RMP
REGIONAL MONITORING PROGRAM FOR WATER QUALITY IN SAN FRANCISCO BAY

sfei.org/rmp

Characterization of Sediment Contamination in South Bay Margin Areas

Prepared by:

Don Yee, Adam Wong, and Nina Buzby
San Francisco Estuary Institute

CONTRIBUTION NO. 962 / November 2019

San Francisco Estuary Institute • 4911 Central Ave., Richmond, CA • www.sfei.org

Characterization of Sediment Contamination in South Bay Margin Areas

Final Report
November 15, 2019

Don Yee, Adam Wong, and Nina Buzby
San Francisco Estuary Institute

SFEI Contribution #962

Suggested Citation:

Yee D., A. Wong, and N. Buzby. 2019. Characterization of Sediment Contamination in South Bay Margin Areas. SFEI Contribution No. 962. San Francisco Estuary Institute, Richmond, CA.

Executive Summary

The Bay margins (i.e., mudflats and adjacent shallow areas of the Bay) are important habitats where there is high potential for wildlife to be exposed to contaminants. However, until recently, these areas had not been routinely sampled by the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) due to logistical considerations. In 2015, the RMP conducted a spatially-distributed characterization of surface sediment contamination and ancillary characteristics within the RMP-defined Central San Francisco Bay margin areas. This was repeated in 2017 within South Bay, which for this report refers to the area collectively encompassing Upper South Bay (usually just called the "South Bay" segment in the Bay RMP, "Upper" added here to distinguish from the combined area), Lower South Bay, and "Extreme" Lower South Bay (previously named "Southern Sloughs") margin areas.

Findings from the 2015 survey of margin areas in Central Bay (Yee et al., 2017) showed contamination in the margin areas accounted for 20% of the PCB mass in Central Bay, which is disproportionately high compared to margin area (5% of Central Bay). Central Bay watersheds contains many of the oldest and most industrialized urban environments within the Bay Area. There was a significant difference in mean contaminant concentrations in sediment from margins and nearby open water areas. In contrast, for South Bay, margins are more proximate to open water areas and represent a greater percentage of the overall Bay surface area. Therefore, as hypothesized, in the South Bay more uniform distributions were found, likely in part due to these physical factors. Average concentrations in South Bay margins were lower than in Central Bay margins, which was also hypothesized, because South Bay watersheds contain more recent industrial development and relatively less older industrial areas as a percentage of total area (~2% vs 5% for Central Bay watersheds). Although combined loads of PCBs from the South Bay watersheds are about 40% higher than from Central Bay areas, their total area is over 5 times larger, and their total runoff volume is more than double.

Ambient margins data in South Bay provide a context against which the severity of contamination at specific sites can be compared. The baseline data could also be useful in setting targets and tracking improvements in watershed loads and their nearfield receiving waters, or for appropriate assessment of re-use or disposal of dredged sediment. These spatially distributed data also provide improved estimates of mean concentrations and contaminant inventories in margins. Based on data from this study, contamination in the margin areas accounts for 35% of PCB mass in the upper 15 cm of surface sediments in South Bay, which is approximately proportional to the relative area of the margin (34% of the region). In contrast, margins only contain 30% of the mercury mass in South Bay, somewhat less than their proportional area.

Given the large inventory of contaminants in the open Bay compared to annual loads, changes may be difficult to see in the open Bay in the short- and mid-term. However, due to their smaller inventories and closer proximity to likely sources and loading pathways, improvements in margin sediments may potentially be detected more easily or sooner as loads are reduced, even if South Bay margins are better connected and more similar in concentrations to adjacent open water areas than in Central Bay.

1. Background

The San Francisco Bay ("Bay") margins (i.e., mud flats and adjacent shallow areas – Figure 1-1) are important habitats where contaminant exposure is high in some known locations. The margins had not been sampled by the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) due to logistical considerations (they are too shallow for the vessel routinely used for sampling the Bay) until a recent survey of the Central Bay Margins in 2015 (Yee et al., 2017). The Bay RMP Status and Trends (Bay RMP S&T) sampling program historically focused on deep water sediment collections, starting with the main channel of the Bay, and eventually moving into areas accessible by a moderately large boat (three foot draft). The RMP Margins Conceptual Model Report (Jones et al., 2012) hypothesized that contamination in margin sediment may contribute to the lack of decreasing trends in PCB concentration (and other persistent bioaccumulative contaminants) in biota (e.g., fish tissue), despite evidence of declining long-term trends in the sediment in some parts of the open Bay.

Analysis of contaminant concentrations in the RMP Margins Conceptual Model Report suggested higher and more variable concentrations in margins. However, much of the past sampling was spatially biased to focus on polluted areas in the margins associated with Superfund sites and other known legacy sources, while the ambient contaminant concentrations in the rest of the Bay margins were generally unknown (Figure A-1-1). Findings from a 2015 survey of margin areas in Central Bay (Yee et al., 2017) showed contamination in the margin areas accounted for 20% of the PCB mass in Central Bay, which is disproportionately high compared to margin area (5% of Central Bay). Given the large inventory of contaminants in the open Bay compared to annual loads, changes may be difficult to see at the Bay scale in the short- and mid-term. However, with margins' smaller areas, PCB inventories and greater proximity to terrestrial sources and loading pathways, improvements in margin sediment may hypothetically be easier to observe than at the whole-Bay scale in response to localized management actions aimed at reducing contaminant loads and impairment.

While the Central Bay Margins Study was informative, the sub-regions of the Bay differ in many aspects, including area, depth, hydrology, supplies of freshwater and sediment, and timing and extent of urban development (including filling and armoring of some former margin areas). Thus the Central Bay margins are not likely to be representative of conditions in margins elsewhere in the Bay. Thus, the South Bay margins study was conducted to further assess sediment quality and advance our conceptual model of those areas.

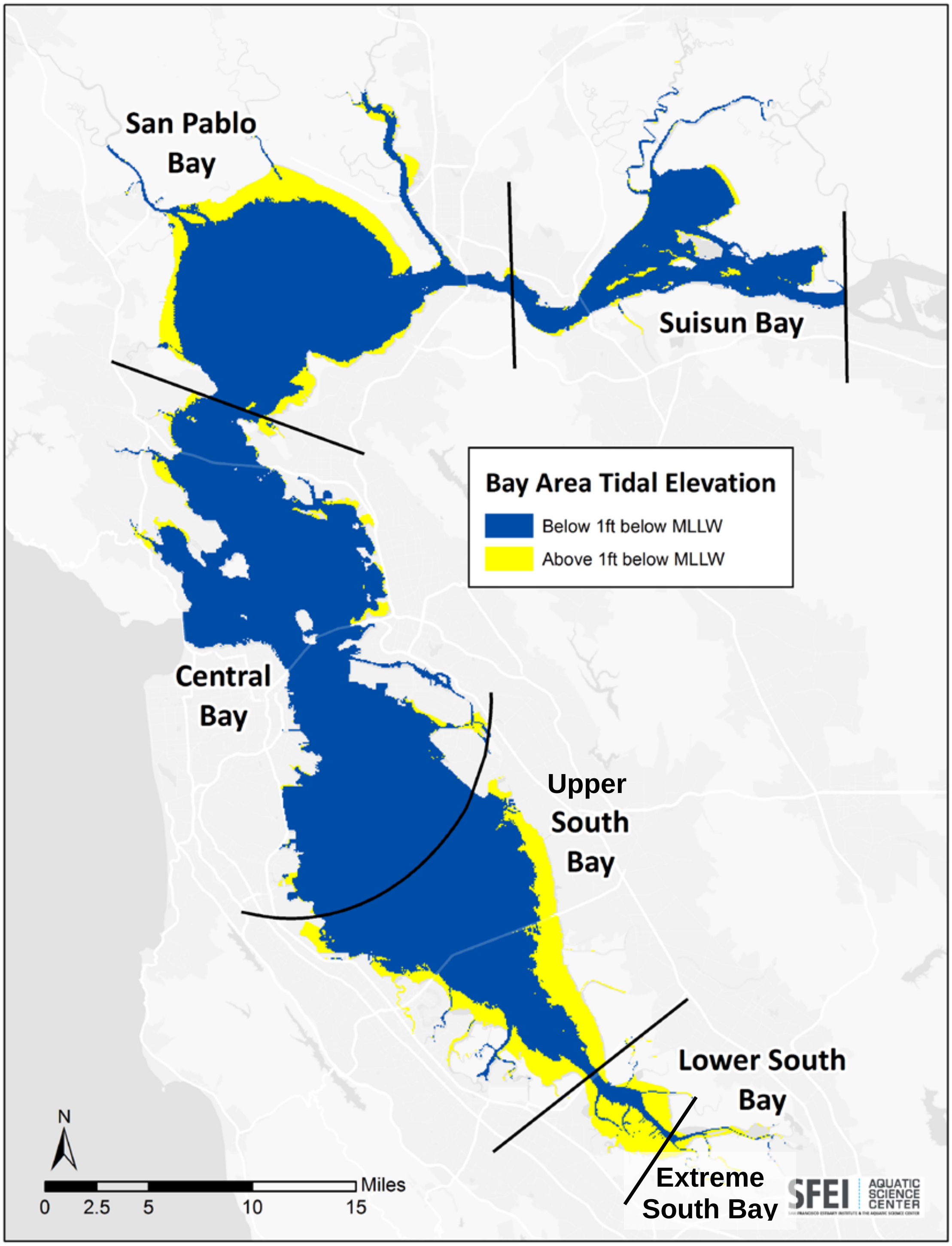


Figure 1-1. Margin areas in San Francisco Bay
Segments denoted by lines transecting the Bay. Margin areas colored yellow, deeper open water areas colored blue.

1.1. Study Objectives

A follow-up study of margins in the South Bay was designed to provide an unbiased, spatially balanced characterization of surface-sediment contamination and ancillary characteristics (grain size and total organic carbon). Unlike the previous Central Bay study where sampling locations were weighted towards urbanized areas, the South Bay sites were distributed throughout each of the three sub-segments in proportion (within integer rounding error) to their respective areas.

The three sub-segments monitored and reported here include Upper South Bay, Lower South Bay, and Extreme Lower South Bay (Figure 1-1). Upper South Bay (simply called the "South Bay Segment" in the Bay RMP S&T Program) includes the section of the Bay the San Bruno and San Leandro shoals (roughly between San Francisco and Oakland airports) and areas south to the Dumbarton Bridge. Lower South Bay includes the area south of Dumbarton Bridge, to a transect slightly to the southeast of Mountain View Slough to Mowry Slough. Extreme Lower South Bay (previously called the "Southern Sloughs" areas in the Bay RMP S&T) includes the area from the Lower South Bay border, east to where Alviso Slough meets up with Coyote Creek. In this report, we will refer to these areas collectively as "South Bay" rather than the RMP designation of "South Bay" which includes only the Upper South Bay sub-segment. It should be noted here that both the Bay RMP S&T "South Bay" segment and collective "South Bay" segments defined here differ from the definition of "South Bay" used by the San Francisco Bay Regional Water Quality Control Board, which includes only areas south of the Dumbarton Bridge.

In the RMP Margins Conceptual Model Report (Jones et al., 2012), it was noted that ambient data on the Bay margins were needed to characterize and model contaminant risk, fate, and trends. Without this information, assessments of exposure and risks to margins biota would have to rely on extrapolation of data from deeper, subtidal, open-water areas of the Bay or targeted cleanup areas in the margins. Both are likely inaccurate representations, with cleanup areas likely unrepresentatively high in concentrations of pollutants of concern, and open water areas potentially less contaminated due to better tidal flushing and dilution. While new information is needed for the ambient margins, continued deterministic sampling at specific contaminated sites is still needed to plan and monitor cleanup actions but is complementary to ambient characterization efforts.

There are broader questions and needs for ambient margins data throughout the Bay (e.g., addressing region-wide ecosystem status and possible trends, paralleling those for the Bay RMP S&T), so building upon the previous effort in Central Bay, this study was focused on South Bay, including some areas adjoining potential management actions on land. It thus provides a baseline against which to evaluate the effectiveness of management actions, especially for PCBs and mercury, which are the targets of TMDL control plans to reduce loads (SFBRWQCB, 2006, 2008). For most of the San Francisco Bay segments, the margin area constitutes a small area relative to the deeper subtidal open water area (Table 1-1, Figure 1-1). The exceptions are Lower South Bay and Extreme Lower South Bay, where the margin areas are greater than the subtidal areas, and there the distinction and distance between open water and margin areas is likely decreased.

Table 1-1 Margin versus Open Bay Areas in RMP-defined Bay Segments.
The South Bay segments include the largest relative margin areas; the margin areas of Lower and Extreme South Bay exceed the areas of open Bay waters.

Bay Segment	Margin Area (km^2)	Open Bay Area (km^2)	Portion of Segment in Margin (%)
Suisun Bay	17.5	72.5	19
Carquinez Strait	2.5	19.4	11
San Pablo Bay	42.2	180.7	19
Central Bay	21.7	382	5
(Upper) South Bay	52.2	143.6	27
Lower South Bay	21.7	5.5	80
Extreme South Bay	4.5	1.2	79

The information needs addressed by these data include:

1. Ambient concentrations of PCBs and other contaminants in margin area sediment – this information facilitates setting achievable targets for load management, sediment management and cleanup goals (dredging, remediation sites) and restoration.
2. Mass balance calculations for PCBs and other contaminants in margin areas – these calculations show the relative importance of watershed loads versus in-Bay inventories in margins and the open Bay in maintaining elevated concentrations in the region.
3. Effectiveness of watershed management projects at reducing loads or concentrations – this provides baseline information that can be used to determine whether management actions are having impact in the near-field receiving waters.
4. Screening for the existence of additional hotspots in areas that have not been sampled to date – although areas around many expected sources have already been sampled, distributed sampling may potentially provide evidence of other major unaccounted sources.

2. Approach

A margin sampling frame for the entire Bay was defined in consultation with Josh Collins of the San Francisco Estuary Institute (SFEI) and the SFEI GIS team, minimizing overlap with other monitoring, such as California Rapid Assessment Method-assessed wetland areas (by excluding vegetated areas) and open Bay areas already sampled in Bay RMP S&T monitoring (areas one foot or more below MLLW). In most areas, the sampling frame is approximately synonymous with mudflat (plus additional shallow subtidal areas).

A Generalized Random Tesselation-Stratified (GRTS) allocation method (Stevens and Olsen, 2004) was used to draw sampling locations (up to 128 per segment) from the margin sampling frame for the whole Bay in an unbiased, equally-weighted manner. Although some open-water sites were previously skipped in the Bay RMP S&T sampling (due to water being too shallow for the vessel to access), Don Stevens, who previously helped design the RMP open Bay GRTS sample draw (Lowe et al., 2005), recommended these areas (perhaps mischaracterized as deeper open water) not be added to the margins frame, as oversample sites had already been sampled to replace those sites.

Prior to the sampling conducted in Central Bay, in consultation with the RMP Technical Review Committee (TRC), criteria were identified for rejecting sites and replacing them with oversample locations. These same logistical criteria were evaluated for the planned sites in South Bay. If these conditions were encountered, sites were moved nearby or replaced by oversample sites:

1. Access/safety: the site could not be accessed safely; OR
2. Substrate: the substrate at the site was too coarse to collect a cohesive sample, was rocky shoreline, was covered with dense aquatic vegetation, or was shell hash; OR
3. Upland area: the planned site was in a salt marsh or upland area.

A desktop exercise was used to pre-identify potential problem sites from aerial imagery and nautical charts. No sites were identified as needing replacements from the oversample list. However, stakeholders on the TRC requested that some specific sites closer to potential management areas of interest be included in the study, so a sequence from the middle of the draw list was selected. In a GRTS sample draw, any contiguous portion of the draw sequence is considered spatially balanced (Stevens and Olsen, 2004). Microplastics, a suite of contaminants of emerging concern (CECs in sediment and water, primarily musks and current use pesticides), and perfluro-alkyl substances (PFAS) were also of interest for other projects. Data for these additional analytes will be presented in separate reports as those studies are completed.

When the field team encountered conditions unsuitable for sampling at the planned coordinates, there was a contingency plan to sample a location with suitable conditions within a 50-meter radius of the target site. To avoid biasing (e.g., always going to the deepest allowed depth) an attempt was made to sample at the expected original depth for the site. Using this approach, all of the planned sites were successfully sampled with only small deviations from planned coordinates. Therefore, none of the sites needed to be replaced by oversample sites.

2.1. Sample Size

Sites were distributed among three sub-regions: Upper South Bay, Lower South Bay, and "Extreme" Lower South Bay (i.e., Southern Sloughs). For the probabilistic ambient margins characterization of South Bay, 40 sites were chosen using area-proportional allocation; 27 were assigned to the Upper South Bay sub-segment, 11 to Lower South Bay, and two to Extreme Lower South Bay (Figure 2-1). These counts are equal to (within integer rounding error) the relative areas for each of the sub-segments in South Bay. An additional deterministic site was added in Extreme Lower South Bay on Coyote Creek for the other special study projects noted previously.

2.2. Sample Frequency

This study plan represented a one-year effort in South Bay to get an initial characterization of ambient conditions in margins of this highly urbanized area, and is the second phase in an overall plan to get a spatially representative characterization of margins Bay-wide. Decisions about repeating sampling of these areas and the timing and scope of monitoring margins in other segments will be made through the RMP multi-year planning process.

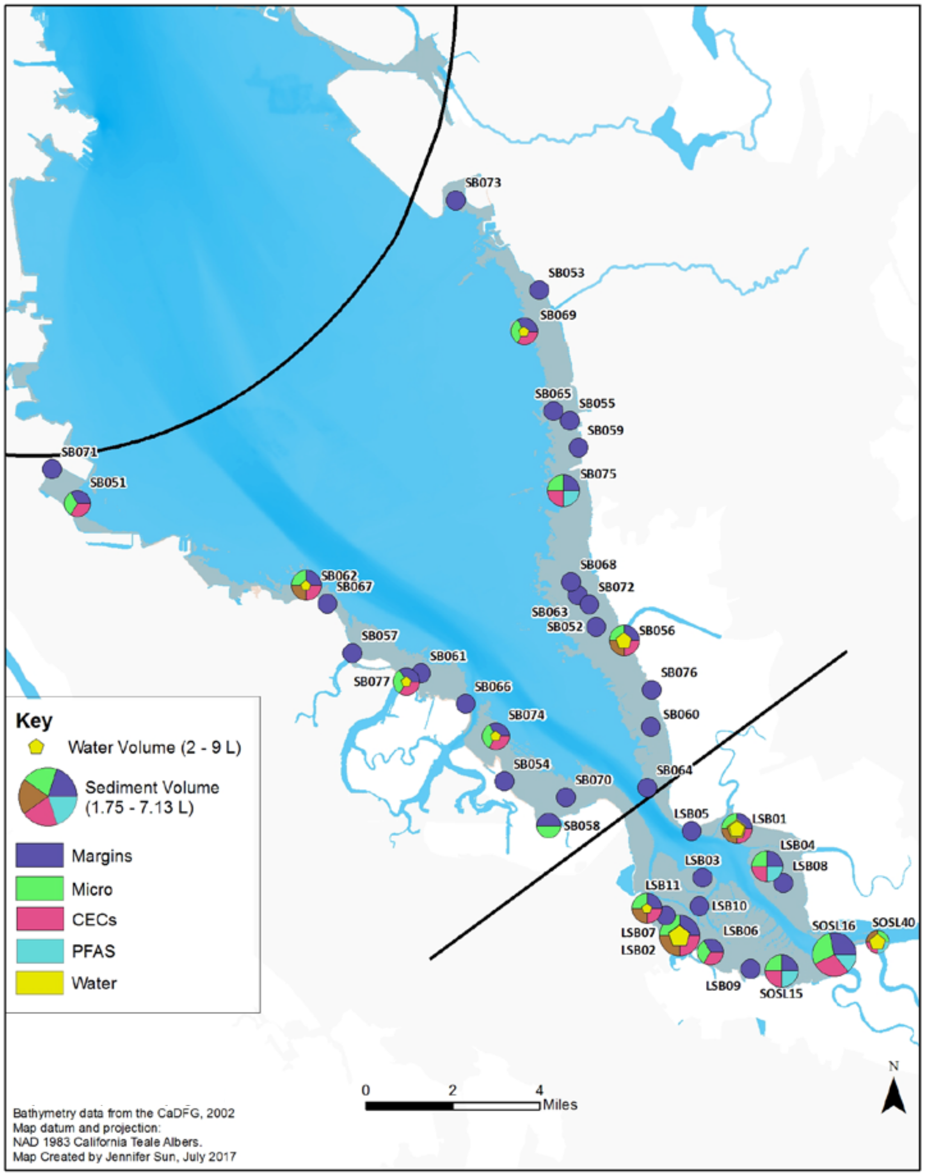


Figure 2-1. RMP South Bay Margin Sampling Sites.
The 40 ambient sites for this study and one deterministic site on Coyote Creek (the lower rightmost site, for some associated special studies) are shown, with bubble areas representing approximate sample volumes necessary for the various analyses. The standard “Margins” analytes (bubbles wholly or partially indigo) include PCBs, pollutant trace metals, and ancillary sediment parameters reported by the RMP. Other samples taken in the margins (indicated in the legend) included microplastics

(micro), a suite of contaminants of emerging concern in sediment (CECs) and in water (Water), and perfluro-alkyl substances (PFAS), analytes also of interest for other projects.

2.3. Target Analytes

Samples for several target analyte groups were collected at different subsets of sites (Figure 2-1). Standard margins samples, including analyses for mercury, PCBs, trace metals, and ancillary parameters, were collected at the 40 probabilistic sites. Extra archive samples were collected so that additional analyses can be conducted in the future.

Standard margin sample parameters were analyzed using the methods currently employed for characterizing ambient sediment samples in the Bay RMP S&T Program, with the same measurement quality objectives and procedures for data handling and flagging as outlined in the Bay RMP QAPP (Yee et al., 2017). The raw data are available for download through the CD3 tool on the SFEI website, and are also accessible through CEDEN.

Samples were also collected for a number of other studies. Microplastic samples and microplastic archives were collected at 16 sites, nanoplastic samples at eight sites, PFAS samples at five sites, and CEC samples at 15 sites. In addition, water samples were collected at six sites for bioanalytical tools analyses and at 12 sites for other CEC analyses (mainly pesticides and musks). Results for these special studies will be presented in separate reports once those studies are completed.

3. Results

3.1. Ambient Contaminant Concentrations in South Bay Margin Areas

Samples were analyzed for 15 target parameters (or 222, if the 209 PCBs are counted as individual congeners, rather than just as two types of PCB sums) (Table 3-1), as well as total organic carbon (TOC), total nitrogen (TN), and grain size, ancillary parameters often used as normalizing or explanatory factors correlated with pollutants of interest. All parameters were detected in all samples, although cadmium concentrations in a few samples were detected but not quantified (DNQ). Grainsize (% fines), TN, and TOC were in a similar range as seen in open Bay samples, although the mean and median of % fines were slightly lower than for the open Bay.

As noted in the Central Bay Margins Study, the current RMP organic analysis lab's (SGS-AXYS) method for extracting sediment PCBs potentially biases the results on average 15% higher than the previous lab's method (the East Bay Municipal Utility District lab was used for samples 2014 and prior). However, the extraction method is identical to the one currently used for RMP S&T sediments. Thus there are no expected biases in PCB results relative to current RMP S&T sampling, and any biases of reported margins concentrations relative to the overall set of open Bay data will decrease as more recent open Bay data are acquired by the newer method.

The means and medians for a majority of analytes (except manganese, methylmercury, and zinc) were less than 10% different, resulting in distributions less right-skewed than the

Central Bay margins sites. This is in line with our expectations given the lower proportion of area in older industrial development than in Central Bay watersheds, with concentrations in suspended particulates entering the South Bay margins possibly more similar to existing ambient sediment concentrations in most locations, and the smaller distances between margin areas and open water areas leading to more uniform mixing of sources.

The difference between open Bay and margin areas was also less at the South Bay sites than at the Central Bay sites. The proximity of margins to open Bay areas in South Bay, combined with the greater distance from tidal flushing processes in the Central Bay or dilution by cleaner sediment from the Delta are likely the main drivers of these differences. Although local tributaries also supply relatively clean sediment, these loads often pass through urban areas, and are mixed and discharged along with contaminants from those urban areas before entering the margins. Therefore smaller gradients between South Bay margins and open water areas are expected and generally seen.

Table 3-1 Range, weighted percentile, and weighted means for the distributions of contaminant concentrations in South Bay margins.

Concentrations are rounded to three significant digits. Units are mg/kg dw unless otherwise noted. Mean values below medians (left skewed distributions) are highlighted in yellow.

Parameter	*Minimum*	*1st Quartile*	*Median*	*3rd Quartile*	*Maximum*	*Mean*
Aluminum (Al)	9760	16200	24300	31400	36600	24100
Arsenic (As)	3.35	5.45	6.97	7.74	14.9	6.84
Cadmium (Cd)	0.052	0.146	0.179	0.214	0.402	0.186
Copper (Cu)	10.4	20.3	30.6	40.5	48	30.3
Iron (Fe)	15900	24900	34400	43300	47800	34300
Lead (Pb)	7.56	14.1	18.8	24.6	31.1	19.4
Manganese (Mn)	273	382	449	626	921	501
Mercury (Hg)	0.039	0.109	0.188	0.223	0.476	0.182
Methylmercury (MeHg) (µg/kg dw)	0.101	0.251	0.357	0.526	1.77	0.424
Nickel (Ni)	31.2	62.5	72.4	91	102	73.5
Selenium (Se)	0.114	0.213	0.305	0.412	0.585	0.32
Silver (Ag)	0.048	0.149	0.254	0.336	0.445	0.244
Sum of 208 PCBs (µg/kg dw)	2.57	7.52	14.3	19.2	53.8	15.1
Sum of 40 PCBs (µg/kg dw)	2.03	5.96	11.3	15.2	40.2	11.9
Zinc (Zn)	36.4	48.5	56.4	77.7	131	65.4
% Fines	5.17	36.5	68.1	84.7	95.7	60.3
Total Organic Carbon %	0.274	0.748	0.935	1.23	1.49	0.935
Total Nitrogen %	0.06	0.118	0.15	0.167	0.23	0.14

3.2. Spatial Variability of Contaminants in Margin Areas of the South Bay

The raw concentrations of mercury and PCBs are plotted on a map of South Bay in Figure 3-1 and Figure 3-2. Although concentrations at some margin sites were elevated relative to open Bay sites, the differences were not as drastic as seen between Central Bay margins versus open Bay sites (Figure 3-3, Figure 3-4).

Mercury concentrations varied 12-fold across all South Bay margin sites with relatively little variation in most areas. The highest mercury concentrations were in Extreme Lower South Bay at SOSL16 near the mouth of Guadalupe Slough (0.48 µg/kg dw), LSB04 near the mouth of Mowry Slough (0.33 µg/kg dw), and LSB02 east of the Palo Alto Airport near the Baylands Nature Preserve (0.28 µg/kg dw). The maximum was only about 2.5 times the median South Bay margins mercury concentration, so the bubbles for these points are only marginally larger than others in Figure 3-1. Although these concentrations are the highest among the South Bay margin sites sampled so far, they are modest in comparison to Central Bay margins, where a maximum mercury concentration of 2.65 µg/kg dw was found.

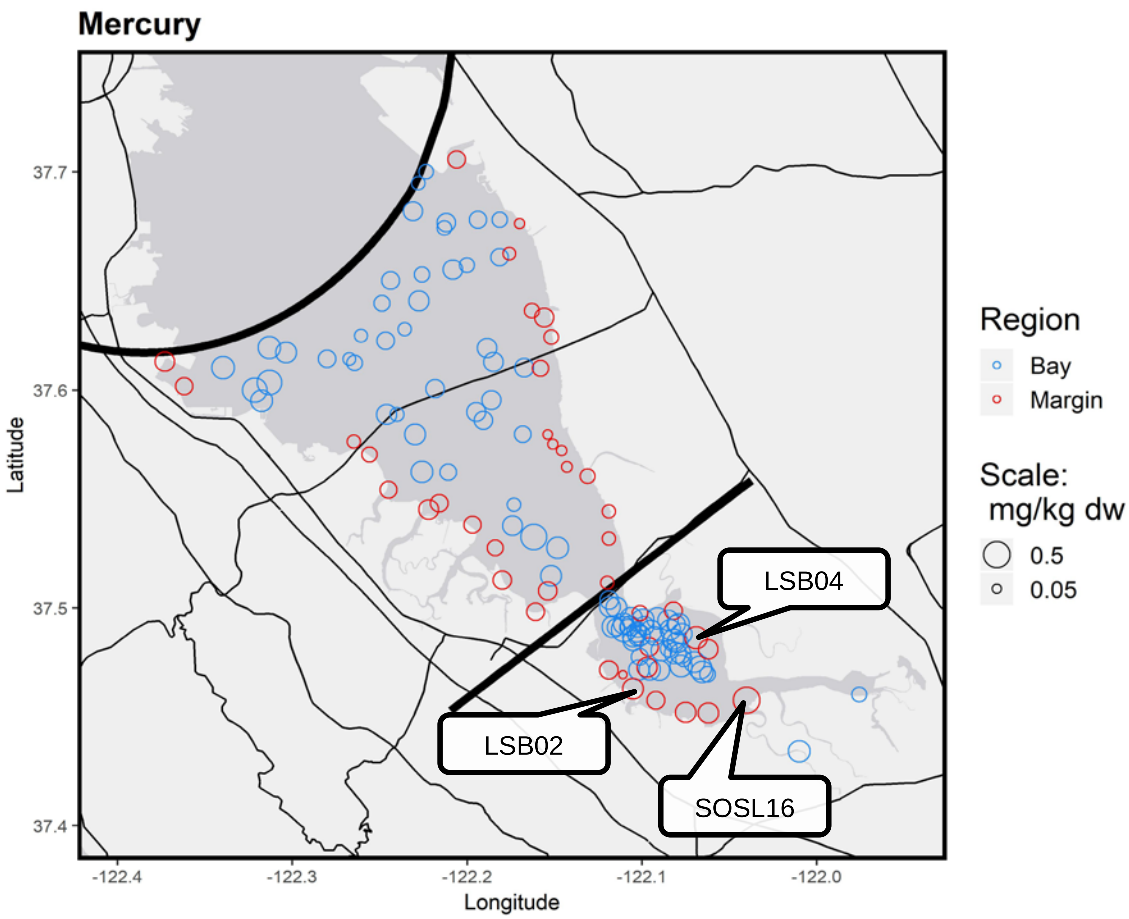


Figure 3-1 Mercury Concentrations –
Raw (not fines-normalized) results for sediment samples. Bubble areas are proportional to concentration (mg/kg dw). In most areas, margins and open Bay sediment concentrations span similar ranges.

Sums of the RMP 40 PCB congeners ranged from 2 to 40 µg/kg dry weight, with the highest concentration found at SB053, near the shore of San Lorenzo; SB061, near the mouth of Steinberger Slough (21 µg/kg dw), and SB073, near Oakland Airport (20 µg/kg dw), had the next highest PCB concentrations (Figure 3-2). The maximum PCB concentration was only about 4 times the South Bay margins median, so the bubbles for these points are only marginally larger than others in Figure 3-2. Similar to the case for mercury, these highest PCB concentrations are modest in comparison to Central Bay margins, where even the 75th percentile PCB result was around 32 µg/kg dw.

See Appendix A-3 for maps of other parameters and tables of concentrations

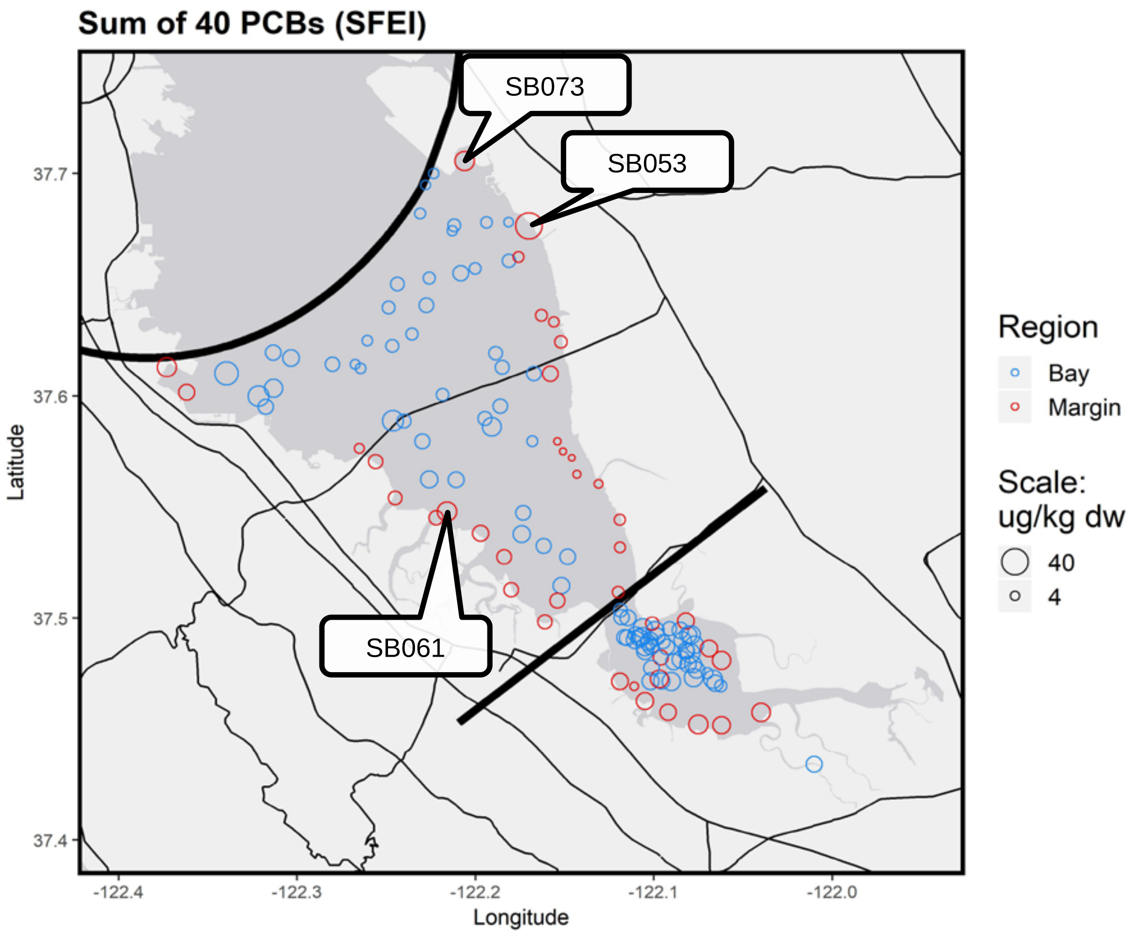


Figure 3-2 Sum of 40 PCBs Concentrations –
Raw (not fines-normalized) results for sediment samples. Bubble areas are proportional to concentration (µg/kg dw). In many areas, margins and open Bay sediment concentrations span similar ranges, but several locations in the margins show moderately higher sediment PCB concentrations than seen in nearby open water locations.

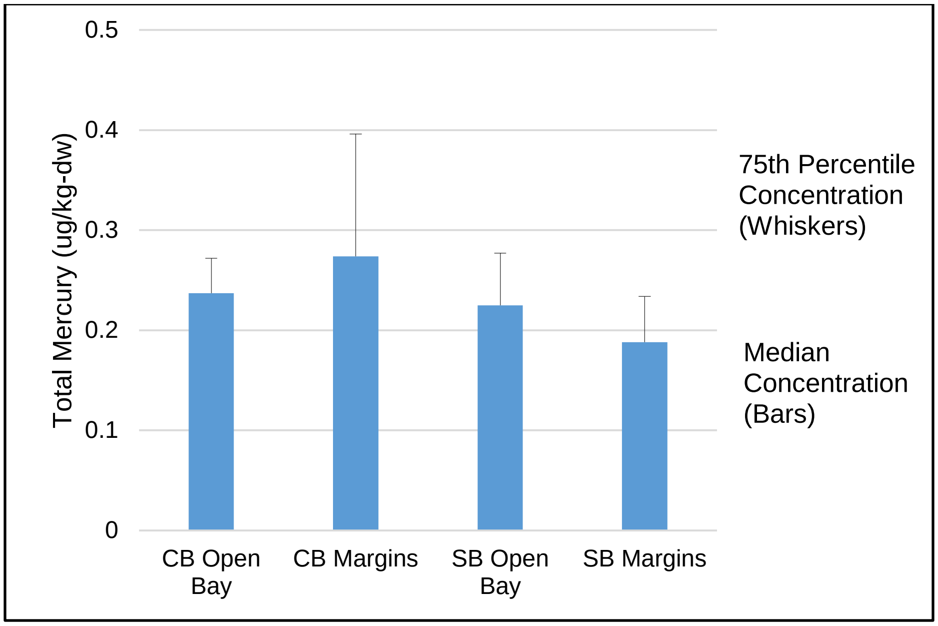


Figure 3-3 Medians and 75th Percentiles of Mercury in Open Bay and Margins Sediment of Central and South Bay.

Open Bay concentrations are similar for Central and South Bay, whereas Central Bay margins concentrations are often higher, while South Bay margins concentrations are generally lower.

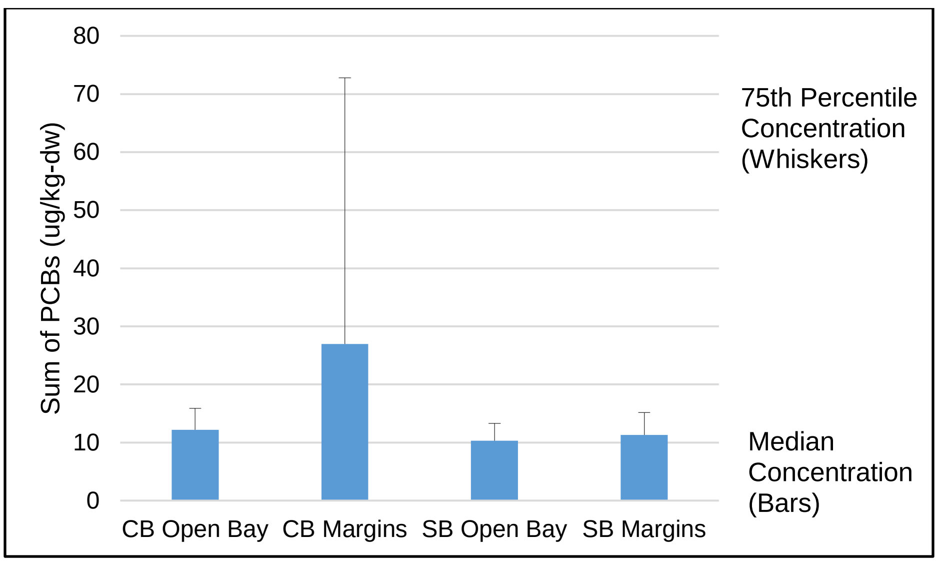


Figure 3-4 Medians and 75th Percentiles of PCBs in Open Bay and Margins Sediment of Central and South Bay

Concentrations are similar for Central Bay open Bay sediments, South Bay open Bay, and South Bay margins, with only Central Bay margins concentrations consistently higher.

3.3. Evaluating Ancillary Parameters to Reduce Variability

Concentrations were fitted to a linear model with either proportion of fines in the sample or TOC (Figure 3-5). While the correlations were significant in most cases, ancillary parameters accounted for over 50% of the observed variance for only about half of the analytes (Table

3-2). Samples with the lowest quartile of mercury or sum of 40 PCB concentrations had lower than median fine sediment (less than 70%) or TOC content (less than 1%). However, the sample with the highest PCBs also had below median fines and TOC content, and many samples with above median Hg concentrations had below median fines and TOC content.

These findings are consistent with the concept that, although there are tendencies for many pollutants to partition to fine particles or TOC, local factors can have a large influence on contaminant concentrations. For example, there is more limited transport and exchange in the margins, and these areas could thus be more heavily influenced by localized sources (of contaminants and common normalizing factors) than sediment in open water subtidal areas of the Bay, where sediments from different sources likely have already mixed or repartitioned.

Table 3-2 Regressions with ancillary parameters (South Bay) –
R-squared and p-value from the F-statistic from linear models of unmodified concentrations vs fines or total organic carbon in margins sediment samples. Correlations to fines and TOC were significant for all analytes except zinc. However, these ancillary parameters often accounted for less than half the total variance ($R^2 < 0.5$)

Parameter	R^2 %Fines	P-value %Fines	R^2 %TOC	p-value %TOC
Aluminum	0.797	9.82E-15	0.764	1.80E-13
Arsenic	0.441	2.97E-06	0.765	1.61E-13
Cadmium	0.316	0.000161	0.561	2.69E-08
Copper	0.785	2.91E-14	0.847	4.78E-17
Iron	0.76	2.49E-13	0.735	1.62E-12
Lead	0.739	1.18E-12	0.793	1.44E-14
Manganese	0.192	0.00463	0.18	0.00632
Methyl Mercury	0.215	0.0026	0.253	0.000948
Mercury	0.605	3.49E-09	0.576	1.39E-08
Nickel	0.535	8.32E-08	0.458	1.63E-06
Selenium	0.439	3.17E-06	0.685	4.47E-11
Silver	0.699	1.85E-11	0.828	4.42E-16
Sum.208 PCBs	0.192	0.00468	0.27	0.000597
Sum.40 PCBs	0.216	0.00251	0.294	0.000304
Zinc	0.0146	0.457	0.0279	0.303

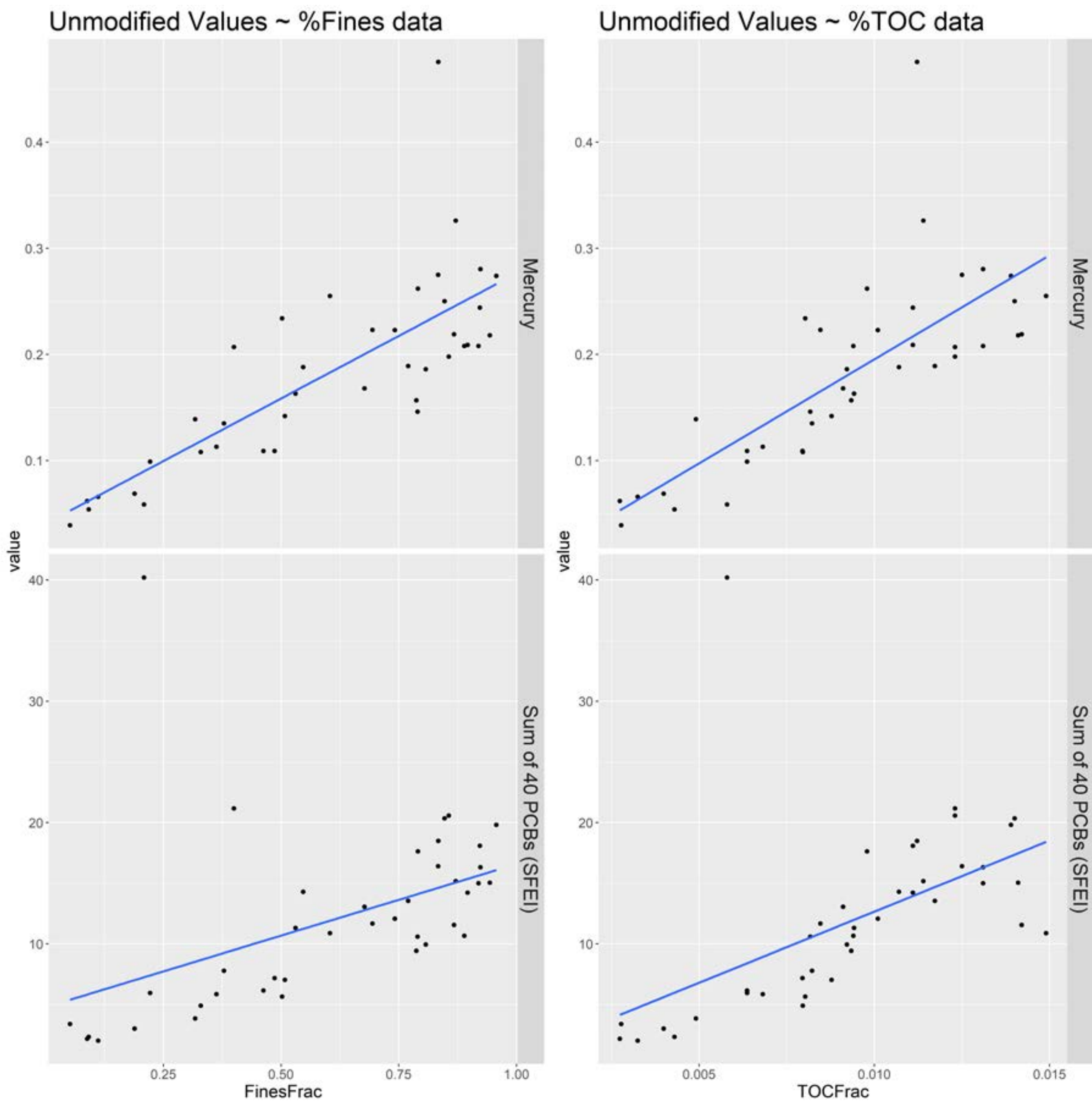


Figure 3-5 Regressions with ancillary parameters (South Bay) –
Linear models of mercury and PCB concentrations to %fines and %TOC (shown as decimal fractions). Although the main population of the margin samples in South Bay suggests correlations to both %fines and %TOC, these factors poorly predict the highest concentration sites.

3.4. Evaluation of Contaminant Distributions for Normality

Unlike Central Bay margin samples, where a variety of transformations of the contaminant distributions to meet conditions of normality were attempted without success, for the South Bay margins samples, the unmodified concentrations were normally distributed for 60% of the analytes (including mercury, and Sum of 40 and Sum of 208 PCBs). The same transformations used in reporting Central Bay data were also explored to see if they were effective at transforming the concentration data to a normal distribution. Each transformed value was weighted, then compiled into an interpolated empirical cumulative distribution function (ECDF). Each interpolated ECDF was then compared to a normal distribution (sharing the same transformed mean and variance) using an Anderson-Darling test. A summary of the normality of the distributions for different analytes after various normalization and transformations is summarized in the appendix (Table A-3-1).

Mercury was normally distributed in its raw concentrations. Although normally distributed variables can be analyzed using parametric statistical methods, some comparisons later in this report were made relative to Central Bay distributions, which were not normally distributed. Therefore all comparisons made in the following sections (even when not comparing to Central Bay distributions) are computed consistently using non-parametric methods to avoid concerns and artifacts in comparability of the statistical methods used.

Although both sediment fines and TOC were significantly correlated to PCB concentrations in South Bay margin sediment, they account for less than 30% of the variance of the sum of 40 PCBs or the sum of 208 PCBs. Thus PCB concentrations normalized to these ancillary parameters yielded less normally-distributed populations due to the majority of samples falling in a narrow near-median concentration range, with a small number of samples with high PCBs but low TOC and/or fine sediment extremely right-skewing the distributions. Nonetheless, similar to the case for mercury, we elected to compare South Bay margin PCB results to other sample groups using non-parametric methods.

4. Data Analysis

4.1. Ambient Concentrations of Contaminants in the Margins Compared to the Open Bay in South Bay

The data from this study showed distributions of ambient sediment concentrations of PCBs and other contaminants in the margin areas spanned a slightly wider range of concentrations than seen in the open Bay (Figure 3-4). The next question is whether these ambient concentrations are significantly higher than in the open Bay as hypothesized in the margins conceptual models (Jones et al., 2012).

Similar to the analysis conducted for reporting on Central Bay margins, comparisons were made between strata (e.g., open Bay versus margins for South Bay, or various sub-segments) using the non-parametric Kolmogorov-Smirnov test of distributions. Raw values for mercury and PCBs (both sum of 40 and sum of 208) were normally distributed (not significantly different from normal distributions with the same means and variances) for South Bay margins. Despite this, we make all comparisons using a non-parametric test to maximize flexibility. This allows the use of the same method regardless of whether both, one, or none of the compared populations are normally distributed.

For the raw concentration data, margins and open Bay sediment in South Bay were significantly different for mercury, selenium, and zinc. For selenium, the median, 75th percentile, and 90th percentile concentrations were all higher in margin sediment compared to those same percentiles for the open Bay. However, mercury and zinc patterns ran counter to our expectations from Central Bay margins. Here higher concentrations were found in the open Bay samples rather than in margin samples.

Table 4-1 Comparison of South Bay Margins to Open Bay Raw Concentration Quantiles – Percentiles for South Bay data weighted for their respective sub-areas (Upper/Lower/Extreme) for both margins and open Bay sites. Comparisons were made using the Kolmogorov-Smirnov test of distributions. Analytes that are significantly different between margin and open Bay areas are shaded; percentiles where the margin concentrations are higher than open Bay are in red, and percentiles where the margin concentrations are lower than open Bay are in blue. Percentiles are also in bold underlined font if the distributions were significantly different. Parameters are reported in mg/kg dw unless otherwise noted.

Analyte	K-S p-value	50th Margins	50th Bay	75th Margins	75th Bay	90th Margins	90th Bay	Mean Margins	Mean Bay
Aluminum	0.65	25500	24500	31400	32300	33600	37100	24200	26000
Arsenic	0.0786	6.97	7.14	7.74	9.35	9.02	10.9	6.85	7.6
Cadmium	0.953	0.18	0.178	0.214	0.22	0.255	0.292	0.186	0.196
Copper	0.234	30.9	31.4	40.6	36.9	44.3	41.6	30.4	31.6
Iron	0.0706	34500	30500	43300	38700	45800	42700	34400	31800
Lead	0.234	18.8	18.6	25	24.2	28.4	25.9	19.5	19.6
Manganese	0.175	455	477	627	708	786	1020	504	604
Mercury	0.0372	0.188	**0.225**	0.234	**0.277**	0.274	**0.327**	0.184	**0.225**
Methyl Mercury (µg/kg dw)	0.162	0.363	0.47	0.525	0.666	0.642	1.01	0.424	0.566
Nickel	0.0842	72.9	69.3	91.5	81.4	95.8	88.3	73.8	67.2
Selenium	0.0388	**0.317**	0.261	**0.421**	0.327	**0.491**	0.396	**0.322**	0.266
Silver	0.109	0.278	0.207	0.342	0.289	0.402	0.323	0.245	0.224
Sum.208 PCBs (µg/kg dw)	0.188	14.4	10.9	20.4	16.4	24.9	23.5	15.2	13.3
Sum.40 PCBs (µg/kg dw)	0.386	11.5	10.3	16	13.3	19.8	18	11.9	11.3
Zinc	1.2E-05	56.4	**90.8**	77.7	**107**	98.5	**130**	65.2	**91.7**
% Fines	0.0659	68.1	77	84.7	92.7	91.9	98.6	60.3	71.9
Total Organic Carbon %	0.0112	0.935	**1.15**	1.23	**1.45**	1.39	**2.17**	0.935	**1.32**
Total Nitrogen %	0.304	0.15	0.132	0.167	0.154	0.18	0.164	0.14	0.132

For fines-normalized concentrations, margins and open Bay sediment in South Bay were significantly different in distributions for a wider range of pollutants (Table 4-2), including PCBs (both Sum of 40 and Sum of 208), copper, lead, nickel, selenium, silver, zinc, and iron. However, once the concentrations were fines-normalized, distributions were not significantly different between margins and open Bay for mercury. Unlike the raw concentrations, which differed significantly between open Bay and margins for only three of the fifteen contaminant parameters, fines-normalized concentrations differed significantly for ten of those fifteen analytes. This may in part be due to differences in fine sediment and TOC content, with margin samples generally having less of both, while pollutant bulk concentrations were similar and not significantly different between the strata.

Table 4-2 Comparison of South Bay Margins to Open Bay Fines-Normalized Concentration Quantiles –

Percentiles for South Bay data for both margins and open Bay sites. Comparisons were made using the Kolmogorov-Smirnov test of distributions. Analytes that are significantly different between margin and open Bay areas are shaded; percentiles where the margin concentrations are higher than open Bay are in red, and percentiles where the margin concentrations are lower than open Bay are in blue. Percentiles are also in bold underlined font if the distributions were significantly different. Parameters are reported in mg/kg dw fines unless otherwise noted.

Analyte	K-S p-value	50th Margins	50th Bay	75th Margins	75th Bay	90th Margins	90th Bay	Mean Margins	Mean Bay
Aluminum	0.236	39400	38200	51500	51300	75000	57400	51700	41100
Arsenic	0.208	10.2	10.1	15.3	12.9	24.7	18.1	15.8	11.4
Cadmium	0.0844	0.293	**0.294**	**0.461**	0.367	**0.617**	0.481	**0.431**	0.306
Copper	0.00567	**51.3**	44.4	**57.6**	51.6	**84.7**	60.6	**62.3**	46.7
Iron	2.84E-09	**54600**	43800	**73600**	49300	**127000**	66900	**80000**	47300
Lead	0.0012	**32.4**	26.7	**39.7**	30.9	**77**	38.7	**42.1**	29.1
Manganese	0.304	818	789	1140	1150	2670	1670	1330	935
Mercury	0.371	0.305	0.305	0.419	0.368	0.569	0.449	0.347	0.325
Methyl Mercury (µg/kg dw)	0.963	0.704	0.683	1.04	1.05	1.46	1.34	0.843	0.813
Nickel	4.96E-07	**112**	91.3	**153**	104	**338**	143	**186**	100
Selenium	3.84E-08	**0.519**	0.376	**0.702**	0.437	**1.16**	0.551	**0.7**	0.394
Silver	7.89E-05	**0.406**	0.306	**0.497**	0.365	**0.553**	0.453	**0.447**	0.333
Sum.208 PCBs (µg/kg dw)	0.0225	**22.4**	17.8	**27.8**	24.6	**33.5**	31.8	**31.2**	21
Sum.40 PCBs (µg/kg dw)	0.00155	**17.6**	14.3	**22.1**	18.4	**26.1**	24.1	**24.3**	16.1
Zinc	6.62E-05	117	**128**	**191**	142	**371**	176	**175**	135

The statistical differences for mercury, where the raw concentration distributions were significantly different but the fines normalized concentrations were not, can be best visualized by plotting both groups as ECDFs. For raw mercury concentrations (Figure 4-1), margin sample results were lower for nearly every percentile. In contrast, after normalizing to percent fines (Figure 4-2), margins and open Bay samples had similar concentrations, with visible separation only at the top and bottom of the range. Although the ECDFs were plotted with logarithmic spacing on the concentration (horizontal) axis, the scaling is immaterial to the statistical tests, as the comparisons are made using a non-parametric test; the p-values for tests using the log-transformed values versus the untransformed (linear scale) values of the raw and fines normalized concentrations were exactly the same.

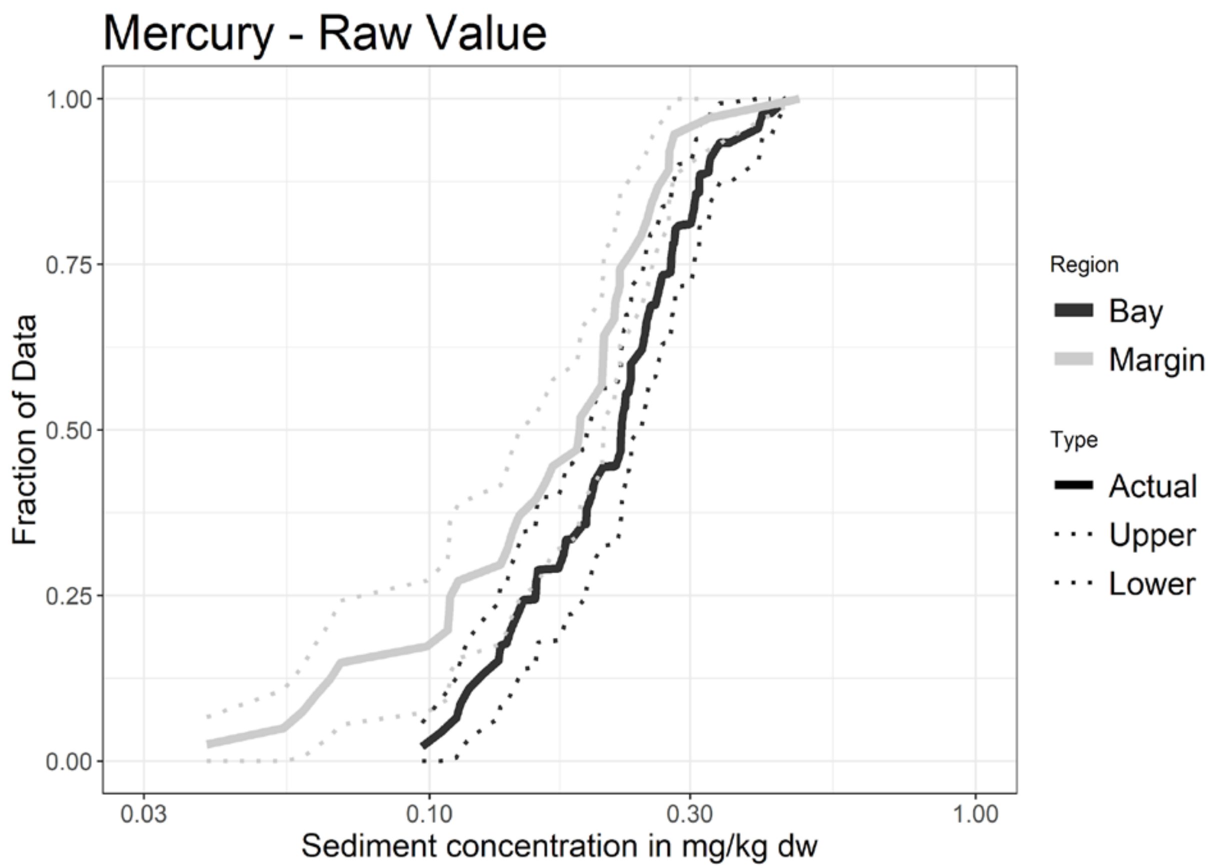


Figure 4-1 Estimated Cumulative Distribution Function of All Sites Comparing Mercury in Bay and Margins –

Solid lines (Bay in black, margin in gray) represent the ECDF estimated value (mercury concentration in mg/kg dw), with the dotted lines indicating the 95% confidence interval lower and upper bounds. Note the concentration scale is plotted with logarithmic spacing.

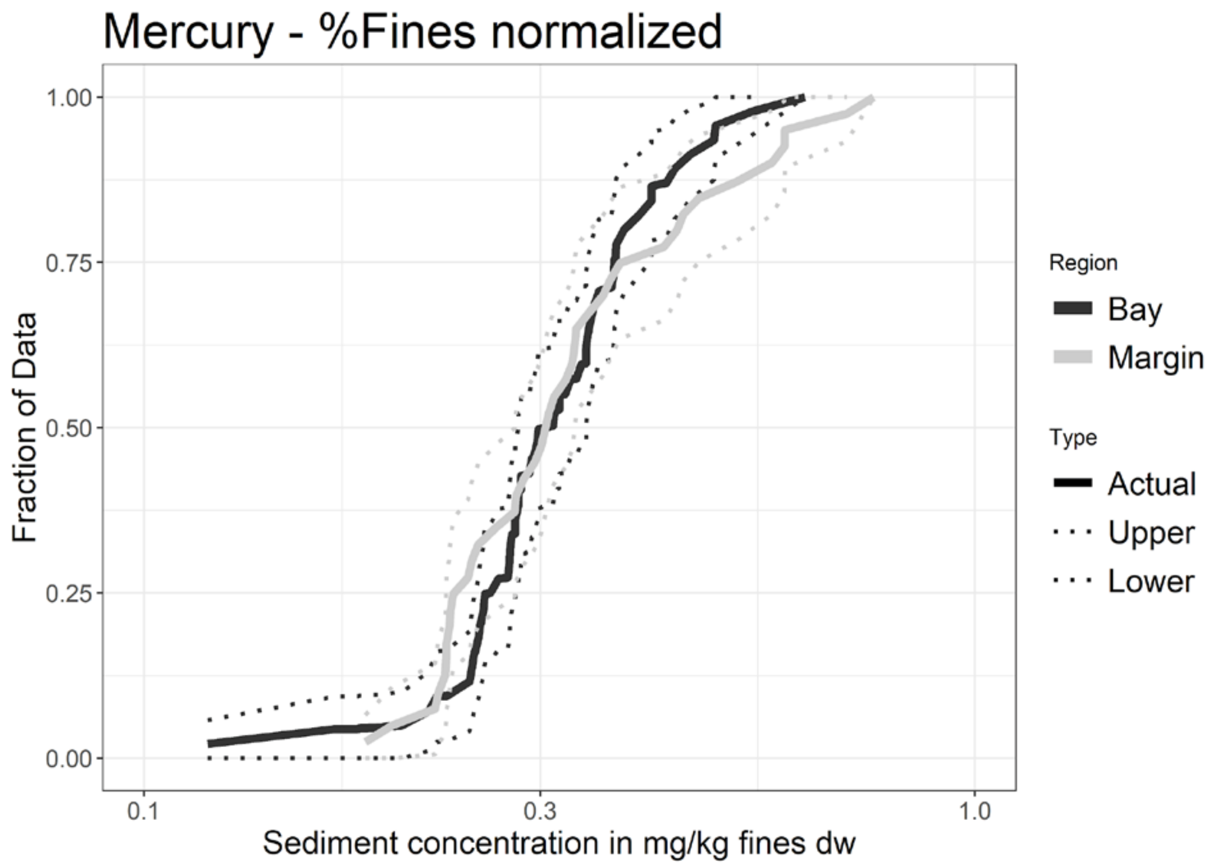


Figure 4-2 Estimated Cumulative Distribution Function of South Bay Sites Comparing Fines-normalized Mercury in Bay and Margins –
Solid lines (Bay in black, Margin in gray) represent the ECDF estimated value (mercury in mg/kg fines dw), with the dotted lines indicating the 95% confidence interval lower and upper bounds. Note that the concentration scale is plotted with logarithmic spacing.

Similarly, the statistical differences for PCBs, where the raw concentration distributions were not significantly different but the fines-normalized concentrations were, can be visualized by plotting both groups as ECDFs using the same axes. For raw Sum of 40 PCBs concentrations (Figure 4-3), margin and open Bay results overlapped, separating a bit only at the bottom and top of the distributions. After normalizing to percent fines (Figure 4-4), margins concentrations were higher for nearly all the percentiles, with the greatest separation in the top decile of the two distributions. Similar to the case for mercury, the plotting of the ECDFs with logarithmic spacing on the concentration (horizontal) axis is immaterial to the statistical differences (or lack thereof), given use of a non-parametric test.

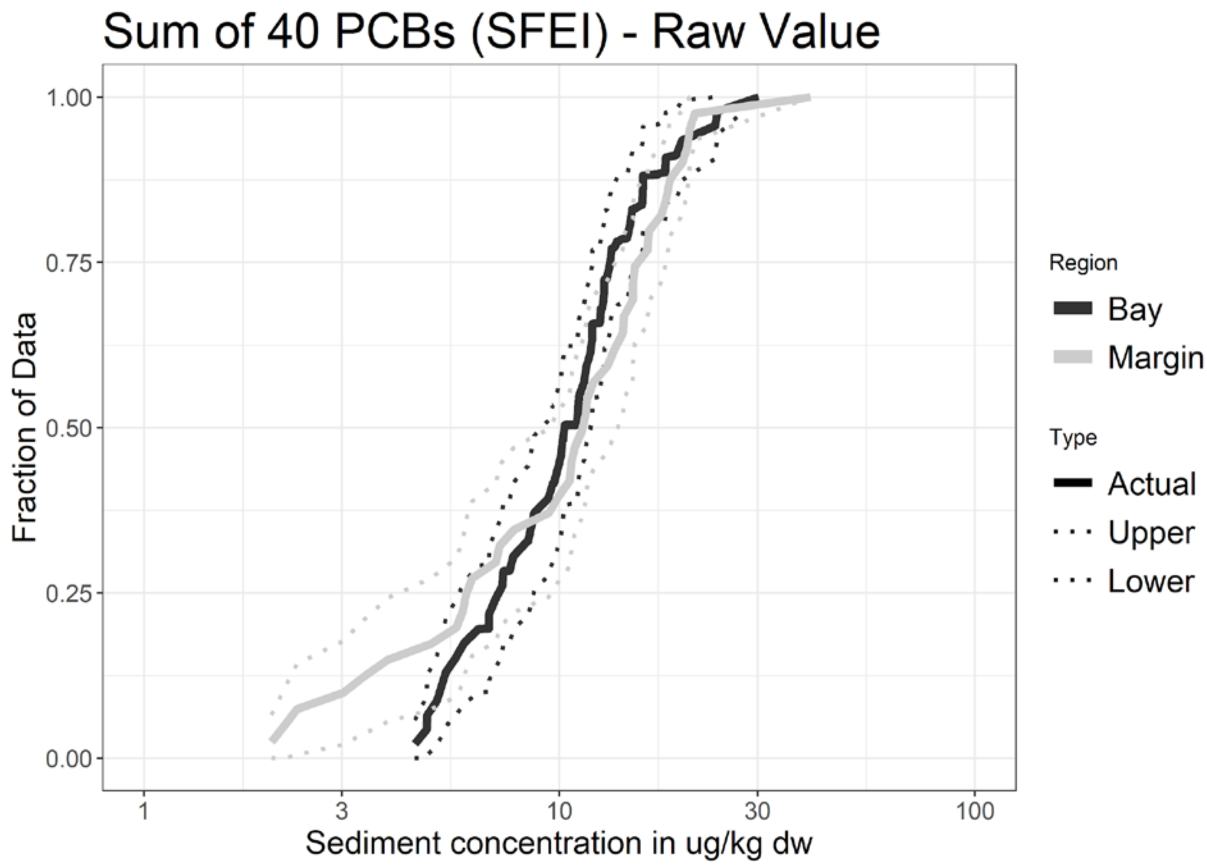


Figure 4-3 Estimated Cumulative Distribution Function of South Bay sites comparing PCBs in Bay and Margins –

Solid lines (Bay in black, Margin in gray) represent the ECDF estimated value (Sum of 40 PCBs in μg/kg dw), with the dotted lines indicating the 95% confidence interval lower and upper bounds. Note that the concentration scale is plotted with logarithmic spacing.

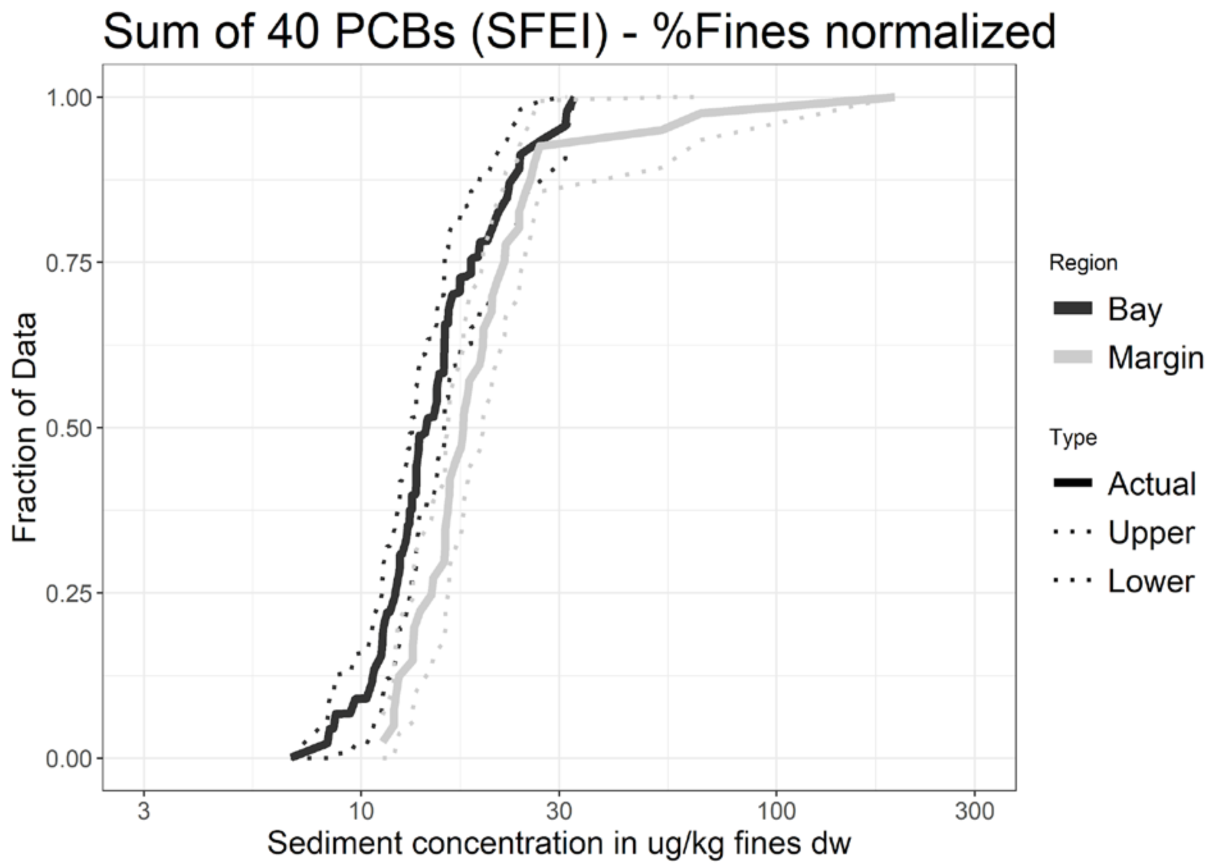


Figure 4-4 Estimated Cumulative Distribution Function of South Bay Sites Comparing Fines-normalized PCBs in Bay and Margins –
Solid lines (Bay in black, Margin in gray) represent the ECDF estimated value (Sum of 40 PCBs in µg/kg fines dw), with the dotted lines indicating the 95% confidence interval lower and upper bounds. Note that the concentration scale is plotted with logarithmic spacing.

Separating the South Bay region into two sub-segments, the "Upper South Bay," and a combined Extreme and Lower South Bay (the areas to the south and east of Dumbarton Bridge) yielded different results in comparisons of raw concentrations in margins and open Bay. For the Upper South Bay, mercury remained significantly different between margins and open Bay, and selenium and zinc were no longer significantly different, while manganese became significantly different between margins and the open Bay. In contrast, for the combined Extreme and Lower South Bay, mercury was no longer significantly different between margins and open Bay, but selenium and zinc were, in addition to manganese, zinc, silver, and aluminum.

The lack of significant differences between margins and open Bay mercury concentrations may be reasonable for the combined Extreme and Lower South Bay, as the largest mercury loads from the New Almaden Mining District may yield concentrations similar to or sometimes higher than inputs from surrounding urbanized areas. In contrast, pollutants entering primarily or only from nearby urbanized areas via local tributaries (or groundwater, in the case of selenium) still show higher concentrations in the margins.

In Upper South Bay, the apparent coarser grainsize of margin sediment may result from finer grained material in more exposed margin areas being more readily resuspended and transported to deeper open water areas. The resultant raw concentrations are more similar between margins and open Bay sediment for many contaminants, while fines normalized concentrations for some anthropogenic pollutants still show some evidence of loading from nearshore or terrestrial pathways.

For smaller subsets of data, the lower sample counts sometimes may lead to spuriously significant or insignificant results, as individual results may have a larger impact on the specific (presumably random, within an underlying distribution) sample draw made. While statistical exploration on subsets of the data as attempted here can provide some insights on distributions of possible sources or environmental processes, the smaller associated sample counts usually result in greater uncertainty in the conclusions drawn. More advanced statistical methods (e.g., leave-one-out, k-fold subsampling, Monte Carlo random draws), can help distinguish robust tendencies and trends from those more subject to random sampling variation. However, more extensive analysis along these lines is beyond the current scope of this report but could be revisited in future comparisons of margins to other Bay strata.

4.2. Margins of South Bay Compared to Central Bay

In addition to comparing South Bay margins to their adjacent open Bay areas, a comparison of South Bay to Central Bay margins was also of interest to evaluate whether some of the sources or other local factors affecting Central Bay pollutant concentrations are also present or prevalent in the South Bay. Similar to the comparison of South Bay margins to their respective open water areas, the Kolmogorov-Smirnov test was applied to determine the probability of the compared strata being from the same distribution. For a majority of the analytes (Table 4-3) Central Bay margins and South Bay margins had significantly different raw concentrations of pollutants, with Central Bay margins having higher median concentrations and higher percentiles in nearly all cases.

This is in line with our expectations prior to undertaking the study. Although San Jose and nearby cities contain areas with older industrial and other developed urban areas, areas around San Francisco, Oakland, and Richmond were more highly industrialized and urbanized by the 1950s, so we expected more extensive and severe contamination for Central Bay margin areas, compared to South Bay, where much of the industrial development has been more recent, and older industrial areas represent a smaller percentage of the total watershed drainage (~2% for South Bay, vs 5% for Central Bay).

Table 4-3 Comparison of Margins Concentration Quantiles, South Bay versus Central Bay– Concentrations are fines normalized for contaminants, raw for ancillary parameters (% fines, TOC, TN). Percentiles and ECDFs for South Bay and Central Bay margins weighted for their respective sub-areas (Extreme/Lower/South for South Bay, and Marin/non-Marin for Central Bay). Analytes with significant differences in ECDFs ($p < 0.05$ for Kolmogorov-Smirnoff test) for the two populations are shaded. Percentiles where the South Bay values are higher are in red and in blue if Central Bay concentrations are higher. Concentrations are in bold and underlined font if the distributions are significantly different. Parameters are reported in mg/kg dw unless otherwise noted.

Analyte (/fines)	K-S p-value	50th SB margins	50th CB margins	75th SB margins	75th CB margins	90th SB margins	90th CB margins	Mean SB margins	Mean CB margins
Aluminum	0.00827	**25500**	22000	**31400**	25500	**33600**	27800	**24200**	19800
Arsenic	0.00587	6.97	**8.31**	7.74	**9.61**	9.02	**10.3**	6.85	**7.81**
Cadmium	0.175	0.18	0.155	0.214	0.24	0.255	0.454	0.186	0.211
Copper	0.595	30.9	35.9	40.6	42	44.3	55.5	30.4	37.6
Iron	0.00781	**34500**	29700	**43300**	34700	**45800**	38000	**34400**	27600
Lead	0.0592	18.8	21.6	25	33.3	28.4	41.2	19.5	26.7
Manganese	9.28E-06	**455**	293	**627**	381	**786**	511	**504**	325
Mercury	0.0253	0.188	**0.232**	0.234	**0.321**	0.274	**0.565**	0.184	**0.317**
Methyl Mercury (µg/kg dw)	0.0537	0.363	0.256	0.525	0.472	0.642	2.08	0.424	0.809
Nickel	0.0162	**72.9**	65.4	**91.5**	71.5	**95.8**	79.4	**73.8**	59.6
Selenium	0.0424	**0.317**	0.281	**0.421**	0.345	**0.491**	0.382	**0.322**	0.259
Silver	0.157	0.278	0.186	0.342	0.269	0.402	0.378	0.245	0.217
Sum.208 PCBs (µg/kg dw)	0.0318	14.4	**16.6**	20.4	**41.1**	24.9	**122**	15.2	**70**
Sum.40 PCBs (µg/kg dw)	0.0318	11.5	**12.6**	16	**32.2**	19.8	**98.3**	11.9	**56.5**
Zinc	1.49E-05	56.4	**100**	77.7	**117**	98.5	**139**	65.2	**97.5**
% Fines	0.0324	68.1	**86.6**	84.7	**95.9**	91.9	**98.5**	60.3	**70.4**
Total Organic Carbon %	0.0757	0.935	1.15	1.23	1.46	1.39	1.78	0.935	1.1
Total Nitrogen %	0.29	0.15	0.12	0.167	0.156	0.18	0.188	0.14	0.117

4.3. Mass Balance Contaminant Inventory

One application of the data from this study is to estimate the inventory of priority contaminants in the margin to evaluate their potential role in the long-term persistence of contaminants in the Bay. The area defined as being in the margin constitutes a moderate portion (nearly 35%) of the combined South Bay segments, much greater than the 5% total area that margins account for in Central Bay.

Table 4-4 shows the spatially averaged sediment concentrations of the reported contaminants in South Bay margins, compared to the average of open Bay sediments from RMP Bay S&T monitoring. Pollutant inventories in South Bay were calculated based on these average concentrations and the relative areas of margin and subtidal habitats, assuming equivalent sediment mixed layer depths for both.

Table 4-4 Comparison of South Bay Margin versus Open Bay Pollutant Mean Concentrations and Percent of Mass in Margins –

Areas and mean concentrations used to calculate inventories in these strata for South Bay, along with percent of pollutant total mass in margins. Concentrations in mg/kg dw unless otherwise noted. Analytes higher in margins colored red, higher in Bay colored blue.

Parameter	Margins Mean	Bay Mean	% in Margin
Area (km2)	78.4	150.3	34.3%
Aluminum	24200	26000	32.7%
Arsenic	6.85	7.6	32.0%
Cadmium	0.186	0.196	33.1%
Copper	30.4	31.6	33.4%
Iron	34400	31800	36.1%
Lead	19.5	19.6	34.2%
Manganese	504	604	30.3%
Mercury	0.184	0.225	29.9%
Methylmercury (µg/kg dw)	0.424	0.566	28.1%
Nickel	73.8	67.2	36.4%
Selenium	0.322	0.266	38.7%
Silver	0.245	0.224	36.3%
Sum of 208 PCBs (µg/kg dw)	15.2	13.3	37.3%
Sum of 40 PCBs (µg/kg dw)	11.9	11.3	35.5%
Zinc	65.2	91.7	27.1%

The mass in the margin never represents over 40% of the total inventory in South Bay for any contaminant, but for several contaminants such as PCBs, silver, and selenium, higher average concentrations in margins yielded margin inventories somewhat greater than their (34%) relative area. This enhancement is much less than seen for Central Bay, where margin concentrations for some analytes averaged over double those in the open Bay. In contrast, for some other pollutants, such as mercury and zinc, South Bay margins concentrations averaged lower than the open Bay, so masses in margins for those were less than their proportion of area in South Bay.

The impact of these slight differences in average concentrations between the margin and open Bay sediments may be compounded by greater productivity and rates of exchange and bio-uptake from the sediment to the water in margin areas. However, we do not currently have representative measurements of these processes in different bay habitats to adequately estimate their net impacts. Additional studies of fate and uptake processes may be needed, especially where there is interest in contaminants that have specific chemical forms with higher bioavailability.

4.4. Management Effectiveness

Although this survey of South Bay margin sediments was not specifically designed or optimized to evaluate potential trends or changes in contaminant concentrations, it does provide a snapshot of the current contaminant distribution that can serve as a baseline for comparison to future regional or localized (e.g., individual site) data. Despite tendencies in South Bay for margins and open Bay areas to be more similarly contaminated, margin areas may still be somewhat more likely than open Bay subtidal areas to show the effects of management actions to reduce contaminant loads due to their proximity to current and historical terrestrial contaminant sources and pathways, as noted in the Margins Conceptual Model report (Jones et al., 2012). The heterogeneity in concentrations over small distances often seen in past studies of contaminated sites suggests that only very large temporal changes may be easily detected in margins. However, open Bay areas are even less likely to show detectable changes, due to their larger (but usually lower concentration) contaminant inventories, greater distances from sources and loading pathway areas and potential management actions, and complexities of influences from numerous interacting sources, pathways, and processes. Thus, aside from tracking or tallying net benefit or change at the location of management action, monitoring sediment concentrations in the margins sub-regionally or near specific sites may provide an opportunity for assessing the net benefit of management (perhaps in conjunction with biological monitoring) in at least a small component of the receiving water.

4.5. Screening for Contaminated Areas

For Central Bay, there was some hope that a survey of margin areas would reveal previously unknown sources. In South Bay, however, large, less-urbanized watersheds upstream of many developed areas deliver large loads of water and sediment that can disperse and dilute urban sources. Furthermore, the greater percentage of margin area and its relative proximity to the open water areas of South Bay may also reduce any apparent distinction of contaminated areas. It was thus expected that although concentrations of many sediment contaminants are higher in South Bay open water sediment than found in open water Central and North Bay, distinctively more contaminated areas in the margin were less likely. South Bay margins would tend to be more similar to the local very nearby areas designated as “open water,” with concentrations spanning a smaller range than Central Bay margins.

Despite the majority of South Bay margin areas having similar contaminant concentrations to open Bay sediments in the sub-region, there were occasional high values, including for

PCBs, mercury, and a handful of other contaminants (arsenic, cadmium, and methyl mercury also had maximum concentrations about two times greater than 75th percentile values for open Bay), suggesting some influence of localized processes or sources despite the greater connectivity and proximity of the Bay and margins areas in the South Bay sub-region. A probabilistic GRTS-distributed sampling scheme is an effective means for obtaining a spatially-balanced, representative sampling of an environmental stratum of interest. At low sample densities, it is at best a weak method for finding or identifying anything but the largest source areas; the review of available shallow margins data in the Margins Conceptual Model report (Jones et al., 2012) suggested rapid dissipation of gradients away from source areas, often disappearing within 0.5 km or less.

The areas with the greatest concentrations of mercury and PCBs in this survey of South Bay margins were not surprising. The highest concentration of mercury found (0.48 μg/kg dw) was in the Extreme Lower South Bay, near the watershed containing the New Almaden Mining District discharges. One of the sites with the highest concentration of PCBs (21 μg/kg dw) was located near the mouth of Steinberger Slough, which drains an urban area containing a site that was issued an order for a cleanup action (SFBRWQCB, 1999). Another site with one of the highest PCB concentrations (20 μg/kg dw) was found near the Oakland Airport, which could indicate some use or disposal of PCBs associated with the airport or other industrial activities nearby. Given contaminated sites found previously by the Bay Protection and Toxic Cleanup Program near the shoreline of Seaplane Harbor at San Francisco International Airport, and at Seaplane Lagoon at the former Naval Air Station, Alameda, PCB contamination in nearshore areas around an airport or airfield are not atypical. Although the contamination found near Oakland Airport was only moderately above Bay average concentrations and not particularly notable relative to the most contaminated sites around the Bay, a PCB source area might still be present nearby, given the rapid drop-off in sediment concentrations away from the identified sources seen at Naval Air Station Alameda, Hunters Point Shipyard, and other sites.

Although ambient sampling of Bay margins using a GRTS randomly distributed allocation scheme has a low probability of identifying highly contaminated areas or finding previously unidentified sources or loading pathways, the chance sampling of sites more contaminated than typical for a given area or stratum may provide some hints for areas to conduct desktop investigations of available data on contaminated upland locations, or review of current and historical land uses that have had highly contaminated sites in the Bay Area or other localities, either nationally or internationally. Once likely suspected sources or pathways of contamination are identified, follow-up deterministic sampling of the source or loading pathway itself, or areas in the near-field of discharges, can help pinpoint or verify the suspected source.

5. Summary and Future Directions

This survey of South Bay margins sediment has achieved its primary goals. In characterizing the ambient concentrations of contaminants in shallow subtidal and intertidal margin habitats, the data obtained generally fit patterns anticipated in the Margins Conceptual Model; concentrations are often somewhat elevated relative to open Bay concentrations, but not to the same degree as seen in the prior survey of Central Bay margins.

With a spatially randomized (representative) sample allocation, we were also able to make estimates of mean concentrations, and thus estimate the masses or inventories of contaminants in margins to compare to their quantities in the open Bay. The degree of contamination in the South Bay margins was usually moderately higher than open Bay concentrations as expected, but for a few analytes such as zinc and mercury, the mean margins concentrations were significantly lower than those of the open Bay.

Some management actions have been taken or are currently planned to remove known highly contaminated areas, and to remediate legacy sources in the landscape. However, the most significant actions for many pollutants may already have been taken through past bans or reductions in usage (and consequently thus perhaps only asymptotically decreasing concentrations), due to a large inventory of dispersed contamination already in the environment. The ambient characterization of margins may thus be useful in the future for evaluating changing loads of specific watersheds or sets of watersheds. The inventory of contaminants in the open Bay is often large compared to annual loads, so changes in the inventory of contaminants in subtidal sediments may be difficult to see in time frames of less than 20 years. However, given their proximity to likely sources and loading pathways, and smaller inventories (but sometimes locally higher concentrations) of pollutants, the current characterization of margin sediments may provide a useful baseline against which to compare progress at different locations and scales.

Characterizing the baseline distribution of contaminant concentrations in margins is also helpful for evaluating and prioritizing areas for management actions. Knowing the background distribution of pollutants in margins environments is also useful for setting possible cleanup targets for cleanup sites, and management of watershed loads and their nearfield receiving waters, or for appropriate assessment of the re-use or disposal of dredged sediment.

As mentioned before, random ambient sampling has a low probability of directly identifying unknown sources or contaminated areas, so should not be the primary driver of any widespread margin sampling effort. However, observations of areas with moderately more contaminated sites than typical for a given area or habitat, obtained from ambient sampling, combined with other information (e.g., historical land uses or surveys, and contamination in upstream watershed areas), can help in focusing and developing targeted (and more deterministic) plans for finding the most highly contaminated areas. Periodic ambient sampling of margins can also serve as a logistical framework on which such targeted sampling efforts can be added.

With the two rounds of characterizing ambient margins sediment in Central and South Bay done, completing the effort of characterizing margins Bay-wide can be achieved by monitoring margins in the North Bay. Although both completed rounds of margins monitoring have largely already confirmed many expectations laid out in the Margins

Conceptual Model, expanding the study of margins to North Bay is still beneficial, as there are nuances of environmental pollutant distributions or processes either regionally or locally that may not be fully anticipated *a priori*. For example, the finding from the South Bay data of generally higher concentrations in the open Bay compared to the margins, runs counter to our conceptual model for Central Bay of contamination entering at the Bay margins propagating outward to deeper open water areas. Locally variable processes of transport may often play an important role in the distribution of contaminants affecting biological exposure and long term fate. Local data from margins Bay-wide will also be useful for calibrating and validating fate and transport or bioaccumulation models. Widespread data to either reinforce or contradict our existing conceptual expectations or numerical models will be useful for continued refinement of our understanding of the ecosystem.

6. References

Davis, J.A., D. Yee, A.N. Gilbreath, L.J. McKee. 2017. Conceptual Model to Support PCB Management and Monitoring in the Emeryville Crescent Priority Margin Unit. SFEI Contribution 824. San Francisco Estuary Institute: Richmond, CA. https://www.sfei.org/documents/conceptual-model-support-pcb-management-and-monitoring-emeryville-crscent-priority-margin

Jones, C., D. Yee, J.A. Davis, L.J. McKee, B.K. Greenfield, A.R. Melwani, M.A. Lent. 2012. Conceptual Model of Contaminant Fate on the Margins of San Francisco Bay. SFEI Contribution 663. San Francisco Estuary Institute, Richmond, CA.

Lowe, S.; Hoenicke, R.; Taberski, K.; Smith, R.; Thompson, B.; Stevens, D.; Leatherbarrow, J. E. 2005. Re-design Process of the San Francisco Estuary Regional Monitoring Program for Trace Substances (RMP) Status & Trends Monitoring Component for Water and Sediment. SFEI Contribution No. 507. San Francisco Estuary Institute: Oakland, CA. https://www.sfei.org/sites/default/files/biblio_files/RMP_2002_No109_RedesignProcess_0.pdf

SFBRWQCB. 1999. San Francisco Bay Region Regional Water Quality Control Board Order No. 99-062 Adoption Of Site Cleanup Requirements For: H.K. Porter Company, Inc., Delta Star, Inc., and Tiegel Manufacturing Company. California Regional Water Quality Control Board, San Francisco Bay Region, Oakland, CA. https://www.waterboards.ca.gov/sanfranciscobay/board_decisions/adopted_orders/1999/R2-1999-0062.pdf

SFBRWQCB. 2006. Resolution R2-2006-0052. Amending The Water Quality Control Plan For The San Francisco Bay Region To Establish New Mercury Water Quality Objecttves And To Amend The Total Maximum Daily Load And Implementation Plan For Mercury In San Francisco Bay. California Regional Water Quality Control Board San Francisco Bay Region, Oakland, CA. https://www.waterboards.ca.gov/sanfranciscobay/board_decisions/adopted_orders/2006/R2-2006-0052.pdf

SFBRWQCB. 2008. Resolution R2-2008-0012. Amending The Water Quality Control Plan For The San Francisco Bay Region To Establish A Total Maximum Daily Load And Implementation Plan For PCBs In San Francisco Bay. California Regional Water Quality Control Board San Francisco Bay Region, Oakland, CA. https://www.waterboards.ca.gov/sanfranciscobay/board_decisions/adopted_orders/2008/R2-2008-0012.pdf

Stevens, Jr., D.L., A.R. Olsen. 2004. Spatially Balanced Sampling of Natural Resources, Journal of the American Statistical Association, 99:465, 262-278, DOI: 10.1198/016214504000000250

Yee, D. A. Wong, I. Shimabuku, and P. Trowbridge. 2017. Characterization of Sediment Contamination in Central Bay Margin Areas. SFEI Contribution 829. San Francisco Estuary Institute, Richmond, CA. https://www.sfei.org/sites/default/files/biblio_files/Central%20Bay%20Margins%20Report%20Final%2020170907%20clean.pdf

Yee, D.; Franz, A.; Wong, A.; Ross, J.; Trowbridge, P. 2017. 2017 Quality Assurance Program Plan for the Regional Monitoring Program for Water Quality in San Francisco Bay. SFEI Contribution No. 828. San Francisco Estuary Institute: Richmond, CA. https://www.sfei.org/documents/2017-quality-assurance-program-plan-regional-monitoring-program-water-quality-san-francisco-bay

Section 1 Appendix. RMP Margins Compared to Previous Data

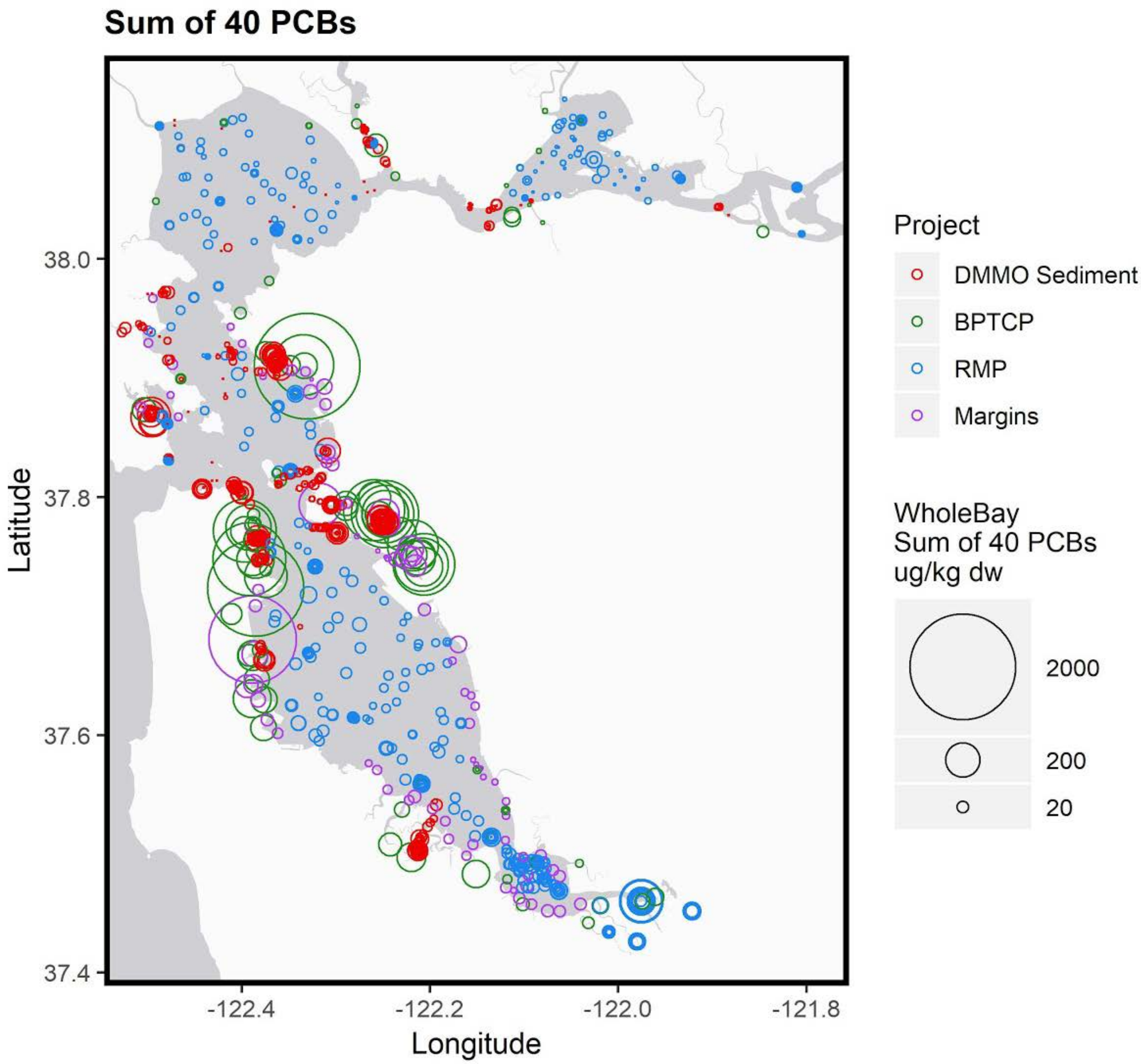


Fig. A-1-1 South Bay margins PCBs compared to other data sources
DMMO = Dredged Material Management Office (data from various dredging projects), BPTCP = Bay Protection Toxic Cleanup Program, RMP = Bay RMP (open Bay) Status & Trends, Margins = prior and current RMP Margins monitoring.

Section 2 Appendix. Sample Sites

Table A-2-1. Table of station codes and latitude/longitude locations

Site Code	Region	Latitude	Longitude
SB051	South Bay	37.601767	-122.362
SB052	South Bay	37.564817	-122.14295
SB053	South Bay	37.676183	-122.169983
SB054	South Bay	37.5128	-122.179733
SB055	South Bay	37.633217	-122.15595
SB056	South Bay	37.560516	-122.130917
SB057	South Bay	37.554167	-122.244883
SB058	South Bay	37.4984	-122.16095
SB059	South Bay	37.624417	-122.152033
SB060	South Bay	37.531883	-122.119017
SB061	South Bay	37.548067	-122.216183
SB062	South Bay	37.576433	-122.265
SB063	South Bay	37.575233	-122.15095
SB064	South Bay	37.511683	-122.12005
SB065	South Bay	37.636233	-122.162983
SB066	South Bay	37.5382	-122.197017
SB067	South Bay	37.57045	-122.255933
SB068	South Bay	37.579633	-122.154016
SB069	South Bay	37.6625	-122.175967
SB070	South Bay	37.507917	-122.154
SB071	South Bay	37.612767	-122.372833
SB072	South Bay	37.572183	-122.145967
SB073	South Bay	37.705683	-122.206017
SB074	South Bay	37.52775	-122.184
SB075	South Bay	37.60995	-122.15805
SB076	South Bay	37.54425	-122.118967
LSB01	Lower South Bay	37.545117	-122.222117
LSB02	Lower South Bay	37.498767	-122.082
LSB03	Lower South Bay	37.4629	-122.105033
LSB04	Lower South Bay	37.482233	-122.096083
LSB05	Lower South Bay	37.486383	-122.068883
LSB06	Lower South Bay	37.497617	-122.10095
LSB07	Lower South Bay	37.457617	-122.092033
LSB08	Lower South Bay	37.4693	-122.111
LSB09	Lower South Bay	37.4811	-122.06195
LSB10	Lower South Bay	37.45215	-122.07495
LSB11	Lower South Bay	37.4727	-122.097167
SOSL15	Extreme Lower South Bay	37.4716	-122.11915
SOSL16	Extreme Lower South Bay	37.4518	-122.06195
SOSL40	Extreme Lower South Bay	37.4576	-122.03995

Section 3 Appendix. Data, Maps, & Analyses

Table A-3-1 Analyte Concentrations (dw) for South Bay Margin Sediment

	Aluminum	Arsenic	Cadmium	Copper	Iron	Lead	Manganese	Nickel	Selenium	Silver	Zinc	Mercury	Methyl Mercury µg/kg	Sum of 40 PCBs (SFEI)	Sum of 208 PCBs (SFEI)	Total Nitrogen	% Fines	% Clay	% Silt	% Sand (All Fraction)	% Sand (Very Fine)	% Sand (Fine)	% Sand (Medium)	% Sand (Coarse)	% Sand (Very Coarse)	% Granule + Pebble	Total Organic Carbon
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	µg/kg	µg/kg	µg/kg	%	%	%	%	%	%	%	%	%	%	%	%
Stratum: ELSB Margins																											
Stations #	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Weight (km^2)	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
SOSL15	31441	7.58	0.217	43.9	45560	27.0	849	97.2	0.433	0.374	49.7	0.275	0.466	16.4	20.7	0.165	83.3	33.9	49.4	16.4	9.6	3.06	2.32	0.68	0.77	0.17	1.25
SOSL16	31020	7.13	0.206	39.5	42594	25.2	638	92.0	0.396	0.343	52.4	0.476	0.526	18.5	23.3	0.16	83.4	35.7	47.7	16.5	15.0	0.35	0.42	0.33	0.38	0.11	1.12
Stratum: LSB Margins																											
Stations #	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Weight (km^2)	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97	1.97
LSB01	33561	8.71	0.182	40.5	43278	22.9	787	93.3	0.394	0.281	48.0	0.208	0.481	15.0	19.0	0.16	91.9	36.7	55.3	8.1	7.7	0.08	0.09	0.10	0.06	0.01	1.31
LSB02	36556	9.03	0.184	44.3	47774	28.8	921	94.9	0.472	0.445	50.3	0.281	0.384	16.3	20.6	0.18	92.3	41.6	50.7	7.6	7.1	0.13	0.11	0.11	0.15	0.05	1.31
LSB03	29013	6.50	0.137	35.6	40317	22.9	480	85.4	0.349	0.284	48.5	0.223	0.643	11.7	14.8	0.14	69.4	30.7	38.7	29.1	27.2	0.97	0.28	0.30	0.35	1.48	0.85
LSB04	32706	7.74	0.212	40.2	43122	24.6	626	91.0	0.393	0.325	49.4	0.326	0.628	15.2	19.2	0.16	87.1	36.2	50.9	12.5	11.3	0.16	0.29	0.40	0.35	0.38	1.14
LSB05	28001	6.97	0.175	32.5	36841	18.8	456	78.7	0.305	0.223	47.4	0.157	0.305	9.4	11.9	0.12	78.7	24.7	54.0	20.6	19.5	0.12	0.14	0.23	0.64	0.69	0.93
LSB06	34399	7.12	0.179	40.7	45079	26.2	678	92.1	0.427	0.377	46.6	0.209	0.308	14.2	17.9	0.17	89.6	37.4	52.2	10.3	9.7	0.12	0.18	0.11	0.20	0.03	1.11
LSB07	9760	3.35	0.155	15.3	18160	10.1	285	36.8	0.209	0.073	36.4	0.039	0.101	3.4	4.3	0.06	5.2	2.4	2.8	88.1	13.7	40.12	27.51	4.58	2.19	4.84	0.28
LSB08	30554	8.16	0.204	41.0	44192	24.4	656	95.0	0.372	0.311	48.8	0.244	0.357	18.1	22.6	0.17	92.2	36.2	56.0	7.6	6.7	0.12	0.19	0.32	0.26	0.11	1.11
LSB09	32822	8.12	0.220	46.2	47163	28.7	813	101.6	0.492	0.402	50.0	0.274	0.508	19.8	25.0	0.19	95.7	42.4	53.4	4.3	3.2	0.17	0.43	0.26	0.26	0.01	1.39
LSB10	33589	6.85	0.214	44.1	44802	30.2	533	97.3	0.456	0.408	60.0	0.262	0.301	17.6	22.3	0.13	79.0	37.8	41.2	20.4	16.2	0.77	1.16	1.11	1.12	0.58	0.98
LSB11	32974	9.09	0.253	46.4	47186	26.6	688	99.1	0.516	0.366	50.4	0.218	0.458	15.0	19.1	0.18	94.3	36.5	57.8	5.6	5.1	0.11	0.16	0.09	0.14	0.03	1.41
Stratum: SB Margins																											
Stations #	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Weight (km^2)	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93	1.93
SB051	25872	7.57	0.215	31.3	34424	21.6	319	66.2	0.225	0.254	110.1	0.189	0.697	13.6	17.5	0.18	77.0	30.7	46.2	20.5	19.4	0.20	0.19	0.27	0.48	2.51	1.17
SB052	14217	3.98	0.079	12.7	24104	9.4	382	64.6	0.172	0.073	70.8	0.069	0.212	3.0	3.8	0.08	18.9	8.8	10.1	77.9	29.9	46.04	0.75	0.53	0.66	0.83	0.40
SB053	12792	4.73	0.280	13.1	17923	16.2	560	37.2	0.171	0.067	56.4	0.059	0.150	40.2	53.8	0.08	20.9	6.2	14.7	78.5	69.1	6.95	1.58	0.52	0.38	0.05	0.58
SB054	31277	10.43	0.255	38.0	42391	23.2	418	79.4	0.412	0.352	115.3	0.219	0.212	11.6	14.9	0.2	86.8	33.1	53.7	13.3	10.9	1.03	0.63	0.43	0.24	0.01	1.42
SB055	20662	5.81	0.155	22.8	28124	15.4	381	56.4	0.213	0.164	77.7	0.234	0.279	5.7	7.2	0.13	50.2	20.2	30.0	48.8	42.4	2.29	1.37	1.49	1.32	0.89	0.80
SB056	16222	4.61	0.115	17.7	25105	11.1	362	58.3	0.149	0.099	67.2	0.139	0.351	3.9	4.9	0.09	31.7	11.9	19.9	65.5	42.1	18.97	3.74	0.33	0.30	2.00	0.49
SB057	24048	6.98	0.203	28.1	32690	17.4	341	65.0	0.241	0.230	95.1	0.186	0.822	10.0	12.5	0.14	80.7	22.7	58.0	19.2	18.6	0.32	0.20	0.09	0.04	0.01	0.92
SB058	25952	7.73	0.162	29.4	35431	18.3	542	67.4	0.268	0.279	98.7	0.208	0.353	10.7	13.6	0.13	88.9	24.2	64.7	11.1	9.9	0.82	0.19	0.07	0.08	0.01	0.94
SB059	16115	5.79	0.176	19.7	24420	14.1	630	50.2	0.268	0.132	69.6	0.135	0.450	7.8	10.0	0.11	37.9	13.2	24.7	62.0	60.2	0.93	0.33	0.24	0.26	0.10	0.82
SB060	19859	5.53	0.125	20.9	29044	14.4	415	67.2	0.225	0.149	80.5	0.113	0.163	5.9	7.5	0.12	36.3	16.1	20.1	60.1	55.3	2.58	0.61	0.80	0.83	3.43	0.68
SB061	23768	9.02	0.247	33.9	34798	20.7	392	69.6	0.545	0.417	89.4	0.207	0.416	21.2	27.2	0.17	40.0	14.7	25.3	33.2	18.8	3.17	2.50	2.96	5.87	26.65	1.23
SB062	16978	5.45	0.176	22.8	24106	14.0	391	50.6	0.282	0.177	63.2	0.108	0.154	4.9	6.2	0.16	33.0	11.2	21.8	28.1	4.2	5.11	4.27	4.86	9.60	38.37	0.80
SB063	12673	4.15	0.052	10.9	24234	8.6	484	73.1	0.117	0.048	63.3	0.062	0.211	2.2	2.8	0.07	8.8	4.4	4.4	87.4	14.6	66.59	4.26	0.81	1.14	1.42	0.27
SB064	13140	5.50	0.105	20.3	22818	13.0	410	51.7	0.174	0.158	60.9	0.109	0.366	7.2	9.1	0.12	48.6	18.0	30.6	49.8	48.4	0.83	0.17	0.16	0.29	1.49	0.80
SB065	20420	5.15	0.172	26.2	28467	16.5	416	59.3	0.290	0.211	72.5	0.142	0.745	7.0	9.0	0.17	50.8	19.8	31.0	30.5	12.5	2.14	2.48	3.94	9.43	18.70	0.88
SB066	20058	7.59	0.204	30.6	31933	18.8	415	67.0	0.322	0.302	85.4	0.188	0.264	14.3	18.0	0.17	54.7	21.5	33.2	21.7	5.4	6.37	3.32	3.29	3.30	23.57	1.07
SB067	17980	6.07	0.174	26.3	28303	17.2	273	62.5	0.232	0.211	78.6	0.146	0.440	10.6	13.2	0.12	79.0	18.7	60.3	20.9	19.8	0.71	0.16	0.12	0.17	0.05	0.82
SB068	11549	3.96	0.064	10.4	21297	7.6	393	65.6	0.114	0.053	56.1	0.054	0.155	2.3	3.2	0.06	9.1	4.8	4.4	85.0	12.7	63.50	4.66	1.63	2.46	4.21	0.43
SB069	11071	3.83	0.104	12.4	15880	10.1	297	31.2	0.143	0.097	42.5	0.099	0.251	6.0	7.4	0.09	22.2	8.6	13.6	58.9	22.2	27.28	3.41	2.09	3.95	17.75	0.64
SB070	28322	7.74	0.175	36.0	39348	22.7	449	80.7	0.355	0.279	104.1	0.223	0.320	12.1	15.4	0.16	74.2	29.9	44.2	17.7	7.6	1.65	2.37	2.48	3.65	8.01	1.01
SB071	32205	8.63	0.326	48.0	43276	31.1	313	86.0	0.367	0.422	130.6	0.250	1.770	20.3	26.1	0.23	84.7	35.7	49.0	15.1	15.0	0.07	0.03	0.01	0.02	0.15	1.40
SB072	13071	4.90	0.072	11.9	24948	10.0	665	75.1	0.130	0.060	67.3	0.066	0.138	2.0	2.6	0.07	11.1	3.7	7.4	90.6	24.4	62.80	2.18	0.64	0.62	0.50	0.33
SB073	33940	7.58	0.402	43.8	43486	28.3	522	92.3	0.462	0.334	54.2	0.198	0.604	20.6	26.8	0.19	85.6	31.0	54.6	11.4	7.7	0.78	0.64	0.74	1.50	2.98	1.23
SB074	29430	7.48	0.185	36.1	39110	21.1	548	81.8	0.585	0.288	41.1	0.163	0.534	11.3	14.3	0.15	53.1	21.6	31.4	18.1	7.0	2.27	2.00	2.08	4.75	28.83	0.94
SB075	24304	6.20	0.193	28.8	32967	17.7	363	72.4	0.355	0.192	42.6	0.168	0.537	13.1	16.4	0.14	67.7	23.4	44.3	26.7	17.7	3.81	1.04	1.49	2.60	5.61	0.91
SB076	19794	5.85	0.146	23.7	29982	15.2	424	65.2	0.241	0.159	41.0	0.109	0.316	6.2	7.8	0.09	46.2	16.7	29.6	53.3	51.4	0.48	0.36	0.40	0.67	0.41	0.64
SB077	33675	14.94	0.320	45.2	46118	26.3	536	90.1	0.547	0.336	42.1	0.255	0.577	10.9	13.7	0.17	60.4	20.0	40.4	12.8	5.6	1.86	1.96	1.61	1.80	27.15	1.49

Table A-3-2 - Anderson-Darling Normality test p-values for analyte transformations and normalizations examined - values above 0.05 are not significantly different from a normal distribution. Significant p-values are in bold red text. Raw concentrations (without normalization or transformation) showed the most parameters appearing normally distributed.

Analyte	Raw Value	%Fines Norm	%TOC Norm	1/sqrt(x)	1/x	Ln Raw Value	Ln %Fines Norm	Ln %TOC Norm	Log_{10} Raw Value	Log_{10} %Fines Norm	Log_{10} %TOC Norm
Aluminum	**4.8E-03**	**2.2E-14**	3.6E-01	**7.3E-05**	**4.3E-06**	**6.1E-04**	**2.2E-06**	8.9E-01	**6.1E-04**	**2.2E-06**	8.9E-01
Arsenic	1.7E-01	**2.2E-14**	**2.0E-08**	**2.5E-02**	**1.6E-03**	1.6E-01	**3.6E-07**	**1.1E-04**	1.6E-01	**3.6E-07**	**1.1E-04**
Cadmium	1.0E-01	**7.7E-17**	**1.7E-12**	**1.4E-06**	**3.8E-10**	**1.0E-03**	**7.2E-04**	**1.2E-05**	**1.0E-03**	**7.2E-04**	**1.2E-05**
Copper	**4.1E-02**	**3.1E-15**	2.5E-01	**1.4E-05**	**9.0E-08**	**7.6E-04**	**1.3E-05**	1.8E-01	**7.6E-04**	**1.3E-05**	1.8E-01
Iron	**1.8E-02**	**3.6E-18**	**6.2E-07**	**1.1E-03**	**9.4E-05**	**5.4E-03**	**7.1E-09**	**5.0E-03**	**5.4E-03**	**7.1E-09**	**5.0E-03**
Lead	3.2E-01	**4.6E-14**	**6.0E-04**	**1.4E-03**	**2.3E-05**	**2.8E-02**	**1.9E-05**	**3.9E-02**	**2.8E-02**	**1.9E-05**	**3.9E-02**
Manganese	**2.4E-02**	**4.8E-17**	**1.2E-07**	6.5E-01	3.9E-01	5.2E-01	**6.8E-05**	1.2E-01	5.2E-01	**6.8E-05**	1.2E-01
Mercury	4.1E-01	**2.3E-05**	**4.0E-04**	**8.6E-06**	**3.1E-09**	**4.8E-03**	**3.9E-02**	7.4E-02	**4.8E-03**	**3.9E-02**	7.4E-02
Methyl Mercury	**2.3E-04**	**1.5E-04**	**1.2E-03**	**1.0E-02**	**1.2E-05**	5.0E-01	5.9E-01	5.7E-01	5.0E-01	5.9E-01	5.7E-01
Nickel	1.1E-01	**5.4E-21**	**5.9E-11**	**5.5E-05**	**3.9E-07**	**2.4E-03**	**1.5E-10**	**1.5E-04**	**2.4E-03**	**1.5E-10**	**1.5E-04**
Selenium	4.1E-01	**2.2E-13**	**9.7E-04**	**8.8E-03**	**1.6E-04**	1.3E-01	**1.8E-03**	1.1E-01	1.3E-01	**1.8E-03**	1.1E-01
Silver	1.0E-01	**9.3E-10**	9.2E-01	**2.1E-07**	**7.1E-11**	**1.8E-04**	**4.7E-03**	7.3E-02	**1.8E-04**	**4.7E-03**	7.3E-02
Sum of 208 PCBs	7.4E-02	**2.5E-22**	**1.4E-15**	**3.9E-06**	**1.7E-10**	**9.4E-03**	**6.4E-07**	**1.7E-02**	**9.4E-03**	**6.4E-07**	**1.7E-02**
Sum of 40 PCBs	1.2E-01	**6.3E-22**	**1.9E-14**	**2.4E-06**	**9.0E-11**	**6.6E-03**	**8.5E-07**	**2.9E-02**	**6.6E-03**	**8.5E-07**	**2.9E-02**
Zinc	**5.7E-04**	**1.7E-12**	**6.5E-04**	3.3E-01	5.3E-01	8.9E-02	**2.3E-03**	2.6E-01	8.9E-02	**2.3E-03**	2.6E-01

Figures A-3.-1 to -15 Analyte Concentrations – raw (not normalized) results shown for sediment samples. Bubble areas are proportional to concentration (units of either mg/kg dw or µg/kg dw as noted in each legend).

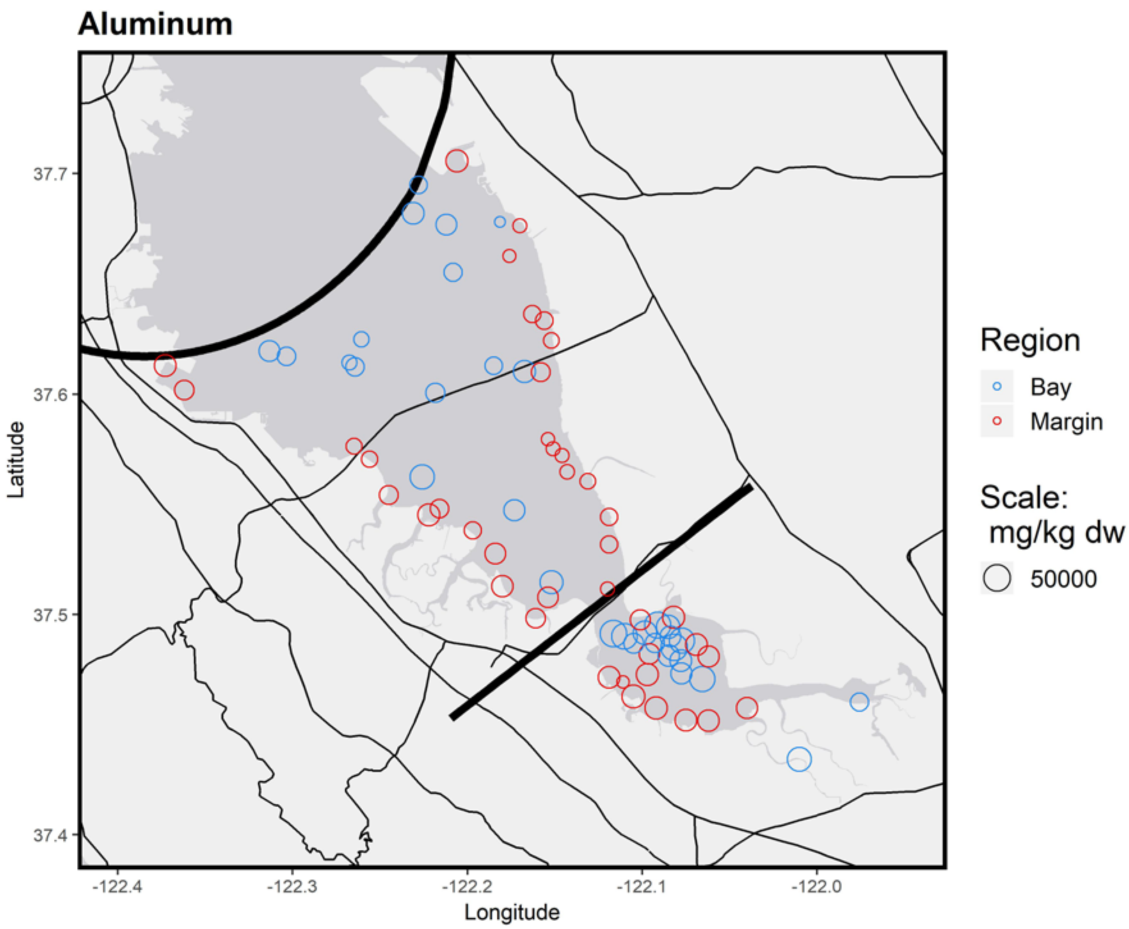


Fig. A-3 1

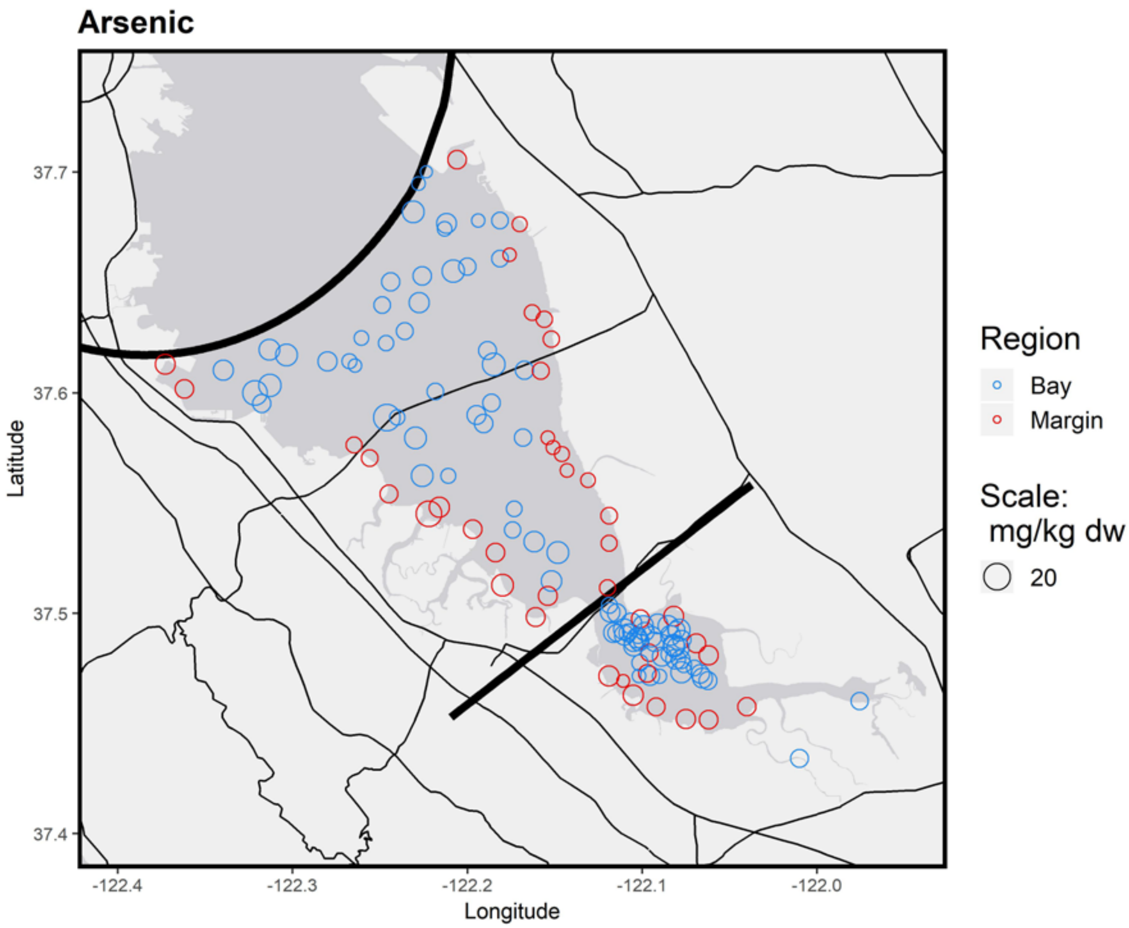
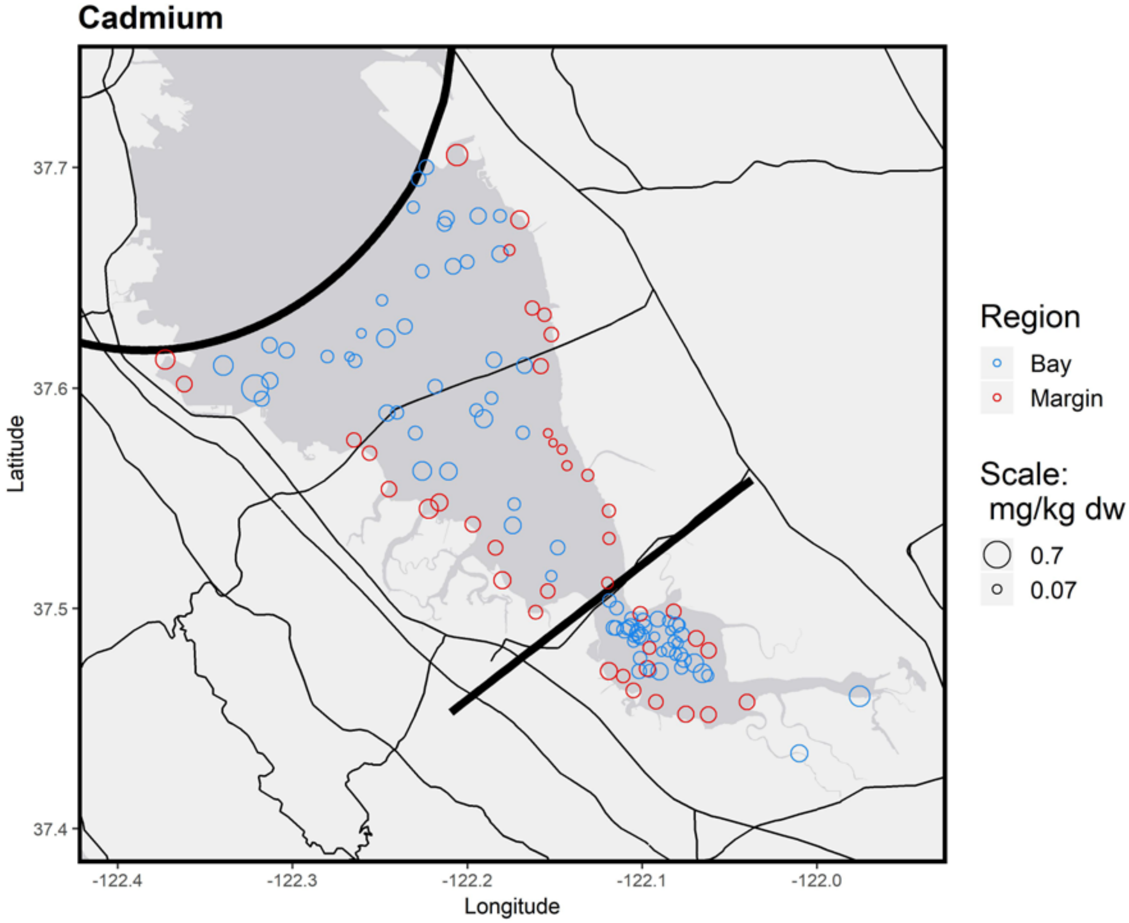
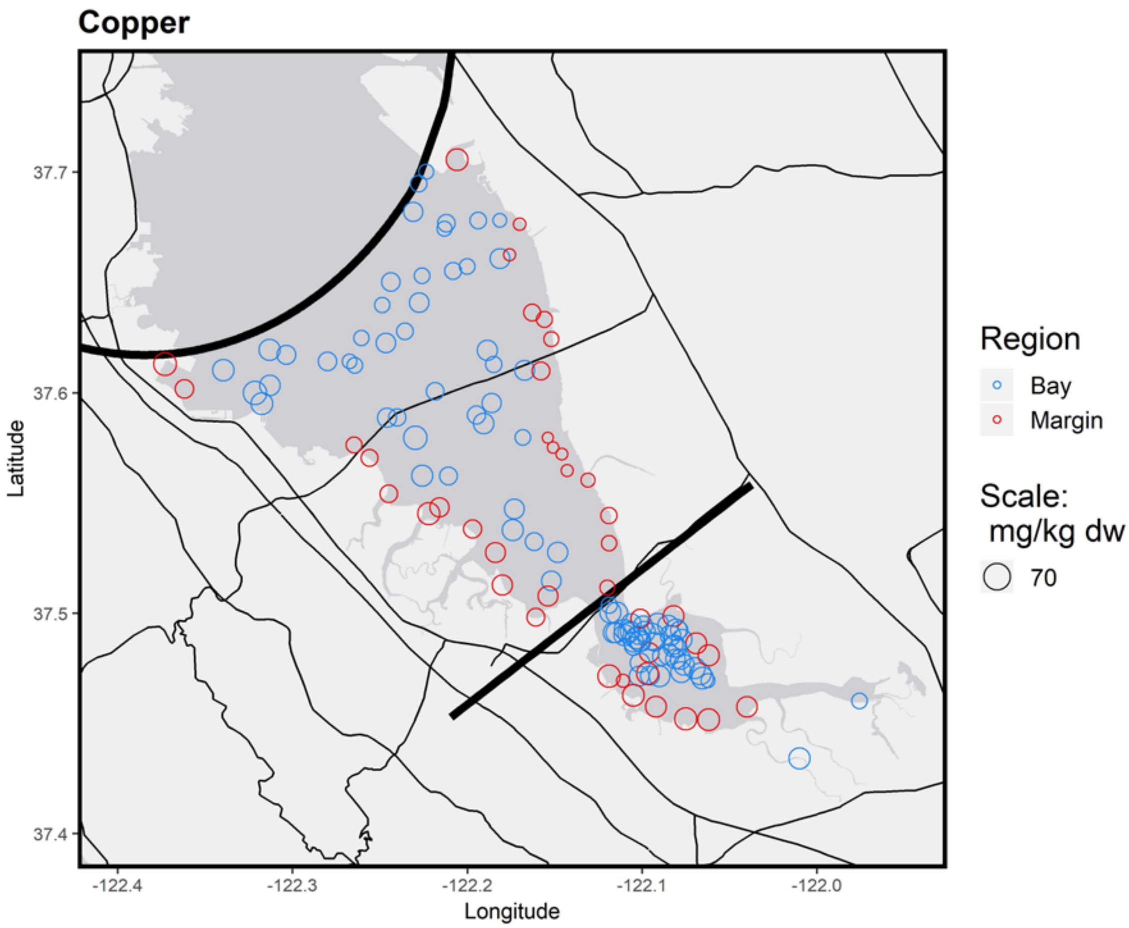

Arsenic
Latitude
37.7
37.6
37.5
37.4
Longitude
-122.4
-122.3
-122.2
-122.1
-122.0
Region
Bay
Margin
Scale:
mg/kg dw
20

Fig. A-3 2



Cadmium
37.7
37.6
37.5
37.4
Latitude
-122.4
-122.3
-122.2
-122.1
-122.0
Longitude
Region
Bay
Margin
Scale:
mg/kg dw
0.7
0.07

Fig. A-3 3



Copper
37.7
37.6
37.5
37.4
Latitude
-122.4
-122.3
-122.2
-122.1
-122.0
Longitude
Region
Bay
Margin
Scale:
mg/kg dw
70

Fig. A-3 4

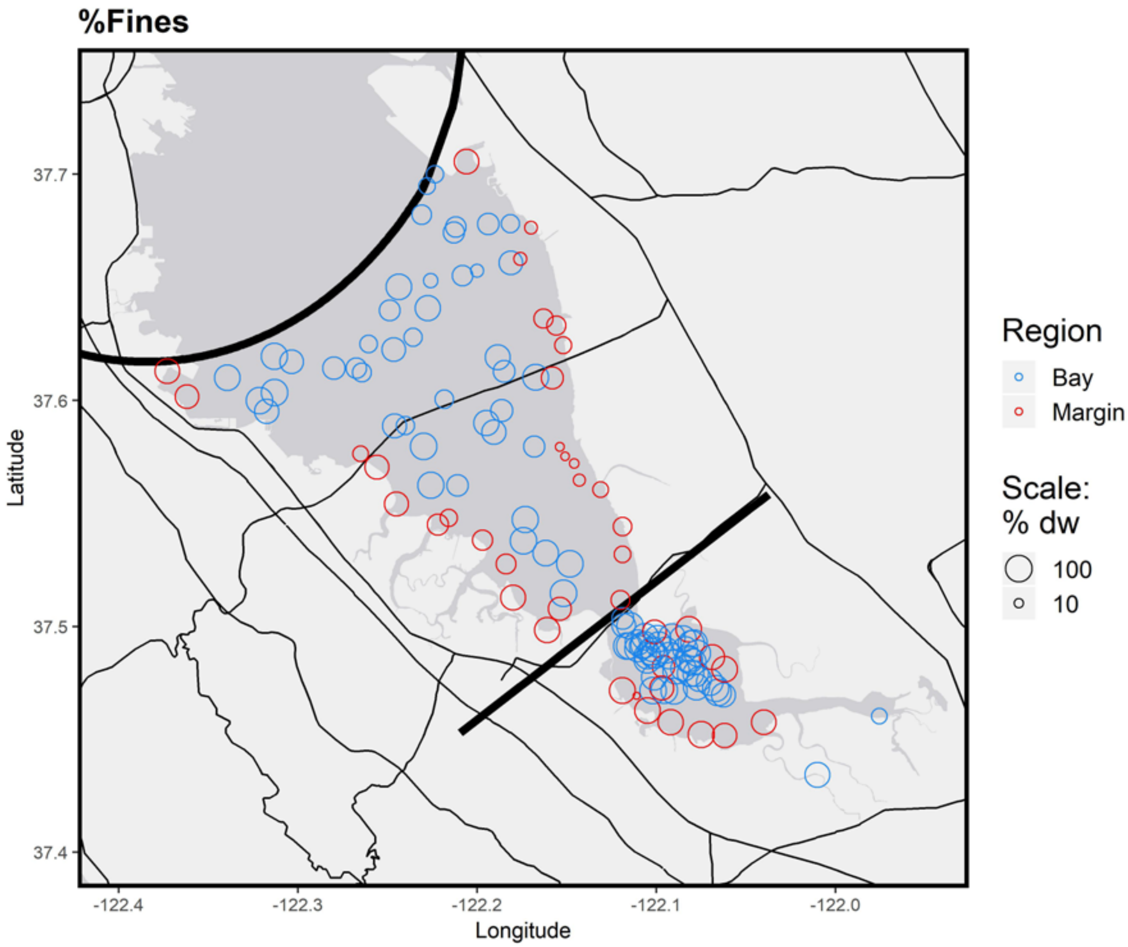

%Fines
37.7
37.6
37.5
37.4
Latitude
-122.4
-122.3
-122.2
-122.1
-122.0
Longitude
Region
Bay
Margin
Scale:
% dw
100
10

Fig. A-3 5

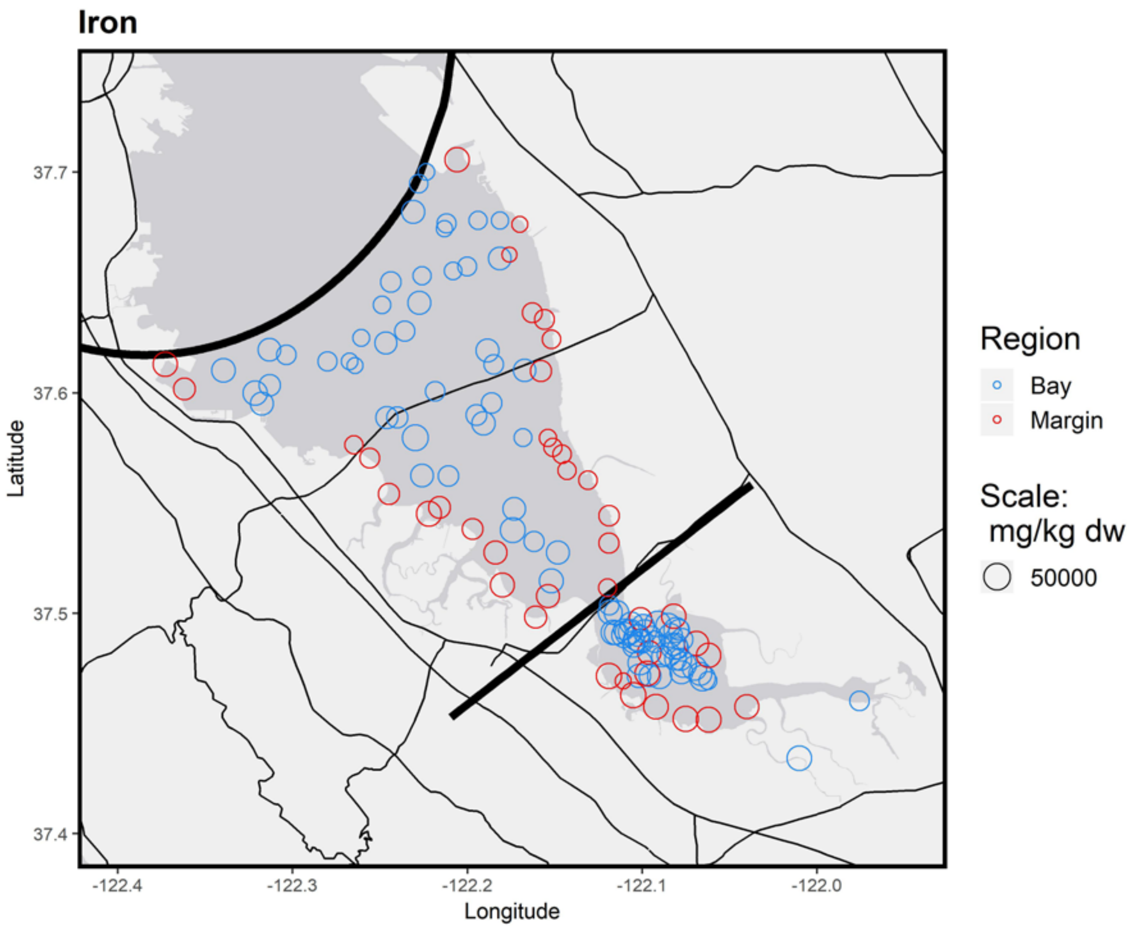
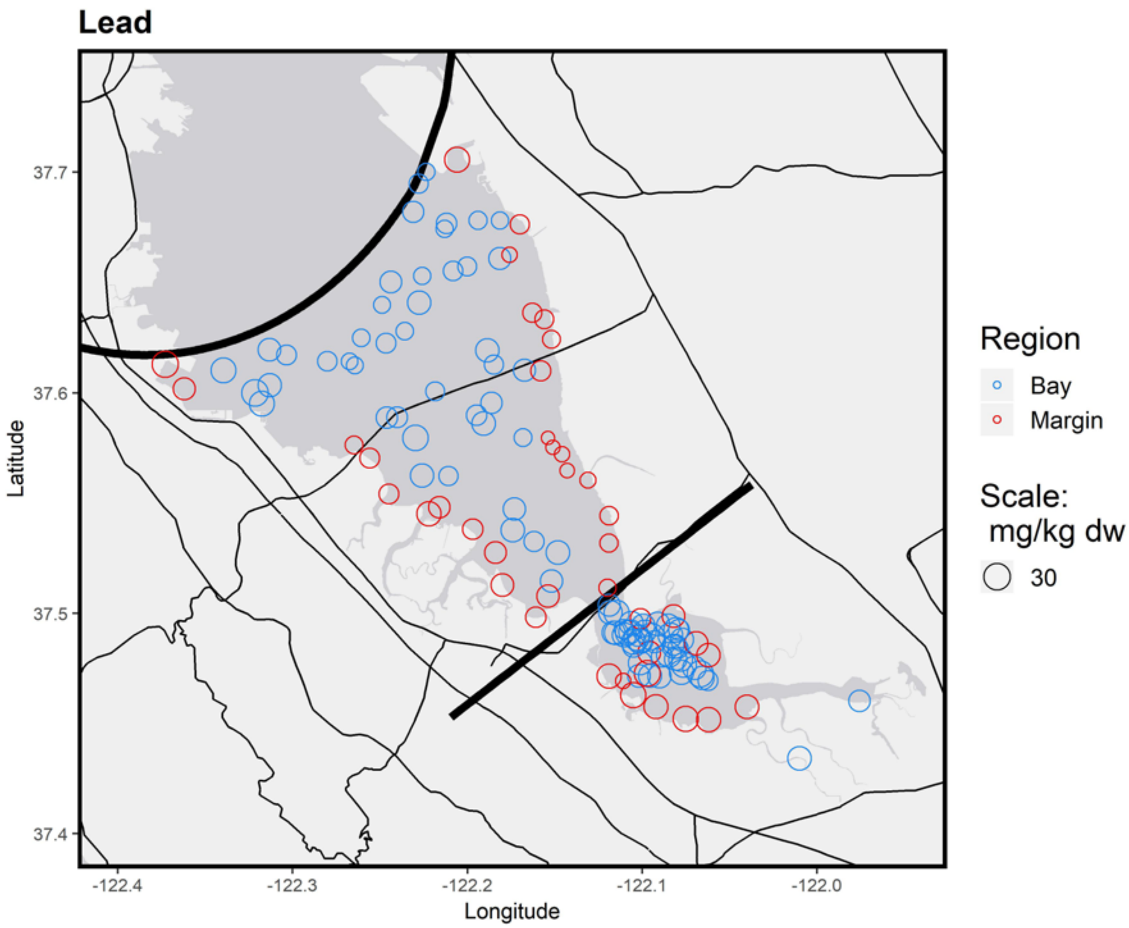

Iron
37.7
37.6
37.5
37.4
Latitude
-122.4
-122.3
-122.2
-122.1
-122.0
Longitude
Region
Bay
Margin
Scale:
mg/kg dw
50000

Fig. A-3 6



Lead
37.7
37.6
37.5
37.4
Latitude
-122.4
-122.3
-122.2
-122.1
-122.0
Longitude
Region
Bay
Margin
Scale:
mg/kg dw
30

Fig. A-3 7

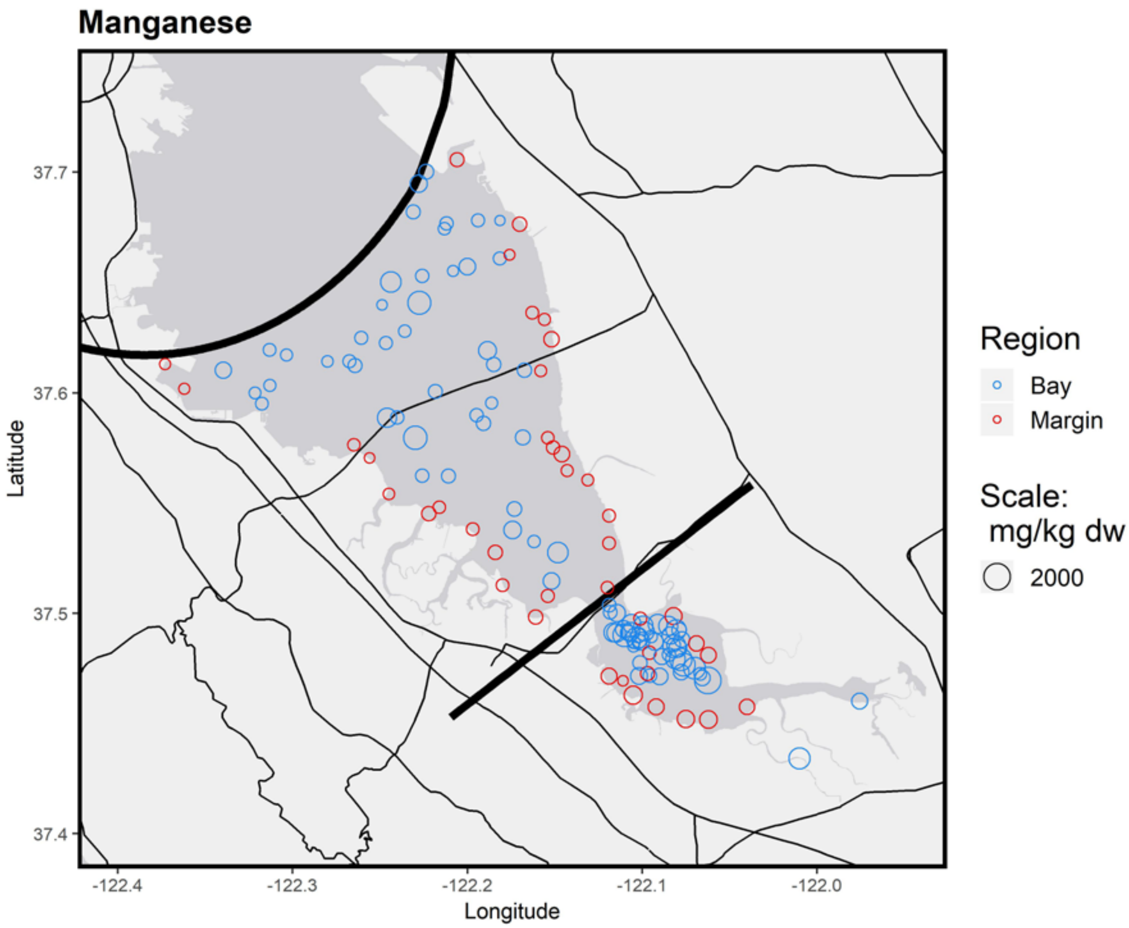

Manganese
37.7
37.6
37.5
37.4
Latitude
-122.4
-122.3
-122.2
-122.1
-122.0
Longitude
Region
Bay
Margin
Scale:
mg/kg dw
2000

Fig. A-3 8

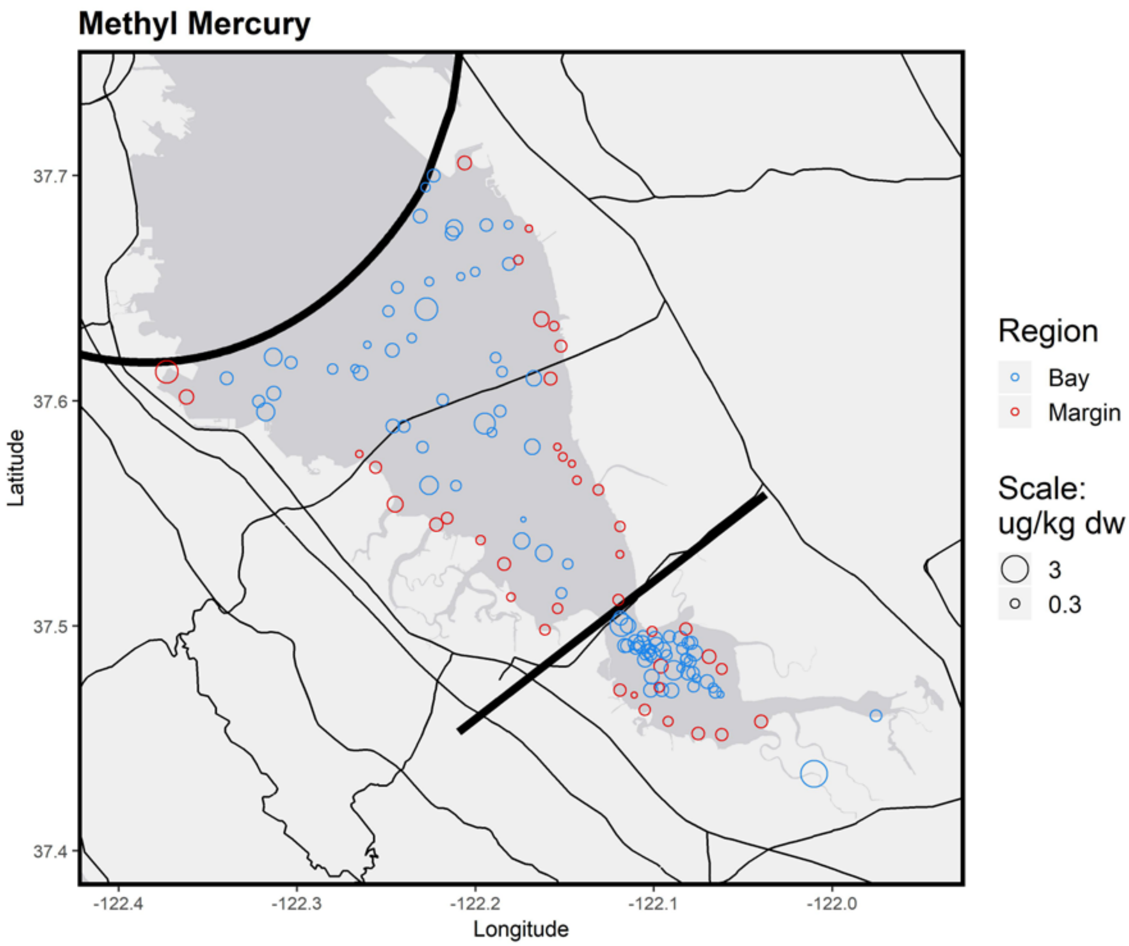

Methyl Mercury
Latitude
37.7
37.6
37.5
37.4
Longitude
-122.4
-122.3
-122.2
-122.1
-122.0
Region
Bay
Margin
Scale:
ug/kg dw
3
0.3

Fig. A-3 9

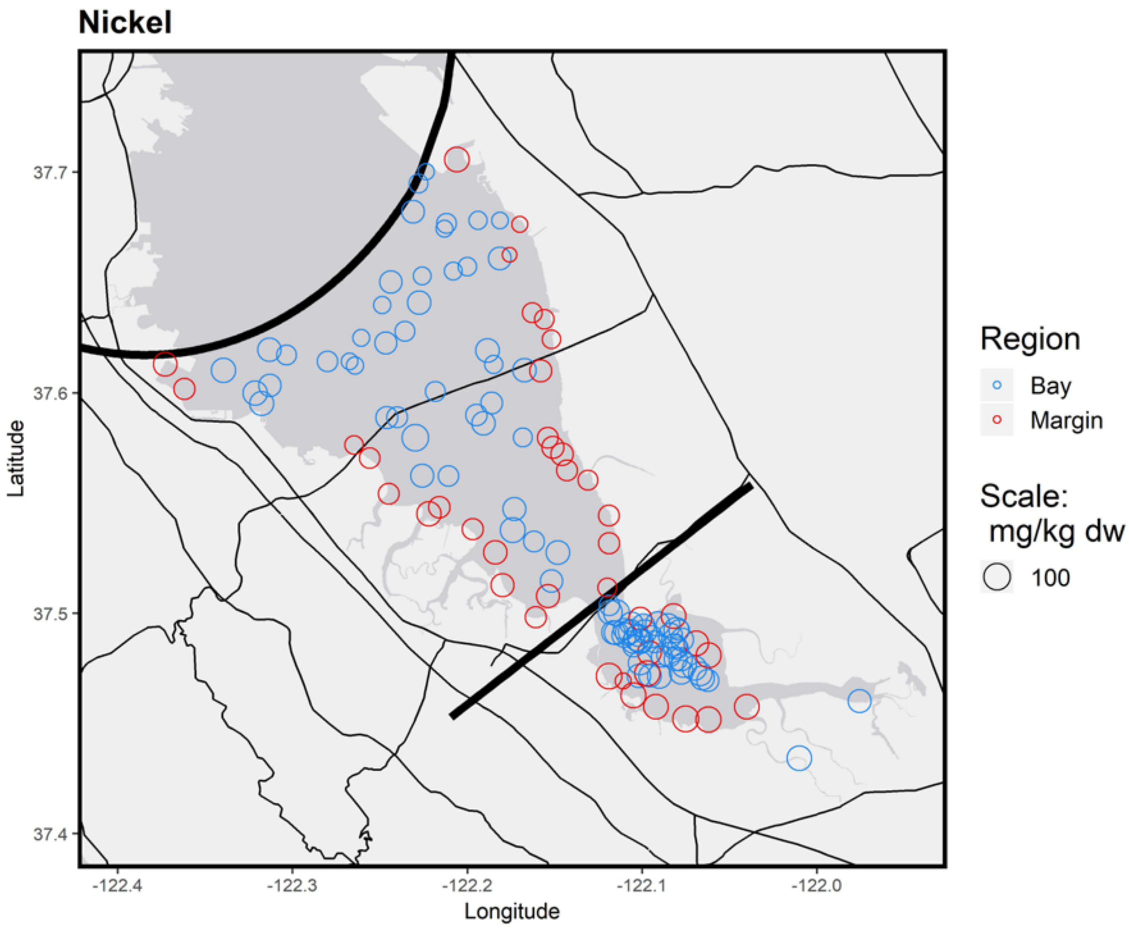

Nickel
37.7
37.6
37.5
37.4
Latitude
-122.4
-122.3
-122.2
-122.1
-122.0
Longitude
Region
Bay
Margin
Scale:
mg/kg dw
100

Fig. A-3 10

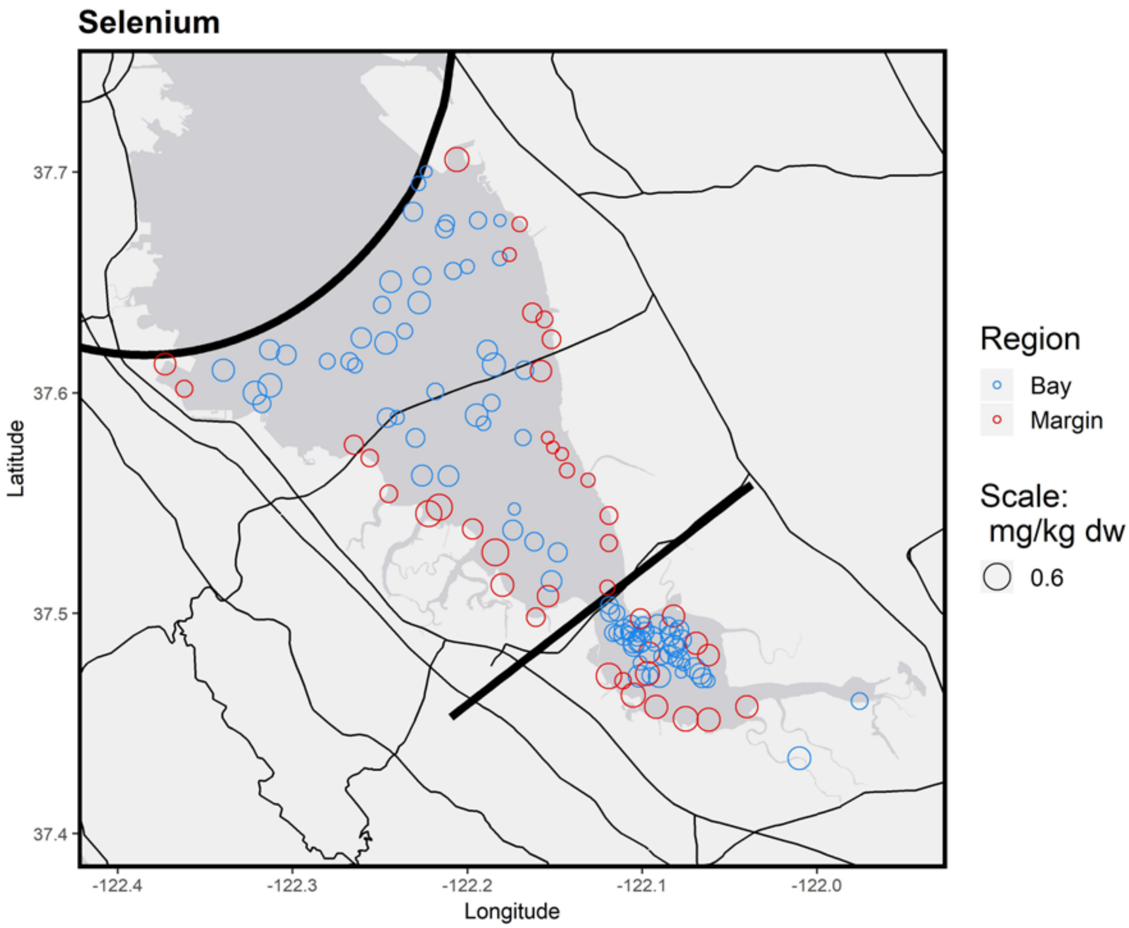

Selenium
37.7
37.6
37.5
37.4
Latitude
-122.4
-122.3
-122.2
-122.1
-122.0
Longitude
Region
Bay
Margin
Scale:
mg/kg dw
0.6

Fig. A-3 11

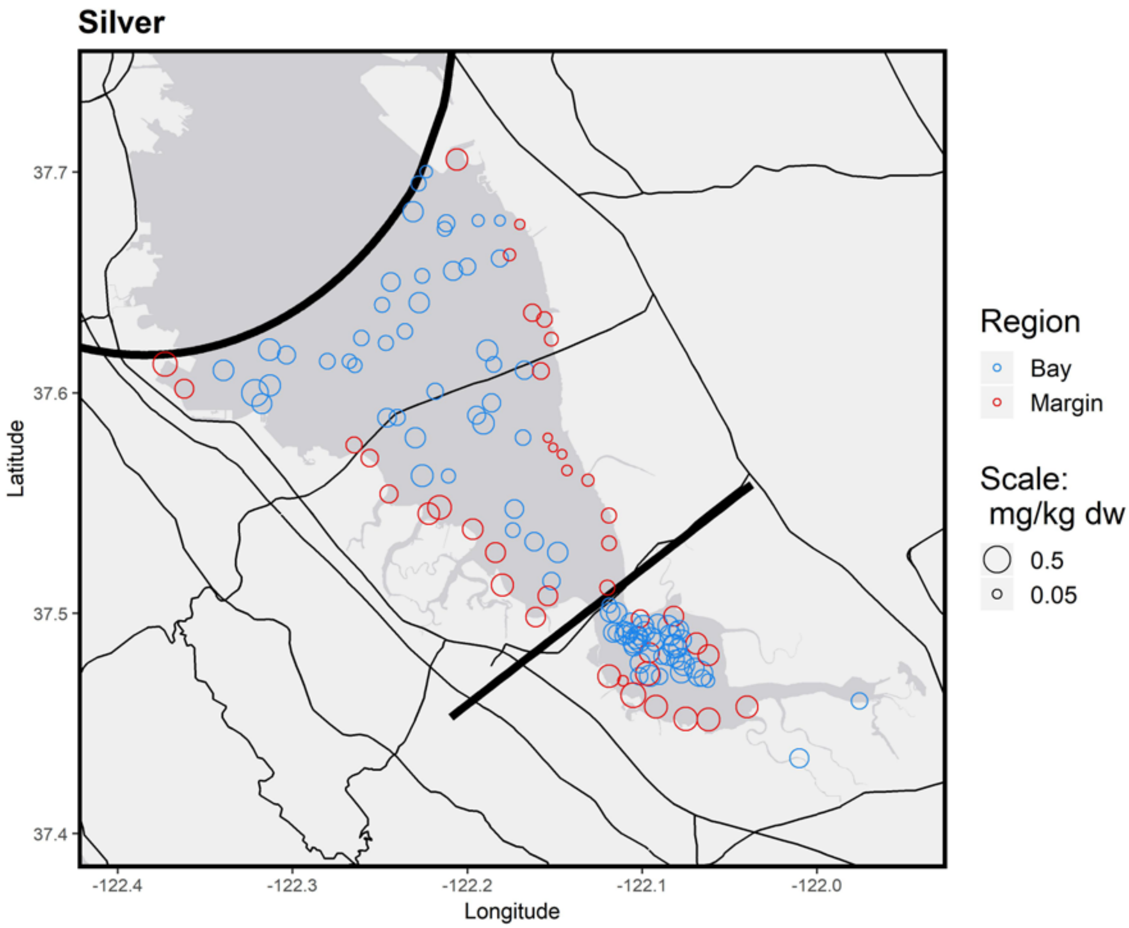
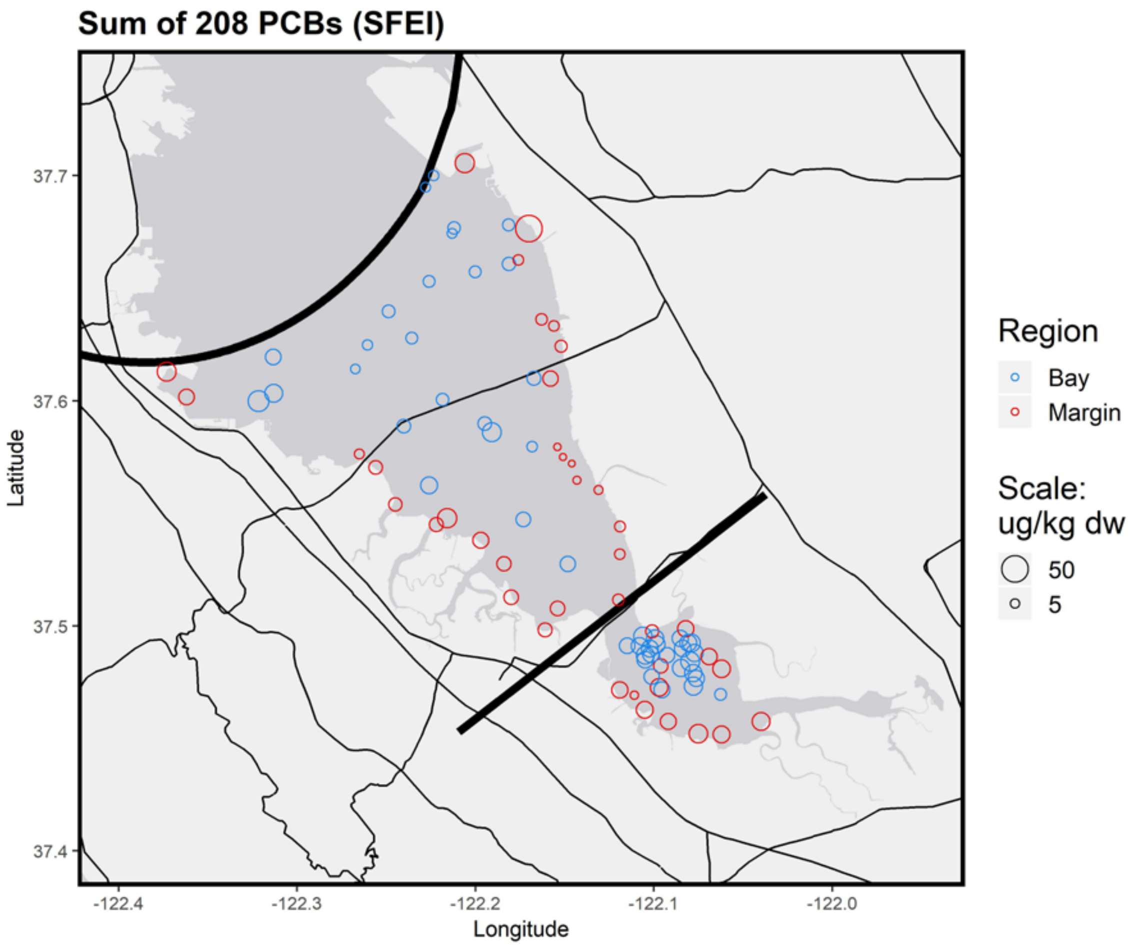
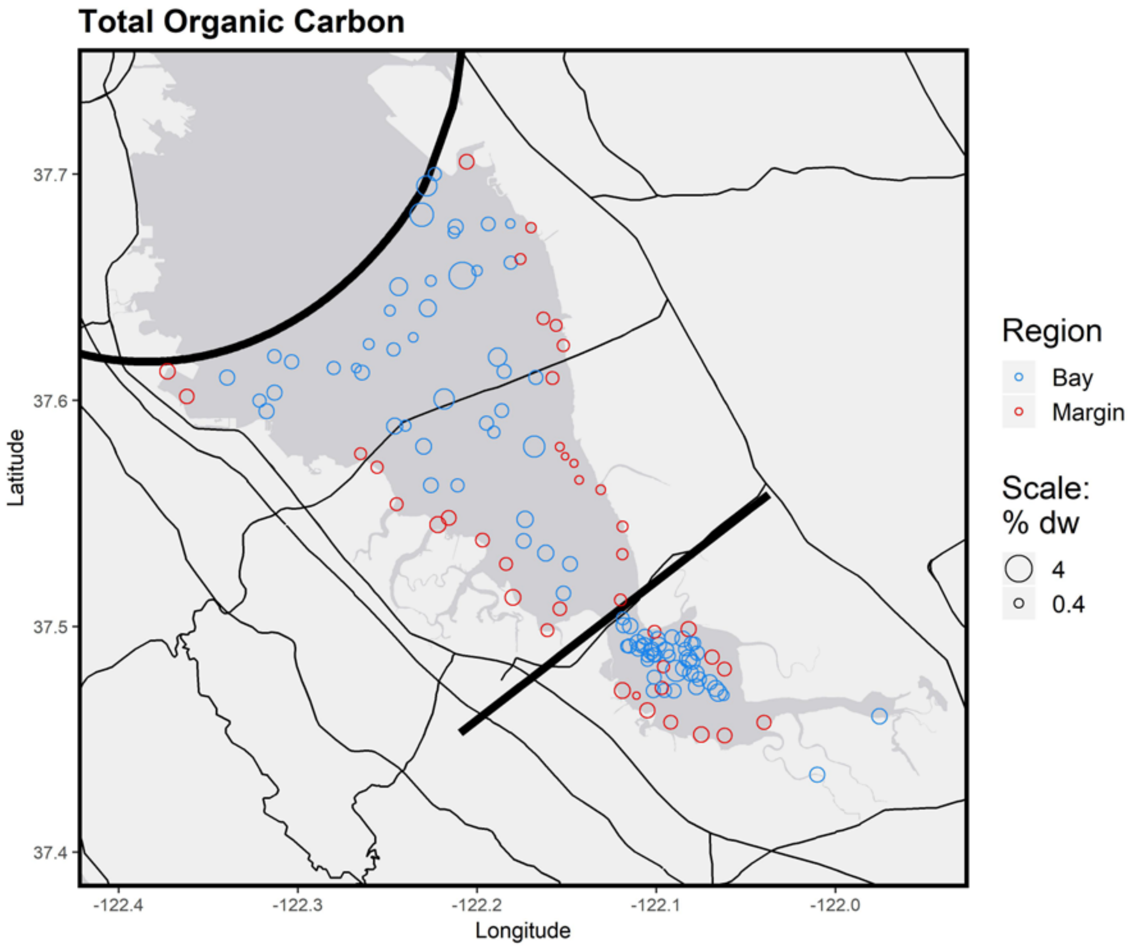

Silver
37.7
37.6
37.5
37.4
Latitude
-122.4
-122.3
-122.2
-122.1
-122.0
Longitude
Region
Bay
Margin
Scale:
mg/kg dw
0.5
0.05

Fig. A-3 12



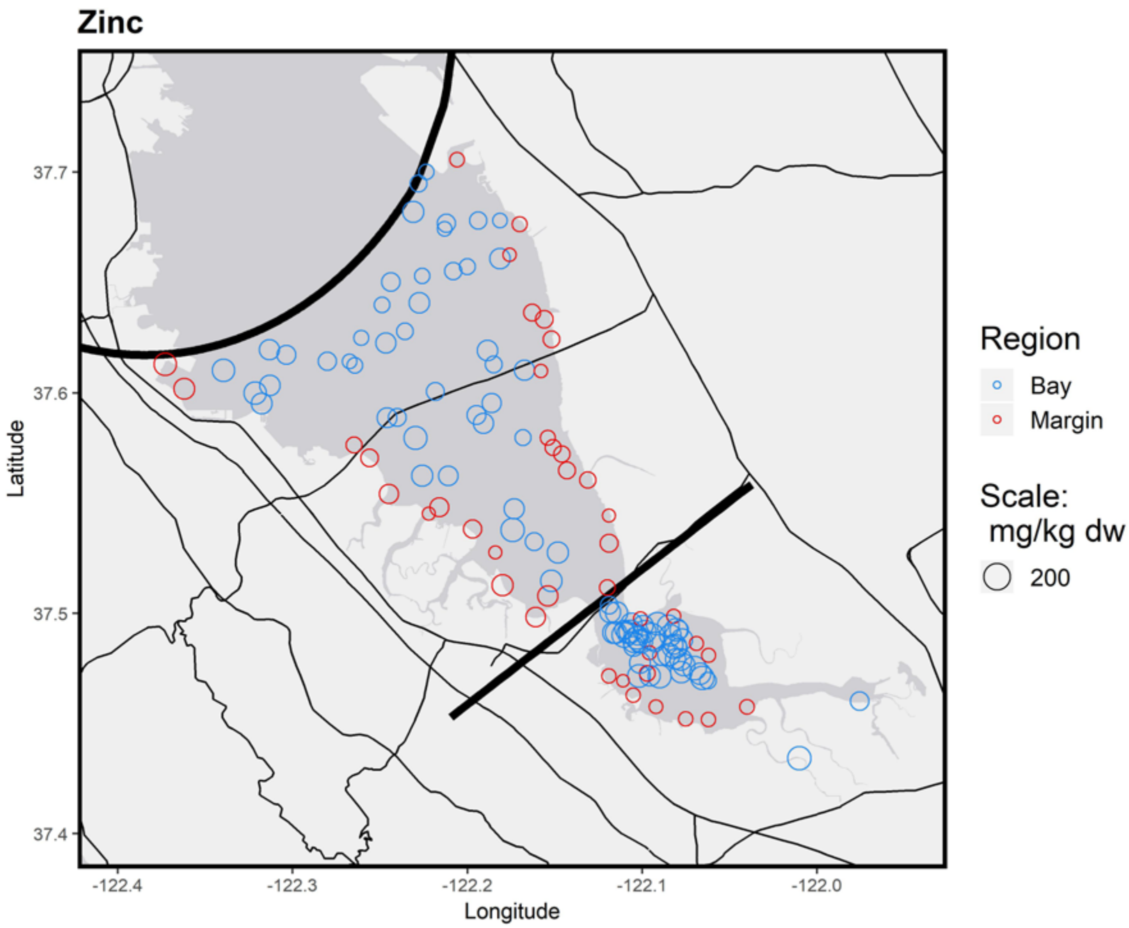
Sum of 208 PCBs (SFEI)
37.7
37.6
37.5
37.4
Latitude
-122.4
-122.3
-122.2
-122.1
-122.0
Longitude
Region
Bay
Margin
Scale:
ug/kg dw
50
5

Fig. A-3 13



Total Organic Carbon
37.7
37.6
37.5
37.4
Latitude
-122.4
-122.3
-122.2
-122.1
-122.0
Longitude
Region
Bay
Margin
Scale:
% dw
4
0.4

Fig. A-3 14



Zinc
37.7
37.6
37.5
37.4
Latitude
-122.4
-122.3
-122.2
-122.1
-122.0
Longitude
Region
Bay
Margin
Scale:
mg/kg dw
200

Fig. A-3 15

Section 4 Appendix. Comparison of South Bay Margins to Other Areas

Table A-4-1 Comparison of South Bay Margins to Open Bay TOC Normalized Concentration Quantiles – Percentiles for South Bay data weighted for their respective sub-areas (South Bay /Lower/Extreme) for margin and open Bay sites. Comparisons were made using the Kolmogorov-Smirnov test of distributions. Analytes with differences are shaded in red where margin percentiles values are higher and in blue where open Bay percentiles are higher. Values are bold underlined if the distributions are significantly different. Parameters are reported in mg/kg TOC dw unless otherwise noted.

Analyte (/TOC)	K-S p-value	50th Margins	50th Open Bay	75th Margins	75th Open Bay	90th Margins	90th Open Bay	Mean Margins	Mean Open Bay
Aluminum	0.119	2670000	2380000	3000000	2930000	3430000	3640000	2700000	2470000
Arsenic	0.000645	**721**	665	809	**892**	997	**1020**	**782**	703
Cadmium	0.00449	**19**	17.6	21.5	**23.5**	23.3	**30.6**	**20.9**	19.6
Copper	0.0317	**3280**	2960	**3570**	3420	3900	4000	**3280**	2890
Iron	2.09E-05	**3620000**	2830000	**4150000**	3580000	**5110000**	4440000	**3990000**	2930000
Lead	0.000645	**2100**	1850	**2270**	2110	**2780**	2630	**2160**	1800
Manganese	0.263	55300	47700	67700	70500	95700	88000	62100	53900
Mercury	0.0404	17.4	**20.2**	22	**24.2**	27.6	**29.7**	19.5	**20.3**
Methyl Mercury	0.348	37.5	44.9	54.7	63.8	75.7	83	46	49.7
Nickel	0.00131	**7640**	6380	**8670**	7400	**13200**	9230	**8940**	6170
Selenium	7.05E-07	**34.5**	22.6	**37.8**	33.8	**43.1**	38	**35.2**	24.5
Silver	0.00248	**24.9**	19.9	**29.5**	25.1	**33.5**	31.9	**25**	20.7
Sum of 208 PCBs (SFEI)	0.735	1490	1360	1750	1750	2070	1950	1630	1430
Sum of 40 PCBs (SFEI)	0.201	1150	1020	1370	1250	1650	1520	1270	1030
Zinc	9.51E-02	7590	**8680**	9730	**10000**	**13100**	11700	8210	**8370**