3.0 Sediment Monitoring

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3.1 Background

Sediments are monitored because they are a fundamental ecosystem component of the Bay, and they play a key role in the adsorption and transport of contaminants. Sediments serve as contaminant sources and sinks, and most contaminants are usually found in concentrations orders of magnitude higher in the upper few centimeters of sediments than in the water column. Information about sediments addresses aspects of all RMP Objectives (listed in the *Overview*). In this section, patterns and trends in sediment contamination are described (Objective 1) and compared to several sets of sediment quality guidelines (Objective 4), while sediment bioassays address contaminant effects (Objective 3).

Information about sediment contamination is used in making decisions related to many important management issues: the identification of sediment "toxic hot spots" and reference areas; the clean-up of numerous sites in the region which requires information about background contaminant levels; and the continued dredging throughout the Estuary which requires testing and comparisons to a reference, or background concentration. The RMP provides information that may be used to assess the condition of Estuary sediments. The San Francisco Estuary Institute's Contaminant Monitoring and Research Program uses information on sediment contamination to better understand the effects of contaminated sediments on benthic infauna, bottom-feeding fish, and other benthic organisms. Sediment contamination information was incorporated into the recent evaluation and redesign of the RMP (see *Introduction*, Grosso and Lowe 2001).

The geochemistry of sediments is complex, and in order to interpret contaminant concentrations measured in sediments, it is necessary to understand how hydrology (flows) and physical sediment characteristics may affect contaminant concentrations. An overview of Estuary hydrology is presented in *Section 2.5.1*. Conductivity, temperature, and depth (CTD) profiles of the water column were collected at all RMP sediment stations. Although not presented in this report, these data are available upon request from the San Francisco Estuary Institute. Several sediment quality parameters that may affect sediment contaminant concentrations (grain-size, organic carbon, ammonia, and sulfides) were also monitored and are listed in the *Data Tables* (see Table 11).

Sediment contaminant monitoring in 2000 included trace elements and trace organic contaminants at 22†RMP Base Program stations. Sediments were also monitored at two stations at the southern end of the Estuary in cooperation with the Regional Board and the cities of San Jose (station C-3-0) and Sunnyvale (station C-1-3). As part of the Estuary Interface Pilot Study, sediments were monitored at two additional stations in the southern end of the Estuary: Standish Dam on Coyote Creek (station BW10) and Alviso Slough near the mouth of the Guadalupe River (station BW15) (see Figure 3.17). For more information see *Results of the Estuary Interface Pilot Study, 1996-1999* (Leatherbarrow and Hoenicke 2002).

The locations of the 22 RMP, two Southern Slough (C-3-0, C-1-3), and two Estuary Interface sampling stations (BW10, BW15) are shown in Figure 1.1. Sediment samples were collected during the wet season (February) and dry season (July). However, as a result of the RMP redesign (see *Introduction*, Grosso and Lowe 2001), the 2000 wet season cruise differed from earlier cruises in that only four stations were sampled in the North Bay and Delta, rather than the standard set of 26 stations throughout the Estuary. Station names, codes, location, and sampling dates are shown in Table 1.3 in the *Introduction*. A complete list of all parameters measured in the 2000 sediment samples is included in Table 1.2 in the *Introduction*. A detailed description of methods of collection and analysis are presented in the *Description of Methods*. Table 1.2 in the *Introduction* lists parameters measured in sediment. Sediment quality parameters, station depths, and all contaminant concentrations are tabulated in *Data Tables* 11-16.

In order to compare sediment results among the major sub-regions of the Estuary, the RMP stations are separated into seven groups of stations (six base program plus the Southern Sloughs) in five Estuary segments based subjectively on geography. The segments used in 2000 are unchanged from previous years: the Southern Sloughs (C-1-3 and C-3-0), South

Bay (seven stations, BA10 through BB70), Central Bay (five stations, BC11 through BC60), Northern Estuary (eight stations, BD15 through BF40), and Rivers (BG20 and BG30). In addition, the Estuary Interface Pilot stations (BW10 and BW15) are included for comparative purposes. Stations with coarse sediments (>60% sand: one station in the wet season and five in the dry season) generally have considerably lower contaminant concentrations and are identified on Figures 3.1–3.15.

3.2 Sediment Quality Guidelines

Currently, no Basin Plan objectives or other regulatory criteria for sediment contaminant concentrations exist for the San Francisco Estuary. However, several sets of sediment quality guidelines (Table 3.1) may be used as informal screening tools for sediment contaminant concentrations, even though they have no regulatory status.

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

A set of sediment quality guidelines developed by the Regional Board and introduced in the *1997 RMP Annual Report* are also used. Ambient Sediment Concentration (ASC) values are derived from samples collected from the cleanest portions of the Estuary by the RMP (1991-1996) and by the Bay Protection and Toxic Cleanup Program (BPTCP) for their 1995 Reference Site study, and are used to distinguish "ambient" from "contaminated" conditions. Given the fact that virtually no San Francisco Estuary mixed surface layer sediments are free of anthropogenic pollutants this approach was thought to define contemporary ambient contaminant levels. Different ASC values are used for sandy (< 40% fines) and muddy (> 40% fines) sediments. For more detailed information on ASC values, see Gandesbery and Hetzel (1999) or Smith and Riege (1998). Both the Long *et al*. (1995) and the ASC guideline values are indicated for comparative purposes on the sediment contaminant concentration bar charts (Figures 3.1–3.15).

Presently the Regional Board is undertaking Total Maximum Daily Load (TMDL) processes which may result in the development of proposed sediment targets for certain pollutants on the "Impaired Waters" list (the 303(d) list). A sediment target for mercury of 0.4 mg/kg has already been developed and proposed (Abu-Saba and Tang 2000). Potentially, these target limits could be used as a new set of sediment quality guidelines, specific to the different segments of the San Francisco Estuary.

3.3 Sediment Bioassays

Sediment bioassays are performed to determine the potential for biological effects from exposure to sediment contamination. Two sediment bioassays were conducted at 13 of the RMP stations in July of 2000 (Figure 3.16). Sampling dates are listed in Table 1.3 in the *Introduction*. Amphipods (*Eohaustorius estuarius*) were exposed to whole sediment for ten days with percent survival as the endpoint. Larval mussels (*Mytilus galloprovincialis*) were exposed to sediment elutriates (water-soluble fraction) and at the sediment-water interface (SWI) for 48 hours with percent normal development as the endpoint. The control for the *Eohaustorius* (amphipod) solid-phase test consisted of home sediment, which was clean, well-sorted fine-grained sand collected at the same place and time as the test amphipods. The *Mytilus* (mussel) sediment elutriate test negative control was clean seawater from Granite Canyon, California. Granite Canyon seawater and Yaquina Bay amphipod home sediment from Northwestern Aquatic Sciences were used as the laboratory control for the *Mytilus* SWI exposure test. The *Description of Methods* contains detailed methods of collection and testing,

and the *QA Tables* contain the relevant quality assurance information.

When a sample is found to be toxic, it is interpreted as an indication of the potential for biological effects. However, since sediments contain numerous contaminants, it is difficult to determine which contaminant(s) may have caused any toxicity observed (see *3.5 Results and Discussion*).

A sample was considered toxic if:

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

In many cases, small between-replicate variance will result in a significant t-test, even though the magnitude of the difference may be small. One way to ensure that statistical significance is determined based on large differences between means, rather than on small variation among replicates is to use the MSD. MSD is a statistic that indicates the difference between the two means that will be considered statistically significant given the observed level of between-replicate variation and the alpha level chosen for the comparison. The detectable difference inherent to a bioassay protocol can be determined by identifying the magnitude of difference detected by the protocol 90% of the time (Schimmel *et al*. 1991; Thursby and Schlekat 1993). This is accomplished by determining the MSD for each t-test, ranking them in ascending order, and identifying the 90th percentile MSD, the MSD that is larger than or equal to 90% of the MSD values generated. The 90th percentile MSD value is the difference that 90% of the t-tests will be able to detect as statistically significant and is equivalent to setting the level of statistical power at 0.90. MSDs were established by analysis of numerous bioassay results for San Francisco Estuary (Anderson and Hunt, unpubl.; Hunt *et al*. 1996). Based on those analyses, the 90th percentile MSD for *Eohaustorius* was 18.8% and for the bivalve larvae test 21%. For the July 2000 sediment bioassays, an amphipod bioassay was toxic if it had below 81.2% survival while the larval bivalve bioassay was toxic it if had below 86% normal development.

3.4 Sediment Trends

Sediment contaminant concentrations have been measured at most of the RMP sites since 1991. Samples were collected in 1991 and 1992 by the State's Bay Protection and Toxic Clean-up Program (BPTCP) Pilot Studies (Flegal *et al*. 1994), and by the RMP since 1993. Combining data from these two programs provides a time-series of 18 sampling events over 10 years. Averages and ranges of concentrations for several trace elements are shown for each major Estuary segment (Figures 3.18–3.31). Arsenic, mercury, and selenium were not measured in 1991 and 1992. Silver for August 1997, and cadmium for July 1999 for the Rivers, Central Bay, and Coarse Sediment stations are unavailable due to quality control problems in the analyses. Chromium concentrations were not measured in 2000. Methylmercury in sediments was measured by the RMP for the first time in 2000.

Except for the Rivers, plots for the various Estuary reaches include only muddy sediment samples (<60% sand). At the River stations, one or both stations had coarse sediments in each sampling period. A separate plot is presented for all samples with coarse (>60% sand) sediments, including the Rivers when sandy.

3.5 Results and Discussion

Sediment contaminant concentrations measured in the San Francisco Estuary exhibit considerable variation depending on the location and time of sampling. High contaminant concentrations generally reflect a proximity to a source, anthropogenic or otherwise, as illustrated by the RMP's Estuary Interface Pilot Study results from Coyote Creek and Guadalupe River in the South Bay (SFEI 1999; Leatherbarrow and Hoenicke 2002). However, complex sediment transport dynamics within the Estuary confound this simplistic model. For example, sediments with more silt- and clay-sized particles contain higher concentrations of most contaminants than coarser, sandier sediments because of their geochemical properties (Luoma 1990, Horowitz 1991). The strength and magnitude of freshwater inflows, through the transport of sediments and contaminants in both the dissolved and particulate fractions of the flows, may alter sediment type and contaminant distribution, particularly in estuarine regions such as San Francisco Bay (Krone 1979). These relationships affect sediment concentrations

measured by the RMP; as a consequence the concentrations reported provide information only about the condition of sediments at the times and locations of sampling. However, RMP sediment monitoring does provide reliable measurements of sediment contamination in the most recently deposited sediments and is useful to examine trends in the concentrations over time.

3.5.1 Spatial Distributions

As in previous years, concentrations of most contaminants were higher in the Southern Sloughs and South Bay when compared to other reaches of the Estuary (Figures 3.1–3.15). This pattern is emphasized by a gradient in contaminant concentrations across the margin of the South Bay (SFEI 1999; 2000; 2001). Contaminant concentrations in sediment samples from the Central Bay, Northern Estuary, and River reaches were lower than those from the Estuary Interface stations situated upstream from the Southern Sloughs. Concentration gradients of arsenic, cadmium, chromium, lead, selenium, zinc, PAHs, and PCBs have been found in an intensive, localized study of creek channels draining into San Leandro Bay (Daum *et al*. 2000).

Average concentrations of cadmium, copper, lead, methylmercury, nickel, selenium, silver, zinc, DDTs, PCBs, and chlordanes were highest in sediment samples from the Estuary Interface sites, Standish Dam (BW10) and Guadalupe River (BW15), whereas PAH concentrations were found to be highest in South Bay sediments. The Northern Estuary reach had the highest average concentrations of arsenic and mercury. In the case of mercury, this was a result of the highest sediment concentration (0.56 mg/kg) measured by the RMP at Pinole Point (BD31). Average concentrations of all contaminants were lowest in the Rivers, except for selenium and arsenic, which were lowest in the Central Bay and Southern Sloughs, respectively. Individual stations with high contaminant concentrations were primarily located at the Estuary Interface. Dieldrin was not detected in sediment samples.

Alameda (BB70) and Horseshoe Bay (BC21) had the highest number of ERL exceedances (see Table 3.2). The number of ERL guideline exceedances and sediment contaminant concentrations were lowest at the coarse sediment stations of Sacramento River (BG20), Davis Point (BD41), Pacheco Creek (BF10), and Red Rock (BC60).

3.5.2 Sediment Contamination Trends

Northern California experienced its sixth consecutive wet or above normal water year in 2000 (http://cdec.water.ca.gov/cgi-progs/iodir/wsihist). Hydrologic conditions in the San Francisco Bay region were typical of wet weather years, notable for greater precipitation and runoff during the winter and spring months, followed by drier conditions in the summer and fall. January started off dry, but precipitation began by the end of the month and continued through March. Sacramento-San Joaquin Delta outflows to the Estuary in February, March, mid-April through early May, and late July were higher than average (Le 2001). Sacramento River mean daily flows peaked at about 2,400 m^3/s in late February, whereas San Joaquin River flow peaked in early March at about 480 m^3/s. Flows then decreased gradually from mid-May through the end of the year.

Sediment samples in February were collected before peak storm flows occurred from the Sacramento-San Joaquin Delta into the Estuary. Except for arsenic and selenium, contaminant concentrations tended to be higher in the Northern Estuary in February than in July (Figures 3.1–3.15). Elevated sediment contaminant concentrations may be due to the flushing of sediment-associated contaminants into the Estuary by flood flows (SFEI 1999), a pattern that is most obvious at sites nearest the major tributaries of the Estuary. Most contaminant concentrations at the Napa (BD15) and Petaluma River (BD50) stations were higher in the wet-sampling compared to the dry-sampling period.

Contamination trends have been observed in RMP sediment samples at both seasonal (wet and dry) and interannual scales. Even so, it is important to recognize that contaminant concentration variation seen in the trends plots may be influenced by physical sediment characteristics, as well as proximity to sources. In general, sediments with more silt and clay (percent fines) and higher total organic carbon (TOC) have higher concentrations than sediments with sandy sediments and low TOC. Therefore, some of the variation represented in the plots could be attributable to spatial and temporal variations in sediment characteristics rather than in changes in concentrations over time *per se*.

After normalizing for grain size and total organic carbon (TOC), significant long-term trends for one or more contaminants were found at 21 of the 22 RMP sites throughout the Estuary (J. Ross, unpub-

lished results). Chromium, DDTs, and cadmium showed significant increases at nine, six, and five of these stations respectively. Significant increases or decreases in other contaminants were documented at four or fewer stations. Numerous significant changes in contaminant concentrations over time were seen in the South Bay at the Dumbarton Bridge, Oyster Point, and Redwood Creek sites. Overall, significant long-term (five to nine years) trends were observed in less than 15% of contaminant analyses at RMP stations through 1999. The Northern Estuary and Central Bay reaches generally had the lowest coefficient of variation over time for trace metals, and South Bay and Southern Sloughs for organics.

The Southern Sloughs and River stations had the fewest number of significant trends, two and six respectively. One possible explanation for this finding may be the inherently dynamic hydrologic conditions in these reaches of the Estuary. Another possibility is an episodic flow of sediment and sediment associated contaminants from the surrounding watersheds due to variation in agricultural activity and rainfall. Time trends analyses require enough measurements over time at a given location to obtain statistically significant results. Whether the finding of no significant changes in contaminant concentrations over time in the majority of analyses was because there were indeed no changes, a consequence of sediment dynamics in the Estuary, or a small sample size has not been established.

Sampling sediments at a series of depths can reveal historical trends in contaminant concentrations. United States Geological Survey (USGS) sediment coring studies in the Estuary allow us to place the observed contaminant trends at RMP stations in a historical context (van Geen and Luoma, 1999). The earliest evidence of contamination associated with human occupation and industrialization was found for mercury, in sediments deposited between 1850 and 1880 as a result of gold mining activities. Maximum concentrations were 20 times the baseline (i.e. pre-anthropogenic) concentrations. Silver, lead, copper, and zinc contamination first appeared in the Bay sediment record after 1910. Concentrations of most contaminants have decreased from the peak levels documented in the 1960s and 1970s (Hornberger *et al*. 1999; Venkatesan *et al*. 1999) probably due to improvements in treatment of wastewater, changes in industrial and shipping technology, product bans, and other regulatory measures.

A complex set of processes that include deposition, resuspension, mixing, transport, and biogeochemistry are reflected in changes in sediment concentrations with time. The interplay of these processes determines the "active sediment layer" and any burial rates. The depth of the active layer was determined to be a key factor in the mass balance and flux of chlorinated hydrocarbons in sediments (Davis and Yoon 1999). An estimate of 33 centimeters was obtained for the depth of the active mixed sediment layer in Richardson Bay, based on the best fit ^{210}Pb simulation for a sediment core collected near the mouth of the bay in 1992 (Fuller *et al*. 1999). Deep mixing generally accounts for the long residence times of contaminants in the surface sediments of the Bay. Fuller *et al*. (1999) propose that even in the absence of continued contaminant inputs at the Richardson Bay location, over 75 years would be required to bury 90% of a deposited contaminant below the active mixed sediment layer.

3.5.3 Sediment Toxicity

Toxicity tests, described in Section 3.3, were conducted to indicate whether sediments were toxic to sensitive organisms. Since these bioassays were conducted using non-resident organisms exposed in laboratory conditions, the results may not necessarily indicate the occurrence of actual ecological impacts.

Estuary sediments were toxic to either amphipods or bivalve embryos in 77% of the 2000 RMP samples; 66% of the RMP samples tested between 1993 and 2000 were toxic to these organisms. Patterns of toxicity for the two test organisms vary at the different RMP sites. Stations located in the northern part of the Estuary, Sacramento River (BG20), San Joaquin River (BG30), Grizzly Bay (BF21), Napa River (BD50), and Davis Point (BD41), exhibit increasing long-term trends in the incidence of bivalve embryo toxicity, but there is a decrease in the incidence of amphipod toxicity at Sacramento River. The previously reported significant increase in toxicity at Yerba Buena Island (BC11) was observed again in 2000 for amphipod but not bivalve embryos. No increases or decreases in the incidence of toxicity were seen at other RMP stations. Bioassay results for 2000 indicate sediments from Horseshoe Bay (BC21), Red Rock (BC60), and Davis Point (BD41) were toxic to neither amphipods nor bivalve larvae. Seasonal patterns could not be examined in 2000, but in

previous years sediments were usually more toxic during the wet sampling period (SFEI 2000; 2001).

Sediment or other environmental factors that cause sediment toxicity to the amphipods and bivalve larvae are poorly understood. Analyses using several years of monitoring data suggest that amphipod toxicity is associated with the cumulative effects of mixtures of contaminants (Thompson *et al*. 1999b). Several individual contaminants were identified as probable determinants of toxicity at some sites. For example, toxicity at Grizzly Bay (BF21) was related to covarying patterns of total chlordane, silver, and cadmium from 1991 through 1996. Seasonal variation in PAHs at Alameda (BB70) and San Bruno Shoal (BB15) were related to percent survival. Sediment elutriates (water soluble fraction) have been observed as being toxic to bivalve larvae at the Sacramento and San Joaquin Rivers, and Grizzly Bay sites since 1993 (SFEI 2000; 2001). Toxicity identification evaluations (TIEs) performed on the sediment elutriates from the Sacramento and San Joaquin Rivers and Grizzly Bay in 1997 and 1998 indicate that dissolved trace metals, particularly copper, were partially responsible for the toxicity, but organic contaminants were also identified as toxic components at the Sacramento River site (Phillips *et al*. 2000). These results suggest that sediment toxicity at the different RMP stations may be related to different contaminants and may vary with time.

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

3.5.4 Assessment of Sediment Quality

Estuary sediments are evaluated through comparisons to several sets of sediment quality guidelines described in *Section 3.2 Sediment Quality Guidelines*. Although these guidelines hold no regulatory status, they do provide concentration thresholds that are useful in assessing the condition of sediments in the San Francisco Estuary.

Sediment contamination and toxicity results were used to evaluate the sediment quality of the 2000 Regional Monitoring Program samples (Table 3.2). Sediment contamination was estimated for each site by considering the number of contaminants in a sample that exceeded the San Francisco Estuary Ambient Sediment Concentration (ASC, Smith and Riege 1998), Effects-Range guidelines (ERL and ERM, Long *et al*. 1995), and the ERM quotients (Long *et al*. 1998). The number of sediment contaminants above the ERL or ERM guidelines has been used previously to predict potential biological effects (Long *et al*. 1998). Samples with more than four ERM exceedances showed toxicity in 68% of tests, while more than 89% of samples were toxic when ten to fourteen ERLs were above the guidelines. Based on these results the 2000 RMP sediment samples were considered potentially toxic if either four or more ERMs, ten or more ERLs, or half (22) of the ASC values were exceeded.

ERM values were used to calculate a mean ERM quotient (mERMq) for each sample. Concentrations of nine trace metals (arsenic, cadmium, chromium, copper, mercury, nickel, lead, silver, zinc), total PCBs, total DDTs, low molecular weight PAHs, and high molecular weight PAHs were divided by their respective ERMs. The quotients for all contaminants were summed and then divided by the number of contaminants whose ERMs were used to calculate each sum. Samples that did not have values for at least 10 of the 13 parameters were not included in the calculations.

The mERMq may be considered a cumulative index of sediment contamination related to adverse biological effects. For example, amphipod toxicity has been found to be significantly and inversely correlated to mERMq (Thompson *et al*. 1999a), suggesting that contaminants individually present in relatively low concentrations in sediments may act together to adversely influence amphipod survival.

After normalizing for grain size and total organic carbon (TOC), no significant long-term trends (1993-1999) in mERMq values were seen at RMP stations (J. Ross, unpublished results). Analysis of RMP data from 1993 through 1999 indicate that mERMq values below 0.177 were never toxic to

amphipods, but mERMq values above 0.300 were toxic in 57% of tests to either amphipod or bivalve larvae. These values were used to evaluate the 2000 RMP sediment samples for potential adverse ecological effects.

Sediment evaluation showed that 8 of 30 samples in 2000 had mERMq values above 0.300, suggesting that they were potentially toxic (Table 3.2). Toxicity tests reveal that Alameda (BB70), Napa River (BD50), and San Joaquin River (BG30) samples were toxic to either amphipod or bivalve larvae. July samples from Standish Dam (BW10), Guadalupe River (BW15), Sunnyvale (C-1-3), Dumbarton Bridge (BA30), and Pinole Point (BD31) were not tested for toxicity, but sediments from these sites had seven or fewer ERL exceedances, one ERM exceedance, and seven or fewer exceedances of ASC guidelines, suggesting a reduced potential for negative biological effects. Spatial and temporal differences were observed in sediment quality. With the notable exception of Central Bay, every reach of the Estuary had sediment samples with mERMq values above 0.300, all sampled during the dry season.

3.6 References

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

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

San Francisco Bay Ambient Sediment Concentrations (ASC) from Smith and Riege (1998).
Ambient sediment levels from background sediments in the Estuary allow one to assess whether a site has elevated levels or is "degraded".

Background sediment concentrations for selected trace elements in the San Francisco Bay, from Hornberger et al. (2000)
Chromium and Nickel ranges were seen throughout the core. All TEs, except Ag, measured by ICAPES. Ag measured by GFAAS.

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

* Chromium concentrations not measured in sediment in 2000.

** Method detection limit (MDL) for February cruise is greater than ERL and ASC-sandy guidelines, and MDL for July cruise is greater than ERL, ASC-muddy, and ASC-sandy guidelines. Therefore, conclusions regarding these benchmarks could not be drawn.

Table 3.2. Summary of sediment quality for the RMP in 2000.
NA = grain size analysis data not available at time of reporting.
. = not tested, * indicates number of exceedances above ASC guidelines for sandy samples

Code	Site Name	Date	mERMq	No. of ASC above Guidelines	No. of ERL above Guidelines	No. of ERM above Guidelines	Toxic to Amphipods?	Toxic to Bivalves?
BD50	Napa River	2/10/00	0.2986	3	5	1	.	.
BD41	Davis Point	2/10/00	0.1649	0*	1	1	.	.
BD22	San Pablo Bay	2/10/00	0.2955	3	8	1	.	.
BD15	Petaluma River	2/10/00	0.2775	2	5	1	.	.
BG20	Sacramento River	7/20/00	0.1655	0*	1	1	no	yes
BG30	San Joaquin River	7/20/00	0.3216	1	3	1	no	yes
BF40	Honker Bay	7/20/00	0.2969	1	5	1	.	.
BF21	Grizzly Bay	7/20/00	0.2419	1	5	1	yes	yes
BF10	Pacheco Creek	7/20/00	0.1681	4*	2	1	.	.
BD50	Napa River	7/21/00	0.3011	1	6	1	yes	no
BD41	Davis Point	7/21/00	0.1690	1*	1	1	no	no
BD31	Pinole Point	7/21/00	0.3055	2	6	1	.	.
BD22	San Pablo Bay	7/21/00	0.2636	1	5	1	.	.
BD15	Petaluma River	7/21/00	0.2582	1	5	1	.	.
BC60	Red Rock	7/24/00	0.1539	0*	1	1	no	no
BC41	Point Isabel	7/24/00	0.2551	1	7	1	.	.
BC32	Richardson Bay	7/24/00	0.2459	5	8	1	.	.
BC21	Horseshoe Bay	7/24/00	0.2272	28*	10	1	no	no
BC11	Yerba Buena Island	7/24/00	0.2249	0	4	1	yes	no
BB70	Alameda	7/24/00	0.3234	21	17	1	yes	no
BB30	Oyster Point	7/25/00	0.1900	0	1	1	.	.
BB15	San Bruno Shoal	7/25/00	0.2870	1	6	1	yes	no
BA41	Redwood Creek	7/25/00	0.2062	1	4	1	yes	no
BA30	Dumbarton Bridge	7/25/00	0.3040	2	6	1	.	.
BA21	South Bay	7/25/00	0.2793	1	5	1	yes	yes
BA10	Coyote Creek	7/25/00	0.2819	2	5	1	no	yes
C-3-0	San Jose	7/26/00	0.2632	25*	5	1	.	.
C-1-3	Sunnyvale	7/26/00	0.3301	4	7	1	.	.
BW10	Standish Dam	7/11/00	0.3641	7	7	1	.	.
BW15	Guadalupe River	7/11/00	0.3721	5	7	1	.	.

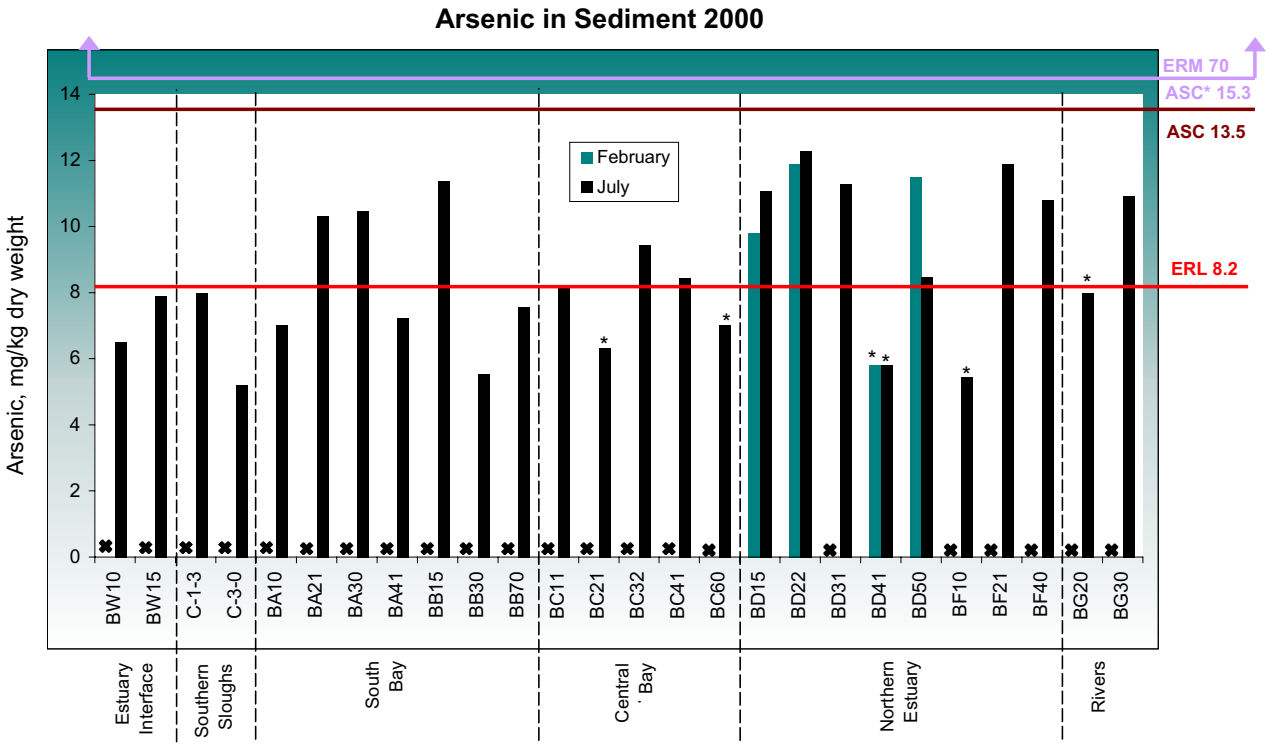

Figure 3.1. Arsenic (As) concentrations in sediments in parts per million, dry weight (ppm) at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ✖ indicates station was not sampled. Arsenic concentrations ranged from 5.21 to 12.26 ppm. The highest concentration was sampled at San Pablo Bay (BD22) and the lowest at San Jose (C-3-0), both in July. Average concentrations were highest (9.75 ppm) in the Northern Estuary in February, and lowest (6.59 ppm) in the Southern Sloughs in July.

Source Data: See Data Table 12

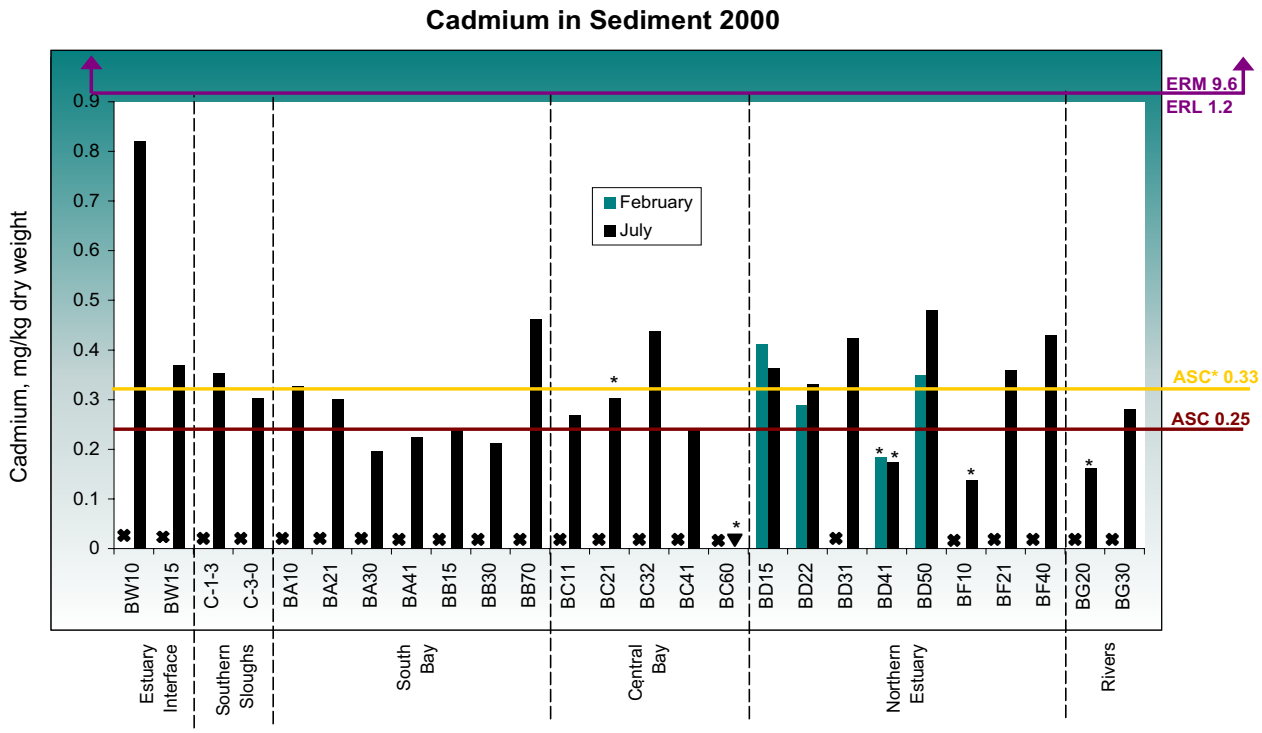

Figure 3.2. Cadmium (Cd) concentrations in sediments in parts per million, dry weight (ppm) at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ✖ indicates station was not sampled. ▼ indicates that analyte was not detected. Cadmium concentrations ranged from not detected (▼) to 0.82 ppm. The highest concentration was sampled at Standish Dam (BW10) in July. Average concentrations were highest (0.6 ppm) in the Estuary Interface and lowest (0.22 ppm) in the Rivers, both in July.

Source Data: See Data Table 12

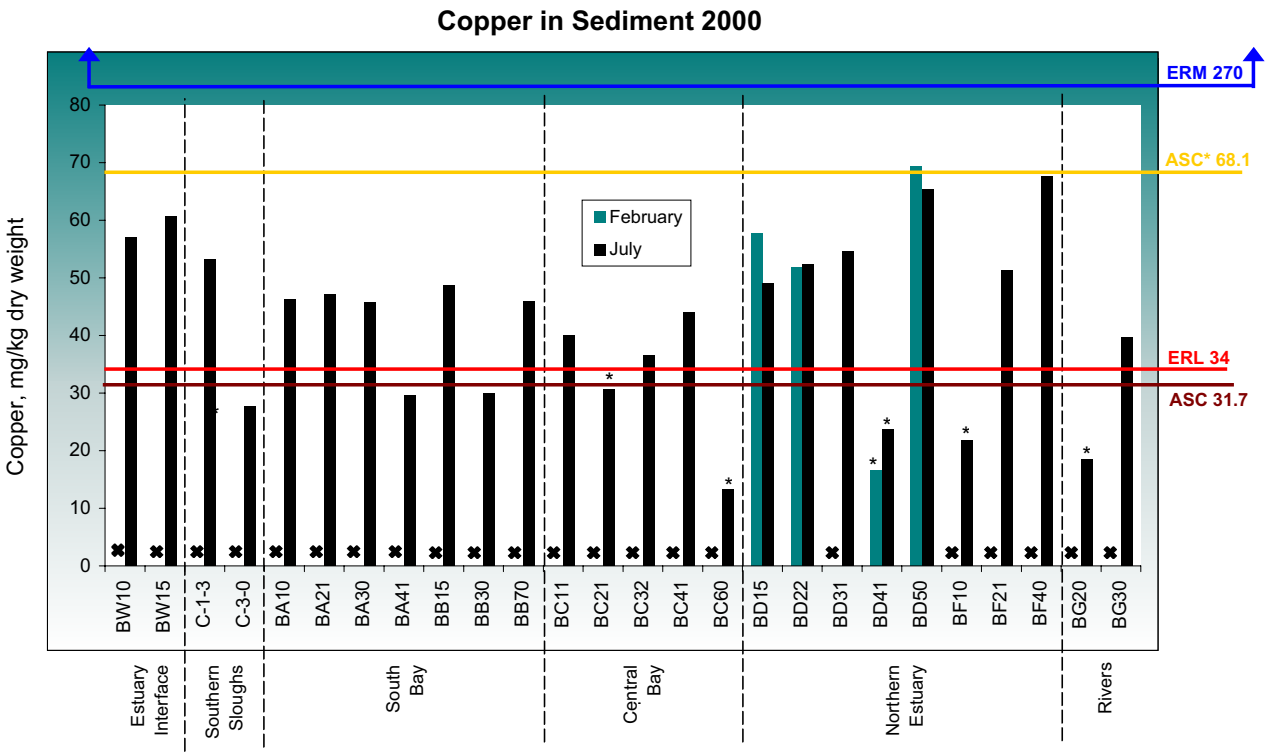

Figure 3.3. Copper (Cu) concentrations in sediments in parts per million, dry weight (ppm) at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ✖ indicates station was not sampled. Copper concentrations ranged from 13.3 to 69.5 ppm. The highest concentration was sampled at Napa River (BD50) in February and the lowest at Red Rock (BC60) in July. Average concentrations were highest (59 ppm) in the Estuary Interface and lowest (29.1 ppm) in the Rivers, both in July.

Source Data: See Data Table 12

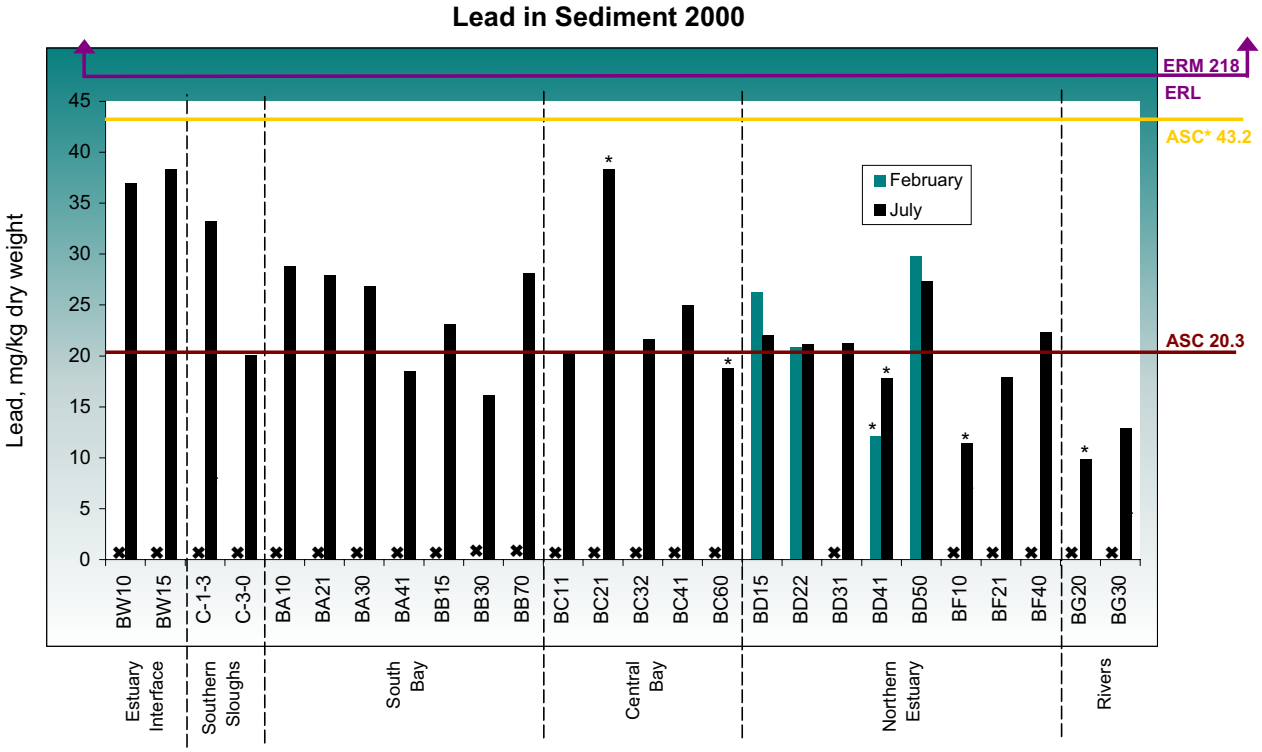

Figure 3.4. Lead (Pb) concentrations in sediments in parts per million, dry weight (ppm) at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ✖ indicates station was not sampled. Lead concentrations ranged from 9.9 to 38.4 ppm. The highest concentration was sampled at Guadalupe River (BW15) and the lowest at Sacramento River (BG20), both in July. Average concentrations were highest (37.7 ppm) in the Estuary Interface and lowest (11.4 ppm) in the Rivers, both in July.

Source Data: See Data Table 12

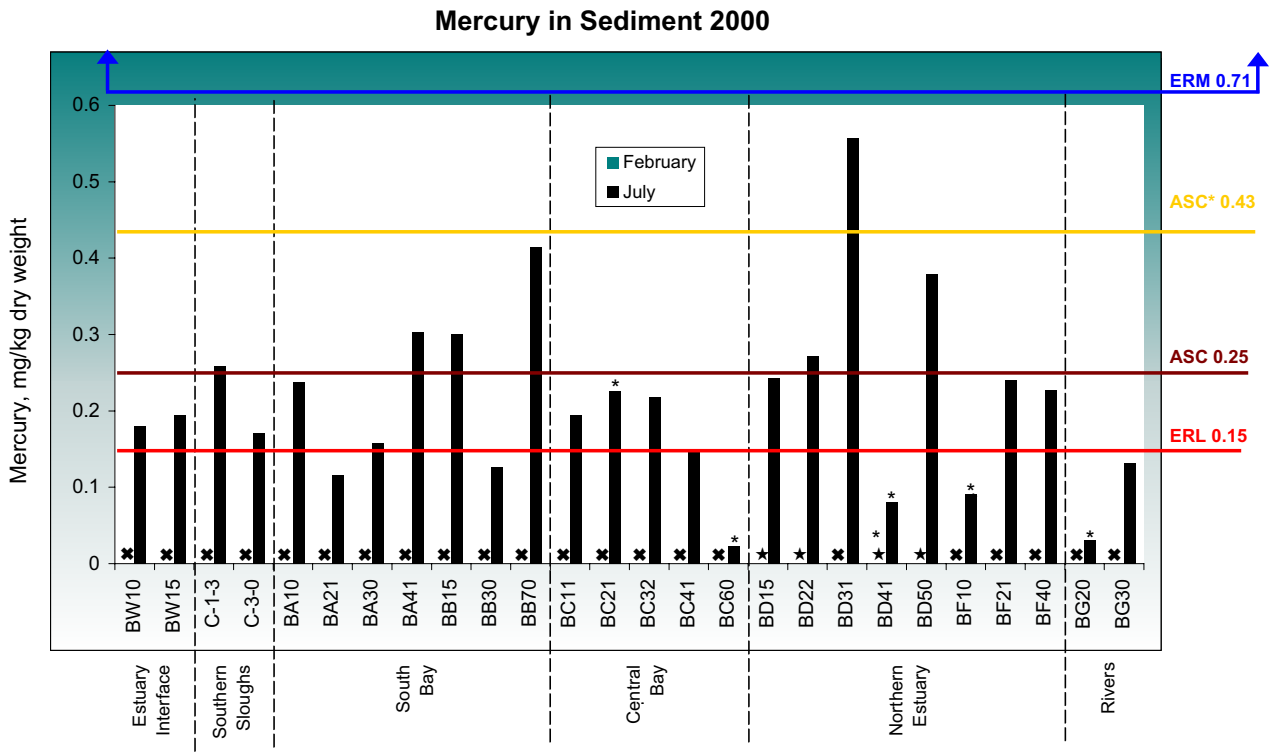

Figure 3.5. Mercury (Hg) concentrations in sediments in parts per million, dry weight (ppm) at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ★ indicates analyte not analyzed. ✖ indicates station was not sampled. Mercury concentrations ranged from 0.02 to 0.56 ppm. The highest concentration was sampled at Pinole Point (BD31) and the lowest at Red Rock (BC60), both in July. Average concentrations were highest (0.26 ppm) in the Northern Estuary and lowest (0.08 ppm) in the Rivers, both in July.

Source Data: See Data Table 12

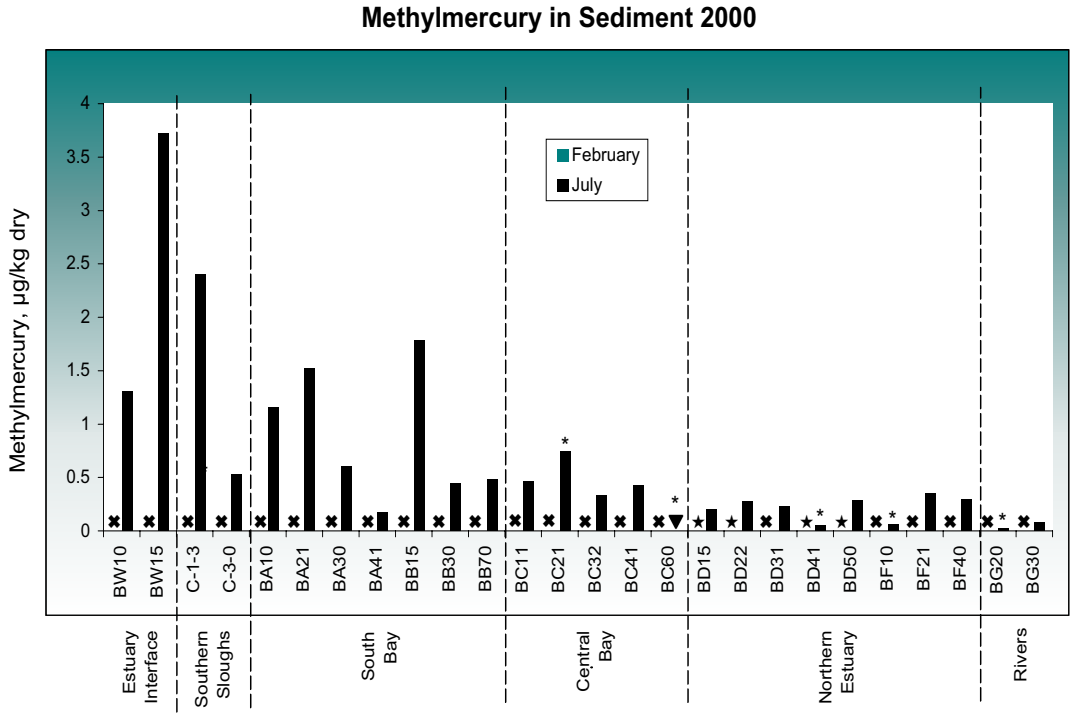

Figure 3.6. Methylmercury (MeHg) concentrations in sediments in parts per billion, dry weight (ppb) at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ★ indicates analyte not analyzed. ✖ indicates station was not sampled. ▼ indicates that analyte was not detected. Methylmercury concentrations ranged from not detected (▼) to 3.73 ppb. The highest concentration was sampled at Guadalupe River (BW15) in July. Average concentrations were highest (2.52 ppb) in the Estuary Interface and lowest (0.06 ppb) in the Rivers, both in July. There are no ERL, ERM, or ASC values for methylmercury.

Source Data: See Data Table 12

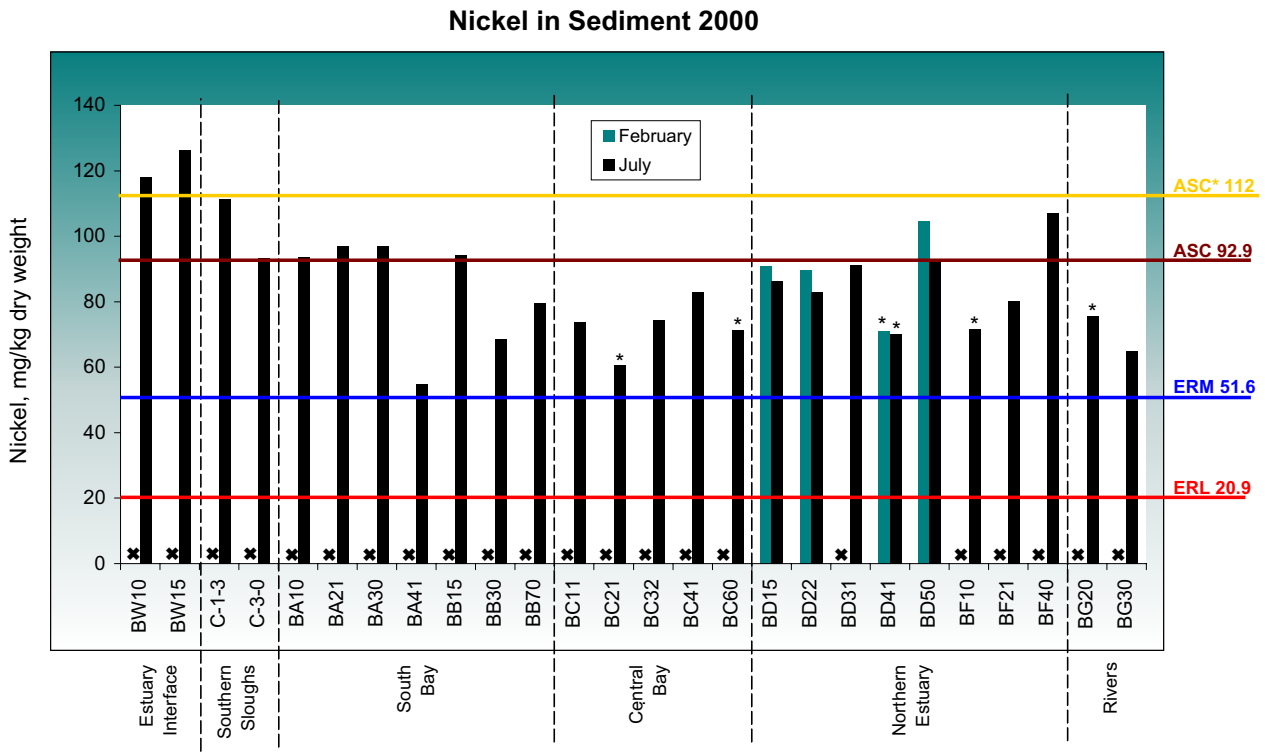

Figure 3.7. Nickel (Ni) concentrations in sediments in parts per million, dry weight (ppm) at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ✖ indicates station was not sampled. Nickel concentrations ranged from 54.9 to 126.3 ppm. The highest concentration was sampled at Guadalupe River (BW15) and the lowest at Redwood Creek (BA41), both in July. Average concentrations were highest (122.2 ppm) in the Estuary Interface and lowest (70.2 ppm) in the Rivers, both in July.

Source Data: See Data Table 12

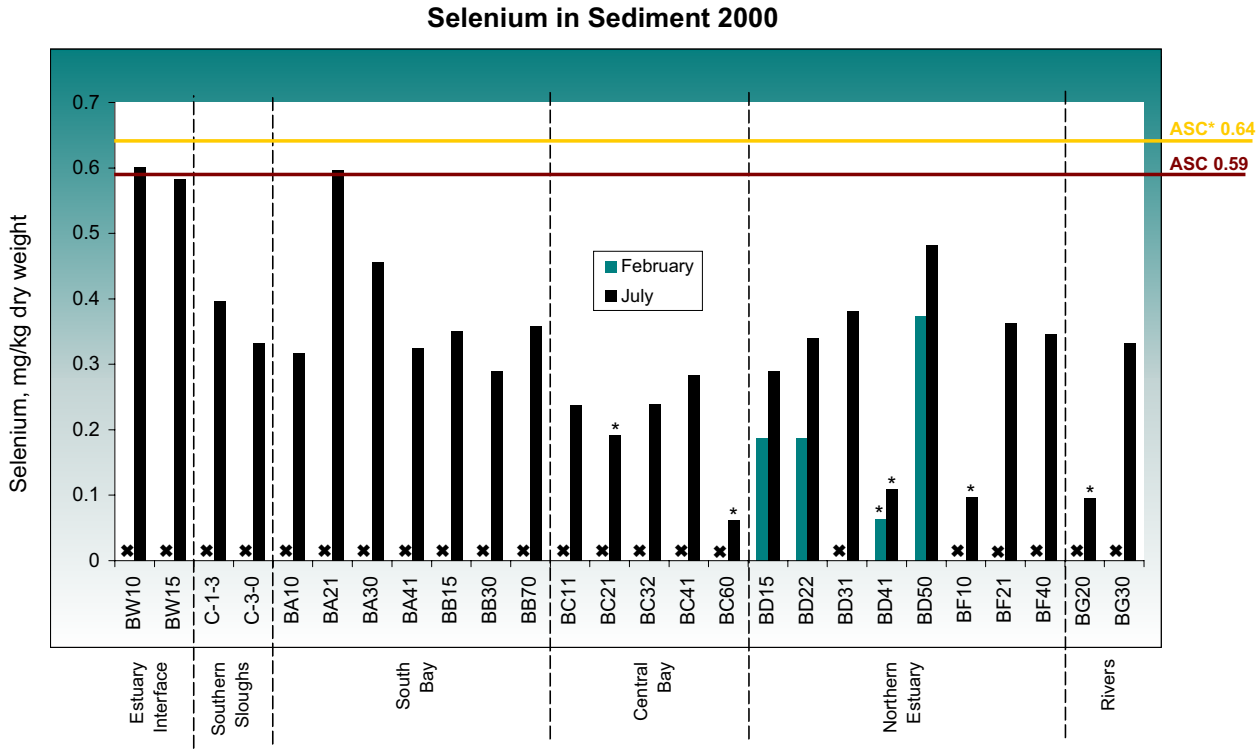

Figure 3.8. Selenium (Se) concentrations in sediments in parts per million, dry weight (ppm) at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ✖ indicates station was not sampled. Selenium concentrations ranged from 0.06 to 0.60 ppm. The highest concentration was sampled at Standish Dam (BW10) and the lowest at Red Rock (BC60), both in July. Average concentrations were highest (0.59 ppm) in the Estuary Interface and lowest (0.20 ppm) in the Central Bay, both in July. There are no ERM and ERL values for selenium.

Source Data: See Data Table 12

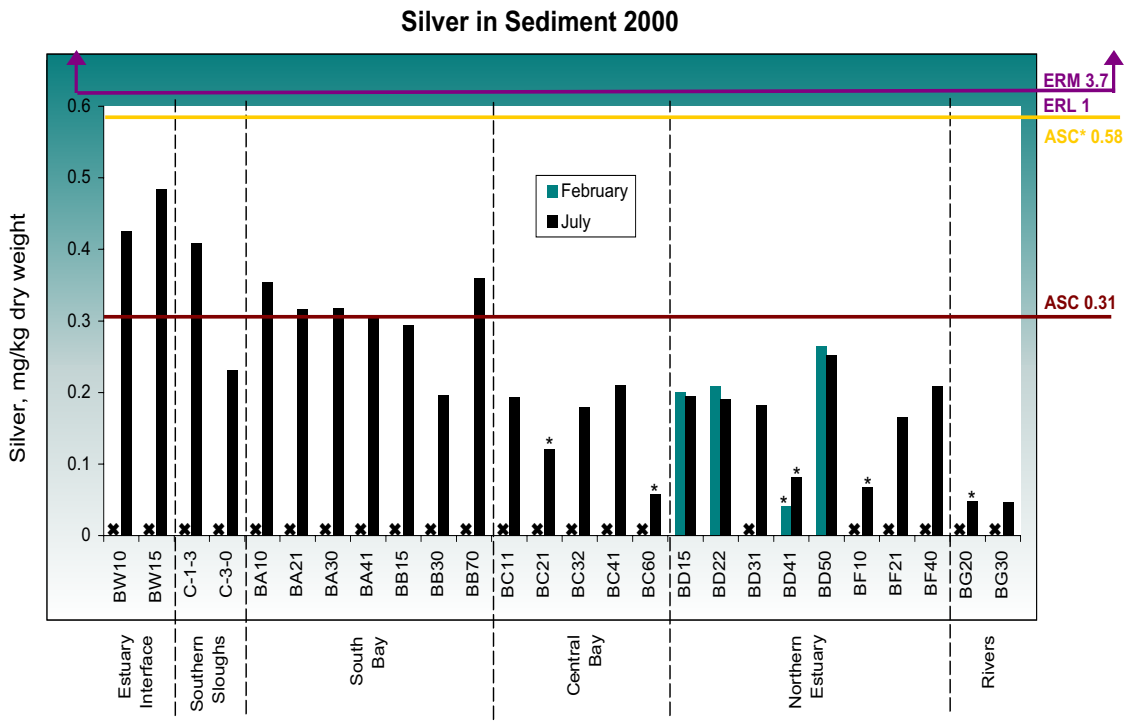

Figure 3.9. Silver (Ag) concentrations in sediments in parts per million, dry weight (ppm) at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ✖ indicates station was not sampled. Silver concentrations ranged from 0.04 to 0.48 ppm. The highest concentration was sampled at Guadalupe River (BW15) in July and the lowest at Davis Point (BD41) in February. Average concentrations were highest (0.45 ppm) in the Estuary Interface and lowest (0.05) in the Rivers, both in July.

Source Data: See Data Table 12

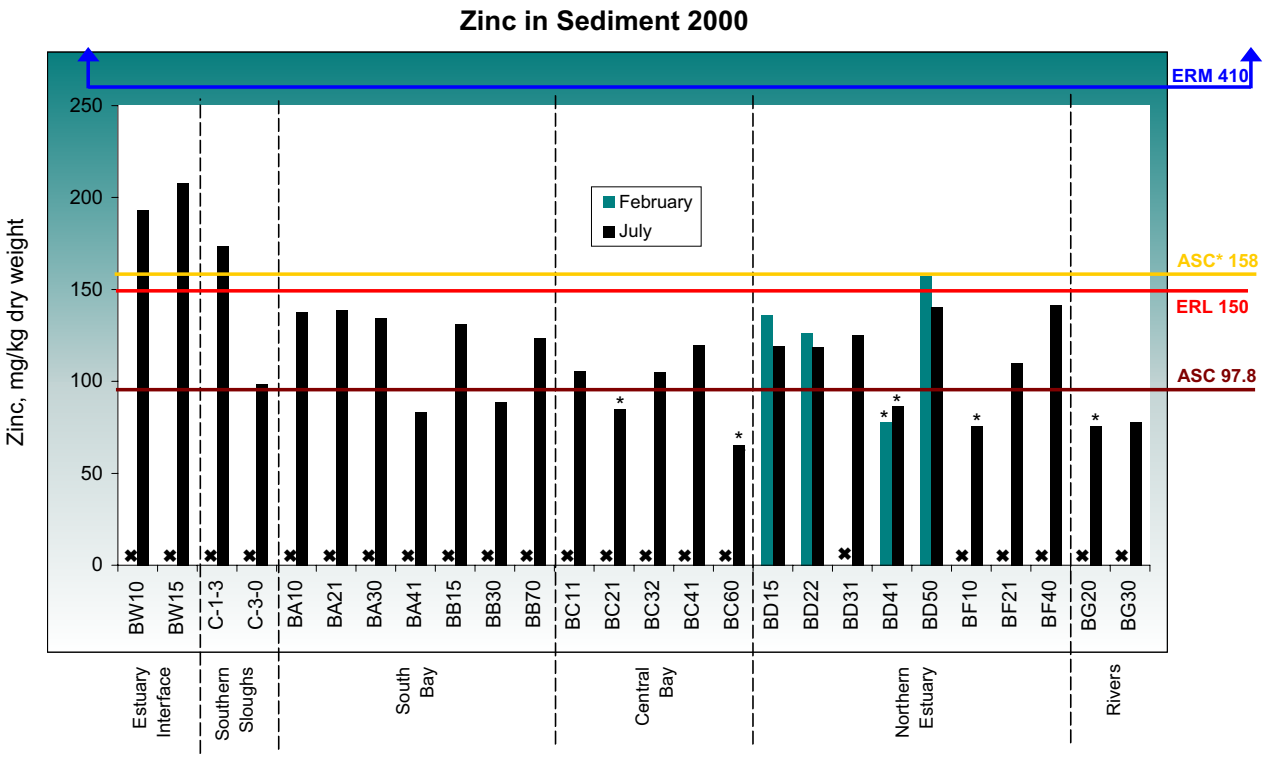

Figure 3.10. Zinc (Zn) concentrations in sediments in parts per million, dry weight (ppm) at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ✖ indicates station was not sampled. Zinc concentrations ranged from 65.5 to 207.7 ppm. The highest concentration was sampled at Guadalupe River (BW15) and the lowest at Red Rock (BC60), both in July. Average concentrations were highest (200.5 ppm) in the Estuary Interface and lowest (76.8 ppm) in the Rivers, both in July.

Source Data: See Data Table 12

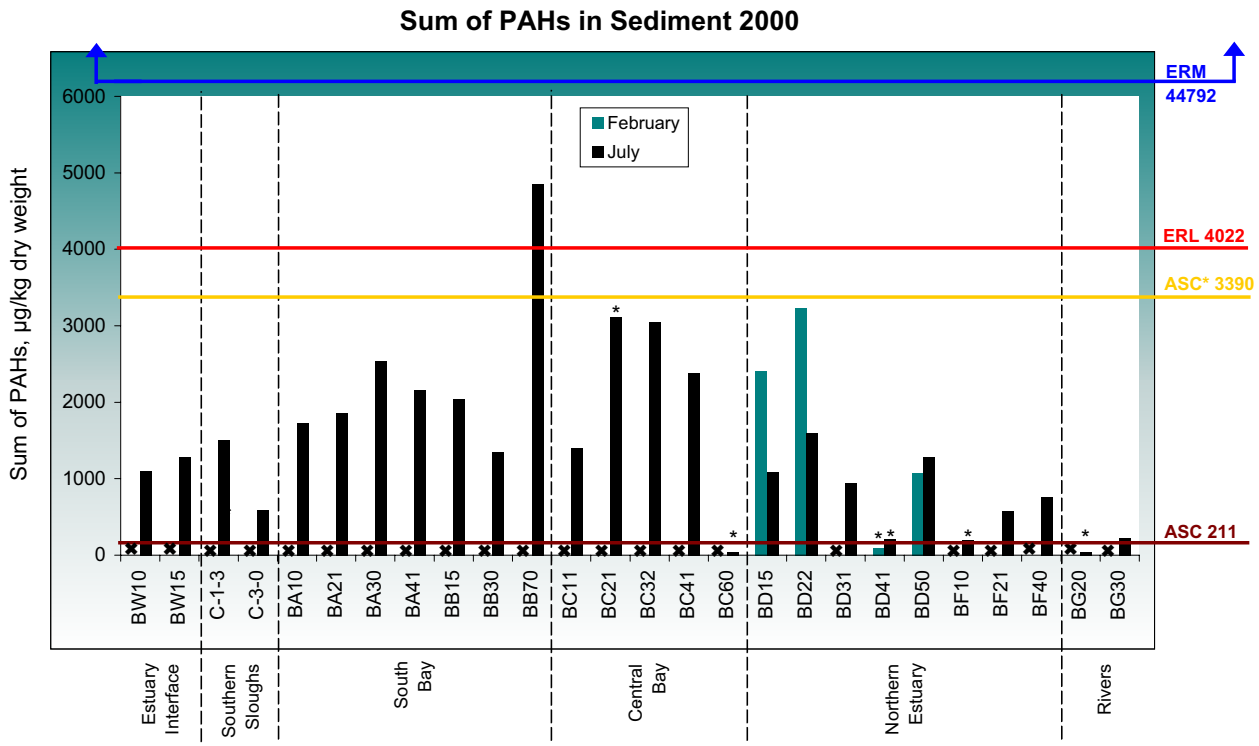

Figure 3.11. Sum of PAH concentrations in sediments in µg/kg, dry weight at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ✖ indicates station was not sampled. PAH concentrations ranged between 40.59 and 4843.84 µg/kg. The highest concentration was sampled at Alameda (BB70) and the lowest at Sacramento River (BG20), both in July. Average concentrations were highest (2358.14 µg/kg) in the South Bay and lowest (133.135 µg/kg) in the Rivers, both in July.

Source Data: See Data Table 13

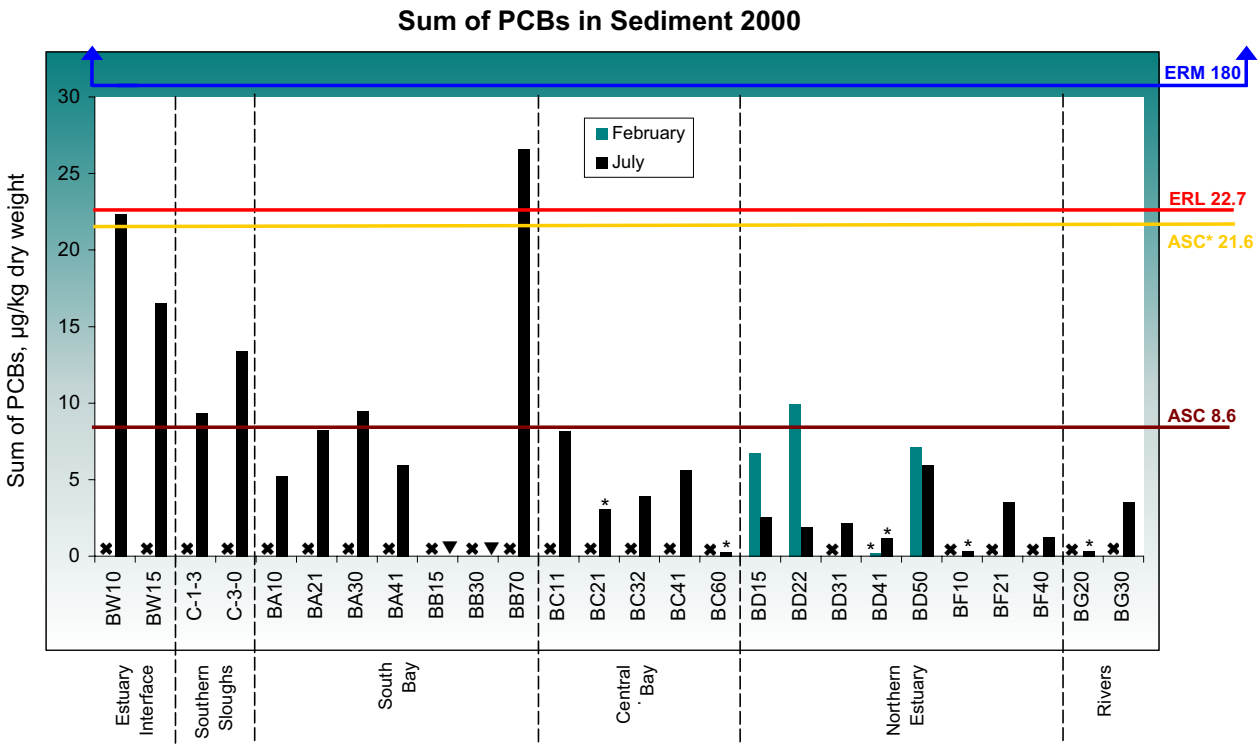

Figure 3.12. Sum of PCB concentrations in sediments in µg/kg, dry weight at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ✖ indicates station was not sampled. ▼ indicates that analyte was not detected. PCB concentrations ranged between not detected (▼) and 26.58 µg/kg. The highest concentration was sampled at Alameda (BB70) in July. Average concentrations were highest (19.41 µg/kg) in the Estuary Interface and lowest (1.92 µg/kg) in the Rivers, both in July.

Source Data: See Data Table 14

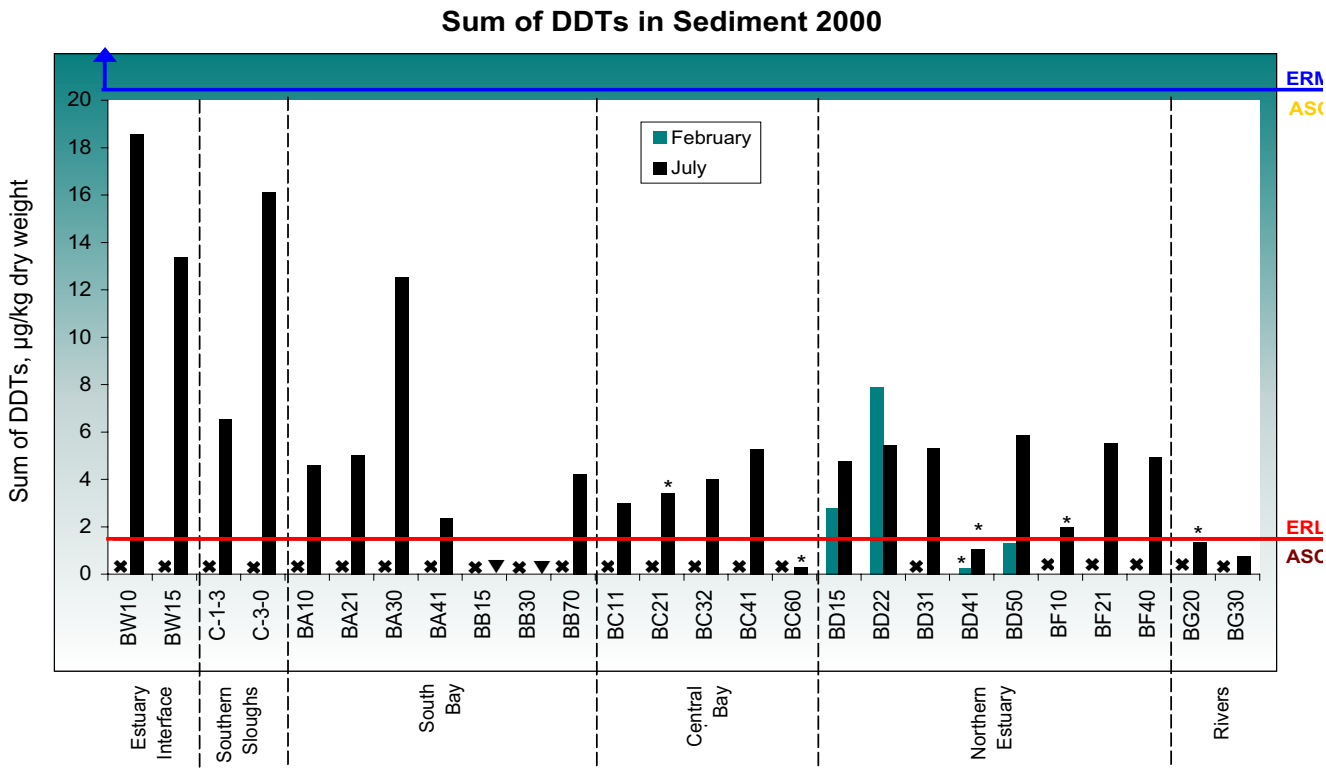

Figure 3.13. Sum of DDT concentrations in sediments in µg/kg, dry weight at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ✖ indicates station was not sampled. ▼ indicates that analyte was not detected. DDT concentrations ranged between not detected (▼) and 18.56 µg/kg. The highest concentration was sampled at Standish Dam (BW10) in July. Average concentrations were highest (15.97 µg/kg) in the Estuary Interface and lowest (1.04 µg/kg) in the Rivers, both in July.

Source Data: See Data Table 15

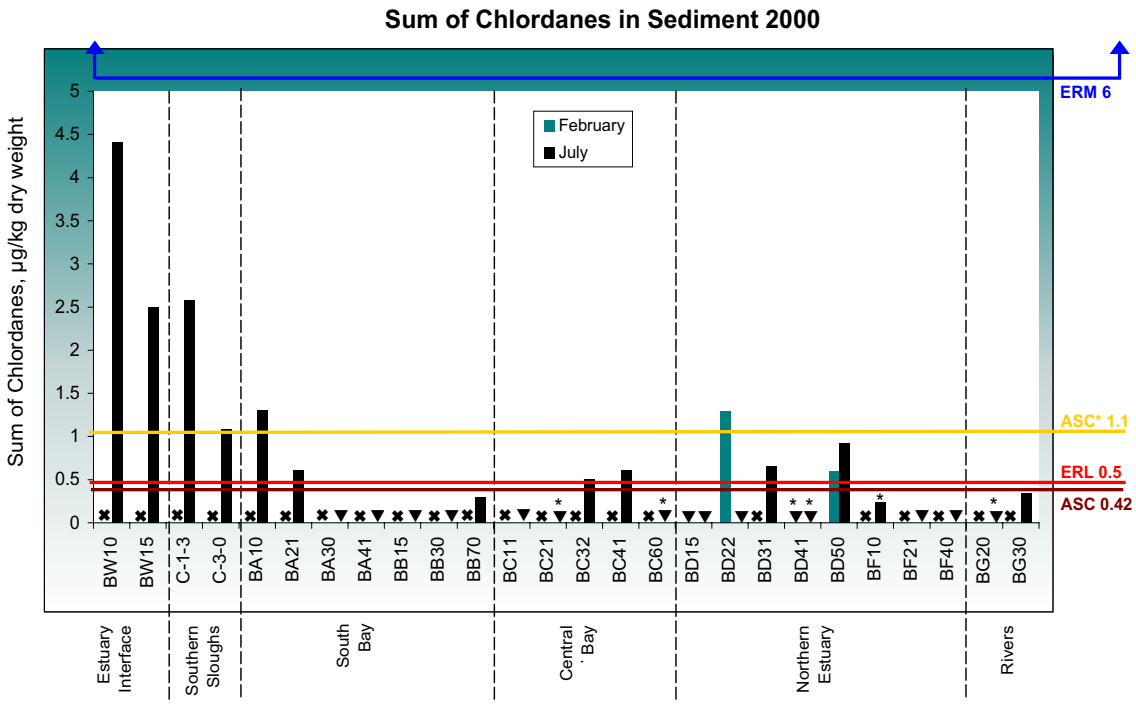

Figure 3.14. Sum of chlordane concentrations in sediments in µg/kg, dry weight at 26 stations sampled in February and July 2000. * indicates coarse sediment stations. ✖ indicates station was not sampled. ▼ indicates that analyte was not detected. Chlordane concentrations ranged between not detected (▼) and 4.42 µg/kg. The highest concentration was sampled at Standish Dam (BW10) in July. Average concentrations were highest (3.46 µg/kg) in the Estuary Interface and lowest (0.35 µg/kg) in the Rivers, both in July.

Source Data: See Data Table 15

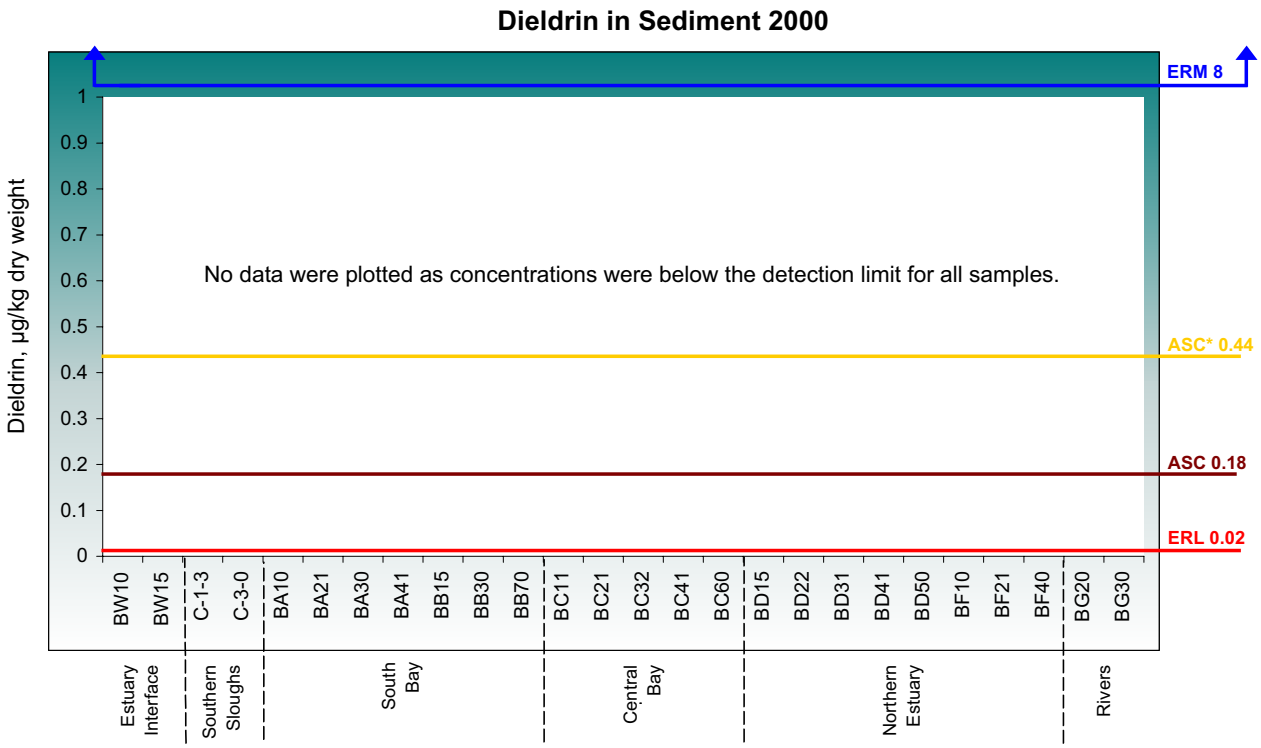

Figure 3.15. Dieldrin concentrations in sediments in µg/kg, dry weight at 26 stations sampled in February and July 2000. No data were plotted as concentrations were below the method detection limit (MDL) for all samples. Since the MDL values were greater than the guidelines for both the wet and dry season cruises, conclusions regarding these benchmarks could not be drawn.

Source Data: See Data Table 15

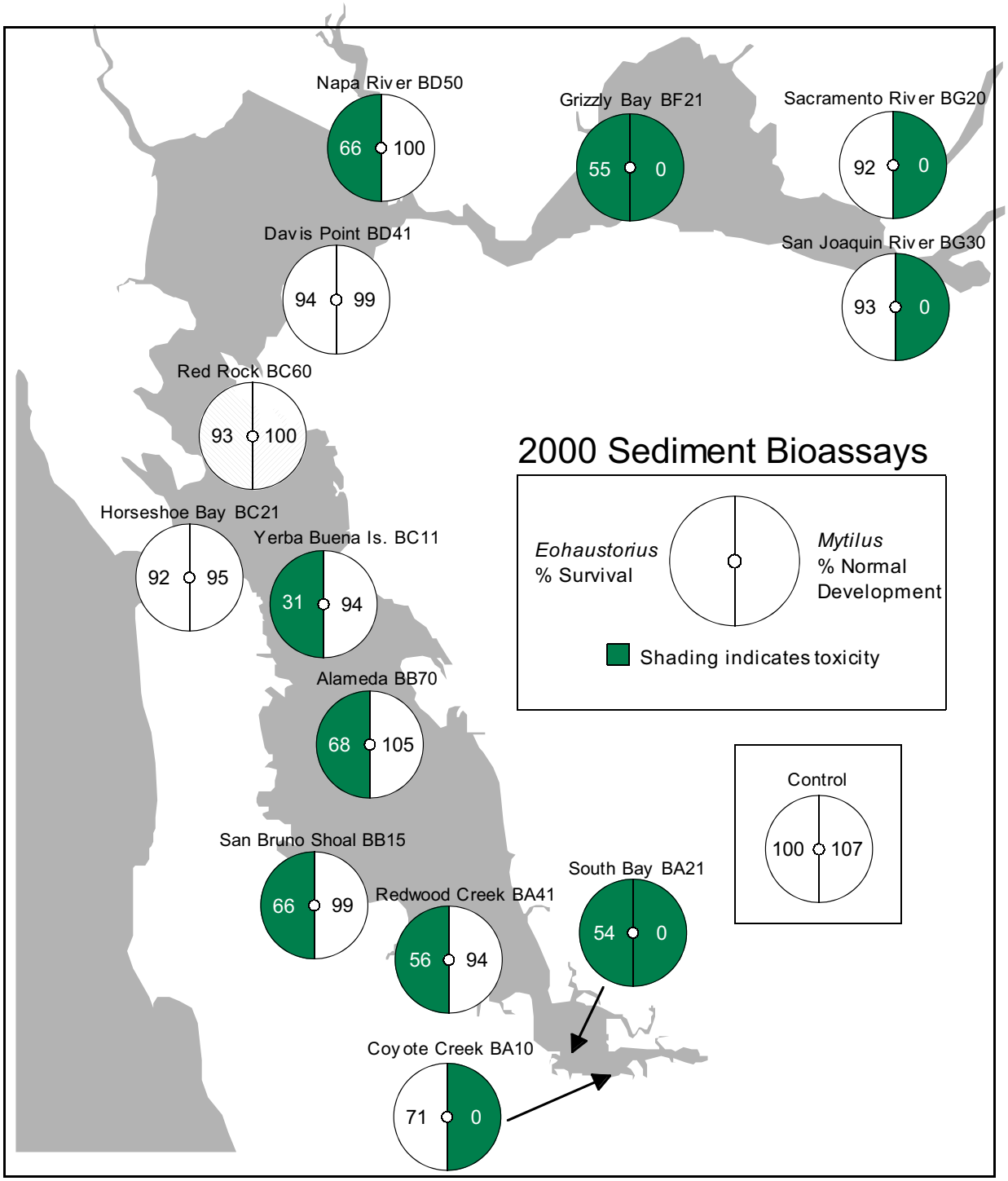

Figure 3.16. Sediment bioassay results for July 2000. Sediments were not toxic (see Section 3.3 Sediment Bioassays) to either amphipods or bivalve larvae at Horseshoe Bay (BC21), Red Rock (BC60), and Davis Point (BD41). Amphipod toxicity was observed in the dry-sampling period at Grizzly Bay (BF21), Napa River (BD50), Yerba Buena Island (BC11), Alameda (BB70), San Bruno Shoal (BB15), Redwood Creek (BA41), and South Bay (BA21). Sediments at the River stations (BG20, BG30) and Coyote Creek (BA10 were not toxic to amphipods. Sediment elutriates were toxic to larval mussels in the dry-sampling period at Sacramento River (BG20), San Joaquin River (BG30), Grizzly Bay (BF21), South Bay (BA21), and Coyote Creek (BA10). They were not toxic to the larvae at the remaining stations. Sediment conditions that could have influenced toxicity are considered in the *Results and Discussion.*

Source Data: See Data Table 16

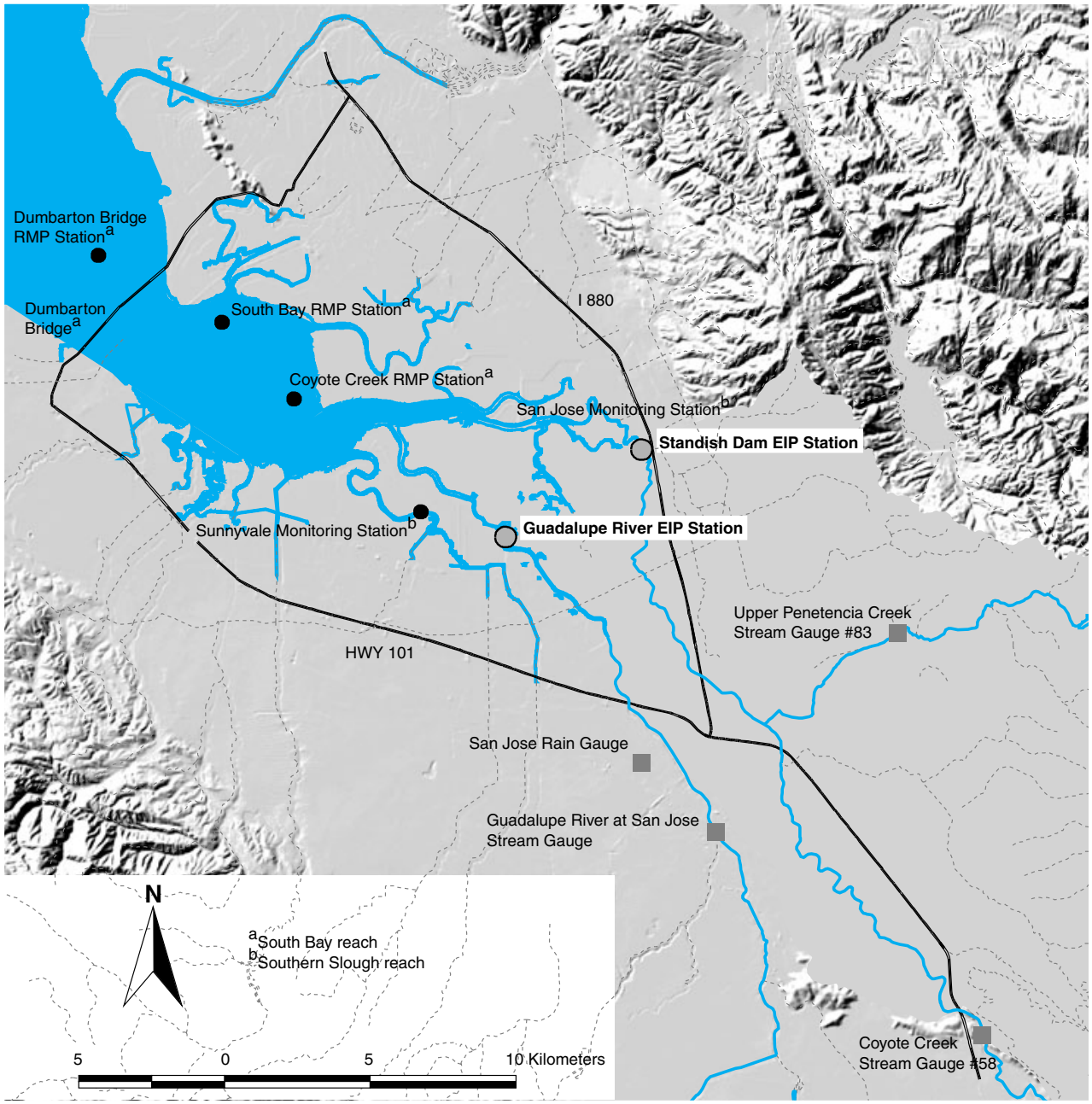

Figure 3.17 Map of the Estuary Interface Pilot Study Stations

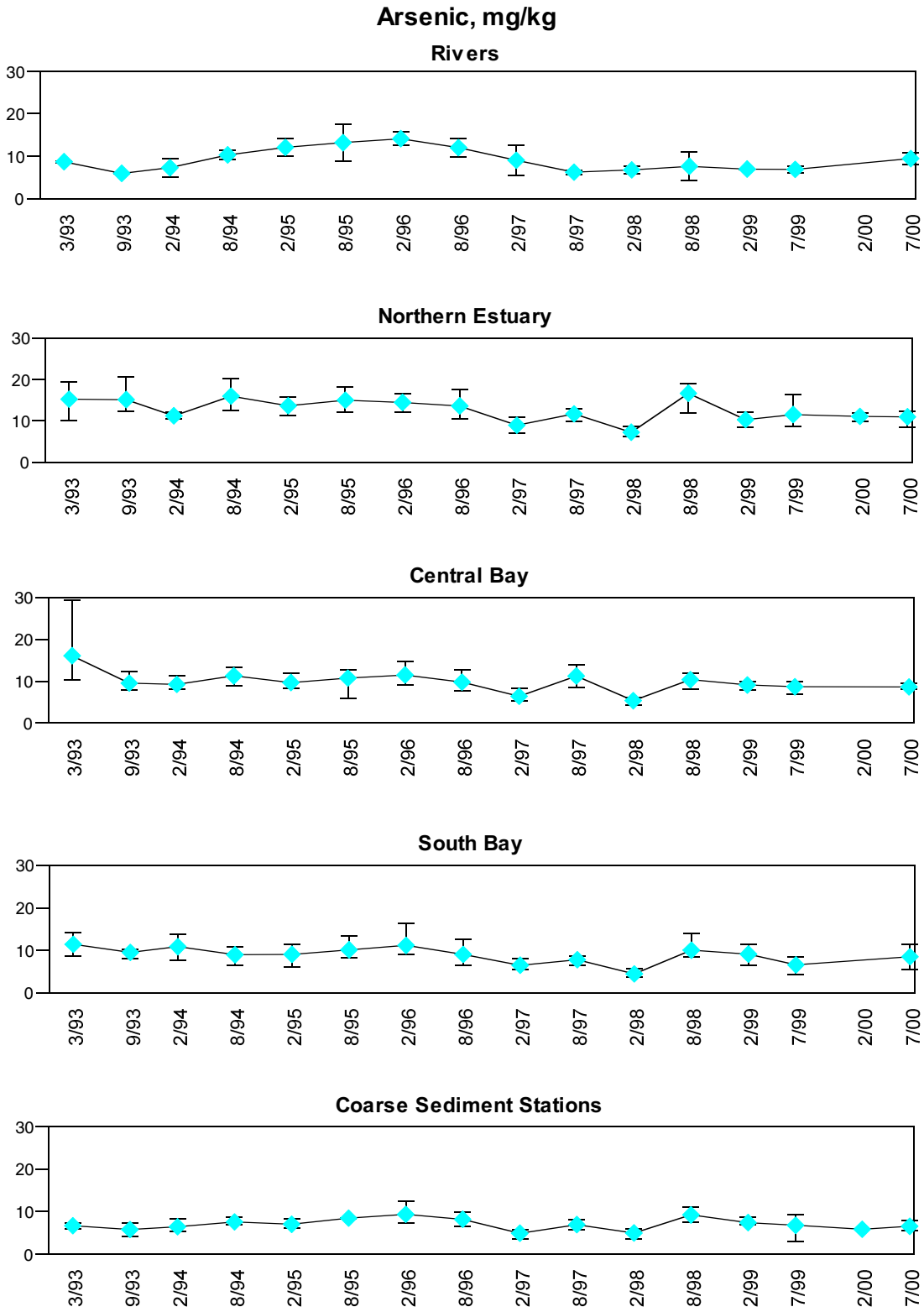

Figure 3.18. Average arsenic concentrations in sediments for each Estuary reach from 1993–2000. The vertical bars represent the range of all values within a reach. The sample size varies between reach and between seasons. The South Bay reach does not include Southern Slough stations. Due to blank contamination, arsenic data for February 1999 is incomplete as follows: some stations in the South Bay and Coarse Sediment reaches are not included in averages; the February Rivers arsenic average consists of only one sample. Due to the RMP redesign, arsenic data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.

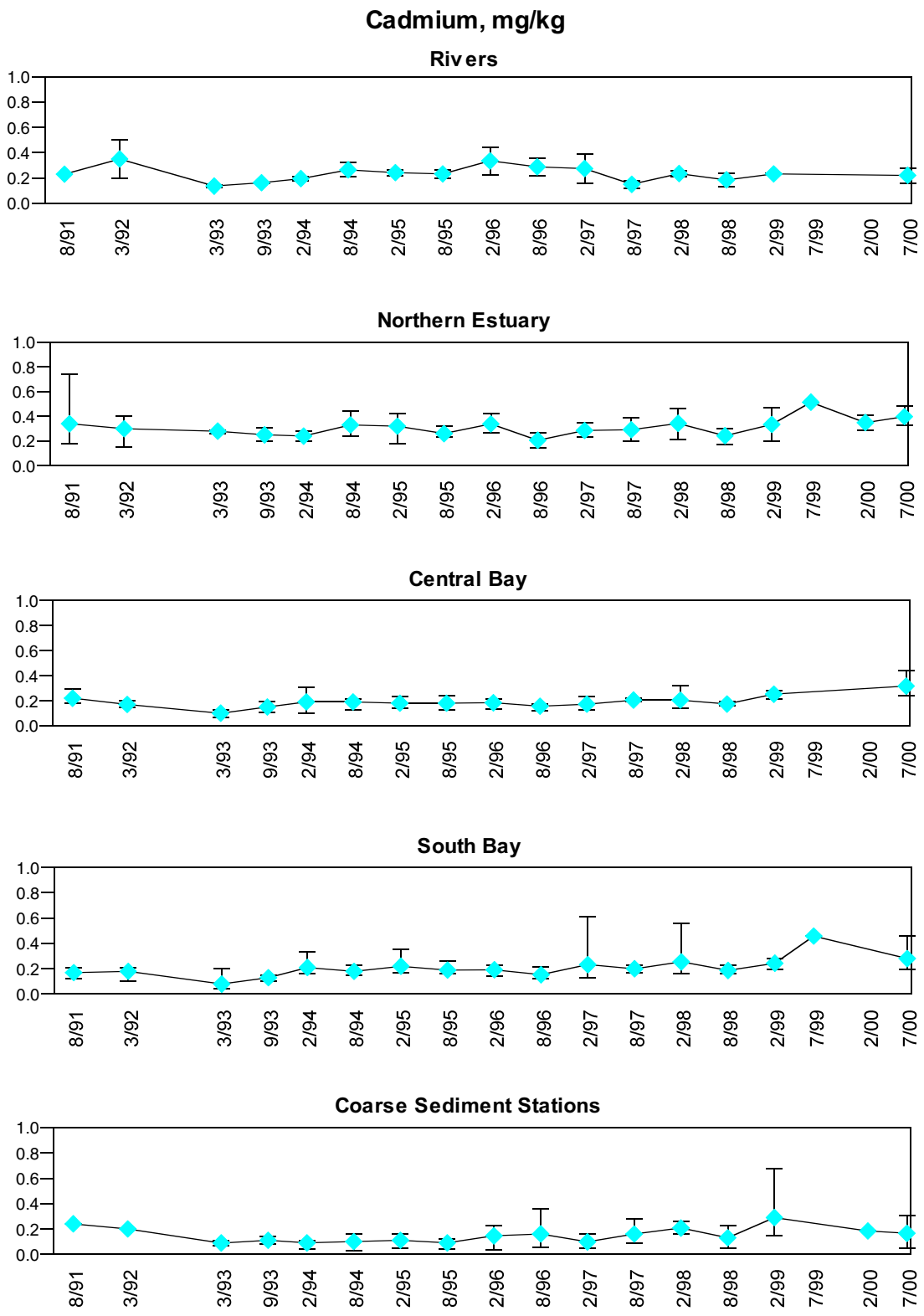

Figure 3.19. Average cadmium concentrations in sediments for each Estuary reach from 1991–2000. The vertical bars represent the range of all values within a reach. The sample size varies between reach and between seasons. The South Bay reach does not include Southern Slough stations. Due to blank contamination there are no data for cadmium in July 1999 for the Rivers, Central Bay and Coarse Sediment Stations; and July 1999 Northern Estuary and South Bay averages consist of only one sample. Due to the RMP redesign, cadmium data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.

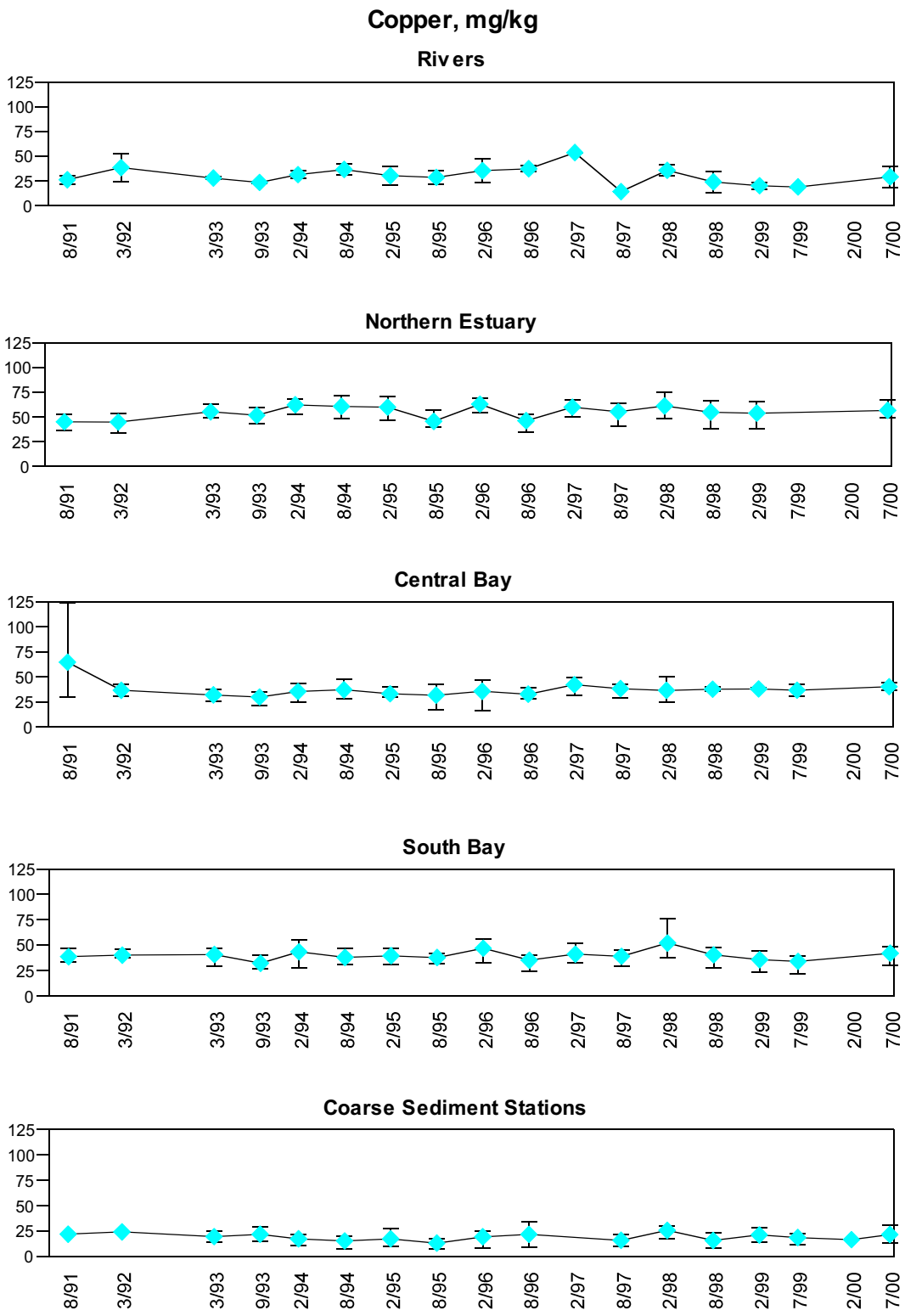

Figure 3.20. Average copper concentrations in sediments for each Estuary reach from 1991–2000. The vertical bars represent the range of all values within a reach. The sample size varies between reach and between seasons. The South Bay reach does not include Southern Slough stations. Due to contaminated blanks, copper data for 1997 are incomplete as follows: February Rivers and Northern Estuary data are incomplete; the February Central Bay average consists of only one sample; February and August South Bay data are incomplete; and there are no February data for the Coarse Sediment stations. Due to the RMP redesign, copper data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.

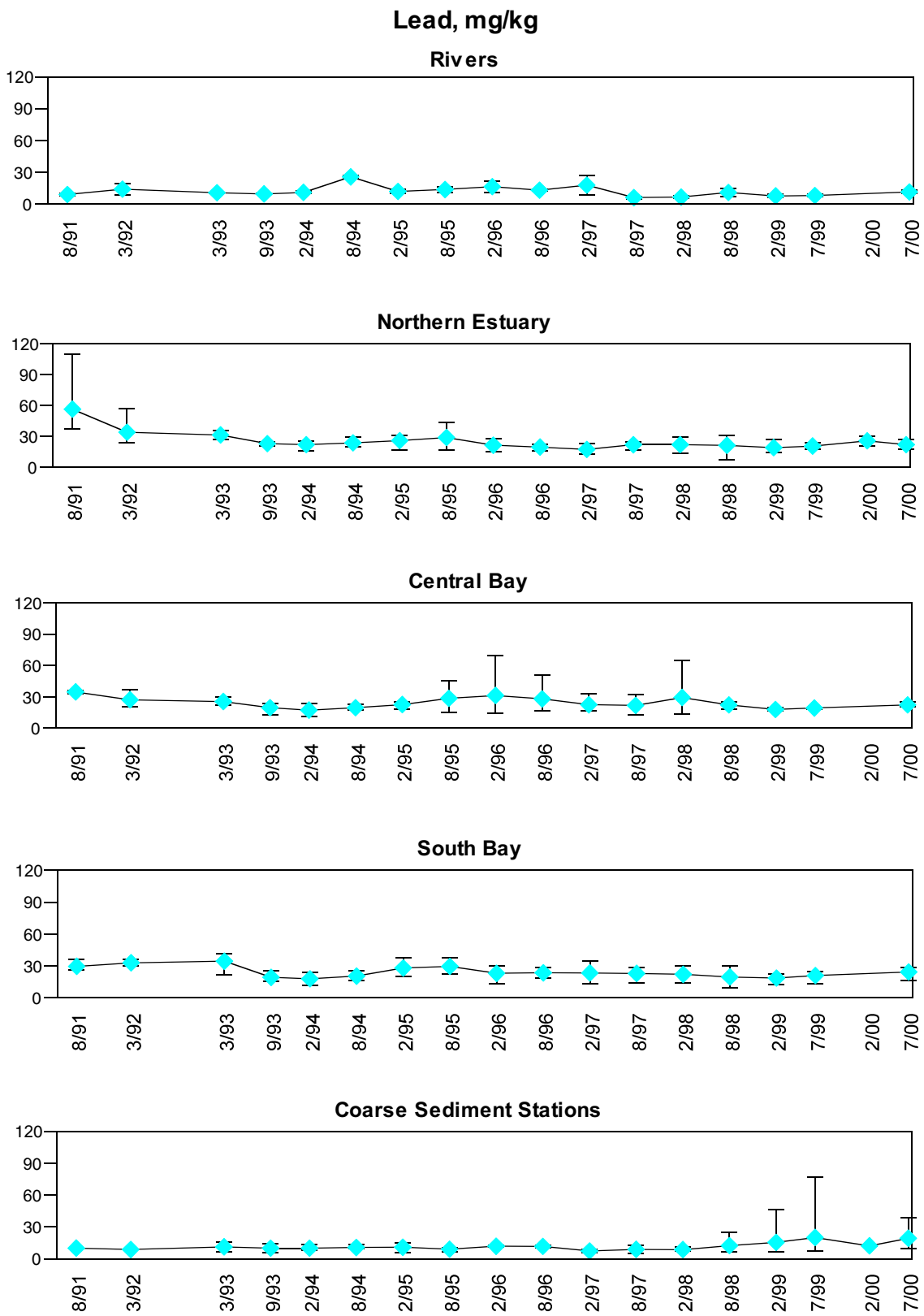

Figure 3.21. Average lead concentrations in sediments for each Estuary reach from 1991–2000. The vertical bars represent the range of all values within a reach. The sample size varies between reach and between seasons. The South Bay reach does not include Southern Slough stations. Due to the RMP redesign, lead data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.

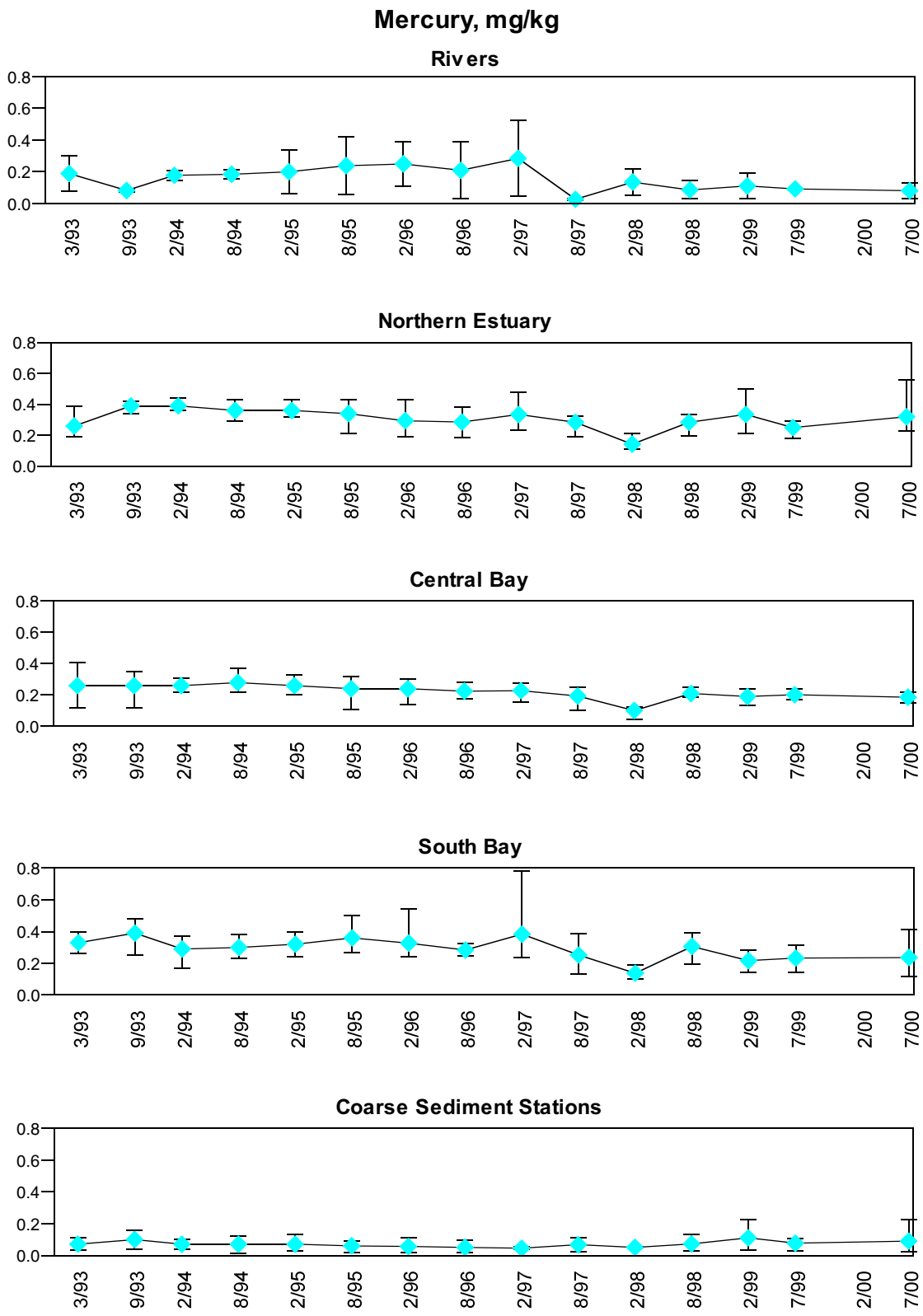

Figure 3.22. Average mercury concentrations in sediments for each Estuary reach from 1993–2000. The vertical bars represent the range of all values within a reach. The sample size varies between reach and between seasons. The South Bay reach does not include Southern Slough stations. Due to blank contamination, mercury data for 1999 are incomplete as follows: July data are not available for some of the Coarse Sediment stations; the July Rivers mercury average consists of only one sample. February 2000 sediments were not analyzed for mercury.

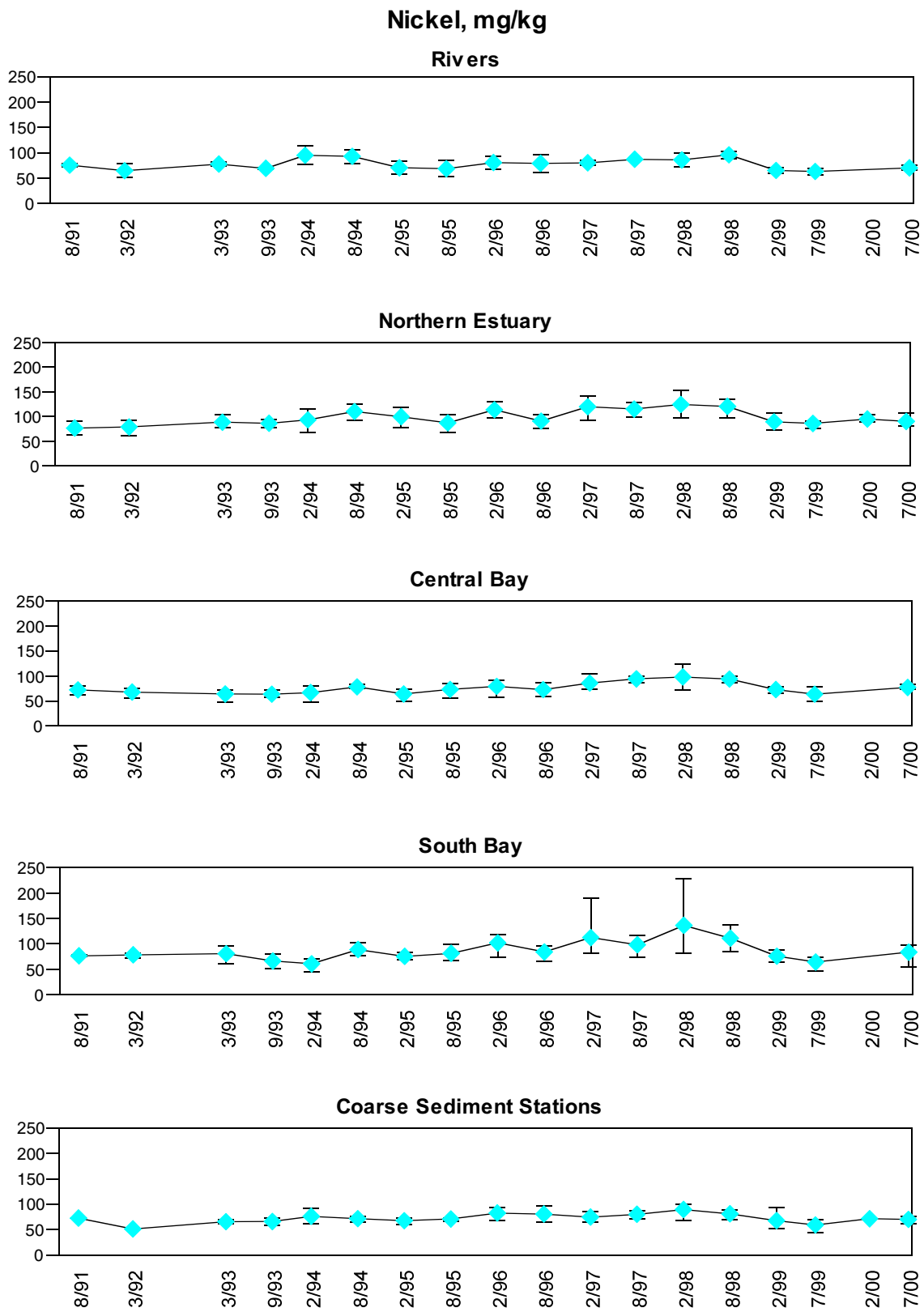

Figure 3.23. Average nickel concentrations in sediments for each Estuary reach from 1991–2000. The vertical bars represent the range of all values within a reach. The sample size varies between reach and between seasons. The South Bay reach does not include Southern Slough stations. Due to the RMP redesign, nickel data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.

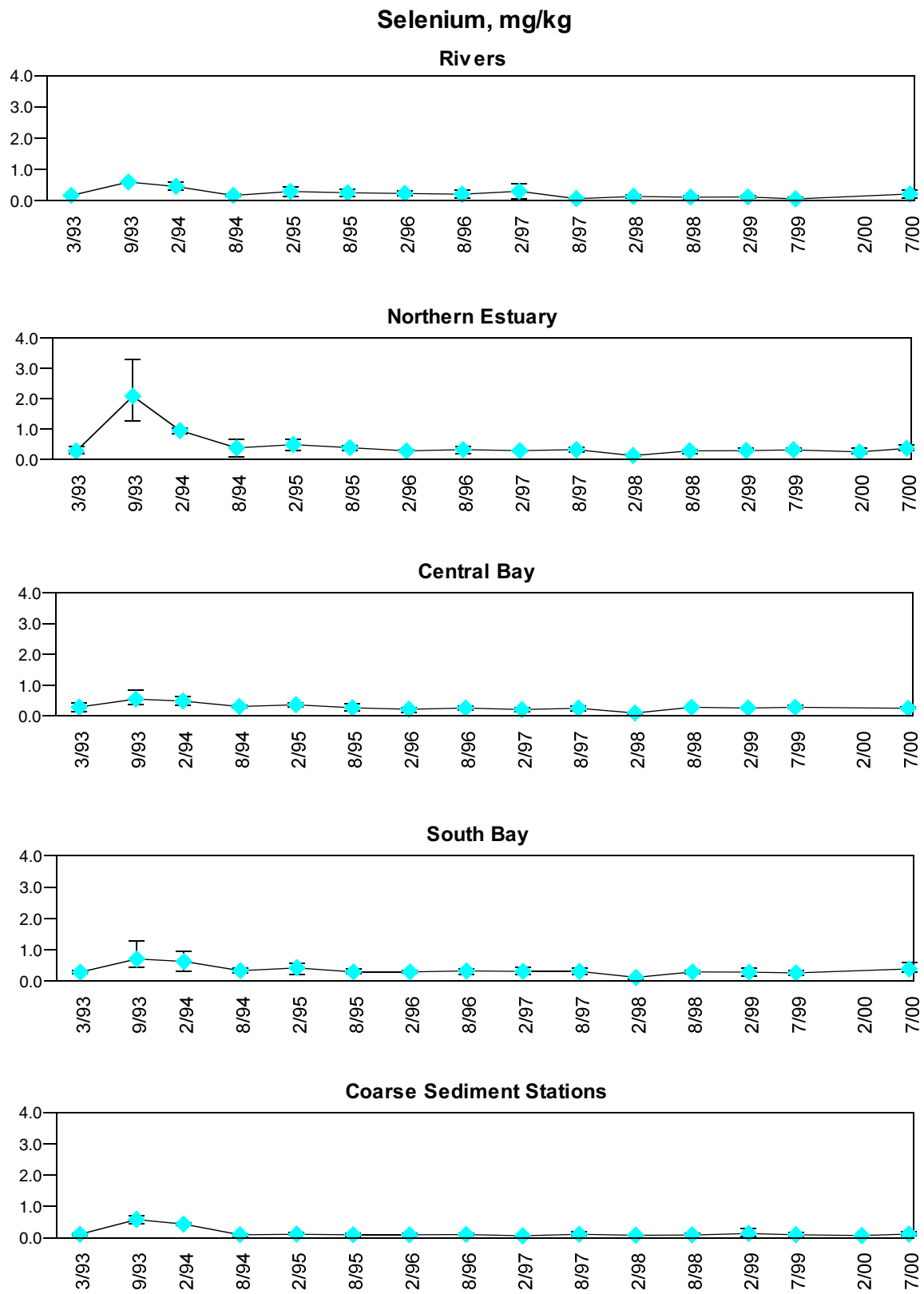

Figure 3.24. Average selenium concentrations in sediments for each Estuary reach from 1993–2000. The vertical bars represent the range of all values within a reach. The sample size varies between reach and between seasons. The South Bay reach does not include Southern Slough stations. Due to the RMP redesign, selenium data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.

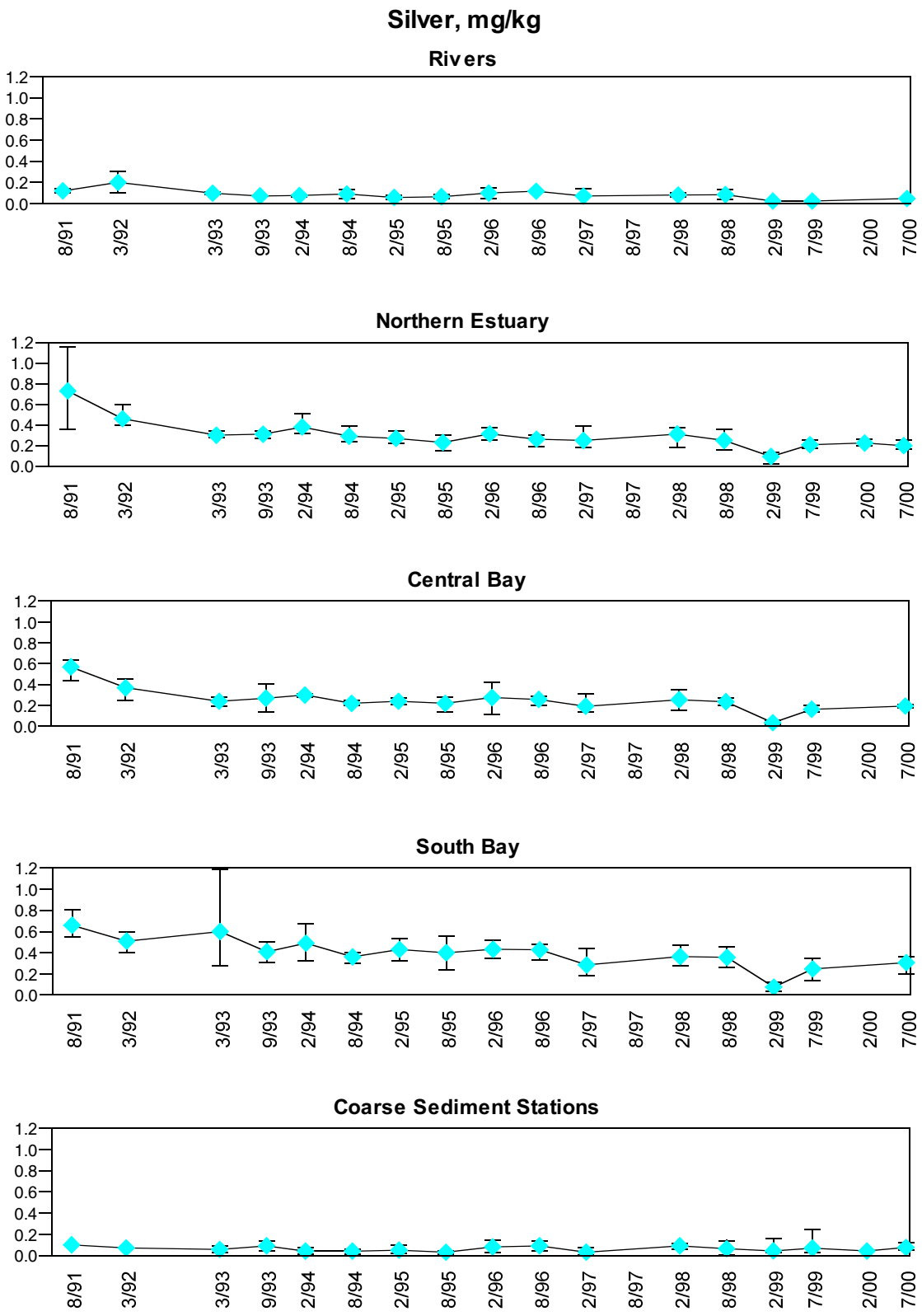

Figure 3.25. Average silver concentrations in sediments for each Estuary reach from 1991–2000. The vertical bars represent the range of all values within a reach. The sample size varies between reach and between seasons. The South Bay reach does not include Southern Slough stations. There are no data for silver in August 1997 because the blanks were contaminated. Due to the RMP redesign, silver data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.

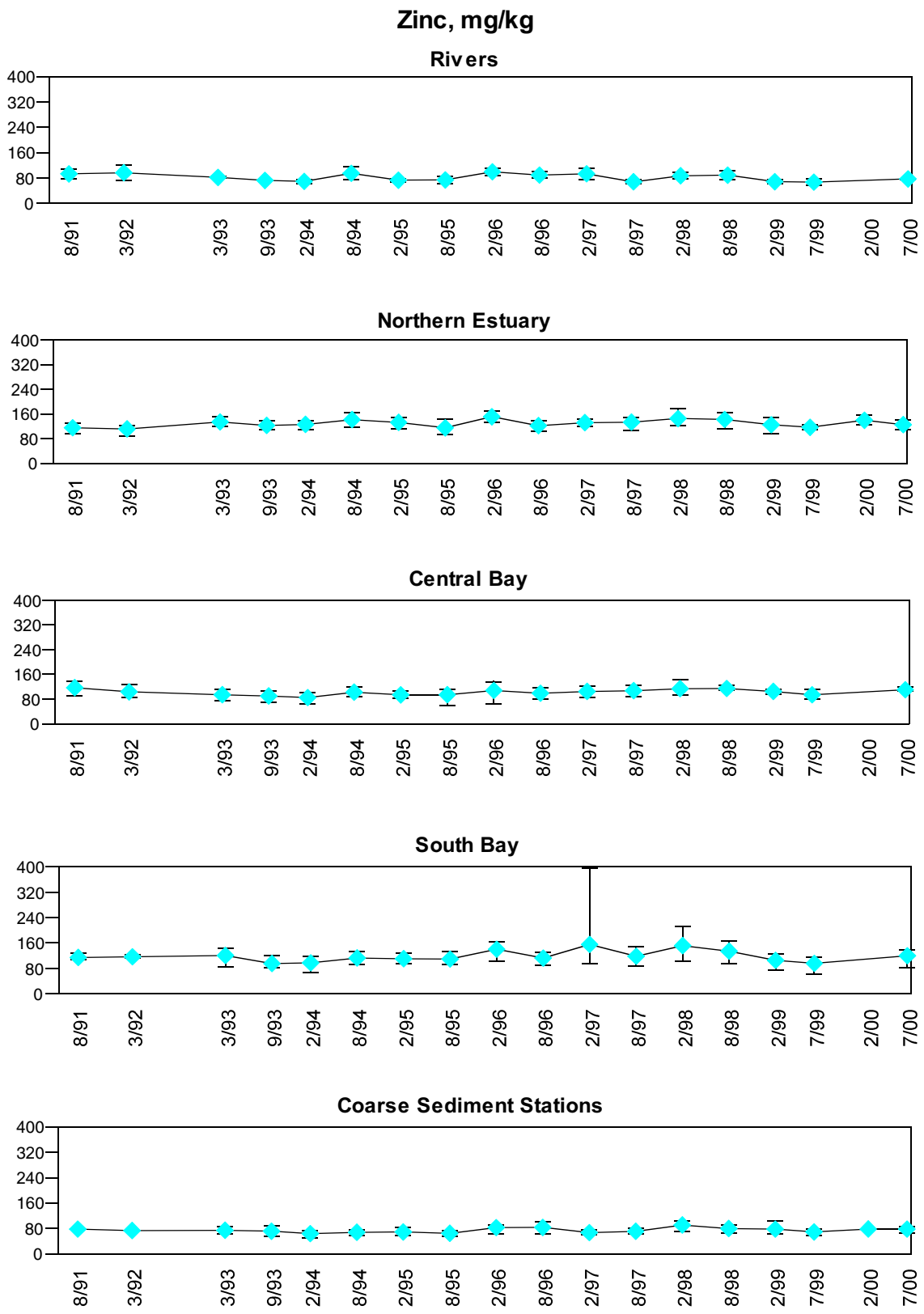

Figure 3.26. Average zinc concentrations in sediments for each Estuary reach from 1991–2000. The vertical bars represent the range of all values within a reach. The sample size varies between reach and between seasons. The South Bay reach does not include Southern Slough stations. Due to the RMP redesign, zinc data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.

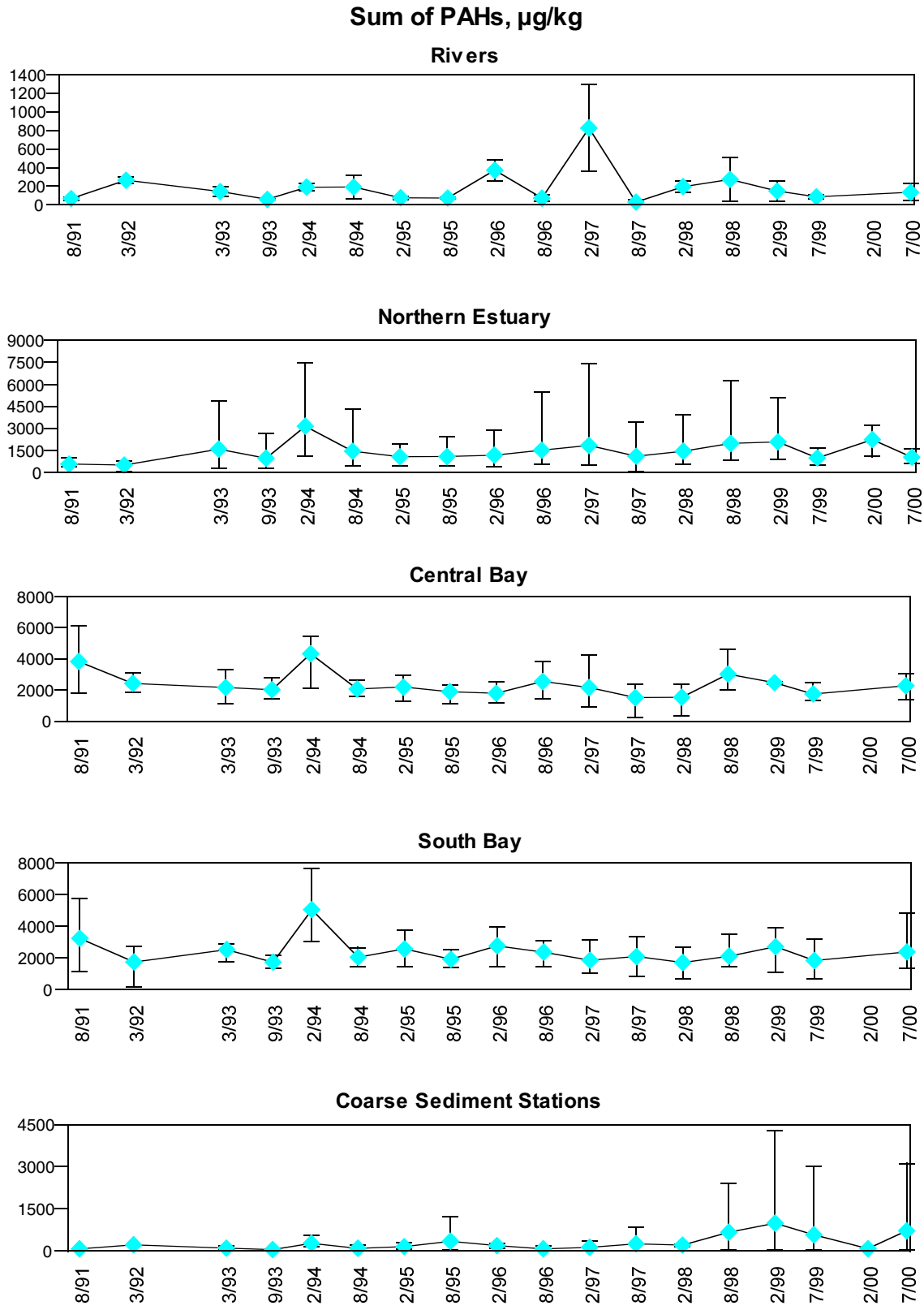

Figure 3.27. Plots of average PAH concentrations in sediments for each Estuary reach from 1991–2000. Units are in parts per billion, ppb. Note scale changes. The vertical bars represent the range of all values within a reach. The sample size varies between sites and between seasons. Due to the RMP redesign, PAH data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.

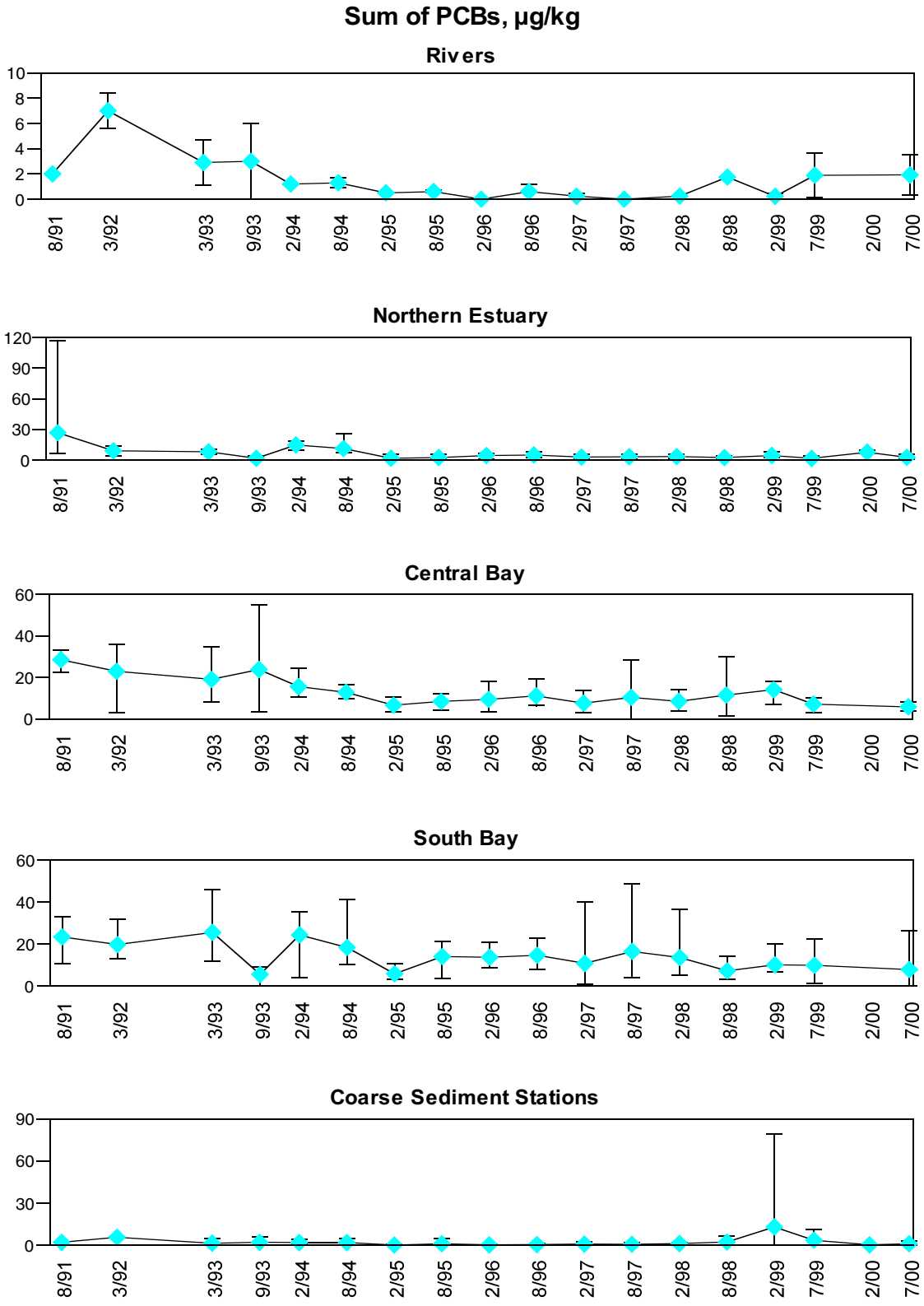

Figure 3.28. Plots of average PCB concentrations in sediments for each Estuary reach from 1991–2000. Units are in parts per billion, ppb. Note scale changes. The vertical bars represent the range of all values within a reach. The sample size varies between sites and between seasons. Due to grain size analysis data being unavailable at time of reporting, Due to the RMP redesign, PCB data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.

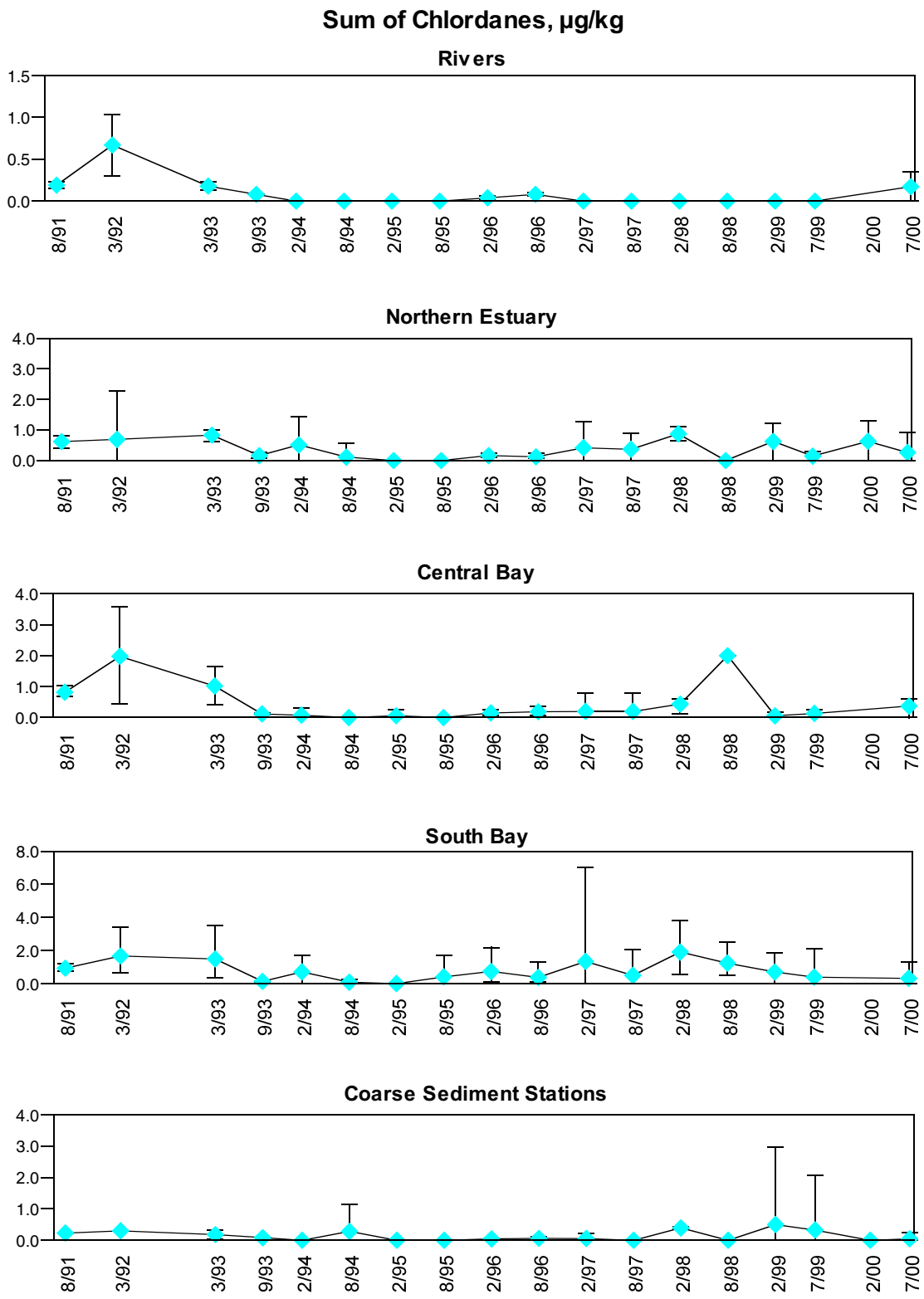

Figure 3.29. Plots of average chlordane concentrations in sediments for each Estuary reach from 1991–2000. Units are in parts per billion, ppb. Note scale changes. Vertical bars represent the range of all values within a reach. Sample size varies between sites and seasons. Chlordanes were not detected for the following reaches and seasons: Rivers: February and August 1998, and February and July 1999; Northern Estuary: August 1998; Coarse Sediment Stations: August 1998. Due to the RMP redesign, chlordane data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.

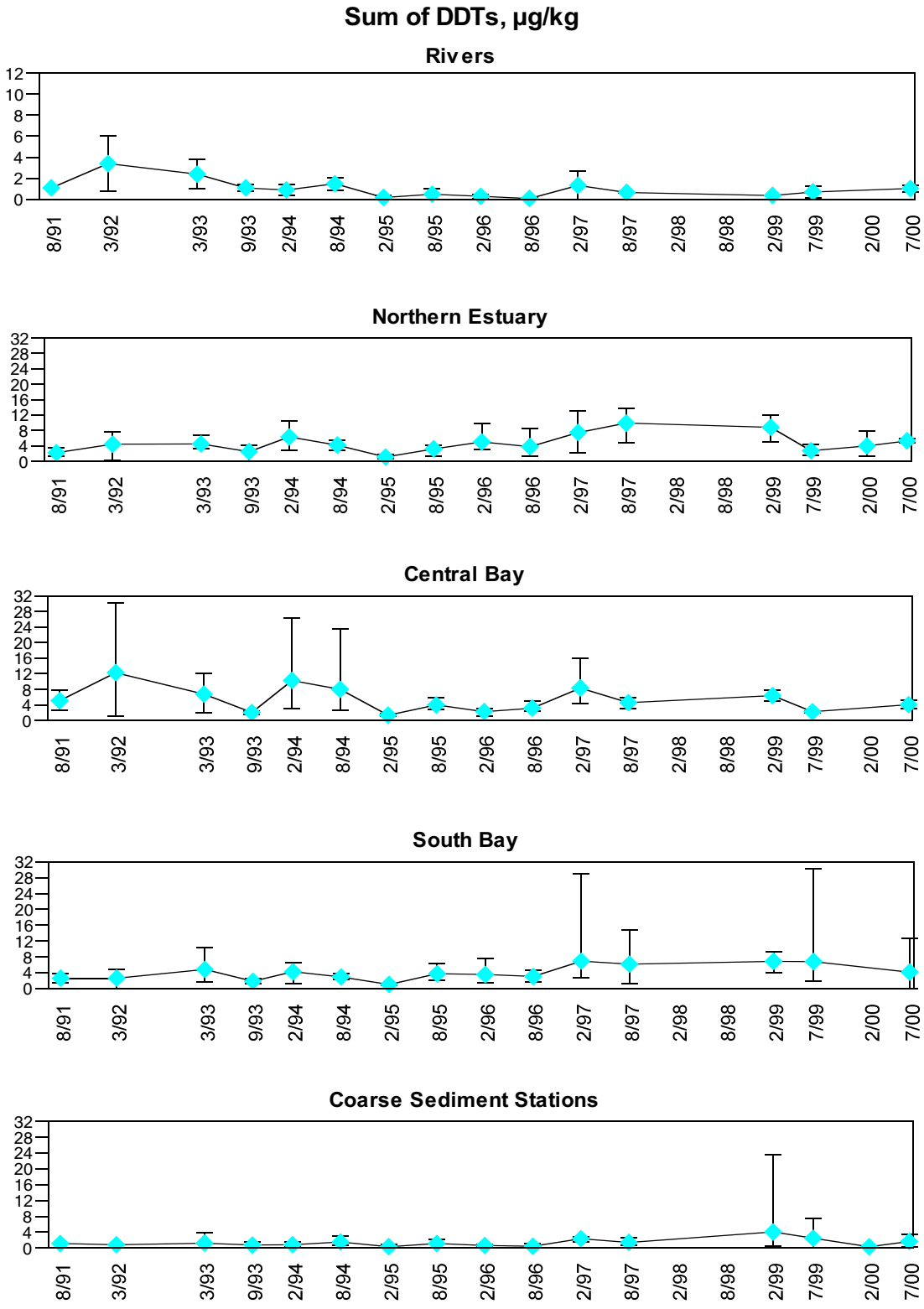

Figure 3.30. Plots of average DDT concentrations in sediments for each Estuary reach from 1991–2000. Units are in parts per billion, ppb. Note scale changes. The vertical bars represent the range of all values within a reach. The sample size varies between sites and between seasons. There were no 1998 DDT data to plot due to matrix interference. Due to the RMP redesign, DDT data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.

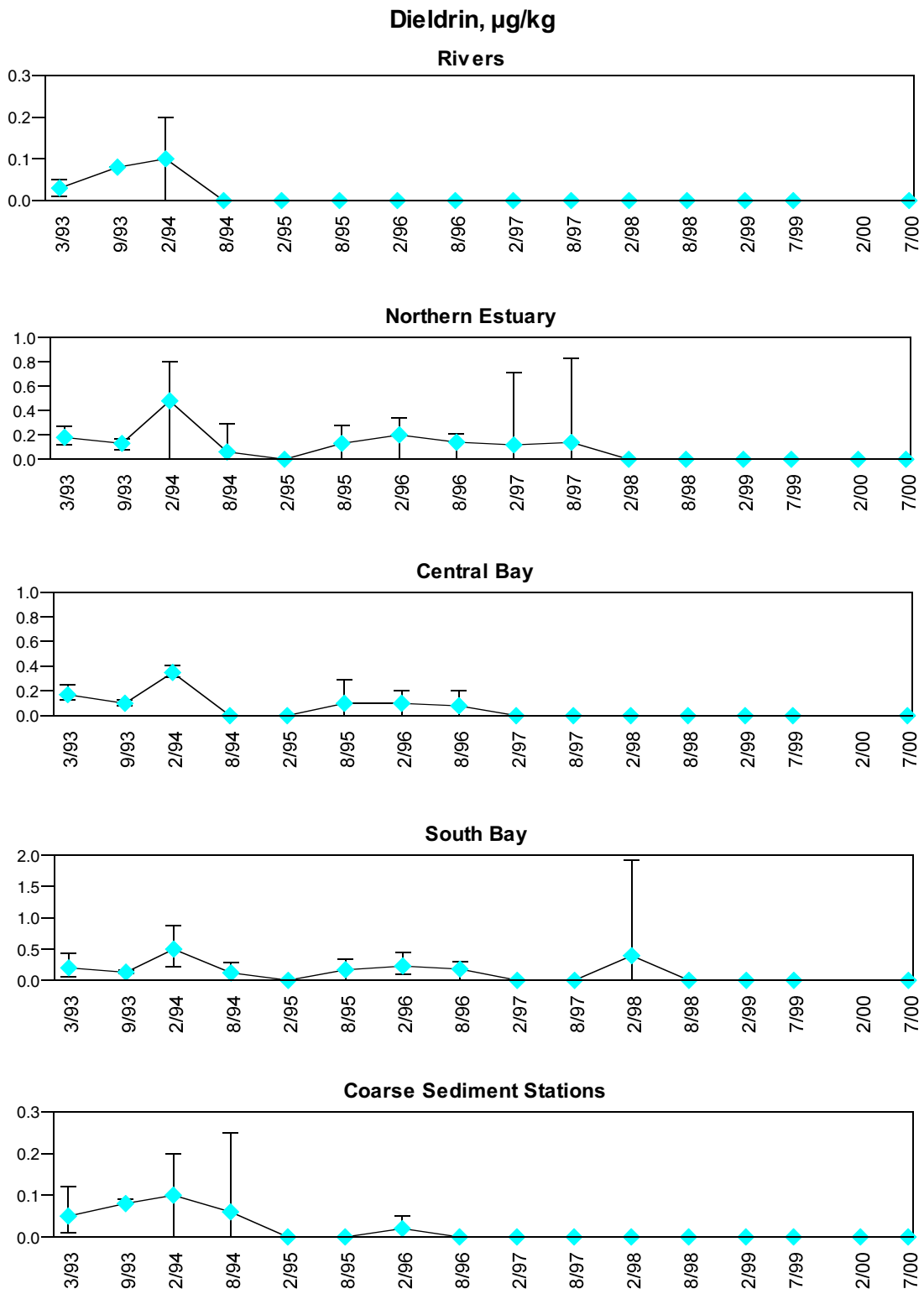

Figure 3.31. Plots of average dieldrin concentrations in sediments for each Estuary reach from 1993–2000. Units are in parts per billion, ppb. Note scale changes. Vertical bars represent the range of all values within a reach. Sample size varies between sites and seasons. Dieldrin was not detected for the following reaches and seasons: Rivers and Central Bay in Feb and Aug 1997 and 1998, Feb and July 1999, and July 2000; Coarse Sediment Stations in Feb and Aug 1997 and 1998, Feb and July 1999 and 2000; South Bay in Feb and Aug 1997, Feb and July 1999, and July 2000; and Northern Estuary in Feb and Aug 1998, Feb and July 1999 and 2000. Due to the RMP redesign, dieldrin data for February 2000 are available only for a few of the Northern Estuary and Coarse Sediment stations.