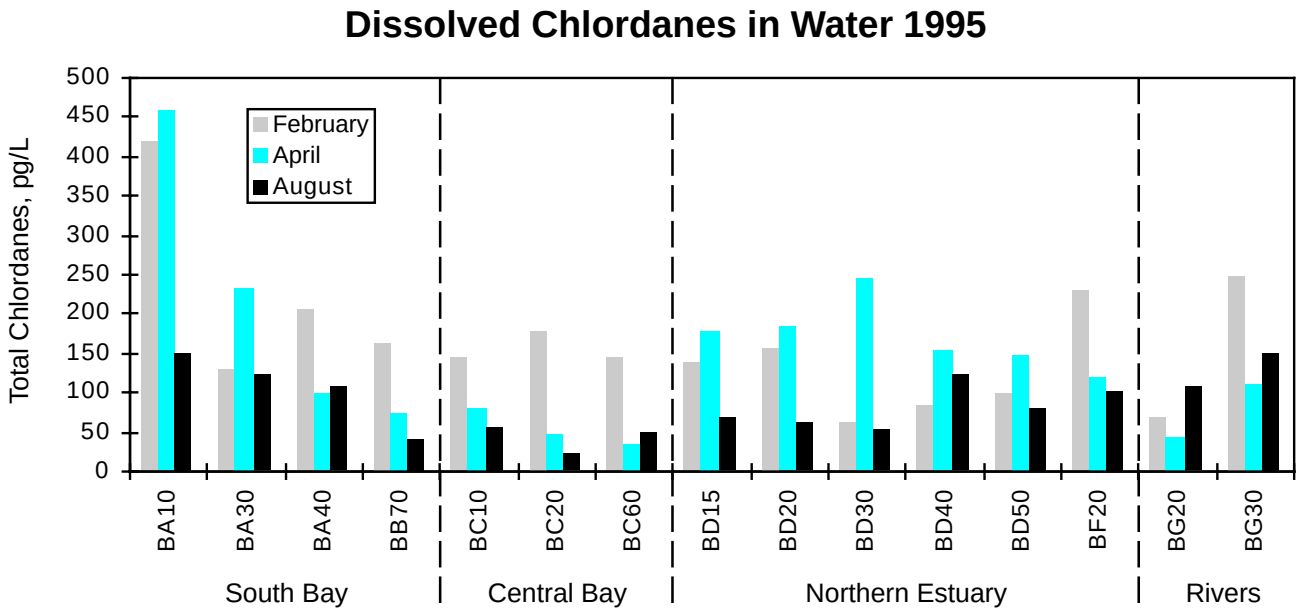

Figure 28. Dissolved chlordane concentrations in water in parts per quadrillion (ppq) at 15 RMP stations sampled in February, April, and August of 1995. Dissolved chlordane concentrations ranged from 21 to 456 ppq. The highest concentration was sampled at Coyote Creek (BA10) in April, and the lowest at the Golden Gate (BC20) in August. Average concentrations were highest in the South Bay in February (228 ppq) and lowest in the Central Bay in August (42 ppq). In general, concentrations were lower in August than in February and April. There is no water quality guideline for dissolved chlordanes.

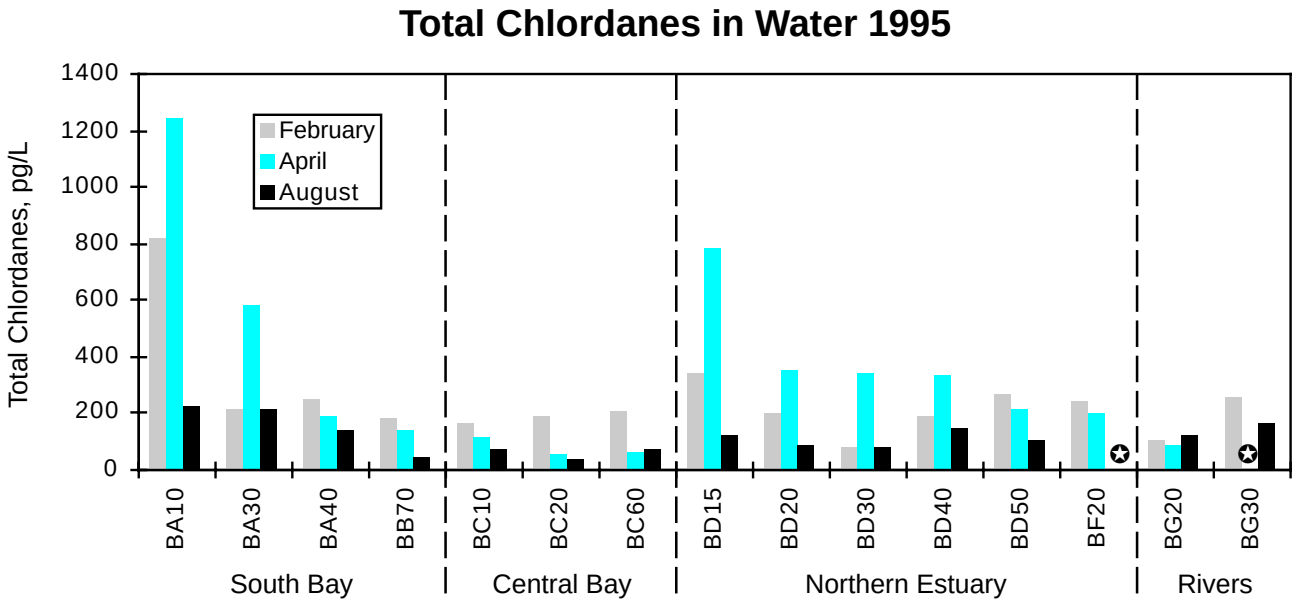

Figure 29. Total chlordane concentrations in water in parts per quadrillion (ppq) at 15 RMP stations sampled in February, April, and August of 1995. (✪) indicates not analyzed. Total chlordane concentrations ranged from 32 to 1,235 ppq. The highest concentration was sampled at Coyote Creek (BA10) in April, and the lowest at the Golden Gate (BC20) in August. Average concentrations were highest in the South Bay in April (533 ppq) and lowest in the Central Bay in August (54 ppq). Concentrations were lower in August than in February and April. The Basin Plan does not have a water quality objective for total chlordanes although several individual compounds have objectives.

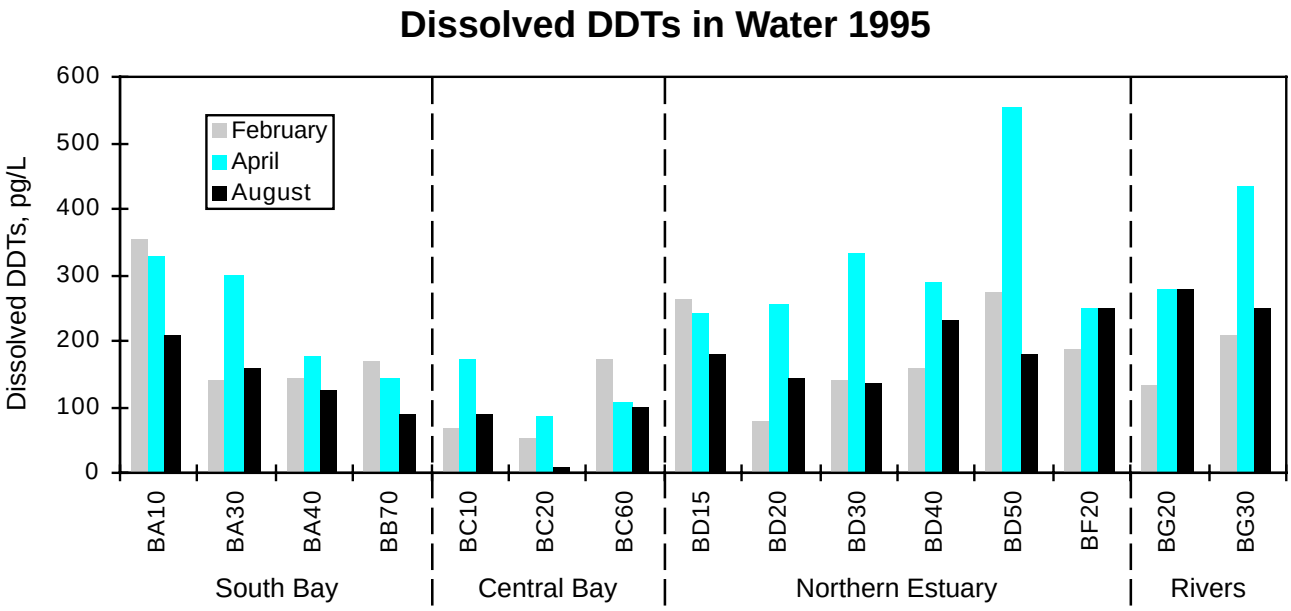

Figure 30. Dissolved DDT concentrations in water in parts per quadrillion (ppq) at 15 RMP stations sampled in February, April, and August of 1995. Dissolved DDT concentrations ranged from 7 to 553 ppq. The highest concentration was sampled at Napa River (BD50) in April, and the lowest at the Golden Gate (BC20) in August. Average concentrations were highest in the Rivers in April (355 ppq) and lowest in the Central Bay in August (65 ppq). In general, concentrations were higher in April than in February or August. There is no water quality guideline for dissolved DDT.

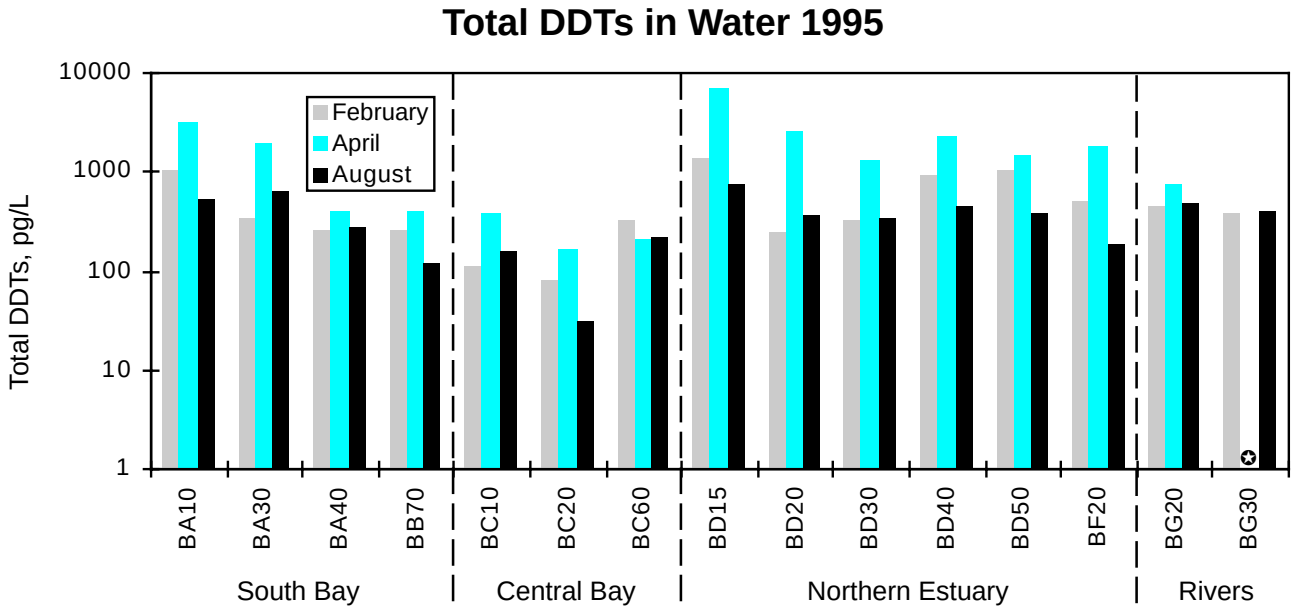

Figure 31. Total DDT concentrations in water in parts per quadrillion (ppq) at 15 RMP stations sampled in February, April, and August of 1995. ✪ indicates not analyzed. Total DDT concentrations ranged from 30 to 6,828 ppq. The highest concentration was sampled at Petaluma River (BD15) in April, and the lowest at Golden Gate (BC20) in August. Average concentrations were highest in the Northern Estuary in April (2,666 ppq) and lowest in the Central Bay in August (131 ppq). In general, concentrations were higher in April than in February or August. Water quality objectives do not exist for total DDTs although individual compounds have criteria.

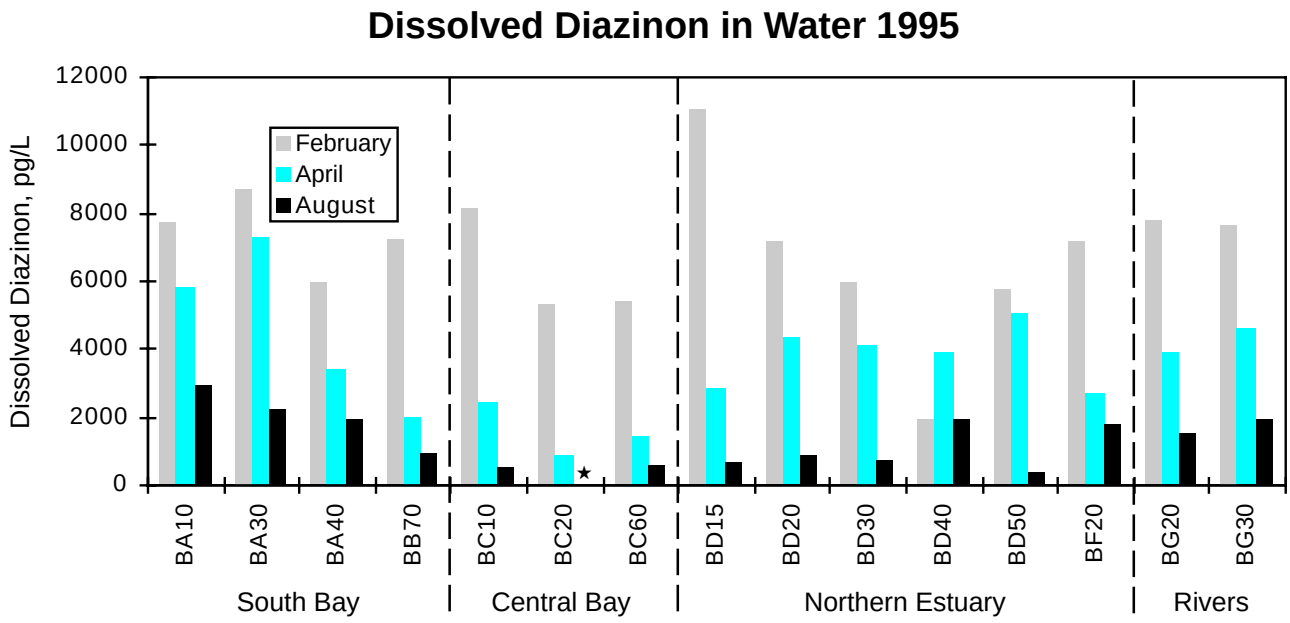

Figure 32. Dissolved diazinon concentrations in water in parts per quadrillion (ppq) at 15 RMP stations sampled in February, April, and August of 1995. ★ indicates not detected. Dissolved diazinon concentrations ranged from below the detection limit to 11,000 ppq. The highest concentration was sampled at Petaluma River (BD15) in February. Average concentrations were highest in the Rivers in February (7,700 ppq) and lowest in the Central Bay in August (510 ppq). In general, concentrations were highest in February, lowest in August, and intermediate in April. The Basin Plan does not have a water quality objective for diazinon. The National Academy of Sciences recommended a guideline of 9,000 ppq for the protection of aquatic life in freshwater. One station was above this guideline during February.

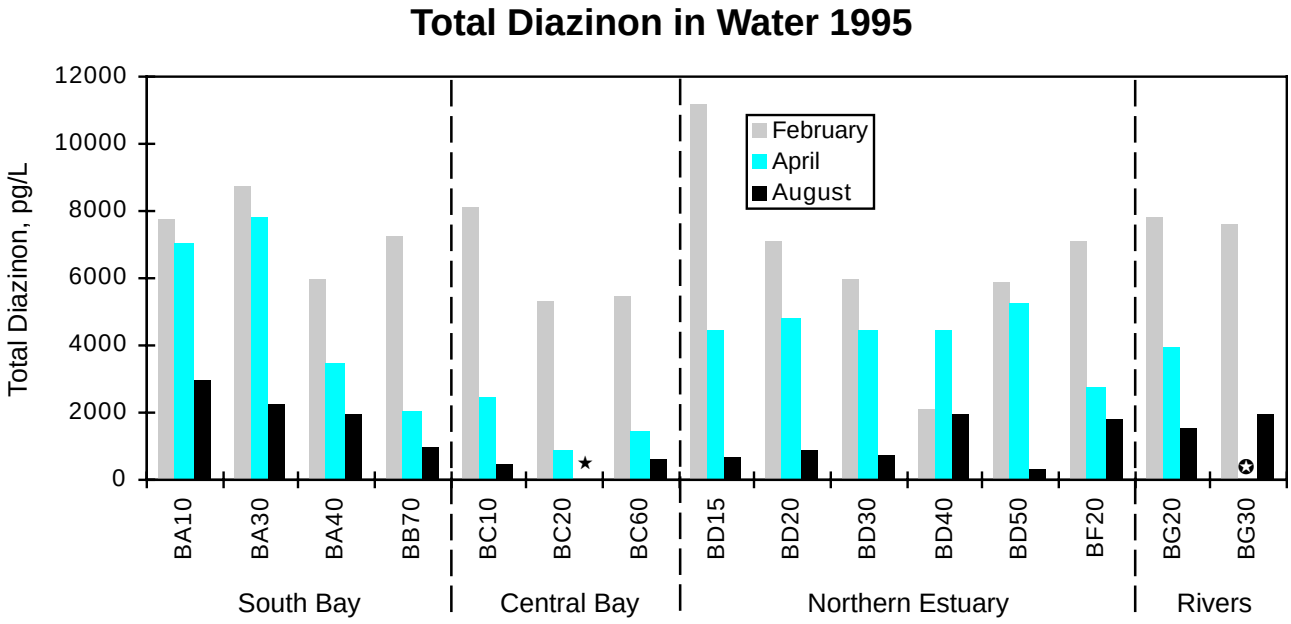

Figure 33. Total diazinon concentrations in water in parts per quadrillion (ppq) at 15 RMP stations sampled in February, April, and August of 1995. ★ indicates not detected. ✪ indicates not analyzed. Total diazinon concentrations ranged from below the detection limit to 11,150 ppq. The highest concentration was sampled at Petaluma River (BD15) in February, and the lowest at the Golden Gate (BC20) in August. Average concentrations were highest in the Rivers in February (7,700 ppq) and lowest in the Central Bay in August (510 ppq). For every station but BD40 concentrations were highest in February, lowest in August, and intermediate in April. The Basin Plan does not have a water quality objective for diazinon. The National Academy of Sciences (1973) recommended a guideline of 9,000 ppq for the protection of aquatic life in freshwater. One station was above this guideline during February.

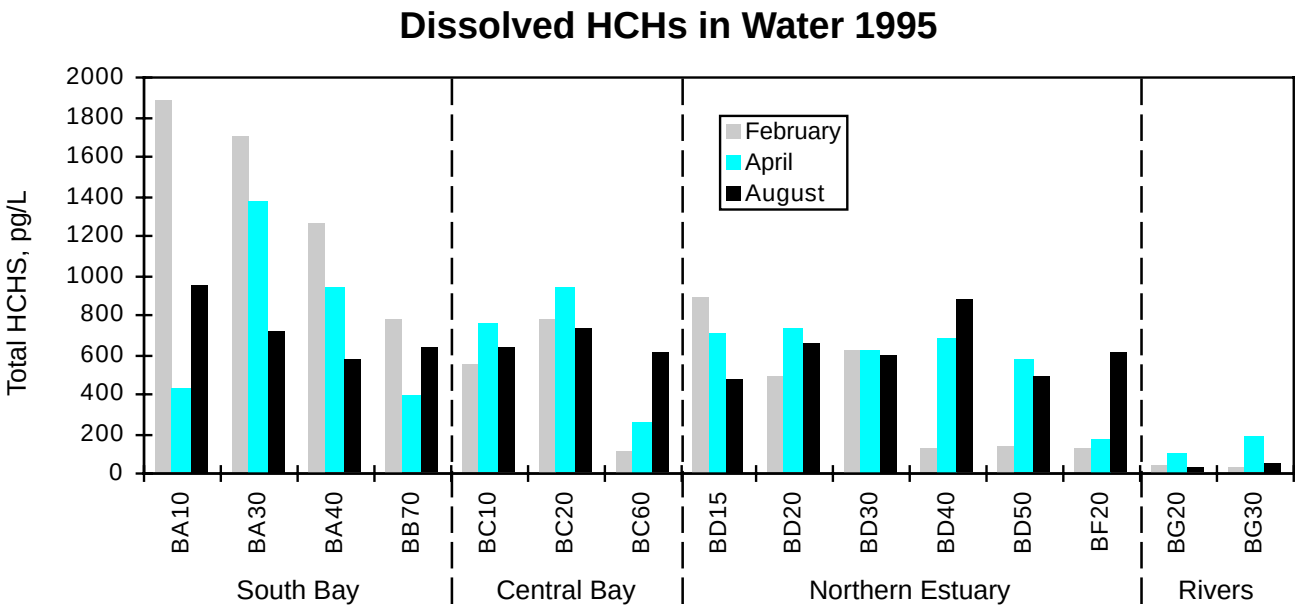

Figure 34. Dissolved hexachlorocyclohexanes (HCHs) concentrations in water in parts per quadrillion (ppq) at 15 RMP stations sampled in February, April, and August of 1995. Dissolved HCH concentrations ranged from 27 to 1,874 ppq. The highest concentration was sampled at Coyote Creek (BA10) in February, and the lowest at the Sacramento River (BG20) in August. Average concentrations were highest in the South Bay in February (1,405 ppq) and lowest in the Rivers in February (34 ppq). No consistent seasonal trend was obseved. The Basin Plan does not have a water quality objective for total HCHs although several individual compounds have criteria.

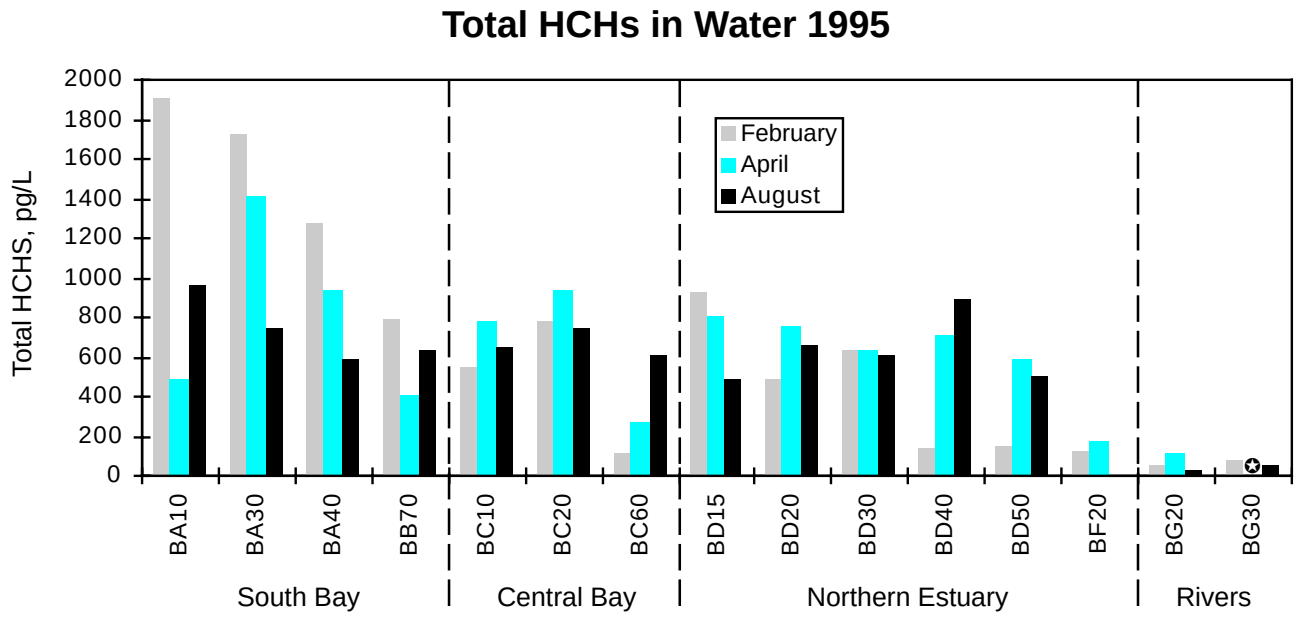

Figure 35. Total hexachlorocyclohexanes (HCHs) concentrations in water in parts per quadrillion (ppq) at 15 RMP stations sampled in February, April, and August of 1995. ✪ indicates not analyzed. Total HCH concentrations ranged from 27 to 1,906 ppq. The highest concentration was sampled at Coyote Creek (BA10) in February, and the lowest at Sacramento River (BG20) in August. Average concentrations were highest in the South Bay in February (1,423 ppq) and lowest in the Rivers in August (37 ppq). Concentrations were highest in February at all stations in the South Bay, but there was no consistent seasonal trend in other Estuary reaches. The Basin Plan does not have a water quality objective for total HCHs although several individual compounds have criteria.

Aquatic Bioassays

Laboratory bioassays using Estuary water were conducted at 13 RMP stations (Figure 36) during the wet sampling season (February) and again in the dry sampling season (August). Sampling dates are listed in Table 3.

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 edulis*) were exposed to Estuary water for 48 hours where percent normal development was the endpoint. Detailed methods are included in Appendix A. Complete test data are included in Appendix C Table 10, and quality assurance information is included in Appendix B Table 5.

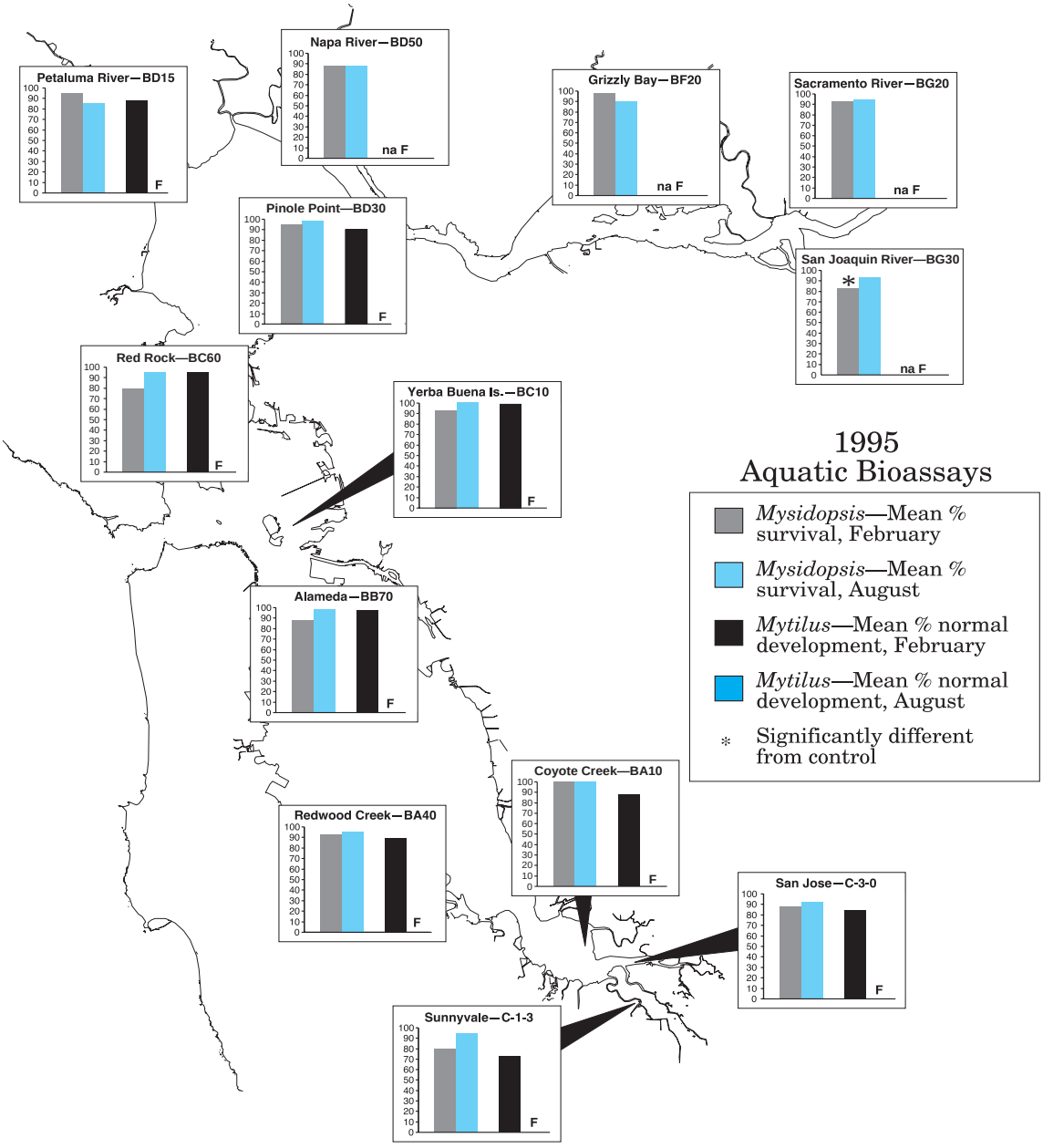

Figure 36. Chart showing results of aquatic bioassays at selected RMP stations. See Appendix A for a full description of the tests used. The controls used in both tests were clean artificial seawater. The only sample that indicated toxicity in 1995 was the *Mysidopsis* test using San Joaquin River water in February. Many tests did not produce usable results. In the February bivalve test, four stations had poor mussel (*Mytilus*) larvae survival in the laboratory controls (na). In August, the oyster stocks apparently did not produce viable sperm or eggs which resulted in extremely poor fertilization or development and none of the tests were successful (F).

Seasonal Fluctuations of Water Quality in San Francisco Bay During the First Three Years of the Regional Monitoring Program, 1993-1995

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Introduction

One objective of the Regional Monitoring Program (RMP) is to determine seasonal and annual trends in the chemical and biological quality of the San Francisco Bay Estuary. An element of the RMP designed specifically to address this objective is a program of monthly water quality measurements conducted by the United States Geological Survey (USGS). This element is designed to describe spatial features of water quality variability along the longitudinal axis of the Bay-Delta, from the lower Sacramento River to the southern limit of the South Bay. These monthly measurements provide supplementary information to describe events of water quality change between the three annual periods of RMP sampling for contaminants and toxicity. The monthly sampling is appropriate for describing seasonal patterns of variability in the state of the Estuary and year-to-year fluctuation of the seasonal patterns. The water quality parameters were chosen (1) as basic descriptors of the chemical-biological status of the Estuary, and (2) as quantities that reflect variability in processes that control the concentration, chemical form, or biological availability of toxic contaminants.

A second objective of the RMP is to identify trends of change in the distribution, concentration, and harmful effects of contaminants in San Francisco Bay. This objective poses a difficult challenge because estuaries have large natural variability that acts as noise around the 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 from any trends of change. A primary mechanism of natural variability in San Francisco Bay is river flow, which controls: the distribution of salt, nutrients, and other dissolved constituents (Peterson *et al.*, 1985), horizontal patterns of water circulation (Monismith *et al.*, 1996), inputs of sediments and other suspended particles (Conomos *et al.*, 1985a), annual recruitment of animals at different levels of the estuarine food web (Jassby *et al.*, 1993), variability of metal enrichment in biota (Luoma *et al.*, 1985), and the timing of biological events such as algal blooms (Cloern and Jassby, 1995). During the first three years of the RMP, flows into the Bay-Delta were highly variable. Here we describe some basic responses of the Estuary to this hydrologic variability, with emphasis on the different seasonal patterns of change observed during 1993, 1994, and 1995. This information is provided as a foundation from which we can begin the more difficult process of interpreting variability of trace substances and their effects.

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 kilometers, from Rio Vista (lower Sacramento River; Figure 37), through Suisun Bay, Carquinez Strait, San Pablo Bay, the Central Bay, and the South Bay to the mouth of Coyote Creek. Vertical profiles are obtained at each station with a submersible instrument package, so this measurement program provides two-dimensional (longitudinal-vertical) descriptions of spatial structure. Sampling along the 145 km

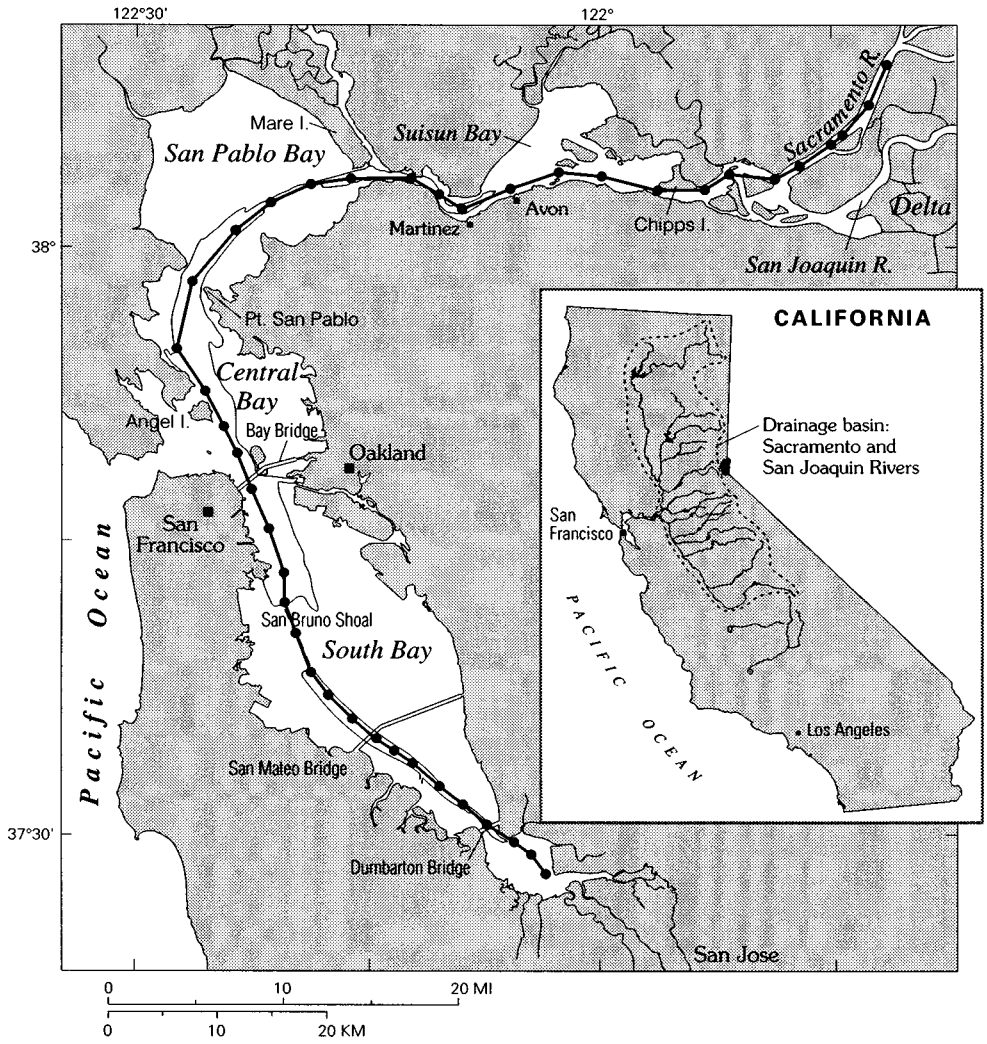

Figure 37. Map showing locations of USGS sampling stations along the axial transect of the San Francisco Bay-Delta, from the lower Sacramento River to the southern South Bay. Distances along the transect are referenced as positive values for the North Bay and negative values for the South Bay (see Figures 38–42), starting at the station south of Angel Island.

transect requires 12–15 hours, so measurements are taken during 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. Therefore, this sampling program is biased toward neap-tide conditions; it provides no information about lateral variability across the shallow habitats (e.g., Powell *et al.*, 1989); and it is confounded by intratidal variability that is superimposed onto the spatial patterns along the axial transect (e.g., Cloern *et al.*, 1989). However, even with these biases and errors, this sampling design provides meaningful descriptions of the primary features of spatial variability along the Estuary.

Water Quality Parameters

This element of the RMP includes measurements of five water quality parameters, each reflecting a different set of processes of variability. Salinity measures the relative proportion of freshwater and seawater along the axial transect, and it 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 watershed. The salinity distribution also provides a first-

order description of water density, a primary force that drives horizontal circulation and transport (Monismith *et al.*, 1996) as well as stratification and vertical mixing (Cloern, 1984). Salinity also has direct influence on the rates of geochemical processes such as adsorption-desorption and the flocculation of dissolved substances into aggregates. Therefore, salinity is an index of the strength of riverine inputs, a descriptor of horizontal and vertical processes of transport, and a geochemical control. All of these processes influence the distribution, chemical form, solute-sediment partitioning, or biological availability of toxic substances. Water temperature is measured as another indicator of mixing, and because the biological transformations of reactive trace substances are temperature-dependent processes.

The concentration of suspended particles (as total suspended sediments, TSS) is one of the most dynamic quantities in estuaries because of the alternating cycles of particle deposition and re-suspension driven by the tidal currents, and because of episodic changes caused by wind-driven re-suspension (Schoellhamer, 1996). Superimposed onto these vertical processes of particle movement are horizontal processes associated with the riverine input of new sediments during periods of high flow. All three of these processes are relevant to the RMP because many trace substances are reactive with particle surfaces. Consequently, the pathways of transport, retention, and incorporation of these contaminants into the estuarine food web can be influenced by the transport of sediments. The monthly 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 non-conservative 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 (CO_2, NO_3, PO_4, etc.) 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* is a simple indicator of the net effect of these biotransformations. Recent observations in South San Francisco Bay show that enhanced algal uptake during blooms leads to rapid reductions in the concentrations of trace metals such as Cd, Zn, and Ni (Luoma *et al.*, in prep); similar dynamic responses are expected for chlorinated hydrocarbons and other reactive trace substances.

Finally, 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 organic matter is consumed by the heterotrophs faster than it is produced by the phototrophs—the Estuary is 'net heterotrophic'. Conversely, supersaturation of oxygen indicates a condition of 'net autotrophy' when the photosynthetic production of new plant biomass within the Estuary is faster than all the processes of consumption. Therefore, DO concentration is an index of the balance between production and 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.

Methods

Data for this RMP element were collected with an instrument package that includes sensors for measuring: depth (Paroscientific pressure transducer), conductivity (Sea-Bird Electronics-4 conductivity sensor), temperature (Sea-Bird Electronics-3 thermistor), TSS (Sea-Bird Electronics-3 optical backscatter sensor), chlorophyll (Sea-Tech invivo fluorometer or WET Labs a-3 absorption meter), and DO (Sea-Bird Electronics-13 oxygen electrode). These sensors are integrated with a Sea-Bird Electronics-9 data acquisition system that digitizes and records signals 24 times per second. The package is lowered through the water column at about 1 m/s, giving a vertical resolution of about 4 cm. Here, we report only the measurements made in the upper meter of the water column as the mean of measurements made between 0.5 and 1.5 m.

The conductivity and temperature sensors were calibrated by the manufacturer at the beginning of each year of sampling. The optical backscatter sensor, fluorometer, and oxygen electrodes were calibrated each sampling date with discrete measurements. Near-surface water samples were collected by pump and aliquots analyzed for: TSS (gravimetric method of Hager, 1993, from samples collected onto 0.4-mm Nuclepore filters); chlorophyll *a* (spectrophotometric method of Lorenzen, 1967, using samples collected onto Gelman A/E filters, extracted in 90% acetone, and calculated with the equations of Riemann, 1978, to correct for pheopigments); and dissolved oxygen (automated Winkler titration of samples collected in 300-ml BOD bottles, following Granéli and Granéli, 1991). Values reported here are calculated quantities based on calibrations of the optical backscatter, fluorescence, and oxygen sensors from linear regressions of measured concentrations versus voltage output of each instrument. We used the empirical equation of Benson and Krause (1984) to calculate oxygen solubility as a function of salinity and temperature.

Detailed methods and the complete data sets for this RMP element are published in annual reports for: 1993 (Caffrey *et al.*, 1994), 1994 (Edmunds *et al.*, 1995), and 1995 (Edmunds *et al.*, 1996). Copies of these reports are available from the USGS in Menlo Park. By the end of 1997 we expect to make these, and subsequent water quality data, available over the Internet through the USGS home page of San Francisco Bay activities (URL = http://sfbay.wr.usgs.gov).

Results

Hydrologic Variability

The RMP design includes three periods of water monitoring each year to characterize variability of trace substances among the periods of high flow (February or March), declining flow (April or May), and low flow (August or September). Therefore, a key feature of RMP design is the description of variability associated with the seasonal hydrologic cycle. The seasonal cycles varied considerably among water years 1993, 1994, and 1995, so the first three years of RMP provides water quality measurements over an extreme range of hydrologic conditions. The water year 1993 was classified as a wet year in California with statewide runoff at 125% of normal (Roos, 1996). Runoff produced three peaks in Delta outflow, with the highest Delta Outflow Index (DOI) of 4,200 m^3/s in late March 1993 (Figure 38). The first RMP water sampling was in early March 1993, when the DOI averaged 995 m^3/s (Table 1). The second sampling (mean DOI of 776 m^3/s) occurred during the spring transition period, and the third sampling (mean DOI of 123 m^3/s) during the summer period of low flow. The second year, 1994, was critically dry when statewide runoff was only 40% of normal (Roos, 1996). The RMP water samplings occurred during a highly damped seasonal cycle of runoff, with DOI ranging from 402 m^3/s during the February 1994 sampling to only 110 m^3/s during the August 1994 sampling (Table 1). In contrast, 1995 was the second wettest year recorded this century, with runoff at 180% of normal (Roos, 1996). This hydrologic year

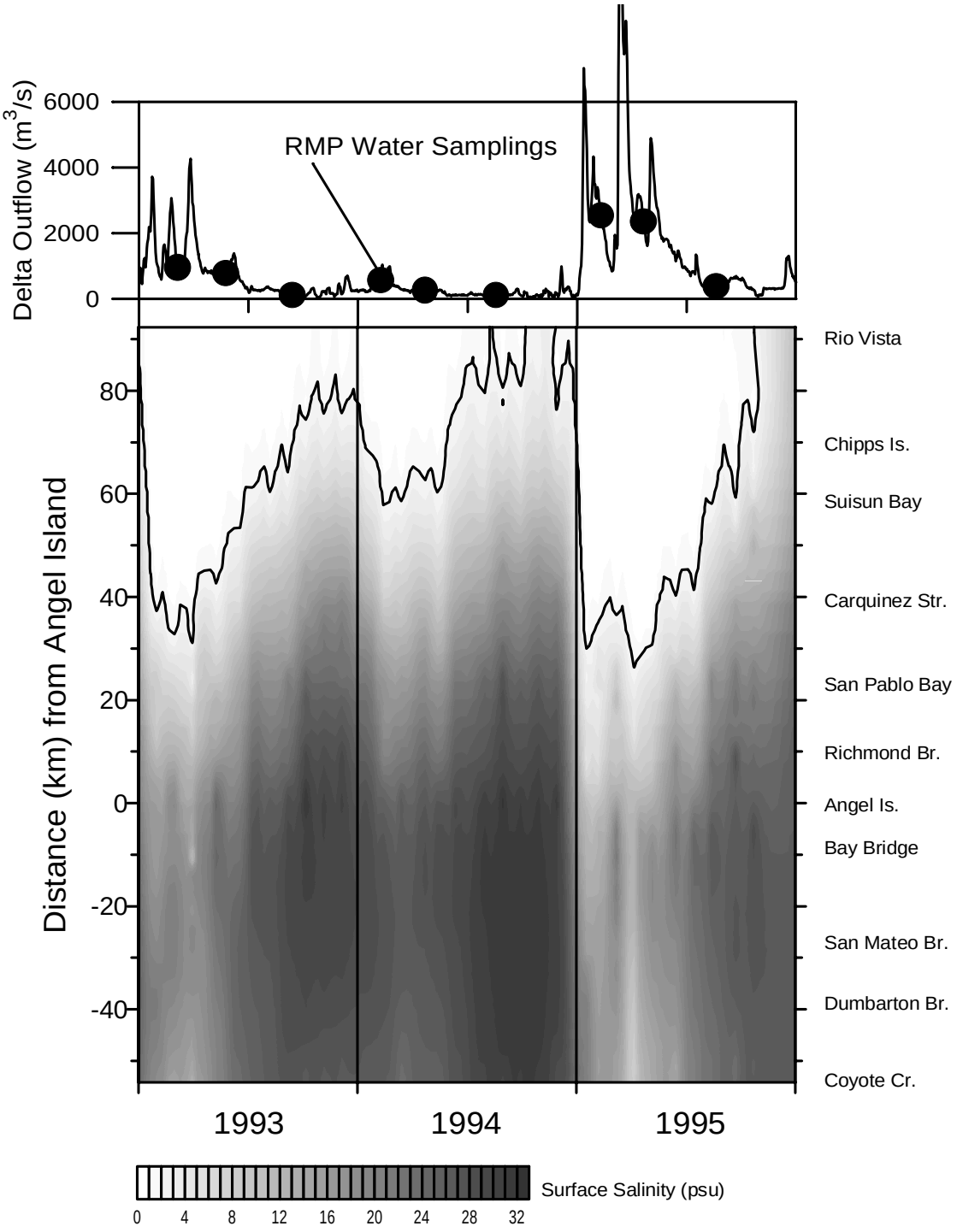

Figure 38. Upper panel shows the daily Delta Outflow Index (from California Department of Water Resources) for 1993–1995; large circles show the timing of the nine RMP water-monitoring samplings. Lower panel shows the changing distribution of surface salinity along the USGS transect (Figure 37). Intensity 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.

Table 1. Summary of hydrographic/water quality conditions in the San Francisco Bay Estuary around the periods of RMP water sampling, 1993–1995. 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. Values for 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 37). Values in parentheses show the 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)

included extremely large floods in January and March, and above-average Delta outflow throughout the year. The first RMP water sampling of 1995 occurred after the January flood peak (mean DOI of 2,490 m^3/s during the sampling period). The second 1995 sampling occurred after the extreme March flood when DOI peaked over 10,000 m^3/s. And the third sampling occurred during a period of unusually high summer flows (mean DOI of 314 m^3/s during the RMP sampling).

Hydrographic/Water Quality Variability

Results of the water quality sampling are summarized in Table 1, which gives the baywide mean and range of each constituent from the USGS monthly samplings that coincided with the nine periods of RMP water monitoring. In 1993 there were lags (up to two weeks) between USGS and RMP water monitoring, but since 1994 the two sampling efforts have been closely coordinated. This table shows that the RMP water monitoring was done over a broad range of hydrologic conditions, from a minimum DOI of 110 m^3/s to a maximum of 2,490 m^3/s. This hydrologic variability was reflected in the surface distributions of salinity in the Bay-Delta, with transect-mean salinity ranging from 23.2 psu during the low-flow sampling of 1994, to only 6.5 psu after the peak flows in February 1995. Results from all the USGS measurements are depicted in Figure 38, which shows the spatial-temporal patterns of salinity as grayscale shadings. The upper panel shows the daily record of the Delta Outflow Index, with circles noting the timing of the nine RMP water samplings. The bottom panel shows salinity as a shaded contour image where shading intensity is proportional to salinity (dark shading = high salinity). 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 temporal variability, with grid lines separating the three annual periods of measurement. This shaded image is based on interpolations of 1,175 measurements, and it shows considerable detail in the changing salinity distribution of the Bay-Delta. However, several large-scale features are relevant to the interpretation of results from the other RMP elements:

1. Northern San Francisco Bay had a persistent longitudinal salinity gradient, whereas the South Bay often had relatively homogeneous salinity. This reflects the role of Delta outflow as a continual source of freshwater flow into the North Bay.
2. The shape of the North Bay salinity gradient changed rapidly in response to changing flows, with the low-salinity region displaced seaward during the high-flow season, and then gradual upstream migration of the salinity gradient as flow receded in summer. This seasonal migration of the salinity gradient is illustrated with the solid line in Figure 38, which shows the changing position of the 2-psu isopleth (the location where surface salinity was 2 psu; this gives a rough index of the changing position of X2, defined as the location where bottom salinity is 2 psu). Note that the surface waters of 2-psu salinity were located upstream, into the Sacramento River (kilometer 92), during the low-flow season of the dry year 1994. At the other extreme, the 2-psu salinity was displaced seaward into the eastern San Pablo Bay (kilometer 25) during the high-flow sampling of February 1995.
3. The salinity distribution in the South Bay changed in response to inputs of freshwater from local streams during storm events. This was evident, for example, during early 1993 when surface salinity was depressed in the region below the Dumbarton Bridge (Figure 38). Therefore, the salt content of the South Bay can be diluted by two different sources of freshwater, one arriving from the northern connection to Delta-derived flows, and the other from runoff in the local watershed. We might expect different chemical changes associated with flows delivered to the South Bay from these two sources.

Water temperature measurements showed a very different pattern of seasonal-spatial variability because temperature change is caused primarily by heat transfers at the water surface rather than from point source inputs. Therefore, the patterns of temperature change in the Bay-Delta were dominated by the seasonal solar cycle (Figure 39). The direction of the spatial temperature gradient shifted seasonally because the incoming river water was colder than the coastal ocean during winter, but the river water was warmer than the coastal ocean during summer. For the nine RMP periods of water monitoring, the transect-mean temperature ranged from a minimum of 10.9 °C in March 1993 to a maximum of 21.2 °C in August 1995. Water temperatures were unusually high during the second half of 1995 (Figure 39). Subtle details of the temperature structure can give clues about mixing patterns in the Bay-Delta. For example, the persistent summer feature of a temperature gradient near kilometer -20 in the South Bay is consistent with the concept that the San Bruno Shoal acts to retard horizontal exchanges between the South Bay and the Central Bay such that water retained below the San Bruno Shoal can develop its own character (Powell *et al.*, 1986). We might expect to find gradients of other constituents, including some trace substances, across this topographic control of mixing.

Although the concentrations of suspended sediments (measured as TSS) are dynamic and patchy in San Francisco Bay, results of the monthly sampling program can be used to describe the seasonal distributions of suspended particles along the Estuary axis. The shaded image of Figure 4 shows that the spatial-temporal patterns of TSS concentration are complex and patchy, but strongly influenced by the riverine input of sediments. River inputs to the North Bay were evident during the high-flow periods of early 1993 and early 1995, when TSS concentrations in surface waters exceeded 150 mg/liter (near-bottom concentrations were even higher). Concentrations of TSS were relatively low during the dry season of 1993 and throughout the dry year 1994. Particle concentrations in the upper Estuary (upstream of Carquinez Strait) were usually greater than 40 mg/liter throughout all of 1995, reflecting the persistent source of sediments delivered by the sustained high flows that year (recall that the USGS sampling is done on neap tides, so these patterns of TSS distribution would show higher concentrations on the spring tides; Schoellhamer, 1996). Riverine inputs also influence the distributions of TSS in the lower South Bay, with highest concentrations (up to 240 mg/liter) observed following inputs of sediment from local streamflow during the storms of early 1993 and 1995 (Figure 40). A persistent spatial feature was the relatively low concentration of suspended solids in the Central Bay, far from the riverine supplies of sediments and far from the shallow habitats where wind-wave resuspension creates high turbidity. Given the large range of TSS concentration among the periods of RMP water sampling (from 1-239 mg/liter; Table 1), we might expect to find associations between the total concentrations of particle-reactive trace substances and the patterns of TSS distribution shown in Figure 40.

Phytoplankton biomass was usually low in the Bay-Delta, with concentrations of chlorophyll *a* often less than 4 mg/m^3 (Figure 41). The prominent exceptions were the South Bay spring blooms when biomass increased rapidly and reached maximum chlorophyll *a* concentrations of 50–70 mg/m^3. These large biological events recur each year, but the spatial extent and duration of the spring bloom changes from year to year, partly in response to annual fluctuations in river flow (Cloern and Jassby, 1995). The spring bloom of 1994 was confined below the San Bruno Shoal (kilometer -20), whereas the 1995 spring bloom developed along the entire South Bay and into Central Bay (Figure 41). These bloom events have a large geochemical influence because they act to remove dissolved inorganic constituents (C, N, P, Si) and transform them into particulate organic forms (Cloern, 1996). Luoma *et al.* (in prep) measured rapid depletions of some trace metals (Cd, Ni, Zn) during the 1994 spring bloom, so these seasonal periods of high phytoplankton biomass and productivity are periods of rapid change in the chemical form of reactive trace substances. The 1993 RMP sampling in March occurred in the early stage of bloom development, so the biogeochemical effect of phytoplankton activity may not be evident from

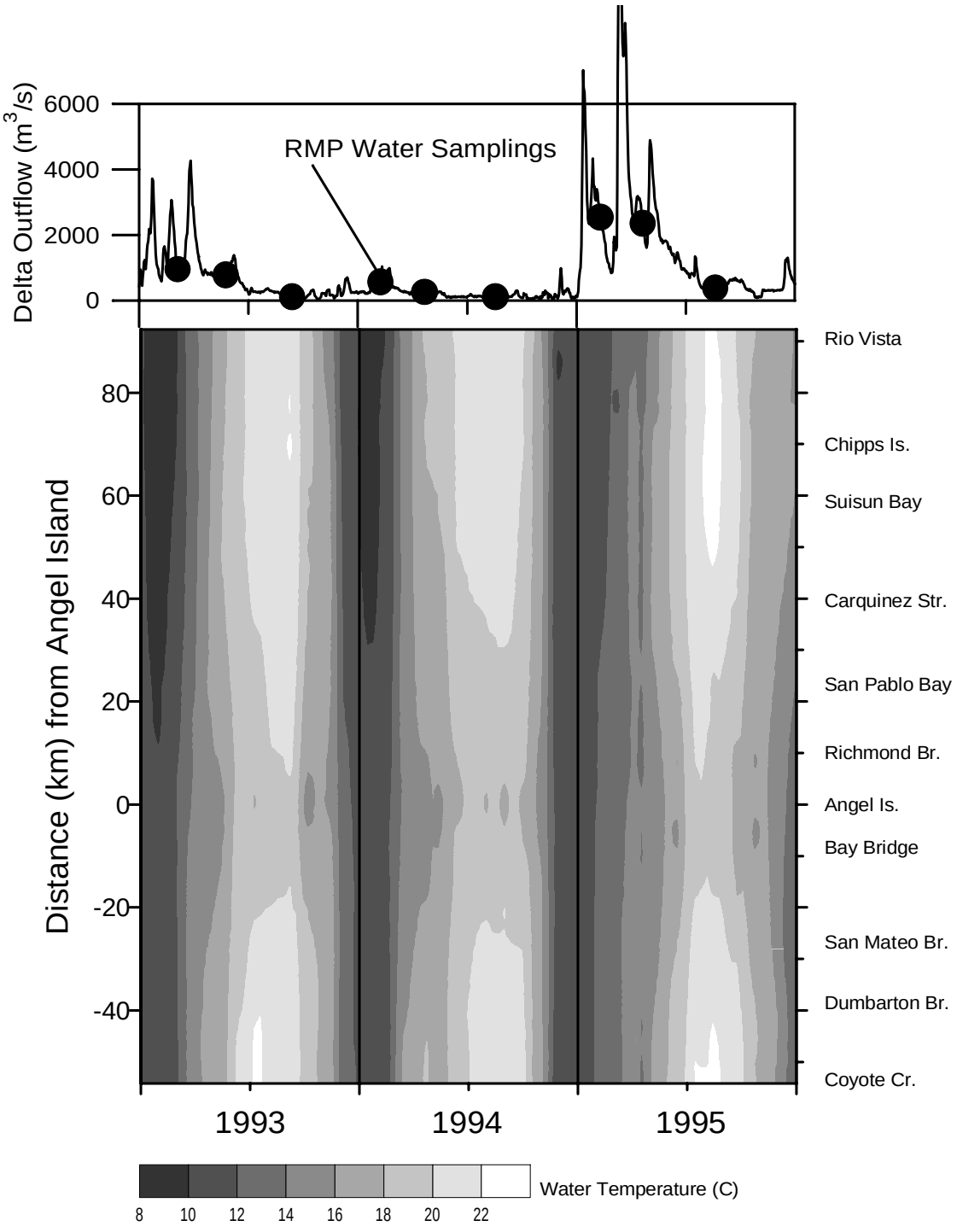

Figure 39. Delta outflow index (top panel) and temperature distribution (lower panel) along the USGS transect for the years 1993–1995 (see Figure 38). Intensity of shading is proportional to temperature, with lighter shadings indicating higher temperatures.

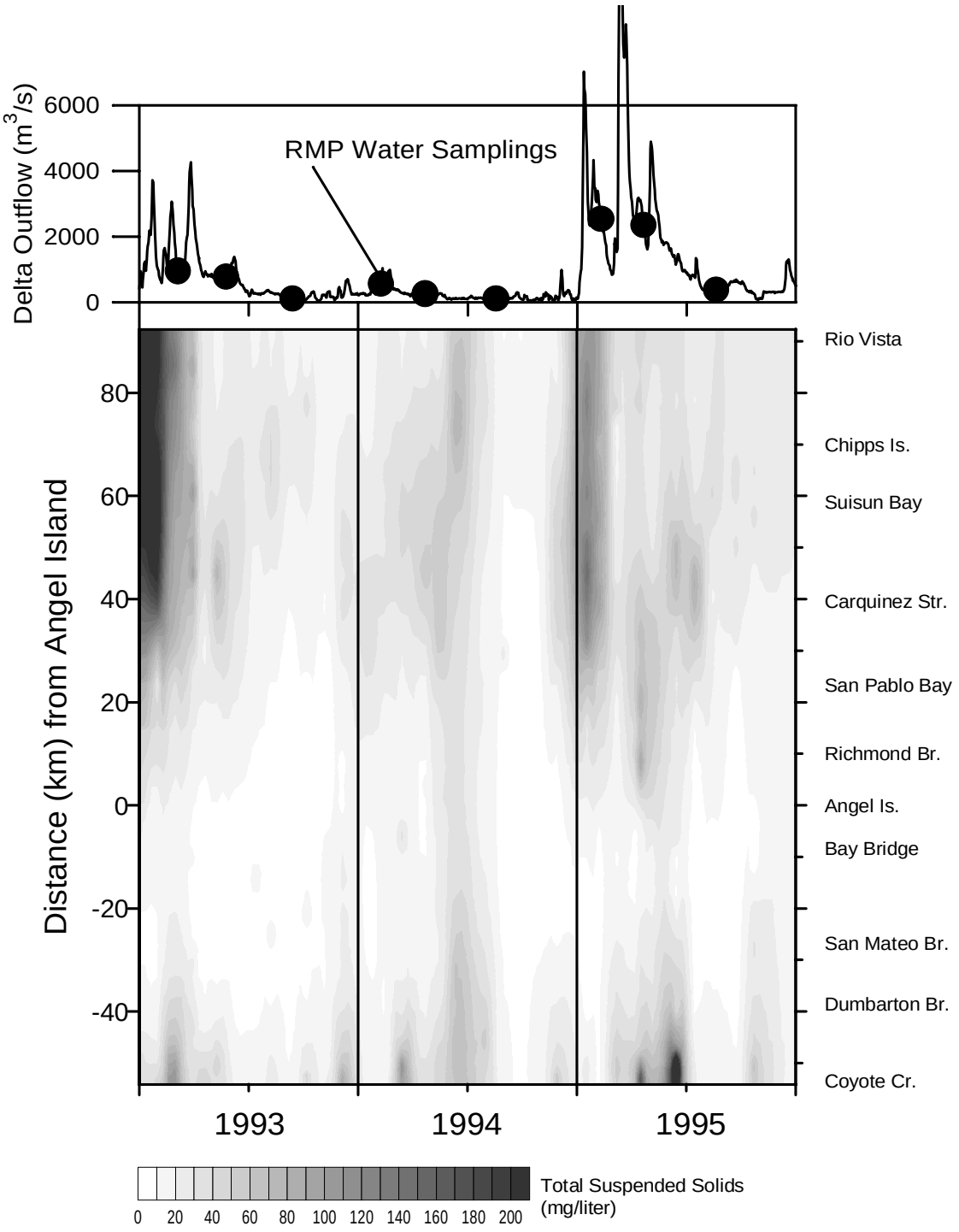

Figure 40. Delta Outflow Index (top panel) and concentrations of total suspended solids (lower panel) along the USGS transect for the years 1993–1995 (see Figure 38). Intensity of shading is proportional to TSS, with darker shadings indicating higher concentrations of suspended solids.

the RMP measurements of 1993. The 1994 RMP sampling in early February occurred well before the bloom began, and the April sampling occurred a month after the period of maximum algal biomass. However, the 1995 RMP sampling in April occurred at the end of a two-month bloom, so we would expect depletions of the dissolved forms of biologically-reactive trace substances then. Contrasts between the February and April RMP samplings in 1995 should, therefore, provide a valuable set of observations for characterizing the role of phytoplankton blooms as mechanisms of variability in the chemical form and the concentration of trace substances. On the other hand, we expect that phytoplankton assimilation was a relatively minor component of trace-substance variability in Suisun Bay, where phytoplankton biomass (Figure 41) and primary productivity (Alpine and Cloern, 1992) are very low .

The distributions of dissolved oxygen were consistent with the inferred patterns of phytoplankton productivity. The oxygen content of surface waters in the Bay-Delta was usually between 90–100% of that at equilibrium with atmospheric oxygen (Figure 42). Large, positive departures from this range occurred in the South Bay during spring blooms when high rates of algal photosynthesis led to DO supersaturation. These episodes of oxygen supersaturation, shown as light-shaded patches in Figure 42, indicate periods of rapid algal activity that would remove some trace contaminants from solution. The image in Figure 42 also shows episodes of reduced (< 80% saturation) oxygen concentrations that were associated with the events of high flow and high turbidity. These events of low DO imply that the estuarine food web was supported by external sources of organic matter (Jassby *et al.*, 1993). We expect the pathways of trophic transfer of matter, including trace contaminants, to be different between these episodes of strong heterotrophy compared to the pathways of trophic transfer during blooms, when the food web was supported primarily by phytoplankton production.

Summary

In this chapter we have used results of the monthly USGS measurement program to describe the key features of water quality variability in San Francisco Bay during the first three years of the Regional Monitoring Program. The patterns of water quality variability are displayed as shaded images that show the annual cycles, the large year-to-year fluctuation of the annual cycles, and the spatial gradients of water quality from the Sacramento River to the southern South Bay. The seasonal, annual, and spatial patterns all changed in response to fluctuations in river flow, and the extreme hydrologic variability from 1993–1995 provides a valuable opportunity to characterize the distribution and effects of trace contaminants across a broad range of flow conditions.

The five water quality parameters described here were chosen as quantities that integrate the effects of different processes of estuarine variability, so results from this program are the logical foundation from which to begin interpretation of the more complex patterns of variability in trace contaminants and their effects. The salinity pattern is the simplest and clearest index of the effect of river flow on the distribution of dissolved constituents. Temperate patterns can be a useful indicator of mixing, and spatial temperature gradients can be used to identify water masses that have acquired their own character. The patterns of suspended solids show the strong effect of flow events as mechanisms that deliver new sediments to the Estuary, and they will be useful in interpreting the changing distributions of those contaminants bound to particle surfaces. Biological processes of transformation are indexed in the patterns of chlorophyll variability because phytoplankton comprise the largest component of living biomass in San Francisco Bay, and because phytoplankton production is a key agent of biological transformation of reactive substances such as trace metals and chlorinated hydrocarbons. The patterns of DO variability show events of enhanced algal productivity, and they also reflect different pathways of trophic transfer in the upper North Bay and the South Bay. Since many contaminants enter food webs through trophic transfer (feeding), these DO patterns might be useful for interpreting patterns of variability in the bioaccumulation of trace substances.

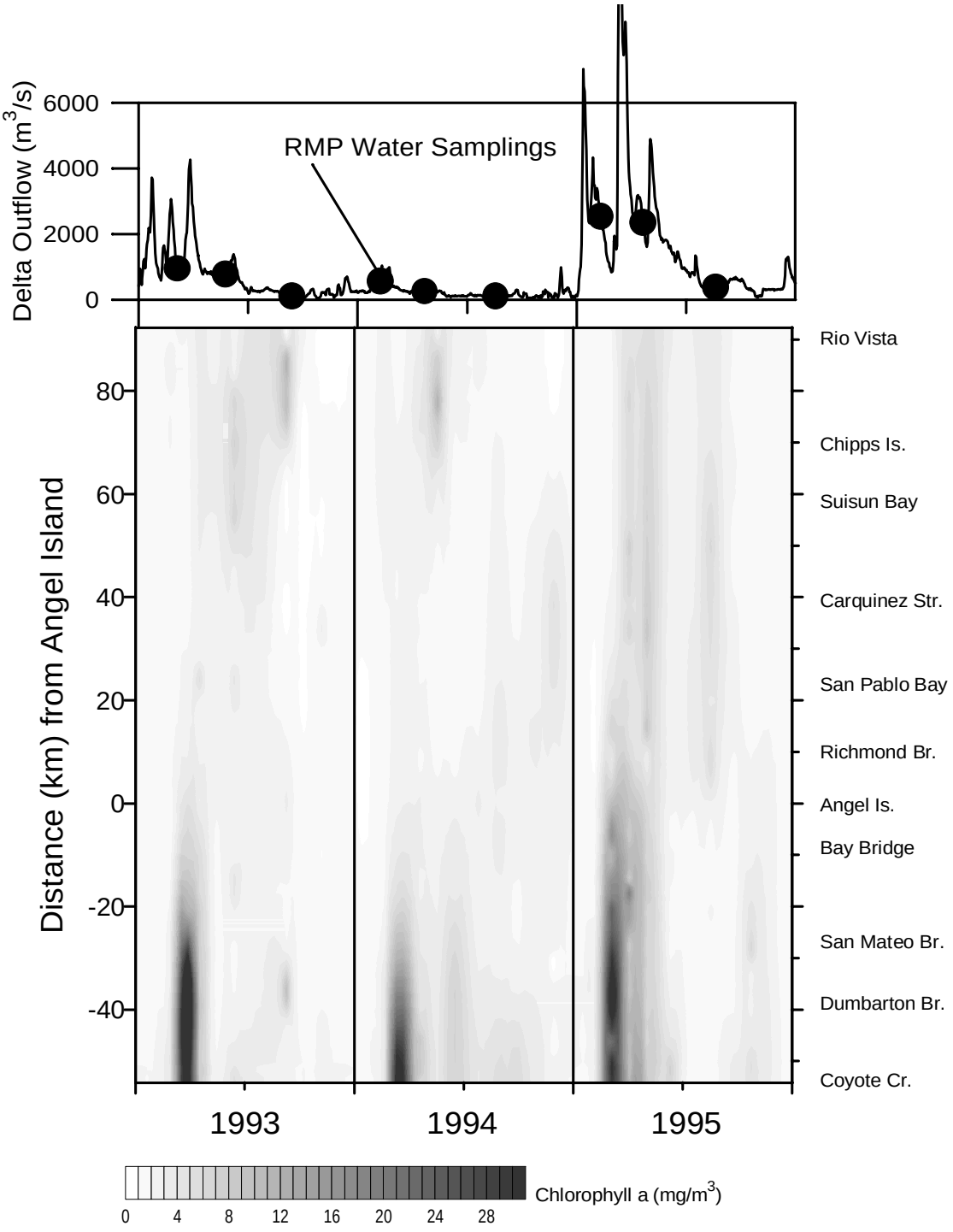

Figure 41. Delta Outflow Index (top panel) and concentrations of chlorophyll *a* (lower panel) along the USGS transect for the years 1993–1995 (see Figure 38). Intensity of shading is proportional to chlorophyll *a*, with darker shadings indicating higher concentrations.

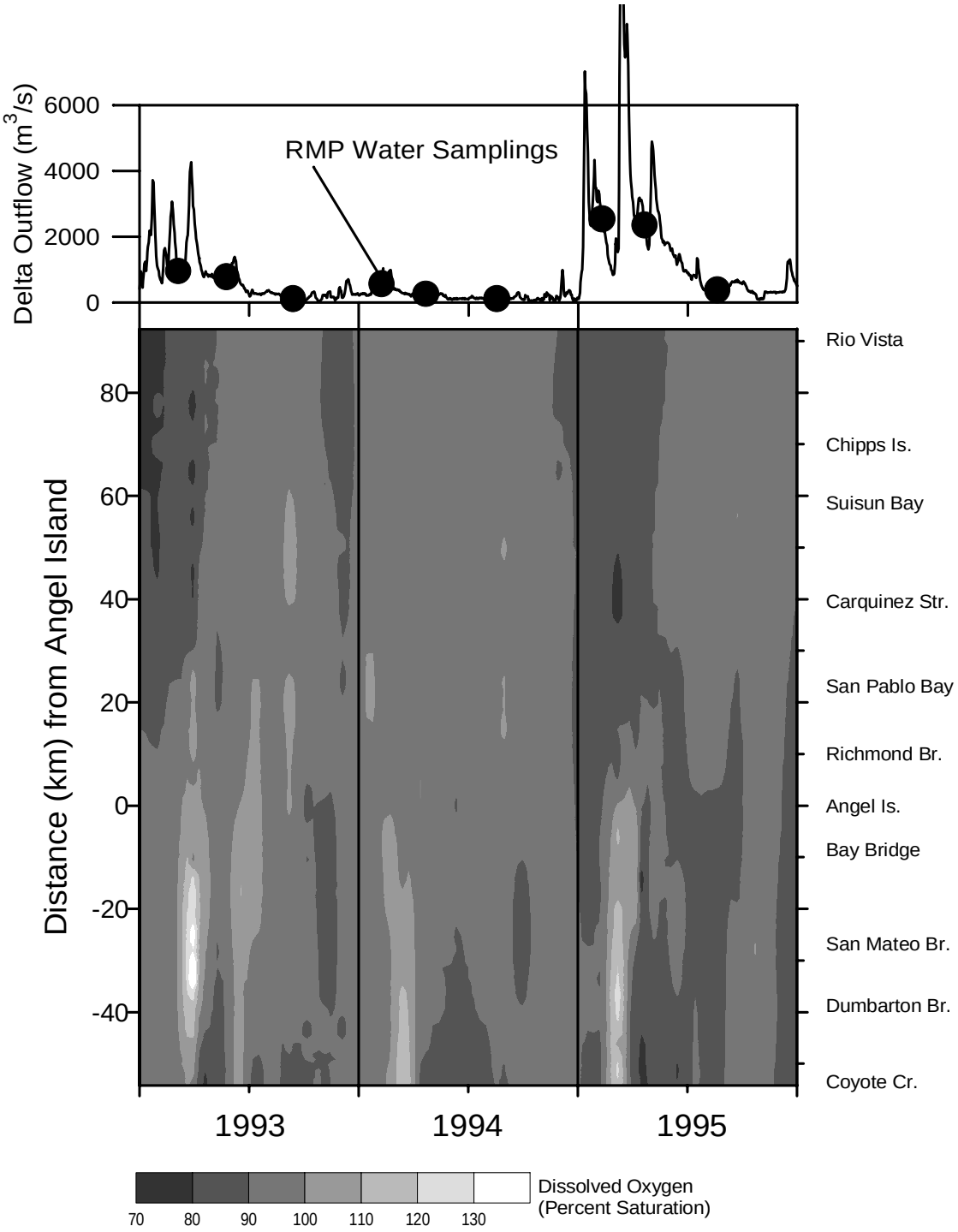

Figure 42. Delta Outflow Index (top panel) and concentrations of dissolved oxygen (lower panel) along the USGS transect for the years 1993–1995 (see Figure 38). Intensity of shading is proportional to DO in the surface waters, with lighter shadings indicating higher concentrations.

Methods for Analysis of Spatial and Temporal Patterns: Summary and Conclusions[1]

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Introduction

The purpose of this summary is to suggest ways in which RMP data can be analyzed to describe spatial patterns and temporal trends. Four specific questions are used to guide and organize the data exploration:

1. How do we determine spatial boundaries within which the data can be summarized and between which comparisons should be made?
2. How can differences in space be detected?
3. How can significant relationships between trace substance concentrations and environmental characteristics be determined?
4. How can differences in time be detected?

Guided by these questions, we arrive at a set of recommendations for analyzing RMP data with an underlying goal of facilitating the upcoming five-year review of the data and program. Due to the size of the data set, the complexity of the issues, and the limited time available, we have not attempted to apply any of these techniques exhaustively to the data set for definitive answers. This is the task of the five-year review. We do offer a specific example of each recommended approach.

We used water column near-total trace element data collected and provided by Russ Flegal and his group at the University of California at Santa Cruz. Although based on the trace element data, our recommendations should be applicable to other trace contaminants as well.

Table 2. RMP and pilot sampling events.

Event	Start	Finish
1	2 Apr. 1989	2 Apr. 1989
2	9 Aug. 1989	11 Aug. 1989
3	2 Dec. 1989	2 Dec. 1989
4	15 Jun. 1990	15 Jun. 1990
5	19 Sep. 1990	21 Sep. 1990
6	12 Jun. 1991	14 Jun. 1991
7	8 Apr. 1992	11 Apr. 1992
8	3 Mar. 1993	6 Mar. 1993
9	25 May 1993	28 May 1993
10	14 Sep. 1993	17 Sep. 1993
11	31 Jan. 1994	9 Feb. 1994
12	19 Apr. 1994	29 Apr. 1994
13	16 Aug. 1994	25 Aug. 1994
14	7 Feb. 1995	16 Feb. 1995
15	19 Apr. 1995	28 Apr. 1995

Spatial Stratification

Horizontal stratification of the Estuary can be of value in reducing the variance of global estimates such as the mean. We investigated model-based clustering of the trace element data as a means for choosing the strata in the case of San Francisco Bay (Figure 43). Two problems were encountered. First, the data are sufficient to identify, at most, only two significant clusters for any sampling event. Second, the clusters change both with the trace element in question and the sampling event. The first problem is a consequence of the limited data. The second problem is an underlying feature of the Estuary. As a result, we believe that the use of clustering in this context is unlikely to be of help, and is prone to mislead unless cluster statistical significance is also assessed. Note that stratification of the Estuary does not have to be optimal in order to be effective in reducing variance so that clustering and other "objective" approaches are not actually necessary.

[1] This summary contains excerpts from a more extensive report available from SFEI. Space limitations did not allow full elaboration of statistical methods in this summary—see the full report for more detail.

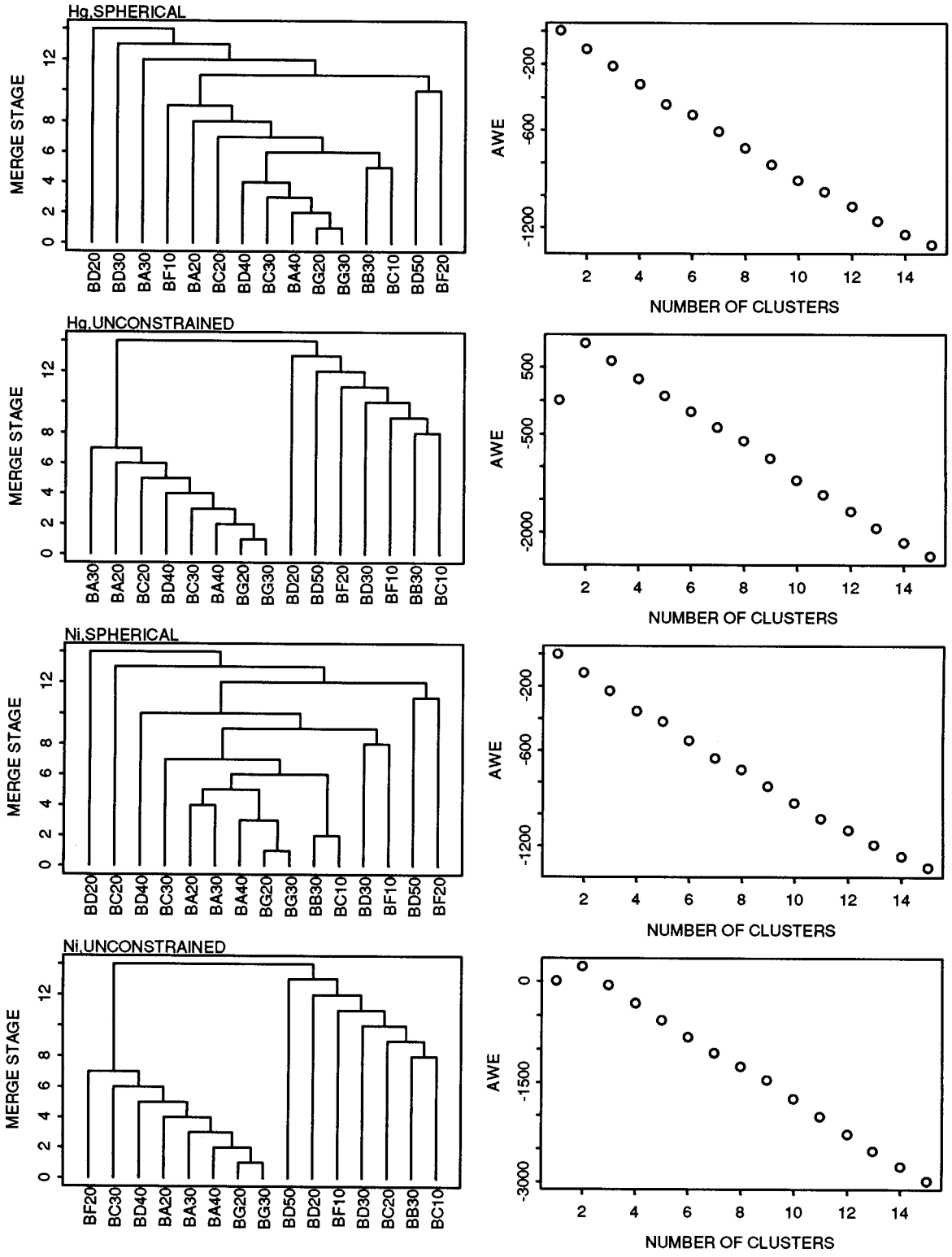

Figure 43. Example of RMP station clusters for mercury and nickel based on sampling events 7–15 (Table 2). Spherical and unconstrained: refer to clustering algorithms; AWE: approximate weight of evidence for determining number of significant clusters. See full report for details.

In any case, stratification to reduce variance is currently a moot point as the RMP stations are not a probability-based sample to begin with and cannot provide proper estimates of the Estuary's mean and variance. The desirability of such global estimates and a possible redesign of station siting needs to be considered carefully.

If global estimates are desired, the stations should be laid out so that proper estimates can be made of global properties such as subembayment means. Given the experience in other systems with significant spatial autocorrelation, a systematic (regular) grid of stations is to be preferred over a random one. This "primary" set of stations should be supplemented with a "secondary" set located nearshore by effluents suspected to be important sources of one or more contaminants. The purpose of the primary set is to establish regional status and trends. The purpose of the secondary set is to provide important supplemental local information that could bear on causality.

The number of primary stations needs to be determined on the basis of a model for the design and the desired performance in terms of trend detection. An important requirement for this determination is inclusion of the spatial correlation structure. The primary grid of stations remains fixed through time, although the exact subset of these stations sampled each year may cycle in some way.

Secondary stations, on the other hand, are determined by an understanding of possible sources. The secondary set may change from year to year in a flexible way depending on the accumulated data and changes in activities within the watershed.

Regional Differences

Spatial stratification can also be pursued for other reasons, such as to identify local point sources. A visual examination of the total trace element spatial patterns, as well as consideration of hydrology and physiography, leads to the choice of three or four subregions: 1. south of San Bruno Shoal (SB); 2. San Bruno Shoal through Point San Pablo (CB); 3. north of Point San Pablo (NB). The latter stratum can be further subdivided between Honker and Grizzly bays, although this leaves only three stations in the upstream stratum (Figure 44).

Spatial autocorrelation in estuaries potentially precludes the use of classical ANOVA for assessing subregion differences. Spatial ANOVA, in which individual sites are influenced not only by their location within subregions, but also by the values at neighboring sites, provides the solution. We examined the data for ten trace elements during 3 sampling events. We were able to determine well-behaved models in 24 of the 30 cases; 4 of the 24 cases required incorporation of spatial autocorrelation effects. In 22 of the 24 cases, we found evidence for distinct spatial subregions. Further analyzing the pairwise differences, the most common pattern (18 of 24 cases) was a depression of "Central Bay" (stratum 2 above) concentrations with respect to both "South" and "North" bay levels; means of the latter two were not significantly different in these cases (Table 3).

Causal Mechanisms

Anomalous stations for any trace element and sampling event can be identified using the Moran scatterplot. Using a robust fit to the Moran scatterplot, we identified the most important positive anomalies for each trace element during sampling event 13. Positive anomalies can be interpreted as important sources. The San Jose station was the most common anomaly, followed by the Petaluma River (Figure 45).

Spatial autocorrelation in estuaries will result in potentially spurious correlations between almost any two variables. The partial Mantel test can be used to examine correlations among variables that are also spatially autocorrelated. As an example, 9 of 10 trace elements were correlated with TSS during sampling event 12, but only one association remained after spatial autocorrelation was accounted for using the partial Mantel statistic (Table 4). Accounting for spatial autocorrelation results in a conservative test for association between two variables; the actual causal relation

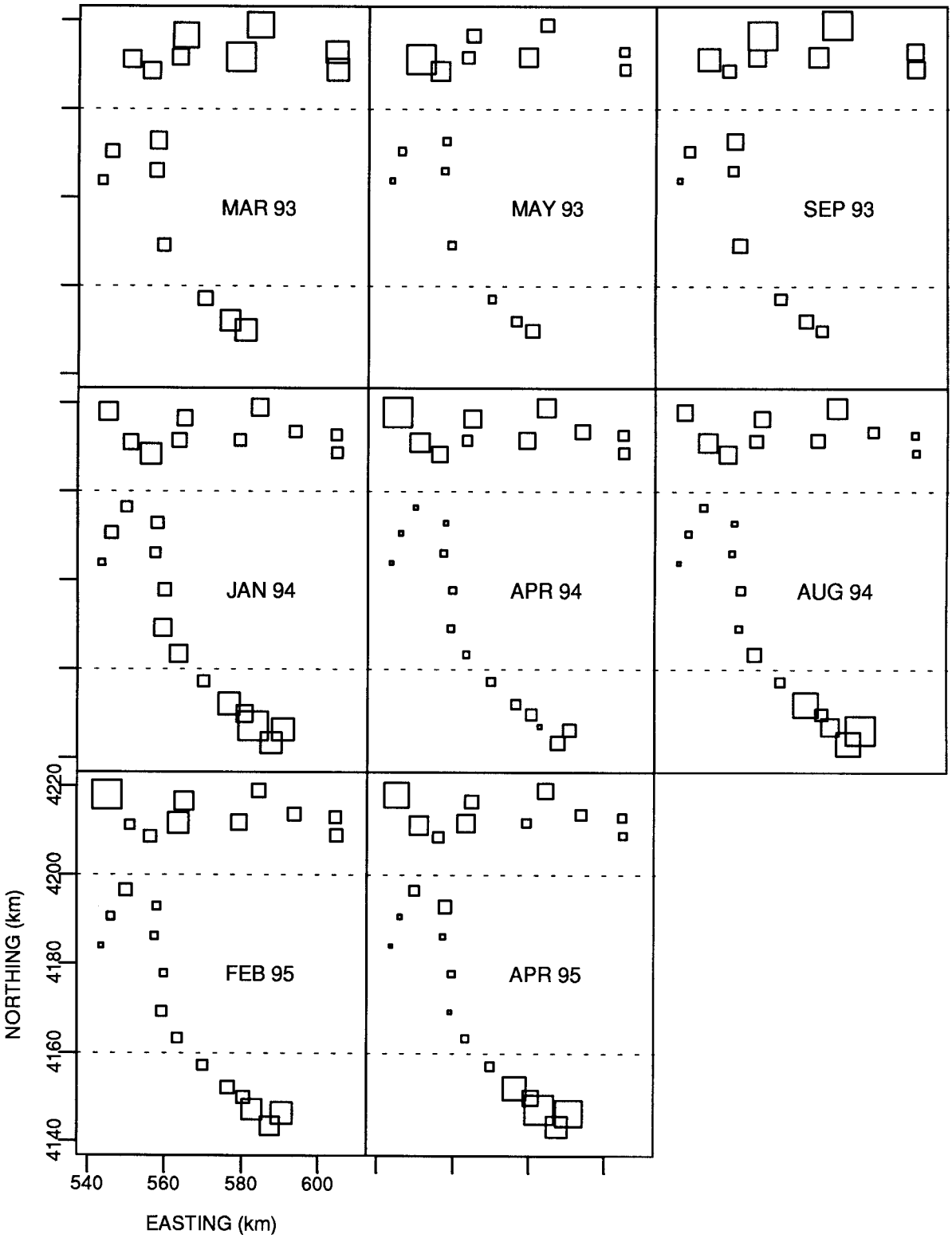

Figure 44. Total mercury distributions mapped in UTM coordinates. Each map corresponds to a single element and single RMP sampling event. The area of each square is proportional to the concentration, expressed as a fraction of the largest value found in each sampling event. The dashed line at 4,160 km separates out all stations south of the San Bruno Shoal. The dashed line at 4,200 km separates out all stations in the North Bay.

Table 3. Summary of spatial ANOVA results. See full report for details.

Element	Event	Model	Subregions Different?	Pairwise Differences
Ag	12	OLS	y	NB>CB, SB>CB
	13	-[1]	-	-
	14	OLS	y	NB>CB, SB>CB
As	12	OLS	-[2]	-
	13	LAG	y	NB>CB, SB>CB
	14	OLS	n	NB>CB
Cd	12	OLS	n	none
	13	-[1]	-	-
	14	OLS	y	SB>CB, SB>NB
Cr	12	OLS	y	NB>CB, SB>CB
	13	OLS	y	NB>CB, SB>CB
	14	OLS	y	NB>CB, SB>CB, NB>SB
Cu	12	OLS	y	NB>CB, SB>CB
	13	OLS	y	NB>CB, SB>CB
	14	OLS	y	NB>CB, SB>CB
Hg	12	OLS	y	NB>CB, SB>CB, NB>SB
	13	ROBUST	y	NB>CB, SB>CB
	14	OLS	y	NB>CB, SB>CB
Ni	12	OLS	y	NB>CB, SB>CB
	13	OLS	y	NB>CB, SB>CB
	14	OLS	y	NB>CB, SB>CB
Pb	12	OLS	y	NB>CB, SB>CB
	13	LAG	y	NB>CB, SB>CB
	14	OLS	y	NB>CB, SB>CB
Se	12	LAG	y	SB>NB
	13	-[1]	-	-
	14	LAG	-[3]	-
Zn	12	OLS	y	NB>CB, SB>CB
	13	LAG	y	NB>CB, SB>CB
	14	LAG	-[3]	-

[1]Diagnostics suggested higher-order process.
[2]Non-normal.
[3]Heteroscedastic.

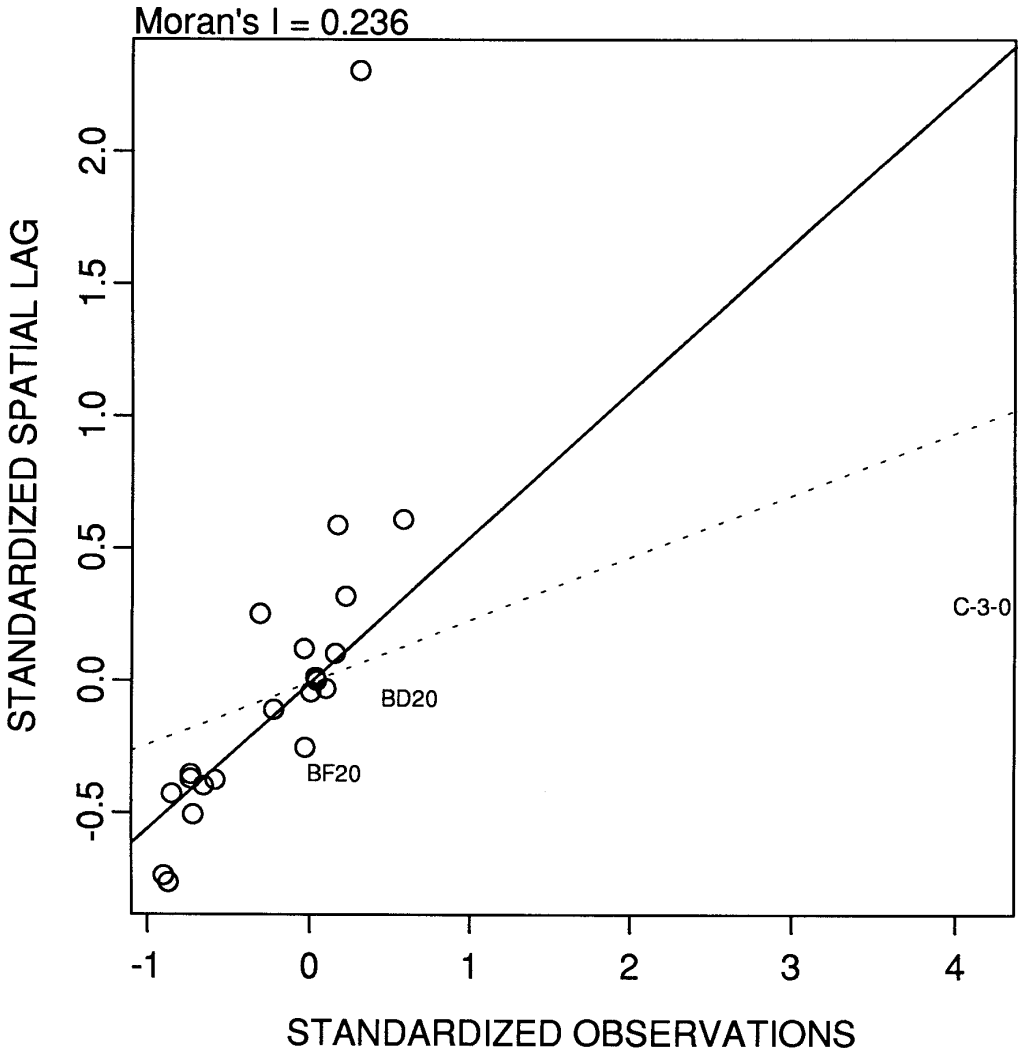

Figure 45. Moran scatterplots for each trace element during sampling event 13. The dashed line is the linear regression line. The solid line is the least trimmed squares regression line. Three points are designated by their station codes rather than by circles. These have the three most negative residuals with respect to the least trimmed squares line.

Table 4. Mantel tests of association between trace element totals, TSS and spatial position for sampling event 12. TE, COG and SPACE refer to the respective distance matrices for the trace element, TSS and spatial position. X·Y denotes the Mantel statistic for X and Y. (X·Y)·Z denotes the partial Mantel statistic for X and Y given Z. Statistics significant at the p=0.05 level are in bold.

Association	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se
TE·COG	**0.71**	**0.79**	**0.34**	**0.98**	**0.93**	**0.97**	**0.91**	**0.86**	-0.12
TE·SPACE	**0.15**	0.08	**0.33**	**0.15**	0.12	**0.16**	0.12	**0.14**	**0.59**
COG·SPACE	**0.14**	**0.14**	**0.14**	**0.14**	**0.14**	**0.14**	**0.14**	**0.14**	**0.14**
(TE·COG)·SPACE	0.06	0.06	-0.39	**0.72**	0.41	0.56	0.34	0.41	-0.54
(COG·SPACE)·TE	-0.31	0.12	-0.18	-0.3	0.01	-0.66	-0.11	0.11	0.13
(TE·SPACE)·COG	-0.09	-0.25	0.25	-0.49	-0.37	-0.4	-0.32	-0.18	0.61

may be significant but simply cannot be verified statistically.

Proper statistical testing of causal connection between two variables does not consist of a single association test, even if it incorporates a correction for spatial autocorrelation. A causal analysis includes an array of possible models, as well as the associations, lack of associations, and arithmetic relationships among associations that accompany each model. The RMP data is very limited in its ability to support such a causal analysis, primarily because of low power. However, the data is sufficient to narrow down the range of possible models. An example using chromium supports a direct effect of TSS on chromium. In general, though, the RMP should not expect any definitive causal analysis resulting from statistical analysis of the RMP data set.

Additional stations can only help, but it is difficult to know how many are really necessary, and there is a possibility of wasting any effort on more stations, at least in this particular context. Regardless of the success of a statistical analysis, an understanding of these causal relationships must be founded also on general chemical and ecological understanding, as well as non-RMP data sets and experimental work. As the RMP encounters the limits of its baseline data collection program in assessing causality on a statistical basis, more attention should be given to how other kinds of field measurements and experiments can narrow down even further the set of possible models.

Temporal Trends

The Mann-Kendall test is an appropriate way for determining trace element trends at individual sites. Individual site trends are by and large not significant. When trends are mapped in space, however, trends of the same sign tend to occur contiguously in apparently nonrandom clusters and suggest systematic changes for subregions of the Estuary (Figure 46).

The seasonal Kendall test can be adapted to test for an overall trend in groups of stations. The increase in the power is such that an overall trend may exist even when no trends can be detected for individual sites. Mapping of the individual trends can guide selection of station groupings. A correction must be made for the covariance among stations, similar to the correction for covariance among months in the conventional use of the seasonal Kendall test. An example is given with copper.

The power of trend tests can be increased by removing exogenous sources of short-term variance. Residuals are determined for a parametric (regression) or nonparametric (LOWESS) fit of the data and a Mann-Kendall test is applied to the residuals. An example is given using Net Delta Outflow (NDO) and cadmium. NDO has a negative effect on cadmium at all stations (Figure 47). Before accounting for NDO, only the San Joaquin station exhibited a (down) trend. After accounting for NDO, this station no longer had a significant trend while two stations near the Napa River showed significant uptrends. Selection of the exogenous variable depends on the exact question being asked and must be considered carefully.

Seasonality may also contribute to short-term variability, even after correcting for seasonal exogenous variables such as flow. The data set is too small at present to correct for seasonality using a dummy variable approach. At certain stations, data may be sufficient for trend tests using second-quarter data only, thus averting the issue of seasonality (Table 5).

Table 5. Number of sampling events per calendar year quarter.

Year	Q1	Q2	Q3	Q4
1989	0	1	1	1
1990	0	1	1	0
1991	0	1	0	0
1992	0	1	0	0
1993	1	1	1	0
1994	1	1	1	0
1995	1	1		
1996				

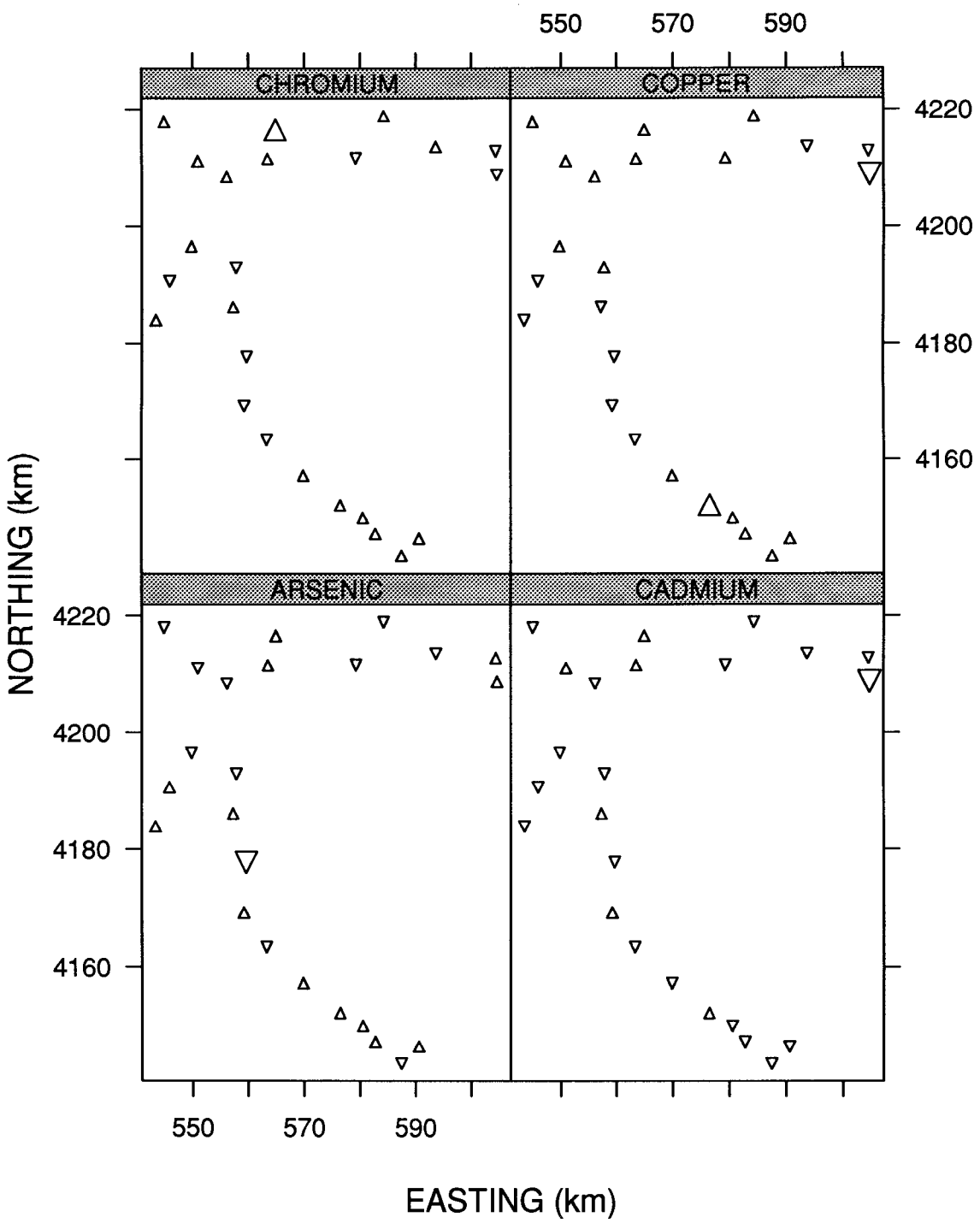

Figure 46. Trends in various trace element totals during 1991–1995. Upright triangle represent uptrends and inverted triangles represent downtrends. Weaker trends ($p>0.1$) are designated by small triangles, stronger trends ($p\leq0.1$) by large triangles.

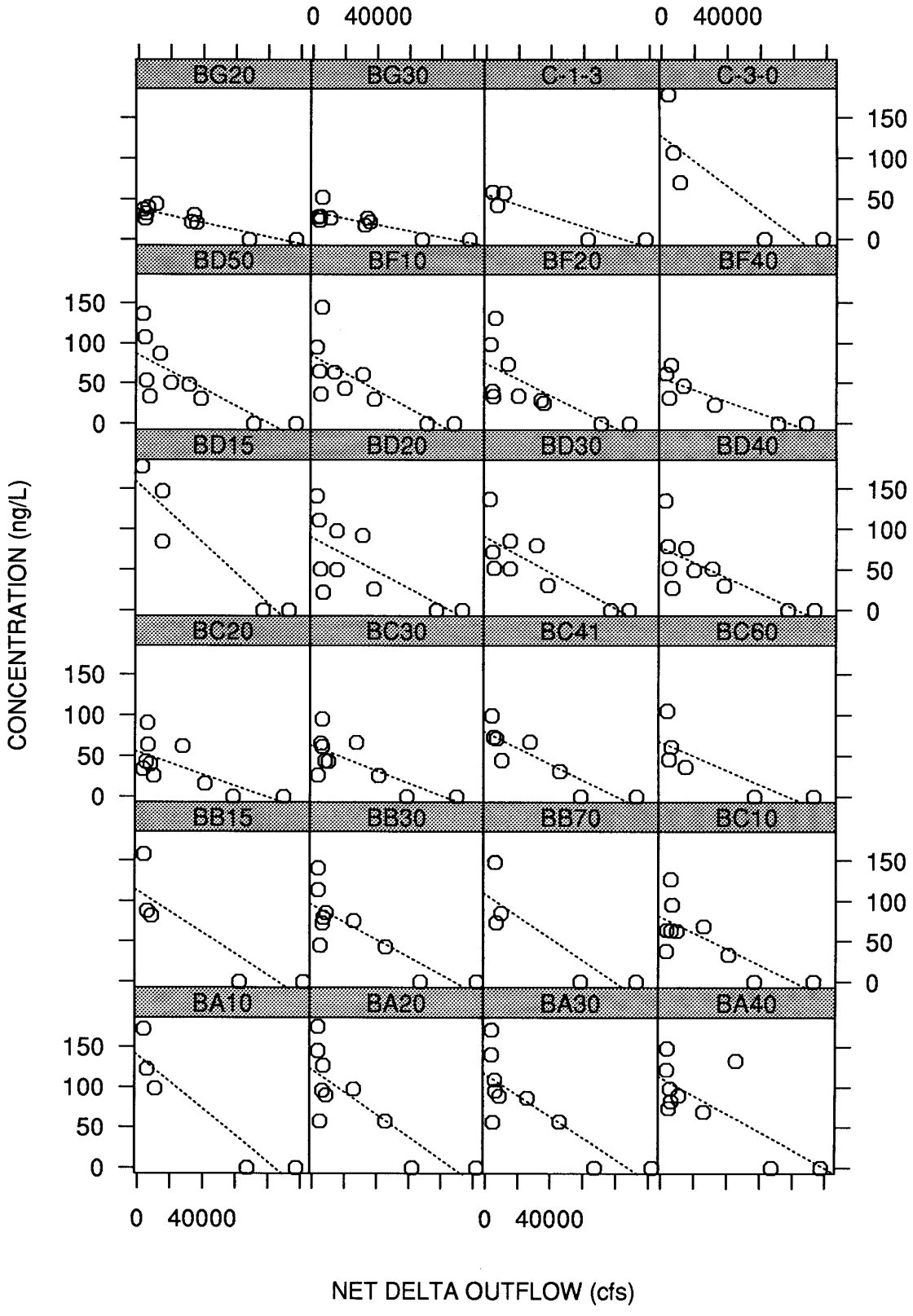

Figure 47. Total cadmium versus Net Delta Outflow. The straight line in each panel is a linear regression fit.

Time Series of Trace Element Concentrations Calculated from Time Series of Suspended Solids Concentrations and RMP Water Samples: Summary and Conclusions[1]

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Introduction

The supply and fate of trace elements in San Francisco Bay, which are partially dependent upon particulate matter in the Estuary, are important management issues. San Francisco Bay receives many waste water discharges, especially in areas south of the Dumbarton Bridge, that contain trace elements that accumulate in benthic organisms (Luoma *et al.*, 1985; Brown and Luoma, 1995). Trace elements tend to adsorb particulate matter (Kuwabara *et al.*, 1989), so the fate of trace elements is partly determined by the fate of suspended solids. Concentrations of dissolved trace elements are greater in the South Bay than elsewhere in San Francisco Bay, and bottom sediments are believed to be a significant source (Flegal *et al.*, 1991). The concentration of suspended particulate chromium in the Bay appears to be controlled primarily by sediment re-suspension (Abu-Saba and Flegal, 1995). Water quality standards for trace elements in the Bay are written in terms of total or near-total trace element concentrations (TEC).

This summary has two objectives. The first is to demonstrate the relationship between suspended solids concentration (SSC) and TEC by developing equations relating SSC to total (or near-total) concentrations of trace elements based on Regional Monitoring Program (RMP) data collected during 1993 and 1994. The second objective is to demonstrate the temporal variability of TEC that are linearly correlated (LCTEC) with SSC by presenting time-series information on LCTEC based on nearly continuous SSC measurements collected during the 1995 water year (October 1, 1994 to September 30, 1995) and the SSC-LCTEC equations.

Data Collection

During 1993 and 1994, the RMP conducted six sampling trips in San Francisco Bay during which water quality samples were collected and analyzed for many constituents, including SSC and TEC (SFEI, 1994; SFEI, 1996). The USGS has also established several SSC monitoring sites in San Francisco Bay at which SSC is measured every fifteen minutes. (Buchanan and Schoellhamer, 1995; Buchanan *et al.*, 1996).

Relations Between RMP SSC and TEC Data

Linear regression was used to determine equations relating RMP SSC and TEC data. The equations were applied to the USGS SSC measurements in Bay waters, so outlying data collected in tributary streams were discarded.

Excellent correlations with SSC were found for seven trace elements—silver, chromium, copper, mercury, nickel, lead, and zinc. For example, the linear regression for mercury is shown in Figure 48 (115 samples, r^2 is 0.90). All regressions are significant at less than the 0.001 level. SSC accounts for approximately 90 percent of the variability in the LCTEC. Poor correlations with SSC were found for the other three trace elements measured by the RMP—arsenic, cadmium, and selenium.

Outlying data from tributaries had either low or high LCTEC compared to the predicted values based on SSC ('x' symbols in Figure 48). These data probably reflect the influent waters, not Bay waters, and therefore were discarded. For example, influent from waste water treatment plants sometimes had a greater ratio of LCTEC to SSC than Bay

[1] This summary contains excerpts from a more extensive report available from SFEI.

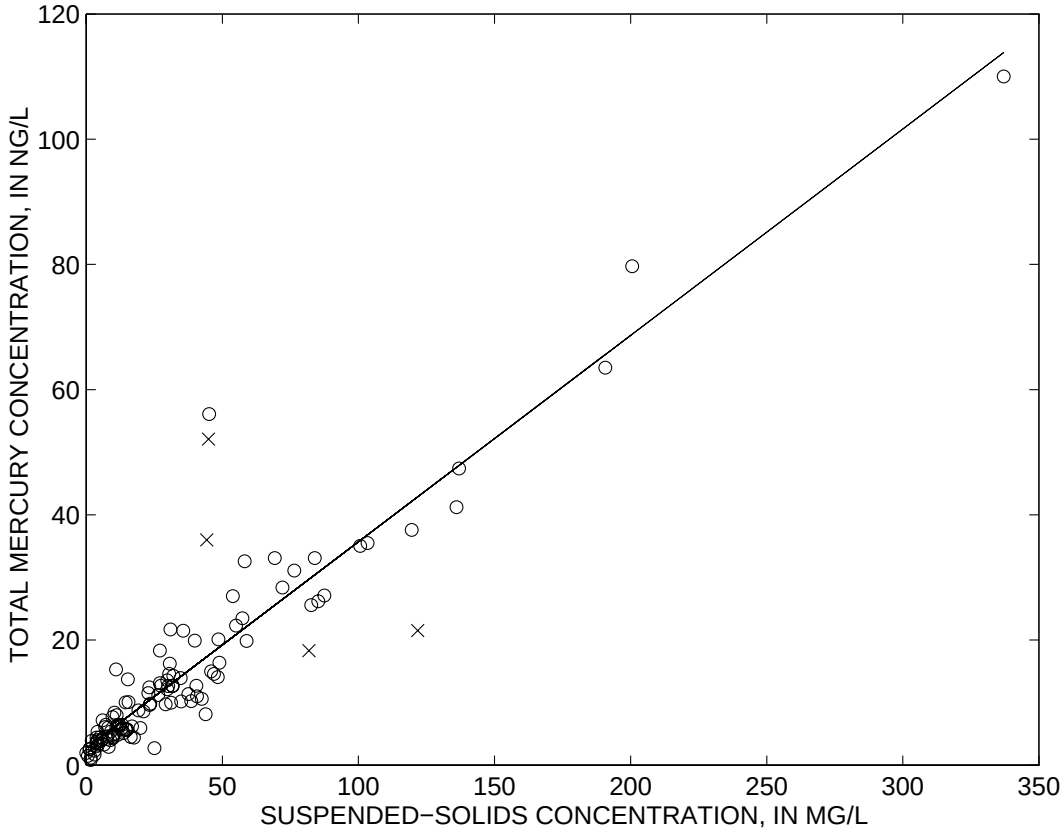

Figure 48. Correlation of SSC and total or near-total concentrations of mercury. Outliers from samples taken from influent waters are indicated with an 'X'

waters, and influent from natural rivers sometimes had a smaller ratio of LCTEC to SSC than Bay waters. Not all data collected at the tributary sites are outliers because Bay waters may be present at the sites (during flood tides for example), the tributary discharge may be small, or the ratio of LCTEC to SSC of the influent water may be close to that of Bay waters.

USGS SSC Data

An example time series of measured SSC data from mid-depth at Point San Pablo is shown in Figure 49. The high frequency variations were caused by tidal advection and tidal re-suspension of suspended solids. The fortnightly variation was caused by the spring-neap cycle. About one-half the variance of SSC was caused by the spring-neap cycle, and SSC lags the spring-neap cycle by about 2 days (Schoellhamer, 1996). The relatively short duration of slack water limited the duration of deposition of suspended solids and consolidation of newly deposited bed sediment during the tidal cycle, so suspended solids accumulated in the water column as a spring tide was approached and slowly deposit as a neap tide was approached. High concentrations in January and March were the result of runoff from the Central Valley, which transported suspended sediments to the Bay. Stronger winds during spring and summer increased sediment re-suspension in shallow water and thus increased SSC throughout the Bay.

Calculated LCTEC During Water Year 1995

LCTEC and SSC vary similarly in time because they are linearly related. An example calculated LCTEC time series for mercury at mid-depth at Point San Pablo is shown in Figure 49. Total mercury concentration varied because of tidal advection and tidal re-suspension of suspended solids and associated mercury, the fortnightly spring-neap cycle, and the seasonally stronger summer winds. The high inflow during January and March increased SSC and, assuming that the relationship between SSC and total

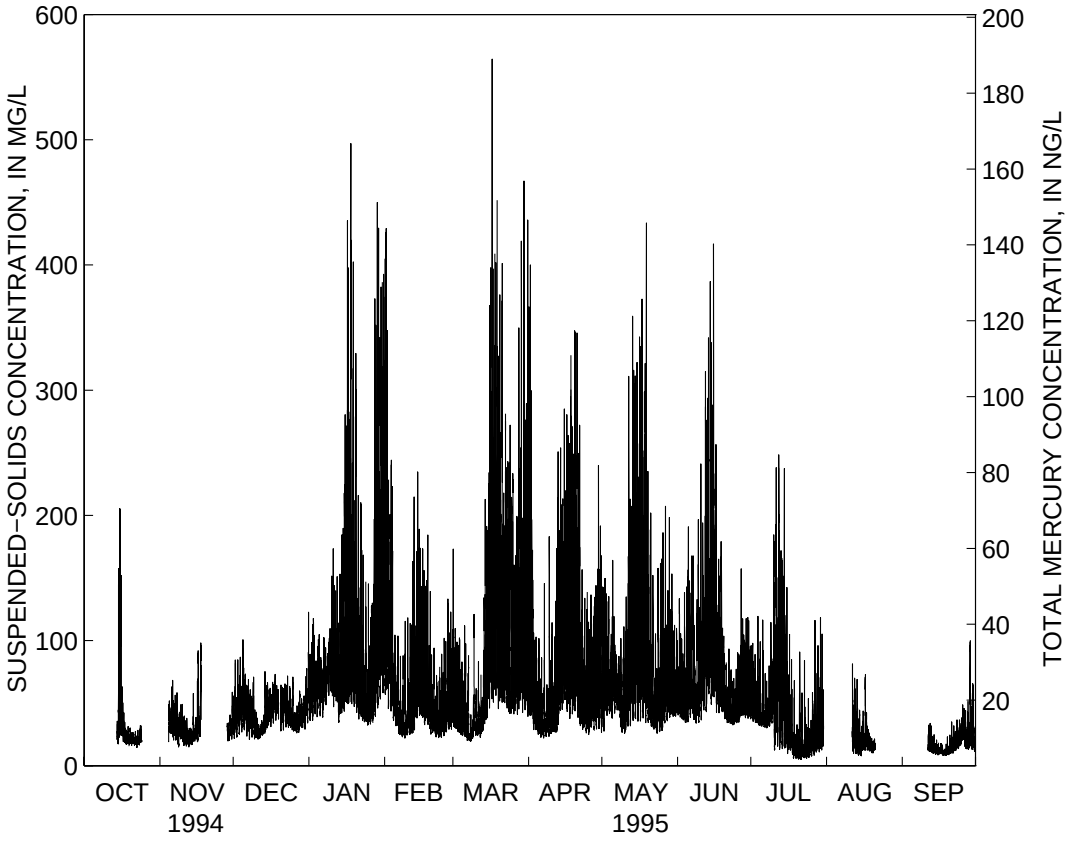

Figure 49. Time series of mid-depth SSC (measured) and total mercury concentration (calculated) at Point San Pablo, water year 1995.

mercury concentration was unchanged at Point San Pablo, increased total mercury concentration. RMP data collected in February and April of 1995 in the Northern Estuary (SFEI, 1995) indicates that the relationship was virtually unchanged in the open Bay waters. As with SSC, about one-half the variance of LCTEC was caused by the spring-neap cycle.

Discussion and Conclusions

Seven TEC are well correlated with SSC for Bay waters. Influent waters from waste water treatment plants sometimes had a greater TEC to SSC ratio than Bay waters, and natural tributaries sometimes had a smaller ratio than Bay waters. Linear equations relating LCTEC and SSC can be applied to the nearly continuous time series of SSC collected by the USGS to produce similar time series of LCTEC.

Because of their relationship with SSC, LCTEC vary with time because of tides, the spring-neap cycle, seasonal winds, and watershed runoff. Frequent sampling, on the order of minutes, is required to observe these variations, but such a TEC sampling program would be prohibitively expensive. The combination of the existing RMP sampling data and USGS SSC data produces computed LCTEC every 15 minutes at the USGS SSC monitoring sites. These computed LCTEC can be used to monitor temporal variations in LCTEC that the RMP sampling program can not observe and thus enhance the existing direct RMP TEC measurements by helping to place them in a proper context.

Acknowledgments

Operation of the SSC monitoring sites during water year 1995 was supported by the US Army Corps of Engineers; the California Regional Water Quality Control Board, San Francisco Bay Region; the USGS Federal/State Cooperative Program; and the USGS San Francisco Bay Ecosystem Initiative. I would like to thank Alan Jassby for his helpful comments.

Toxic Phytoplankton in San Francisco Bay

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Introduction

The Regional Monitoring Program (RMP) was conceived and designed to document the changing distribution and effects of trace substances in San Francisco Bay, with focus on toxic contaminants that have become enriched by human inputs. However, coastal ecosystems like San Francisco Bay also have potential sources of naturally-produced toxic substances that can disrupt food webs and, under extreme circumstances, become threats to public health. The most prevalent source of natural toxins is from blooms of algal species that can synthesize metabolites that are toxic to invertebrates or vertebrates. Although San Francisco Bay is nutrient-rich, it has so far apparently been immune from the epidemic of harmful algal blooms in the world's nutrient-enriched coastal waters. This absence of acute harmful blooms does not imply that San Francisco Bay has unique features that preclude toxic blooms. No sampling program has been implemented to document the occurrence of toxin-producing algae in San Francisco Bay, so it is difficult to judge the likelihood of such events in the future. This issue is directly relevant to the goals of RMP because harmful species of phytoplankton have the potential to disrupt ecosystem processes that support animal populations, cause severe illness or death in humans, and confound the outcomes of toxicity bioassays such as those included in the RMP. Our purpose here is to utilize existing data on the phytoplankton community of San Francisco Bay to provide a provisional statement about the occurrence, distribution, and potential threats of harmful algae in this Estuary.

A Brief Review of the Regional Problem

The incidence of toxic or noxious algal blooms is increasing worldwide, especially in estuaries and shallow inshore waters that are impacted by human activities that lead to nutrient enrichment or the introduction of exotic species (Smayda, 1990; Hallegraeff, 1993; Anderson, 1995). Harmful algal blooms are caused by those species of planktonic microalgae that produce toxic or noxious substances; develop high density blooms that degrade water quality; or, because they are unsuitable prey species, disrupt food webs. Toxin-producing species are the most widely recognized, but these represent only about 40 of over 5000 phytoplankton species (Hallegraeff, 1995). For some species, their "harmfulness" is situational. For example, some diatoms (*Chaetoceros* spp.) have long spines that can damage the gills of fishes (Horner *et al.*, in press). Some phytoplankton (e.g., *Heterosigma akashiwo*; Maestrini and Bonin, 1981) produce bioactive compounds that affect other phytoplankton species, while others produce substances that directly affect the health of fish, birds, mammals, or even humans.

In coastal waters of western North America, dinoflagellates of the genus *Alexandrium* produce saxitoxins, the causative agent of Paralytic Shellfish Poisoning (PSP). The seasonal toxicity of shellfish was well known by coastal tribes of native Americans, and PSP was reported by early European explorers (Price *et al.*, 1991). Blooms of *Alexandrium* are common events; Price *et al.* (1991) reported that PSP-toxic blooms were detected in 22 of the 28 years between 1962 and 1989. PSP toxins accumulate in the tissues of filter-feeders, and toxin levels in mussels *(Mytilus californianus)* are monitored along the

coast by the California Department of Health Services (Langlois, 1992).

Domoic acid-producing diatoms that result in Amnesic Shellfish Poisoning (ASP) are a recently recognized problem in California waters (Todd, 1993). In September of 1991, more than 100 brown pelicans and Brandt's cormorants were found dead or suffering from unusual neurological symptoms caused by domoic acid in Monterey Bay (Fritz *et al.*, 1992; Work *et al.*, 1993). This event was followed by occurrences of domoic acid poisoning along the coasts of Oregon and Washington, in which humans were afflicted after consuming domoic acid-contaminated clams (Todd, 1993). The 1991 domoic acid-poisoning event in central California was attributed to a bloom of *Pseudo-nitzschia australis* (Buck *et al.*, 1992; Fritz *et al.*, 1992; Garrison *et al.*, 1992). Domoic acid production has now been reported for five species of *Pseudo-nitzschia*: *P. australis*, *P. pungens* f. *multiseries*, *P. pseudodelicatissima*, and *P. seriata*. These species all occur along the west coast of North America.

Red tides (blooms discoloring the water) are also common on the central and southern California coast. Several dinoflagellate species, including *Lingulodinium polyedrum (=Gonyaulax polyedra), Prorocentrum micans, Gymnodinium splendens, G. flavum, Ceratium furca, C. fusus,* and *Protoperidinium* spp., have been reported to form dense blooms at various times and locations (Horner *et al.*, in press). Visible blooms of the pigmented ciliate *Mesodinium rubrum* occur in San Francisco Bay, especially during years of heavy rainfall (Cloern *et al.*, 1994). All of the red tides reported in California waters have been formed by non-toxic species. However, zooplankton avoid dense populations of some red tide algae (Fiedler, 1982) and some species may be harmful to filter-feeders, including pelagic larvae (Cardwell *et al.*, 1979). Species of *Dinophysis* (associated with Diarrhetic Shellfish Poisoning), noxious bloom-forming species such as *Phaeocystis pouchetii,* and diatom species that damage fish gills (e.g., *Chaetoceros convolutus, C. concavicornis,* and *C. danicus*), are also common in California waters but have not been associated with any adverse conditions here.

There is little information about the occurrence of these toxic or harmful species of phytoplankton in San Francisco Bay. Since there is free exchange of waters through the Golden Gate, it is likely that harmful marine species are regularly introduced into the Bay from adjacent coastal waters. Moreover, with inflows from the Sacramento-San Joaquin Rivers, freshwater cyanobacteria (Codd *et al.*, 1995) could also develop blooms and produce harmful or toxic conditions in the northern regions of the Bay-Delta. As a first step to address these hypotheses, we analyzed an historical phytoplankton database. Our objectives were to (1) review recent information to determine the occurrence and distribution of phytoplankton species known to produce toxins or degrade water quality, and (2) to give a provisional judgment about the potential effects of harmful blooms in the context of the broader RMP objectives of understanding the origin and effects of toxic substances in the San Francisco Bay-Delta.

The Phytoplankton Database

From 1992 through 1995, phytoplankton samples were collected monthly at a series of stations in San Francisco Bay (Figure 37) by the United States Geological Survey (USGS). Sampling in 1993 was supported as a pilot program of the San Francisco Estuary Regional Monitoring Program for Trace Substances (SFEI, 1994; Caffrey *et al.*, 1994). Additional samples, up to several samplings per month, were collected in South San Francisco Bay during the spring blooms. Water samples for plankton analysis were collected in the surface layer by pump or Niskin bottle, and subsamples were preserved with Lugol's iodine solution (1%) or glutaraldehyde. Aliquots examined for species counts ranged from 2–5 mL depending on sample turbidity. Cells were concentrated in sedimentation chambers and then counted and identified using a phase-contrast inverted microscope. Phytoplankton cells greater than 30 μm in diameter were enumerated at 125X

magnification. Smaller cells were counted at 1250X. At least 100 cells of the most numerous taxa were counted using the strip count method at 1250X (American Public Health Association, 1989). Identifications of diatoms and dinoflagellates were made after the cell contents were cleared in 30% hydrogen peroxide.

The USGS database listed 231 algal species. To simplify the spatial analysis, we grouped stations by region: South Bay (SB) included USGS stations 21–36; Central Bay (CB) included stations 15–18; and North Bay (NB) stations 2–14 and the Sacramento River station 657 (Figure 37). The sampling dates for each region are summarized in Table 1, along with notations of harmful bloom events in nearby coastal waters.

Results and Analysis

Over twenty algal taxa regarded to be harmful, noxious, or toxin-producing were reported in the USGS database (Table 6). The occurrences of these taxa ranged from common to relatively rare, and some reached moderately high densities. Some species showed marked variations in abundance and frequency of occurrence among the different regions within San Francisco Bay.

Toxic species

Alexandrium species that produce saxitoxins causing Paralytic Shellfish Poisoning (PSP) were the most prevalent toxic forms in San Francisco Bay. *Alexandrium* cells were abundant during spring in the South and Central Bays, reaching densities of 10^5 cells/L (Table 6, Figure 50). This group of dinoflagellates was persistent in South San Francisco Bay during the prolonged spring bloom of 1995 (Cloern *et al.*, 1996). PSP toxin levels in *Mytilus californianus* are monitored by the California Department of Health Services (CDHS), but no samples have been taken from San Francisco Bay in recent years. PSP toxins were detected in mussels sampled north of San Francisco Bay in Marin County and south of San Francisco Bay in San Mateo County (Figure 51) during May–June, roughly corresponding to the periods when *Alexandrium* was reported in San Francisco Bay. The seasonal coherence of these data may indicate a connection between oceanic and estuarine blooms, but the correlation of toxin levels from the outer-coast with *Alexandrium* abundances in South San Francisco Bay is weak. For example, the persistently high abundances of *Alexandrium* during the spring of 1995 (Figure 50) were not matched by high PSP levels in coastal mussels (Figure 51).

Alexandrium blooms are generally believed to originate from resuspended benthic resting stages (Price *et al.*, 1991), but there is no information about the occurrence of benthic seed stocks within the Bay. The pattern of toxin accumulation in filter-feeding animals of other California estuaries and embayments suggests that *Alexandrium* blooms develop in ocean waters and are advected into embayments by tidal currents (e.g., Drakes Bay: Price *et al.*, 1991; Langlois, 1992). *Alexandrium* abundances in California ocean waters are deduced from toxin accumulation in shellfish (Price *et al.*, 1991), but there is little direct information about actual population densities. Cell counts from samples collected off the Santa Cruz wharf suggest that *Alexandrium catenella* densities rarely exceed 200 cells/L in Monterey Bay (Chris Scholin, pers. comm.; Monterey Bay Aquarium Research Institute). The high densities of *Alexandrium* found in South San Francisco Bay (one or two orders of magnitude greater), and the weak correlation between toxin levels in coastal mussels and *Alexandrium* abundances in the South Bay, suggest that the high *Alexandrium* abundances are the result of population growth within the Estuary.

We were surprised to find low frequencies of domoic acid-producing diatoms *(Pseudo-nitzschia)* in the records from San Francisco Bay (Figure 52, Table 6). There was a widespread bloom of *Pseudo-nitzschia australis* along the open coast during the autumn of 1991 (Buck *et al.*, 1992; Garrison *et al.*, 1992; Walz *et al.*, 1994). Populations in Marin County and Monterey Bay were abundant at several periods during 1992-1995 (Table 7). Within San

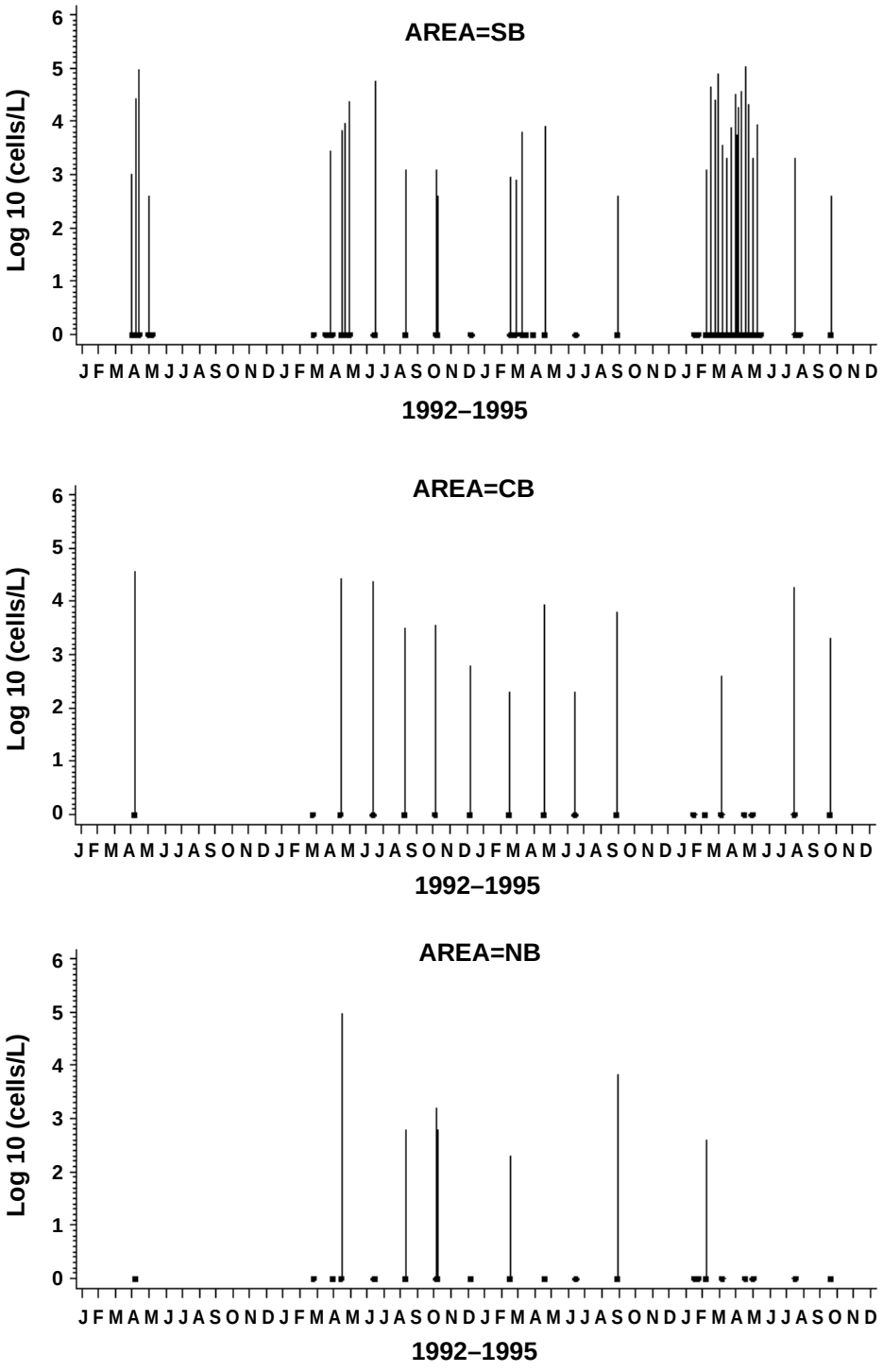

Figure 50. Abundance (x10^n cells/L) of *Alexandrium* spp. cells at South Bay (a), Central Bay (b), and North Bay (c) locations during the study period (1992–1995). Points (•) indicate sampling dates in each region.

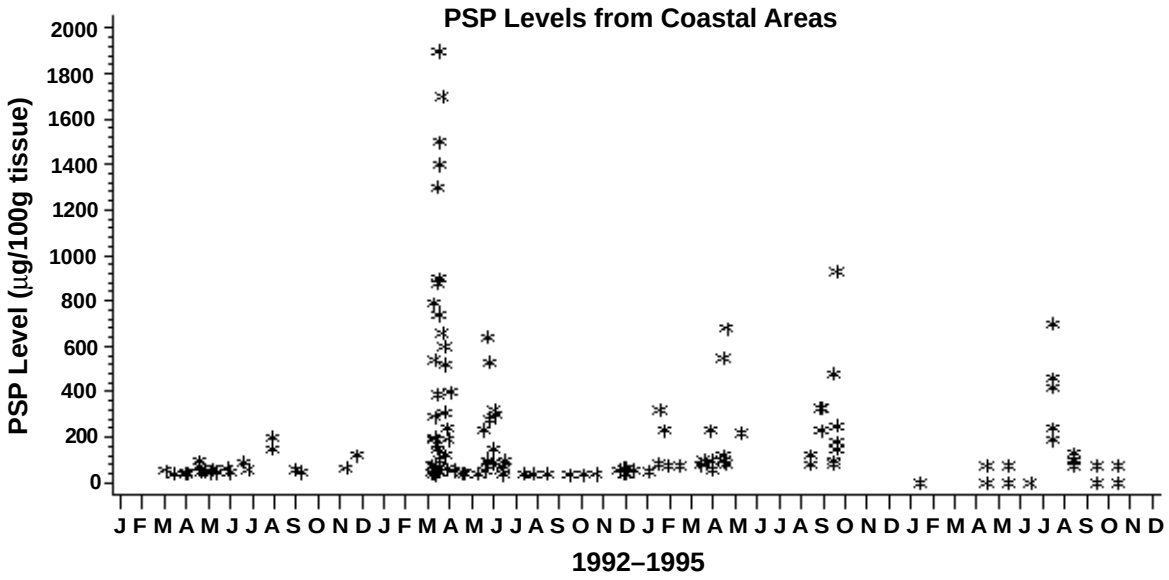

Figure 51. Paralytic Shellfish Poisoning (PSP) toxin levels, measured as µg/100g of shellfish tissue, from the California Department of Health Services (CDHS) Toxic Phytoplankton Monitoring Program on the outer coast of California. Observed levels are taken from Marin and San Mateo Counties from 1992–1995.

Francisco Bay, CDHS reported blooms of a *Pseudo-nitzschia* species, tentatively identified as *P. pseudodelicatissima,* with densities of $4.6x10^6$ cells/L in the Berkeley Marina during July–August 1993 (Table 7). None of these events were reflected in the San Francisco Bay records, however, because USGS did not collect samples at the times and locations of these *Pseudo-nitzschia* blooms.

Oscillatoria, a freshwater cyanobacterium that produces neurotoxin, was present at North Bay stations where freshwater is brought into the Estuary (Figure 53). Another toxic freshwater cyanobacterium, *Anabaena* spp., was occasionally found in the San Francisco records (Table 6).

Red-tides

Red tide-forming dinoflagellates were generally poorly represented in the data records from San Francisco Bay, although visible red tides formed by the protozoan *Mesodinium rubrum* were documented during this period (Cloern *et al.,* 1994). A *Ceratium* spp. was found at high densities but with only a few observations. In the South Bay, *Prorocentrum* spp. was common at high densities from 1992–1995 as part of the spring phytoplankton assemblage, and this genus was also persistent during the prolonged spring bloom of 1995 (Figure 54). The low frequency and abundance of red tide-forming dinoflagellates probably reflects a bias in the sampling program rather than an absence of these forms from San Francisco Bay. Red tides in central California are most common during the summer and autumn months and are associated with stratification following a relaxation of coastal upwelling (Bolin and Abbott, 1963; Horner *et al.*, in press). However, the USGS sampling was most intensive during the spring bloom periods, and in some years late summer samples were absent or very sparse (Table 7, Figures 50, 52–54).

Other Harmful or Noxious Species

Most of the potentially harmful or noxious species of phytoplankton within San Francisco Bay (e.g., species of *Aphanizomenon, Coscinodiscus, Cerataulina pelagica, Dinophysis, Distephanus, Noctiluca,* and *Schizothrix* in the North Bay) had few occur-

Table 6. Maximum abundance and number of occurrences of harmful, toxic, or noxious microalgal taxa in three regions of San Francisco Bay. Total numbers of samples collected in each region are shown in parentheses (see Table 7).

Species	Central Bay		North Bay		South Bay	
	Maximum Abundance (cells/L)	Occurrences (of 18 samples)	Maximum Abundance (cells/L)	Occurrences (of 66 samples)	Maximum Abundance (cells/L)	Occurrences (of 125 samples)
Alexandrium spp.	35200	13	93400	7	104000	35
Anabaena spp.	-	-	98000	7	-	-
Aphanizomenon flos-aquae	-	-	38000	1	-	-
Cerautulina pelagica	-	-	-	-	3000	1
Ceratium furca	-	-	1200	1	-	-
Ceratium minutum	19600	4	500	1	1200	2
Chaetoceros debile	10800	4	187800	2	72500000	7
Chaetoceros socialis	1800	3	179000	4	8125000	14
Dinophysis spp.	1200	4	200	2	2400	3
Coscinodiscus concinnus	-	-	-	-	104800	2
Cylindrotheca closterium	125000	9	62500	2	766025	19
Dictyocha speculum	1600	3	-		200	1
Gymnodinium spp.	36400	6	1062500	5	24000	12
Planktolyngbya subtilis	344000	1	137600	1	-	-
Mesodinium rubrum	10000	7	344300	13	4601333	42
Noctiluca sp.	3400	4	400	1	5300	6
Oscillatoria spp.	-		6019000	10	74000	5
Peridinium sp.	200	1	1800	1	23000	3
Phormidium sp.	-	-	206400	1	-	-
Prorocentrum spp.	20400	10	34400	4	1376000	34
Protoperidinium spp.	7000	10	600	2	500000	27
Pseudo-nitzschia sp.	32400	5	1600	1	960000	8
Schizothrix sp.	-	-	500000	2	-	-

Table 7. Phytoplankton sampling dates in San Francisco Bay, 1992–1995. Columns 2–4 show the total number of samples taken, by region, for each month. Other toxic events were those reported by the California Department of Health Services* or by Walz *et al.* (1994)**.

Year	Month	Central Bay	North Bay	South Bay	Other Toxic Events in the Region
1992	January				
	February				
	March				
	April	1	2	8	*Elevated PSP levels, Drakes Bay
	May			2	
	June				*Elevated PSP levels, Stinson Beach
	July				
	August				
	September				
	October				***Pseudo-nitzschia* in Monterey Bay
	November				***Pseudo-nitzschia* in Monterey Bay
	December				
1993	January				
	February	1	3	2	
	March		2	8	*Elevated PSP levels in Marin, Sonoma, Mendocino Co.
	April	1	3	10	*March-May Quarantine in Marin, Sonoma, Mendocino Co.
	May				***Pseudo-nitzschia* in Monterey Bay
	June	1	7	5	*Elevated PSP levels, Drakes Bay
	July				*Berkeley marina *Pseudo-nitzschia* bloom
	August	1	3	2	
	September				
	October	1	7	4	
	November				
	December	1	3	2	
1994	January				*Elevated PSP levels, Drakes Bay
	February	1	3	3	**Pseudo-nitzschia* abundant in Drakes Estero
	March			3	*Elevated PSP levels, Drakes Bay
	April	1	3	4	*Elevated PSP levels, Drakes Bay
	May				
	June	1	4	2	
	July				
	August	1	4	4	*Elevated PSP levels Marin, San Mateo Co.
	September				*Elevated PSP levels, Drakes Bay
	October				
	November				
	December				
1995	January	1	4	5	
	February	1	3	14	
	March	1	3	13	
	April	1	3	19	
	May	1	3	10	
	June				
	July	1	3	3	*Elevated PSP levels Marin (Rodeo Beach)
	August				*"Red tide" of *Gymnodinium splendens*
	September	1	3	2	
	October				
	November				**Pseudo-nitzschia* abundant in Marin, SF Co. (Ocean)
	December				**Pseudo-nitzschia* abundant in Marin Co., Farallone Is.
	TOTALS	18	66	125	

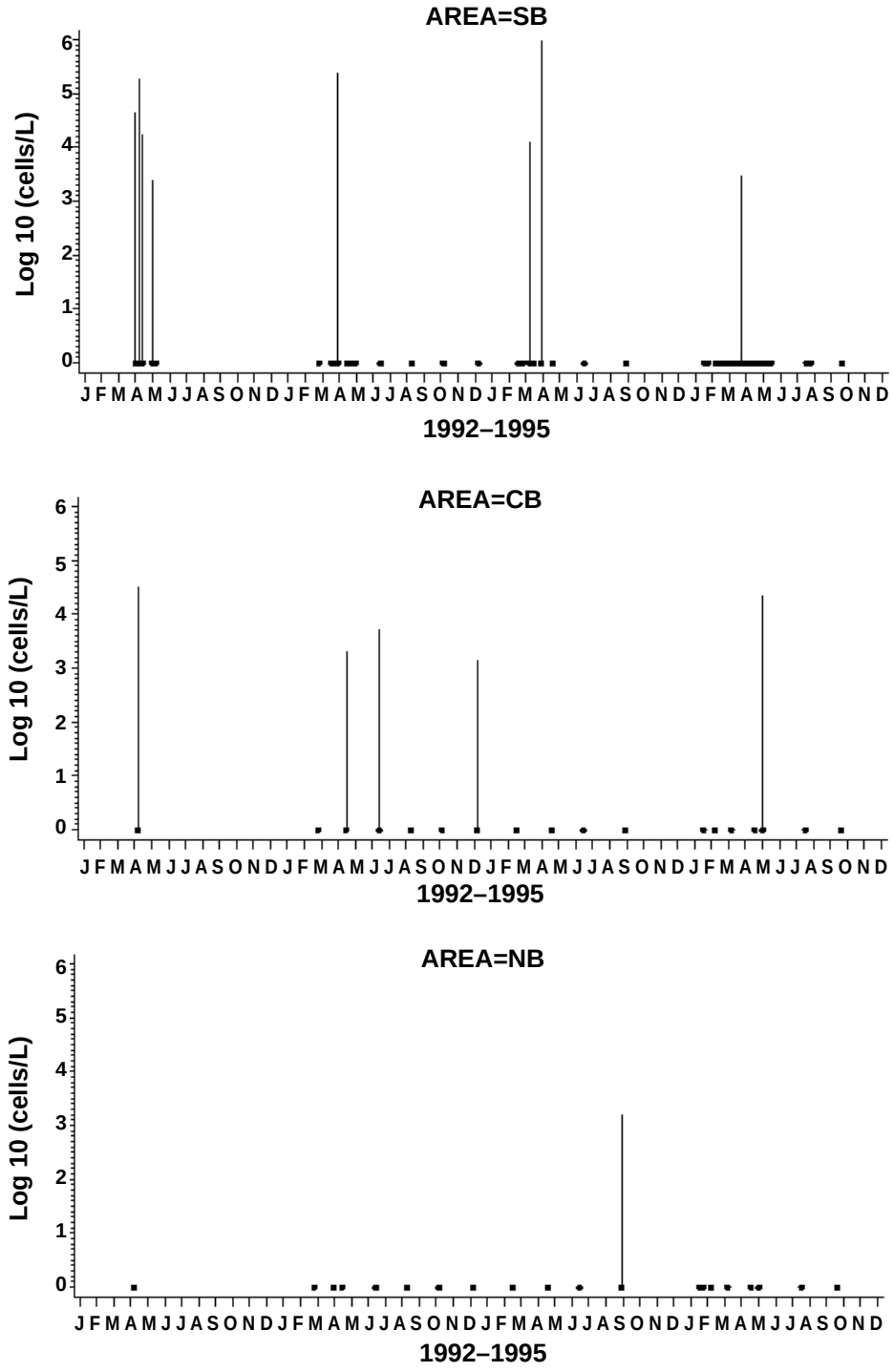

Figure 52. Abundance (x10^{n} cells/L) of *Pseudo-nitzschia* spp. cells at South Bay (a), Central Bay (b), and North Bay (c) locations during the study period (1992–1995). Points (•) indicate sampling dates in each region.

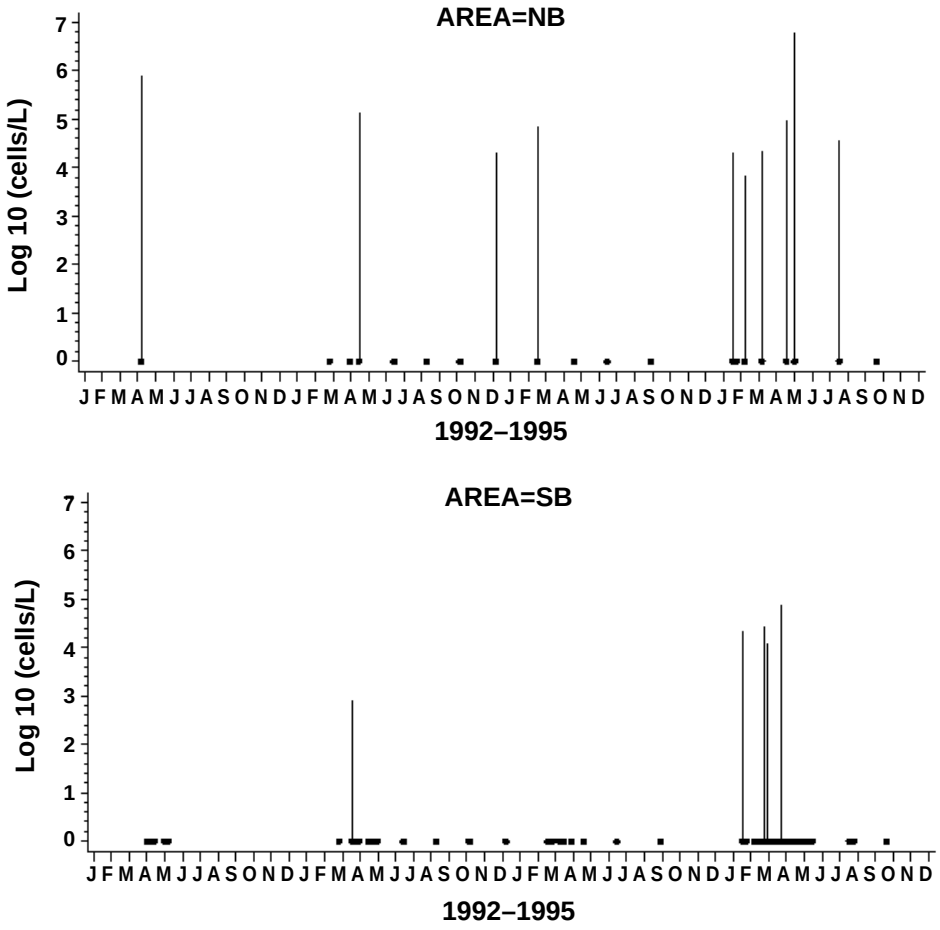

Figure 53. Abundance (x10^n cells/L) of *Oscillatoria* spp. cells at North Bay (a) and South Bay (b) locations during the study period (1992–1995). No observations from Central Bay. Points (•) indicate sampling dates in each region.

rences and were recorded at relatively low densities (Table 6). Other taxa, such as *Chaetoceros, Planktolyngbya subtilis*, and *Phormidium*, however, were found frequently in San Francisco Bay. Two species of *Chaetoceros, C. debile* and *C. socialis*, produce mucilaginous colonies harmful to larval fish, and these occurred in high densities during March and April. *Cylindrotheca closterium*, a diatom species associated with blooms producing water discoloration and mucilaginous aggregates (Hasle and Fryxell, 1995), was also found in the South Bay at high densities.

The Potential for Harmful Algal Blooms in San Francisco Bay

So far there have been no reports of serious toxic or harmful phytoplankton blooms in San Francisco Bay. However, our examination of recent data shows that a number of species responsible for such blooms in other locations do exist in San Francisco Bay waters, and at times these species reach high abundances. Thus the potential exists for toxic or noxious bloom problems. Moreover, the present study should be regarded as conservative because of biased temporal sampling (i.e. the low frequency of sampling in late summer and autumn) and the focus on identifying and enumerating the dominant species (e.g., many harmful species may be present at low densities as part of the "hidden flora").

The primary toxin-producing algae in San Francisco Bay appear to be dinoflagellates of the genus *Alexandrium*. Abundances of these

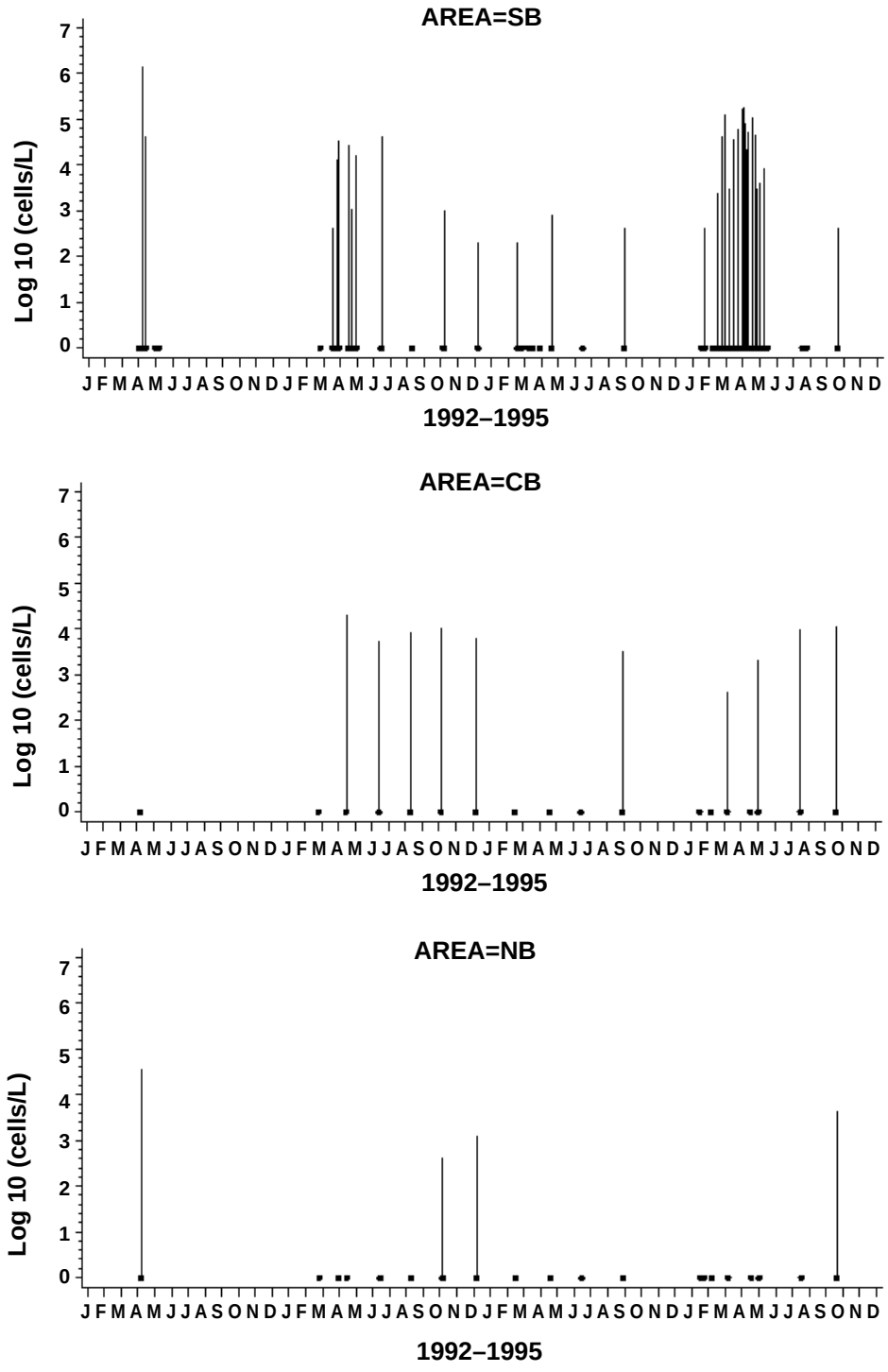

Figure 54. Abundance (x10^{n} cells/L) of *Prorocentrum* spp. cells at South Bay (a), Central Bay (b), and North Bay (c) locations during the study period (1992–1995). Points (•) indicate sampling dates in each region.

species were seasonally correlated with toxic periods in nearby coastal marine waters, but the separate sampling designs of the USGS and CDHS programs do not allow us to address the hypothesis that coastal blooms propagate into the Bay. The high densities of *Alexandrium* in South San Francisco Bay may indicate population growth or retention within the Estuary, since densities in ocean waters are typically lower than those observed during the peak abundances in the South Bay. Whereas the CDHS monitoring program is appropriate for assessing PSP toxins on the open coast, an independent *Alexandrium* bloom in the San Francisco estuarine system could go undetected. Moreover, if cell densities in the Bay reach levels higher than on the open coast (as discussed above), there is the potential for high toxin accumulation in estuarine benthic consumers. For example, a bloom of *Alexandrium catenella* in the Beagle Channel (Argentina) at densities of 8.2×10^5 cells/L (similar to peak abundances recorded in San Francisco Bay) resulted in high toxin levels in mussels *Mytilus chilensis* (Benavides *et al.*, 1995).

Because toxic species of *Pseudo-nitzschia* are common in adjacent coastal ocean waters (Walz *et al.*, 1994), and these diatoms develop blooms in Oregon and Washington estuaries (Sayce and Horner, 1996), there is a potential for domoic acid-producing blooms in San Francisco Bay. The absence of such events in the USGS database is likely a result of temporal bias in the sampling program. *Pseudo-nitzschia* blooms are most common in late summer and autumn (Buck *et al.*, 1992; Walz *et al.*, 1994), and therefore could have been missed in the USGS surveys. Blooms within the Bay, such as the *Pseudo-nitzschia* bloom in the Berkeley Marina (July 1993), may be limited spatially as well as temporally and thus escape detection during monthly surveys with limited spatial coverage. The nutrient concentrations in South San Francisco Bay may be an important regulator of domoic acid-producing blooms, should they develop. Domoic acid concentrations within *Pseudo-nitzschia* cells depend on silicate-limited conditions with an excess of nitrogen (Bates *et al.*, 1991; Pan *et al.*, 1996). Coastal waters receiving anthropogenic inputs of nitrogen can have low silicate:nitrogen ratios that are optimal for domoic acid-producing blooms (Garrison *et al.*, 1992).

In summary, our analysis of recent data shows that toxin-producing species of phytoplankton occur in Bay-Delta waters, sometimes at abundances that could have harmful effects on invertebrate and vertebrate animals. Persistent and abundant occurrences of some forms, such as the dinoflagellates *Alexandrium* and *Prorocentrum* during spring of 1995, suggest that populations of harmful algae develop within the Bay. However, these inferences are made from a data set that has incomplete spatial and temporal coverage. Therefore, the existing information is inadequate for developing a definitive statement about the ecological significance of these harmful algae in San Francisco Bay. The existing information does suggest that RMP managers should consider a new element of Bay monitoring to characterize the phytoplankton community, especially at those times/locations when water and sediment samples are taken for bioassays. The existing information also shows that harmful species are present in San Francisco Bay, so RMP participants should recognize the potential for acute events of algal-caused animal mortality in this nutrient-rich coastal system.

Observations on Trace Organic Concentrations in RMP Water Samples

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This section supplements the discussion of trends in trace organic contaminants presented in the *Water Monitoring Discussion* section of this report, and includes a more detailed discussion of some of the points mentioned and offers some additional observations.

Polychlorinated Biphenyls (PCBs)

In addition to simply analyzing concentrations of the sum of individual congeners (ΣPCBs), information on spatial variation and sources of organic contaminants can also be obtained by examining the "profiles", or relative proportions of individual compounds, within the major classes of organics. Spatial variation in PCB congener profiles is discussed here as it appears to relate to PCB sources.

PCBs were sold and used as mixtures known as Aroclors. There were several different classes of Aroclors, and these classes had different congener profiles. If the sources of Aroclors contributing to PCB contamination in the Estuary were variable, as could reasonably be hypothesized, then it should be possible to find different profiles in different parts of the Estuary.

Two of the highest levels of ΣPCBs in water during the 1995 RMP were found at the Petaluma River (BD15) in the Northern Estuary and Coyote Creek (BA10) in the South Bay. Despite the difference in location, the PCB

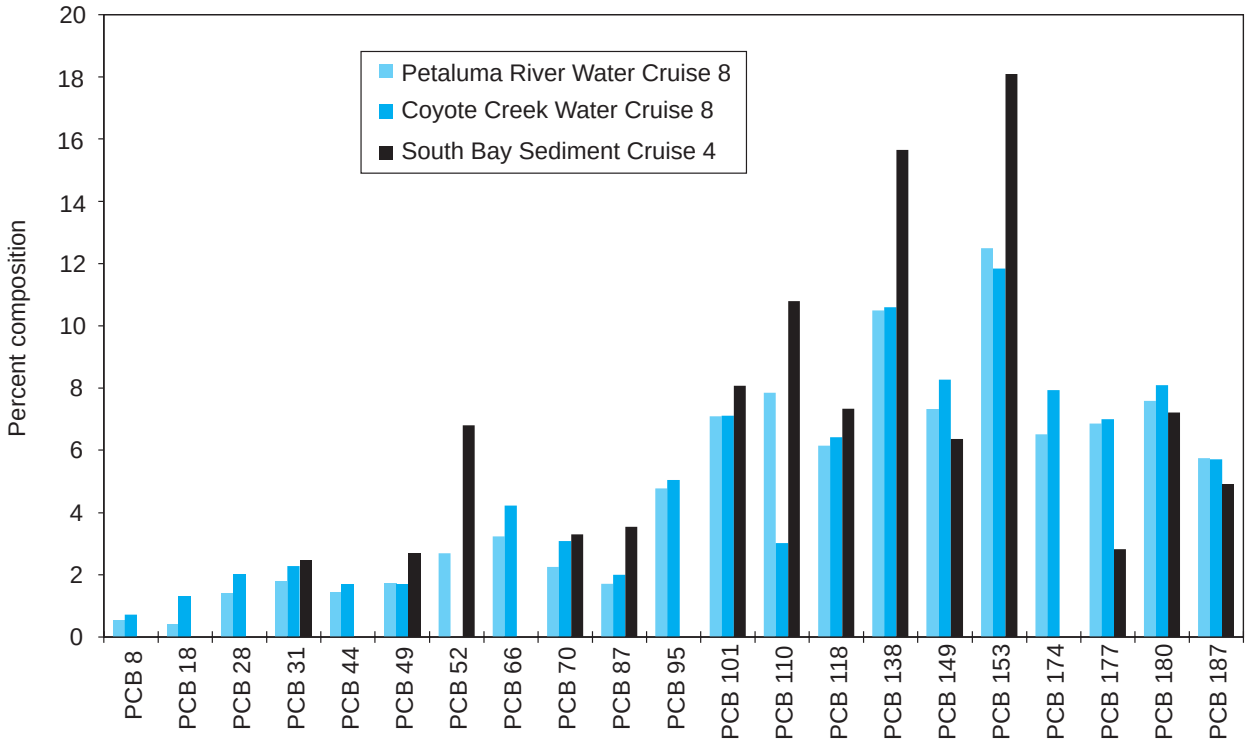


Figure 55. Comparison of PCB congeners in water from Coyote Creek (BA10) and Petaluma River (BD15; April samples) and in sediment from South Bay (BA21; February 1994 sample). Concentrations expressed a percentage of ΣPCB.

profiles are very similar (Figure 55). PCB congener data for sediment from the South Bay site (BA21, Cruise 4, 1994) also share this same profile (Figure 55). In the sediment samples PCBs 8, 18, 28, 44, 66, 95, and 174 were not detected throughout the Estuary. One explanation for this general similarity is that the PCB sources in the northern and southern Bay have similar congener compositions. Another possibility is that the sediments are the source of PCBs found in the water column, and despite past differences in the composition of inputs (i.e., different Aroclors), the mixing of sediment over time and the degradation of the Aroclor mixtures has resulted in similar profiles in the two locations. This latter hypothesis would make the historical deposition and accumulation of PCBs into the sediments the major source of PCBs in the water column, as also suggested by Risebrough (this report). A more detailed analysis of PCB "fingerprints" in the Estuary will be conducted in 1997, and will reveal whether the similarities among the stations discussed here are coincidental or not.

It is also possible to obtain information on PCB dynamics in the Estuary by examining temporal trends in congener profiles. Some seasonal variation in congener profiles can be seen. The congener-specific analysis (for all congeners greater than 3% of the ΣPCB) for the four regions in 1995 is presented by cruise in Figure 56. The highest concentrations of ΣPCBs were measured the spring. In the South Bay, Central Bay, and Northern Estuary this cruise also had the highest average TSS. The South Bay wet-season sampling yielded a low concentration of total suspended sediments (TSS) and this is reflected by the high percentage of lighter chlorinated congeners which tend to dissolve in the water column to a greater extent than the more heavily chlorinated congeners. Although concentrations of congeners are similar in the Central Bay for all three cruises, the patterns are not. This is probably due to the low concentrations, which are near the detection limit and thus have greater variability.

One historical data set that can be used for comparisons of PCBs and other organic contaminants in Estuary waters is that of de Lappe *et al.* (1983b). In a study for the City and County of San Francisco, prior to the construction of the Southwest Ocean Outfall, de Lappe *et al.* examined the baseline concentrations of organic contaminants both outside and inside the Estuary. Of particular relevance are the "vicinity of Angel Island" and Golden Gate Channel stations sampled for PCBs (Aroclor-based measurements) in August 1980. Using sampling equipment roughly comparable to that currently used in the RMP (glass fiber particulate filter and polyurethane foam) de Lappe *et al.* (1983) reported a ΣPCB concentration of 647 pg/L at the Golden Gate. A liquid/liquid extraction of whole water at the Golden Gate yielded a value of 850 pg/L. At Angel Island a ΣPCB concentration of 664 pg/L was reported.

In tissue samples from wildlife, Aroclor-based ΣPCB results are two or more times higher than the ΣPCB based on the sum of individual congeners in the same sample (Turle *et al.*, 1991). It is not known if this is true in water samples, but it is probably similar in that Aroclor-based values would be higher than congener-based ΣPCB values from the same samples. The average concentration of congener-based ΣPCBs in the Central Bay for RMP cruises has been approximately 400 pg/L. Congener-based ΣPCB concentrations in other regions of the Estuary are frequently much higher. The concentrations detected in these older studies and those detected currently in the RMP are roughly equivalent. Despite variations in both sampling and analytical methodology these data indicate that PCB concentrations have not declined appreciably since the early 1980s.

Pesticides

Average total (particulate plus dissolved) concentrations of the most commonly detected pesticides for each reach are presented in Figure 57.

The concentrations of diazinon, dacthal, and oxadiazon reported in the RMP must be interpreted with caution. No studies of the

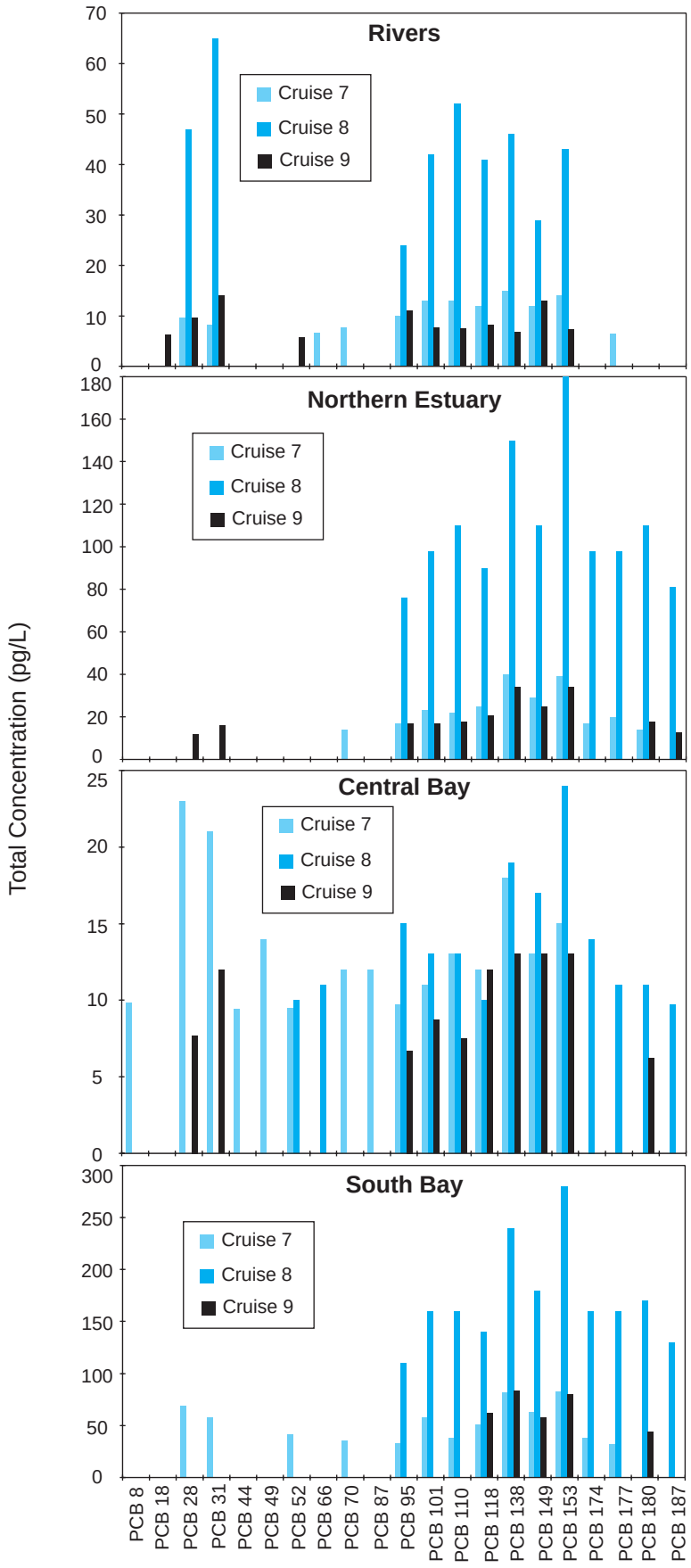


Figure 56. Congener-specific PCB concentrations (totals) for 1995, by reach.

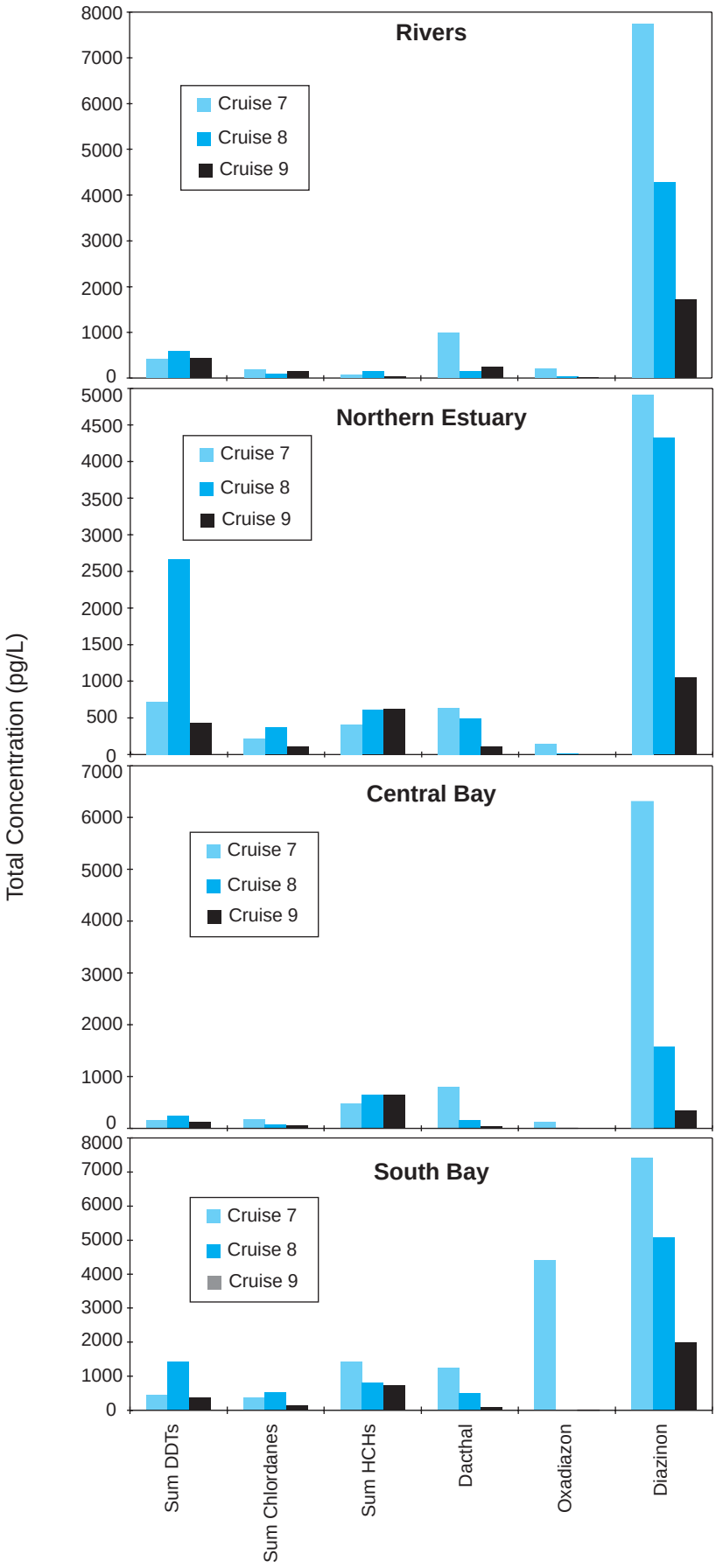


Figure 57. Total concentrations of pesticides in water for each reach of the Estuary, 1995.

relative recoveries of these compounds have been undertaken with the glass fiber filter/ polyurethane foam water sampler used in the RMP since 1993. The values reported must be considered preliminary until sampling efficiency has been documented. However, Domagalski and Kuivila (1993) reported levels of diazinon in San Francisco Bay collected in 1991 in the Northern Estuary (Carquinez Strait, Suisun Bay, and Chipps Island) and found very similar levels (4,600–13,000 pg/L) in the dissolved phase to those reported in the RMP. In addition, diazinon is the only pesticide in the RMP water samples that is quantified by gas chromatography/mass spectrometry (GCMS), the most reliable (least likely to give a false positive) way to quantify analytes. Although these diazinon concentrations seem high, assuming the total volume of water in San Francisco Bay to be approximately 6.66 X 10^9 m^3 (Conomos *et al.*, 1985a), it takes only 66 kg of diazinon to contaminate the Bay to an average concentration of 10,000 pg/L in the water.

The pesticide with the second highest concentrations reported in 1995 was oxadiazon in the South Bay during February (Figure 57). However, this average is skewed by two extremely high stations (Coyote Creek [BA10] at 3100 pg/L and Dumbarton Bridge [BA30] at 14,000 pg/L). These values should be confirmed by GCMS before any conclusions can be drawn. Oxadiazon has been detected in biota in Southern California (Crane and Younghans-Haug, 1992). Oxadiazon is a pre-emergent herbicide. Pesticide use data collected by the California Environmental Protection Agency (Cal EPA) in 1993 indicate that 19,000 pounds of oxadiazon were applied in California by licensed applicators, mostly for landscape maintenance (CAL EPA, 1996).

Dacthal (also known as "chlorthal-dimethyl") concentrations during 1995 were similar for the four areas and show a decrease from February to August, similar to diazinon (Figure 57). Dacthal is a pre-emergent herbicide, and thus it would be expected that the highest concentrations found in the Estuary would occur in the winter. Cal EPA pesticide-use data show that 660,000 pounds of dacthal were applied by licensed applicators in California in 1993, mostly on food crops such as broccoli and onions (CAL EPA, 1996).

As mentioned above, de Lappe *et al.* (1983b) measured selected organic contaminants in water, including pesticides, in the Central Bay (Golden Gate and Angel Island) in the summer of 1980. A comparison of these results to those of the two summer RMP cruises are presented in Table 8. As opposed to the PAHs and PCBs, in both the chlordanes and DDTs (two banned classes of organochlorine pesticides), there seems to have been a downward trend. The hexachlorocyclohexanes (HCHs), another class of organochlorine insecticide, however, do not seem to be decreasing. This might be attributed to high deposition of atmospheric HCHs, as reported in other areas (Wittlinger and

Table 8. Concentrations of pesticides in the Central Bay, 1980–1995. Data in pg/L.

	deLappe *et al.* (1983)			RMP 1994 and 1995	
	Golden Gate 1980		Angel Island 1980	Cent. Bay dry-season	Cent. Bay dry-season
	Part. + Dissolved	Whole water	Part. + Dissolved	Part. + Dissolved	Part. + Dissolved
Sum DDT	260	320	206	190	100
Sum HCH	730	1160	1700	825	660
Sum Chlordane*	250	310	200	36	40

* *trans* and *cis* chlordane, and *trans* nonachlor

Ballschmiter, 1990; Hinckley and Bidleman, 1991).

One interesting form of seasonal variation was observed for p,p'-DDE, one of the predominant forms of DDT. Regressions of p,p'-DDE versus TSS were performed for each cruise, and the regression line for the spring cruise (April) had a markedly higher slope than the lines for the other cruises (discussed further in "General Spatial Patterns of Trace Organics" below). The slopes of the lines in February and April were significantly different (their 95% confidence intervals did not overlap), while the slope of the line for the dry-season (August) had a wider confidence interval and was not significantly different from the slope for the spring cruise (April). These results suggest that the suspended solids circulating in the Estuary were relatively more contaminated with p,p'-DDE in April. Since freshwater runoff into the Estuary was extremely high during April, a plausible explanation for this pattern is that relatively contaminated sediments were being washed into the Estuary from upstream portions of the watershed.

Hydrocarbons

In general, higher molecular weight hydrocarbons can be derived from either biogenic (produced from living organisms) or petroleum sources. The hydrocarbons measured in the RMP can be broken into two major classes: the aliphatic hydrocarbons (AHC), which are straight-chain or branched hydrocarbons, and the polycyclic aromatic hydrocarbons (PAHs), which are fused aromatic rings. The AHCs are produced by higher plants, bacteria, and plankton; in addition they are also major constituents of petroleum products. The PAHs are major components of petroleum, products of combustion, and products of the degradation of organic matter; they are primarily of anthropogenic origin in the Estuary.

In the RMP approximately 24 individual AHCs and 14 PAHs are measured in water. The patterns of both the AHCs and PAHs and their relative concentrations can yield information regarding the source (i.e., biogenic or petroleum-derived) of the hydrocarbons in the water of the Estuary. For example, the AHCs derived from biogenic sources have a large odd-to-even

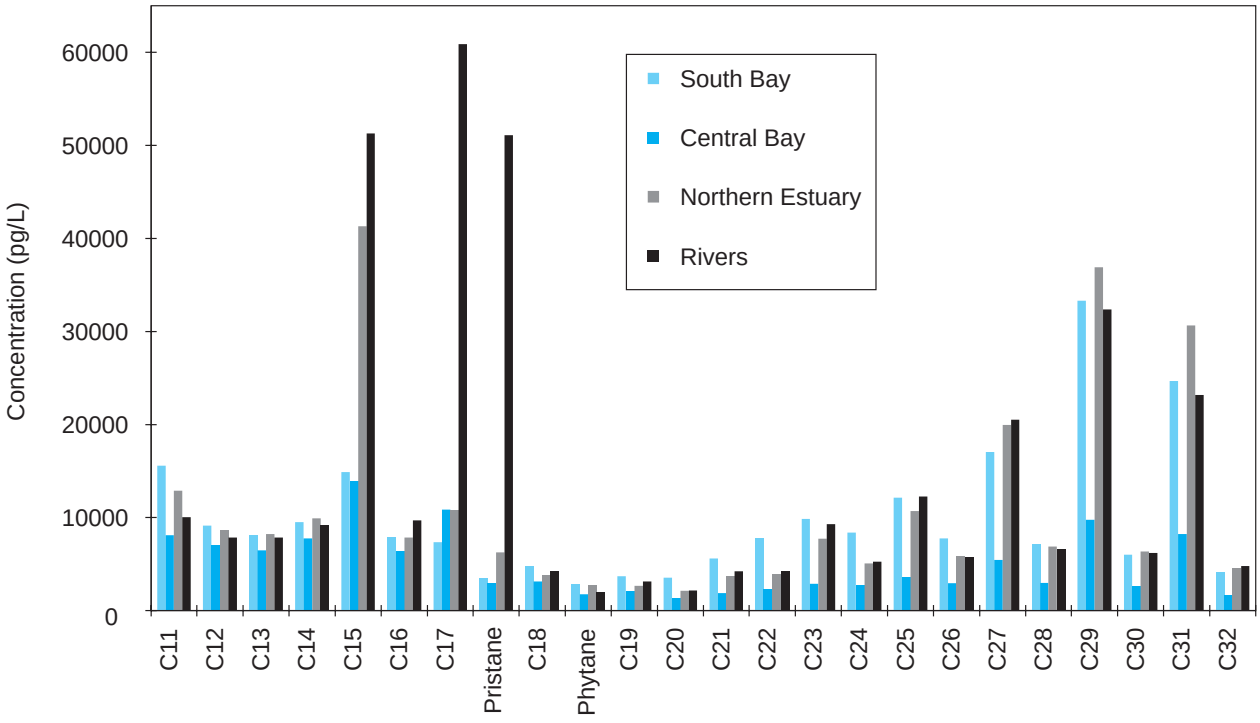


Figure 58. Total concentrations of aliphatic hydrocarbons (AHCs) in RMP water samples, August 1995. Concentrations are averages for each reach.

alkane ratio; this is sometimes called a carbon preference index. This is because the biogenic sources produce a greater proportion of the odd-number alkanes (e.g., n-C_{15}, n-C_{17}, n-C_{19} if derived from algae, n-C_{25}-n-C_{35} if derived from higher plant waxes). Another example is the use of the pristane to phytane ratio to determine recent biogenic hydrocarbons; pristane and phytane are branched AHCs produced by plankton. In unpolluted biogenic sources the pristane concentration is much greater than the phytane concentration. The pattern of the PAHs are also characteristic of their source (see RMP News Summer 1996).

The profiles of the total (dissolved plus particulate) water AHCs for the August cruise are presented in Figure 58. The river profiles for the AHCs in August show a distinct pattern of biogenic input; the profile is dominated by n-C_{15}, n-C_{17}, and pristane, probably as a result of spring and summer plankton blooms. The profile from the Northern Estuary shows a predominance of n-C_{15}, also probably as a result of plankton. Of interest is the characteristic pattern of plant wax alkanes (n-C_{25}, n-C_{27}, n-C_{29}, and n-C_{31}) in all areas of the Estuary, except the Central Bay. The southern and Central Bay show no odd/even preferences (except for the plant waxes) which is probably the result of no fresh biogenic source of AHCs.

The patterns of PAHs for 1995 are presented in Figure 59. As with the PCBs, the PAHs are highly correlated with TSS, and thus in general, the levels in the samples are correlated with TSS concentration. The dominant PAHs in the water are phenanthrene (PHN), sum methylphenanthrene (sum MPH), fluoranthene (FLA), pyrene (PYR), benzo[B]fluoranthene (BBF), and indeno[1,2,3-cd]pyrene (IND). However, the relative proportions of these PAHs varies greatly within the Estuary and by season. These PAHs are in general representative of petroleum combustion, but there are some notable differences and similarities. As with the PCBs, the patterns in the Northern Estuary and South Bay are similar for April. In the River stations the pattern varies greatly with season. During April the dominant PAH in the River stations and South Bay was IND, which has been reported to be the dominate PAH in sediment traps deployed near metal refineries in Sweden (Näf *et al.*, 1992). The very different patterns of PAHs in the Estuary reflect the many possible sources of PAHs (e.g., petroleum, automobile, refineries, and runoff: Readman *et al.*, 1986).

A comparison of the patterns of PAHs found in the sediments and water (total concentrations) for the South Bay and Northern Estuary is presented in Figure 60. Despite the fact that

Table 9. Concentrations of hydrocarbons in the Central Bay, 1980–1995. Data in pg/L.

	deLappe *et al.* (1983)			RMP 1994 and 1995	
	Golden Gate 1980		Angel Island 1980	Cent. Bay dry-season	Cent. Bay dry-season
	Part. + Dissolved	Whole water	Part. + Dissolved	Part. + Dissolved	Part. + Dissolved
n-C_{15}	310	800	330	14000	5900
n-C_{17}	33000	2400	4860	11000	5900
n-C_{18}	1300	1100	1700	3200	1400
nC_{-29}	6000	10000	14000	9700	1300
pristane	780	1400	2900	2900	1900
phytane	840	900	2000	1700	900
S-resolved alkanes	92000	100000	150000	120000	239000
phenanthrene	5000	3800	3100	1300	8700
anthracene	240	700	500	600	0
pyrene	3900	700	5600	2300	2500

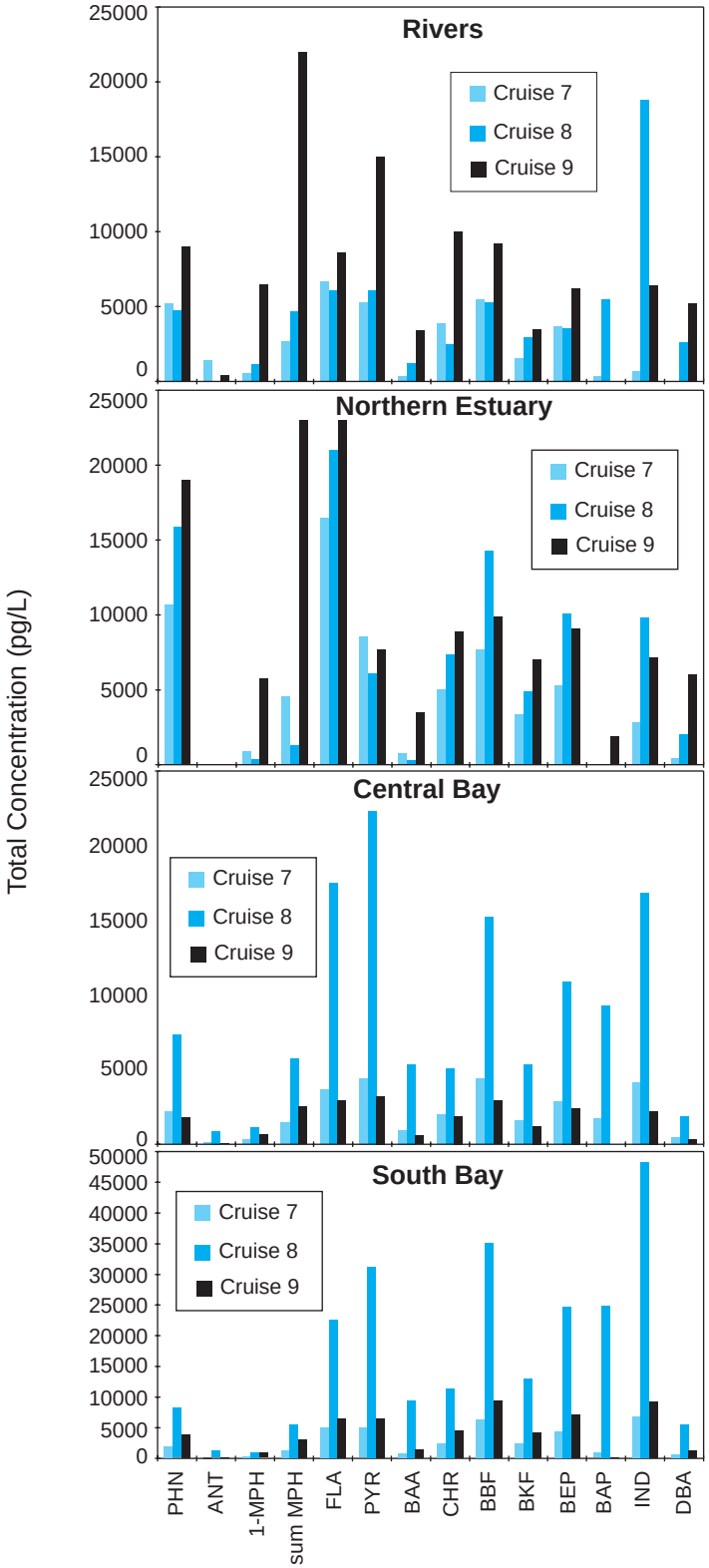


Figure 59. Total concentrations of PAHs in RMP water samples, 1995. Concentrations are averages for each reach.

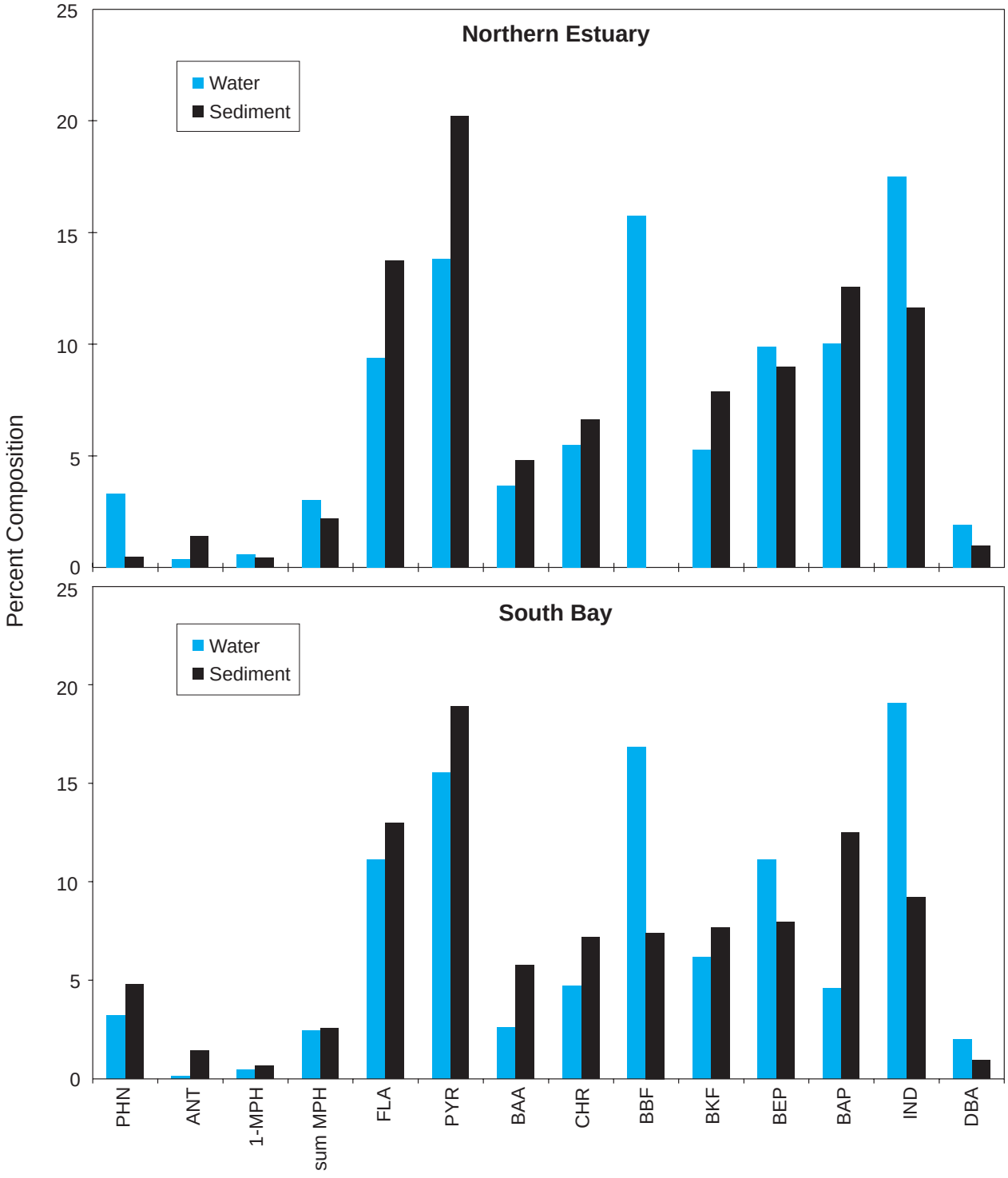


Figure 60. Comparison of PAH profiles in water and sediment from a) the Northern Estuary, and b) the South Bay. Concentrations expressed as percent of ΣPAH. Northern Estuary sediment collected in San Pablo Bay (BA21), February 1994, and water from the Petaluma River station (BD15), February 1995. South Bay sediment collected from station BA21, February 1994, and water from Coyote Creek (BA10), February 1995.

these sediment and water samples were collected one year apart, and they represent only one sample each, there are some obvious patterns. Although not as similar as the PCB sediment and water profiles (Figure 60), the patterns in the sediment and water are similar from both areas of the Bay, suggesting that sediments may be a source of the PAHs to the water column. However, atmospheric transport and deposition has been reported to be a significant source of PAHs (and PCBs) to lakes (Sanders *et al.*, 1996), and must be included as a potential source along with the rivers and urban runoff. Atmospheric deposition of trace contaminants in the Bay region will be investigated in an RMP pilot study in 1997 that will include deposition measurements in the field. Unlike the PCBs, the patterns from the North and South Bay for both sediment and water differ by region. This is probably due to different sources of PAHs, different stability of the PAHs (e.g., selective degradation in the sediments), or the differential partitioning of the individual PAHs into the water column because of their different water solubilities.

de Lappe *et al.* (1983b) reported total saturated hydrocarbon (resolved and unresolved) and selected AHCs (n-C_{15}, n-C_{17}, n-C_{18}, n-C_{29}, pristane, and phytane) and PAHs (PHN, ANT, and PYR) in particulate, dissolved, and whole water samples from sites at the Golden Gate and in the "vicinity of Angel Island". Table 9 compares the hydrocarbon values reported by de Lappe *et al.* (1983) collected in the summer of 1980 and the data from the RMP summer cruises for the Central Bay in 1994 and 1995. Despite different sampling methodologies, different analytical methodologies, and different instrumentation, in general, the levels are very similar over a 15-year period (Table 10). Although n-C_{15} and n-C_{17} vary over an order of magnitude, this can be explained by the fact they are produced by algae and their concentrations are dependent on algal production; most of the rest of the hydrocarbons measured show values which are within a factor of two. The concentrations (and ratios) of PHN, ANT, and PYR are very consistent. The similarity of the patterns and levels of hydrocarbons (in this limited data set) in the Central Bay over the past 15 years indicates that the magnitude and composition of hydrocarbon sources to the Estuary have not changed dramatically in the recent past.

General Spatial Patterns of Trace Organics

Spatial variation in total concentrations of the hydrophobic trace organics is more apparent when the influence of TSS is removed using linear regression. Regressions of TSS versus these contaminants were highly significant (p values for these regressions were all less than 0.00004), accounting for 33% of the variance for PCB 153 (used as an indicator for PCBs as a group), 37% for ΣPAH, 52% for Σchlordanes, and 83-95% for p,p'-DDE (for p,p'-DDE regressions were performed for each cruise, since the regression line for one cruise had a markedly different slope than lines for the other cruises). The adjusted concentrations of PCB 153 (Figure 61a) and ΣPAH (Figure 61b) had similar spatial patterns, with consistently high values in the South Bay from BA10 to BA30, high values at the Petaluma River (BD15), intermediate values in the Central Bay, and consistently low values in the Rivers and Northern Estuary. These data suggest the existence of relatively high concentrations of PCBs and PAHs in the South Bay and at the Petaluma River station (BD15). Adjusted p,p'-DDE concentrations (Figure 61c) were consistently high in the Rivers and Northern Estuary, consistently low at Redwood Creek (BA40), and generally inconsistent at other stations. Adjusted Σchlordanes (Figure 61d) were highest in the South Bay (especially at Coyote Creek—BA10) and lowest at the Sacramento River (BG20).

Overall, the dissolved and TSS-adjusted trace organics data clearly indicate the presence of elevated concentrations in the South Bay for all of the organics and at the Rivers for DDTs. Through modeling or detailed statistical analysis it might be possible to determine whether these elevated concentrations are a

result of remobilization from deposited sediment, but such an analysis is beyond the scope of this report. It is also possible that trace organics in the waters of the Estuary originate from other sources, such as inputs from contaminated areas further upstream in the watershed, atmospheric deposition, or other pathways, but the existing RMP sampling array may be inadequate for distinguishing among these possibilities.

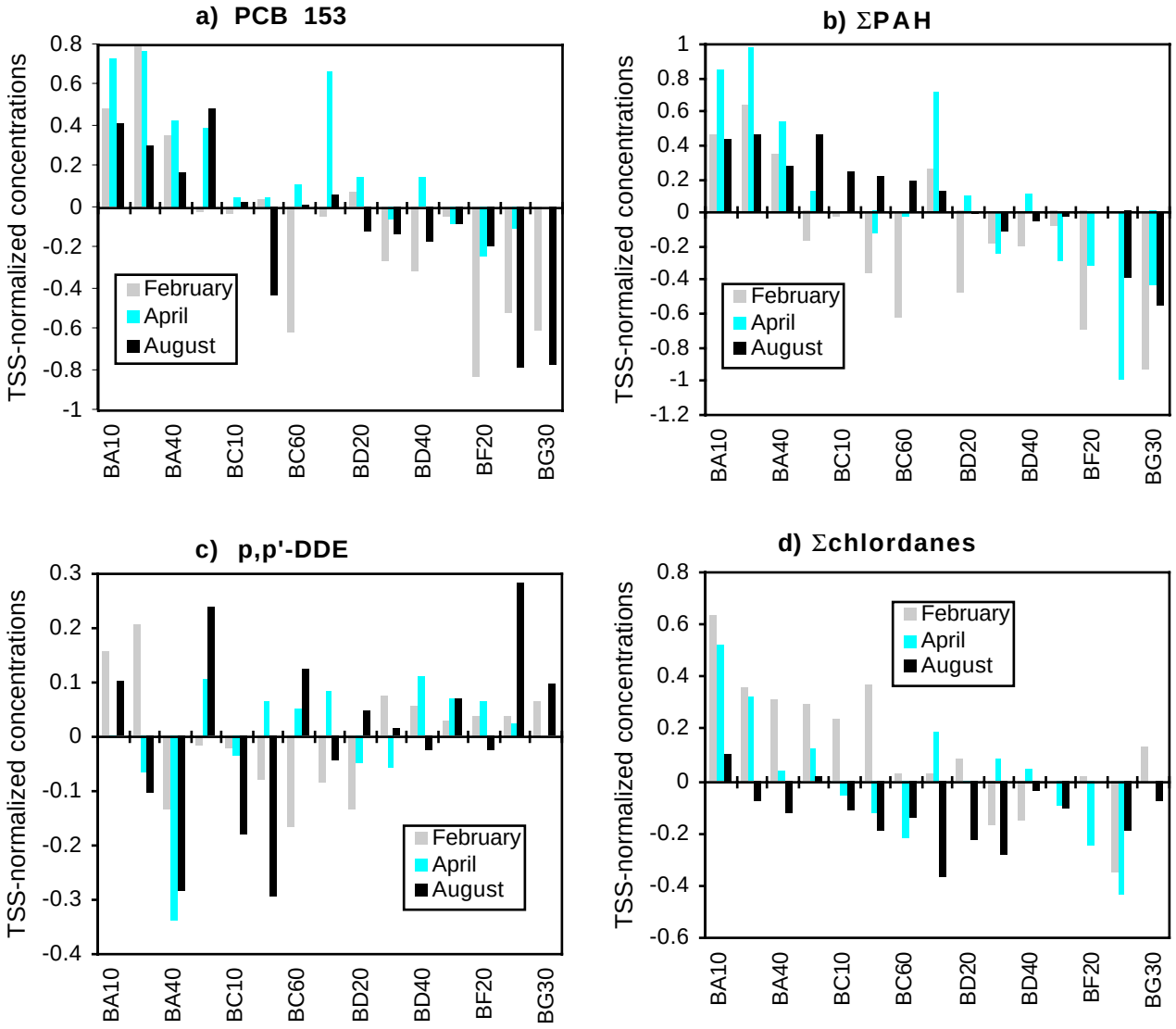


Figure 61. RMP water trace organic concentrations (1995) normalized to TSS through linear regression. Concentrations are represented by the residuals of regressions of TSS with each contaminant. a) PCB 153, b) ΣPAH, c) p,p'-DDE, d) Σchlordanes

Water Monitoring Discussion

One theme that is present in the Water Monitoring section is that information on trends in environmental variables other than contaminants can be extremely valuable in determining trends in contaminant concentrations. Jassby (this report) discussed how short-term variability in exogenous variables (e.g., Delta outflow and TSS) can disguise broader-scale trends. As an example he demonstrated the linear correlation between Delta outflow and cadmium, and showed that by adjusting the cadmium data to Delta outflow, increasing trends in cadmium were revealed at two stations.

Total suspended sediments (TSS) is another exogenous variable that exerts a strong influence on the total (dissolved + particulate) water concentrations of many trace elements and trace organics. Schoellhamer (this report) discussed the close relationship between TSS and total concentrations of certain trace elements. He exploited this close relationship to predict short-term variability in total trace element concentrations based on detailed TSS data. He also observed that there was a clear spatial pattern in the residuals of linear regressions of many trace elements with TSS. In other words, after removing the effect of TSS on the total trace element concentrations, clear spatial patterns became evident. This approach was based on linear regression and residual analysis, the same approach used by Jassby (this report) for cadmium and Delta outflow.

TSS is also closely related to total water concentrations of hydrophobic trace organics (Jarman and Davis, this report). As with the trace elements, removal of the effect of TSS on total concentrations of hydrophobic trace organics reveals a clearer picture of other variability, including spatial and temporal variation.

Trace Elements

Spatial patterns

TSS concentrations are the primary determinant of concentrations of many trace elements. Variation in total (dissolved + particulate) concentrations of these elements are therefore primarily related to variation in sediment resuspension in the Estuary. Dissolved trace element concentrations are useful in assessing spatial patterns because they are relatively independent of spatial variation in TSS concentrations, and therefore provide a better measure of actual differences in degree of contamination. In 1995, dissolved trace element concentrations during all cruises were generally elevated at the Southern Slough stations (San Jose, C-3-0 and Sunnyvale, C-1-3) and the South Bay stations (from BA10 to BB70) compared to other RMP stations. The principal source of these high concentrations appears to be a combination of waste water inputs, remobilization of contaminants from deposited sediments, and urban and non-urban runoff (Flegal, this report).

Silver (Ag) was the only exception to this prevailing pattern of high concentrations in the southern portion of the Estuary. Dissolved Ag concentrations exhibited distinct seasonal variability. In February, concentrations were high in the Southern Sloughs (especially Sunnyvale, C-1-3), but only slightly elevated in the South Bay relative to the rest of the Estuary. In April, concentrations were fairly uniform throughout the Estuary. Only in August were concentrations in the South Bay were substantially higher than most of the other measurements for the entire year.

Sources of trace element contamination in the water column, indicated by the presence of high concentrations relative to the rest of the Estuary, were only observed in a few instances for other regions of the Estuary. Dissolved cadmium concentrations in the Central Bay were high relative to stations further upstream and comparable to South Bay concentrations; ocean waters on the California coast are relatively enriched with this element. Dissolved Ag concentrations in a few Central Bay and Northern Estuary stations (BC30, BC41, BC60, BD15, BD20) were relatively high in August,

suggesting the presence of a source in this region at that time. Concentrations of dissolved As, Cu, and Ni were much higher at the Petaluma River station (BD15) than at adjacent stations. This pattern also held for Cu and Ni in all 1994 cruises, but for only one cruise for As. These data strongly indicate the presence of a source of Cu and Ni near this station. The only elements found at high relative concentrations in the River stations were Pb (especially the Sacramento River station, BG20) and Hg (the San Joaquin River station, BG30, in April).

As, Cd, and Se occur mostly in the dissolved fraction, so spatial patterns for total concentrations are the same as for the dissolved fraction. However, total concentrations of the other elements (Cr, Cu, Pb, Hg, Ni, Ag, and Zn) are much higher than dissolved. The spatial distribution of total concentrations of these elements resembles the distribution for TSS, with the highest concentrations in the Southern Sloughs and at the Petaluma River, intermediate concentrations at the Northern Estuary and River stations, and lowest concentrations in the Central Bay. After removing the influence of TSS through linear regression, the TSS-adjusted data showed that Ag, Cu, Hg, Ni, Pb, and Zn were highest in the South Bay and that Cu and Zn had local maxima in the North Bay (Schoellhamer, this report). These findings are generally consistent with the conclusions on spatial patterns based on dissolved concentrations.

Temporal trends

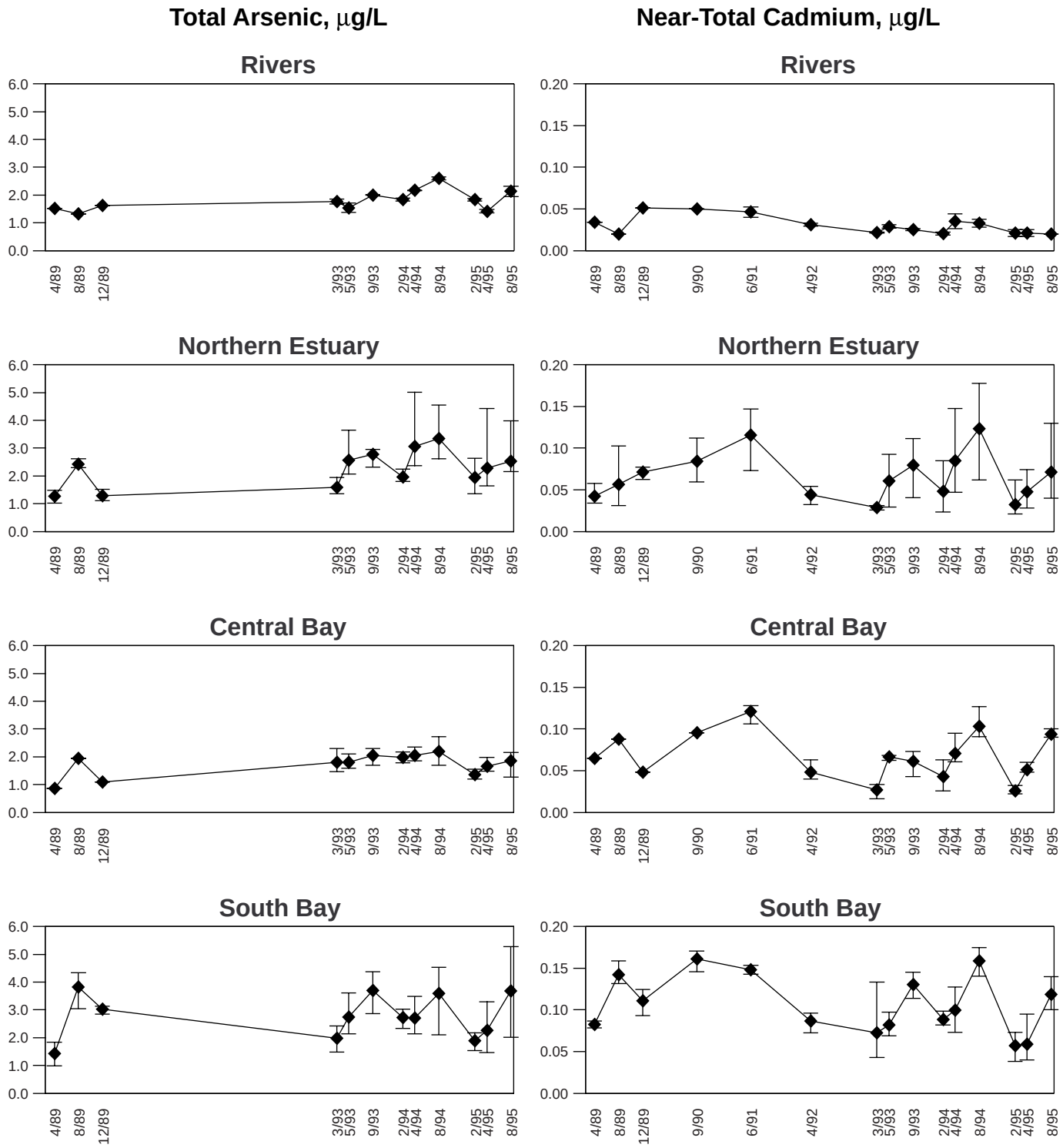
Seasonal Variation

Clear seasonal variation was observed for As, Cd, and dissolved Ag. As and Cd concentrations throughout the Estuary were high in August. This same pattern was observed in 1994. For Cd this pattern could be due to the increased influence in the dry season of ocean water, which is relatively high in Cd. Arsenic, in contrast, is not present in high concentrations in the ocean. High As concentrations in August may be due to the increased influence of sources such as outfalls or atmospheric deposition that become more obvious in the absence of runoff. Ag concentrations were also elevated in August, especially in the South Bay. This pattern was not evident in the 1994 sampling, but suggests the presence of a continuous source of Ag in the South Bay during this period. Total concentrations of the elements that tend to be particle-associated (Cr, Cu, Pb, Hg, Ni, Ag, and Zn) were often highest in April, coinciding with high concentrations of TSS.

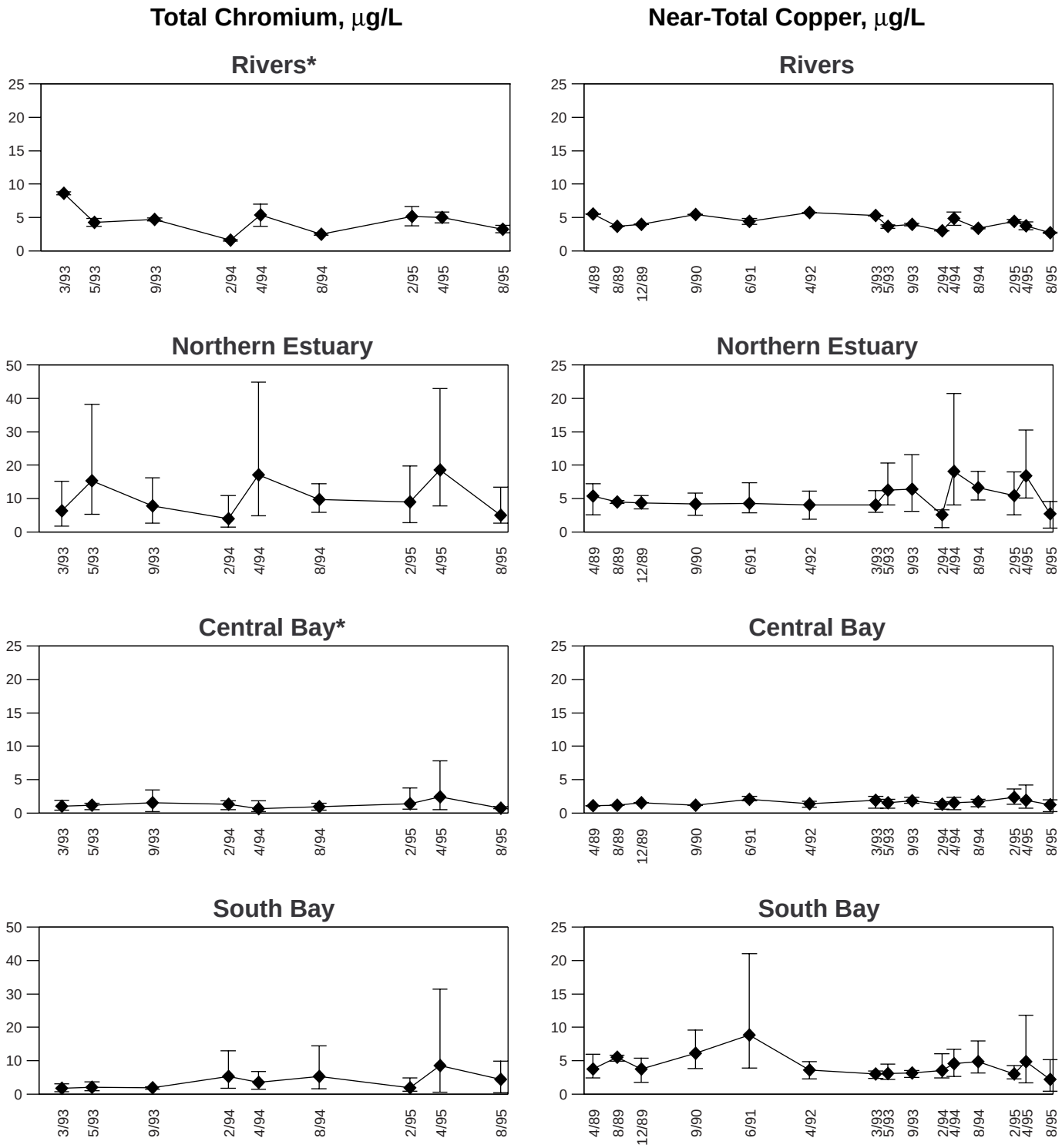
Long-term Trends

Long-term trends in total trace element concentrations were examined in detail using data collected from April 1989 to April 1995 under the RMP and pilot studies that preceded the RMP (Jassby, this report). Trends were essentially nonexistent in the raw data. In a station-by-station analysis of trends for all of the trace elements only 3 of 240 tests showed significant trends, even fewer than would be expected due to chance alone. Contiguous stations often showed consistent, though non-significant, trends. Jassby examined whether contiguous stations could be grouped in order to detect statistically significant trends, but the results for Cu, which appeared to show consistent trends among stations in subregions of the Estuary, were not significant. Plots that summarize trace element data collected in the pilot studies and the RMP are shown in Figures 62–71.

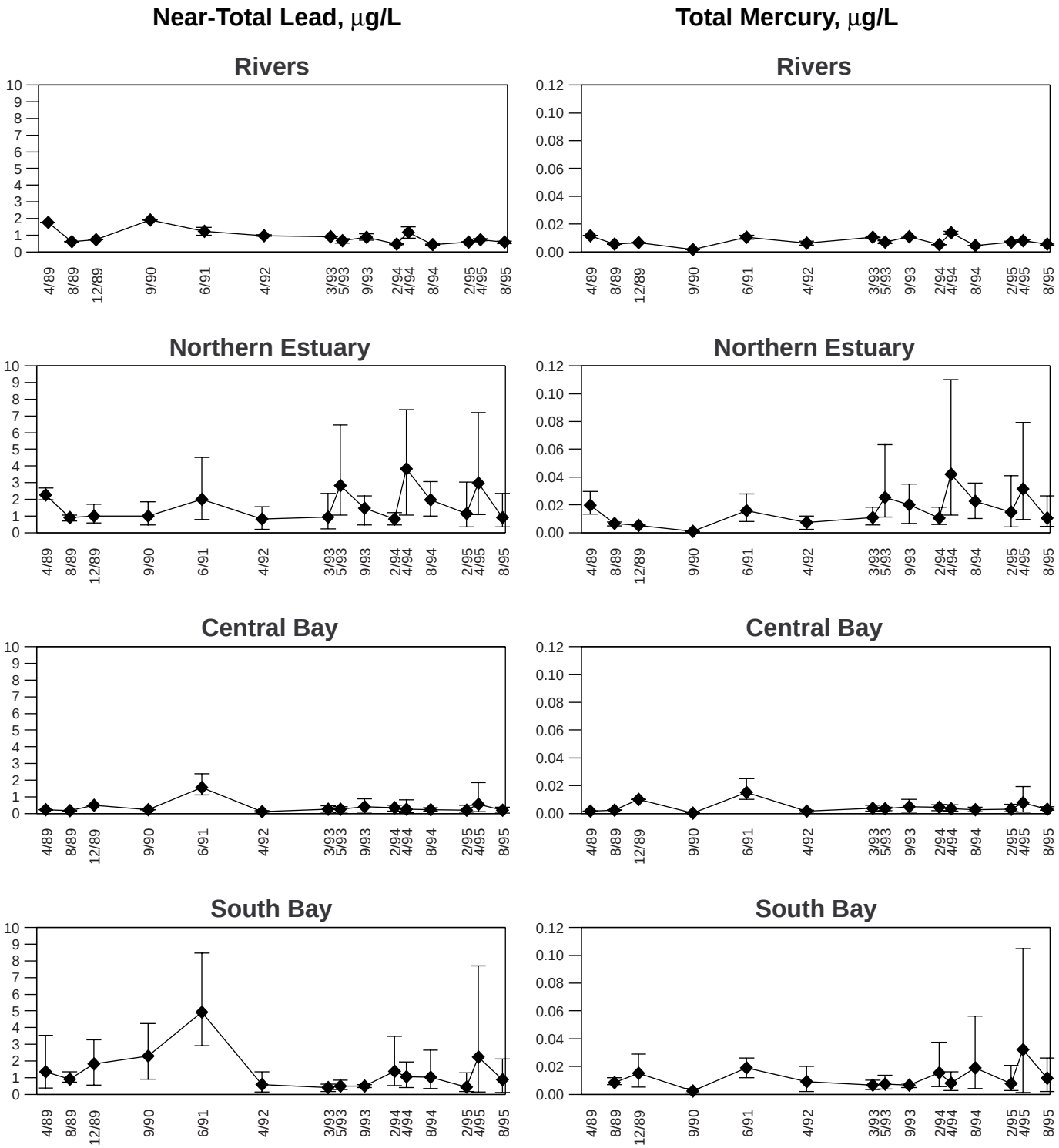
As mentioned above, variability in exogenous factors, such as Delta outflow, can mask trends in trace element concentrations, and statistical removal of the influence of such factors can provide a better representation of temporal trends (Jassby, this report). Indeed, the absence of significant trends in trace element concentrations after six years of sampling suggests that the *only* way to detect trends with the present sampling regime, without waiting decades, is to establish the quantitative relationships of trace element concentrations with important environmental factors and then remove the effect of those factors statistically.



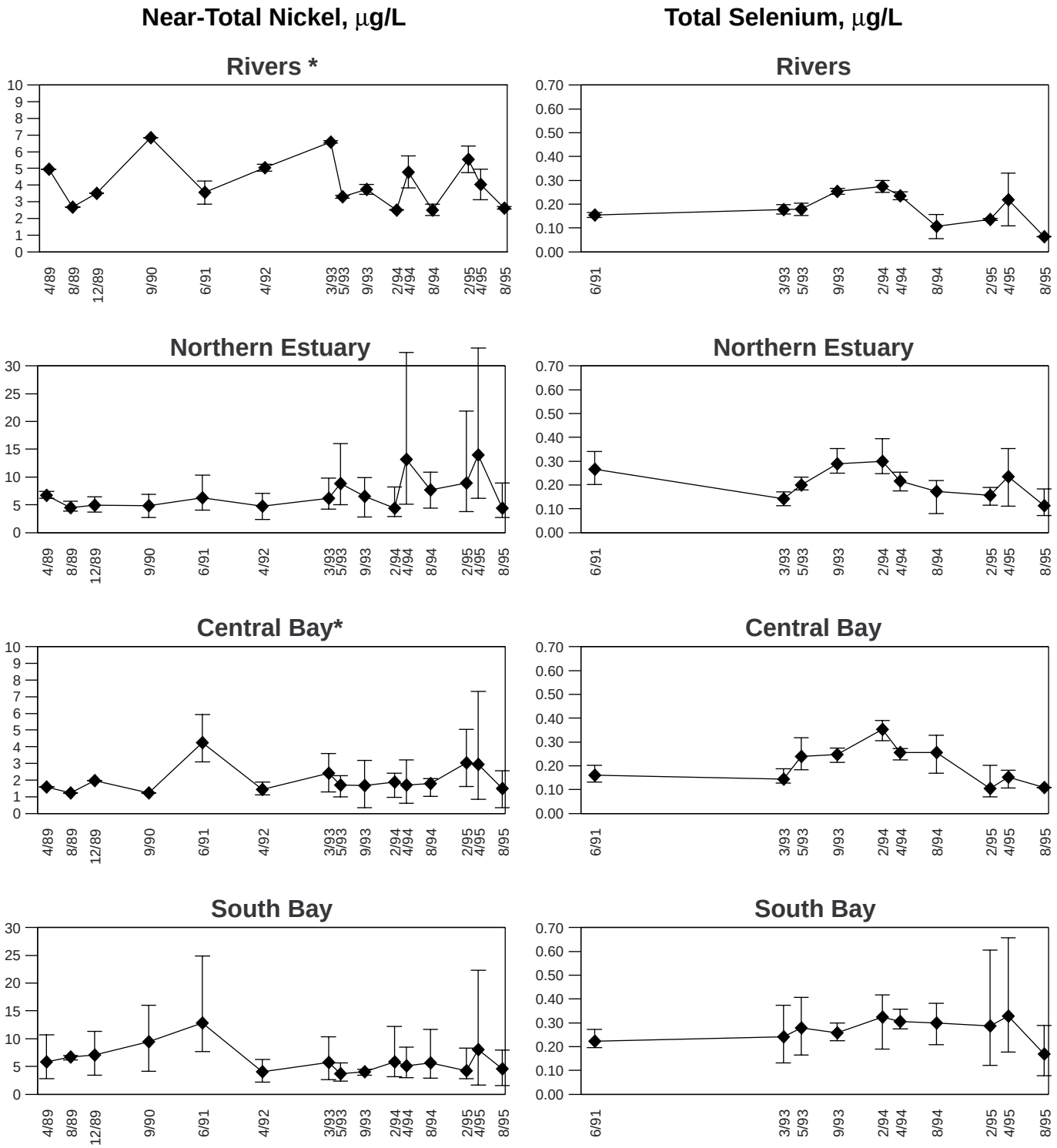
Figures 62 and 63. Plots of average arsenic and cadmium concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1995. Note that arsenic was not sampled during 1990–1992. The vertical bars represent ranges of values. Sample sizes for arsenic are as follows: South Bay 1989 and 1993 n=4, 1994–1995 n=7; Central Bay 1989 n=1, 1993 n=4, 1994–1995 n=5; Northern Estuary 1989 n=4, 1993 n=6, 1994–1995 n=8; Rivers 1989 n=1, 1993–1995 n=2. Sample sizes for cadmium are as follows: South Bay 1989–1993 n=4, 1994–1995 n=7; Central Bay 1989–1990 n=1, 1991 n=3, 1992–1993 n=4, 1994–1995 n=5; Northern Estuary 1989–1990 n=4, 1991–1992 n=7, 1993 n=6, 1994–1995 n=8; Rivers 1989–1990 n=1, 1991–1995 n=2.



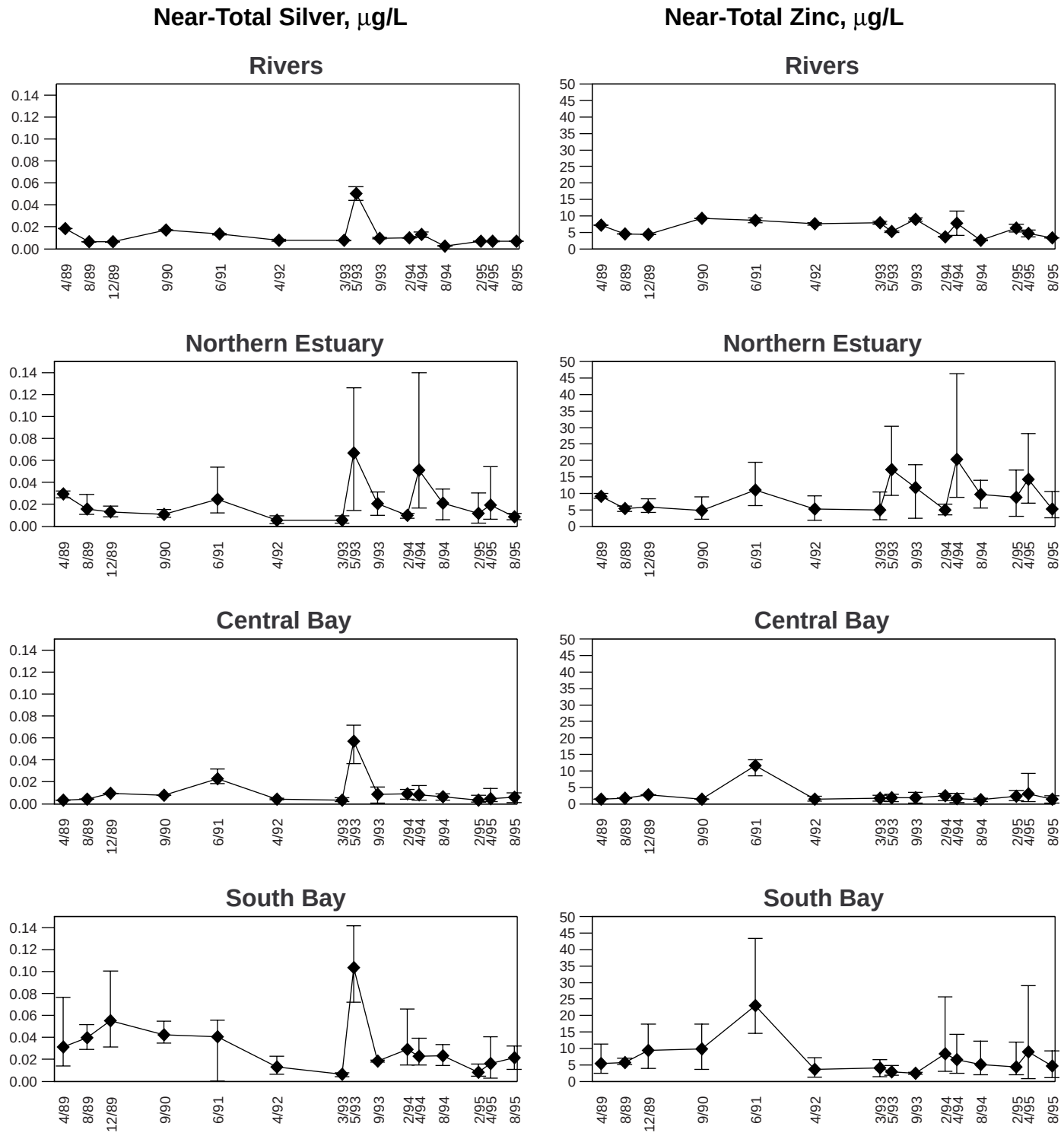
Figures 64 and 65. Plots of average chromium and copper concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1995. Note that chromium was not sampled prior to 1993. The vertical bars represent ranges of values. Sample sizes for chromium are as follows: South Bay 1993 n=4, 1994–1995 n=7; Central Bay 1993 n=4, 1994–1995 n=5; Northern Estuary 1993 n=6, 1994–1995 n=8; Rivers 1993–1995 n=2. Sample sizes for copper are as follows: South Bay 1989–1993 n=4, 1994–1995 n=7; Central Bay 1989–1990 n=1, 1991 n=3, 1992–1993 n=4, 1994–1995 n=5; Northern Estuary 1989–1990 n=4, 1991–1992 n=7, 1993 n=6, 1994–1995 n=8; Rivers 1989–1990 n=1, 1991–1995 n=2.* indicates different scale.



Figures 66 and 67. Plots of average lead and mercury concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1995. The vertical bars represent ranges of values. Sample sizes for lead and mercury are as follows: South Bay 1989–1993 n=4, 1994–1995 n=7; Central Bay 1989–1990 n=1, 1991 n=3, 1992–1993 n=4, 1994–1995 n=5; Northern Estuary 1989–1990 n=4, 1991–1992 n=7, 1993 n=6, 1994–1995 n=8; Rivers 1989–1990 n=1, 1991–1995 n=2.



Figures 68 and 69. Plots of average nickel and selenium concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1995. The vertical bars represent ranges of values. Sample sizes for nickel are as follows: South Bay 1989–1993 n=4, 1994–1995 n=7; Central Bay 1989–1990 n=1, 1991 n=3, 1992–1993 n=4, 1994–1995 n=5; Northern Estuary 1989–1990 n=4, 1991–1992 n=7, 1993 n=6, 1994–1995 n=8; Rivers 1989–1990 n=1, 1991–1995 n=2. Sample sizes for selenium are as follows: South Bay 1991 and 1993 n=4, 1994–1995 n=7; Central Bay 1991 n=3, 1993 n=4, 1994–1995 n=5; Northern Estuary 1991 n=7, 1993 n=6, 1994–1995 n=8; Rivers 1991 & 1993–1995 n=2. * indicates different scale.



Figures 70 and 71. Plots of average silver and zinc concentrations (parts per billion, ppb) in water in each Estuary reach from 1989–1995. The vertical bars represent ranges of values. Sample sizes for silver and zinc are as follows: South Bay 1989–1993 n=4, 1994–1995 n=7; Central Bay 1989–1990 n=1, 1991 n=3, 1992–1993 n=4, 1994–1995 n=5; Northern Estuary 1989–1990 n=4, 1991–1992 n=7, 1993 n=6, 1994–1995 n=8; Rivers 1989–1990 n=1, 1991–1995 n=2.

Trace Organics

Spatial patterns

In principle, dissolved trace organics concentrations can be used to indicate sources in a manner similar to the dissolved trace element concentrations. However, two features of the RMP dissolved organics data limit their value in this regard. First, the variance at a given station for trace organics is generally greater than for trace elements. Second, the filter used to separate particles from the dissolved fraction for the water organics samples has a pore size of 1 µm, significantly greater than the 0.45 µm filters used for trace elements, making the measured "dissolved" fraction a looser representation of the "true" dissolved fraction.

In spite of these limitations, general spatial patterns are evident in the dissolved trace organic data. Like the dissolved trace elements, most dissolved trace organics, including PCBs, chlordanes, DDTs, HCHs, and diazinon, were elevated in the South Bay relative to other reaches of the Estuary, with concentrations progressively decreasing from the Coyote Creek station (BA10) to the Golden Gate station (BC20). In the Northern Estuary dissolved concentrations of DDTs were consistently high, dissolved diazinon was relatively high in April and August, and dissolved chlordanes were high in April relative to other reaches of the Estuary. The River stations (BG20 and BG30) were occasionally high in dissolved pesticides (chlordanes, DDTs, and diazinon). February concentrations of diazinon were apparently uniformly high throughout the Estuary, even at the Golden Gate station (BC20). Dissolved HCHs were much lower at the River stations than in the rest of the Estuary, including the Golden Gate station.

Diazinon and HCHs occur mostly in the dissolved fraction, so spatial patterns for total concentrations are the same as for the dissolved fraction. Total concentrations of the more hydrophobic trace organics (PAHs, PCBs, DDTs, and chlordanes) generally displayed the same spatial pattern as TSS (Figure 1), with high concentrations in the South Bay, low concentrations in the Central Bay, high concentrations in the Northern Estuary, and intermediate concentrations in the Rivers. The highest total concentrations of the hydrophobic organics were measured at stations with the highest TSS concentrations (BA10, BA30, and BD15 in April).

Spatial variation in total concentrations of the hydrophobic trace organics is more apparent when the influence of TSS is removed using linear regression (Jarman and Davis, this report). The TSS-adjusted concentrations of PCBs and PAHs had similar spatial patterns, with consistently high values in the South Bay from BA10 to BA30, high values at the Petaluma River (BD15), intermediate values in the Central Bay, and consistently low values in the Rivers and Northern Estuary. These data suggest the existence of sources of PCBs and PAHs in the South Bay and at the Petaluma River station (BD15). Adjusted DDT concentrations were consistently high in the Rivers and Northern Estuary, consistently low at Redwood Creek (BA40), and generally inconsistent at other stations. Adjusted chlordane concentrations were highest in the South Bay (especially at Coyote Creek—BA10) and lowest at the Sacramento River (BG20). Overall, the dissolved and TSS-adjusted trace organics data clearly indicate the presence of sources in the South Bay for all of the organics and at the Rivers for DDTs.

Temporal trends

Seasonal Variation

Some of the dissolved trace organics displayed obvious seasonal variation. Dissolved ΣPAHs were much higher at all stations in August than in February and April. The explanation for this variation is not obvious. Only the dissolved fraction was high in August; the particulate fraction was generally highest in April. High water temperatures occured in August, but these would have similarly affected dissolved ΣPAH concentrations in 1994 and August concentrations were not elevated in that year. Diazinon concentrations were uni-

formly high in February, intermediate in April, and low in August. More information on the persistence of diazinon in Bay waters and seasonal variation in local use of diazinon would be needed to interpret whether the observed variation corresponds with seasonal variation in diazinon loadings to the Estuary.

Total concentrations of the trace organics that tend to be particle-associated (PAHs, PCBs, chlordanes, and DDTs) were often highest in April, coinciding with high concentrations of TSS. Examination of the relationship between TSS and DDTs during each cruise suggested that large freshwater flows in April carried relatively contaminated sediments into the Estuary (Jarman and Davis, this report).

Long-term Trends

A detailed statistical analysis of long-term trends, as was conducted for the trace elements, has not been conducted for the trace organics. Figures 72–77 are summary plots of available RMP data for total (dissolved + particulate) concentrations of trace organics in water. From visual inspection of these plots there are two cases where declines seem possible. First, diazinon at the Rivers was much higher in February 1994 than in subsequent sampling events. Since diazinon loads to the Estuary are highly episodic, however, the high concentrations in February 1994 may simply have been due to sampling coinciding with transport of a pulse of diazinon from upstream. Second, ΣDDTs at the Rivers was higher in February 1993 than in subsequent sampling. With only one point elevated above the others, however, many hypotheses other than an actual long-term trend could provide a plausible explanation for these results.

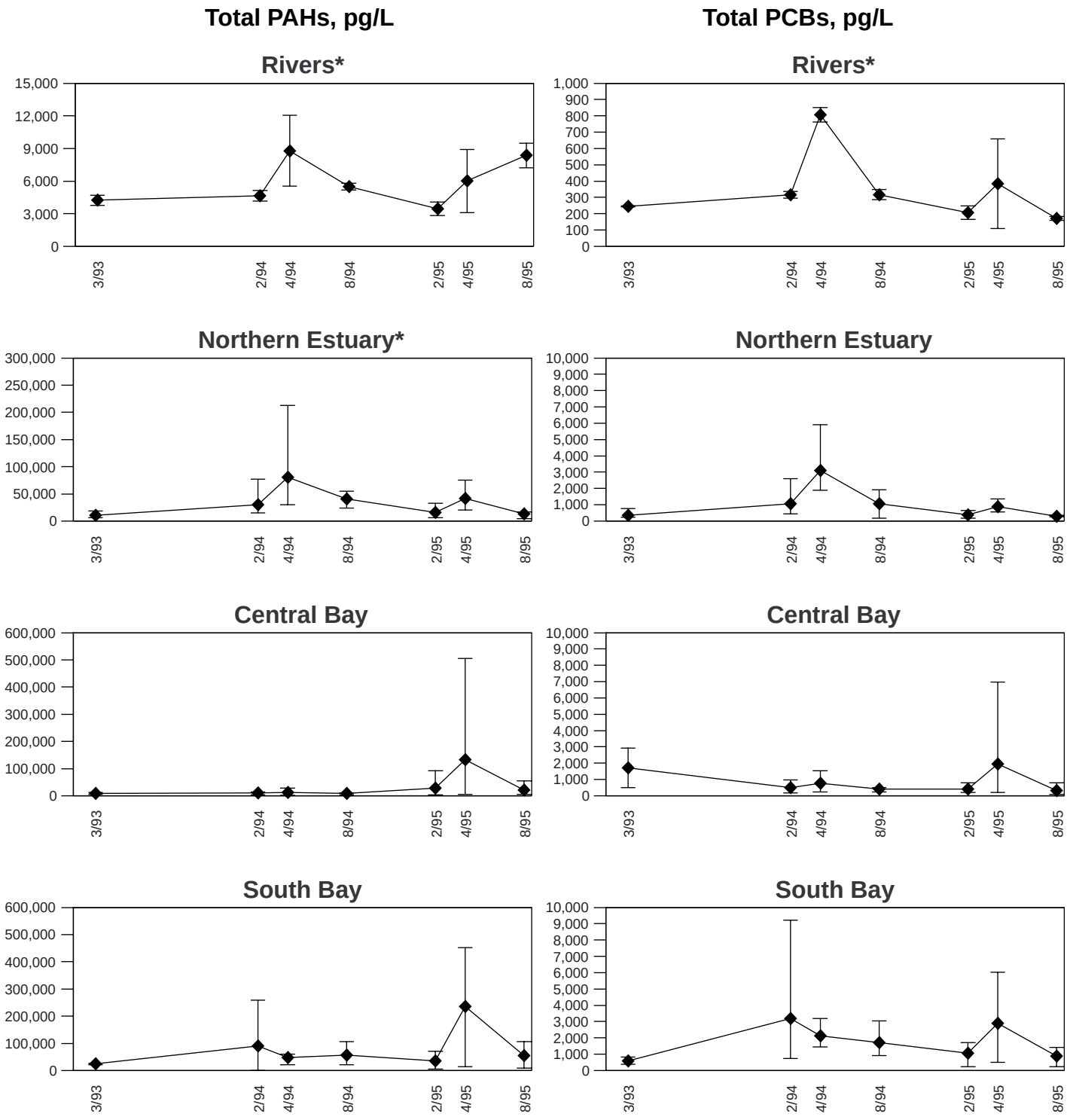
Overall it is likely that, similar to the trace elements, a rigorous analysis of trends in the total trace organics data would not detect statistically significant trends. Also, similar to the trace elements, it is likely that the best way to attempt to uncover trends in the water trace organics will be to establish their relationships with important exogenous variables and then remove the influence of those variables, leaving a clearer picture of temporal variation.

For certain persistent trace organics, the long-term rate of decline in concentrations appears to be very slow (see Jarman and Davis, this report, for a more detailed discussion). The historic water data are particularly relevant (Risebrough, this report). Mean Aroclor-based ΣPCB concentrations measured in the Central Bay in 1975 were approximately 900 pg/l. In 1980 de Lappe *et al.*, (1983) measured Aroclor-based ΣPCB concentrations in the Central Bay, obtaining values of 647 pg/L at the Golden Gate and 664 pg/L at Angel Island. The average concentration of congener-based ΣPCBs in the Central Bay for RMP cruises has been approximately 400 pg/L. Congener-based ΣPCB concentrations in other regions of the Estuary are frequently much higher. Since Aroclor-based ΣPCB values are inherently probably two or more times higher than congener-based ΣPCB values, the concentrations detected in these older studies and those detected currently in the RMP are roughly equivalent. These data indicate that PCBs levels have not declined appreciably since the mid-1970s.

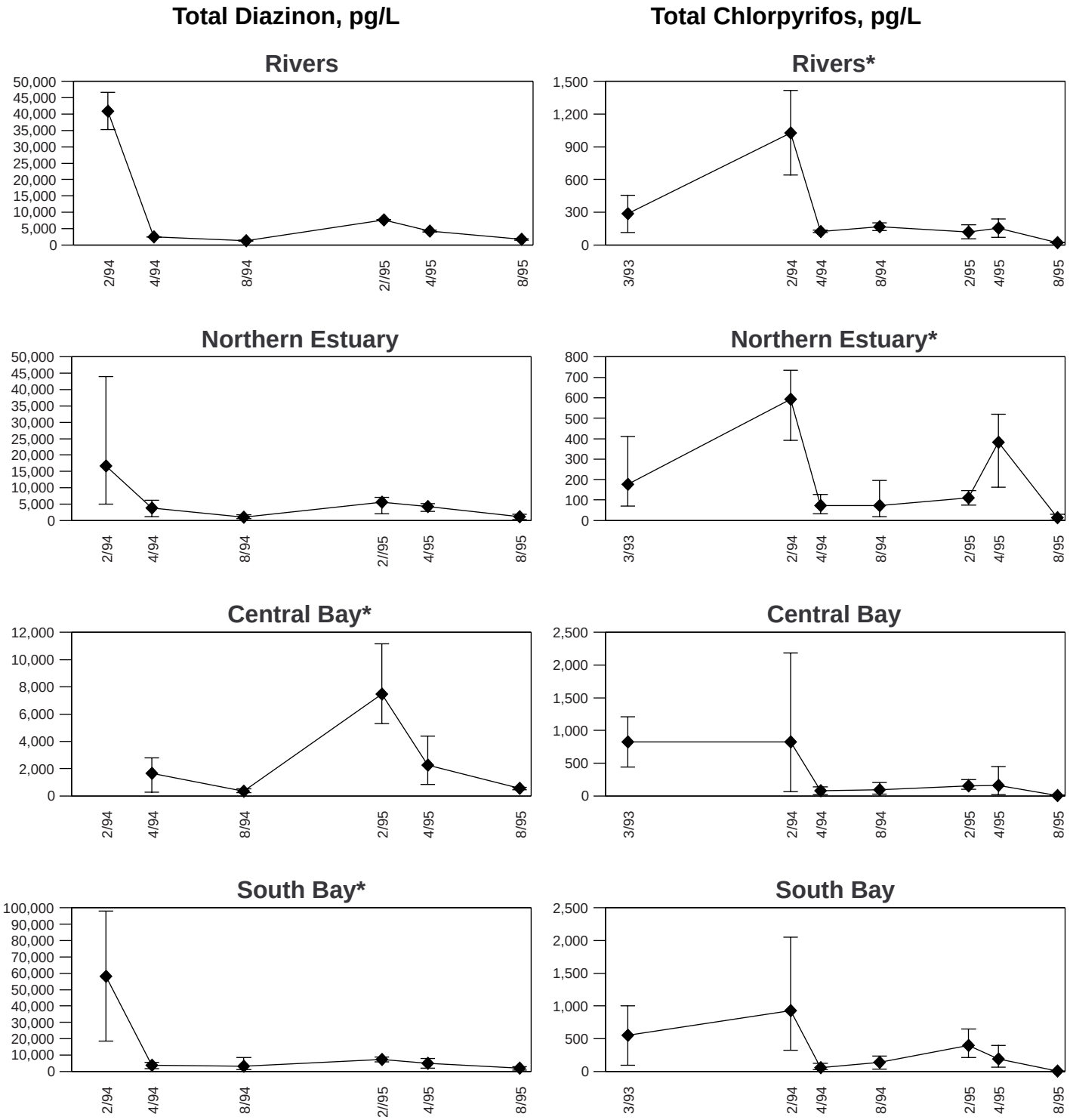
Comparison to Water Quality Guidelines

This section provides an overview of how 1995 RMP data compare to water quality guidelines (i.e., criteria and objectives). Guidelines used for these comparisons are shown in Tables 10–12. It should be noted that in a number of cases RMP data are not strictly comparable to the available guidelines, as discussed in the Background section of this chapter.

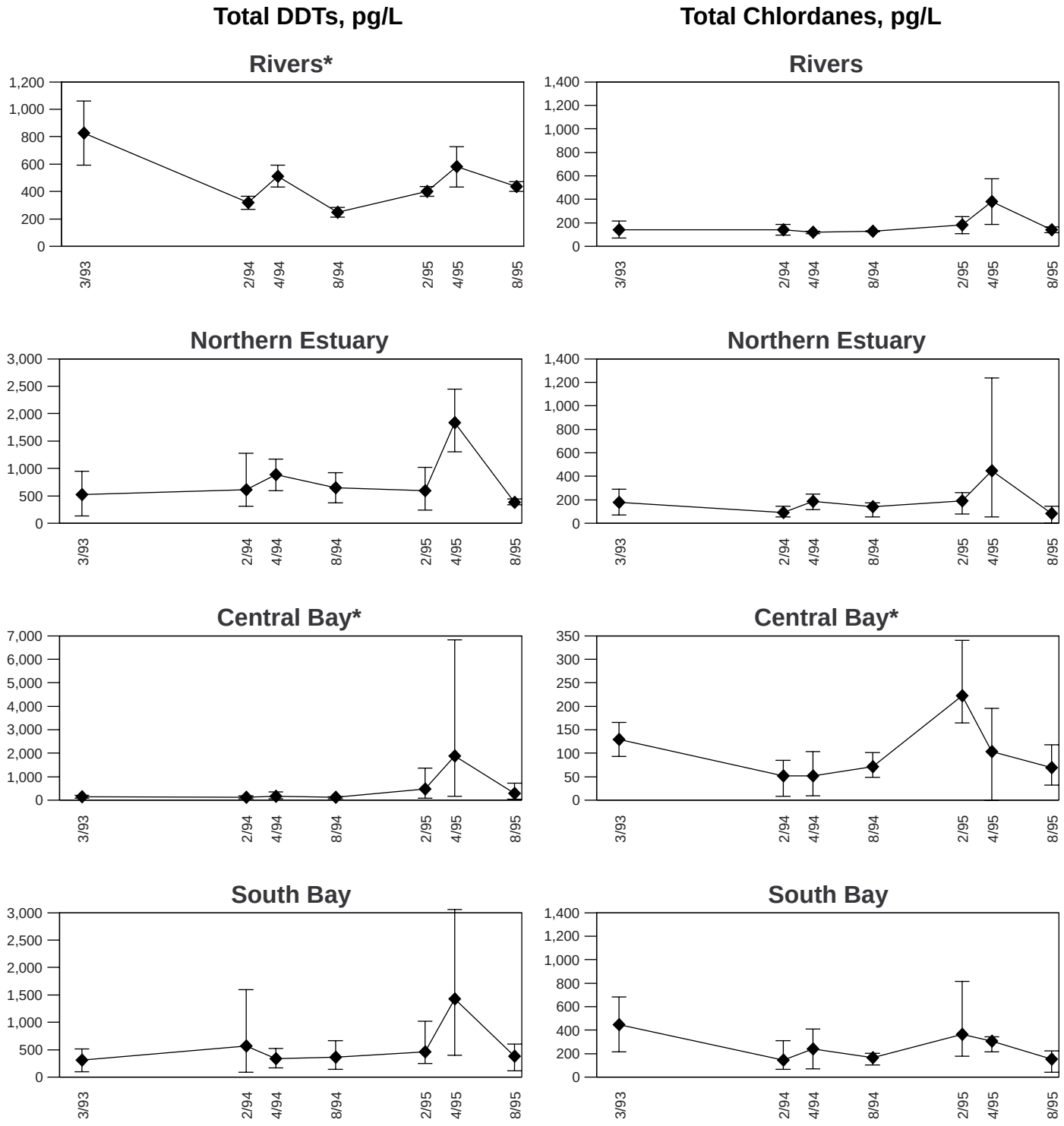
Of the ten trace elements measured, concentrations of Cr, Cu, Pb, Hg, and Ni were higher than guidelines on one or more occasions (Table 13). Cu, Hg, and Ni were most frequently above guidelines, with high concentrations occurring especially in the Southern Sloughs, South Bay, and the Northern Estuary. Several classes of trace organics also had concentrations above guidelines, including PCBs, PAHs, DDTs, chlordanes, dieldrin, and diazinon.



Figures 72 and 73. Plots of average PAH and PCB concentrations (parts per quadrillion, ppq) in water in each Estuary reach from 1993–1995. The vertical bars represent ranges of values. Sample sizes are as follows: South Bay 1993 n=2, 1994–1995 n=4; Central Bay 1993 n=2, 1994–1995 n=4; Northern Estuary 1993 n=5, 1994–1995 n=6; Rivers 1993–1995 n=2. * indicates different scale.



Figures 74 and 75. Plots of average diazinon and chlorpyrifos concentrations (parts per quadrillion, ppq) in water in each Estuary reach from 1993–1995. The vertical bars represent ranges of values. Sample sizes are as follows: South Bay 1993 n=2, 1994–1995 n=4; Central Bay 1993 n=2, 1994–1995 n=4; Northern Estuary 1993 n=5, 1994–1995 n=6; Rivers 1993–1995 n=2. * indicates different scale.



Figures 76 and 77. Plots of average DDT and chlordane concentrations (parts per quadrillion ppq) in water in each Estuary reach from 1993–1995. The vertical bars represent ranges of values. Sample sizes are as follows: South Bay 1993 n=2, 1994–1995 n=4; Central Bay 1993 n=2, 1994–1995 n=4; Northern Estuary 1993 n=5, 1994–1995 n=6; Rivers 1993–1995 n=2. * indicates different scale.

Table 10. Basin Plan water quality objectives for toxic pollutants in surface waters. From *San Francisco Bay Basin (Region 2), Water Quality Control Plan* (June 21, 1995). Values are in µg/L. H = hardness. Refer to Basin Plan for further information.

FRESH WATER Parameter	Instantaneous Maximum	24-hour average	1-hour average	4-day average
Ag	1.2	.	.	.
As	.	.	360	190
Cd	.	.	$e^{(1.128H - 3.828)}$	$e^{(0.7852H - 3.4590)}$
Cr	.	.	16	11
Cu	.	.	$e^{(0.9422H - 1.464)}$	$e^{(0.8545H - 1.465)}$
Hg	.	.	2.4	0.025
Ni	1100	56	$e^{(0.846H + 3.3612)}$	$e^{(0.846H + 1.1645)}$
Pb	.	.	$e^{(1.273H - 1.460)}$	$e^{(1.273H - 4.705)}$
Zn	170	58	$e^{(0.8473H - 0.8604)}$	$e^{(0.8473H - 0.7614)}$
TOTAL PAHs[A]	.	15	.	.

SALT WATER Parameter	Instantaneous Maximum	24-hour average	1-hour average	4-day average
Ag	2.3	.	.	.
As	.	.	69	36
Cd	.	.	43	9.3
Cr	.	.	1100	50
Cu	.	.	4.9	.
Hg	.	.	2.1	0.025
Ni	140	7.1	.	.
Pb	.	.	140	5.6
Zn	170	58	.	.
TOTAL PAHs[A]	.	15	.	.

[A] Compounds identified in EPA Method 610.

Table 11. Conversion factors for trace elements in water. From the May 4, 1995 Federal Register, Part IV- EPA 40 CFR Part 131, pg. 22231 (Table 2: freshwater and Table 3: saltwater). H = hardness.

Parameter	Convert Total to Dissolved Fresh Water		Salt Water
	1-hour average	4-day average	1-hour average [A]
Ag	0.85	.	0.85
As	1	1	1
Cd	1.136672-[(ln(H)*(0.041838)]	1.101672-[(ln(H)*(0.041838)]	0.994
Cr	0.982	0.962	0.993
Cu	0.96	0.96	0.83
Hg	na [B]	na [B]	na [B]
Ni	0.998	0.997	0.99
Pb	1.46203-[(ln(H)*(0.145712)]	1.46203-[(ln(H)*(0.145712)]	0.951
Se	.	.	0.998
Zn	0.978	0.986	0.946

[A] Conversion factors for 4-day salt water averages are not currently available. Use 1-hour conversion factors.

[B] Mercury is judged on a total basis as the objective is based on mercury residues in aquatic organisms rather than toxicity.

Table 12. EPA ("National Toxics Rule") water quality criteria for priority toxic pollutants. From *Federal Register*, December 22, 1992—Vol. 57, No. 246. Rules and Regulations.

Parameter	Aquatic Life				Human Health (10-6 risk for carcinogens)	
	Fresh Water		Salt Water		Fresh Water	Salt and Fresh Water
	1-hour average	4-day average	1-hour average	4-day average	Water & Organisms	Organisms only
Ag	$e^{(1.72H -6.52)}$	.	2.3	.	.	.
As	360	190	69	36	0.018	0.14
Cd	$e^{(1.128H - 3.828)}$	$e^{(0.7852H - 3.4590)}$	43	9.3	.	.
Cr	16	11	1100	50	.	.
Cu	$e^{(0.9422H - 1.464)}$	$e^{(0.8545H - 1.465)}$	2.9	2.9	.	.
Hg	2.4	0.012	2.1	0.025	0.14	0.15
Ni	$e^{(0.846H + 3.3612)}$	$e^{(0.846H + 1.1645)}$	75	8.3	610	4600
Pb	$e^{(1.273H - 1.460)}$	$e^{(1.273H - 4.705)}$	220	8.5	.	.
Se	20	5	300	71	.	.
Zn	$e^{(0.8473H - 0.8604)}$	$e^{(0.8473H - 0.7614)}$	95	86	.	.
Anthracene	.	.	.	.	0.00012	0.00054
Benz(a)anthracene	.	.	.	.	0.0028	0.031
Benzo(a)pyrene	.	.	.	.	0.0028	0.031
Benzo(b)fluoranthene	.	.	.	.	0.0028	0.031
Benzo(k)fluoranthene	.	.	.	.	0.0028	0.031
Chrysene	.	.	.	.	0.0028	0.031
Dibenz(a,h)anthracene	.	.	.	.	0.0028	0.031
Fluoranthene	.	.	.	.	300	370
Indeno(1,2,3-cd)pyrene	.	.	.	.	0.0028	0.031
Phenanthrene	.	.	.	.	.	.
Pyrene	.	.	.	.	960	11000
Alpha-HCH	.	.	.	.	0.0039	0.013
Beta-HCH	.	.	.	.	0.014	0.046
Chlordane	2.4	0.0043	0.09	0.004	0.00057	0.00059
Delta-HCH	.	.	.	.	.	.
Dieldrin	2.5	0.0019	0.71	0.0019	0.00014	0.00014
Endosulfan I	0.22	0.056	0.034	0.0087	0.93	2
Endosulfan II	0.22	0.056	0.034	0.0087	0.93	2
Endosulfan Sulfate	.	.	.	.	0.93	2
Endrin	0.18	0.0023	0.037	0.0023	0.76	0.81
Gamma-HCH	2	0.08	0.16	.	0.019	0.063
Heptachlor	0.52	0.0038	0.053	0.0036	0.00021	0.00021
Heptachlor Epoxide	0.52	0.0038	0.053	0.0036	0.0001	0.00011
Hexachlorobenzene	.	.	.	.	0.00075	0.00077
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
Total PCBs [A]	.	0.014	.	0.03	0.000044	0.000045

[A] Total PCBs are not in the Federal Register, but individual Aroclors are. All Aroclors have the same value.

Table 13. Summary of contaminants that were above water quality objectives or criteria at each 1995 RMP water sampling station. Trace element objectives are from the Basin Plan (Table 10). The Basin Plan does not have an objective for selenium. This criterion comes from the EPA (Federal Register, May 4, 1995). Trace organics results are compared to the human health (10^6 risk for carcinogens), fresh and salt water criteria for the consumption of organisms only, found in the EPA Federal Register, May 4, 1995. The total PAHs objective is from the Basin Plan as the Federal Register does not have a criterion for total PAHs. The diazinon guideline is from the National Academy of Sciences. W = Wet season (February), S = Spring sampling (late May), D = Dry season (August), - = not above guideline, * = not available or not sampled.

		Chromium	Copper	Mercury	Nickel	Lead	Selenium	Zinc	Anthracene	Benzo(a)pyrene	Benzo(b)fluoranthene	Diazinon	Dieldrin	Heptachlor Epoxide	Indeno(1,2,3-cd)pyrene	p,p'-DDD	p,p'-DDE	p,p'-DDT	Total PCBs (SFEI)	Total PAHs (SFEI)
	Guideline	**50**	**4.9**	**0.025**	**7.1**	**5.6**	**5**	**58**	**540**	**31000**	**310**	**9000**	**140**	**110**	**31000**	**840**	**590**	**590**	**45**	**31000**
Station Name	**Station Code**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/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**
Sunnyvale	C-1-3	-,S,-	-,-,-	-,S,D	-,-,D	-,-,D	-,-,-	-,-,-	*	*	*	*	*	*	*	*	*	*	*	*
San Jose	C-3-0	-,S,-	-,-,-	-,S,D	-,-,D	-,-,D	-,-,-	-,-,-	*	*	*	*	*	*	*	*	*	*	*	*
Coyote Creek	BA10	-,-,-	-,S,D	-,S,-	W,S,-	-,S,-	-,-,-	-,-,-	-,S,-	-,S,-	-,S,-	-,-,-	-,-,D	W,S,-	-,S,-	-,S,-	-,S,-	-,-,-	W,S,D	W,S,D
South Bay	BA20	-,-,-	-,S,-	-,S,-	-,S,D	-,-,-	-,-,-	-,-,-	*	*	*	*	*	*	*	*	*	*	*	*
Dumbarton Bridge	BA30	-,-,-	-,S,-	-,S,D	-,S,D	-,-,-	-,-,-	-,-,-	-,S,-	-,S,-	-,S,-	-,-,-	-,-,-	-,-,-	-,S,-	-,-,-	-,S,-	-,-,-	W,S,D	W,S,D
Redwood Creek	BA40	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	W,S,D	-,S,D
San Bruno Shoal	BB15	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	*	*	*	*	*	*	*	*	*	*	*	*
Oyster Point	BB30	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	*	*	*	*	*	*	*	*	*	*	*	*
Alameda	BB70	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	W,S,D	-,-,-
Yerba Buena Island	BC10	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,*	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	W,S,D	-,-,-
Golden Gate	BC20	-,-,-	-,-,-	-,-,*	-,-,-	-,-,-	-,-,*	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	W,-,-	-,-,-	-,-,-	-,-,-	-,-,-	W,S,D	-,-,-
Richardson Bay	BC30	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	*	*	*	*	*	*	*	*	*	*	*	*
Point Isabel	BC41	-,-,-	-,-,-	-,-,-	-,S,-	-,-,-	-,-,*	-,-,-	*	*	*	*	*	*	*	*	*	*	*	*
Red Rock	BC60	-,-,*	-,-,-	-,-,-	-,-,-	-,-,-	-,-,*	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	W,S,D	-,-,-
Petaluma River	BD15	W,S,-	-,-,-	W,S,D	-,-,D	-,-,-	-,-,-	-,-,-	-,S,-	-,S,-	-,S,-	W,-,-	-,-,-	W,-,-	-,S,-	-,S,-	-,S,-	-,S,-	W,S,D	W,S,D
San Pablo Bay	BD20	-,-,-	-,S,-	-,S,-	-,S,-	-,-,-	-,-,*	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	W,-,-	-,-,-	-,-,-	-,S,-	-,-,-	W,S,D	-,S,-
Pinole Point	BD30	-,S,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,S,-	-,-,-	-,-,-	-,S,-	-,-,-	W,S,D	-,-,-
Davis Point	BD40	-,S,-	W,-,-	-,S,-	W,-,-	-,-,-	-,-,-	-,-,*	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,S,-	-,-,-	W,S,D	-,S,-
Napa River	BD50	-,-,-	W,S,-	-,-,-	W,S,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,S,-	-,-,-	W,S,D	W,-,-
Pacheco Creek	BF10	-,-,-	W,S,-	-,-,-	W,-,-	-,-,-	-,-,-	-,-,-	*	*	*	*	*	*	*	*	*	*	*	*
Grizzly Bay	BF20	-,-,-	W,S,-	-,S,-	-,S,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	W,-,-	-,-,-	-,-,-	-,S,-	-,-,-	W,S,D	-,-,-
Honker Bay	BF40	-,-,*	W,S,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	*	*	*	*	*	*	*	*	*	*	*	*
Sacramento River	BG20	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,*	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,D	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	W,S,D	-,-,-
San Joaquin River	BG30	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	-,-,-	W,-,-	-,-,-	-,-,-	-,-,-	-,-,-	W,S,D	-,-,-

Congener-based ΣPCBs were well above the Aroclor-based 45 pg/L guideline in all RMP samples. The lowest ΣPCB concentration measured in the RMP was 83 pg/L at the Golden Gate (BC20) in August, still well above the guideline. ΣPAHs were above the 31,000 pg/L guideline at several stations, and during all cruises at Coyote Creek (BA10), Dumbarton Bridge (BA30), and Petaluma River (BD15). Concentrations of some individual DDT isomers and individual PAHs were above guidelines in April, coinciding with high TSS concentrations in a very wet period. Diazinon was above the 9,000 pg/L NAS guideline in one sample from the Petaluma River (BD15) in February. The stations with the largest numbers of concentrations above guidelines were Coyote Creek (BA10), the Dumbarton Bridge (BA30), and the Petaluma River (BD15). Unusually high TSS at the Petaluma River station (BD15) was partially responsible for the occurrence of high concentrations of several contaminants there in April.

In some cases different guidelines are used in this report than were used in the 1994 report, so the frequencies of guideline exceedances included in the 1994 report may not be directly comparable to those in this report. For a direct comparison of 1994 and 1995, the same criteria used in this report were applied to the 1994 data (data not shown). The overall pattern of exceedances was very similar in the two years, with the following exceptions. Concentrations of Cu, Ni, diazinon, and dieldrin were above guidelines distinctly more frequently in 1994. On the other hand, concentrations of p,p'-DDE and heptachlor epoxide were above guidelines more frequently in 1995. In 1994, as in 1995, Coyote Creek (BA10), Dumbarton Bridge (BA30), and Petaluma River (BD15) frequently had concentrations above guidelines, but the Grizzly Bay (BF20), Pinole Point (BD30), and San Pablo Bay (BD20) stations were also frequently above guidelines.

Effects of Water Contamination

Aquatic toxicity was observed in only one water sample in 1995, in a *Mysidopsis* test of San Joaquin River (BG30) water collected in February (Figure 36). While this result was statistically significant, its biological significance may be questioned, since the reduction in survival of test organisms relative to controls was not large. Many of the attempted tests did not produce usable results due to poor mussel larvae survival in some February controls and production of inviable sperm or eggs by oyster stocks in August.

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 that were not targeted at specific contaminants, the likelihood is low that short-duration contamination events would have been detected. The lack of significant results in 1995, therefore, does not necessarily mean that the Estuary was free of ambient toxicity for the entire year. Results obtained in February 1996, in contrast to 1995 results, showed clear statistically and biologically significant toxicity in the *Mysidopsis* test at the Sacramento River (BG20), San Joaquin River (BG30), and Grizzly Bay (BF20) stations. 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. This sampling strategy should provide valuable information on the acute toxicity associated with storm runoff, which may be an important source of many contaminants of concern in the Estuary.

CHAPTER THREE

Sediment Monitoring

Background

Sediment quality, trace elements, and trace organic contaminants were measured at 22 RMP base program stations. In addition, trace elements were measured at two stations in the southern end of the Estuary in cooperation with the Regional Board and the Cities of San Jose (C-3-0) and Sunnyvale (C-1-3). Conductivity, temperature, and depth profiles were also taken in the water column at all RMP stations (station depth is reported in Appendix C, Table 11). 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 shown on Table 3 in Chapter One: Introduction. Detailed methods of collection and analysis are included in Appendix A. Measurements made on sediment samples are listed in Table 3 in Chapter One: Introduction.

This section contains graphs and data tables for sediment trace elements (Figures 1–10) and trace organic contaminants (Figures 11–13). Tabulated data for sediment quality parameters, such as grain-size and organic material, are included in Appendix C. New in 1995 are data on ammonia and sulfides in Estuary sediments.

In order to compare results among the major areas, or reaches of the Estuary, the RMP stations are separated into six groups of stations based subjectively on geography, similarities in sediment types, and patterns of trace contaminant concentrations.

The five Estuary reaches are: 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). The coarse sediment stations (BC60, BD41, BF10, and BG20) showed different sediment chemistry and were grouped separately for analytical comparisons.

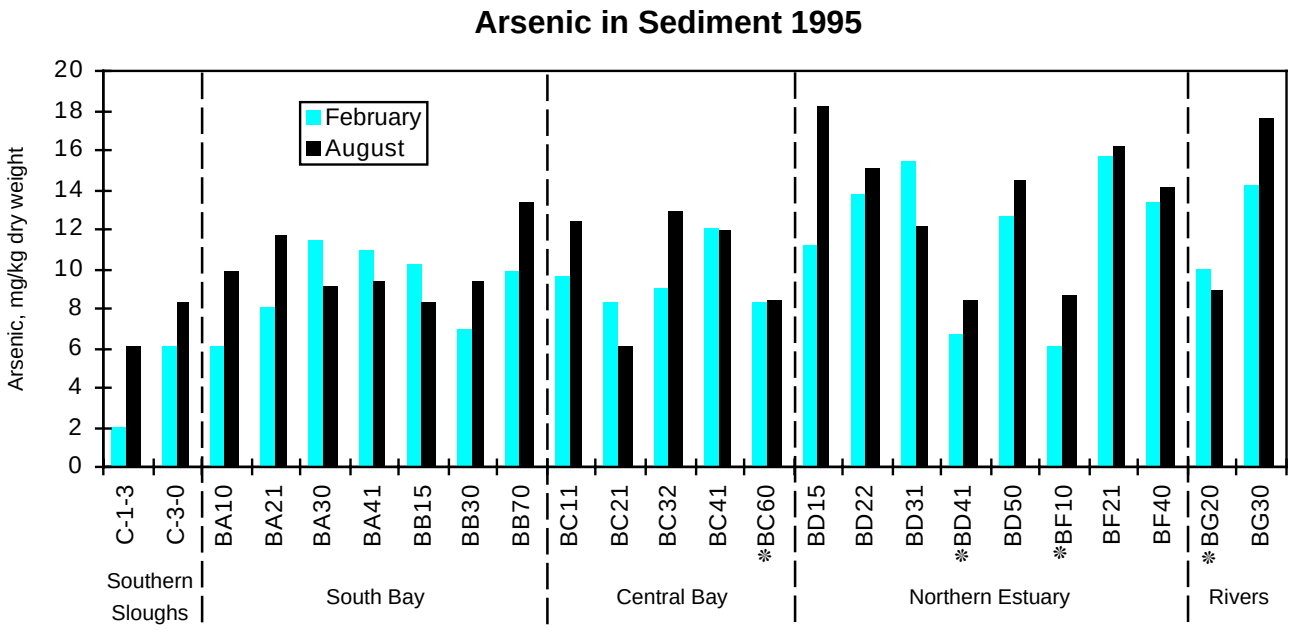


Figure 1. Arsenic (As) concentrations in sediment in parts per million, dry weight (ppm) at 24 RMP stations sampled in February and August of 1995. * indicates coarse sediment stations. Arsenic concentrations ranged from 2.00 to 18.23 ppm. The highest concentration was sampled at Petaluma River (BD15) in August and the lowest at Sunnyvale (C-1-3) in February. Average concentrations were highest in the Northern Estuary in August (13.36 ppm). Concentrations were highest in August for the Southern Slough stations, but there was no consistent seasonal trend in other Estuary reaches. Arsenic concentrations were below the ERM value of 70 ppm at all stations. However, concentrations were above the ERL value of 8.2 ppm at 17 stations in February and 21 stations in August.

Sediment Quality Guidelines

There are currently no Basin Plan objectives or other regulatory criteria for sediment contaminant concentrations in the Estuary. However, the US EPA has produced draft objectives for five trace contaminants: three PAHs—acenapthene, fluoranthene, and phenanthrene—and two pesticides—dieldrin and endrin (EPA, 1991). Those draft objectives, along with the National Oceanic and Atmospheric Administration's (NOAA) Effects Range-Median (ERM) and Effects Range-Low (ERL) values (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.

The NOAA guidelines are based on data compiled in 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 ERL is the concentration above which 10% of the studies showed effects, and the ERM is the concentration above which 50% of the studies showed effects. Concentrations between the ERL and ERM are interpreted to indicate a "possible effects range" within which effects would occasionally occur. Concentrations above the ERM are interpreted to indicate a "probable effects range" within which effects frequently occur (Long *et al.*, 1995).

There are no sediment guidelines for several contaminants. Earlier versions of the ERLs (Long and Morgan, 1990) included guidelines for chlordanes, aldrin, and endrin, but they were not included in the more recent guidelines because of insufficient data. Further, effects range values for nickel and DDTs have low levels of confidence associated with them. There are no ERLs or ERMs for selenium, but the Regional Board has suggested that concentrations below 1.4 ppm are acceptable for wetland creation when covered by three feet of sediments with concentrations below 0.7 ppm (Wolfenden and Carlin, 1992). Therefore, it should be recognized that the NOAA guidelines do not provide comprehensive guidelines for all sediment contaminants.

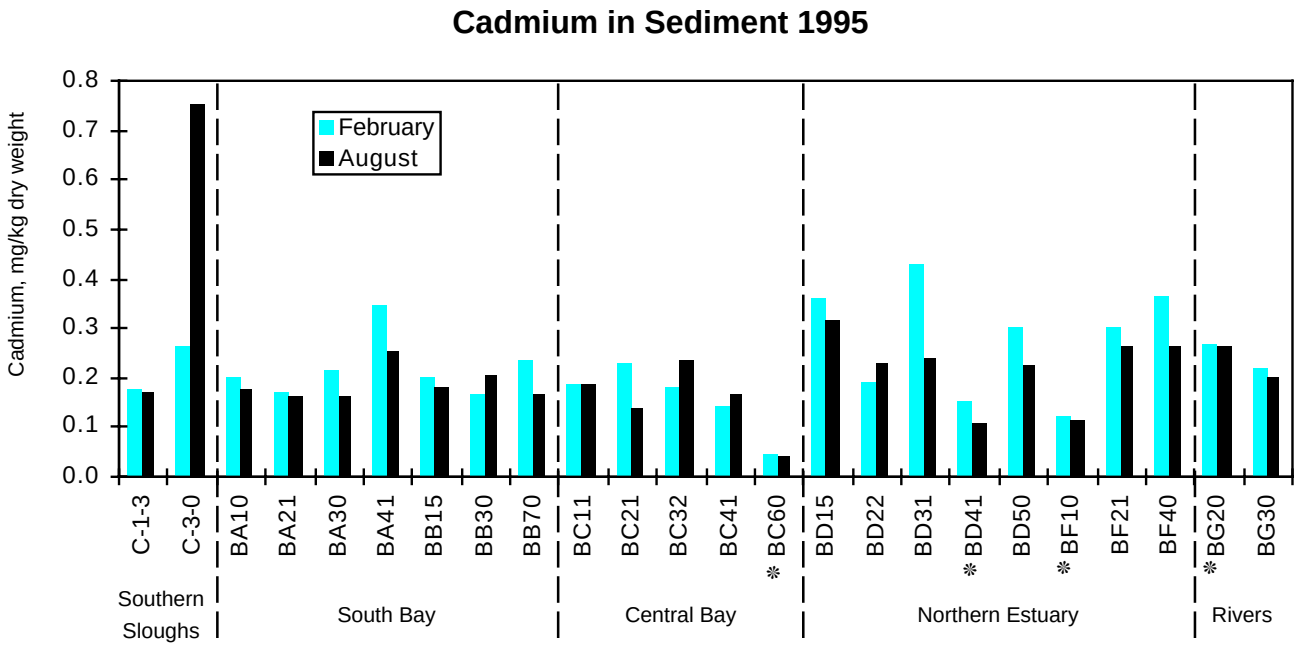


Figure 2. Cadmium (Cd) concentrations in sediment in parts per million, dry weight (ppm) at 24 RMP stations sampled in February and August of 1995. ❊ indicates coarse sediment stations. Cadmium concentrations ranged from 0.041 to 0.75 ppm. The highest concentration was sampled at San Jose (C-3-0) in August and lowest at Red Rock (BC60) in August. Average concentrations were highest in the Southern Sloughs in August (0.46 ppm). In general, concentrations were higher in February than in August. Cadmium concentrations were all below the ERM value of 9.6 ppm and the ERL value of 1.2 ppm.

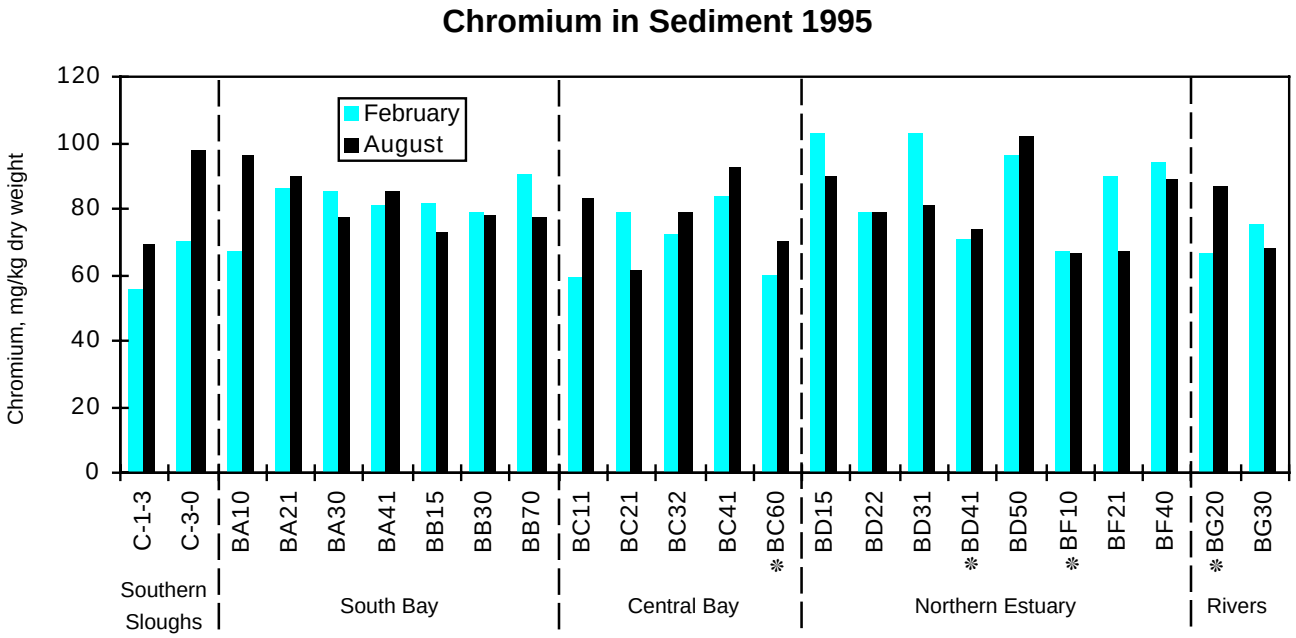


Figure 3. Chromium (Cr) concentrations in sediment in parts per million, dry weight (ppm) at 24 RMP stations sampled in February and August of 1995. ❊ indicates coarse sediment stations. Chromium concentrations ranged from 55.63 to 102.74 ppm. The highest concentration was sampled at Pinole Point (BD31) in February and the lowest concentration was at Sunnyvale (C-1-3) in February. Average concentrations were highest in the Northern Estuary in February (87 ppm). Concentrations were higher in August in the Southern Sloughs, but there was no consistent seasonal trend in other Estuary reaches. Chromium concentrations were below the ERM value of 370 ppm at all stations. However, concentrations were above the ERL value of 81 ppm at 10 stations in February and 11 stations in August.

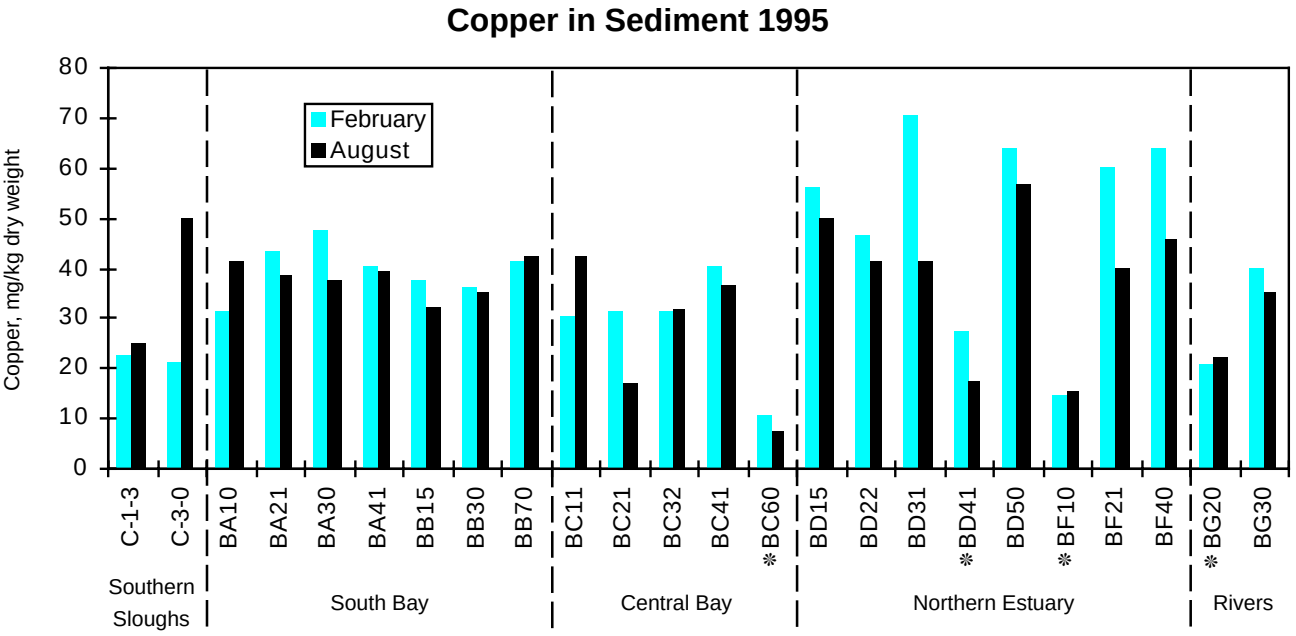


Figure 4. Copper (Cu) concentrations in sediment in parts per million, dry weight (ppm) at 24 RMP stations sampled in February and August of 1995. ❊ indicates coarse sediment stations. Copper concentrations ranged from 7.20 to 70.62 ppm. The highest concentration was sampled at Pinole Point (BD31) in February and the lowest at Red Rock (BC60) in August. Average concentrations were highest in the Northern Estuary in February (50.25 ppm). Concentrations were higher in August for the Southern Sloughs and in Febuary for most stations in the Northern Estuary, but there was no consistent seasonal trend in other Estuary reaches. Copper concentrations were below the ERM value of 270 ppm at all stations. However, concentrations were above the ERL value of 34 ppm at 14 stations in February and 16 stations in August.

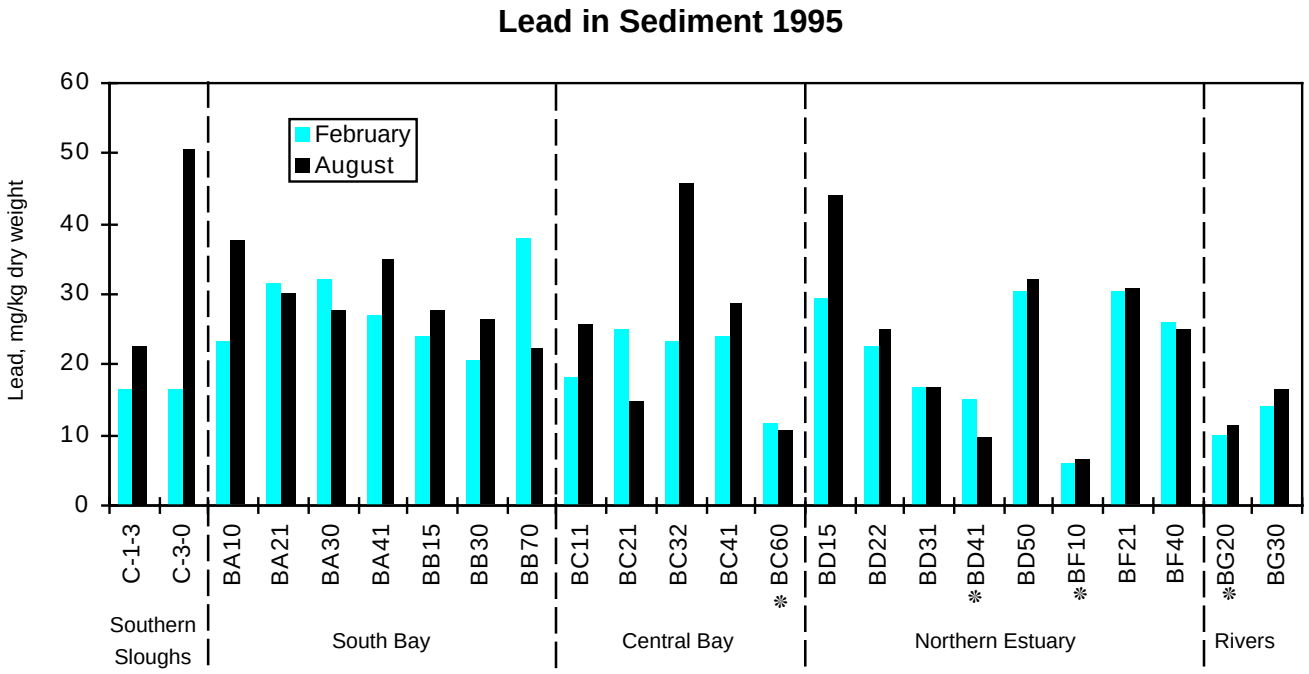


Figure 5. Lead (Pb) concentrations in sediment in parts per million, dry weight (ppm) at 24 RMP stations sampled in February and August of 1995. ❊ indicates coarse sediment stations. Lead concentrations ranged from 5.86 to 50.60 ppm. The highest concentration was sampled at San Jose (C-3-0) in August and the lowest concentration at Pacheco Creek (BF10) in February. Average concentrations were highest in the Southern Sloughs in August (36.50 ppm) but were also high at the South Bay stations in August (29.41 ppm). In general, concentrations were higher in August than in February for all Estuary reaches. Lead concentrations were below the ERM value of 218 ppm at all stations. However, concentrations were above the ERL value of 46.7 ppm at one station in August.

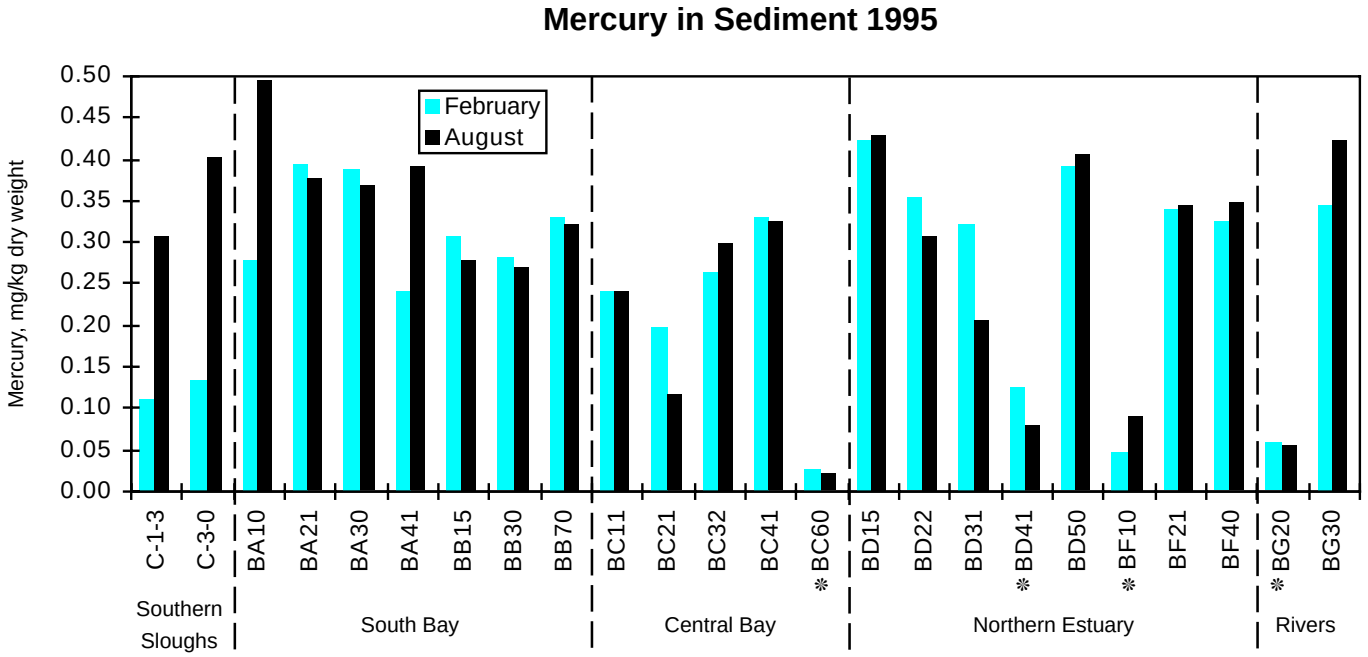


Figure 6. Mercury (Hg) concentrations in sediments in parts per million, dry weight (ppm) at 24 RMP stations sampled in February and August of 1995. ❊ indicates coarse sediment stations. Mercury concentrations ranged from 0.03 to 0.48 ppm. The highest concentration was sampled at Coyote Creek (BA10) in August and the lowest at Red Rock (BC60). Average concentrations were highest in the South Bay in August (0.356 ppm), but were nearly as high in the Southern Sloughs and Northern Estuary stations in August. Concentrations were higher in August than in February in the Southern Sloughs, but there was no consistent seasonal trend in the other Estuary reaches. Mercury 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 18 stations in February and 19 stations in August.

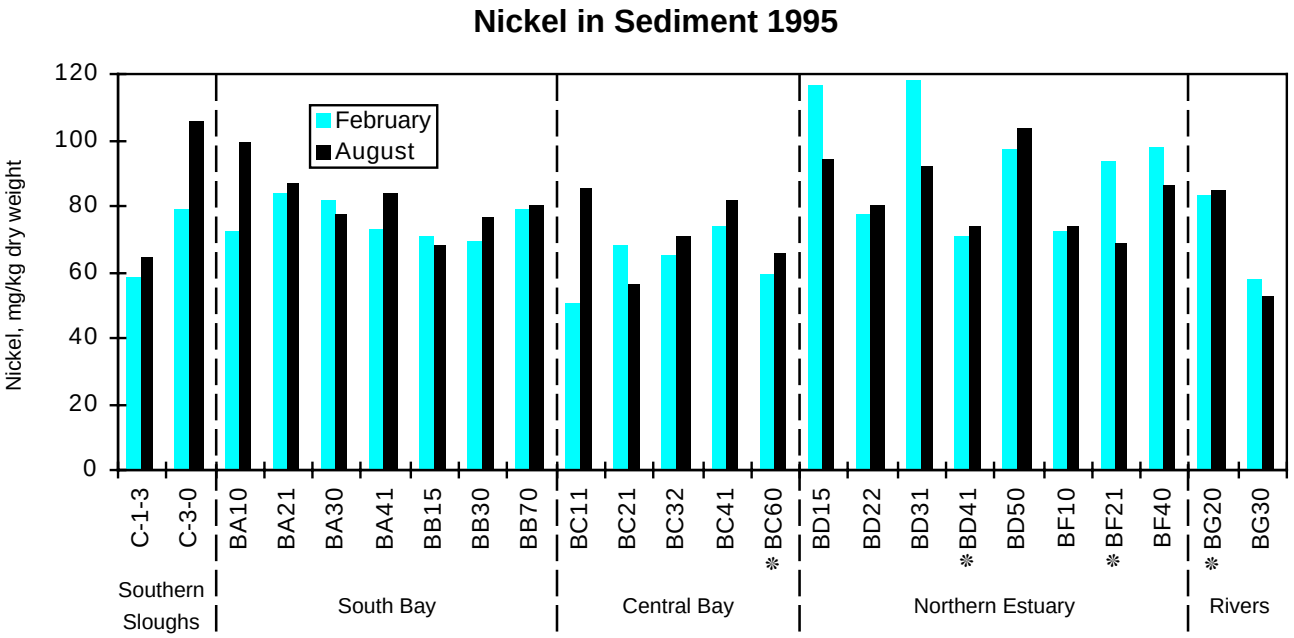


Figure 7. Nickel (Ni) concentrations in sediments in parts per million, dry weight (ppm) at 24 RMP stations sampled in February and August of 1995. ❊ indicates coarse sediment stations. Nickel concentrations ranged from 49.90 to 117.54 ppm. The highest concentration was sampled at Pinole Point (BD31) in February and the lowest concentration at Yerba Buena Island (BC11) in February. Average concentrations were highest in the Northern Estuary in February (92.55 ppm). Concentrations were higher in August than in February for Southern Slough stations but ther was no consistent seasonal trend in other Estuary reaches. Nickel concentrations were above the ERM value of 51.6 ppm for all stations in August and all but one (BC11) in February. That concentration was above the ERL value of 20.9 ppm.

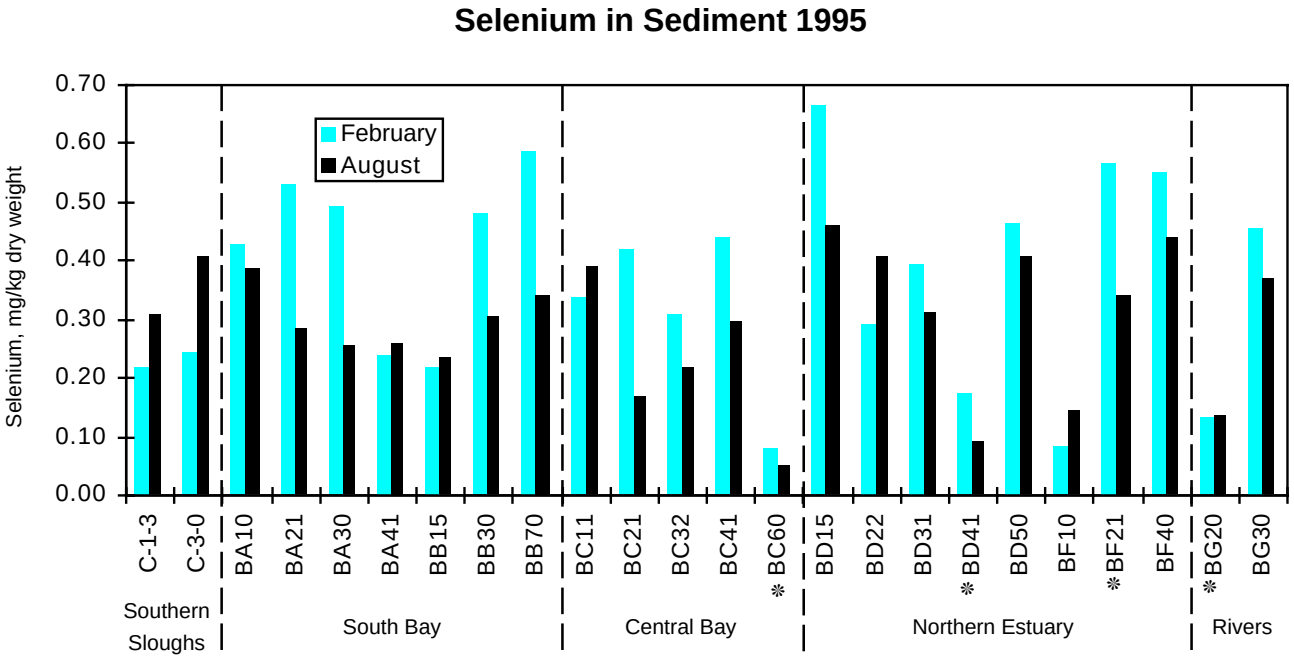


Figure 8. Selenium (Se) concentrations in sediments in parts per million, dry weight (ppm) at 24 RMP stations sampled in February and August of 1995. ❊ indicates coarse sediment stations. Selenium concentrations ranged from 0.05 to 0.66 ppm. The highest concentration was sampled at Petaluma River (BD15) in February and the lowest concentration was at Red Rock (BC60) in August. Average concentrations were highest in the South Bay in February (0.42 ppm), but were nearly as high in the Northern Estuary stations in February (0.40 ppm). Concentrations were higher in August than in February in the Southern Sloughs, but there was no consistent seasonal trend in the other Estuary reaches. There are no ERM and ERL values for selenium.

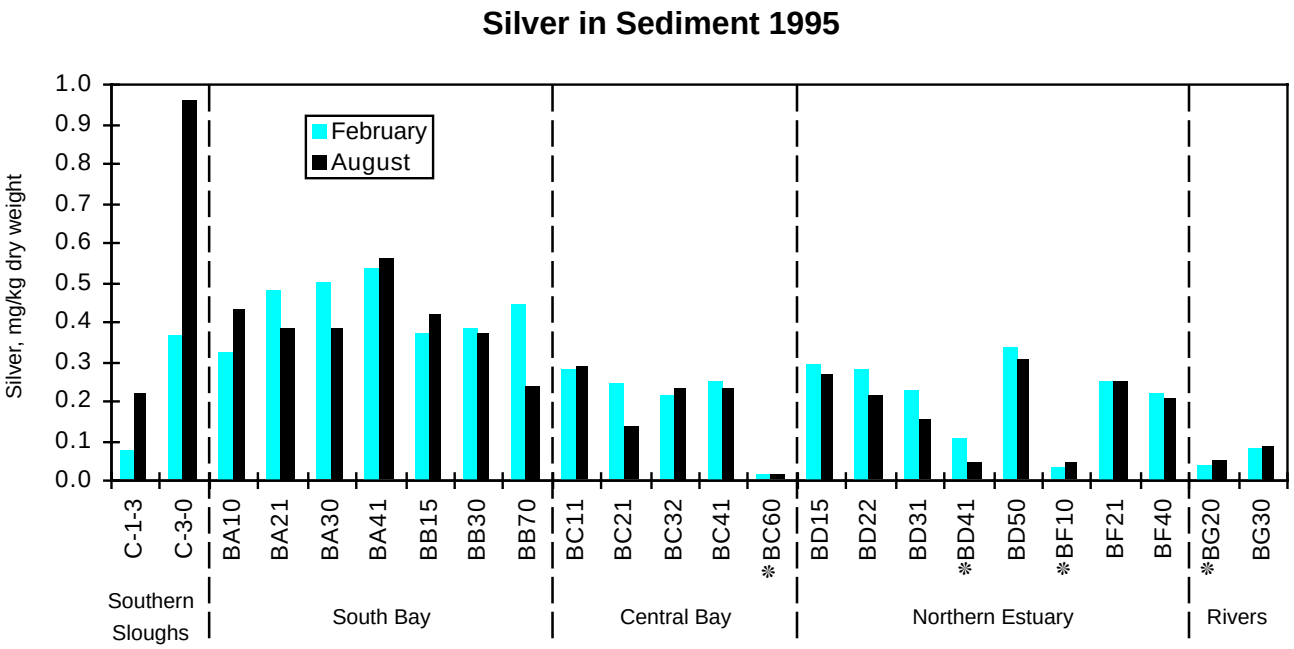


Figure 9. Silver (Ag) concentrations in sediments in parts per million, dry weight (ppm) at 24 RMP stations sampled in February and August of 1995. ❊ indicates coarse sediment stations. Silver concentrations ranged from 0.01 to 0.96 ppm. The highest concentration was sampled at San Jose (C-3-0) in August and the lowest concentration at Red Rock (BC60) in August. Average concentrations were highest in the Southern Sloughs in August (0.59 ppm). Concentrations were higher in August than in February for Southern Slough stations, but there was no consistent seasonal trend in other Estuary reaches. Silver concentrations were below ERM value of 3.7 ppm and ERL value of 1 ppm at all stations.

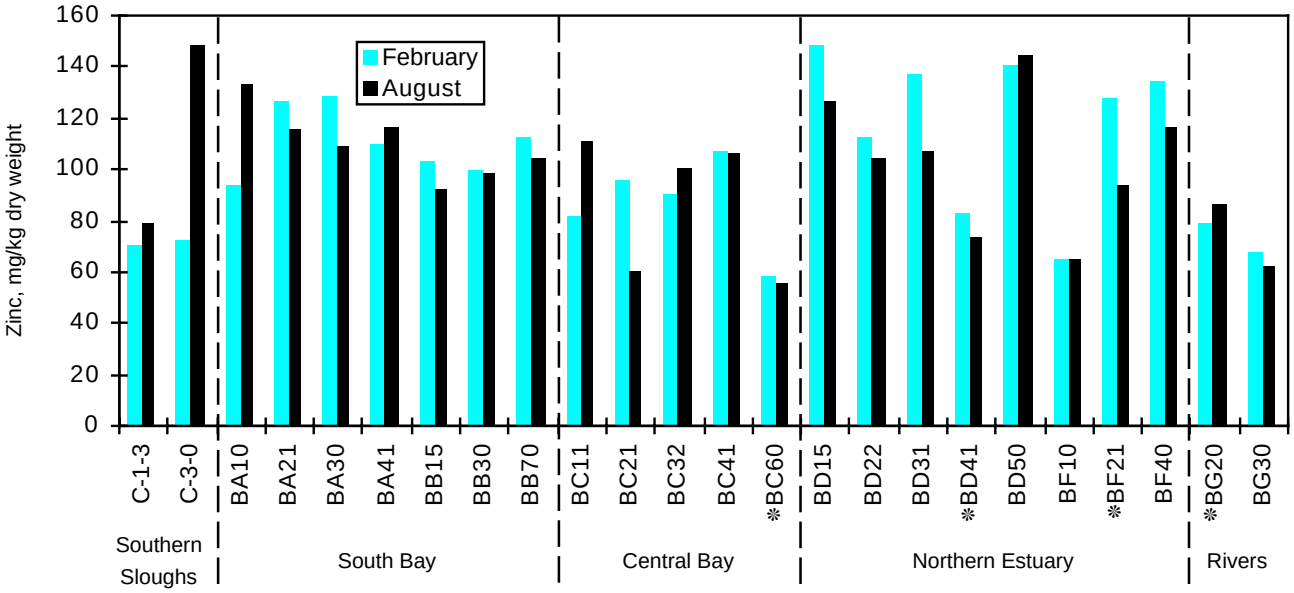


Figure 10. Zinc (Zn) concentrations in sediments in parts per million, dry weight (ppm) at 24 RMP stations sampled in February and August of 1995. ❊ indicates coarse sediment stations. Zinc concentrations ranged from 55.0 to 148.0 ppm. The highest concentration was sampled at San Jose (C-3-0) in August and the lowest concentration was at Red Rock (BC60) in August. Average concentrations were highest in the Northern Estuary in February (118.0 ppm). Concentrations were higher in August than in February in the Southern Sloughs, but there was no consistent seasonal trend in the other Estuary reaches. Zinc concentrations were below the ERM value of 410 ppm and the ERL value of 150 ppm at all stations.

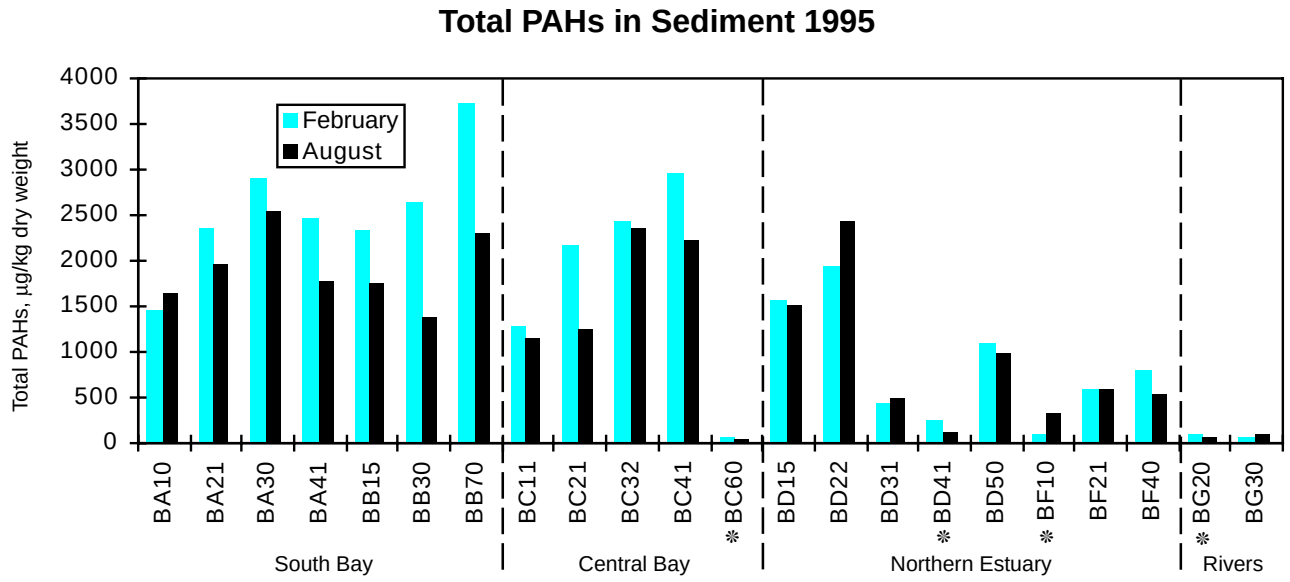


Figure 11. Total PAH concentrations in sediment in parts per billion, dry weight (ppb) at 22 RMP stations sampled in February and August of 1995. ❊ indicates coarse sediment stations. Total PAH concentrations ranged between 16 and 3722 ppb. The highest concentration was sampled at Alameda (BB70) in Febuary and the lowest concentration was measured at Red Rock (BC60) in August. Average concentrations were highest in the South Bay in August (2,544 ppb) and lowest at the River stations in August. Concentrations were highest in Febuary for all stations in the South and Central Bay stations except BA10. There was no consistent seasonal trend in other Estuary reaches. Total PAH concentrations were below the ERM value of 44,792 ppb and the ERL value of 4,022 ppb at all stations.

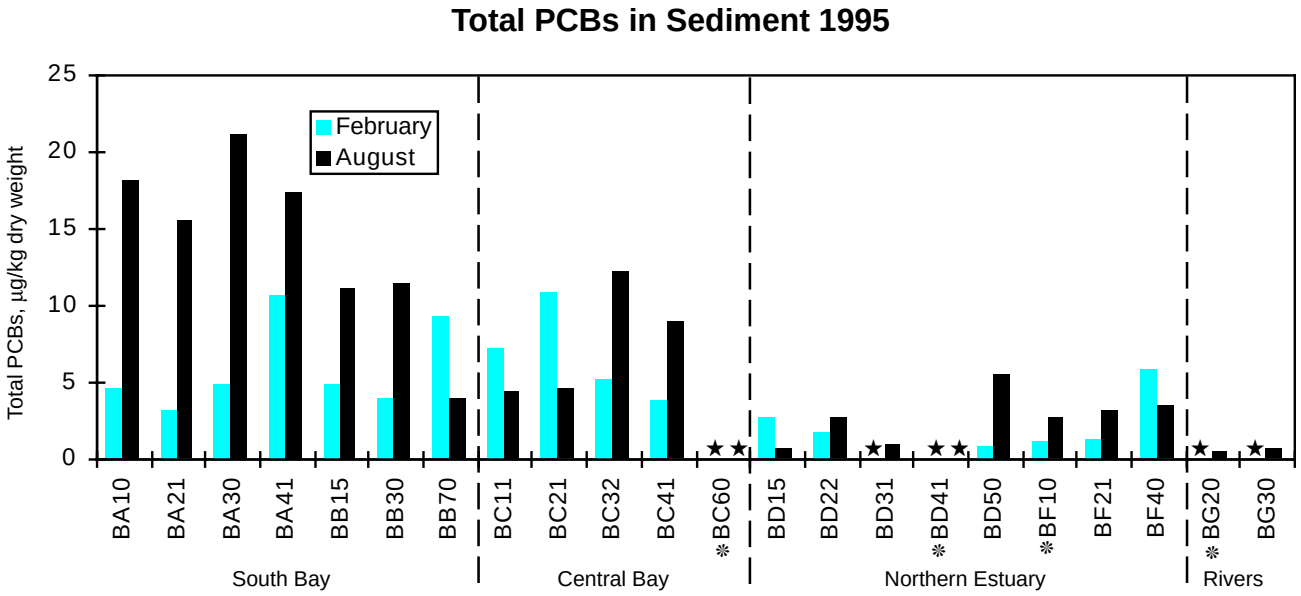


Figure 12. Total PCB concentrations in sediment (ppb, dry weight) at 22 RMP stations sampled in Febuary and August 1995. ❊ indicates coarse sediment stations. Total PCB concentrations ranged between not detected (★) and 21 ppb (see Appendix B, Table 3 for MDLs). The highest concentration was sampled at Dumbarton Bridge (BA30) in August and the lowest concentration was "below detection limits" at several stations. Total PCBs were not detected at Richardson Bay (BD30), Sacramento River (BG20) and San Joaquin River (BG30) in Febuary and neither sampling period at Davis Point (BD41) and Red Rock (BC60). Concentrations were highest in the South Bay in August (14 ppb) and lowest at the River stations in August. Concentrations were highest in August for all South Bay stations except Alameda (BB70). There was no consistent seasonal trend in other Estuary reaches. Total PCB concentrations were below the ERM value of 180 ppb and the ERL value of 22.7 ppb at all stations.

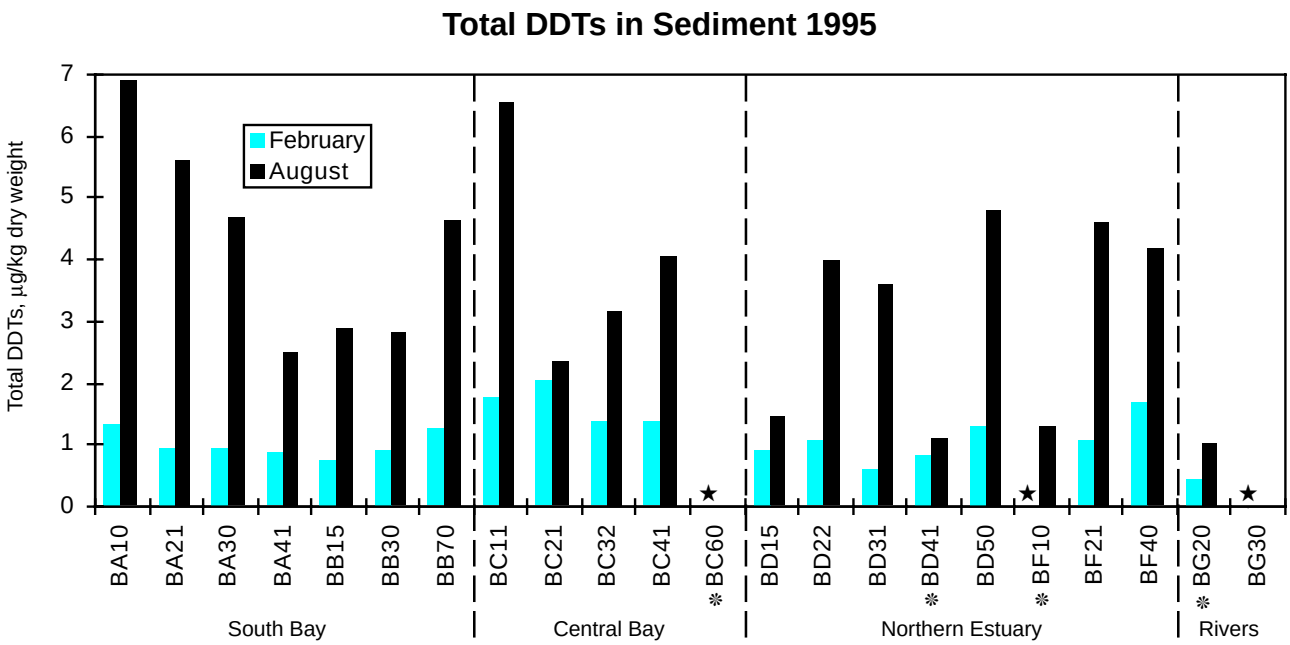


Figure 13. Total DDT concentrations in sediment in parts per billion, dry weight (ppb) at 22 RMP stations sampled in February and August 1995. ❊ indicates coarse sediment stations. DDT concentrations ranged between not detected (★) and 6.87 ppb (see Appendix B, Table 3 for MDLs). The highest concentration was sampled at Coyote Creek (BA10) in August (6.87). DDTs were not detected at several stations. Average concentrations were highest in the South and Central Bay in August (4 ppb). Concentrations were consistently higher in August than in Febuary throughout the Estuary. Total DDT concentrations were below the ERM value of 46 ppb. However, concentrations were above the ERL value of 1.58 ppb at 1 station in February and 16 stations in August.

Sediment Bioassays

Two sediment bioassays were conducted at 12 of the RMP stations (Figure 14) in February and again in August of 1995. Sampling dates are listed in Table 3 in the Introduction.

Amphipods (*Eohaustorius estuarius*) were exposed to whole sediment for 10 days with percent survival as the endpoint. Larval mussels (*Mytilus edulis*) 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, Table 6.

The designation of "toxic" used in the 1995 RMP sediment bioassays is different than that used in previous Annual Reports. Previously, toxicity was indicated when a statistically significant difference between the test results and laboratory controls was obtained. However, this practice sometimes resulted in designations of toxicity when the variance among the control replicates was low. For example, if the laboratory sediment control produced 98 % $\pm$ 2 % (standard deviation) survival, then any test below about 94% would be considered toxic. It is unrealistic to conclude that such survival would indicate toxicity.

Most laboratories conducting sediment bioassays now indicate toxicity if two criteria are met:

1. There is a significant difference between the laboratory control and the test using a t-test, as used in past RMP reports, and
2. Mean organism response in the bioassay test was less than 80% of the laboratory control value.

Application of the second criterion eliminates the problem of designating toxicity based only on comparison to controls with low replicate variance. The 1995 RMP sediment bioassays were evaluated in this way.

The 80% of control criterion was established by statistical analysis of many amphipod data sets by other investigators (e.g., Thursby and Schlekat, 1993). The two criterion approach is currently being used by the US EPA's EMAP (Schimmel *et al.*, 1994), and by the State's Bay Protection and Toxic Clean-up Program (BPTCP).

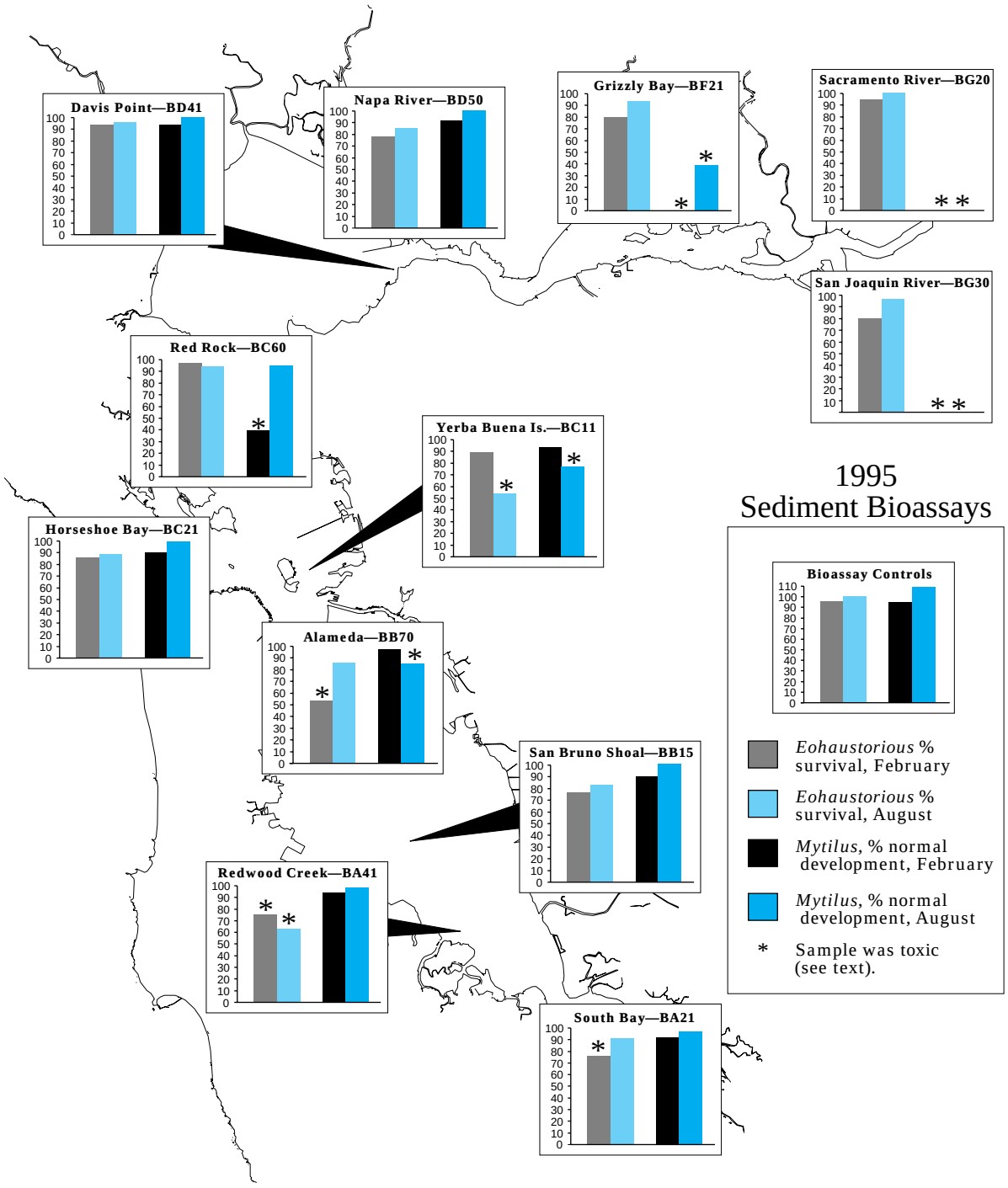


Figure 14. Chart showing results of sediment bioassays at selected RMP stations. The control used in the *Eohaustorius* amphipod test was home sediment from Yaquina Bay, Oregon where the amphipods were collected. The control used for the *Mytilus* (mussel) test was clean Granite Canyon, California seawater. See Appendix A for a description of the tests used. The 1995 results showed that sediments were toxic (see text) at many Estuary stations. There was no indication of sediment toxicity at San Bruno Shoal (BB15), Horseshoe Bay (BC21), Davis Point (BD41), or Napa River (BD50) in 1995. The amphipod test indicated toxicity at three stations in February and two stations in August, all in the Central and South Bay. Redwood Creek (BA41) was toxic to amphipods in both sampling periods. The mussel larvae development test indicated toxicity at four stations in February and five stations in August, but none of the South Bay stations were toxic. Grizzly Bay (BF21), Sacramento and San Joaquin Rivers (BG20, BG30) were toxic to mussel larvae during both sampling periods. Yerba Buena Island (BC11) was toxic to both amphipods and bivalve larvae in August.

Patterns in Sediment Toxicity 1991–1995

Bruce Thompson, San Francisco Estuary Institute
John Hunt and Brian Anderson, University of California, Santa Cruz

The RMP has been conducting sediment bioassays since the program began in 1993. Prior to that, the State's Bay Protection and Toxic Cleanup Program (BPTCP) conducted sediment bioassays at most of the RMP sites as Pilot Studies in 1991 and 1992. Information from both surveys was combined to identify key patterns in sediment toxicity over the past six years.

Incidence of Toxicity

Bioassays conducted over the past six years in the San Francisco Estuary have indicated that toxicity (less than 80% of control value) in Estuary sediments was widespread in space and time. Overall, the highest incidence of toxicity occurred at Grizzly Bay (BF21) where sediments were toxic in 60% of the tests. Toxicity occurred much less frequently in the Central Bay, and sediments were never toxic at Davis Point (BD41), probably due to the low contamination in sandy sediments (Figure 15).

Although the results of the amphipod and larval bivalve tests were significantly correlated ($r=.24$, $p=.009$), there were considerable differences in the patterns of toxicity between them. Ninety percent of the amphipod tests were toxic at Redwood Creek (BA41). There was no amphipod toxicity at the coarse sediment stations (Red Rock, BC60; Davis Point, BD41) or at the San Joaquin River (BG30). Sediments were always toxic to bivalve larvae at the Rivers confluence stations (BG20, BG30). No bivalve toxicity was observed at Pinole Point (BD31), Davis Point (BD41), or San Bruno Shoal (BB15).

There were also temporal differences in toxicity. Incidence of amphipod toxicity generally decreased between 1991–1995. There was always more toxicity to amphipods during the wet-season sampling than in the following dry-season suggesting that runoff may contribute substantially to sediment toxicity. Larval bivalve toxicity generally remained constant through the six years, but was more frequent in the dry-seasons than the wet-seasons between 1994–1996.

Relationship to Sediment Guidelines

Since sediments contain mixtures of numerous contaminants, the cause(s) of the observed toxicity is not readily obvious. Analysis of these relationships is underway using the 1991–1996 data base. The relationships between the Effects Range Guidelines (Long, *et al.*, 1995) used in the RMP and sediment toxicity were evaluated first.

In theory, any individual contaminant present in sediments in high enough concentrations could cause toxicity. However, as discussed in the Annual Reports, only nickel in sediments generally exceeds the ERMs throughout the Estuary, and arsenic, chromium, copper, mercury, nickel, and total DDTs usually exceed ERLs at most stations.

Two qualifications must be made in interpreting ERLs and ERMs: 1) the effects ranges for nickel and DDTs are not considered to be very accurate and should be used with caution, and 2) Effects Ranges for some of the total trace organic concentrations (e.g., PCBs, DDTs, PAHs) are based on sums of different sets of individual compounds from those used by the RMP, but these differences are considered to be slight.

Evaluation of how well exceedances of the ERL guidelines predict toxicity was conducted by examining the relationship between the sediment bioassay endpoints and ERLs. For the amphipod test, there was a significant inverse relationship between amphipod survival and

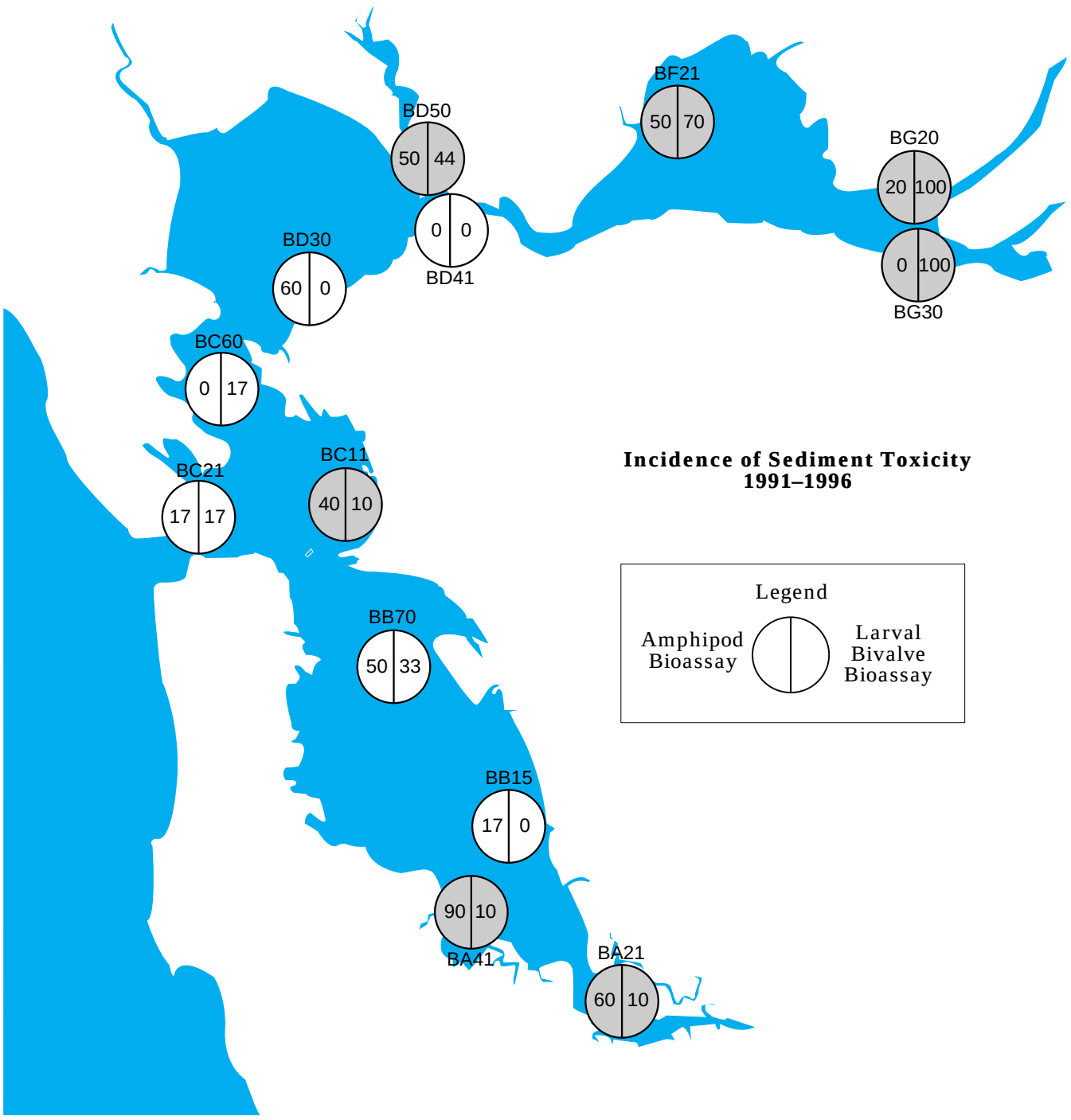
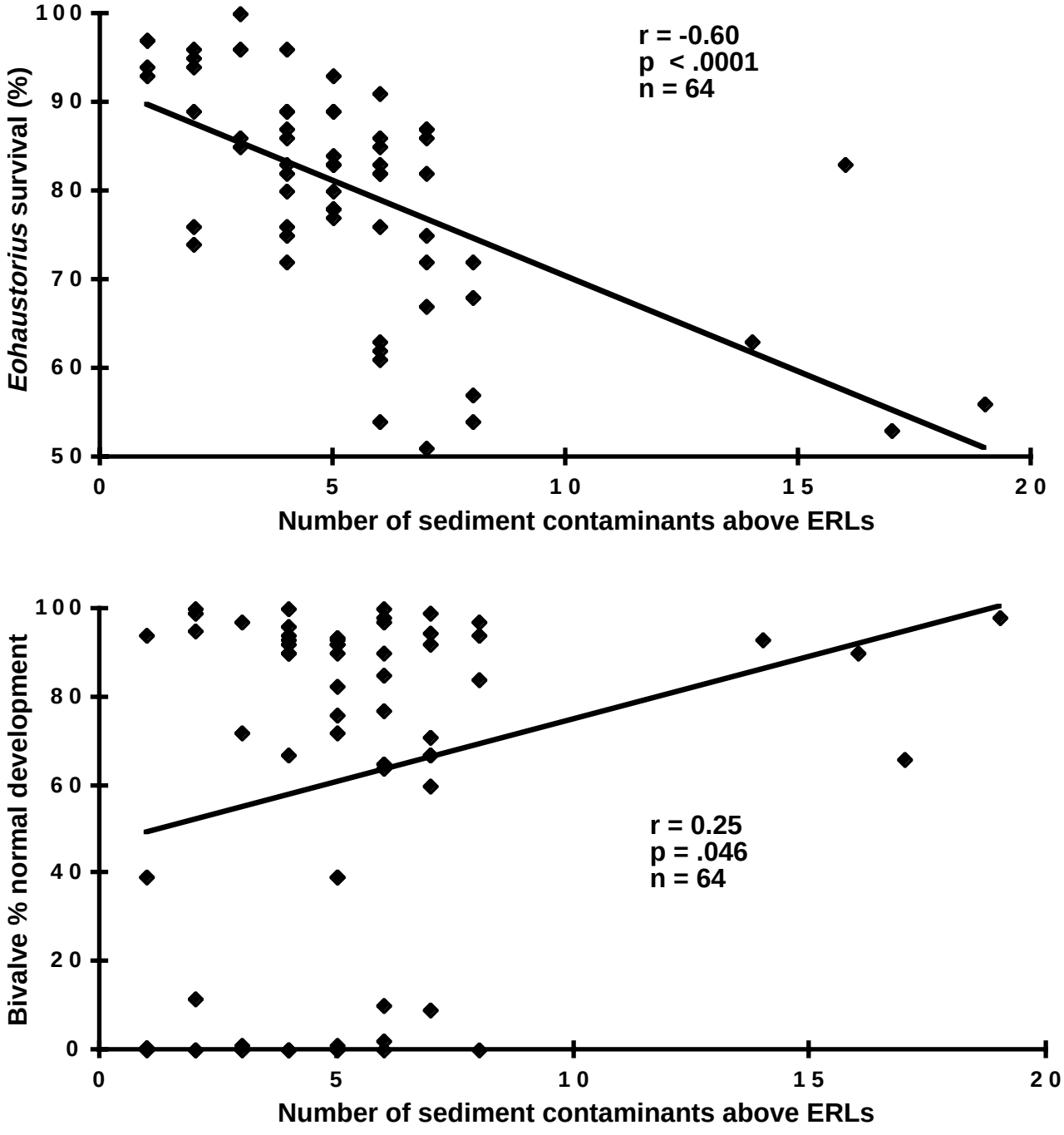


Figure15. Percentage of sediment bioassays (larval bivalve and *Eohaustorius* tests) that were toxic (less than 80% of control value) at RMP stations from 1991–1996. Shaded sites show where tests were conducted in all sampling periods (n=10 tests). At least five tests were conducted at the unshaded sites.



Figures 16. Plots showing relationships between the number of ERL exceedances and bioassay endpoints at each RMP station, 1993–1995.

the number of contaminants that exceeded the ERL at each stations (Figure 16). This plot predicts that when there are more than seven ERL exceedances at a station, toxicity should be observed (using 80% of control survival). Although the overall relationship is statistically significant, only 7 of the 64 samples had more than seven ERL exceedances, therefore this relationship should be interpreted cautiously.

These results suggest that toxicity may be caused by additive effects from low concentrations of several contaminants. There is growing evidence from other studies that such additive effects may cause toxicity (Swartz 1988, 1995; Plesha, 1988). Arsenic, chromium, copper, mercury, nickel, and DDTs are usually above ERLs at most stations (Table 2 in Sediment Monitoring Discussion section) and may contribute to toxicity. Interestingly, all of the points on Figure 16 with more than eight ERL exceedances occurred in February of 1994, where in addition to the contaminants named above, there were exceedances of numerous PAH compounds. The reasons for this increase in PAHs was not determined.

While the ERLs appear to be a good predictor of amphipod toxicity, they are not a good predictor for the larval bivalve bioassay (Figure 16). There was a direct, significant relationship between percent normal development and number of ERL exceedances, whereas an inverse relationship should be expected. This is probably because ERLs are based on bulk sediment measurements, but the elutriates used in the bivalve bioassays represent only the water-soluble fraction, and no chemical measurements were made on sediment elutriates. However, this test provided potentially important information about sediment toxicity, particularly at the northern Estuary RMP stations, and should continue to be used. Clearer relationships may be found using elutriate chemistry in similar analyses. The RMP should consider measuring elutriate chemistry at some of the test stations in order to improve the ability to interpret this test in the future.

One problem with interpreting these results is that measurements of contaminant concentrations in bulk sediment samples may not be good estimates of the bioavailable fractions that could cause toxicity. Some metals may be bound to sulfides in sediments, and organic contaminants may be bound to organic material in sediments, thereby decreasing the concentrations dissolved in pore water available to organisms. Measurements of acid volatile sulfides and simultaneously extracted metals (AVS / SEM), or normalizing organic contaminants to organic carbon may provide better estimates of contaminant concentrations that may cause toxicity. These methods should be investigated in future RMP data analyses.

Further Development of a Chronic *Ampelisca abdita* Bioassay as an Indicator of Sediment Toxicity: Summary and Conclusions[1]

Donald P. Weston, University of California, Berkeley

Introduction

Sediment toxicity tests are a critical component in many programs to assess environmental quality. Recently there has been interest expressed in using growth rates of the amphipod *Ampelisca abdita* as a potential measure of sediment toxicity (Scott and Redmond, 1989; Redmond *et al.*, 1994). The use of an *A. abdita* growth toxicity test offers several attractive features.

- A chronic growth rate test could be a more sensitive indicator of pollution than acute mortality, and thus the use of a growth test may provide a greater degree of environmental protection.
- Standardized procedures for collection and laboratory maintenance are already established (ASTM, 1993; EPA, 1994).
- Some information already exists on sensitivity to toxicants. Exposure to contaminated harbor sediments has caused a reduction in growth rate and reduced egg production by the smaller females (Scott and Redmond, 1989), demonstrating that an impaired individual growth rate can have negative consequences at the population level.

As a dominant organism in the Bay, *A. abdita* is a particularly attractive species for sediment toxicity testing because of the direct and immediate relevance of results to the Bay ecosystem. If growth rate can be shown to be a sensitive indicator of sediment toxicity, then it may be possible to acquire similar data from size-frequency analysis of field populations. The use of the same endpoint for both laboratory toxicity tests and monitoring of field populations is an attractive unifying concept that has been largely unexplored.

This report provides data on one component of a larger study funded by the RMP to develop an *A. abdita* sediment toxicity test using growth rate and chronic survival as endpoints. Earlier results have already been presented (RMP, 1995) and include the following conclusions:

- *A. abdita* juveniles have been readily available in collections to date (May–September).
- Greater than 90% survival is consistently achieved in a wide variety of Bay sediments having very different grain size distributions and organic contents.
- Growth rates of about 1 mm/month are observed in the laboratory populations fed an algal diet.
- Bay sediments considered to be non-toxic based on *A. abdita* growth have also been shown to be relatively unimpacted based on chemical analyses and benthic community structure.

If *A. abdita* growth is to be used for sediment toxicity testing in the Bay, it is important that a growth rate test be of equal or greater sensitivity than acute mortality tests and that the species be no less sensitive to toxicants than other amphipod species that have been routinely used for toxicity testing such as *Rhepoxynius abronius* and *Eohaustorius estuarius*. Since *E. estuarius* is currently used in the RMP, comparative sensitivity to this species is of particular concern. This report provides results on comparative toxicity tests, using sediments spiked with cadmium, DDT, or crude oil. Results are described within two experimental series. Experiment 1 was conducted to establish if the growth endpoint is a more sensitive measure of toxicity (i.e., effects demonstrable at lower toxicant concentration)

[1] This document is an excerpt of a longer report. Readers desiring more details may request the full report from the San Francisco Estuary Institute.

than 10-day mortality for *A. abdita*. Sediments were spiked with cadmium or crude oil. Parallel standard 10-day mortality and 17-day growth tests were also conducted. Experiment 2 was conducted to establish if *A. abdita* was more or less sensitive to the toxicants than the other species. Sediments were spiked with cadmium, DDT, or crude oil. Parallel tests with all three species under identical conditions were conducted.

The RMP is also in the midst of regular monitoring of a San Francisco Bay *A. abdita* population in order to establish if juveniles are available throughout the year for growth-based toxicity tests and if laboratory growth rates are independent of the time of collection provided constant exposure conditions (e.g., temperature, food supply) are maintained. These results are not included here, but will be provided in later RMP reports.

Results

Experiment 1—Mortality

Experiment 1 was intended to determine if use of 17-day mortality and growth endpoints provided more sensitive indicators of cadmium and crude oil toxicity than the standard 10-day mortality test. Mortality results are provided in Table 1.

Good survival was obtained in the home sediment (Alameda control) in most of the Experiment 1 trials. After a 10-day exposure, survival rates were 93% and 91% for cadmium and crude oil experiments, respectively. After a 17-day exposure, the equivalent survival rates were 88% and 83%. The latter value is slightly lower than typical for our laboratory (88–95%).

Cadmium significantly decreased survival (70–75%) at the lowest concentration used of 22 mg kg^{-1}. The 10-day exposures were noteworthy in that this survival rate remained essentially constant from 22 through 180 mg kg^{-1}, rather than following a typical dose-response relationship. A preliminary study in our lab using the same sediment also found ~70% survival to be the case up to 270 mg kg^{-1}, but with near total mortality at 810 mg kg^{-1}. The results from the 17-day exposures followed the more typical pattern of increasing mortality with increasing dosage, although the dose-response relationship was interrupted by the absence of significant mortality at 45 mg kg^{-1}.

In the weathered crude oil exposures, survival remained comparable to the control at

Table 1. Percent survival of *A. abdita* in Experiment 1 using Alameda home sediments, and cadmium or crude oil-spiked home sediments. Values shown are means and standard deviations. Those treatments significantly different from the home sediment control at $p<0.05$ are denoted with *.

Sediment	10-day	17-day
Cadmium		
Home (Alameda)	93 ± 12	88 ± 5
22 mg kg^{-1}	75 ± 6*	70 ± 85*
45 mg kg^{-1}	71 ± 6*	74 ± 14
90 mg kg^{-1}	59 ± 10*	45 ± 6*
180 mg kg^{-1}	75 ± 7*	15 ± 18*
Weathered crude oil		
Home (Alameda)	91 ± 9	83 ± 9
150 mg kg^{-1}	90 ± 12	94 ± 6
460 mg kg^{-1}	90 ± 11	85 ± 7
1400 mg kg^{-1}	79 ± 12	88 ± 10
4200 mg kg^{-1}	25 ± 11*	33 ± 15*

concentrations of 150, 460, and 1,400 mg kg^{-1}. A dramatic reduction in survival to 25–33% occurred at 4,200 mg kg^{-1} in both the 10- and 17-day exposures.

10-day and 17-day experiments provided very similar results. With only one exception (45 mg kg^{-1} cadmium) the concentrations which produced significant 10-day mortality were the same ones that produced significant 17-day mortality. For the single exception, 17-day survival was marginally higher, not lower as might be expected. In non-toxic sediments, mean survival of amphipods in the 17-day tests was higher than after 10 days in two of the five cases.

Experiment 1—growth

Growth in the cadmium tests of Experiment 1 was atypically rapid, probably because of the small size of the amphipods collected at that time. The amphipods used had an initial mean body length of 2.3 mm (s.d. ± 0.6). Within the 17 days of the test, average length in control sediments had increased to 3.8 mm (± 0.7), or an increase in length of 65%. The oil exposures were conducted approximately 40 days later, but in the intervening period the animals in the source population had grown to a mean length of 3.2 mm (± 0.5). Over the 17 days of the oil exposure tests, animals in the control sediment grew to an average length of 3.9 mm (± 0.5), or 22%.

Relative to the control sediment, cadmium concentrations of 22 and 45 mg kg^{-1} had no effect on rate of growth. Animals held at 90 mg kg^{-1} had a size-frequency distribution that was significantly shifted towards smaller animals after 17 days.

A crude oil concentration of 1,400 mg kg^{-1} depressed the growth of *A. abdita* to the point that there was little change in body length over the 17-day exposure. Mean body length of both the initial population and the individuals exposed to 1,400 mg kg^{-1} for 17 days were identical (3.2 ± 0.5). It is possible that growth was impaired at lower concentrations of crude oil, but high interreplicate variability prevented statistical analysis. The size-frequency distributions of animals in both the 150 and 460 mg kg^{-1} treatments appeared to contain smaller individuals than the control, but it was not possible to attain a homogeneous population for these treatments without elimination of two or more replicates. This situation prevents determination of growth effects.

Experiment 2—mortality

Experiment 2 was intended to determine the relative toxicant sensitivity of *A. abdita*, *E. estuarius* and *R. abronius*, when all three species were tested under identical conditions. The three amphipod species tested differ in their preferred sediment type, thus finding a single sediment suitable for all species was problematic. The Bodega Bay sediment used for the Bodega control and all toxicant spikes appeared to be acceptable for all species. For *E. estuarius*, survival in Bodega control sediment was identical to that in the control (93%). For *R. abronius*, survival tended to be lower in the Bodega control (79% vs. 92% in home sediment), but because of interreplicate variability these means were not statistically different. The survival rate of *A. abdita* in Bodega control sediment was 89%, higher than the home sediment, and typical for uncontaminated sediments tested in our laboratory.

Solvent control survival rates were indistinguishable from the Bodega control for *E. estuarius* and *R. abronius*, demonstrating no acute toxicity of the acetone carrier solvent used for the DDT spikes. Solvent control survival was less than Bodega control only in the *A. abdita* tests, but the lower concentration DDT treatments had survival rates as high as the Bodega control, suggesting that the mortality in the solvent control was unrelated to the acetone.

Survival data upon exposure to the three toxicants are shown in Table 2 and Figure 17. It should be recognized that the *E. estuarius* and *R. abronius* tests were done for 10 days using standard protocols (ASTM, 1993; EPA, 1994), while the *A. abdita* tests represent a 17-day exposure since survival data were collected as part of a growth test. Previous work in our laboratory has shown that survival rates of *A.*

Table 2. Percent survival of the three species tested in their respective home sediments, Bodega control sediment (used for all spiked treatments), the solvent control (acetone carrier used in DDT spikes), and the various spiked treatments. Values shown are means and standard deviations. Those treatments significantly different from the Bodega control (or solvent control in the case of DDT exposures for *A. abdita*) at $p<0.05$ are denoted with *.

Sediment or Treatment	*A. abdita*	*E. estuarius*	*R. abronius*
Home sediment	75 ± 13*	93 ± 8	92 ± 9
Bodega control	89 ± 5	93 ± 3	79 ± 16
Solvent control	79 ± 4*	97 ± 4	74 ± 17
Cadmium			
12 mg kg^{-1}	83 ± 19	86 ± 4	74 ± 17
37 mg kg^{-1}	89 ± 14	92 ± 4	84 ± 17
110 mg kg^{-1}	95 ± 6	95 ± 5	84 ± 2
330 mg kg^{-1}	83 ± 6	93 ± 8	67 ± 16
1,000 mg kg^{-1}	19 ± 19*	94 ± 7	0 ± 0*
DDT			
120 µg kg^{-1}	79 ± 13	95 ± 6	78 ± 4
370 µg kg^{-1}	88 ± 8	77 ± 7*	80 ± 8
1,100 µg kg^{-1}	14 ± 7*	9 ± 2*	35 ± 12*
3,300 µg kg^{-1}	0 ± 0*	0 ± 0*	0 ± 0*
10,000 µg kg^{-1}	0 ± 0*	0 ± 0*	0 ± 0*
Weathered crude oil			
60 mg kg^{-1}	83 ± 15	91 ± 7	85 ± 10
180 mg kg^{-1}	84 ± 10	88 ± 6	73 ± 12
530 mg kg^{-1}	44 ± 17*	42 ± 10*	31 ± 10*
1,000 mg kg^{-1}	5 ± 6*	23 ± 12*	14 ± 23*
5,000 mg kg^{-1}	1 ± 2*	1 ± 2*	5 ± 11*

abdita in uncontaminated sediments are comparable between 10 and 30 days, and in Experiment 1, exposures to cadmium and crude oil, there was little difference between 10- and 17-day mortality rates. Thus, mortality comparisons between the three species should be valid in spite of the different exposure periods.

Concentrations of cadmium up to 330 mg kg^{-1} had no effect on mortality rates for any of the amphipod species. An increase in cadmium concentration to 1,000 mg kg^{-1} resulted in the complete mortality of *R. abronius* in all replicates, and an average survival rate of only 19% for *A. abdita*. *E. estuarius*, was unaffected by the highest cadmium concentration used of 1,000 mg kg^{-1} with a survival rate of 94%, a value comparable to the unspiked controls.

Despite the insensitivity of *E. estuarius* to cadmium, it was the first species to show decreased survival with increasing sediment concentrations of DDT. At a DDT concentration of 370 µg kg^{-1}, survival rates for the species dropped from 93% (Bodega control) to 77%. Survival rates of the other two species remained indistinguishable from the controls. At a concentration of 1,100 µg kg^{-1}, the survival rates of all species dropped precipitously (means of 9 to 35% survival). No individual of any species survived exposure to DDT concentrations of 3,300 µg kg^{-1} or more.

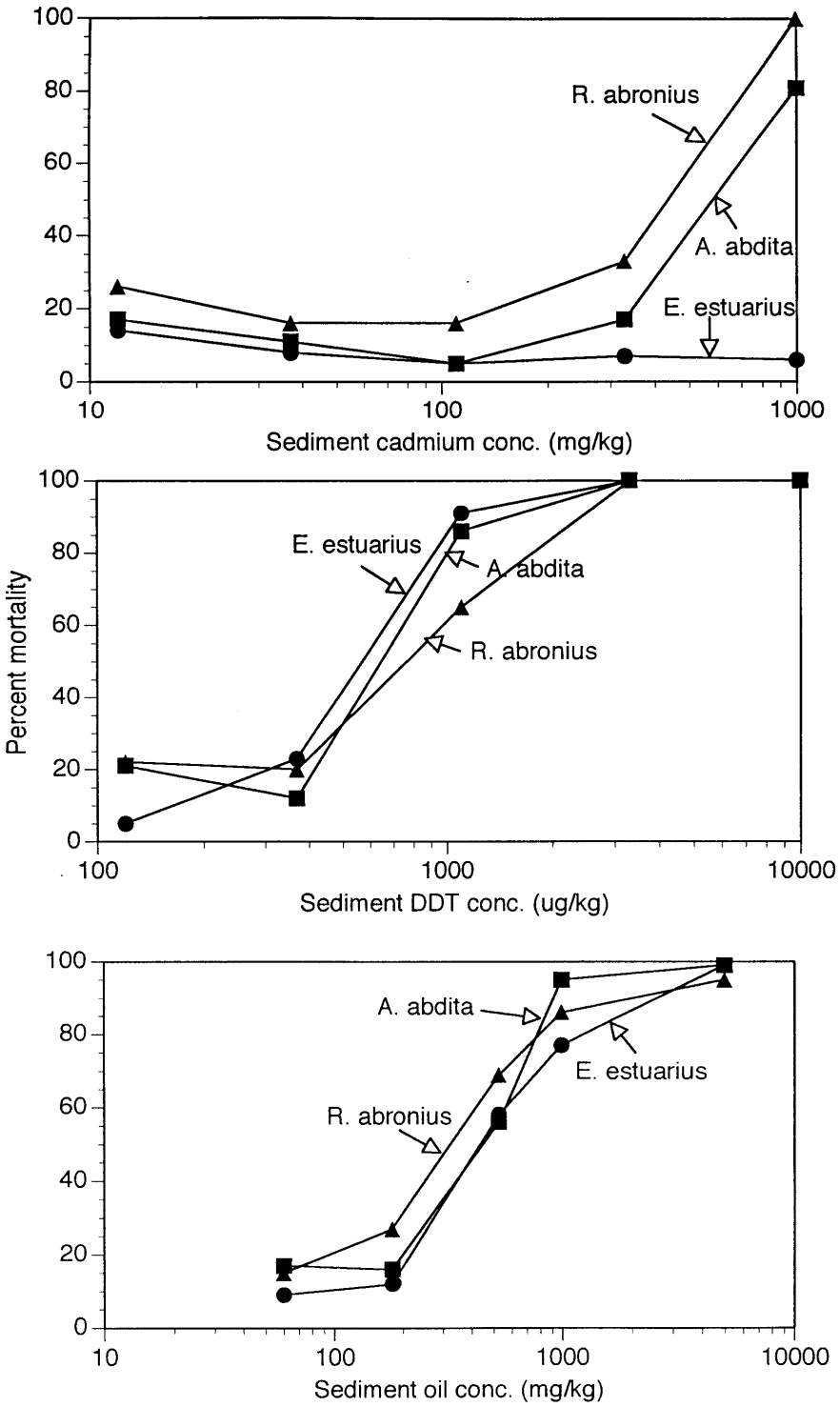


Figure 17. Mortality of the three amphipod species with increasing concentrations of cadmium, DDT, and crude oil. The values shown are means. Error bars are not provided for the sake of graphical clarity, but the data are available in Table 4.

The toxicity of weathered crude oil was very consistent among the three species, with no measurable affect of 180 mg kg^{-1}, and about 40% survival at a concentration of 530 mg kg^{-1}. Survival continued to decline in all species with increasing crude oil concentrations, with only a few individuals surviving exposure to 5,000 mg kg^{-1}.

Differences in sensitivity among the three species are illustrated in Table 3 on the basis of LC_{50} values. The cadmium LC_{50} for *E. estuarius* is shown only as >1,000 mg kg^{-1}, since the highest concentration used in this study had no affect on mortality rate of the species.

Experiment 2—growth

A. abdita individuals that survived exposures to the controls or spiked sediments were measured and used to determine a growth rate endpoint in addition to the mortality endpoint discussed above. Individuals used in the growth assays had an initial mean body length of 3.2 mm (s.d.=0.6). After 17 days in the Bodega control sediment their length had increased to an average of 4.2 mm (s.d.=0.6), or a gain of 31%. Body sizes of animals in the acetone control were indistinguishable from the Bodega control ($p>0.05$, all size comparisons by Kolmogorov-Smirnov test). Body size was greater in home sediment (mean = 4.6 mm ± 0.6) than in Bodega control even though the survival rate was reduced, perhaps suggesting differential mortality of smaller individuals.

In the cadmium treatments the size-frequency distribution after exposure to the 37 mg kg^{-1} treatment was significantly shifted towards smaller individuals relative to the Bodega control. The same was true of the 110 mg kg^{-1} cadmium treatment, but the difference was marginally non-significant ($0.1>p>0.05$). At a concentration of 330 mg kg^{-1} the difference was significant once again ($p<0.05$).

DDT had no adverse affect on growth rate at the two lowest concentrations, 120 and 370 µg kg^{-1}. At the next highest concentration of 1,100 µg kg^{-1} there was an 86% mortality, leaving too few individuals to reliably estimate growth rates.

Weathered crude oil did not adversely affect growth rates at concentrations of 180 mg kg^{-1} or less. Significant effects ($p<0.05$) were apparent at 530 mg kg^{-1}.

Discussion

Cadmium LC_{50} values were quite variable, both among the two sediments used in these experiments and in comparison to literature values. Our sediment cadmium 10-day LC_{50} of 479 mg kg^{-1} for *R. abronius* is far higher than the 10-day LC_{50} of 6.9 mg kg^{-1} reported for the species by Swartz *et al.* (1985) for Yaquina Bay sediment. Conversely, our sediment cadmium LC_{50}'s for *A. abdita* of >180 (Experiment 1, 10 day), 91 (Experiment 1, 17 day) and 643 mg kg^{-1} (Experiment 2) are far less than the values of 1,070 to 2,850 mg kg^{-1} using sediments from New England (DiToro *et al.*, 1990). These differences may reflect variations in sensitivity

Table 3. LC_{50} values and 95% confidence intervals for the three amphipod species exposed to cadmium, DDT and weathered crude oil in Experiment 2.

Toxicant	*A. abdita* LC_{50}	*E. estuarius* LC_{50}	*R. abronius* LC_{50}
Cadmium (mg kg^{-1})	643 (632–654)	>1,000	479 (426–538)
DDT (µg kg^{-1})	769 (708–835)	554 (510–601)	1,036 (882–1217)
Crude oil (mg kg^{-1})	528 (444–627)	630 (540–735)	505 (429–594)

among populations of the test animals, or may reflect variation in cadmium bioavailability among the sediments. The work of DiToro *et al.* (1990) suggests bioavailability differences may be related to the concentrations of acid volatile sulfides (AVS) in the sediments. These AVS analyses, however, are still in progress with our sediments, so consideration of this possibility is premature.

Crude oil toxicity to *A. abdita* also varied among sediments from a 17-day LC_{50} of 3,334 mg kg^{-1} in the Alameda sediment to 528 mg kg^{-1} in the Bodega Bay sediment. In part these differences may be related to differing organic contents of the sediments and its affect on bioavailability. Normalization of the LC_{50} values to organic carbon reduced the difference between the sediments from 6-fold to 4-fold (0.95% TOC at Alameda = LC_{50} of 350 mg g^{-1} o.c.; 0.55% TOC at Bodega Bay = LC_{50} of 96 mg g^{-1} o.c.).

When normalized to organic carbon, our LC_{50} measurements for DDT show remarkable consistency with other data reported in the literature. Based on an organic carbon content of 0.55% in the Bodega Bay sediment, our DDT 17-day LC_{50} values were 101 µg g^{-1} o.c. (*E. estuarius*), 140 µg g^{-1} o.c. (*A. abdita*), and 188 µg g^{-1} o.c. (*R. abronius*).

There have been few attempts to compare toxicant sensitivity of the various amphipod species used in sediment toxicity testing. In most cases, comparisons among studies is complicated by differences in test conditions, and often made uninterpretable because of potential bioavailability differences among sediments. In our experiments all conditions (e.g., temperature, salinity, light regime, feeding, water source, sediment) were held constant for tests with all three species. The tests differed only in the duration of exposure (17-day for *A. abdita* and 10-day for the other species), and Experiment 1 data have shown this difference to be of little consequence for cadmium and crude oil. Data are lacking for 10-day versus 17-day mortality for DDT.

In comparing the relative toxicant sensitivities of the three species, it is apparent that no one species is consistently more or less sensitive than the others across all toxicants. If relative sensitivity is defined on the basis of LC_{50} values, then these experiments yield the following ranking:

Cadmium sensitivity:

R. abronius > *A. abdita* >> *E. estuarius*

DDT sensitivity:

E. estuarius > *A. abdita* > *R. abronius*

Crude oil sensitivity:

R. abronius = *A. abdita* = *E. estuarius*

R. abronius is the most sensitive species to cadmium toxicity, but is only slightly more sensitive than *A. abdita*. One of the most striking observations in this study is the dramatic tolerance of *E. estuarius* to cadmium. A sediment concentration of 1,000 mg kg^{-1} (0.1% cadmium) had no affect on acute mortality of *E. estuarius*, yet resulted in 81% mortality in *A. abdita* and 100% mortality in *R. abronius*. This tolerance to cadmium was also apparent in the water-only 96-hr exposures in which the LC_{50} for *E. estuarius* was an order-of-magnitude higher than for the other species. These data indicate that *E. estuarius* is a poor choice for toxicity testing if cadmium is among the potential toxicants. Relative sensitivity to the other metals is unknown but would merit further evaluation.

E. estuarius is the most sensitive of the three species to DDT, yet the differences in sensitivity among the three species are relatively small. All DDT LC_{50} values varied by less than a factor of 2. The three species are equally sensitive to crude oil, with LC_{50} values being essentially indistinguishable.

Taken together, the data show that the use of *A. abdita* for sediment toxicity testing does not result in any appreciable loss in sensitivity relative to *R. abronius* or *E. estuarius* for the contaminants tested. To the contrary, use of the species provides a substantial increase in sensitivity relative to *E. estuarius* in cases of cadmium toxicity. The tubiculos nature of *A. abdita* does not appear to compromise its usefulness for toxicity testing. Either the tube wall is not a barrier to diffusion of sediment-associated toxicants, or exposure via the near-bottom waters within a few millimeters of the sediment-water interface is comparable to that of the pore water exposure experienced by the two fossorial species.

The data from these experiments permit consideration of whether a growth endpoint

provides greater sensitivity to toxicants than a mortality endpoint (either 10- or 17-day exposure). Neither growth nor mortality endpoints provided a clear advantage in two of the five trials involving the three toxicants examined (Table 4). In two other cases, growth was the more sensitive endpoint; i.e., the toxicant concentrations necessary to depress growth rates were less than those necessary to cause mortality. Finally, in one case (cadmium, Experiment 1), growth was a less sensitive endpoint. Interpretation of results in this one case are problematic. First, there is no apparent mechanism for mortality to be a more sensitive endpoint of cadmium toxicity in one sediment (Alameda sediment of Experiment 1), but growth to be a more sensitive endpoint in another sediment (Bodega Bay sediment of Experiment 2). It is plausible that the most sensitive endpoint would depend upon the toxicant (e.g., one which would impair growth and another whose toxic effects are through other growth-independent mechanisms), but it does not seem reasonable that the most sensitive endpoint would be sediment dependent. Secondly, a cadmium concentration of 22 mg kg^{-1} was sufficient to increase mortality in both the 10- and 17-day exposures, yet there was no increased mortality after 17 days at 45 mg kg^{-1}. Thus, the lack of a consistent dose-response relationship makes interpretation of the cadmium mortality data difficult at the lower concentrations.

While a growth endpoint was a more sensitive measure than acute toxicity for some contaminants and sediments, it was not demonstrated to be consistently so in all cases. One reason for this may have been the 3x intervals used in sediment spiking (e.g., 12, 37, 110, 330, and 1,000 mg kg^{-1} cadmium). While these intervals would have been sufficient to detect large differences in sensitivity between the endpoints based on NOEC/LOEC values, the demonstration of more subtle differences would require more closely spaced intervals.

Table 4. Minimum effective concentration of the toxicants used in the experiments as based on each of the three endpoints. Values shown are NOEC and LOEC, with the minimum concentration necessary to elicit a response expected to fall between these two points. In cases where one endpoint provides a more sensitive measure than the others, the effective concentration is in bold type. Concentrations are: Cd = mg kg^{-1}; DDT = μg kg^{-1}; and weathered crude oil = mg kg^{-1}.

Toxicant	10-day survival	17-day survival	17-day growth
Cadmium (Exp. 1)	**0–22**	45–90[a]	45–90
Cadmium (Exp. 2)		330–1,000	**110–330**[b]
DDT (Exp. 2)		370–1,100	>370[c]
Crude oil (Exp. 1)	1400–4200	1,400–4,200	**<1400**[d]
Crude oil (Exp. 2)		180–530	180–530

[a]Mortality was significantly greater than the control at 22 and 90 mg kg^{-1}, but not at 45 mg kg^{-1}. Therefore, the more conservative interpretation is taken here in presenting 45 and 90 mg kg^{-1} as the NOEC and LOEC, respectively.

[b]The size frequency distribution contained significantly smaller individuals relative to the control at 37 and 330 mg kg^{-1}. At 110 mg kg^{-1}, however, the effect was marginally non-significant ($0.05<p<0.1$). Therefore, the more conservative interpretation is taken here in presenting 110 and 330 mg kg^{-1} as the NOEC and LOEC, respectively.

[c]The LOEC is unknown since at DDT concentrations greater than 370 μg kg^{-1} the mortality rate was too great to provide sufficient individuals for growth determination.

[d]At oil concentrations of 150 and 460 mg kg^{-1} growth superficially appeared less than the control, but high interreplicate variability prohibited demonstration of statistical significance. Growth impairment was clearly evident at 1,400 mg kg^{-1}, and that value is shown above, but the actual effective concentration may be much lower.

1995 Benthic Pilot Study

Bruce Thompson, San Francisco Estuary Institute;
Heather Peterson, Department of Water Resources; and
Michael Kellogg, City and County of San Francisco

Introduction

The RMP Benthic Pilot Study continued in 1995 with only a few changes from the 1994 study described in the *1994 Annual Report*. The objective of this pilot study remains the same: to evaluate the use of benthic information for determining environmental conditions in the Estuary. Benthos may respond to many different environmental changes, thus a major goal of this pilot study is to learn how to interpret those responses by the benthos, not just to contaminants, but to all major environmental changes such as salinity, sedimentation, and dredging.

In order to understand benthic changes, it is important to define what a "normal" benthic assemblage is in the Estuary. Knowledge of such a "reference" provides context against which to compare sites suspected of contamination or other impacts. Because the Estuary is highly variable in space and time, there are probably several normal assemblages, each characteristic of a different set of ecological conditions such as salinity regimes or sediment types.

The following is a working definition proposed for a "normal" benthic assemblage: *An assemblage of organisms that includes species known to be sensitive to contamination, does not include species known to be tolerant of contamination, but exhibits natural fluctuations in abundances of species in response to changes in salinity, sediment type, or the influx of other species.*

This definition assumes knowledge of natural variations in space and time, related to non-contaminant or other anthropogenic factors, and expected responses to contaminated sediments. Decades of study of San Francisco Estuary benthos have provided much of the information needed to determine the range of natural variation (e.g., Nichols and Pamatmat, 1988; Hymanson, *et al*., 1993). Responses to contamination have been well studied throughout the world and provide the information necessary for such a determination. Table 5 lists several benthic parameters commonly used to determine both contaminant impacts and "reference" conditions. This report focuses on analyses that may identify reference assemblages in the Estuary.

Methods

Methods of sampling, processing, and data analysis were detailed in the *1994 Annual Report*. Collaboration continued with the Department of Water Resources' (DWR) compliance monitoring program that sampled nine stations monthly in the Northern Estuary and Delta (Figure 18). Similarly, there was collaboration with the Bay Area Dischargers Association's (BADA) Local Effects Monitoring Program which sampled three stations near each of the City and County of San Francisco (CCSF), East Bay Municipal Utility District (EBMUD), and the Contra Costa Central Sanitary District (CCCSD) outfalls in February and August. Nine RMP stations were sampled

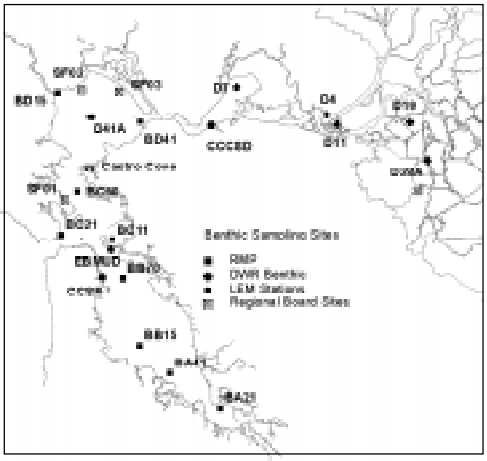


Figure 18. Benthic sampling sites.

Table 5. Characteristics of "normal" or reference benthic assemblages and those impacted by contaminants. Compiled from Word *et al.*, 1977; Nichols and Pamatmat, 1978; Chapman, *et al.*, 1987; Canfield *et al.*, 1996.

Indicators of Normal or Reference Benthic Assemblages		Indicators of Impacted Benthic Assemblages	
Relatively moderate to high numbers of species and abundances. Presence of amphipods and/or echinoderms.		Relatively reduced numbers of species. Absence of amphipods and echinoderms.	
Presence of:			
Marine/Estuarine:	Freshwater:	Marine/Estuarine:	Freshwater:
Spiophanes missionensis	*Rhyacodrilus* sp.	*Capitella* spp.	*Limnodrilus* sp.
Tellina sp.	*Stylodrilus heringianus*	Oligochaetes	Midge deformities
Monoculoides sp.		*Streblospio benedicti*	*Chironomus spp.*
		Polydora ligni	*Cricotpus spp.*

in February and August. In 1995, sampling at the RMP Petaluma River station (BD15) was added. The Regional Board's reference stations in San Pablo Bay and at Paradise Cove were not sampled in 1995.

Included in this year's data analysis were four stations sampled in 1992 at Castro Cove by the Regional Board's Bay Protection and Toxic Cleanup Program (BPTCP). These stations had elevated levels of contamination (mainly PAHs) in the sediments which were highly toxic (Carney *et al.*, 1994). These sites were included for contrast to potential "reference" sites in order to evaluate how ordination and classification analysis would identify and separate the stations.

All of the sites listed above were included in the data analysis. Eventually, evaluations may be made of how annual and seasonal variation, sediment type, other spatial heterogeneity, and degrees of contamination affected the benthos. However, not all of the necessary data are available.

As discussed in the Water Monitoring section of this report, 1995 was a very wet year. In contrast, 1994 was a critically dry year. These opposite water-year types provided a good opportunity to observe how the benthos in the Estuary change in relation to delta outflow and increased runoff in the other parts of the Estuary. Using multivariate ordination and classification methods, those differences were expected to produce site groupings that reflected environmental differences.

Results

Four major benthic assemblages were identified based on ordination and classification analysis of the 1994 and 1995 benthic samples (Table 6). Each assemblage contains similar species composition and abundances. However, they also included sub-assemblages where there were shifts in the most abundant organisms.

Delta and Rivers Assemblage

This assemblage included samples from the DWR Delta and River stations (Table 6). The benthos inhabiting those stations had similar species composition and abundances. However, there were shifts in dominance among samples collected within and between each station. The Sacramento River station (D4C) had sandy sediments which indicate a dynamic environment, and had greatly reduced abundances forming a sub-assemblage. In general, the 1994 and 1995 samples grouped together suggesting no major seasonal or annual differences in species composition within this assemblage, although many of the species had fluctuating abundances.

Table 6. Major benthic assemblages in the San Francisco Estuary in 1994 and 1995. Note that each assemblage contains one or more sub groups (see text) that differed in relative abundances of the species listed. * indicate species was not found.

These Benthic Assemblages	(at these) Stations	(had these) Common Species	(with these) Average Abundances (per sample)			
			Feb 94	Aug 94	Feb 95	Aug 95
Delta and Rivers Assemblage	Old River (D19C)	*Manayunkia speciosa*	1347	562	1501	949
(oligohaline)	Frank's Tract (D28A L, R)	*Corbicula fluminea*	92	165	194	394
	Sherman Is. (D11C)	*Varichaetadrilus angustipenis*	135	176	151	325
	Sacramento River (D4L, R)	*Limnodrilus hoffmeisteri*	259	110	139	462
	Sacramento River (D4C)	*Corophium stimpsoni*	182	170	70	418
		Gammarus daiberi	33	150	10	139
Estuarine Assemblage	San Pablo Bay (D41A)	*Marenzelleria viridis*	*	2	567	150
(euryhaline)	Contra Costa outfall (CCCSD)	*Hemileucon hinumensis*	126	*	274	55
	Petaluma River (BD15)	*Potamocorbula amurensis*	2702	825	135	1030
	Reg. Bd. Reference. (SF02,3)	*Corophium alienense*	41	135	65	*
	Davis Pt. (BD41)	*Streblospio benedicti*	10	4	26	39
	South Bay (BA21)	*Grandidierella japonica*	1	*	2	*
	Grizzly Bay (D7C)					
	Castro Cove					
Central Bay Assemblage	Yerba Buena Is. (BC11)	*Ampelisca abdita*	709	1460	3953	19395
(stenohaline, fine sediment)	Horseshoe Bay (BC21)	*Euchone limnicola*	6	112	1267	4
	Alameda (BB70)	*Leptochelia dubia*	52	184	591	1158
	Paradise Cove (SF01)	*Mediomastus spp.*	394	338	445	215
	San Bruno Shoal (BB15)	*Corophium heteroceratum*	123	387	53	895
	Redwood Creek (BA41)	*Corophium acherusicum*	9	10	11	44433
	EBMUD outfall (EBMUD)					
	San Francisco outfall (CCSF)					
Central Bay Assemblage	Red Rock (BC60)	*Grandifoxus grandis*	*	*	*	16
(stenohaline, coarse sediment)		*Heteropodarke heteromorpha*	*	22	1	*

Estuarine Assemblage

This assemblage included most of the moderate salinity estuarine stations in the Northern Estuary and South Bay (Table 6). The species composition and abundances were generally similar among these stations and over time. The Grizzly Bay station (D7C) was also inhabited by some species found in the Delta and Rivers, thus it is considered a transitional sub-assemblage. Grizzly Bay is located within the range of the entrapment zone where salinities fluctuate greatly depending on Delta outflow. The stations near the CCCSD outfall were also included in this assemblage. The stations at Castro Cove were included in this assemblage as they were inhabited by many of the same species. However, several indicators of contamination (Table 5) were sampled there, thus it is considered to represent a moderately contaminated sub-assemblage.

Central Bay, Fine Sediment Assemblage

This assemblage included all sites in the Central Bay (Table 6). All of these sites had fine, silty, clay sediments. One sub-assemblage consisted of sites on the periphery of the Central Bay, at Paradise Cove (SF01), San Bruno Shoal (BB15), and Redwood Creek (BA41), and appears to represent a transitional assemblage between the estuarine and the Central Bay assemblages. Another interesting sub-assemblage included the samples collected at CCSF and EBMUD outfalls, Yerba Buena Island (BC11), and Alameda (BB70) collected in August 1995. These sites were dominated by the amphipods *Corophium acherusicum* and *Ampelisca abdita*. Another sub-assemblage consisted of all 1994 and 1995 samples at Horseshoe Bay dominated by the polychaete *Mediomastus* spp. There were no obvious differences between the 1994 and 1995 samples except for the large influx of *C. acherusicum* in the Central Bay.

Central Bay, Coarse Sediment Assemblage

All samples from Red Rock (BC60) were classified as a distinct assemblage. That site is a mid-channel location composed of over 85% sand. It was inhabited by a unique assemblage of organisms, dominated by the polychaete *Heteropodarke heteromorpha* and the amphipod *Grandifoxus grandis*, and characterized by low numbers of species and abundances typical of sandy locations.

Diversity and Biomass

337 benthic species have been identified in the 1994 and 1995 surveys. In general, numbers of species were highest in the Central Bay fine sediment assemblage. The lowest numbers of species occurred at the sandy sediment stations at Red Rock (BC60), near the CCCSD outfall, and at the Sacramento River (D4C). A gradient of increasing numbers of species and individuals exists between the South Bay and Central Bay. Then, beginning at Red Rock (a sandy site) numbers of species remained low through the Northern Estuary to the Sacramento River, and then increased slightly into the Delta (Figure 19). Contrary to the 1994 results, numbers of species in 1995 were higher at Yerba Buena Island (BC11) than at the CCSF and EBMUD outfalls. There was no obvious seasonal or annual trend in numbers of species, as numbers of species were similar to those sampled in 1994.

Average abundances (number of individuals) were highest (~ 375,000 per square meter) at the EBMUD outfall stations in the August samples. These very high abundances were due to the occurrence of the amphipod *Corophium acherusicum*. This species was absent or rare in previous years and in February 1995. They immigrated or recruited at most South and Central Bay sites (Redwood Creek to Yerba Buena Island and EBMUD) in August 1995 possibly in response to the very wet winter of 1995. The lowest abundances were at the sandy stations.

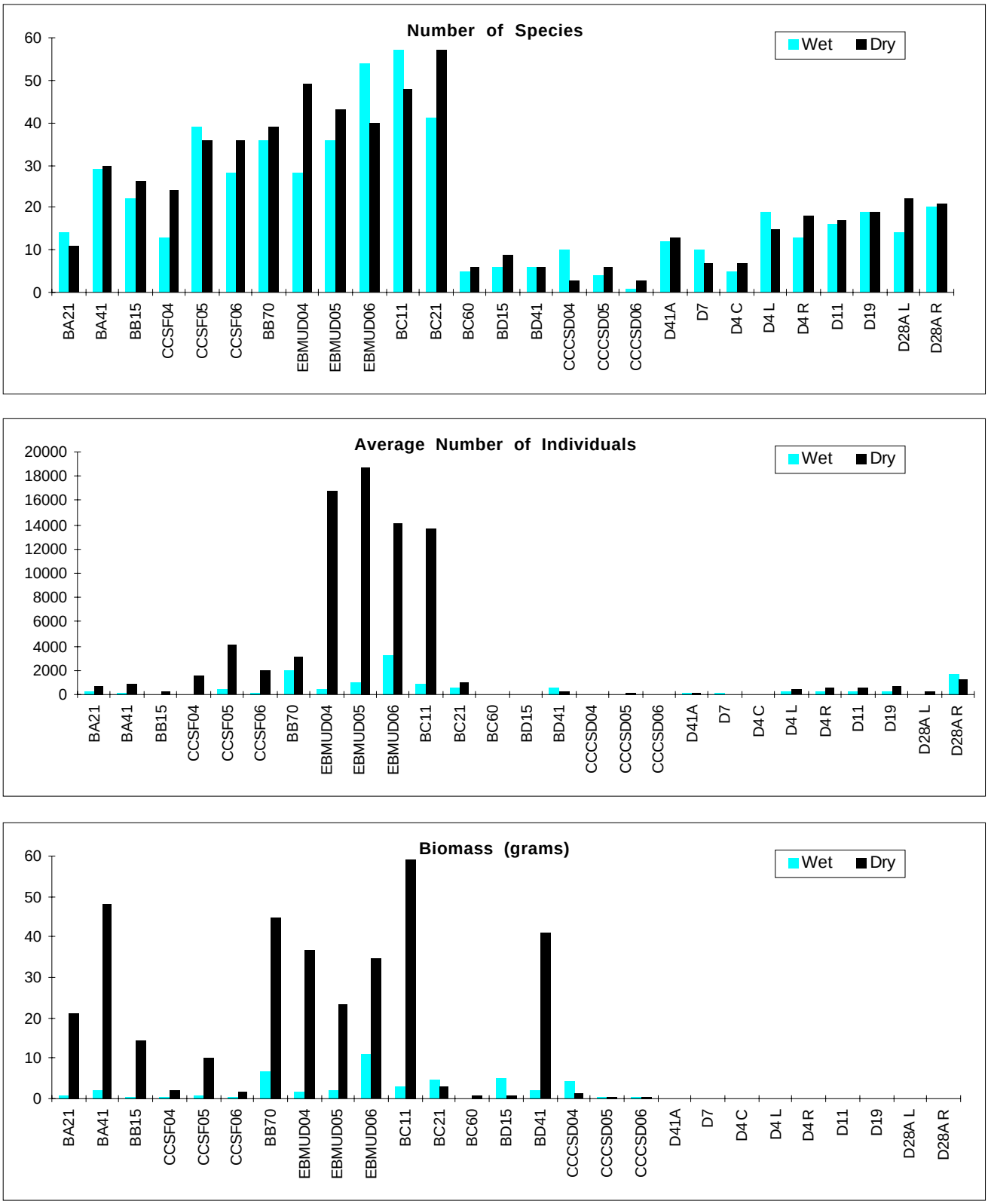


Figure 19. Mean numbers of species, number of individuals, and biomass per sample collected in February (wet) and August (dry) sampling periods in 1995. Biomass was not measured at the DWR stations.

Benthic biomass was highest at Yerba Buena Island (BC11) and EBMUD outfall stations due to the presence of very large numbers of amphipods described above. Biomass was also elevated at Redwood Creek (BA41) and Davis Point (BD41) due to the presence of the clam *Potamocorbula amurensis*. Biomass was elevated at Alameda (BB70) in August 1995 due to presence of the tunicate *Molgula*. Biomass was not measured by DWR.

Discussion and Conclusions

Indicators of reference conditions (Table 5) were observed at all stations except for Red Rock (BC60) where they may not occur due to sandy conditions. Instead, it may be necessary to recognize the species there as "normal" for those conditions. Sandy sediments also have naturally reduced numbers of species and abundances because of the dynamic nature of that environment. Therefore, reduced diversity and/or abundances cannot be used as an indicator of contamination at such sites. Ophiuroids and amphipods occurred in the Central Bay assemblage and amphipods occurred in the Estuarine and the Delta and Rivers assemblages; amphipods often dominated those assemblages.

Indicators of contamination occurred at some sites. In the Delta and Rivers assemblage, the oligochaete *Limnodrilus* sp. and the midge *Chironomus* sp. occurred suggesting some degree of impact. Further, the reduced diversity at the Grizzly Bay (D7) site may indicate some degree of impact. Alternatively, it may represent a natural response to life in the entrapment zone. If the fresh/brackish water assemblage is impacted, the question then becomes what does a "normal" assemblage look like? Further study is warranted. In Castro Cove, the polychaetes *Capitella "capitata", Polydora ligni*, and *Streblospio benedicti* were collected; diversity and abundances generally decreased along a gradient into the Cove. Amphipods were among the most abundant species at all Castro Cove stations, although abundances of *Ampelisca abdita* decreased in the Cove (Carney *et al.*, 1994). These observations suggest that Castro Cove is a moderately contaminated area forming a sub-assemblage of the estuarine assemblage.

In the Central Bay, the EBMUD and CCSF outfall stations were inhabited by several indicators of contamination and several indicators of reference conditions, suggesting that benthos there are only slightly impacted by the outfalls. Average abundances of *C. "capitata"* were higher at those sites in both 1994 and 1995 than at the adjacent non-outfall sites. Additionally, the outfall sites had numbers of species and abundances among the highest in the Estuary, which generally suggest enrichment and/or moderate levels of contamination (Pearson and Rosenberg, 1978; Swartz, *et al.*, 1986). However, indicators of reference conditions also inhabited those sites.

Based on the 1994 and 1995 Benthic Pilot data, four major assemblages have been identified for the San Francisco Estuary which are generally consistent with benthic patterns in other estuaries (Boesch, 1977). Each assemblage is characteristic of a range of salinity and/or sediment types. In general, each assemblage is believed to represent the "normal" benthic condition for their respective salinity and sediment type regime. However, as discussed above, there is still some uncertainty as to whether the presence of indicators of contamination in the Delta and Rivers assemblage in fact indicate an impact. Further, within each assemblage, sub-assemblages or sites contain some indications of contamination. However, in no case were differences strong enough to form distinct assemblages with completely different species composition, suggesting only slight effects of contamination. Thus, it is a question of the degree of effects and just how different from a "reference" condition a site must be considered impacted.

In general, no large changes in species composition were observed in any of the assemblages between 1994 and 1995 data. The most obvious change was the large influx of *Corophium acherusicum* in the Central Bay. It was anticipated that some sites would switch from one assemblage type to another over time

in response to seasonal changes in salinities as suggested by Nichols and Pamatmat (1988) and Hymanson *et al.*, (1993). It was rather surprising to observe little seasonal or annual change in assemblage composition at DWR's Northern Estuary sites. Because of the very wet year in 1995, Grizzly Bay was expected to be more like the fresh/brackish water stations in the wet season samples. However, that was not observed. Instead, the changes at that station were more subtle with minor shifts in dominance and composition. With only two years of data, how the assemblages described herein may change over time is still uncertain. Most of these assemblages include the Asian clam *Potamocorbula amurensis*. Although it is not a native species, it is now an established resident and must be included in our definition of "normal" for this Estuary.

Yet to be determined is how non-contaminant factors influence the abundances of the indicators on Table 5. We need to evaluate how other water year types change the assemblages presented. Questions about how to interpret impacts in the Delta and Rivers assemblage need further investigation. Relationships between benthic parameters and the range of environmental parameters (contaminants, sediments, salinity, etc.) need to be evaluated. This analysis is scheduled for the *1996 Annual Report* using three years of Pilot Data. And finally, we need to develop an objective way to determine what is "reference". The BPTCP has developed a benthic index that partitions reference and impacted benthos in southern California estuaries, and a reference envelope for marine benthos was developed in southern California (EPA, 1993a).

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Bay Protection and Toxic Cleanup Program: Evaluation of Sediment Reference Sites and Toxicity Tests in San Francisco Bay

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Introduction

In previous studies (Long *et al.*, 1990a; Flegal *et al.*, 1994), attempts have been made to identify sediment reference sites in San Francisco Bay and other coastal embayments in order to compare reference site conditions with those at test sites. In these studies, toxicity tests at reference sites not only exhibited toxicity but also a great deal of variability. One of the main purposes of the Bay Protection and Toxic Cleanup Program (BPTCP) is to identify "toxic hot spots". In order to identify sites that may need remediation, it is important to be able to distinguish between these sites and those that exhibit optimal ambient conditions as characterized by reference sites.

The BPTCP recently conducted a study with the following objectives:

1. To identify and characterize sediment reference sites in San Francisco Bay,
2. To evaluate appropriate sediment toxicity test methods for use in San Francisco Bay,
3. To evaluate a statistical method, the reference envelope approach, to distinguish toxic samples from those characteristic of ambient conditions, and
4. To investigate the use of toxicity identification evaluations (TIEs) in determining the causes of toxicity at sites with both high and low concentrations of anthropogenic chemicals.

Methods

Five sites were selected as potential reference sites to be used in future toxicity assessments in San Francisco Bay. These sites are described in Table 7. Sites were selected based on criteria established in previous studies (EPA, 1986; PTI, 1991; Long *et al.*, 1990b). These criteria were: low concentrations of anthropogenic chemicals, distance from known major sources of pollution, and natural features such as grain size and total organic carbon that are similar to test sediments. Sites with fine grain sediment were selected because most heavily contaminated sites are found in depositional areas with fine grain sediment.

As part of the evaluation of toxicity tests and the reference envelope statistical approach, sites in Tomales Bay and Bolinas Lagoon were also investigated because they had been previously considered as reference sites and found to exhibit toxicity, although concentrations of anthropogenic contaminants were low. In addition, one sample was collected from each of

Table 7. Reference sites.

Water Body	Location	Latitude	Longitude	Sampling Dates
San Pablo Bay	Tubbs Island	38,06,87N	122,25,16W	4/94, 9/94, 3/95
San Pablo Bay	Island #1	38,06,72N	122,19,71W	4/94, 9/94, 3/95
Central SF Bay	Paradise Cove	37,53,95N	122,27,86W	4/94, 9/94, 3/95
South SF Bay	North Site	37,34,23N	122,08,98W	3/95
South SF Bay	South Site	37,32,18N	122,07,16W	3/95

three sites (Islais Creek, Castro Cove, and Clipper Cove) where previous studies had shown either high toxicity or high levels of toxic chemicals (Long *et al.*, 1988, Flegal *et al.*, 1994, Anderson *et al.*, 1995). Data from these sites were compared against reference sites. All sites are shown in Figure 20.

Reference sites in San Pablo Bay and the Central Bay were sampled during three different hydrologic conditions. Sites in the South Bay were sampled only once. Three field replicates were collected at each potential reference site during each sampling period. Chemical analyses, total organic carbon, and

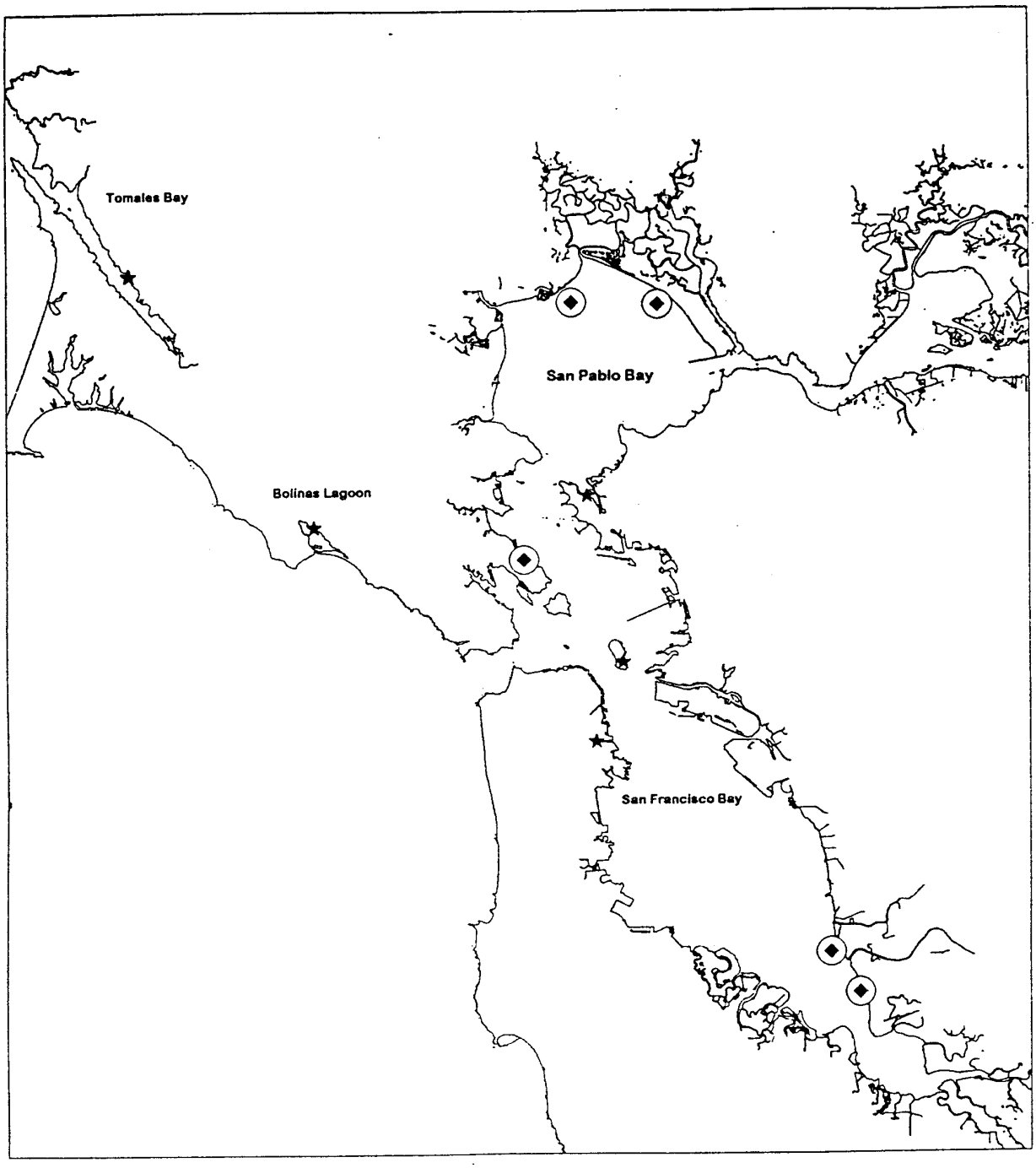


Figure 20. Overview map of study sites in and near San Francisco Bay. Circles indicate candidate reference sites; stars indicate contaminated sites or uncontaminated sites that have exhibited toxicity and were used for comparison.

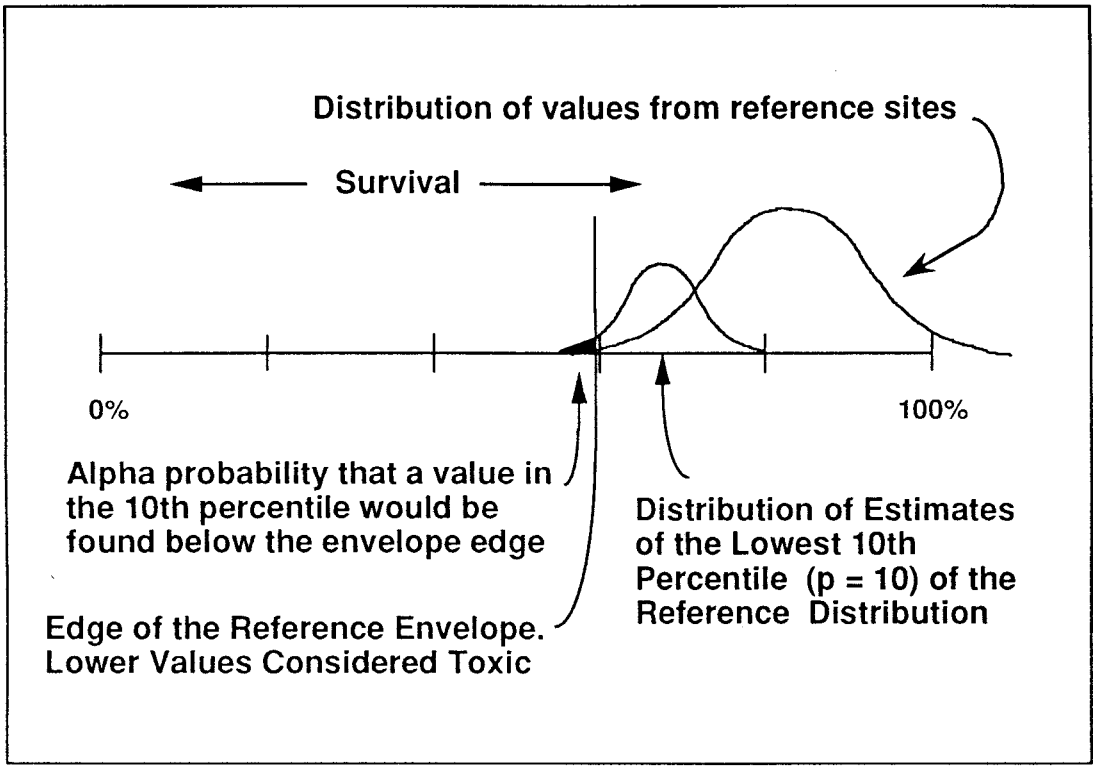


Figure 21. Schematic illustration of the method for determining the lower tolerance interval bound (edge of the reference envelope) to determine sample toxicity relative to a percentile of the reference site distribution.

grain size analyses were conducted at all potential reference sites. Benthic community analyses were conducted at potential reference sites in San Pablo Bay and the Central Bay. Up to nine toxicity tests were conducted on each sample from all sites. These tests included the solid phase amphipod survival test using *Eohaustorius* and *Ampelisca*, survival of *Eohaustorius* in intact cores and in pore water (for TIEs), the larval development test in pore water using the mussel *Mytilus* and the urchin *Strongylocentrotus*, the urchin development test at the sediment/water interface, the *Neanthes* growth and survival test and a survival test with *Nebalia*, a Leptostracan crustacean. Tests were evaluated for control response acceptability, laboratory replicate variability, and sensitivity.

As mentioned above, one of the primary objectives of the BPTCP is the identification of specific areas of water or sediment quality concern, "toxic hot spots", where adverse biological impacts are observed in areas with localized concentrations of pollutants. While it is possible that all of the sediment in San Francisco Bay is degraded to some extent, logistical constraints require that efforts be focused on localized areas that are significantly more toxic than optimal ambient conditions that exist at reference sites. In this study we are using a "reference envelope" statistical approach to make that distinction. Tolerance limits can serve as a relative standard against which to compare results from tests at sites of concern. One of the major advantages of this approach is that it accounts for major variance components, such as variability in time, space and among field and laboratory replicates.

Figure 21 illustrates the reference envelope method for calculating tolerance limits. In the reference envelope approach, explicit decisions must be made regarding the choice of two statistical parameters, values for "p" and "alpha". The values chosen will depend on the degree of certainty necessary in a particular regulatory setting. In Figure 21 a "p" or lower

percentile value of 10 was chosen. Tolerance limits were calculated for all test protocols, with manipulation of "p" and "alpha" values to evaluate the use of the reference envelope technique with sediment toxicity data.

In order to investigate the causes of toxicity, TIE protocols were developed for *Eohaustorius*, and the mussel and urchin larval development tests in sediment pore water. TIEs were conducted on four sediment samples that exhibited toxicity. These samples were from Tomales Bay (Marconi Cove), Islais Creek, China Basin (Mission Creek), and Guadalupe Slough.

Results

Sediment samples from five candidate reference sites in San Francisco Bay were found to have low concentrations of measured chemicals, and to exhibit low toxicity and low variability in space and time. Toxicity tests with *Ampelisca* and *Eohaustorius* in homogenized sediment had acceptable control survival, low between replicate variability, and were capable of resolving differences between sediments from reference sites and suspected contaminated sites. Pore water and sediment/water interface tests with sea urchin embryos met control acceptability requirements in all tests, had very low variability, and were sensitive to toxicants at suspected contaminated sites. However, the sensitivity of the urchin and mussel development tests to ammonia may limit the use of these tests in pore water. The sediment/water interface exposure seems to minimize this problem and also provides a more environmentally relevant test. Tests with *Eohaustorius* in pore water and in intact cores provided highly variable results. Tests with *Neanthes* and *Nebalia* appeared to be insensitive to sediment contaminants at test sites and also did not meet other acceptability criteria.

Data from candidate reference sites have been used to calculate reference envelope tolerance limits for each toxicity test. However, the potential effect of temporal and spatial variability on reference envelope results is still being investigated. Tolerance limits for specific toxicity tests may need to be recalculated once this analysis is complete. Additional data from screening surveys is being added to the data base to make the calculation of tolerance limits more robust.

TIE results indicate that in the samples from Islais Creek and China Basin ammonia and hydrogen sulfide were partially responsible for toxicity in the sea urchin development test. Toxicity remained, however, even after ammonia and hydrogen sulfide were removed. In the Tomales Bay sample, ammonia was partially responsible for toxicity with the same test. However, ammonia seemed to increase significantly in stored samples between the time initial toxicity screening of the samples was performed and the time the TIEs were performed (about 1 week). For samples from Islais Creek, Tomales Bay and Guadalupe Slough, significant toxicity remained even after all of the TIE procedures were conducted to remove ammonia, hydrogen sulfide, metals and non-polar organics. The remaining toxicity at China Basin degraded after ammonia and hydrogen sulfide were removed. Therefore, TIE procedures to remove metals and non-polar organics were not be performed.

The BPTCP is currently screening 95 sites throughout the Bay for toxicity. The toxicity tests being conducted are the sea urchin development test in pore water and at the sediment/water interface and the solid phase amphipod test using *Eohaustorius*. Reference sites evaluated in the reference site study are being sampled along with test sites. The reference envelope approach, along with others, is being used to determine if a sample should be considered toxic. Full chemical analysis is being performed on samples that exhibit significant toxicity. PCB and mercury analyses are being performed on all samples to identify sediments that may contribute to bioaccumulation of these chemicals of concern.

Sediment Monitoring Discussion

Patterns in Sediment Contamination in 1995

Despite the very wet year of 1995, the distributions and concentrations of sediment contaminants in the Estuary remained similar to those in previous years. For trace elements in 1995, there were two patterns: 1) average concentrations of As, Cr, Cu, Ni, and Zn were highest in the Northern Estuary (specifically, Cr, Cu, and Ni were highest at Pinole Point (BD31) in February; 2) average concentrations of Ag, Cd, Pb, Hg, and Se were highest in the South Bay and Southern Sloughs (specifically, Cd, Pb, Ag, and Zn were highest at San Jose (C-3-0) in August). Concentrations of most metals (except As and Cr) were lowest at the coarse sediment stations, usually at Red Rock (BC60); reflecting the influence of sediment type on sediment metals concentrations.

The only consistent seasonal pattern in 1995 was that nearly all metal concentrations were higher in August than in February at both Southern Slough stations. These results are probably related to the very wet winter. However, except for Pb and As, similar trends were generally not observed at the Sacramento, San Joaquin, Napa, or Petaluma River stations.

For trace organics, sediment concentrations were always higher south of the Golden Gate than in other parts of the Estuary. Concentrations of PCBs and DDTs were lowest at the coarse sediment stations, but PAH concentrations were lowest at the Rivers confluence stations.

Seasonally, PAHs were generally highest in February in the South and Central Bays. PCBs were generally highest in August in the South Bay, but DDTs were always higher in August than February throughout the Estuary.

Long Term Trends in Sediment Contamination 1991–1995

Combining RMP sediment monitoring data 1993–1995 allows for examination of trends in sediment contaminant concentrations over the first three years of the RMP. Average concentrations were calculated for each Estuary reach for each of six sampling periods (Figures 22–35).

Trace metals concentrations have remained rather constant in all reaches and through all three years with no increasing or decreasing trends observed (Figures 22–31). In general, differences in means and ranges of concentrations were small. Mean As concentrations appeared to increase slightly in the Rivers. Hg in the Rivers was more variable during the wettest sampling periods (February 1993, 1995) than in the dry sampling periods; concentrations in the San Joaquin River increased considerably during high flows. Pb was elevated in the Rivers in August 1994, and Se was elevated in the Northern Estuary in August 1993. There were no obvious differences in concentrations related to wet or dry seasons or years.

For trace organic contaminants, data from the State's Bay Protection and Toxic Cleanup Program (BPTCP) Pilot Monitoring Studies in San Francisco Estuary, 1991–1992 (Flegal *et al.* 1994), and the RMP data, 1993–1995, were combined (Figures 32–35). In general, differences in means and ranges of concentrations were small. There were no observable increasing or decreasing trends in PAHs. However, PAH concentrations were elevated in the Northern Estuary, Central, and South Bays in February 1994. These increases caused many stations to have numerous Effects Range Low (ERL) exceedances (up to 19) that included a number of individual PAH compounds. The cause of the elevated PAHs is not known. That increase did not occur at the River stations which showed a different pattern of variation with larger differences between sampling periods. Average PCB concentrations appear to have decreased in the River, Northern Estuary, and Central Bay, but the ranges of values nearly overlap. This observation corresponds to the information presented by Risebrough (this report). Average DDTs appear to have de-

creased in the Rivers, but ranges nearly overlap. There were no observable differences in other reaches. Average chlordanes have also decreased in most Estuary reaches, although ranges of values in the Northern Estuary generally overlap. Beginning in 1994, concentrations were greatly reduced in the Rivers and Central Bay, but concentrations remained variable in the Northern Estuary and South Bay.

The trends discussed above should be interpreted cautiously. Rigorous statistical time-series analysis generally requires more than 6 to 8 samplings. Each year the RMP adds two more data points which will gradually improve our understanding of sediment contamination.

Comparisons to Sediment Quality Guidelines

Although the RMP has used ERL and ERM guidelines (Long and Morgan, 1990a; Long, *et al.*, 1995) since 1993, those are not the only sediment quality guidelines available. The ERL and ERM guidelines are currently the most widely used sediment guidelines world-wide. Although not specifically developed for the San Francisco Estuary, they do include data from the Estuary. One of the recommendations from a recent NOAA sediment quality workshop was to use information from any and all available guidelines in sediment assessments (Chapman *et al.*, in press). Table 8 lists several other national and west coast guidelines for comparison. The USGS background values from sediment coring are not actually sediment quality guidelines *per se*, but provide valuable context of historic concentrations in the Estuary. Other sediment guidelines commonly used include those for Florida (MacDonald, 1993) and freshwater guidelines from Ontario (Persaud *et al.*, 1992). The San Francisco Bay Regional Water Quality Control Board is currently developing Apparent Effects Threshold (AET) values for the Estuary.

A listing of the contaminants above the ERL and ERM guidelines at each RMP station in 1995 is shown on Table 9. As in past years, nearly all samples had Ni concentrations above the ERM. Ni is a natural component of serpentine soils abundant in the region, and Ni concentrations in the USGS sediment cores have been generally constant for centuries. Similar to past years, concentrations of As, Cr, Cu, Hg, Ni, and total DDTs were usually above the ERL (Table 9). In 1995, several PAH compounds had concentrations above ERLs at Alameda (BB70).

Stations with the most exceedances of ERLs included Alameda (BB70) where eight contaminants exceeded ERL concentrations in February and Honker Bay (BF40) with six stations with the fewest ERL exceedances were the stations with coarse sediments (more sand or gravel): Davis Point (BD41), Pacheco Creek (BF10), Red Rock (BC60), and Sunnyvale (C-1-3) had only one or two ERL exceedances.

Effects of Sediment Contamination

The RMP currently uses sediment bioassays as an indicator of the potential for ecological effects from contaminated sediments. Other ecological indicators of contamination are being developed through RMP Pilot and Special Studies (summarized below), as well as by other programs (e.g., USGS, BASMAA, BPTCP, and US EPA). It is clear that the RMP needs to include a broader range of sediment indicators. Identification of potential new sediment indicators was included in the RMP Ecological Indicators Workshop held in October 1995 (Thompson *et al.*, this report). The need for, and selection of, additional sediment indicators will be considered during the RMP five-year program review in 1997.

The RMP sediment bioassays continued to indicate toxicity at most stations throughout the Estuary. Analyses of the first three years of sediment bioassays (Thompson *et al.*, this report) showed that when more than seven contaminants exceed ERLs at a station, amphipod toxicity usually occurs. This suggests that the additive effects of low levels of several contaminants may be causing the observed toxicity. However, toxicity to bivalve larvae was

Table 8. 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			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			4022	44792	.	.	
DDE	µg/kg		.	.	15	.	
DDD	µg/kg		.	.	43	.	
DDT	µg/kg		.	.	.	.	
TOTAL DDTs			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 USGS SF Bay sediment cores.**
From: Hornberger *et al.* (unpublished)

Table 9. Summary of contaminants in sediments that were above sediment Effects Range Low (ERL) and Effects Range Median (ERM) guidelines at each 1995 RMP sediment sampling station. W = Wet season (February), D = Dry season (August), - = not above guideline.

		METALS ERL						ERM	ORGANICS ERL				
		Arsenic	Chromium	Copper	Mercury	Nickel	Lead	Nickel	Anthracene	Fluorene	Phenanthrene	Sum of DDTs	p,p'-DDE
	Guideline	8.2	81	34	0.15	20.9	46.7	51.6	85.3	19	240	1.58	2.2
Station Name	Code	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	µg/Kg	µg/Kg	µg/Kg	µg/Kg	µg/Kg
Sunnyvale	C-1-3	-,-	-,-	-,-	-,D	W,D	-,-	W,D	-,-	-,-	-,-	-,-	-,-
San Jose	C-3-0	-,-	-,D	-,D	-,D	W,D	-,D	W,D	-,-	-,-	-,-	-,-	-,-
Coyote Creek	BA10	-,D	-,D	-,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,D	-,D
South Bay	BA21	-,D	W,D	W,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,D	-,-
Dumbarton Bridge	BA30	W,D	W,-	W,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,D	-,-
Redwood Creek	BA41	W,D	-,D	W,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,D	-,-
San Bruno Shoal	BB15	W,D	W,-	W,-	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,D	-,-
Oyster Point	BB30	-,D	-,-	W,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,D	-,-
Alameda	BB70	W,D	W,-	W,D	W,D	W,D	-,-	W,D	W,-	W,D	W,-	-,D	-,-
Yerba Buena Island	BC11	W,D	-,D	-,D	W,D	W,D	-,-	-,D	-,-	-,-	-,-	W,D	-,-
Horseshoe Bay	BC21	W,-	-,-	-,-	W,-	W,D	-,-	W,D	-,-	-,-	-,-	W,D	-,-
Richardson Bay	BC32	W,D	-,-	-,-	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,D	-,-
Point Isabel	BC41	W,D	W,D	W,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,D	-,-
Red Rock	BC60	-,D	-,-	-,-	-,-	W,D	-,-	W,D	-,-	-,-	-,-	-,-	-,-
Petaluma River	BD15	W,D	W,D	W,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,-	-,-
San Pablo Bay	BD22	W,D	-,-	W,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,D	-,-
Pinole Point	BD31	W,D	W,-	W,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,D	-,-
Davis Point	BD41	-,D	-,-	-,-	-,-	W,D	-,-	W,D	-,-	-,-	-,-	-,-	-,-
Napa River	BD50	W,D	W,D	W,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,D	-,-
Pacheco Creek	BF10	-,D	-,-	-,-	-,-	W,D	-,-	W,D	-,-	-,-	-,-	-,-	-,-
Grizzly Bay	BF21	W,D	W,-	W,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,D	-,-
Honker Bay	BF40	W,D	W,D	W,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	W,D	-,-
Sacramento River	BG20	W,D	-,D	-,-	-,-	W,D	-,-	W,D	-,-	-,-	-,-	-,-	-,-
San Joaquin River	BG30	W,D	-,-	W,D	W,D	W,D	-,-	W,D	-,-	-,-	-,-	-,-	-,-

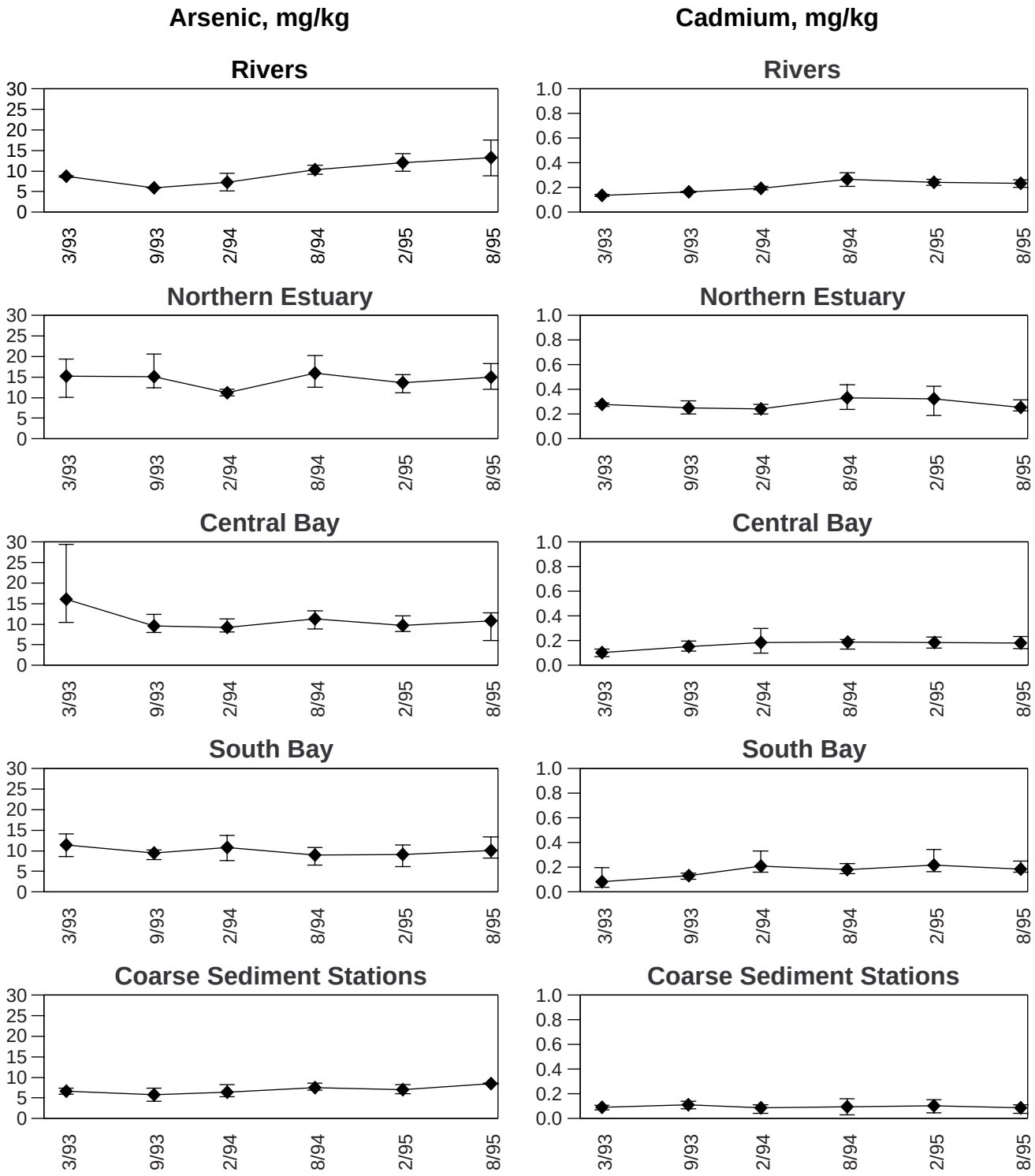
not related to the ERLs which are based on bulk chemistry measurements. The bivalve bioassay provides different information about sediment toxicity than the amphipod test, and the RMP needs to find better ways to interpret that information.

The RMP Special Studies on the development of bioassays using the resident amphipod *Ampelisca abdita* showed that it is equally or more sensitive to contamination than other amphipods commonly used in bioassays (Weston, this report). Results of the comparisons of sensitivity between sublethal growth endpoints and acute mortality depended on which toxicant was used in the exposure. Since *A. abdita* is numerically dominant at many RMP benthic stations and can be used in controlled sediment bioassays, they could be a powerful indicator for the RMP in the quest for understanding sediment contaminant effects.

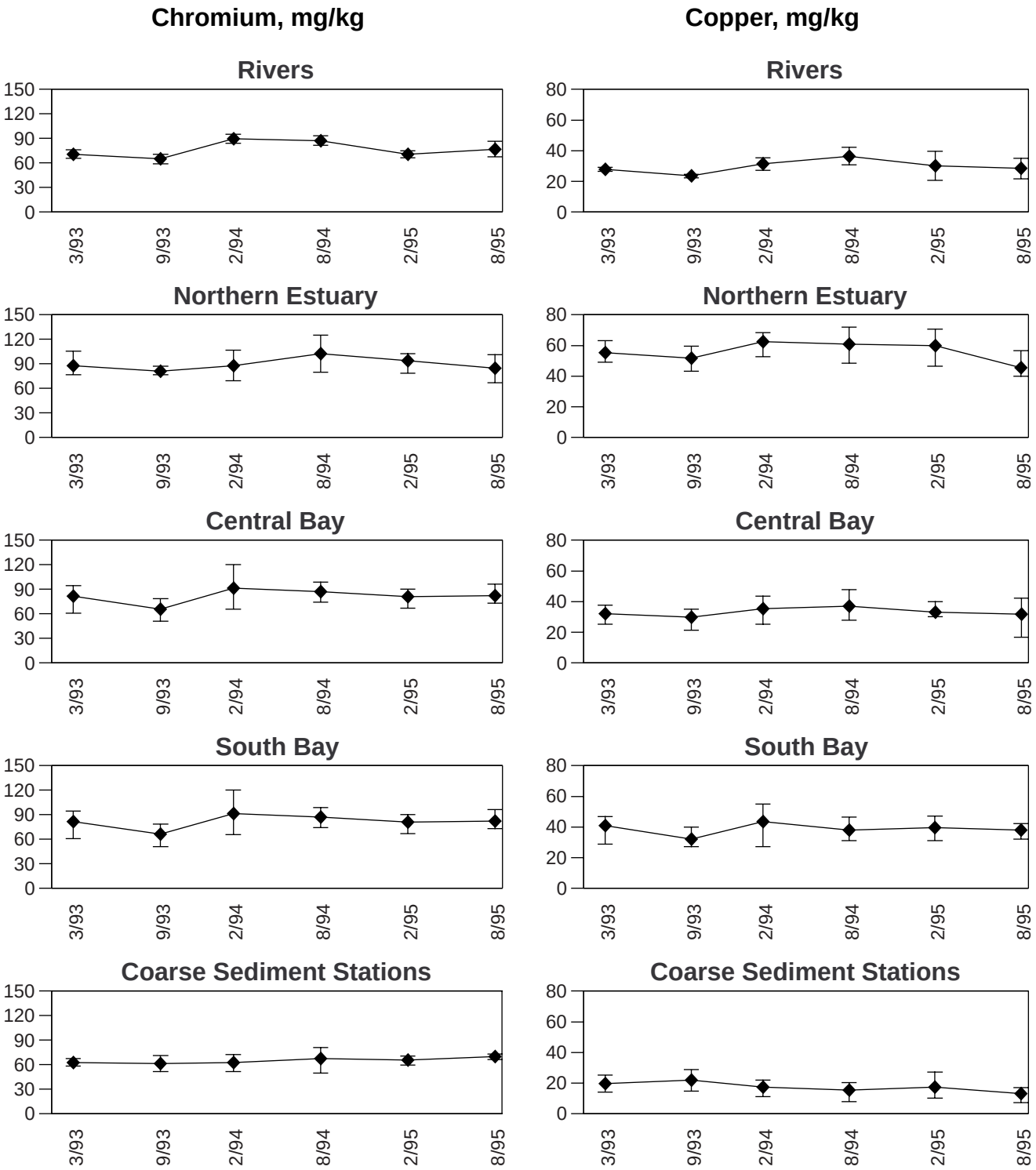
The RMP Benthic Pilot Study (Thompson, *et al.*, this report) showed that it may be possible to identify normal, or "reference" benthic assemblages for specific Estuary salinity and sediment types. This knowledge will be useful for comparisons to sites where the benthos may be degraded due to contamination or other factors. Only minor benthic impacts were observed near some outfalls in Central Bay. Indicators of contamination were also observed in Castro Cove and possibly in the brackish water benthos of the Northern Estuary. With only two years of Pilot data, these conclusions should be considered preliminary.

The State's BPTCP has also worked on the identification of sediment reference sites in the Estuary for comparisons to toxic "hot spots". (Taberski and Hunt, this report). Their approach is based on comparisons of impacted and "reference" sediments using information about sediment chemistry, toxicity, and benthos (the sediment quality triad). Together with RMP data, a detailed understanding of Estuary sediments is being developed.

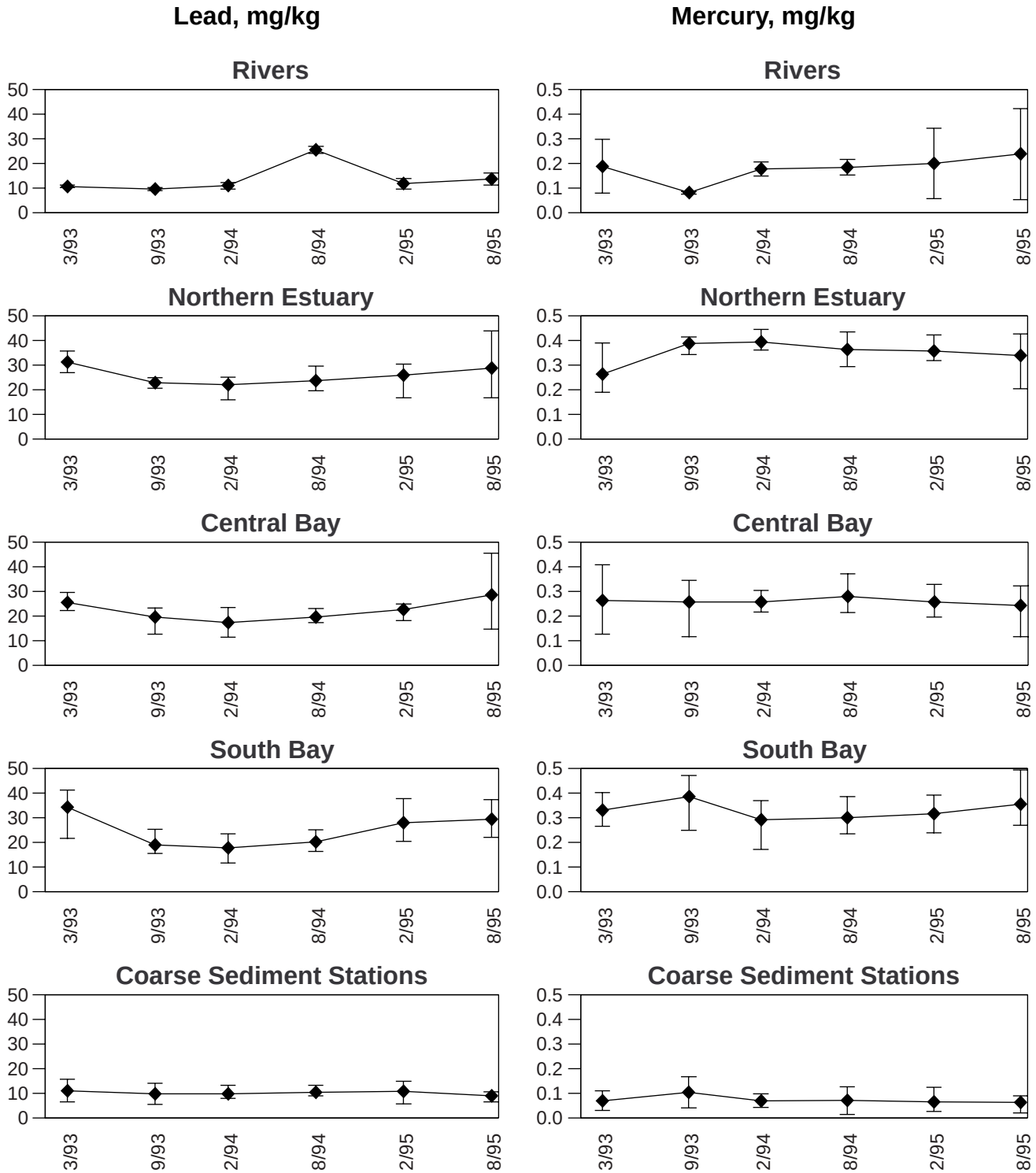
In summary, the RMP and other studies are increasing our understanding of contaminated sediments and their possible ecological effects. Based on the number of stations with sediment concentrations above the ERLs or ERMs, sediment bioassays, and benthic studies presented in this report, contaminants in sediments at some of the RMP stations are toxic, but in general, benthic assemblages appear mostly unimpacted.



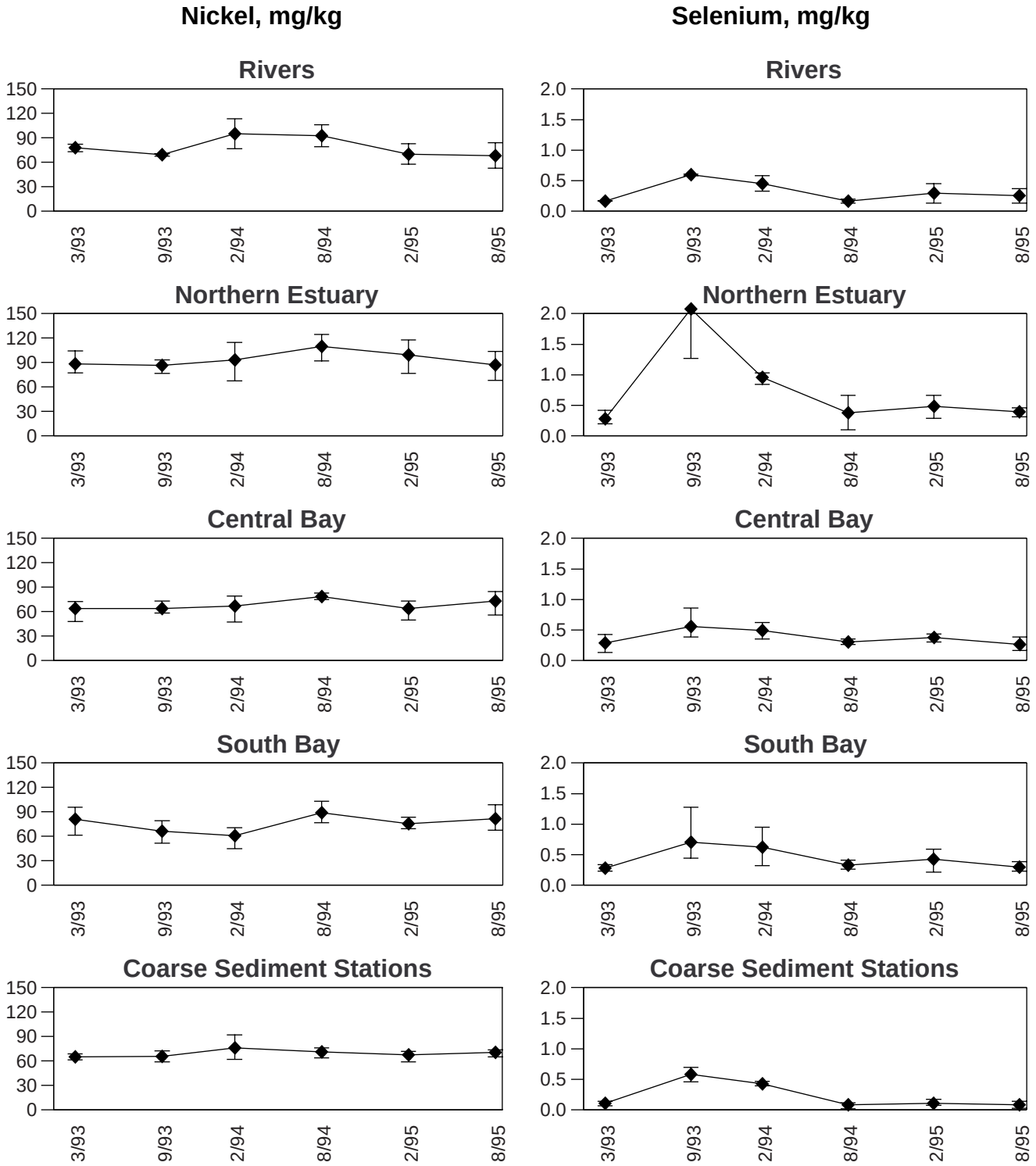
Figures 22–23. Plots of average arsenic and cadmium concentrations (parts per million, ppm) in sediments in each Estuary reach in 1993–1995. The vertical bars represent ranges of values. Sample sizes are as follows: South Bay, 1993 n=4, 1994 n=6, 1995 n=7; Central Bay, 1993–1995 n=4, Northern Estuary, 1993 n=4, 1994 n=5, 1995 n=6; coarse sediment stations,1993 n=2, 1994–1995 n=3; Rivers 1993–1995 n=2.



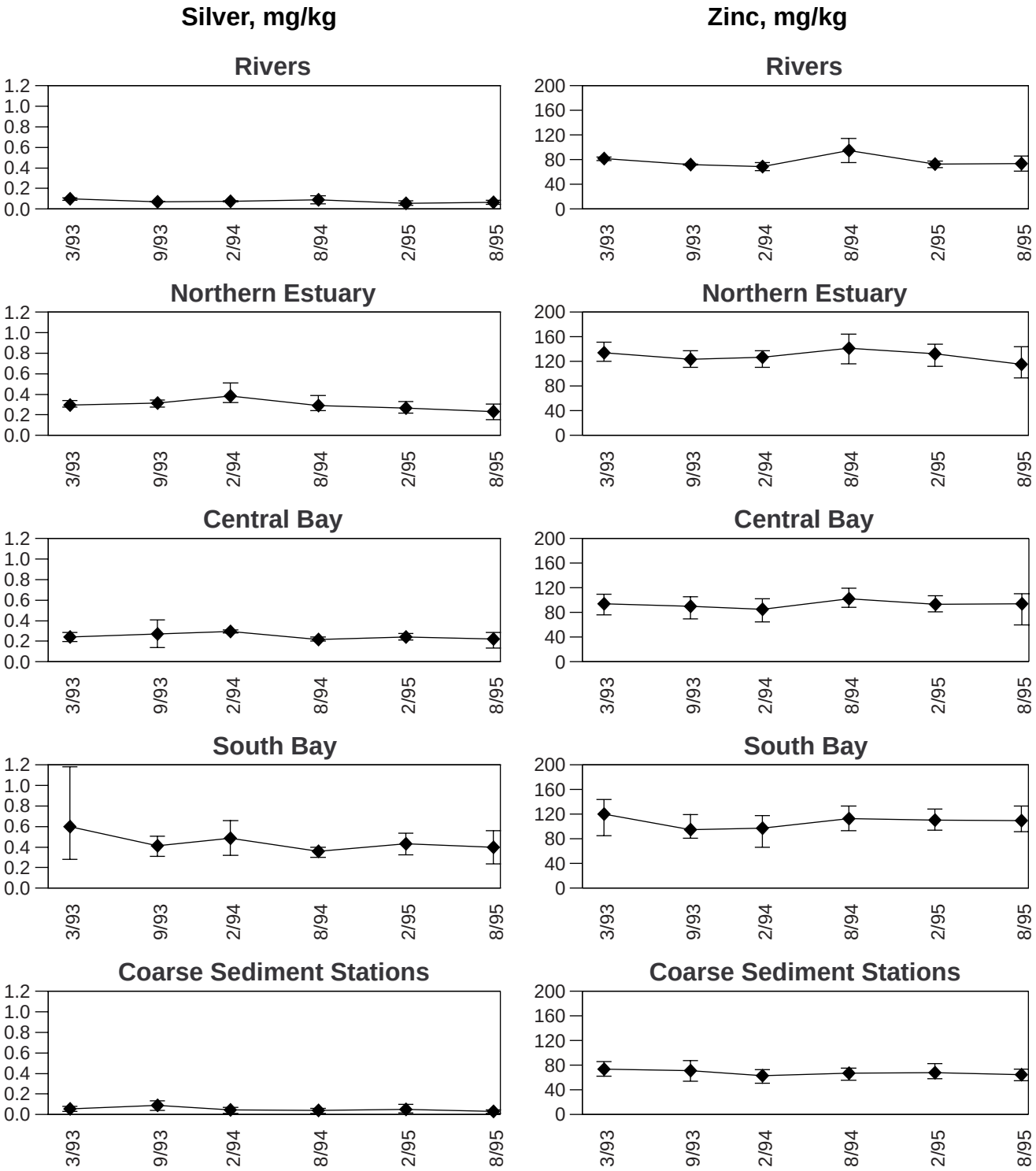
Figures 24–25. Plots of average chromium and copper concentrations (parts per million, ppm) in sediments in each Estuary reach in 1993–1995. The vertical bars represent ranges of values. Sample sizes are as follows: South Bay, 1993 n=4, 1994 n=6, 1995 n=7; Central Bay, 1993–1995 n=4, Northern Estuary, 1993 n=4, 1994 n=5, 1995 n=6; coarse sediment stations,1993 n=2, 1994–1995 n=3; Rivers 1993–1995 n=2.



Figures 26–27. Plots of average lead and mercury concentrations (parts per million, ppm) in sediments in each Estuary reach in 1993–1995. The vertical bars represent ranges of values. Sample sizes are as follows: South Bay, 1993 n=4, 1994 n=6, 1995 n=7; Central Bay, 1993–1995 n=4, Northern Estuary, 1993 n=4, 1994 n=5, 1995 n=6; coarse sediment stations,1993 n=2, 1994–1995 n=3; Rivers 1993–1995 n=2.



Figures 28–29. Plots of average nickel and selenium concentrations (parts per million, ppm) in sediments in each Estuary reach in 1993–1995. The vertical bars represent ranges of values. Sample sizes are as follows: South Bay, 1993 n=4, 1994 n=6, 1995 n=7; Central Bay, 1993–1995 n=4, Northern Estuary, 1993 n=4, 1994 n=5, 1995 n=6; coarse sediment stations,1993 n=2, 1994–1995 n=3; Rivers 1993–1995 n=2.



Figures 30–31. Plots of average silver and zinc concentrations (parts per million, ppm) in sediments in each Estuary reach in 1993–1995. The vertical bars represent ranges of values. Sample sizes are as follows: South Bay, 1993 n=4, 1994 n=6, 1995 n=7; Central Bay, 1993–1995 n=4, Northern Estuary, 1993 n=4, 1994 n=5, 1995 n=6; coarse sediment stations,1993 n=2, 1994–1995 n=3; Rivers 1993–1995 n=2.

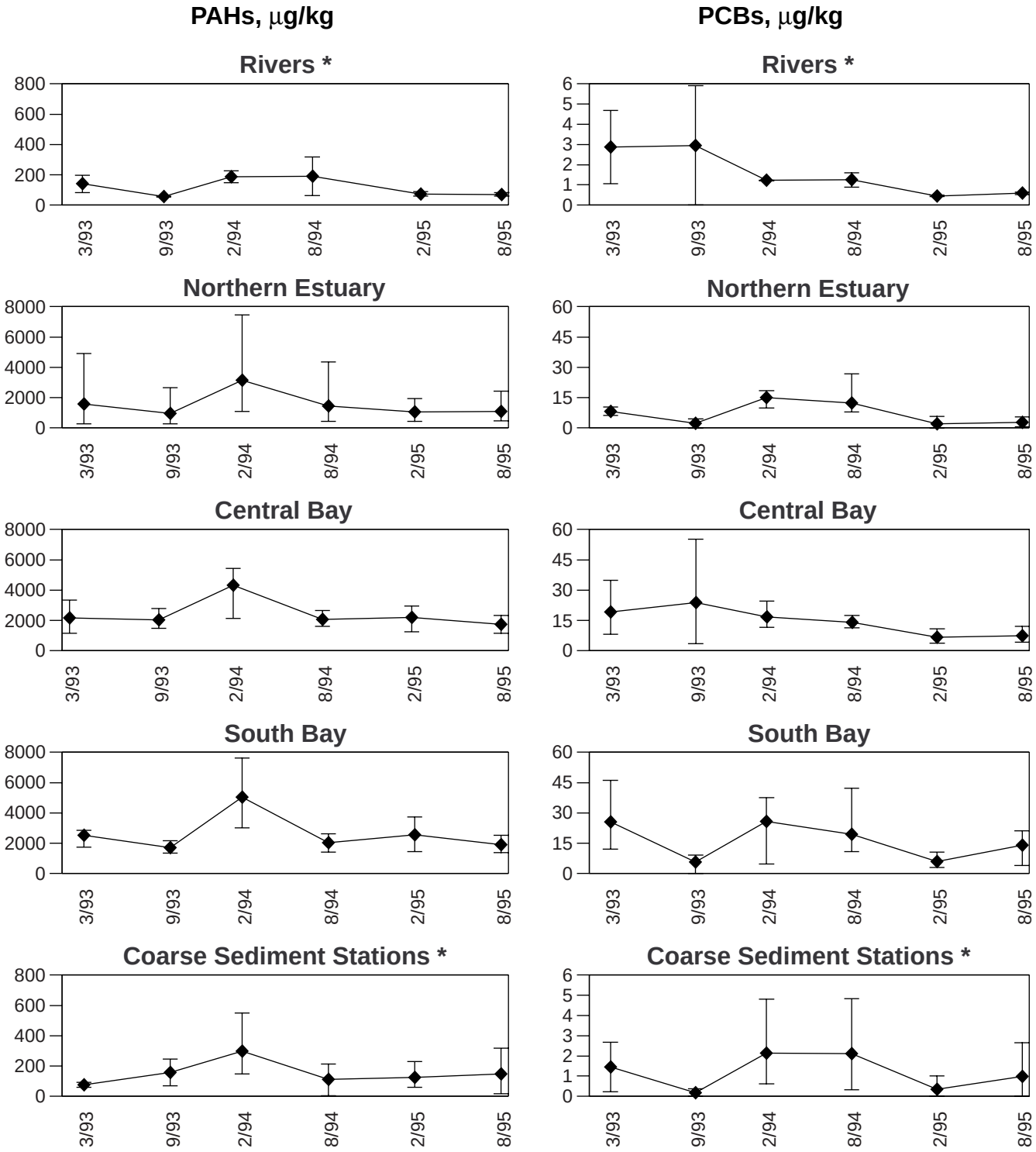


Figure 32–33. Plots of average PAH and PCB concentrations (parts per billion, ppb) in sediments in each Estuary reach in 1993-1995. The vertical bars represent ranges of values. Sample sizes are as follows: South Bay, 1993 n=4, 1994 n=6, 1995 n=7; Central Bay, 1993–1995 n=4, Northern Estuary, 1993 n=4, 1994 n=5, 1995 n=6; coarse sediment stations,1993 n=2, 1994–1995 n=3; Rivers 1993-1995 n=2. * indicates different scale

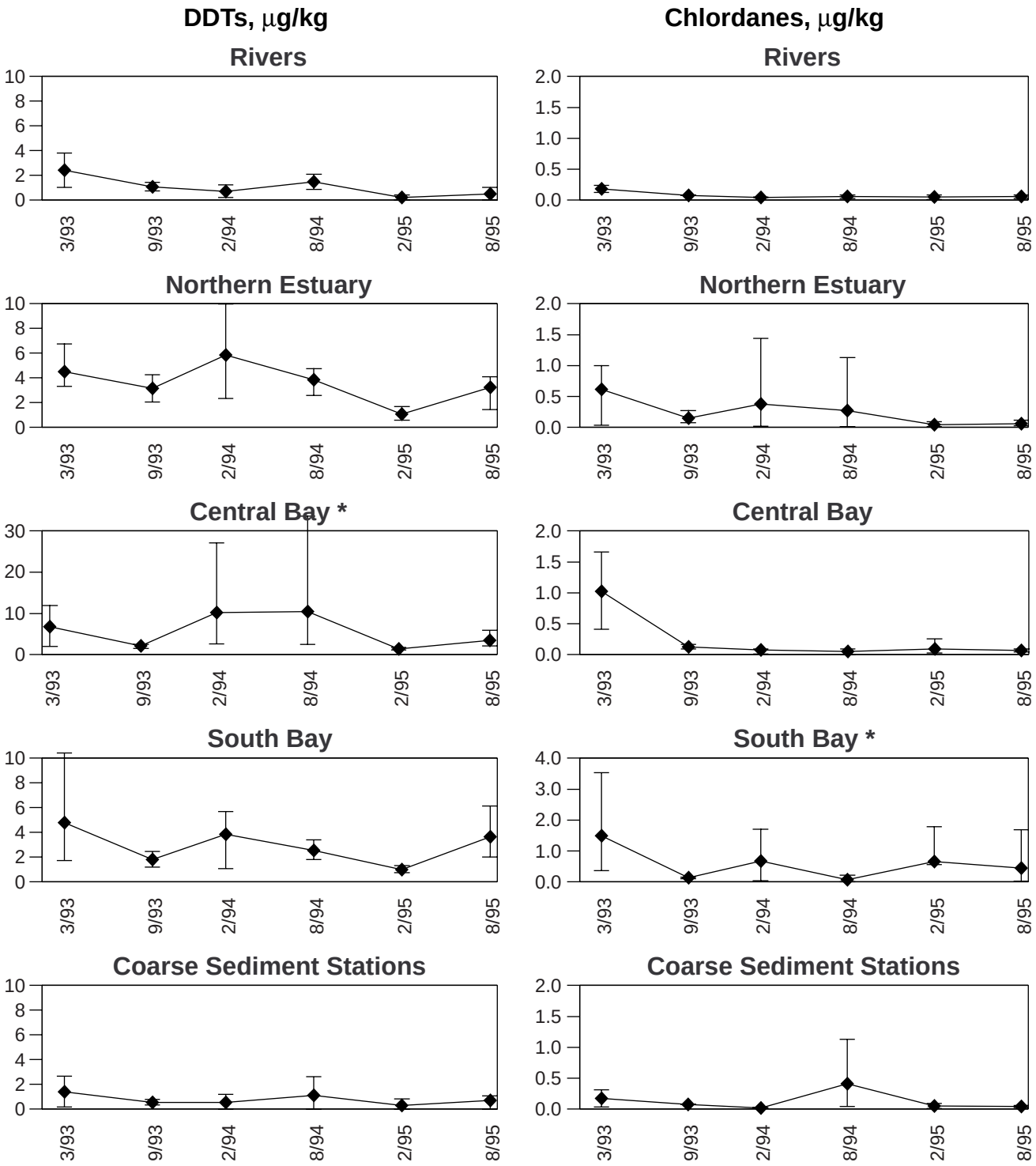


Figure 34–35. Plots of average DDT and chlordane concentrations (parts per billion, ppb) in sediments in each Estuary reach in 1993-1995. The vertical bars represent ranges of values. Sample sizes are as follows: South Bay, 1993 n=4, 1994 n=6, 1995 n=7; Central Bay, 1993–1995 n=4, Northern Estuary, 1993 n=4, 1994 n=5, 1995 n=6; coarse sediment stations,1993 n=2, 1994–1995 n=3; Rivers 1993-1995 n=2. * indicates different scale

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 difference between the contaminant-specific kinetics of uptake and depuration associated with 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). Bioaccumulation of contaminants, however, does not necessarily imply that toxic effects exist. The combined measurements of trace contaminants in Estuary water, sediment, and tissue allow for investigation of quantitative relationships between contaminants in the San Francisco Estuary and contaminant uptake by organisms living in the Estuary.

Bivalves were collected from sites thought to be uncontaminated and transplanted to 15 stations in the Estuary during the wet season (February through May) and the dry season (June through 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. Composites 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 condition of animals at control sites at Lake Isabella (*Corbicula fluminea*), Bodega Head (*Mytilus californianus*), Tomales Bay, and Dabob Bay, Washington (*Crassostrea gigas*) was also determined at the end of each deployment period in order to sort out Estuary effects from natural factors affecting bivalve condition.

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.

Guidelines: Maximum Tissue Residue Levels (MTRLs)

In the following figures, tissue concentrations of various trace contaminants are compared to Maximum Tissue Residue Levels (MTRLs), as used to evaluate data from the California State Mussel Watch Program (Rasmussen, 1994). 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 not used as compliance or enforcement criteria. Since no regulatory tissue standards for trace metal and organic contaminants exist in the United States, comparisons to these guidelines serve only as a relative yard stick.

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.

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 the degree of accumulation or depuration (loss of constituents from bivalve tissue) during the 90–100 day deployment period. 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. An AF of 0.5 indicates that the bivalve sample lost 50% of the contaminant concentration during the deployment period, while an AF above 1 indicates accumulation.

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 capable of bioaccumulation at most sites.

Overall, the goal of obtaining enough tissue for contaminant and condition determination was achieved in 1995, with complete retrieval of all deployed bags at the 15 sites after the wet-season deployment. During the dry season, one of the moorings with bivalves was lost at the San Pablo Bay site (BD20).

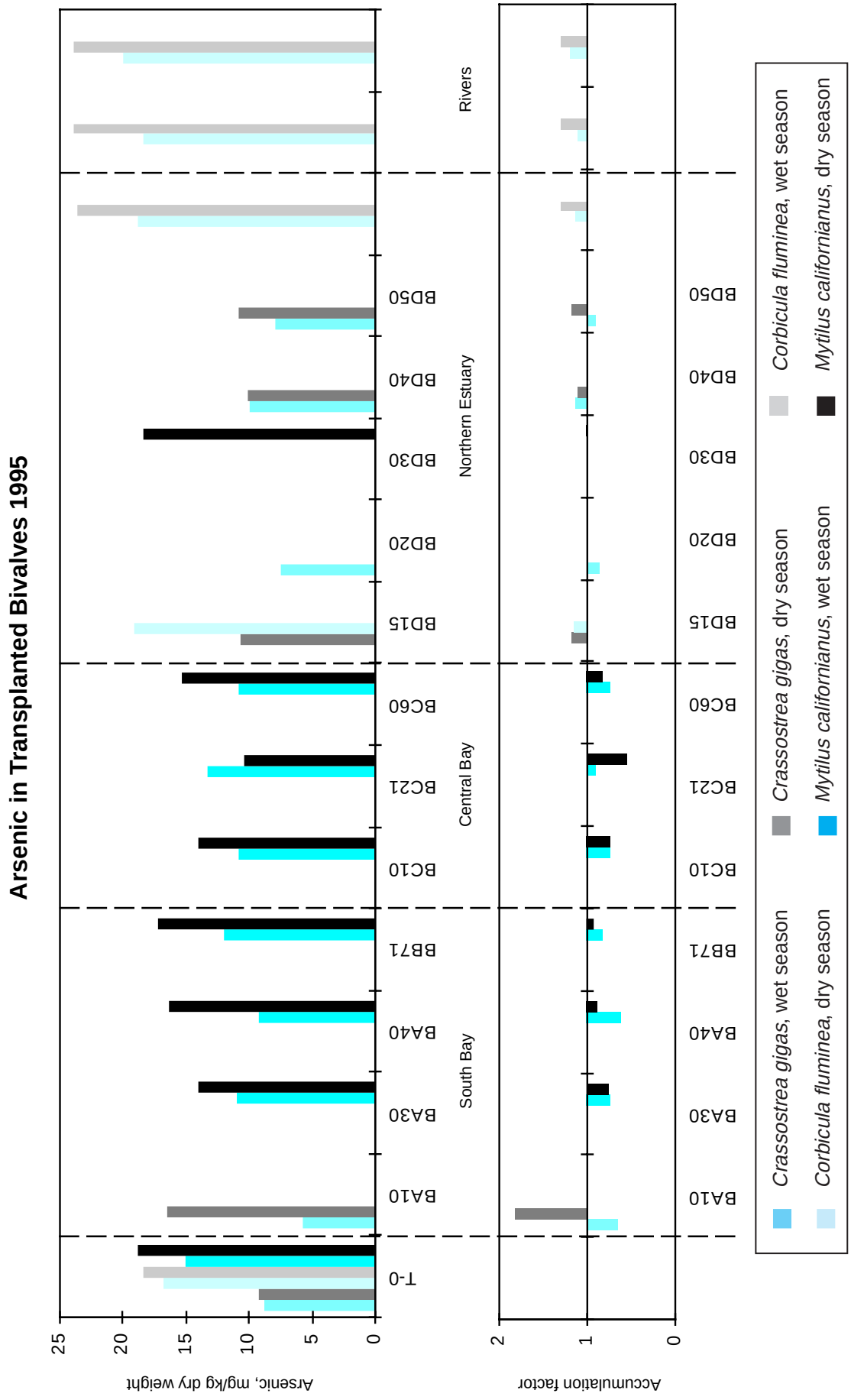


Figure 1. Arsenic concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of arsenic measured on a subsample of each species 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 0.55, indicating depuration, to 1.80, and averaged highest in the Rivers. Tissue concentrations throughout the Estuary were generally higher during the dry season than the wet season. Clams consistently accumulated higher arsenic concentrations than mussels or oysters. All stations, including the reference site (T-0), for which MTRLs are applicable, were higher than the guideline of 1.4 mg/kg. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

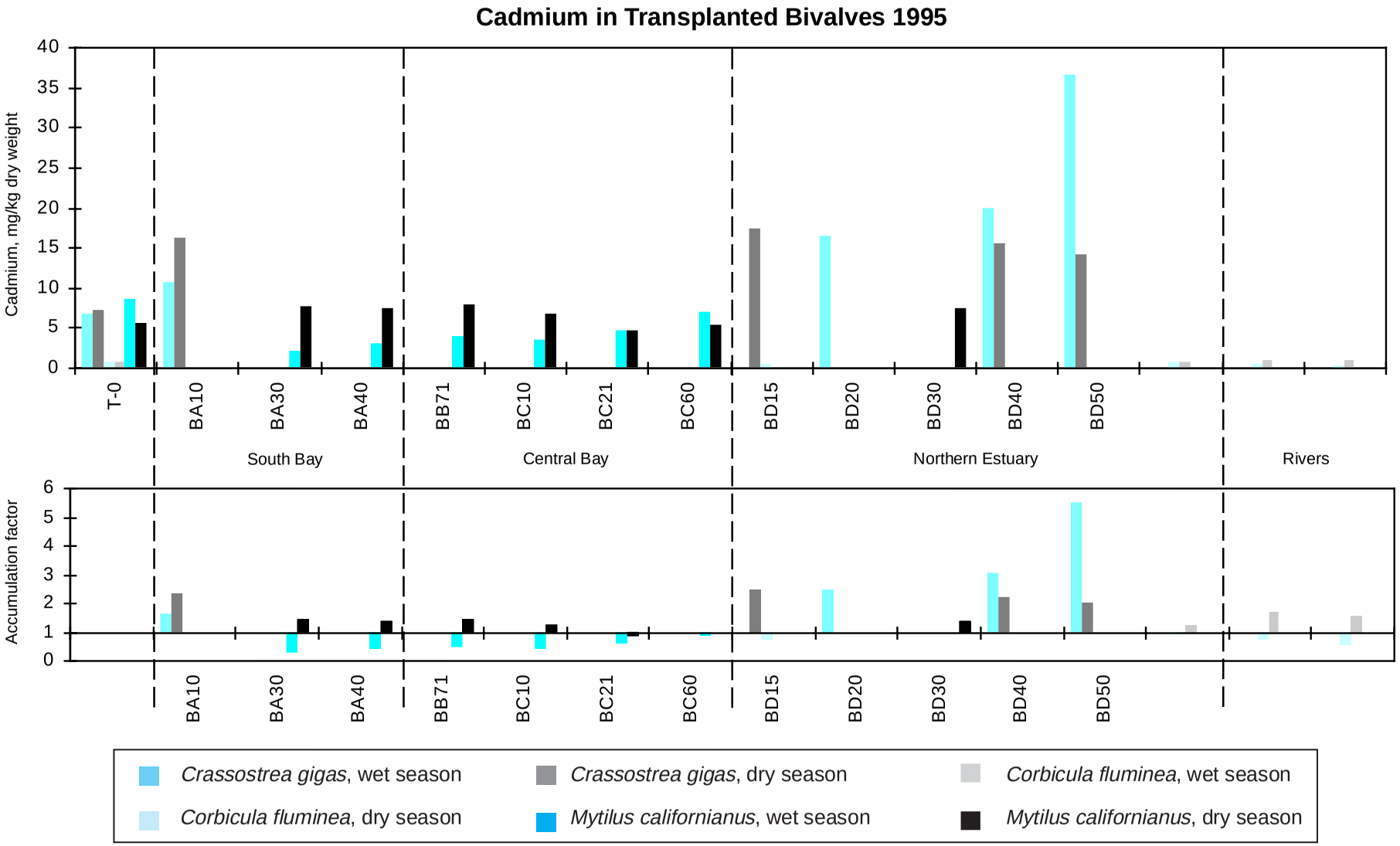


Figure 2. Cadmium concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of cadmium measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Accumulation factors were > 2 at the Northern Estuary stations where *C. gigas* were deployed during the wet season and at the *C. gigas* station in the South Bay during the dry season. Accumulation factors ranged from 0.25, indicating depuration, to 5.48. During the wet season, both *Mytilus* and *Corbicula* depurate cadmium and during the dry season they accumulate cadmium. Oysters accumulated higher concentrations and had higher accumulation factors than mussels and clams. The highest concentration in oysters occurred at Napa River (BD50). All freshwater stations had tissue concentrations much lower than the applicable tissue residue level of 4.48 mg/kg. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

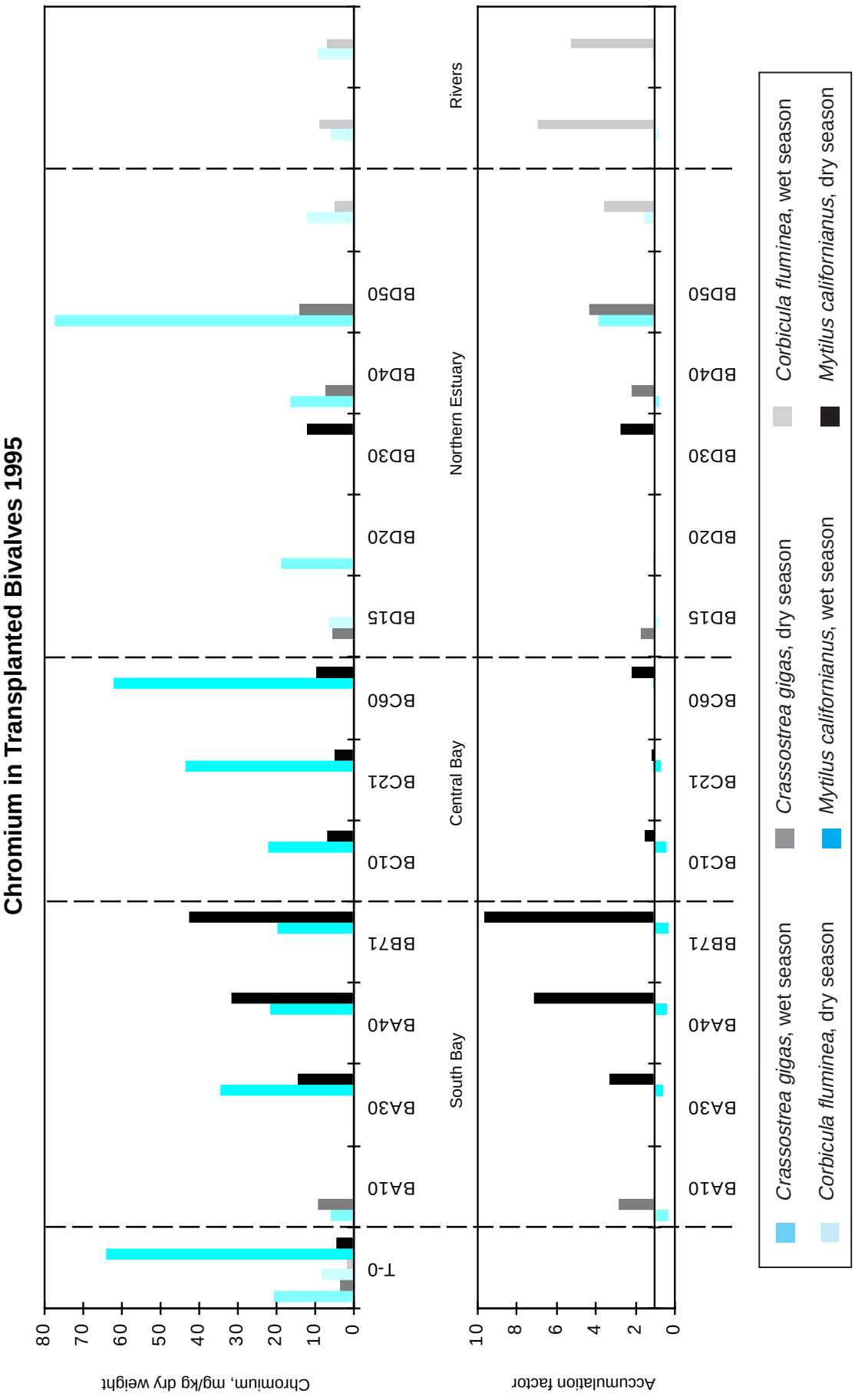


Figure 3. Chromium concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of chromium measured on a subsample of each species taken from the reference locations at the time of deploymentin the Estuary. Control mussels in the wet season had unusually high concentrations. There are no MTRL guidelines for this compound. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

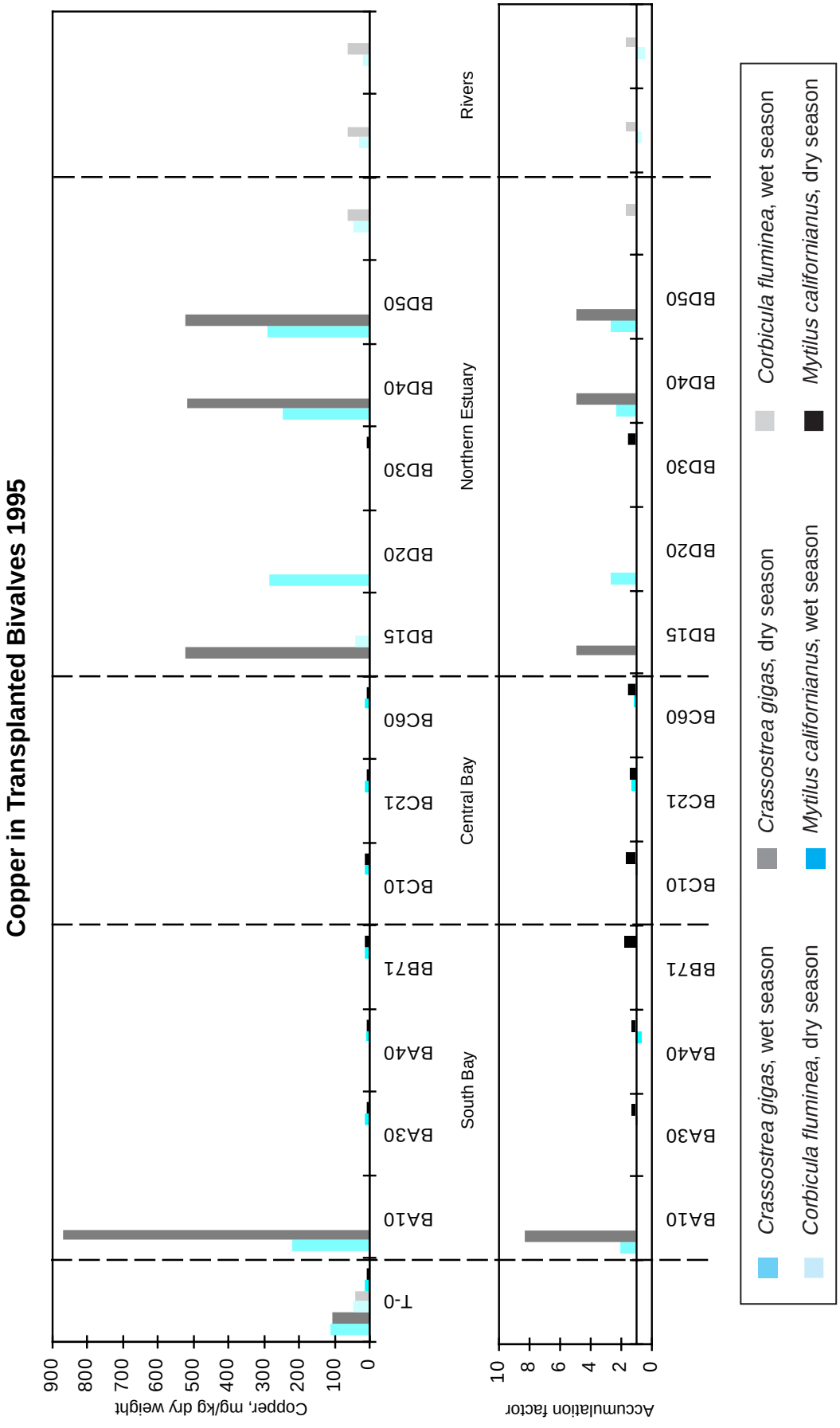


Figure 4. Copper concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of copper measured on a subsample of each species 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 the dry season. Accumulation factors ranged from 0.38, indicating depuration, to 8.21. Oysters had substantially higher accumulation factors and concentrations than clams and mussels. Concentrations in oysters were consistently high in the dry season. There are no MTRL guidelines for this compound. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

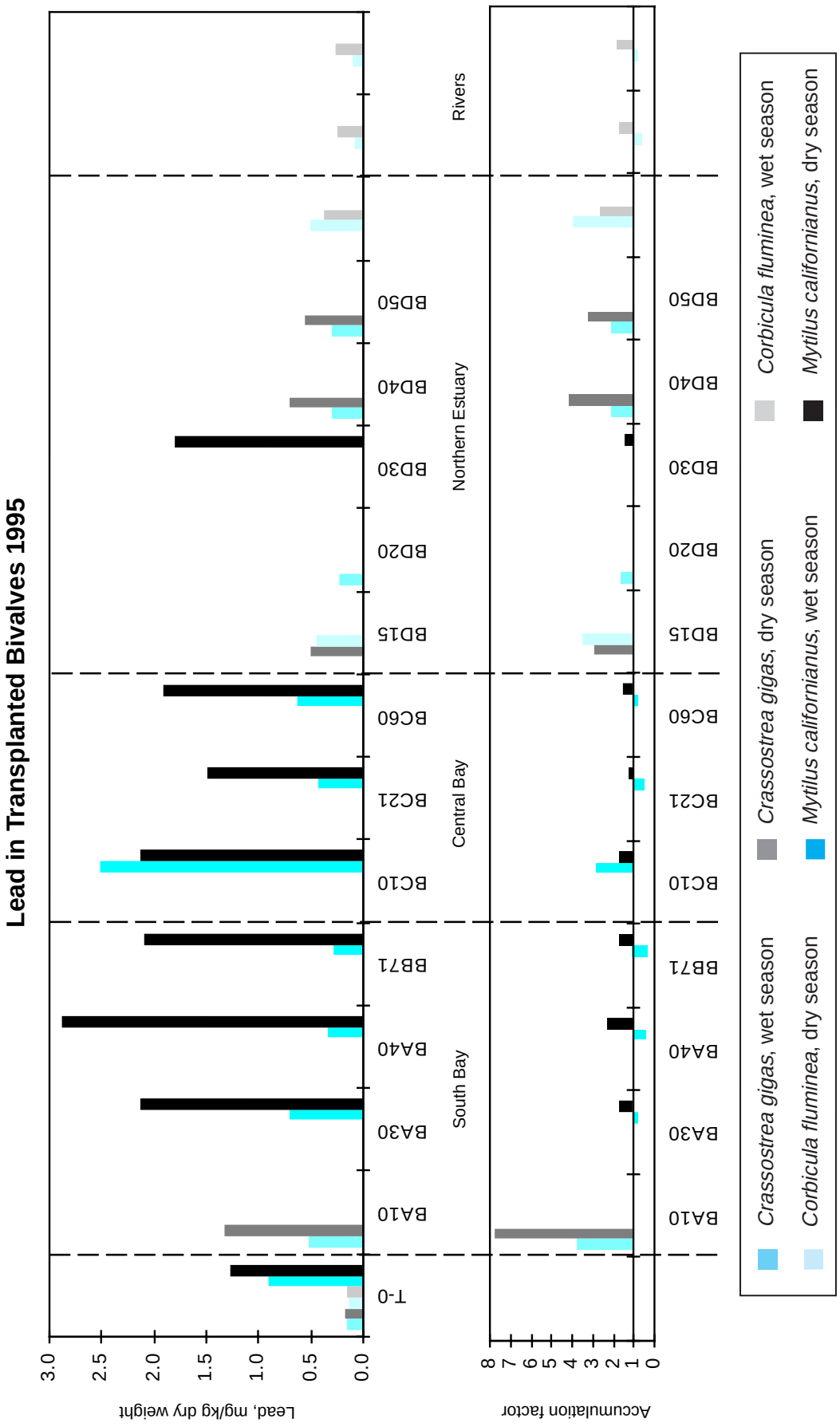


Figure 5. Lead concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of lead measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Accumulation factors were > 2 at all stations where *C. gigas* were deployed during the dry season. Accumulation factors ranged from 0.30, indicating depuration, to 7.76. Mussels exhibited higher concentrations than oysters and clams, especially in the dry season. Oysters, however, generally had the highest accumulation factors. There are no MTRL guidelines for this compound. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

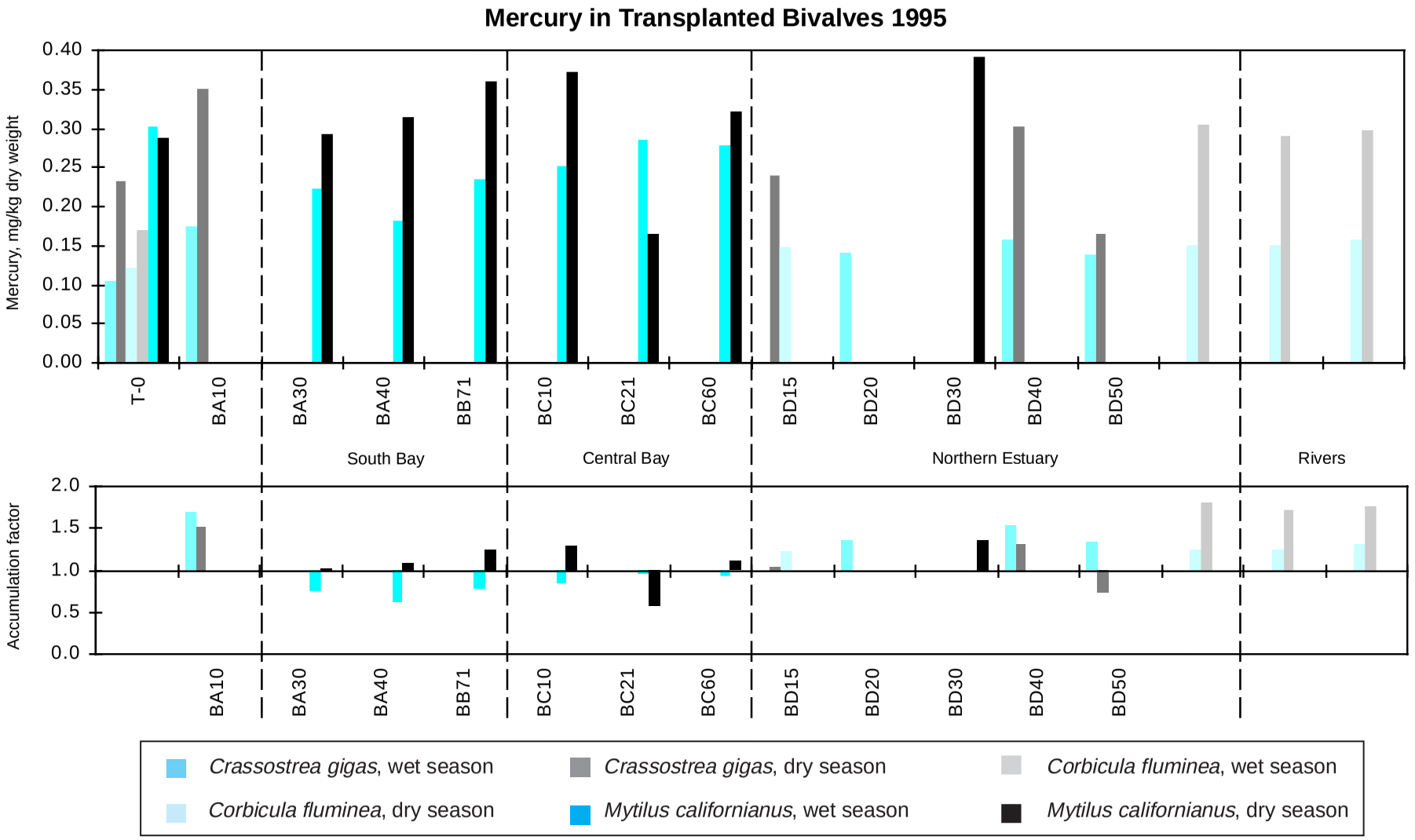


Figure 6. Mercury concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of mercury measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Accumulation factors at all stations were below 2 with the highest values found in *C. fluminea* at the River stations and at Grizzly Bay (BF20) during the dry season. Accumulation factors ranged from 0.57, indicating depuration, to 1.81. Clams had the highest average accumulation factors, followed by oysters and mussels. Concentrations in the three species were similar. Dry season concentrations were higher than wet season concentrations at most stations. All stations had tissue concentrations much lower than the Maximum Tissue Residue Level of 7 ppm dry weight during both seasons. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

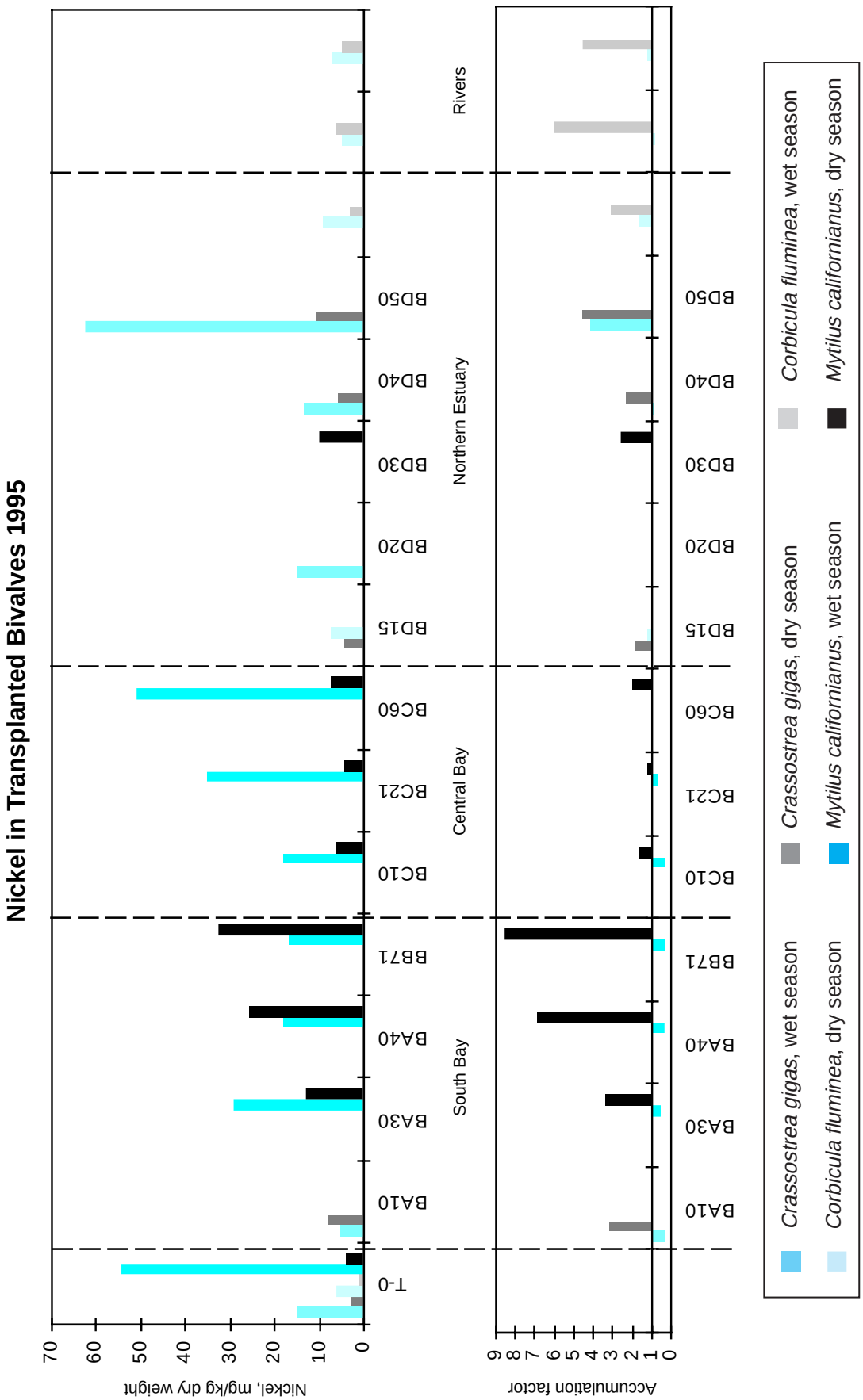


Figure 7. Nickel concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of nickel measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Accumulation factors were > 2 during the dry season at many stations in the Northern Estuary and in the South Bay. The Napa River station (BD50) showed accumulation factors > 2 during both seasons. Accumulation factors ranged from 0.30, indicating depuration, to 854. Although the highest concentration occurred in oysters at the Napa River in the wet season, mussels had the highest average concentrations among the three species. Control mussels in the wet season had unusually high concentrations. All stations, including the reference stations, showed tissue concentrations much lower than the Maximum Tissue Residue Level (MTRL) of 1,540 ppm dry weight in saltwater and 196 ppm in freshwater during both seasons. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

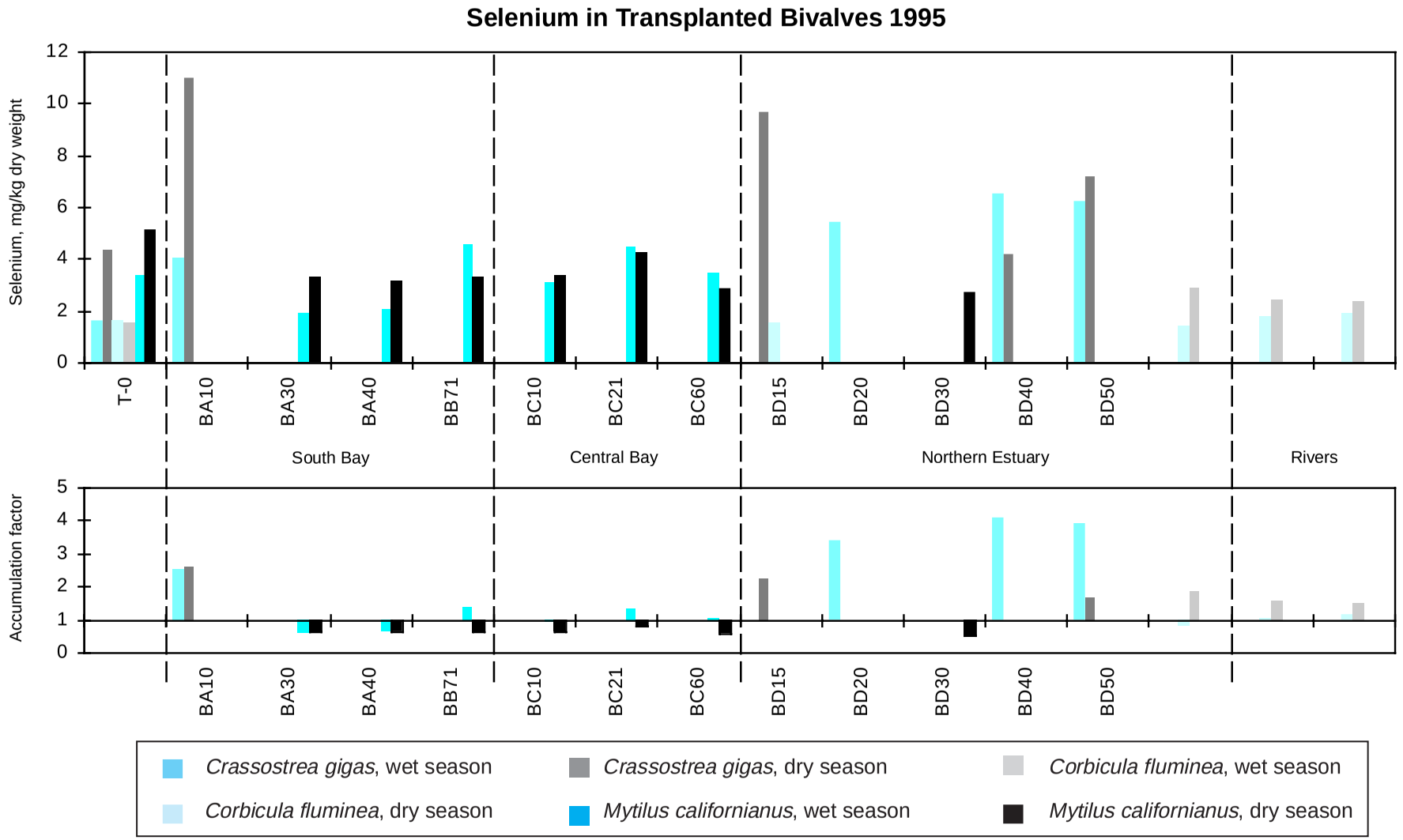


Figure 8. Selenium concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of selenium measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Accumulation factors were > 2 at all stations where *C. gigas* were deployed during the wet season and at Coyote Creek (BA10) and Petaluma River (BD15), both *C. gigas* stations, during the dry season. Accumulation factors ranged from 0.53, indicating depuration, to 4.11. Oysters had positive accumulation factors and the highest concentrations among the three species. Mussels had intermediate concentrations but on average showed depuration in the Estuary. Clams had low concentrations and slightly positive accumulation factors. There are no MTRL guidelines for selenium. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

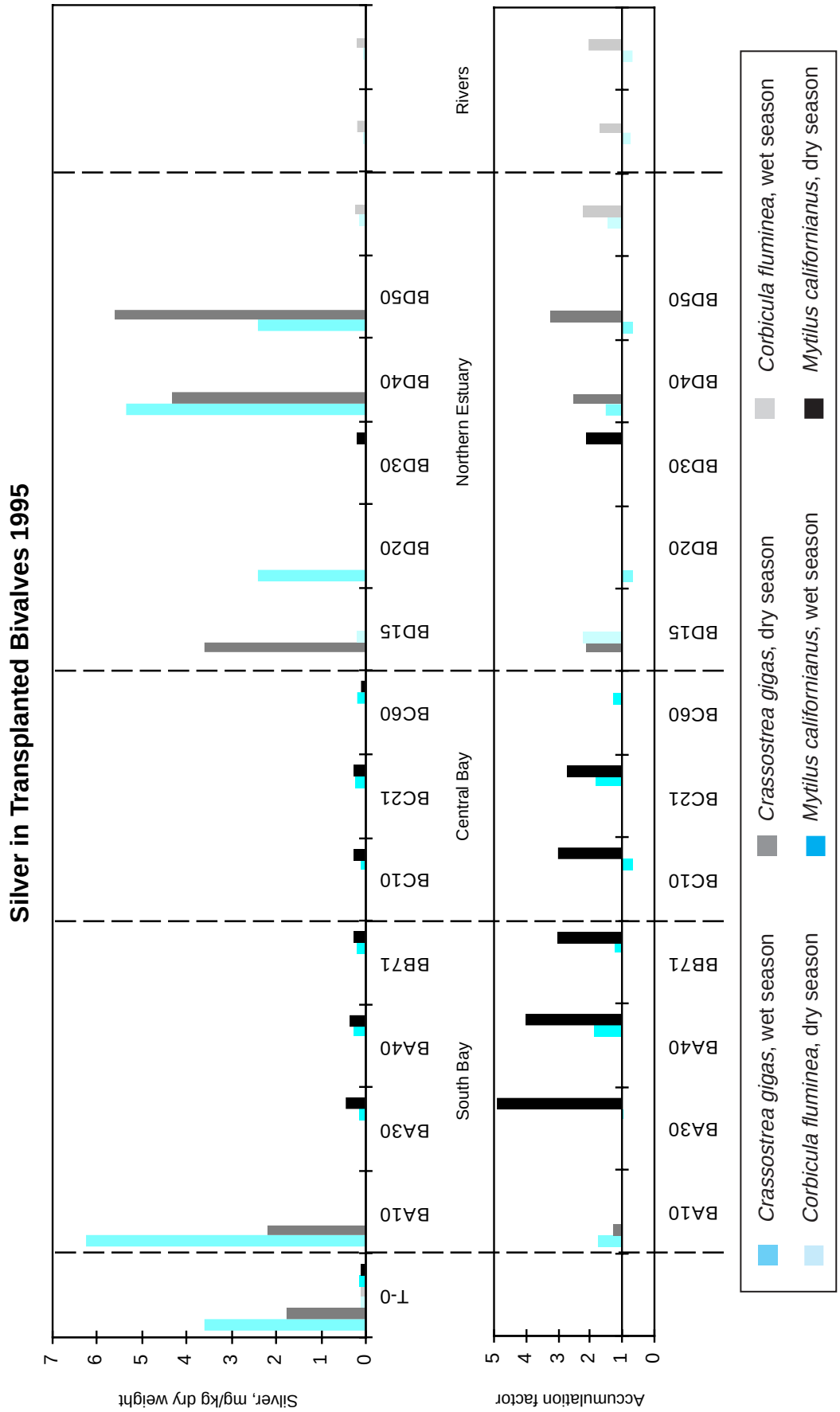


Figure 9. Silver concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of silver measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Accumulation factors were > 2 during the dry season at all stations with the exception of one station for each deployed species: *M. californianus* at Red Rock (BC60), *C. gigas* at Coyote Creek (BA10), and *C. fluminea* at Grizzly Bay (BF20). Accumulation factors were below 2 during the wet season except for the Petaluma River station (BD15). Accumulation factors ranged from 0.66, indicating depuration, to 4.89. Silver concentrations inoysters were considerably higher than in mussels or clams, but not much greater than the T-0 controls. Mussels had the highest average accumulation factors, but did not accumulate high concentrations relative to oysters. There are no MTRL guidelines for this compound. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

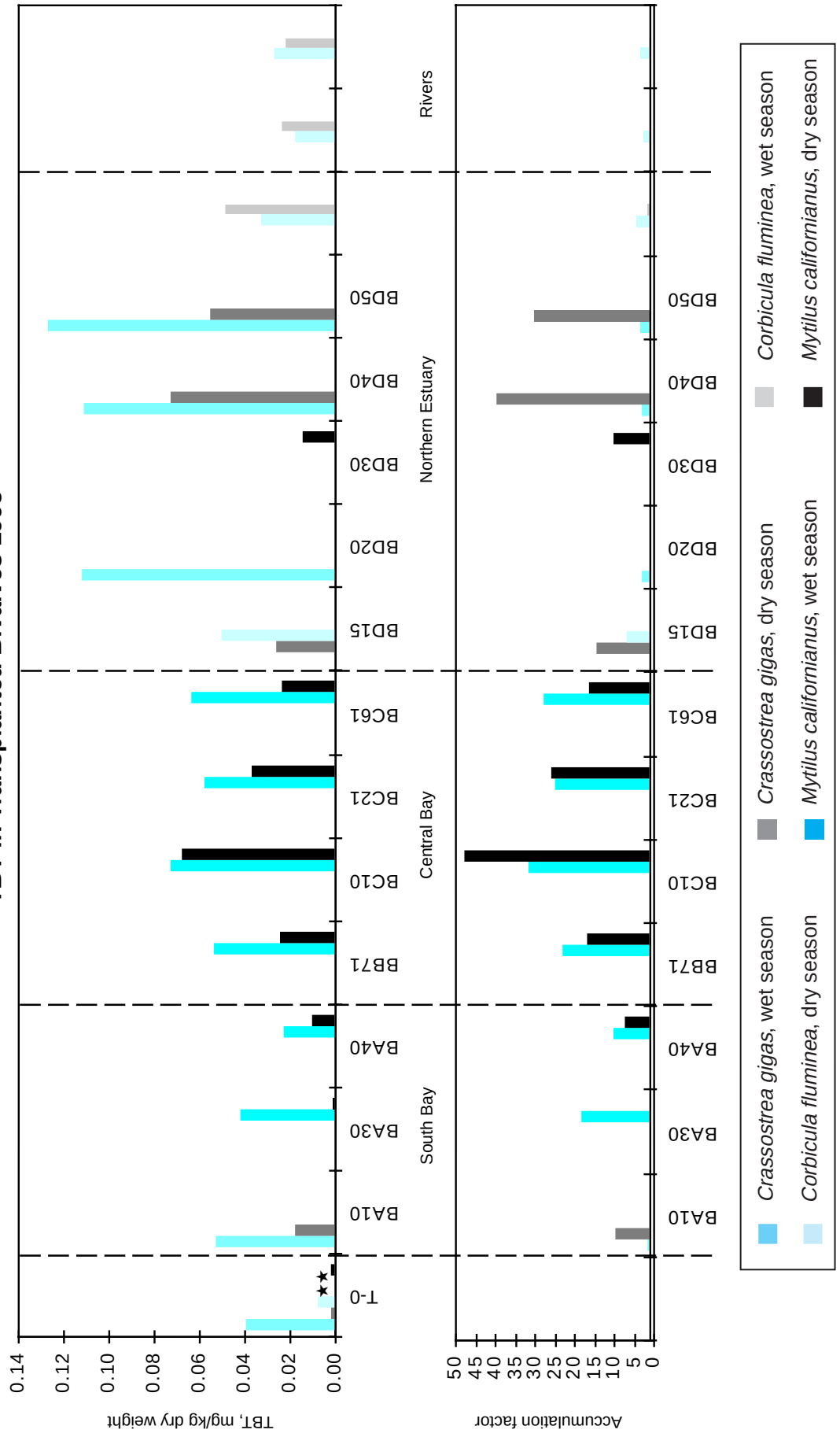


Figure 10. Tributyltin (TBT) concentrations, expressed in terms of total tin (Sn) (ppm dry weight), in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. ★ indicates not detected. Where the T-0 concentration was not detected, the MDL was used to calculated the accumulation factor. 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. There are no MTRL guidelines for this compound. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30). Accumulation factors are calculated for C. fluminea during the dry season and M. californianus during the wet season using the method detection limit (0.031 and 0002 ppb respectively), as the initial T-0 concnetrations were below the detection limit.

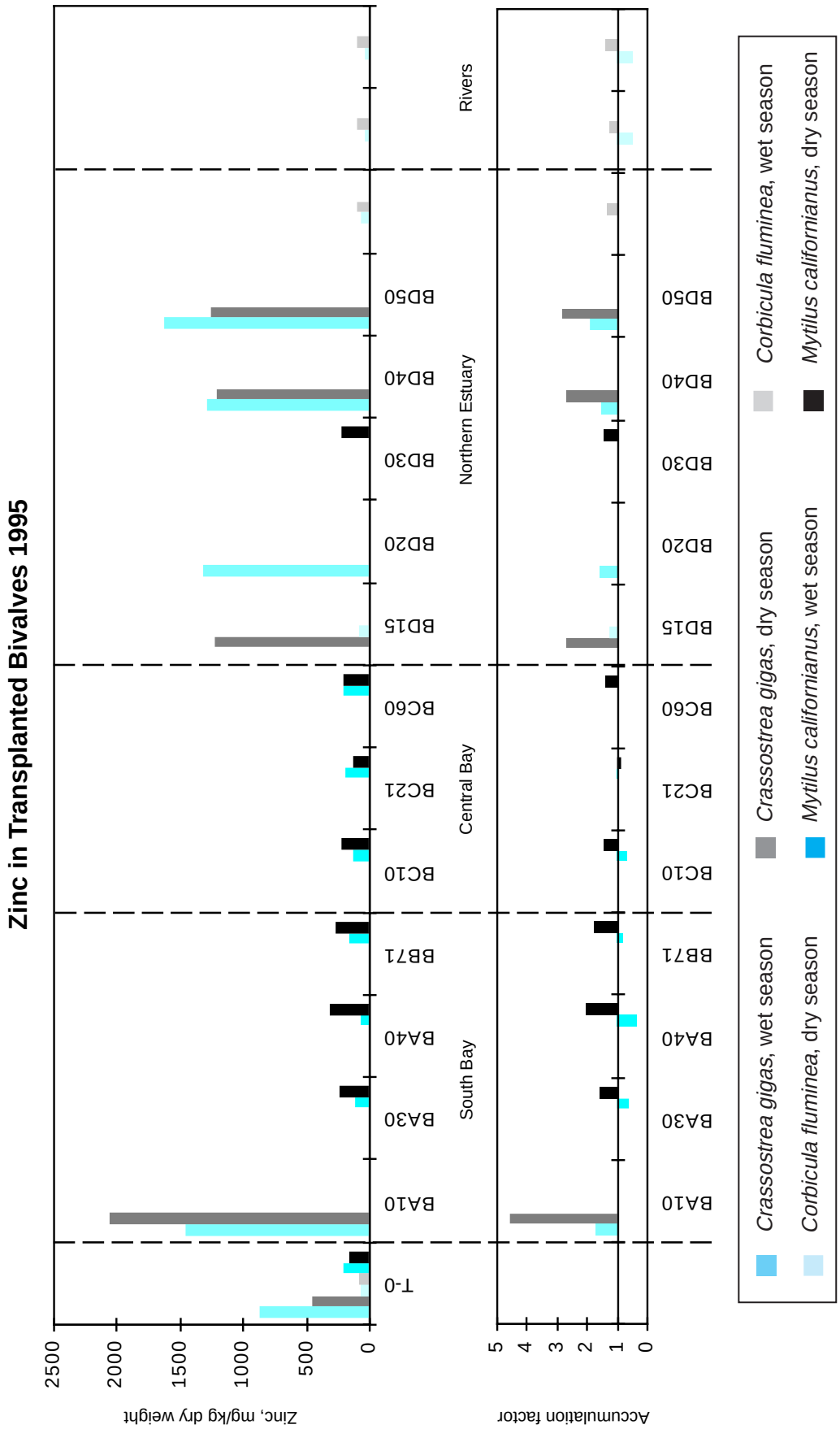


Figure 11. Zinc concentrations in parts per million dry weight (ppm) in three species of transplanted bivalves at 15 RMP stations during the wet (Jananuary–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of zinc measured on a subsample of each species 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 0.35, indicating depuration, to 4.52. Oysters had by far the highest accumulation factors and absolute concentrations among the three species. The highest concentration was observed at Coyote Creek (BA10) in the dry season. There are no MTRL guidelines for this compound. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

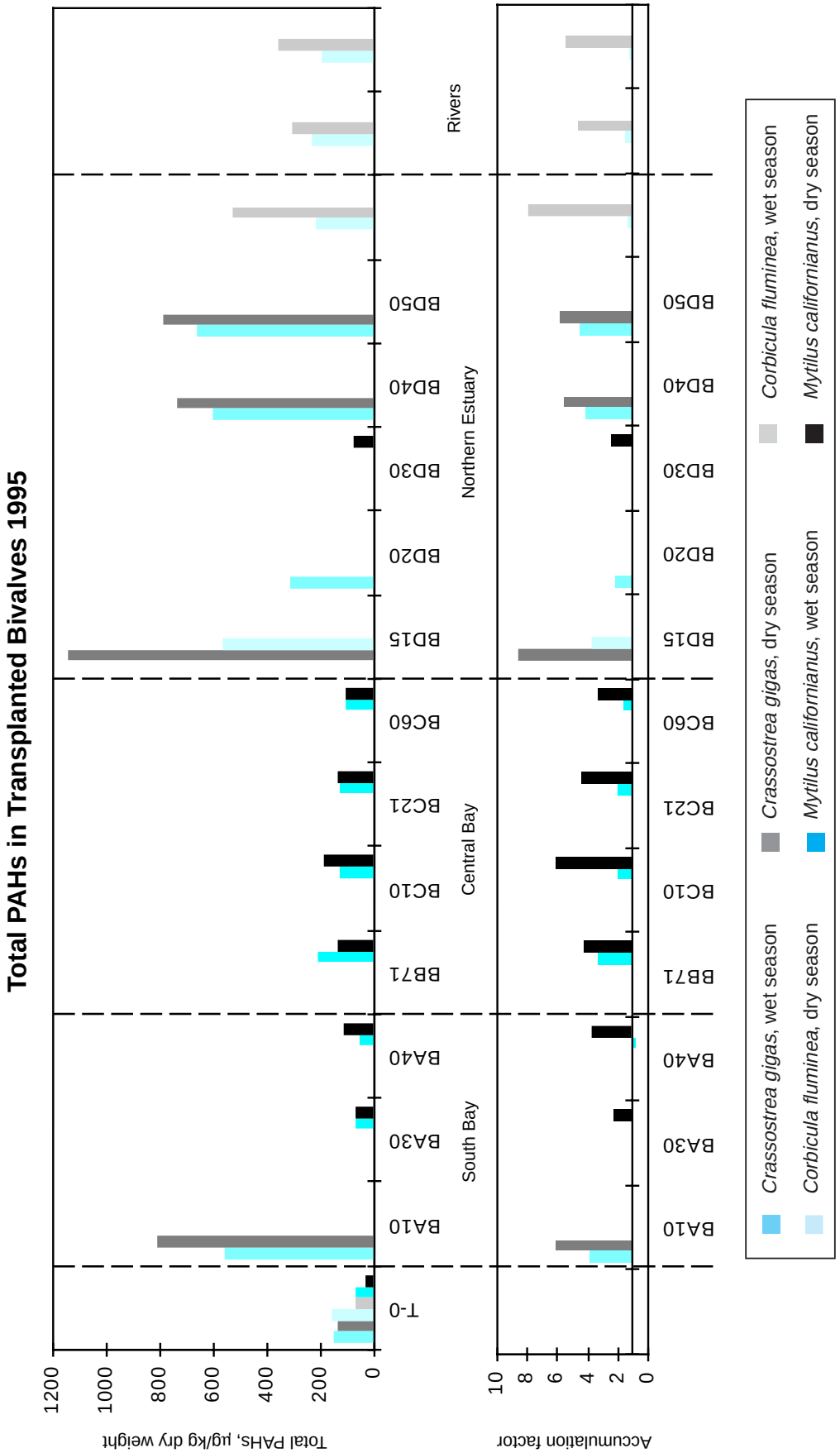


Figure 12. Total PAH concentrations in parts per billion dry weight (ppb) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of total PAHs measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Oysters accumulated the highest median concentrations, clams were intermediate, and mussels were lowest. The highest concentration was measured in oysters at Petaluma River (BD15) in the wet season. Accumulation factors were > 2 during the dry season for all deployed species, and at all stations where *C. gigas* were deployed during the wet season. Accumulation factors ranged from 0.84, indicating depuration, to 8.50. All stations, including the reference stations, had total PAH concentrations that were higher than the MTRL of 6.51 ppb dry weight during both seasons. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

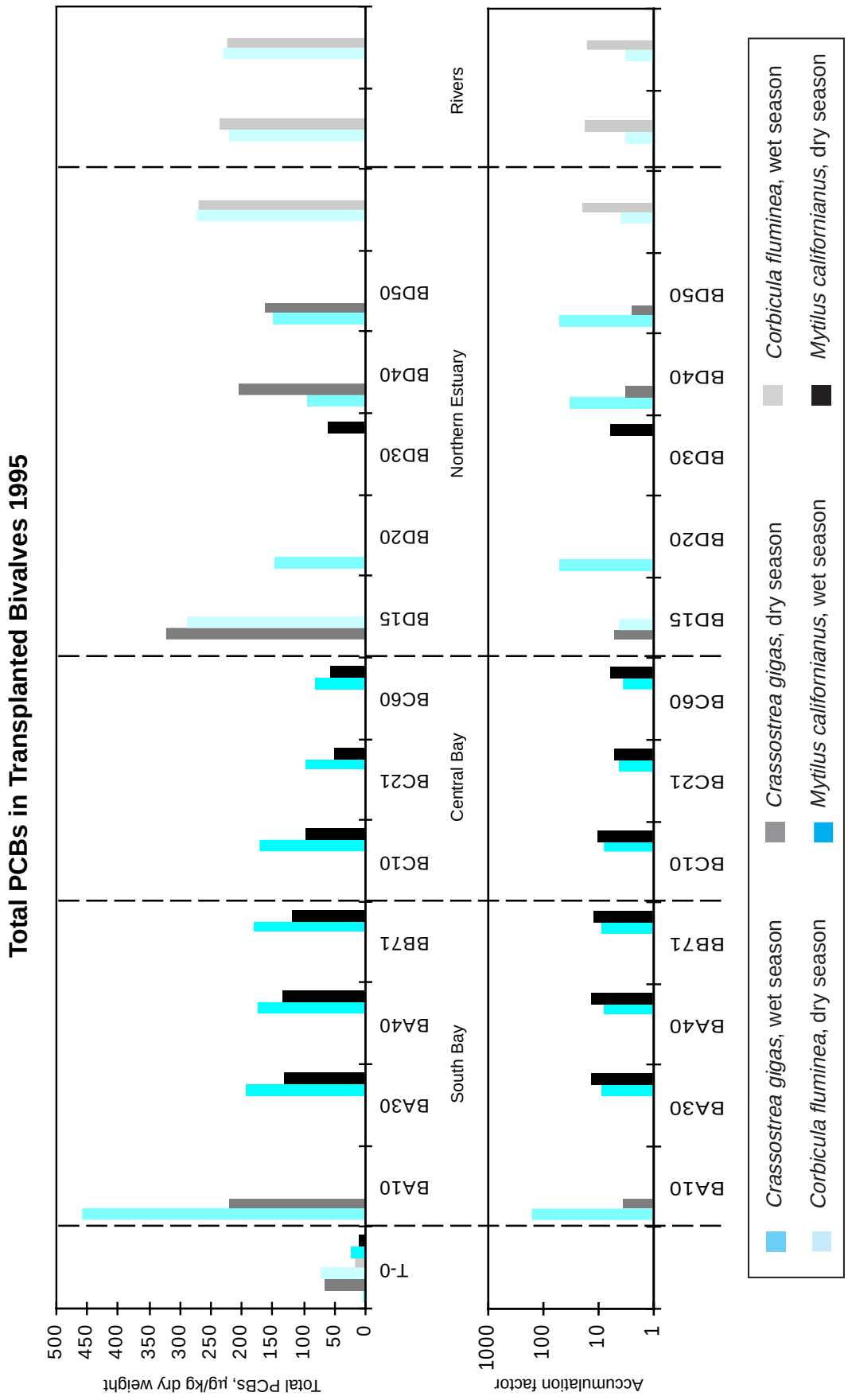


Figure 13. Total PCB concentrations in parts per billion dry weight (ppb) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of total PCBs measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Clams accumulated the highest median total PCB concentrations, oysters were intermediate, and mussels were lowest. The highest concentration was measured in oysters at Coyote Creek (BA10) in the wet season. Accumulation factors were > 2 for all deployed species during both seasons. All stations, except for the following reference stations (*C. gigas* during the wet season, *C. fluminea* and *M. californianus* during the dry season) had total PCB concentrations that were higher than the MTRL of 15.4 ppb dry weight during both seasons. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

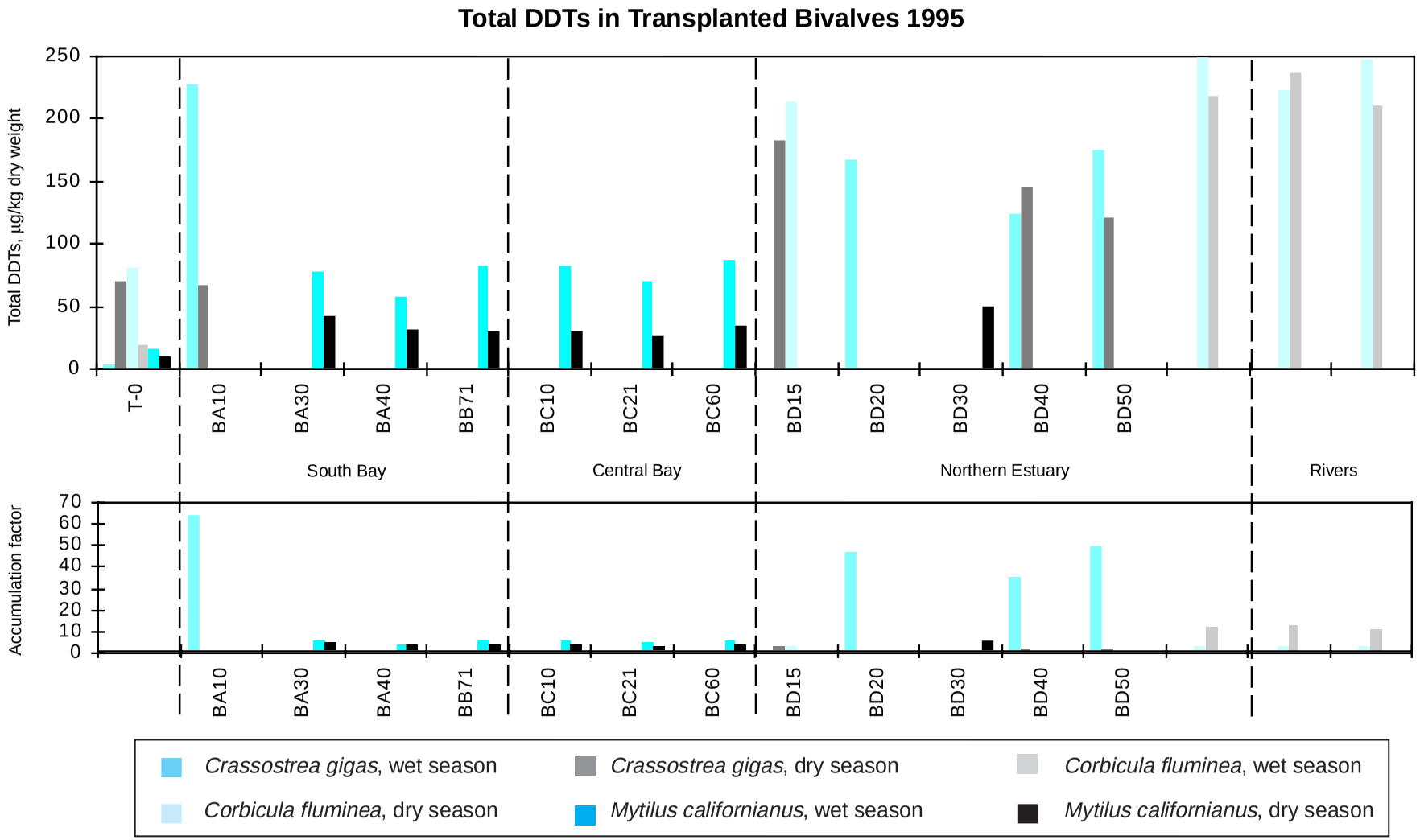


Figure 14. Total DDT concentrations in parts per billion dry weight (ppb) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. T-0 (time zero) indicates the initial concentrations of total DDTs measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Clams accumulated the highest median concentrations, oysters were intermediate, and mussels were lowest. Concentrations were relatively constant at the stations where clams were deployed. Accumulation factors were > 2 at all stations where *C. gigas* were deployed during the wet season. Accumulation factors were highly variable for oysters due to the use of two different control sites with very different levels of contamination, and for clams due to seasonal variation in concentrations at the control site. Three stations had total DDT concentrations that were higher than the 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. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

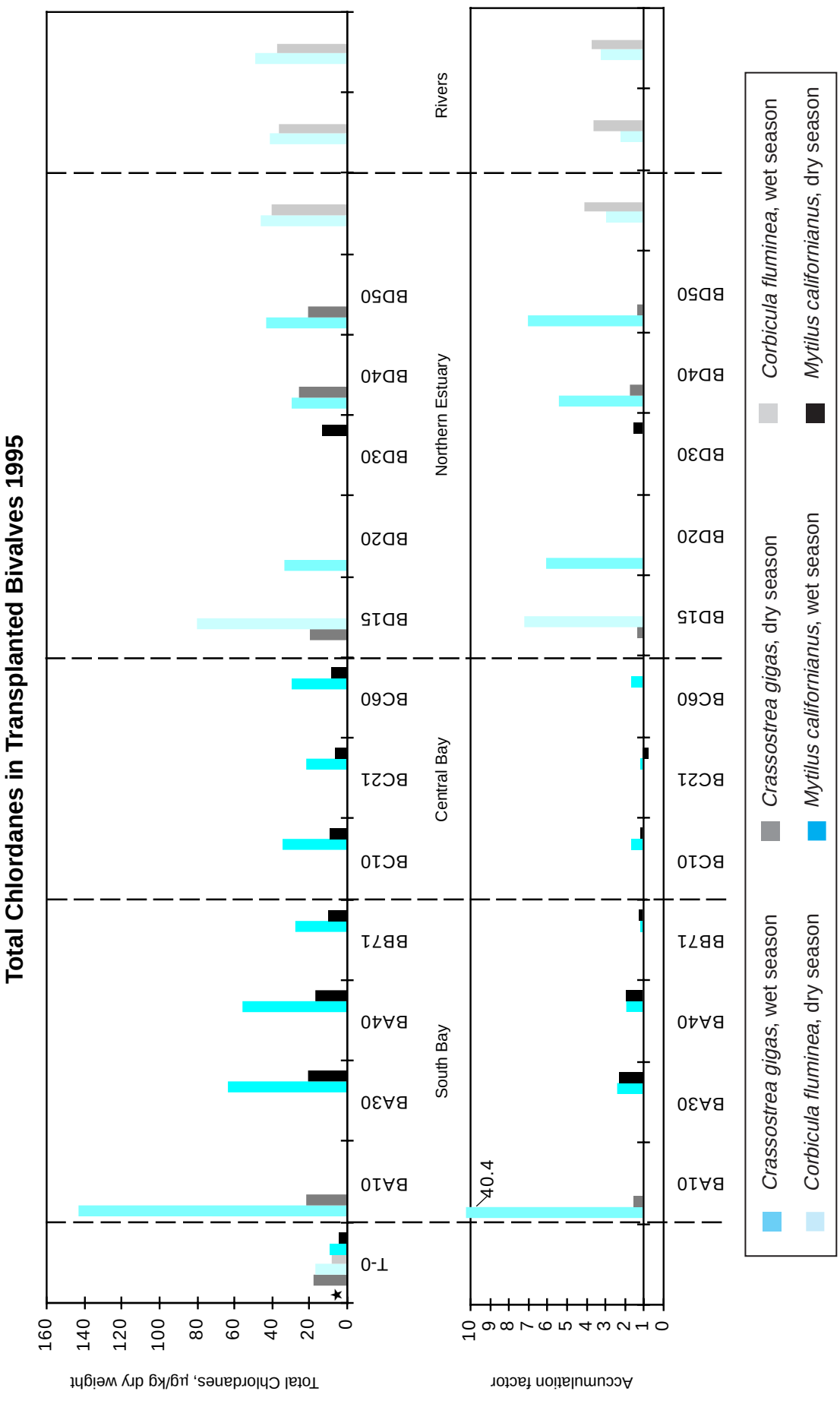


Figure 15. Total chlordane concentrations in parts per billion dry weight (ppb) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. ★ indicates not detected. T-0 (time zero) indicates the initial concentrations of total chlordanes measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Where the T-0 concentration was not detected, the MDL was used to calculate the accumulation factor. Accumulation factors were > 2 during the wet season at all stations where *C. fluminea* and *C. gigas* were deployed and at only one *M. californianus* station (Dumbarton Bridge-BA30). During the dry season, accumulation factors were > 2 at all the stations where *C. fluminea* were deployed and again at one *M. californianus* station (Dumbarton Bridge-BA30). Accumulation factors are calculated for *C. gigas* during the wet season using the method detection limit (1.4 ppb), as initial T-0 concentrations were below the detection limit. Accumulation factors were highly variable for oysters due to the use of two different control sites with very different levels of contamination. The highest concentration by far was measured in oysters at Coyote Creek (BA10) in the wet season. During the wet season, all stations had total chlordane concentrations that exceeded the MTRL of 8.4 ppb dry weight, including two of the T-0 samples (*C. fluminea* and *M. californianus*). Twelve stations had concentrations that were higher than the MTRL during the dry season, including one of the T-0 samples (*C. gigas*). Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point.

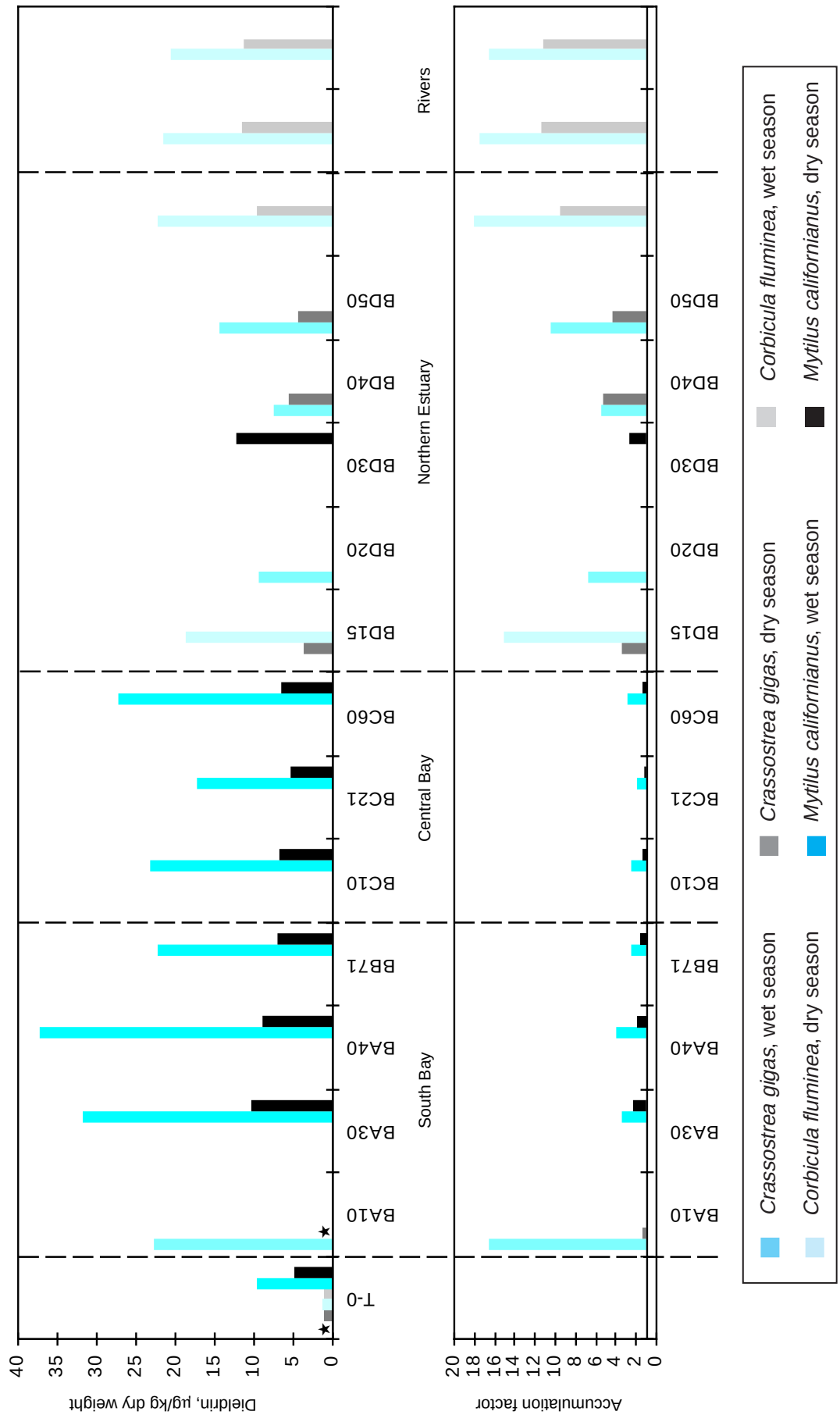


Figure 16. Dieldrin concentrations in parts per billion dry weight (ppb) in three species of transplanted bivalves at 15 RMP stations during the wet (January–May) and dry (June–September) sampling periods. ★ indicates not detected. T-0 (time zero) indicates the initial concentrations of dieldrin measured on a subsample of each species taken from the reference locations at the time of deployment in the Estuary. Where the T-0 concentration was not detected, the MDL was used to calculate the accumulation factor. Accumulation factors were much higher for clams than for mussels and oysters, but the control site for mussels was relatively contaminated. Accumulation factors are recalculated for *C. gigas* during the wet season using the method detection limit (1.4 ppb), as initial T-0 concentrations were below the detection limit. In all species wet season concentrations were consistently higher than the dry season concentrations. With the exception of the reference stations for *C. gigas* and *C. fluminea*, all stations had concentrations that were higher than the MTRL of 4.9 ppb dry weight during the wet season. Eleven stations had concentrations that were higher than the MTRL for dieldrin during the dry season. Due to a lost mooring, *C. gigas* was not analyzed in the wet season at San Pablo Bay (BD20). Due to 0% survival, *M. californianus* was not analyzed in the dry season at Pinole Point (BD30).

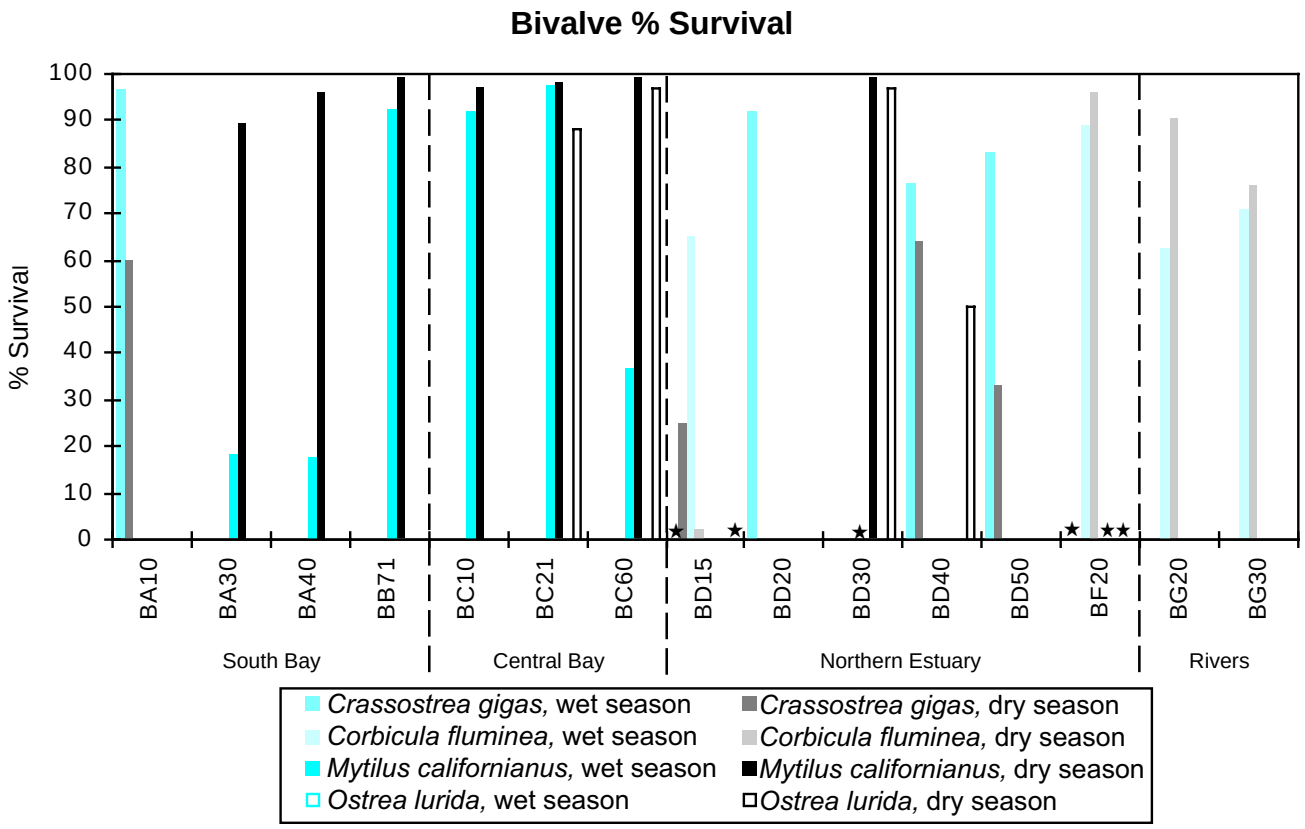


Figure 17. Percent survival in four species of transplanted bivalves following exposure to Estuary water during the wet (January–May) and dry season (June–September) deployment periods. ★ indicates 0% survival. There were reduced rates of survival during wet season versus dry season deployments for *M. californianus* at Dumbarton Bridge (BA30), Redwood Creek (BA40), Red Rock (BC60) and Pinole Point (BD30). *C. fluminea* had reduced survival at the Sacramento River (BG20) during the wet-season. 1995 was an unusually wet year, which may explain the significant differences in survival between the wet and dry season deployments of *M. californianus*, a species less tolerant of low salinities. The survival of *C. gigas*,which appears to be tolerant of lower salinities than *M. californianus*, in the South Bay during the wet season is perhaps further evidence pointing to low salinities as an explanation for the low wet-season survival of *M. californianus*.

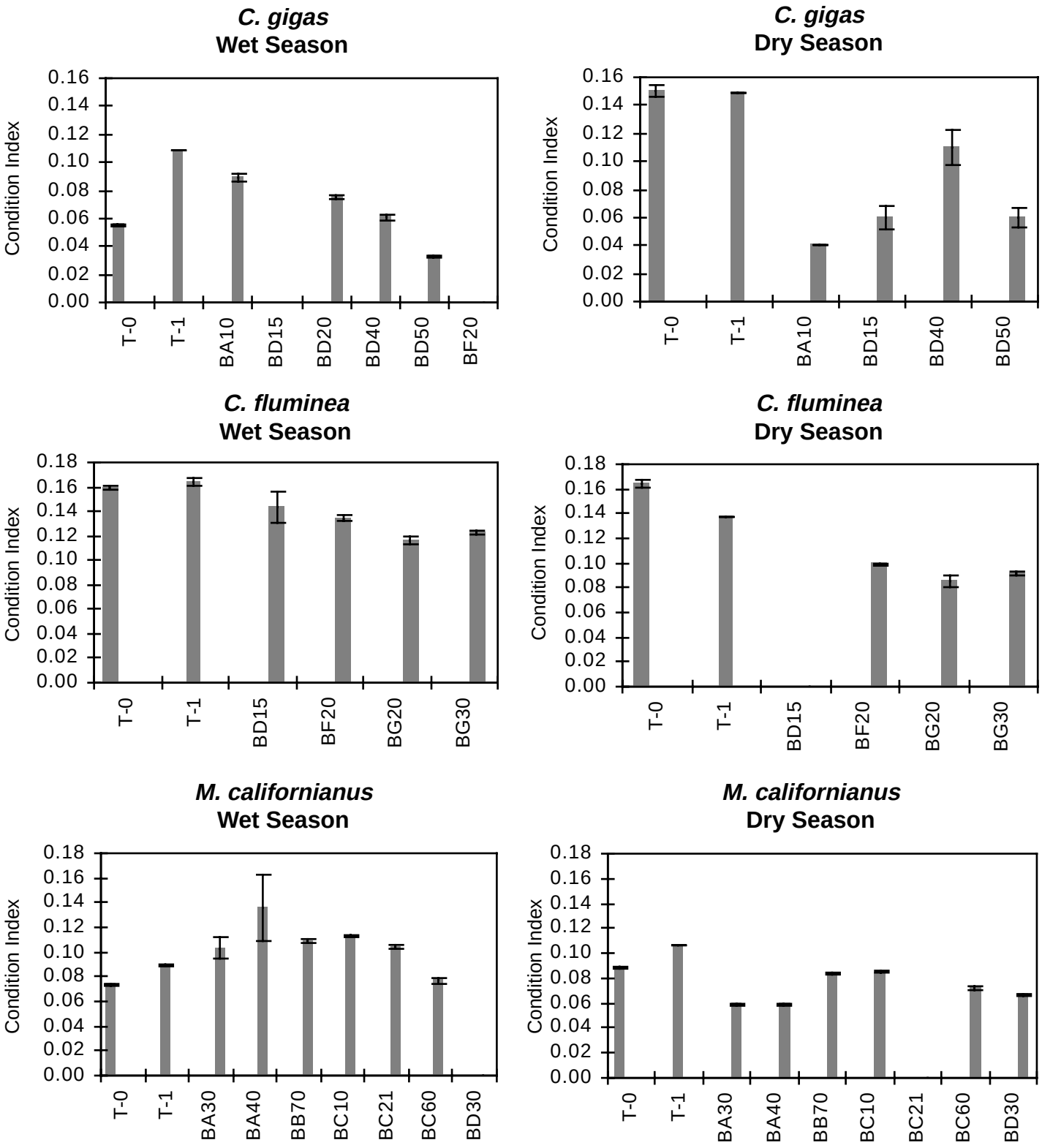


Figure 18. Condition indices of three species of bivalves at reference locations prior to deployment (T0), at the end of the deployment period (T1), and at their deployment locations after exposure to Estuary water during the wet (January–May) and dry season (June–September) deployment periods. Stations with incomplete data show no histogram bars or no error bars. The reference sites were Bodega Head (*M. californianus)*, Tomales Bay (*C. gigas*), and Lake Isabella (*C. fluminea*). Error bars represent 95% confidence interval.

A Comparison of Selenium and Mercury Concentrations in Transplanted and Resident Bivalves from North San Francisco Bay

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Monitoring With Bioindicator Species

Many of the methodologies for effective use of organisms to monitor and study contamination in estuaries are well established (Phillips, 1980; Phillips and Rainbow, 1993). Understanding the processes that determine bioaccumulation and determining concentrations of contaminants in biological tissues are best employed in conjunction with analysis of other environmental media (e.g., water, suspended particulate material, or sediment). Together these provide complementary lines of field evidence indicative of complexities that affect the exposures of organisms to contaminants. While tissue analysis is not universally suitable as a measure of exposure for all contaminants in all organisms or all circumstances, it does have important advantages when properly used:

1. Concentrations in tissues may be more responsive to environmental contamination than concentrations in water and/or sediments in some circumstances, providing a unique perspective on understanding exposures.
2. Measurements of contaminant concentrations in organisms provide a time-averaged assessment. Temporal variability can be a problem in understanding contamination. However, temporal variability is moderated by biological processes in animal tissues compared to other environmental media; thus organisms are described as "integrators" of contamination.
3. Understanding bioaccumulated concentrations can provide a more direct measure of bioavailability than determination of concentrations in water or sediments. One of the important difficulties in understanding the effects of pollutants in nature lies in understanding how biological and geochemical factors influence the dose that an organism experiences. Tissue concentrations of contaminants can be a direct measure of dose, and thus help reduce ambiguities in interpreting environmental exposures.

Results of tissue analyses are most sensitive to environmental contamination when the bioindicator species chosen for study is highly responsive to changes in contaminant exposure. Appropriate sample size (number of individuals; number of replicate analyses) and sample mass are crucial for interpretable results because variability can be large among individual organisms of the same species, especially in contaminated environments. Tissue, life stage, reproductive condition, size, sex, and gut content can be sources of variability and at least need to be considered. Probably most importantly, contaminant concentrations are directly comparable only within the same species, unless proven otherwise. Bioaccumulation of trace element contaminants can differ among even closely related species; although trends in time and space are often similar among species.

Residents Versus Transplanted Organisms

Either resident populations or individuals transplanted from one environment to another can be employed to monitor and assess contaminant exposures, fate, distribution, or bioavailability. The California State Mussel Watch Program, the Regional Monitoring Program (RMP) and numerous specific studies (Smith *et al.*, 1986; Phillips, 1988; Rasmussen,

1994) have employed the transplant approach. In the RMP, bivalves are collected from sites thought to be uncontaminated and transplanted to San Francisco Bay. Tissue concentrations are determined at the beginning of the deployment and after a 90–100 day deployment period. Detailed methodologies for employing mussels (*Mytilus edulis; Mytilus californianus*) in transplant experiments are well developed (Phillips, 1988) and are described in the Background section of this chapter and in Appendix A.

An extensive literature is also available on the use of resident species as bioindicators (Phillips, 1980; Phillips and Rainbow, 1993; see also *The RMP Workshop on Ecological Indicators of Contaminant Effects*, this report). A suitable resident indicator species should be (1) widely distributed and abundant in the ecosystem(s) of interest; (2) feasible to collect in numbers suitable for statistical validity (>15–20 per collection); (3) sufficient in tissue mass that analysis is practical; (4) sufficiently tolerant to contaminants that the species will be present (i.e. survive) in at least moderately contaminated situations; and (5) sufficiently restricted in movement that values are representative of the location or region of interest.

The most important advantage of employing transplanted species is that the same species may be placed at any station whether or not the species is present naturally. A second advantage is that transplanted populations may provide a common baseline from which to evaluate contamination. The deployed organisms should have a common history of exposure to only low levels of contamination. Thus, tissue concentrations in transplanted organisms should reflect only changes in concentration that have occurred during the deployment period.

Some practical disadvantages can hinder the transplant approach. Changes in behavior of the transplanted organisms because of the deployment is always a consideration, although in the history of California Mussel Watch this does not seem to prevent evaluations of trends in space and time (Phillips, 1988; Rasmussen, 1994). Nevertheless it is difficult to determine if behavioral attributes important to bioaccumulation are similar in transplanted and native organisms (i.e., if stress from deployment has affected results; Cain and Luoma, 1985). In estuaries the advantage of deploying a single species to all sites is partly countered by wide ranging and variable salinities. The RMP transplant approach does not solely use mussels in San Francisco Bay because the range of salinities is broad. The RMP employs mussels (*Mytilus californianus*), oysters (*Crassostrea gigas*), and freshwater/brackish water clams (*Corbicula fluminea)*, respectively, in reaches of the Estuary with progressively lower salinities. The use of different species will affect direct comparability of data, at least for some contaminants. Contaminant concentrations in transplanted organisms also represent a kinetic view of contamination. In the RMP they reflect uptake after 90–100 days, which may or may not reflect steady state with concentrations in the environment. Finally, the spatial and temporal intensity of sampling transplanted organisms may be limited by the expense and cumbersome nature of the methods, transplanted individuals may not survive, or some locations may be unsuitable in terms of access, proper habitat, or interference from shipping or vandalism.

The most important concerns about the use of resident species as bioindicators include the availability of animals in critical locations or at critical times and the variability (or effects on interpretation) caused by differences in life cycle, size, or genetic and physiological changes. Resident bioindicator species can be absent from a location because the distribution is patchy or because of natural or anthropogenic stresses. The history of contaminant exposure is not known for resident species unless samples are collected intensively over time. Differences in contaminant history might affect interpretation of recent contamination or add variability to the responses of residents.

The use of resident species also has advantages. The organisms are living in the habitat of interest, and effects of caging or moving the animals is not a consideration in interpretations. Concentrations in tissues should also reflect natural steady state concentrations; or in highly variable environments temporal

variability and the history of changes in concentrations can be assessed directly by frequent sampling. While resident species may indeed be absent or difficult to collect in some circumstances, in other circumstances they may be more practical to collect frequently than would transplants or they may be present in areas otherwise unsuitable for deploying transplanted animals.

Uncertainties in employing resident bioindicators can be reduced by careful determination of the responsiveness of the species as well as the environmental accuracy and precision of responses to contamination (Brown and Luoma, 1995). Brown and Luoma (1995) studied use of the bivalve *Potamocorbula amurensis* as a resident bioindicator of metal exposures in North San Francisco Bay. They studied responses to metal exposures in this species in laboratory studies and in near monthly collections from six sites between January 1991 and March 1992. The most important advantage of employing this opportunistic species was its very broad distribution in the North Bay, where it has been abundant since 1987. *P. amurensis* is highly euryhaline (i.e., it tolerates wide salinity ranges and fluctuations) and available from a wide range of conditions in the North Bay. Breeding populations were found throughout the study period at a site toward the mouth of the Sacramento River (see Figure 1 in Chapter One: Introduction), where salinities ranged from 0.5 ‰ to 12.0 ‰. They were also found throughout most of Suisun and San Pablo Bays and in the South Bay, where salinities ranged from 25.2 ‰ to 31.8 ‰. Populations were found in a variety of types of sediment and intertidally as well as subtidally. Because *P. amurensis* was present throughout a contamination gradient in Suisun Bay, it was inferred that the species was at least moderately pollution-tolerant. Variability in metal concentrations was reduced to manageable levels with careful methodologies. To determine the effect of animal size, the shell length versus concentration regression was assessed for each metal at each site. Where correlation occurred, methods were presented to counter such biases. Undigested gut content material did not cause a detectable bias in tissue concentrations where concentrations in particulate materials were substantially lower than concentrations in tissues (see *Quantification of Trace Element Measurement Errors in Bioaccumulation Studies Associated with Sediment in the Digestive Tract*, this report). For trace elements that occur in high concentrations in particles, a 24 hour depuration removed sufficient gut content to eliminate effects on tissue concentrations. Brown and Luoma (1995) also addressed the question of local variability in bioaccumulated metal that might result from the combination of biological and geochemical uncertainties (i.e., within a site, between adjacent sites, between adjacent times). The variability of replicates collected at one time and one place was similar to the variability among adjacent locations or times, if inputs did not change. Methodologies that employed relatively large numbers of organisms per sample (see Methods) had the statistical power to detect 20% differences in mean concentrations along regional gradients, at the higher range of the standard deviation (25%), and the sensitivity to detect 10% differences at the lower range of a typical standard deviation (12%). Although less detailed, earlier studies also showed the usefulness of employing the clams *Macoma balthica* (Luoma *et al.*, 1985) and *Corbicula* sp. (Luoma *et al.*, 1990) as resident bioindicators in North and South San Francisco Bay. However, neither of these species were distributed as widely in the Bay as *P. amurensis*.

The comparability of results between resident and transplant approaches has not been fully studied. In some circumstances transplanted organisms rapidly reach the same contaminant concentrations as native species (Bryan and Gibbs, 1983; Nelson *et al.*, 1995). However in other circumstances (especially contaminated environments), large differences between transplanted and resident species remained after months of exposure (Bryan and Hummerstone, 1978; Cain and Luoma, 1985; Widdows *et al.*, 1984).

Selenium Trends in the North Bay

Bioindicators are especially effective in monitoring selenium (Se) contamination, one of the most important contaminants in the North Bay. The bivalves *Corbicula* sp., *Macoma balthica* and *Mytilus edulis* were all responsive to changes in Se exposure in San Francisco Bay in past studies, either as resident or transplanted species (Risebrough, 1977; Johns *et al.*, 1988). A distinct gradient in Se contamination, with maximum concentrations near Carquinez Straits, was a feature of North Bay in 1976 in *Mytilus edulis* (Risebrough, 1977) and 1985–1986 in *Corbicula fluminea* (Johns *et al.*, 1988). Se concentrations in suspended particulate materials were also highest near Carquinez Straits after the flood of 1986 (Cutter, 1989) but were more widespread later in the year, when river inflows were reduced and residence times were longer in San Pablo Bay and Suisun Bay.

Bivalves were effective bioindicators of Se distributions because of the pathway of Se bioaccumulation in the North Bay (Luoma *et al.*, 1992). The most important species of dissolved Se in the North Bay was selenite, which, when taken up by phytoplankton, was biotransformed to organo-selenium. Organo-selenium was efficiently transferred to bivalves (clams) that ingested phytoplankton with suspended particulate material (Luoma *et al.*, 1992). Direct exposure to dissolved Se was an insignificant source of exposure for the clams. The clams were a logical vector for Se exposure for diving ducks that contained high concentrations of Se (White and Hofman, 1988; Chadwick *et al.*, 1991). Selenium bioaccumulation in *P. amurensis* was not studied previously, even though it is now the predominant resident bivalve in the North Bay.

Study Design

The goal of the present study was to compare selenium and mercury (Hg) concentrations in resident bivalves (principally *P. amurensis)* in the North Bay with concentrations determined in transplanted bivalves in the 1995 RMP studies. These elements were chosen because they are two of the pollutants of greatest concern in San Francisco Bay. The data reported here are from May 1995 through June 1996. A period of drought in the watershed of San Francisco Bay ended in 1993 and especially in 1995; the latter was a year of exceptionally high and long-lasting riverine inflows into the system due to high precipitation and snowpack in the watershed (Cloern, this report). Hydrologic inputs to San Francisco Bay in 1996 were similar to the long-term average for the ecosystem. In contrast to the two relatively stable hydrologic years for metal bioaccumulation reported for *P. amurensis* by Brown and Luoma (1995), the temporal environmental influences that might affect the responses of a biosentinel species to contamination in the Estuary were probably accentuated in 1995 and 1996.

The comparison of transplanted and native species had four parts. The first goal was to compare bioaccumulated Se concentrations in different species. Assuming such concentrations might differ among species, the sampling was also designed to compare spatial trends in Se bioaccumulation indicated by the resident and transplanted bivalves. Resident clams were collected from three locations near RMP bagged bivalve sites in May 1996: Grizzly Bay (BF20), Davis Point at the mouth of Carquinez Strait (BD40), and San Pablo Bay near Pinole Point (BD30) (seeFigure 1 in Chapter One: Introduction). Resident animals were also collected at USGS Station 8.1 in the Carquinez Strait, across the channel from the Napa River bagged bivalve site (BD50). *P. amurensis* were present at three of the four sites (they were absent at Davis Point). *Macoma balthica* were collected at Davis Point and, for comparison with *P. amurensis* at a site on the west side of Pinole Point. In the RMP, *Corbicula fluminea* was deployed in Grizzly Bay, and *Crassostrea gigas* at the other stations.

The third goal was to compare temporal variability in concentrations. In October 1995, *P. amurensis* were collected from five locations in the Napa River (including near bagged bivalve site BD50); and from United States

Table 1. Determination of selenium and mercury in standard reference materials at the time of analyses of tissue samples by USGS Se-Hg laboratory. * July 19, 1995 run; **August 1996 run. Reference materials were chosen to represent both sediments and tissues and to cover a range of Se and Hg concentrations. Laboratory results also were comparable with other laboratories in intercalibration exercises with NOAA-NRC Canada DORM reference materials.

Reference	Sample	Observed Se (mg/g)	Certified Se (mg/g)	Observed Hg (mg/g)	Certified Hg (mg/g)
NIST	SJS-sed	1.6, 1.6*	1.6 ± 0.1	1.3, 1.4*	1.4 ± 0.08
NRC-Can	DORM-1-sediment	1.6, 1.9* 1.8, 1.8**	1.6 ± 0.1	0.76, 0.81* 0.78**	0.8 ± 0.07
NIST	Oyster	1.9, 1.9*	2.2 ± 0.2	0.08*	0.06 ± 0.01
IAEA	MA-B-3 - Fish	1.2* 1.4, 1.5**	1.4–1.7	0.45, 0.50**	0.47–0.61
NRC-Can.	TORT-1	6.5*	6.9 ± 0.5	0.30*, 0.29**	0.33 ± 0.06
NRC-Can.	TORT-2	5.5, 5.7**	5.6 ± 0.7	0.27, 0.25**	0.27 ± 0.06
NRC-Can.	DOLT-2	5.6, 6.2**	6.1 ± 0.5	2.11, 2.12**	1.99 ± 0.10

Geological Survey (USGS) sites in Suisun Bay (6.1), Carquinez Strait (repeat sampling at 8.1) and San Pablo Bay (subtidal site 12.5, comparable to BD30). Thus the May and October sampling of residents was comparable to the wet season, dry season sampling of the RMP.

The fourth goal was to repeatedly sample resident bivalves at one station to verify any temporal trends. *P. amurensis* were collected for Se analysis monthly, between December 1995 and June 1996 from Carquinez Strait (USGS 8.1). USGS 12.5 in San Pablo Bay was resampled in June 1996.

Methods

Resident clams *(P. amurensis* or *Corbicula* sp.) were collected from the subtidal zone with a Van Veen grab and 1 or 2 mm sieves. Channel depths ranged from 8–20 m. The subtidal sites adjacent to marshes in Honker Bay and the Napa River (Figure 1 in Chapter One: Introduction) were located in the shallows at an average depth of 1–3 m. Clams (*P. amurensis* and *Macoma balthica*) were also collected intertidally at three sites, at low tide with a shovel, sieve and bucket. Between 60–120 clams of all sizes were collected at each time and each site and placed into containers of water collected at the site. The clams were kept in this ambient water in a constant temperature room at 10°C to depurate for 48 hours, as previous studies showed a residence time of material in the gut of *P. amurensis* approximately 24 hours in this species (Decho and Luoma, 1991). Clams from each site were separated into size classes of 1 mm difference and composite samples were made of similar sized individuals. Samples of larger numbers of individuals were necessary for smaller size classes in order to obtain enough mass for analysis. Mean concentrations characteristic of a site and at a particular time were thus determined from analyses of usually 3 replicate composite samples each containing 20–60 clams (each composite was contained at least 250 mg dry weight soft tissue). Mercury and selenium were determined by Hydride Atomic Absorption Spectrophotometry. A separate subsample was decomposed for mercury as well as one for selenium. Mercury subsamples were digested at 100° C in *aqua regia*, re-digested in 10 percent nitric acid plus potassium dichromate and then reduced at the time of the hydride analysis. Selenium subsamples were digested in concentrated nitric and perchloric acids at 200°C and reconstituted in hydrochloric acid.

All glassware and field collection apparatus were acid-washed, thoroughly rinsed in ultra-clean deionized water, dried in a dust-free positive-pressure environment, sealed and stored in a dust free cabinet. Quality control was maintained by frequent analysis of blanks,

analysis of National Institute of Standards and Technology standard reference materials (tissues and sediments) with each analytical run, and internal comparisons with prepared quality control standards. A full QA/QC plan is available upon request. Analyses of National Institute of Technical Standards (NITS) reference materials (oyster tissue, San Joaquin soils) were within an acceptable range of certified values reported by NITS or were consistent where the nitric acid digest did not completely decompose the sediment samples (see Brown and Luoma, 1995 and Luoma *et al.*, 1995 for metals; see Table 1 for Hg and Se).

Spatial Trends: May 1995

Concentrations of Se observed in resident and bagged bivalves are compared in Table 2 and Figure 19. Bioaccumulation of Se differed among some, but not all species, when compared at the same location. *P. amurensis* appeared to accumulate Se more efficiently than *C. fluminea*. In Grizzly Bay, concentrations of Se in *C. fluminea* were 1.35 mg/g compared to 3.90 ± 0.8 mg/g in *P. amurensis*. At comparable locations, concentrations in *C. gigas* were slightly greater than concentrations in *P. amurensis* (5.43 mg/g compared to 3.70 ± 0.7 mg/g, respectively, in San Pablo Bay) and *M. balthica* (6.52 mg/g compared to 3.60 ± 1.1 mg/g at Davis Point) in May. *M. balthica* and *P. amurensis* did not differ significantly in Se concentrations at Pinole Point ($p>0.1$).

Spatial distributions observed in the resident species were generally similar to those indicated by the transplanted bivalves in May 1995, although some details differed. If all bivalve data were compared, the RMP data indicated that Se concentrations were lower in Grizzly Bay in May 1995 than in San Pablo Bay, the Napa River, and at Davis Point. This was due to the difference in bioaccumulation between *C. fluminea* and *C. gigas*. Bioaccumulated Se concentrations were similar in Grizzly Bay and San Pablo Bay in *P. amurensis*. If it is assumed that concentrations

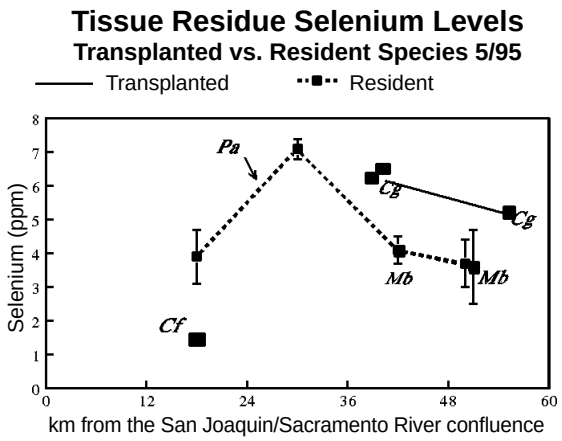

Figure 19. Spatial trends in concentrations of Se in soft tissues of transplanted *Crassostrea gigas* (Cg) and *Corbicula fluminea* (Cf) compared to trends in concentrations in resident *Potamocorbula amurensis* (Pa) and *Macoma balthica* (Mb) in May 1995, as a function of distance from the San Joaquin/Sacramento River confluence.

Table 2. Comparison of selenium concentrations in transplant and resident species in the North Bay in May 1995. Locations are km from the mouth of the San Joaquin/Sacramento Rivers confluence.

Site	Location	Species: Transplant	Se (mg/g dry)	Species: Resident	Se (mg/g dry)	Location
Grizzly Bay	18 km	*C. fluminea*	1.35	*P. amurensis*	3.90 (0.8)	18 km
Napa River (Carquinez)	39 km	*C. gigas*	6.22	*P. amurensis*	7.10 (0.3)	30 km
Davis Point	40 km	*C. gigas*	6.52	*M. balthica*	4.10 (0.4)	42 km
San Pablo Bay	55 km	*C. gigas*	5.43	*P. amurensis*	3.70 (0.7)	50 km
San Pablo Bay				*M. balthica*	3.60 (1.1)	50 km

in *M. balthica* are comparable to *P. amurensis*, Grizzly Bay was similar to Davis Point.

Probably the most important difference between the resident species survey and the RMP bagged bivalves was the elevated concentrations of Se observed in Carquinez Straits in *P. amurensis*. This aspect of Se distributions was slightly ambiguous in the RMP, because bivalves were not deployed in this waterway. This was an instance where the widespread nature of the resident species and relative ease of collection offered an advantage compared to the transplant approach. Because Se enrichment in Carquinez Strait was also indicated in earlier studies; this location might be considered a critical site for biomonitoring in the future.

The spatial distribution and concentrations of Se observed in transplanted and resident species in May, 1995, may have been influenced by the hydrologic regime at the time. The RMP deployment and the May resident samplings occurred in the middle of a prolonged period of high river inflow. During low flow periods (summer and fall) the total outflow index at Chipps Island, calculated by the US Bureau of Reclamation, is typically less than 7,000 cubic feet per second (cfs). In the 1995 water year (October 1994 to October 1995) outflow first exceeded 10,000 cfs during 15 days in December 1994. Between January and the end of June average daily outflow for each month was 44,000–80,000 cfs (United States Bureau of Reclamation Delta Outflow Computation Tables, unpublished); outflows greater than 10,000 cfs continued into September.

Temporal Trends

Significant differences in Se trends were observed between resident *P. amurensis* and bagged bivalves in October 1995. Concentrations in *P. amurensis* indicated a substantial increase in Se contamination in Suisun Bay, San Pablo Bay, and the Napa River in the resident food web by October 1995. An unambiguous increase was not indicated in the deployed bivalves.

In the RMP, Se concentrations in *C. fluminea* transplanted to Grizzly Bay were 1.35 mg/g deployment (Figure 8). The latter are not exceptionally high concentrations for *C. fluminea*; they are below the higher values observed by Johns *et al.* (1988) near Grizzly Bay in this species in 1985–1986. Concentrations of Se in *C. gigas* transplanted to the Napa River were only slightly higher (statistical significance could not be determined) in October compared to May. Concentrations of Se were substantially lower in October than May in *C. gigas* transplanted to Davis Point. Concentrations of Se in mussels at Pinole Point were not high in October, compared to those observed by Risebrough *et al.* (1977); and Se was not determined in bagged bivalves from San Pablo Bay in October. Thus, the RMP data alone did not indicate any great change in the relatively low levels of Se in the food web of the Suisun/San Pablo Bay region between May and October 1995.

In contrast to the RMP results, substantial, statistically significant increases in Se concen-

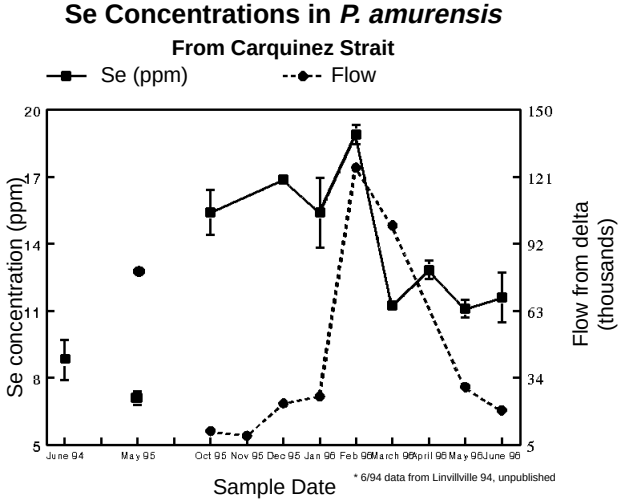

Figure 20. Concentrations of Se in soft tissues of resident *Potamocorbula amurensis* collected subtidally from Carquinez Straits (USGS 8.1) and average monthly river inflow in thousands of cubic feet per second, as computed by the US Bureau of Reclamation for the time period May 1995 through June 1996. Data from June 1994 are also shown as reported by Linville, R. and Kegley, S. E. Selenium enrichment surrounding oil refineries: Analysis of *Potamocorbula amurensis* and sediment. 1994 Biology Fellows Undergraduate Research Symposium, Berkeley, CA.

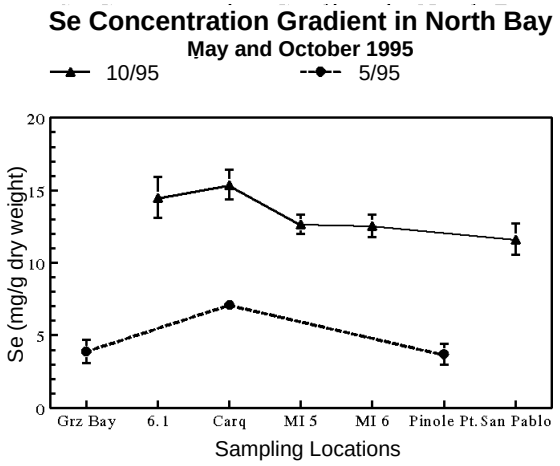

Figure 21. Spatial trends of Se concentrations in tissues of *Potamocorbula amurensis* in May 1995 and October 1995.

trations in *P. amurensis* were observed between May and October 1995. Concentrations at all locations in October were the highest ever reported for bivalves in North Bay, ranging from a maximum of 15.4 ± 1.0 mg/g at USGS 8.1 in Carquinez Strait to a minimum of 11.6 ± 1.1 mg/g at USGS 12.5 in San Pablo Bay (Figures 20 and 21; Table 3). Concentrations were also elevated throughout the Napa River (ranging from 12.5 ± 1.0 mg/g to 15.3 ± 1.0 mg/g at the six sites) in October. All concentrations in *P. amurensis* were substantially higher than observed in *C. gigas* at comparable locations, in contrast to the May results. All values exceeded the concentrations of Se that cause adverse effects in fish and birds when ingested in food (i.e.>10 mg/g) .

Highly elevated Se concentrations were observed repeatedly in Carquinez Strait between October 1995 and June 1996. Concentrations of Se in *P. amurensis* ranging from 15.4 ± 1.0 mg/g to 18.9 ± 0.4 mg/g were observed between October 1995 through February 1996 at station 8.1. Concentrations declined slightly, to a range of 10.0 ± 0.7 µg/g to 12.8 ± 0.4 µg/g, between March 1996 and June 1996. The decline in concentrations coincided with the annual increase mean monthly river inflow to North Bay (Figure 20).

Figure 22 summarizes results from past studies with bivalves in the North Bay, showing mean concentrations of Se for each species studied at the station nearest Carquinez Strait. Elevated Se concentrations have been observed in all studies since 1976. However, mean concentrations in the dominant bivalve in the system (*C. fluminea* in 1985 compared to *P. amurensis* in 1996) have almost tripled in recent years, suggesting the possibility of a large increase in Se dose to upper trophic level organisms feeding on bivalves. Oysters transplanted in a study in 1985 achieved a concentration very similar to oysters transplanted in 1996. On the other hand, the ambiguities of the oyster results between May and October in the RMP raise questions about whether bagged oysters would be sensitive to increases in environmental concentrations. It cannot be discounted that Se concentrations in Carquinez Strait increased after October 1995. But it is also possible that the higher Se in 1995–1996 compared to 1985–1986 might be the result of the replacement of *C. fluminea* by the invasion of a species that bioaccumulates Se more efficiently, the opportunist *P. amurensis*. Dissolved Se concentrations were not determined in October, and in 1995 elevated river

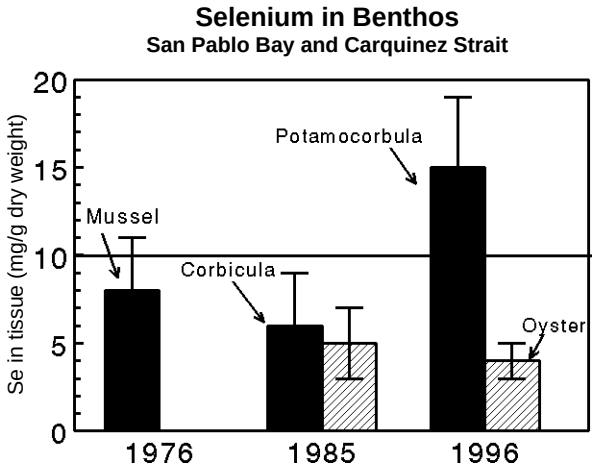

Figure 22. Selenium concentrations in tissues of mussels (transplanted *Mytilus californianus*, as reported by Risebrough, 1977), *Corbicula fluminea* (resident species, as reported by Johns *et al.*, 1988), transplanted oysters (*Crassostrea gigas*) and *Potamocorbula amurensis.* All values are grand means of all analyses conducted at the station nearest Carquinez Strait in each study.

Table 3. Selenium concentrations in mg/g dry weight in *Potamocorbula amurensis* at nine locations in North San Francisco Bay (Figure 1 in the Introduction) in October 1995, and between October 1995 and June 1996 at Station 8.1 in Carquinez Strait. Values are means ± one standard deviation. (#) is the number of composites analyzed. Each composite included approximately 20–60 individual *P. amurensis*, and >250 mg dry weight soft tissue. Napa River stations are numbered North-to-South ascending.

Site	10/95	12/95	1/96	2/96	3/96	4/96	5/96	6/96
6.1	14.5±1.4 (3)							
8.1 (Carq. Straits)	15.4±1.0 (3)	16.9 (1)	15.4±1.6 (3)	18.9±0.4 (3)	11.3±0.2 (2)	12.8±0.4 (3)	11.1±0.4 (3)	11.6±1.1 (3)
12.5 (San Pablo)	11.6±1.1 (5)							10.0±0.7 (4)
Napa 1	12.5±1.0 (3)							
Napa 2	15.3 (1)							
Napa 3	14.1±0.5 (3)							
Napa 4	14.0±0.9 (3)							
Napa 5	12.7±0.6 (2)							
Napa 6	12.6±0.8 (5)							

inflows were present when the August sampling of Se was conducted.

Accumulation factors in *C. gigas* exceeded 1 in the wet season in the RMP transplant. This indicates that Se was taken up when animals were deployed from uncontaminated environments to the North Bay. However, accumulation factors in the dry season (October) in both *C. gigas* and *M. edulis* were low, indicating little Se uptake after deployment. It is possible that deployed animals either were feeding little during the dry season, or were feeding on a food source of lower Se bioavailability than that experienced by the resident species. The reduced condition indices of both *C. gigas* and *M. californianus* in October support the former contention (Figure 18). Detrital freshwater algae could be an important food source for filter feeders in North Bay, especially during periods of high river inflows. Such sources are less available during low flow periods. Behavioral changes as a result of the deployment or as a result of high Se concentrations on particulate materials are possible. But it seems more likely that the low standing stock of phytoplankton and algal detritus in North Bay affected the feeding or availability of food to *C. gigas* and *M. californianus* in October. If so, differences in food sources between deployed and resident species must be a consideration in interpreting transplant data, especially with regard to elements like Se that are bioaccumulated from food. One possible explanation may be the change in phytoplankton standing stock in the water column of the North Bay in recent years. Transplanted mussels or oysters may not be feeding the way they have in the past, affecting their exposures to Se.

Summary of Selenium Comparison

The differences between trends in resident species and those in transplanted bivalves were small in May 1995. The most important difference may have been the lack of an RMP station in the region most influenced by Se inputs: Carquinez Strait. However, it is of concern that the substantial change in the Se contamination of the benthos in the North Bay that occurred in October 1995, was not indicated by data from deployed bivalves, especially *C. gigas* and *M. edulis*. It becomes important to better understand the food source(s) exploited during periods of low river inflows by the highly successful *P. amurensis*, because that appears to carry Se in a form that is highly bioavailable during a time when vulnerable migratory species (e.g., diving ducks) are arriving in San Francisco Bay. Alternatively, deployed bivalves may obtain food in a manner different from how resident animals obtain food.

The temporal trends in Se concentrations in *P. amurensis* in the North Bay point out the interactions among the important issues affecting San Francisco Bay. River inflow appeared to influence bioavailable Se concentrations in North Bay in 1995 and 1996, presumably by affecting residence times and dilution of local Se inputs by freshwater. Concentrations of Se were lowest in *P. amurensis* during a prolonged period of high inflows (May 1995) and increased greatly after inflows subsided in October 1995. Similarly, the concentrations of Se in the transplanted *C. fluminea* were lower than any concentrations observed in resident *C. fluminea* by Johns *et al.* (1988) during 1985–1986. The latter study included no period of high river flow as prolonged as occurred in May 1995. A smaller decrease in Se bioaccumulation also occurred coincident with the pulse of high inflows in January–March 1996. Further investigation is warranted of the potentially important linkage between these issues.

The susceptibility of the Bay to invasions by exotic species also appeared to affect Se contamination of the food web. After the invasion of the Estuary by *P. amurensis* in 1986, Se concentrations in dominant resident bivalve in 1996 increased to levels three times greater than the contamination of the dominant bivalves in the mid-1980. Whatever the cause, it is clear that predators of bivalves in the food web of the North Bay could have been exposed to much more Se in 1996 than they were in the late 1980, when most studies of upper trophic levels were conducted.

Mercury Concentrations in Bagged and Resident Bivalves

Mercury concentrations were low in *P. amurensis* (0.08–0.24 mg/g) at all locations studied in the North Bay and at all times (Table 4). No spatial trends were evident in the data. Concentrations doubled between May 1995 and October 1995 to June 1996; but the increase in absolute terms was small. Mercury concentrations in the two resident bivalves included in this study were not comparable. Concentrations in *M. balthica* were higher than concentrations in *P. amurensis* at Pinole Point. Comparing mercury concentrations in *M. balthica* between Pinole Point and Davis Point suggested greater contamination in resident species at the former site in May 1995.

Mercury concentrations in bagged bivalves ranged from 0.14–0.39 mg/g in May and October 1995 at the North Bay sites, approximately the same range as the resident species. The bagged bivalve data indicated that greater contamination occurred during the dry season than during the wet season, as observed in *P. amurensis*. The highest mercury concentrations in the RMP data and in the resident species data was observed at Pinole Point (~ 3.9 mg/g in *M. californianus* in October 1995; Figure 6), although it was unclear if the different species were directly comparable.

Bagged bivalves and resident species thus showed generally the same trends in mercury contamination in the North Bay. Most important, both indicated that substantial mercury contamination was not found in the benthos of the North Bay, either during high flows or during wet flows. Johns *et al.* (1988) drew similar conclusions from mercury analyses of *C. fluminea* at six sites in the North Bay in September 1986. They observed a range of concentration of 0.08–0.18 mg/g Hg dry weight among sites, similar to the concentration observed in bagged *C. fluminea* in May, 1995, but less than the 0.30 mg/g observed in RMP collections in October 1995.

Mercury contamination has been found in longer-lived higher trophic level species in the North Bay. That contamination may not be transferred via the benthic food web. Interactions between mercury and selenium have also been reported in the literature. If such interactions occur in North San Francisco Bay, they have only a minor influence on concentrations. Mussels and *M. balthica* may be the best bioindicators for mercury contamination in the benthos of San Francisco Bay.

Acknowledgements

This study was conducted in partnership with the San Francisco Bay Region, California Regional Water Quality Control Board.

Table 4. Mercury concentrations in mg/g dry weight in *Potamocorbula amurensis* and *Macoma balthica* at five locations in North San Francisco Bay (Figure 1 in Chapter One: Introduction) in October, 1995; between October 1995 and June 1996 at Station 8.1 in Carquinez Strait and at station 12.5 in San Pablo Bay in June 1996. Mercury concentrations in *Macoma balthica* also shown for May 1995. Values are means ± one standard deviation. (#) is the number of composites analyzed. Each composite included approximately 50 individual *P. amurensis*, and >250 mg dry weight soft tissue. Napa River stations are numbered North-to-South ascending.

Site	5/95	10/95	12/95	1/96	2/96	6/96
P. amurensis.						
Carquinez Straits	0.10±0.00 (2)	0.18±.01 (3)	0.2 (1)	0.21±.02 (3)	0.24±.01 (3)	0.19±.02 (3)
San Pablo Bay	0.08±.01 (3)					
Napa 1		0.21±.01 (3)				
Napa 3		0.20±.02 (3)				
Napa 5		0.23±.01 (2)				
Macoma						
Davis Point	0.24±.04 (3)					
San Pablo Bay	0.37±.04 (4)					

Bioaccumulation of Contaminants by Transplanted Bivalves in the San Francisco Estuary: A Summary of Status and Trends with Emphasis on Local Effects Monitoring Programs[1]

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San Francisco Estuary Institute

Introduction

San Francisco Bay Area dischargers, through the Bay Area Dischargers Association (BADA) and the South Bay Dischargers, have analyzed bioaccumulation in transplanted bivalves for their Local Effects Monitoring Program (LEMP) since 1989. Five separate surveys have been conducted. Except for the first survey, the surveys have been termed "Rounds". The objectives of this summary were to:

1. provide information on the bioaccumulation of contaminats in bivalves sampled in LEMP Rounds 3 and 4;
2. evaluate the similarities and differences in bioaccumulation among sampling locations (outfalls of the City and County of San Francisco, East Bay Municipal Utility District, and Contra Costa Central Sanitary District);
3. evaluate similarities and differences between reference sites and sites along outfall gradients wherever possible;
4. evaluate trends in bioaccumulation over time between sites located along transects along three outfall areas and their respective reference sites;
5. compare the trends in bioaccumulation between outfall sites, Regional Monitoring Program reference sites, and State Mussel Watch sites in the Bay; and
6. compare bioaccumulation patterns when bivalves are transplanted in the wet season versus the dry season.

The reader is referred to the full report for a detailed description of the reference envelope approach (see also Taberski, this report), data tables, and figures.

Beginning with the BADA surveys (Rounds 1–4), samples were located along gradients from three major Estuary sewage outfalls belonging to the City and County of San Francisco (SFSE), the East Bay Municipal Utilities District (EBMUD), and the Contra Costa Central Sanitary District (CCCSD). Sites "near", "mid", "far" (from the outfall) and "out" (reference sites presumably outside outfall influences) were sampled. Bivalve deployments were made below the water surface and/or above the bottom in the cases of SFSE and EBMUD, and just below the surface for CCCSD, and for 30 and/or 90 days. One to three replicate samples for analysis of trace metals and organics were collected at each station. Oysters, *Crassostrea gigas*, were used at CCCSD, and mussels, *Mytilus californianus*, were used at EBMUD and at SFSE. These surveys collected samples during successive dry and wet season in the Estuary.

General Patterns

Differences between the 30- and 90-day deployments and between the shallow and deep deployments during Round 1 and 2 were described in previous reports (O'Connor *et al.*, 1992; Davis and Daum, 1993). Those reports made several conclusions that are important in considering the results of Rounds 3 and 4 presented in this document. In general, the 90-day deployments had higher concentrations than the 30-day deployments except for polycyclic aromatic hydrocarbons (PAHs) which were

[1] This is a summary of *Bioaccumulation of Contaminants by Transplanted Bivalves in the San Francisco Estuary: Status and Trends*, available through SFEI.

more often higher in the 30-day deployments. There was no clear pattern of greater accumulation at the surface or bottom (deep) deployments except for pesticides which had higher concentrations in the deep deployments in Round 1. Bioaccumulation of contaminants by transplanted bagged bivalves during LEMP Rounds 3 and 4 showed three general patterns;

1. There was no evidence of bioaccumulation of arsenic, cadmium, and chromium in mussels. However, cadmium did accumulate in some of the CCCSD samples.
2. Only copper accumulated in all mussel samples and the majority of oyster samples. Most other metals accumulated in some samples, but not in others, even within individual study areas. Only copper at SFSE indicated a possible outfall-related effect (Round 4).
3. All of the trace organic contaminants accumulated at all locations and sites. At EBMUD polychlorinated biphenyls (PCBs) showed a pattern of accumulation that suggested a "near-outfall" source. At SFSE only PAHs showed such a pattern, and at CCCSD none of the trace organic contaminants exhibited this pattern.

Spatial Patterns of Accumulation

If outfalls were sources of biologically available contaminants, concentrations in bivalves might be expected to decrease with distance from the outfalls. For most contaminants, this expectation did not hold true. It is possible that depending on the tidal or river flow (in the case of CCCSD), or the feeding regime of the bivalves, one could find greater tissue contamination farther away from the outfall as compared to the end of the pipe. Only PAHs and copper levels at SFSE and PCBs at EBMUD were elevated at "near-outfall" stations relative to more distant ones. Other contaminants did not show any spatial gradients that could be attributed to the outfalls. When comparing sites nearest the outfalls with multiple reference locations throughout the Estuary using a "reference envelope" approach (SFEI, 1996) that included, silver, selenium, and PAHs exhibited higher concentrations nearest the outfalls, while other constituents could not be differentiated from Estuary "background". Other contaminants were frequently elevated at the "near-outfall" locations, but in an inconsistent or indistinct manner; these included nickel at CCCSD, pesticides and PCBs at EBMUD, and copper at SFSE. No other contaminants were distinctly elevated at the "near-outfall" locations.

One non-outfall location, the "far" station for EBMUD, consistently had very high concentrations of PAHs (up to 7000 ng/g dry-weight in Round 3).

Temporal Patterns of Accumulation

In general, there was little evidence of temporal trends over the four LEMP Rounds, i.e., no consistent increases or decreases over time could be discerned for most contaminants. Only copper and zinc increased over the four Rounds at EBMUD, while PCBs exhibited a decreasing trend over the four Rounds at the CCCSD locations. It should be noted, however, that all of these observations are qualitative only.

Comparisons with Other Data

A relatively large database exists for contaminant concentrations in transplanted mussels in the Estuary due to the long-term monitoring of the State Mussel Watch Program (SMW), the database of the Bay Protection and Toxic Cleanup Program, and the more recent inception of the RMP. This extensive data set is very suitable for comparison to the bioaccumulation data from the various Rounds of the LEMP, the Western States Petroleum Association (WSPA) LEM from 1993, and the South Bay LEM from 1989–1990. For transplanted oysters, the Bay Protection and Toxic Cleanup Program and the RMP provide a frame of reference. Table 5 summarizes comparisons of data distributions from the Local Effects Monitoring Programs, the RMP, and the SMW.

Table 5. Summary of comparisons of data distributions from the LEMP, RMP, and SMW.

Contaminant	Mussels	Oysters
Silver	Some values at EBMUD and SFSE exceed the RMP distribution and are in the upper end of the distribution of SMW measurements in the Bay. South Bay concentrations overlap RMP and SMW distributions.	All values at CCCSD exceed the RMP distribution.
Arsenic	LEMP data overlap those from the other programs, with the exception of some very low (and probably spurious) values from the South Bay.	General overlap between CCCSD and RMP distributions, but greater range for CCCSD.
Cadmium	LEMP data are near the center of the SMW distribution. RMP distribution is unusually broad, and has a lower median than the SFSE and EBMUD outfall distributions. High end of RMP distribution consists of values from October 1993. South Bay distribution a bit lower than SFSE and EBMUD.	CCCSD distribution has higher median than the RMP distribution.
Chromium	SFSE and EBMUD distributions are toward the low end of the RMP distribution, but the upper end of the SMW distribution. RMP data are high relative to the SMW and include the highest values observed for chromium in the Bay. The highest value (81 ppm) was associated with a spring-neap tide at the Petaluma River.	General overlap between CCCSD and RMP distributions, with some unusually high RMP values.
Copper	LEMP data generally are in good agreement with SMW data. RMP data are substantially lower than LEMP or SMW. Methodological differences seem a possible explanation.	CCCSD distribution has higher median than the RMP distribution.
Mercury	General overlap among all distributions.	General overlap between CCCSD and RMP distributions.
Nickel	LEM distributions toward low end of RMP distribution.	General overlap between CCCSD and RMP distributions.
Lead	SFSE and EBMUD comparable to upper end of RMP distribution, but the lower-middle range of the SMW distribution. South Bay concentrations relatively low.	Detected values from CCCSD exceed the upper boundary of the RMP distribution, but most values were below detection limits.
Selenium	A few values at SFSE and EBMUD exceed the upper limit of the RMP distribution and are comparable to the upper end of the SMW distribution. South Bay concentrations are relatively low.	General overlap between CCCSD and RMP distributions.
Zinc	All distributions generally overlap each other.	General overlap between CCCSD and RMP distributions.
alpha-Chlordane	LEMP and RMP overlap each other and are a bit low relative to SMW.	CCCSD distribution slightly lower than RMP distribution.
Dieldrin	General overlap among SFSE, EBMUD, and RMP, which compare with the low end of the SMW distribution.	CCCSD distribution slightly lower than RMP distribution.
p,p'-DDD	SFSE and EBMUD are toward lower end of RMP and SMW distributions.	CCCSD distribution has lower median than the RMP distribution.
p,p'-DDE	SFSE and EBMUD are toward lower end of RMP and SMW distributions.	CCCSD distribution has lower median than the RMP distribution.
PCB 153	Close correspondence in LEMP, RMP, and SMW distributions.	CCCSD distribution lower than RMP distribution.
Sum PAHs	Many SFSE values exceed the RMP distribution, but the SFSE distribution is not exceptionally high relative to the SMW distribution. EBMUD values are low relative to other distributions.	General overlap between CCCSD and RMP distributions.

Two contaminants, silver in mussels and oysters and selenium in mussels, reached distinctly elevated concentrations at the "near-outfall" locations, accumulating to concentrations that were high relative to both the RMP and State Mussel Watch (SMW) data. Silver in mussels and oysters and selenium in mussels in 1994 also were shown to exceed the upper boundary of the "reference envelope" based on 1994 RMP data (SFEI 1996).

The sum of all measured PAH compounds (ΣPAH) at SFSE was clearly and consistently elevated relative to RMP data and exceeded the upper boundary of the "reference envelope" based on 1994 RMP data (SFEI 1996). Relative to the SMW data, however, SFSE ΣPAH concentrations were not exceptionally high. SFSE ΣPAH concentrations were in the upper half of the SMW distribution, but the highest SFSE concentration approximated the 75th percentile of the SMW distribution. While a PAH signal has clearly been detected near the SFSE outfall, the concentrations measured are not exceptionally high relative to data for the Bay as a whole.

For two contaminants, cadmium and copper, LEMP concentrations were high relative to RMP data, but RMP data were generally lower than SMW data. Even SMW stations that should have been comparable to RMP stations had higher concentrations. These results raise the possibility that methodological differences might be a factor contributing to the patterns observed among these data sets, particularly in cases where the RMP and SMW distributions are clearly offset from each other.

The South Bay data were generally within the range of the LEMP data, with some notable exceptions: arsenic and selenium concentrations were much lower than concentrations in any of the other datasets, suggesting methodological artifacts. The South Bay data as a whole were slightly lower than the "near-outfall" data points at SSFE and EBMUD for silver, copper, and cadmium. Compared to the 1993/94 RMP data, copper and cadmium concentrations in the South Bay were relatively high.

Seasonal Differences in Bioaccumulation

None of the data revealed any consistent differences in bivalve tissue concentrations between wet and dry seasons, although PCB concentrations at EBMUD and copper at CCCSD at the stations nearest their respective outfalls suggested higher concentrations during the dry season than during the wet season.

Efficacy of Bivalve Monitoring

One of the goals of the Local Effects Monitoring Program was to evaluate potential bioaccumulation differences between near-outfall sites and those presumably less influenced by treated waste water. Bivalves are an effective tool for providing time-averaged concentrations for contaminants that bioaccumulate. Therefore, the LEMP data, together with those generated by the RMP and the State Mussel Watch Program, are useful in determining water quality trends that snapshot water-column sampling may not be able to reflect accurately (see Schoellhamer, this report). The LEMP data show that areas near outfalls are, with exceptions of a few contaminants, comparable to the Estuary as a whole. However, the lack of, or comparable levels of, bioaccumulation near outfalls compared to reference sites does not necessarily indicate a lack of contaminant effects due either to direct toxicity or loadings to the Estuary over time. Additional indicators are needed to obtain a more complete picture of the success of pollution prevention programs.

Some difficulties exist with regard to interpretation of transplanted bivalve data. Some of the difficulty is due to sampling design problems, such as the loss of bivalves from some transect stations, inability to differentiate spatial variability at outfall locations, and use of several species that preclude spatial comparisons. Another difficulty is a low degree of accumulation of some contaminants in transplants relative to initial concentrations at presumably clean sites. The meaning of bioaccumulation of contaminants in an ecological

context is also difficult to determine, although bioaccumulation data have great potential in ecological risk assessment when used to evaluate impacts to bivalve predators, such as fish, birds, and mammals. Regional site-specific exposure information can add greatly to the certainty of ecological risk assessments.

Monitoring with transplanted bivalves does indicate that contaminants are capable of entering the food web. Evaluation of bioaccumulation along a waste discharge gradient, as has been done by the LEMP, also provides an indication of whether or not the outfalls may be directly contributing contaminants beyond Estuary background levels that are available for bioaccumulation. Only the patterns observed for PAHs at SFSE , PCBs at EBMUD, and copper at SFSE suggest that outfalls may be direct contributors. Silver (all outfalls) and selenium (SFSE and EBMUD) did not show a gradient with distance from the outfall, but concentrations measured near the outfalls were high relative to both RMP and SMW data, suggesting that concentrations in the areas surrounding the outfalls are elevated. The lack of a contaminant gradient away from the outfalls seems to indicate that many contaminants in treated waste water may not be appreciably different from the receiving water, although contaminant levels for the Estuary as a whole are (in some cases considerably) elevated in bivalve tissue compared to non-urbanized reference areas along the Pacific coast.

Another question to consider is whether other species or methods of sampling could be used. *C. gigas* no longer lives in the Estuary (although it once did). Transplanting organisms into bags placed on the bottom of the Estuary, which is not their natural habitat, may cause unnatural bioaccumulation patterns. Perhaps resident/native bivalves, such as *Ostrea lurida*, should be used, since they would have integrated their lifetime exposure and do not exhibit the large seasonal fluctuation in body burdens due to their different reproductive strategy as brooders. Another candidate resident species that has been used by USGS is *Potamocorbula amurensis* (see Luoma and Linville, this report).

Resolving these questions will no doubt require some pilot studies to determine the best design.

Quantification of Trace Element Measurement Errors in Bioaccumulation Studies Associated with Sediment in the Digestive Tract

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Introduction

As far back as the late 1960s, research indicated that contamination of biological samples by ingestion of sediment may cause significant measurement errors (Martin, 1969; Bertine and Goldberg, 1972; Martin and Knaur, 1973; Flegal and Martin, 1977). Despite this recognition, however, many individual studies and even large-scale monitoring programs have failed to include analysis of elements characteristic of lithogenic material to account for potential artifacts. Particularly those programs that are concerned with quantifying the bioavailable portion of various trace elements for purposes of water pollution trend evaluations may be impacted by this oversight.

Lobel *et al.* (1991a) determined that the amount of sediment in the intestinal tracts of caplin (*Mallotus villosus*) was highly correlated with the concentrations of a number of metals, especially aluminum, manganese, and iron. They concluded that metals bound to sediment in the intestinal tracts of marine organisms can interfere with the determination of the true level of metals incorporated into the organism's tissue and may result in an overestimation of true tissue concentrations. Moreover, in cases where bivalves are used to integrate contaminant levels in the water column over time and to assess the "bioavailable" portion of the contaminant spectrum the organism is exposed to, sediment artifacts may cause problems in interpreting bioaccumulation results.

Although references to measurement artifacts are numerous, we have found no published reports that attempted to estimate the magnitude of error for a variety of trace elements, particularly those that are toxic to aquatic life or humans and of interest to environmental managers. Quantifying the exact contribution of intestinal sediment to the proportion of toxic trace elements found in the organism as a whole would require separate analyses of sediment-free organisms and intestinal sediment. Obviously, this exercise would prove logistically difficult and tedious at best. Another approach, taken by Stephenson (1992), would be to compare tissue concentrations of depurated bivalves with those of undepurated ones, but as Flegal and Martin (1977) point out, even purged animals still contain significant amounts of lithogenic material in their digestive tracts. In this study, we used a third approach, suggested by Lobel *et al.* (1989, 1991), whereby aluminum, as an element known to be of lithogenic origin and shown not to be incorporated into bivalve tissue, was used as surrogate for sediment in the intestinal tract of bivalves. An important consideration in this approach is that either the surrogate trace element concentration in the particulate fraction of the water column is known or, at a minimum, the concentration in sediment near the bivalve deployment site. The San Francisco Estuary Regional Monitoring Program for Trace Substances (RMP) has collected data since 1994 that enabled us in this present study to estimate the magnitude of bioaccumulation measurement error associated with intestinal sediment for ten trace elements of concern.

Sediment and bivalve bioaccumulation sampling and analyses were conducted by the RMP using methods described in Appendix A.

The following formula was applied to adjust tissue concentrations in bivalves based on their aluminum concentrations:

$$\frac{TE_{biv} - Al_{biv}/(Al_{sed}/TE_{sed})}{1 - (Al_{biv})(1/Al_{sed})} = TE_{tis}$$

where

TE_{biv} is the trace element concentration in the bivalve (tissue and ingested sediment)

Al_{biv} is the aluminum concentration in the bivalve (assumed to be in ingested sediment only)

Al_{sed} is the aluminum concentration in sediment

TE_{sed} is the trace element concentration in sediment, and

TE_{tis} is the trace element concentration in tissue only, without the portion associated with sediment in the digestive tract.

Current measurements assume that trace element concentrations in undepurated bivalves are equal to "real" tissue concentrations that factor out the contribution of trace elements associated with ingested sediment (TE_{biv} is equal to TE_{tis}). This hypothesis is easily tested with this fairly large data set involving three species of bivalves at six stations in the Estuary for four different deployment periods (wet and dry seasons of 1994 and 1995).

Results

After applying the correction equation listed above, results of uncorrected and corrected tissue concentrations are depicted in Figure 23.

The most striking differences occurred in the case of lead (Figure 23). Interestingly, at three stations in 1995, the corrected values were negative, indicating that the contribution of lead contained in ingested sediment accounted for all of the lead measured in the animals. Ingested sediment appears to contribute heavily to the total lead concentrations measured in all three species of bivalves. Two metals known to be strongly associated with suspended solids—chromium and nickel—also showed some indication of a positive bias in uncorrected bivalve concentrations, but much less consistently than lead. After pooling results from all species, chromium and nickel show significant differences between corrected and uncorrected values. When species data were pooled, arsenic, cadmium, and selenium also showed significant differences between corrected and uncorrected bivalve concentrations. However, these differences were much less pronounced and less consistent between years and species than for the other elements listed above. Also, unlike lead, chromium, and nickel, corrected concentrations for arsenic, cadmium, and selenium were slightly higher than uncorrected concentrations, suggesting that sediment in the intestinal tract "dilutes" the tissue signal to some extent. Somewhat surprisingly, mercury, which also is strongly associated with sediment particles, showed differences between corrected and uncorrected bivalve concentrations only in 1994, after concentration results from all three species were pooled. Corrected and uncorrected mercury concentrations of individual species, when examined separately, were not significantly different. Bivalve mercury concentrations closely resemble those in nearby sediment, indicating that total mercury is not biomagnified by bivalves.

Silver was the only trace element that showed no significant difference between corrected and uncorrected values for all four deployment periods and all species. Corrected copper concentrations were only statistically different from uncorrected values in mussels, and after pooling results from all three species, no differences were apparent. The same results applied to zinc.

Discussion

At first glance, measurement artifacts seem to be pervasive for a majority of RMP trace elements. Differences in the trace element uptake characteristics between species and amount of ingested sediment at different stations seem to influence the magnitude of measurement errors. Although statistically significant differences were found between corrected and uncorrected bivalve concentra-

Figure 23. The original (blue) and 'corrected' (black) bioaccumulation results. Units are in mg/kg.

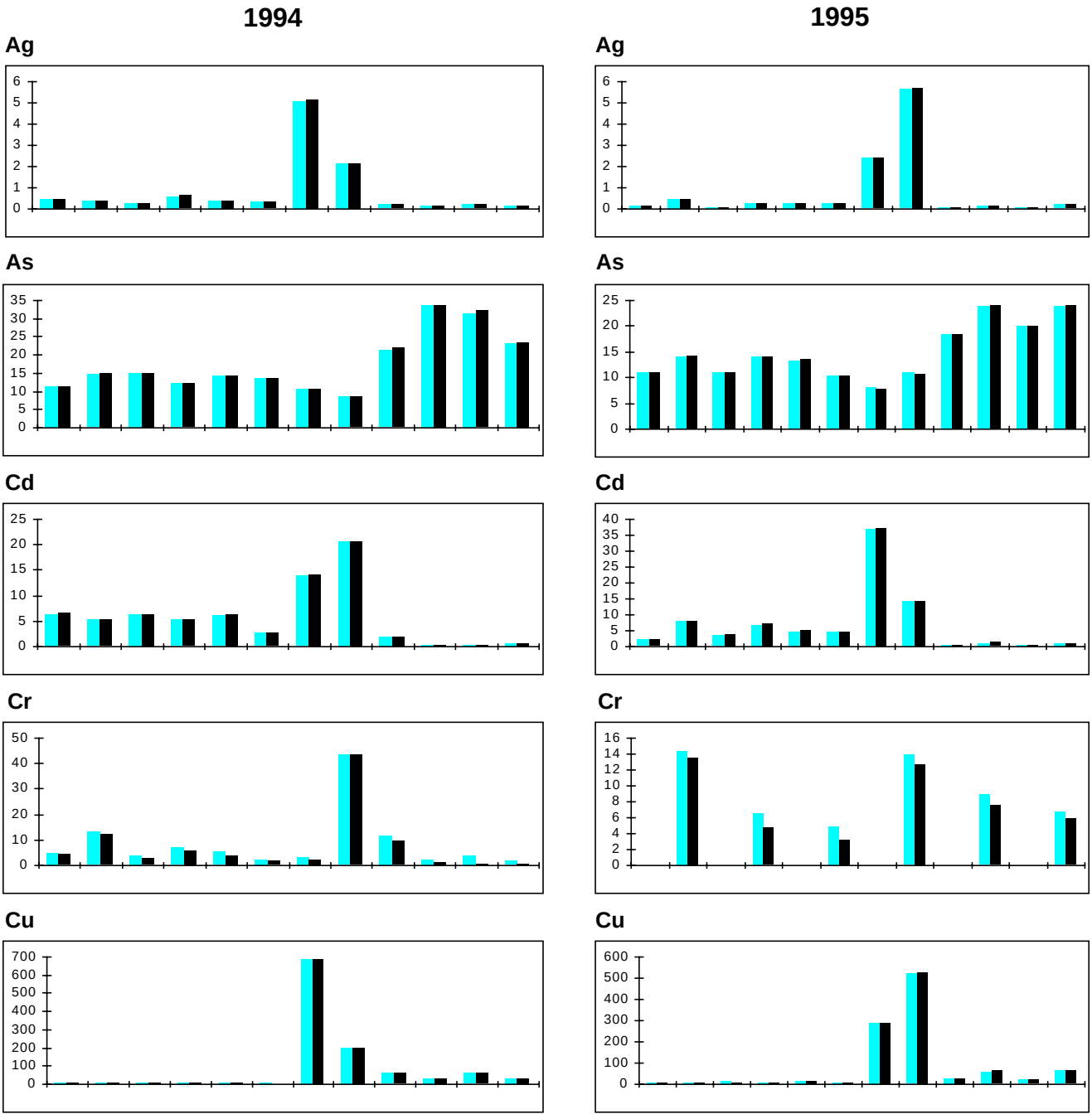
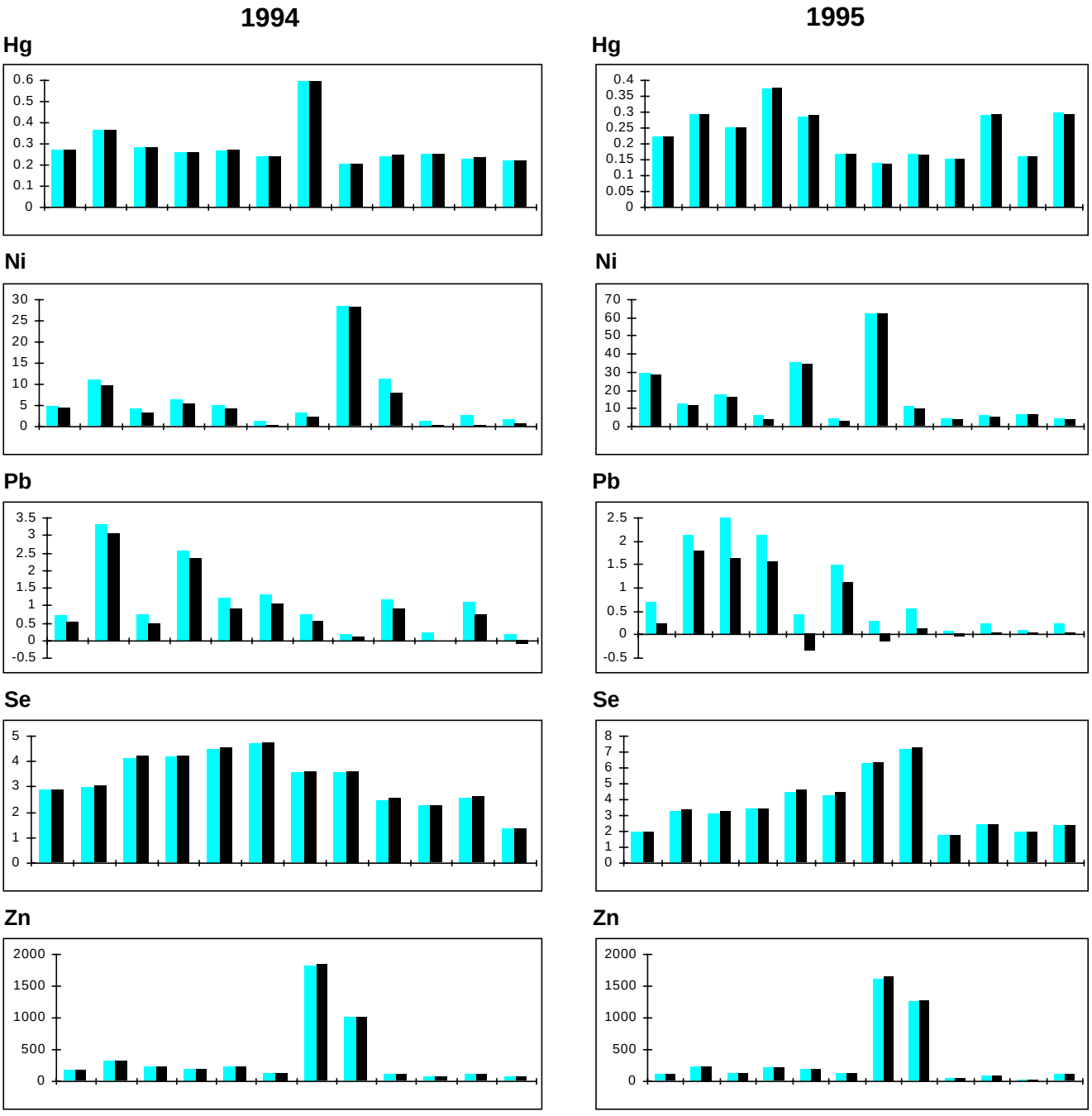


Figure 23 (continued). The original (blue) and 'corrected' (black) bioaccumulation results. Units are in mg/kg.



tions, they do not appear to be of a magnitude that would impair data interpretation, with the exception of lead and possibly chromium and nickel. For lead, differences were substantial and have implications with respect to how much lead is actually bioavailable. Apparent bioaccumulation factors for lead, calculated by dividing bivalve concentrations after the 90-day deployment periods by the initial bivalve concentrations at reference sites, seem to be heavily influenced by sediment in the intestinal tract (see Figure 5). This is consistent with findings by Stephenson (1992) who compared mussels depurated in clean Granite Canyon seawater with undepurated ones and found statistically significant differences for lead.

The somewhat surprising finding that certain trace elements show statistically higher tissue concentrations after factoring out the lithogenic material in the gut may be spurious. However, the fact that those elements that are not affiliated with suspended sediments (notably arsenic, cadmium, and selenium) exhibit higher corrected values, may indicate that "true" tissue concentrations are disproportionately higher than those contained in the gut sediments. For these elements, the bioavailable portion may actually be underestimated if correction factors are not applied.

Bivalve Monitoring Discussion

The primary purpose of the bivalve bioaccumulation component of the Regional Monitoring Program 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 varying concentrations during the three-month deployment period that are reflected in their tissues. Together with bioaccumulation studies conducted by dischargers near waste water outfalls, this type of monitoring is also useful in determining potential differences between reference sites and those close to a discharge point (see Arnold and Haskins, this report) and helps in evaluating general pollution source categories or pinpointing pollution hot spots.

Time series of bivalve concentrations starting in 1993 are depicted in Figures 24–36. 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 any of the contaminants, and quantitative relationships of bivalve concentrations with key environmental factors should be established so that the influence of non-contaminant factors can be removed statistically.

Trace Elements

As a whole, tissue trace element concentrations in the Estuary were generally comparable between the three years investigated so far. Table 6 shows average trace element concentrations statewide (State Mussel Watch) and in the Estuary (RMP) from 1991 to 1995. Because of the varying seasonal and annual salinity levels in the Estuary, and resulting use of three different species of bivalves that have different contaminant uptake characteristics, it is difficult under the current design to compare individual stations over time. Especially in the Northern Estuary, and to a lesser degree in the South Bay, freshwater inflows and hydrologic conditions determine which bivalve species survives and can be used for bioaccumulation measurements. The extremely wet year of 1995 limited the number of stations where mussels survived to those located primarily in the Central Bay and South Bay, thus limiting the ability to interpret any spatial gradients.

Species differences in bioaccumulation potential seem to be consistent from year to year, independent of the location. Oyster tissue contains similar levels of most contaminants compared to mussels and clams prior to deployment in the Estuary, with the exception of silver and zinc, which are higher than in the other two species, and lead, which is higher in mussels. However, the three-year RMP database suggests that the bioaccumulation potential for oysters is considerably higher than for the other two species in the case of copper, silver, selenium, and zinc, while mussels accumulate lead to a greater extent than the other two species. This is consistent with previous findings by O'Connor (1992) and Stephenson (1992).

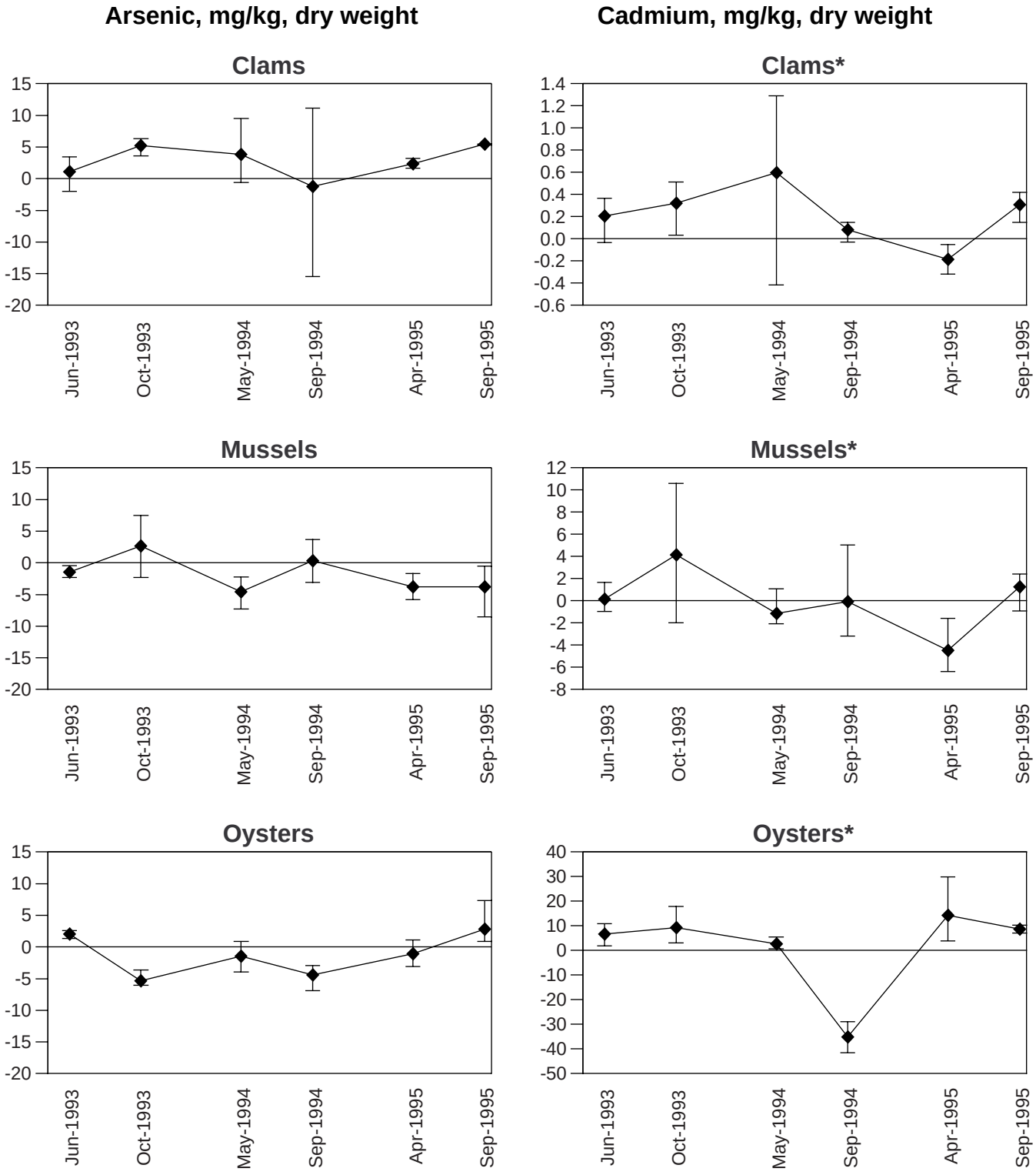
Unlike in previous years, lead and nickel were the only trace metals that accumulated substantially above background concentrations (between two and thirty-three times) in all three species during their deployment in the Estuary (see Figures 5 and 7). Lead bioaccumulated at all Estuary stations, and nickel at all but one. Arsenic and mercury showed no appreciable differences in pre-and post-deployment tissue concentrations. Cadmium, chromium, copper, selenium, silver, and zinc increased over reference concentrations between two and nine 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

Table 6. Average trace element concentrations in bivalve tissue statewide and in the Estuary, 1991–1995. State Mussel Watch data are the average of all samples, statewide.
Units are ppm (µg/g) dry weight. n = number of samples.

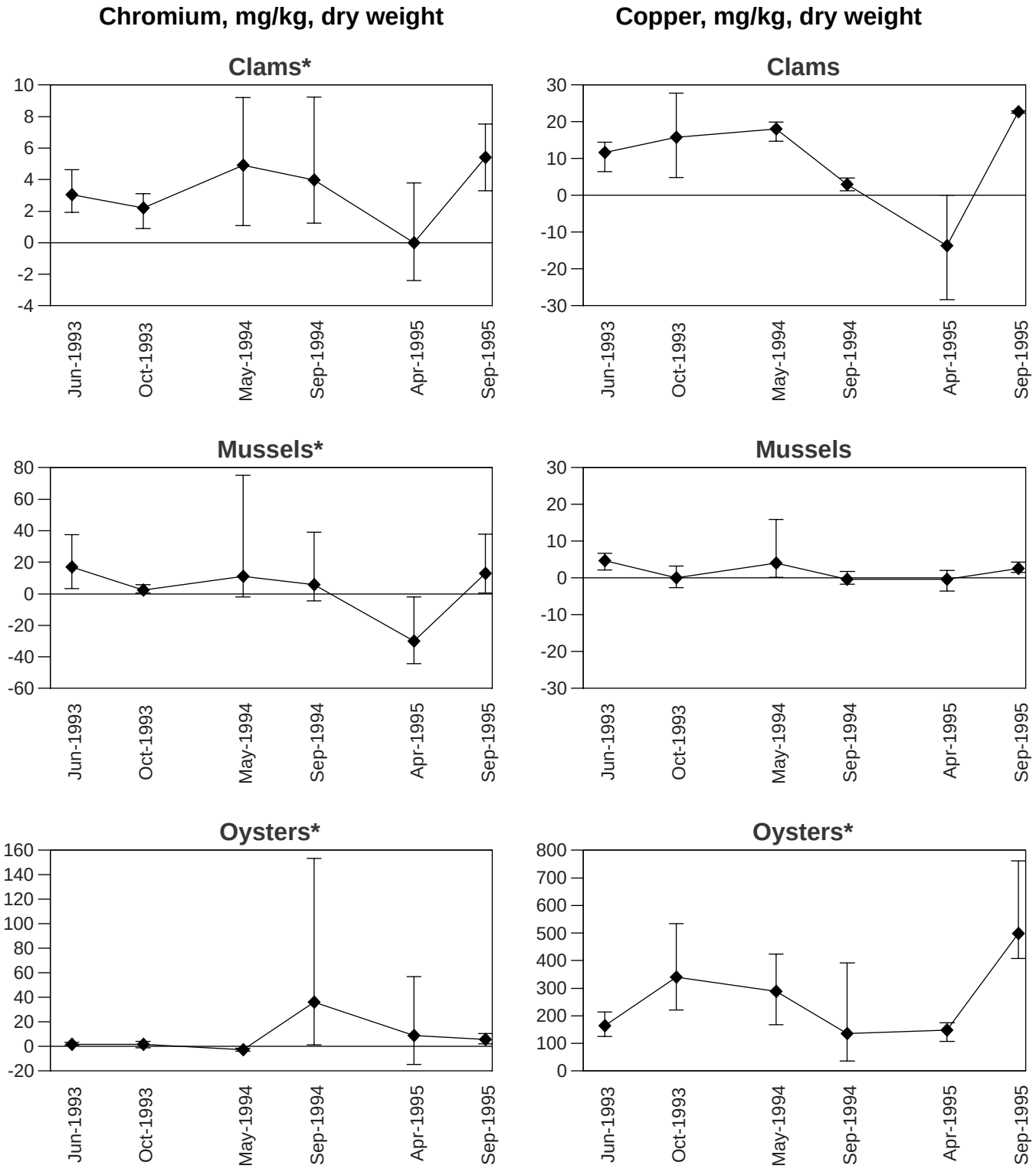
Metal	RMP Pilot 1991 *Corbicula fluminea* Average n=26	Min.	Max.	RMP 1993 *Corbicula fluminea* Average n=6	Min.	Max.	RMP 1994 *Corbicula fluminea* Average n=6	Min.	Max.	RMP 1995 *Corbicula fluminea* Average n=7	Min.	Max.	State Mussel Watch (87–93) *Corbicula fluminea* Average n=64	Min	Max
Ag	0.4	0.2	0.6	0.1	0.1	0.3	0.2	0.1	0.4	0.1	0.1	0.2	0.2	0.0	0.8
Al	3920.0	790.0	7050.0				543.2	79.0	983.9	333.7	103.6	534.2	1423.5	37.8	8000.0
As	9.0	6.0	12.0	15.6	10.6	18.6	23.4	6.8	33.4	21.0	18.3	23.8	8.6	4.8	15.8
Cd	2.7	2.4	2.9	0.6	0.1	1.0	0.8	0.2	1.9	0.7	0.3	1.0	6.4	0.4	110.0
Cr	19.6	8.2	31.0	5.7	1.4	10.2	5.8	1.7	11.5	6.7	4.6	8.8	12.5	0.4	61.0
Cu	65.0	45.0	85.0	39.0	29.1	55.5	42.8	27.8	58.1	43.7	17.1	60.1	78.0	27.5	250.0
Hg	0.3	0.2	0.4	0.2	0.2	0.3	0.2	0.2	0.3	0.2	0.1	0.3	0.3	0.1	1.8
Ni	68.5	41.0	96.0	5.2	2.3	7.8	5.2	1.3	11.1	6.0	3.2	9.2	8.7	1.4	26.0
Pb	1.5	0.7	2.4	0.7	0.4	1.1	0.7	0.2	1.2	0.3	0.1	0.5	1.2	0.1	7.1
Se	3.1	3.0	3.1	3.0	1.7	4.2	2.2	1.4	3.0	2.0	1.4	2.9	4.3	2.1	9.6
Zn	160.0	120.0	200.0	101.2	62.0	126.6	84.6	57.0	114.6	70.3	29.1	96.0	160.0	74.0	470.0

Metal	RMP Pilot 1991 *Crassostrea gigas* Average n=24	Min.	Max.	RMP 1993 *Crassostrea gigas* Average n=7	Min.	Max.	RMP 1994 *Crassostrea gigas* Average n=11	Min.	Max.	RMP 1995 *Crassostrea gigas* Average n=8	Min.	Max.
Ag	6.8	4.3	8.3	1.8	0.7	3.0	5.1	0.7	9.1	4.0	2.2	6.3
Al	635.0	390.0	950.0				259.2	90.0	484.0	442.2	262.0	870.8
As	6.8	5.5	9.0	8.1	6.2	10.7	8.9	5.0	13.0	9.8	5.6	16.4
Cd	8.0	6.1	9.8	13.7	5.1	25.3	13.0	7.9	20.5	18.3	10.6	36.5
Cr	3.6	1.1	6.0	3.5	1.2	6.4	21.9	1.7	154.8	8.8	5.3	13.9
Cu	286.6	180.0	420.0	334.6	154.9	634.2	406.0	188.0	683.6	431.2	218.0	867.1
Hg	0.2	0.1	0.3	0.3	0.2	0.3	0.3	0.1	0.6	0.2	0.1	0.3
Ni	71.4	49.0	95.0	2.7	0.8	4.5	15.7	1.3	113.0	15.5	4.3	62.2
Pb	0.8	0.5	1.6	0.7	0.2	1.5	0.6	0.2	1.0	0.5	0.2	1.3
Se	3.5	2.7	4.3	5.0	2.0	8.3	3.4	1.9	5.2	6.8	4.0	11.0
Zn	3687.8	900.0	21002.0	1244.4	554.6	2646.5	1428.9	764.0	3268.0	1422.6	1207.0	2050.0

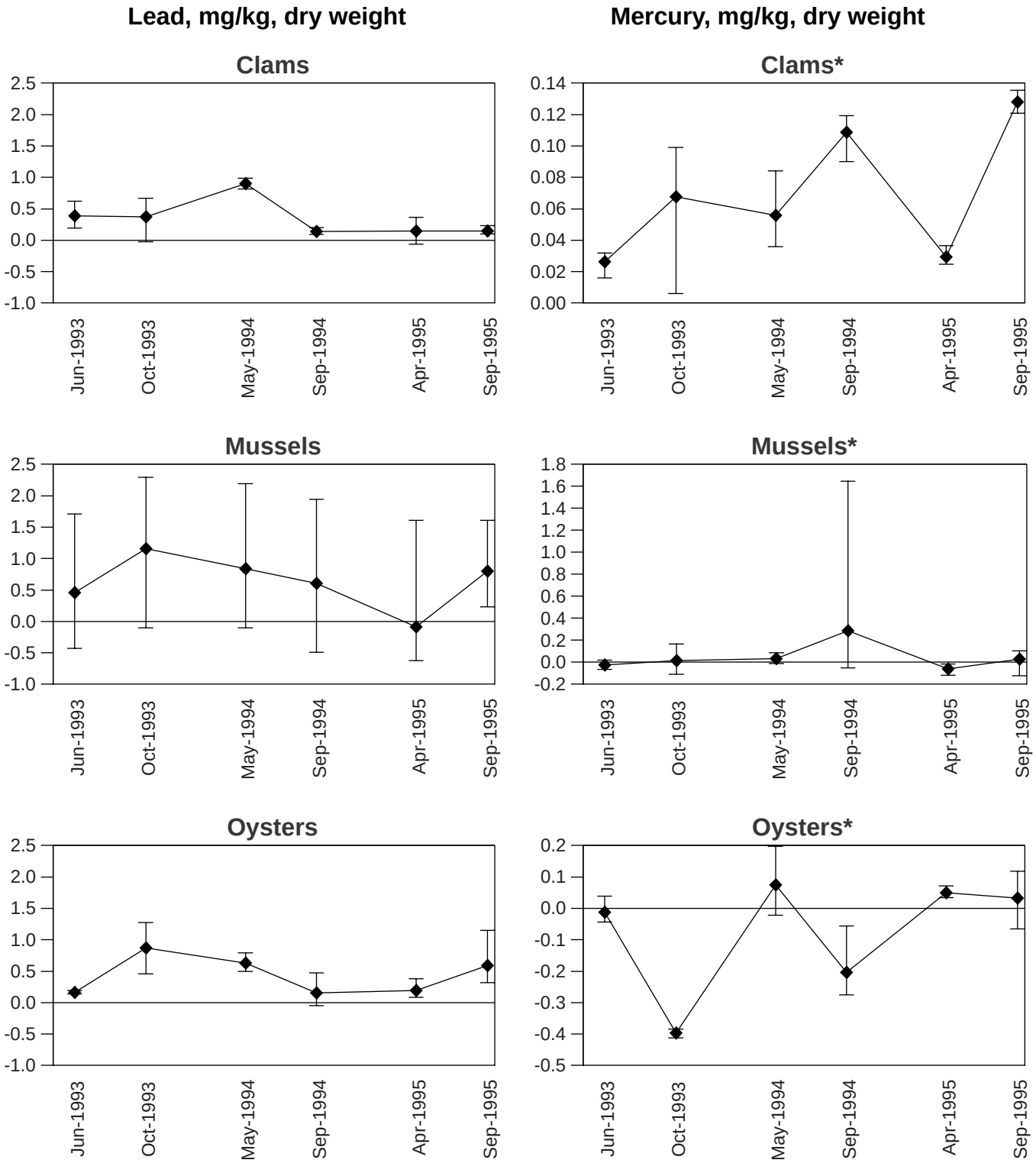
Metal	RMP Pilot 1991 *Mytilus californianus* Average n=30	Min.	Max.	RMP 1993 *Mytilus californianus* Average n=12	Min.	Max.	RMP 1994 *Mytilus californianus* Average n=6	Min.	Max.	RMP 1995 *Mytilus californianus* Average n=13	Min.	Max.	State Mussel Watch (87–93) *Mytilus californianus* Average n=432	Min	Max
Ag	0.2	0.1	0.5	0.5	0.0	1.1	0.4	0.2	0.7	0.2	0.1	0.4	0.3	0.0	2.9
Al	1530.6	640.0	2000.0				433.1	103.0	1199.1	538.7	250.0	1042.3	611.2	15.0	3200.0
As	8.5	7.7	10.0	11.6	7.2	18.6	12.1	7.9	15.2	13.2	9.1	18.3	9.5	4.3	14.0
Cd	9.1	7.0	12.0	8.6	1.4	19.5	5.9	1.8	10.0	5.5	2.1	7.9	7.6	1.3	24.0
Cr	8.0	2.2	19.0	11.1	2.6	40.9	14.7	2.1	80.9	17.2	4.8	42.2	4.3	0.5	170.0
Cu	10.7	7.0	13.0	5.9	2.7	8.6	7.5	3.4	22.0	8.7	6.5	12.2	26.1	4.4	303.7
Hg	0.3	0.2	0.3	0.3	0.2	0.5	0.4	0.2	1.9	0.3	0.2	0.4	0.2	0.0	1.5
Ni	29.7	20.0	54.0	9.3	3.0	28.9	11.4	1.3	64.4	20.4	4.5	50.7	2.4	0.7	6.2
Pb	2.6	1.8	3.9	2.2	0.0	4.2	1.8	0.6	3.3	1.5	0.3	2.9	5.0	0.1	47.5



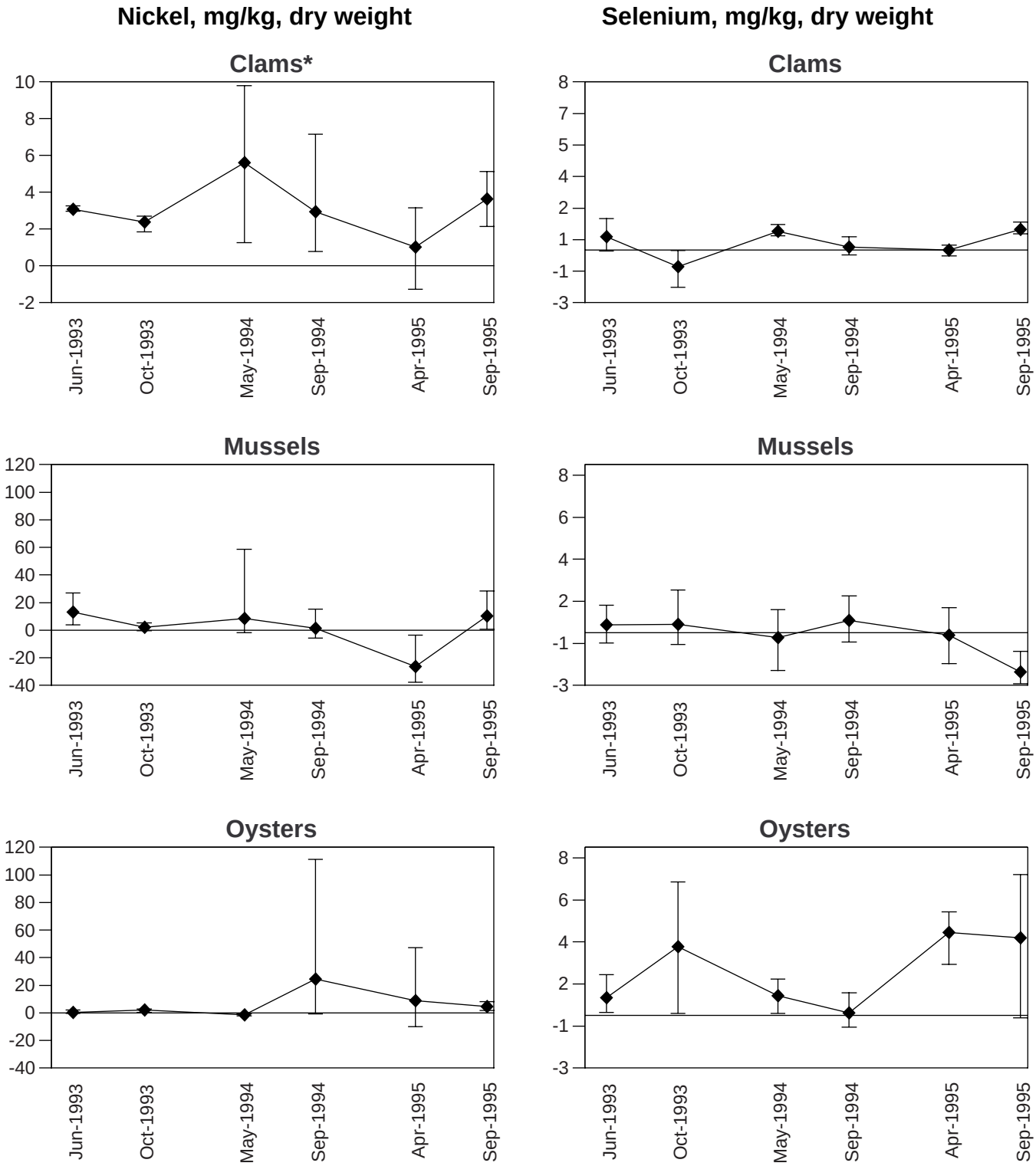
Figures 24 and 25. Arsenic and cadmium accumulation or depuration in parts per million, dry weight (ppm) in three species of transplanted bivalves for six sampling periods from 1993–1995. Initial (T-0) concentrations are subtracted from tissue concentrations after retrieval to give concentrations accumulated or depurated (negative value) during deployment in the Estuary. Bars indicate the range of values of all stations where species were deployed. Note different scales (*).



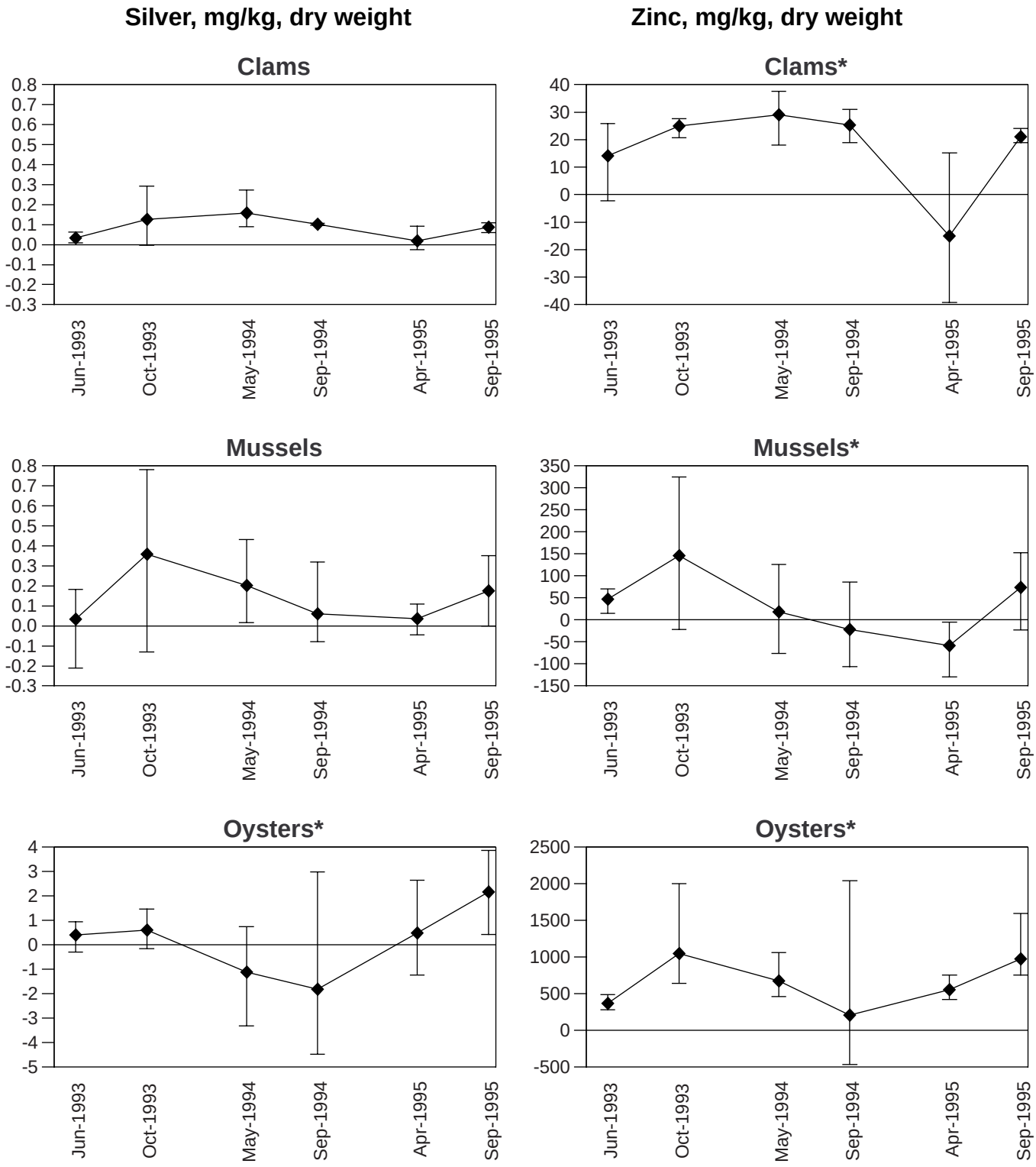
Figures 26 and 27. Chromium and copper accumulation or depuration in parts per million, dry weight (ppm) in three species of transplanted bivalves for six sampling periods from 1993–1995. Initial (T-0) concentrations are subtracted from tissue concentrations after retrieval to give concentrations accumulated or depurated (negative value) during deployment in the Estuary. Bars indicate the range of values of all stations where species were deployed. Note different scales (*).



Figures 28 and 29. Lead and mercury accumulation or depuration in parts per million, dry weight (ppm) in three species of transplanted bivalves for six sampling periods from 1993–1995. 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 scales (*).



Figures 30 and 31. Nickel and selenium accumulation or depuration in parts per million, dry weight (ppm) in three species of transplanted bivalves for six sampling periods from 1993–1995. 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 scale (*).



Figures 32 and 33. Silver and zinc accumulation or depuration in parts per million, dry weight (ppm) in three species of transplanted bivalves for six sampling periods from 1993–1995. 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 scales (*).

any of the three species at any station since the inception of the RMP. Chromium, copper, lead, nickel, and zinc, the same metals as in the previous two years, showed much higher tissue concentrations in the Estuary than at the reference locations. Silver was accumulated to a lesser degree, with remarkably similar spatial patterns as in the previous two years.

It is interesting to note that no signal from the high mercury loads suspected to have been transported into the Estuary via the Guadalupe River, possibly from mobilization of mine tailings (see Arnold and Haskins, this report), was observable in bivalve tissue at any of the South Bay stations (see Figure 6), despite the unusually high sediment concentrations of 1.1 ppm and 2.9 ppm seen at the San Jose/Sunnyvale Local Effects Monitoring station (C-1-7) in February and June, respectively. Clams deployed in Grizzly Bay (BF20) and the River Stations (BG20, BG30) also did not reflect the large mercury loads that were transported via the Yolo Bypass into the Estuary during periods of high runoff in 1995 (Chris Foe, CVRWQCB, personal communication).

Trace Organic Contaminants

Bivalves accumulate many trace organic contaminants to a much larger degree than trace elements, particularly the lipophilic compounds. For some 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. Especially for the chlorinated compounds, but also for PAHs, the observed bioaccumulation left no doubt that these contaminants were taken up in the Estuary.

Total PCBs were uniformly lower in 1995 compared to the year before, although this was much less pronounced at the River stations (Figures 13 and 35). Seasonal differences in PCBs were less pronounced than in 1994, although many of the chlorinated pesticides showed distinct seasonal differences at most stations. Particularly elevated wet-season concentrations were observed at the Coyote Creek station for DDTs, chlordanes, and dieldrin, possibly implicating runoff as a source, despite the fact that these chlorinated pesticides have long been banned. In 1996, the RMP launched a Watershed Pilot Study to test this hypothesis, and preliminary data show that, indeed, sediment samples taken at the upper end of the tidal prism of Coyote Creek proper contain much higher chlorinated pesticide concentrations than adjacent Bay sediments. These data will be discussed in detail in the 1996 Annual Report. PAH concentrations in the Estuary were much more variable between seasons, without any consistent patterns.

Broad spatial patterns, such as those observed in 1994 for PCBs, did not hold in 1995. In 1994, the South Bay had uniformly higher concentrations of many PCB congeners than the other reaches, while in 1995, only the Coyote Creek station, but none of the other South Bay stations, showed consistently higher tissue levels than all others. As in 1994, the Petaluma River station exhibited elevated concentrations of most trace organic contaminants, but here too, the signal was more muted compared to the previous year. The mixture of PAHs, although not individual concentrations, was again fairly uniform throughout the Estuary, suggesting multiple inputs via urban runoff or direct aerial deposition.

Comparison with Guidelines

For this report, a more comprehensive summary of applicable tissue concentration guidelines was tabulated than last year, 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 7). This table summarizes threshold contaminant concentrations for human consumption of fish and shellfish. None of these guidelines are ideal for comparisons for reasons outlined below. It should be kept in mind that these guidelines were developed for a variety of purposes and do not have any regulatory implications.

Table 7. Commonly used tissue guidelines for trace contaminants. Converted to dry weight using a multiplication factor of 7.

	Unit	MTRL[1] (fish, shellfish & drinking water) Dry weight	Great Lakes[2] (fish) Dry weight	SFRWQCB[3] Pilot Study (fish) Dry weight	NAS[4] Recommended Guideline (fresh water shellfish) Dry weight	FDA[5] (fresh & marine shellfish) Dry weight	MIS[6] (shellfish) Dry weight
Arsenic	mg/kg	1.4*			.	.	9.8
Cadmium	mg/kg	4.48*		2.3	.	.	7.0
Chromium	mg/kg	.			.	.	7
Copper	mg/kg	.			.	.	140
Lead	mg/kg	.			.	.	14
Mercury	mg/kg	7		0.14	.	7	3.5
Nickel	mg/kg	1540 / 196*			.	.	.
Selenium	mg/kg	.		11.67	.	.	2.1
Zinc	mg/kg	.			.	.	490
Aldrin	µg/kg	2.31 / 0.35*			.	2100	.
Alpha-HCH	µg/kg	11.9 / 3.5*			.	.	.
Beta-HCH	µg/kg	42 / 12.6*			.	.	.
Dieldrin	µg/kg	4.9 / 4.55*		10.5	.	2100	.
Endrin	µg/kg	22400 / 21000*		4900	.	2100	.
Gamma-HCH	µg/kg	56.7 / 17.5*			.	.	.
Heptachlor	µg/kg	13.3 / 12.6*			.	2100	.
Heptachlor Epoxide	µg/kg	5.6		18.2	.	2100	.
Hexachlorobenzene	µg/kg	42		102.2	.	.	.
Sum Chlordanes	µg/kg	8.4 / 7.7*		125.3	.	.	.
Sum DDTs	µg/kg	224		480.2	7000	.	.
Total Endosulfan	µg/kg	3500 / 1750*		24500	.	.	.
Total PAHs	µg/kg	6.51 / 0.56*			.	.	.
Total PCBs (Aroclors)	µg/kg	15.4	1470–7000	21	3500	14000	.

* Values are MTRLs for inland surface waters (fresh water).

[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 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] SFRWQCB Pilot Study from: Contaminant Levels in Fish Tissue from San Francisco Bay, Final 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 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)

The San Francisco Regional Water Quality Control Board conducted a pilot study entitled "Contaminant Levels in Fish Tissue from San Francisco Bay" (SFRWQCB, 1995) in which they developed Pilot Study Screening Values which have received extensive public and scientific review. Although fish tissue guidelines are not necessarily applicable to shellfish, they are included, because they identify potential chemicals of concern and are based on fairly recent toxicological and exposure information. 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 rates and a standard weight of 70 kg (the weight of an average male adult). The Pilot Study Screening Values were calculated based on the EPA Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories (US EPA, 1993) using a consumption rate of 30 g per day (rather than the EPA rate of 6.5 g/day), and the Great Lakes guideline was based on a consumption rate of 7.4 g per day. Only in rare cases is the consumption rate of shellfish expected to approach the same levels as those for fish.

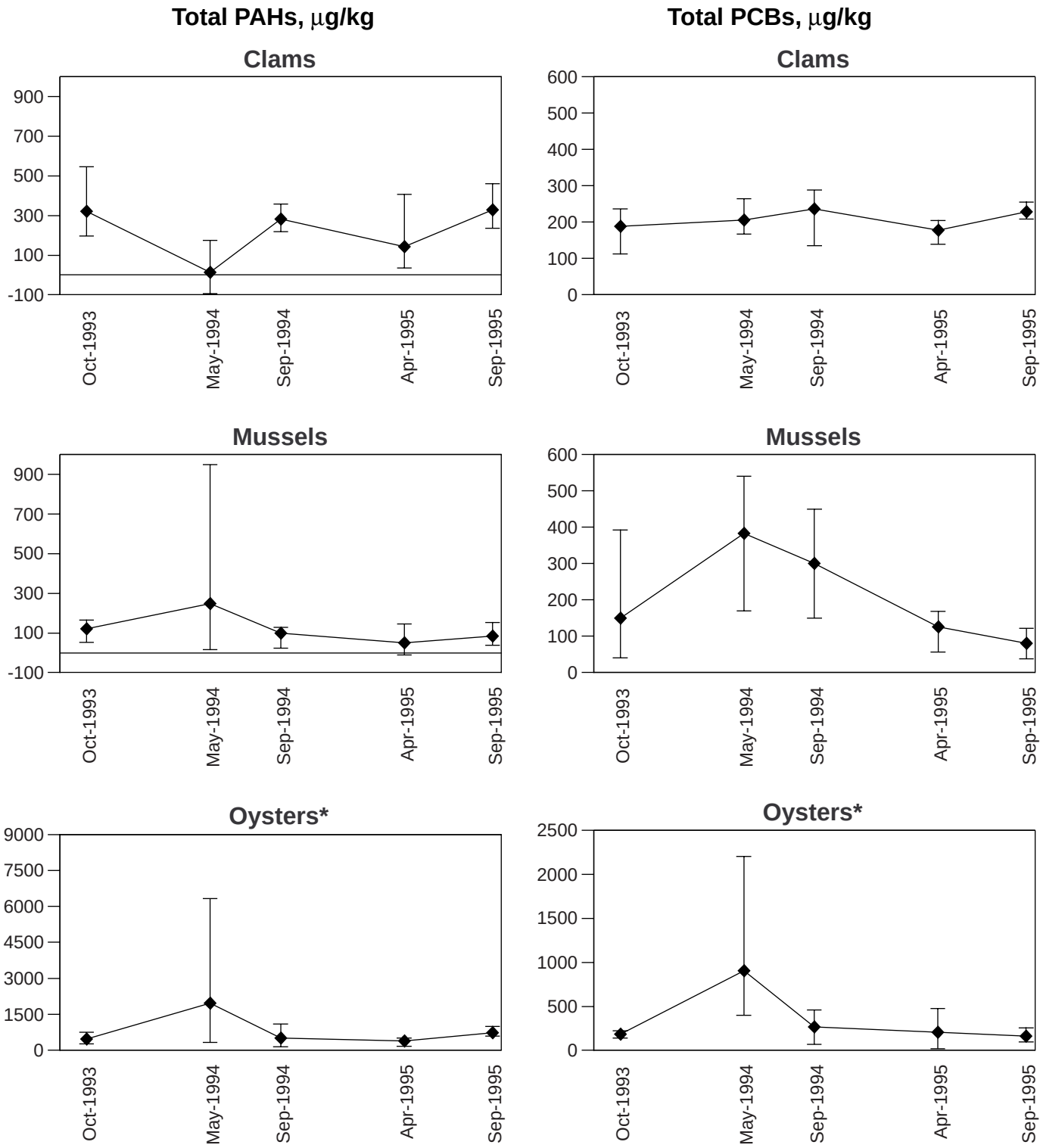
Median International Standards (MIS), while applicable to shellfish, are based on fairly outdated information. MIS have a varying degree of toxicological and exposure information associated with them, and are generally considered of low value to health risk managers. MIS were compiled by the United Nations based on a survey of health protection criteria used by member nations (Nauen, 1983). The MIS do not apply within the United States but indicate what other nations consider to be elevated concentrations of trace elements in shellfish.

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 an assessment tool only and are extremely conservative. For example, even at clean background sites, MTRLs are exceeded for dieldrin and arsenic.

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. As with the MIS, these guidelines are quite outdated (NAS, 1973) and are primarily applicable to marine fish. Only two guidelines apply to freshwater clams.

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.

Because MTRLs are the most recent guidelines applicable to seafood in general, the 1995 report only uses these criteria for comparison purposes. Arsenic, cadmium, nickel (freshwater only), and mercury are the only trace elements for which MTRLs apply, and, with the exception of arsenic, bivalve tissue concentrations were far below the threshold level for each of these elements. It should be noted, however, that the MTRL for arsenic is exceeded even at the uncontaminated control site at Lake Isabella. As in the previous years, most of the trace organic compounds analyzed by the RMP for which MTRL guidelines exist were higher than their respective threshold levels. Table 8 summarizes the exceedances of guidelines for the three bivalve species. The same patterns as in the previous years occurred, with the Coyote Creek station (BA10) during the wet season and the Rivers during both wet and dry seasons showing levels consistently above the MTRLs for most pesticides. PCB and PAH tissue levels were consistently far above MTRLs throughout the Estuary. Once the database is sufficiently large, bioaccumulation data may be compared



Figures 34 and 35. Total PAHs and total PCBs accumulation or depuration in parts per million, dry weight (ppm) in three species of transplanted bivalves for six sampling periods from 1993–1995. 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 scales (*).

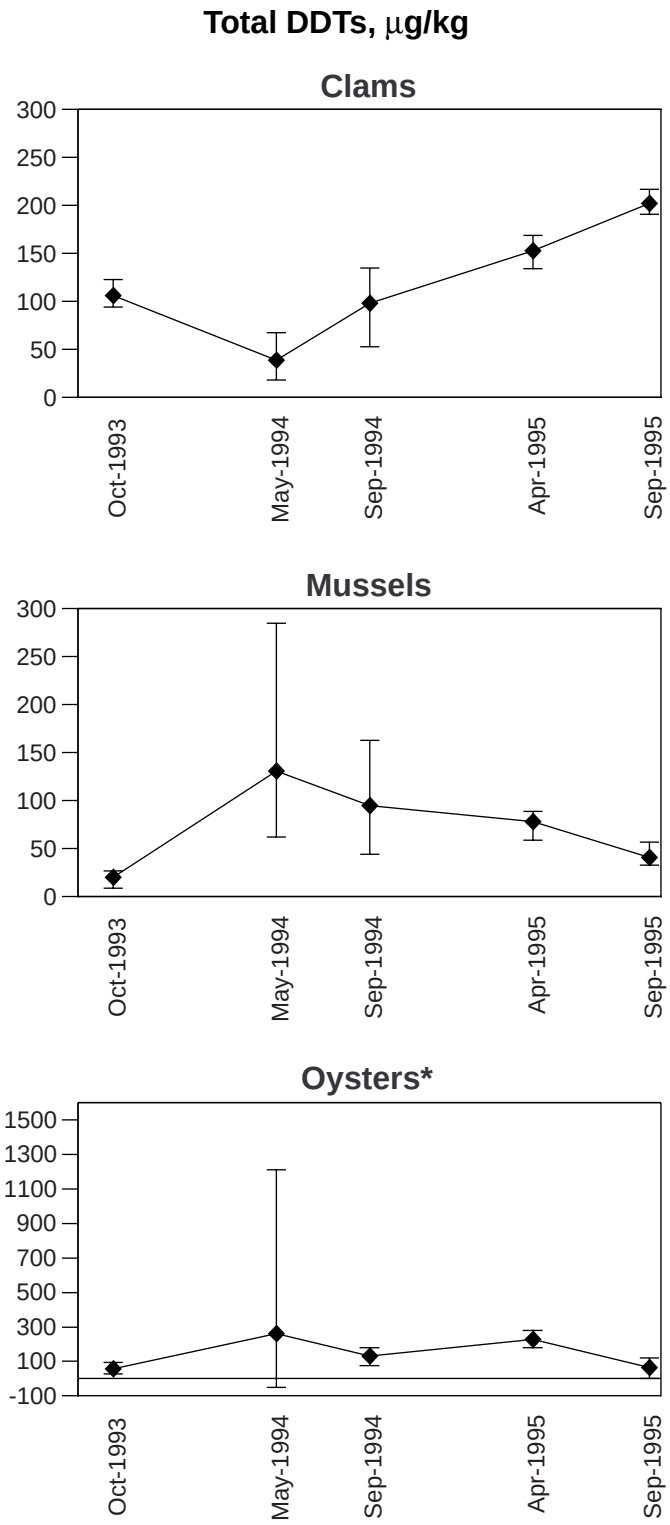


Figure 36. Total DDTs accumulation or depuration in parts per million, dry weight (ppm) in three species of transplanted bivalves for six sampling periods from 1993–1995. Initial (T-0) concentrations are subtracted from tissue concentrations after retrieval to give concentrations accumulated or depurated (negative value) during deployment in the Estuary. Bars indicate the range of values of all stations where species were deployed. Note different scales (*).

Table 8. Summary of contaminants that were above the MTRLs at each 1995 RMP bioaccumulation sampling station. W = Wet season (February - April), D = Dry season (June – August), - = not above guideline, * = not available or not sampled. Species: CGIG—*Crassostrea gigas*, CFLU—*Corbicula fluminea*, MCAL—*Mytilus californianus*.

			Aldrin	Dieldrin	Heptachlor Epoxide	Sum Chlordanes	Sum DDTs	Total PAHs	Total PCBs
	MTRL Guideline		2.31	4.9	5.6	8.4	224	6.51	15.4
Station Name	Code	Species	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
Lake Isabella	T-0	CFLU	-,-	-,-	-,-	W,-	-,-	W,D	W,-
Dabob Bay, WA (Wet), Tomales Bay (Dry)	T-0	CGIG	-,-	-,-	-,-	-,D	-,-	W,D	-,D
Bodega Head	T-0	MCAL	-,-	W,-	-,-	W,-	-,-	W,D	W,-
Coyote Creek	BA10	CGIG	-,-	W,-	-,-	W,D	W,-	W,D	W,D
Dumbarton Bridge	BA30	MCAL	-,-	W,D	-,-	W,D	-,-	W,D	W,D
Redwood Creek	BA40	MCAL	-,-	W,D	W,-	W,D	-,-	W,D	W,D
Alameda	BB71	MCAL	-,-	W,D	-,-	W,D	-,-	W,D	W,D
Yerba Buena Island	BC10	MCAL	-,-	W,D	-,-	W,D	-,-	W,D	W,D
Horseshoe Bay	BC21	MCAL	-,-	W,D	-,-	W,-	-,-	W,D	W,D
Red Rock	BC60	MCAL	-,-	W,D	-,-	W,-	-,-	W,D	W,D
Petaluma River	BD15	CFLU/CGIG	-,-	W,-	-,-	W,D	-,-	W,D	W,D
San Pablo Bay	BD20	CGIG	-,*	W,*	-,*	W,*	-,*	W,*	W,*
Pinole Point	BD30	MCAL	*,-	*,D	*,-	*,D	*,-	*,D	*,D
Davis Point	BD40	CGIG	-,-	W,D	-,-	W,D	-,-	W,D	W,D
Napa River	BD50	CGIG	-,-	W,-	-,-	W,D	-,-	W,D	W,D
Grizzly Bay	BF20	CFLU	-,D	W,D	-,-	W,D	W,-	W,D	W,D
Sacramento River	BG20	CFLU	-,-	W,D	-,-	W,D	-,D	W,D	W,D
San Joaquin River	BG30	CFLU	-,-	W,D	-,-	W,D	W,-	W,D	W,D

to a running mean of concentrations at RMP stations, rather than to guidelines.

Bivalve Condition and Survival

Survival and condition measurements are taken primarily to account for confounding factors that could affect bioaccumulation measurements and to determine if animals were capable of pollutant uptake. The causes for poor bivalve condition and low survival can be numerous, but are probably primarily related to the varying seasonal and year-to-year salinity regimes. However, the data indicate low survival at several sites (Figure 17) that does not appear attributable to salinity stress. High survival and good condition are not necessarily related, and different factors may 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). Similar to 1994, condition for each bivalve species was determined both at the beginning and the end of each deployment period in the Estuary and the control sites, in recognition of the fact that the bivalves' reproductive cycle noticeably influences the ratio of dry weight to shell volume, and without taking condition fluctuations into account at control sites, it is more difficult, if not altogether impossible to interpret changes in condition at the Estuary deployment sites. If condition decreases at the "clean" reference sites, i.e. decreases between T-0 and T-1 measurements, natural factors are presumed to be the likely causes. As an improvement to the 1994 program, the reference-site bivalves were treated the same as the Estuary transplants, i.e., they were bagged to control for handling factors that might influence the condition of the animals.

Oyster condition during the wet season deployment increased at the control sites (Bodega Marine Laboratory and Tomales Bay) between January and April, while oyster condition in the Estuary either significantly decreased or increased to a much lesser degree than controls. During the dry-season deployment, oyster condition remained essentially the same at the control sites, while oyster condition in the Estuary showed dramatic decreases, especially at the Coyote Creek and Petaluma River sites. Although causal relationships cannot be established without special follow-up studies, it is interesting to note that for the second year in a row, the two sites with the most elevated contaminant concentrations in tissue also showed pronounced condition index decreases.

Clam condition increased slightly at the Lake Isabella control site during the wet-season deployment, but decreased at all stations where they survived. Dry-season condition decreased at the control site, but dramatically more so in the Estuary.

Compared to controls, mussels improved their condition at all stations during the wet season, except at Red Rock (BC60), but showed approximately 20–45% reductions in condition during the dry season.

Any correspondence between contaminant concentrations in the water column or tissue and condition and survival may be spurious. However, because both survival and condition measurements are relatively straightforward, their usefulness as indicators of contamination should be explored with controlled laboratory experiments.

As a special study not funded by the RMP, Applied Marine Science began deploying the native oyster *Ostrea lurida* with the RMP bivalves during the wet-season cruise of 1995. The purpose of these deployments was to investigate the potential value of this resident native bivalve species for bioaccumulation studies in the Estuary and its possibly higher sensitivity to contaminants indicated by lower survival and decreased condition. At this point, not enough data have been accumulated to evaluate condition and survival response to contamination. However, it is clear that it survives well in salinities as low as 15 ppt, its low reproductive effort as a brooder, as opposed to broadcast spawners like *M. californianus* and *C. gigas*, reduces variability in contami-

nant body burdens and condition, and its small size facilitates deployment.

Condition and survival are not indicators of population-level effects, especially since bivalves are known to tolerate and survive contaminant levels far in excess of those observed in the water column of the Estuary. However, bivalve condition indices of the last three years are remarkably similar not only with respect to spatial patterns but also when comparing wet and dry seasons and the absolute index values. During the wet season, the Central Bay stations where mussels were deployed appear to promote healthy animals whose condition index actually increased relative to the reference site. Oyster condition was roughly comparable to reference sites during the wet season, and clam condition was always slightly lower than at the reference site. With the exception of Horseshoe Bay (BC21) and Yerba Buena Island (BC10), the condition index at all other stations decreased for all species during the dry season in 1995, and in 1994, condition decreased everywhere for all species. Natural environmental and physiological factors may play an important role in these highly consistent patterns, but year-to-year variation in condition indices has been much lower than for ancillary water quality parameters, such as salinity or total suspended sediments, and possible contaminant influences on condition should be investigated.

CHAPTER FIVE

Pilot and Special Studies

Background

In addition to the primary monitoring activities, the Regional Monitoring Program (RMP) also supports two other types of related activities: pilot studies and special studies.

Pilot studies employ methods that are under evaluation for potential incorporation into the RMP monitoring program. In 1995, two pilot studies were conducted: a Benthic Pilot Study started in 1994 and a Tidal Wetlands Pilot Study started in 1995. The Benthic Pilot results are reported in Chapter 3: Sediment Monitoring.

Special studies help improve interpretation or collection of RMP data. The results of a special study on analysis of trends in water trace elements is reported in Chapter 2: Water Monitoring. Continued studies on improved sediment bioassays using the amphipod *Ampelisca abdita* are reported in Chapter 3: Sediment Monitoring. A report of the workshop on ecological indicators of contaminant effects and the intercomparison exercise are included below.

Contamination in Tidal Wetlands

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Introduction

Wetlands have enormous popularity worldwide as centers for 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). In the United States, wetlands are notorious as arenas for testing the relations between environmental science and regulatory policy (Kusler, 1983), and there is a wealth of methodologies for conducting natural resource inventories that are based on wetlands studies (e.g., Cowardin *et al.*, 1979; FWS, 1989; Brinson, 1993; Ferren *et al.*, 1996).

The Bay Area public is concerned about wetlands. This concern 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; SF Bay Habitat Joint Venture, 1995; CALFED, 1996).

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 wetlands investigations that are based in different disciplines is an ongoing challenge, even when the investigators agree to be coordinated.

The challenge for coordination is well illustrated by the different approaches that have been used to study tidal marsh contamination and other aspects of marsh condition in the Bay Area. The few previous studies of tidal marsh contamination have adopted a very general definition of study sites, disregarding the variations in physiography and geomorphic controls within a marsh. 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. 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, sedimentation, and living resources of all kinds.

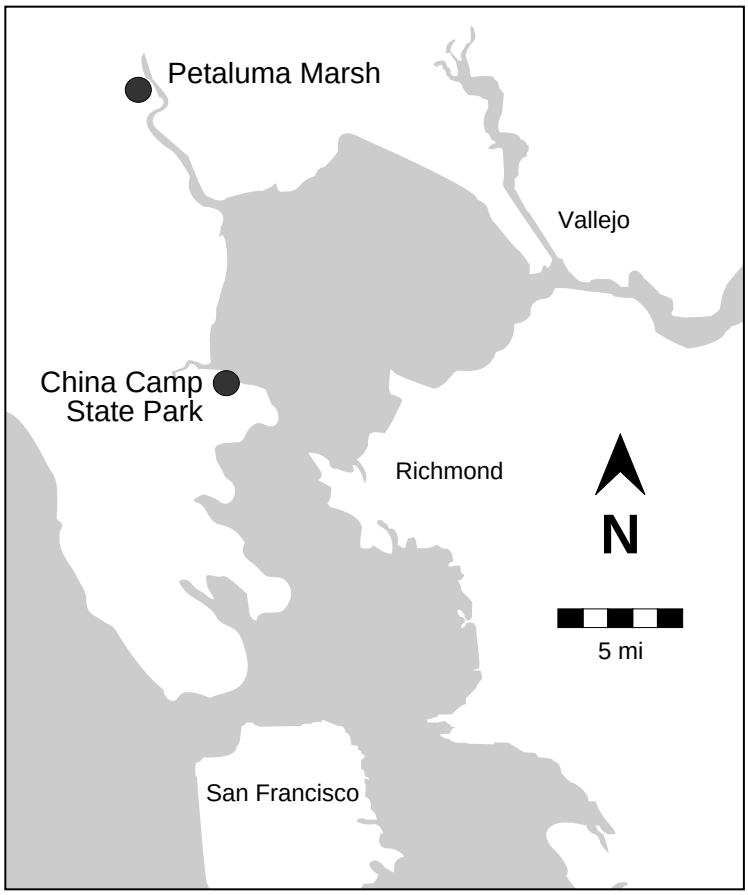


Figure 1. Location of RMP wetland sampling sites.

Because past studies of tidal marsh contaminants and ecological resources differ in sampling approach, there is poor spatial or temporal correspondence between data for contaminant concentrations and other descriptors of tidal marshland. For example, assessments of wildlife hazards and restoration success are less likely to use contaminant data because they are not related to specific habitats. In some cases, the problem relates to inexact records of sample site locations for contaminants, but more commonly the problem is due to inadequate spatial resolution of the contaminant sampling design. Use of similar sampling designs (e.g., having a standard stratification scheme) would help link together studies of tidal marsh contamination, hydrogeomorphology, and ecological function.

Now is the time to begin laying 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 sampling efforts. 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 help assure that the wetlands pilot can lead to a monitoring program for trace substances that yields comparable data for bays, wetlands, and watersheds, and that the wetlands data contribute to the local and regional expressions of wetlands condition.

- Develop equipment and train personnel to sample tidal marsh sediments for contaminant analysis. The methodology

should 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.

- Gain insight about the usefulness of natural tidal marsh physiography as a spatial template for sampling sediment contaminants within and among tidal marshes.

Sampling Plan

Field Locations

The RMP wetlands pilot was conducted in tidal marshlands at China Camp State Park in Marin County, and Petaluma Marsh in Sonoma County (Figure 1). 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) they are public with easy access, such that this new sampling effort is not complicated by logistical problems; (4) they contain areas 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 are logical geographic extensions of the existing RMP for bays.

Spatial Design

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.

The most obvious elements of the 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

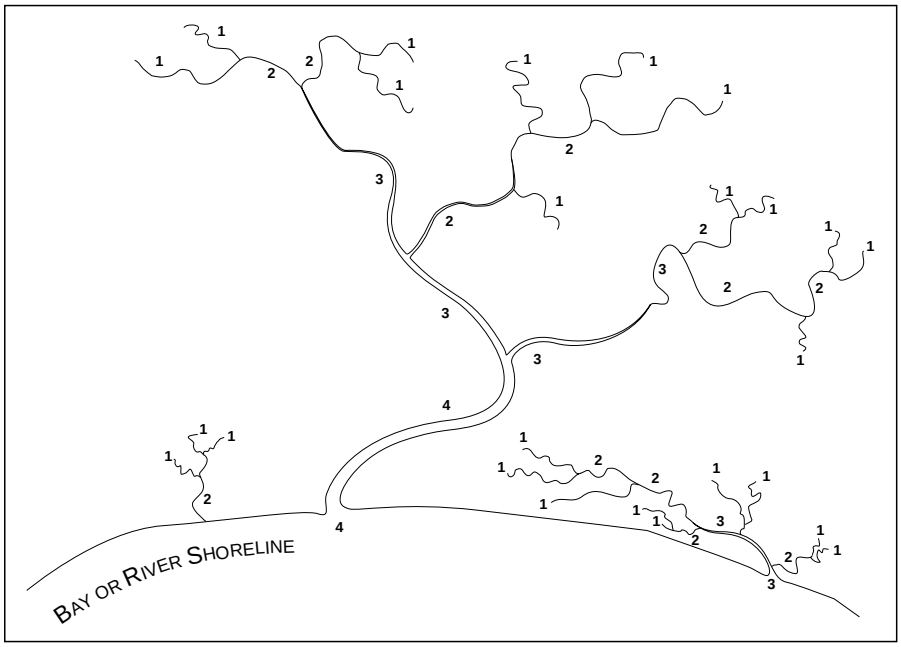


Figure 2. Wetland channel order classification.

(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 2). 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 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. Two typical third-order drainage networks were selected at each location, China Camp and Petaluma.

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.

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 from the sediment surface to a depth of 5 cm. The volume of a sample was therefore about 500 cm^3, which is comparable to the volume of an RMP subaqeuous in-bay sediment sample.

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 is common on the surface of recent slump blocks and the surface of actively accreting point bars on the inside of meander bends. The maximum sample depth of 5 cm did not extend into the black obvious 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.

Temporal Design

During 1995, samples were taken from the two replicate drainage divides and 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 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 the two replicate networks and drainage divides selected at Petaluma Marsh. Winter results for Petaluma Marsh suggest that the replicate drainage networks and 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.

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

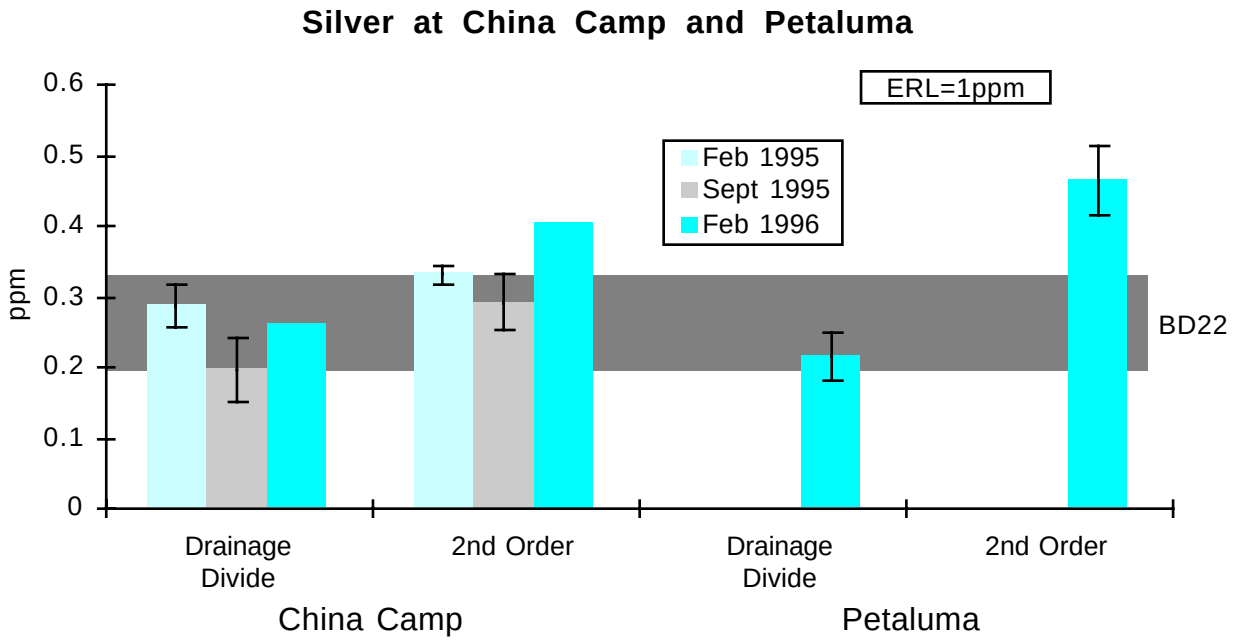
10% HCL, and finally rinsed with petroleum ether. The cleaned scoops were stored in sealed Ziploc® bags until used in the field. Following the detergent wash, the glass coring tubes and Teflon®-coated bucket were rinsed with tap water, followed by three rinses with deionized water, a rinse with 10% HCL, 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.

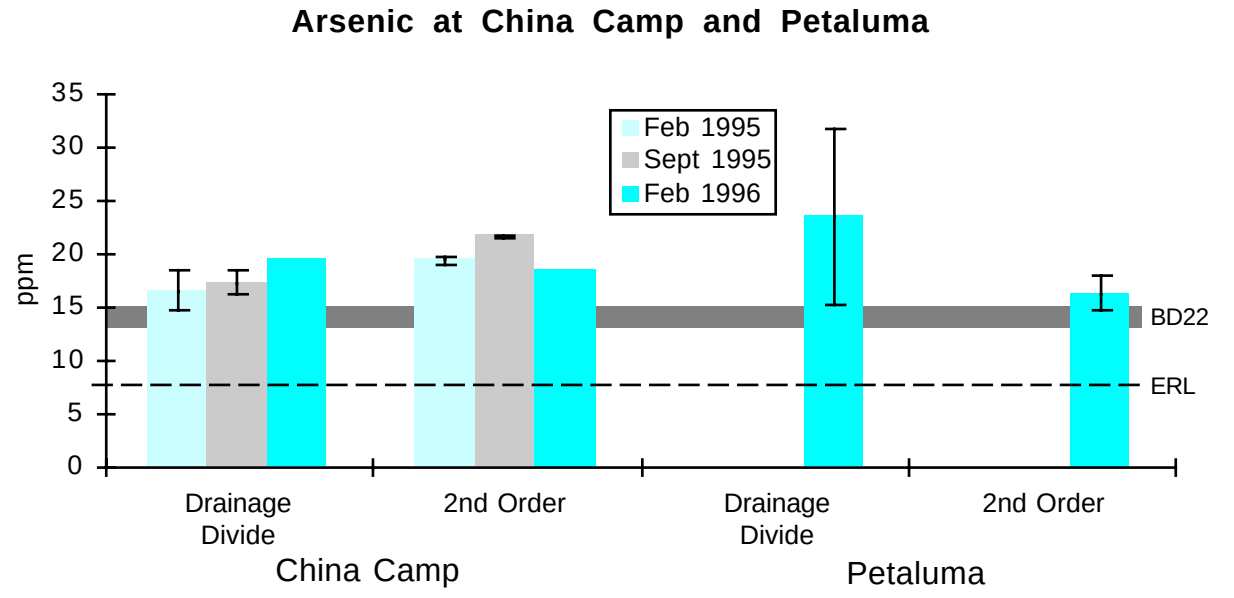
2. All samples were taken with a thick-walled, 2 m long glass tube, having an inside diameter of 5 cm.
3. For channel stations, sub-samples were randomly selected in unconsolidated fine-grain sediment below the exposed root zone of the bank vegetation and above the bed of the channel. For drainage divide 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. 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 10% HCL, and one rinse with methanol. Spent chemicals were bottled separately and disposed of properly.

Results

The data are available for trace metals and trace organics from samples taken at China Camp during the fall and winter 1995 RMP sampling periods and the winter 1996 sampling period, and at Petaluma Marsh for the winter 1996 sampling period. The data have been reduced for the comparable stations for second-order channels and drainage divides.

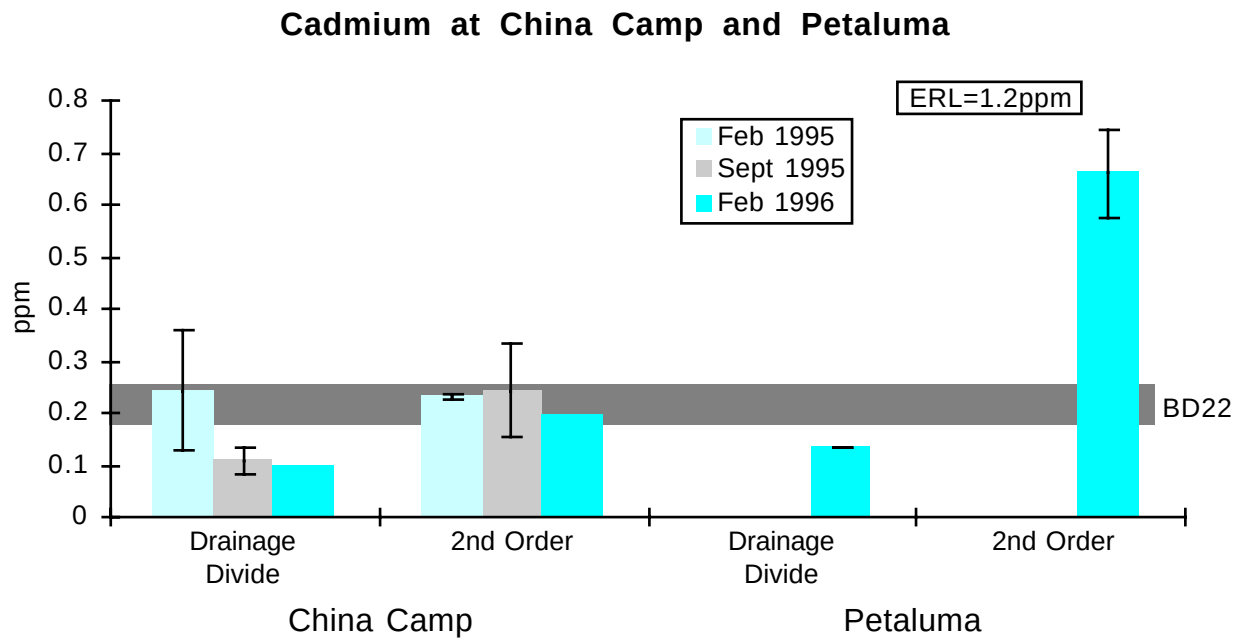
RMP Wetlands
Trace Elements 1995-1996

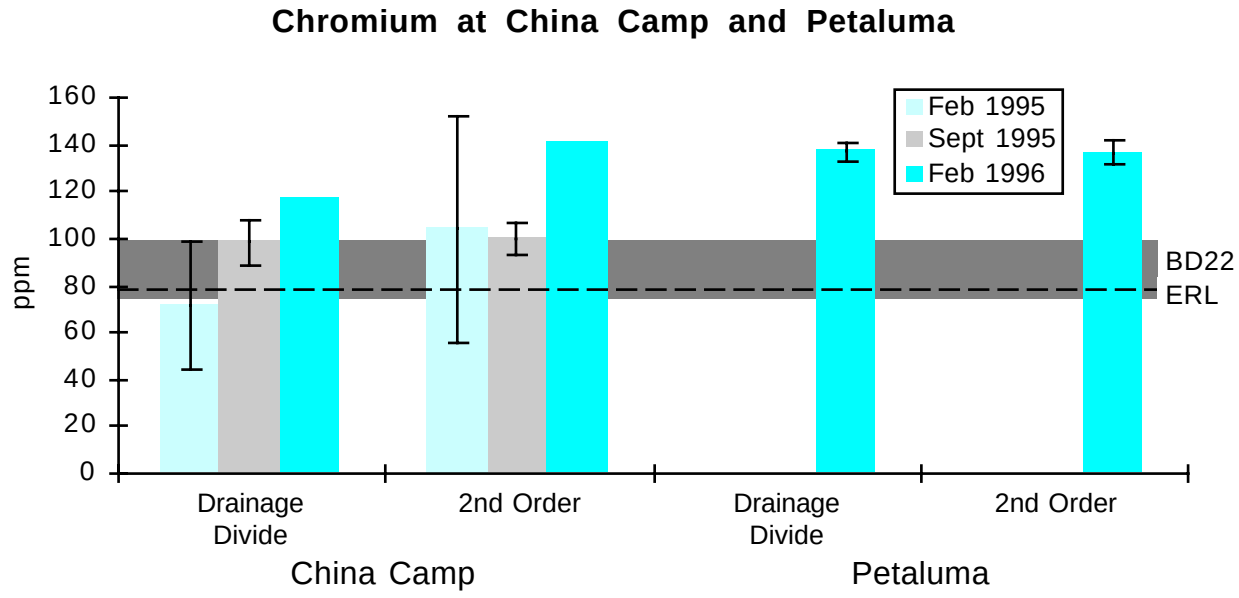




Figures 3 and 4. RMP wetlands trace element results. Data pooled among drainage systems. Only one drainage system measured at China Camp in February of 1996. Vertical bars indicate range between drainage systems. Grey band indicates range of bay sediment station BD22. ERL = effects range low; ERM = effects range median (see Chapter 3: Sediment Monitoring for an explanation).

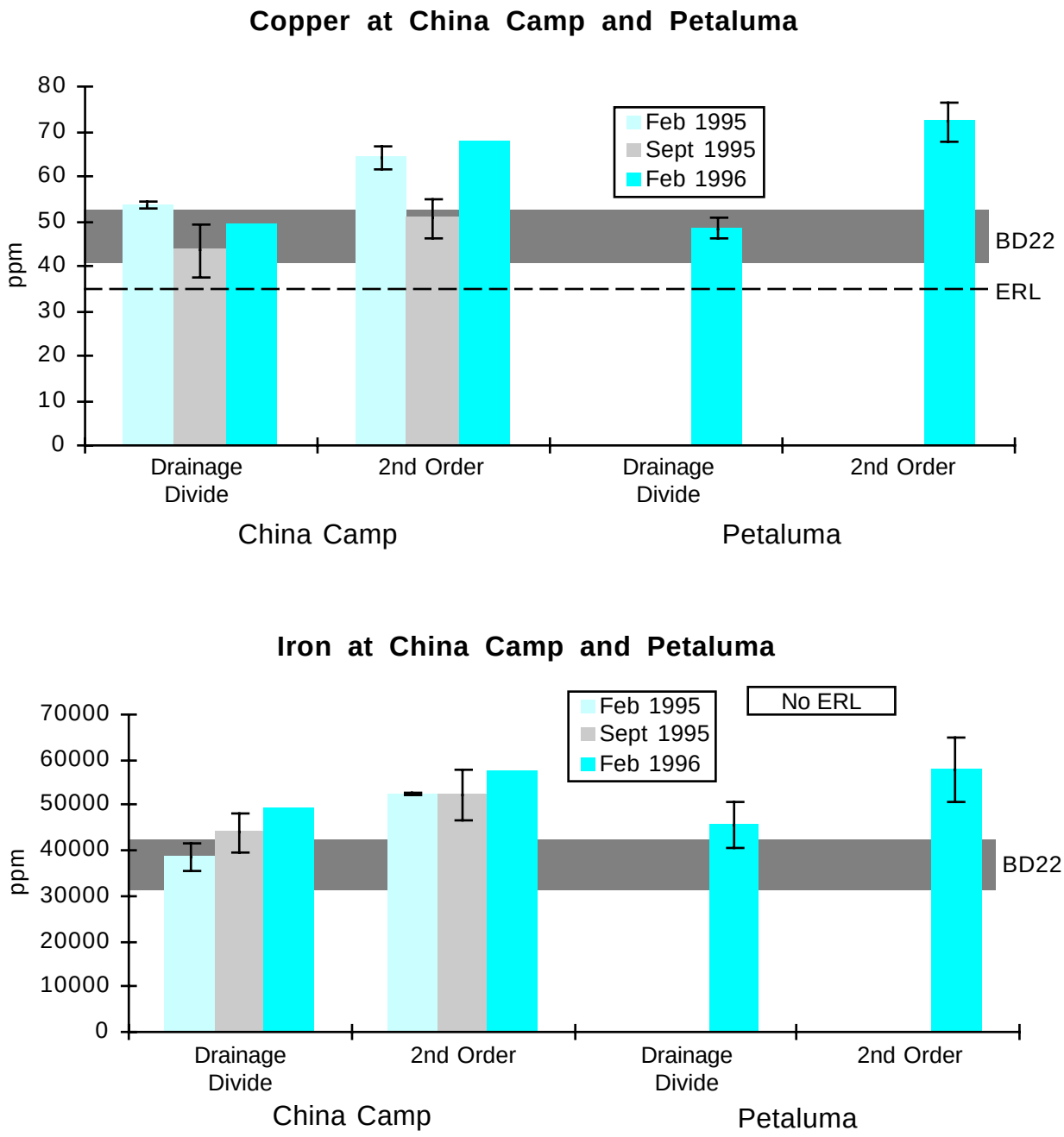
RMP Wetlands
Trace Elements 1995-1996





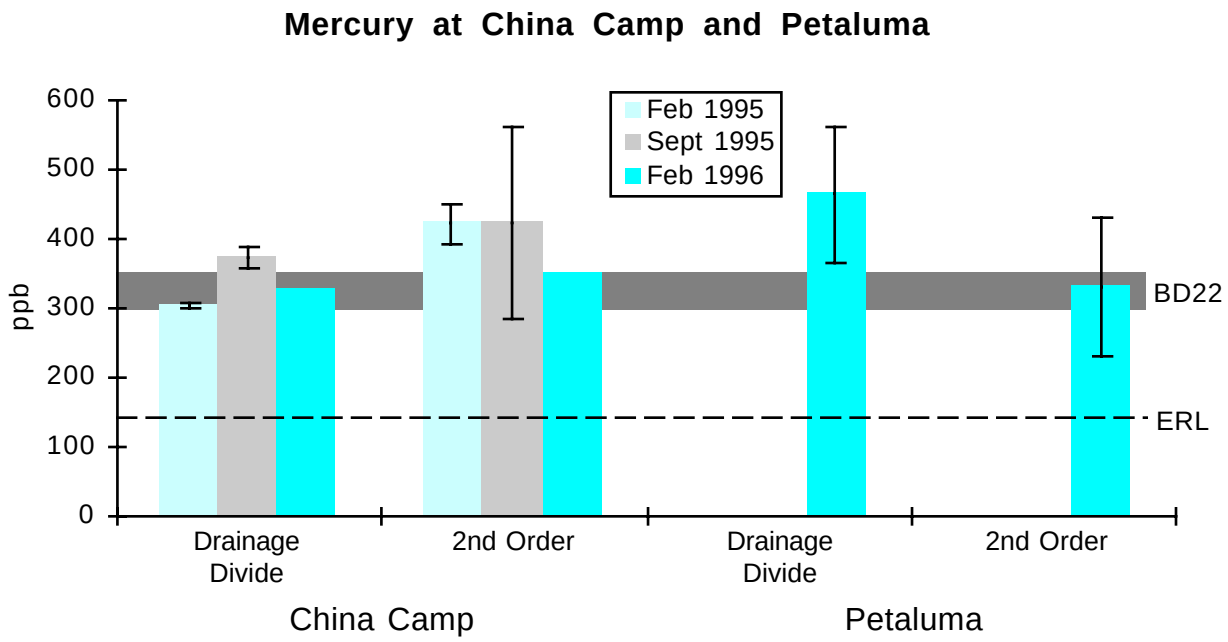
Figures 5 and 6. RMP wetlands trace element results. Data pooled among drainage systems. Only one drainage system measured at China Camp in February of 1996. Vertical bars indicate range between drainage systems. Grey band indicates range of bay sediment station BD22. ERL = effects range low; ERM = effects range median (see Chapter 3: Sediment Monitoring for an explanation).

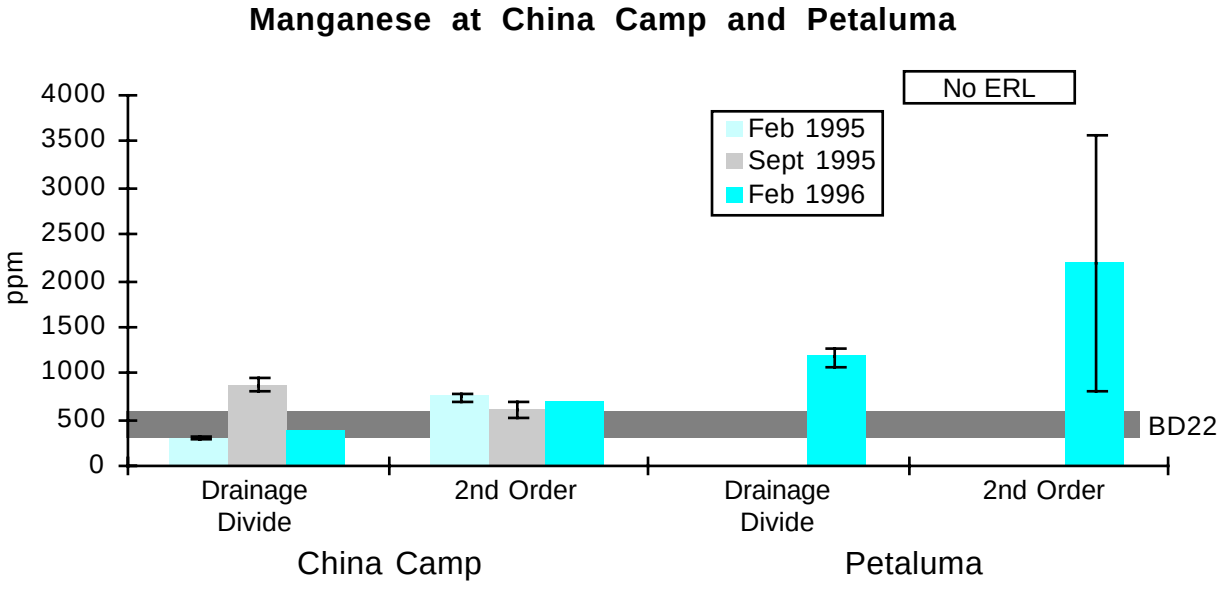
RMP Wetlands
Trace Elements 1995-1996



Figures 7 and 8. RMP wetlands trace element results. Data pooled among drainage systems. Only one drainage system measured at China Camp in February of 1996. Vertical bars indicate range between drainage systems. Grey band indicates range of bay sediment station BD22. ERL = effects range low; ERM = effects range median (see Chapter 3: Sediment Monitoring for an explanation).

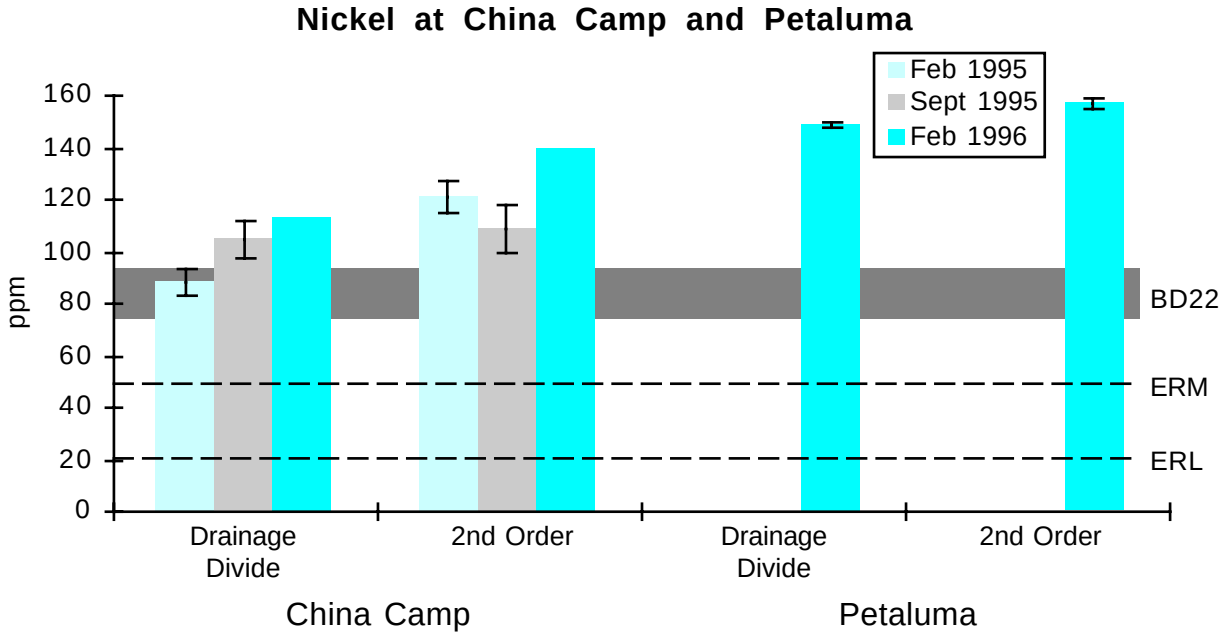
RMP Wetlands
Trace Elements 1995-1996

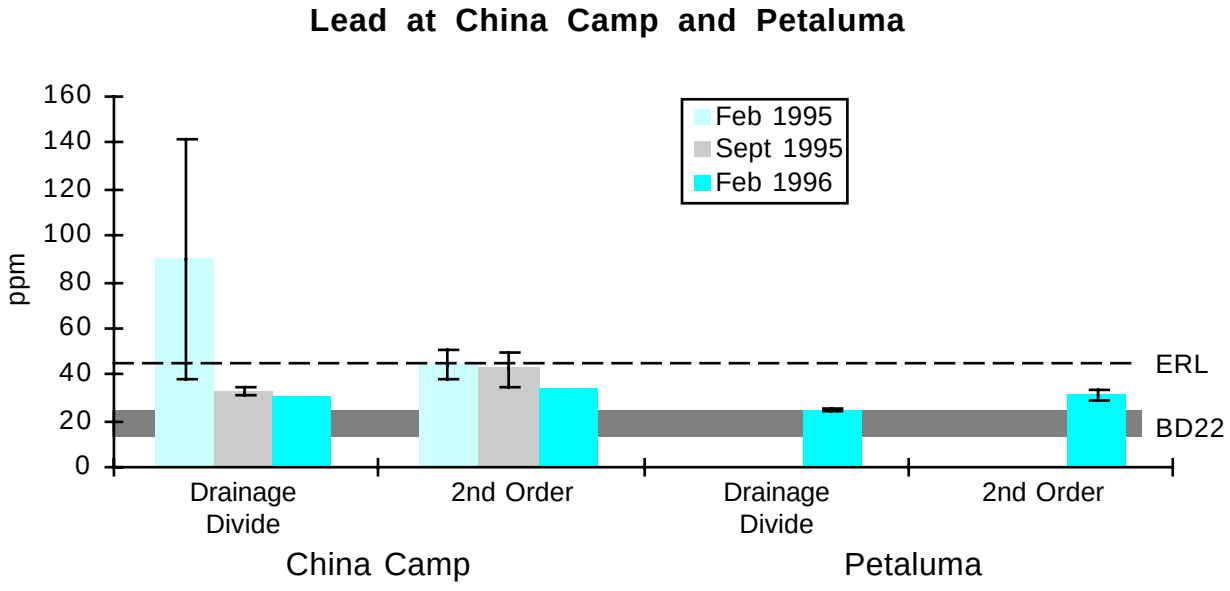




Figures 9 and 10. RMP wetlands trace element results. Data pooled among drainage systems. Only one drainage system measured at China Camp in February of 1996. Vertical bars indicate range between drainage systems. Grey band indicates range of bay sediment station BD22. ERL = effects range low; ERM = effects range median (see Chapter 3: Sediment Monitoring for an explanation).

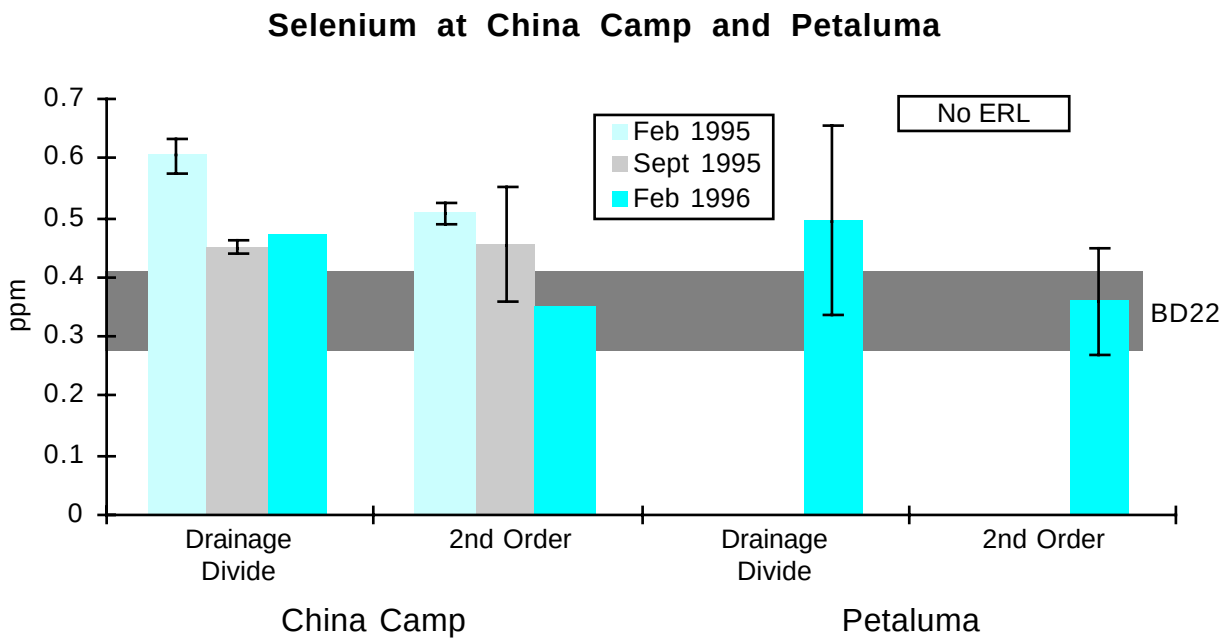
RMP Wetlands
Trace Elements 1995-1996

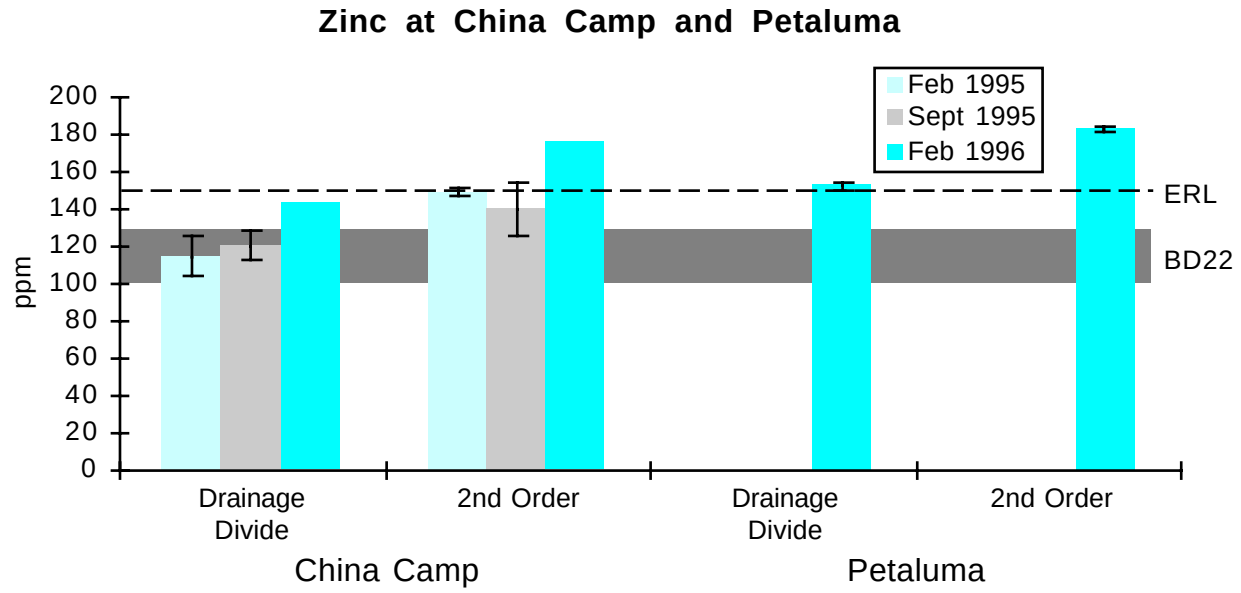




Figures 11 and 12. RMP wetlands trace element results. Data pooled among drainage systems. Only one drainage system measured at China Camp in February of 1996. Vertical bars indicate range between drainage systems. Grey band indicates range of bay sediment station BD22. ERL = effects range low; ERM = effects range median (see Chapter 3: Sediment Monitoring for an explanation).

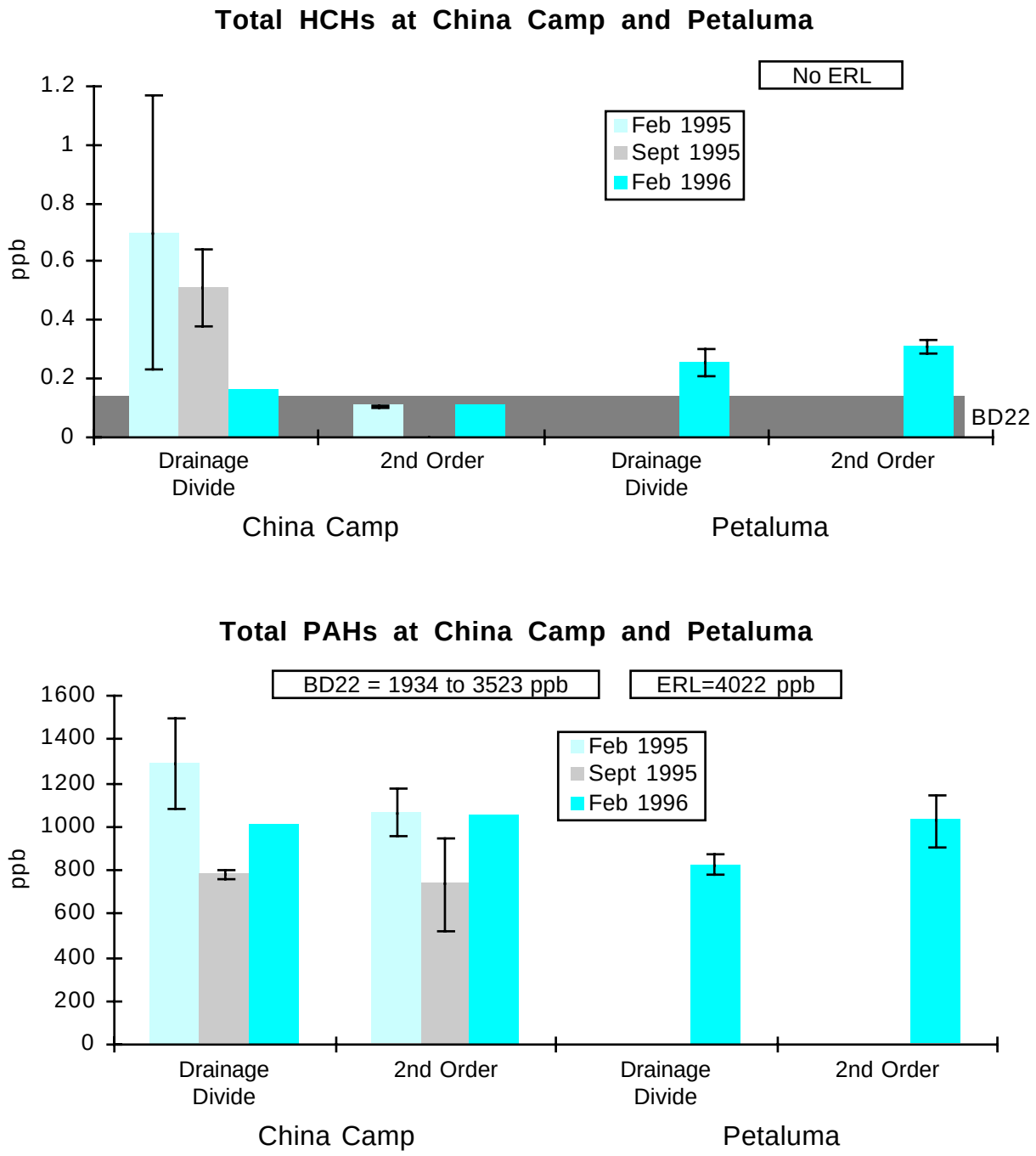
RMP Wetlands
Trace Elements 1995-1996





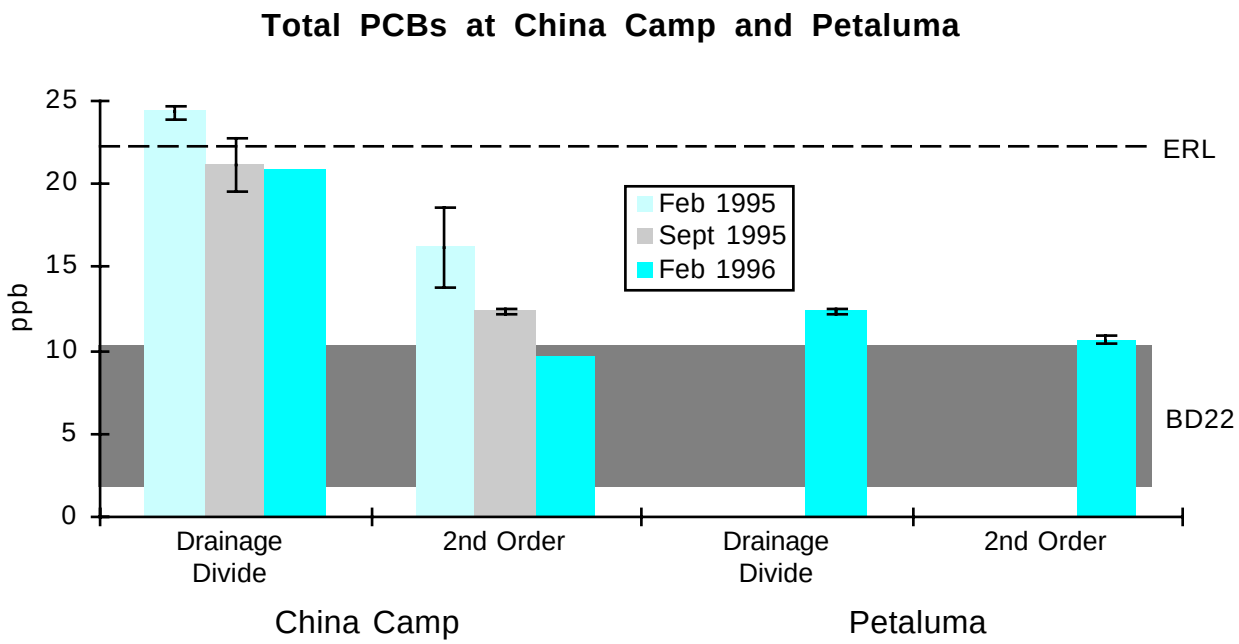
Figures 13 and 14. RMP wetlands trace element results. Data pooled among drainage systems. Only one drainage system measured at China Camp in February of 1996. Vertical bars indicate range between drainage systems. Grey band indicates range of bay sediment station BD22. ERL = effects range low; ERM = effects range median (see Chapter 3: Sediment Monitoring for an explanation).

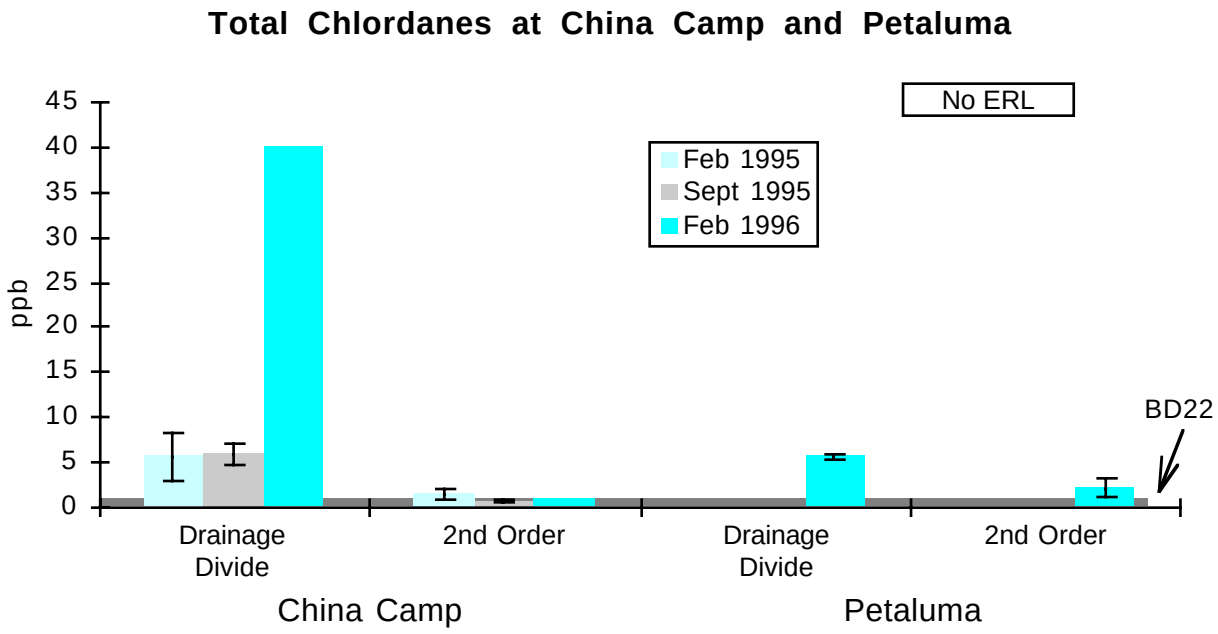
RMP Wetlands
Organics 1995-1996



Figures 15 and 16. RMP wetlands organics results. Data pooled among drainage systems. Only one drainage system measured at China Camp in February of 1996. Vertical bars indicate range between drainage systems. Grey band indicates range of bay sediment station BD22. ERL = effects range low; ERM = effects range median (see Chapter 3: Sediment Monitoring for an explanation).

RMP Wetlands
Organics 1995-1996





Figures 17 and 18. RMP wetlands organics results. Data pooled among drainage systems. Only one drainage system measured at China Camp in February of 1996. Vertical bars indicate range between drainage systems. Grey band indicates range of bay sediment station BD22. ERL = effects range low; ERM = effects range median (see Chapter 3: Sediment Monitoring for an explanation).

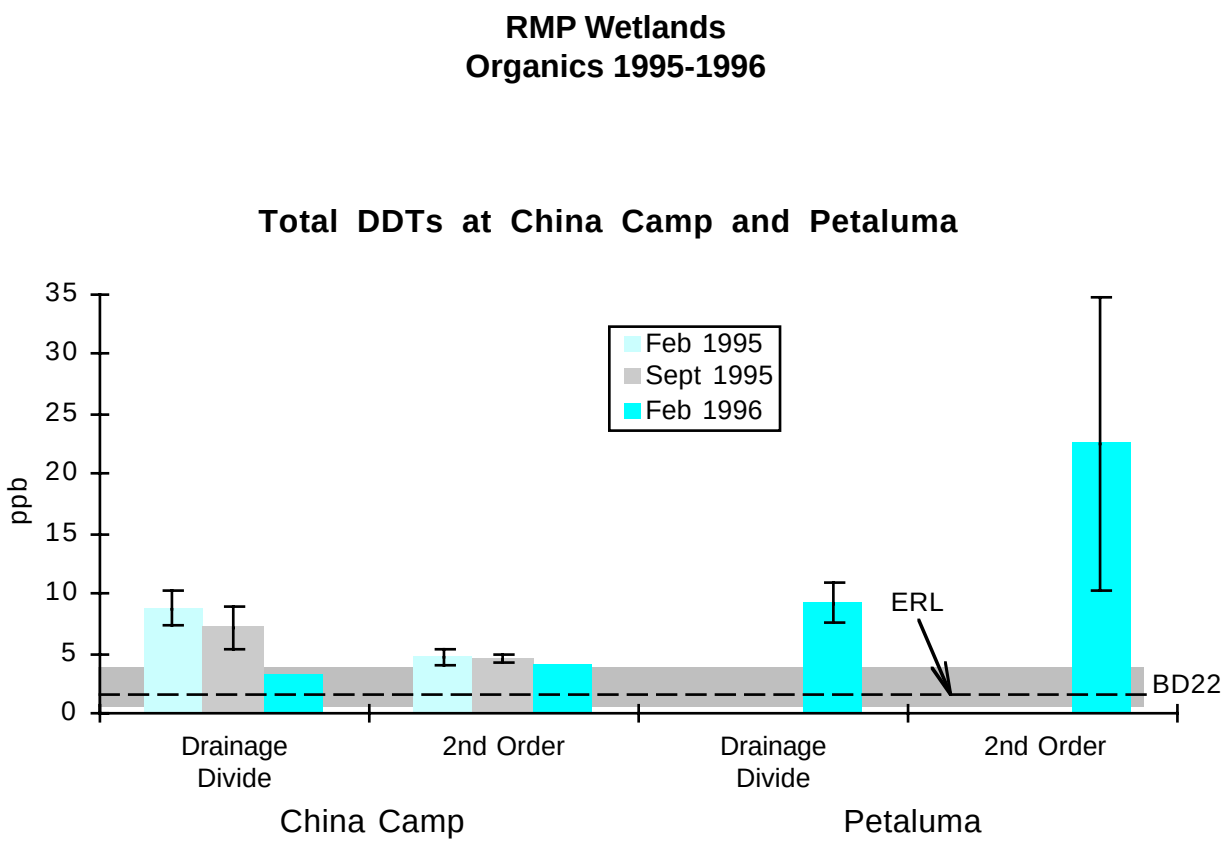


Figure 19. RMP wetlands DDT results. Data pooled among replicate drainage systems. Only one drainage system sampled at China Camp in February of 1996. Vertical bars indicate range between drainage systems. Grey band indicates range of bay sediment station BD22.
ERL = effects range low; ERM = effects range median (see Chapter 3: Sediment Monitoring for an explanation).

Figures 3–19 show the concentrations of trace metals 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 winter (February) 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 12 month period between the 1995 and 1996 winter sample periods.

Only non-validated data for trace organics are available for 1996. All results shown here pertain only to total concentrations, and should be regarded as preliminary. A full report on the wetlands pilot will be prepared after all the data, including the outstanding data for fall 1996, have been validated.

Discussion

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. However, the wetlands data have not been subject to some of the conventional treatments, such as standardization for total organic content, and not all the data for trace organics have been validated. Therefore, the wetlands

pilot data must be regarded as preliminary at this time.

Sample Plan

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 and chromium. 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, 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 charaterize tidal marshlands. Drainage divide stations as defined in this pilot project may not be adequate to characterize the sediment chemistry of mature, high-elevation tidal marsh plains. Each 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.

The bottoms and lower banks of the tidal marsh channels are both low in the intertidal zone. Differences in elevation between the bottom and midbanks of the channels, there-

Table 1. Spatial and temporal patterns in trace element concentrations.

	Ag	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se
MOST SAMPLES EXCEED MAXIMA FOR BD22		•		•	•	•	•	•	•	•	•
MOST SAMPLES EXCEED ERL		•		•	•	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 = not applicable

Table 2. Spatial and temporal patterns in trace organics concentrations.

	Total HCHs	Total PAHs	Total PCBs	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 = not applicable

fore, correspond to relatively slight differences in tidal regime. The data for channel stations as defined in this pilot project are therefore likely to generally characterize channel exposure to trace substances.

Trace Metal Patterns

No consistent seasonal pattern was observed for any trace metals except silver and copper, which tended to be higher in winter (Table 1). It is not obvious, however, what period of deposition is represented by the samples, given that neither the residence time of the sediment within the channel network, nor the rate of vertical fluctuations of trace metals on the drainage divides is known.

For all metals 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 metals for which an ERL has been established.

Concentrations tended to be higher in the channel stations than on the drainage divides for all trace metals except lead 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 were consistently 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.

Trace Organic Patterns

No consistent seasonal pattern was observed for any trace organics except PAH's and chlordanes, which tended to be higher in winter (Table 2). As with the trace metal data, it is not obvious what period of time is represented by the trace organic samples, given that neither

the residence time of the sediment within the channel network nor the rate of vertical fluctuations of trace metals on the drainage divides is known.

For all compounds except PAH's, 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. Concentrations also exceeded the ERL for DDT's.

Concentrations of trace organics tended to be much higher on the drainage divides than in the marsh channels. This pattern is essentially the reverse of 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 HCH's and PAH's apparently relate to combustion products rather than petroleum.

No overall difference was apparent between trace organics concentration at China Camp and Petaluma Marsh, although the concentration of total PCB's tended to be much higher at China Camp. The data for trace organics was generally more variable than the data for trace metals.

Conclusions

The RMP wetlands pilot project, although of short duration and limited scope, produced a practical methodology for sampling tidal marsh sediments yielding data on contaminants that are 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 channels large and small and drainage divides as major strata, and substrate types as minor strata, new patterns of contaminant concentration were revealed that relate well to the assessment of plant and animal habitats. Although the data are rather scant, the patterns of higher concentrations of trace organic compounds on drainage divides, and higher concentrations of trace metals 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. This does not preclude the rather obvious need, however, to assess the effect of these high concentrations upon the ecological functions of the tidal marshes.

A more focused monitoring program should proceed. Based upon this pilot project, a monitoring program could be designed to focus on high levels of trace organics on drainage divides, high levels of trace metals in channels, or exceptions to the general patterns observed. The question is, what should the focus be? When the data set is complete, we will outline a variety of options that follow directly from the considerations of different monitoring objectives, including the support of endangered species, the filtration of local pollutants, and the assessment of inputs from local watersheds.

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The RMP Workshop on Ecological Indicators of Contaminant Effects

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Background

This report summarizes a workshop sponsored by the Regional Monitoring Program (RMP) on Ecological Indicators of Contaminant Effects held on October 11, 1995 at the United States Environmental Protection Agency's (USEPA) Regional Laboratory on the Richmond Field Station. The goal of the workshop was to produce recommendations for ecological indicators of contaminant effects that the RMP could consider using.

Determination of which indicators should be used in monitoring programs requires that the goals and objectives of the program are clearly stated. Monitoring variables should be tied directly to the specific questions to be answered and the resources at risk. Changes in the status of the selected variables must unambiguously reflect changes in the resources at risk (National Research Council, 1990).

Another use of indicators was stated by the Comprehensive Conservation and Management Plan (CCMP) which called for Regional Monitoring to "provide information to assess the effectiveness of management actions that have been taken to improve conditions in the Estuary and to protect its resources" (SFEP, 1993). Such use of indicators underscores the importance that monitoring measurements are related to, and appropriate to the achievement of program goals and objectives.

The RMP currently operates using a set of program objectives adopted at its inception in 1993 (see Chapter One: Introduction). These objectives address monitoring the status and trends of contaminants in water, sediment, and transplanted bivalve tissues, and evaluating compliance with water quality guidelines. Although the Basin Plan specifically contains references to the evaluation of ecological effects of contaminants, at this time there are no specific RMP objectives to conduct such assessments.

The CCMP's goals for Regional Monitoring (SFEP, 1993) mandated that biological effects are monitored to "evaluate the ecological 'health' of the Estuary and enhance scientific understanding of the ecosystem." Ecological health is an important concept that implies the knowledge of conditions or effects of contamination, in addition to indicators of many other types.

Currently, the RMP measures aquatic toxicity (two tests), sediment toxicity (two tests), bioaccumulation and condition of transplanted bivalves, and, as pilot studies, macrobenthic and phytoplankton community composition and abundances. Although there is currently no monitoring of fish, birds, or mammals, a fish contamination pilot study oriented towards human health began in 1996.

As the RMP enters its fifth year, the program objectives are being reevaluated, including the need to monitor for effects. The results of this workshop provide a beginning for considerations of which indicators will be useful once those revised objectives are in place. The focus on ecological indicators reflects the need for the RMP to provide direct, easily interpreted measurements of contaminant effects on the habitats and biota of the Estuary.

The RMP indicators will be used, in conjunction with indicators provided by other major monitoring programs, in the evaluation of overall Estuary health as envisioned by the CCMP. Any individual indicator is but one component of a comprehensive ecological health assessment.

What is an Ecological Indicator?

Webster's New Collegiate Dictionary defines an indicator as "an organism or ecological community so strictly associated with particular environmental conditions that its presence is indicative of the existence of these conditions."

The US EPA's Environmental Monitoring and Assessment Program (EMAP) defines an indicator as "an environmental characteristic that can be measured to assess the status and trends of environmental quality, i.e., the ability to support a desired human or ecological condition" (Hunsaker and Carpenter, 1990).

Ecological indicators should be sensitive within the range of conditions encountered within the system to be monitored, i.e., they should respond in the "worst case conditions" in the system, and show little or no response when disturbance/contamination is minimal. If not (and there are usually exceptions), then the other sources of variability should be known, measured, and/or controlled.

Since indicators work best for the level of biological organization at which they are measured, no single indicator can provide a comprehensive assessment of condition. They should provide an early indication of a potentially worsening situation at a higher level of biological organization (e.g., communities and ecosystems).

Indicators of exposure should be indicative of classes of chemical compounds (e.g., divalent cations, PAHs, coplanar PCBs, etc.) Links between exposure and effect, and between markers of effects on different levels of organization can provide deeper insight into the total effects of contaminants/alterations in the ecosystem.

Indicator Concepts

One of the best developed indicator concepts is used by EMAP. This national program has developed a formal indicator strategy (Hunsaker and Carpenter, 1990) which is summarized below. It has been widely adopted throughout the country for environmental assessments, and has received wide scientific review and discussion. The EMAP framework is summarized here as an example. The RMP may consider adopting a similar framework, or components of the EMAP framework, in the future.

The EMAP framework begins by identifying what are important as environmental values and then proceeds hierarchically through assessment endpoints to indicators. The main components of the EMAP indicator strategy are defined below.

Environmental value: A characteristic that contributes to the quality of life provided to an area's inhabitants, i.e., the ability of the area to provide desired functions such as food, clean water and air, aesthetic experience, recreation, and desired animal and plant species. For example, productivity, sustainability, biodiversity, fishability, biological integrity.

Assessment endpoint: An explicit expression of the environmental value that is to be protected. For example, population abundance or mortality, contaminant concentrations in a population, susceptibility to invasions of exotic species.

Measurement endpoint: A measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint. Measurement endpoints are often expressed as the statistical or arithmetic summaries of the observations that comprise the measurement. For example, individual growth, mortality, fecundity, toxicity, overt symptomology, biomarkers, population age structure, pollutant concentrations, species diversity.

Indicator: An environmental characteristic that can be measured to assess the status and trends of environmental quality, i.e., the ability to support a desired human or ecological condition. EMAP uses several different types of indicators:

- *Response Indicators* represent characteristics of the environment measured to provide evidence of the ecological condi-

tion of a resource at the organismal, population, community, ecosystem, or landscape level of organization.

- *Exposure Indicators* are characteristics of the environment measured to provide evidence of the occurrence or magnitude of a response indicator's contact with a physical, chemical, or biological stressor.
- *Habitat Indicators* are physical, chemical, or biological attributes measured to characterize conditions necessary to support an organism, population, community, or ecosystem in the absence of pollutants (e.g., substrate of stream bottom; vegetation type, extent, and spatial pattern).
- *Stressor Indicators* are characteristics measured to quantify natural processes, environmental hazards, or management actions that can effect changes in exposure and habitat (e.g., climate fluctuations, pollutant releases, species introductions). Information on stressors will often be measured and monitored by programs other than EMAP.

Previous work on indicators for use in the San Francisco Estuary include the National Oceanic and Atmospheric Administration's (NOAA) Status and Trends Program San Francisco Bay Study. NOAA proposed a set of criteria for selection of biological effects measures and evaluated 16 endpoints from seven ecological indicators including sediment bioassays, benthos, and fish. Most of NOAA's indicators performed well and could qualify as candidate indicators for the Status and Trends Program (NOAA, 1989).

The State Board's Bay Protection and Toxic Cleanup Program (BPTCP) proposed criteria for selection of biological effects measures. The BPTCP does not have a formal definition of indicators, but uses measurements to guide their identification and designation of "hot spots." Their documentation states that "the most appropriate and scientifically defensible approach currently available appears to be choosing not one, but an array of tests that determine multiple endpoints using a number of individual species or ecological assemblages, and that can also assess various routes of exposure" (BPTCP, 1993). Their measurements may include toxicity testing, histopathology, biomarkers, and benthic community analysis.

Many other reports and papers have been written about biological indicators. Criteria for bioaccumulation indicators were considered by Phillips and Segar (1986), criteria for biomarker indicators were discussed by Mayer *et al*. (1992), and criteria for indicator species were discussed by Young and Young (1982).

Workshop Results

In preparation for the workshop, background material on the RMP and ecological indicators were produced. A listing of indicators commonly used in aquatic and sediment bioassays, bioaccumulation, and biomarker measurement was also produced (Suer, 1995). Copies of the workshop preparatory materials are available from the San Francisco Estuary Institute (SFEI).

Approximately 50 scientists attended the one-day workshop representing a wide range of agencies or companies and expertise (Table 3). The workshop began with presentations on the RMP, the need for additional ecological indicators, and background on ecological indicators including a review of indicators and their application. Most of that information is presented in this summary.

For use in the RMP it was suggested that a suite of ecological indicators should be identified that could reflect effects including those from:

- several "important" habitat types,
- several levels of organization, e.g., molecular to ecosystem,
- several trophic levels or ecological compartments,
- a variety of contaminant types, and
- reflect results of management actions.

It was also suggested that habitat and exposure indicators (similar to EMAP) should be identified and measured synoptically with response indicators in order to develop understanding of the relationships between them.

Workshop participants were provided with a set of draft criteria for RMP indicators (Table 4)

Table 3. Ecological indicators workshop participants.

Rob	Aldenhuysen	California State University—Biology
Brian	Anderson	Marine Pollution Studies Laboratory
Jack	Anderson	Columbia Analytical Services, Inc.
John	Andrew	US Environmental Protection Agency
Andree	Breaux	SFB RWQCB
Geoff	Brosseau	BASMAA
Cindy	Brown	US Geological Survey
Jay	Davis	San Francisco Estuary Institute
Debra	Denton	US Environmental Protection Agency
Jody	Edmunds	US Geological Survey
Chris	Foe	Central Valley RWQCB
Michael	Fry	University of California
Will	Gala	Chevron Products Company
Tom	Gandesbery	SFB RWQCB
M.H.	Garcia	California State University—Biology
Jordan	Gold	Applied Marine Sciences
Steve	Hansen	SR Hansen & Associates
Susan	Hatfield	US Environmental Protection Agency
Bruce	Herbold	US Environmental Protection Agency
Rainer	Hoenicke	San Francisco Estuary Institute
Erika	Hoffman	US Environmental Protection Agency
Frances	Hostettler	US Geological Survey
John	Hunt	University of California, Santa Cruz
Michael	Kellogg	City & County of San Francisco
Chris	Kitting	California State University—Biology
Dianne	Kopec	Earth Island Institute
Oscar	Mace	US Geological Survey
Jeff	Miller	AQUA-Science
Trish	Mulvey	Clean South Bay
Francis	Parchaso	US Geological Survey
Wilfred	Pereira	US Geological Survey
Harlan	Proctor	California Department of Water Resources
Bob	Risebrough	Bodega Bay Institute
Jim	Salerno	City and County of San Francisco
Steven	Schwarzbach	US Fish & Wildlife Service
Robert	Spies	Applied Marine Sciences
Mark	Stephenson	California Department of Fish & Game
Lynn	Suer	SFB RWQCB
Karen	Taberski	SFB RWQCB
Patti	TenBrook	EBMUD
Bruce	Thompson	San Francisco Estuary Institute
Janet	Thompson	US Geological Survey
Amy	Wagner	US Environmental Protection Agency
Don	Weston	University of California—EEHSL
Dave	Young	US Environmental Protection Agency

to help in the evaluation of various proposed candidate indicators. Some of the work groups modified these criteria (Table 8).

The workshop participants broke into three groups:

1. water column indicators,
2. sediment indicators, and
3. upper trophic level indicators.

Each group was given the tasks of:

1. ratifying or modifying proposed criteria in Table 5,
2. focusing on response indicators, and
3. discussing and rating currently used RMP and new candidate indicators using a common format.

The types of indicators to be considered may include those in Table 4. Workshop participants suggested candidate indicators, then rated them based on the criteria in Table 5 or as modified. The ratings are not included in this summary because the lists of indicators are not comprehensive.

Water Column Indicators

The water column indicator work group reviewed the proposed list of criteria for the usefulness of ecological response indicators to "pressure" or "stressors" in the Estuary's open-water habitat. The group agreed that the proposed criteria were useful and modified a few. Changes in the originally proposed wording listed in Table 5 are in italics:

1. The *measurement* endpoint is ecologically relevant.
2. Use *(historically)* resident species or a critical life stage in the Estuary.
3. The *measurement* endpoint can be easily and unambiguously interpreted. It measures a consistent response (accounting for natural variation, such as seasonality), and it has a high signal-to-noise ratio.
4. Adequately *and quickly* reflects *temporal and spatial* changes in contaminant concentrations in water or sediment.
5. Can be used throughout the region, e.g., over a wide salinity range and seasonally.
6. Is cost-effective, easily measured, and has well developed protocols.

The work group developed a list of candidate response indicators of "stressors" or "pressures" affecting them and subsequently ranked each based on each of the six ranking criteria. The matrix, including comments pertaining to each candidate indicator, is shown in Table 6.

The candidate indicators discussed by the work group can be placed into four general categories:

1. bioassays with various endpoints (growth, mortality, condition),
2. population densities of key species,
3. biomarkers (fish histopathology, enzyme induction, reporter genes), and
4. contaminant body burdens.

Several comments were made in relation to these indicator categories: bioassays need to explicitly state measurement endpoints and life stages, and laboratory experiments need to be combined with field measurements to address the "ecological relevance" criterion.

Population density measurements of key species need to be related to some kind of benchmark or baseline. Few are capable of sorting out natural from human-induced "pressures".

The ecological relevance of biomarkers depends on how they are used, and the work group deferred discussion on this subject. The enzyme inductors can be used as screening tools and for prioritization. Histopathology evaluation is a useful tool if tied to other measurements and bioassays. These kinds of evaluations are very species- and life stage-specific.

Contaminant body burdens are not a response indicator *per se,* but they serve as a relative measurement of improvement in "pressures".

Sediment Indicators

The sediment indicators work group discussed both laboratory and field sediment indicators. The group only had time to discuss

Table 4. Examples of ecological indicators for several levels of biological organization.

Ecosystem Indicators
- primary production
- fisheries production
- diversity and abundance of top predators
- health of top predators (re: chlorinated hydrocarbons)
- characteristics of special features (size and position of the null zone)
- balance of habitat types
- species extinctions
- introduced species

Community
- species richness
- diversity
- dominance
- bacterial activity
- short lived opportunists vs. longer lived "climax" species
- nematode/copepod
- presence of indicator species
- bacterial abundance/activity: ATP
- benthic metabolism
- nuisance species

Population
- density (BACI)
- production
- altered allelic frequency—toxicological/adaptive
- parasite load

Individual and organ system
- growth
- hormone level
- reproductive success
- immune function (macrophage phagocytosis)
- disease
- bioassays
- genetic alteration
- teratogenicity

Tissue
- histopathology (hyperplasia, necrosis, melanin macrophage centers, etc.)

Cellular
- metallothioneins
- mixed-function oxidases
- chromosomal aberrations
- activated oncogenes
- sister chromatid exchange
- lysosomal latency
- heat stress proteins

and evaluate ten of the indicators in Table 7, but considered bioassays, fish, benthos, wetlands, eel grass, and exposure indicators. Evaluations for the remaining entries were returned after the workshop. Obviously, many other indicators could be considered and rated for use in the RMP (e.g., those listed in Suer, 1995).

The sediment group adopted the general criteria in Table 5 *per se*. First they discussed the currently used RMP sediment indicators—the *Eohaustorius* 10-day bioassay and the larval bivalve elutriate bioassay. Those indicators received moderate ratings. Among the laboratory indicators, the larval bivalve bioassay using undisturbed sediment water interface samples received the highest average rating, but the currently used *Eohaustorius* and larval bivalve elutriate bioassays were rated nearly as high.

Table 5. General criteria for ecological indicators.

1. Endpoint is ecologically relevant (may be linked).
2. Use resident species.
3. Endpoint can be easily and unambiguously interpreted. It measures a consistent response (accounting for natural variation such as seasonality), it has a high signal-to-noise ratio.
4. Adequately reflects changes in contaminant concentration in water or sediment.
5. Can be used throughout the region. e.g., over a wide salinity range, seasonally.
6. Cost effective, easily measured, well developed protocols.

Table 6. Candidate water column indicators discussed at the workshop.

	Candidate Indicator	Indicator Type	Contaminant Type
1	Arrow shrimp; snails	Bioassays; presence/absence	All
2	*Ostrea lurida*	Population densities/condition; bioaccumulation	All
3	Anchovies; jack/top smelt	Bioaccumulation over 6 mo (>3 measurement pts) slope	All
4	Top smelt; striped bass	Growth bioassay; histopathology	All
5	*Crangon*	Population densities; bioaccumulation	All
6	Reporter Gene System (human cells)	Exposure biomarker	Dioxin-like compounds, PAHs
7	P450 induction in fish	Biomarker screening tool; prioritization	Organic contaminants
8	Fish	Bile analysis	All
9	Phytoplankton species composition	Population/community	All
10	Phytoplankton	Bioassay, growth	All
11	Kelp; macroalgae	Bioassay, growth	All
12	Bivalves, barnacles	Bioassay, larval development	All
13	Microtox	Bioassay, genotoxicity	All
14	Ames test (cells)	Bioassay, genotoxicity	All
15	Staghorn sculpin; flounder	Histopathology	All
16	*Holmesimysis*	Bioassay, growth, survival	All
17	*Neomysis*	Bioassay, growth, survival	All
18	*Acartia tonsa*	Bioassay, survival	All
19	*Tapes japonica*	Contaminant body burdens	All
20	*Mya*	Contaminant body burdens	All
21	*Potamocorbula*	Contaminant body burdens	All
22	*Procambarus*	Contaminant body burdens	All

Table 7. Candidate sediment indicators discussed at the workshop.

Candidate Indicators	Indicator Type		Contaminant Types
Laboratory Indicators			
Eohaustorius bioassay	Organismal bioassay	10 d mortality	All
Larval bivalve bioassay (elutriates)	Larval bioassay	48 h normal devel.	All
Larval bivalve bioassay (sed. water interface)	Larval bioassay	48 h normal devel.	All
Larval bivalve bioassay (pore water)	Larval bioassay	48 h normal devel.	All
Ampelisca bioassay	Organismal bioassay	10 d mortality	All
Ampelisca bioassay	Organismal bioassay	long term growth	All
Rhepoxinius bioassay	Organismal bioassay	10 d mortality	All
Urchin larvae (sed. water interface)	Larval bioassay	96 h normal devel.	All
Urchin larvae (pore water)	Larval bioassay	96 h normal devel.	All
Field Indicators			
Demersal fish abundances	Community / Population	abundances	All
Demersal fish biomarkers	Exposure biomarker	P450 in liver	PAHs PCBs, Dioxins
Fish tissue bioaccumulation	Bioaccumulation	bioaccumulation	All
Fish tissue histopathology	Organism / Tissues	disease	All
Fish livers metallothinein	Organism / Tissues	enzyme induction	All
Benthic community	Community / Population	various abundances	All
Benthic reciprocal transplants	Community / Population	survival / recruitment	All
Benthic recolonization	Community / Population	recruitment / growth	All
Caged amphipods	Population	survival / growth	All
Ampelisca abundances	Population	growth, mortality	All
Demersal zooplankton	Community	abundances	All
Potamocorbula bioaccumulation	Bioaccumulation	bioaccumulation	All
Wetland changes	Community	change in area	All
Eel grass beds	Community	change in area	All
P450-RGS	Exposure biomarker	enzyme induction	PAHs PCBs, Dioxins

Discussions highlighted the importance of specifying the exact test or sampling protocol, whether the test used bulk sediment or spiked sediments, which bivalve species to use, the exposure medium (water or sediment), and the effectiveness of the indicator.

Among the field indicators, the use of an exposure biomarker, P450, in fish was rated the highest. There was considerable support from the sediment work group that field indicators were more important than laboratory indicators in overall ecological assessments.

Many of the indicators discussed could be specified better. For example, separate ratings could be produced for a number of different fish community indicators (abundances, diversity, biomass, production, catch statistics, etc.) Similarly, wetland indicators could be greatly specified to include what wetland types (seasonal, diked, etc.), which plant or animal species to focus on, etc.

Upper Trophic Level Indicators

Much of the discussion in the upper trophic level work group centered on the criteria to be used in the evaluation of indicators. The draft list of criteria provided to the work groups (Table 5) was modified and expanded to a list of ten criteria (Table 8).

Since many indicators are available for evaluation of contaminant effects in high trophic level species, several different indicators for each species were discussed (Table 9). The group evaluated two species: double-crested cormorants and harbor seals. Black-crowned night herons and avocets/stilts were mentioned as species that may also be useful indicators, but the group did not have time to evaluate specific markers for these species.

The types of indicators considered included those for molecular, tissue, individual, and population levels. The molecular and tissue biomarkers have the advantage of being related to specific contaminants or contaminant classes, but are less closely linked to population level effects. The population level indicators, on the other hand, are closely linked to population level effects, but are difficult to relate to contaminants in general, much less particular contaminants. Combinations of markers from both high and low levels of organization can provide information that is both ecologically relevant and attributable to specific contaminants.

Discussion and Conclusions

The workshop provided the beginning of discussion and consideration of which indicators the RMP should be using. Based on this summary, it is obvious that many indicators are available for consideration to expand the list of indicator candidates. Before any list of indicator candidates will be useful to the RMP, much

Table 8. Revised criteria for evaluation of upper trophic level indicators.

1. Ecological relevance
   1. Indicator of exposure 2: Adverse effect on individual 3: Direct effects on population
2. Uses resident species. Indicator response measured is a result of contaminants accumulated from the Estuary
3. Endpoint can be easily and accurately measured. It measures a consistent response (accounting for natural variation such as seasonality) and has a high signal-noise ratio.
4. Adequately reflects changes in contaminant concentration in water or sediment. Responsive to variation in contaminant concentrations within the Estuary and from year to year.
5. Can be used throughout the region (over a wide salinity range), seasonally
6. Cost effective, easily measured, well developed protocol
7. Helps to identify sources of contamination
8. Linked to human health. Consumes prey that are part of human food chain or is directly consumed by humans.
9. Indicators of regional patterns in contamination
10. Suitable reference populations available.

Table 9. Evaluation of upper trophic level indicators in relation to criteria for ecological indicators.

Candidate Indicator		Indicator Type	Contaminant Types
Double-crested cormorants	EROD	Molecular marker	Dioxin TEQs (PCBs, dioxins)
	Eggshell thickness	Tissue	DDE
	Hatchability, deformities	Individual	All
	Reproductive success (colony production)	Population	All
	Retinol/retinol palmitate	Molecular marker	Dioxin TEQs (PCBs, dioxins)
Harbor Seals	Pup ratio (pup/non-pup)	Population	All
	Population size	Population	All
	Retinol/retinol palmitate	Molecular marker	Dioxin TEQs (PCBs, dioxins)
Black-crowned night herons	EROD	Molecular marker	Dioxin TEQs (PCBs, dioxins)
	Eggshell thickness	Tissue	DDE
	Hatchability, deformities	Individual	All
	Retinol/retinol palmitate	Molecular marker	Dioxin TEQs (PCBs, dioxins)
	Reproductive success (colony production)	Population	All
American avocets/ black-necked stilts	Hatchability, deformities	Individual	All
	Reproductive success (colony production)	Population	All

more specific RMP objectives and assessment questions need to be stated that specifically link objectives to indicators. In that regard, the EMAP framework provides a useful model.

The RMP steering committee is currently considering new objectives and assessment questions that may provide the cornerstones for a revised RMP indicator framework. The revised objectives and assessment questions will be considered in the 1997 Program Review. At that time, the results of this workshop and future efforts to determine indicators will become useful. It is envisioned that the RMP will eventually utilize a suite of indicators that, together, will provide an assessment of the condition of the Estuary in terms of contamination.

There are several other efforts to determine useful ecological indicators in the region. The Ecotoxicology Unit of the Office of Environmental Health Hazard Assessment (OEHHA) has been developing guidance and methodologies for identifying ecological endpoints to evaluate potential adverse effects to ecosystems from chemical stressor exposure. However, their work does not focus on open water estuarine habitat, but does include wetlands. Their report will be available in late 1996.

In support of the CALFED process, a series of workshops were held in late 1995/early 1996 to determine ecosystem indicators. Their report is in preparation.

Working with these programs, as well as evolving programs in wetlands and watersheds at SFEI, will eventually provide a battery of ecological indicators that may be used to evaluate the overall condition of the San Francisco Estuary.

1995 Intercomparison Exercise

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An important function of the Regional Monitoring Program (RMP) is to provide data on background or ambient concentrations for comparison to monitoring data collected by discharge agencies or their contractors. In order to accomplish this, it is necessary to demonstrate that samples taken near outfalls or nonpoint sources are collected and analyzed in a comparable manner to those collected as part of the RMP. Comparability is defined as "the confidence with which one data set can be compared to another" (Stanley and Verner, 1985). In addition, a number of Bay Area waste water treatment plant laboratories are interested in directly participating in the analyses of sediment and bivalve tissue, and would like to evaluate their performance relative to each other and the laboratories currently analyzing RMP samples. These laboratories are part of the Bay Area Dischargers Association and will be referred to throughout this chapter as BADA laboratories.

Although individual laboratories can evaluate the performance of their own analytical operations against standard reference materials, the most complete mechanisms for the evaluation of analysis system variability is through the use of split samples. Comparability is then assessed through application of appropriate statistical tests (e.g., t-tests, ANOVA), and results are considered comparable if there are no significant differences, or if data meet pre-determined data quality objectives.

Objectives

The 1995 Intercomparison Exercise had the following objectives:

1. To establish a measure of comparability between analytical operations among local laboratories and for initial demonstrations of capability using a non-certified San Francisco Bay sediment sample (SFERM-S95) collected at an RMP site (BD50, Napa River).
2. To check relative performance among participating laboratories through the intercomparison for trace metals and organics in marine sediments and biological tissues sponsored by the National Oceanic and Atmospheric Administration (NOAA).
3. To ascertain the overall performance of the participating laboratories with regard to analytical capabilities, project management, data documentation, timeliness of data submission, and responsiveness to problem solutions.

These exercises also provided a tool for continuous improvement of laboratory measurements by helping analysts identify and resolve problems in methodology and/or QA/QC, and by pointing out and subsequently rectifying challenges in data transfer and management. We chose not to mention individual laboratories by name in this chapter, but rather assigned numbers that are known only to the individual laboratories.

Project Organization

SFEI provided overall project oversight and developed the objectives, design, and implementation plan. Initially, RMP Participating Agency representatives were contacted to determine the level of interest in intercomparison and to agree on an intercomparison approach. For the first round of performance evaluations, three separate analyses were agreed on: the local, non-certified sediment reference sample (SFERM-S95), the sediment samples, and tissue samples distributed by the National Research Council Canada (NRCC) and the National Institute of Standards and Technology (NIST) as part of the NOAA-sponsored intercomparison.

Four BADA laboratories, one contract laboratory for a number of storm water management agencies, and three RMP contract laboratories participated in the intercomparison exercise involving the local reference sample.

Several planning meetings were held to agree on the analyte list, extraction procedures for sediment, and data submittal procedures. The intercomparison plan was finalized prior to the distribution of samples and served as a reference document.

Two of three RMP contract laboratories and five BADA laboratories (the same four that participated in the SFERM-S95 analysis and one additional laboratory) participated in the NOAA exercise involving an unknown and a reference sample for both sediment and tissue. The laboratories were requested to follow instructions received through the distributors of the sample material (NRCC and NIST) and to submit data directly, rather than through SFEI. Both exercises were logistically quite challenging due to the number of participants involved. Table 10 shows the different samples analyzed by the various laboratories.

Methods

A large sample of sediment from the Napa River station (BD50) was collected in February 1995 with a dykon-coated van Veen grab using standard RMP sampling methods. The sample was transferred to an independent laboratory (California Department of Fish and Game (CDFG) laboratory, Moss Landing) and homogenized under clean conditions. “Mega-sample” homogeneity was determined by analyzing four sub-samples each for trace elements and trace organics. Trace elements were analyzed by CDFG and trace organics at Long Marine Laboratory (UCSC Trace Organics Facility). Results from these initial determinations were included in the overall evaluation of laboratory performance. No specific analysis methods were prescribed, although data quality objectives and target method detection limits were agreed upon prior to analysis.

The CDFG laboratory completely digested the four sediment sub-samples using hydrofluoric acid, while all other laboratories used *aqua regia* for digestion (Flegal, 1981; Tetra Tech, 1986). This represented a major difference between laboratories and biased the data for refractory elements, particularly aluminum and chromium, toward the low end for those laboratories using *aqua regia* extraction. The same extraction procedure was used for sediment samples analyzed for the NOAA-sponsored intercomparison exercise.

In order to determine laboratory performance, three criteria were used: ability to meet target method detection limits, ability to meet precision targets, and ability to meet accuracy targets as specified in the 1994 Quality Assurance Project Plan.

Results

Reference material (SFERM-S95)

Eleven trace elements of interest to the RMP were evaluated and compared among all participating laboratories (Figure 20). BADA laboratories only quantified the agreed-upon PCB congeners and PAH isomers (Figures 21 and 22). No data are available for chlorinated pesticides from the BADA laboratories.

Laboratory results were compared using Bonferroni (Dunn) multiple comparison tests. The Bonferroni multiple comparisons are very conservative, i.e., they are less likely to detect statistically significant differences between treatments than other tests. For our purposes, the Bonferroni test is adequate, and results are presented in Tables 11 and 12 as the mean value of three to five replicates for each laboratory and a letter grouping for each laboratory. The Bonferroni letter group for each compound means that laboratories with the same letter are not significant. It should be noted, however, that those laboratories with high precision (i.e., low intra-laboratory variance) tend to be more often significantly different than laboratories with high variability among replicates, and therefore, the multiple comparison tests only provide a general screening of laboratory differences, without taking into account any

Table 10. Summary of samples analyzed in the RMP's 1995 intercomparison studies.

A. San Francisco Estuary Reference Material	DFG	UCSCOL	GERG	BRL	UCSCDET	CCSF	CCCSD	CSJWTP	EBMUD	TOXSCAN
	TE	ORG	ORG	TE	TE	TE	TE &ORG	TE	TE &ORG	TE
Napa River Sediment Reference Material (SFERM-S95)	√	√	√	√	√	√	√	√	√	√

B. NOAA Intercomparison Exercise	NRC/NIST	UCSCOL	GERG	BRL	UCSCDET	CCSF	CCCSD	CSJWTP	EBMUD	USD
1995 NOAA **Trace Elements:**										
Sediment-W	√				√	√	√	√	√	√
Sediment CRM BCSS-1					√	√		√	√	√
Trace Elements:										
Tissue-X	√					√	√	√		√
Tissue SRM 1566a	√					√		√		√
Trace Organics:										
Tissue, Fish Homogenate III (QA95FSH3)	√	√	√				√[1]			
Tissue, CRM Carp-1	√	√	√				√[1]			
Trace Organics:										
Sediment, Sediment V	√		√							
Sediment, SRM 1941a	√		√							

[1]Only PCBs were submitted.

BRL	Brooks Rand Laboratories	GERG	Texas A & M
CCCSD	Contra Costa Central Sanitary District	SJWTP	San Jose Wastewater Treatment Plant
CCSF	City and County of San Francisco	UCSCDET	UCSC Environmental Toxicology
DFG	Department of Fish and Game (Moss Landing)	UCSCOL	UCSC Organics Laboratory
EBMUD	East Bay Municipal Utilities District	USD	Union Sanitary District

other factors that identify laboratory performance.

Cadmium, mercury, selenium, and silver exhibited high inter-laboratory variability. Chromium, copper, nickel, and zinc results were comparable among laboratories (excluding CDFG, having used a different extraction procedure), while arsenic and lead were intermediate.

Contrary to expectations, PCB concentrations in SFERM-S95 were low and close to the detection limit. Only four congeners for which semi-quantitative values were obtained could be compared among laboratories. Twenty-two PAH isomers were analyzed by four laboratories, two of them BADA laboratories. For many PAH isomers close to the detection limit, results of the participating laboratories varied widely.

Comparisons to RMP Data Quality Objectives

For the initial intercomparison exercise, the target method detection limit was met only for chromium, nickel, and zinc by all participating laboratories (Table 13). All BADA laboratories were able to meet the target for copper, but none of them were able to meet MDL targets for cadmium and silver, and only one BADA laboratory met the target for selenium. Of the two BADA laboratories that measured PCBs and PAHs, one met MDL targets in all cases, while the other's detection limits were almost five times higher (Table 14).

The precision measurements for almost all the trace element results were lower for the five BADA laboratories compared to the RMP laboratories and the contract laboratory for storm water agencies, although they were within precision target range for all elements except aluminum, selenium, silver, and cadmium which were exceeded by one or two of the BADA laboratories (Table 15).

NOAA-95

Five BADA laboratories and one RMP contract laboratory participated in the NOAA/9 Ninth Round Intercomparison for Trace Metals in Sediments and Biological Tissue (Figures 23–26).

One BADA laboratory and two RMP contract laboratories participated in the NIST/NOAA NS&T/EPA EMAP Intercomparison Exercise Program for Organic Contaminants in the Marine Environment, 1995 (Figures 27–30). Two BADA laboratories analyzed 1994 NOAA sediment for organic contaminants, which will be compared to the other 1994 participants.

Table 11. San Francisco Estuary Reference Material-Sediment 95 trace element multiple comparison results using the Bonferroni (Dunn) T test, where alpha = 0.05. Below are the mean values of three replicates and the Bonferroni assigned groupings. Missing values are a result of the values being below the MDL, not detected, or data were not reported. Laboratory results associated with the same letter are not significantly different.

Tetra Tech Method	Ag	Al	As	Cd	Cr	Cu	Fe
Laboratory 2	. .	. .	12.30 (CB)	. .	130.00 (B)	66.57 (A)	. .
Laboratory 3	. .	94320.00 (A)	19.14 (A)	0.21 (C)	103.27 (C)	58.63 (A)	36541.00 (B)
Laboratory 9	. .	. .	15.53 (B)	. .	124.67 (B)	71.10 (A)	. .
Laboratory 4	0.25 (B)	60000.00 (B)	9.33 (C)	0.30 (B)	200.00 (A)	68.75 (A)	55500.00 (A)
Laboratory 5	0.35 (A)	29211.00 (C)	10.18 (C)	0.44 (A)	89.30 (C)	64.47 (A)	39737.00 (BA)
Laboratory 11	0.36 (A)	32535.00 (C)	15.03 (B)	0.26 (CB)	106.33 (C)	60.33 (A)	43723.00 (BA)

Tetra Tech Method	Hg	Mn	Ni	Pb	Se	Zn
Laboratory 2	0.35 (B)	. .	94.70 (CB)	23.10 (C)	. .	148.33 (CB)
Laboratory 3	. .	853.90 (B)	84.15 (C)	32.27 (A)	3.16 (A)	151.28 (B)
Laboratory 9	. .	. .	100.30 (B)	26.23 (BC)	0.40 (B)	142.00 (CB)
Laboratory 4	0.27 (C)	941.75 (A)	125.00 (A)	31.00 (BA)	. .	175.00 (A)
Laboratory 5	0.45 (A)	806.14 (B)	92.81 (CB)	32.37 (A)	0.34 (B)	132.63 (C)
Laboratory 11	0.34 (CB)	784.08 (B)	106.69 (B)	28.88 (BA)	0.41 (B)	145.25 (CB)

Note: Laboratory 4 used the hydrofluoric acid extraction method.

Table 12. San Francisco Estuary Reference Material-Sediment 95 (SFERM-S95) organics multiple comparison results using the Bonferroni (Dunn) T test, where alpha = 0.05. Below are the mean values of three replicates and the Bonferroni assigned groupings. Missing values are a result of the values being below the MDL, not detected, or data were not reported. Laboratory results associated with the same letter are not significantly different.

SFERM-S95 PCBs	PCB 138	PCB 153	PCB 180	PCB 187
Laboratory 2	1.04 (B)	0.82 (B)	0.53 (A)	0.41 (A)
Laboratory 12	1.25 (A)	1.02 (A)	0.60 (A)	0.45 (A)

* Unlisted PCB compounds were either below the detection limit or not reported for all participating laboratories.

SFERM-S95 Pesticides	1-Methylnaphthalene	1-Methylphenanthrene	2,6-Dimethylnaphthalene	2-Methylnaphthalene	Acenanaphthene	Acenanaphthylene
Laboratory 2	8.14 (A)	10.60 (A)	10.10 (A)	30.53 (A)	7.84 (A)	5.09 (A)
Laboratory 5						
Laboratory 6	6.53 (A)	5.18 (B)	5.98 (B)	9.60 (C)	4.43 (B)	5.22 (A)
Laboratory 12	7.48 (A)	9.86 (A)		16.58 (B)	5.23 (B)	

SFERM-S95 Pesticides	Anthracene	Benz(a)anthracene	Benzo(a)pyrene	Benzo(b)flouranthrene	Benzo(e)pyrene	Benzo(ghi)perylene
Laboratory 2	14.27 (A)	59.93 (B)	116.67 (B)	161.33 (A)	76.70 (A)	68.13 (B)
Laboratory 5		78.95 (A)	105.26 (B)	105.26 (B)	78.95 (A)	122.81 (A)
Laboratory 6	10.59 (A)	38.63 (C)	87.55 (C)	92.57 (B)	59.53 (B)	109.66 (A)
Laboratory 12	13.78 (A)	46.33 (C)	146.75 (A)	140.75 (A)	81.38 (A)	131.50 (A)

SFERM-S95 Pesticides	Benzo(k)flouranthrene	Biphenyl	Chrysene	Dibenz(a,h)anthracene	Flouranthrene	Fluorene
Laboratory 2	42.07 (A)	14.03 (A)	56.20 (B)	10.00 (B)	118.33 (B)	14.20 (A)
Laboratory 5			87.72 (A)		131.58 (BA)	
Laboratory 6	26.58 (B)	6.48 (C)	51.31 (B)	10.03 (B)	92.72 (C)	7.17 (B)
Laboratory 12	42.73 (A)	9.32 (B)	47.58 (B)	18.30 (A)	141.50 (A)	9.87 (B)

SFERM-S95 Pesticides	Indeno(1,2,3-cd)pyrene	Perylene	Phenanthrene	Pyrene
Laboratory 2	88.67 (B)	99.87 (CB)	57.83 (A)	160.33 (A)
Laboratory 5	105.26 (BA)	350.88 (A)	43.86 (BA)	78.95 (C)
Laboratory 6	85.85 (B)	39.32 (C)	33.09 (B)	109.49 (B)
Laboratory 12	129.00 (A)	115.50 (B)	54.78 (BA)	159.25 (A)

Table 13. Comparison of the method detection limits for trace elements in sediment. Sediment reference material SFERM-S95. ">10X MDL?" = Is the sample value greater than ten times the MDL?

Trace		RMP-Laboratories		BADA- Laboratories				Other	
Element	Target	11	1	3	9	2	5	10	4
Ag									
MDL	0.001	0.07			0.25	1.2	0.08	0.1	0.01
>10X MDL?		NO			NO	NO	NO		YES
Al									
MDL	70	5428					0.60		1
>10X MDL?		NO					YES		YES
As									
MDL	1.6		0.01		2	1.2	0.01	0.1	0.2
>10X MDL?			YES		NO	YES	YES	YES	YES
Cd									
MDL	0.00002	0.01			0.2	0.37	0.06	0.1	0.01
>10X MDL?		YES			NO	NO	NO	NO	YES
Cr									
MDL	9.44	7			2.5	1.2	0.18	0.1	0.1
>10X MDL?		YES			YES	YES	YES	YES	YES
Cu									
MDL	4.57	6.8			2.5	1.2	0.06	0.1	1
>10X MDL?		NO			YES	YES	YES	YES	YES
Hg									
MDL	0.005		0.008		5	0.002	0.20	0.02	0.03
>10X MDL?			YES		NO	YES	NO	NO	NO
Ni									
MDL	4.28	5.9			5	3	0.20	0.1	0.1
>10X MDL?		YES			YES	YES	YES	YES	YES
Pb									
MDL	0.1	1			5	2.5	0.60	0.1	0.1
>10X MDL?		YES			NO	NO	YES	YES	YES
Se									
MDL	2.2		0.01		0.2	1.2	0.02	0.1	0.2
>10X MDL?			YES		NO	NO	YES	NO	NO
Zn									
MDL	18.9	12			2.5	1.2	0.60	1	0.02
>10X MDL?		YES			YES	YES	YES	YES	YES

NOAA/9 Trace Elements

In general, statistically significant differences between laboratories could be discerned, with the exception of Hg for Sediment-W, As for the Sediment SRM BCSS-1, chromium, copper and lead for Tissue-X and silver, lead, and zinc for the tissue standard reference material, SRM 1566a (Table 18).

Not all laboratories analyzed the complete list of eleven trace elements of interest to the RMP. In comparing the participating laboratories with the NRCC accepted and certified values for both sediment and tissue, the percentage of results that were within the accepted confidence interval (95% confidence interval) are presented in Table 19.

Comparisons to RMP Data Quality Objectives

The data summaries did not contain the method detection limits that were achieved by participating laboratories and therefore could not be compared to RMP targets.

Table 14. Comparison of the method detection limits for organics in sediment. Sediment Reference Material SFERM-S95. ">10X MDL?" = Is the sample value greater than ten times the MDL?

			RMP-Lab	BADA-Labs	
Units are in µg/Kg		Target	6	2	5
1-Methylnaphthalene	MDL	5	4	5	
	>10 X MDL?		NO	NO	
1-Methylphenanthrene	MDL	5	2	5	
	>10X MDL?		NO	NO	
2,6-Dimethylnaphthalene	MDL	5	2	5	
	>10X MDL?		NO	NO	
2-Methylnaphthalene	MDL	5	4	5	
	>10X MDL?		NO	NO	
Acenaphthene	MDL	5	2	5	
	>10X MDL?		NO	NO	
Acenaphthylene	MDL	5	2	5	
	>10X MDL?		NO	NO	
Anthracene	MDL	5	2	5	
	>10X MDL?		NO	NO	
Benzo(a)anthracene	MDL	5	1	5	24
	>10X MDL?		YES	YES	NO
Benzo(a)pyrene	MDL	5	1	5	24
	>10X MDL?		YES	YES	NO
Benzo(b)fluoranthene	MDL	5	1	5	24
	>10X MDL?		YES	YES	NO
Benzo(e)pyrene	MDL	5	1	5	79
	>10X MDL?		YES	YES	NO
Benzo(ghi)perylene	MDL	5	1	5	24
	>10X MDL?		YES	YES	NO
Benzo(k)fluoranthrene	MDL	5	1	5	
	>10X MDL?		YES	NO	
Biphenyl	MDL	5	1	5	
	>10X MDL?		NO	NO	
Chrysene	MDL	5	1	5	16
	>10X MDL?		YES	YES	NO
Dibenz(a,h)anthracene	MDL	5	1	5	
	>10X MDL?		NO	NO	
Fluoranthene	MDL	5	1	5	24
	>10X MDL?		YES	YES	NO
Fluorene	MDL	5	2	5	
	>10X MDL?		NO	NO	
Indo(1,2,3-cd)pyrene	MDL	5	1	5	55
	>10X MDL?		YES	YES	NO
Perylene	MDL	5	10	5	79
	>10X MDL?		NO	YES	NO
Phenanthrene	MDL	5	2	5	24
	>10X MDL?		YES	YES	NO
Pyrene	MDL	5	1	5	24
	>10X MDL?		YES	YES	NO
PCB028	MDL	1		0.1	
	>10X MDL?			NO	
PCB128	MDL	1		0.5	
	>10X MDL?			NO	
PCB138	MDL	1		0.6	
	>10X MDL?			NO	
PCB153	MDL	1		0.2	
	>10X MDL?			NO	
PCB180	MDL	1		0.4	
	>10X MDL?			NO	
PCB187	MDL	1		0.5	
	>10X MDL?			NO	
PCB28	MDL	1	0.5		
	>10X MDL?		NO		
4,4'-DDT	MDL	1			1.3
	>10X MDL?				YES
4,4'DDD	MDL	1	0.2		
	>10X MDL?		NO		
4,4'DDE	MDL	1	0.2		
	>10X MDL?		NO		

Table 15. Precision evaluation for the 1995 sediment trace element intercomparison exercises of participating laboratories. Precision is determined by the relative standard deviation (RSD, also known as the coefficient of variation) of replicate sample analyses. The RMP target precision guideline for trace elements measured in sediment is ±15% (±35 for As, Hg, and Se). Compounds that exceeded the RSD are indicated with an X. ND indicates not detected, blanks indicate not analyzed.

Laboratory 2

	SED-BCSS-1	SED-W	SFERM-S95
Ag		21 **X**	ND
As		11	9
Cd	NO	3	
Cr	DATA	8	7
Cu		6	11
Fe			
Hg		12	3
Ni		16 **X**	3
Pb		8	1
Se		ND	
Zn		2	1

Laboratory 3

	SED-BCSS-1	SED-W	SFERM-S95
Ag	ND	ND	ND
As	5	4	10
Cd	33 **X**	6	12
Cr	2	2	7
Cu	1	2	11
Fe	2	2	32 **X**
Hg	5	6	
Ni	1	4	1
Pb	4	2	15
Se	ND	ND	71 **X**
Zn	1	4	2

Laboratory 4

	SED-BCSS-1	SED-W	SFERM-S95
Ag			3
As			6
Cd	NO DATA		4
Cr			7
Cu			5
Fe			11
Hg			5
Ni			10
Pb			6
Se			
Zn			7

Laboratory 5

	SED-BCSS-1	SED-W	SFERM-S95
Ag	ND	177 **X**	15 **X**
As	5	2	1
Cd	22 **X**	14	18 **X**
Cr	1	2	1
Cu	4	6	2
Fe	2	2	1
Hg	3	19	15
Ni	3	8	2
Pb	4	3	4
Se	23	7	8
Zn	1	3	1

Laboratory 8

	SED-BCSS-1	SED-W	SFERM-S95
Ag		11	
As		7	
Cd	NO	2	NO
Cr	DATA	2	DATA
Cu		10	
Fe		2	
Hg		3	
Ni		7	
Pb		12	
Se		5	
Zn		2	

Laboratory 9

	SED-BCSS-1	SED-W	SFERM-S95
Ag	14	5	ND
As	29	5	9
Cd	3	1	
Cr	2	2	3
Cu	3	6	5
Fe			
Hg	11	10	
Ni	3	5	2
Pb	5	5	3
Se		3	0
Zn	3	3	5

Laboratory 11

	SED-BCSS-1	SED-W	SFERM-S95
Ag	5	18 **X**	4
As			9
Cd	4	5	2
Cr	4	5	1
Cu	3	4	1
Fe	4	8	3
Hg			4
Ni	3	2	0
Pb	4	1	3
Se			3
Zn	4	5	1

Laboratory 13

	SED-BCSS-1	SED-W	SFERM-S95
Ag	4	11	
As			
Cd	7	1	NO
Cr			DATA
Cu	16 **X**	6	
Fe			
Hg			
Ni	9	4	
Pb	3	6	
Se			
Zn	1	5	

Laboratory 10

	SED-BCSS-1	SED-W	SFERM-S95
Ag			
As			2
Cd	NO DATA		5
Cr			2
Cu			1
Fe			
Hg			3
Ni			2
Pb			0
Se			1
Zn			1

SED-BCSS-1 = NOAA/9 Sediment Standard Reference Material; SED-W = NOAA/9 Sediment Unknown; SFERM-S95 = RMP Sediment Reference Material

Table 16. Precision evaluation for the 1995 tissue trace element intercomparison exercises of participating laboratories. Precision is determined by the relative standard deviation (RSD, also known as the coefficient of variation) of replicate sample analyses. The RMP target precision guideline for trace elements measured in tissue is±15% (±35 for As, Hg, and Se). Compounds that exceeded the RSD are indicated with an X. Blanks indicate not analyzed.

Laboratory 2

	TISS-SRM1566	TISS-X
Ag		18
As		12
Cd	NO DATA	11
Cr		30 **X**
Cu		14
Hg		2
Ni		13
Pb		42 **X**
Se		12
Zn		6

Laboratory 3

	TISS-SRM1566	TISS-X
Ag	14	36 **X**
As	3	12
Cd	2	3
Cr	4	14
Cu	1	4
Hg	15	6
Ni	17	11
Pb	44 **X**	16
Se	22	36 **X**
Zn	3	8

Laboratory 8

	TISS-X (sample 1)	TISS-X (sample 2)
Ag		4
As	4	
Cd	2	1
Cr	5	14
Cu	9	1
Hg	10	2
Ni	8	
Pb	51 **X**	39 **X**
Se	9	
Zn	4	

Laboratory 9

	TISS-SRM1566	TISS-X
Ag	1	4
As		
Cd	1	3
Cr	3	4
Cu	1	2
Hg	13	8
Ni	7	7
Pb	8	8
Se	5	6
Zn	1	3

Laboratory 13

	TISS-SRM1566	TISS-X
Ag	1	5
As		
Cd	2	6
Cr		
Cu	1	5
Hg		
Ni	13	29 **X**
Pb	19	9
Se		
Zn	4	2

TISS-SRM1566 = NOAA/9 Tissue Standard Reference Material; TISS-X = NOAA/9 Tissue Unknown.

Table 17. Precision evaluation for the 1995 tissue organics intercomparison exercises of participating laboratories. Precision is determined by the relative standard deviation (RSD, also known as the coefficient of variation) of replicate sample analyses. The RMP target precision guideline for organic compounds measured in tissue is ±15%. Compounds that exceeded the RSD are indicated with an X.

Tissue Intercomparison Organics: NIST/NOAA 95 (Fish homogenate III (QA95fsh3) and the Standard Reference Material CARP-1).

	BADA Laboratory Laboratory 2		RMP Laboratory Laboratory 6		Other Laboratories Laboratory 7		Laboratory 12	
	QA95FSH3	SRM CARP-1	QA95FSH3	SRM CARP-1	QA95FSH3	SRM CARP-1	QA95FSH3	SRM CARP-1
2,4'-DDD			2	4	3	4	17 X	2
2,4'-DDE			11	24 X	1	7	23 X	8
2,4'-DDT			3	9	5	4	11	15 X
4,4'-DDD			4	5	2	2	17 X	3
4,4'-DDE			3	4	2	2	12	9
4,4'-DDT	PESTICIDE DATA		1	1	3	2	46 X	10
alpha-HCH	NOT AVAILABLE			8		6		3
cis-chlordane			3	6	3	3	10	8
cis-nonachlor			4	9	5	5	5	4
dieldrin			9	9	4	2	13	13
gama-HCH			7	5	4	8	15	5
heptachlor								15 X
heptachlor epoxide				22 X		2		12
hexachlorobenzene			15	14	2	2	20 X	6
mirex				3				8
oxychlordane				18 X		3		4
trans-chlordane			7	7	4	2	12	9
trans-nonachlor			4	4	6	1	13	2
PCB 8	6	9	17 X	13			5	2
PCB 18	15 X	11	10	6	2	9	17 X	7
PCB 28	15 X	15	11	9	4	3	7	6
PCB 44	12	8	5	6	2	2	11	9
PCB 52	28 X	5	6	4	5	2	10	9
PCB 105	5	7	2	3	2	6	12	7
PCB 118	6	10	3	4	5	5	11	9
PCB 128	3	6	4	6	3	5	13	6
PCB 153	3	5	7	13	16 X	3	10	10
PCB 180	3	5	5	5	2	3	12	8
PCB 195	17 X	21 X	8	5	392 X	3	2	6
PCB 206	9	34 X	13	8	4	5	4	5
PCB 209	14	7	3	6	3	7	1	6
PCB 101/90	0	6	3	4	6	2	7	10
PCB 138/163/164	5	10	3	6	2	5	11	8
PCB 170/190	10	27 X	13	4	3	3	3	4
PCB 187/182	7	5	4	8	2	5	9	11
PCB 66/95	5	11	6	3	4	2	14	12

Table 18. NOAA/9 trace element multiple comparison results using the Bonferroni (Dunn) T test, where alpha = 0.05. Below are the mean values of three replicates and the Bonferroni assigned groupings. Missing values are a result of the values being below the MDLs, not detected, or data were not reported. Laboratory results associated with the same letter are not significantly different.

Sediment-W	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Zn
Laboratory 2	0.14 (C)		20.62 (B)	2.15 (BA)	40.74 (CD)	124.80 (BA)		1.50 (A)		23.74 (C)	213.60 (BA)	0.26 (D)	332.60 (BA)
Laboratory 3	2.00 (A)	1.79 (B)	22.38 (B)	1.94 (BDC)	35.90 (ED)	114.62 (B)	2.70 (B)	1.36 (A)	338.52 (B)	23.48 (C)	183.88 (C)	4.00 (A)	294.12 (C)
Laboratory 5	0.66 (B)		26.90 (A)	2.32 (A)	46.58 (B)	135.80 (A)	2.83 (BA)	1.47 (A)	335.50 (B)	28.40 (BA)	208.40 (BAC)	1.30 (B)	353.40 (A)
Laboratory 9	0.25 (C)		16.92 (C)	1.69 (D)	46.10 (CB)	126.40 (BA)		1.45 (A)	415.20 (A)	24.22 (BC)	191.40 (BC)	0.73 (C)	329.40 (BA)
Laboratory 11	0.41 (CB)	1.28 (C)		2.15 (BA)	34.80 (E)	137.42 (A)	2.39 (C)		317.40 (B)	25.76 (BAC)	35.14 (D)		343.80 (A)
Laboratory 13	0.26 (C)			2.08 (BAC)		131.80 (A)				28.90 (A)	206.00 (BAC)		338.00 (BA)
Laboratory 8	0.33 (CB)	5.21 (A)	20.00 (B)	1.83 (DC)	60.20 (A)	139.80 (A)	3.09 (A)	1.24 (A)	462.40 (A)	27.48 (BAC)	222.40 (A)	1.20 (B)	316.60 (BC)

Sediment BCSS-1	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Zn
Laboratory 2													
Laboratory 3	2 (A)	2.726 (A)	12.44 (A)	0.28 (A)	57.1 (B)	15.72 (BA)	3.124 (A)	0.199 (A)	191.2 (B)	48.44 (B)	20.6 (B)	4 (A)	107 (BA)
Laboratory 5	0.34 (B)	1.424 (C)	9.08 (A)	0.24 (A)	51.88 (B)	11 (D)	2.642 (C)	0.177 (B)	199 (B)	51.5 (BA)	19.8 (BC)	0.316 (B)	99.36 (C)
Laboratory 9	0.08 (C)		10.72 (A)	0.192 (A)	68.62 (A)	17.4 (A)		0.16 (B)	212.8 (A)	51.5 (BA)	18.12 (C)		109.8 (A)
Laboratory 11	0.11 (C)	1.904 (B)		0.262 (A)	53.6 (B)	12.54 (DC)	2.914 (B)		178.8 (C)	52.44 (BA)	21.46 (BA)		103.8 (BC)
Laboratory 13	0.08 (C)			0.276 (A)		14.08 (BC)				54.66 (A)	22.54 (A)		101.2 (C)
Laboratory 8													

Tissue-X	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Laboratory 2	0.33 (BC)		3.30 (B)	1.27 (BC)	1.85 (A)	10.92 (A)		0.16 (B)	0.68 (BAC)	16.40 (A)	1.28 (B)	113.00 (A)
Laboratory 3	0.32 (C)	159.60 (B)	3.68 (B)	1.13 (C)	1.49 (A)	9.96 (A)	377.60 (C)	0.18 (A)	0.48 (C)	11.38 (A)	2.54 (A)	103.52 (BA)
Laboratory 9	0.59 (A)			1.35 (BA)	1.65 (A)	9.85 (A)	424.40 (B)	0.18 (A)	0.89 (A)	9.65 (A)	1.76 (B)	104.40 (BA)
Laboratory 13	0.50 (BA)			1.43 (A)		11.12 (A)			0.87 (BA)	14.56 (A)		101.64 (B)
Laboratory 8	0.58 (A)	470.80 (A)	7.08 (A)	1.30 (BA)	1.86 (A)	10.50 (A)	465.20 (A)	0.15 (B)	0.65 (BC)	14.56 (A)	1.86 (BA)	95.60 (B)

Tissue SRM-1566a	Ag	Al	As	Cd	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Laboratory 2												
Laboratory 3	1.5 (A)	100 (A)		4.03 (B)	0.876 (B)	59.86 (C)	463.4 (B)	0.105 (A)	2.4 (A)	0.38 (A)	3.04 (A)	824.4 (A)
Laboratory 9	1.56 (A)			4.216 (A)	1.328 (A)	62.3 (B)	491.6 (A)	0.072 (B)	2.508 (A)	0.388 (A)	1.98 (B)	831 (A)
Laboratory 13	1.51 (A)			4.016 (B)		65.7 (A)			1.78 (B)	0.406 (A)		847.6 (A)
Laboratory 8		189 (B)										

Table 19. Percentage of the 1995 intercomparison studies performed by each laboratory that were within the 95% confidence interval or the RMP accuracy guidelines. Results were counted if one or more of the replicates fell within either limit.

		RMP -Laboratories			BADA- Laboratories					Other	
	Trace Elements	11	1	6	3	2	5	9	13	12	8
Sediment											
	NOAA/9 (Sed-W & BCSS-1)	75	NA	NA	64	70	82	79	92	NA	100
Tissue											
	NOAA/9 (TISS-X & SRM1566)	NA	NA	NA	86	90	NA	100	100	NA	100
	Organics	11	1	6	3	2	5	9	13	12	7
Sediment											
	NIST SRM 1941A	NA	NA	27	NA	40	39	NA	NA	NA	
Tissue											
	NIST/NOAA (QA95FSH3 & CARP-1)	NA	NA	61	NA	72	NA	NA	NA	79	88

The inter-laboratory precision evaluation for both sediment and tissue is presented as the relative standard deviation (RSD) of three replicate samples run by each laboratory. Results are presented in Tables 15 and 16. It should be noted that Laboratory 9 showed excellent precision, for all samples analyzed, for both sediment and tissue. In sediment, cadmium and silver did not meet precision target ranges for some laboratories, while lead proved to be difficult to measure in tissue.

NOAA/NIST Organics

Of the participating laboratories, only one BADA laboratory analyzed tissue organics for the 1995 NOAA/NIST intercomparison exercise. Inter-laboratory results were found to be significantly different with the exception of PCBs 18, 153, and 170/190 for the certified reference material, Carp-1, and PCBs 18, 52, 153, 195, and 170/190 for the unknown tissue sample QA95FSH3 (Tables 20 and 21).

It is interesting to note that between the unknown tissue samples and the Standard Reference Material (SRM), a consistent pattern occurred, with PCBs 18, 153, and 170/190 having no significant difference between laboratories for both materials.

Comparisons to RMP Data Quality Objectives

The inter-laboratory precision evaluation for tissue organics is presented as the relative standard deviation (RSD) of three replicate samples run by each laboratory. Results are presented in Table 17. In general, it seems that it was easier to meet precision targets for PCBs than for pesticides.

Accuracy was generally high for PCBs in tissue for all laboratories that participated in the comparison (Figures 29 and 30).

The 1995 intercomparison exercises revealed some unanticipated challenges with respect to project management, data documentation, and data submission. After the first round, it became obvious that a very specific project management plan, outlining clear guidelines for communication and responsibilities, was needed to meet the expectations of everyone involved. Initially, only meeting minutes and various memos were distributed that contained information critical to all participating laboratory staff. This proved to be insufficient for effective guidance and has been corrected.

Many lessons in data reporting and file transfer were learned by all parties involved. The most important one was that data reporting spreadsheets need to be intuitive to the bench chemist, rather than to the data man-

Table 20. NIST/NOAA pesticide multiple comparison results using the Bonferroni (Dunn) T test, where alpha = 0.05. Below are the mean values of three replicates and the Bonferroni assigned groupings. Missing values are a result of the values being below the MDL, not detected, or data were not reported. Laboratory results associated with the same letter are not significantly different.

CRM Carp-1 PEST	2,4,-DDE	2,4-DDD	2,4-DDT	4,4-DDD	4,4-DDE	4,4-DDT	Aldrin	Alpha-HCH	Cis-chlordane	Cis-nonachlor
Laboratory 7	2.19 (B)	26.67 (A)	7.72 (A)	74.83 (A)	128.33 (B)	7.62 (B)		6.82 (A)	10.53 (A)	6.50 (A)
Laboratory 6	2.64 (B)	8.67 (B)	3.59 (B)	58.87 (B)	123.67 (B)	0.63 (C)		1.43 (B)	6.18 (B)	4.49 (B)
Laboratory 12	5.09 (A)	24.77 (A)	3.83 (B)	74.10 (A)	171.33 (A)	27.83 (A)		0.62 (C)	4.85 (B)	3.91 (B)

CRM Carp-1 PEST	Dieldrin	Gama-HCH	Heptachlor	Heptachlorepoxide	Hexachlorobenzene	Mirex	Oxychlordane	Trans-chlordane	Trans-nonachlor
Laboratory 7	4.65 (A)	1.32 (A)		1.36 (B)	3.29 (BA)		2.32 (B)	8.17 (A)	11.97 (A)
Laboratory 6	4.68 (A)	0.65 (B)		11.44 (A)	3.54 (A)	0.41 (B)	5.89 (A)	4.41 (B)	7.00 (C)
Laboratory 12	5.40 (A)	0.70 (B)		1.58 (B)	2.65 (B)	1.01 (A)	1.27 (C)	4.13 (B)	9.40 (B)

QA95FSH3-PEST	2,4,-DDE	2,4-DDD	2,4-DDT	4,4-DDD	4,4-DDE	4,4-DDT	Aldrin	Alpha-HCH	Cis-chlordane	Cis-nonachlor
Laboratory 7	3.01 (B)	21.83 (A)	8.47 (A)	97.07 (A)	147.00 (B)	4.31 (B)		5.60 (A)	7.56 (A)	5.29 (A)
Laboratory 6	2.79 (B)	9.17 (B)	3.49 (B)	59.77 (B)	115.00 (C)	0.64 (B)		1.07 (B)	6.22 (B)	4.84 (BA)
Laboratory 12	5.42 (A)	27.27 (A)	4.29 (B)	86.80 (A)	180.67 (A)	30.80 (A)		0.66 (C)	4.86 (C)	4.46 (B)

QA95FSH3-PEST	Dieldrin	Gama-HCH	Heptachlor	Heptachlorepoxide	Hexachlorobenzene	Mirex	Oxychlordane	Trans-chlordane	Trans-nonachlor
Laboratory 7	8.52 (A)	2.14 (A)			4.20 (A)			4.19 (A)	10.77 (A)
Laboratory 6	6.01 (B)	1.37 (B)		12.66 (A)	4.40 (A)	0.33 (B)	6.24 (A)	4.44 (A)	8.07 (B)
Laboratory 12	6.33 (B)	0.89 (C)		1.70 (B)	3.51 (A)	1.11 (A)	1.45 (B)	4.32 (A)	10.93 (A)

Table 21. NIST/NOAA PCB multiple comparison results using the Bonferroni (Dunn) T test, where alpha = 0.05. Below are the mean values of three replicates and the Bonferroni assigned groupings. Missing values are a result of the values being below the MDL, not detected, or data were not reported. Laboratory results associated with the same letter are not significantly different.

CRM Carp-1 PCB	PCB 8	PCB 18	PCB 28	PCB 44	PCB 52	PCB 105	PCB 118	PCB 128	PCB 153
Laboratory 12	0.95 (B)	20.87 (A)	21.83 (C)	84.10 (B)	127.33 (B)	48.77 (A)	127.00 (BC)	17.23 (A)	89.43 (A)
Laboratory 2	1.89 (A)	22.83 (A)	54.37 (A)	98.00 (A)	154.33 (A)	47.13 (A)	156.33 (A)	16.47 (A)	101.67 (A)
Laboratory 6	1.37 (BA)	21.67 (A)	29.97 (B)	83.13 (B)	131.67 (B)	34.67 (B)	101.33 (C)	12.67 (B)	97.10 (A)
Laboratory 7		25.53 (A)	22.90 (CB)	67.60 (C)	117.67 (B)	54.80 (A)	135.67 (BA)	19.00 (A)	91.53 (A)

CRM Carp-1 PCB	PCB 180	PCB 195	PCB 206	PCB 209	PCB 101/90	PCB 138/163/164	PCB 170/190	PCB 187/182	PCB 66/95
Laboratory 12	51.17 (A)	3.98 (B)	4.69 (A)	4.47 (A)	134.67 (BA)	97.33 (BA)	16.50 (A)	32.97 (A)	197.33 (A)
Laboratory 2	44.67 (A)	2.41 (C)	2.92 (A)	3.36 (B)	145.33 (A)	119.33 (A)	16.53 (A)	33.07 (A)	165.33 (BA)
Laboratory 6	33.43 (B)	5.93 (A)	4.12 (A)	4.28 (A)	116.67 (B)	75.67 (B)	18.73 (A)	26.40 (A)	141.33 (B)
Laboratory 7	44.87 (A)	4.15 (B)	4.23 (A)	3.43 (B)	131.33 (BA)	113.67 (A)	16.93 (A)	32.77 (A)	155.00 (B)

QA95FSH3-PCB	PCB 8	PCB 18	PCB 28	PCB 44	PCB 52	PCB 105	PCB 118	PCB 128	PCB 153
Laboratory 12	3.87 (B)	29.63 (A)	27.50 (C)	92.47 (BA)	141.00 (A)	54.03 (A)	133.33 (B)	21.97 (A)	97.43 (A)
Laboratory 2	4.96 (BA)	29.97 (A)	65.50 (A)	112.33 (A)	194.33 (A)	48.57 (A)	160.33 (A)	16.00 (B)	104.33 (A)
Laboratory 6	5.73 (A)	30.70 (A)	38.27 (B)	87.80 (B)	138.00 (A)	34.17 (B)	96.33 (C)	12.70 (B)	96.23 (A)
Laboratory 7		31.00 (A)	31.63 (CB)	79.17 (B)	139.00 (A)	58.10 (A)	147.67 (BA)	20.73 (A)	113.00 (A)

QA95FSH3-PCB	PCB 180	PCB 195	PCB 206	PCB 209	PCB 101/90	PCB 138/163/164	PCB 170/190	PCB 187/182	PCB 66/95
Laboratory 12	54.97 (A)	4.08 (A)	4.66 (A)	4.84 (A)	141.33 (A)	106.33 (A)	17.90 (A)	34.60 (BA)	218.67 (A)
Laboratory 2	47.20 (A)	2.16 (A)	2.50 (C)	2.82 (C)	148.33 (A)	116.67 (A)	21.27 (A)	31.50 (B)	162.33 (BC)
Laboratory 6	34.10 (B)	6.10 (A)	4.16 (BA)	4.63 (BA)	106.00 (B)	75.33 (B)	19.17 (A)	25.20 (C)	144.67 (C)
Laboratory 7	51.33 (A)	13.33 (A)	3.42 (BC)	3.71 (BC)	141.67 (A)	124.00 (A)	20.57 (A)	38.43 (A)	198.00 (BA)

ager. After the first round of analyses, it became clear that complex instructions on file structures served neither the data generators nor the recipients, and the data reporting was subsequently simplified.

Conclusions

The first two intercomparison exercises showed that statistically significant differences between laboratories exist. For most trace elements, however, values were comparable most of the time when data quality criteria were applied, with some notable exceptions, primarily silver, cadmium, selenium, and mercury. One laboratory seemed to have a systematic offset in trace element measurements and consistently had lower values than all others. This difference needs to be taken into consideration when comparing sediment results generated by this particular laboratory with those of others. Trace organic contaminants were comparable between laboratories, although in one case, detection limits were too high to evaluate results in any meaningful way.

An assessment of each individual laboratory's quality assurance programs would be the first step in reducing the variation in long-term data sets from laboratories involved in analyzing Estuary water, sediment, or tissue parameters. Continued analysis of split samples and participation in large-scale intercomparison exercises, such as the one organized by NOAA, will help improve the quality and comparability of results from participating RMP laboratories as well as other local monitoring efforts.

Based on the lessons learned, plans should be made to include additional laboratories in intercomparisons. The United States Geological Survey laboratories in Menlo Park and Sacramento, for example, generate a wealth of data that should have a great degree of comparability with data generated by other monitoring programs, so that data sets can be confidently combined for various assessments. The degree of comparability, however, has not yet been formally determined. The same applies to data being collected in the Delta and the Sacramento and San Joaquin Rivers. The annual NOAA-sponsored "round robin" may be an appropriate and cost-effective mechanism.

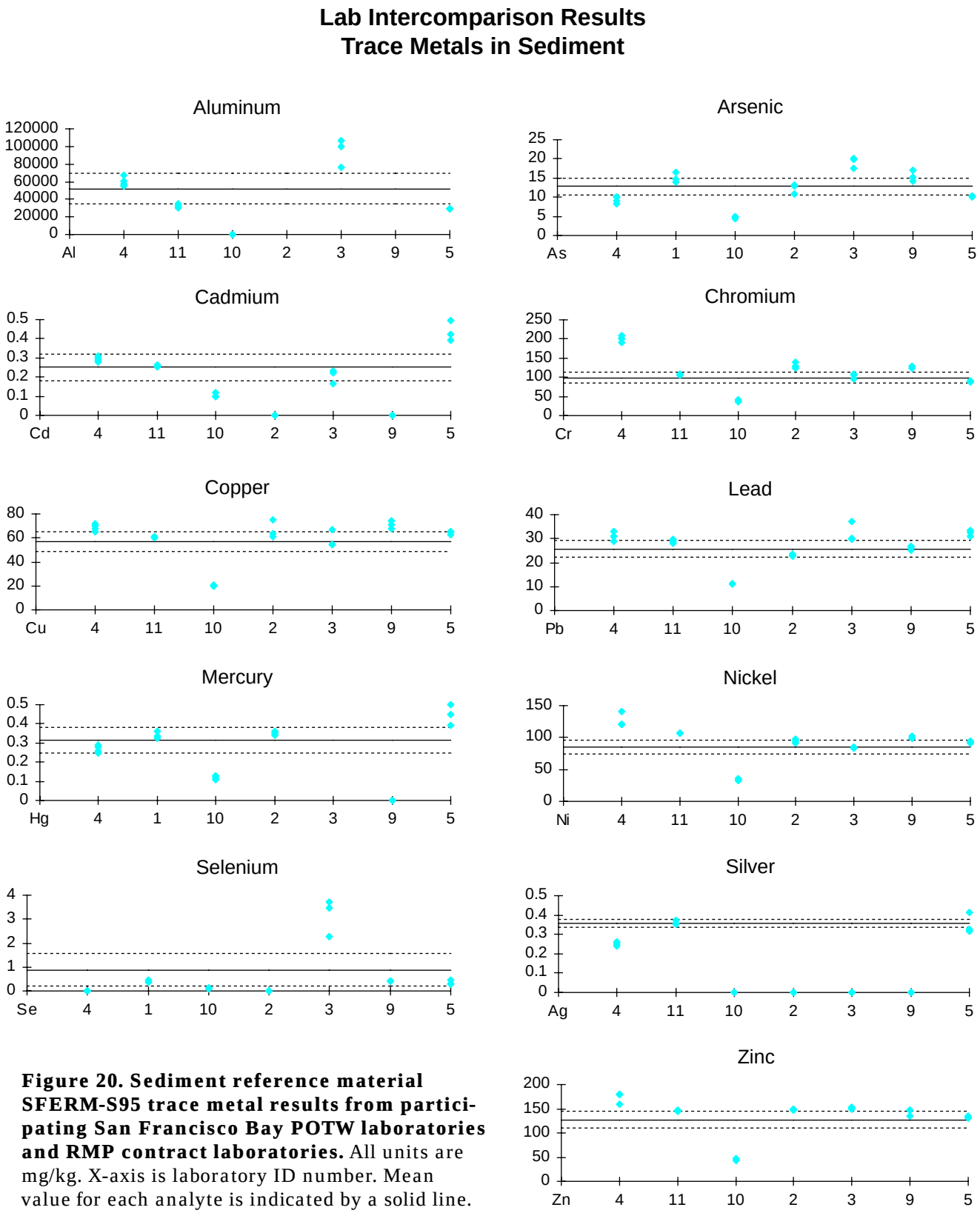

Figure 20. Sediment reference material SFERM-S95 trace metal results from participating San Francisco Bay POTW laboratories and RMP contract laboratories. All units are mg/kg. X-axis is laboratory ID number. Mean value for each analyte is indicated by a solid line. The mean value is calculated from all participating laboratories. The 95% confidence interval is indicated by the dashed lines. Please note that laboratory # 4 used the hydrofluoric acid extraction method while the other laboratories used the *aqua regia* for sediment extraction.

Lab Intercomparison Results
Organics in Sediment

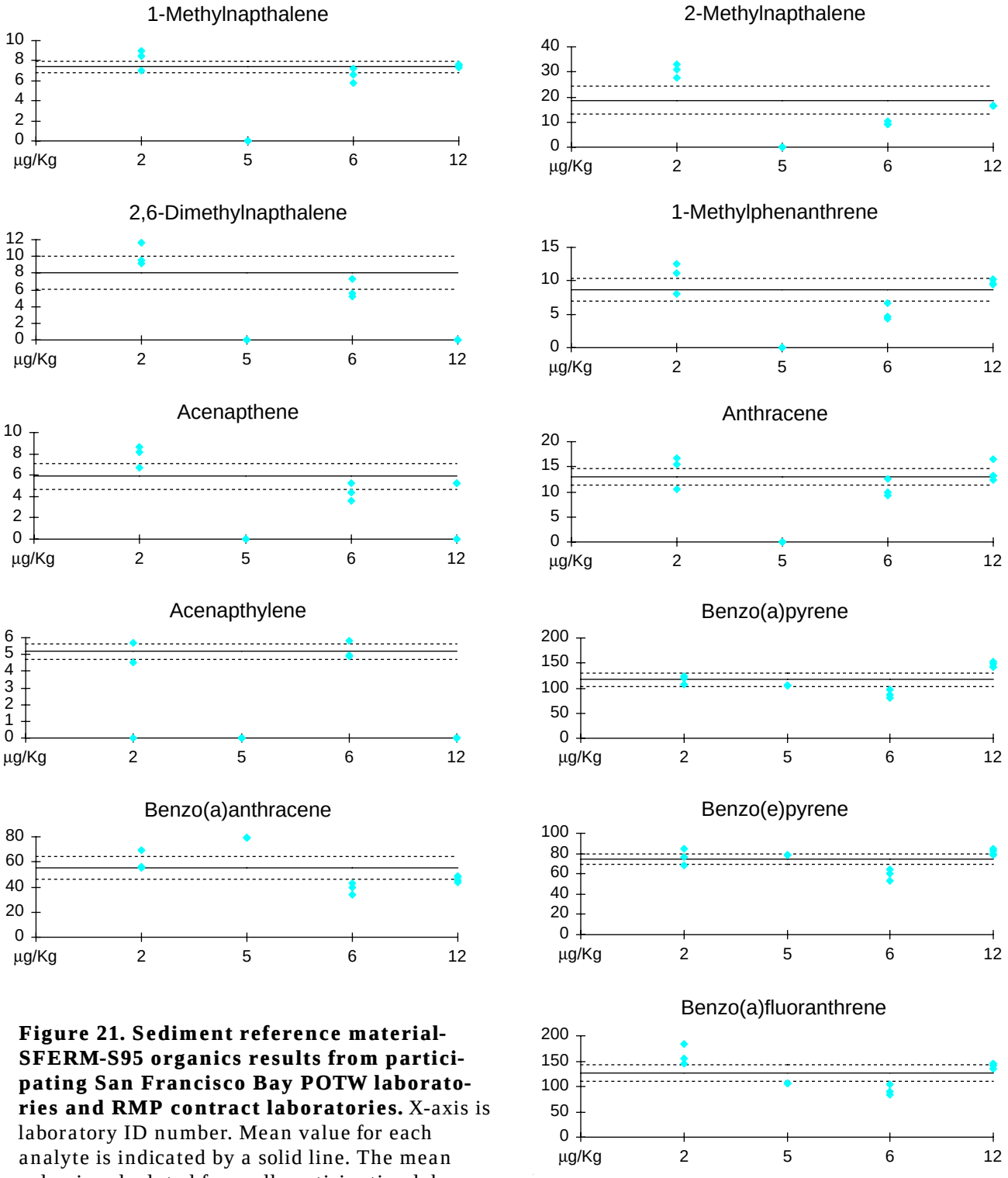

Figure 21. Sediment reference material-SFERM-S95 organics results from participating San Francisco Bay POTW laboratories and RMP contract laboratories. X-axis is laboratory ID number. Mean value for each analyte is indicated by a solid line. The mean value is calculated from all participating laboratories. The 95% confidence interval is indicated by the dashed lines.

Lab Intercomparison Results
Organics in Sediment

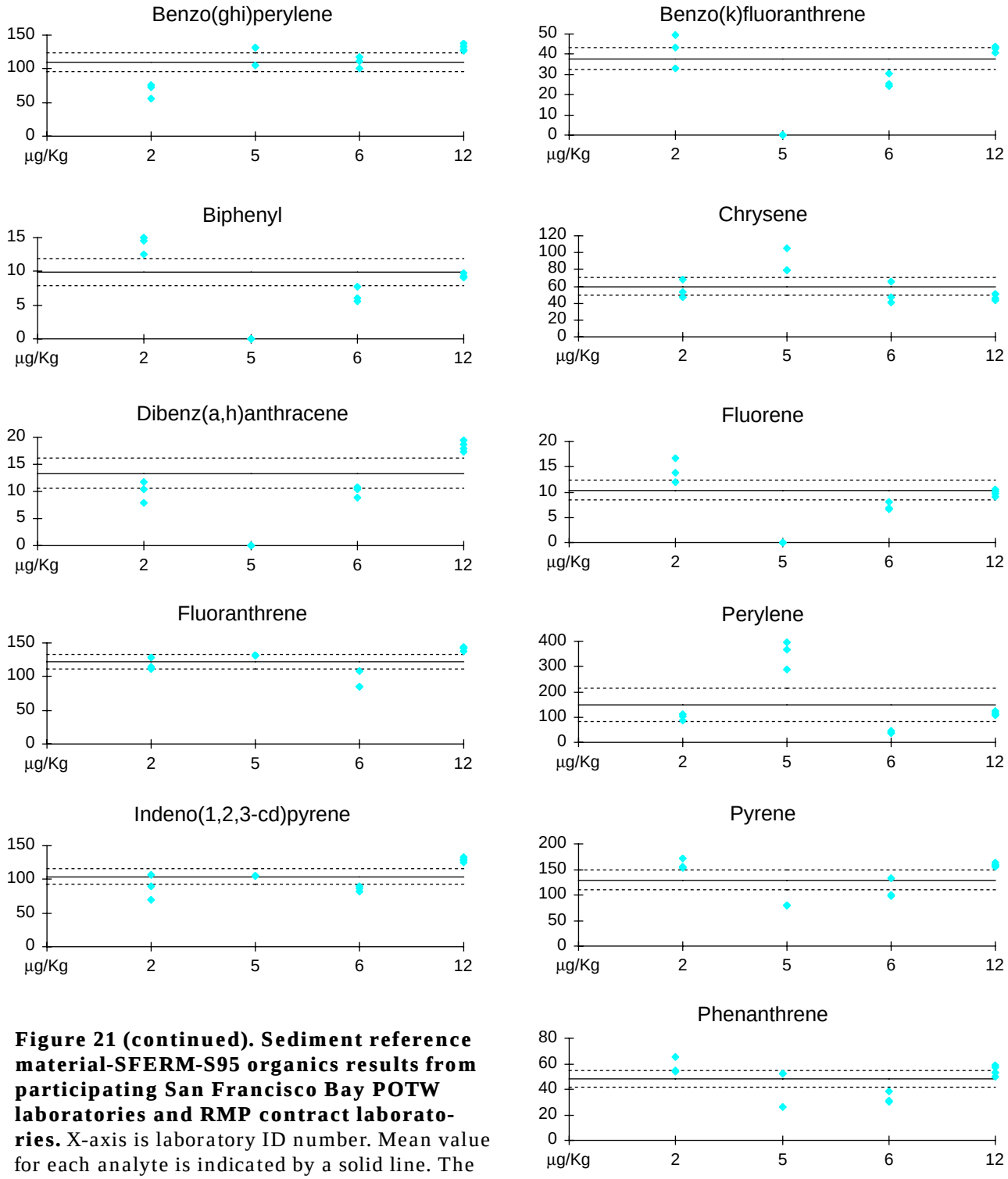

Figure 21 (continued). Sediment reference material-SFERM-S95 organics results from participating San Francisco Bay POTW laboratories and RMP contract laboratories. X-axis is laboratory ID number. Mean value for each analyte is indicated by a solid line. The mean value is calculated from all participating laboratories. The 95% confidence interval is indicated by the dashed lines.

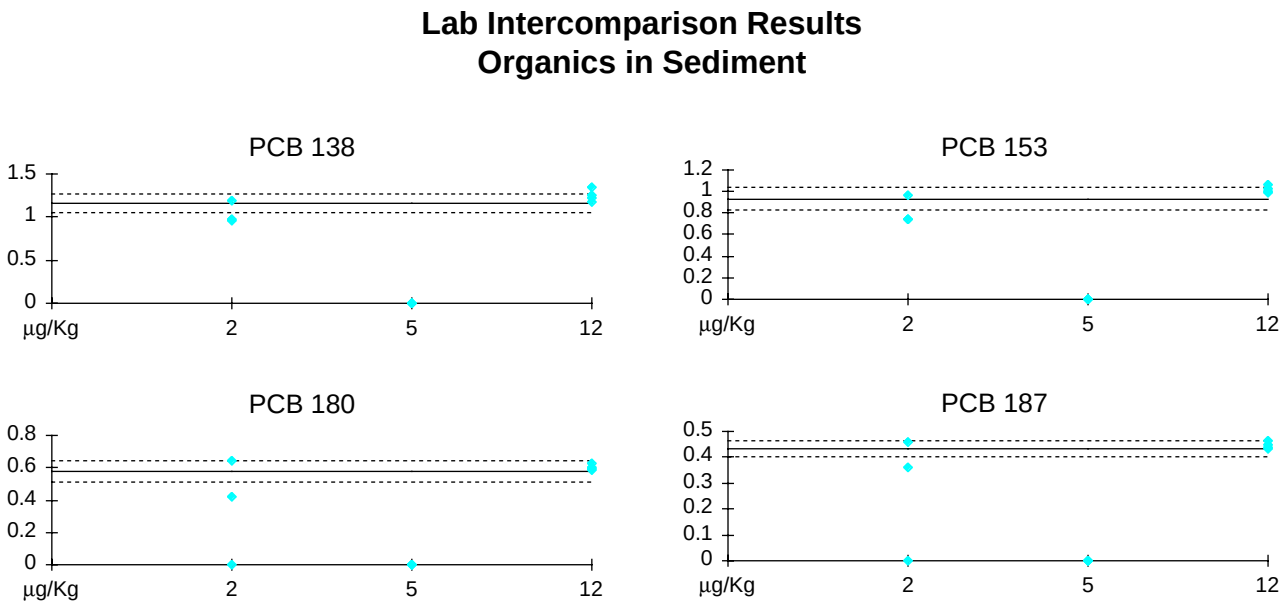

Figure 22. Sediment reference material-SFERM-S95 organics results from participating San Francisco Bay POTW laboratories and RMP contract laboratories. X-axis is laboratory ID number. Mean value for each analyte is indicated by a solid line. The mean value is calculated from all participating laboratories. The 95% confidence interval is indicated by the dashed lines.

Lab Intercomparison Results
Trace Metals in Sediment

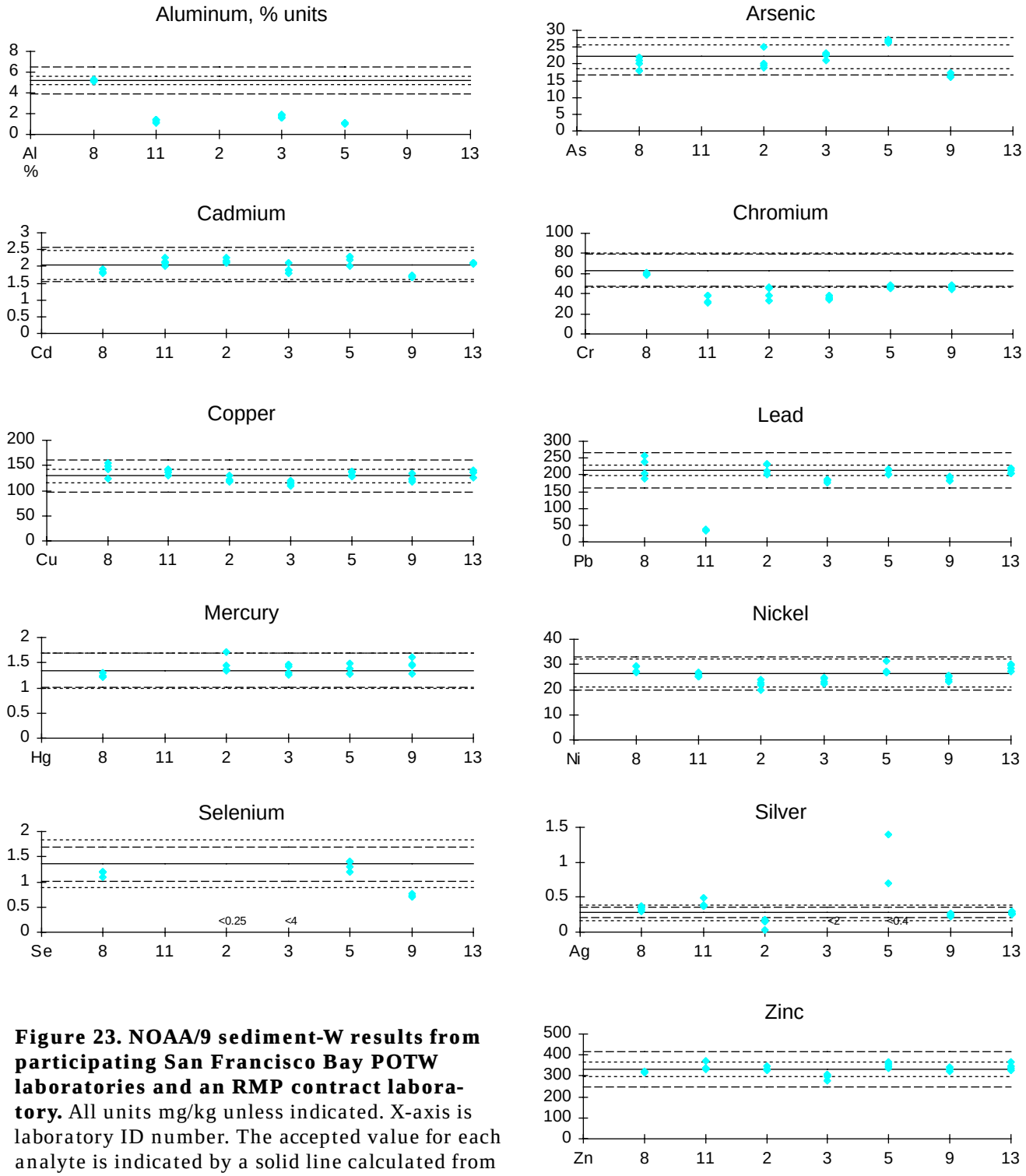

Figure 23. NOAA/9 sediment-W results from participating San Francisco Bay POTW laboratories and an RMP contract laboratory. All units mg/kg unless indicated. X-axis is laboratory ID number. The accepted value for each analyte is indicated by a solid line calculated from the mean of all NOAA/9 particiapting laboratories. The 95% confidence interval is indicated by the dotted lines. The RMP data quality objective (DQO) is indicated by the dashed lines. The RMP DQO for trace elements is ±25% accuracy for As, Hg, and Se and ±30% for all others. Please refer to the NRC, NOAA/9 publication (November, 1995) for more information.

Lab Intercomparison Results
Trace Metals in Sediments

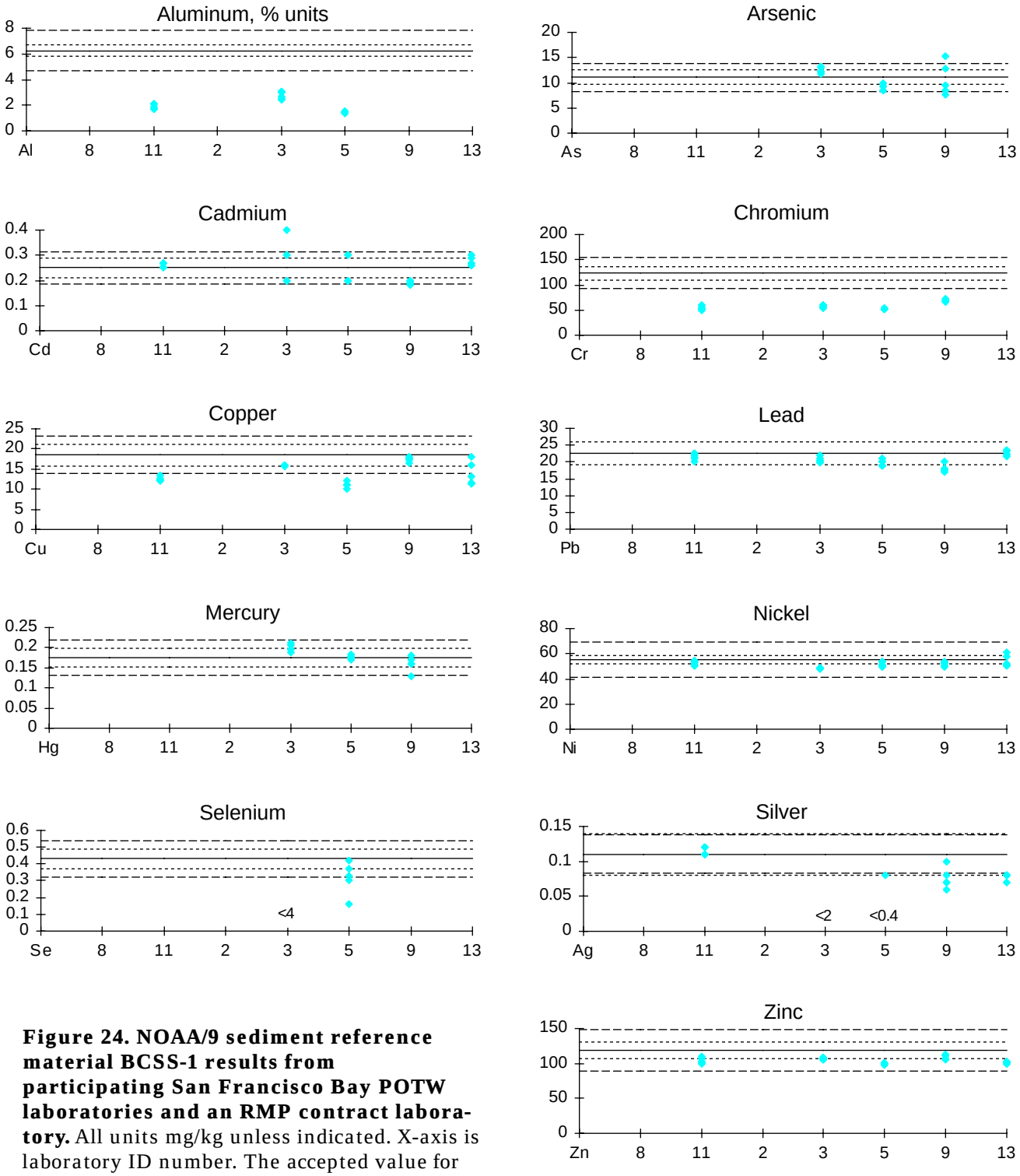

Figure 24. NOAA/9 sediment reference material BCSS-1 results from participating San Francisco Bay POTW laboratories and an RMP contract laboratory. All units mg/kg unless indicated. X-axis is laboratory ID number. The accepted value for each analyte is indicated by a solid line calculated from the mean of all NOAA/9 particiapting laboratories. The 95% confidence interval is indicated by the dotted lines. The RMP data quality objective (DQO) is indicated by the dashed lines. The RMP DQO for trace elements is ±25% accuracy for As, Hg, and Se and ±30% for all others. Please refer to the NRC, NOAA/9 publication (November, 1995) for more information.

Lab Intercomparison Results
Trace Metals in Tissue

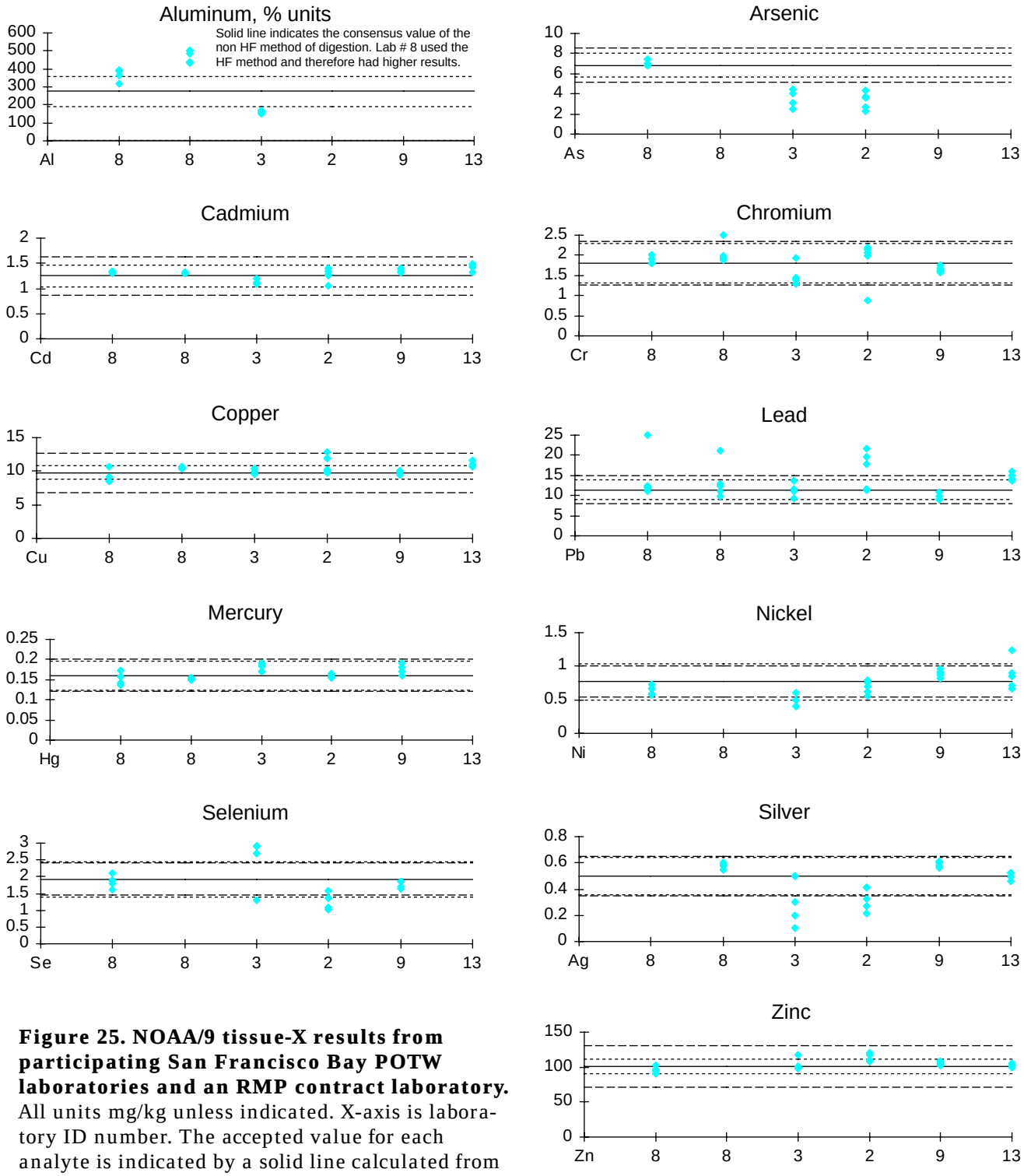

Figure 25. NOAA/9 tissue-X results from participating San Francisco Bay POTW laboratories and an RMP contract laboratory. All units mg/kg unless indicated. X-axis is laboratory ID number. The accepted value for each analyte is indicated by a solid line calculated from the mean of all NOAA/9 particiapting laboratories. The 95% confidence interval is indicated by the dotted lines. The RMP data quality objective (DQO) is indicated by the dashed lines. The RMP DQO for trace elements is ±25% accuracy for As, Hg, and Se and ±30% for all others, except Al which does not have a RMP DQO. Please refer to the NRC, NOAA/9 publication (November, 1995) for more information.

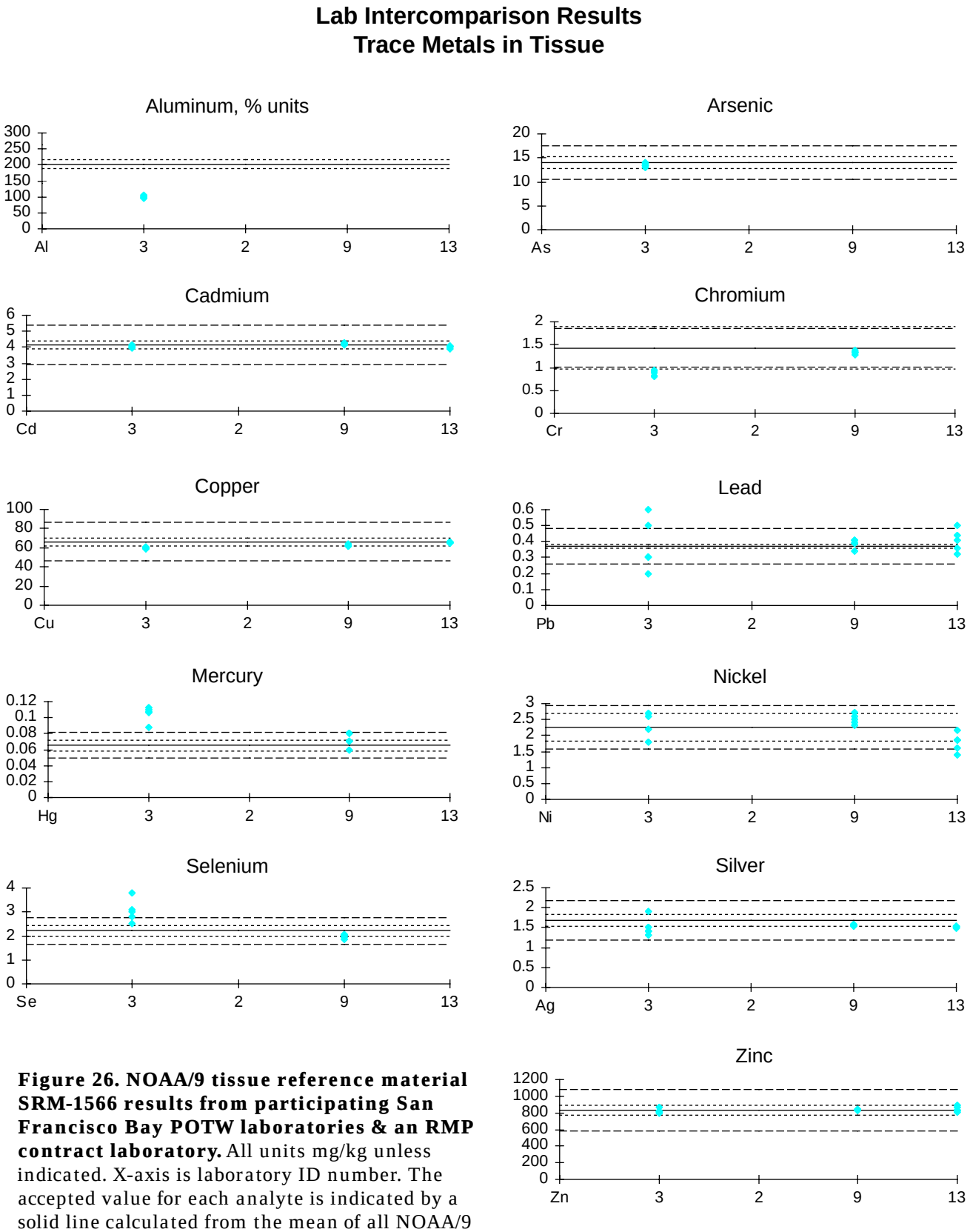

Figure 26. NOAA/9 tissue reference material SRM-1566 results from participating San Francisco Bay POTW laboratories & an RMP contract laboratory. All units mg/kg unless indicated. X-axis is laboratory ID number. The accepted value for each analyte is indicated by a solid line calculated from the mean of all NOAA/9 particiapting laboratories. The 95% confidence interval is indicated by the dotted lines. The RMP data quality objective (DQO) is indicated by the dashed lines. The RMP DQO for trace elements is ±25% accuracy for As, Hg, and Se and ±30% for all others, except Al which does not have a RMP DQO. Please refer to the NRC, NOAA/9 publication (November, 1995) for more information.

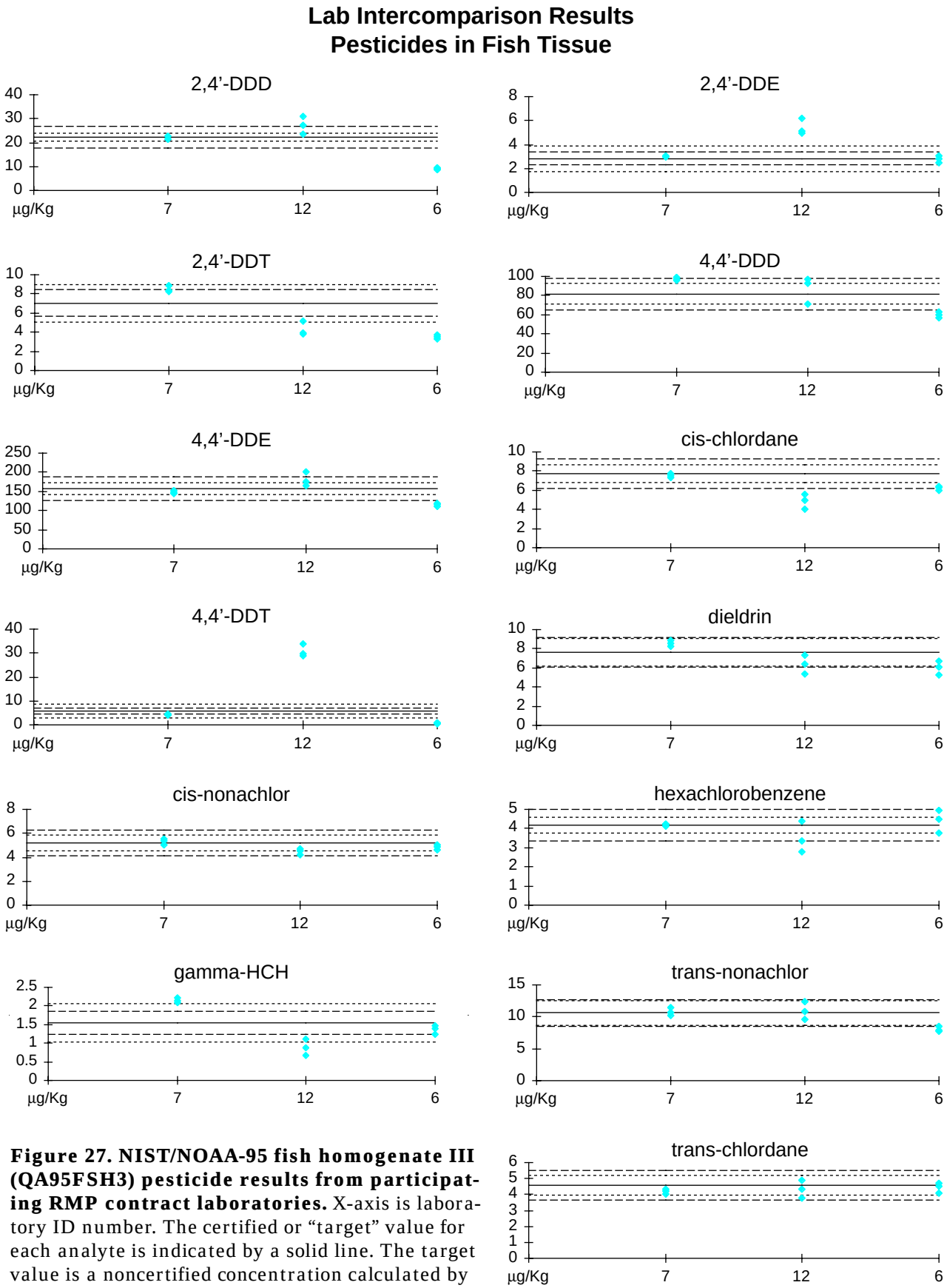

Figure 27. NIST/NOAA-95 fish homogenate III (QA95FSH3) pesticide results from participating RMP contract laboratories. X-axis is laboratory ID number. The certified or "target" value for each analyte is indicated by a solid line. The target value is a noncertified concentration calculated by NIST. The 95% confidence interval is indicated by dotted lines. The RMP data quality objective of ±20% accuracy is indicated by the dashed lines.

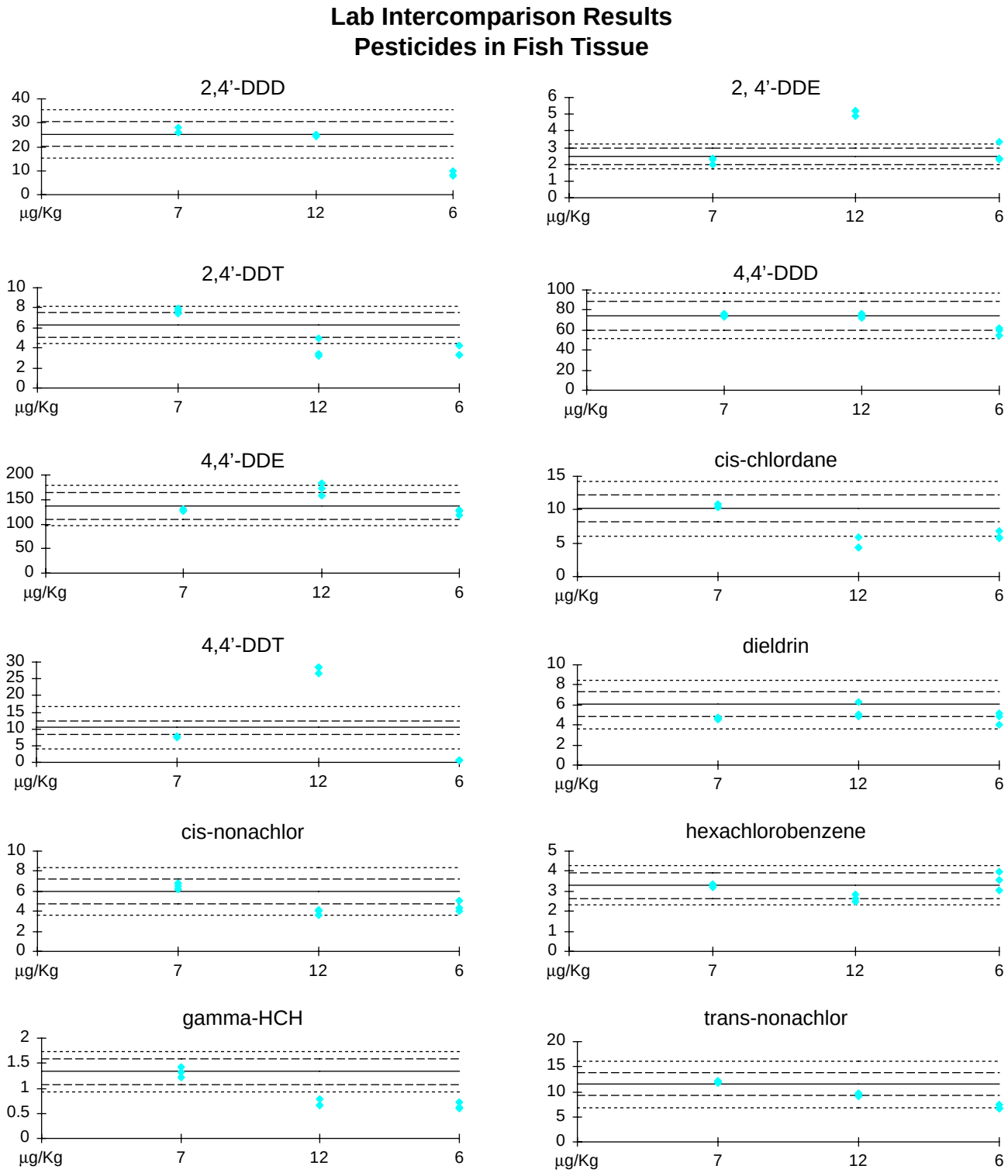

Figure 28. NIST/NOAA-95 fish certified reference material (Carp 1) persticide results from participating RMP contract laboratories. All units mg/kg unless indicated. X-axis is laboratory ID number. The certified or "target" value for each analyte is indicated by a solid line. The target value is a noncertified concentration calculated by NIST. The 95% confidence interval is indicated by dotted lines. The RMP data quality objective of±20% accuracy is indicated by the dashed lines.

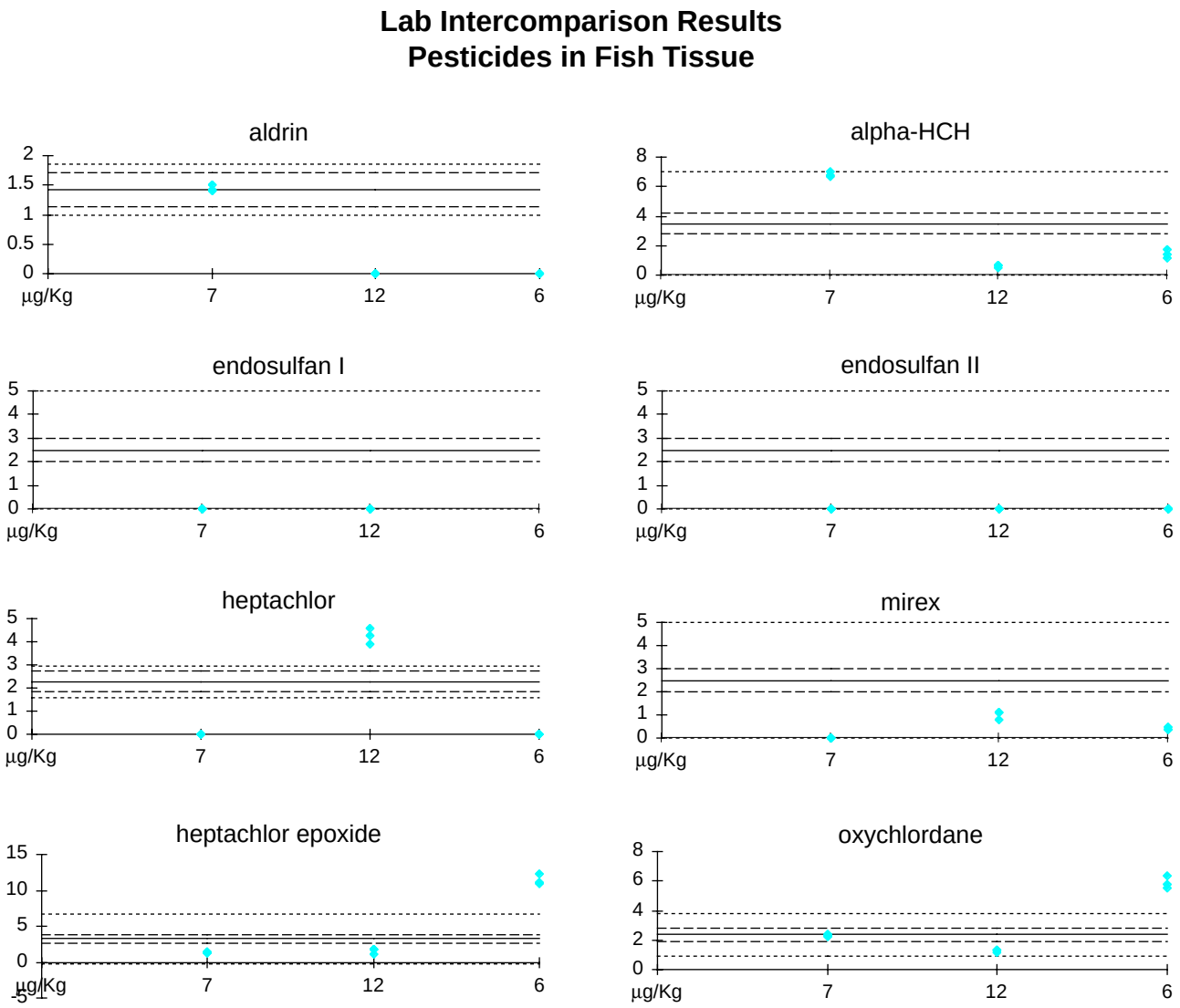

Figure 28 (continued). NIST/NOAA-95 fish certified reference material (Carp 1) persticide results from participating RMP contract laboratories. All units mg/kg unless indicated. X-axis is laboratory ID number.The certified or "target" value for each analyte is indicated by a solid line. The target value is a noncertified concentration calculated by NIST. The 95% confidence interval is indicated by dotted lines. The RMP data quality objective of ±20% accuracy is indicated by the dashed lines.

Lab Intercomparison Results
PCBs in Fish Tissue

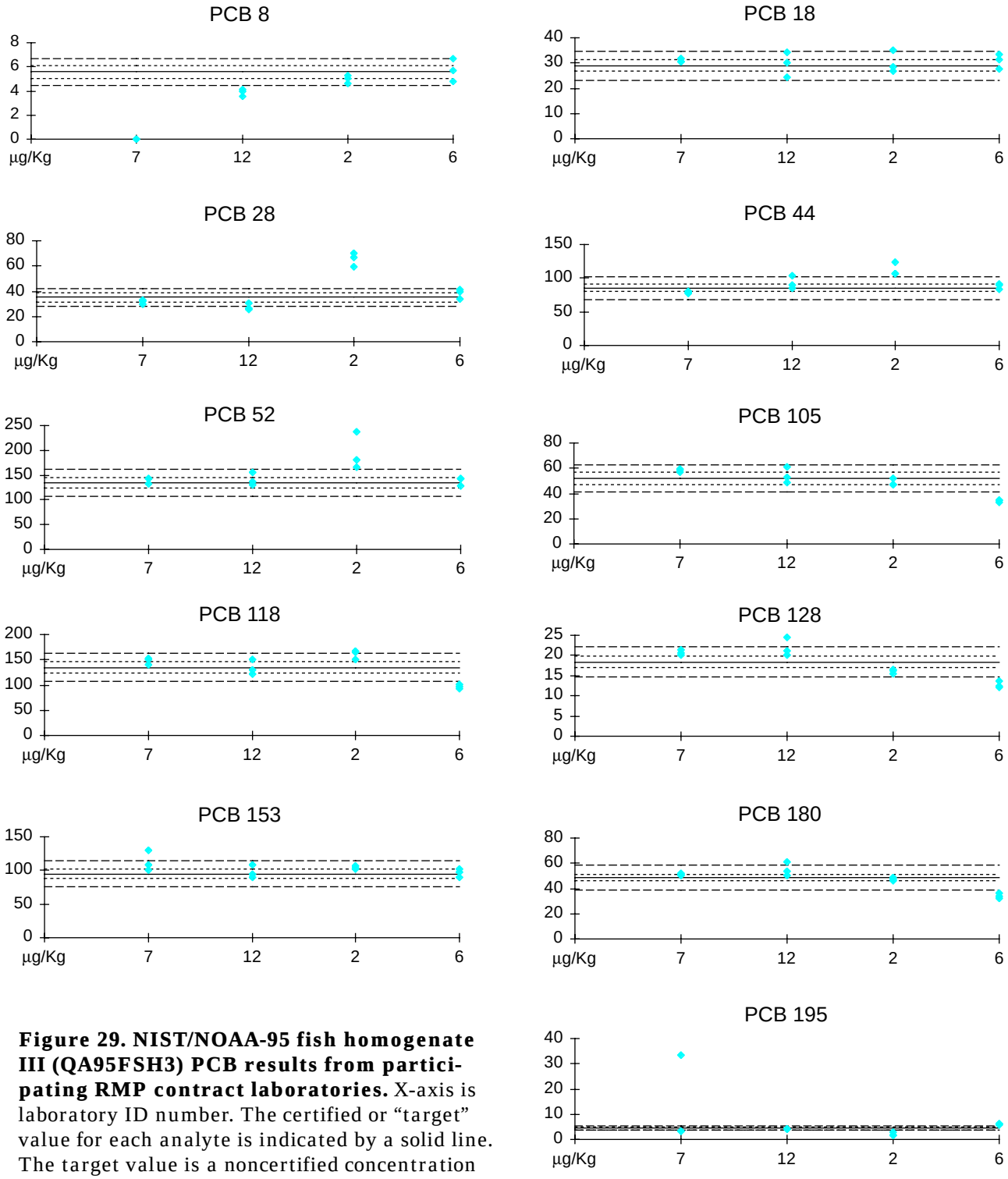

Figure 29. NIST/NOAA-95 fish homogenate III (QA95FSH3) PCB results from participating RMP contract laboratories. X-axis is laboratory ID number. The certified or "target" value for each analyte is indicated by a solid line. The target value is a noncertified concentration calculated by NIST. The 95% confidence interval is indicated by dotted lines. The RMP data quality objective of ±20% accuracy is indicated by the dashed lines.

Lab Intercomparison Results
PCBs in Fish Tissue

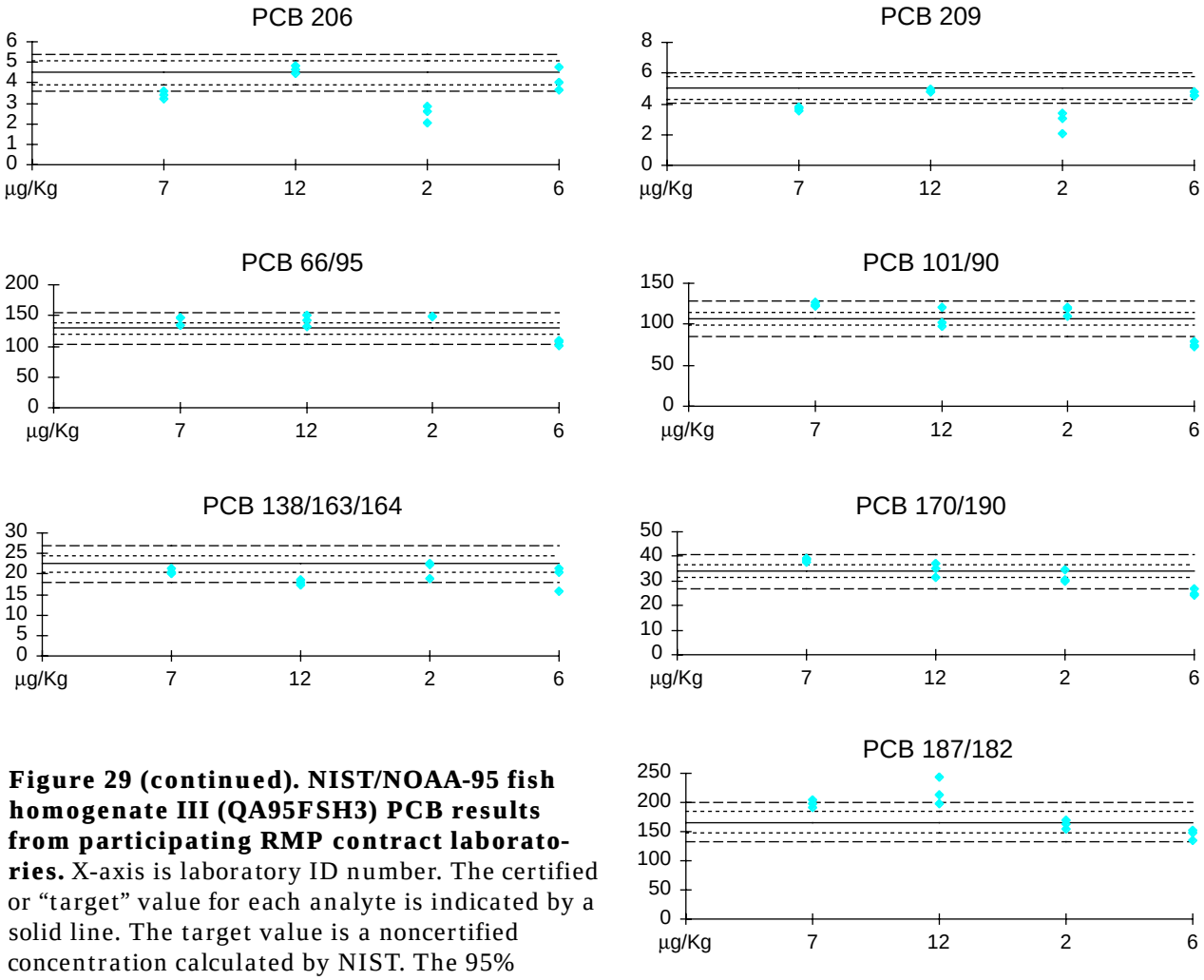

Figure 29 (continued). NIST/NOAA-95 fish homogenate III (QA95FSH3) PCB results from participating RMP contract laboratories. X-axis is laboratory ID number. The certified or "target" value for each analyte is indicated by a solid line. The target value is a noncertified concentration calculated by NIST. The 95% confidence interval is indicated by dotted lines. The RMP data quality objective of ±20% accuracy is indicated by the dashed lines.

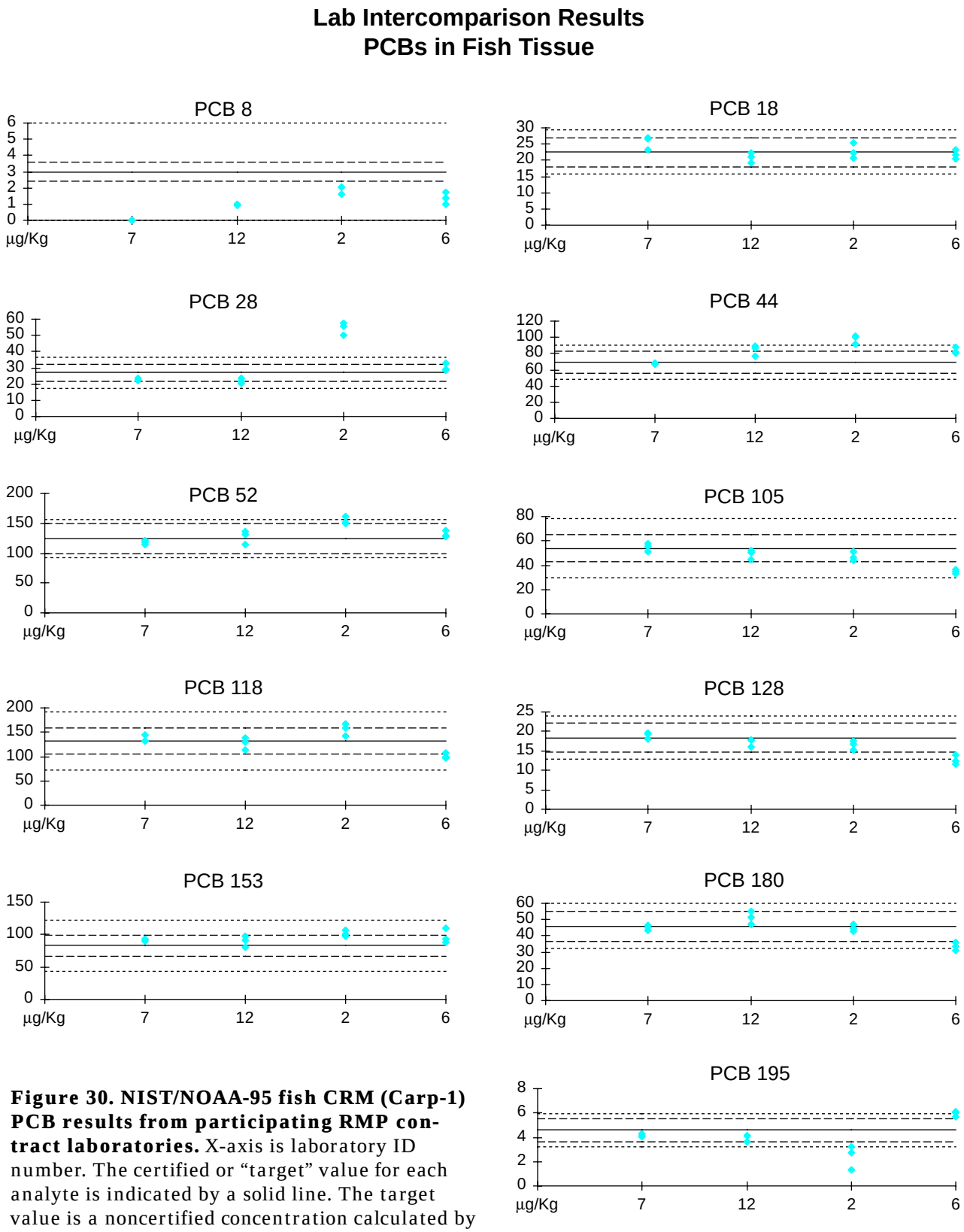

Figure 30. NIST/NOAA-95 fish CRM (Carp-1) PCB results from participating RMP contract laboratories. X-axis is laboratory ID number. The certified or "target" value for each analyte is indicated by a solid line. The target value is a noncertified concentration calculated by NIST. The 95% confidence interval is indicated by dotted lines. The RMP data quality objective of ±20% accuracy is indicated by the dashed lines.

Lab Intercomparison Results
PCBs in Fish Tissue

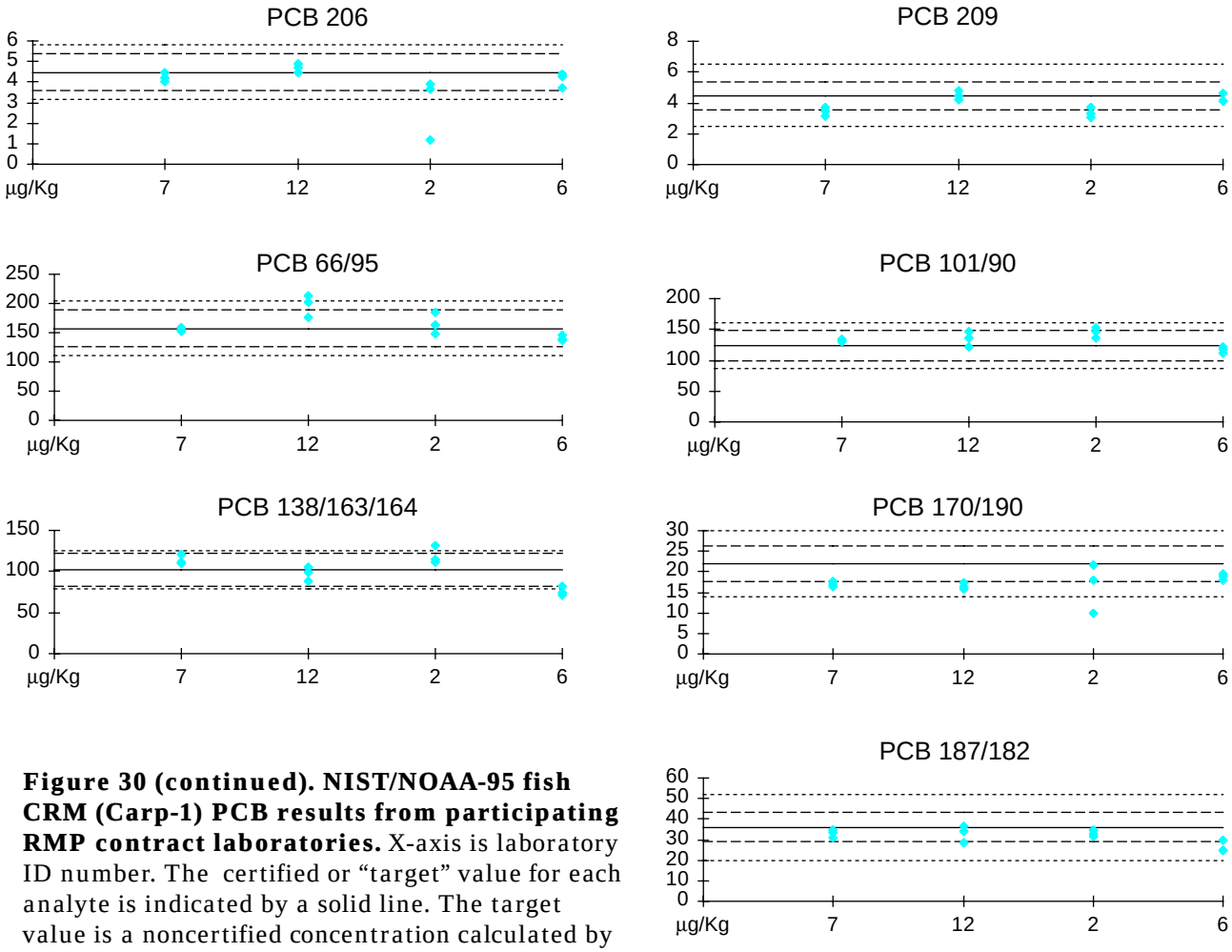

Figure 30 (continued). NIST/NOAA-95 fish CRM (Carp-1) PCB results from participating RMP contract laboratories. X-axis is laboratory ID number. The certified or "target" value for each analyte is indicated by a solid line. The target value is a noncertified concentration calculated by NIST. The 95% confidence interval is indicated by dotted lines. The RMP data quality objective of ±20% accuracy is indicated by the dashed lines.

CHAPTER SIX

Other Monitoring Activities

A Summary of the South Bay Local Effects Monitoring Program

Don Arnold, City of San Jose
John Haskins, San Francisco Estuary Institute

This report is a compilation of data from two sources: *Near Field Receiving Water Monitoring of Trace Metals in Clams (Macoma balthica) and Sediments Near the Palo Alto and San Jose/Sunnyvale Water Quality Control Plants in South San Francisco Bay: December 1994 through December 1995* (Luoma *et al.*, 1996), and Local Effects Monitoring data collected through the Regional Monitoring Program for Trace Substances (RMP).

The stations included in this report are defined as follows:

1. San Jose (station code C-3-0) is located in Coyote Creek, midway between Artesian Slough and Mud Slough; sampling and analysis are conducted through the San Francisco Estuary Institute (SFEI).
2. Sunnyvale (station code C-1-3) is located in Guadalupe Slough approximately one kilometer downstream from the Sunnyvale Water Pollution Control Plant; sampling and analysis are conducted through SFEI.
3. SJ/SV(station code C-1-7) is located in the mouth of Coyote Creek midway between Alviso Slough and Guadalupe Slough; sampling and analysis are conducted through the United States Geological Survey (USGS).
4. Palo Alto (with no station code) is located one kilometer downstream from the Palo Alto Regional Water Quality Control Plant; sampling and analysis are conducted through USGS.

Local Effects Monitoring Program (LEMP) data collection and analysis for stations C-3-0 and C-1-3 was performed by methods and techniques identical to the RMP. The USGS data are generally comparable, with exception of grain size analysis. A copy of the LEMP report has been filed with the Regional Water Quality Control Board.

Samples from the San Jose (C-3-0) and Sunnyvale (C-1-3) sites were collected using a modified Van Veen grab with a surface area of 0.1 m^2. The top 5 cm of sediment was scooped from each of two replicate grabs and mixed in a bucket to provide a single composite sample for each station. The same collection method was employed by USGS at the SJ/SV (C-1-7) site. Sediments at the Palo Alto site were collected

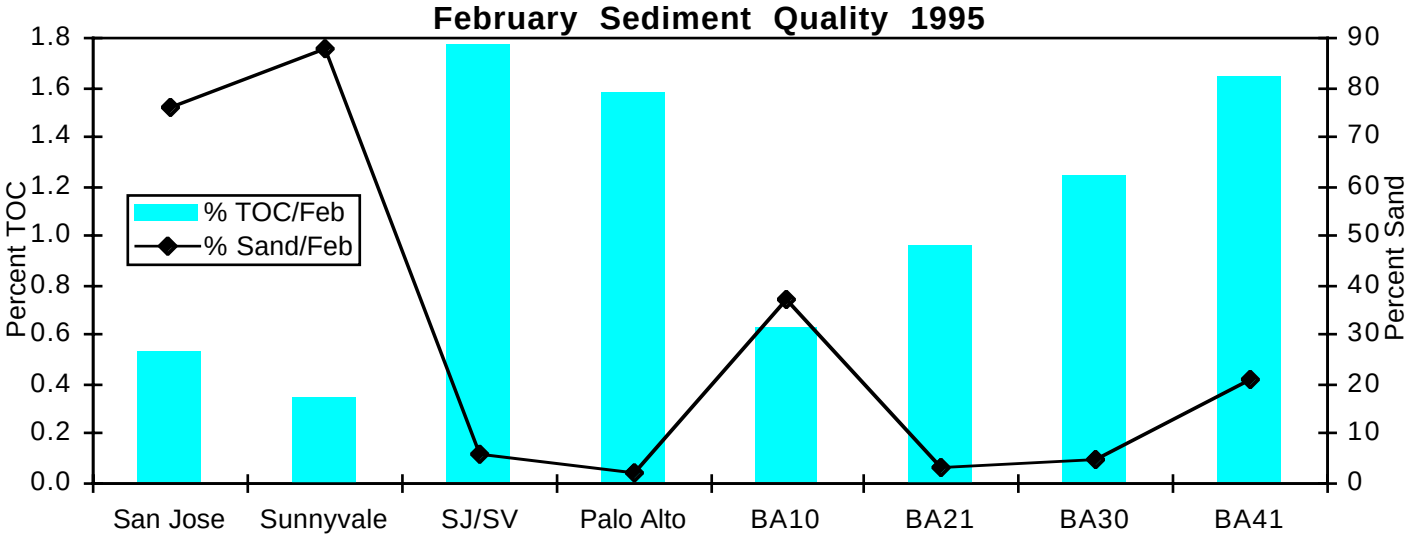

Figure 1. Percent TOC and sand in sediment samples during the month of February.

by hand and shovel and were scraped from the top 1–2 cm of the mudflat. The sediments were then sieved through 100 µm polyethylene mesh with distilled water to remove the larger grains. This was not done at the San Jose (C-3-0) and Sunnyvale (C-1-3) sites and thus may bias interpretation.

Clams and oysters were collected in a similar manner but had some differences. USGS collected more than 40 individuals of *Macoma balthica* and held them in ocean water for 48 hours to depurate undigested material from their digestive tract. In contrast, RMP collected individuals of *Crassostrea gigas* and did not hold animals for depuration. Based on findings by Stephenson (1992) during the 1992 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, there were no significant differences found in trace metal concentrations between mussels held for 48 hours in "clean" Granite Canyon seawater before homogenization and undepurated mussels. Slightly different analytical techniques were also used by USGS and RMP laboratories though these differences are unlikely to affect comparisons between stations.

The 1995 sediment analysis resulted in a similar relationship between percent total organic carbon (TOC) and concentration of trace metals as the 1994 sediment samples (Tables 1 and 2). In general, metal concentrations increased with an increase in percent TOC. Manganese, selenium, and cadmium were the exceptions to this trend. Manganese concentrations increased with percent TOC at all stations except San Jose (C-3-0) where concentrations decreased as percent TOC increased. At the SJ/SV (C-1-7) station selenium concentrations remained the same with a decrease in percent TOC. At the Palo Alto site selenium concentrations increased slightly with decreasing percent TOC. Cadmium at the Sunnyvale (C-1-3) site and selenium at the SJ/SV (C-1-7) site remained the same as percent TOC increased and decreased respectively. All the other metals followed the trend without deviation.

The San Jose (C-3-0) and Sunnyvale (C-1-7) sites increased in percent TOC and decreased in percent sand from the wet to dry season (Figures 1 and 2). The SJ/SV (C-1-7) and Palo Alto sites showed the opposite trend, decreasing in percent TOC and increasing in percent sand from the wet to dry season (Figures 1 and 2). The San Jose (C-3-0) site demonstrated a

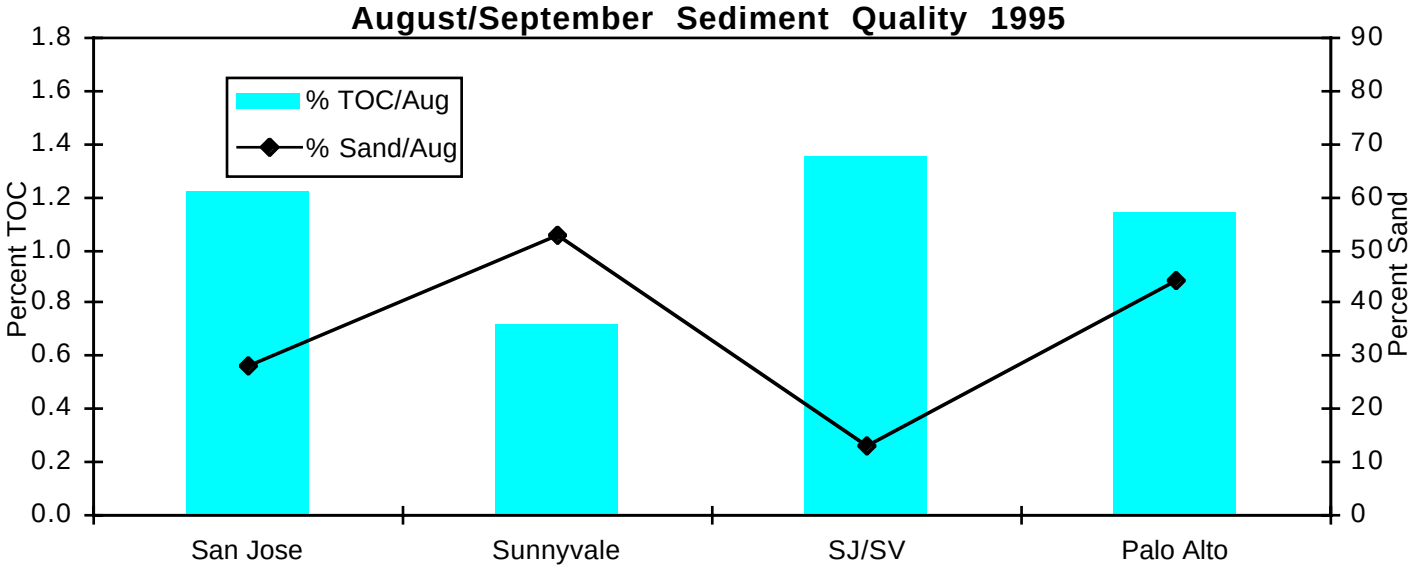

Figure 2. Percent TOC and sand in sediment samples during the August/September sampling.

Table 1. Trace elements, TOC and sand in sediment samples. Trace element data in mg/kg dry weight.

Parameter	Sediment Analysis February 1994				Sediment Analysis February 1995			
	San Jose (C-3-0)	Sunnyvale (C-1-3)	SJ/SV (C-1-7)	Palo Alto (No ID)	San Jose (C-3-0)	Sunnyvale (C-1-3)	SJ/SV (C-1-7)	Palo Alto (No ID)
Ag	0.13	1.11	0.51	1.00	0.36	0.07	0.36	0.84
Al	14,891.00	46,785.00	38,200.00	42,300.00	12,231.00	11,896.00	58,916.00	53,127.00
As	6.97	7.89	N/A	N/A	6.10	2.00	na	na
Cd	0.18	0.48	0.20	0.19	0.26	0.17	0.35	0.25
Cr	81.00	170.50	101.00	120.00	70.00	55.60	148.00	125.00
Cu	21.99	94.59	45.00	52.00	21.10	22.70	58.10	47.60
Fe	29,996.00	82,760.00	39,000.00	47,700.00	22,962.00	20,640.00	54,500.00	73,197.00
Hg	0.07	0.41	0.37	0.34	0.13	0.11	1.10	0.42
Mn	2,817.00	1,250.00	1,229.00	1,202.00	888.00	400.00	904.00	1,232.00
Ni	68.56	130.82	92.00	107.00	78.20	57.90	140.00	97.30
Pb	10.64	45.40	38.00	49.00	16.30	16.50	61.50	40.90
Se	0.30	0.87	0.30	0.30	0.24	0.22	0.50	0.40
Zn	60.77	221.84	136.00	156.00	72.00	70.00	175.00	144.80
% Sand	93.00	1.00	41.00	52.00	76.00	88.00	6.00	2.00
% TOC	0.33	1.63	1.24	1.39	0.53	0.35	1.77	1.57

Table 2. Trace elements, TOC and sand in sediment samples. Trace element data in mg/kg dry weight.

Parameter	Sediment Analysis August 1994				Sediment Analysis August/September 1995			
	San Jose (C-3-0)	Sunnyvale (C-1-3)	SJ/SV (C-1-7)	Palo Alto (No ID)	San Jose (C-3-0)	Sunnyvale (C-1-3)	SJ/SV (C-1-7)	Palo Alto (No ID)
Ag	0.98	0.28	0.58	0.67	0.96	0.22	0.22	0.22
Al	27,009.00	18,749.00	45,100.00	31,200.00	21,185.00	20,510.00	na	34,850.00
As	8.02	7.51	N/A	N/A	8.20	6.00	na	na
Cd	0.68	0.30	0.26	0.24	0.75	0.17	0.23	0.20
Cr	107.70	75.10	112.00	85.00	97.70	69.10	109.00	95.30
Cu	57.81	34.79	47.00	33.00	49.80	24.90	42.00	35.70
Fe	38,405.00	26,248.00	44,000.00	33,800.00	34,018.00	28,103.00	na	37,425.00
Hg	0.54	0.24	0.41	0.33	0.40	0.31	0.60	0.30
Mn	559.00	467.00	542.00	863.00	595.00	728.00	na	888.70
Ni	118.59	81.13	104.00	78.00	105.70	63.80	101.00	86.80
Pb	41.22	27.98	39.00	31.00	50.60	22.40	45.00	36.70
Se	0.42	0.54	0.30	0.23	0.41	0.31	0.50	0.42
Zn	162.92	112.49	140.00	106.00	148.00	78.00	137.00	116.80
% Sand	4.00	38.00	10.00	40.00	28.00	53.00	13.00	44.00
% TOC	1.39	1.06	1.33	0.98	1.22	0.71	1.35	1.14

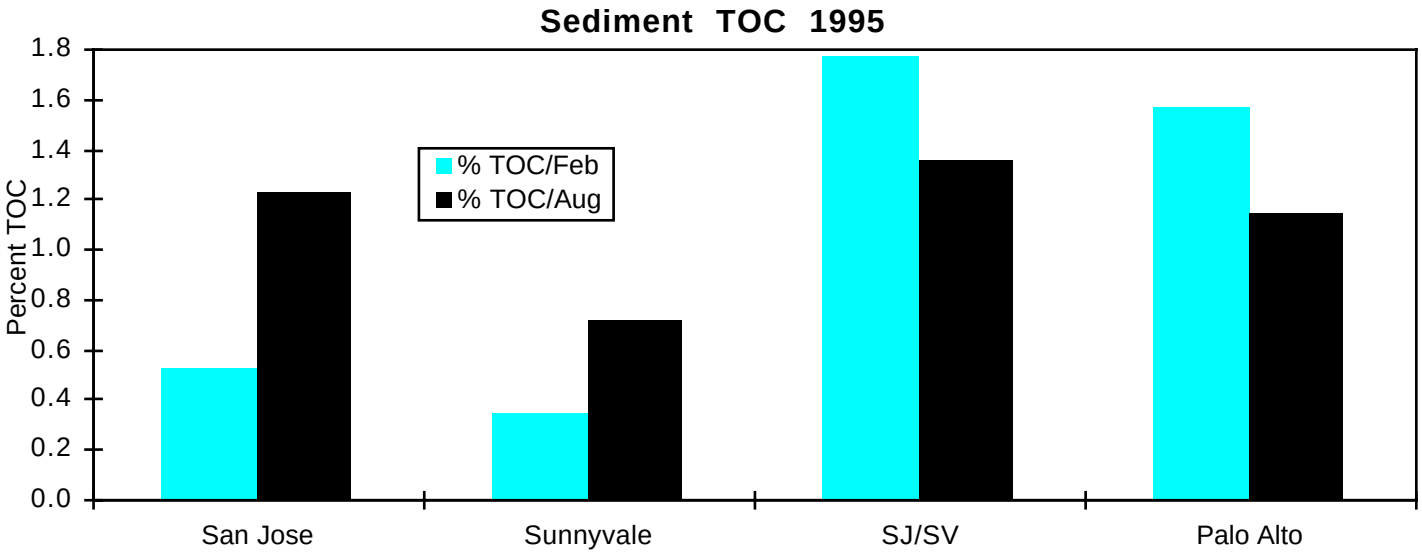

Figure 3. Percent TOC in sediment samples during the wet and dry seasons.

large increase in percent TOC whereas both the SJ/SV (C-1-7) and Palo Alto sites decreased from February to August (Figure 3). The largest decrease in percent sand was at the San Jose (C-3-0) site and the largest increase in percent sand was at the Palo Alto site (Figure 4).

A notable observation in 1995 was the high concentrations of mercury seen in February at the SJ/SV (C-1-7) station (1.1 µg/g), and an even higher concentration of 2.9 µg/g in June (Near Field Receiving Water Monitoring, USGS). The concentration in August (0.6 µg/g) at this site was higher than any other RMP station in either 1994 or 1995. These peaks were not seen at the Palo Alto, Sunnyvale (C-1-3), or San Jose (C-3-0) sites. Salinities at the SJ/SV (C-1-7) site were lowest in February, April, and June, increased slightly during low flow in September and declined again in December 1995. This USGS data suggests that local runoff could be an important source of sedimentary mercury during years of high precipitation.

In general, all the trace elements had very similar seasonal trends within stations, though these trends were not consistent between stations. For the majority of trace elements, concentrations at the San Jose (C-3-0) site increased from February to August for both 1994 and 1995. At the Sunnyvale (C-1-3), site concentrations of all trace elements decreased from February to August in 1994 and increased in 1995. At the SJ/SV (C-1-7) the opposite case was the trend. Concentrations generally increased in 1994 and decreased in 1995. Concentrations at the Palo Alto site generally decreased from February to August during both years.

Silver, chromium, iron, and selenium had maximum and minimum concentrations that were observed at the same stations. The lowest concentration for all of these metals were observed at the Sunnyvale (C-1-3) site in February 1995. The highest concentrations were observed at this site in February of 1994. Average concentrations were generally about the same for both years with the exception of Sunnyvale (C-1-3) which had higher average concentrations in 1994 than 1995. The ranges of concentrations were as follows; silver, from 0.07 to 1.11 ppm; chromium, from 55.6 to 170.5 ppm; iron, from 20640 to 83760 ppm; and selenium, from 0.217 to 0.87 ppm.

The highest concentrations of copper and zinc were also observed at Sunnyvale (C-1-3), and their lowest concentrations were observed at the San Jose (C-3-0) site in February of 1995 for copper and February 1994 for zinc. Copper concentrations ranged from 21.1 to 94.59 ppm, and zinc concentrations ranged from 60.77 to 221.8 ppm. Average concentrations were generally consistent from 1994 to 1995 except for a notably higher concentration at the Sunnyvale (C-1-3) site in 1994 for both of these metals.

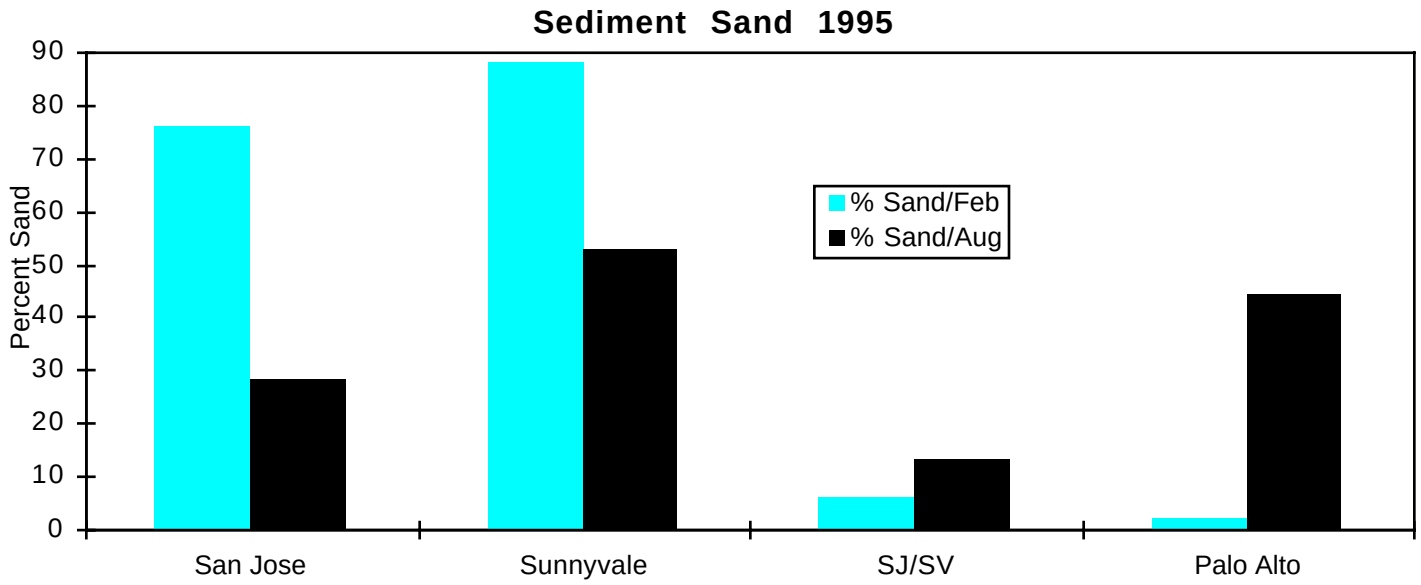

Figure 4. Percent sand in sediment during the wet and dry seasons.

The highest concentrations of lead, mercury, aluminum, and nickel were observed at the SJ/SV (C-1-7) site in February of 1995. The lowest concentrations of mercury and lead were observed at the San Jose (C-3-0) site in February of 1995, but the lowest concentrations of nickel and aluminum were observed at the Sunnyvale (C-1-3) site in February 1995. In general, average concentrations for these metals were consistent at each station except for SJ/SV (C-1-7) which had higher average concentrations in 1995 than in 1994. Nickel and aluminum also had higher average concentrations at the Sunnyvale (C-1-3) site in 1994 than in 1995. Concentrations of these metals exhibited the following ranges: lead, from 10.64 to 61.5 ppm; mercury, from 0.072 to 1.1 ppm; aluminum, 11896 to 58916 ppm; and nickel, from 57.9 to 140.

The highest concentrations of magnesium and cadmium were observed at San Jose (C-3-0) in February 1994 and August 1995 respectively. The lowest concentrations were both observed at Sunnyvale (C-1-3) in February 1995. Average concentrations of cadmium were consistent, but the average magnesium concentration was larger in San Jose (C-3-0) in February 1994.

To measure bioaccumulation of trace elements in tissue, two different species of bivalves were used. The RMP measured the oyster, *Crassostrea gigas*, while at the USGS sites the clam *Macoma balthica* was analyzed. Bioaccumulation was not measured at the San Jose (C-3-0) or Sunnyvale (C-1-3) sites, thus comparisons are made to the next closest RMP site which is Coyote Creek (BA10).

At the Palo Alto site, concentrations in tissues were analyzed once each month in 1995 except for May and November. The San Jose/Sunnyvale (C-1-7) site was sampled six times in 1995. The RMP Coyote Creek station (BA10) was sampled in April and September. Wet and dry season (April and September) concentrations at all three sites are shown in Tables 3A and 3B.

At the Palo Alto site, the lowest concentrations observed were in April except for zinc which had its lowest concentration in March. The highest concentrations were not as consistent, but generally were observed either in October or December. Thus, when comparing April and September at this site, the concentrations of each metal increased respectively.

At the SJ/SV (C-1-7) site, cadmium, copper, lead, selenium, and silver exhibited a similar trend of highest concentrations found in December. This was similar to concentrations observed in 1994. Other metals had variable concentrations throughout the year. Mercury concentrations were slightly higher in early 1995 compared to early 1994 but were essen-

tially the same in September of both years. This increase in tissue was not comparable to the increase observed in sediments. There was no consistent trend for when the lowest concentrations were observed.

In Coyote Creek (BA10), concentrations were higher in September compared to April for all metals except for silver which had a lower concentration in September, and chromium which had no data in April. This was different from last year at this site where there was no consistent trend of increasing concentrations from wet to dry season.

Comparisons between these four stations were made possible by the efforts of personnel to coordinate sampling design, analytical methods, and collection techniques. The LEM database is large enough to warrant a more in-depth analysis of sediment chemistry near the outfalls compared to RMP reference sites. This program could benefit from sediment grain size intercalibration and quantification of methodological differences in sediment chemistry.

Table 3A. Mean trace metal concentrations in the deposit-feeding bivalve, *Macoma balthica*, collected during the wet (April) and dry (September) season in 1995, at the Local Effects Monitoring sites, SJ/SV and Palo Alto. STD = standard deviation, SEM = standard error of the mean.

Trace Elements in *Macoma balthica*	Ag	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
SJ/SV April 1994									
Mean (ug/g)	1.80	0.10	5.90	30.50	★	7.80	4.10	4.60	231.00
STD	0.30	*	2.00	3.90		1.90	1.00	1.50	21.00
SJ/SV Sept.1994									
Mean (ug/g)	1.60	0.30	4.80	33.80	0.43	7.60	4.40	3.90	163.00
STD	0.30	*	1.60	5.80		1.60	0.80	1.30	24.00
SJ/SV April 1995									
Mean (ug/g)	1.20	0.56	3.20	28.00	*	7.40	2.40	*	412.00
SEM	0.30	0.01	0.40	6.00		1.50	0.40		100.00
SJ/SV Sept. 1995									
Mean (ug/g)	3.50	0.50	1.90	80.00	0.42	4.40	2.60	5.40	255.00
SEM	0.60	0.10	0.30	13.00	0.40	0.40	0.30	0.10	11.00
Palo Alto April 1995									
Mean (ug/g)	2.50	0.31	1.60	23.00	0.33	3.40	1.20	4.00	305.00
SEM	0.40	0.03	0.20	2.00	0.02	0.30	0.10	0.30	35.00
Palo Alto Sept. 1995									
Mean (ug/g)	5.90	0.50	1.90	67.00	0.37	5.00	2.70	4.60	336.00
SEM	0.30	0.08	0.10	4.00	0.04	0.20	0.30	0.50	18.00

* Not enough animals found to perform analysis. ★ Incomplete data sets.

Table 3B. Trace metal concentrations in the tissue of the filter-feeding bivalve, *Crassostrea gigas*, transplanted for 90 days, during the wet (April) and dry (September) season in 1995, at the RMP site, Coyote Creek (BA10).

	Ag	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Coyote Creek–April (ug/g)	6.25	10.60	*	218.00	0.17	5.00	0.52	4.00	1,443.00
Coyote Creek.–Sept. (ug/g)	2.16	16.20	9.10	867.00	0.35	8.00	1.32	11.00	2,050.00

Sacramento Coordinated Water Quality Monitoring Program

T.R. Grovhoug
Larry Walker Associates, Davis, California

Introduction

The Sacramento Coordinated Water Quality Monitoring Program (CMP) is a cooperative 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 waste water and storm water in the vicinity of Sacramento 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 develop a scientifically defensible database of water quality information on the Sacramento and American Rivers at selected locations in the Sacramento metropolitan area. Key features of the CMP include:

1. The Ambient Water Quality Monitoring Program (Ambient Program) for the Sacramento American Rivers.
2. Coordination of ongoing surface water quality monitoring programs within the Sacramento area.
3. A water quality database management system for water quality data produced by the Ambient Program and other City and County programs.
4. Special studies to address specific monitoring needs and to address new regulatory initiatives.
5. An annual technical report summarizing the data collected under the Ambient Program, the results of special studies, and proposed changes in the CMP for the upcoming year.

The Ambient Program is the primary water quality data collection element of the CMP. Sampling under the Ambient Program began in December 1992. The 1996 Annual Report for the Sacramento CMP assesses the results of Ambient Program monitoring completed through July 1996.

Monitoring program features, monitoring results from the first year and one half of Ambient Program sampling (December 1992 through July 1996 covering 77 sampling events), and future direction of the program are summarized below.

Ambient 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 mouth; see Figure 5). Monitoring at the Folsom Lake site upstream of Nimbus on the American River was discontinued in October 1995. The monitoring sites have been selected to provide water quality data upstream and downstream of the influence of discharges from the Sacramento community.

Sampling is performed by a two-person sampling crew using peristaltic pumps. Methods for sample collection include mid-depth shore samples at Nimbus and cross-sectional spatial composite samples taken by boat at the other four sites.

Samples are taken monthly at each site. Additionally, two episodic storm events are sampled in coordination with the Sacramento Stormwater Monitoring Program.

Parameters monitored include trace elements (total and dissolved), cyanide, and conventional parameters (pH, TSS, TDS,

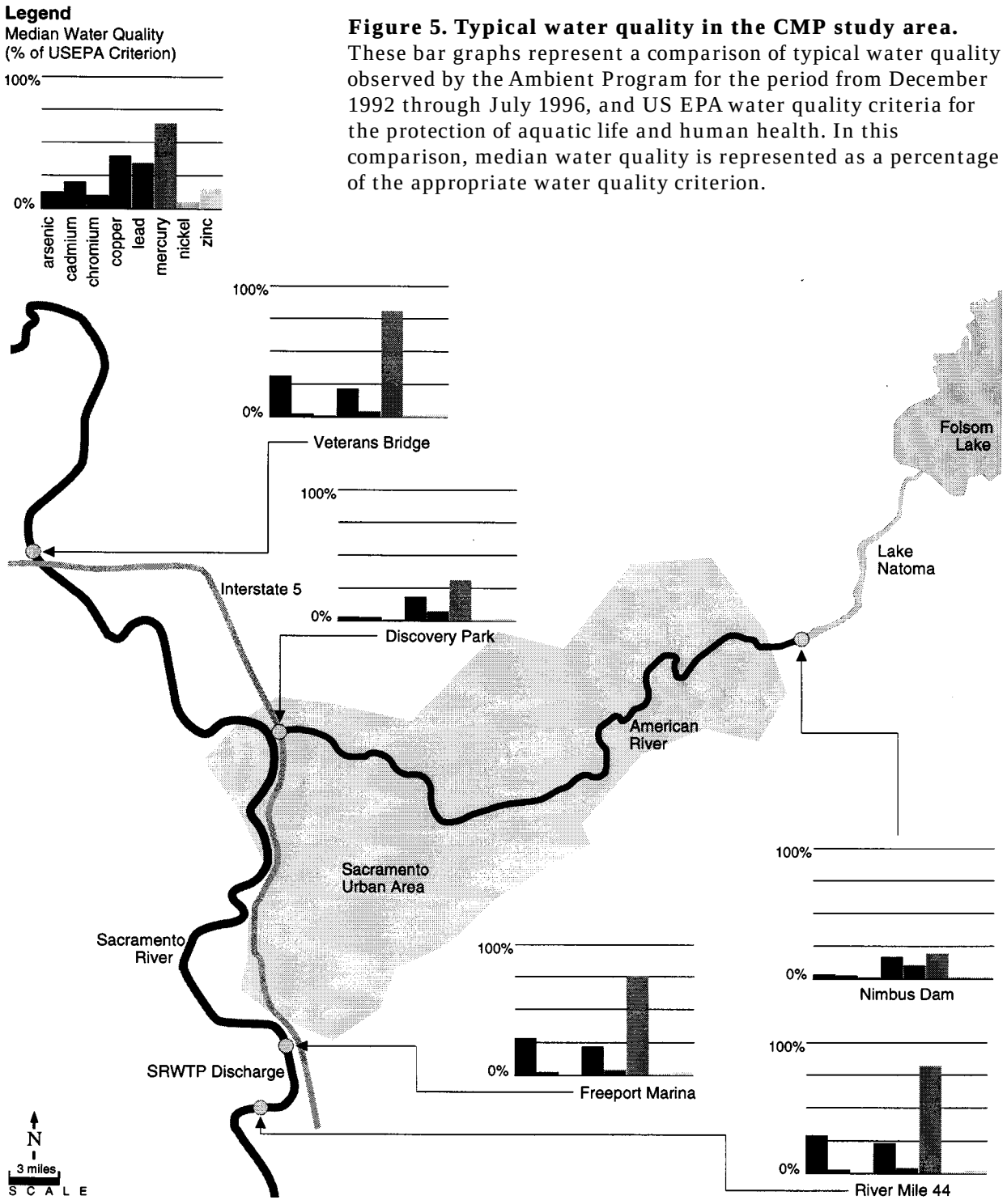

Figure 5. Typical water quality in the CMP study area. These bar graphs represent a comparison of typical water quality observed by the Ambient Program for the period from December 1992 through July 1996, and US EPA water quality criteria for the protection of aquatic life and human health. In this comparison, median water quality is represented as a percentage of the appropriate water quality criterion.

hardness, TOC, temperature). For the storm sampling, organophosphate pesticides are also monitored. The frequency of analysis varies by constituent, ranging from monthly to quarterly to annually.

Clean sampling and analytical methods are employed to produce contaminant-free samples with low detection limits. Sample containers, equipment cleaning, field quality control, and laboratory QA/QC procedures are described below.

Sample Containers and Preservatives: High density polyethylene containers are used for all samples except mercury. Teflon bottles are used for mercury samples. Trace element samples are acidified with ultrapure reagent grade nitric acid (ULTREX II). Cyanide samples are preserved with NaOH. Total organic carbon and hardness samples are preserved with sulfuric acid. Dissolved samples are filtered in the laboratory within 72 hours of collection.

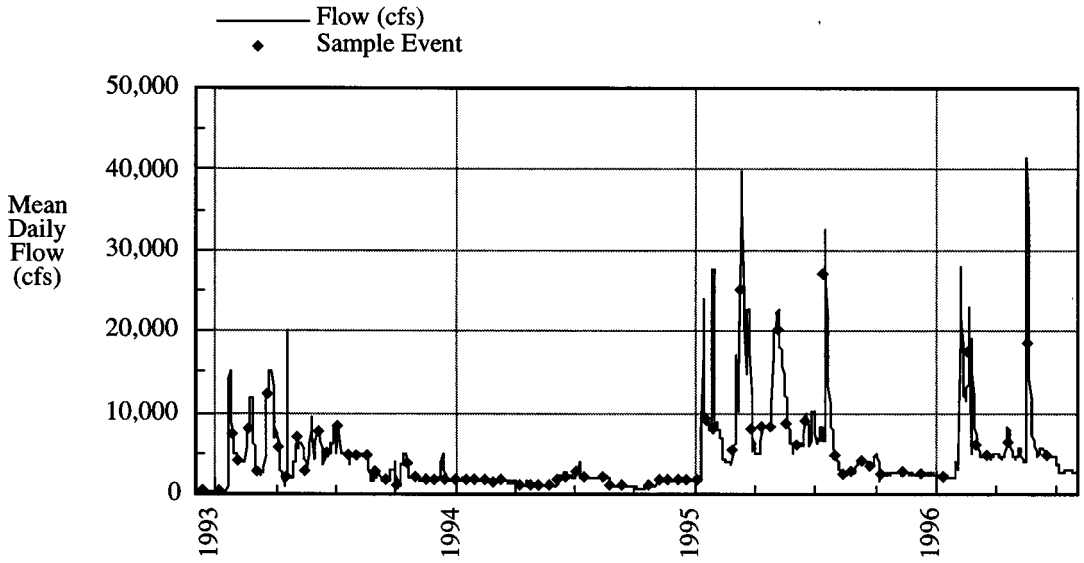

Figure 6. Ambient Program sample events and mean daily river flows: American River at Discovery Park.

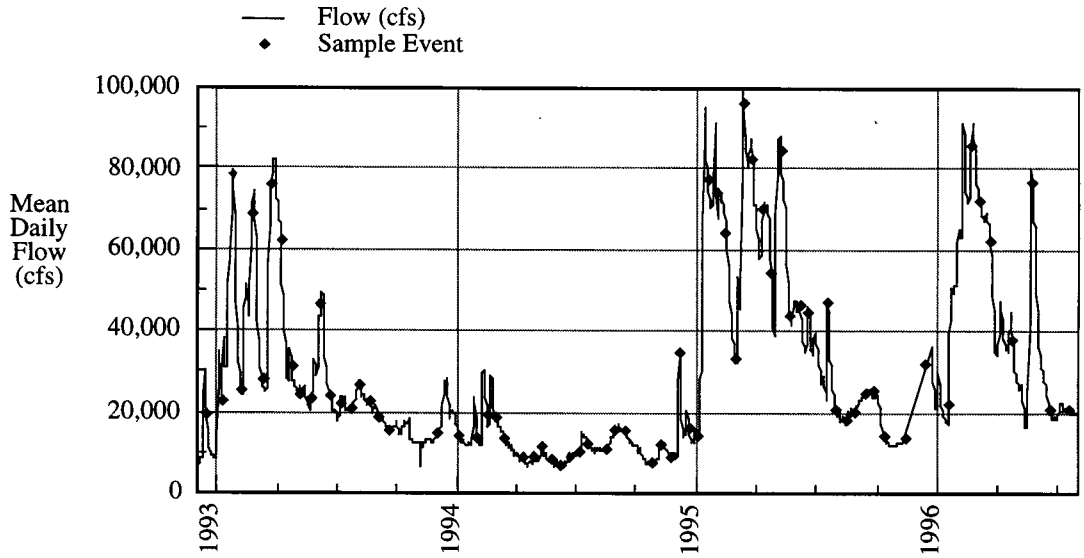

Figure 7. Ambient Program sample events and mean daily river flows: Sacramento River at Freeport.

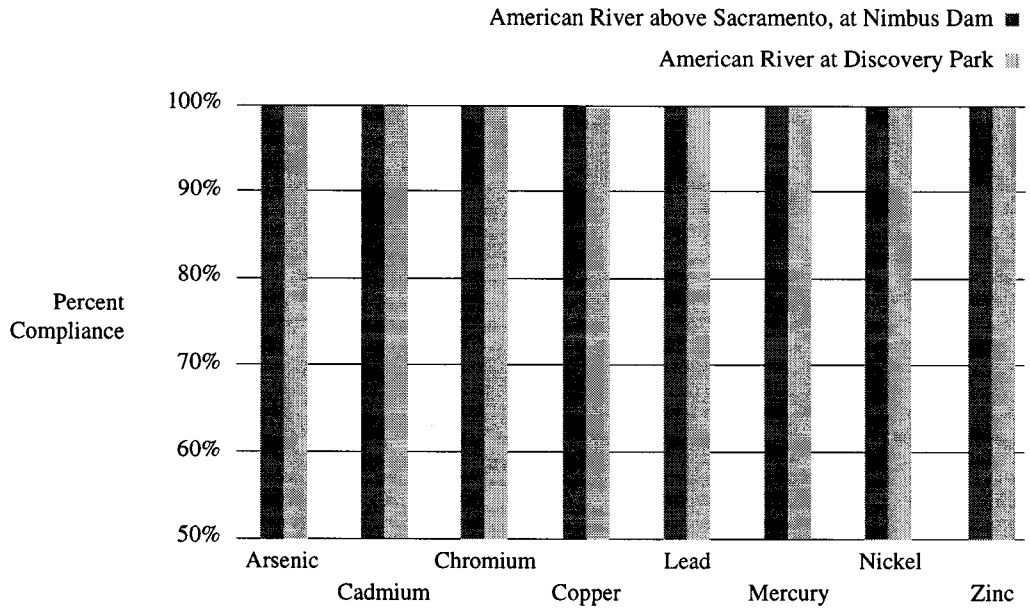

Figure 8. Compliance with US EPA water quality criteria: American River sites.

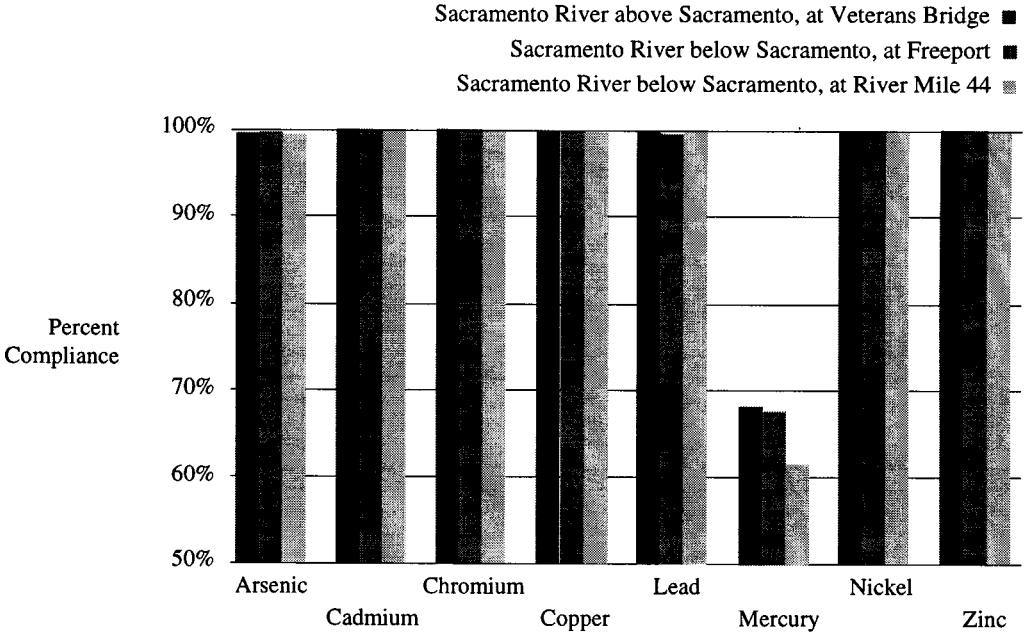

Figure 9. Compliance with US EPA water quality criteria: Sacramento River sites.

Equipment Cleaning: All sample tubing and sample containers are acid rinsed and soaked in concentrated nitric acid before use. After washing, tubing ends are covered and tubing is placed in acid rinsed plastic bags for transport to the field.

Field Quality Control: Field quality control includes sampling procedures to avoid contamination and use of field control samples. Field control samples include field blanks, bottle blanks, and Milli-Q water blanks.

Laboratory QA/QC Procedures: Both external and internal laboratory QA/QC procedures are employed. External laboratory quality control samples include blind field duplicates, blind spike samples, and blind duplicate spikes. Internal laboratory quality control samples include laboratory duplicates, matrix spikes, matrix spike duplicates, method blanks, and filter blanks. One set of internal QC samples is run with each batch of field samples.

Monitoring Results

Data collected over the three plus years of the Ambient Program have indicated the following:

1. The monitoring effort has taken place over a wide range of flow conditions in the Sacramento and American Rivers (Figures 6 and 7). The monitoring data collected to date demonstrates the dynamic water quality conditions which exist in these water bodies.
2. Total recoverable levels of most trace metals generally exhibit a seasonal pattern in the Sacramento River, with higher concentrations occurring during the wet season (November through April) when river flows and suspended solids levels are highest. The pattern of correlations between river flows and total recoverable metals concentrations is consistent with the hypothesis that episodic high river flows are a primary mechanism of both sediment and trace element transport in the Sacramento River system.
3. Levels of trace elements in the American River generally do not exhibit significant correlation with river flow. Median values of suspended solids, temperature, hardness, organic carbon, and trace metals are typically lower in the American River than in the Sacramento River.
4. For compliance evaluation purposes, it is assumed that Environmental Protection Agency (EPA) criteria will be interpreted as dissolved (as recommended by EPA) for all trace elements except mercury and selenium. A compliance problem exists with EPA human health criteria for total mercury in the Sacramento River. A compliance problem would arise for arsenic in both rivers if EPA's controversial human health criterion (0.018 µg/L) is applied. For all other trace elements, no compliance problems have been observed (Figures 8 and 9).
5. An analysis of trace element concentration changes in the Sacramento River indicate a slight increase in the concentration of zinc downstream of the Sacramento metropolitan area. In the American River, small concentration increases have been observed for copper, lead, and mercury.

Future Direction

The Ambient Program is producing data in accordance with the monitoring objectives of the CMP. The CMP Steering Committee annually reviews the program to reconfirm goals and make appropriate adjustments. It is expected that the CMP monitoring effort will ultimately be incorporated into the Sacramento River Watershed Program monitoring plan which is now being developed and is scheduled for implementation in 1997.

Sacramento River Watershed Program and the Sacramento River Toxic Pollutant Control Program

Val Connor, Central Valley Regional Water Quality Control Board
Sacramento, California

The Sacramento River Toxic Pollutant Control Program (SRTPCP) was initiated in October of 1995. The long-term goal of the SRTPCP is to develop and implement a program that will bring the Sacramento River and its tributaries into compliance with water quality standards for toxic pollutants and thereby protect beneficial uses. The SRTPCP is intended to be a long-term, multi-year program, and its success will require the active participation of the various parties who have a "stake" in the quality of the River and its tributaries (i.e. the "stakeholders"). For that reason, a second goal of the SRTPCP is to assist in the formation and maintenance of a viable organization of watershed stakeholders. It is intended that the stakeholder organization address not only the toxic pollutant-related issues in the watershed, but the broader water quality issues necessary to protect and enhance surface and ground waters throughout the watershed. The broader program being conducted by this stakeholder organization has been named the Sacramento River Watershed Program (SRWP). The SRTPCP is just one element of the SRWP.

The SRWP, although initiated by the SRTPCP, is much broader in scope. The SRWP is intended to address all water quality-related issues within the watershed, not just toxic pollutants. Potential additional issues include, but are not limited to, habitat, endangered species, flow, temperature, sedimentation, and groundwater. The goal of the SRWP is to ensure that current and potential uses of the watershed's resources are sustained, restored, or, where possible, enhanced, while promoting the long-term social and economic vitality of the region. The SRWP consists of many individual projects, programs, and specific tasks. Two cornerstones of the SRWP are comprehensive monitoring and communication. Currently, information on existing monitoring programs is being compiled for two reasons: to summarize the existing state of the watershed regarding toxic pollutants and to identify overlap and "holes" in the existing watershed monitoring programs. Participation in the SRWP does not require individual projects to assume a single common goal. Instead, the SRWP relies on information exchange to connect existing and potential projects.

In September 1997, the first State of the Watershed report will be released. This first report will focus on summarizing what is known about toxic pollutants in the Sacramento Watershed. The report will include information and data from all recent or ongoing monitoring, research, demonstration and planning programs and other activities related to the sources, effects, extent, and control of toxic pollutants within the Watershed. Recommendations will be developed for future research, monitoring, and other activities that will facilitate the control of toxic pollutants within the Watershed.

A comprehensive monitoring program is being designed to augment and link the existing programs. This comprehensive monitoring plan will build on the current monitoring programs of the Department of Water Resources (DWR), the Department of Pesticide Regulation (DPR), the Department of Fish and Game (DFG), the US Geological Survey, Sacramento's Ambient Monitoring Program (AMP), the Regional Monitoring Program, and others. The components of the monitoring program are being phased in as funding becomes available. Toxicity testing with the EPA's three species (fathead minnow, *Ceriodaphnia dubia*, and *Selenastrum capricornutum*) began

in August 1996. Chemical monitoring is scheduled to begin in January 1997. Biological and habitat assessment of urban creeks and tributaries to the Sacramento River will begin in June 1997; these assessments will be conducted by local community groups, high schools, and colleges. All components of the monitoring program will have strong quality assurance elements.

One of the major goals of the SRWP is to promote the exchange of information among the existing programs and projects within the watershed. This is being accomplished by meetings and education workshops on topics of interest. Three workshops are planned for 1997, covering groundwater issues, drinking water issues, and mercury.

The SRWP has several subcommittees focusing on the following areas: monitoring, toxic pollutants, education, coordination, tributary watershed conservancies and programs, funding, biological and habitat assessments, and the SRTPCP grants. To participate in any of these subcommittees, the SRWP, or to be put on the SRWP mailing list, contact Shelly Morford at (916) 255–3100. For more information on either the SRWP or the SRTPCP, contact Val Connor at (916) 255–3111 or by e-mail at: valc@bptcp1.swrcb.ca.gov

San Francisco Bay Area Storm Water Runoff Monitoring Data Analysis, 1988–1995 Summary and Recommendations

Bay Area Stormwater Management Agencies Association

This brief summary represents an excerpt of a report prepared for the Bay Area Stormwater Management Agencies Association (BASMAA) highlighting the findings of storm water runoff monitoring programs from 1988 to 1995.[1] Runoff data have been collected by a number of Bay Area agencies for a variety of purposes including characterization of pollutant concentrations from different land-use areas, assessment of compliance with receiving water quality objectives, source identification of pollutants and toxicity, and evaluation of Best Management Practice (BMP) effectiveness. The focus of this data analysis project was to compile all Bay Area runoff data into a cohesive database and to perform analysis typically conducted by each agency. Combination of all data provides a greater understanding of the quality of runoff and increases the confidence in the conclusions drawn from statistical and regulatory comparisons.

Bay Area Monitoring Data: Findings

Review of existing storm water quality monitoring data collected in the San Francisco Bay Area have yielded the following findings:

- Concentrations of metals in runoff from urban areas are generally lower than the Environmental Protection Agency's (EPA) dissolved water quality criteria for the protection of aquatic life.
- Concentrations of total cadmium, copper, lead, nickel, and zinc are sometimes higher than the Basin Plan water quality objectives for the protection of aquatic life. However, results from toxicity identification evaluations indicate that when toxicity is found in waterways it is generally attributable to nonpolar organics and not due to particulates or dissolved metal ions.
- Storm water runoff is often toxic to the laboratory test organism *Ceriodaphnia dubia* (water flea). For most waterways, the organisms die between 1 to 7 days of exposure to runoff. The commonly used organophosphate insecticide diazinon has been identified as the cause of the observed toxicity in some residential watersheds.
- Concentrations of total mercury are generally higher than the chronic EPA Water Quality Criteria (WQC) and Basin Plan Water Quality Objectives (WQOs). However, these standards are designed to prevent accumulation of mercury in fish tissues to levels that are hazardous to eat. It is unclear if the duration of storm flows in creeks is long enough to permit accumulation to hazardous levels. A similar objective for the Bay is based on a 30-day averaging period.
- Concentrations of metals in runoff from different types of urban land uses (residential, commercial, industrial, transportation) are generally not statistically different from one another. Within any one monitoring station, variations in storm characteristics, timing, and specific urban activities cause the concentrations to vary over a wide range, hampering our ability to observe differences between watersheds caused by differing land use.
- Runoff from developed urban areas generally contains higher concentrations of metals than runoff from undeveloped areas. However, total metal concentrations in runoff from open space can be

1 Copies of the full report are available through BASMAA (510) 286-0615.

higher than metals in runoff from heavy industrial areas due to elevated concentrations of suspended and settleable solids associated with erosion.

Effectiveness of Monitoring

The two primary goals of the long-term stream monitoring are:

1. Determine trends in water quality and augment the long-term database to include a range of hydrological and water quality conditions for representative waterways in the Bay Area.
2. Determine how receiving water quality during storm events compares with available water quality and toxicity objectives.

The ability to determine trends in water quality due to implementation of BMPs in the four to six monitored watersheds is limited by our understanding of the influence of variations in hydrology on water quality. At selected stations, enough monitoring data have been collected to allow establishing relationships between event and antecedent conditions and water quality. At one watershed such an analysis has been conducted and shown that much of the variability can be explained by changes in hydrologic factors (WCC, 1995; WCC, 1996). These observations indicate that if detection of trends is a desired goal many (greater than 15) storm events need to be monitored over several years to encompass the range of hydrologic conditions. Therefore, at stations with few storms sampled, such as those in Contra Costa County, trend detection will be difficult until an adequate database has been established.

Existing monitoring results are adequate to provide a general understanding of how water quality compared with available water quality objectives and criteria and toxicity objectives for most trace metals. Data on organic compounds at detection levels that are adequate to compare with federal criteria are more sparse. Specifically, low-level monitoring for PAH compounds has been conducted for a few events at four waterway stations in Santa Clara County and three waterway stations in Alameda County. Few waterway stations have been monitored for low-level diazinon/chlorpyrifos and none have been monitored for low-level PCBs. However, the utility of monitoring for PCBs is questionable as these compounds have been banned since the 1970s and few, if any, active source control efforts could be enacted by storm water agencies. Additionally, diazinon/chlorpyrifos control is currently the focus of an intensive BASMAA special study and workgroup funded in part through an EPA grant. Therefore, it is not clear that additional long-term monitoring by BASMAA agencies is necessary at this time.

PAH data are adequate to show certain compounds exceed the federal water quality criteria designed to prevent food fish from accumulating hazardous levels of PAHs. However, it is unclear if PAH concentrations in runoff persist long enough to allow accumulation in fish. Also fish tissue quality in the Bay is currently the focus of an extensive Regional Monitoring Program Special Study. It is recommended that the RMP study explore the possibility of sampling fish from streams with significant fisheries as well as the Bay.

Recommendations for Changes to Monitoring

Five changes to monitoring programs in the San Francisco Bay Area are recommended:

1. Dissolved metal concentrations are rarely found to be higher than the EPA WQC. However, total metals often exceed the WQO in the San Francisco Bay Basin Plan. To determine if the particulate metals in storm water are causing a potential impact to sediment dwelling organisms, it is recommended that a pilot sediment assessment program be initiated. This pilot program should use sediment toxicity testing, and chemical characterization, as well as biological assessment techniques to evaluate potential impacts. Because most of these techniques are in the developmental stage the program should be initiated on a trial basis in one watershed to allow refinement of these tools for urban waterways.

2. Duration and variability of dissolved metal concentrations during and after storm events has not been investigated for most urban waterways. Because sediment/water interaction is complex, it is not known if dissolved metal concentrations increase or decrease following storm events. It is recommended that a special study be conducted using in-field filtration to determine how dissolved metal concentrations vary within and following storm events.
3. Few reliable measurements of stream quality during dry weather have been conducted. It is recommended that some effort be spent to determine metal and diazinon concentrations in waterways with significant dry weather flows.
4. Few reliable measurements of chromium (VI) have been performed. As chromium (VI) is the predicted form of chromium in fresh water it is recommended that grab samples be collected and analyzed for dissolved chromium (VI) using improved low-level methods appropriate to environmental surface water monitoring. These results can be used to confirm previous results which used older EPA methods.
5. Hydrologic factors are responsible for a large portion of the observed variability in individual watersheds. If the goal of the monitoring program is to detect changes in water quality due to BMP implementation, the variability due to hydrology should be accounted for in order to detect a trend. It is recommended for those watersheds where trend detection is desired that a range of storms should be sampled which reflect the distribution of antecedent and event-specific hydrologic parameters. Additionally, records should be kept of rainfall and flow in the monitored watershed to allow calculation of appropriate hydrologic statistics.

CHAPTER SEVEN

Conclusions

Temporal and Spatial Variations in Trace Element Contamination in the San Francisco Bay Estuary

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University of California, Santa Cruz

Introduction

The San Francisco Estuary Regional Monitoring Program (RMP) has established a systematic, and relatively comprehensive, survey of temporal and spatial distributions of trace elements in the Estuary. The program has replaced a hodgepodge of disparate surveys that used a variety of methods to measure different trace element concentrations in different parts of the Estuary during different periods. With the new program, it is now possible to identify areas of anomalistically high trace element concentrations in the Estuary, determine the factors causing that pollution, and develop means to control it. As such, the RMP now serves as the national model, promulgated by the United States Environmental Protection Agency's Office of Water, for monitoring trace element contamination in aquatic systems.

Establishing A Systematic Program of Sampling and Analyses

Previous programs to investigate trace element contamination in San Francisco Bay were characterized by their limited scope and analytical inconsistencies. Without a system-wide perspective, the studies were usually limited to a few measurements in a specific region of the Estuary within a small time period. The parochialism of those sampling designs precluded a comprehensive assessment of the state of the Estuary. Previous reports of trace element concentrations in the Estuary also varied by orders of magnitude, because of inconsistencies among the sampling and analytical techniques employed in different studies. Consequently, it was impossible to derive even a superficial perspective of the distribution of trace elements in the Estuary through a composite analysis of data collected in those previous programs.

Those problems have been resolved with the creation of a systematic sampling program for the entire Estuary. Since samples are collected from the freshwater confluence of the Sacramento and San Joaquin Rivers at the northernmost reach of the Estuary down to sloughs in the southernmost reach of the Estuary, pronounced spatial differences in some trace element concentrations are readily apparent in plots of those data. Since three sets of samples are collected each year and the program has been in place for several years, seasonal and annual variations in the spatial gradients are also readily apparent. Finally, since rigorous sampling and analytical protocols have been utilized in the generation of all of those data, comparisons of spatial and temporal variations in the trace element data are not circumspect.

Identification of Areas of Concern

The program has identified two principal problems with trace element contamination in the Estuary. Copper and nickel concentrations exceed water quality criteria in the southern reaches of the Estuary during some periods when freshwater discharges to the Estuary are lowest. These seasonal increases have been highest during drought years when freshwater discharges to the Estuary have been minimal.

Consequently, trace element contamination in the southern reach of the Estuary appears to be caused by a combination of local and system-wide factors. These include:

1. Temporal reductions in freshwater discharges from the Sacramento and San Joaquin Rivers,

2. Local inputs from waste water outfalls into the South Bay,
3. Seasonal releases from contaminated sediments within the South Bay, and
4. Surface runoff from areas surrounding the South Bay.

The impacts of each of those factors are briefly summarized in the following sections.

Hydraulic Flushing

Many trace element concentrations in the South Bay vary inversely with the volume of freshwater discharges into the Sacramento and San Joaquin Rivers. Notably, copper and nickel concentrations often exceed water quality criteria in the South Bay during summer periods when riverine flows to the Estuary are lowest, and trace element concentrations in the South Bay are often lowest during the winter and early spring when those riverine flows are greatest. This pattern corresponds with the hydraulic flushing model proposed by the United States Geological Survey nearly three decades ago to account for the similar temporal variations of nutrient concentrations in the Estuary. Consequently, (1) elevated trace metal concentrations in the South Bay may be controlled by freshwater discharges to the northern reach of the Estuary and (2) factors controlling trace element concentrations in the Estuary may be partially resolved by analogies with factors controlling nutrient concentrations in the Estuary.

Waste Water Discharges

While a cursory analysis of the monitoring data supports the common public perception that waste water discharges are solely responsible for pollution in the San Francisco Bay Estuary, more detailed analyses show that other sources are also important. The seasonally high concentrations of copper and nickel in the southern reach of the Estuary fit a simple dilution mixing line between the concentrations of those elements in sea water and in waste water discharges into the South Bay, but more rigorous mass balance calculations and geochemical analyses demonstrate that inputs of trace elements (including copper and nickel) from other sources may be equal to, or in some cases exceed, inputs from waste water discharges into that area. Those analyses are corroborated by similarities in trace element excesses in the northern reach of the Estuary for the past two decades, in spite of one to two orders of magnitude reductions in trace element discharges into the Estuary during that period. [The comparison of temporal variations in the northern reach of the Estuary over that extended period is possible because there is one set of data for that period that was collected and analyzed with comparable trace metal clean techniques, which have been intercalibrated with the analyses utilized in the current program.] Therefore, other internal sources must contribute to the seasonal excesses of some trace elements within the Estuary.

Sedimentary Inputs

While sediments have historically been considered a “sink” for trace elements in estuarine waters, they now appear to be one of the principal “sources” of trace elements in San Francisco Bay during some periods when there is an intense decomposition of organic material within those sediments. This sedimentary input of trace metals to the overlaying water column is based on parallels in seasonally elevated concentrations of trace elements and nutrients within the water column, which coincide with the decomposition of organic matter in benthic sediments that solubilizes nutrients and trace elements. Preliminary mass balance calculations indicate that benthic fluxes of some trace elements are much greater than their inputs from rivers draining into the Estuary; and, in some cases, the estimated benthic fluxes of some trace elements are comparable to their inputs from waste water discharges into the Estuary. Consequently, the elevated trace element concentrations in San Francisco Bay waters appear to be partially due to chronic inputs from historically contaminated sediments within the Estuary.

Urban Runoff

One of the limitations in the preceding analyses of the total amounts and relative contributions of different sources to trace element concentrations in the Estuary is the absence of comparable information on trace element fluxes from non-point sources or surface runoff. This includes runoff from both urban and rural areas that drain into the Estuary. Based on analogies with nutrient fluxes in other estuaries (because there are also insufficient data on surface runoff of trace elements in others estuaries), surface runoff is believed to be an important source of some trace elements in San Francisco Bay. This includes copper, which may be elevated in the South Bay by surface runoff containing relatively high concentrations of copper dust generated from the abrasion of automobile brake pads.

Rural Runoff

While the program has not monitored surface runoff directly, analyses of temporal variations in some of the program's data provide evidence of the relative importance of surface runoff from rural runoff or agricultural drainage. This was first indicated by the coincidence of anomalistically high chromium concentrations in the northern reach of the Estuary and episodic discharges of freshwater from the Yolo Bypass. It is now being evaluated with more complex geochemical analyses and mass balance calculations. Although those inputs may be ephemeral, they may substantially impact the Estuary for a protracted period, because they may increase the recycling of trace elements and nutrients from the estuarine sediments.

The potentially substantial impact of freshwater discharges from the Yolo Bypass on trace element and nutrient distributions in the Estuary was only detected after several years of data had been collected. An extended sampling period was needed to identify those agricultural inputs, because they are episodic and only occur during periods of unusually large freshwater discharges. Since there were no large discharges from the Yolo Bypass during the drought years when the program was initiated, bypass releases of freshwater with anomalistically high chromium and silicate concentrations were not detected during that period. Moreover, those releases would not have been apparent until a sufficient amount of data on the variability of trace element and nutrient concentrations in freshwater discharges to the Estuary had been acquired.

Multiphase Approaches to Remediation

The suite of information on trace element distributions and cycles in the Estuary generated by this program has been incorporated in multiphased approaches to remediate problems of trace element contamination within the Estuary. For example, problems of copper and nickel contamination in the South Bay may be diminished by actions that address each or all of the preceding factors that contribute to those elevated concentrations. This creates a series of options that may be evaluated in terms of their relative efficacy and cost. For example, the feasibility of reducing surface runoff of copper by controlling its use in brake pads is being considered as an alternative means of decreasing copper concentrations in the South Bay, because waste water discharges of copper to the South Bay have already been decreased by 95% and additional reductions in waste water copper loadings may not be cost-effective. That innovative approach to control trace element contamination in San Francisco Bay has been recognized nationally as a model for collaborations among industry, municipalities, regulatory agencies, and public interest groups.

Catalysis of Complementary Studies

By identifying areas of concern, the RMP has catalyzed additional studies that specifically address those concerns. Notable among these are studies to determine whether the water quality criteria for copper in the South Bay are appropriate. These include measure-

ments of the chemical speciation of copper, which show that a large fraction of the dissolved copper in the South Bay is in forms that are not readily available to the biota. There have also been studies with estimates of the relative importance of inputs of copper to the South Bay from waste water discharges and contaminated sediments, which indicate that both contribute to the elevated levels observed during the summer period. These, and similar studies, have facilitated the development of appropriate actions to address those areas of concern.

The complementary studies have benefited from the RMP in three other ways. First, the program has provided an efficient means to collect additional samples and conduct complementary analyses. Second, the programs sampling cruises have often been coordinated with those of other programs (e.g., the United States Geological Survey) to expand the breadth and scope of the collections. Third, data from the program have been provided for evaluation and modeling by other groups (e.g., Stanford, University of California, USGS) interested in the cycling of trace elements in the Estuary. Consequently, the data base for trace elements in the Estuary is now much greater than the one generated by the RMP alone, and numerous groups are involved in analyses of that expanded data base.

The National Model for Monitoring Trace Elements in Aquatic Systems

The success of the RMP has been recognized on a national level. The Office of Water of the US EPA has developed new protocols for measuring trace elements in aquatic systems that are based, in large part, on the RMP. These include ten new methods for sampling, processing, measuring, and reporting trace element concentrations using techniques employed in the RMP. That methodology has been presented at two US EPA national meetings in Norfolk, Virginia, and five US EPA Trace Metal Workshops around the United States (Boston, Massachusetts; Chicago, Illinois; Denver, Colorado; San Antonio, Texas; Seattle, Washington). Presentations at each of those meetings have included both a video of the sampling program in San Francisco Bay and a discussion of the success of that program. As a result, the RMP is now serving as the national model for monitoring trace elements in aquatic systems.

Judicial Confirmation of the Methodology in Civil Litigation

The judicial credibility of the methodology incorporated in the monitoring program has been substantiated in litigation. This occurred in a Proposition 65 class action suit in California, which was based on analyses of elevated lead concentrations in solutions in some lead crystal glassware. Since the analyses used the same protocols as the monitoring program, which had been approved by both the California State Water Resources Control Board and US EPA, the judge ruled the analyses were valid. As a consequence, the resulting settlement favored the complaints of the citizens of California.

A Summary of Mercury Effects, Sources, and Control Measures[1]

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Darell G. Slotton, University of California, Davis

Introduction

Mercury is but one of the toxic heavy metals that contaminates much of the waters and sediments of the San Francisco Estuary. It has been found throughout the Estuary at elevated concentrations in water, sediment, and biota. It accumulates in tissues and is magnified in higher orders of the food web. The form of mercury that typically bioaccumulates in fish is monomethyl mercury, which can constitute 85% of the total tissue mercury. The balance is the soluble, ionic form of mercury, Hg^{+2} which is commonly found in the gut lining. However, in edible muscle tissue (fillet), the portion normally consumed, virtually all of the incorporated mercury is in the monomethyl form. Fish at the top of the food web can harbor mercury concentrations in their tissues over one million times the mercury concentration in the water in which they swim.

Bivalves appear to accumulate mercury in a manner different from fish. Mercury in these organisms accumulates principally as Hg^{+2} and only 15–20% of the total mercury is methyl mercury. Consequently, a doubling of the most toxic form of mercury, monomethyl mercury, can occur in bivalves without producing a statistically significant change in concentration of total tissue mercury.

Partly as a result of the tremendous increase in mercury production and use in this century and partly as a result of the many soluble species of mercury, mercury contamination is now virtually worldwide in extent and widespread in our environment. It travels easily through different environmental media, including the atmosphere, in a variety of chemical forms and is toxic to humans and biota in extremely low concentrations. In water environments, conjugation with particles dominates the movement and fate of mercury (PTI, 1994; Schoellhamer, this report). In addition to experiencing the general, industrially-related, global increase in mercury distribution over the last century, California is unique in also being the site of massive bulk contamination by the element. The California Coast Range contains one of the world's great geologic deposits of mercury. This mercury was mined intensively during the late 1800s and early 1900s, largely to supply Gold Rush era gold mining in the Sierra Nevada, where the mercury was used in the gold extraction process. A legacy of leaking Coast Range mercury mines and lost Sierra Nevada quicksilver now provides a significant, additional, ongoing burden of mercury to the Delta and Bay from both sides of the state.

Mercury Sources

Mercury, which occurs as a result of both natural and anthropogenic sources in our environment, continually cycles in the marine environment of the Estuary. The cycle involves different forms and species of mercury as a result of both chemical and biological reactions in aerobic and anoxic microenvironments. Until several years ago, estimates of the natural background level of mercury were unrealistically high due to erroneous data, giving the impression that anthropogenic contributions to the global mercury flux were less than they truly are (Fitzgerald and Clarkson, 1991). The generation of erroneous data arose because of a lack of appreciation for the ease of cross-contamination and the lack of sufficiently sensitive instrumentation to measure mercury in soil, water, and air. A schematic of the cycle is shown in Figure 1.

[1] This summary contains excerpts from a more extensive report available from SFEI.

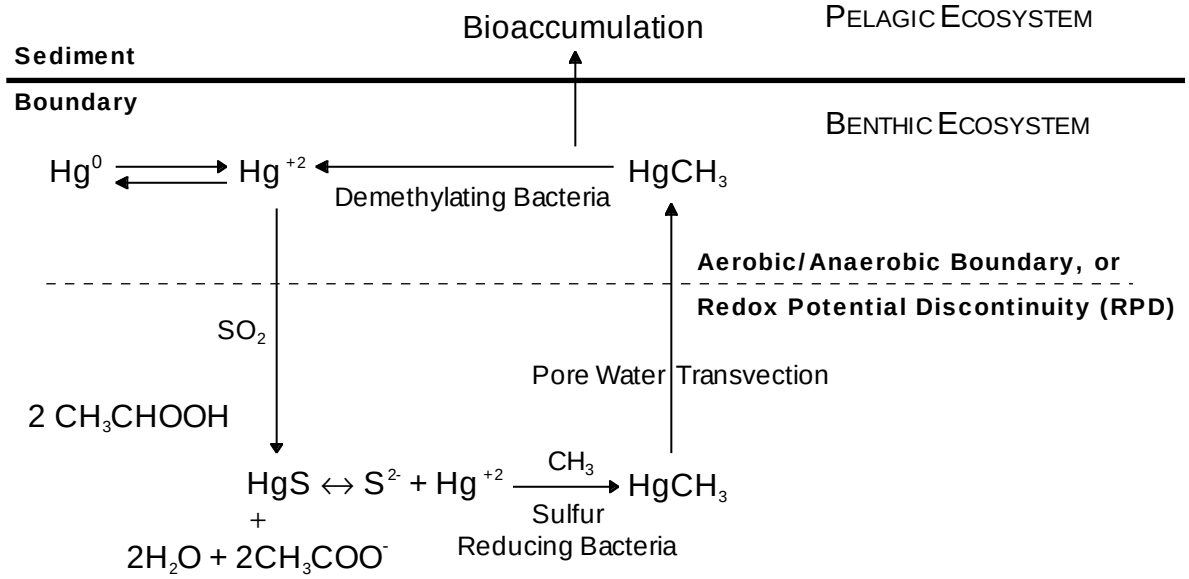

Figure 1. Mercury cycling in a marine environment.

The bulk of the mercury is normally present as Hg^{+2} in the early stages of deposition, but over time it is probably converted by inorganic chemical reactions to the more insoluble cinnabar (HgS). In California, cinnabar is the primary form of the Coast Range mercury deposits. The mercury used in gold mining in the Sierra Nevada was refined liquid quicksilver (elemental mercury, Hg^0), though this elemental mercury likely experienced various transformations once back in the environment. The concentration and rate of formation of $HgCH_3$ (methyl mercury) in anaerobic sediment and water is thought to be proportionate to the amount of HgS, not the amount of total mercury. There are other factors which influence these reactions including pH, temperature, oxygen/redox level, salinity, toxicity, rate of sediment deposition, rate of pore water transvection, rate of mercury deposition, species of mercury deposited (Hg^0 or Hg^{+2}), and the rate of $HgCH_3$ removal by bioaccumulation.

On a world-wide scale, volcanic deposits and mining sources are geographically localized but, in California, they are of great importance. Most additional mercury sources are part of a widespread, global cycle. The release, deposition, and movement of mercury through these global pools has been catalogued, as shown in Table 1.

Natural Sources

Mercury occurs naturally in the environment and thus has a background concentration independent of man's releases. Mercury can occur naturally in a variety of valence states and conjugations and as an organometal such as methyl mercury (CH_3Hg and $(CH_3)_2Hg$). Moreover, through natural chemical and biological reactions, mercury changes form among these species, becoming alternately more or less soluble in water, more or less toxic, and more or less biologically available.

As with any site on the globe, there is natural mercury contamination in San Francisco Bay. The recent spate of forest fires in Northern California alone undoubtedly contributed some mercury to this environment. Clearly, in California there is an ongoing load of some magnitude associated with the general export of mercury from natural cinnabar deposits, in addition to mining-related point sources. It is difficult to determine just what proportion of mercury in the Bay Area is from natural sources because what is natural varies greatly from one part of the world to the next. Because of airborne mercury pathways, there is no part of the globe today untouched by the

Table 1. Global atmospheric mercury (Fitzgerald and Clarkson, 1991)

Sources	Hg Movement 10^9 g/yr	Reference
Atmospheric Hg Deposition:	5–6	Fitzgerald, 1986
	6	Slemr *et. al.,* 1981
Atmospheric Hg Emissions:		
Anthropogenic	2	Watson, 1979
Natural	3.6	Nriagu and Pacyna, 1988
Volcanic	0.06	Fitzgerald, 1986
Other Continental Sources:	1–2	
Crustal Degassing		
Forest Fires		
Biological Mobilization		
Oceanic Sources:		
Equatorial Pacific	0.2	Kim and Fitzgerald, 1986
World Ocean	2	Nriagu and Pacyna, 1988
Fluvial Hg Input:	0.2	Gill and Fitzgerald, 1987

world-wide increase in both use and release of mercury by man in this century. Current and proposed research at the University of California, Davis, seeks to differentiate and quantify the generalized global atmospheric contribution of mercury in California, as compared to regional and point sources.

Volcanic

Mercury is initially released into the biosphere through volcanic activity. Mercury is present in the earth's crust at a concentration of 0.5 ppm. Mercury typically forms the sulfide (HgS) because of the prevalence of sulfides in volcanic gases. In this fashion it is found naturally in deposits as the red sulfide ore, cinnabar. It is commercially mined as this form. Volcanic sources emit an estimated global total of 60,000 kg of mercury per year.

Forest fires

Biomass, particularly trees and brush, accumulate and harbor a substantial fraction of the biosphere's mercury. When forest fires heat these fuels to temperatures well above the boiling point of mercury (357°C), the mercury may be released to the atmosphere as either Hg^{+2} or the decomposed Hg^0. The Hg^0 released may be oxidized in the atmosphere over time to Hg^{+2} which is also quite soluble in water and so dissolves in the moisture in the air when released in this fashion.

Forest fires and rain are responsible for the transport and deposition of mercury over much of the world's surface, regardless of its source.

Oceanic releases

Mercury is also a component of seawater and is released naturally through the evaporation of elemental mercury from the ocean's surface. Both elemental and ionic mercury are soluble in water, although elemental mercury to a much smaller degree. As less soluble elemental mercury evaporates, the equilibrium reaction is pulled towards more elemental mercury, which then releases more elemental mercury from the ocean's surface. The equilibrium reaction between ionic and elemental mercury is shown below in Equation 1:

$$Hg^{+2}_{Aq} + 2e^{-} \leftrightarrow Hg^{0}_{Atmos} \qquad \text{Equation 1}$$

Ionic mercury can form from the oxidation of elemental mercury or from the demethylation of monomethylmercury.

Anthropogenic Sources

Mercury is used in a broad array of more than 2,000 manufacturing industries and products (Kurita, 1987). These include barometers, thermometers, hydrometers, pyrometers,

Table 2. Sources and uses of mercury (USDHHS, 1992)

Name	Form	Source or Use
Mercury	Metallic or Elemental (Hg^0)	Chlorine-alkali manufacturing Dental fillings Gold mining Electrical equipment (batteries, switches) Instruments (thermometers, barometers)
Mercuric mercury	Inorganic (Hg^{+2})	Electrical equipment (batteries, lamps) Skin care products Medicinal products
Mercurous mercury	Inorganic (Hg^{1+})	Electrical equipment (batteries) Medicinal products
Methyl mercury	Organic (CH_3Hg^{1+})	Diet (e.g., contaminated fish) Polluted sediment
Phenyl mercury	Organic ($C_6H_5Hg^{1+}$)	Fungicides Pigments (paints)

mercury arc lamps, switches, fluorescent lamps, mercury boilers, mercury salts, mirrors, catalysts for the oxidation of organic compounds, gold and silver extraction from ores, rectifiers, cathodes in electrolysis/electroanalysis, and in the generation of chlorine and caustic paper processing, batteries, dental amalgams, as a laboratory reagent, lubricants, caulks and coatings, in pharmaceuticals as a slimicide, in dyes, wood preservatives, floor wax, furniture polish, fabric softeners, and chlorine bleach (Volland, 1991). Individual industries use different forms of mercury as well, as shown in Table 2.

The United States produced about 3,435 tons of mercury in 1986 and imported another 6.5 tons. It is estimated that the US exported about 32.5 tons of mercury that year, yielding a net domestic annual use of about 3,409 tons of mercury. Of this use, 50% to 56% was used in the electrical industry, 12% to 25% was used in chloralkali plants to generate chlorine and caustic soda, 10% to 12% was used in paint manufacturing, and about 3% was used in the preparation of dental amalgams (Sills, 1992).

Mining

In addition to the generalized global and local industrial sources of mercury described above, the watershed of the San Francisco Estuary contains a tremendous amount of mining-related, bulk mercury contamination. Historically, mercury was mined intensively in the Coast range and transported across the Central Valley for use in Sierra Nevada placer gold mining operations. Virtually all of the quicksilver used in these operations was ultimately lost into Sierran watersheds. It has been estimated that, in river drainages of the Mother Lode region alone, approximately 7,600 tons of refined quicksilver were inadvertently deposited in conjunction with Gold Rush era mining (CVRWQCB, 1987). Additional mercury was used throughout the gold mining belt of the northwestern and central Sierra Nevada. The majority of Coast Range mercury mines which supplied this practice have since been abandoned and remain unreclaimed. As a result of these two activities, bulk mercury contamination exists today on both sides of the Valley.

Larry Walker and Associates (1995) measured mercury concentrations and loads at index stations on the Sacramento, Feather and Yuba Rivers. In related work, Slotton *et al.* (1995) have, since 1993, evaluated the local bioavailability of mercury in all major river tributaries throughout the northwestern Sierra. The water quality data indicate that a significant amount of Gold Rush era mercury still exists in sediment in the upper Yuba watershed and that this is being transported down into Englebright reservoir, where it is largely

trapped. Bioavailability studies confirm that the reservoir acts as an interceptor of not only inorganic, sediment-based mercury, but of bioavailable methyl mercury as well. Despite the fact that elevated levels of mercury are found in the heavily mined upstream tributaries and, particularly, within Englebright Reservoir itself, the aquatic biota below the impoundment consistently demonstrate significantly reduced concentrations of mercury, as compared to above the reservoir. However, as a cautionary note, the United States Geological Survey (USGS) observed high concentrations of mercury associated with particulate matter in high flows downstream of Englebright Reservoir last winter. The USGS believes the mercury was deposited in the streambed before construction of the dam and is only now being eroded away (Joseph Domagalski, personal communication). Therefore, much, but clearly not all, of the mercury remaining in the Sierras from historic gold mining may be unavailable for downstream transport and biomagnification in the Estuary. In the few high mercury rivers without dams, particularly the Consumnes, direct transport of historic gold mining mercury into the Estuary remains unimpeded.

Recent work suggests that the Coast Range, rather than the Sierra Nevada, may be a dominant source of mercury to Central Valley Rivers and the Estuary.

Another mercury mass load export study was undertaken by the Central Valley Regional Board in the southwestern part of the Sacramento River watershed during 1995. The spring of 1995 was wet, and water from the Sacramento Valley entered the Estuary through both the Sacramento River and Yolo Bypass. Highly elevated concentrations of mercury were repeatedly observed in the Bypass. The source of a significant portion of the mercury was traced to Cache Creek, which drains Clear Lake and which is estimated to have exported about a thousand kilograms of mercury to the Estuary in 1995. Follow-up studies by the Central Valley Regional Water Quality Control Board and Slotton et al. are underway to determine (1) whether the source(s) of the mercury are localized to mines and (2) to determine the spatial trends in *in situ* bioavailability of mercury throughout the watershed.

Also in 1995, a comprehensive synoptic study was undertaken in the small Marsh Creek watershed of Contra Costa County (Slotton *et al.*, 1996). This research was conducted during a period of steady high flow, immediately following a series of large storms, to identify and quantify mercury sources and local aquatic bioavailability. All significant tributaries were sampled. The small drainage was found to export 10–20 grams of mercury per day, with greater amounts during actual storm events. Mass balance calculations indicate that about 95% of the entire watershed's mercury load originated from the Mount Diablo mining area; about 93% of this was from a relatively small patch of exposed mine tailings.

Coal-Fired Power Plants

Coal is known to contain mercury as a result of testing done upon the flue gas emitted from power plant stacks. The quantity released by burning coal is estimated to be on the order of 3,000 tons per year globally, about the same amount released through all industrial processes (Joensuu, 1971). The concentration of mercury in coal varies form as low as 70 ng/g up to 22,800 ng/g (ppb). During the burning of coal, mercury is initially decomposed to elemental mercury and then, as the flue gas cools and exits the plant, the majority of the mercury is quickly oxidized, probably catalytically due to the presence of other metals in the gas, to its water-soluble, ionic form, Hg^{+2}.

Gasoline and Oil Combustion

Crude petroleum is known to contain small but measurable amounts of mercury. A study performed on the mass of metals in crude oils from 32 different sources stored in the nation's Strategic Petroleum Reserves (SPR) in salt domes in Oklahoma has determined that the average of mercury in petroleum is 0.41 ppm (Shur and Stepp, 1993). The standard deviation for this average was a rather large 0.90 with

one crude oil (Arabian) containing 5.2 ppm mercury. Another study of metals performed on petroleum found a range of mercury concentration from 0.03 to 0.1 ppm (Speight, 1991). Both of these studies were performed using older mercury analysis methods with method detection limits of approximately 0.11 ppm. However, these studies also indicate minimum mercury concentrations in crude oil.

Approximately 16 to 18 million barrels (672 to 756 million gallons) of crude oil are consumed daily in the United States. At an average concentration of 0.41 ppm mercury and an average density crude oil of 6.9 lbs per gallon, the minimum total amount of mercury vaporized daily is therefore 1,901 lbs. This value represents an annual discharge of 347 tons of mercury nationwide, assuming that all of the oil is combusted. Certainly, the greatest proportion of the petroleum used in the United States is burned in vehicles. It is unclear whether the mercury present in crude oil is vaporized during the refining process or whether it remains in the refined petroleum. Because of the very large volumes of oil consumed, even a small concentration of mercury clearly represents a major source of atmospheric deposition of mercury. More work with the more sensitive analytical methods developed in the past few years should be performed to confirm these numbers.

Smelting

The smelting of ores to yield pure metals is thought to release some mercury into the atmosphere. Most metal ores are thought to have higher concentrations of mercury than coal, although the volumes of ore that are smelted each year pale in comparison with the volume of coal burned for power generation.

Chlor-Alkali Plants

Elemental mercury is employed as the electrode in the electrochemical production of chlorine gas and caustic soda (sodium hydroxide). Near most paper and pulp facilities which employ this technology to bleach the paper product white, the sediment is contaminated with high concentrations of mercury.

Mildew Suppression, Laundry facilities

An infrequent and historical point source of mercury contamination has been the use of mercury compounds for mildew suppression by laundry facilities, which have a chronic problem with moisture and bacterial growth (Sills, 1992). This contamination source type should no longer be a problem. The use of mercury as a fungicide in interior latex paints has been similarly banned by the US EPA.

Sewage Treatment

Sewage treatment represents the focal point of today's urban industrial, commercial, and domestic liquid waste streams. The secondary treatment of sewage involves dewatering, which necessarily concentrates the solids and all non-volatile contaminants, but does little to treat or remove inorganic dissolved contaminants. Mercury is commonly found in urban sewage through point source discharges from dental offices and industrial manufacturing processes such as battery fabrication. As the sewage is dewatered and the solids concentrated, mercury can be either sequestered by the organic humus of sludge or, if the sludge is caked and dried, can be released to the atmosphere in the drying process.

If the sludge has been dried, the fate of the sludge itself then dictates the extent of mercury contamination. Commonly, the dried product is incinerated or spread upon tree farms as a fertilizer and organic material. Sewage sludge incineration probably accounts for no more than 3,000 kg/yr in mercury emissions (US EPA, 1990). The distribution of sludge in this fashion also spreads concentrated mercury over a large area where it is either taken up in the biomass or contributes to surface water runoff and consequently downstream contamination.

Difficulties can arise when dissolved inorganic contaminants are not removed from treated wastewater prior to its reintroduction to receiving sewage. In Michigan's upper peninsula, the sediments and fish of 900-acre

Deer Lake near Ishpeming were found in 1981 to be severely contaminated with mercury as a result of releases from the Ishpeming waste water treatment plant and combined storm sewer overflows (Sills, 1992). The upstream discharge that contaminated the sewage releases was from the laboratories of an iron ore mining company.

Mercury dumping from naval vessels

The US Navy has surfaced as a major source of near-shore marine mercury pollution because of the use of mercury as ballast in its subsurface vessel fleet. During inter-ship ballast transfer operations, elemental mercury is occasionally spilled into marine waters, resulting in contamination of both sediment and water. This could be a significant point source of mercury directly within the Estuary.

Influences upon Mercury Pollution

pH

The pH of inland surface waters has been found to dramatically affect the amount of mercury taken up by biota (Gilmour and Henry, 1991). Specifically, mercury in fish tissue is present predominantly as methyl mercury, so changes in the biogeochemistry of this compound of mercury may account for any increase in bioaccumulation. It has been determined that inorganic mercury binds to organic matter more strongly as the pH declines (Schindler *et al.*, 1980), thus decreasing mercury's solubility. Conversely, in sediments a lower pH may increase the solubility of HgS (Ramal *et al.*, 1995).

Salinity

Salinity has been statistically linked to dissolved mercury concentrations in an inverse relationship, suggesting that local runoff may be an important source of dissolved mercury in the South Bay. As runoff increases and salinity decreases, the concentration of dissolved mercury increased (SFEI, 1993). Increasing salinity has also been associated with a decline in the rate of mercury methylation and in equilibrium methyl mercury concentrations (Compeau and Bartha, 1984).

Sulfate concentration

The microbial methylation of mercury is thought to proceed through the metabolic action of sulfur-reducing bacteria (SRB) in anoxic environments (Gilmour and Henry, 1991). The concentration of sulfate in marine waters is approximately 28 mM, which is considerably higher than freshwater sulfur concentrations. In freshwater systems, it is clear that an increase in sulfur concentration increases sediment sulfate-reduction rates (Rudd *et al.*, 1986). However, there appears to be a window of sulfate concentration that promotes the highest mercury methylation rate. Optimum mercury methylation by SRB in sediments is at 200–500 mM. Above this range, the formation of sulfide appears to inhibit methylation. At the same time, the presence of other sulfide-forming metals, such as iron, may affect the equilibrium between sulfate and sulfide in the pore water of the system.

Percent Fines

In aquatic sediments, mercury and other heavy metal contamination is most strongly correlated with the proportion of fine particles. This is particularly the case when the heavy metal load entering the system is largely in a very diffuse, molecular form, such as in atmospheric deposition, mine leakage of dissolved metals, and direct introduction to the environment of liquid or vaporized elemental mercury. In local research at a Sierra Nevada foothill reservoir, bottom sediment concentrations of mercury, as well as copper, zinc, and cadmium, were found to increase exponentially at average sediment grain sizes of less than 24 micrometers (Slotton *et al.*, 1994; Slotton and Reuter, 1995). In addition to largely determining the *concentration* of mercury in the sediments, sediment particle size also affects the diffusion of oxygen, minerals, and ions which therefore affects bacterial activity and the production of methyl mercury.

Aerobic and Anaerobic Microenvironments

Each transformation of mercury from one valence state or one species to another takes place in specific microenvironmental compartments (Figure 1). At the aerobic/anaerobic boundary in sediment, which is the limiting depth for oxygen penetration into the sediment, there is a redox potential discontinuity (RPD). In the oxygen-rich environment of the upper sediment, the electrochemical potential is oxidizing, thus favoring oxygen metabolism and the ionized (soluble) states of metals (e.g., Hg^{+2}). Conversely, the oxygen-poor lower sediment exhibits a reducing electrochemical potential that favors sulfur metabolism by sulfur reducing bacteria (SRBs). Two products of microbial sulfur metabolism are HgS (which is highly insoluble) and CH_3Hg (which is the form of mercury most commonly found in tissue), when mercury is present in the sediment.

Where the water itself becomes anaerobic, methyl mercury production can increase dramatically and transfer rapidly and efficiently into the aquatic food web (Slotton, 1991; Slotton *et al.*, 1995a). Piscivorous largemouth bass in this system accumulated filet mercury at concentrations up to 10 times the 0.5 ppm health guideline.

Both the proportions of total and dissolved mercury concentrations in the water and their absolute values can change due to shifts in the electrochemical potential of the sediment and/or water. Hydrological impacts such as the deposition of abnormally high volumes of silt, scouring, growth of algae or other oxygen-scavenging flora can dramatically alter mercury biogeochemistry and, consequently, the production, transformation, and concentration of the different mercury species.

Mercury's Health Effects

As mercury cycles through various forms and media, its bioavailability and toxicity change through both biological and chemical reactions. Because mercury is found throughout the environment, everyone is exposed to low levels of mercury. Dental amalgams are themselves about half mercury and it is known that mercury in the breath of persons with mercury amalgam fillings is higher than those without. However, the health effects of dental amalgams is unknown. Mercury emanating from amalgams is, at least initially, entirely in inorganic forms, which are not readily accumulated by the body as compared to methyl mercury. Other principal means of human mercury exposure are through the use of skin care products and, particularly, through the consumption of methyl mercury-contaminated fish. The three pathways of exposure are then inhalation, absorption, and ingestion.

The principal target of long-term exposure to low levels of metallic and organic mercury is the nervous system. The principal target of long-term exposure to low levels of inorganic mercury appears to be the kidneys (USDHHS, 1992). Short-term exposure to higher levels of any form of mercury can result in damage to the brain, kidneys, and to fetuses. Mercury has not been found to be carcinogenic. However, there are significant differences in the toxicity of the major forms of mercury. Mercury has been found to have a deleterious effect upon a wide range of systems including the respiratory, cardiovascular, hematologic, immune, and reproductive systems.

The bioaccumulation of mercury in various forms contributes in large measure to its toxicity. Concentrations that have been documented in a typical freshwater lake food web are shown in Table 3.

The common markers for human mercury exposure are blood, hair, and urine mercury concentrations. The mean total mercury levels in whole blood and urine of the general human population are approximately 8 µg/L and 4 µg/L, respectively (WHO, 1990). This background level of mercury can vary considerably, however, with the incidence of dental mercury amalgams and the consumption of fish. Individuals whose diet consists of large amounts of fish can have blood methyl mercury levels as high as 200 µg/L with a daily intake of 200 µg of mercury.

Table 3. Methyl mercury concentrations in the food web (PTI, 1994)

Planktivores	0.680 mg/kg wet	Piscivores	1.130 mg/kg wet
Zooplankton	0.260 mg/kg wet	Benthivores	0.480 mg/kg wet
Phytoplankton	0.032 mg/kg wet	Benthic Macroinvertebrates	0.025 mg/kg wet
Lake Water	0.0000003 mg/L (0.3 ng/L)	Pore Water	0.000002 mg/L (2 ng/L)

Data Trends in the Regional Monitoring Program

One of the apparently striking conclusions that can be drawn from the data is the lack of bioaccumulation of mercury in the bivalves transplanted for periods of 90 to 100 days to various locations in the Bay for any of the three years of the RMP. Bivalves generally do not accumulate dramatically elevated mercury concentrations, and the mercury they do contain (primarily inorganic mercury) is transferred to consumers far less efficiently than is methyl mercury. The food chain pathway of methyl mercury through larger, piscivorous fish is typically of primary importance in consumption-related toxicity to higher order consumers, including humans. Mercury bioaccumulation in larger piscivorous fish has resulted in tissue concentrations 10^5 times higher than concentrations in adjacent water (PTI, 1994). No piscivorous fish or any organism at the higher end of the food chain has been studied for the RMP for trace metal bioaccumulation. However, as part of the Bay Protection and Toxic Cleanup Program, a fish contamination study was conducted for the San Francisco Estuary (Taberski *et al.*, 1992), and findings revealed tissue concentrations above levels of human health concern in several fish species analyzed.

There has been an appreciable correlation between sediment mercury concentrations and the percentage of fines in the sediment for each of the three years. The greatest proportion of most metals, including mercury (Reimers and Krenkel, 1974), in marine environments is associated with particulates and specifically with the small size fractions of sediment. (See *Times Series of Trace Element Concentrations* in this report). Local freshwater sediment research at Camanche Reservoir reported similar findings (Slotton *et al.*, 1994; Slotton and Reuter, 1995).

Potential Control Measures

Control of anthropogenic sources of mercury pollution involves both point source and area source control. Point source control is often wielded through mechanical or chemical means, while area control is often executed by administrative means. It is always true that it is easier to recover mercury at the source, where it is more concentrated, than it is to recover it after it has dispersed in different forms and species throughout the environment. The continuous cycling of mercury through its many different forms also dramatically complicates the job of devising effective technologies to remove mercury from the environment.

Source Control

Investigators of point sources of mercury pollution have been very effective in isolating sources in the environment. Extremely sensitive analytical instrumentation is now available to monitor total mercury emissions or to analyze mercury's different forms down to the picogram level.

Remediation of Abandoned Mines

As a result of the Coast Range mercury deposits, soils in several locations throughout the San Francisco Estuary watershed are naturally high in mercury, and a great number of abandoned mines exist that, to this day, release substantial amounts of mercury into

surface waters as rain falls onto mine tailings. When high sulfur ore is exposed to the combination of water and oxygen, sulfuric acid is produced. The resulting acidic drainage from man-made tailings piles and mine workings dissolves mercury and transports the dissolved metal, as well as mercury-bearing particles, into creek channels. Ongoing research in the Marsh Creek watershed has found the source of downstream mercury to be highly localized to upstream mine tailings, as opposed to a generalized, regional source (Slotton *et al.*, 1996). This work has identified potentially effective control and remediation strategies, and has developed site-specific biological and chemical markers which will be used to guide future remediation efforts and quantify their effectiveness. On a larger areal scale, the Cache Creek project is currently underway to evaluate potential mercury control strategies in that important drainage. Both of these projects may serve as models for control and remediation of abandoned mines throughout the San Francisco Estuary watershed.

In contrast, the gold-mining mercury in the Sierra Nevada has been found to be largely dispersed and unsuitable for point-source cleanup approaches (Slotton *et al.*, 1995b). However, a considerable amount of mercury is extracted from Sierran rivers in the course of ongoing placer gold mining. A buy-back program is currently being developed by the Central Valley Regional Water Quality Control Board to encourage the collection and removal of this mercury.

Waste Stream Capture

Dental offices contribute a fair portion of municipal mercury waste. Mercury constitutes almost 50% of the material in dental amalgam tooth fillings. When this material is removed or when a new amalgam is fitted, some particulate-associated mercury is invariably released into waste water. Entrapment of this particulate mercury waste stream could appreciably reduce the mass of mercury entering municipal waste water. It is estimated that each dentist in the US uses an average over 1 kg of amalgam annually (Goering *et al.*, 1992). It is not yet clear whether the highly bound, inorganic mercury of dental amalgams is appreciably available for methylation and incorporation into the food web. Indeed, a very important future area of research involves the determination of the short and long term dissolution and methylation potential of all the major inorganic forms of mercury, including cinnabar, elemental mercury (quicksilver), and dental amalgams.

A good deal of the anthropogenic mercury release world-wide is dissolved in waste water streams. In many industries that use large amounts of mercury, dissolved mercury is routinely captured from waste streams through a variety of technologies utilizing either the ionic nature of most dissolved mercury or the unique and consistent size of dissolved mercury ions. The installation of such traps and filters can be a very effective measure at preventing mercury releases from low volume emitters particularly, because the capacity of such systems can be engineered to require regular but infrequent changeouts.

Flue Gas Scrubbing

Scrubbers are added as air emission control devices to a variety of incinerators to remove toxic or hazardous compounds, most commonly the sulfates. Mercury is present in some concentration in virtually all incineration processes. Commonly, the emitted gas is scrubbed by an aqueous counter-current to both cool the gas and to solubilize compounds in the gas. Other common scrubbing technologies are scrubber/fabric filters, lime injection directly into the combustion chamber, and electrostatic precipitators. At the high temperatures used in most incinerators (or in any process with a temperature greater than 900°C), all forms of mercury are decomposed to reduced elemental mercury, Hg^0. As the temperature of flue gas quickly drops, Hg^0 is oxidized to soluble Hg^{+2} (probably in part due to the catalytic contributions of other trace metals in the gas) and thus most mercury scrubbed from incinerator gas will dissolve in the cooling water and be transported to the settling ponds.

If flue gas is not scrubbed, mercury can be conveyed both far (as elemental mercury by the wind) and near (as Hg^{+2} dissolved in atmospheric moisture and deposited as rain). In municipal waste incineration, most mercury is released as the volatile mercuric chloride, $HgCl_2$ (Braun and Gerig, 1991).

Area Control

The mercury that evaporates from dental amalgams and is inhaled can have a surprisingly large impact upon the human body's mercury burden, particularly for inorganic mercury (Goering *et al.*, 1992). However, in many parts of the US and the world, ingestion of fish and other seafood contaminated with methyl mercury is an additional and often dominant source of mercury exposure. Administrative controls to limit the exposure of humans to mercury include warning limits on the amount of fish consumed in a given period.

When sediments are determined to be contaminated with mercury, capping is often a useful measure to limit exposure to the environment. Capping naturally produces an anoxic environment in the underlayment which, over time, can promote the formation of insoluble HgS if sufficient amounts of sulfate are present. Capping also eliminates the potentially harmful effects associated with some forms of dredging to remove contaminated sediments. Dredging can mix sediments with relatively high concentrations of mercury where it can disperse into the water column, aerate sediments and thus promote transformation of mercury to oxidized, soluble Hg^{+2}, and result in the frequently more onerous issue of remediating or disposing of highly contaminated dredge spoils on-land.

Some forms of dredging have been deliberately engineered to minimize the hazards outlined above. The watertight clamshell is one, and vacuum suction dredging is another. These technologies seek to recover only contaminated sediment without mixing with the water column and without further contaminating clean, underlying sediment.

Finally, mercury-contaminated soil and sediment can be washed with any of a variety of surfactants, solvents, or redox reagents to concentrate and/or chemically alter the mercury. The mercury can either be recovered as the element or condensed as the vapor to prevent merely exchanging a problem in one medium for one in another.

In the Estuary system, mercury contamination is probably far too widespread for direct/physical areal control measures to be effective or economically feasible. However, significant opportunities may exist for effective point source remediation of important mercury discharges, which would otherwise continue to be transported into the Estuary.

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Polychlorinated Biphenyls in the San Francisco Bay Ecosystem: A Preliminary Report on Changes Over Three Decades

Robert W. Risebrough, The Bodega Bay Institute

In 1967, while attempting to identify prominent peaks in a chromatogram of an extract of an unhatched egg of a Peregrine Falcon from Baja, California, peaks that were also present in all chromatograms of fish extracts from San Francisco Bay, I came across commercial brochures (Monsanto Chemical Company) that indicated the availability in the San Francisco Bay area of polychlorinated biphenyls (PCBs) in railway car quantities. If smaller amounts were needed, 520-lb steel drums or 50-lb cans of the several Aroclors could also be purchased. We were on to something.

On March 3, 1969, shortly after the publication of our paper on the global distribution of the polychlorinated biphenyls (PCBs; Risebrough *et al*., 1968), the Monsanto Chemical Company, sole US manufacturer of the PCBs, issued a release that was highly skeptical of our results:

> Polychlorinated biphenyls are stable chemical compounds which are essentially insoluble in water. Their use does not make them easily released into the natural environment ... It has also been implied that polychlorinated biphenyls are “highly toxic” chemicals. This is not true. The toxicity of any material, whether it be chemicals, drugs, natural plants or even foods, is relative.... PCBs are not hazardous when properly handled and used ... This raises the question ... whether they are compounds which, due to the metabolism of other materials in the marine environment, appear to be PCBs.

But a year later, three senior officials of the Monsanto Company, Dr. Robert Keller, Manager of Applied Sciences, Mr. William Papageorge, Manager, Environmental Control, and Mr. Elmer Wheeler, Manager, Environmental Health, visited our laboratory in Berkeley. We poured over chromatograms of fish from San Francisco Bay, of seabirds from around the world, and of mothers' milk, and then went to lunch (seafood at Spengers'; how unlike our relationships with Montrose and the other pesticide companies at that time). On June 30, 1970, Mr. John Mason, the Assistant General Manager of Monsanto, wrote to Congressman William Ryan of New York, who had proposed legislation to ban all further uses of PCBs, that as of August 30 of that year, Monsanto would no longer sell PCBs for open-system applications, of which there had been many: additives to pesticides to reduce loss by vaporization, additives to paints, to fire-retardants, uses in carbon-less copy paper, etc.

Along the California coast in the late 1960s, species after species was showing symptoms of contaminant effects, usually eggshell thinning, but also there were local extinctions and population declines. The fear was that more and more species would be affected if contaminant levels increased. To detect any such change, and to document point sources of contamination, David Young of the Southern California Coastal Water Research Project began one of the first 'Mussel Watch' programs to address these questions. The survey was repeated in 1974; many of these sites were picked up later by the National Mussel Watch program which began in 1976 and the California State Mussel Watch Program which began in 1977. These programs indicated that PCBs, as well as the DDTs, declined by up to an order of magnitude over this interval, with most of the decline occurring between 1971 and 1974 after the Monsanto Company had restricted open-system applications (Risebrough *et al*.,

1980b; de Lappe *et al*., 1980b; Goldberg *et al*., 1978). The principal uses of PCBs, however, as dielectric fluids in transformers and capacitors, which were considered to be "closed-system" applications, continued throughout the early 1970s.

Passage of the Toxic Substances Control Act in 1976 ended any further new uses of PCBs in the United States. Now, in 1996, 20 years later, PCBs are considered a major, and probably the major, continuing pollution problem in San Francisco Bay. What happened?

This paper attempts to answer this question, but because of insufficient time, it has not been possible to construct a comprehensive report. The extensive data base compiled by the State Mussel Watch program is not included. Also not included are extensive unpublished data from the National Mussel Watch program, and unpublished data from our laboratory on the analysis of archived samples preserved in frozen storage since the 1960s. Rather, I have compiled data from obscure grey-literature reports and other obscure publications from our laboratory to make these available in one place as a preliminary examination of the history of PCB contamination in San Francisco Bay. For lack of time, as noted above, the Mussel Watch data in Table 4 include only a fraction of the potentially available data from our own laboratory, and do not include the extensive data base of the California Mussel Watch Program. The intent is to incorporate these data into a more comprehensive report at a later time.

The oldest data set is of DDT and PCB levels in several species of fish from San Francisco Bay in 1965, including the shiner perch, *Cymatogaster aggregata*. DDTs and PCBs in three of the 1965 collections (Risebrough, 1969) are compared with shiner perch data from 1994 (SFBRWQCB *et al*., 1995) in Table 5.

The PCBs in the 1965 samples were quantified by comparing the summed heights of the three principal PCB peaks with the summed heights of those peaks in the most closely matching Aroclor, Aroclor 1254. The 1994 data are also reported as "Aroclor equivalents". The two methods, however, can not be assumed to be equivalent, but the uncertainty is probably no more than about 20–50%, not enough to modify the conclusion that environmental levels of PCBs have dropped by a factor of about 5 since the mid 1960s. This magnitude of change is comparable to the decline documented along the coast in the Mussel Watch programs during the early 1970s and most likely also occurred after the ending of those PCB uses that resulted in immediate entry into the environment.

While Mussel Watch data from the Southern California Bight over the period 1971–1985 indicate a sharp drop in PCB and DDE levels between 1971 and 1974, with the decline continuing at a lower rate through 1977, thereafter levels appeared to stabilize through 1985 (Risebrough, 1987). The Bodega Head data suggest a similar pattern, with no pronounced changes in PCB and DDE values between 1976 and 1994. In San Francisco Bay, the data are consistent with a modest decline of PCB levels since the mid 1970s, but a convincing case cannot be made from this (incomplete) data set. Because of the uncertainty that the transplanted mussels of the RMP have achieved equilibrium, and because the transplanted mussels are of a different species, a rigorous comparison cannot be made between data from RMP transplanted mussels and the earlier data from native mussels. Also, there were differences in analytical methodologies, and the analyses were done in different laboratories at different times without appropriate quality control. Nevertheless, the geometric mean PCB concentration in the 1993 transplants (n=17) of 350 ng/g is of the same magnitude of the geometric mean PCB concentrations of 540 ng/g in mussels from 27 bay-wide sites in 1976 (Risebrough *et al*., 1980a). Analysis of additional archived samples and systematic collections in the future are necessary to construct the best picture of changes in PCB levels in the San Francisco Bay ecosystem since the mid 1970s.

The water-column data (Table 6) suggest initially that PCB levels might even have increased over the past twenty years. When

Table 4. Selected mussel watch data from Bodega Head and San Francisco Bay 1971–1992, with RMP transplant data, 1993 and 1994
ng/g dry weight except where indicated.

	Sites/ Collections	Location	Analytical Replicates	PCBs	DDE	Packed/ Capillary	Year Analyzed	Reference	Comments
Bodega Head									
1971	1		1	76	90	P	1971	de Lappe *et al.,* 1980	
16 Apr 73	1		1	49	44	C	1993	Risebrough, unpublished	
1976	10		1	16	13	P	1976	Goldberg *et al.,* 1978	
24 Mar 76	1		1	23	24	C	1993	Risebrough, unpublished	
2 Jul 76	1		1	22	19	C	1993	Risebrough, unpublished	
1977	12		1	15	16	P	1978	Farrington *et al.,* 1982	monthly collections
1978	2		1	17.5	9	P	1978	Risebrough *et al.,* 1980b	
25 Feb 93	1		1	18	22	C	1993	RMP-BBI	
25 Jun 93	1		1	37	2.7	C	1993	RMP-GERG	Data anomalous
17 Jan 94	1		1	15	24	C	1993	RMP-GERG	
26 May 94	1		1	21	15	C	1993	RMP-GERG	
San Francisco Bay									
21 Dec. 1974	1	Berkeley Pier	1	64	7.3	P	1975	Anderlini *et al.,* 1976	wet weight
2 Feb. 1975	1	Berkeley Pier	1	70	4.5	P	1975	Anderlini *et al.,* 1976	wet weight
8 Feb. 1975	1	Berkeley Pier	1	67	2.4	P	1975	Anderlini *et al.,* 1976	wet weight
1976	27	Baywide	1	540	33	P	1976	Risebrough *et al.,* 1980a	
1977	1	South Bay	1	590	57	P	1976	Farrington *et al.,* 1982, 1983	
1978	1	Angel Is	1	790	56	P	1978	Risebrough *et al.,* 1980b	
20 Mar. 78	1	Berkeley Pier	10	430	---	P	1978	Risebrough *et al.,* 1980b	Geom mean
20 Mar. 78	1	Berkeley Pier	4	490	---	C	1983	Risebrough, unpublished	Geom mean
3 Apr. 92	1	Berkeley Pier	1	150	18	C	1993	Risebrough, unpublished	
2 Jul. 92	1	Brickyard Jetty	1	410	36	C	1993	Risebrough, unpublished	
RMP Transplants, *Mytilus californianus*									
1994	17	Baywide	1	350	43	C	1994	RMP 1994	Geom mean

Table 5. DDTs and PCBs, Aroclor basis, in shiner perch from San Francisco Bay, 1965 vs. 1994.
ng/g (ppb) wet weight

Locality	Number	Date	DDTs	PCBs	Reference	Size or Weight
Central San Francisco Bay	14	20 Oct. 65	1000	1200	Risebrough, 1969	5.5 gm
Central San Francisco Bay	10	20 Oct. 65	1400	400	Risebrough, 1969	26.7 gm
Central San Francisco Bay	15	4 Nov. 65	1100	1200	Risebrough, 1969	15.3 gm
San Mateo Bridge	20	3 May 94	27	120	SFBRWQCB, 1995	
Dumbarton Bridge	20	2 May 94	18	100	SFBRWQCB, 1995	
Richmond Harbor	20	10 May 94	42	180	SFBRWQCB, 1995	104 mm
Richmond Harbor	20	10 May 94	37	150	SFBRWQCB, 1995	91 mm
Richmond Harbor	20	10 May 94	34	170	SFBRWQCB, 1995	83 mm
Berkeley Pier	20	9 May 94	21	140	SFBRWQCB, 1995	108 mm
Berkeley Pier	20	9 May 94	15	91	SFBRWQCB, 1995	92 mm
Berkeley Pier	20	9 May 94	14	93	SFBRWQCB, 1995	83 mm
Oakland Inner Har, Fruitvale	20	6 May 94	73	370	SFBRWQCB, 1995	104 mm
Oakland Inner Har, Fruitvale	20	6 May 94	27	250	SFBRWQCB, 1995	
Oakland Inner Har, Fruitvale	20	6 May 94	30	240	SFBRWQCB, 1995	83 mm
Double Rock (Candlestick)	20	4 May 94	33	320	SFBRWQCB, 1995	94 mm
Islais Creek	20	4 May 94	20	100	SFBRWQCB, 1995	85 mm
Oakland Middle Harbor Pier	20	5 May 94	47	170	SFBRWQCB, 1995	93 mm

Geometric means	1965	1994	1965/1994
DDTs	1150	28	41
PCBs	832	161	5

only Central Bay stations, however, are included, this apparent upward trend disappears. The earliest measurements of PCBs in the water column of San Francisco Bay were undertaken in 1975, before and after an experimental dredge spoil operation designed to assess whether the disposal of dredge spoils within the Bay would increase the local contaminant burden (Anderlini *et al*., 1976). The geometric mean concentrations measured at that time, 880 and 950 pg/l, are of the same order as current measurements in the Central Bay. Occasional recent measurements in the South Bay and in the Petaluma River have been substantially higher.

Following a report by Holden (1970) that waste waters were significant sources of PCBs in coastal environments, we obtained waste water samples from the principal treatment plants of California in November–December 1970 (Schmidt *et al*., 1971; Table 7). Input of PCBs into Bay waters from the East Bay Municipal Utility District (EBMUD) was estimated to be in the order of 2 kg/day. Assuming a mean concentration of 900 pg/liter in Bay waters, the PCB burden in the water column, from a volume of 6.66×10^9 m^3 (Conomos, 1979), would have been about 6 kg in the early 1970s. This number is of the same order as the daily input from waste water treatment plants at that time. Almost all of the input PCBs must therefore have been deposited in the sediments with the particulate loads, which were much higher at that time than they are now. A corollary to this conclusion is that most of these PCBs deposited in the past are probably still in the sediments of San Francisco Bay.

Samples of waste waters from EBMUD in 1974–1975 had PCB concentrations almost an order of magnitude lower than in 1970 (Table 7). The samples from the San Francisco Southeast Treatment Plant showed a five-fold drop between 1970 and 1979. Although the data are few and scattered, they are consistent with other available data presented here that indicate a significant decrease of PCB environmental inputs in the early 1970s.

The present water-column burden of PCBs is therefore approximately equivalent to what it was 20 years ago, about 6 kg. Discarding loss through metabolism and redeposition in sediments, the principal net losses must be to the Pacific Ocean and to the atmosphere. Assuming: 1) the net water volume discharged into the Pacific is equivalent to the sum of: a) an annual river input of 20.9×10^9 m^3 (Conomos, 1979); b) an estimated yearly input from waste water treatment plants of 0.69×10^9 m^3 on the basis of a daily input of 500 mgd^{-1}; and c) oceanic waters equivalent to an input per tidal cycle of 0.34×10^9 m^3 new ocean water (Conomos, 1979) which mixes with Bay waters; and 2) the PCB concentration averages 800 pg/liter, allowing for dilution with incoming seawater, the yearly loss of PCBs from the Bay to the ocean would be about 216 kg, 36 times the water column burden at any one time. The water column burden must therefore renew itself every 10 days.

Modification of any of these assumptions would result in corresponding changes in this preliminary mass balance equation; the assumption about the volume of incoming oceanic waters that become mixed with Bay waters is probably the most susceptible to revision.

The magnitude of loss to the atmosphere is unknown. It can be assumed that the chemical potentials of PCB congeners in the offshore oceanic atmosphere are equivalent to those in surface waters because of the long time available for the attainment of equilibrium, and that these are much lower than those of congeners in the San Francisco Bay water column. The net flux is therefore from water to air in San Francisco Bay whenever the prevailing winds consist predominantly of oceanic air.

From the estimates, subject to update, of a daily discharge into San Francisco Bay of 500 million gallons of waste waters, with a PCB concentration of 500 pg/liter, also subject to update upon the availability of current data, current input from treatment plants would be only about 350 g/year, an insignificant portion of the estimated yearly loss to the ocean. The

Table 6. PCBs in the water column of San Francisco Bay, 1976–1994. Geometric means, picograms/liter

Date	Locality	Number Samples	PCBs pg/liter	Interval, 1 std	Source
8–9 Jan. 75	E. of Angel Island	11	880	580–1,350	Anderlini *et al.,* 1976
3–4 Mar. 75	E. of Angel Island	8	950	580–1,560	Anderlini *et al.,* 1976
3–4 Aug. 78	E. of Angel Island	1	660		de Lappe *et al.,* 1983
Apr. 92	Baywide	10	1,130	750–1,700	SedQual III
Apr. 92	Central Bay	5	1,000	660–1,600	SedQual III, Risebrough unpublished
Mar. 93	Baywide	7	420	260–670	SFEI, 1994
Mar. 93	Central Bay	4	310	230–420	SFEI, 1994
Feb. 94	Baywide	11	1,100	450–2,600	SFEI, 1995
Feb. 94	Central Bay	3	690	440–1,100	SFEI, 1995
Apr. 94	Baywide	11	2,100	1,100–3,800	SFEI, 1995
Apr. 94	Central Bay	3	1,100	660–1,700	SFEI, 1995
Aug. 94	Baywide	10	1,100	640–1,900	SFEI, 1995
Aug. 94	Central Bay	3	600	430–820	SFEI, 1995

Golden Gate, Grizzly Bay, Sacramento River and San Joaquin River stations not included

Table 7. Past inputs of PCBs into waters of San Francisco Bay from waste water treatment plants.

Date	Plant	Concentration in wastewaters picograms/liter	Est. Daily Discharge kg	Comments	Source
16 Dec. 1970	EBMUD 155 mgd	3,400,000	2	4 replicates, mostly Aroclor 1260	Schmidt *et al.,* 1971
16 Dec. 1970	San Francisco Southeast 31.5 mgd	4,800,000	0.6	2 replicates, mostly Aroclor 1260	Schmidt *et al.* , 1971
5–13 Dec. 1974	EBMUD 80 mgd	570,000	0.2	Mean of three composites Mostly Aroclor 1254	Anderlini *et al.,* 1976
10–20 Feb. 1975	EDMUD 80 mgd	340,000	0.1	Mean of three composites Mostly Aroclor 1254	Anderlini *et al.,* 1976
16 Feb. 1979	EDMUD	61,000	0.02	Mixture of 1242 and 1254 Mean of 2 grab samples	Sistek and Risebrough, 1979
20 Feb. 1979	EDMUD	240,000	0.08	Mixture of 1242 and 1254 Mean of 2 grab samples	Sistek and Risebrough, 1979
March 1979	San Jose/ Santa Clara	130,000		Composite over 4–22 March Mixture of 1242 and 1254	Sistek and Risebrough, 1979
April 1979	San Jose/ Santa Clara	22,000		Composite over 1–19 April Mixture of 1242 and 1254	Sistek and Risebrough, 1979
11 March 1979	San Francisco Southeast	1,300,000	0.16	Mixture of 1242 and 1254 Mean of 2 grab samples	Sistek and Risebrough, 1979
6–7 March 1979	Central Contra Costa	12,000		Mixture of 1242 and 1254 Mean of 2 grab samples	Sistek and Risebrough, 1979

daily input, in the order of a gram, is a small fraction of the water column burden.

Two generalities emerge from this analysis that are relevant to policy. The current input from waste waters, if the estimate of 500 pg/liter is in the correct order of magnitude, could come entirely from human excretion. If so, elimination of pollution at the source is not, in this case, a viable option. Furthermore, a criterion of 70 pg/liter of PCBs in waste waters, which has apparently been adopted by the Regional Board, would not contribute significantly to a reduction of water column concentrations in the foreseeable future unless some waste water concentrations substantially exceed 500 pg/liter.

Of the estimated daily input into the water column of 600 g, a minor fraction enters the Bay in rivers. In the absence of any known other major input sources, the sediments are the plausible source of the remainder.

Table 8 includes only a few measurements of PCBs in sediments, from the dredging study mentioned above. The 1975 concentrations in Table 8 have been reduced by one third from the original packed-column values to eliminate any bias in comparing packed column with capillary column results. Again, there is a suggestion of change since the mid 1970s, but PCBs in a 1993 sediment sample from Yerba Buena were comparable to those of the 1975 samples (Table 8).

A mean concentration of 10 ng/g of PCBs in dry sediments over an area of 1.24×10^9 m^2, including mudflats (Conomos, 1979) to a depth equivalent to 5 gm dry sediment/cm^2 would yield an estimate of 600 kg in the surface sediments. This is not a sufficient quantity to maintain water column levels over a period of many years. Available data are not sufficient to provide a more accurate estimate of the total PCB burden in San Francisco Bay sediments. Collection and analysis of dateable cores from selected areas would significantly improve the data base.

The currently accepted theory of equilibrium partitioning (DiToro *et al.*, 1991) provides a theoretical basis for predicting concentrations of a nonpolar organic contaminant in the lipid pools of organisms from either its concentrations in water or in the organic carbon component of the sediments. Thus, the ratio of the concentration of a PCB congener in fish lipid to its dissolved concentration in ambient water is expected to be the same as its octanol-water partition coefficient (K_{ow}). From a K_{ow} of 1,000,000 and a water concentration of 70 pg/liter, the current guideline for acceptable PCB concentrations in the waters of San Francisco Bay, a concentration of about 3 ppb (60 ppb on a lipid basis in a fish with 5 % lipid content) can be predicted. This concentration of 3 ppb is the currently accepted guideline criterion (Pilot Study Screening Value, PS-SV) for PCBs in fish from San Francisco Bay (SFBRWQCB *et al.*, 1995).

The equilibrium partition theory assumes that the organic carbon matrices of sediments, biological lipids and octanol are equivalent. Real-world measurements in an intertidal marsh of San Francisco Bay (Maruya *et al.*, 1996, Maruya *et al.* in press) have shown that this assumption is not universally valid. If, however, allowances are made for the nature of the organic carbon matrix, the concept of equilibrium partitioning is strengthened and its predictive capability is enhanced. In general terms, therefore, sediment quality criteria for PCBs on an organic carbon basis would be equivalent to those in fish lipid. All recent measurements of PCBs on an organic carbon basis are substantially higher than a criterion of 60 ng/g. As long as the sediment concentrations exceed this level, water column concentrations will exceed 70 pg/liter.

The SedQual I and III programs (Risebrough, 1994a, 1994b), like the RMP which followed, have not detected any “hot spots” of PCB contamination. But several sites in the SedQual programs had PCB concentrations on an organic carbon basis substantially higher than the average. These included Cerrito Creek Mouth (21 ppm), Davis Point (17 ppm), Richmond Inner Harbor (15 ppm), EBMUD Storm Drain (5.6 ppm) and San Leandro Bay (3.7 ppm). All of these sites are

Table 8. PCBs in surface sediments of San Francisco Bay, 1974–1993, and in sediments at 176 US coastal sites in the mid 1980s.
ng/g dry weight

Locality	# of Sites	Date	Total PCBs Geom. means	Interval of 1 std dev	Reference	Comments
Central San Francisco Bay East of Angel Island	6	20 Dec. 1974 – 2 Jan. 1975	17	14.4–20.4	Anderlini *et al.,* 1976	Geometric mean; three analytical replicates/site Original packed column values reduced by one third Archived samples available for reanalysis
EBMUD Outfall East of Yerba Buena Island	8	Dec. 1974 Feb. 1975	39	24–65	Anderlini *et al.,* 1976	Geometric mean; three analytical replicates/site 10 meter contour south of the outfll Original packed column values reduced by one third
US coastal sites	176	mid 1980s	18.5 (median value)		NOAA, 1988	National Status and Trends Program
San Francisco Bay SedQual I Program	45	Jan., Mar. 1990	9.5	3–26	Risebrough, 1994b	
San Francisco Bay SedQual III Program	17	1991, 1992	13	5–34	Risebrough, 1994a	12 stations sampled in two seasons; used geometric means of the two samples
San Francisco Bay Marshes SedQual III Program	32	1991, 1992	18	5–63	Risebrough, 1994a	
All Stations, RMP	16	March 1993	7.9	2–29	SFEI, 1994	
South Bay	4	March 1993	22	12–39	SFEI, 1994	
Yerba Buena	1	March 1993	35	35	SFEI, 1994	

close to shore and could indicate the existence of a "hot spot" where PCBs were discharged in the past. Because of equilibrium partitioning, fluxes of PCBs from the sediments into the water column in these areas are expected to be higher than elsewhere in the Bay, whether or not even higher areas of contamination exist in their vicinities. These areas of higher contamination are likely to be the principal current sources of continuing PCB inputs into the water column.

Recent political efforts to secure funding for "toxics cleanup" in the Bay have seriously mislead both the public and the concerned environmental groups. Neither high-temperature incineration of a substantial fraction of the sediments of San Francisco Bay which would be required to attain an effective cleanup; nor dredging the sediments (yes, all of the surface sediments except those that are predominantly sand) and disposal at some upland site or at sea are feasible options. What then is the funding to be used for?

Is the present concern about PCB contamination in the Bay justified? After all, levels were higher in the 1960s (production peaked in 1970) and the world did not collapse. Sufficient time has elapsed to detect any pattern of new cancers among people who consumed fish from the Great Lakes that have had much higher levels of PCB contamination than fish from San Francisco Bay. The very low PS-SV of 3 ppb would make virtually every fish in California a potential cancer risk. Such is the range of uncertainty, including the uncertainty that PCBs are a human carcinogen, that the assignment of any PS-SV can not be justified in scientific terms; following the most conservative approach in the protection of human health against a potential threat is the justification. Specifically, the current criterion of 70 pg/liter is based on a rationale that does not derive from empirical science.

Other considerations, however, argue for a low criterion, although not necessarily as low as that for the perceived cancer risk. Children born to mothers who had consumed fish from Lake Michigan had lower memory retention and performed poorly in other tests of mental capability in infancy and at age 4 years (Fein *et al*., 1984; Jacobson *et al*., 1984, 1985, 1992). The latest report from this study, published in 1996, reported that these differences have persisted to eleven years of age, with the children exposed *in utero* to contaminants in Lake Michigan fish performing more poorly in IQ tests (Jacobson and Jacobson, 1996). A follow-up study of children born to mothers who consumed Lake Ontario fish has begun; the initial results indicate poorer reflex responses just after birth for the more highly exposed group (Lonky *et al*., 1996). The assumption that PCBs are the responsible contaminant is supported by animal studies, but the contribution of other organochlorines such as toxaphene cannot be ruled out.

The no-adverse-effect level on visual recognition memory is currently considered to be about two orders of magnitude higher than the estimated one-in-a-million cancer risk over a lifetime (Swain, 1991). The most contaminated fish of San Francisco Bay would therefore fall within the effects range, i.e. above approximately 0.3 ppm, lowering the IQs of children born to women who consume large amounts of these fish. Unlike the perceived cancer risk which has such a large interval of uncertainty, this conclusion derives support from empirical data.

In 1970 the means to accomplish the aim of reducing environmental levels of PCBs were obvious: end the uses of PCBs and reduce their environmental inputs. In 1996–97 the means to accomplish the aim of reducing further the environmental levels are not at all obvious. Given the small if any reduction in levels over the past 20 years, more-of-the-same monitoring of sediments, water, shellfish and fish can not be expected to produce any information useful to this end. Two kinds of measurements might, however, produce information that could result in effective action. Measurements of PCBs in waste waters with a detection limit at least as low as the receiving water criterion of 70 pg/liter would indicate whether there are still sources discharging into the waste water

treatment systems beyond the PCBs that are being recycled through humans. In addition, a sampling grid in those areas that showed highest sediment PCB levels in the SedQual programs might detect a "hot spot" about which something could be done to slow the inevitable entry over time of PCBs into the water column. Mixing with cleaner sediments with a lower PCB content on an organic carbon basis, or disposal of cleaner dredged sediments in these areas are options that would reduce the rate of input into the water column, and thereby reduce the water column burden.

Within a national perspective, PCB contamination in San Francisco Bay falls towards the "cleaner" end of 176 sites sampled in National Oceanic and Atmospheric Administration's (NOAA) Status and Trends Program of the mid 1980s. The median value was 18.5 ng/g, substantially higher than the values recorded in the SedQual programs (NOAA, 1988; Table 8).

Are There "New PCBs" Out There?

PCBs were detected by identifying unknown peaks on gas chromatograms. In the RMP prominent peaks have been identified by GC/MS as the herbicides trifluralin and oxadiazon; these compounds have since been added to the list of reported contaminants. But chromatograms, particularly of the most polar fraction of the dissolved water phase, literally contain hundreds of peaks that have not been identified. Do any of these compounds pose, like the PCBs, a potential hazard to any species in the ecosystem, including humans? Until they are identified and investigated, no conclusions are possible. The 'surveillance' component of the concept of monitoring is currently being ignored; the list of reported contaminants is a very imperfect description of the real world. A survey of potentially beneficial plants in a rainforest using a guidebook that identifies only bananas, the coconut palm, and five species of orchids would be equally incomplete.

Summary of Estuary Condition in Terms of Contamination

The Discussions of the water, sediment, and bivalve monitoring sections in this report have summarized the 1995 monitoring results. The following is a synthesis of those discussions made to generally assesses the condition of the Estuary in terms of contamination.

Contaminants of concern in the Estuary were generally different depending on the medium sampled (water, sediment, tissue). In water, PCBs and nickel were most often above applicable guidelines. PCBs were above EPA criteria at nearly all stations sampled and nickel was above the Basin Plan Objective at about half the stations. All other contaminants were above guidelines at fewer than half the stations. In sediments, arsenic, chromium, copper, mercury, nickel, lead, and DDTs were above ERLs at most Estuary stations. In bivalve tissues, dieldrin, chlordanes, PAHs and PCBs were usually above the MTRLs at all stations.

The total number of contaminants above concentration guidelines at each RMP station provides some indication of where contaminants may be the greatest problem and where they may be the least problem. For water, Coyote Creek (BA10) and Petaluma River (BD15) had the largest numbers of water quality exceedances and the Central Bay stations generally had the fewest partially due to TSS effects. For sediments, Alameda (BB70) and Honker Bay (BF40) had the most ERL exceedances, and the stations with the coarsest sediments at Red Rock (BC60) and Davis Point (BD41) had the fewest ERL exceedances. For bivalve bioaccumulation, the number of MTRL exceedances were about the same (seven to ten) at most stations sampled. However, stations in San Pablo Bay (BD20, BD30) had only four exceedances.

Considering the number of "hits" to the RMP biological effects measurements (aquatic and sediment bioassays, bivalve condition and survival) shows that the Sacramento and San Joaquin Rivers had the most indications of possible biological effects. As shown in a recent RMP Newsletter article (Summer 1996), those results are similar to the trend in biological effects seen in all RMP data (1993–1995) where the San Joaquin River station indicated biological effects in about 50% of the measurements made. Grizzly Bay and Napa River indicated biological effects about 47% of the time.

It is difficult to make comparisons among stations because not all contaminants and effects indicators are measured at each station. With that in mind, Coyote Creek, Dumbarton Bridge, Petaluma River, and Napa River indicated the most contaminant exceedances and biological effects "hits", while Red Rock and Horseshoe Bay in the Central Bay indicated the fewest.

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REGIONAL MONITORING PROGRAM

Statement of Income and Expense for Twelve-Month Period Ending December 31, 1995

Income:

Participant Fees:		
Municipal Dischargers	$ 880,003.00	
Industrial Dischargers	$ 219,999.00	
Cooling Water Dischargers	$ 80,000.00	
Stormwater Dischargers	$ 470,000.00	
Dredged Material Dischargers	$ 100,200.00	
Additional Sampling Assistance	$ 41,325.00	
In-Kind Fees	$ 249,800.00	
Interest	$ 68,019.00	
	Total Income	**$ 2,109,346.00**

Expense:

Program Management, Coordination and Public Information	$ 168,223.00	
Quality Assurance/Quality Control	$ 51,509.00	
Data Analysis	$ 30,160.00	
Data Management	$ 132,827.00	
Annual Report	$ 196,916.00	
Monitoring Program	$ 1,273,469.00	
Pilot Studies	$ 119,910.00	
Special Studies	$ 46,471.00	
1993 RMP Deficit	$ 12,543.00	
	Total Expense	**$ 2,032,028.00**

Net Gain (Loss) **$ 77,336.00**

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 the SFEI work on the Annual Report was done during calendar year 1996 and therefore the final cost of the Annual Report is not reflected in these figures.

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Appendices

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Appendix A
Descriptions of Methods

Water Sampling

One of the objectives of the RMP is to evaluate if water quality objectives at the stations sampled are met. Therefore, the sampling and analysis methods have to be able to meet quantification levels below the water quality objectives. 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).

Water samples were collected approximately one meter below the water surface using 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.

Particulate and dissolved fractions of Estuary water were collected. The evolution of the trace organic sampling system has been described in a series of papers (Risebrough *et al*., 1976; de Lappe *et al*., 1980a; 1983). Water was pumped by a Teflon impeller pump with 3/4 inch Teflon tubing through a glass fiber filter (1 µm) providing a sample of particulate-associated contaminants. The water was then passed through four exhaustively cleaned polyurethane foam plugs mounted in series which adsorbed the dissolved material. The entire sampling system was thoroughly rinsed with methanol prior to sampling, and an all-Teflon-stainless steel system further minimized potential contamination. During sampling, the system was closed to outside sources of contamination, and extreme precaution was taken at other times to minimize, if not eliminate, the introduction of contaminants. Total organics were calculated by adding particulate and dissolved fractions.

For trace metals, water samples were collected using a peristaltic pump system equipped with C-Flex tubing in the pump head. Sample aliquoting was conducted on deck on the windward side of the ship to minimize contamination from shipboard sources. The applicability of this sampling procedure has been demonstrated previously with intercalibrated analyses of water collected with the California Institute of Technology Deep Water Sampler and General Oceanics, Inc. trace metal clean Go-Flos (Flegal and Stukas, 1987). Filtered water was 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 was pumped directly into sample containers. Prior to collecting water, several liters of water were pumped through the system, and bottles were rinsed three times before filling. Samples were acidified on board the vessel at the end of each second day except for chromium, which was acidified and extracted within an hour of collection.

Samples for conventional water quality parameters were collected using the same apparatus as for trace metals. Water samples were collected for toxicity tests using the same pumping apparatus as for the collection of the trace organics sample, 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 laboratory. Two field blanks were collected each cruise consisting of water known to be non-toxic from the Bodega Marine Laboratory and then filtered (0.45 µm).

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 composite sediments were also

constructed of Teflon or stainless steel coated with Dykon®. Sediment sampling equipment was thoroughly cleaned prior to each sampling event.

When the sampler was on deck, a sub-core was removed for measurement of 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 and for sediment toxicity tests. Duplicate samples for archiving were collected from a composite of two additional grabs. The quality of grab samples was ensured by requiring each sample to satisfy a set of criteria concerning depth of penetration and disturbance of the sediment within the grab.

Benthos Sampling

Benthic invertebrates were collected with a 0.05 m^2 Ponar grab sampler, with assistance from staff of the City and County of San Francisco. Samples were screened through 1.0 mm and 0.5 mm mesh screens and fixed in 10% borax-buffered formalin. In the laboratory, the samples were transferred to 70% ethanol, sorted to major taxa, and identified to the lowest practical taxon, usually species.

Bivalve Bioaccumulation Sampling

Bivalves were collected from uncontaminated sites and transplanted to 15 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) and at the end of the 90–100 day deployment period. The condition of animals at control sites at Lake Isabella (*Corbicula fluminea*), Bodega Head (*Mytilus californianus*) and Tomales and Dabob Bays (*Crassostrea gigas*) was also determined at the end of each deployment period in order to sort out Estuary effects from natural factors affecting bivalve condition. 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.

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 expected to have the highest salinities, west of Carquinez Strait. *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) or Dabob Bay, Washington, 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 Lake Isabella and deployed at sites with the lowest salinities. *Corbicula fluminea* tolerates salinities from 0 ppt to perhaps 10 ppt (Foe and Knight, 1986). At several sites, more than one species was deployed in order to insure survival of at least one set of bivalves in case of unanticipated salinity variations. 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.

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-fifty oysters and 160 mussels and clams were randomly allocated for deployment at the appropriate sites, with the same number being used as a travel blank (time zero) sample 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 metals and organic compounds. Based on findings by Stephenson (1992) during the RMP Pilot Program, bivalve guts were not depurated before homogenization for tissues 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 held 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 and introduce an unspecified amount of error into the measurement process.

Analytical Methods

Conventional Water Quality Parameters

Samples for dissolved phosphates, silicates, nitrate, nitrite, and ammonia were analyzed following the procedures described by Parsons *et al.* (1984). Total chlorophyll was measured using a fluorometric technique with filtered material from 200 ml samples (Parsons *et al.*, 1984). Shipboard measurements for temperature and salinity were obtained using a portable conductivity/salinity meter (YSI model 33), pH was measured with a portable pH meter (Orion SA250), and dissolved oxygen content was measured using a portable dissolved oxygen meter (YSI model 58). Dissolved organic carbon (DOC) was measured using high-temperature catalytic oxidation with a platinum catalyst (Fitzwater and Martin, 1993). Total suspended solids (TSS) were 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 lab 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. Later, SFEI calculated density and total suspended solids (TSS), which were compared with measurements obtained using the standard methods described above. Although the CTD data are not detailed in this report, SFEI maintains the data.

Trace Elements

Total and dissolved (0.45 µm filtered) concentrations of arsenic, chromium, mercury, and selenium in water were measured, and near-total and dissolved concentrations of cadmium, copper, nickel, lead, silver, and zinc in water were measured. Near-total concentrations were used in the RMP for consistency

with the Bay Protection and Toxic Cleanup Program (BPTCP) pilot studies results. Total metals in water are usually extracted with boiling *aqua regia* (a mixture of three parts concentrated hydrochloric acid and one part concentrated nitric acid) which extracts virtually all metals from the sample. Near-total metals are extracted with a weak acid (pH < 2) for a minimum of one month, resulting in measurements that approximate bioavailability of some metals to Estuary organisms (Smith and Flegal, 1993). Near-total concentrations underestimate total metals concentrations by an unknown amount. Therefore, comparisons to water quality objectives tend to be rather conservative.

To determine total chromium concentrations, the particulate matter in the sample was extracted and analyzed, rather than analyzing unfiltered samples. Total mercury samples were photo-oxidized with the addition of bromium chloride and quantified using a cold vapor atomic fluorescence technique. Trace metals (except for arsenic, mercury, and selenium) in water were measured using graphite furnace atomic absorption spectrometry preceded by sample preconcentration using the APDC/DDC organic extraction method (Bruland *et al.,* 1985; Flegal *et al.,* 1991).

Results for cadmium, copper, nickel, lead, silver, and zinc were reported by the laboratory in units of µg/kg. For use in this report, those values are reported as µg/L, without taking into account the difference in density between Estuary water and distilled water. This difference is much less than the precision of the data, which was on the order of 10%. In some instances, dissolved metals concentrations are reported as higher than total (dissolved + particulate) metals 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 all of metal is in the dissolved phase.

Metals in sediments were extracted with *aqua regia* and analyzed as described in the standard methods developed for measuring trace element concentrations in marine sediments and waste water sludge for the California State Water Resources Control Board (Flegal *et al.,* 1981). This report compares several extraction procedures. 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, as is the case with hydrofluoric acid digestion. In order to eliminate possible confusion between the terms near-total concentrations of metals in water and sediment, the term near-total extraction in sediment based on the *aqua regia* digestion is avoided.

Bivalve tissue samples were analyzed with techniques used in the California State Mussel Watch (e.g., Flegal *et al*., 1981; Smith *et al.,* 1986) and consistent with the Pilot Program (Stephenson, 1992). 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, plugs and filters were extracted in custom-built soxhlet extraction units. Extracts were reduced to 1–2 ml in hexane for cleanup with florisil-column chromatography. Chlorinated hydrocarbons (CH) in each of the three analytical fractions (F1, F2, F3) were analyzed on a Hewlett Packard 5890 Series II capillary gas chromatograph utilizing electron capture detectors (GC/ECD). A single

2 µL splitless injection was directed onto two 60 m x 0.25 mm columns of different polarity (DB-17 and DB-5) using a y-splitter to provide two-dimensional confirmation of each analyte. The quantitation internal standard utilized for the CH analysis was dibromooctafluorobiphenyl (DOB). Decachlorobiphenyl (PCB 209) was introduced to each sample prior to fractionation. This compound was treated as a surrogate standard, and analyte concentrations were corrected for PCB 209 losses prior to reporting.

PAHs were quantified in the F-2 fraction by analysis on a Hewlett-Packard 5890 Series II 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). Samples quantitated at a final volume of 1mL utilized deuterated fluoranthene. Deuterated phenanthrene and deuterated chrysene were spiked into each sample prior to fractionation. All PAH concentrations were corrected for deuterated phenanthrene recoveries prior to reporting.

Sediment samples were freeze-dried, mixed with kiln-fired sodium sulfate, and soxhlet-extracted with methylene chloride. 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.

Aquatic Bioassays

Water column toxicity was evaluated using a 48-hour mollusk 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 edulis* were used in the February samples, and larval *Crassostrea gigas* were used in the August samples. Different species were used due to seasonal differences in larval availability. 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 four replicates, and with 20 larvae per replicate. Wastes, 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 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 sea water, shaking for 10 seconds, allowing to settle for 24 hours, and carefully decanting (EPA and COE, 1977; Tetra Tech, 1986). Larval mussels (*Mytilus edulis*) were used in both sampling periods, where percent normally developed larvae was the endpoint 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 such as length, weight, volume, or ratios of those measurements have been used as indicators of integrated physiological response to contaminants in water (Pridmore *et al*., 1990; KLI 1984). Measurements were made on subsamples of specimens before deployment and on the deployed specimens following exposure. Condition was also determined on bagged controls at the clean reference sites at the end of the deployment period. 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^{o} 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.

Appendix B
Quality Assurance

The following section contains summaries of quality assurance information for the 1995 Regional Monitoring Program (RMP). A description of the RMP's quality assurance program can be found in the *1994 RMP Annual Report*, Appendix 2 and the 1996 Quality Assurance Program Plan.

Table 1. Quality assurance and control summary for laboratory analyses of water.
Cruise 7: February 95, Cruise 8: April 95, and Cruise 9: August 95

Analysis Type: Water Elements, Dissolved

Cruise #	Parameter	Units	MDL Target	MDL Measured	Precision Target (+/- %)	Precision Measured (rsd)[1]	Accuracy Target (+/- %)	Accuracy Measured (+/- %)	No. Blanks/Batch
7	Ag	µg/L	0.0003	0.0002	15	10	25	NA[2]	12/24
7	As	µg/L	0.002	0.056	25	5	25	5	2/20
7	Cd	µg/L	0.0003	0.0001	15	4	25	25	12/24
7	Cr	µg/L	0.0250	0.0924	15	9	25	1	6/24
7	Cu	µg/L	0.0058	0.0074	15	5	25	18	12/24
7	Hg	µg/L	0.0001	0.0001	25	10	25	3	2/20
7	Ni	µg/L	0.0054	0.0025	15	5	25	10	12/24
7	Pb	µg/L	0.0028	0.0004	15	11	25	10	12/24
7	Se	µg/L	0.005	0.019	35	12	35	5	2/20
7	Zn	µg/L	0.0008	0.0039	15	3	25	8	12/24
8	Ag	µg/L	0.0003	0.0002	15	20	25	NA[2]	12/24
8	As	µg/L	0.002	0.043	25	7	25	5	2/20
8	Cd	µg/L	0.0003	0.0001	15	1	25	12	12/24
8	Cr	µg/L	0.0250	no data	15	no data	25	no data	
8	Cu	µg/L	0.0058	0.0046	15	4	25	6	12/24
8	Hg	µg/L	0.0001	0.0001	25	8	25	5	2/20
8	Ni	µg/L	0.0000	0.0126	15	8	25	4	12/24
8	Pb	µg/L	0.0028	0.0013	15	7	25	13	12/24
8	Se	µg/L	0.005	0.019	35	14	35	5	2/20
8	Zn	µg/L	0.0008	0.0045	15	2	25	9	12/24
9	Ag	µg/L	0.0003	0.0001	15	6	25	NA[2]	15/24
9	As	µg/L	0.002	0.100	25	7	25	9	2/20
9	Cd	µg/L	0.0003	0.0000	15	2	25	10	15/24
9	Cr	µg/L	0.0250	no data	15	no data	25	no data	
9	Cu	µg/L	0.0058	0.0008	15	2	25	5	15/24
9	Hg	µg/L	0.0001	0.0001	25	6	25	5	2/20
9	Ni	µg/L	0.0054	0.0012	15	3	25	3	15/24
9	Pb	µg/L	0.0028	0.0005	15	6	25	24	
9	Se	µg/L	0.005	0.019	35	14	35	6	2/20
9	Zn	µg/L	0.0008	0.0008	15	8	25	2	15/24

Table 1. Quality assurance and control summary for laboratory analyses of water (continued). Cruise 7: February 95, Cruise 8: April 95, and Cruise 9: August 95

Analysis Type: Water Elements, Total

Cruise #	Parameter	Units	MDL Target	MDL Measured	Precision Target (+/- %)	Precision Measured (rsd)[1]	Accuracy Target (+/- %)	Accuracy Measured (+/- %)	No. Blanks/Batch
7	Ag	µg/L	0.0012	0.0009	15	11	25	NA[2]	12/24
7	As	µg/L	0.0020	0.0560	25	5	25	5	2/20
7	Cd	µg/L	0.0004	0.0010	15	4	25	18	12/24
7	Cr	µg/L	0.3530	0.0733	15	4	40	29	6/24
7	Cu	µg/L	0.0066	0.0098	15	5	25	14	12/24
7	Hg	µg/L	0.0001	0.0001	25	10	25	3	2/20
7	Ni	µg/L	0.0095	0.0221	15	6	25	6	12/24
7	Pb	µg/L	0.0050	0.0032	15	5	25	18	12/24
7	Se	µg/L	0.0050	0.0190	35	12	35	5	2/20
7	Zn	µg/L	0.0074	0.0087	15	2	25	19	12/24
8	Ag	µg/L	0.0012	0.0010	15	8	25	NA[2]	8/24
8	As	µg/L	0.0020	0.0430	25	7	25	5	2/20
8	Cd	µg/L	0.0004	0.0012	15	3	25	16	8/24
8	Cr	µg/L	0.3530	0.4710	15	16	40	33	5/24
8	Cu	µg/L	0.0066	0.0119	15	6	25	12	8/24
8	Hg	µg/L	0.0001	0.0001	25	8	25	5	2/20
8	Ni	µg/L	0.0095	0.0031	15	3	25	6	8/24
8	Pb	µg/L	0.0050	0.0006	15	10	25	16	8/24
8	Se	µg/L	0.0050	0.0190	35	14	35	5	2/20
8	Zn	µg/L	0.0074	0.0164	15	5	25	3	8/24
9	Ag	µg/L	0.0012	0.0003	15	20	25	NA[2]	12/24
9	As	µg/L	0.0020	0.1000	25	7	25	9	2/20
9	Cd	µg/L	0.0004	0.0001	15	4	25	4	12/24
9	Cr	µg/L	0.3530	0.0001	15	16	40	30	
9	Cu	µg/L	0.0066	0.0049	15	3	25	10	12/24
9	Hg	µg/L	0.0001	0.0001	25	6	25	5	2/20
9	Ni	µg/L	0.0095	0.0046	15	6	25	22	
9	Pb	µg/L	0.0050	0.0051	15	8	25	3	
9	Se	µg/L	0.0050	0.0190	35	14	35	6	2/20
9	Zn	µg/L	0.0074	0.0039	15	4	25	11	11/24

[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 7: February 95, Cruise 8: April 95, and Cruise 9: August 95

Analysis Type: Water 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] (% rpd)
7	Aliphatics	pg/L	50	11	20	< 20	< 20
7	PAHs	pg/L	50	50	20	< 20	< 20
7	PCBs	pg/L	50	0.5	20	< 20	< 20
7	Pesticides	pg/L	50	not available	20	< 20	< 20
8	Aliphatics	pg/L	50	11	20	< 30	< 30
8	PAHs	pg/L	50	50	20	< 30	< 30
8	PCBs	pg/L	50	0.5	20	< 30	< 30
8	Pesticides	pg/L	50	not available	20	< 30	< 30
9	Aliphatics	pg/L	50	24	20	< 30	< 30
9	PAHs	pg/L	50	50	20	< 30	< 30
9	PCBs	pg/L	50	0.5	20	< 30	< 30
9	Pesticides	pg/L	50	not available	20	< 30	< 30

[1] relative standard deviation

[2] Based on NIST standard solutions and calibration standards.

* **Note:** Certified reference Materials for trace organic contaminants in water are not available. Accuracy was measured using continuing calibration check solutions. Recoveries of these solutions were consistently 95 +/- 15%.

Table 3. Quality Assurance and Control Summary for Laboratory Analyses of Sediment. Cruise 7: February 95, and Cruise 9: August 95

Analysis Type: Sediment Metals

Cruise #	Parameter	Units	MDL Target	MDL Measured	Precision Target (+/- %)	Precision Measured (rsd)*	Accuracy Target (+/- %)	Accuracy Measured (+/- %)	No. Blanks/Batch
7	Ag	mg/Kg	0.0012	0.0000	15	4	25	NA[2]	3/24
7	Al	mg/Kg	70	156	25	9	25	73	3/24
7	As	mg/Kg	1.6	0.3	25	8	25	8	2/20
7	Cd	mg/Kg	0.00002	0.0000	15	14	25	90	3/24
7	Cr	mg/Kg	9.44	3.42	15	5	60	62	3/24
7	Cu	mg/Kg	4.57	2.40	15	3	25	24	3/24
7	Fe	mg/Kg	140	167	15	2	25	17	3/24
7	Hg	mg/Kg	5	0.14	35	5	25	13	2/20
7	Mn	mg/Kg	27	17	25	4	25	8	3/24
7	Ni	mg/Kg	4.28	0.80	15	4	25	78	3/24
7	Pb	mg/Kg	0.1	0	15	11	25	7	3/24
7	Se	mg/Kg	2.2	0	35	16	35	13	2/20
7	Zn	mg/Kg	18.8	.	15	.	25	.	3/24
9	Ag	mg/Kg	0.0012	0.0004	25	6	25	NA[2]	3/24
9	Al	mg/Kg	70	135	25	8	25	76	3/24
9	As	mg/Kg	1.6	0.03	25	8	25	5	2/20
9	Cd	mg/Kg	0.00002	0.0003	25	3	25	2	3/24
9	Cr	mg/Kg	9.4	3.0	25	7	60	62	3/24
9	Cu	mg/Kg	4.57	0.70	25	5	25	7	3/24
9	Fe	mg/Kg	140	444	25	4	25	15	3/24
9	Hg	mg/Kg	5	0.14	35	6	25	8	2/20
9	Mn	mg/Kg	27	33	25	3	25	28	3/24
9	Ni	mg/Kg	4.26	2.00	25	5	25	9	3/24
9	Pb	mg/Kg	0.01	0.01	25	6	25	2	3/24
9	Se	mg/Kg	2.2	0.01	35	15	35	14	2/20
9	Zn	mg/Kg	18.9	19.0	25	5	25	16	3/24

Analysis Type: Sediment Organics

Cruise #	Parameter	Units	QA batch#	MDL Target	MDL Measured	Precision Target (+/- %)	Precision Measured (rsd)*	Accuracy Target (+/- %)	Accuracy Measured (+/- %)	Blank Frequency[1]
7	Aliphatics	µg/Kg	M2257	5	0.8 - 91.6	±20	3	±20	9	5% min.
7	Aliphatics	µg/Kg	M2258	5	0.8 - 91.6	±20	2	±20	10	5% min.
7	PAHs	µg/Kg	M2257	5	0.4-10.7	±20	12	±20	7	5% min.
7	PAHs	µg/Kg	M2258	5	0.4-10.7	±20	12	±20	8	5% min.
7	PCBs	µg/Kg	M2257	1	0.2	±20	3	±20	13	5% min.
7	PCBs	µg/Kg	M2258	1	0.2	±20	6	±20	3	5% min.
7	Pesticides	µg/Kg	M2257	1	0.1	±20	6	±20	1	5% min.
7	Pesticides	µg/Kg	M2258	1	0.1	±20	2	±20	7	5% min.
9	Aliphatics	µg/Kg	M2403	5	1 - 95	±20	5	±20	8	5% min.
9	Aliphatics	µg/Kg	M2404	5	1 - 95	±20	4	±20	1	5% min.
9	PAHs	µg/Kg	M2403	5	0.4-13.7	±20	5	±20	9	5% min.
9	PAHs	µg/Kg	M2404	5	0.4-13.7	±20	13	±20	12	5% min.
9	PCBs	µg/Kg	M2403	1	0.2-0.7	±20	5	±20	10	5% min.
9	PCBs	µg/Kg	M2404	1	0.2-0.7	±20	2	±20	14	5% min.
9	Pesticides	µg/Kg	M2403	1	0.1-0.3	±20	4	±20	16	5% min.
9	Pesticides	µg/Kg	M2404	1	0.1-0.3	±20	3	±20	4	5% min.

* relative standard deviation

[1] Maximum Batch size is 20 samples.

[2] There are no SRM certified values for silver.

Table 4. Quality Assurance and Control Summary for Laboratory Analyses of Bivalve Tissue. Cruise 7: February 95, and Cruise 9: August 95

Analysis Type: Tissue Metals

Cruise #	Parameter	Units	MDL Target	MDL Measured	Precision Target (+/- %)	Precision Measured (rsd)*	Accuracy Target (+/- %)	Accuracy Measured (+/- %)	No. Blanks/Batch
7	Ag	mg/Kg	0.0012	0.023	30	7	35	1	3/24
7	As	mg/Kg	1.6	0.01	25	12	25	3	2/20
7	Cd	mg/Kg	0.00002	0.064	30	14	25	8	3/24
7	Cr	mg/Kg	9.44	0.048	30	16	25	NA	3/24
7	Cu	mg/Kg	4.57	2.41	30	13	25	11	3/24
7	Hg	µg/Kg	1	0.27	35	4	25	4	2/20
7	Ni	mg/Kg	4.26	0.4	30	4	25	3	3/24
7	Pb	mg/Kg	0.1	0.03	30	15	25	9	3/24
7	Se	mg/Kg	2.2	0.013	35	9	35	3	2/20
7	Zn	mg/Kg	18.9	4.68	30	6	25	22	3/24
9	Ag	mg/Kg	0.0012	0	25	5	30	0	3/24
9	Al	mg/Kg	.	11.6	.	10	.	83	3/24
9	As	mg/Kg	1.6	0.01	25	4	25	4	2/20
9	Cd	mg/Kg	0.00002	0.13	25	6	30	6	3/24
9	Cr	mg/Kg	9.4	0.08	25	20	60	33	3/24
9	Cu	mg/Kg	4.57	1.3	25	7	30	24	3/24
9	Hg	µg/Kg	1	0.14	35	20	25	3	2/20
9	Ni	mg/Kg	4.26	0.04	25	12	30	7	3/24
9	Pb	mg/Kg	0.01	0.05	25	10	30	22	3/24
9	Se	mg/Kg	2.2	0.008	35	3	35	11	2/20
9	Zn	mg/Kg	18.9	23.1	25	5	30	7	3/24

Analysis Type: Tisssue Organics

Cruise #	Parameter	Units	QA batch#	MDL Target	MDL Measured	Precision Target (+/- %)	Precision Measured (rsd)*	Accuracy Target (+/- %)	Accuracy Measured (+/- %)	Blank Frequency[1]
7	PAHs	µg/Kg	M1570	5	2.0-75	±20	7	±20	10	5% min.
7	PCBs	µg/Kg	M1570	1	0.9-4.4	±20	2	±20	2	5% min.
7	Pesticides	µg/Kg	M1570	1	0.7-2.2	±20	2	±20	3	5% min.
9	PAHs	µg/Kg	M1628	5	.9-32.2	±20	6	±20	5	5% min.
9	PAHs	µg/Kg	M1631	5	.9-32.2	±20	NA	±20	1	5% min.
9	PCBs	µg/Kg	M1628	1	.8-2.2	±20	3	±20	9	5% min.
9	PCBs	µg/Kg	M1631	1	.8-2.2	±20	NA	±20	11	5% min.
9	Pesticides	µg/Kg	M1628	1	0.4-1.1	±20	5	±20	22	5% min.
9	Pesticides	µg/Kg	M1631	1	.4-1.1	±20	NA	±20	26	5% min.

* relative standard deviation

[1] Maximum Batch size is 20 samples.

Table 5. Reference toxicant and QA information for the aquatic bioassays.

	Salinity (‰)	EC50*	EC25**	QA Notes:
February				
Mytilus edulis	25–30	**15**	**12**	Controls failed to meet % normal development (%ND) of 70% on two dates:
coefficient of variation:		13.7	13.7	2/8/95 67%ND—no significant effect on interpretation.
				2/15/95 44%ND—test terminated due to uncontrolable conditions.
				(this affects Napa River, Grizzly Bay, Sacramento River, San Joaquin River)
Mysidopsis bahia	25–30	**6**	**5**	No exceptions
coefficient of variation:		12.7	9.4	
August				
Mysidopsis bahia	20–30	**6**	**4**	Growth in control samples were slightly less than the protocol of >= 0.20 mg.
coefficient of variation:		13.1	9.0	Average was 0.18 mg/mysid. However, growth of field samples exceeded protocol.
				Low growth of control thought not to affect interpretation.
				Sacramento River sample had low growth at 50% but not at 100%.
				Since no negative effect found in 100% sample, Sacramento River judged not to be toxic.
Crassostrea gigas	Tests not performed			Oysters were unable to produce viable gametes.

*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	3–8	15–16	n.d.–0.018	0.001–0.008	Amphipod survival in all control samples was 96 +/- 4.2% indicating test organisms were healthy and not affected by test conditions.
Mytilus edulis **embryos**	1.5–5.5	27–31	n.d.–0.095	n.d.–0.011	Mean % normal development of test controls was 95 +/- 2.6% well above protocol minimum of 70%.
August					
Eohaustorius estuarius	3–33	12–17	0.003–0.937	n.d.	Amphipod survival in all control samples was 100 +/- 0% indicating test organisms were healthy and not affected by test conditions.
Mytilus edulis **embryos**	1.5–5.5	27–29	n.d.–132	n.d.	Mean % normal development of test controls was 109 +/- 6% well above protocol miniumum of 70%. (Value exceeds 100 because of variability in estimate of the number of embyos introduced into the test containers.)

[1] Effects concentration of reference toxicant at which 50% of the organisms exhibit effects.

[2] From the overlying water

Table 1. Conventional water quality parameters (at 1 meter depth), 1995.
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 = data not quantifiable, NS = not sampled

Station Code	Station	Date	Cruise	Ammonia	Chlorophyll-a	Conductivity	DO	DOC	Hardness	Nitrate	Nitrite	pH	Phaeophytin	Phosphate	Salinity	Silicates	Temperature	TSS
				µM	mg/m³	mho	mg/L	µM	µM	µM	µM	pH	mg/m³	µM	‰	µM	˚C	mg/L
BA10	Coyote Creek	02/07/95	7	15.2	11.2	14900	8.2	324	.	203.2	5.1	7.6	5.0	12.7	10.9	191.8	14.0	23.9
BA20	South Bay	02/06/95	7	7.9	29.0	19900	8.1	280	.	76.4	2.8	7.7	16.2	8.7	14.8	152.9	13.7	6.0
BA30	Dumbarton Bridge	02/06/95	7	5.4	14.5	20500	9.4	276	.	76.1	2.4	7.7	8.1	7.6	15.8	149.0	14.2	3.2
BA40	Redwood Creek	02/07/95	7	9.4	23.8	21000	8.7	248	.	44.8	1.9	7.7	12.2	4.8	16.2	141.2	13.7	6.9
BB15	San Bruno Shoal	02/06/95	7	8.2	3.2	19500	8.3	227	.	29.0	1.4	7.6	1.7	3.4	15.1	146.1	12.7	3.4
BB30	Oyster Point	02/06/95	7	8.6	9.8	17000	9.3	232	.	36.0	1.4	7.6	4.9	3.5	15.3	171.1	12.2	1.6
BB70	Alameda	02/08/95	7	6.7	29.0	17000	9.0	239	.	31.3	1.1	7.8	16.6	2.6	13.5	220.3	13.0	2.8
BC10	Yerba Buena Island	02/08/95	7	25.5	15.7	16500	9.5	223	.	24.8	1.2	7.8	10.2	2.4	13.2	161.2	12.4	3.3
BC20	Golden Gate	02/09/95	7	2.5	10.7	26500	8.8	149	.	17.5	1.0	7.8	7.0	1.4	23.0	95.6	12.2	2.0
BC30	Richardson Bay	02/09/95	7	6.2	2.1	15900	8.1	240	.	26.9	1.1	7.7	1.2	2.3	11.6	187.0	13.0	3.4
BC41	Point Isabel	02/08/95	7	4.5	24.2	1500	9.1	249	.	23.9	0.9	7.8	16.2	2.1	11.5	189.3	13.5	2.2
BC60	Red Rock	02/08/95	7	4.8	6.5	9300	9.3	256	.	27.3	1.0	7.6	4.3	2.2	7.4	209.8	12.1	24.1
BD15	Petaluma River	02/13/95	7	7.9	45.3	4250	9.9	364	580	50.5	2.0	7.7	30.7	4.7	3.2	405.0	12.0	110.2
BD20	San Pablo Bay	02/13/95	7	4.4	9.7	13700	9.0	205	.	20.6	1.0	7.7	7.1	1.8	11.2	374.0	11.8	15.0
BD30	Pinole Point	02/13/95	7	4.3	17.9	16700	9.1	217	.	23.9	1.0	7.9	11.6	1.8	13.2	381.0	12.2	6.0
BD40	Davis Point	02/13/95	7	4.7	15.1	11800	9.1	226	.	25.4	1.1	7.8	9.2	2.0	9.0	386.6	11.8	63.1
BD50	Napa River	02/14/95	7	5.7	6.5	2320	9.1	238	320	28.8	0.9	7.6	4.8	2.3	ND	166.9	10.8	62.7
BF10	Pacheco Creek	02/14/95	7	4.0	12.6	257	9.7	221	72	29.7	0.7	7.7	8.2	1.7	ND	218.3	11.0	34.8
BF20	Grizzly Bay	02/14/95	7	3.0	7.4	148	9.8	208	60	26.2	0.7	7.7	5.7	1.7	ND	133.1	10.6	44.3
BF40	Honker Bay	02/14/95	7	2.5	7.2	135	9.9	216	64	23.2	0.6	7.7	5.1	1.8	ND	116.7	10.8	39.9
BG20	Sacramento River	02/15/95	7	2.6	15.9	138	9.6	207	68	25.3	0.5	7.7	11.1	1.5	ND	134.6	10.1	45.5
BG30	San Joaquin River	02/15/95	7	5.2	6.1	131	9.6	340	64	40.6	1.0	7.5	3.1	1.9	ND	130.6	11.1	23.0
C-1-3	Sunnyvale	02/07/95	7	130.9	46.8	1620	7.7	578	390	548.8	44.6	7.5	26.4	65.8	ND	343.3	14.7	31.7
C-3-0	San Jose	02/07/95	7	49.1	14.2	7000	6.6	460	680	483.0	11.2	7.6	8.2	39.5	4.7	359.3	15.6	28.4
BA10	Coyote Creek	04/24/95	8	9.6	204.0	14000	8.1	389	.	185.1	8.0	8.0	100.8	14.1	9.3	143.5	17.7	172.7
BA20	South Bay	04/25/95	8	5.6	72.6	18700	8.0	292	.	41.6	3.6	8.0	38.6	6.9	13.6	133.5	16.9	48.4
BA30	Dumbarton Bridge	04/24/95	8	5.7	44.6	18200	8.5	342	.	43.8	3.6	8.0	27.9	7.2	13.3	131.0	16.9	72.3
BA40	Redwood Creek	04/24/95	8	0.6	17.6	20800	8.7	219	.	15.8	1.4	8.0	10.0	0.1	15.8	118.1	15.6	18.3
BB15	San Bruno Shoal	04/25/95	8	2.7	232.0	21500	9.0	245	.	12.3	1.4	8.1	48.8	3.6	16.2	124.2	15.4	6.3
BB30	Oyster Point	04/24/95	8	2.0	14.6	22000	9.4	174	.	7.2	0.7	7.9	7.8	1.8	17.0	132.7	13.4	4.2
BB70	Alameda	04/26/95	8	0.9	175.3	23800	9.0	158	.	15.1	0.6	8.0	96.8	1.7	18.9	112.2	13.6	4.2
BC10	Yerba Buena Island	04/27/95	8	0.3	5.3	22400	9.2	173	.	14.1	0.5	7.9	2.6	1.5	18.1	141.4	13.5	7.3
BC20	Golden Gate	04/26/95	8	0.6	64.1	31200	7.9	124	.	19.2	0.5	7.9	36.9	1.8	27.0	84.9	11.9	1.4
BC30	Richardson Bay	04/26/95	8	0.2	30.8	26500	8.9	168	.	5.5	0.4	8.0	16.1	1.3	21.8	88.5	13.9	4.6
BC41	Point Isabel	04/26/95	8	0.2	36.2	22000	9.8	176	.	12.9	0.5	8.1	21.4	1.6	17.3	155.6	14.6	59.9

Table 1. Conventional water quality parameters (at 1 meter depth), 1995 (continued).
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 = data not quantifiable, NS = not sampled

Station Code	Station	Date	Cruise	Ammonia	Chlorophyll-a	Conductivity	DO	DOC	Hardness	Nitrate	Nitrite	pH	Phaeophytin	Phosphate	Salinity	Silicates	Temperature	TSS
				µM	mg/m³	mho	mg/L	µM	µM	µM	µM	pH	mg/m³	µM	‰	µM	˚C	mg/L
BC60	Red Rock	04/27/95	8	0.9	32.6	25100	8.4	145	.	15.9	0.5	8.0	17.9	1.7	20.9	129.0	13.2	3.6
BD15	Petaluma River	04/19/95	8	14.7	106.3	6000	7.5	517	630	42.8	2.2	7.8	12.9	8.5	4.7	150.6	13.9	414.4
BD20	San Pablo Bay	04/19/95	8	5.3	27.0	8900	9.1	222	.	12.6	0.7	7.8	17.4	2.3	6.6	212.7	12.7	148.4
BD30	Pinole Point	04/20/95	8	4.9	7.5	43500	8.9	220	400	13.9	0.5	7.8	4.3	1.7	2.2	204.2	13.6	73.1
BD40	Davis Point	04/19/95	8	4.3	2.6	5800	8.7	228	630	15.3	0.4	7.7	1.4	2.1	5.8	175.6	13.1	90.1
BD50	Napa River	04/18/95	8	3.6	1.1	355	9.6	233	76	12.3	0.5	7.8	0.6	1.5	ND	245.3	13.9	62.7
BF10	Pacheco Creek	04/20/95	8	2.9	2.5	121	10.2	214	48	11.8	0.4	7.9	1.2	1.6	ND	265.0	13.1	54.9
BF20	Grizzly Bay	04/20/95	8	2.8	1.1	125	10.3	211	60	10.9	0.4	7.9	0.6	1.6	ND	257.4	12.7	141.7
BF40	Honker Bay	04/20/95	8	2.1	ND	130	10.0	199	60	8.5	0.3	7.9	ND	1.4	ND	262.4	12.6	54.5
BG20	Sacramento River	04/18/95	8	2.5	0.1	118	9.9	193	56	8.7	0.3	7.6	ND	1.1	ND	192.8	12.3	39.3
BG30	San Joaquin River	04/18/95	8	3.7	ND	134	9.9	295	68	16.0	0.7	7.7	ND	2.1	ND	190.2	13.7	24.0
C-1-3	Sunnyvale	04/25/95	8	18.8	80.3	5200	6.1	572	620	457.0	21.7	8.1	183.0	36.4	2.6	141.1	18.2	82.4
C-3-0	San Jose	04/25/95	8	23.2	316.5	3200	7.3	462	510	495.3	12.8	7.9	203.0	24.4	2.6	220.9	18.9	181.0
BA10	Coyote Creek	08/14/95	9	8.3	2.6	33700	5.9	279	.	64.7	3.1	7.8	1.7	16.3	21.8	175.0	24.1	19.4
BA20	South Bay	08/15/95	9	10.4	2.8	30900	5.5	304	.	63.8	4.9	7.7	2.0	19.7	19.9	196.0	23.4	21.5
BA30	Dumbarton Bridge	08/15/95	9	8.1	1.9	33300	6.2	250	.	40.5	2.0	7.8	2.9	14.8	22.1	170.0	22.9	55.6
BA40	Redwood Creek	08/15/95	9	9.1	0.8	35300	6.4	171	.	22.8	1.5	7.9	1.3	8.5	23.8	122.0	22.4	20.2
BB15	San Bruno Shoal	08/14/95	9	5.3	0.9	35200	7.0	181	.	19.2	1.3	7.8	0.5	7.8	23.8	93.0	22.6	3.8
BB30	Oyster Point	08/15/95	9	5.7	0.8	37200	6.0	266	.	6.2	0.8	7.9	0.9	3.1	27.2	71.0	19.4	5.0
BB70	Alameda	08/16/95	9	6.6	1.2	37100	5.8	316	.	13.7	1.2	7.8	0.5	4.5	26.0	93.0	20.4	0.3
BC10	Yerba Buena Island	08/16/95	9	7.1	1.2	37100	6.2	123	.	5.1	0.7	7.8	1.0	2.3	27.5	65.0	18.6	2.3
BC20	Golden Gate	08/16/95	9	ND	25.4	38500	9.2	159	.	0.1	0.1	8.2	5.3	0.9	32.5	29.0	13.3	0.5
BC30	Richardson Bay	08/17/95	9	1.6	11.0	36000	8.0	148	.	2.0	0.3	8.0	2.1	2.0	27.8	72.0	17.8	3.4
BC41	Point Isabel	08/17/95	9	2.5	1.0	36100	6.8	116	.	3.8	0.6	7.8	1.5	2.1	27.5	57.0	17.3	0.4
BC60	Red Rock	08/17/95	9	3.2	4.8	34300	7.3	124	.	2.9	0.4	7.9	1.1	2.4	23.0	79.0	18.2	2.7
BD15	Petaluma River	08/21/95	9	ND	16.1	26400	7.3	196	.	ND	0.3	7.8	3.3	3.4	17.5	87.0	21.8	70.6
BD20	San Pablo Bay	08/21/95	9	0.9	13.8	30500	7.9	134	.	3.3	0.4	8.0	3.0	2.1	21.4	59.0	20.3	9.8
BD30	Pinole Point	08/21/95	9	0.9	19.3	29300	7.5	140	.	3.8	0.4	7.9	3.0	2.1	20.4	81.0	19.9	12.3
BD40	Davis Point	08/21/95	9	3.8	6.6	23700	6.9	131	.	8.1	0.3	7.8	1.2	2.5	15.4	110.0	20.0	14.4
BD50	Napa River	08/22/95	9	1.4	4.5	21200	7.1	188	.	3.7	0.4	7.8	1.4	2.3	14.8	114.0	20.3	9.3
BF10	Pacheco Creek	08/22/95	9	4.4	2.2	7900	7.8	159	990	13.6	0.5	7.7	1.3	2.6	5.5	218.0	21.3	16.3
BF20	Grizzly Bay	08/22/95	9	3.2	2.6	8400	8.6	165	990	14.5	0.6	7.7	1.4	2.6	5.2	164.0	21.5	25.6
BF40	Honker Bay	08/22/95	9	1.8	2.2	2200	8.1	162	270	13.9	1.1	7.7	3.3	2.3	1.2	129.0	21.7	59.2
BG20	Sacramento River	08/23/95	9	4.2	1.9	NS	8.0	146	56	11.7	1.1	7.7	1.7	1.8	0.0	271.0	21.5	21.0
BG30	San Joaquin River	08/23/95	9	2.0	3.5	190	8.0	189	76	12.1	0.6	7.7	2.9	2.1	0.0	196.0	23.3	26.5
C-1-3	Sunnyvale	08/14/95	9	31.6	4.5	22200	4.5	581	.	171.9	11.0	7.7	7.5	31.6	13.5	243.0	25.0	192.0
C-3-0	San Jose	08/14/95	9	36.9	3.6	13200	4.1	456	.	474.7	21.1	7.6	5.5	36.8	7.8	229.0	25.3	186.6

Table 2. Dissolved concentrations of trace elements in water (at 1 meter depth), 1995.
. = no data, NA = not analyzed, ND = data not quantifiable, Q = outside the QA limit

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
BA10	Coyote Creek	02/07/95	7	0.0018	2.14	0.06	0.31	3.03	0.0025	4.499	0.1816	0.466	6.161
BA20	South Bay	02/06/95	7	0.0016	1.94	0.07	0.16	2.95	0.0020	3.489	0.0884	0.373	2.640
BA30	Dumbarton Bridge	02/06/95	7	0.0021	1.91	0.07	0.17	2.78	0.0021	3.248	0.0738	0.298	2.076
BA40	Redwood Creek	02/07/95	7	0.0023	1.63	0.05	0.18	2.37	0.0013	2.703	0.0287	0.158	1.266
BB15	San Bruno Shoal	02/06/95	7	0.0030	1.53	0.05	0.16	2.14	0.0013	2.264	0.0131	0.143	0.888
BB30	Oyster Point	02/06/95	7	0.0027	1.51	0.04	0.15	1.92	0.0013	2.209	0.0121	0.122	0.816
BB70	Alameda	02/08/95	7	0.0011	1.43	0.03	0.20	2.02	0.0011	2.192	0.0130	0.079	0.819
BC10	Yerba Buena Island	02/08/95	7	0.0013	1.59	0.03	0.17	1.89	0.0012	2.088	0.0179	0.116	0.896
BC20	Golden Gate	02/09/95	7	0.0016	1.37	0.03	0.15	1.00	0.0006	1.099	0.0051	0.065	0.384
BC30	Richardson Bay	02/09/95	7	0.0011	1.37	0.03	0.18	1.88	0.0012	1.972	0.0156	0.158	0.943
BC41	Point Isabel	02/08/95	7	0.0008	1.20	0.03	0.19	2.01	0.0012	2.164	0.0178	0.145	0.727
BC60	Red Rock	02/08/95	7	0.0013	1.14	0.03	0.47	2.14	0.0018	2.215	0.0553	0.104	0.815
BD15	Petaluma River	02/13/95	7	0.0006	1.91	0.02	0.21	3.41	0.0024	9.451	0.0088	0.172	0.598
BD20	San Pablo Bay	02/13/95	7	0.0009	1.24	0.03	0.29	1.56	0.0009	2.018	0.0219	0.111	0.649
BD30	Pinole Point	02/13/95	7	0.0008	1.33	0.03	0.39	1.66	0.0015	2.111	0.0341	0.164	0.742
BD40	Davis Point	02/13/95	7	0.0007	1.40	0.03	0.43	1.93	0.0021	2.217	0.0187	0.273	0.810
BD50	Napa River	02/14/95	7	0.0004	1.25	0.01	0.37	1.98	0.0011	2.136	0.0318	0.140	0.511
BF10	Pacheco Creek	02/14/95	7	0.0005	1.35	0.01	0.20	1.99	0.0012	1.476	0.0095	0.127	0.227
BF20	Grizzly Bay	02/14/95	7	0.0006	1.45	0.01	0.21	1.83	0.0010	1.498	0.0085	0.101	0.181
BF40	Honker Bay	02/14/95	7	0.0013	1.63	0.01	0.64	1.95	0.0017	1.769	0.0902	0.128	0.701
BG20	Sacramento River	02/15/95	7	0.0013	1.42	0.01	0.61	1.86	0.0013	1.564	0.0753	0.145	0.650
BG30	San Joaquin River	02/15/95	7	0.0005	1.37	0.01	0.18	2.34	0.0015	1.792	0.0109	0.098	0.445
C-1-3	Sunnyvale	02/07/95	7	0.0180	0.74	0.02	0.23	1.76	0.0027	2.860	0.2058	2.080	17.360
C-3-0	San Jose	02/07/95	7	0.0034	1.49	0.05	0.38	3.48	0.0026	7.723	0.4596	1.200	22.408
BA10	Coyote Creek	04/24/95	8	0.0016	2.59	0.07	0.18	4.29	0.0022	4.738	0.6122	0.697	5.497
BA20	South Bay	04/25/95	8	0.0018	3.10	0.06	0.21	2.89	0.0022	3.100	0.0854	0.414	1.040
BA30	Dumbarton Bridge	04/24/95	8	0.0014	2.24	0.06	0.13	2.80	0.0017	2.882	0.0671	0.323	0.973
BA40	Redwood Creek	04/24/95	8	0.0014	1.82	0.03	0.11	1.91	0.0015	2.035	0.0292	0.140	0.570
BB15	San Bruno Shoal	04/25/95	8	0.0007	1.80	0.03	0.12	1.92	0.0007	1.876	0.0306	0.310	0.486
BB30	Oyster Point	04/24/95	8	0.0006	1.50	0.03	0.12	1.16	0.0006	1.307	0.0061	0.194	0.385
BB70	Alameda	04/26/95	8	0.0006	1.37	0.03	0.12	0.99	Q	1.096	0.0059	0.180	0.359
BC10	Yerba Buena Island	04/27/95	8	0.0007	1.31	0.05	0.12	0.96	Q	1.130	0.0054	0.160	0.359
BC20	Golden Gate	04/26/95	8	0.0009	1.61	0.07	0.12	0.47	Q	0.680	0.0067	0.116	0.297
BC30	Richardson Bay	04/26/95	8	0.0009	1.50	0.06	0.11	0.94	Q	1.065	0.0067	0.155	0.705
BC41	Point Isabel	04/26/95	8	0.0009	1.49	0.05	0.12	1.10	Q	1.214	0.0058	0.161	0.381
BC60	Red Rock	04/27/95	8	0.0010	1.55	0.06	0.12	0.80	ND	0.978	0.0038	0.095	0.369

Table 2. Dissolved concentrations of trace elements in water (at 1 meter depth), 1995 (continued).
. = no data, NA = not analyzed, ND = data not quantifiable, Q = outside the QA limit

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
BD15	Petaluma River	04/19/95	8	0.0005	2.47	0.03	0.13	4.77	0.0016	8.073	0.0065	0.269	0.549
BD20	San Pablo Bay	04/19/95	8	0.0008	1.41	0.02	0.14	1.55	Q	1.686	0.0033	0.192	0.347
BD30	Pinole Point	04/20/95	8	0.0006	1.25	0.01	0.13	1.37	ND	1.222	0.0043	0.220	0.266
BD40	Davis Point	04/19/95	8	0.0004	1.50	0.03	0.14	1.41	0.0005	1.748	0.0046	0.066	0.360
BD50	Napa River	04/18/95	8	0.0003	1.23	0.01	0.15	1.43	0.0007	1.231	0.0169	0.235	0.189
BF10	Pacheco Creek	04/20/95	8	0.0015	1.20	0.01	0.37	1.49	0.0010	1.237	0.0779	0.170	0.539
BF20	Grizzly Bay	04/20/95	8	0.0018	1.21	0.01	0.73	1.66	0.0016	1.349	0.1052	0.179	0.639
BF40	Honker Bay	04/20/95	8	0.0020	1.23	0.01	0.89	1.78	0.0018	1.530	0.1175	0.105	0.808
BG20	Sacramento River	04/18/95	8	0.0013	1.02	0.01	0.34	1.52	0.0007	0.990	0.0441	0.101	0.440
BG30	San Joaquin River	04/18/95	8	0.0020	1.29	0.01	0.57	1.62	0.0023	1.334	0.1274	0.301	0.723
C-1-3	Sunnyvale	04/25/95	8	0.0008	3.47	0.06	0.19	4.01	0.0026	3.683	0.2097	1.920	5.179
C-3-0	San Jose	04/25/95	8	0.0009	2.49	0.07	0.20	4.05	0.0018	6.849	0.3371	1.270	14.351
BA10	Coyote Creek	08/14/95	9	0.0104	4.83	0.15	0.13	4.13	0.0019	3.901	0.0632	0.300	1.219
BA20	South Bay	08/15/95	9	0.0096	4.50	0.15	0.15	4.37	0.0021	4.407	0.0691	0.225	1.492
BA30	Dumbarton Bridge	08/15/95	9	0.0123	3.72	0.14	0.18	3.74	0.0018	3.349	0.0463	0.143	0.953
BA40	Redwood Creek	08/15/95	9	0.0089	2.93	0.12	0.17	2.25	0.0011	1.967	0.0221	0.103	0.591
BB15	San Bruno Shoal	08/14/95	9	0.0095	3.46	0.12	0.13	2.16	0.0011	1.987	0.0215	0.090	0.494
BB30	Oyster Point	08/15/95	9	0.0052	1.89	0.10	0.16	1.16	Q	1.091	0.0102	Q	0.504
BB70	Alameda	08/16/95	9	0.0055	2.23	0.13	0.14	1.48	0.0010	1.218	0.0112	ND	0.614
BC10	Yerba Buena Island	08/16/95	9	0.0041	1.89	0.11	0.11	1.09	0.0011	0.987	0.0203	0.076	0.750
BC20	Golden Gate	08/16/95	9	0.0006	1.60	0.05	0.15	0.28	Q	0.472	0.0031	Q	0.094
BC30	Richardson Bay	08/17/95	9	0.0020	1.84	0.09	0.12	1.04	0.0005	1.031	0.0069	Q	0.472
BC41	Point Isabel	08/17/95	9	0.0048	1.67	0.10	0.08	1.08	0.0007	0.973	0.0100	Q	0.480
BC60	Red Rock	08/17/95	9	0.0030	1.80	0.09	0.13	1.24	0.0007	1.205	0.0080	0.094	0.422
BD15	Petaluma River	08/21/95	9	0.0019	3.14	0.12	0.13	2.63	0.0006	2.740	0.0048	0.118	0.488
BD20	San Pablo Bay	08/21/95	9	0.0026	2.03	0.09	0.12	1.61	Q	1.429	0.0079	Q	0.384
BD30	Pinole Point	08/21/95	9	0.0011	2.41	0.07	0.08	1.49	Q	1.382	0.0045	0.072	0.361
BD40	Davis Point	08/21/95	9	0.0011	2.09	0.07	0.10	1.62	Q	1.460	0.0052	0.154	0.471
BD50	Napa River	08/22/95	9	0.0010	2.18	0.07	0.11	1.98	Q	2.100	0.0075	0.142	0.530
BF10	Pacheco Creek	08/22/95	9	0.0005	1.83	0.04	0.10	1.71	Q	1.085	0.0056	0.138	0.410
BF20	Grizzly Bay	08/22/95	9	0.0006	1.74	0.05	0.10	1.76	0.0006	1.118	0.0034	0.126	0.372
BF40	Honker Bay	08/22/95	9	0.0003	1.82	0.02	0.11	1.56	Q	0.866	0.0061	0.120	0.311
BG20	Sacramento River	08/23/95	9	0.0009	1.59	0.01	0.14	1.47	0.0010	0.986	0.0547	0.076	0.512
BG30	San Joaquin River	08/23/95	9	0.0002	1.85	0.01	0.35	1.55	0.0005	0.716	0.0115	0.108	0.249
C-1-3	Sunnyvale	08/14/95	9	0.0024	5.49	0.12	0.15	4.29	0.0019	6.118	0.2271	0.575	3.311
C-3-0	San Jose	08/14/95	9	0.0021	3.91	0.09	0.14	3.87	0.0020	10.936	0.2762	0.666	9.065

Table 3. Total or near total* concentrations of trace elements in water (at 1 meter depth), 1995.
. = no data, NA = not analyzed, ND = data not quantifiable, Q = outside the QA limit

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
BA10	Coyote Creek	02/07/95	7	0.0156	2.18	0.0670	4.78	4.24	0.0208	8.29	1.28	0.61	11.98
BA20	South Bay	02/06/95	7	0.0057	2.02	0.0710	1.49	3.33	0.0078	4.52	0.39	0.42	4.40
BA30	Dumbarton Bridge	02/06/95	7	0.0067	2.10	0.0730	1.48	3.21	0.0078	4.16	0.38	0.35	3.96
BA40	Redwood Creek	02/07/95	7	0.0121	1.93	0.0570	1.53	2.81	0.0051	3.54	0.35	0.18	3.39
BB15	San Bruno Shoal	02/06/95	7	0.0057	1.59	0.0480	1.41	2.61	0.0044	3.22	0.32	0.12	2.71
BB30	Oyster Point	02/06/95	7	0.0048	1.82	0.0460	1.26	2.49	0.0048	3.29	0.23	0.15	2.36
BB70	Alameda	02/08/95	7	0.0060	1.54	0.0380	0.80	2.29	0.0027	2.76	0.15	0.17	1.98
BC10	Yerba Buena Island	02/08/95	7	0.0026	1.55	0.0320	0.85	2.27	0.0025	2.81	0.15	0.07	2.01
BC20	Golden Gate	02/09/95	7	0.0017	1.30	0.0260	0.53	1.32	0.0011	1.60	0.08	0.09	0.98
BC30	Richardson Bay	02/09/95	7	0.0033	1.31	0.0250	0.84	2.27	0.0024	2.77	0.16	0.20	2.00
BC41	Point Isabel	02/08/95	7	0.0020	1.20	0.0250	0.80	2.34	0.0030	2.90	0.17	0.08	2.04
BC60	Red Rock	02/08/95	7	0.0078	1.39	0.0220	3.77	3.55	0.0067	5.04	0.48	0.08	4.14
BD15	Petaluma River	02/13/95	7	0.0303	2.63	0.0490	19.71	8.96	0.0410	21.89	3.04	0.17	17.07
BD20	San Pablo Bay	02/13/95	7	0.0036	1.38	0.0270	2.95	2.86	0.0039	3.96	0.35	0.16	3.32
BD30	Pinole Point	02/13/95	7	0.0029	1.36	0.0280	2.74	2.56	0.0071	3.77	0.33	0.18	3.05
BD40	Davis Point	02/13/95	7	0.0231	2.32	0.0620	14.39	7.55	0.0208	12.34	1.68	0.14	13.75
BD50	Napa River	02/14/95	7	0.0097	1.91	0.0250	9.66	5.74	0.0169	8.85	1.20	0.19	9.57
BF10	Pacheco Creek	02/14/95	7	0.0096	1.57	0.0240	9.05	5.68	0.0116	7.77	1.01	0.12	8.86
BF20	Grizzly Bay	02/14/95	7	0.0075	1.85	0.0210	6.26	4.95	0.0093	6.52	0.75	0.13	7.44
BF40	Honker Bay	02/14/95	7	0.0079	2.50	0.0240	6.53	4.91	0.0084	6.19	0.69	0.16	7.65
BG20	Sacramento River	02/15/95	7	0.0068	1.78	0.0250	6.62	4.68	0.0066	6.35	0.62	0.14	7.46
BG30	San Joaquin River	02/15/95	7	0.0067	1.88	0.0170	3.72	4.16	0.0076	4.75	0.54	0.13	5.04
C-1-3	Sunnyvale	02/07/95	7	0.0821	1.00	0.0240	2.61	3.82	0.0167	6.11	1.38	2.24	22.56
C-3-0	San Jose	02/07/95	7	0.0360	1.69	0.0470	4.93	4.86	0.0222	11.13	1.54	1.21	28.79
BA10	Coyote Creek	04/24/95	8	0.0407	3.17	0.0950	31.45	11.79	0.1050	22.31	7.69	0.66	29.02
BA20	South Bay	04/25/95	8	0.0227	3.30	0.0600	9.31	5.61	0.0291	9.06	2.24	0.40	9.91
BA30	Dumbarton Bridge	04/24/95	8	0.0297	2.69	0.0630	13.48	7.19	0.0682	13.03	3.78	0.38	14.85
BA40	Redwood Creek	04/24/95	8	0.0094	2.03	0.0410	3.12	3.22	0.0096	4.52	1.04	0.25	4.19
BB15	San Bruno Shoal	04/25/95	8	0.0034	1.64	0.0400	1.08	2.58	0.0065	2.91	0.35	0.25	1.93
BB30	Oyster Point	04/24/95	8	0.0030	1.51	0.0400	0.50	1.66	0.0014	1.68	0.13	0.18	0.86
BB70	Alameda	04/26/95	8	0.0043	1.47	0.0740	0.74	1.84	0.0052	2.43	0.32	0.19	1.78
BC10	Yerba Buena Island	04/27/95	8	0.0033	1.63	0.0480	1.64	1.80	0.0034	2.63	0.35	0.18	2.23
BC20	Golden Gate	04/26/95	8	0.0022	1.49	0.0600	0.47	0.69	0.0011	0.84	0.12	0.11	0.74
BC30	Richardson Bay	04/26/95	8	0.0018	1.55	0.0510	0.78	1.57	0.0025	1.96	0.21	0.17	1.63
BC41	Point Isabel	04/26/95	8	0.0142	1.98	0.0480	7.78	4.17	0.0194	7.31	1.85	0.18	9.23
BC60	Red Rock	04/27/95	8	0.0028	1.63	0.0490	1.22	1.34	0.0124	1.91	0.26	0.13	1.49

Table 3. Total or near total* concentrations of trace elements in water (at 1 meter depth), 1995 (continued).
. = no data, NA = not analyzed, ND = data not quantifiable, Q = outside the QA limit

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
BC60	Red Rock	04/27/95	8	0.0028	1.63	0.0490	1.22	1.34	0.0124	1.91	0.26	0.13	1.49
BD15	Petaluma River	04/19/95	8	0.0543	4.42	0.0740	42.98	15.28	0.0793	33.23	7.20	0.35	28.22
BD20	San Pablo Bay	04/19/95	8	0.0175	2.53	0.0540	24.83	10.04	0.0435	18.36	4.41	0.30	19.53
BD30	Pinole Point	04/20/95	8	0.0117	1.94	0.0290	11.65	5.46	0.0138	9.81	1.70	0.17	9.84
BD40	Davis Point	04/19/95	8	0.0309	2.40	0.0710	21.71	10.16	0.0381	15.69	3.71	0.26	17.32
BD50	Napa River	04/18/95	8	0.0122	1.84	0.0300	11.48	6.49	0.0220	7.94	1.94	0.11	10.27
BF10	Pacheco Creek	04/20/95	8	0.0063	1.65	0.0280	7.82	5.10	0.0095	6.21	1.09	0.32	7.01
BF20	Grizzly Bay	04/20/95	8	0.0153	1.83	0.0660	19.82	9.05	0.0299	13.68	2.55	0.17	14.66
BF40	Honker Bay	04/20/95	8	0.0082	1.65	0.0300	8.39	5.39	0.0140	7.02	1.16	0.20	7.61
BG20	Sacramento River	04/18/95	8	0.0075	1.35	0.0250	5.79	4.30	0.0088	4.94	0.80	0.11	5.67
BG30	San Joaquin River	04/18/95	8	0.0067	1.48	0.0170	4.18	3.14	0.0073	3.13	0.67	0.33	3.62
C-1-3	Sunnyvale	04/25/95	8	0.0107	4.04	0.0660	12.90	7.66	0.0566	11.81	3.14	1.51	17.72
C-3-0	San Jose	04/25/95	8	0.0829	3.14	0.0890	29.15	10.68	0.0909	22.67	6.51	1.45	39.64
BA10	Coyote Creek	08/14/95	9	0.0280	5.01	0.1400	6.00	5.13	0.0158	6.45	1.18	0.22	6.59
BA20	South Bay	08/15/95	9	0.0320	5.27	0.1400	8.10	5.47	0.0190	7.55	1.48	0.29	7.56
BA30	Dumbarton Bridge	08/15/95	9	0.0280	4.59	0.1300	9.90	5.20	0.0262	7.96	2.12	0.19	9.31
BA40	Redwood Creek	08/15/95	9	0.0260	3.16	0.1100	3.50	3.17	0.0095	3.88	0.75	0.13	3.77
BB15	San Bruno Shoal	08/14/95	9	0.0120	3.41	0.1100	1.40	2.78	0.0058	3.07	0.35	0.11	2.35
BB30	Oyster Point	08/15/95	9	0.0110	2.02	0.1000	0.90	1.57	0.0026	1.57	0.20	0.08	1.52
BB70	Alameda	08/16/95	9	0.0130	2.34	0.1000	0.40	1.77	0.0021	1.69	0.10	ND	1.08
BC10	Yerba Buena Island	08/16/95	9	0.0100	2.02	0.0900	0.60	1.33	0.0022	1.43	0.18	Q	1.48
BC20	Golden Gate	08/16/95	9	0.0010	1.27	0.1000	ND	0.19	Q	0.35	0.01	Q	0.22
BC30	Richardson Bay	08/17/95	9	0.0050	1.86	0.1000	0.90	1.42	0.0027	1.71	0.21	0.11	1.63
BC41	Point Isabel	08/17/95	9	0.0090	1.99	0.0900	0.70	1.16	0.0026	1.39	0.18	Q	1.27
BC60	Red Rock	08/17/95	9	0.0060	2.16	0.0900	NA	2.00	0.0048	2.56	0.36	Q	2.51
BD15	Petaluma River	08/21/95	9	0.0080	3.99	0.1300	12.90	6.57	0.0263	8.93	2.36	0.11	10.51
BD20	San Pablo Bay	08/21/95	9	0.0100	2.58	0.0800	2.70	2.45	0.0070	3.31	0.60	Q	3.69
BD30	Pinole Point	08/21/95	9	0.0060	2.15	0.0800	2.20	2.03	0.0044	2.73	0.33	0.10	2.56
BD40	Davis Point	08/21/95	9	0.0080	2.30	0.0700	2.70	2.58	0.0067	3.51	0.60	0.14	.
BD50	Napa River	08/22/95	9	0.0070	2.23	0.0800	2.80	3.12	0.0071	4.08	0.55	0.18	3.49
BF10	Pacheco Creek	08/22/95	9	0.0080	2.20	0.0400	3.60	2.90	0.0070	3.03	0.53	0.09	3.83
BF20	Grizzly Bay	08/22/95	9	0.0120	2.29	0.0500	4.70	3.46	0.0103	3.93	0.84	0.07	5.15
BF40	Honker Bay	08/22/95	9	0.0110	2.52	0.0400	7.88	4.58	0.0154	5.75	1.44	0.11	7.77
BG20	Sacramento River	08/23/95	9	0.0070	1.94	0.0200	2.70	2.62	0.0048	2.70	0.50	Q	3.36
BG30	San Joaquin River	08/23/95	9	0.0070	2.32	0.0200	3.80	2.77	0.0063	2.55	0.63	0.06	3.37
C-1-3	Sunnyvale	08/14/95	9	0.0890	6.74	0.1300	39.30	11.13	0.1010	23.47	7.49	0.71	29.99
C-3-0	San Jose	08/14/95	9	0.1370	6.02	0.1300	26.90	10.74	0.1050	23.70	8.08	0.67	31.66

Table 4. Dissolved PAH and Alkanes concentrations in water samples (at 1 meter depth), 1995. ND = not detected, NS = not sampled, Q = outside the QA limit, LPAHs = low molecular weight PAHs, HPAHs = high molecular weight PAHs.

Station Code	Station	Date	Cruise	Sum of Alkanes (SFEI)	Sum of PAHs (SFEI)	Sum of LPAHs (SFEI)	Sum of HPAHs (SFEI)	Anthracene	Phenanthrene	1-Methylphenanthrene	Benz(a)anthracene
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BA10	Coyote Creek	02/07/95	7	13083	4050	420	3630	ND	420	ND	ND
BA30	Dumbarton Bridge	02/06/95	7	74610	5232	1982	3250	62	1500	420	ND
BA40	Redwood Creek	02/07/95	7	26210	1487	250	1237	ND	250	ND	ND
BB70	Alameda	02/08/95	7	33750	2446	630	1816	ND	630	ND	ND
BC10	Yerba Buena Island	02/08/95	7	127770	4900	1330	3570	ND	1200	130	ND
BC20	Golden Gate	02/09/95	7	76020	1661	670	991	ND	670	ND	ND
BC60	Red Rock	02/08/95	7	38360	1270	490	780	ND	490	ND	ND
BD15	Petaluma River	02/13/95	7	61460	1114	270	844	ND	270	ND	ND
BD20	San Pablo Bay	02/13/95	7	49140	1521	810	711	ND	[700]	[110]	ND
BD30	Pinole Point	02/13/95	7	28110	1880	610	1270	ND	610	ND	ND
BD40	Davis Point	02/13/95	7	34780	1760	870	890	ND	870	ND	ND
BD50	Napa River	02/14/95	7	21793	4166	1400	2766	ND	1400	ND	ND
BF20	Grizzly Bay	02/14/95	7	22698	1150	440	710	ND	440	ND	ND
BG20	Sacramento River	02/15/95	7	48200	997	260	737	ND	260	ND	ND
BG30	San Joaquin River	02/15/95	7	27560	612	180	432	ND	180	ND	ND
BA10	Coyote Creek	04/24/95	8	70370	5477	960	4517	ND	960	ND	87
BA30	Dumbarton Bridge	04/24/95	8	27350	2531	1100	1431	ND	1100	ND	Q
BA40	Redwood Creek	04/24/95	8	16070	1539	720	819	Q	720	Q	Q
BB70	Alameda	04/26/95	8	22180	2306	1100	1206	Q	1100	ND	ND
BC10	Yerba Buena Island	04/27/95	8	29120	2535	1400	1135	Q	1400	Q	Q
BC20	Golden Gate	04/26/95	8	43960	1678	1000	678	Q	1000	ND	Q
BC60	Red Rock	04/27/95	8	27200	2040	1100	940	ND	1100	ND	ND
BD15	Petaluma River	04/19/95	8	33930	972	500	472	Q	500	ND	Q
BD20	San Pablo Bay	04/19/95	8	28190	1557	860	697	Q	[860]	ND	ND
BD30	Pinole Point	04/20/95	8	26480	1863.8	1093	770.8	Q	1000	93	9.8
BD40	Davis Point	04/19/95	8	80600	1950	1120	830	Q	1000	120	Q
BD50	Napa River	04/18/95	8	44290	3112	1700	1412	Q	1700	ND	Q
BF20	Grizzly Bay	04/20/95	8	95770	812	490	322	Q	[400]	[90]	Q
BG20	Sacramento River	04/18/95	8	42280	1222	640	582	Q	500	140	Q
BG30	San Joaquin River	04/18/95	8	14880	393	168	225	Q	(140)	28	Q
BA10	Coyote Creek	08/14/95	9	134000	7824	3011	4813	21	2300	690	200
BA30	Dumbarton Bridge	08/15/95	9	65770	6162	2693	3469	23	2500	170	75
BA40	Redwood Creek	08/15/95	9	81600	6448	1908	4540	28	1400	480	150
BB70	Alameda	08/16/95	9	61750	5339	2500	2839	Q	2100	400	150
BC10	Yerba Buena Island	08/16/95	9	68170	8240	2490	5750	Q	1900	590	180
BC20	Golden Gate	08/16/95	9	55690	4610	1150	3460	ND	730	420	160
BC60	Red Rock	08/17/95	9	71300	6410	2720	3690	Q	2200	520	180
BD15	Petaluma River	08/21/95	9	65000	4084	860	3224	ND	510	350	130
BD20	San Pablo Bay	08/21/95	9	83310	4949	1947	3002	37	1400	510	170
BD30	Pinole Point	08/21/95	9	53870	5919	2189	3730	19	1600	570	150
BD40	Davis Point	08/21/95	9	101000	6417	2306	4111	26	1800	480	150
BD50	Napa River	08/22/95	9	62880	4832	1310	3522	ND	880	430	120
BF20	Grizzly Bay	08/22/95	9	67930	4137	1487	2650	17	970	500	130
BG20	Sacramento River	08/23/95	9	87200	5445	1225	4220	45	[620]	[560]	[220]
BG30	San Joaquin River	08/23/95	9	66800	4253	1193	3060	43	670	480	150

[ ] Internal standard recovery < 70% ( ) Internal standard recovery > 120%

Table 4. Dissolved PAH and Alkanes concentrations in water samples (at 1 meter depth), 1995 (continued). ND = not detected, NS = not sampled, Q = outside the QA limit, LPAHs = low molecular weight PAHs, HPAHs = high molecular weight PAHs.

Station Code	Station	Date	Cruise	Chrysene	Fluoranthene	Pyrene	Benzo(a)pyrene	Benzo(e)pyrene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Dibenz(a,h)anthracene	Indeno(1,2,3-cd)pyrene
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BA10	Coyote Creek	02/07/95	7	290	1400	1700	ND	120	120	ND	ND	ND
BA30	Dumbarton Bridge	02/06/95	7	230	1800	870	ND	240	110	ND	ND	ND
BA40	Redwood Creek	02/07/95	7	130	940	89	ND	ND	78	ND	ND	ND
BB70	Alameda	02/08/95	7	86	1200	530	ND	ND	ND	ND	ND	ND
BC10	Yerba Buena Island	02/08/95	7	160	1800	1500	ND	ND	110	ND	ND	ND
BC20	Golden Gate	02/09/95	7	61	790	140	ND	ND	ND	ND	ND	ND
BC60	Red Rock	02/08/95	7	ND	590	90	ND	ND	100	ND	ND	ND
BD15	Petaluma River	02/13/95	7	62	460	230	ND	ND	92	ND	ND	ND
BD20	San Pablo Bay	02/13/95	7	ND	[620]	[91]	ND	ND	ND	ND	ND	ND
BD30	Pinole Point	02/13/95	7	ND	630	640	ND	ND	ND	ND	ND	ND
BD40	Davis Point	02/13/95	7	ND	730	160	ND	ND	ND	ND	ND	ND
BD50	Napa River	02/14/95	7	76	1100	1500	ND	ND	90	ND	ND	ND
BF20	Grizzly Bay	02/14/95	7	ND	330	380	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	02/15/95	7	20	240	280	ND	69	92	36	ND	ND
BG30	San Joaquin River	02/15/95	7	72	140	220	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	04/24/95	8	430	1400	190	ND	370	740	220	130	950
BA30	Dumbarton Bridge	04/24/95	8	62	960	31	ND	130	200	48	ND	ND
BA40	Redwood Creek	04/24/95	8	31	650	ND	ND	ND	110	28	ND	ND
BB70	Alameda	04/26/95	8	ND	980	Q	ND	ND	190	36	ND	ND
BC10	Yerba Buena Island	04/27/95	8	35	1100	ND	ND	ND	ND	ND	ND	ND
BC20	Golden Gate	04/26/95	8	18	660	ND	ND	ND	ND	ND	ND	ND
BC60	Red Rock	04/27/95	8	ND	940	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	04/19/95	8	35	420	17	ND	ND	ND	ND	ND	ND
BD20	San Pablo Bay	04/19/95	8	47	[620]	30	ND	ND	ND	ND	ND	ND
BD30	Pinole Point	04/20/95	8	39	670	52	ND	ND	ND	ND	ND	ND
BD40	Davis Point	04/19/95	8	53	690	87	ND	ND	ND	ND	ND	ND
BD50	Napa River	04/18/95	8	62	1000	350	ND	ND	ND	ND	ND	ND
BF20	Grizzly Bay	04/20/95	8	22	[300]	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	04/18/95	8	32	310	240	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	04/18/95	8	24	(61)	(140)	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	08/14/95	9	540	2200	1300	ND	290	190	93	ND	ND
BA30	Dumbarton Bridge	08/15/95	9	200	1900	540	ND	160	140	74	220	160
BA40	Redwood Creek	08/15/95	9	410	1400	630	190	350	330	220	440	420
BB70	Alameda	08/16/95	9	400	1200	520	75	190	120	84	100	ND
BC10	Yerba Buena Island	08/16/95	9	450	3100	730	220	310	210	210	ND	340
BC20	Golden Gate	08/16/95	9	260	280	150	200	270	270	280	770	820
BC60	Red Rock	08/17/95	9	450	1600	650	ND	210	160	100	140	200
BD15	Petaluma River	08/21/95	9	370	990	1400	ND	130	150	54	ND	ND
BD20	San Pablo Bay	08/21/95	9	430	1100	980	ND	170	98	54	ND	ND
BD30	Pinole Point	08/21/95	9	390	1400	950	ND	170	210	110	160	190
BD40	Davis Point	08/21/95	9	500	1700	1500	ND	130	92	39	ND	ND
BD50	Napa River	08/22/95	9	410	1700	1200	ND	92	ND	ND	Q	Q
BF20	Grizzly Bay	08/22/95	9	360	870	990	ND	130	120	50	ND	ND
BG20	Sacramento River	08/23/95	9	[610]	[460]	[1200]	ND	[260]	[460]	[200]	[390]	[420]
BG30	San Joaquin River	08/23/95	9	500	390	970	ND	180	300	90	200	280

[ ] Internal standard recovery < 70% ( ) Internal standard recovery > 120%

Table 5. Total (particulate plus dissolved) PAH and Alkanes concentrations in water samples, 1995 (at 1 meter depth). ND = not detected, NS = not sampled, Q = outside the QA limit, LPAHs = low molecular weight PAHs, HPAHs = high molecular weight PAHs.

Station Code	Station	Date	Cruise	Sum of Alkanes (SFEI)	Sum of PAHs (SFEI)	Sum of LPAHs (SFEI)	Sum of HPAHs (SFEI)	Anthracene	Phenanthrene	1-Methylphenanthrene	Benz(a)anthracene
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BA10	Coyote Creek	02/07/95	7	247503	70212	2722	67490	92	2320	310	1900
BA30	Dumbarton Bridge	02/06/95	7	159019	39362	3212	36150	62	2600	550	740
BA40	Redwood Creek	02/07/95	7	117190	29248	1131	28117	ND	1050	81	410
BB70	Alameda	02/08/95	7	95220	5946	860	5086	ND	860	ND	ND
BC10	Yerba Buena Island	02/08/95	7	207950	8993	1560	7433	ND	1430	130	63
BC20	Golden Gate	02/09/95	7	131810	3199	850	2349	ND	850	ND	ND
BC60	Red Rock	02/08/95	7	213690	5902	930	4972	ND	930	ND	82
BD15	Petaluma River	02/13/95	7	410517	92684	4080	88604	350	3170	560	3500
BD20	San Pablo Bay	02/13/95	7	161970	6483	1260	5223	ND	1150	110	82
BD30	Pinole Point	02/13/95	7	180590	8206	1146	7060	ND	1070	76	ND
BD40	Davis Point	02/13/95	7	361500	24710	3140	21570	100	2670	370	790
BD50	Napa River	02/14/95	7	377252	32906	4590	28316	120	4000	470	1200
BF20	Grizzly Bay	02/14/95	7	159075	6706	1046	5660	ND	960	86	ND
BG20	Sacramento River	02/15/95	7	304300	4092	484	3348	ND	650	94	ND
BG30	San Joaquin River	02/15/95	7	164680	2822	680	2142	280	400	ND	ND
BA10	Coyote Creek	04/24/95	8	488630	452477	17960	434517	2200	13960	1800	18087
BA30	Dumbarton Bridge	04/24/95	8	380200	401331	18100	383231	2300	14100	1700	17000
BA40	Redwood Creek	04/24/95	8	115700	74449	3230	71219	70	2820	340	2200
BB70	Alameda	04/26/95	8	81500	14097	1725	12372	Q	1670	55	66
BC10	Yerba Buena Island	04/27/95	8	95560	13838	2036	11802	Q	1970	66	57
BC20	Golden Gate	04/26/95	8	83080	4654	1240	3414	Q	1240	ND	16
BC60	Red Rock	04/27/95	8	78620	9157	1604	7553	Q	1560	44	33
BD15	Petaluma River	04/19/95	8	1235330	504872	32200	472672	4100	24500	3600	24000
BD20	San Pablo Bay	04/19/95	8	402820	75357	6660	68697	470	5360	830	3500
BD30	Pinole Point	04/20/95	8	439362	24074.8	3184	20891	31	(2700)	(453)	(510)
BD40	Davis Point	04/19/95	8	513523	60190	6640	53550	(420)	(5300)	(920)	(2200)
BD50	Napa River	04/18/95	8	261144	20229	3497	16732	37	3200	260	760
BF20	Grizzly Bay	04/20/95	8	510110	27878	3346	24532	96	2800	450	1200
BG20	Sacramento River	04/18/95	8	159940	3155	1017	2138	Q	810	207	58
BG30	San Joaquin River	04/18/95	8	14880	8973	168	8805	Q	140	28	[190]
BA10	Coyote Creek	08/14/95	9	283500	60806	5383	55423	73	4200	1110	1300
BA30	Dumbarton Bridge	08/15/95	9	283570	107044	6843	100201	(333)	(5700)	(810)	(3175)
BA40	Redwood Creek	08/15/95	9	279300	42843	3868	38975	28	3000	840	970
BB70	Alameda	08/16/95	9	93240	8119	2880	5239	Q	2420	460	270
BC10	Yerba Buena Island	08/16/95	9	105110	13657	2970	10687	Q	2270	700	390
BC20	Golden Gate	08/16/95	9	93910	6069	1312	4757	ND	850	462	196
BC60	Red Rock	08/17/95	9	158120	13083	3173	9910	Q	2610	563	470
BD15	Petaluma River	08/21/95	9	367900	54894	3060	51834	(200)	(2110)	(750)	(1430)
BD20	San Pablo Bay	08/21/95	9	224510	15599	2627	12972	37	1920	670	420
BD30	Pinole Point	08/21/95	9	158890	13756	2826	10930	46	2060	720	400
BD40	Davis Point	08/21/95	9	241800	17133	3092	14041	42	2380	670	550
BD50	Napa River	08/22/95	9	238270	14812	1990	12822	ND	1390	600	500
BF20	Grizzly Bay	08/22/95	9	325690	.	.	.	NS	NS	NS	NS
BG20	Sacramento River	08/23/95	9	318960	9545	1625	7920	45	890	690	380
BG30	San Joaquin River	08/23/95	9	389070	7279	1553	5726	43	900	610	300

[ ] Internal standard recovery < 70% ( ) Internal standard recovery of particulate > 120%

Table 5. Total (particulate plus dissolved) PAH and Alkanes concentrations in water samples, 1995 (at 1 meter depth; continued). ND = not detected, NS = not sampled, Q = outside the QA limit, LPAHs = low molecular weight PAHs, HPAHs = high molecular weight PAHs.

Station Code	Station	Date	Cruise	Chrysene	Fluoranthene	Pyrene	Benzo(a)pyrene	Benzo(e)pyrene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Dibenz(a,h)anthracene	Indeno(1,2,3-cd)pyrene
				pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L	pg/L
BA10	Coyote Creek	02/07/95	7	3390	8000	11200	3300	8020	12120	4400	1430	13730
BA30	Dumbarton Bridge	02/06/95	7	2830	5900	4470	ND	4840	6910	2500	730	7230
BA40	Redwood Creek	02/07/95	7	2630	4140	3189	ND	3900	5178	2100	440	6130
BB70	Alameda	02/08/95	7	566	1820	760	ND	560	830	390	ND	160
BC10	Yerba Buena Island	02/08/95	7	670	2520	1760	ND	660	970	470	100	220
BC20	Golden Gate	02/09/95	7	261	1160	250	ND	260	330	88	ND	ND
BC60	Red Rock	02/08/95	7	530	1260	560	ND	630	950	340	ND	620
BD15	Petaluma River	02/13/95	7	5262	8960	13230	9600	9400	15092	5000	1830	16730
BD20	San Pablo Bay	02/13/95	7	550	1440	601	ND	640	880	420	ND	610
BD30	Pinole Point	02/13/95	7	750	1570	1460	ND	860	1100	430	60	830
BD40	Davis Point	02/13/95	7	2100	3730	3960	360	2500	3800	1300	300	2730
BD50	Napa River	02/14/95	7	2476	5100	6300	210	2800	4590	1600	510	3530
BF20	Grizzly Bay	02/14/95	7	630	1180	940	ND	760	1000	580	70	500
BG20	Sacramento River	02/15/95	7	460	830	630	71	419	622	176	ND	140
BG30	San Joaquin River	02/15/95	7	312	510	430	ND	270	480	140	ND	ND
BA10	Coyote Creek	04/24/95	8	17430	40400	57190	54000	48370	66740	25220	11130	95950
BA30	Dumbarton Bridge	04/24/95	8	22062	38960	56031	45000	39130	57200	21048	8800	78000
BA40	Redwood Creek	04/24/95	8	4431	7950	10000	Q	9300	14110	4628	1600	17000
BB70	Alameda	04/26/95	8	1100	2780	1300	Q	1700	2190	976	360	1900
BC10	Yerba Buena Island	04/27/95	8	1135	2700	1100	Q	1600	2200	620	390	2000
BC20	Golden Gate	04/26/95	8	328	1350	110	ND	450	790	260	ND	110
BC60	Red Rock	04/27/95	8	740	2240	610	Q	980	1300	590	220	840
BD15	Petaluma River	04/19/95	8	20035	67420	90017	51000	47000	68000	22000	8200	75000
BD20	San Pablo Bay	04/19/95	8	3647	11620	15030	2200	7300	9500	3800	1100	11000
BD30	Pinole Point	04/20/95	8	(1339)	(4370)	(4752)	ND	(2200)	(2500)	(1500)	(420)	(3300)
BD40	Davis Point	04/19/95	8	(2653)	(11690)	(14087)	(2000)	(4800)	(6200)	(2500)	(720)	(6700)
BD50	Napa River	04/18/95	8	1162	4100	3850	Q	1600	2100	900	260	2000
BF20	Grizzly Bay	04/20/95	8	1522	5600	6300	270	2200	2900	1200	340	3000
BG20	Sacramento River	04/18/95	8	212	840	470	ND	160	210	88	33	67
BG30	San Joaquin River	04/18/95	8	[294]	[381]	[750]	[1100]	[550]	[850]	[500]	[490]	[3700]
BA10	Coyote Creek	08/14/95	9	5140	7800	7900	10	7990	10190	3993	1100	10000
BA30	Dumbarton Bridge	08/15/95	9	(8100)	(11300)	(12540)	32	(14160)	(20140)	(8074)	(2520)	(20160)
BA40	Redwood Creek	08/15/95	9	4010	5300	4830	255	5550	6430	3820	1290	6520
BB70	Alameda	08/16/95	9	750	1700	620	75	650	730	344	100	ND
BC10	Yerba Buena Island	08/16/95	9	1070	3930	1030	287	1020	1130	780	400	650
BC20	Golden Gate	08/16/95	9	380	380	173	278	390	390	390	1050	1130
BC60	Red Rock	08/17/95	9	1230	2700	1110	ND	1310	1460	920	340	370
BD15	Petaluma River	08/21/95	9	(4770)	(5890)	(8500)	Q	(7630)	(9550)	(4254)	(810)	(9000)
BD20	San Pablo Bay	08/21/95	9	1530	2300	2380	ND	1870	2398	654	220	1200
BD30	Pinole Point	08/21/95	9	1270	2500	1950	ND	1370	1710	490	420	820
BD40	Davis Point	08/21/95	9	1600	3000	3000	ND	1830	2192	599	270	1000
BD50	Napa River	08/22/95	9	1610	3000	2600	ND	1492	1700	880	150	890
BF20	Grizzly Bay	08/22/95	9	NS	NS	NS	NS	NS	NS	NS	NS	NS
BG20	Sacramento River	08/23/95	9	1060	960	1720	ND	710	1090	420	670	910
BG30	San Joaquin River	08/23/95	9	1020	750	1360	ND	530	750	270	370	376

[ ] Internal standard recovery < 70% ( ) Internal standard recovery of particulate > 120%

Table 6. Dissolved PCB concentrations in water samples, 1995.
. = no data, ND = not detected, M = matrix interference, CE = coelution

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 003/30	PCB 008	PCB 015	PCB 018	PCB 027	PCB 028	PCB 029	PCB 031	PCB 044	PCB 049	PCB 052	PCB 060	PCB 064	PCB 066
				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
BA10	Coyote Creek	02/07/95	7	353	.	8.6	.	17.0	1.4	25.0	ND	22.0	11.0	12.0	36.0	ND	.	8.2
BA30	Dumbarton Bridge	02/06/95	7	1156	.	17.0	.	42.0	8.5	180.0	ND	140.0	30.0	18.0	60.0	ND	.	28.0
BA40	Redwood Creek	02/07/95	7	219	.	4.1	.	7.2	ND	17.6	ND	14.0	10.0	9.3	18.0	ND	.	6.1
BB70	Alameda	02/08/95	7	128	.	2.8	.	4.4	ND	9.9	ND	6.9	4.5	7.2	5.2	ND	.	4.5
BC10	Yerba Buena Island	02/08/95	7	286	.	19.0	.	15.0	ND	29.0	ND	30.0	12.0	22.0	12.9	ND	.	4.3
BC20	Golden Gate	02/09/95	7	191	.	4.0	.	3.1	ND	23.5	ND	16.5	5.4	10.5	ND	ND	.	5.6
BC60	Red Rock	02/08/95	7	112	.	6.3	.	2.3	ND	8.5	ND	7.8	6.0	4.4	9.1	ND	.	4.0
BD15	Petaluma River	02/13/95	7	132	.	2.0	.	2.7	0.9	5.9	ND	4.9	3.7	1.5	4.4	ND	.	4.0
BD20	San Pablo Bay	02/13/95	7	337	.	2.1	.	4.3	3.0	M	ND	M	2.7	7.6	17.0	ND	.	4.6
BD30	Pinole Point	02/13/95	7	81	.	1.5	.	2.7	ND	5.5	ND	4.0	3.8	3.2	3.5	ND	.	2.3
BD40	Davis Point	02/13/95	7	74	.	0.6	.	2.8	ND	3.3	ND	2.7	2.6	1.8	2.0	ND	.	2.3
BD50	Napa River	02/14/95	7	84	.	1.6	.	2.8	ND	4.2	ND	3.7	2.6	1.1	2.2	ND	.	2.0
BF20	Grizzly Bay	02/14/95	7	75	.	3.1	.	2.8	ND	6.2	ND	6.0	2.5	2.6	2.2	ND	.	2.2
BG20	Sacramento River	02/15/95	7	76	.	2.2	.	3.0	ND	7.3	ND	5.8	2.8	4.9	M	ND	.	2.4
BG30	San Joaquin River	02/15/95	7	102	.	1.9	.	2.2	ND	7.5	ND	6.4	3.6	3.0	12.0	ND	.	3.4
BA10	Coyote Creek	04/24/95	8	448	.	8.7	M	29.0	2.2	23.0	1.2	20.0	16.0	5.2	6.2	8.3	.	33.0
BA30	Dumbarton Bridge	04/24/95	8	327	.	9.0	M	12.0	ND	11.0	0.7	11.0	9.8	10.0	9.6	6.4	.	16.0
BA40	Redwood Creek	04/24/95	8	206	.	2.3	M	5.0	ND	13.0	ND	17.0	5.4	5.6	4.1	2.1	.	8.1
BB70	Alameda	04/26/95	8	104	.	1.3	M	2.6	ND	5.2	ND	5.4	2.4	1.2	4.9	1.6	.	3.7
BC10	Yerba Buena Island	04/27/95	8	121	.	4.0	M	7.1	ND	6.4	1.7	6.6	5.1	4.1	4.2	1.6	.	6.9
BC20	Golden Gate	04/26/95	8	107	.	1.1	M	4.4	ND	5.8	ND	7.0	4.4	4.1	12.0	ND	.	4.5
BC60	Red Rock	04/27/95	8	92	.	1.4	M	2.7	ND	3.7	ND	4.7	2.8	3.3	2.9	ND	.	5.5
BD15	Petaluma River	04/19/95	8	139	.	1.5	M	4.1	0.8	4.7	2.0	3.0	4.7	4.0	16.0	1.1	.	5.8
BD20	San Pablo Bay	04/19/95	8	120	.	1.1	M	3.4	0.5	2.8	0.6	2.3	3.2	3.9	2.5	2.1	.	6.2
BD30	Pinole Point	04/20/95	8	124	.	1.2	M	4.7	ND	3.8	0.6	4.8	3.9	3.7	4.4	1.3	.	6.9
BD40	Davis Point	04/19/95	8	128	.	1.1	M	5.2	ND	4.5	ND	4.4	2.5	3.3	2.3	1.4	.	13.0
BD50	Napa River	04/18/95	8	125	.	1.6	M	4.7	1.1	5.6	1.5	3.5	4.6	6.3	2.7	ND	.	7.5
BF20	Grizzly Bay	04/20/95	8	96	.	1.1	M	2.1	ND	5.7	ND	5.9	3.9	6.1	1.5	ND	.	8.4
BG20	Sacramento River	04/18/95	8	562	.	4.4	M	11.0	12.0	45.0	ND	64.0	12.0	9.6	16.0	7.6	.	17.0
BG30	San Joaquin River	04/18/95	8	108	.	0.9	M	4.4	ND	3.1	ND	3.4	3.6	3.7	4.9	ND	.	7.7
BA10	Coyote Creek	08/14/95	9	455	ND	ND	ND	14.0	4.3	23.0	11.0	24.0	9.4	6.1	15.0	2.5	4.3	13.0
BA30	Dumbarton Bridge	08/15/95	9	233	ND	5.8	ND	9.5	ND	10.0	0.8	17.0	7.9	4.6	5.4	3.0	2.5	6.9
BA40	Redwood Creek	08/15/95	9	204	ND	ND	ND	6.4	ND	7.6	0.5	15.0	5.9	2.6	ND	2.8	1.9	22.0
BB70	Alameda	08/16/95	9	137	ND	1.7	ND	4.0	ND	5.7	1.2	8.8	3.2	2.5	5.3	1.9	1.5	5.4
BC10	Yerba Buena Island	08/16/95	9	93	ND	2.4	ND	4.2	ND	6.1	2.7	10.0	3.7	2.2	M	1.5	1.6	3.1
BC20	Golden Gate	08/16/95	9	55	ND	2.4	ND	1.8	ND	3.8	1.6	6.6	1.3	0.9	M	1.4	0.8	2.0
BC60	Red Rock	08/17/95	9	90	ND	ND	ND	4.9	ND	6.4	1.0	10.0	3.4	1.6	3.3	2.3	1.7	1.4
BD15	Petaluma River	08/21/95	9	113	ND	3.2	ND	3.7	ND	6.4	0.7	9.2	3.9	1.3	4.0	1.8	2.2	2.9
BD20	San Pablo Bay	08/21/95	9	86	ND	3.5	ND	4.2	ND	5.0	ND	8.4	3.2	0.9	4.8	1.6	1.7	2.9
BD30	Pinole Point	08/21/95	9	79	ND	2.5	ND	4.1	ND	5.0	2.6	6.6	3.3	1.8	2.1	2.1	1.6	3.6
BD40	Davis Point	08/21/95	9	96	ND	2.4	ND	3.7	ND	5.5	1.0	8.3	3.2	1.4	1.8	2.3	1.5	3.8
BD50	Napa River	08/22/95	9	116	ND	2.2	ND	4.8	ND	6.5	1.7	8.8	4.0	1.1	3.4	2.9	2.0	4.0
BF20	Grizzly Bay	08/22/95	9	163	ND	ND	ND	9.1	ND	10.0	0.9	16.0	6.1	1.8	12.0	3.3	3.5	4.0
BG20	Sacramento River	08/23/95	9	116	ND	2.3	ND	6.0	ND	7.7	ND	12.0	3.3	2.0	5.5	2.2	1.8	4.4
BG30	San Joaquin River	08/23/95	9	116	ND	2.2	ND	5.4	ND	7.9	3.2	11.0	4.7	1.7	4.0	2.5	2.6	3.4

Table 6. Dissolved PCB concentrations in water samples, 1995 (continued).
. = no data, ND = not detected, M = matrix interference, CE = coelution

Station Code	Station	Date	Cruise	PCB 070	PCB 074	PCB 084	PCB 085	PCB 087	PCB 089	PCB 095	PCB 097	PCB 099	PCB 101	PCB 103	PCB 105	PCB 110	PCB 114	PCB 118
				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
BA10	Coyote Creek	02/07/95	7	17.0	5.2	.	6.9	12.0	.	15.0	6.9	8.5	27.0	ND	1.0	11.0	ND	12.0
BA30	Dumbarton Bridge	02/06/95	7	57.0	23.0	.	M	37.0	.	35.0	26.0	27.0	63.0	ND	12.0	M	ND	59.0
BA40	Redwood Creek	02/07/95	7	9.0	3.6	.	2.3	9.6	.	7.6	4.3	6.0	9.8	ND	0.9	6.9	ND	8.6
BB70	Alameda	02/08/95	7	5.2	2.1	.	1.4	4.9	.	5.2	2.4	3.2	8.4	ND	0.9	4.7	ND	4.3
BC10	Yerba Buena Island	02/08/95	7	16.0	6.8	.	4.0	11.0	.	3.5	3.5	4.7	7.8	ND	1.9	12.9	ND	11.0
BC20	Golden Gate	02/09/95	7	6.4	4.8	.	3.0	6.8	.	8.2	3.7	3.7	5.6	ND	ND	11.8	ND	8.6
BC60	Red Rock	02/08/95	7	4.8	2.0	.	M	4.3	.	3.8	1.9	2.1	4.6	ND	0.8	3.0	ND	3.5
BD15	Petaluma River	02/13/95	7	4.5	2.3	.	2.8	6.2	.	4.8	2.2	4.1	9.2	ND	0.5	7.2	ND	6.2
BD20	San Pablo Bay	02/13/95	7	11.0	4.4	.	M	9.9	.	12.0	8.1	4.9	14.0	ND	8.0	M	ND	22.0
BD30	Pinole Point	02/13/95	7	3.3	1.2	.	1.1	M	.	3.1	1.4	2.1	5.0	ND	0.5	4.9	ND	3.5
BD40	Davis Point	02/13/95	7	3.7	1.7	.	M	ND	.	3.6	1.2	3.5	5.5	ND	0.5	2.8	ND	3.3
BD50	Napa River	02/14/95	7	3.5	1.2	.	1.6	4.6	.	3.8	1.3	2.2	5.0	ND	ND	3.2	ND	3.5
BF20	Grizzly Bay	02/14/95	7	3.6	1.4	.	2.9	2.3	.	3.2	1.2	2.1	3.9	ND	ND	2.3	ND	3.0
BG20	Sacramento River	02/15/95	7	3.4	1.3	.	2.9	2.1	.	3.8	0.8	2.9	4.1	ND	ND	4.2	ND	3.3
BG30	San Joaquin River	02/15/95	7	4.4	1.3	.	3.2	2.9	.	3.9	1.3	2.7	5.3	ND	ND	3.9	ND	3.5
BA10	Coyote Creek	04/24/95	8	11.0	4.9	.	M	9.1	.	40.0	7.4	14.0	25.0	ND	ND	18.0	ND	13.0
BA30	Dumbarton Bridge	04/24/95	8	9.9	4.7	.	M	6.4	.	27.0	5.7	12.0	17.0	ND	0.6	20.0	ND	11.0
BA40	Redwood Creek	04/24/95	8	6.1	3.1	.	M	3.9	.	14.0	5.2	4.7	13.0	ND	0.5	13.0	ND	9.4
BB70	Alameda	04/26/95	8	1.5	1.0	.	M	4.9	.	7.3	2.5	2.7	4.9	ND	ND	4.1	ND	4.5
BC10	Yerba Buena Island	04/27/95	8	4.6	2.5	.	M	2.2	.	8.8	1.7	3.0	6.6	ND	ND	7.7	ND	3.5
BC20	Golden Gate	04/26/95	8	3.6	2.0	.	M	2.4	.	7.9	2.2	2.6	4.7	ND	ND	3.2	ND	3.5
BC60	Red Rock	04/27/95	8	3.6	1.4	.	M	1.8	.	7.2	1.0	2.8	3.3	ND	ND	3.1	ND	3.7
BD15	Petaluma River	04/19/95	8	2.2	1.8	.	M	2.2	.	10.0	1.5	4.1	5.6	ND	ND	6.7	ND	4.0
BD20	San Pablo Bay	04/19/95	8	4.0	1.8	.	M	2.3	.	10.0	1.2	4.0	8.4	ND	ND	6.3	ND	3.7
BD30	Pinole Point	04/20/95	8	3.4	2.1	.	M	2.4	.	10.0	1.4	3.9	7.1	ND	ND	5.9	ND	5.9
BD40	Davis Point	04/19/95	8	4.4	2.0	.	M	2.7	.	11.0	1.1	4.3	7.5	ND	ND	1.1	ND	4.2
BD50	Napa River	04/18/95	8	3.8	2.0	.	M	2.2	.	10.0	1.6	4.0	7.6	ND	ND	5.1	ND	4.3
BF20	Grizzly Bay	04/20/95	8	2.8	2.8	.	M	1.0	.	6.8	ND	1.5	4.0	ND	ND	5.4	ND	3.9
BG20	Sacramento River	04/18/95	8	15.0	8.6	.	M	11.0	.	20.0	9.5	7.5	37.0	ND	1.2	46.0	ND	38.0
BG30	San Joaquin River	04/18/95	8	2.4	1.4	.	M	1.6	.	7.0	3.0	2.6	7.3	ND	ND	7.6	ND	3.5
BA10	Coyote Creek	08/14/95	9	17.0	8.6	ND	2.5	5.5	4.0	14.0	7.5	9.7	16.0	ND	4.6	21.0	.	31.0
BA30	Dumbarton Bridge	08/15/95	9	8.5	4.1	ND	1.5	3.0	0.9	16.0	4.4	5.4	12.0	ND	2.0	12.0	.	12.0
BA40	Redwood Creek	08/15/95	9	5.6	3.9	ND	1.1	2.6	1.2	16.0	3.2	4.1	10.0	ND	1.9	9.2	.	11.0
BB70	Alameda	08/16/95	9	3.0	1.8	ND	0.9	1.9	1.0	11.0	1.6	3.6	5.8	ND	1.6	4.6	.	5.1
BC10	Yerba Buena Island	08/16/95	9	2.5	1.7	ND	0.7	1.8	0.9	6.4	1.9	2.7	5.3	ND	0.9	4.5	.	2.9
BC20	Golden Gate	08/16/95	9	3.6	1.3	ND	ND	0.9	0.5	2.6	0.7	1.1	1.9	ND	0.7	1.7	.	3.6
BC60	Red Rock	08/17/95	9	3.1	2.5	ND	0.7	1.7	0.9	1.9	1.4	1.9	4.1	ND	1.2	3.6	.	5.2
BD15	Petaluma River	08/21/95	9	2.6	1.1	ND	0.9	2.0	1.6	5.1	2.3	3.0	4.9	ND	0.5	5.5	.	3.6
BD20	San Pablo Bay	08/21/95	9	2.2	1.6	ND	0.6	1.7	1.4	4.8	1.8	2.0	3.7	ND	ND	4.4	.	3.8
BD30	Pinole Point	08/21/95	9	2.2	1.5	ND	ND	1.4	1.0	7.4	1.4	2.1	3.4	ND	0.6	2.9	.	2.8
BD40	Davis Point	08/21/95	9	2.7	1.1	ND	0.7	1.0	1.2	8.8	1.8	2.5	3.6	ND	1.1	3.8	.	4.7
BD50	Napa River	08/22/95	9	3.2	2.1	ND	0.7	2.0	1.4	11.0	1.9	3.0	4.8	ND	1.2	4.7	.	5.3
BF20	Grizzly Bay	08/22/95	9	5.0	1.7	ND	1.1	3.3	2.0	7.9	2.7	3.2	6.2	ND	1.1	7.6	.	4.8
BG20	Sacramento River	08/23/95	9	3.3	2.1	ND	0.8	2.4	1.2	7.9	1.6	2.0	4.2	ND	1.3	4.3	.	5.4
BG30	San Joaquin River	08/23/95	9	3.1	1.9	ND	0.6	2.2	1.7	11.0	1.7	2.1	4.4	ND	0.7	4.1	.	4.0

Table 6. Dissolved PCB concentrations in water samples, 1995 (continued).
. = no data, ND = not detected, M = matrix interference, CE = coelution

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 119	PCB 128	PCB 132	PCB 137	PCB 138	PCB 141	PCB 146	PCB 149	PCB 151	PCB 153	PCB 156	PCB 157	PCB 158	PCB 167
				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
BA10	Coyote Creek	02/07/95	7	353	CE	2.4	4.5	1.1	16.0	.	.	22.0	.	21.0	0.9	0.5	2.1	.
BA30	Dumbarton Bridge	02/06/95	7	1156	6.0	20.0	24.0	2.5	79.0	.	.	46.0	.	64.0	1.3	0.5	11.0	.
BA40	Redwood Creek	02/07/95	7	219	CE	1.7	3.2	0.6	11.9	.	.	12.0	.	15.0	0.9	0.5	1.6	.
BB70	Alameda	02/08/95	7	128	ND	1.2	2.0	ND	5.9	.	.	7.6	.	6.4	0.8	ND	1.1	.
BC10	Yerba Buena Island	02/08/95	7	286	ND	2.5	2.5	2.0	11.9	.	.	8.9	.	10.0	3.8	1.1	2.2	.
BC20	Golden Gate	02/09/95	7	191	ND	1.9	2.7	1.9	16.4	.	.	8.0	.	12.2	1.3	0.7	1.3	.
BC60	Red Rock	02/08/95	7	112	ND	0.9	1.9	ND	4.4	.	.	4.9	.	5.5	0.7	0.5	0.9	.
BD15	Petaluma River	02/13/95	7	132	CE	1.3	2.3	ND	11.0	.	.	8.0	.	9.8	ND	1.0	1.1	.
BD20	San Pablo Bay	02/13/95	7	337	6.8	13.0	13.0	2.2	49.0	.	.	25.0	.	39.0	5.3	1.7	4.0	.
BD30	Pinole Point	02/13/95	7	81	ND	0.7	1.8	ND	3.2	.	.	6.0	.	3.7	0.6	ND	1.0	.
BD40	Davis Point	02/13/95	7	74	ND	ND	1.8	ND	5.4	.	.	4.8	.	6.1	0.5	ND	ND	.
BD50	Napa River	02/14/95	7	84	ND	0.7	1.9	ND	8.9	.	.	5.7	.	4.1	ND	ND	0.9	.
BF20	Grizzly Bay	02/14/95	7	75	ND	ND	1.4	ND	4.7	.	.	3.7	.	3.1	ND	ND	0.5	.
BG20	Sacramento River	02/15/95	7	76	ND	ND	1.2	ND	3.1	.	.	3.8	.	3.2	ND	ND	ND	.
BG30	San Joaquin River	02/15/95	7	102	ND	0.8	1.9	ND	5.1	.	.	5.3	.	5.4	ND	ND	0.5	.
BA10	Coyote Creek	04/24/95	8	448	ND	2.6	6.0	ND	24.0	.	.	28.0	1.1	31.0	0.6	ND	3.3	.
BA30	Dumbarton Bridge	04/24/95	8	327	ND	1.8	4.7	ND	19.0	.	.	21.0	1.6	25.0	ND	ND	2.4	.
BA40	Redwood Creek	04/24/95	8	206	ND	2.3	3.1	ND	12.0	.	.	12.0	ND	16.0	1.3	ND	1.5	.
BB70	Alameda	04/26/95	8	104	ND	1.1	1.9	ND	8.2	.	.	6.7	ND	8.7	ND	ND	1.0	.
BC10	Yerba Buena Island	04/27/95	8	121	ND	0.6	1.5	ND	5.4	.	.	6.7	ND	7.5	ND	ND	0.7	.
BC20	Golden Gate	04/26/95	8	107	ND	0.6	1.5	ND	4.6	.	.	6.1	ND	6.7	ND	ND	ND	.
BC60	Red Rock	04/27/95	8	92	ND	0.6	1.5	ND	6.0	.	.	5.6	ND	7.2	ND	0.1	0.7	.
BD15	Petaluma River	04/19/95	8	139	ND	0.7	2.1	ND	11.0	.	.	8.4	ND	9.1	ND	ND	3.1	.
BD20	San Pablo Bay	04/19/95	8	120	ND	0.8	1.9	ND	7.7	.	.	8.8	ND	11.0	ND	ND	0.8	.
BD30	Pinole Point	04/20/95	8	124	ND	0.8	2.2	ND	6.6	.	.	8.7	ND	8.8	ND	ND	0.5	.
BD40	Davis Point	04/19/95	8	128	ND	ND	2.2	ND	8.3	.	.	9.3	0.5	10.0	ND	ND	1.0	.
BD50	Napa River	04/18/95	8	125	ND	0.8	1.8	0.7	7.5	.	.	8.2	0.8	8.8	ND	ND	0.8	.
BF20	Grizzly Bay	04/20/95	8	96	ND	0.7	1.6	ND	4.6	.	.	5.3	0.7	6.3	ND	ND	3.0	.
BG20	Sacramento River	04/18/95	8	562	0.9	8.1	7.6	1.3	36.0	.	.	24.0	1.5	34.0	4.3	3.3	5.0	.
BG30	San Joaquin River	04/18/95	8	108	ND	0.8	1.8	0.9	7.6	.	.	7.3	0.6	7.5	0.7	ND	1.7	.
BA10	Coyote Creek	08/14/95	9	455	.	1.9	8.9	ND	29.0	3.6	2.5	33.0	7.4	35.0	2.2	0.5	3.3	0.8
BA30	Dumbarton Bridge	08/15/95	9	233	.	0.9	4.1	ND	16.0	1.0	1.6	14.0	4.4	18.0	0.5	ND	1.7	ND
BA40	Redwood Creek	08/15/95	9	204	.	0.9	3.8	ND	14.0	1.1	1.5	9.9	4.4	16.0	ND	ND	1.4	ND
BB70	Alameda	08/16/95	9	137	.	0.6	2.4	ND	14.0	0.7	0.9	9.5	2.5	12.0	ND	ND	1.1	ND
BC10	Yerba Buena Island	08/16/95	9	93	.	ND	2.1	ND	2.8	0.7	0.7	3.8	1.8	3.8	ND	ND	0.7	ND
BC20	Golden Gate	08/16/95	9	55	.	ND	0.9	ND	1.9	ND	ND	5.2	0.7	1.8	ND	ND	ND	ND
BC60	Red Rock	08/17/95	9	90	.	ND	1.8	ND	3.7	0.8	0.5	6.0	1.4	3.5	ND	ND	0.8	ND
BD15	Petaluma River	08/21/95	9	113	.	0.6	2.8	ND	8.3	0.6	0.8	5.8	2.4	10.0	0.5	ND	0.9	ND
BD20	San Pablo Bay	08/21/95	9	86	.	ND	2.1	ND	2.6	0.6	0.5	4.0	2.0	3.4	ND	ND	ND	ND
BD30	Pinole Point	08/21/95	9	79	.	ND	1.5	ND	3.1	0.6	ND	3.9	1.3	2.7	ND	ND	ND	ND
BD40	Davis Point	08/21/95	9	96	.	ND	1.8	ND	4.3	0.8	0.5	6.5	1.4	4.7	ND	ND	0.8	ND
BD50	Napa River	08/22/95	9	116	.	0.5	2.2	ND	6.9	0.8	0.5	7.9	1.9	5.6	ND	ND	0.9	ND
BF20	Grizzly Bay	08/22/95	9	163	.	0.6	3.6	ND	9.5	1.0	0.7	7.2	3.9	11.0	ND	ND	0.9	ND
BG20	Sacramento River	08/23/95	9	116	.	0.5	2.3	ND	3.6	0.7	0.5	8.6	3.1	4.3	ND	ND	0.9	ND
BG30	San Joaquin River	08/23/95	9	116	.	0.5	2.8	ND	3.6	0.8	0.5	7.5	2.5	3.9	ND	ND	0.7	ND

Table 6. Dissolved PCB concentrations in water samples, 1995 (continued).
. = no data, ND = not detected, M = matrix interference, CE = coelution

Station Code	Station	Date	Cruise	PCB 170	PCB 174	PCB 177	PCB 178	PCB 180	PCB 183	PCB 187	PCB 189	PCB 194	PCB 195	PCB 198	PCB 200	PCB 203	PCB 206	PCB 207
				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
BA10	Coyote Creek	02/07/95	7	1.3	3.7	3.9	.	2.9	1.5	2.6	ND	.	ND	0.8	.	ND	1.9	ND
BA30	Dumbarton Bridge	02/06/95	7	2.8	3.9	4.1	.	16.0	2.3	3.8	ND	.	0.5	1.1	.	2.7	1.8	ND
BA40	Redwood Creek	02/07/95	7	1.3	2.5	3.5	.	2.2	1.4	2.0	ND	.	0.6	0.8	.	1.2	1.6	ND
BB70	Alameda	02/08/95	7	1.2	1.9	2.5	.	2.7	1.1	2.7	ND	.	ND	0.5	.	1.1	1.6	ND
BC10	Yerba Buena Island	02/08/95	7	0.6	1.9	2.1	.	1.6	0.9	2.6	ND	.	ND	0.5	.	1.9	1.7	ND
BC20	Golden Gate	02/09/95	7	0.6	1.9	1.2	.	1.7	1.6	3.1	ND	.	ND	ND	.	1.4	1.1	0.7
BC60	Red Rock	02/08/95	7	0.9	2.2	2.5	.	2.3	0.9	2.1	ND	.	ND	ND	.	1.2	1.4	ND
BD15	Petaluma River	02/13/95	7	1.4	2.3	3.8	.	2.2	2.0	2.5	ND	.	ND	1.0	.	1.1	1.6	ND
BD20	San Pablo Bay	02/13/95	7	2.1	11.0	20.0	.	2.7	1.9	2.5	ND	.	ND	ND	.	ND	1.7	ND
BD30	Pinole Point	02/13/95	7	ND	3.4	2.1	.	2.2	1.0	1.0	ND	.	ND	ND	.	ND	1.3	ND
BD40	Davis Point	02/13/95	7	ND	2.3	2.5	.	1.3	1.3	1.0	ND	.	ND	0.8	.	ND	1.9	ND
BD50	Napa River	02/14/95	7	0.6	1.8	2.3	.	1.4	2.3	0.5	ND	.	ND	0.6	.	0.5	1.3	ND
BF20	Grizzly Bay	02/14/95	7	ND	1.8	1.5	.	1.3	1.2	0.8	ND	.	ND	ND	.	0.7	1.2	ND
BG20	Sacramento River	02/15/95	7	0.7	1.6	1.5	.	1.0	ND	0.7	ND	.	ND	ND	.	0.5	1.2	ND
BG30	San Joaquin River	02/15/95	7	ND	2.2	2.2	.	1.4	1.1	1.2	ND	.	ND	ND	.	ND	1.7	0.9
BA10	Coyote Creek	04/24/95	8	5.0	12.0	9.8	.	9.6	3.9	11.0	ND	.	0.7	ND	.	3.1	1.6	ND
BA30	Dumbarton Bridge	04/24/95	8	3.4	8.4	8.1	.	6.5	3.1	9.2	ND	.	ND	ND	.	1.6	1.6	ND
BA40	Redwood Creek	04/24/95	8	1.8	5.2	3.9	.	3.7	1.5	4.6	ND	.	ND	ND	.	0.8	1.0	ND
BB70	Alameda	04/26/95	8	1.0	4.6	2.1	.	2.5	0.9	1.8	ND	.	ND	ND	.	1.0	1.0	ND
BC10	Yerba Buena Island	04/27/95	8	0.8	2.8	1.6	.	1.4	0.8	1.9	ND	.	ND	ND	.	0.5	1.0	ND
BC20	Golden Gate	04/26/95	8	ND	3.2	2.4	.	1.3	0.8	2.0	ND	.	ND	ND	.	0.8	1.4	ND
BC60	Red Rock	04/27/95	8	1.1	3.8	2.5	.	2.3	0.9	2.8	ND	.	ND	ND	.	0.8	1.0	ND
BD15	Petaluma River	04/19/95	8	1.6	4.7	2.9	.	3.2	1.0	3.1	ND	.	ND	ND	.	0.8	1.2	ND
BD20	San Pablo Bay	04/19/95	8	1.3	4.4	3.2	.	3.5	0.9	3.4	ND	.	ND	ND	.	0.6	0.9	ND
BD30	Pinole Point	04/20/95	8	1.5	4.7	2.8	.	3.4	0.9	3.4	ND	.	ND	ND	.	0.7	1.1	ND
BD40	Davis Point	04/19/95	8	1.2	5.0	2.9	.	4.6	1.1	3.7	ND	.	ND	ND	.	1.2	1.4	ND
BD50	Napa River	04/18/95	8	1.1	4.2	2.4	.	3.2	0.7	2.7	ND	.	ND	ND	.	0.8	1.2	ND
BF20	Grizzly Bay	04/20/95	8	0.8	3.2	1.7	.	1.6	ND	2.6	ND	.	ND	ND	.	0.7	ND	ND
BG20	Sacramento River	04/18/95	8	6.2	9.6	7.7	.	10.0	1.7	5.9	ND	.	ND	ND	.	1.2	1.2	ND
BG30	San Joaquin River	04/18/95	8	ND	3.5	1.7	.	2.3	0.5	1.2	ND	.	ND	0.7	.	0.6	0.6	ND
BA10	Coyote Creek	08/14/95	9	4.7	5.6	4.3	1.1	18.0	5.3	11.0	ND	1.4	0.5	ND	5.3	1.0	0.7	ND
BA30	Dumbarton Bridge	08/15/95	9	1.3	1.8	1.7	0.5	3.1	1.8	4.5	ND	ND	ND	ND	1.3	ND	ND	ND
BA40	Redwood Creek	08/15/95	9	1.2	1.9	1.5	0.6	2.5	2.1	3.4	ND	ND	ND	ND	2.8	ND	ND	ND
BB70	Alameda	08/16/95	9	1.0	0.9	0.9	ND	1.7	0.8	2.2	1.2	ND	ND	ND	0.6	ND	0.7	ND
BC10	Yerba Buena Island	08/16/95	9	0.7	0.8	0.7	ND	1.3	0.7	1.6	ND	ND	ND	ND	0.7	ND	0.7	ND
BC20	Golden Gate	08/16/95	9	ND	0.6	ND	ND	0.9	0.5	0.9	ND	ND	ND	ND	ND	ND	0.6	ND
BC60	Red Rock	08/17/95	9	0.6	0.7	0.7	ND	1.4	0.5	1.6	ND	ND	ND	ND	0.6	0.1	0.6	ND
BD15	Petaluma River	08/21/95	9	0.7	0.8	0.9	ND	1.6	1.1	2.4	ND	ND	ND	ND	ND	ND	ND	ND
BD20	San Pablo Bay	08/21/95	9	0.6	0.7	0.7	ND	1.2	0.9	1.6	ND	ND	ND	ND	0.5	ND	ND	ND
BD30	Pinole Point	08/21/95	9	ND	0.6	0.5	ND	0.9	0.8	1.3	ND	ND	ND	ND	ND	ND	ND	ND
BD40	Davis Point	08/21/95	9	0.7	0.8	0.7	ND	1.4	0.8	1.8	ND	ND	ND	ND	0.6	ND	ND	ND
BD50	Napa River	08/22/95	9	0.6	0.8	0.6	ND	1.5	0.5	1.7	ND	ND	ND	ND	0.8	ND	ND	ND
BF20	Grizzly Bay	08/22/95	9	0.9	1.3	1.1	ND	2.0	1.6	3.0	ND	ND	ND	ND	0.6	ND	0.5	ND
BG20	Sacramento River	08/23/95	9	0.7	0.9	0.7	ND	1.8	0.8	1.9	ND	ND	ND	ND	0.8	ND	0.5	ND
BG30	San Joaquin River	08/23/95	9	0.8	1.0	0.8	ND	1.5	0.7	2.2	ND	ND	ND	ND	ND	ND	0.5	ND

Table 7. Total (particulate plus dissolved) PCB concentrations in water samples, 1995 (at 1 meter depth). . = no data, ND = not detected, M = matrix interference, CE = coelution

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 003/30	PCB 008	PCB 015	PCB 018	PCB 027	PCB 028	PCB 029	PCB 031	PCB 044	PCB 049	PCB 052	PCB 060	PCB 064	PCB 066
				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
BA10	Coyote Creek	02/07/95	7	1595	.	13.2	.	20.6	1.4	46.0	ND	47.0	27.0	31.0	55.0	ND	.	40.2
BA30	Dumbarton Bridge	02/06/95	7	1696	.	17.8	.	46.3	8.5	192	ND	153	34.5	29	78	ND	.	47
BA40	Redwood Creek	02/07/95	7	642	.	6.1	.	8.4	ND	25.4	ND	21.5	12.1	12.1	28.0	ND	.	17.1
BB70	Alameda	02/08/95	7	245	.	2.8	.	6	ND	11.8	ND	9.2	5.7	8.8	8.3	ND	.	6.5
BC10	Yerba Buena Island	02/08/95	7	396	.	19.0	.	15.0	ND	32.6	ND	33.6	13.6	23.9	14.2	ND	.	7.0
BC20	Golden Gate	02/09/95	7	261	.	4	.	3.1	ND	25.8	0.7	18.4	5.4	10.5	1.6	ND	.	8.5
BC60	Red Rock	02/08/95	7	212	.	6.3	.	4.2	ND	11.8	ND	11.5	9.2	6.1	12.4	ND	.	7.3
BD15	Petaluma River	02/13/95	7	771	.	3.3	.	4.5	0.9	16.9	ND	18.9	7.7	5.6	19.4	ND	.	24
BD20	San Pablo Bay	02/13/95	7	416	.	2.1	.	4.3	3.0	1.9	ND	2.2	3.4	9.0	19.9	ND	.	7.2
BD30	Pinole Point	02/13/95	7	185	.	1.5	.	2.7	ND	8.1	ND	6.8	4.9	4.2	7.1	ND	.	4.9
BD40	Davis Point	02/13/95	7	370	.	1.2	.	4.5	0.7	10.3	ND	10.8	6.1	5.4	8.3	ND	.	12.3
BD50	Napa River	02/14/95	7	649	.	2.9	.	5.6	ND	13.7	ND	15.7	6	5.9	16.2	ND	.	20
BF20	Grizzly Bay	02/14/95	7	168	.	3.1	.	2.8	ND	9.7	ND	9.5	4.2	3.9	5.0	ND	.	4.5
BG20	Sacramento River	02/15/95	7	240	.	2.2	.	3	ND	9.9	ND	8.1	4.2	7	M	ND	.	8.6
BG30	San Joaquin River	02/15/95	7	163	.	1.9	.	2.2	ND	9.2	ND	8.2	4.1	3.6	14.4	ND	.	4.5
BA10	Coyote Creek	04/24/95	8	6018	.	32.7	M	59.0	4.5	91.0	3.8	104.0	77.0	77.2	6.2	29.3	.	193.0
BA30	Dumbarton Bridge	04/24/95	8	4081	.	24.0	M	22.0	0.9	46.0	0.7	58.0	41.8	52.0	9.6	20.4	.	115.0
BA40	Redwood Creek	04/24/95	8	982	.	4.7	M	6.6	ND	17.6	ND	23.1	12.1	14.2	11.8	12.1	.	27.1
BB70	Alameda	04/26/95	8	493	.	1.3	M	3.3	ND	8.1	ND	8.5	7.0	5.9	16.9	7.1	.	13.2
BC10	Yerba Buena Island	04/27/95	8	338	.	4.6	M	7.8	ND	9.5	1.7	9.2	7.5	6.8	12.5	4.5	.	12.8
BC20	Golden Gate	04/26/95	8	200	.	1.6	M	4.4	ND	6.8	ND	7.7	4.4	4.1	15.6	ND	.	8.0
BC60	Red Rock	04/27/95	8	257	.	2.6	M	3.3	ND	5.6	ND	6.9	4.2	5.5	2.9	2.5	.	11.2
BD15	Petaluma River	04/19/95	8	6974	.	28.5	M	22.1	3.8	75.7	6.1	96.0	76.7	94.0	146.0	69.1	.	175.8
BD20	San Pablo Bay	04/19/95	8	1361	.	6.5	M	8.4	0.5	16.8	1.3	21.3	17.2	22.9	32.5	15.1	.	39.2
BD30	Pinole Point	04/20/95	8	724	.	2.7	M	7.5	ND	12.3	0.6	14.5	11.7	12.1	56.4	6.6	.	24.9
BD40	Davis Point	04/19/95	8	1174	.	5.1	M	10.0	ND	18.5	0.7	22.4	17.5	21.3	19.3	14.4	.	47.0
BD50	Napa River	04/18/95	8	607	.	3.1	M	8.3	1.1	12.8	2.2	11.5	11.7	13.7	10.2	4.3	.	19.5
BF20	Grizzly Bay	04/20/95	8	562	.	2.4	M	2.1	ND	12.6	ND	12.9	9.9	11.5	8.6	3.3	.	20.4
BG20	Sacramento River	04/18/95	8	658	.	4.4	M	11.0	12.0	47.0	ND	65.4	14.0	10.4	18.0	7.6	.	19.5
BG30	San Joaquin River	04/18/95	8	0	.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	.	NA
BA10	Coyote Creek	08/14/95	9	1239	ND	2.5	5.2	11.8	4.3	38.0	11.6	41.0	17.3	11.9	22.6	9.2	7.4	36.0
BA30	Dumbarton Bridge	08/15/95	9	1395	ND	8.3	5.4	16.2	ND	28.0	1.7	36.0	17.9	12.0	18.4	13.0	6.5	36.9
BA40	Redwood Creek	08/15/95	9	663	ND	3.3	ND	7.5	ND	13.8	0.5	23.5	9.4	5.3	M	7.4	3.2	37.0
BB70	Alameda	08/16/95	9	227	ND	2.2	ND	4.0	ND	7.1	1.2	12.4	4.7	3.1	5.3	2.5	1.5	7.3
BC10	Yerba Buena Island	08/16/95	9	231	ND	2.4	ND	4.9	ND	8.3	2.7	12.8	5.1	3.5	1.5	3.3	2.3	5.4
BC20	Golden Gate	08/16/95	9	83	ND	2.4	ND	1.8	ND	5.1	1.6	8.6	1.8	1.5	5.0	1.4	0.8	2.0
BC60	Red Rock	08/17/95	9	226	ND	ND	ND	5.9	ND	9.6	1.0	13.9	5.0	3.0	3.3	4.3	2.8	4.3
BD15	Petaluma River	08/21/95	9	798	ND	3.2	ND	6.8	ND	18.4	0.7	22.2	10.1	5.9	9.7	8.1	5.1	20.9
BD20	San Pablo Bay	08/21/95	9	278	ND	3.5	ND	5.5	ND	9.1	0.6	14.0	5.8	2.3	6.6	3.5	2.6	6.9
BD30	Pinole Point	08/21/95	9	268	ND	2.5	ND	5.1	ND	8.1	3.2	11.3	5.5	3.2	5.0	3.8	2.7	7.0
BD40	Davis Point	08/21/95	9	295	ND	2.4	ND	5.1	ND	10.2	1.0	14.2	5.4	2.3	4.2	5.2	2.6	8.4
BD50	Napa River	08/22/95	9	295	ND	2.2	ND	5.7	ND	10.2	2.2	13.3	6.2	2.7	5.7	5.3	3.2	7.2
BF20	Grizzly Bay	08/22/95	9	342	ND	ND	ND	10.2	ND	14.7	0.9	21.3	8.1	3.5	12.0	5.3	4.4	8.1
BG20	Sacramento River	08/23/95	9	160	ND	2.3	ND	7.1	ND	9.4	ND	14.0	4.0	2.0	6.3	2.2	1.8	5.2
BG30	San Joaquin River	08/23/95	9	182	ND	2.2	ND	5.4	ND	9.8	3.2	13.9	5.5	2.6	5.1	2.5	2.6	4.8

Table 7. Total (particulate plus dissolved) PCB concentrations in water samples, 1995 (at 1 meter depth; continued). . = no data, ND = not detected, M = matrix interference, CE = coelution

Station Code	Station	Date	Cruise	PCB 070	PCB 074	PCB 084	PCB 085	PCB 087	PCB 089	PCB 095	PCB 097	PCB 099	PCB 101	PCB 103	PCB 105	PCB 110	PCB 114	PCB 118
				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
BA10	Coyote Creek	02/07/95	7	45.0	17.2	.	17.9	32.0	.	60.0	21.9	35.5	82.0	ND	17.0	75.0	ND	70.0
BA30	Dumbarton Bridge	02/06/95	7	71	28.6	.	5.6	47	.	46	30.4	46	100	ND	15.7	31	ND	91
BA40	Redwood Creek	02/07/95	7	19.0	8.3	.	7.3	18.5	.	16.9	9.5	14.4	33.8	ND	4.2	29.9	ND	33.6
BB70	Alameda	02/08/95	7	8.5	3.5	.	2.4	7.6	.	8.2	3.7	6	14.4	ND	1.6	9.2	ND	10.7
BC10	Yerba Buena Island	02/08/95	7	18.6	8.1	.	5.1	16.5	.	8.6	4.8	7.2	13.4	ND	3.7	17.0	ND	16.2
BC20	Golden Gate	02/09/95	7	8.3	5.61	.	3	10.2	.	11.5	5.3	5.8	9.6	ND	1	15.3	ND	11.5
BC60	Red Rock	02/08/95	7	8.2	3.6	.	1.5	8.5	.	9.1	3.1	4.3	9.8	ND	1.5	7.3	ND	9.5
BD15	Petaluma River	02/13/95	7	23.5	9.4	.	20.8	16.2	.	31.8	10.4	23.1	42.2	ND	2.9	46.2	ND	46.2
BD20	San Pablo Bay	02/13/95	7	14.0	5.9	.	M	13.2	.	16.7	9.2	7.1	18.2	ND	8.5	3.9	ND	26.6
BD30	Pinole Point	02/13/95	7	7.3	3.4	.	2.2	3.5	.	6.4	2.8	5	10.7	ND	1	8.1	ND	9.7
BD40	Davis Point	02/13/95	7	11.1	7.9	.	3.1	6.2	.	16.2	5.5	11.5	21.5	ND	1.4	21.8	ND	21.3
BD50	Napa River	02/14/95	7	19.5	8	.	19.6	15.6	.	25.8	5.6	18.2	34	ND	2.1	28.2	ND	37.5
BF20	Grizzly Bay	02/14/95	7	7.2	2.7	.	6.0	4.7	.	6.3	2.3	4.4	8.9	ND	ND	7.3	ND	7.8
BG20	Sacramento River	02/15/95	7	8.8	2.6	.	7	5.2	.	13.8	4.41	7.1	17.1	ND	0.8	18.2	ND	17.3
BG30	San Joaquin River	02/15/95	7	6.6	2.4	.	4.6	3.8	.	6.2	2.1	4.1	8.9	ND	ND	6.9	ND	6.9
BA10	Coyote Creek	04/24/95	8	141.0	55.9	.	M	91.1	.	230.0	79.4	164.0	325.0	ND	3.9	328.0	ND	293.0
BA30	Dumbarton Bridge	04/24/95	8	87.9	40.7	.	M	58.4	.	147.0	53.7	109.0	227.0	ND	3.4	230.0	ND	221.0
BA40	Redwood Creek	04/24/95	8	19.1	9.8	.	M	14.9	.	41.0	15.2	24.7	54.0	ND	1.3	55.0	ND	45.4
BB70	Alameda	04/26/95	8	8.2	4.2	.	M	10.8	.	23.3	9.0	12.0	26.9	ND	ND	25.1	ND	18.5
BC10	Yerba Buena Island	04/27/95	8	8.0	4.8	.	M	5.3	.	17.1	5.2	8.0	16.6	ND	ND	18.7	ND	12.1
BC20	Golden Gate	04/26/95	8	5.8	3.2	.	M	3.9	.	12.0	3.4	4.8	10.2	ND	0.6	10.3	ND	8.0
BC60	Red Rock	04/27/95	8	7.3	3.2	.	M	4.5	.	14.5	3.3	6.9	12.2	ND	ND	10.2	ND	10.7
BD15	Petaluma River	04/19/95	8	122.2	64.8	.	M	93.2	.	260.0	90.5	184.1	385.6	2.9	3.4	426.7	ND	334.0
BD20	San Pablo Bay	04/19/95	8	29.0	11.8	.	M	21.3	.	55.0	19.2	31.0	62.4	ND	0.6	78.3	ND	64.7
BD30	Pinole Point	04/20/95	8	16.4	8.7	.	M	11.2	.	33.0	9.2	18.9	37.1	ND	ND	38.9	ND	33.9
BD40	Davis Point	04/19/95	8	22.4	11.5	.	M	20.7	.	53.0	16.1	33.3	53.5	ND	0.7	63.1	ND	56.2
BD50	Napa River	04/18/95	8	12.8	6.9	.	M	9.5	.	30.0	8.1	15.0	26.6	ND	ND	34.1	ND	24.3
BF20	Grizzly Bay	04/20/95	8	12.4	8.3	.	M	7.9	.	23.8	3.7	9.2	25.0	ND	0.5	34.4	ND	26.9
BG20	Sacramento River	04/18/95	8	17.4	9.7	.	M	12.6	.	23.5	10.4	9.4	41.8	ND	2.2	52.0	ND	41.3
BG30	San Joaquin River	04/18/95	8	NA	NA	.	NA	NA	.	NA	NA	NA	NA	NA	NA	NA	NA	NA
BA10	Coyote Creek	08/14/95	9	35.0	18.6	ND	6.2	12.9	5.1	39.0	17.4	27.7	44.0	ND	17.6	53.0	.	88.0
BA30	Dumbarton Bridge	08/15/95	9	33.5	16.1	ND	7.8	12.1	3.1	53.0	19.4	32.4	51.0	ND	20.0	58.0	.	96.0
BA40	Redwood Creek	08/15/95	9	14.4	7.9	ND	3.4	6.3	2.1	31.0	8.4	14.1	26.0	ND	9.9	28.2	.	50.0
BB70	Alameda	08/16/95	9	4.7	3.0	ND	0.9	2.9	1.0	16.2	2.8	5.0	9.3	ND	3.1	7.7	.	12.0
BC10	Yerba Buena Island	08/16/95	9	4.1	3.1	ND	1.5	3.2	1.3	9.5	3.5	5.8	10.5	ND	2.9	9.9	.	13.9
BC20	Golden Gate	08/16/95	9	4.2	1.3	ND	ND	1.5	0.5	4.7	1.2	1.6	3.7	ND	0.7	2.6	.	5.0
BC60	Red Rock	08/17/95	9	5.4	3.8	ND	1.4	3.2	1.7	5.9	3.2	5.4	12.0	ND	3.1	10.0	.	16.2
BD15	Petaluma River	08/21/95	9	11.3	5.2	ND	3.7	7.6	4.3	28.1	13.3	20.0	34.9	ND	11.5	36.5	.	45.6
BD20	San Pablo Bay	08/21/95	9	4.9	3.2	ND	1.5	3.6	2.0	10.2	4.5	6.3	10.4	ND	3.3	13.6	.	16.8
BD30	Pinole Point	08/21/95	9	4.8	2.8	ND	0.9	3.6	1.9	13.0	4.2	6.8	13.4	ND	2.9	12.1	.	13.8
BD40	Davis Point	08/21/95	9	6.0	2.7	ND	1.6	3.0	2.1	18.8	4.2	7.1	13.6	ND	4.1	13.6	.	17.7
BD50	Napa River	08/22/95	9	5.6	3.4	ND	1.4	3.6	2.3	15.3	4.7	7.6	14.8	ND	3.8	13.8	.	16.3
BF20	Grizzly Bay	08/22/95	9	8.2	3.0	0.8	1.9	4.9	2.7	15.6	5.1	6.4	16.2	ND	3.6	15.9	.	16.8
BG20	Sacramento River	08/23/95	9	4.1	2.1	ND	0.8	3.1	1.2	9.4	2.2	2.7	6.8	ND	1.3	7.1	.	8.1
BG30	San Joaquin River	08/23/95	9	4.6	2.5	ND	0.6	2.9	1.7	13.3	3.0	3.6	8.4	ND	1.5	7.9	.	8.5

Table 7. Total (particulate plus dissolved) PCB concentrations in water samples, 1995 (continued).
. = no data, ND = not detected, M = matrix interference, CE = coelution

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 119	PCB 128	PCB 132	PCB 137	PCB 138	PCB 141	PCB 146	PCB 149	PCB 151	PCB 153	PCB 156	PCB 157	PCB 158	PCB 167
				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
BA10	Coyote Creek	02/07/95	7	1595	CE	18.4	29.5	3.5	116.0	.	.	103.0	.	135.0	17.9	8.3	8.9	.
BA30	Dumbarton Bridge	02/06/95	7	1696	6	28.6	35	5	136	.	.	86	.	120	4.3	2.1	17.1	.
BA40	Redwood Creek	02/07/95	7	642	CE	8.1	12.0	2.7	56.9	.	.	46.0	.	60.0	7.2	2.6	6.1	.
BB70	Alameda	02/08/95	7	245	CE	3.3	4.3	2	18.9	.	.	16.3	.	17.8	2.2	0.77	2.8	.
BC10	Yerba Buena Island	02/08/95	7	396	ND	4.2	4.5	2.0	20.2	.	.	16.0	.	18.3	5.0	2.0	3.6	.
BC20	Golden Gate	02/09/95	7	261	ND	2.86	3.9	3.5	21.2	.	.	12.2	.	17.3	2.2	0.7	2.01	.
BC60	Red Rock	02/08/95	7	212	0.5	2.6	3.6	0.5	12.2	.	.	11.8	.	10.6	1.2	0.5	2.3	.
BD15	Petaluma River	02/13/95	7	771	CE	9.5	15.3	1.8	60	.	.	51	.	74.8	4	4.69	4.1	.
BD20	San Pablo Bay	02/13/95	7	416	6.8	13.9	14.7	2.7	53.3	.	.	30.7	.	43.6	6.2	1.7	4.9	.
BD30	Pinole Point	02/13/95	7	185	ND	2.39	4.1	0.6	13.4	.	.	13.6	.	13.7	1.5	0.5	2.05	.
BD40	Davis Point	02/13/95	7	370	ND	3.6	6.0	1.7	30.4	.	.	25.8	.	32.1	2.9	1.8	1.9	.
BD50	Napa River	02/14/95	7	649	ND	7.61	12.9	1.7	67.9	.	.	42.7	.	60.1	9	3.3	3.6	.
BF20	Grizzly Bay	02/14/95	7	168	0.7	ND	3.5	ND	12.3	.	.	9.9	.	8.3	ND	ND	1.1	.
BG20	Sacramento River	02/15/95	7	240	1.1	1.1	4.7	0.8	20.1	.	.	14.8	.	17.2	1	ND	1.4	.
BG30	San Joaquin River	02/15/95	7	163	ND	0.8	3.4	ND	10.6	.	.	9.5	.	10.9	ND	ND	0.5	.
BA10	Coyote Creek	04/24/95	8	6018	17.0	58.6	95.0	8.3	484.0	.	.	378.0	121.1	541.0	45.6	10.0	54.3	.
BA30	Dumbarton Bridge	04/24/95	8	4081	7.1	45.8	63.7	6.4	349.0	.	.	251.0	77.6	415.0	33.0	6.4	33.4	.
BA40	Redwood Creek	04/24/95	8	982	ND	10.7	15.1	1.5	79.0	.	.	64.0	15.0	107.0	6.0	1.2	7.6	.
BB70	Alameda	04/26/95	8	493	ND	5.8	8.1	0.9	39.2	.	.	34.7	8.4	53.7	1.5	0.6	4.0	.
BC10	Yerba Buena Island	04/27/95	8	338	ND	2.7	5.4	ND	23.4	.	.	21.7	0.9	30.5	1.0	ND	2.9	.
BC20	Golden Gate	04/26/95	8	200	ND	1.3	3.6	ND	12.0	.	.	12.4	ND	15.7	ND	ND	1.1	.
BC60	Red Rock	04/27/95	8	257	ND	2.5	4.6	ND	21.0	.	.	17.6	0.6	26.2	0.6	0.1	2.4	.
BD15	Petaluma River	04/19/95	8	6974	13.0	80.7	102.1	11.0	571.0	.	.	398.4	140.0	679.1	64.0	24.0	45.1	.
BD20	San Pablo Bay	04/19/95	8	1361	2.3	12.8	20.9	1.9	101.7	.	.	83.8	24.0	131.0	12.0	2.9	10.2	.
BD30	Pinole Point	04/20/95	8	724	1.3	5.8	10.7	0.8	45.6	.	.	43.7	9.8	60.8	3.1	1.8	6.1	.
BD40	Davis Point	04/19/95	8	1174	2.3	11.0	19.2	1.5	91.3	.	.	74.3	21.5	109.0	6.2	1.3	8.3	.
BD50	Napa River	04/18/95	8	607	ND	6.3	9.6	0.7	41.5	.	.	39.2	10.8	53.8	2.1	0.6	4.8	.
BF20	Grizzly Bay	04/20/95	8	562	ND	6.3	11.6	ND	43.6	.	.	33.3	10.7	53.3	3.0	0.8	7.7	.
BG20	Sacramento River	04/18/95	8	658	0.9	9.1	9.3	1.3	45.7	.	.	29.3	2.1	42.5	4.9	3.3	6.4	.
BG30	San Joaquin River	04/18/95	8	0	NA	NA	NA	NA	NA	.	.	NA	NA	NA	NA	NA	NA	.
BA10	Coyote Creek	08/14/95	9	1239	.	9.9	28.9	ND	110.0	9.0	12.5	86.0	20.4	106.0	7.2	1.8	8.9	4.4
BA30	Dumbarton Bridge	08/15/95	9	1395	.	14.9	34.1	ND	136.0	8.8	17.6	88.0	24.4	128.0	9.1	3.2	15.7	4.4
BA40	Redwood Creek	08/15/95	9	663	.	4.8	14.8	ND	66.0	3.7	7.0	40.9	12.0	62.0	2.3	1.1	4.4	2.0
BB70	Alameda	08/16/95	9	227	.	1.3	5.0	ND	25.0	1.5	1.7	15.9	4.1	22.0	ND	ND	2.1	ND
BC10	Yerba Buena Island	08/16/95	9	231	.	0.8	5.8	ND	18.8	1.9	1.9	14.8	5.0	17.8	0.9	ND	2.1	ND
BC20	Golden Gate	08/16/95	9	83	.	ND	1.5	ND	3.5	ND	ND	8.0	1.5	3.3	ND	ND	ND	ND
BC60	Red Rock	08/17/95	9	226	.	1.1	5.6	ND	17.7	1.9	1.8	16.0	4.4	18.5	ND	ND	2.1	ND
BD15	Petaluma River	08/21/95	9	798	.	7.8	21.8	ND	78.3	4.5	9.6	53.8	15.4	79.0	4.4	0.9	6.8	2.5
BD20	San Pablo Bay	08/21/95	9	278	.	1.6	7.5	ND	23.6	1.8	2.2	19.0	6.4	23.4	0.5	ND	4.2	0.7
BD30	Pinole Point	08/21/95	9	268	.	1.4	6.6	ND	22.1	1.9	1.8	18.9	5.7	24.7	0.6	ND	1.9	0.6
BD40	Davis Point	08/21/95	9	295	.	1.7	7.1	ND	24.3	2.2	2.3	20.5	5.0	24.7	ND	ND	2.6	0.6
BD50	Napa River	08/22/95	9	295	.	1.8	7.2	ND	25.9	2.1	2.2	20.9	5.2	24.6	ND	ND	3.1	ND
BF20	Grizzly Bay	08/22/95	9	342	.	2.1	8.5	ND	29.5	2.1	2.2	19.2	7.4	29.0	ND	ND	2.6	ND
BG20	Sacramento River	08/23/95	9	160	.	1.0	4.0	ND	6.3	0.7	1.0	12.6	4.6	6.8	ND	ND	1.9	ND
BG30	San Joaquin River	08/23/95	9	182	.	1.1	5.1	ND	7.3	1.3	1.1	14.2	4.6	7.7	ND	ND	1.6	ND

Table 7. Total (particulate plus dissolved) PCB concentrations in water samples, 1995 (continued).
. = no data, ND = not detected, M = matrix interference, CE = coelution

Station Code	Station	Date	Cruise	PCB 170	PCB 174	PCB 177	PCB 178	PCB 180	PCB 183	PCB 187	PCB 189	PCB 194	PCB 195	PCB 198	PCB 200	PCB 203	PCB 206	PCB 207
				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
BA10	Coyote Creek	02/07/95	7	30.3	99.7	75.9	.	68.9	20.5	59.6	1.9	.	3.3	1.9	.	25.0	11.2	1.4
BA30	Dumbarton Bridge	02/06/95	7	6.2	24.9	24.1	.	28	6.3	25.8	ND	.	2.3	4.7	.	8.5	5.6	1.5
BA40	Redwood Creek	02/07/95	7	7.8	23.5	20.5	.	19.2	5.0	21.0	ND	.	3.5	1.7	.	6.4	4.5	1.0
BB70	Alameda	02/08/95	7	3.8	5.2	8	.	5.7	2.5	5.7	ND	.	0.69	1.9	.	3.5	4.4	ND
BC10	Yerba Buena Island	02/08/95	7	2.3	4.8	6.5	.	9.1	2.2	5.1	ND	.	0.7	1.7	.	4.4	4.9	0.6
BC20	Golden Gate	02/09/95	7	1.43	3.9	4	.	5	2.33	5.5	ND	.	ND	0.71	.	2.4	3.4	1.3
BC60	Red Rock	02/08/95	7	2.6	4.6	5.2	.	4.3	2.1	4.3	ND	.	0.8	1.1	.	3.3	3.0	ND
BD15	Petaluma River	02/13/95	7	11.4	33.3	36.8	.	30.2	6.2	27.5	1.1	.	1.9	5.05	.	8.1	8.8	1.6
BD20	San Pablo Bay	02/13/95	7	3.6	13.6	24.3	.	4.8	3.1	4.8	ND	.	0.5	1.1	.	1.9	3.2	ND
BD30	Pinole Point	02/13/95	7	1.1	6.6	7.6	.	4.8	2.4	3.6	ND	.	0.7	1.3	.	2.3	2.9	ND
BD40	Davis Point	02/13/95	7	4.2	14.3	12.5	.	15.3	4.4	10.5	0.7	.	1.4	3.2	.	4.3	4.6	1.1
BD50	Napa River	02/14/95	7	9.46	27.8	29.3	.	24.4	6.1	22.5	1.2	.	1.9	4.31	.	6.8	5.5	1
BF20	Grizzly Bay	02/14/95	7	1.5	5.2	7.5	.	3.7	2.8	3.0	ND	.	0.9	1.3	.	3.2	3.1	ND
BG20	Sacramento River	02/15/95	7	2.4	5.2	7.3	.	3.6	4.4	3.1	ND	.	ND	1.2	.	2.7	2.8	ND
BG30	San Joaquin River	02/15/95	7	1.1	4.5	5.7	.	3.0	2.2	2.6	ND	.	1.0	0.9	.	1.7	3.1	0.9
BA10	Coyote Creek	04/24/95	8	165.0	362.0	319.8	.	369.6	77.9	261.0	5.5	.	29.7	6.3	.	143.1	67.6	8.3
BA30	Dumbarton Bridge	04/24/95	8	113.4	218.4	228.1	.	246.5	55.1	199.2	3.8	.	19.0	3.7	.	88.6	41.6	6.7
BA40	Redwood Creek	04/24/95	8	20.8	51.2	50.9	.	50.7	12.5	43.6	ND	.	2.6	0.5	.	20.8	9.8	1.4
BB70	Alameda	04/26/95	8	12.0	27.6	23.1	.	21.5	7.2	19.8	ND	.	1.1	0.5	.	7.8	4.8	1.0
BC10	Yerba Buena Island	04/27/95	8	9.3	16.8	13.6	.	13.4	4.1	11.9	ND	.	0.7	ND	.	2.6	4.4	ND
BC20	Golden Gate	04/26/95	8	3.1	9.3	6.9	.	6.4	2.0	6.1	ND	.	0.1	0.2	.	2.0	3.4	ND
BC60	Red Rock	04/27/95	8	4.2	14.8	11.3	.	11.9	3.6	11.0	ND	.	0.6	ND	.	2.6	3.8	ND
BD15	Petaluma River	04/19/95	8	181.6	354.7	372.9	.	413.2	99.0	313.1	7.9	.	34.0	9.3	.	190.8	93.2	15.0
BD20	San Pablo Bay	04/19/95	8	39.3	74.4	70.2	.	79.5	18.9	55.4	0.5	.	4.7	2.4	.	35.6	18.9	2.5
BD30	Pinole Point	04/20/95	8	15.5	33.7	31.8	.	32.4	8.4	25.4	ND	.	2.1	1.2	.	16.7	9.3	1.2
BD40	Davis Point	04/19/95	8	32.2	63.0	57.9	.	61.6	15.1	45.7	0.6	.	3.8	2.3	.	23.2	14.4	2.1
BD50	Napa River	04/18/95	8	14.1	35.2	29.4	.	32.2	7.2	22.7	ND	.	2.0	1.3	.	17.8	8.8	1.2
BF20	Grizzly Bay	04/20/95	8	12.8	28.2	26.7	.	27.6	6.6	21.6	ND	.	2.2	1.8	.	18.7	7.9	1.8
BG20	Sacramento River	04/18/95	8	9.0	16.2	12.7	.	15.8	2.7	8.8	ND	.	ND	ND	.	3.9	3.5	0.6
BG30	San Joaquin River	04/18/95	8	NA	NA	NA	.	NA	NA	NA	NA	.	NA	NA	.	NA	NA	NA
BA10	Coyote Creek	08/14/95	9	28.7	19.6	20.3	4.5	67.0	18.3	43.0	1.5	15.4	3.1	0.5	19.3	3.8	4.5	1.2
BA30	Dumbarton Bridge	08/15/95	9	37.3	19.8	24.7	6.6	72.1	19.8	60.5	2.7	22.0	3.8	0.5	21.3	3.9	11.0	1.7
BA40	Redwood Creek	08/15/95	9	14.2	9.6	9.5	3.1	31.5	9.5	24.4	0.9	8.1	1.4	ND	12.3	1.7	2.6	0.6
BB70	Alameda	08/16/95	9	3.3	2.3	2.6	0.6	4.8	2.4	5.6	1.2	1.3	ND	ND	2.4	ND	1.6	ND
BC10	Yerba Buena Island	08/16/95	9	4.4	3.1	3.5	0.6	11.3	2.8	6.4	ND	2.0	0.5	ND	3.0	0.6	2.0	ND
BC20	Golden Gate	08/16/95	9	ND	1.1	ND	ND	1.6	0.5	1.9	ND	ND	ND	ND	ND	ND	1.2	ND
BC60	Red Rock	08/17/95	9	4.0	3.1	3.4	0.6	5.8	2.6	6.4	ND	1.9	ND	ND	2.1	0.6	2.0	ND
BD15	Petaluma River	08/21/95	9	21.7	11.8	14.9	3.0	44.6	12.1	33.4	1.1	12.0	2.5	ND	10.0	2.6	8.8	1.3
BD20	San Pablo Bay	08/21/95	9	4.8	4.2	4.5	0.9	13.2	3.6	8.9	ND	1.4	ND	ND	2.8	0.7	1.6	ND
BD30	Pinole Point	08/21/95	9	3.7	4.1	3.9	0.9	11.9	3.7	9.2	ND	2.1	ND	ND	2.3	0.7	1.2	ND
BD40	Davis Point	08/21/95	9	5.2	4.5	4.2	0.9	13.4	3.6	9.0	ND	2.5	ND	ND	2.8	0.9	1.3	ND
BD50	Napa River	08/22/95	9	4.5	4.1	4.1	0.8	12.5	3.2	8.6	ND	2.4	0.6	ND	2.7	0.7	1.5	ND
BF20	Grizzly Bay	08/22/95	9	5.1	4.4	4.6	0.8	13.0	3.9	9.4	ND	2.5	0.5	ND	2.9	0.8	2.1	ND
BG20	Sacramento River	08/23/95	9	2.1	1.9	1.6	ND	3.6	1.6	3.8	ND	0.8	ND	ND	1.5	ND	1.4	ND
BG30	San Joaquin River	08/23/95	9	2.5	2.9	2.5	ND	3.6	1.6	5.1	ND	0.9	ND	ND	1.0	ND	1.3	ND

Table 8. Dissolved pesticide concentrations in water samples, 1995 (at 1 meter depth). ND = not detected, NS = not sampled

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 (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
BA10	Coyote Creek	02/07/95	7	353	38	7	ND	180	89	39	418	140	120	18	87	ND	42	11
BA30	Dumbarton Bridge	02/06/95	7	137	5	6	ND	61	59	7	128	31	62	3	32	ND	ND	ND
BA40	Redwood Creek	02/07/95	7	141	11	7	ND	84	39	ND	204	57	49	9	44	ND	41	4
BB70	Alameda	02/08/95	7	167	17	4	ND	82	41	23	161	35	26	6	13	ND	79	3
BC10	Yerba Buena Island	02/08/95	7	64	2	3	ND	12	48	ND	143	15	21	5	18	ND	83	2
BC20	Golden Gate	02/09/95	7	51	1	2	ND	14	33	ND	178	9	10	3	16	ND	140	ND
BC60	Red Rock	02/08/95	7	170	24	3	ND	80	63	ND	145	26	25	6	16	ND	70	2
BD15	Petaluma River	02/13/95	7	261	30	5	ND	140	66	20	138	39	29	7	24	ND	39	ND
BD20	San Pablo Bay	02/13/95	7	76	ND	4	ND	14	58	ND	155	19	17	4	13	ND	100	2
BD30	Pinole Point	02/13/95	7	139	13	1	ND	80	45	ND	61	21	18	5	17	ND	ND	ND
BD40	Davis Point	02/13/95	7	157	15	5	ND	86	51	ND	82	20	21	5	21	ND	11	4
BD50	Napa River	02/14/95	7	274	15	7	ND	150	71	31	98	30	24	5	22	ND	17	ND
BF20	Grizzly Bay	02/14/95	7	184	4	4	ND	92	76	8	228	20	14	3	11	ND	180	ND
BG20	Sacramento River	02/15/95	7	130	8	1	ND	33	82	6	68	14	11	3	10	ND	30	ND
BG30	San Joaquin River	02/15/95	7	208	ND	6	ND	66	120	16	246	26	27	4	17	ND	170	3
BA10	Coyote Creek	04/24/95	8	328	35	4	ND	130	120	39	456	100	93	23	63	18	146	13
BA30	Dumbarton Bridge	04/24/95	8	300	46	2	2	160	68	22	233	42	51	16	40	9	62	13
BA40	Redwood Creek	04/24/95	8	173	21	1	ND	120	31	ND	96	12	14	6	18	ND	37	10
BB70	Alameda	04/26/95	8	141	5	ND	1	96	23	16	75	17	17	7	12	ND	22	ND
BC10	Yerba Buena Island	04/27/95	8	172	23	2	2	100	38	8	78	18	18	9	17	ND	12	4
BC20	Golden Gate	04/26/95	8	85	12	3	2	31	28	9	47	9	10	6	10	ND	9	3
BC60	Red Rock	04/27/95	8	105	10	1	1	60	31	2	33	7	6	4	7	ND	9	ND
BD15	Petaluma River	04/19/95	8	242	13	8	3	130	63	25	177	35	32	7	18	ND	80	5
BD20	San Pablo Bay	04/19/95	8	253	24	4	3	150	57	16	182	38	40	13	26	ND	61	4
BD30	Pinole Point	04/20/95	8	329	7	6	4	180	90	43	243	44	47	15	25	ND	107	5
BD40	Davis Point	04/19/95	8	287	11	3	4	140	90	40	153	39	42	10	25	ND	33	3
BD50	Napa River	04/18/95	8	553	37	7	6	360	100	44	145	36	40	9	33	ND	24	3
BF20	Grizzly Bay	04/20/95	8	248	9	9	2	120	94	14	119	23	17	8	16	ND	56	ND
BG20	Sacramento River	04/18/95	8	277	9	7	1	110	138	11	42	6	10	3	11	ND	12	ND
BG30	San Joaquin River	04/18/95	8	433	4	10	4	210	190	15	109	25	31	6	23	ND	23	ND
BA10	Coyote Creek	08/14/95	9	208	37	2	ND	110	45	14	149	43	39	16	27	ND	21	3
BA30	Dumbarton Bridge	08/15/95	9	157	25	4	ND	85	35	8	122	39	32	12	19	ND	18	2
BA40	Redwood Creek	08/15/95	9	123	19	1	ND	70	26	8	106	32	32	10	17	ND	13	3
BB70	Alameda	08/16/95	9	86	5	2	1	46	18	14	40	14	11	5	8	ND	ND	2
BC10	Yerba Buena Island	08/16/95	9	89	14	ND	2	48	12	13	54	14	11	3	10	2	11	3
BC20	Golden Gate	08/16/95	9	7	ND	ND	ND	ND	3	5	21	5	5	ND	4	4	3	ND
BC60	Red Rock	08/17/95	9	99	9	1	ND	63	20	5	50	14	12	4	14	ND	4	2
BD15	Petaluma River	08/21/95	9	178	29	2	ND	110	29	8	67	21	16	7	13	ND	8	2
BD20	San Pablo Bay	08/21/95	9	141	23	3	1	83	23	8	61	17	17	4	12	ND	9	2
BD30	Pinole Point	08/21/95	9	135	16	1	4	82	25	7	52	15	13	5	10	ND	7	2
BD40	Davis Point	08/21/95	9	230	35	2	1	150	28	15	121	34	35	10	20	ND	18	4
BD50	Napa River	08/22/95	9	176	26	2	1	110	31	7	80	24	18	8	18	ND	9	3
BF20	Grizzly Bay	08/22/95	9	246	36	4	2	140	49	15	101	30	23	10	23	2	10	3
BG20	Sacramento River	08/23/95	9	278	35	5	3	96	130	9	106	27	25	6	28	2	18	ND
BG30	San Joaquin River	08/23/95	9	249	36	4	1	90	109	9	149	45	40	10	36	4	11	4

Table 8. Dissolved pesticide concentrations in water samples, 1995 (at 1 meter depth; continued).
ND = not detected, NS = not sampled

Station Code	Station	Date	Cruise	Dieldrin	Endrin	Sum of HCHs (SFEI)	Alpha-HCH	Beta-HCH	Delta-HCH	Gamma-HCH	Hexachlorobenzene	Mirex	Dacthal	Diazinon	Endosulfan I	Endosulfan II	Endosulfan Sulfate	Oxadiazon	Chlorpyrifos
				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
BA10	Coyote Creek	02/07/95	7	ND	ND	1874	250	180	44	1400	12	ND	1100	7700	ND	ND	ND	3100	610
BA30	Dumbarton Bridge	02/06/95	7	3	120	1699	590	230	9	870	22	ND	1700	8700	ND	ND	ND	14000	180
BA40	Redwood Creek	02/07/95	7	7	28	1265	400	150	15	700	11	ND	1400	5900	ND	ND	ND	400	450
BB70	Alameda	02/08/95	7	ND	ND	780	290	130	ND	360	10	ND	720	7200	ND	ND	ND	91	280
BC10	Yerba Buena Island	02/08/95	7	ND	7	540	190	86	34	230	16	ND	640	8100	ND	ND	ND	120	130
BC20	Golden Gate	02/09/95	7	ND	7	773	340	150	3	280	10	ND	710	5300	ND	ND	ND	110	93
BC60	Red Rock	02/08/95	7	15	ND	104	22	63	ND	19	10	ND	990	5400	ND	ND	ND	120	120
BD15	Petaluma River	02/13/95	7	18	ND	886	310	100	46	430	13	ND	1300	11000	ND	ND	ND	210	210
BD20	San Pablo Bay	02/13/95	7	10	5	483	210	150	3	120	ND	ND	620	7100	ND	ND	ND	160	120
BD30	Pinole Point	02/13/95	7	6	8	622	240	100	2	280	8	ND	470	5900	ND	ND	ND	83	120
BD40	Davis Point	02/13/95	7	ND	2	120	20	67	11	22	13	ND	240	1900	ND	ND	ND	99	44
BD50	Napa River	02/14/95	7	4	8	139	34	51	3	51	12	ND	580	5700	ND	ND	ND	96	100
BF20	Grizzly Bay	02/14/95	7	ND	4	117	M	72	21	24	9	ND	300	7100	ND	ND	ND	110	67
BG20	Sacramento River	02/15/95	7	28	ND	39	7	3	8	21	7	ND	660	7800	ND	ND	ND	260	53
BG30	San Joaquin River	02/15/95	7	ND	ND	29	6	16	ND	7	16	ND	1200	7600	ND	ND	ND	130	170
BA10	Coyote Creek	04/24/95	8	ND	ND	430	75	170	65	120	20	ND	430	5800	ND	ND	ND	ND	290
BA30	Dumbarton Bridge	04/24/95	8	87	ND	1374	440	140	14	780	12	ND	710	7300	ND	ND	ND	ND	110
BA40	Redwood Creek	04/24/95	8	66	ND	929	350	110	9	460	7	ND	530	3400	ND	ND	ND	ND	120
BB70	Alameda	04/26/95	8	26	ND	388	140	140	8	100	28	ND	200	2000	ND	ND	ND	ND	50
BC10	Yerba Buena Island	04/27/95	8	ND	ND	757	370	150	7	230	ND	ND	290	2400	ND	ND	ND	ND	120
BC20	Golden Gate	04/26/95	8	ND	ND	930	500	210	ND	220	12	ND	85	840	ND	ND	ND	ND	14
BC60	Red Rock	04/27/95	8	ND	ND	249	110	78	ND	61	10	ND	120	1400	ND	ND	ND	ND	11
BD15	Petaluma River	04/19/95	8	36	ND	701	340	72	9	280	18	ND	340	2800	ND	ND	ND	ND	180
BD20	San Pablo Bay	04/19/95	8	16	ND	723	350	74	9	290	16	ND	340	4300	ND	ND	ND	ND	260
BD30	Pinole Point	04/20/95	8	41	ND	618	250	62	6	300	19	ND	870	4100	ND	ND	ND	ND	300
BD40	Davis Point	04/19/95	8	ND	ND	683	300	74	9	300	20	ND	440	3900	ND	ND	ND	30	380
BD50	Napa River	04/18/95	8	5	ND	575	190	53	22	310	18	ND	490	5000	ND	ND	ND	4	380
BF20	Grizzly Bay	04/20/95	8	ND	ND	164	25	26	58	55	15	ND	230	2700	ND	ND	ND	20	110
BG20	Sacramento River	04/18/95	8	3	ND	100	29	15	21	35	25	ND	51	3900	ND	ND	ND	26	57
BG30	San Joaquin River	04/18/95	8	ND	ND	183	59	63	ND	61	27	ND	250	4600	ND	ND	ND	37	240
BA10	Coyote Creek	08/14/95	9	140	ND	946	220	110	56	560	7	ND	130	2900	ND	ND	ND	11	2
BA30	Dumbarton Bridge	08/15/95	9	77	ND	715	180	120	45	370	2	ND	82	2200	ND	ND	ND	ND	1
BA40	Redwood Creek	08/15/95	9	98	ND	574	280	140	4	150	2	ND	80	1900	ND	ND	ND	8	2
BB70	Alameda	08/16/95	9	49	4	632	290	140	22	180	3	ND	38	900	ND	ND	ND	ND	2
BC10	Yerba Buena Island	08/16/95	9	48	2	634	310	160	4	160	2	ND	36	460	ND	ND	ND	9	4
BC20	Golden Gate	08/16/95	9	5	2	730	420	210	ND	100	3	ND	11	ND	ND	ND	ND	3	10
BC60	Red Rock	08/17/95	9	67	ND	604	320	130	4	150	3	ND	54	560	ND	ND	ND	ND	6
BD15	Petaluma River	08/21/95	9	54	ND	474	230	98	6	140	2	ND	78	640	ND	ND	ND	7	1
BD20	San Pablo Bay	08/21/95	9	60	ND	652	310	120	22	200	3	ND	82	830	ND	ND	ND	3	7
BD30	Pinole Point	08/21/95	9	42	ND	593	280	110	23	180	ND	ND	84	730	ND	ND	ND	ND	2
BD40	Davis Point	08/21/95	9	104	ND	871	370	150	21	330	2	ND	130	1900	ND	ND	ND	3	13
BD50	Napa River	08/22/95	9	39	ND	486	220	76	20	170	ND	ND	100	320	ND	ND	ND	ND	14
BF20	Grizzly Bay	08/22/95	9	129	ND	610	220	66	4	320	4	ND	180	1800	ND	ND	ND	12	29
BG20	Sacramento River	08/23/95	9	162	ND	27	ND	14	4	10	3	ND	200	1500	ND	ND	ND	7	18
BG30	San Joaquin River	08/23/95	9	72	ND	47	5	22	4	15	14	ND	280	1900	ND	ND	ND	8	19

Table 9. Total (particulate plus dissolved) pesticide concentrations in water samples, 1995 (at 1 meter depth). ND = not detected, NS = not sampled.

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 (SFEI)	Alpha-Chlordane	Gamma-Chlordane	cis-Nonachlor	trans-Nonachlor	Heptachlor	Heptachlor Epoxide	Oxychlordane	Dieldrin	Endrin
				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
BA10	Coyote Creek	02/07/95	7	1021	82	31	ND	370	339	199	817	207	187	45	162	ND	202	14	ND	ND
BA30	Dumbarton Bridge	02/06/95	7	327	14	9	ND	120	145	39	213	55	83	13	62	ND	ND	ND	3	120
BA40	Redwood Creek	02/07/95	7	250	20	11	ND	123	96	ND	248	70	59	15	59	ND	41	4	10	28
BB70	Alameda	02/08/95	7	250	21	7	ND	99	83	40	177	40	30	7	18	ND	79	3	ND	ND
BC10	Yerba Buena Island	02/08/95	7	106	2	4	ND	12	88	ND	165	18	24	5	22	ND	94	2	ND	9
BC20	Golden Gate	02/09/95	7	79	1	4	ND	14	60	ND	185	12	13	3	18	ND	140	ND	ND	7
BC60	Red Rock	02/08/95	7	309	28	7	ND	111	163	ND	201	32	31	7	23	ND	105	2	17	ND
BD15	Petaluma River	02/13/95	7	1370	92	22	ND	570	406	280	340	74	62	23	57	ND	124	ND	23	ND
BD20	San Pablo Bay	02/13/95	7	237	7	10	ND	40	139	42	193	24	23	5	17	ND	121	2	10	5
BD30	Pinole Point	02/13/95	7	322	20	3	ND	116	145	38	79	26	22	8	23	ND	ND	ND	6	8
BD40	Davis Point	02/13/95	7	885	32	26	ND	216	431	180	187	33	34	10	38	ND	68	4	3	2
BD50	Napa River	02/14/95	7	1018	53	23	ND	310	401	231	260	51	45	13	49	ND	102	ND	10	8
BF20	Grizzly Bay	02/14/95	7	491	7	24	ND	100	346	13	241	24	20	3	13	ND	182	ND	ND	4
BG20	Sacramento River	02/15/95	7	435	8	16	ND	53	352	6	106	18	16	5	13	ND	54	ND	30	ND
BG30	San Joaquin River	02/15/95	7	366	ND	14	ND	66	270	16	254	28	30	4	19	ND	170	3	ND	ND
BA10	Coyote Creek	04/24/95	8	3058	255	69	ND	1230	1434	70	1235	320	313	118	264	18	177	25	20	ND
BA30	Dumbarton Bridge	04/24/95	8	1850	166	19	15	770	678	202	574	141	131	62	123	9	90	18	94	ND
BA40	Redwood Creek	04/24/95	8	400	43	3	1	210	141	2	185	34	37	17	41	ND	47	10	71	ND
BB70	Alameda	04/26/95	8	395	20	7	2	177	143	46	136	30	31	14	32	ND	30	ND	26	ND
BC10	Yerba Buena Island	04/27/95	8	376	38	5	4	170	151	8	110	25	27	14	24	ND	16	4	ND	ND
BC20	Golden Gate	04/26/95	8	160	19	8	2	54	61	17	53	11	13	6	11	ND	9	3	3	ND
BC60	Red Rock	04/27/95	8	199	12	8	1	64	112	2	59	13	14	8	11	ND	13	ND	ND	ND
BD15	Petaluma River	04/19/95	8	6828	193	155	7	2630	3178	665	781	195	192	86	184	2	109	14	45	ND
BD20	San Pablo Bay	04/19/95	8	2443	117	62	20	670	1159	416	344	85	85	33	70	ND	67	4	38	ND
BD30	Pinole Point	04/20/95	8	1303	49	45	10	440	700	60	336	67	73	27	48	ND	117	5	45	ND
BD40	Davis Point	04/19/95	8	2266	121	59	9	810	1190	77	331	88	92	34	73	ND	40	3	4	ND
BD50	Napa River	04/18/95	8	1401	40	55	8	392	842	64	213	50	61	18	53	ND	28	3	10	ND
BF20	Grizzly Bay	04/20/95	8	1754	13	94	4	157	1455	31	196	47	40	16	31	ND	62	ND	ND	ND
BG20	Sacramento River	04/18/95	8	728	11	29	1	127	548	11	83	19	23	3	26	ND	12	ND	3	ND
BG30	San Joaquin River	04/18/95	8	NS	NS	NS	NS	NS	NS	NS	0	NS	NS	NS	NS	NS	NS	NS	NS	NS
BA10	Coyote Creek	08/14/95	9	520	61	12	4	210	195	39	222	64	61	27	46	ND	21	3	155	ND
BA30	Dumbarton Bridge	08/15/95	9	601	62	19	3	255	215	47	213	64	57	28	41	ND	21	2	97	ND
BA40	Redwood Creek	08/15/95	9	268	29	8	ND	128	82	22	134	39	42	14	24	ND	13	3	103	ND
BB70	Alameda	08/16/95	9	117	5	2	1	56	27	25	43	14	11	5	8	ND	3	2	51	4
BC10	Yerba Buena Island	08/16/95	9	151	16	4	2	68	32	29	65	17	14	5	12	2	11	3	53	2
BC20	Golden Gate	08/16/95	9	30	ND	2	ND	9	11	8	32	8	8	ND	6	4	5	ND	20	5
BC60	Red Rock	08/17/95	9	214	11	4	ND	108	71	19	64	18	16	5	18	ND	4	2	73	ND
BD15	Petaluma River	08/21/95	9	723	68	10	2	310	279	55	118	33	30	15	26	ND	12	2	61	ND
BD20	San Pablo Bay	08/21/95	9	352	35	8	2	156	119	32	82	23	24	7	17	ND	9	2	67	ND
BD30	Pinole Point	08/21/95	9	337	28	5	4	146	125	29	77	23	21	8	16	ND	7	2	51	ND
BD40	Davis Point	08/21/95	9	444	49	5	1	217	124	48	146	40	43	14	26	ND	18	4	106	ND
BD50	Napa River	08/22/95	9	375	40	5	2	179	122	27	106	31	25	11	25	ND	11	3	46	ND
BF20	Grizzly Bay	08/22/95	9	180	NS	8	3	NS	169	NS	0	NS	NS	NS	NS	NS	NS	NS	135	ND
BG20	Sacramento River	08/23/95	9	470	35	15	3	99	310	9	116	30	28	6	32	2	18	ND	169	ND
BG30	San Joaquin River	08/23/95	9	399	45	7	1	108	229	9	165	49	43	10	40	4	15	4	75	ND

Table 9. Total (particulate plus dissolved) pesticide concentrations in water samples, 1995 (at 1 meter depth; continued). ND = not detected, NS = not sampled.

Station Code	Station	Date	Cruise	Sum of HCHs (SFEI)	Alpha-HCH	Beta-HCH	Delta-HCH	Gamma-HCH	Hexachlorobenzene	Mirex	Dacthal	Diazinon	Endosulfan I	Endosulfan II	Endosulfan Sulfate	Oxadiazon	Chlorpyrifos
				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
BA10	Coyote Creek	02/07/95	7	1906	253	184	49	1419	19	ND	1135	7700	ND	ND	ND	3145	650
BA30	Dumbarton Bridge	02/06/95	7	1726	597	244	9	875	25	ND	1700	8700	ND	ND	ND	14000	209
BA40	Redwood Creek	02/07/95	7	1275	403	153	15	704	14	ND	1418	5900	ND	ND	ND	418	458
BB70	Alameda	02/08/95	7	785	290	132	ND	363	10	ND	739	7200	ND	ND	ND	91	286
BC10	Yerba Buena Island	02/08/95	7	540	190	86	34	230	16	ND	661	8100	ND	ND	ND	132	134
BC20	Golden Gate	02/09/95	7	773	340	150	3	280	10	ND	725	5300	ND	ND	ND	110	99
BC60	Red Rock	02/08/95	7	114	22	68	2	23	14	ND	1020	5400	ND	ND	ND	120	139
BD15	Petaluma River	02/13/95	7	916	316	116	46	438	36	ND	1388	11150	ND	ND	ND	225	253
BD20	San Pablo Bay	02/13/95	7	486	213	150	3	120	3	ND	638	7100	ND	ND	ND	160	132
BD30	Pinole Point	02/13/95	7	631	243	103	2	282	15	ND	491	5900	ND	ND	ND	93	131
BD40	Davis Point	02/13/95	7	135	24	73	11	26	30	ND	306	2100	ND	ND	ND	147	75
BD50	Napa River	02/14/95	7	151	37	55	3	56	31	ND	653	5870	ND	ND	ND	154	145
BF20	Grizzly Bay	02/14/95	7	124	5	74	21	24	16	ND	359	7100	ND	ND	ND	110	75
BG20	Sacramento River	02/15/95	7	51	14	8	8	21	11	ND	770	7800	ND	ND	ND	283	58
BG30	San Joaquin River	02/15/95	7	78	28	35	ND	15	27	ND	1212	7600	ND	ND	ND	130	183
BA10	Coyote Creek	04/24/95	8	491	80	185	68	158	63	ND	491	7000	ND	ND	ND	12	400
BA30	Dumbarton Bridge	04/24/95	8	1410	450	150	14	797	32	ND	752	7810	ND	ND	ND	ND	161
BA40	Redwood Creek	04/24/95	8	939	353	112	9	465	12	ND	537	3400	ND	ND	ND	ND	140
BB70	Alameda	04/26/95	8	399	146	140	8	105	31	ND	200	2000	ND	ND	ND	ND	68
BC10	Yerba Buena Island	04/27/95	8	771	373	155	7	237	4	ND	294	2400	ND	ND	ND	ND	137
BC20	Golden Gate	04/26/95	8	932	502	210	ND	220	14	ND	85	840	ND	ND	ND	ND	19
BC60	Red Rock	04/27/95	8	267	119	81	ND	67	14	ND	123	1400	ND	ND	ND	8	24
BD15	Petaluma River	04/19/95	8	795	354	123	13	305	168	ND	429	4400	ND	ND	ND	ND	450
BD20	San Pablo Bay	04/19/95	8	750	354	89	9	298	51	ND	388	4820	ND	ND	ND	ND	410
BD30	Pinole Point	04/20/95	8	632	253	66	6	308	43	ND	890	4410	ND	ND	ND	ND	391
BD40	Davis Point	04/19/95	8	697	300	79	9	309	53	ND	491	4420	ND	ND	ND	30	520
BD50	Napa River	04/18/95	8	586	193	56	22	315	37	ND	517	5200	ND	ND	ND	4	423
BF20	Grizzly Bay	04/20/95	8	172	30	29	58	55	51	ND	230	2700	ND	ND	ND	20	163
BG20	Sacramento River	04/18/95	8	115	33	18	21	43	32	ND	57	3900	ND	ND	ND	26	69
BG30	San Joaquin River	04/18/95	8	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	240
BA10	Coyote Creek	08/14/95	9	961	222	113	62	563	10	1	136	2900	ND	ND	ND	18	4
BA30	Dumbarton Bridge	08/15/95	9	737	185	126	51	375	6	ND	90	2200	ND	ND	ND	6	6
BA40	Redwood Creek	08/15/95	9	578	280	140	6	152	2	ND	84	1900	ND	ND	ND	12	9
BB70	Alameda	08/16/95	9	632	290	140	22	180	3	ND	38	900	ND	ND	ND	ND	2
BC10	Yerba Buena Island	08/16/95	9	640	312	160	6	162	2	ND	39	460	ND	ND	ND	9	4
BC20	Golden Gate	08/16/95	9	744	423	217	ND	105	5	ND	31	ND	ND	ND	ND	30	11
BC60	Red Rock	08/17/95	9	606	320	130	6	150	5	ND	61	560	ND	ND	ND	4	7
BD15	Petaluma River	08/21/95	9	490	233	103	12	143	6	1	81	640	ND	ND	ND	13	3
BD20	San Pablo Bay	08/21/95	9	655	310	120	25	200	3	ND	88	830	ND	ND	ND	3	8
BD30	Pinole Point	08/21/95	9	601	282	112	26	182	ND	ND	90	730	ND	ND	ND	ND	2
BD40	Davis Point	08/21/95	9	880	372	152	25	332	4	ND	132	1900	ND	ND	ND	3	14
BD50	Napa River	08/22/95	9	493	220	76	25	172	ND	ND	105	320	ND	ND	ND	3	15
BF20	Grizzly Bay	08/22/95	9	0	NS	NS	NS	NS	8	1	188	1800	ND	ND	ND	15	29
BG20	Sacramento River	08/23/95	9	27	ND	14	4	10	3	ND	209	1500	ND	ND	ND	7	21
BG30	San Joaquin River	08/23/95	9	47	5	22	4	15	17	ND	284	1900	ND	ND	ND	8	20

Table 10. Water toxicity data for 1995 RMP cruises.

Station Code	Station	Date	*Mytilus edulis* Mean % Normal Development		*Mysidopsis bahia* Mean % Survival	
			100% Ambient Water	Control	100% Ambient Water	Control
BA10	Coyote Creek	02/07/95	88	67	100	93
BA40	Redwood Creek	02/07/95	89	67	93	93
BB70	Alameda	02/08/95	97	95	88	80
BC10	Yerba Buena Island	02/08/95	99	95	93	80
BC60	Red Rock	02/08/95	95	95	80	80
BD15	Petaluma River	02/13/95	88	91	95	93
BD30	Pinole Point	02/13/95	90	91	95	93
BD50	Napa River	02/14/95	N/A	N/A	88	95
BF20	Grizzly Bay	02/14/95	N/A	N/A	98	95
BG20	Sacramento River	02/15/95	N/A	N/A	93	100
BG30	San Joaquin River	02/15/95	N/A	N/A	83*	100
C-1-3	Sunnyvale	02/07/95	73	67	80	93
C-3-0	San Jose	02/07/95	84	67	88	93

Station Code	Station	Date	*Crassostrea gigas* Mean % Normal Development		*Mysidopsis bahia* Mean % Survival	
			100% Ambient Water	Control	100% Ambient Water	Control
BA10	Coyote Creek	08/14/95	F	F	100	95
BA40	Redwood Creek	08/15/95	F	F	95	90
BB70	Alameda	08/16/95	F	F	98	95
BC10	Yerba Buena Island	08/16/95	F	F	98	100
BC60	Red Rock	08/17/95	F	F	100	93
BD15	Petaluma River	08/21/95	F	F	95	95
BD30	Pinole Point	08/21/95	F	F	85	95
BD50	Napa River	08/22/95	F	F	88	90
BF20	Grizzly Bay	08/22/95	F	F	90	90
BG20	Sacramento River	08/23/95	F	F	93	98
BG30	San Joaquin River	08/23/95	F	F	95	98
C-1-3	Sunnyvale	08/14/95	F	F	95	92.5
C-3-0	San Jose	08/14/95	F	F	92.5	92.5

F In August, the oyster stocks did not produce viable sperm or eggs which resulted in extremely poor fertilization and none of the tests were successful.

N/A Test terminated due to control failure.

* Statistically significantly different from the control at the 0.05 level

Table 11. General characteristics of sediment samples, 1995.
ND = not detected, NA = not analyzed

Station Code	Station	Date	Cruise	% Clay (<4um)	% Silt (4um - 63um)	% Sand (63um - 2mm)	% Gravel+Shell (>2mm)	Depth (meters)	Ammonia	Hydrogen Sulfide	pH	TOC	Total Sulfide
				%	%	%	%		mg/L	mg/L	pH	%	mg/L
BA10	Coyote Creek	02/22/95	7	44	15	37	4	6	1.05	0.007	7.72	0.625	0.066
BA21	South Bay	02/21/95	7	72	25	3	0	4	4.36	0.017	7.17	0.96	0.058
BA30	Dumbarton Bridge	02/21/95	7	68	27	5	0	8	0.34	0.003	7.75	1.24	0.032
BA41	Redwood Creek	02/21/95	7	48	19	21	12	3.5	0.62	0.005	7.62	1.64	0.038
BB15	San Bruno Shoal	02/21/95	7	54	28	16	2	12	2.41	0.009	7.14	1.11	0.03
BB30	Oyster Point	02/20/95	7	46	21	27	6	8.5	3.01	0.006	7.46	1.17	0.034
BB70	Alameda	02/21/95	7	50	26	24	0	10	0.84	0.009	7.31	1.01	0.04
BC11	Yerba Buena Island	02/20/95	7	46	21	29	3	6.5	0.53	0.007	7.54	1.24	0.044
BC21	Horseshoe Bay	02/20/95	7	38	28	34	0	12	2.4	0.012	7.26	1.01	0.046
BC32	Richardson Bay	02/20/95	7	33	40	27	0	3	0.46	0.009	7.07	0.8	0.026
BC41	Point Isabel	02/20/95	7	54	35	11	0	2.5	0.57	0.007	7.21	1.04	0.026
BC60	Red Rock	02/17/95	7	5	2	89	4	10.5	0.55	ND	7.53	0.54	ND
BD15	Petaluma River	02/17/95	7	70	27	3	0	4	3.69	0.011	7.02	1.44	0.03
BD22	San Pablo Bay	02/17/95	7	52	33	14	2	4	1.95	0.017	7.2	0.95	0.06
BD31	Pinole Point	02/17/95	7	79	15	6	0	7	3.37	0.026	7	1.46	0.068
BD41	Davis Point	02/17/95	7	21	9	67	2	7.3	1.52	0.004	7.5	0.98	0.024
BD50	Napa River	02/17/95	7	70	23	4	3	3.3	2.72	0.01	7.26	1.365	0.04
BF10	Pacheco Creek	02/16/95	7	7	4	89	0	6	0.84	0.004	7.46	0.7	0.024
BF21	Grizzly Bay	02/16/95	7	62	37	1	0	2.5	1.84	ND	7.32	1.375	ND
BF40	Honker Bay	02/16/95	7	62	35	3	0	3	1.95	ND	7.44	1.48	ND
BG20	Sacramento River	02/16/95	7	8	4	87	0	8.5	0.21	ND	7.01	0.271	ND
BG30	San Joaquin River	02/16/95	7	34	30	36	0	6.5	2.74	0.019	6.48	0.52	0.028
C-1-3	Sunnyvale	02/22/95	7	8	4	88	0	2.5	4.07	0.022	7.61	0.345	0.16
C-3-0	San Jose	02/22/95	7	13	5	76	5	3.5	0.9	0.016	7.75	0.527	0.154
BA10	Coyote Creek	08/30/95	9	73	23	3	1	6	0.42	0.011	7.55	1.42	0.073
BA21	South Bay	08/29/95	9	67	31	2	0	4	5.22	ND	7.15	1.33	ND
BA30	Dumbarton Bridge	08/30/95	9	60	36	4	0	8	5.01	0.02	6.9	1.25	0.046
BA41	Redwood Creek	08/29/95	9	58	22	13	7	3.5	0.22	ND	7.49	1.13	ND
BB15	San Bruno Shoal	08/29/95	9	45	21	30	4	12	0.49	ND	7.79	0.88	ND
BB30	Oyster Point	08/30/95	9	48	20	30	2	8.5	1.35	0.024	7.29	1.05	0.099
BB70	Alameda	08/28/95	9	69	28	5	0	10	1.94	0.013	7.34	2.22	0.059
BC11	Yerba Buena Island	08/28/95	9	71	21	7	1	6.5	1.06	0.036	7.47	1.68	0.206
BC21	Horseshoe Bay	08/28/95	9	19	12	66	3	12	0.63	0.013	7.61	0.55	0.095
BC32	Richardson Bay	08/28/95	9	41	39	20	0	3	0.66	0.009	7.04	0.93	0.024
BC41	Point Isabel	08/28/95	9	51	37	12	0	2.5	0.54	ND	7.41	1.12	ND
BC60	Red Rock	08/25/95	9	4	1	85	10	10.5	0.26	0.034	7.89	NA	0.459
BD15	Petaluma River	08/25/95	9	64	25	8	3	4	2.68	ND	7.52	1.2	ND
BD22	San Pablo Bay	08/25/95	9	57	33	9	1	4	0.27	ND	7.66	1.36	ND
BD31	Pinole Point	08/25/95	9	43	20	37	0	7	4.49	ND	7	1.08	ND
BD41	Davis Point	08/25/95	9	14	6	79	1	7.3	0.25	0.03	7.68	0.37	0.259
BD50	Napa River	08/25/95	9	77	21	2	0	3.3	0.66	0.012	7.27	1.5	0.046
BF10	Pacheco Creek	08/24/95	9	17	8	74	0	6	0.35	0.036	7.76	0.65	0.361
BF21	Grizzly Bay	08/24/95	9	63	34	3	1	2.5	1.16	ND	7.45	1.4	ND
BF40	Honker Bay	08/24/95	9	61	31	7	0	3	1.11	ND	6.82	1.46	ND
BG20	Sacramento River	08/24/95	9	18	9	73	0	8.5	0.53	ND	7.22	0.77	ND
BG30	San Joaquin River	08/24/95	9	40	39	21	0	6.5	0.73	ND	6.32	0.55	ND
C-1-3	Sunnyvale	08/29/95	9	33	15	53	0	2.5	2.12	ND	7.64	0.71	ND
C-3-0	San Jose	08/29/95	9	52	20	28	0	3.5	2.78	0.016	7	1.22	0.042

Table 12. Concentration of trace elements for sediment samples, 1995.

Station Code	Station	Date	Cruise	Ag	Al	As	Cd	Cr	Cu	Fe
				mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
BA10	Coyote Creek	02/22/95	7	0.32	18218	6.1	0.20	66.8	31.1	29423
BA21	South Bay	02/21/95	7	0.48	24748	8.0	0.17	85.9	43.1	38304
BA30	Dumbarton Bridge	02/21/95	7	0.50	22619	11.4	0.22	84.7	47.2	38122
BA41	Redwood Creek	02/21/95	7	0.54	25768	10.9	0.34	80.4	40.4	33758
BB15	San Bruno Shoal	02/21/95	7	0.37	25945	10.2	0.20	81.5	37.6	32990
BB30	Oyster Point	02/20/95	7	0.38	24288	6.9	0.17	78.8	35.7	31907
BB70	Alameda	02/21/95	7	0.45	25894	9.8	0.23	90.2	41.4	35346
BC11	Yerba Buena Island	02/20/95	7	0.28	17874	9.5	0.19	58.7	30.1	23675
BC21	Horseshoe Bay	02/20/95	7	0.24	22258	8.3	0.23	78.8	31.4	30791
BC32	Richardson Bay	02/20/95	7	0.21	21466	9.0	0.18	71.9	31.1	30634
BC41	Point Isabel	02/20/95	7	0.25	23106	12.0	0.14	83.4	40.1	33858
BC60	Red Rock	02/17/95	7	0.02	9692	8.2	0.04	59.3	10.3	26710
BD15	Petaluma River	02/17/95	7	0.29	34345	11.2	0.36	102.5	55.9	43673
BD22	San Pablo Bay	02/17/95	7	0.28	23312	13.7	0.19	78.7	46.6	35016
BD31	Pinole Point	02/17/95	7	0.23	32873	15.4	0.43	102.7	70.6	47886
BD41	Davis Point	02/17/95	7	0.10	18095	6.7	0.15	70.3	27.3	31576
BD50	Napa River	02/17/95	7	0.33	28189	12.6	0.30	95.8	63.8	43794
BF10	Pacheco Creek	02/16/95	7	0.03	16213	6.0	0.12	67.1	14.6	30540
BF21	Grizzly Bay	02/16/95	7	0.25	25589	15.7	0.30	89.8	59.7	40255
BF40	Honker Bay	02/16/95	7	0.22	27929	13.3	0.37	93.6	63.5	42698
BG20	Sacramento River	02/16/95	7	0.04	15718	10.0	0.27	66.4	20.7	26853
BG30	San Joaquin River	02/16/95	7	0.08	27137	14.2	0.22	74.7	39.7	31446
C-1-3	Sunnyvale	02/22/95	7	0.07	11896	2.0	0.17	55.6	22.7	20640
C-3-0	San Jose	02/22/95	7	0.36	12231	6.1	0.26	70.0	21.1	22962
BA10	Coyote Creek	08/30/95	9	0.43	29207	9.8	0.18	96.1	41.0	41500
BA21	South Bay	08/29/95	9	0.38	26947	11.6	0.16	89.8	38.3	38579
BA30	Dumbarton Bridge	08/30/95	9	0.38	18783	9.1	0.16	77.4	37.3	32568
BA41	Redwood Creek	08/29/95	9	0.56	23468	9.4	0.25	85.4	39.1	35040
BB15	San Bruno Shoal	08/29/95	9	0.42	16784	8.2	0.18	72.8	32.0	26179
BB30	Oyster Point	08/30/95	9	0.37	19709	9.4	0.21	77.9	34.9	30473
BB70	Alameda	08/28/95	9	0.24	19209	13.4	0.17	76.8	42.1	32393
BC11	Yerba Buena Island	08/28/95	9	0.28	26243	12.4	0.18	82.9	42.1	36382
BC21	Horseshoe Bay	08/28/95	9	0.14	13156	6.0	0.13	61.1	16.9	22043
BC32	Richardson Bay	08/28/95	9	0.23	24373	12.8	0.24	78.7	31.7	31383
BC41	Point Isabel	08/28/95	9	0.23	27834	11.9	0.17	92.5	36.4	34058
BC60	Red Rock	08/25/95	9	0.01	11896	8.3	0.04	69.8	7.2	27986
BD15	Petaluma River	08/25/95	9	0.26	13804	18.2	0.31	89.6	49.6	30186
BD22	San Pablo Bay	08/25/95	9	0.21	25833	15.1	0.23	78.5	41.0	35273
BD31	Pinole Point	08/25/95	9	0.15	23565	12.1	0.24	81.0	41.3	34433
BD41	Davis Point	08/25/95	9	0.05	13944	8.4	0.11	73.1	17.2	25680
BD50	Napa River	08/25/95	9	0.31	26484	14.5	0.22	101.5	56.7	37208
BF10	Pacheco Creek	08/24/95	9	0.04	14128	8.6	0.11	66.4	15.2	27058
BF21	Grizzly Bay	08/24/95	9	0.25	23088	16.1	0.26	67.2	39.8	42395
BF40	Honker Bay	08/24/95	9	0.21	32633	14.0	0.26	88.9	45.3	41869
BG20	Sacramento River	08/24/95	9	0.05	18683	8.9	0.26	86.4	21.8	32690
BG30	San Joaquin River	08/24/95	9	0.08	27787	17.5	0.20	67.4	35.2	34060
C-1-3	Sunnyvale	08/29/95	9	0.22	20510	6.0	0.17	69.1	24.9	28103
C-3-0	San Jose	08/29/95	9	0.96	21185	8.2	0.75	97.7	49.8	34018

Table 12. Concentration of trace elements for sediment samples, 1995 (continued).

Station Code	Station	Date	Cruise	Hg	Mn	Ni	Pb	Se	Zn
				mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
BA10	Coyote Creek	02/22/95	7	0.277	695	72.3	23.3	0.426	94
BA21	South Bay	02/21/95	7	0.392	903	83.4	31.4	0.528	126
BA30	Dumbarton Bridge	02/21/95	7	0.388	484	81.2	32.1	0.493	128
BA41	Redwood Creek	02/21/95	7	0.238	517	72.5	26.9	0.236	109
BB15	San Bruno Shoal	02/21/95	7	0.307	445	70.2	23.9	0.218	103
BB30	Oyster Point	02/20/95	7	0.281	392	69.3	20.4	0.479	99
BB70	Alameda	02/21/95	7	0.330	355	78.7	37.8	0.587	112
BC11	Yerba Buena Island	02/20/95	7	0.241	283	49.9	18.2	0.335	81
BC21	Horseshoe Bay	02/20/95	7	0.196	296	68.0	25.0	0.418	95
BC32	Richardson Bay	02/20/95	7	0.263	307	64.7	23.3	0.308	90
BC41	Point Isabel	02/20/95	7	0.328	381	73.1	24.0	0.438	107
BC60	Red Rock	02/17/95	7	0.027	537	59.2	11.7	0.076	58
BD15	Petaluma River	02/17/95	7	0.423	936	116.6	29.1	0.664	148
BD22	San Pablo Bay	02/17/95	7	0.351	511	76.8	22.5	0.289	112
BD31	Pinole Point	02/17/95	7	0.320	811	117.5	16.9	0.391	137
BD41	Davis Point	02/17/95	7	0.124	408	70.8	14.9	0.170	82
BD50	Napa River	02/17/95	7	0.390	720	96.7	30.3	0.461	140
BF10	Pacheco Creek	02/16/95	7	0.047	377	71.9	5.9	0.080	64
BF21	Grizzly Bay	02/16/95	7	0.338	879	92.9	30.5	0.565	127
BF40	Honker Bay	02/16/95	7	0.324	988	97.2	26.0	0.548	133
BG20	Sacramento River	02/16/95	7	0.058	575	83.1	9.7	0.131	78
BG30	San Joaquin River	02/16/95	7	0.343	451	57.5	14.0	0.455	67
C-1-3	Sunnyvale	02/22/95	7	0.110	400	57.9	16.5	0.217	70
C-3-0	San Jose	02/22/95	7	0.132	888	78.2	16.3	0.243	72
BA10	Coyote Creek	08/30/95	9	0.494	1151	98.6	37.4	0.385	133
BA21	South Bay	08/29/95	9	0.374	1093	86.3	30.1	0.284	115
BA30	Dumbarton Bridge	08/30/95	9	0.368	761	77.2	27.5	0.254	108
BA41	Redwood Creek	08/29/95	9	0.391	441	83.6	34.7	0.258	116
BB15	San Bruno Shoal	08/29/95	9	0.277	320	67.3	27.7	0.233	92
BB30	Oyster Point	08/30/95	9	0.269	383	76.4	26.4	0.302	98
BB70	Alameda	08/28/95	9	0.320	667	80.2	22.1	0.341	103
BC11	Yerba Buena Island	08/28/95	9	0.240	488	84.9	25.4	0.387	110
BC21	Horseshoe Bay	08/28/95	9	0.116	193	55.9	14.8	0.166	60
BC32	Richardson Bay	08/28/95	9	0.297	235	70.5	45.6	0.219	100
BC41	Point Isabel	08/28/95	9	0.324	269	81.3	28.8	0.295	106
BC60	Red Rock	08/25/95	9	0.021	424	65.1	10.7	0.051	55
BD15	Petaluma River	08/25/95	9	0.427	777	93.6	43.9	0.459	126
BD22	San Pablo Bay	08/25/95	9	0.306	445	80.1	24.9	0.407	104
BD31	Pinole Point	08/25/95	9	0.205	466	91.5	16.7	0.313	107
BD41	Davis Point	08/25/95	9	0.077	305	73.5	9.6	0.089	73
BD50	Napa River	08/25/95	9	0.404	589	103.5	31.9	0.407	144
BF10	Pacheco Creek	08/24/95	9	0.091	316	73.3	6.6	0.142	65
BF21	Grizzly Bay	08/24/95	9	0.344	848	68.3	30.7	0.338	94
BF40	Honker Bay	08/24/95	9	0.348	698	85.8	24.8	0.440	116
BG20	Sacramento River	08/24/95	9	0.055	496	84.2	11.3	0.135	86
BG30	San Joaquin River	08/24/95	9	0.423	486	52.6	16.2	0.369	61
C-1-3	Sunnyvale	08/29/95	9	0.307	728	63.8	22.4	0.307	78
C-3-0	San Jose	08/29/95	9	0.400	595	105.7	50.6	0.406	148

Table 13. PAH and alkanes concentrations in sediment, 1995.
ND = not detected. Data in dry weight.

Station Code	Station	Date	Cruise	Sum of Alkanes (SFEI)	Sum of PAHs (SFEI)	Sum of LPAHs (SFEI)	Sum of HPAHs (SFEI)	Biphenyl	Naphthalene	1-Methylnaphthalene	2-Methylnaphthalene	2,6-Dimethylnaphthalene	2,3,5-Trimethylnaphthalene	Acenaphthene	Acenaphthylene	Anthracene	Dibenzothiophene	Fluorene
				ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g
BA10	Coyote Creek	02/22/95	7	1005	1451	199	1252	6	20	5	8	5	2	5	14	29	5	8
BA21	South Bay	02/21/95	7	1517	2339	239	2101	9	26	7	9	9	4	10	16	35	5	10
BA30	Dumbarton Bridge	02/21/95	7	1538	2897	336	2561	12	43	10	12	14	7	11	21	38	7	14
BA41	Redwood Creek	02/21/95	7	1060	2448	338	2110	8	31	6	10	7	3	9	26	48	8	15
BB15	San Bruno Shoal	02/21/95	7	1137	2314	353	1961	10	51	7	12	8	3	14	22	43	9	13
BB30	Oyster Point	02/20/95	7	1203	2638	344	2294	12	35	13	16	10	8	14	18	43	7	14
BB70	Alameda	02/21/95	7	1450	3722	939	2783	19	53	30	39	19	8	116	20	115	19	79
BC11	Yerba Buena Island	02/20/95	7	938	1258	181	1078	5	19	6	9	5	3	7	11	24	4	8
BC21	Horseshoe Bay	02/20/95	7	1291	2154	369	1785	9	30	9	12	10	3	16	24	51	10	18
BC32	Richardson Bay	02/20/95	7	957	2409	339	2069	9	35	8	13	8	5	10	20	48	8	15
BC41	Point Isabel	02/20/95	7	1386	2955	427	2528	11	42	14	19	10	7	14	21	60	10	14
BC60	Red Rock	02/17/95	7	222	59	21	38	3	5	3	3	ND	ND	ND	ND	2	ND	ND
BD15	Petaluma River	02/17/95	7	3003	1555	168	1387	6	26	5	8	5	ND	5	12	17	4	7
BD22	San Pablo Bay	02/17/95	7	1748	1934	219	1715	10	20	8	9	7	5	9	11	26	5	8
BD31	Pinole Point	02/17/95	7	4183	420	97	323	6	11	ND	9	13	ND	6	ND	8	4	5
BD41	Davis Point	02/17/95	7	743	228	35	194	1	5	ND	3	2	ND	ND	2	4	ND	2
BD50	Napa River	02/17/95	7	3017	1092	162	930	9	16	8	11	10	7	6	6	16	5	11
BF10	Pacheco Creek	02/16/95	7	411	85	27	58	2	5	ND	4	2	3	2	ND	2	ND	2
BF21	Grizzly Bay	02/16/95	7	2822	586	79	508	4	11	5	9	5	3	ND	5	8	ND	5
BF40	Honker Bay	02/16/95	7	4559	796	116	679	5	15	6	10	7	3	3	5	12	3	6
BG20	Sacramento River	02/16/95	7	705	90	40	49	6	9	7	6	2	ND	ND	ND	1	ND	2
BG30	San Joaquin River	02/16/95	7	861	58	2	56	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	08/30/95	9	1293	1644	221	1422	10	28	8	13	10	5	6	12	20	6	9
BA21	South Bay	08/29/95	9	1256	1957	314	1643	19	35	10	15	12	4	10	17	37	5	14
BA30	Dumbarton Bridge	08/30/95	9	826	2516	347	2168	11	35	8	13	8	6	10	21	42	9	15
BA41	Redwood Creek	08/29/95	9	870	1765	195	1570	7	21	4	11	6	2	8	11	19	5	7
BB15	San Bruno Shoal	08/29/95	9	893	1742	238	1504	8	25	5	7	9	5	9	12	26	6	11
BB30	Oyster Point	08/30/95	9	493	1365	182	1183	8	19	5	7	6	3	7	12	22	5	7
BB70	Alameda	08/28/95	9	1438	2278	474	1804	8	22	8	12	13	9	11	20	74	13	20
BC11	Yerba Buena Island	08/28/95	9	1218	1141	186	955	7	17	7	8	8	4	11	8	21	5	10
BC21	Horseshoe Bay	08/28/95	9	527	1229	240	989	6	15	5	7	5	5	7	15	56	4	11
BC32	Richardson Bay	08/28/95	9	672	2344	287	2056	9	25	5	8	8	5	13	16	38	5	10
BC41	Point Isabel	08/28/95	9	1068	2206	344	1862	8	27	8	10	8	6	13	19	58	7	14
BC60	Red Rock	08/25/95	9	104	16	2	14	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	08/25/95	9	1134	1490	133	1357	5	22	ND	6	5	5	5	9	13	4	6
BD22	San Pablo Bay	08/25/95	9	2037	2415	292	2123	10	30	7	9	7	4	9	15	37	9	10
BD31	Pinole Point	08/25/95	9	2228	466	90	376	4	9	4	5	5	2	4	4	9	3	6
BD41	Davis Point	08/25/95	9	511	112	26	86	2	3	ND	ND	ND	ND	3	ND	2	ND	3
BD50	Napa River	08/25/95	9	2212	969	116	854	6	15	ND	10	8	ND	4	5	12	4	8
BF10	Pacheco Creek	08/24/95	9	1021	317	122	195	3	4	3	4	3	ND	11	1	8	4	13
BF21	Grizzly Bay	08/24/95	9	2779	577	90	487	6	11	ND	8	7	4	5	3	7	3	5
BF40	Honker Bay	08/24/95	9	3124	527	77	450	5	9	ND	7	5	3	ND	4	8	2	6
BG20	Sacramento River	08/24/95	9	1374	60	5	54	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	08/24/95	9	1015	82	8	74	1	3	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 13. PAH and alkanes concentrations in sediment, 1995 (continued).
ND = not detected. Data in dry weight.

Station Code	Station	Date	Cruise	Phenanthrene	1-Methylphenanthrene	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
				ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g
BA10	Coyote Creek	02/22/95	7	83	9	62	77	171	231	143	90	150	24	16	32	142	115
BA21	South Bay	02/21/95	7	88	10	114	151	237	432	243	150	225	85	21	61	203	180
BA30	Dumbarton Bridge	02/21/95	7	127	20	141	161	331	552	299	180	284	85	21	70	232	205
BA41	Redwood Creek	02/21/95	7	147	20	128	140	275	361	255	149	246	52	27	56	229	192
BB15	San Bruno Shoal	02/21/95	7	140	18	115	136	286	375	216	135	63	203	23	52	197	161
BB30	Oyster Point	02/20/95	7	137	17	122	151	309	554	253	154	260	46	19	59	194	172
BB70	Alameda	02/21/95	7	390	31	197	201	488	517	303	179	291	106	24	65	216	195
BC11	Yerba Buena Island	02/20/95	7	72	8	64	71	148	190	128	75	120	32	13	29	115	92
BC21	Horseshoe Bay	02/20/95	7	159	18	122	136	273	343	201	115	198	41	21	54	152	129
BC32	Richardson Bay	02/20/95	7	142	20	128	162	282	331	256	145	237	66	26	55	208	173
BC41	Point Isabel	02/20/95	7	179	26	189	184	377	492	294	164	272	87	21	71	198	179
BC60	Red Rock	02/17/95	7	5	ND	2	4	5	7	4	3	4	2	ND	ND	4	3
BD15	Petaluma River	02/17/95	7	65	8	64	77	168	244	159	105	143	46	16	53	174	138
BD22	San Pablo Bay	02/17/95	7	90	10	95	104	235	364	193	119	181	58	13	64	154	134
BD31	Pinole Point	02/17/95	7	32	4	14	25	46	72	29	22	34	7	ND	21	31	22
BD41	Davis Point	02/17/95	7	12	3	10	16	28	37	18	14	7	22	2	8	18	14
BD50	Napa River	02/17/95	7	49	8	47	63	137	169	93	66	98	36	8	50	89	74
BF10	Pacheco Creek	02/16/95	7	5	ND	4	3	15	16	4	3	5	2	ND	ND	4	3
BF21	Grizzly Bay	02/16/95	7	21	3	21	39	54	95	49	37	58	12	4	44	52	43
BF40	Honker Bay	02/16/95	7	36	6	35	46	81	104	71	49	71	24	9	54	77	58
BG20	Sacramento River	02/16/95	7	6	2	3	5	7	10	5	4	5	2	ND	ND	5	4
BG30	San Joaquin River	02/16/95	7	2	ND	2	2	3	3	2	2	3	1	ND	36	2	1
BA10	Coyote Creek	08/30/95	9	84	11	69	99	162	216	157	105	181	38	18	51	174	153
BA21	South Bay	08/29/95	9	121	15	93	122	189	250	183	116	209	37	25	49	193	177
BA30	Dumbarton Bridge	08/30/95	9	150	21	128	155	265	355	244	147	266	56	28	65	237	223
BA41	Redwood Creek	08/29/95	9	84	9	79	114	173	234	184	115	182	46	20	55	192	178
BB15	San Bruno Shoal	08/29/95	9	102	13	92	101	166	224	180	110	175	33	22	48	187	166
BB30	Oyster Point	08/30/95	9	73	7	73	78	133	181	135	83	136	38	15	41	141	128
BB70	Alameda	08/28/95	9	212	53	174	182	223	300	204	109	188	45	25	53	157	144
BC11	Yerba Buena Island	08/28/95	9	70	10	63	72	103	133	108	71	111	25	12	46	112	99
BC21	Horseshoe Bay	08/28/95	9	94	9	69	86	127	165	105	60	119	21	12	32	98	94
BC32	Richardson Bay	08/28/95	9	130	14	125	148	259	332	236	142	231	76	25	69	209	206
BC41	Point Isabel	08/28/95	9	148	17	125	158	251	313	214	123	207	32	24	60	183	173
BC60	Red Rock	08/25/95	9	1	ND	1	1	2	2	2	1	2	ND	ND	ND	2	1
BD15	Petaluma River	08/25/95	9	47	6	58	82	136	195	151	105	170	23	15	71	185	166
BD22	San Pablo Bay	08/25/95	9	129	16	138	156	246	338	250	154	243	55	29	66	231	216
BD31	Pinole Point	08/25/95	9	31	4	23	32	45	57	40	25	43	5	5	19	44	36
BD41	Davis Point	08/25/95	9	11	1	4	7	14	15	9	6	9	3	1	ND	10	8
BD50	Napa River	08/25/95	9	38	6	41	55	85	112	79	56	100	95	11	49	94	76
BF10	Pacheco Creek	08/24/95	9	64	4	14	22	43	36	12	10	21	3	1	9	12	10
BF21	Grizzly Bay	08/24/95	9	27	4	26	34	45	61	49	37	60	7	6	49	64	48
BF40	Honker Bay	08/24/95	9	25	3	22	33	46	63	43	34	53	10	5	39	56	45
BG20	Sacramento River	08/24/95	9	3	1	4	6	6	9	6	4	7	2	ND	ND	6	5
BG30	San Joaquin River	08/24/95	9	3	ND	2	4	4	5	3	2	3	ND	ND	45	3	2

Table 14. PCB concentrations in sediment, 1995.

. = no data ND = not detected, M = matrix interference. Data in dry weight.

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 007/9	PCB 008/5	PCB 015	PCB 016/32	PCB 018	PCB 022/51	PCB 024/27	PCB 025	PCB 028	PCB 029	PCB 031	PCB 033/53/20	PCB 037/42/59	PCB 040	PCB 041/64	PCB 044	PCB 045	PCB 046
				ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g
BA10	Coyote Creek	02/22/95	7	5	ND	ND	ND	ND	ND	0.72	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA21	South Bay	02/21/95	7	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	02/21/95	7	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA41	Redwood Creek	02/21/95	7	11	ND	ND	ND	ND	ND	1.10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB15	San Bruno Shoal	02/21/95	7	5	ND	ND	ND	ND	ND	0.76	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB30	Oyster Point	02/20/95	7	4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB70	Alameda	02/21/95	7	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	02/20/95	7	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	02/20/95	7	11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC32	Richardson Bay	02/20/95	7	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	02/20/95	7	4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC60	Red Rock	02/17/95	7	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	02/17/95	7	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	02/17/95	7	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	02/17/95	7	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD41	Davis Point	02/17/95	7	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	02/17/95	7	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF10	Pacheco Creek	02/16/95	7	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF21	Grizzly Bay	02/16/95	7	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	02/16/95	7	6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	02/16/95	7	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	02/16/95	7	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	08/30/95	9	18	ND	ND	ND	0.93	ND	ND	ND	ND	0.56	ND	ND	ND	ND	ND	M	ND	ND	ND
BA21	South Bay	08/29/95	9	15	ND	ND	ND	0.83	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BA30	Dumbarton Bridge	08/30/95	9	21	ND	ND	ND	0.90	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BA41	Redwood Creek	08/29/95	9	17	ND	0.50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BB15	San Bruno Shoal	08/29/95	9	11	ND	0.67	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BB30	Oyster Point	08/30/95	9	11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BB70	Alameda	08/28/95	9	4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BC11	Yerba Buena Island	08/28/95	9	4	ND	0.77	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BC21	Horseshoe Bay	08/28/95	9	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BC32	Richardson Bay	08/28/95	9	12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BC41	Point Isabel	08/28/95	9	9	ND	0.53	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BC60	Red Rock	08/25/95	9	0	ND	0.30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BD15	Petaluma River	08/25/95	9	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BD22	San Pablo Bay	08/25/95	9	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BD31	Pinole Point	08/25/95	9	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BD41	Davis Point	08/25/95	9	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BD50	Napa River	08/25/95	9	6	ND	0.75	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BF10	Pacheco Creek	08/24/95	9	3	ND	0.41	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BF21	Grizzly Bay	08/24/95	9	3	ND	0.79	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BF40	Honker Bay	08/24/95	9	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BG20	Sacramento River	08/24/95	9	1	ND	0.53	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND
BG30	San Joaquin River	08/24/95	9	1	ND	0.64	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M	ND	ND	ND

Table 14. PCB concentrations in sediment, 1995 (continued).
. = no data, ND = not detected, M = matrix interference. Data in dry weight.

Station Code	Station	Date	Cruise	PCB 047/48/75	PCB 049	PCB 052	PCB 056/60	PCB 066	PCB 070	PCB 074	PCB 082	PCB 083	PCB 084	PCB 085	PCB 087/115	PCB 088	PCB 092	PCB 097	PCB 099	PCB 100	PCB 101/90
				ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g
BA10	Coyote Creek	02/22/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA21	South Bay	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA41	Redwood Creek	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	0.52	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB15	San Bruno Shoal	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB30	Oyster Point	02/20/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB70	Alameda	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.70
BC11	Yerba Buena Island	02/20/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.45	ND	ND	ND	ND	ND	0.43
BC21	Horseshoe Bay	02/20/95	7	ND	ND	ND	ND	0.43	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.66	ND	ND	ND
BC32	Richardson Bay	02/20/95	7	ND	ND	ND	ND	0.51	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	02/20/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC60	Red Rock	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD41	Davis Point	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF10	Pacheco Creek	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF21	Grizzly Bay	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	08/30/95	9	ND	ND	0.54	ND	0.71	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.80
BA21	South Bay	08/29/95	9	ND	ND	ND	ND	0.60	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.75
BA30	Dumbarton Bridge	08/30/95	9	ND	ND	0.66	ND	0.70	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.71	ND	1.33
BA41	Redwood Creek	08/29/95	9	ND	ND	0.64	ND	ND	0.43	ND	ND	ND	ND	ND	0.59	ND	ND	ND	0.74	ND	1.29
BB15	San Bruno Shoal	08/29/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.46	ND	0.67
BB30	Oyster Point	08/30/95	9	ND	ND	ND	ND	0.58	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.50
BB70	Alameda	08/28/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	08/28/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	08/28/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.34
BC32	Richardson Bay	08/28/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.62
BC41	Point Isabel	08/28/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.53
BC60	Red Rock	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD41	Davis Point	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	08/25/95	9	ND	ND	0.54	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF10	Pacheco Creek	08/24/95	9	ND	ND	ND	1.89	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF21	Grizzly Bay	08/24/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	08/24/95	9	ND	ND	ND	0.54	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	08/24/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	08/24/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 14. PCB concentrations in sediment, 1995 (continued).
. = no data, ND = not detected, M = matrix interference. Data in dry weight.

Station Code	Station	Date	Cruise	Sum of PCBs (SFEI)	PCB 105	PCB 107/108/144	PCB 110/77	PCB 118	PCB 128	PCB 129	PCB 136	PCB 137/176	PCB 138/160	PCB 141/179	PCB 146	PCB 149/123	PCB 151	PCB 153/132	PCB 156/171	PCB 158	PCB 167	PCB 170/190
				ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g
BA10	Coyote Creek	02/22/95	7	5	ND	ND	.	ND	1.24	ND	ND	ND	0.57	ND	ND	0.45	ND	0.55	ND	ND	ND	0.47
BA21	South Bay	02/21/95	7	3	ND	ND	.	ND	1.62	ND	ND	ND	ND	ND	ND	ND	ND	0.59	ND	ND	ND	0.87
BA30	Dumbarton Bridge	02/21/95	7	5	ND	ND	.	ND	2.18	ND	ND	ND	0.62	ND	ND	ND	ND	0.81	ND	ND	ND	1.24
BA41	Redwood Creek	02/21/95	7	11	ND	ND	.	ND	1.91	ND	ND	ND	0.63	ND	ND	0.48	ND	0.66	ND	ND	ND	5.27
BB15	San Bruno Shoal	02/21/95	7	5	ND	ND	.	ND	1.56	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.56
BB30	Oyster Point	02/20/95	7	4	ND	ND	.	ND	2.10	ND	ND	ND	0.52	ND	ND	ND	ND	0.65	ND	ND	ND	0.58
BB70	Alameda	02/21/95	7	9	ND	ND	.	0.75	2.02	ND	ND	ND	1.33	ND	ND	0.66	ND	1.78	ND	ND	ND	0.64
BC11	Yerba Buena Island	02/20/95	7	7	ND	ND	.	0.49	1.38	ND	ND	ND	0.89	ND	ND	0.70	ND	0.79	ND	ND	ND	0.66
BC21	Horseshoe Bay	02/20/95	7	11	ND	ND	.	0.49	2.15	ND	ND	ND	0.54	ND	ND	0.64	ND	0.62	ND	ND	0.47	3.27
BC32	Richardson Bay	02/20/95	7	5	ND	ND	.	ND	3.15	ND	ND	ND	0.39	ND	ND	0.51	ND	ND	ND	ND	ND	0.67
BC41	Point Isabel	02/20/95	7	4	ND	ND	.	ND	2.48	ND	ND	ND	ND	ND	ND	ND	ND	0.73	ND	ND	ND	0.52
BC60	Red Rock	02/17/95	7	0	ND	ND	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	02/17/95	7	3	ND	ND	.	ND	0.86	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.76
BD22	San Pablo Bay	02/17/95	7	2	ND	ND	.	ND	1.67	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	02/17/95	7	0	ND	ND	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD41	Davis Point	02/17/95	7	0	ND	ND	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	02/17/95	7	1	ND	ND	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.77
BF10	Pacheco Creek	02/16/95	7	1	ND	ND	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.02
BF21	Grizzly Bay	02/16/95	7	1	ND	ND	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.24
BF40	Honker Bay	02/16/95	7	6	ND	ND	.	ND	ND	ND	ND	ND	0.62	ND	ND	ND	ND	ND	ND	ND	ND	5.20
BG20	Sacramento River	02/16/95	7	0	ND	ND	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.49
BG30	San Joaquin River	02/16/95	7	0	ND	ND	.	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.42
BA10	Coyote Creek	08/30/95	9	18	0.54	ND	1.28	2.08	ND	ND	ND	ND	2.38	ND	ND	0.81	ND	2.23	ND	ND	ND	M
BA21	South Bay	08/29/95	9	15	0.58	ND	1.14	1.88	ND	ND	ND	ND	2.24	ND	ND	0.65	ND	2.14	ND	ND	ND	M
BA30	Dumbarton Bridge	08/30/95	9	21	0.78	ND	1.75	2.61	ND	ND	ND	ND	2.74	ND	ND	0.80	ND	2.61	ND	ND	ND	M
BA41	Redwood Creek	08/29/95	9	17	0.53	ND	1.66	1.65	ND	ND	ND	ND	2.38	ND	ND	0.97	ND	2.63	ND	ND	ND	M
BB15	San Bruno Shoal	08/29/95	9	11	ND	ND	0.95	0.89	ND	ND	ND	ND	1.61	ND	ND	0.66	ND	1.87	ND	ND	ND	M
BB30	Oyster Point	08/30/95	9	11	ND	ND	0.80	1.22	ND	ND	ND	ND	1.77	ND	ND	0.63	ND	1.62	ND	ND	ND	M
BB70	Alameda	08/28/95	9	4	ND	ND	ND	ND	ND	ND	ND	ND	1.10	ND	ND	ND	ND	1.44	ND	ND	ND	M
BC11	Yerba Buena Island	08/28/95	9	4	ND	ND	ND	ND	ND	ND	ND	ND	1.15	ND	ND	ND	ND	1.20	ND	ND	ND	M
BC21	Horseshoe Bay	08/28/95	9	5	ND	ND	0.35	0.53	ND	ND	ND	ND	0.93	ND	ND	ND	ND	0.87	ND	ND	ND	M
BC32	Richardson Bay	08/28/95	9	12	ND	ND	0.93	1.12	ND	ND	ND	ND	1.96	ND	ND	0.69	ND	1.89	ND	ND	ND	M
BC41	Point Isabel	08/28/95	9	9	ND	ND	0.79	0.75	ND	ND	ND	ND	1.39	ND	ND	0.54	ND	1.48	ND	ND	ND	M
BC60	Red Rock	08/25/95	9	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M
BD15	Petaluma River	08/25/95	9	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M
BD22	San Pablo Bay	08/25/95	9	3	ND	ND	0.48	ND	ND	ND	ND	ND	0.74	ND	ND	ND	ND	0.81	ND	ND	ND	M
BD31	Pinole Point	08/25/95	9	1	ND	ND	ND	ND	ND	ND	ND	ND	0.50	ND	ND	ND	ND	0.44	ND	ND	ND	M
BD41	Davis Point	08/25/95	9	0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M
BD50	Napa River	08/25/95	9	6	ND	ND	0.60	ND	ND	ND	ND	ND	0.99	ND	ND	ND	ND	1.07	ND	ND	ND	M
BF10	Pacheco Creek	08/24/95	9	3	ND	ND	ND	ND	ND	ND	ND	ND	0.36	ND	ND	ND	ND	ND	ND	ND	ND	M
BF21	Grizzly Bay	08/24/95	9	3	ND	ND	ND	ND	ND	ND	ND	ND	0.81	ND	ND	ND	ND	0.82	ND	ND	ND	M
BF40	Honker Bay	08/24/95	9	3	ND	ND	0.52	ND	ND	ND	ND	ND	0.82	ND	ND	ND	ND	0.81	ND	ND	ND	M
BG20	Sacramento River	08/24/95	9	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M
BG30	San Joaquin River	08/24/95	9	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	M

Table 14. PCB concentrations in sediment, 1995 (continued).
. = no data, ND = not detected, M = matrix interference. Data in dry weight.

Station Code	Station	Date	Cruise	PCB 172	PCB 174	PCB 177	PCB 178	PCB 180	PCB 183	PCB 185	PCB 187/182/159	PCB 189	PCB 191	PCB 194	PCB 195/208	PCB 196/203	PCB 200	PCB 201	PCB 205	PCB 206	PCB 209
				ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g
BA10	Coyote Creek	02/22/95	7	ND	ND	0.61	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA21	South Bay	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA41	Redwood Creek	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB15	San Bruno Shoal	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB30	Oyster Point	02/20/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB70	Alameda	02/21/95	7	ND	ND	ND	ND	0.85	ND	ND	0.52	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	02/20/95	7	ND	ND	0.81	ND	0.52	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	02/20/95	7	ND	ND	ND	ND	1.51	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC32	Richardson Bay	02/20/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	02/20/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC60	Red Rock	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD41	Davis Point	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF10	Pacheco Creek	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF21	Grizzly Bay	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	08/30/95	9	ND	ND	0.74	0.95	1.65	0.54	ND	0.85	ND	ND	ND	ND	ND	ND	0.59	ND	ND	ND
BA21	South Bay	08/29/95	9	ND	ND	0.62	1.22	1.43	ND	ND	0.73	ND	ND	ND	ND	ND	ND	0.65	ND	ND	ND
BA30	Dumbarton Bridge	08/30/95	9	ND	0.60	0.60	1.32	1.60	ND	ND	0.74	ND	ND	ND	ND	ND	ND	0.69	ND	ND	ND
BA41	Redwood Creek	08/29/95	9	ND	0.51	ND	ND	1.16	ND	ND	0.69	ND	ND	ND	ND	ND	ND	0.50	ND	ND	0.42
BB15	San Bruno Shoal	08/29/95	9	ND	0.53	ND	ND	1.12	ND	ND	0.68	ND	ND	ND	ND	ND	ND	0.50	ND	ND	0.43
BB30	Oyster Point	08/30/95	9	ND	0.51	0.53	0.69	1.31	ND	ND	0.68	ND	ND	ND	ND	ND	ND	0.60	ND	ND	ND
BB70	Alameda	08/28/95	9	ND	ND	ND	ND	1.34	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	08/28/95	9	ND	ND	ND	ND	1.22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	08/28/95	9	ND	ND	ND	0.46	0.70	ND	ND	0.36	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC32	Richardson Bay	08/28/95	9	ND	0.52	0.45	1.34	1.35	0.43	ND	0.47	ND	ND	ND	ND	ND	ND	0.42	ND	ND	ND
BC41	Point Isabel	08/28/95	9	ND	0.52	ND	ND	1.00	ND	ND	0.48	ND	ND	ND	ND	ND	ND	0.50	ND	ND	0.47
BC60	Red Rock	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	08/25/95	9	ND	ND	ND	0.69	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	08/25/95	9	ND	ND	ND	ND	0.67	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD41	Davis Point	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	08/25/95	9	ND	ND	ND	ND	0.84	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.72
BF10	Pacheco Creek	08/24/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF21	Grizzly Bay	08/24/95	9	ND	ND	ND	ND	0.70	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	08/24/95	9	ND	ND	ND	ND	0.79	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	08/24/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	08/24/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 15. Pesticide concentrations in sediment samples, 1995.
ND = not detected. Data in dry weight.

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 (SFEI)	Alpha-Chlordane	Gamma-Chlordane	cis-Nonachlor	trans-Nonachlor
				ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g
BA10	Coyote Creek	02/22/95	7	1.322	ND	ND	ND	0.532	0.79	ND	ND	ND	ND	ND	ND
BA21	South Bay	02/21/95	7	0.924	ND	ND	ND	0.456	0.469	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	02/21/95	7	0.94	ND	ND	ND	0.492	0.448	ND	ND	ND	ND	ND	ND
BA41	Redwood Creek	02/21/95	7	0.846	ND	ND	ND	0.422	0.424	ND	ND	ND	ND	ND	ND
BB15	San Bruno Shoal	02/21/95	7	0.753	ND	ND	ND	0.401	0.353	ND	ND	ND	ND	ND	ND
BB30	Oyster Point	02/20/95	7	0.883	ND	ND	ND	0.511	0.372	ND	ND	ND	ND	ND	ND
BB70	Alameda	02/21/95	7	1.255	ND	ND	ND	0.777	0.478	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	02/20/95	7	1.765	0.202	ND	ND	1.03	0.532	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	02/20/95	7	2.021	0.275	ND	ND	1.232	0.513	ND	0.257	0.257	ND	ND	ND
BC32	Richardson Bay	02/20/95	7	1.343	0.258	ND	ND	0.624	0.461	ND	ND	ND	ND	ND	ND
BC41	Point Isabel	02/20/95	7	1.344	ND	ND	ND	0.93	0.413	ND	ND	ND	ND	ND	ND
BC60	Red Rock	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	02/17/95	7	0.893	ND	ND	ND	0.473	0.42	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	02/17/95	7	1.038	ND	ND	ND	0.552	0.486	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	02/17/95	7	0.594	ND	ND	ND	ND	0.594	ND	ND	ND	ND	ND	ND
BD41	Davis Point	02/17/95	7	0.836	ND	ND	ND	0.32	0.516	ND	ND	ND	ND	ND	ND
BD50	Napa River	02/17/95	7	1.285	ND	ND	ND	0.691	0.594	ND	ND	ND	ND	ND	ND
BF10	Pacheco Creek	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF21	Grizzly Bay	02/16/95	7	1.068	ND	ND	ND	0.587	0.481	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	02/16/95	7	1.668	ND	ND	ND	0.641	1.027	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	02/16/95	7	0.422	ND	ND	ND	0.169	0.253	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	08/30/95	9	6.87	0.74	ND	ND	2.91	2.7	0.52	1.69	0.44	0.32	0.39	0.54
BA21	South Bay	08/29/95	9	5.6	0.52	ND	ND	2.55	2.02	0.51	0.94	0.29	ND	0.31	0.34
BA30	Dumbarton Bridge	08/30/95	9	4.68	0.52	ND	ND	2.14	1.68	0.34	0.25	ND	ND	0.25	ND
BA41	Redwood Creek	08/29/95	9	2.47	0.46	ND	ND	1.05	0.96	ND	ND	ND	ND	ND	ND
BB15	San Bruno Shoal	08/29/95	9	2.88	0.64	ND	ND	1.35	0.89	ND	ND	ND	ND	ND	ND
BB30	Oyster Point	08/30/95	9	2.79	0.39	ND	ND	1.43	0.97	ND	ND	ND	ND	ND	ND
BB70	Alameda	08/28/95	9	4.63	1.08	ND	ND	2.07	1.48	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	08/28/95	9	6.52	0.64	ND	ND	2.18	1.31	2.39	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	08/28/95	9	2.32	0.24	ND	ND	1.4	0.68	ND	ND	ND	ND	ND	ND
BC32	Richardson Bay	08/28/95	9	3.15	0.39	ND	ND	1.56	0.91	0.29	ND	ND	ND	ND	ND
BC41	Point Isabel	08/28/95	9	4.03	0.76	ND	ND	2.1	1.17	ND	ND	ND	ND	ND	ND
BC60	Red Rock	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	08/25/95	9	1.44	ND	ND	ND	0.95	0.49	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	08/25/95	9	3.98	0.72	ND	ND	1.56	1.46	0.24	ND	ND	ND	ND	ND
BD31	Pinole Point	08/25/95	9	3.57	0.49	ND	ND	1.29	1.54	0.25	ND	ND	ND	ND	ND
BD41	Davis Point	08/25/95	9	1.07	ND	ND	ND	0.49	0.58	ND	ND	ND	ND	ND	ND
BD50	Napa River	08/25/95	9	4.77	0.67	ND	ND	2.12	1.98	ND	ND	ND	ND	ND	ND
BF10	Pacheco Creek	08/24/95	9	1.3	0.21	ND	ND	0.48	0.61	ND	ND	ND	ND	ND	ND
BF21	Grizzly Bay	08/24/95	9	4.57	0.56	ND	ND	1.93	1.61	0.47	ND	ND	ND	ND	ND
BF40	Honker Bay	08/24/95	9	4.17	0.62	ND	ND	1.75	1.8	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	08/24/95	9	1.02	ND	ND	ND	0.46	0.56	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	08/24/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 15. Pesticide concentrations in sediment samples, 1995 (continued).
ND = not detected. Data in dry weight.

Station Code	Station	Date	Cruise	Heptachlor	Heptachlor Epoxide	Oxychlordane	Aldrin	Dieldrin	Endrin	Alpha-HCH	Beta-HCH	Delta-HCH	Gamma-HCH	Hexachlorobenzene	Mirex
				ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g
BA10	Coyote Creek	02/22/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA21	South Bay	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA41	Redwood Creek	02/21/95	7	ND	ND	ND	ND	ND	ND	0.262	ND	ND	ND	ND	ND
BB15	San Bruno Shoal	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB30	Oyster Point	02/20/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB70	Alameda	02/21/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	02/20/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	02/20/95	7	ND	ND	ND	ND	ND	ND	0.33	ND	ND	ND	ND	ND
BC32	Richardson Bay	02/20/95	7	ND	ND	ND	ND	ND	ND	0.291	ND	ND	ND	ND	ND
BC41	Point Isabel	02/20/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC60	Red Rock	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD41	Davis Point	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	02/17/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF10	Pacheco Creek	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF21	Grizzly Bay	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF40	Honker Bay	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	02/16/95	7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	08/30/95	9	ND	ND	ND	ND	0.34	ND	ND	0.41	ND	ND	ND	ND
BA21	South Bay	08/29/95	9	ND	ND	ND	ND	0.33	ND	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	08/30/95	9	ND	ND	ND	ND	ND	ND	ND	0.31	ND	ND	ND	ND
BA41	Redwood Creek	08/29/95	9	ND	ND	ND	ND	0.27	ND	ND	ND	ND	ND	ND	ND
BB15	San Bruno Shoal	08/29/95	9	ND	ND	ND	ND	0.22	ND	ND	ND	ND	ND	ND	ND
BB30	Oyster Point	08/30/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB70	Alameda	08/28/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC11	Yerba Buena Island	08/28/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.32	0.51	ND
BC21	Horseshoe Bay	08/28/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.56	ND
BC32	Richardson Bay	08/28/95	9	ND	ND	ND	ND	ND	ND	ND	0.28	ND	ND	ND	ND
BC41	Point Isabel	08/28/95	9	ND	ND	ND	ND	0.29	ND	ND	ND	ND	ND	ND	ND
BC60	Red Rock	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD22	San Pablo Bay	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD31	Pinole Point	08/25/95	9	ND	ND	ND	ND	0.23	ND	0.4	ND	ND	ND	ND	ND
BD41	Davis Point	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	08/25/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF10	Pacheco Creek	08/24/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF21	Grizzly Bay	08/24/95	9	ND	ND	ND	ND	0.27	ND	ND	ND	ND	ND	0.45	ND
BF40	Honker Bay	08/24/95	9	ND	ND	ND	ND	0.25	ND	ND	ND	ND	ND	0.31	ND
BG20	Sacramento River	08/24/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	08/24/95	9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 16. Sediment toxicity data for 1995 RMP cruises.

			Mytilus		*Eohaustorius*	
Station Code	**Station**	**Date**	**Mean % Normal Development**	**SD - Mean % Normal Development**	**Mean % Survival**	**SD - Mean % Survival**
Control	N/A	N/A	95	2.6	96	4.2
BA21	South Bay	02/22/95	92	4	76*	6.5
BA41	Redwood Creek	02/21/95	94	5.9	75*	11.2
BB15	San Bruno Shoal	02/21/95	90	7.8	77*	9.7
BB70	Alameda	02/21/95	97	3.3	54*	23
BC11	Yerba Buena Island	02/20/95	93	8	89	9.6
BC21	Horseshoe Bay	02/20/95	90	2.8	86	9.6
BC60	Red Rock	02/17/95	39*	5	97	4.5
BD41	Davis Point	02/17/95	94	5.4	94	8.2
BD50	Napa River	02/17/95	92	5.9	78*	13
BF21	Grizzly Bay	02/16/95	0*	0	80*	9.4
BG20	Sacramento River	02/16/95	0*	0	95	6.1
BG30	San Joaquin River	02/16/95	0*	0	80*	7.9

			Mytilus		*Eohaustorius*	
Station Code	**Station**	**Date**	**Mean % Normal Development**	**SD - Mean % Normal Development**	**Mean % Survival**	**SD - Mean % Survival**
Control	N/A	N/A	[109]	6	100	0
BA21	South Bay	08/29/95	97	9	91	9
BA41	Redwood Creek	08/29/95	98	16	63*	26
BB15	San Bruno Shoal	08/29/95	[101]	6	83	11
BB70	Alameda	08/28/95	85*	8	86	13
BC11	Yerba Buena Island	08/28/95	77*	8	54*	19
BC21	Horseshoe Bay	08/28/95	99	3	89*	4
BC60	Red Rock	08/25/95	95	10	94	4
BD41	Davis Point	08/25/95	100	3	96	2
BD50	Napa River	08/25/95	100	8	85*	4
BF21	Grizzly Bay	08/24/95	39*	2	93	4
BG20	Sacramento River	08/24/95	0*	0	100	0
BG30	San Joaquin River	08/24/95	0*	0	96	4

* Significantly different from laboratory controls based on separate-variance t-tests (1 tailed, alpha = 0.01).
[ ] Values are >100% because more larvae were counted at the end of the test than inoculated embryos at the beginning of the test.

Table 17. Bivalve condition index and survival, 1995.
. = no data, NA = not analyzed

Station Code	Station	Date	Cruise	Species	Condition Index–Mean	Condition Index–Standard Deviation	Survival Per Species (%)
BA10	Coyote Creek	4/25/95	7	CGIG	0.089	0.008	96.6
BA30	Dumbarton Bridge	4/25/95	7	MCAL	0.103	0.01	18.1
BA40	Redwood Creek	4/25/95	7	MCAL	0.136	0.03	17.5
BB71	Alameda	4/25/95	7	MCAL	0.109	0.004	92.5
BC10	Yerba Buena Island	4/25/95	7	MCAL	0.113	0.003	91.9
BC21	Horseshoe Bay	4/26/95	7	MCAL	0.104	0.004	97.5
BC61	Red Rock	4/26/95	7	MCAL	0.077	0.004	36.5
BD15	Petaluma River	4/26/95	7	CFLU	0.144	0.013	65
BD15	Petaluma River	4/26/95	7	CGIG	.	.	0
BD20	San Pablo Bay	4/26/95	7	CGIG	0.075	0.004	91.9
BD30	Pinole Point	4/26/95	7	MCAL	.	.	0
BD40	Davis Point	4/26/95	7	CGIG	0.061	0.005	76.5
BD50	Napa River	4/26/95	7	CGIG	0.033	0.002	83.2
BF20	Grizzly Bay	4/27/95	7	CFLU	0.134	0.006	88.8
BF20	Grizzly Bay	4/27/95	7	CGIG	.	.	0
BF20	Grizzly Bay	4/27/95	7	OLUR	.	.	0
BG20	Sacramento River	4/27/95	7	CFLU	0.116	0.007	62.3
BG30	San Joaquin River	4/27/95	7	CFLU	0.123	0.005	70.6
T-0	Lake Isabella	1/20/95	7	CFLU	0.159	0.005	NA
T-0	Dabob Bay, WA	1/20/95	7	CGIG	0.055	0.003	NA
T-0	Bodega Head	1/20/95	7	MCAL	0.074	0.002	NA
T-1	Dabob Bay, WA	6/1/95	7	CGIG	0.108	0.011	NA
T-1	Bodega Head	6/15/95	7	MCAL	0.089	0.002	NA
T-1	Lake Isabella	6/16/95	7	CFLU	0.164	0.008	NA
BA10	Coyote Creek	9/12/95	9	CGIG	0.04	0.002	60
BA30	Dumbarton Bridge	9/12/95	9	MCAL	0.059	0.002	89
BA40	Redwood Creek	9/12/95	9	MCAL	0.059	0.001	96
BB70	Alameda	9/12/95	9	MCAL	0.083	0.002	99
BC10	Yerba Buena Island	9/12/95	9	MCAL	0.085	0.003	97
BC21	Horseshoe Bay	9/13/95	9	MCAL	0.131	0.007	98
BC21	Horseshoe Bay	9/13/95	9	OLUR	.	.	88
BC61	Red Rock	9/13/95	9	MCAL	0.072	0.003	99
BC61	Red Rock	9/13/95	9	OLUR	.	.	97
BD15	Petaluma River	9/13/95	9	CFLU	.	.	2
BD15	Petaluma River	9/13/95	9	CGIG	0.06	0.01	25
BD15	Petaluma River	9/13/95	9	OLUR	.	.	0
BD20	San Pablo Bay	9/13/95	9	CGIG	NA	NA	NA
BD30	Pinole Point	9/13/95	9	MCAL	0.067	0.002	99
BD30	Pinole Point	9/13/95	9	OLUR	.	.	97
BD40	Davis Point	9/13/95	9	CGIG	0.11	0.03	64
BD40	Davis Point	9/13/95	9	OLUR	.	.	50
BD50	Napa River	9/13/95	9	CGIG	0.06	0.01	33
BF20	Grizzly Bay	9/14/95	9	CFLU	0.099	0.003	96
BF20	Grizzly Bay	9/14/95	9	OLUR	.	.	0
BG20	Sacramento River	9/14/95	9	CFLU	0.085	0.005	90
BG30	San Joaquin River	9/14/95	9	CFLU	0.091	0.004	76
T-0	Lake Isabella	6/16/95	9	CFLU	0.164	0.008	NA
T-0	Tomales Bay	6/16/95	9	CGIG	0.15	0.01	NA
T-0	Bodega Head	6/16/95	9	MCAL	0.089	0.002	NA
T-1	Lake Isabella	9/14/95	9	CFLU	0.137	.	.
T-1	Tomales Bay	9/14/95	9	CGIG	0.149	.	.
T-1	Bodega Head	9/14/95	9	MCAL	0.106	.	.

CGIG–*Crassostrea gigas* , CFLU–*Corbicula fluminea* , MCAL–*Mytilus californianus* , OLUR–*Ostrea lurida*

Table 18. Trace element concentrations in bivalve tissues, 1995.
. = no data, ND = not detected. Data expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading.

Station Code	Station	Date	Cruise	Species	Ag	Al	As	Cd	Cr	Cu	Hg	Ni
					mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
BA10	Coyote Creek	4/25/95	7	CGIG	6.25	417	5.6	10.6	5.6	218	0.174	5
BA30	Dumbarton Bridge	4/25/95	7	MCAL	0.13	326	10.9	2.1	34.4	9	0.222	29
BA40	Redwood Creek	4/25/95	7	MCAL	0.24	286	9.1	3.1	21.4	7	0.181	18
BB71	Alameda	4/25/95	7	MCAL	0.16	786	12.0	3.9	19.4	10	0.233	17
BC10	Yerba Buena Island	4/25/95	7	MCAL	0.09	955	10.8	3.4	21.8	9	0.250	18
BC21	Horseshoe Bay	4/26/95	7	MCAL	0.23	699	13.2	4.7	43.2	12	0.284	35
BC61	Red Rock	4/26/95	7	MCAL	0.16	1042	10.8	6.9	61.9	12	0.277	51
BD15	Petaluma River	4/26/95	7	CFLU	0.17	534	19.0	0.5	6.0	38	0.146	7
BD20	San Pablo Bay	4/26/95	7	CGIG	2.39	403	7.4	16.4	18.7	282	0.139	15
BD40	Davis Point	4/26/95	7	CGIG	5.33	871	9.8	20.0	16.0	245	0.158	13
BD50	Napa River	4/26/95	7	CGIG	2.37	425	7.9	36.5	77.2	285	0.138	62
BF20	Grizzly Bay	4/27/95	7	CFLU	0.11	437	18.8	0.6	12.0	46	0.150	9
BG20	Sacramento River	4/27/95	7	CFLU	0.06	187	18.3	0.4	5.8	26	0.149	5
BG30	San Joaquin River	4/27/95	7	CFLU	0.05	104	19.9	0.3	9.0	17	0.158	7
T-0	Lake Isabella	1/20/95	7	CFLU	0.08	94	16.7	0.6	8.2	45	0.121	6
T-0	Dabob Bay, WA	1/20/95	7	CGIG	3.60	14	8.7	6.7	20.3	110	0.103	15
T-0	Bodega Head	1/20/95	7	MCAL	0.13	188	14.9	8.5	63.8	10	0.301	54
BA10	Coyote Creek	9/12/95	9	CGIG	2.16	435	16.4	16.2	9.1	867	0.349	8
BA30	Dumbarton Bridge	9/12/95	9	MCAL	0.44	250	14.0	7.7	14.3	7	0.292	13
BA40	Redwood Creek	9/12/95	9	MCAL	0.36	305	16.3	7.4	31.3	7	0.313	26
BB71	Alameda	9/12/95	9	MCAL	0.27	383	17.2	7.9	42.2	10	0.358	32
BC10	Yerba Buena Island	9/12/95	9	MCAL	0.27	626	13.9	6.8	6.5	9	0.370	6
BC21	Horseshoe Bay	9/13/95	9	MCAL	0.24	350	10.3	4.5	4.8	8	0.165	4
BC61	Red Rock	9/13/95	9	MCAL	0.09	604	15.3	5.2	9.5	8	0.320	7
BD15	Petaluma River	9/13/95	9	CGIG	3.59	262	10.6	17.3	5.3	520	0.239	4
BD30	Pinole Point	9/13/95	9	MCAL	0.19	390	18.3	7.4	11.9	8	0.390	10
BD40	Davis Point	9/13/95	9	CGIG	4.30	382	10.0	15.4	6.9	513	0.301	5
BD50	Napa River	9/13/95	9	CGIG	5.60	342	10.7	14.1	13.9	519	0.165	11
BF20	Grizzly Bay	9/14/95	9	CFLU	0.20	371	23.6	0.8	4.6	60	0.303	3
BG20	Sacramento River	9/14/95	9	CFLU	0.15	320	23.8	1.0	8.8	59	0.289	6
BG30	San Joaquin River	9/14/95	9	CFLU	0.18	383	23.8	1.0	6.7	60	0.295	5
T-0	Lake Isabella	6/16/95	9	CFLU	0.09	141	18.3	0.6	1.3	37	0.168	1
T-0	Tomales Bay	6/16/95	9	CGIG	1.74	166	9.1	7.1	3.2	106	0.230	2
T-0	Bodega Head	6/16/95	9	MCAL	0.09	181	18.8	5.5	4.4	5	0.288	4

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus* * Tins are reported in terms of total tin.

Table 18. Trace element concentrations in bivalve tissues, 1995 (continued).
. = no data, ND = not detected. Data expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading.

Station Code	Station	Date	Cruise	Species	Pb	Se	Zn	DBT	MBT	TBT	TTBT
					mg/kg	mg/kg	mg/kg	µg/kg Sn*	µg/kg Sn*	µg/kg Sn*	µg/kg Sn*
BA10	Coyote Creek	4/25/95	7	CGIG	0.52	4.0	1443	ND	ND	53	ND
BA30	Dumbarton Bridge	4/25/95	7	MCAL	0.69	1.9	114	ND	ND	42	ND
BA40	Redwood Creek	4/25/95	7	MCAL	0.33	2.1	69	12	ND	23	ND
BB71	Alameda	4/25/95	7	MCAL	0.27	4.5	157	11	ND	53	ND
BC10	Yerba Buena Island	4/25/95	7	MCAL	2.50	3.1	124	14	ND	73	ND
BC21	Horseshoe Bay	4/26/95	7	MCAL	0.43	4.4	179	10	ND	57	ND
BC61	Red Rock	4/26/95	7	MCAL	0.63	3.4	193	ND	ND	63	ND
BD15	Petaluma River	4/26/95	7	CFLU	0.44	1.6	84	ND	ND	50	ND
BD20	San Pablo Bay	4/26/95	7	CGIG	0.23	5.4	1312	ND	ND	112	ND
BD40	Davis Point	4/26/95	7	CGIG	0.29	6.5	1282	ND	ND	111	ND
BD50	Napa River	4/26/95	7	CGIG	0.29	6.2	1613	ND	ND	127	ND
BF20	Grizzly Bay	4/27/95	7	CFLU	0.50	1.4	68	12	ND	33	ND
BG20	Sacramento River	4/27/95	7	CFLU	0.07	1.7	33	10	ND	17	ND
BG30	San Joaquin River	4/27/95	7	CFLU	0.09	1.9	29	9	ND	26	ND
T-0	Lake Isabella	1/20/95	7	CFLU	0.13	1.6	68	ND	ND	8	ND
T-0	Dabob Bay, WA	1/20/95	7	CGIG	0.14	1.6	859	ND	ND	39	ND
T-0	Bodega Head	1/20/95	7	MCAL	0.89	3.4	198	ND	ND	ND	ND
BA10	Coyote Creek	9/12/95	9	CGIG	1.32	11.0	2050	ND	ND	18	ND
BA30	Dumbarton Bridge	9/12/95	9	MCAL	2.13	3.3	237	ND	ND	1	ND
BA40	Redwood Creek	9/12/95	9	MCAL	2.87	3.1	303	ND	ND	10	ND
BB71	Alameda	9/12/95	9	MCAL	2.09	3.3	266	22	ND	24	ND
BC10	Yerba Buena Island	9/12/95	9	MCAL	2.13	3.4	213	ND	ND	68	ND
BC21	Horseshoe Bay	9/13/95	9	MCAL	1.49	4.3	127	ND	ND	36	ND
BC61	Red Rock	9/13/95	9	MCAL	1.91	2.8	200	ND	ND	23	ND
BD15	Petaluma River	9/13/95	9	CGIG	0.49	9.7	1217	ND	ND	26	ND
BD30	Pinole Point	9/13/95	9	MCAL	1.79	2.7	217	ND	ND	14	ND
BD40	Davis Point	9/13/95	9	CGIG	0.69	4.2	1207	ND	ND	72	ND
BD50	Napa River	9/13/95	9	CGIG	0.54	7.2	1257	16	ND	55	ND
BF20	Grizzly Bay	9/14/95	9	CFLU	0.37	2.9	92	41	ND	48	ND
BG20	Sacramento River	9/14/95	9	CFLU	0.24	2.4	91	ND	ND	23	ND
BG30	San Joaquin River	9/14/95	9	CFLU	0.25	2.3	96	ND	ND	22	37.80
T-0	Lake Isabella	6/16/95	9	CFLU	0.14	1.6	72	ND	ND	ND	ND
T-0	Tomales Bay	6/16/95	9	CGIG	0.17	4.3	454	ND	ND	2	ND
T-0	Bodega Head	6/16/95	9	MCAL	1.26	5.1	150	ND	ND	1	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, 1995.

. = no data, ND = not detected. Data expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading. LPAHs= low molecular weight PAHs, HPAHs = high molecular weight PAHs.

Station Code	Station	Date	Cruise	Species	Total PAHs (SFEI)	Total LPAHs (SFEI)	Total HPAHs (SFEI)	1-Methylnaphthalene	1-Methylphenanthrene	2,3,5-Trimethylnaphthalene	2,6-Dimethylnaphthalene	2-Methylnaphthalene	Acenaphthene	Acenaphthylene	Anthracene	Benz(a)anthracene	Benzo(a)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
BA10	Coyote Creek	04/25/95	7	CGIG	557	10	547	ND	ND	ND	ND	ND	ND	ND	10	24	22
BA30	Dumbarton Bridge	04/25/95	7	MCAL	65	19	46	ND	ND	ND	ND	19	ND	ND	ND	ND	ND
BA40	Redwood Creek	04/25/95	7	MCAL	54	0	54	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB71	Alameda	04/25/95	7	MCAL	209.04	22	188	ND	12	ND	ND	ND	ND	ND	9	9	12
BC10	Yerba Buena Island	04/25/95	7	MCAL	128.29	15	113	ND	ND	ND	ND	ND	8	ND	7	ND	4
BC21	Horseshoe Bay	04/26/95	7	MCAL	127.95	36	92	ND	ND	ND	ND	19	9	ND	8	ND	4
BC60	Red Rock	04/26/95	7	MCAL	105.04	0	105	ND	ND	ND	ND	ND	ND	ND	ND	ND	6
BD15	Petaluma River	04/26/95	7	CFLU	561.18	56	505	ND	9	12	8	17	ND	ND	11	10	6
BD20	San Pablo Bay	04/26/95	7	CGIG	311.05	0	311	ND	ND	ND	ND	ND	ND	ND	ND	12	12
BD40	Davis Point	04/26/95	7	CGIG	597.06	21	577	ND	ND	ND	21	ND	ND	ND	ND	39	15
BD50	Napa River	04/26/95	7	CGIG	658.16	0	658	ND	ND	ND	ND	ND	ND	ND	ND	44	14
BF20	Grizzly Bay	04/27/95	7	CFLU	211.46	5	206	ND	5	ND	ND	ND	ND	ND	ND	7	ND
BG20	Sacramento River	04/27/95	7	CFLU	231.25	26	205	ND	7	ND	11	ND	ND	ND	8	14	ND
BG30	San Joaquin River	04/27/95	7	CFLU	190.74	5	186	ND	5	ND	ND	ND	ND	ND	ND	8	ND
T-0	Lake Isabella	01/20/95	7	CFLU	154.68	32	123	8	ND	ND	6	12	ND	ND	6	ND	ND
T-0	Dabob Bay, WA	01/20/95	7	CGIG	145.69	9	137	ND	ND	ND	ND	ND	ND	ND	9	7	ND
T-0	Bodega Head	01/20/95	7	MCAL	63.94	21	42	ND	ND	ND	8	10	ND	ND	3	ND	ND
BA10	Coyote Creek	09/12/95	9	CGIG	809.09	8	801	ND	ND	ND	ND	ND	ND	ND	8	30	49
BA30	Dumbarton Bridge	09/12/95	9	MCAL	68.39	7	62	ND	ND	ND	ND	ND	ND	ND	7	ND	ND
BA40	Redwood Creek	09/12/95	9	MCAL	111.17	17	94	ND	ND	ND	ND	11	ND	ND	6	6	6
BB71	Alameda	09/12/95	9	MCAL	129.72	16	114	ND	ND	ND	ND	8	ND	ND	8	6	6
BC10	Yerba Buena Island	09/12/95	9	MCAL	184.08	27	158	ND	ND	ND	ND	9	ND	5	13	8	6
BC21	Horseshoe Bay	09/13/95	9	MCAL	131.97	26	106	ND	ND	ND	ND	12	5	ND	9	5	3
BC60	Red Rock	09/13/95	9	MCAL	101.26	16	85	ND	ND	ND	ND	8	ND	ND	8	5	4
BD15	Petaluma River	09/13/95	9	CGIG	1139.27	37	1102	ND	ND	ND	ND	11	ND	8	18	45	73
BD30	Pinole Point	09/13/95	9	MCAL	72.74	8	64	ND	ND	ND	ND	ND	ND	ND	8	ND	ND
BD40	Davis Point	09/13/95	9	CGIG	735.28	17	719	ND	ND	ND	ND	ND	ND	ND	17	46	25
BD50	Napa River	09/13/95	9	CGIG	783.52	70	713	7	12	ND	7	11	7	7	19	46	23
BF20	Grizzly Bay	09/14/95	9	CFLU	527.17	45	482	ND	ND	ND	ND	7	ND	9	29	23	7
BG20	Sacramento River	09/14/95	9	CFLU	302.38	30	272	ND	ND	ND	ND	13	ND	6	11	12	ND
BG30	San Joaquin River	09/14/95	9	CFLU	354.58	39	315	ND	13	ND	ND	8	ND	6	14	15	ND
T-0	Lake Isabella	06/16/95	9	CFLU	66.26	8	58	ND	ND	ND	ND	6	ND	ND	3	ND	ND
T-0	Tomales Bay	06/16/95	9	CGIG	134.07	47	87	12	ND	ND	7	26	ND	ND	2	3	ND
T-0	Bodega Head	06/16/95	9	MCAL	30.69	10	21	ND	ND	ND	ND	8	ND	ND	2	ND	ND

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus*

Table 19. PAH concentrations in bivalve tissues, 1995 (continued).

. = no data, ND = not detected. Data expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading. LPAHs = low molecular weight PAHs, HPAHS = high molecular weight PAHs

Station Code	Station	Date	Cruise	Species	Benzo(b)fluoranthene	Benzo(e)pyrene	Benzo(ghi)perylene	Benzo(k)fluoranthene	Biphenyl	Chrysene	Dibenz(a,h)anthracene	Dibenzothiophene	Fluoranthene	Fluorene	Indeno(1,2,3-cd)pyrene	Naphthalene	Perylene	Phenanthrene	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	µg/kg
BA10	Coyote Creek	04/25/95	7	CGIG	53	55	25	17	ND	59	ND	ND	88	ND	11	22	ND	37	135
BA30	Dumbarton Bridge	04/25/95	7	MCAL	ND	ND	ND	ND	ND	5	ND	ND	6	ND	ND	16	ND	11	9
BA40	Redwood Creek	04/25/95	7	MCAL	ND	ND	ND	ND	ND	8	ND	ND	6	ND	ND	20	ND	12	8
BB71	Alameda	04/25/95	7	MCAL	11	7	9	4	ND	15	ND	ND	24	6	6	22	ND	26	35
BC10	Yerba Buena Island	04/25/95	7	MCAL	6	5	5	ND	ND	8	ND	ND	15	8	ND	22	ND	22	19
BC21	Horseshoe Bay	04/26/95	7	MCAL	5	5	ND	ND	ND	11	ND	ND	ND	10	ND	23	ND	33	ND
BC60	Red Rock	04/26/95	7	MCAL	ND	5	ND	ND	ND	10	ND	ND	15	ND	ND	30	ND	20	20
BD15	Petaluma River	04/26/95	7	CFLU	11	15	9	5	ND	34	ND	5	147	10	5	14	ND	61	172
BD20	San Pablo Bay	04/26/95	7	CGIG	20	21	8	8	ND	28	ND	ND	67	ND	ND	27	ND	28	82
BD40	Davis Point	04/26/95	7	CGIG	35	28	14	34	ND	49	ND	ND	129	14	7	30	ND	67	115
BD50	Napa River	04/26/95	7	CGIG	36	37	ND	24	ND	75	ND	ND	153	ND	ND	47	ND	67	163
BF20	Grizzly Bay	04/27/95	7	CFLU	4	6	ND	ND	5	22	ND	ND	66	ND	ND	ND	ND	27	69
BG20	Sacramento River	04/27/95	7	CFLU	ND	2	ND	ND	ND	15	ND	ND	69	ND	ND	14	ND	32	59
BG30	San Joaquin River	04/27/95	7	CFLU	4	4	ND	ND	ND	19	ND	ND	42	ND	ND	16	ND	26	67
T-0	Lake Isabella	01/20/95	7	CFLU	ND	ND	ND	ND	ND	ND	ND	3	24	11	ND	20	4	43	18
T-0	Dabob Bay, WA	01/20/95	7	CGIG	8	6	ND	ND	ND	ND	ND	ND	34	ND	ND	36	ND	11	34
T-0	Bodega Head	01/20/95	7	MCAL	ND	ND	ND	ND	ND	ND	ND	2	4	ND	ND	19	ND	13	4
BA10	Coyote Creek	09/12/95	9	CGIG	131	100	68	28	ND	64	7	4	91	ND	29	17	23	21	139
BA30	Dumbarton Bridge	09/12/95	9	MCAL	5	3	4	ND	ND	ND	ND	4	7	ND	ND	13	ND	11	14
BA40	Redwood Creek	09/12/95	9	MCAL	8	5	5	ND	ND	ND	ND	5	10	ND	ND	17	4	10	18
BB71	Alameda	09/12/95	9	MCAL	6	5	5	4	ND	9	ND	3	16	ND	ND	15	ND	13	27
BC10	Yerba Buena Island	09/12/95	9	MCAL	9	6	6	ND	ND	12	ND	3	27	9	4	14	3	24	27
BC21	Horseshoe Bay	09/13/95	9	MCAL	4	3	5	ND	ND	5	ND	3	17	6	ND	12	ND	24	18
BC60	Red Rock	09/13/95	9	MCAL	6	3	5	ND	ND	6	ND	2	10	5	ND	12	3	10	13
BD15	Petaluma River	09/13/95	9	CGIG	146	111	56	40	ND	88	6	5	143	ND	35	15	64	17	258
BD30	Pinole Point	09/13/95	9	MCAL	6	4	4	ND	ND	ND	ND	5	8	ND	ND	14	ND	10	13
BD40	Davis Point	09/13/95	9	CGIG	73	59	19	20	ND	62	3	5	158	ND	11	10	28	24	175
BD50	Napa River	09/13/95	9	CGIG	61	53	20	21	ND	65	5	7	145	8	10	12	32	27	177
BF20	Grizzly Bay	09/14/95	9	CFLU	19	24	8	3	ND	43	ND	3	130	ND	4	12	15	19	172
BG20	Sacramento River	09/14/95	9	CFLU	10	12	5	3	ND	33	ND	5	59	ND	ND	12	6	10	105
BG30	San Joaquin River	09/14/95	9	CFLU	9	13	4	ND	ND	37	ND	2	58	ND	ND	12	6	11	148
T-0	Lake Isabella	06/16/95	9	CFLU	3	2	ND	ND	ND	7	ND	1	16	ND	ND	6	3	6	13
T-0	Tomales Bay	06/16/95	9	CGIG	ND	2	ND	ND	ND	8	ND	2	18	ND	ND	16	4	12	23
T-0	Bodega Head	06/16/95	9	MCAL	ND	ND	ND	ND	ND	ND	ND	2	ND	ND	ND	11	ND	4	4

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus*

Table 20. PCB congeners in bivalve tissues, 1995.
M = matrix interference, ND = not detected. Data expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading.

Station Code	Station	Date	Cruise	Species	Total PCBs (SFEI)	PCB 007/9	PCB 008/5	PCB 015	PCB 016/32	PCB 018	PCB 022/51	PCB 024/27	PCB 025	PCB 026	PCB 028	PCB 029	PCB 031
					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
BA10	Coyote Creek	4/25/95	7	CGIG	457	ND	ND	ND	ND	ND	ND	ND	3.1	ND	2.2	3.4	ND
BA30	Dumbarton Bridge	4/25/95	7	MCAL	191	ND	ND	ND	ND	ND	ND	ND	3.2	ND	ND	ND	ND
BA40	Redwood Creek	4/25/95	7	MCAL	174	ND	ND	ND	ND	ND	ND	ND	3.0	ND	ND	ND	ND
BB71	Alameda	4/25/95	7	MCAL	180	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC10	Yerba Buena Island	4/25/95	7	MCAL	171	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	4/26/95	7	MCAL	95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC60	Red Rock	4/26/95	7	MCAL	79	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	4/26/95	7	CFLU	286	ND	ND	ND	ND	1.7	ND	ND	4.0	ND	ND	1.5	ND
BD20	San Pablo Bay	4/26/95	7	CGIG	144	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD40	Davis Point	4/26/95	7	CGIG	92	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	4/26/95	7	CGIG	148	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF20	Grizzly Bay	4/27/95	7	CFLU	271	ND	ND	ND	3.9	2.7	2.8	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	4/27/95	7	CFLU	219	ND	ND	ND	4.1	ND	ND	1.9	ND	ND	ND	ND	ND
BG30	San Joaquin River	4/27/95	7	CFLU	228	ND	ND	ND	4.3	ND	ND	ND	ND	ND	ND	2.7	ND
T-0	Lake Isabella	1/20/95	7	CFLU	70	ND	ND	ND	ND	ND	ND	ND	ND	2.4	ND	ND	ND
T-0	Dabob Bay, WA	1/20/95	7	CGIG	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Bodega Head	1/20/95	7	MCAL	22	ND	M	ND	1.3	ND	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	9/12/95	9	CGIG	219	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	9/12/95	9	MCAL	130	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA40	Redwood Creek	9/12/95	9	MCAL	132	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB71	Alameda	9/12/95	9	MCAL	118	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC10	Yerba Buena Island	9/12/95	9	MCAL	96	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	9/13/95	9	MCAL	48	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC60	Red Rock	9/13/95	9	MCAL	55	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	9/13/95	9	CGIG	322	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD30	Pinole Point	9/13/95	9	MCAL	59	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD40	Davis Point	9/13/95	9	CGIG	205	2.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	9/13/95	9	CGIG	159	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF20	Grizzly Bay	9/14/95	9	CFLU	269	ND	ND	ND	ND	2.6	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	9/14/95	9	CFLU	236	ND	ND	ND	ND	4.0	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	9/14/95	9	CFLU	223	ND	ND	1.5	ND	4.0	ND	ND	2.1	ND	ND	ND	ND
T-0	Lake Isabella	6/16/95	9	CFLU	14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Tomales Bay	6/16/95	9	CGIG	64	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Bodega Head	6/16/95	9	MCAL	10	ND	2.8	ND	ND	ND	ND	1.0	ND	ND	ND	ND	ND

CGIG—*Crassostrea gigas*, CFLU—*Corbicula fluminea*, MCAL—*Mytilus californianus*

Table 20. PCB congeners in bivalve tissues, 1995 (continued).
M = matrix interference, ND = not detected. Data expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading.

Station Code	Station	Date	Cruise	Species	PCB 033/53/20	PCB 037/42/59	PCB 040	PCB 041/64	PCB 044	PCB 045	PCB 046	PCB 047/48/75	PCB 049	PCB 052	PCB 056/60	PCB 066	PCB 070
					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
BA10	Coyote Creek	4/25/95	7	CGIG	ND	ND	ND	M	7.1	ND	ND	3.0	6.0	12.8	5.7	3.6	10.6
BA30	Dumbarton Bridge	4/25/95	7	MCAL	ND	ND	ND	M	5.1	ND	ND	ND	3.4	5.6	ND	1.8	5.0
BA40	Redwood Creek	4/25/95	7	MCAL	ND	ND	ND	M	5.4	ND	ND	ND	2.8	5.1	ND	ND	4.7
BB71	Alameda	4/25/95	7	MCAL	ND	ND	ND	M	2.5	ND	ND	ND	2.5	4.1	1.9	ND	3.0
BC10	Yerba Buena Island	4/25/95	7	MCAL	ND	ND	ND	M	2.8	ND	ND	ND	2.8	4.6	1.6	ND	3.7
BC21	Horseshoe Bay	4/26/95	7	MCAL	ND	ND	ND	M	1.9	ND	ND	ND	2.0	3.1	2.7	ND	ND
BC60	Red Rock	4/26/95	7	MCAL	ND	ND	ND	M	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	4/26/95	7	CFLU	ND	ND	ND	M	7.7	ND	ND	ND	4.1	16.4	3.9	1.9	15.2
BD20	San Pablo Bay	4/26/95	7	CGIG	ND	ND	ND	M	ND	ND	ND	ND	ND	3.1	3.7	ND	ND
BD40	Davis Point	4/26/95	7	CGIG	ND	ND	ND	M	ND	ND	ND	ND	ND	ND	3.5	ND	ND
BD50	Napa River	4/26/95	7	CGIG	ND	ND	ND	M	ND	ND	ND	ND	ND	5.3	7.3	ND	ND
BF20	Grizzly Bay	4/27/95	7	CFLU	ND	ND	ND	M	6.3	ND	ND	ND	3.1	15.8	4.8	ND	23.4
BG20	Sacramento River	4/27/95	7	CFLU	ND	1.1	ND	M	7.7	ND	ND	ND	3.7	15.2	5.4	ND	18.9
BG30	San Joaquin River	4/27/95	7	CFLU	ND	ND	ND	M	6.9	ND	ND	ND	2.9	17.9	4.5	2.2	19.4
T-0	Lake Isabella	1/20/95	7	CFLU	ND	ND	ND	M	3.9	ND	ND	ND	1.6	2.4	ND	3.4	3.2
T-0	Dabob Bay, WA	1/20/95	7	CGIG	ND	ND	ND	M	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Bodega Head	1/20/95	7	MCAL	ND	ND	ND	M	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	9/12/95	9	CGIG	ND	ND	ND	M	ND	ND	ND	2.9	2.6	2.4	ND	ND	2.3
BA30	Dumbarton Bridge	9/12/95	9	MCAL	ND	ND	ND	M	ND	ND	ND	ND	2.4	2.5	1.9	ND	3.1
BA40	Redwood Creek	9/12/95	9	MCAL	ND	ND	ND	M	2.0	ND	ND	ND	1.9	2.7	ND	ND	2.7
BB71	Alameda	9/12/95	9	MCAL	ND	ND	ND	M	ND	ND	ND	ND	1.5	2.6	1.3	ND	1.9
BC10	Yerba Buena Island	9/12/95	9	MCAL	ND	ND	ND	M	ND	ND	ND	ND	1.3	2.5	1.8	ND	2.2
BC21	Horseshoe Bay	9/13/95	9	MCAL	ND	ND	ND	M	ND	ND	ND	ND	1.1	1.8	ND	ND	1.4
BC60	Red Rock	9/13/95	9	MCAL	ND	ND	ND	M	ND	ND	ND	ND	ND	1.3	ND	ND	1.3
BD15	Petaluma River	9/13/95	9	CGIG	ND	ND	ND	M	3.4	ND	ND	1.9	ND	5.7	3.7	2.7	5.4
BD30	Pinole Point	9/13/95	9	MCAL	ND	ND	ND	M	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD40	Davis Point	9/13/95	9	CGIG	ND	ND	ND	M	2.2	ND	ND	1.7	2.5	3.6	3.0	ND	3.4
BD50	Napa River	9/13/95	9	CGIG	ND	ND	ND	M	1.6	ND	ND	ND	2.2	3.1	1.7	ND	2.9
BF20	Grizzly Bay	9/14/95	9	CFLU	ND	3.7	ND	M	8.0	ND	ND	ND	4.0	13.3	4.4	1.6	4.8
BG20	Sacramento River	9/14/95	9	CFLU	ND	4.7	ND	M	8.6	ND	ND	ND	3.7	14.2	4.1	1.7	4.1
BG30	San Joaquin River	9/14/95	9	CFLU	ND	3.9	ND	M	8.3	ND	ND	ND	5.1	13.4	3.5	1.8	4.7
T-0	Lake Isabella	6/16/95	9	CFLU	ND	ND	ND	M	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Tomales Bay	6/16/95	9	CGIG	ND	1.4	ND	M	3.5	ND	ND	ND	2.3	4.3	1.4	ND	1.2
T-0	Bodega Head	6/16/95	9	MCAL	ND	ND	ND	M	ND	ND	2.1	ND	ND	ND	ND	ND	ND

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus*

Table 20. PCB congeners in bivalve tissues, 1995 (continued).
M = matrix interference, ND = not detected. Data expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading.

Station Code	Station	Date	Cruise	Species	Total PCBs (SFEI)	PCB 074	PCB 082	PCB 083	PCB 084	PCB 085	PCB 087/115	PCB 088	PCB 092	PCB 097	PCB 099	PCB 100	PCB 101/90
					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
BA10	Coyote Creek	4/25/95	7	CGIG	457	5.1	3.6	ND	22.7	ND	5.4	8.6	9.8	8.7	12.4	ND	28.6
BA30	Dumbarton Bridge	4/25/95	7	MCAL	191	3.2	2.1	ND	9.8	ND	2.1	5.6	ND	4.4	4.2	ND	11.7
BA40	Redwood Creek	4/25/95	7	MCAL	174	2.9	ND	ND	5.2	ND	2.4	4.8	ND	4.8	4.2	ND	9.2
BB71	Alameda	4/25/95	7	MCAL	180	1.6	2.0	ND	3.5	ND	2.5	2.5	3.7	4.7	6.1	ND	11.0
BC10	Yerba Buena Island	4/25/95	7	MCAL	171	2.1	3.3	ND	5.4	ND	2.5	2.5	2.2	4.0	5.3	ND	11.2
BC21	Horseshoe Bay	4/26/95	7	MCAL	95	ND	2.2	ND	2.9	ND	ND	ND	2.5	3.0	3.3	ND	6.5
BC60	Red Rock	4/26/95	7	MCAL	79	ND	2.6	ND	6.2	ND	ND	ND	ND	3.4	3.1	ND	5.7
BD15	Petaluma River	4/26/95	7	CFLU	286	2.3	2.9	3.4	14.3	ND	1.9	6.0	6.3	9.0	6.1	ND	14.4
BD20	San Pablo Bay	4/26/95	7	CGIG	144	ND	5.2	ND	3.9	ND	ND	ND	3.6	5.6	5.1	ND	8.2
BD40	Davis Point	4/26/95	7	CGIG	92	ND	3.1	ND	3.1	ND	ND	ND	ND	3.2	3.5	ND	6.2
BD50	Napa River	4/26/95	7	CGIG	148	ND	ND	ND	5.8	ND	ND	ND	5.0	5.7	7.9	ND	9.0
BF20	Grizzly Bay	4/27/95	7	CFLU	271	1.7	8.2	1.5	3.9	ND	2.1	3.3	5.3	12.9	3.5	ND	7.9
BG20	Sacramento River	4/27/95	7	CFLU	219	1.8	6.2	ND	2.1	ND	1.6	1.9	5.0	10.7	3.2	ND	6.0
BG30	San Joaquin River	4/27/95	7	CFLU	228	ND	7.6	ND	4.1	ND	1.7	2.4	5.8	10.2	3.0	ND	7.1
T-0	Lake Isabella	1/20/95	7	CFLU	70	ND	ND	ND	ND	ND	ND	ND	1.5	3.7	1.7	ND	3.3
T-0	Dabob Bay, WA	1/20/95	7	CGIG	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Bodega Head	1/20/95	7	MCAL	22	ND	ND	ND	14.4	ND	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	9/12/95	9	CGIG	219	ND	ND	ND	ND	ND	3.3	ND	ND	4.2	8.7	.	14.6
BA30	Dumbarton Bridge	9/12/95	9	MCAL	130	ND	ND	ND	3.7	ND	2.2	1.9	ND	3.1	5.5	.	10.1
BA40	Redwood Creek	9/12/95	9	MCAL	132	ND	ND	ND	2.6	ND	1.9	ND	ND	2.6	6.0	.	9.7
BB71	Alameda	9/12/95	9	MCAL	118	ND	ND	ND	1.4	ND	1.6	ND	1.5	2.1	7.1	.	9.8
BC10	Yerba Buena Island	9/12/95	9	MCAL	96	ND	ND	ND	1.2	ND	ND	ND	ND	1.5	4.8	.	7.0
BC21	Horseshoe Bay	9/13/95	9	MCAL	48	ND	0.9	ND	1.7	ND	ND	ND	ND	1.1	3.2	.	4.0
BC60	Red Rock	9/13/95	9	MCAL	55	ND	ND	ND	ND	ND	ND	ND	ND	1.3	3.1	.	4.1
BD15	Petaluma River	9/13/95	9	CGIG	322	2.5	ND	3.4	4.8	ND	3.7	4.2	2.9	6.2	17.2	.	25.2
BD30	Pinole Point	9/13/95	9	MCAL	59	ND	ND	ND	2.7	ND	ND	ND	ND	2.2	2.5	.	4.0
BD40	Davis Point	9/13/95	9	CGIG	205	1.9	1.7	ND	5.3	ND	1.9	2.2	6.7	3.9	7.9	.	12.5
BD50	Napa River	9/13/95	9	CGIG	159	1.6	1.6	ND	4.2	ND	ND	1.8	5.8	3.1	6.7	.	9.7
BF20	Grizzly Bay	9/14/95	9	CFLU	269	2.1	2.8	1.2	6.5	ND	2.5	3.4	7.1	10.6	7.5	.	12.8
BG20	Sacramento River	9/14/95	9	CFLU	236	1.8	3.8	ND	4.1	ND	1.7	ND	6.2	9.1	4.1	.	10.7
BG30	San Joaquin River	9/14/95	9	CFLU	223	2.0	3.8	ND	4.8	ND	1.9	2.2	4.9	8.8	3.5	.	9.5
T-0	Lake Isabella	6/16/95	9	CFLU	14	ND	ND	ND	2.7	ND	ND	ND	ND	ND	1.1	.	1.9
T-0	Tomales Bay	6/16/95	9	CGIG	64	ND	2.1	ND	2.1	ND	ND	ND	1.3	2.9	2.9	.	4.6
T-0	Bodega Head	6/16/95	9	MCAL	10	ND	ND	ND	M	ND	ND	ND	ND	ND	ND	.	ND

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus*

Table 20. PCB congeners in bivalve tissues, 1995 (continued).
M = matrix interference, ND = not detected. Data expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading.

Station Code	Station	Date	Cruise	Species	PCB 105	PCB 107/108/144	PCB 110/77	PCB 118	PCB 128	PCB 129	PCB 136	PCB 137/176	PCB 138/160	PCB 141/179	PCB 146	PCB 149/123
					µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BA10	Coyote Creek	4/25/95	7	CGIG	4.1	9.9	24.4	20.4	2.8	ND	ND	3.7	41.3	11.5	6.2	32.1
BA30	Dumbarton Bridge	4/25/95	7	MCAL	1.9	3.1	10.9	8.9	2.1	ND	ND	2.0	17.7	5.5	3.6	13.3
BA40	Redwood Creek	4/25/95	7	MCAL	1.9	4.0	7.3	8.2	ND	ND	ND	2.3	18.3	5.6	3.4	12.7
BB71	Alameda	4/25/95	7	MCAL	1.7	3.7	9.3	7.5	1.8	ND	ND	3.7	20.6	3.1	3.1	12.2
BC10	Yerba Buena Island	4/25/95	7	MCAL	1.9	2.6	8.8	7.7	2.0	ND	ND	3.1	17.8	3.1	2.3	11.4
BC21	Horseshoe Bay	4/26/95	7	MCAL	ND	2.1	4.9	4.0	ND	ND	ND	2.4	12.8	2.2	ND	6.7
BC60	Red Rock	4/26/95	7	MCAL	ND	ND	5.1	3.1	ND	ND	ND	3.1	11.3	4.0	ND	5.8
BD15	Petaluma River	4/26/95	7	CFLU	2.7	2.6	11.4	14.3	3.7	2.1	ND	5.2	21.4	3.8	3.7	12.7
BD20	San Pablo Bay	4/26/95	7	CGIG	ND	3.9	7.4	5.6	2.6	ND	ND	5.9	16.8	4.1	ND	12.0
BD40	Davis Point	4/26/95	7	CGIG	ND	ND	5.3	3.6	ND	ND	ND	4.3	12.5	ND	ND	7.8
BD50	Napa River	4/26/95	7	CGIG	ND	ND	7.1	5.4	ND	ND	ND	6.4	18.3	4.4	ND	10.6
BF20	Grizzly Bay	4/27/95	7	CFLU	2.0	ND	8.6	9.8	8.7	3.8	ND	15.0	24.9	4.8	ND	10.6
BG20	Sacramento River	4/27/95	7	CFLU	1.8	ND	6.6	9.3	4.7	3.7	ND	11.0	19.4	3.3	ND	6.2
BG30	San Joaquin River	4/27/95	7	CFLU	1.9	ND	7.5	10.2	4.5	4.3	ND	8.7	17.7	5.8	ND	6.7
T-0	Lake Isabella	1/20/95	7	CFLU	ND	ND	3.2	7.0	ND	ND	ND	ND	6.3	7.4	ND	2.2
T-0	Dabob Bay, WA	1/20/95	7	CGIG	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Bodega Head	1/20/95	7	MCAL	ND	ND	ND	ND	ND	ND	ND	ND	2.2	ND	ND	ND
BA10	Coyote Creek	9/12/95	9	CGIG	2.2	5.0	10.5	14.9	ND	ND	ND	ND	22.0	3.4	5.9	16.7
BA30	Dumbarton Bridge	9/12/95	9	MCAL	ND	2.8	8.3	9.5	3.0	ND	ND	ND	16.5	ND	2.9	8.6
BA40	Redwood Creek	9/12/95	9	MCAL	1.9	2.8	7.5	8.9	2.5	ND	ND	ND	18.1	ND	3.4	8.7
BB71	Alameda	9/12/95	9	MCAL	1.8	2.6	6.3	6.7	1.9	ND	ND	ND	14.4	ND	2.8	7.5
BC10	Yerba Buena Island	9/12/95	9	MCAL	ND	1.8	4.8	7.2	ND	ND	ND	ND	11.7	ND	1.7	5.7
BC21	Horseshoe Bay	9/13/95	9	MCAL	ND	0.8	3.2	3.5	ND	ND	ND	ND	6.4	ND	ND	3.0
BC60	Red Rock	9/13/95	9	MCAL	ND	1.1	3.5	4.0	ND	ND	ND	ND	8.3	ND	ND	4.0
BD15	Petaluma River	9/13/95	9	CGIG	2.8	2.5	19.6	13.7	ND	ND	2.2	ND	24.5	1.9	6.5	32.0
BD30	Pinole Point	9/13/95	9	MCAL	ND	ND	4.2	5.2	ND	ND	ND	ND	9.3	ND	ND	4.2
BD40	Davis Point	9/13/95	9	CGIG	2.1	3.8	10.4	9.6	1.8	ND	ND	1.8	19.2	2.9	3.9	14.4
BD50	Napa River	9/13/95	9	CGIG	ND	3.1	8.8	8.0	ND	ND	ND	ND	15.2	2.9	2.9	11.7
BF20	Grizzly Bay	9/14/95	9	CFLU	3.0	3.5	13.9	14.0	4.4	ND	ND	5.5	25.1	3.6	3.5	13.7
BG20	Sacramento River	9/14/95	9	CFLU	3.5	2.5	9.8	14.4	2.1	ND	ND	4.8	20.9	3.3	2.1	9.0
BG30	San Joaquin River	9/14/95	9	CFLU	2.3	3.3	10.5	13.8	3.4	ND	ND	5.1	18.6	2.4	2.1	8.6
T-0	Lake Isabella	6/16/95	9	CFLU	ND	ND	ND	1.1	ND	ND	ND	ND	1.6	ND	ND	ND
T-0	Tomales Bay	6/16/95	9	CGIG	1.1	ND	3.8	5.6	ND	ND	ND	ND	5.4	1.5	ND	1.9
T-0	Bodega Head	6/16/95	9	MCAL	ND	ND	ND	ND	ND	ND	ND	ND	1.3	ND	ND	ND

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus*

Table 20. PCB congeners in bivalve tissues, 1995 (continued).
M = matrix interference, ND = not detected. Data expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading.

Station Code	Station	Date	Cruise	Species	Total PCBs (SFEI)	PCB 151	PCB 153/132	PCB 156/171	PCB 158	PCB 167	PCB 170/190	PCB 172	PCB 174	PCB 177	PCB 178	PCB 180	PCB 183
					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
BA10	Coyote Creek	4/25/95	7	CGIG	457	8.9	67.3	ND	ND	ND	ND	ND	ND	5.8	3.4	24.5	6.7
BA30	Dumbarton Bridge	4/25/95	7	MCAL	191	3.9	26.9	ND	ND	ND	ND	ND	ND	2.0	ND	10.1	3.7
BA40	Redwood Creek	4/25/95	7	MCAL	174	3.7	25.5	ND	ND	ND	ND	ND	ND	2.2	ND	11.6	4.2
BB71	Alameda	4/25/95	7	MCAL	180	3.3	27.7	ND	ND	2.0	ND	ND	ND	2.2	ND	13.1	4.6
BC10	Yerba Buena Island	4/25/95	7	MCAL	171	3.0	23.4	ND	ND	1.8	ND	ND	ND	1.6	ND	16.5	3.8
BC21	Horseshoe Bay	4/26/95	7	MCAL	95	ND	14.7	ND	ND	ND	ND	ND	ND	ND	ND	7.6	3.0
BC60	Red Rock	4/26/95	7	MCAL	79	ND	12.6	ND	ND	ND	ND	ND	ND	ND	ND	6.9	3.0
BD15	Petaluma River	4/26/95	7	CFLU	286	4.3	36.9	1.8	3.2	2.1	1.6	ND	ND	2.1	1.5	11.6	4.5
BD20	San Pablo Bay	4/26/95	7	CGIG	144	ND	20.9	ND	ND	ND	ND	ND	ND	ND	ND	12.9	5.2
BD40	Davis Point	4/26/95	7	CGIG	92	ND	15.3	ND	ND	ND	ND	ND	ND	ND	ND	11.5	3.6
BD50	Napa River	4/26/95	7	CGIG	148	ND	21.1	ND	ND	ND	ND	ND	ND	ND	ND	16.1	5.8
BF20	Grizzly Bay	4/27/95	7	CFLU	271	2.7	29.1	1.8	2.7	2.4	ND	ND	ND	ND	1.8	12.4	8.9
BG20	Sacramento River	4/27/95	7	CFLU	219	ND	25.7	1.9	2.6	2.0	ND	ND	ND	ND	ND	14.9	6.2
BG30	San Joaquin River	4/27/95	7	CFLU	228	2.5	26.7	2.0	2.5	1.9	ND	ND	ND	ND	1.4	12.2	5.2
T-0	Lake Isabella	1/20/95	7	CFLU	70	ND	15.9	ND	ND	ND	ND	ND	ND	ND	ND	3.8	ND
T-0	Dabob Bay, WA	1/20/95	7	CGIG	3	ND	3.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Bodega Head	1/20/95	7	MCAL	22	ND	2.6	ND	ND	1.5	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	9/12/95	9	CGIG	219	4.8	57.7	ND	ND	ND	5.6	ND	ND	3.4	ND	7.5	ND
BA30	Dumbarton Bridge	9/12/95	9	MCAL	130	2.4	24.0	ND	ND	ND	2.5	ND	ND	ND	ND	7.2	ND
BA40	Redwood Creek	9/12/95	9	MCAL	132	2.7	26.8	ND	ND	ND	ND	ND	ND	ND	ND	8.7	ND
BB71	Alameda	9/12/95	9	MCAL	118	2.1	21.9	ND	ND	ND	ND	ND	ND	1.5	ND	9.5	1.9
BC10	Yerba Buena Island	9/12/95	9	MCAL	96	1.6	19.0	ND	ND	ND	2.8	ND	ND	ND	ND	12.0	1.3
BC21	Horseshoe Bay	9/13/95	9	MCAL	48	ND	8.4	ND	ND	ND	1.5	ND	ND	ND	ND	4.0	ND
BC60	Red Rock	9/13/95	9	MCAL	55	ND	11.8	ND	ND	ND	3.7	ND	ND	ND	ND	4.5	ND
BD15	Petaluma River	9/13/95	9	CGIG	322	4.2	78.2	ND	ND	ND	7.6	ND	ND	4.8	ND	10.8	3.0
BD30	Pinole Point	9/13/95	9	MCAL	59	ND	10.6	ND	ND	ND	6.7	ND	ND	ND	ND	5.0	ND
BD40	Davis Point	9/13/95	9	CGIG	205	3.0	33.4	ND	ND	ND	3.9	ND	ND	2.0	ND	16.7	2.0
BD50	Napa River	9/13/95	9	CGIG	159	2.7	26.8	ND	ND	ND	4.9	ND	ND	1.7	ND	14.5	1.7
BF20	Grizzly Bay	9/14/95	9	CFLU	269	2.6	39.4	ND	ND	1.9	1.3	ND	ND	1.7	ND	20.4	4.1
BG20	Sacramento River	9/14/95	9	CFLU	236	1.7	36.9	ND	ND	1.7	ND	ND	ND	ND	ND	28.2	2.8
BG30	San Joaquin River	9/14/95	9	CFLU	223	1.9	29.5	ND	ND	1.8	ND	ND	ND	ND	ND	21.1	3.0
T-0	Lake Isabella	6/16/95	9	CFLU	14	ND	1.5	ND	ND	ND	1.6	ND	ND	ND	ND	ND	ND
T-0	Tomales Bay	6/16/95	9	CGIG	64	ND	11.9	ND	ND	ND	ND	ND	ND	ND	ND	3.1	ND
T-0	Bodega Head	6/16/95	9	MCAL	10	ND	1.1	ND	ND	ND	1.3	ND	ND	ND	ND	ND	ND

CGIG—*Crassostrea gigas*, CFLU—*Corbicula fluminea*, MCAL—*Mytilus californianus*

Table 20. PCB congeners in bivalve tissues, 1995 (continued).
M = matrix interference, ND = not detected. Data expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading.

Station Code	Station	Date	Cruise	Species	PCB 185	PCB 187/182/159	PCB 189	PCB 191	PCB 194	PCB 195/208	PCB 196/203	PCB 200	PCB 201	PCB 205	PCB 206	PCB 209
					µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/k
BA10	Coyote Creek	4/25/95	7	CGIG	ND	21.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	4/25/95	7	MCAL	ND	8.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA40	Redwood Creek	4/25/95	7	MCAL	ND	8.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB71	Alameda	4/25/95	7	MCAL	ND	8.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC10	Yerba Buena Island	4/25/95	7	MCAL	ND	6.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	4/26/95	7	MCAL	ND	4.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC60	Red Rock	4/26/95	7	MCAL	ND	3.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	4/26/95	7	CFLU	ND	8.3	ND	ND	ND	ND	1.4	ND	ND	ND	ND	ND
BD20	San Pablo Bay	4/26/95	7	CGIG	ND	8.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD40	Davis Point	4/26/95	7	CGIG	ND	5.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	4/26/95	7	CGIG	ND	7.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF20	Grizzly Bay	4/27/95	7	CFLU	1.7	6.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	4/27/95	7	CFLU	ND	3.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	4/27/95	7	CFLU	ND	3.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Lake Isabella	1/20/95	7	CFLU	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Dabob Bay, WA	1/20/95	7	CGIG	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Bodega Head	1/20/95	7	MCAL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA10	Coyote Creek	9/12/95	9	CGIG	ND	18.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA30	Dumbarton Bridge	9/12/95	9	MCAL	ND	5.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BA40	Redwood Creek	9/12/95	9	MCAL	ND	7.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BB71	Alameda	9/12/95	9	MCAL	ND	5.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC10	Yerba Buena Island	9/12/95	9	MCAL	ND	4.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	9/13/95	9	MCAL	ND	2.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BC60	Red Rock	9/13/95	9	MCAL	ND	2.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD15	Petaluma River	9/13/95	9	CGIG	ND	14.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD30	Pinole Point	9/13/95	9	MCAL	ND	2.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD40	Davis Point	9/13/95	9	CGIG	ND	10.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	9/13/95	9	CGIG	ND	8.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BF20	Grizzly Bay	9/14/95	9	CFLU	ND	8.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG20	Sacramento River	9/14/95	9	CFLU	ND	5.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BG30	San Joaquin River	9/14/95	9	CFLU	ND	5.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Lake Isabella	6/16/95	9	CFLU	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.5
T-0	Tomales Bay	6/16/95	9	CGIG	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-0	Bodega Head	6/16/95	9	MCAL	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, 1995.
ND = not detected. Data expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading.

Station Code	Station	Date	Cruise	Species	Sum DDTs (SFEI)	o,p'-DDD	o,p'-DDE	o,p'-DDT	p,p'-DDD	p,p'-DDE	p,p'-DDT	Sum Chlordanes (SFEI)	Alpha-Chlordane	Gamma-Chlordane	cis-Nonachlor	trans-Nonachlor
					µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg
BA10	Coyote Creek	4/25/95	7	CGIG	227	16.7	3.4	10.1	49.0	120.3	27.8	142.4	40.4	34.3	20.0	40.4
BA30	Dumbarton Bridge	4/25/95	7	MCAL	78	7.3	1.6	2.4	19.7	40.9	5.7	63.4	15.2	17.9	8.0	15.6
BA40	Redwood Creek	4/25/95	7	MCAL	57	5.1	ND	1.5	15.5	31.0	3.9	55.0	12.2	15.7	6.7	12.3
BB71	Alameda	4/25/95	7	MCAL	81	7.0	2.2	2.0	19.2	42.8	7.9	27.6	7.2	7.4	3.6	6.6
BC10	Yerba Buena Island	4/25/95	7	MCAL	82	6.8	2.7	3.6	19.1	40.9	9.1	34.0	10.4	8.5	4.3	8.1
BC21	Horseshoe Bay	4/26/95	7	MCAL	69	5.9	2.7	2.5	14.8	36.5	7.0	21.5	7.0	5.7	2.7	5.0
BC60	Red Rock	4/26/95	7	MCAL	87	7.8	3.7	2.4	17.6	46.8	8.6	28.9	10.1	7.7	3.4	6.0
BD15	Petaluma River	4/26/95	7	CFLU	213	14.5	8.0	5.1	50.2	122.5	13.2	79.5	22.5	18.6	12.4	19.7
BD20	San Pablo Bay	4/26/95	7	CGIG	166	12.5	3.9	7.7	29.8	94.7	17.8	33.2	8.3	7.6	6.5	10.8
BD40	Davis Point	4/26/95	7	CGIG	124	8.0	3.2	5.6	21.8	70.4	15.1	29.1	7.4	7.6	5.2	9.0
BD50	Napa River	4/26/95	7	CGIG	175	12.5	5.6	4.8	33.8	101.1	17.1	42.2	9.6	11.6	6.8	14.2
BF20	Grizzly Bay	4/27/95	7	CFLU	249	14.9	6.4	6.6	40.6	160.5	19.6	45.7	9.0	11.7	8.4	15.4
BG20	Sacramento River	4/27/95	7	CFLU	223	11.3	5.9	4.5	29.0	152.0	20.0	41.1	6.9	10.4	8.0	14.7
BG30	San Joaquin River	4/27/95	7	CFLU	246	11.9	6.9	5.9	35.3	166.4	20.2	48.8	10.2	11.3	7.8	16.0
T-0	Lake Isabella	1/20/95	7	CFLU	80	3.5	2.9	ND	11.0	62.7	ND	16.8	3.1	3.7	3.5	6.5
T-0	Dabob Bay, WA	1/20/95	7	CGIG	4	ND	ND	ND	ND	3.6	ND	0.0	ND	ND	ND	ND
T-0	Bodega Head	1/20/95	7	MCAL	15	1.9	0.7	ND	1.7	11.0	ND	8.6	6.4	1.5	ND	0.8
BA10	Coyote Creek	9/12/95	9	CGIG	66	5.2	1.5	2.6	12.0	43.5	1.3	20.9	6.2	3.5	4.4	6.8
BA30	Dumbarton Bridge	9/12/95	9	MCAL	41	4.4	0.9	1.8	12.1	22.3	ND	20.4	6.9	4.8	3.8	4.9
BA40	Redwood Creek	9/12/95	9	MCAL	31	3.3	ND	1.4	8.6	17.5	ND	16.3	5.7	4.1	2.8	3.7
BB71	Alameda	9/12/95	9	MCAL	30	2.9	1.1	0.9	8.9	14.0	2.0	9.6	3.6	2.2	1.5	2.2
BC10	Yerba Buena Island	9/12/95	9	MCAL	29	2.9	ND	0.7	9.5	14.2	1.6	8.8	3.4	2.3	1.1	1.9
BC21	Horseshoe Bay	9/13/95	9	MCAL	26	2.8	0.5	ND	10.0	11.9	1.1	6.0	2.3	1.5	0.7	1.5
BC60	Red Rock	9/13/95	9	MCAL	33	3.0	0.6	ND	9.9	18.5	1.3	7.9	3.1	2.0	1.1	1.7
BD15	Petaluma River	9/13/95	9	CGIG	182	12.3	4.3	2.3	52.8	106.2	4.1	19.2	5.4	4.1	4.0	5.7
BD30	Pinole Point	9/13/95	9	MCAL	50	4.8	ND	1.2	15.5	26.7	1.9	12.7	4.7	3.7	1.8	2.5
BD40	Davis Point	9/13/95	9	CGIG	146	10.1	3.1	3.2	37.9	84.9	6.6	25.1	6.9	5.7	5.0	7.5
BD50	Napa River	9/13/95	9	CGIG	120	8.6	2.2	2.1	29.7	73.3	4.7	20.1	5.3	4.6	3.7	6.4
BF20	Grizzly Bay	9/14/95	9	CFLU	217	13.7	2.7	1.0	52.7	135.6	11.4	40.1	9.8	8.9	6.9	13.4
BG20	Sacramento River	9/14/95	9	CFLU	236	14.0	3.6	2.0	37.4	161.3	17.4	35.5	8.5	7.5	5.7	12.7
BG30	San Joaquin River	9/14/95	9	CFLU	209	11.7	2.4	1.3	35.3	146.7	11.9	36.4	8.7	7.7	5.9	12.4
T-0	Lake Isabella	6/16/95	9	CFLU	19	0.8	1.0	0.6	3.3	10.9	2.2	7.9	2.4	1.0	2.3	2.2
T-0	Tomales Bay	6/16/95	9	CGIG	70	2.2	2.6	0.5	7.8	53.7	2.7	17.2	4.1	3.0	2.5	6.8
T-0	Bodega Head	6/16/95	9	MCAL	9	0.6	ND	ND	1.7	6.1	0.8	4.3	3.0	0.8	ND	0.5

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus*

Table 21. Pesticide concentrations in bivalve tissues, 1995 (continued).
ND = not detected. Data expressed as dry weight. T-0 = time of bivalve deployment into the Estuary from the source indicated under station name heading.

Station Code	Station	Date	Cruise	Species	Heptachlor	Heptachlor Epoxide	Oxychlordane	Aldrin	Dieldrin	Endrin	Alpha-HCH	Beta-HCH	Delta-HCH	Gamma-HCH	Hexachlorobenzene	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
BA10	Coyote Creek	4/25/95	7	CGIG	ND	3.3	4.0	ND	22.6	ND	2.1	ND	ND	3.0	ND	ND
BA30	Dumbarton Bridge	4/25/95	7	MCAL	ND	4.8	2.0	ND	31.7	2.6	2.9	0.9	ND	2.4	ND	ND
BA40	Redwood Creek	4/25/95	7	MCAL	ND	6.1	2.0	ND	37.1	ND	3.3	ND	ND	2.5	ND	ND
BB71	Alameda	4/25/95	7	MCAL	ND	1.7	1.0	ND	22.0	1.2	2.1	ND	ND	1.5	ND	ND
BC10	Yerba Buena Island	4/25/95	7	MCAL	ND	1.7	0.9	ND	23.0	1.3	2.2	ND	ND	1.3	ND	ND
BC21	Horseshoe Bay	4/26/95	7	MCAL	ND	1.2	ND	ND	17.0	ND	2.5	ND	ND	1.3	ND	ND
BC60	Red Rock	4/26/95	7	MCAL	ND	1.7	ND	ND	27.1	ND	2.5	ND	ND	1.3	ND	ND
BD15	Petaluma River	4/26/95	7	CFLU	ND	3.7	2.6	ND	18.7	3.9	1.9	ND	ND	10.5	1.5	ND
BD20	San Pablo Bay	4/26/95	7	CGIG	ND	ND	ND	ND	9.2	ND	2.3	ND	ND	ND	ND	ND
BD40	Davis Point	4/26/95	7	CGIG	ND	ND	ND	ND	7.4	ND	1.8	ND	ND	ND	ND	ND
BD50	Napa River	4/26/95	7	CGIG	ND	ND	ND	ND	14.2	ND	3.2	ND	ND	2.6	ND	ND
BF20	Grizzly Bay	4/27/95	7	CFLU	ND	ND	1.2	ND	22.2	2.5	1.8	ND	ND	9.2	1.6	ND
BG20	Sacramento River	4/27/95	7	CFLU	ND	ND	1.2	ND	21.5	ND	ND	ND	ND	10.8	1.4	ND
BG30	San Joaquin River	4/27/95	7	CFLU	ND	2.4	1.1	ND	20.4	2.4	1.7	0.7	ND	6.4	2.6	ND
T-0	Lake Isabella	1/20/95	7	CFLU	ND	ND	ND	ND	1.2	ND	1.8	ND	ND	6.1	0.7	ND
T-0	Dabob Bay, WA	1/20/95	7	CGIG	ND	ND	ND	ND	ND	ND	2.2	ND	ND	ND	ND	ND
T-0	Bodega Head	1/20/95	7	MCAL	ND	ND	ND	ND	9.5	1.3	2.6	0.8	ND	1.1	ND	ND
BA10	Coyote Creek	9/12/95	9	CGIG	ND	ND	ND	ND	ND	3.2	ND	ND	ND	2.9	ND	ND
BA30	Dumbarton Bridge	9/12/95	9	MCAL	ND	ND	ND	ND	10.2	1.9	1.5	ND	ND	1.5	ND	ND
BA40	Redwood Creek	9/12/95	9	MCAL	ND	ND	ND	ND	8.9	1.1	1.8	ND	ND	1.4	ND	ND
BB71	Alameda	9/12/95	9	MCAL	ND	ND	ND	ND	6.9	ND	1.3	ND	ND	0.8	ND	ND
BC10	Yerba Buena Island	9/12/95	9	MCAL	ND	ND	ND	ND	6.6	1.5	1.1	ND	ND	ND	ND	ND
BC21	Horseshoe Bay	9/13/95	9	MCAL	ND	ND	ND	ND	5.2	1.0	2.1	1.0	ND	0.9	ND	ND
BC60	Red Rock	9/13/95	9	MCAL	ND	ND	ND	ND	6.3	1.1	1.3	ND	ND	ND	ND	ND
BD15	Petaluma River	9/13/95	9	CGIG	ND	ND	ND	ND	3.5	ND	2.0	ND	ND	ND	ND	ND
BD30	Pinole Point	9/13/95	9	MCAL	ND	ND	ND	ND	12.2	3.4	2.3	ND	ND	1.7	1.1	ND
BD40	Davis Point	9/13/95	9	CGIG	ND	ND	ND	ND	5.4	5.4	1.5	ND	ND	3.0	ND	ND
BD50	Napa River	9/13/95	9	CGIG	ND	ND	ND	ND	4.4	3.4	1.2	ND	ND	2.3	ND	ND
BF20	Grizzly Bay	9/14/95	9	CFLU	ND	ND	1.0	3.4	9.6	ND	1.6	ND	ND	2.3	2.3	ND
BG20	Sacramento River	9/14/95	9	CFLU	ND	ND	1.1	2.2	11.4	ND	1.3	ND	ND	2.1	2.5	ND
BG30	San Joaquin River	9/14/95	9	CFLU	ND	0.7	0.8	ND	11.2	ND	1.3	ND	ND	2.4	5.2	ND
T-0	Lake Isabella	6/16/95	9	CFLU	ND	ND	ND	ND	1.0	0.6	2.5	1.1	ND	1.3	ND	ND
T-0	Tomales Bay	6/16/95	9	CGIG	ND	ND	0.8	ND	1.0	ND	1.7	ND	ND	2.5	1.9	ND
T-0	Bodega Head	6/16/95	9	MCAL	ND	ND	ND	ND	4.8	0.9	3.8	1.3	ND	1.0	0.5	ND

CGIG—*Crassostrea gigas* , CFLU—*Corbicula fluminea* , MCAL—*Mytilus californianus*