Survey of Sediment Quality in the Sacramento-San Joaquin Delta

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EXECUTIVE SUMMARY

The area of the convergence of the Sacramento and San Joaquin Rivers in central California has been urbanized for over 100 years and it is impacted by multiple types of anthropogenic stressors. The Sacramento-San Joaquin River Delta (Delta) is formed by the confluence of the two rivers and by natural and man-made channels, wetlands, and levees. In the Delta, riverine freshwater and saltwater from the San Francisco Bay mix to create a rich habitat. The Delta is an area of great importance to humans because it is the center of California's water distribution system and has significant cultural value. The intense uses of the Delta's water and other anthropogenic modifications have stressed this ecosystem.

Evidence of a stressed ecosystem has been found by multiple studies investigating the Delta's pelagic organism decline (POD). According to POD studies, some fish species have low abundances and long-term declines in population numbers. Contaminants, in addition to other types of stressors, are thought to be important contributors to adverse ecological impacts in the Delta. Most contamination studies have investigated water column contaminants and little information is available to characterize the extent and impacts of sediment contamination. Understanding sediment quality in this area is of key importance because sediments play an important role in determining the fate and effects of contaminants in estuaries. The lack of sediment contaminant information for the Delta is a critical data gap to understanding ecological impacts in the Delta.

The Delta Survey was conducted to characterize sediment quality in the Delta and its main tributaries. This survey investigated the presence and magnitude of sediment contamination, measured sediment toxicity, and characterized the benthic community in the Delta. The samples for this study were collected in 2007 and 2008. Potential temporal and spatial trends were investigated with the data generated.

A total of 144 samples were collected during the Delta Survey, with analyses conducted following a tiered approach. First, all 144 samples were analyzed with a 10-day amphipod survival and growth test using *Hyalella azteca*. The benthic macrofauna at each station were identified and enumerated to characterize community composition. The initial toxicity results were used to select a subset of 75 sediment samples for further toxicity testing and chemical analysis. The second bioassay was a 10-day survival and growth test conducted with midge larvae (*Chironomus dilutus (tentans)*). Legacy (e.g., DDTs) and currently discharged contaminants (e.g., pyrethroid pesticides) were analyzed in the sediment to characterize chemical exposure. Chemical index analyses (e.g., Logistic Regression Modeling) were conducted to determine the sediment's toxicity potential.

The results of the Delta Survey showed widespread chemical contamination in sediments, but at relatively low concentrations. Sediment contaminants included metals, legacy trace organics, and current use pesticides. In general, there were few differences in chemical concentrations between sampling events. Some spatial trends in sediment contamination were observed. For example, higher levels of PAHs, DDTs, piperonyl butoxide, and diuron were present at the convergence of the Sacramento and San Joaquin Rivers. Higher PCB concentrations were observed in samples collected near Chipps Island and Stockton Channel when compared to concentrations found in other study areas.

Chemical index analyses indicated that there was low potential for toxicity associated with sediment contamination in the Delta. Analyses of acid volatile sulfides (AVS) and simultaneously extracted metals (SEM) indicated low bioavailability and potential for toxicity from divalent metals such as copper, cadmium, and mercury. Toxic units (TUs) were calculated for PAHs and pyrethroids and showed that sediment concentrations of these contaminants had little toxic potential. Only 1% of the sediments tested had pyrethroid TUs that could potentially cause toxicity. Characterization of overall chemical exposure using the California Logistic Regression Model index (CALRM) also showed that most of the sediments collected in the Delta Survey had low toxicity potential. The CALRM classified most sediment samples as providing minimal or low chemical exposure with regards to the likelihood of observing biological effects.

Exposure to Delta sediments caused little mortality in either of the toxicity tests conducted. However, sublethal responses such as decreased growth or biomass were observed in both amphipods and midges. Sublethal effects were found during both sampling events, but no specific patterns were observed. During the first sampling event (2007) sediments from 10 to 14% of the stations caused a decrease in either growth or biomass of one of the species. No sublethal effects were observed in amphipods exposed to 2008 sediment samples. In contrast, *C. dilutus* showed decreased growth or biomass when exposed to sediments from 24% of the stations sampled in 2008. There was little indication of a higher prevalence of toxicity in specific areas of the Delta. Some toxicity was observed in sediments from stations located in slough areas and channels; however, most of the stations exhibited no toxicity to either test species. In only one case was toxicity detected in samples collected at the same station during both sampling events.

The benthic species collected during the Delta Survey were representative of a tidal freshwater assemblage and dominated by annelids, arthropods, and mollusks. The two species most commonly found were the freshwater clam *Corbicula fluminea* (90% of the samples) and the oligochaete worm *Limnodrilus hoffmeisteri* (80% of the samples). Approximately 17% of the taxa were non-indigenous, including dominant species such as *C. fluminea* and the amphipod *Gammarus daiberi*. The freshwater polychaete worm *Manayunkia speciosa* had the highest average abundance among the samples.

Some temporal shifts in dominant macrobenthic taxa were found. Annelids accounted for 98% of the total abundance in 2007, while arthropods accounted for 99% of the total abundance in 2008. However, there were no differences in mean total abundance or mean number of taxa between 2007 and 2008. There were spatial differences in species composition which reflected three sub-habitat types. These sub-habitats were: main and open channels dominated by amphipods (*Americorophium spp*., *G. daiberi*), smaller cross-channels and back bays dominated by *M. speciosa* and *G. daiberi*, and the more distal freshwater channels dominated by oligochaetes. However, the dominant fauna among these sub-habitats had 50 to 60% similarity.

The Delta Survey provides some of the most comprehensive data to date to investigate the quality of the sediments in the Sacramento-San Joaquin Delta. The results indicate that most of the area surveyed had good sediment quality with respect to impacts from chemical contamination. This conclusion is supported by the presence of only low levels of sediment toxicity and multiple chemical indices that indicate low toxicity potential. There were no clear relationships between the chemical concentrations and sediment toxicity. The cause of the mortality and the sublethal effects from the toxicity tests cannot be attributed to specific

compounds with the results of this study. Further research is needed to evaluate whether Delta macrobenthic communities are impacted by the relatively low levels of sediment contaminants detected in the Delta ecosystem.

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This report was originally prepared in draft form in 2010, but not released for public distribution at the time. Publication of the final version of this report at this time is being made in recognition of the importance of these data towards understanding sediment quality in the Delta and establishing a foundation for future study. Aside from updating portions of the text to reference research conducted subsequent to the study, minimal changes to the 2010 version of the report have been made in order to preserve the original contributions of the authors and context of the discussion. The authors thank Tom Grovhoug (Larry Walker Associates), and Lisa Thompson, Rebecca Franklin, and Timothy Mussen (Sacramento Regional County Sanitation District) for their assistance in completing this report.

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INTRODUCTION

Estuaries in urbanized areas are impacted by diverse types of anthropogenic stressors related to urban development and agricultural practices. The San Francisco Bay estuary has been intensively modified for more than 100 years due to urbanization (Nichols et al. 1986). The Sacramento-San Joaquin River Delta (Delta) is formed by the confluence of the two rivers and lies east of Suisun Bay (an upper arm of San Francisco Bay). The Delta consists of natural and man-made channels, wetlands and levees. Freshwater from the rivers mixes with saline water from the San Francisco Bay, creating a complex ecosystem. The Delta is also the center of California's water distribution system. Approximately two-thirds of the State and millions of acres of irrigated farmland depend on water from the Delta. Human uses of the Delta's water and other modifications (e.g., construction, dredging, waste disposal, and freshwater flow changes) have impacted the ecosystem. A variety of contaminant types have been discharged historically (e.g., DDTs) or currently (e.g., pyrethroid pesticides) into the area. These contaminants may come from municipal and industrial effluents, or from urban and agricultural runoff. Evidence of a stressed ecosystem has been found by multiple studies investigating the Delta's pelagic organism decline (POD). Several fish species show low abundances and long-term declines in population numbers. Considerable research has taken place to understand the POD causes (Kimmerer 2008, Brander et al. 2009, Glibert 2010, Werner et al. 2010). More recent studies and reviews reinforce the concept that multiple stressors, including contaminants, water flows, salinity, temperature, turbidity, nutrients, and in particular, the invasion of the Asian clam *Potamocorbula amurensis* have affected native organisms in the Delta (Lucas and Thompson 2012, Cloern et al. 2014, IEP MAST 2015, Dahm et al. 2016, Fong et al. 2016, Healey et al. 2016, MacWilliams et al. 2016, Ward and Paerl 2017, Cloern 2018).

Many factors are likely causing ecological impacts in the Delta and contaminants are thought to be potentially important contributors. Several studies have investigated contamination in the water column (Edmunds et al. 1999, Linville et al. 2002, Davis et al. 2003) and how it affects organisms (Saiki and Jennings 1992, Bailey et al. 1994, Whitehead et al. 2004, Fong et al. 2016). However, little information is available regarding sediment contamination. Understanding sediment quality in this area is important, because sediments play a critical role in determining contaminant fate and effects. Multiple lines of evidence are needed to determine the influence of chemical contaminants on sediment quality. It is necessary to investigate the potential cause by analyzing sediment chemistry, and to investigate biological effects by conducting toxicity bioassays and assessing the health of the benthic community. These three lines of evidence are known as the sediment quality triad (Chapman et al. 1997). Invertebrate monitoring efforts led by the California Department of Water Resources (DWR) have provided extensive benthic community data, but most of these efforts did not measure sediment chemistry or sediment toxicity (Fields and Messer 1999, Lowe et al. 2007, Peterson and Vayssiere 2010). The lack of sediment quality triad information is a critical data gap to understanding ecological impacts of chemical contamination in the Delta. The present study (Delta Survey) was designed to collect sediment quality triad information in the Delta and its main tributaries.

The objectives of the Delta Survey were to investigate the presence and concentration of sediment contaminants, to measure sediment toxicity, and to characterize the benthic community in the Sacramento-San Joaquin Delta. Sediment samples were collected from 144 stations located in the tidal freshwater habitat of the Delta. The samples for this study were collected in

fall 2007 and spring 2008 to investigate potential temporal patterns. This report describes the Delta Survey results in three different sections: chemistry, toxicity and benthic community. Each section presents results of the temporal and spatial analyses.

METHODS

Study Design

Samples of Delta surface sediment (top 5 cm) were collected to conduct sediment quality triad analyses (chemistry, toxicity, and benthos). The study had a spatially extensive coverage and analyzed samples from the lower portion of the Delta, at the confluence of the Sacramento and San Joaquin rivers and its tributaries (Figure 1). The samples were collected in two separate sampling events to investigate potential temporal patterns of contamination and biological responses. The sampling design for this study is too limited over time to permit identifications of temporal trends with confidence; reference to temporal changes or trends in this report are intended solely to characterize differences between sampling events, not to imply long-term trends over time.

The first sampling event occurred between September 17 and October 16, 2007. The second sampling event occurred between May 19 and June 3, 2008. The stations were selected to build upon the existing DWR sampling program. Most stations were selected by random stratification. Additional stations were selected because they had been historically sampled by DWR. Several new stations were added to better characterize some of the Delta tributaries and investigate areas where elevated contamination was expected. These additional samples focused on areas with soft bottoms, little water circulation and a high possibility of contaminant deposition (e.g., nearby agricultural runoff). Sampling was conducted in coordination with the DWR program.

A total of 144 samples were collected from 121 stations. 19% of the stations were sampled during both events (Appendix A). A tiered approach was followed to conduct sample analysis. In the first screening step, all 144 samples were analyzed with a 10-day amphipod survival and growth bioassay to determine toxicity. Benthic invertebrates were also collected from all the stations to characterize their presence and abundance. The initial toxicity results were used to select a subset of 75 samples for chemical and additional toxicity analysis using a second toxicity test. Legacy and currently discharged contaminants were analyzed in the 75 sediment samples to characterize exposure potential (e.g., metals, DDTs, PCBs, PAHs, and current use pesticides). The second toxicity test was a 10-day midge larvae survival and growth test.

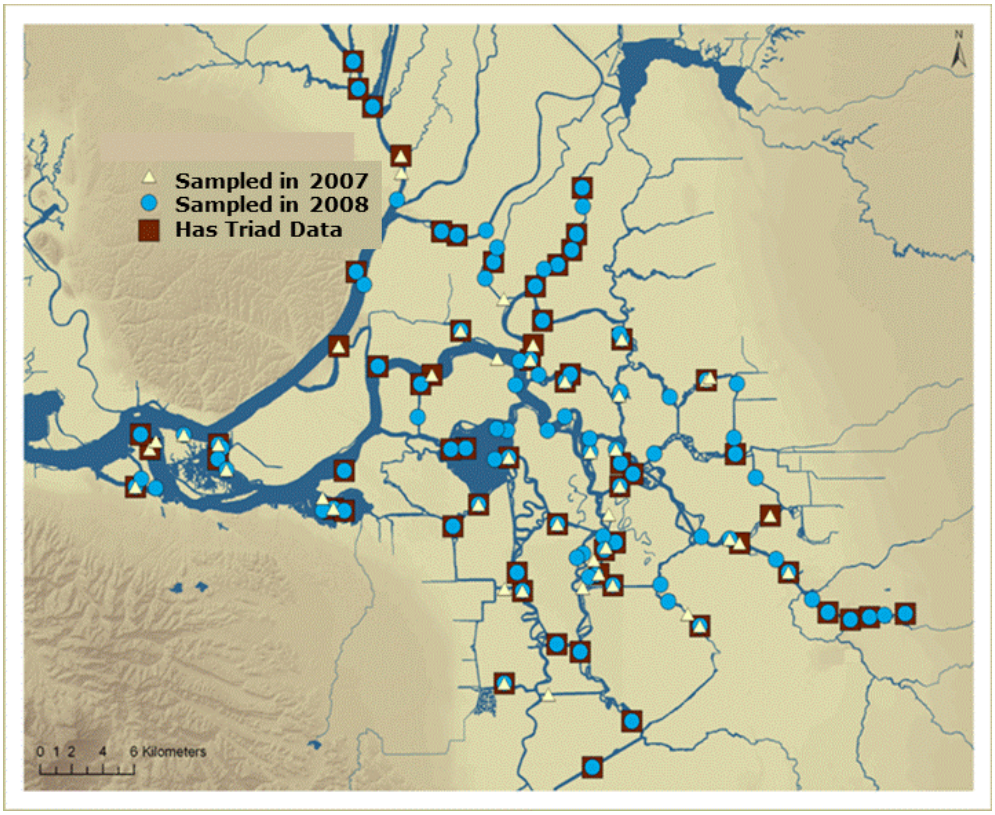

Figure 1. Station locations in the Sacramento-San Joaquin Delta.

Sampling Methods

Benthic macrofauna samples were collected using a 0.05 m^2 Ponar grab. The depth of each sample varied with the sediment characteristics at each station. The contents of the grab were brought to the surface and placed in a large plastic bucket. Water was added to the sample to create slurry and the bucket contents were carefully washed over a Standard No. 30 stainless steel mesh sieve to remove the sediment. All material remaining on the screen after washing was preserved in a solution of 20% buffered formalin. Benthic macrofauna samples were later transferred to 70% ethanol for storage until taxonomic analysis.

Most sediment samples used in toxicity and chemistry analyses were collected during separate cruises from those used for collecting benthic macrofauna. However, both sets of samples were collected within three weeks of each other. Sediment samples for sediment chemistry and toxicity testing were collected using a Young-modified Van Veen grab with a surface area of 0.1 m^2. The grab was made of stainless steel coated with Dykon®. All scoops, buckets, and stirrers used to collect and homogenize sediments were constructed of stainless steel coated with Dykon®. Sediment sampling equipment was cleaned (sequentially with detergent, acid, methanol, and rinsed with ultrapure water) at each location prior to collecting the samples. Two to three sediment grabs were taken at each site. The top 5 cm of sediment was scooped from the

grab and homogenized in a bucket. Samples were aliquoted into containers and stored on ice or frozen according to methods appropriate for each analysis.

Sample and Data Analysis

Chemistry

Sediment samples were analyzed for polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine pesticides (dichlorodiphenyltrichloroethanes (DDTs), chlordanes, cyclopentadienes, and hexachlorohexanes; Appendix B). Current use pesticides (e.g., pyrethroids) and acid volatile sulfides (AVS) and simultaneously extracted metals (SEM) were also measured. Each dataset received from the analytical laboratories was reviewed for data quality measures which included completeness, sensitivity, contamination, accuracy, and precision. Analytical results that did not meet the quality objectives outlined by the project's Quality Assurance Project Plan were not used for statistical analysis.

Sediment metals analyses were conducted using USEPA method 1638 for aluminum, arsenic, cadmium, copper, iron, manganese, nickel, lead, silver, and zinc and were analyzed with coupled plasma mass spectrometry. Selenium samples were analyzed following the USEPA Method 200.2. Total mercury was analyzed following the USEPA 1631 method using cold vapor atomic fluorescence spectrometry. Metal quantification used internal standard calibration curves, with regression coefficients of at least 0.99. Calibration curve verifications were frequently analyzed and were between 80 and 120% of the expected concentration; duplicate and matrix spiked samples were also analyzed. Matrix spike samples were analyzed in the same manner as unspiked samples to determine the presence of matrix interferences.

Organic samples were also analyzed following standardized protocols (Appendix B). PAHs were analyzed following the USEPA Method 3630C, 3610B, and 8270CM using gas chromatography mass spectrometry (GC-MS). Organochlorine pesticides were analyzed by GC-MSMS or using gas chromatograph with ECD following the USEPA 8081 BM method. PCBs were analyzed by GC-MSMS. Pyrethroid pesticides were analyzed by method 8081 GC-ECD with confirmation analysis by GC-MSMS or liquid chromatography–mass spectrometry. Piperonyl butoxide was quantified by LC-MS. Carbamate pesticides were analyzed by LC-MSMS (EPA method 632M). Quality control measures consisted of procedural blanks, duplicate analyses, and spike analyses. Standard surrogates were used to determine compound losses during extraction and processing, percent recoveries ranged from 80 to 120%.

Descriptive statistics were used to investigate temporal and spatial differences of sediment chemistry results. Mean concentrations, and other values were calculated using SigmaStat 2.03 software (Chicago, IL). When a compound was below detection, then half of the method detection limit (MDL) for that analyte was used in calculations. In the tables and thematic maps created to analyze the data, non-detects were represented as the MDL. For maps showing sediment concentration ranges, the values were grouped into bins. The bin cutoffs for each constituent were based on concentration values corresponding to the quartiles for all the samples in which the constituent was detected. Cumulative proportion plots were calculated using JMP V9 (Cary, NC) to compare the results of this study and results from previous studies conducted

in other California embayments. Data for comparison in the cumulative proportion plots were obtained from the California Sediment Quality Objectives (CA SQO) Database and consisted of 1255 samples of surface sediment. The State data used for comparison can be found at http://www.sccwrp.org/Data/SearchAndMapData/DataCatalog/CaliforniaSedimentQualityObjectivesDatabase.aspx.

The toxicity potential of the sediment contamination was investigated using three chemical indices. The difference between SEM and AVS concentrations was used to evaluate the potential for toxicity from divalent trace metals. When SEM minus AVS (SEM-AVS) values were > 0, a sediment sample was considered to have potential for metal toxicity (USEPA 2002a). Toxic units (TUs) for total PAHs and for pyrethroids were calculated using sediment concentrations normalized to the total organic carbon content of the sample (µg/g OC). The concentration of nondetected analytes was assumed to be zero for TU calculation. TUs were calculated as the concentration of the analyte divided by the laboratory-derived lethal concentration (LC50) value for that constituent. TU values > 1 indicated toxicity potential, higher TUs implied a greater chance that an analyte would cause toxicity (USEPA 2002b). Pyrethroid LC50 values for *Hyalella azteca* were obtained from Amweg et al (2005) and PAH LC50 values were obtained from USEPA (2003).

The logistic regression model chemical index (CALRM), developed for the California sediment quality objectives program (SQO) was also used. CALRM analysis used regression calculations to estimate the probability of sediment toxicity based on chemical concentrations. The relationships between chemical concentration and the probability of toxicity have been established for cadmium, copper, lead, mercury, zinc, high PAHs, low PAHs, alpha chlordane, dieldrin, trans nonachlor, total PCBs, and 4,4'-DDT (Bay et al. 2008). To determine the CALRM index score, the probability of toxicity for each target chemical in a sediment sample was first determined using individual logistic regressions. The maximum probability value (Pmax) among the target compounds was selected to estimate the overall toxicity probability for the sample (Field et al. 2002). The Pmax was compared to thresholds to determine the overall chemical exposure categories of: Minimal Exposure (Pmax < 0.33), Low Exposure (≥ 0.33 to ≤ 0.49); Moderate Exposure (> 0.49 to ≤ 0.66), and High Exposure (> 0.66). Although some data analysis tools from the SQO program were used in this study, the full SQO assessment framework was not used due to the lack of benthic indices and data interpretation thresholds for the Delta habitats.

Toxicity

Sediment toxicity was measured using laboratory survival and growth bioassays with the amphipod *Hyalella azteca* and larvae of the midge *Chironomus dilutus (tentans)*. These bioassays followed standardized protocols (USEPA 2001). The exposures were conducted under static conditions with aeration. The photoperiod for the test was 16 hours light: 8 hours dark and the temperature was 23 ± 1°C. Eight replicates were tested for each bioassay type. Before the start of the test, the sediments were mixed to provide a homogeneous sample and inspected to remove visible indigenous organisms. The overlying water was renewed twice daily.

The amphipod test was conducted using 7- to 14-day old *Hyalella azteca,* obtained from Chesapeake Cultures (Hayes, VA). Ten amphipods were placed into each replicate container and allowed to interact with the test sediments. Each amphipod replicate was fed 1.5 ml of YCT per day. After a 10-day exposure, the sediment was sieved to recover the amphipods, and live animals were counted to determine the percentage that survived the exposure, and to determine their growth and biomass. Animals from each replicate were dried and weighed. Missing animals and animals that did not respond to gentle probing were considered dead. Sediment toxicity was characterized by the mean percent survival and growth (± standard deviation) for each sediment sample. This was compared to the survival, growth, and biomass observed in negative control samples. Negative controls consisted of amphipods exposed to formulated sediment (Anderson et al. 2007).

The midge toxicity test was conducted using second or third instar *Chironomus dilutus* (approximately 10 days old) supplied by Aquatic Biosystems (Fort Collins, CO). Ten midge larvae were placed into each replicate container and allowed to interact with the test sediments. Midge larvae were fed 10 ml of 4 g/L Tetrafin slurry daily. After 10 days, the sediment was sieved to recover the larvae, and live animals were counted to determine the percentage survival. Then, midge larvae from each replicate were dried and weighed, then ashed and reweighed for determination of growth and biomass. Sediment toxicity was characterized by the mean percent survival, growth, and biomass (± standard deviation) for each sediment sample. Statistical analysis was based on comparisons to the negative control.

For both test species, there were three toxicity endpoints: survival, growth, and biomass. In addition, a fourth endpoint for growth based on ash-free dry weight was calculated for the midge bioassay. Survival was calculated as the percent of individuals still alive at the end of the test. Growth was calculated as the total weight of all survivors at the end of the test minus their initial weight. Biomass was calculated as the total weight of all survivors divided by the initial number of individuals in the test.

A sample was considered toxic when the response was less than 80% of the control and significantly different from the control. Control adjusted percent survival was calculated as:

(mean survival in test sample/ mean survival of control) x 100

Statistical comparisons between negative controls and test samples were conducted using a one-tailed Student’s t-test assuming unequal variance (alpha= 0.05).

A 10-day, water-only cadmium chloride reference toxicant test was performed with each set of field samples tested. The cadmium test was used as a positive control. The half maximal lethal concentration (LC50) of the reference toxicant was calculated. The LC50 is the concentration at which the toxicant induces 50% mortality. The LC50 for cadmium was within two standard deviations of the historical mean for the laboratory. All test batches also included negative controls. Mean control survival for each negative control treatment was 80% or greater. In some cases, more than 10 survivors were discovered at the conclusion of exposure during the midge larvae bioassay. This indicated that more than 10 individuals were used at the beginning of the test. Because the initial number could not be determined in such circumstances, these replicates were excluded from statistical analyses. Ammonia, hardness, alkalinity and pH were measured at the beginning and at the end of the tests. Water temperature and dissolved oxygen were regularly

monitored throughout the tests. Water quality data were always within the appropriate parameters determined by the protocols used (USEPA 2001).

Descriptive statistics (mean, maximum and minimum values) were calculated with SigmaStat 2.03 software. The toxicity results of the sediment samples collected in this study were compared to previous studies conducted in other California embayments using cumulative proportion plots (JMP V9). Statewide toxicity data were obtained from the CA SQO Database and consisted of 1065 samples of *Eohastorius estuarius* 10-day amphipod survival data compiled from regional monitoring and dredged material characterization tests (1992-2003) of surface sediments from marine, polyhaline, and mesohaline embayments throughout California, including portions of San Francisco Bay. Cumulative proportion plots were generated by calculating the control-adjusted mortality results for each sample, sorting the results by species in ascending order, and calculating the cumulative proportion of samples associated with each mortality value.

Benthic Community

The benthic organisms collected were sorted, identified, and counted. In the laboratory, the field preservative was decanted, and the sample was washed with deionized water over a Standard No. 30 stainless steel mesh screen. Organisms were then placed in 70% ethyl alcohol for identification and enumeration. Identification and enumeration of the benthic macrofauna was conducted by scientists with documented expertise in analyzing environmental samples from the Delta.

Species level identifications were carried out to the lowest practical taxon. A stereoscopic dissecting microscope (70X-120X) was used to identify macrobentic organisms. When taxonomic features were too small for identification under the dissecting scope, the animals were placed on a slide and examined under a compound microscope. When more than 3 hours of picking were required and a sample contained many organisms but few species, a one-fourth volume subsample was chosen at random from the sample. Subsequently, the subsample was picked, and the results were multiplied by 4 to represent the total sample. The remainder of the sample was once more checked to ensure that no taxa were overlooked.

Benthic community structure for each sample was characterized using conventional metrics. The average, maximum and minimum abundance values were calculated. Abundance was considered as the number of individuals of the same species in a sample. The species percent occurrence was calculated as the percent of total samples where that species was present. Species abundance data and hierarchical cluster analysis were used to identify benthic assemblages (Thompson et al. 2011). For further analysis, the results of this study were compared to data from other benthic studies previously conducted in the Delta area.

RESULTS AND DISCUSSION

Sediment Chemistry

Chemical contamination of Delta sediments was widespread, based on the frequency of detection of anthropogenic trace organics (Table 1). Sediment contamination levels were similar between the two sampling events for most analytes (Table 1). The highest metal concentrations were found for zinc (ranging from 11 to 608 mg/kg) and the highest organic concentrations were found for PAHs (ranging from 4 to 1454 µg/kg). The maximum concentration values for some chemicals differed between sampling events, reflecting patchiness among different locations, and low rates of detection for some compounds. For example, the maximum concentration of carbofuran in 2008 was almost 4 times higher than the concentrations found in 2007. Maximum values of cadmium, lead, zinc, hexachlorobenzene, and PCBs were 3 to 7 times higher in 2007 than in 2008. However, mean and median concentrations for those chemicals that were frequently detected with generally similar (within a factor of two) between sampling events. Box plots comparing the concentration distributions of copper, mercury, lead, zinc, DDTs, PAHs, diuron, and bifenthrin by year are shown in Figure 2.

Only a few compounds showed occurrence differences between sampling events, and these differences did not follow a consistent pattern. For example, dieldrin was not detected in 2007, but it was found in 52% of the 2008 samples (Table 1). Methoxychlor was detected in 96% of the 2007 samples but was not detected in any 2008 samples. Other organic constituents that varied widely in frequency of detection between years were carbaryl (higher in 2007), and bifenthrin (higher in 2008). Bifenthrin was the only pyrethroid detected in both sampling events; other pyrethroids were either not detected at the detection limit (0.5-4 µg/kg) or detected too infrequently (less than 5% of samples) to permit examination of temporal differences.

There was some evidence of spatial clustering for certain contaminants in the Delta. Higher levels of total PAHs, total DDTs, piperonyl butoxide (PBO), and diuron tended to occur in the San Joaquin River and several of its tributaries (Figures 3 to 5). Concentrations of total pyrethroids were below detection limits or detectable, but low, in most of the samples. Relatively higher pyrethroid levels were evident at the confluence of the Sacramento and San Joaquin Rivers. Higher PCB concentrations were also observed in samples from stations near Chip's Island and Stockton Channel (approximately 53 µg/L) when compared to other areas. However, the distribution of sediment mercury did not show a spatial pattern. A full list of the chemicals analyzed for this study and summary analysis results can be found in Appendix C.

Table 1. Sediment concentrations and percent of detection for selected compounds. N= 50 sites for 2007 and 25 sites for 2008. When non-detects occurred for a given constituent, the minimum MDL value for that year was used as the "Min" value. When a given constituent was not detected within any batch, the maximum MDL value was used for the "Max" column. Results for contaminant classes (i.e., DDTs, PAHs, PCBs, chlordanes, and pyrethroids) include all measured analytes within each group.

	2007				2008			
Chemical	Mean	Min	Max	% Detects	Mean	Min	Max	% Detects
Metals (mg/kg)								
Arsenic	8.93	1.95	28.2	100	8.24	2.23	16.2	100
Cadmium	0.37	0.02	1.56	100	0.3	0.05	0.5	100
Copper	51.31	3.73	165	100	38.8	6.79	74.9	100
Lead	15.47	2.42	121	100	10.2	2.64	16.9	100
Mercury	0.15	0.01	0.78	100	0.15	0.02	0.36	100
Zinc	108.9	10.7	608	100	81.2	26.9	117	100
Organics (µg/kg)								
Carbaryl	0.17	< 0.1	1.32	66	0.18	< 0.1	1.6	16
Carbofuran	0.03	< 0.05	0.17	8	0.12	< 0.05	0.7	24
Chlorpyrifos	0.54	< 0.25	5.13	50	0.73	< 0.53	3.02	16
DDTs	11.97	< 0.27	70.87	90	8.21	< 0.54	32.04	88
Dieldrin	0.45	< 0.52	<1.6	0	2.2	< 1.12	7.11	52
Diuron	16	< 0.2	93.2	96	27.5	< 0.2	203	92
Endosulfan I	0.58	< 0.68	<2.07	0	1.31	< 1.45	<4.73	0
Endrin	0.2	< 0.22	0.95	2	0.42	< 0.47	<1.52	0
Hexachlorobenzene	0.79	< 0.42	15	10	0.95	< 0.9	4.16	4
Linuron	0.15	< 0.2	1.6	8	0.66	< 0.2	4.71	24
Methiocarb	0.25	< 0.5	<0.5	0	0.25	< 0.5	<0.5	0
Methomyl	0.05	< 0.1	<0.1	0	0.05	< 0.1	<0.1	0
Methoxychlor	1.26	< 0.18	9.16	96	0.34	< 0.38	<1.23	0
PAHs	264.1	< 0.6	1453.7	98	280	4.27	1457.39	100
PCBs	7.57	< 0.15	152.3	76	9.17	1.51	24.01	100
Piperonyl butoxide	1.67	< 0.1	19.2	92	2.48	< 0.1	21.4	92
Chlordanes	0.37	< 0.43	<1.33	0	0.89	< 0.86	2.68	8
Pyrethroids	2.5	< 1.81	24.8	32	4.6	< 1.81	30.6	92

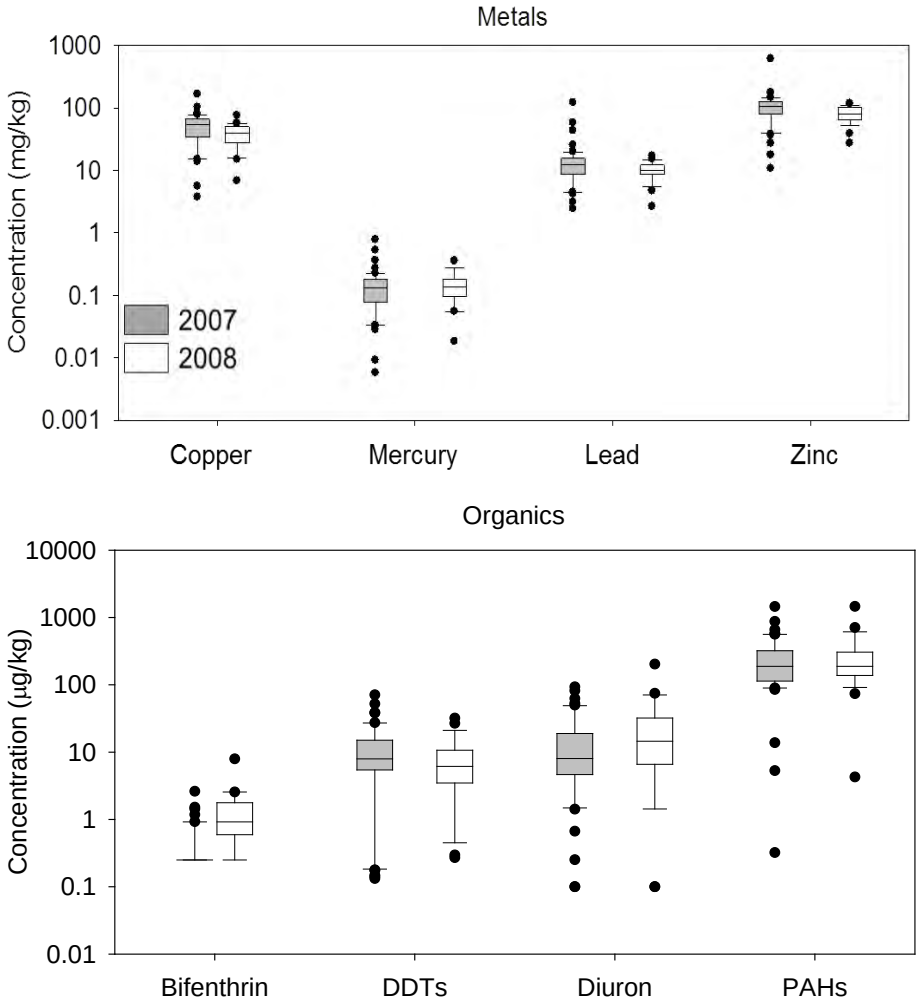

Figure 2. Sediment concentrations of selected constituents. Horizontal lines on each plot show the 10th, 25th, 50th (median), 75th, and 95th percentiles.

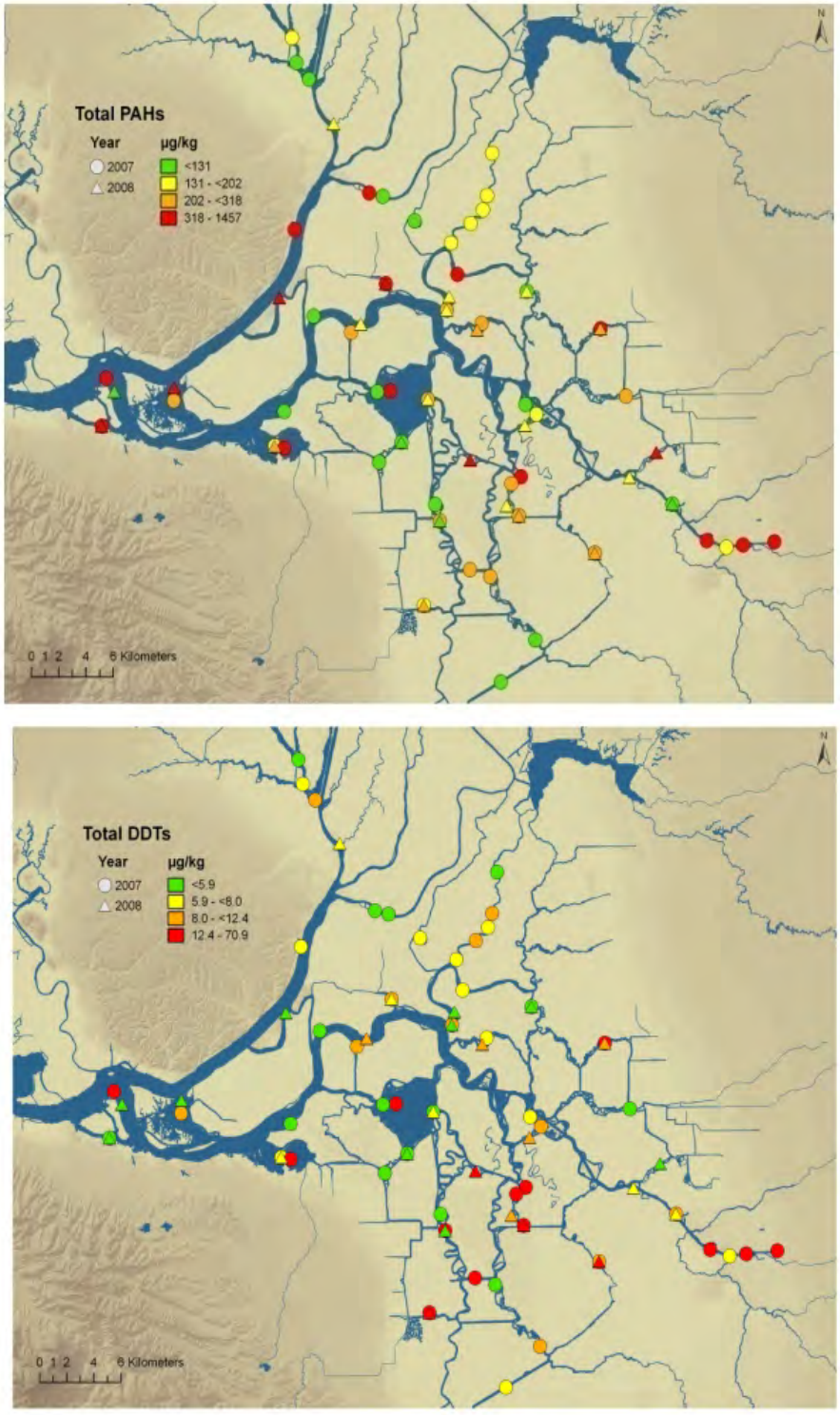

Figure 3. Sediment concentration ranges for PAHs and DDTs. Samples with results above detection limits are in groups based on quartiles for each constituent. All non-detects were assigned to the lowest category (coded green).

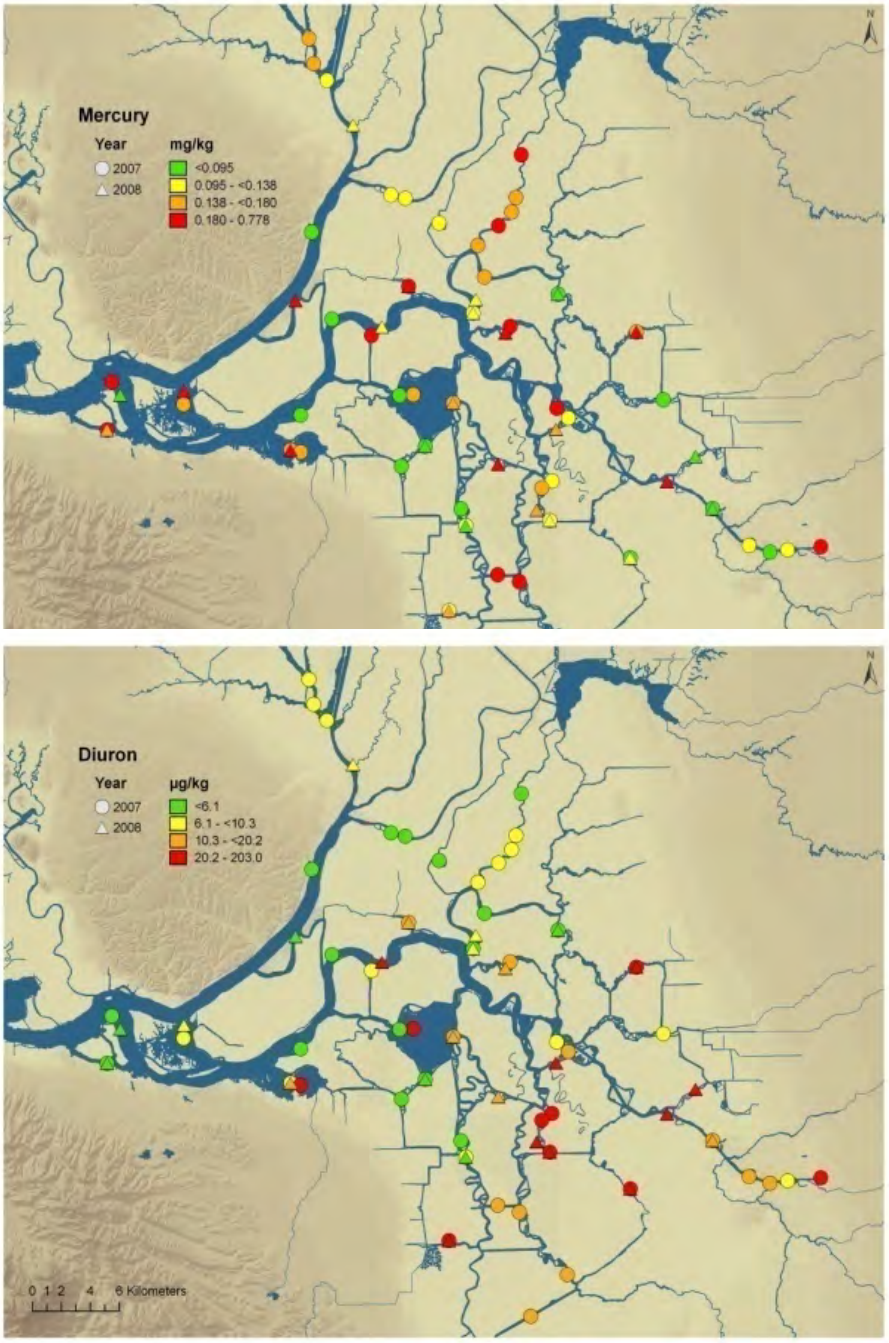

Figure 4. Sediment concentration ranges for mercury and diuron. Samples with results above detection limits are in groups based on quartiles for each constituent. All non-detects were assigned to the lowest category (coded green).

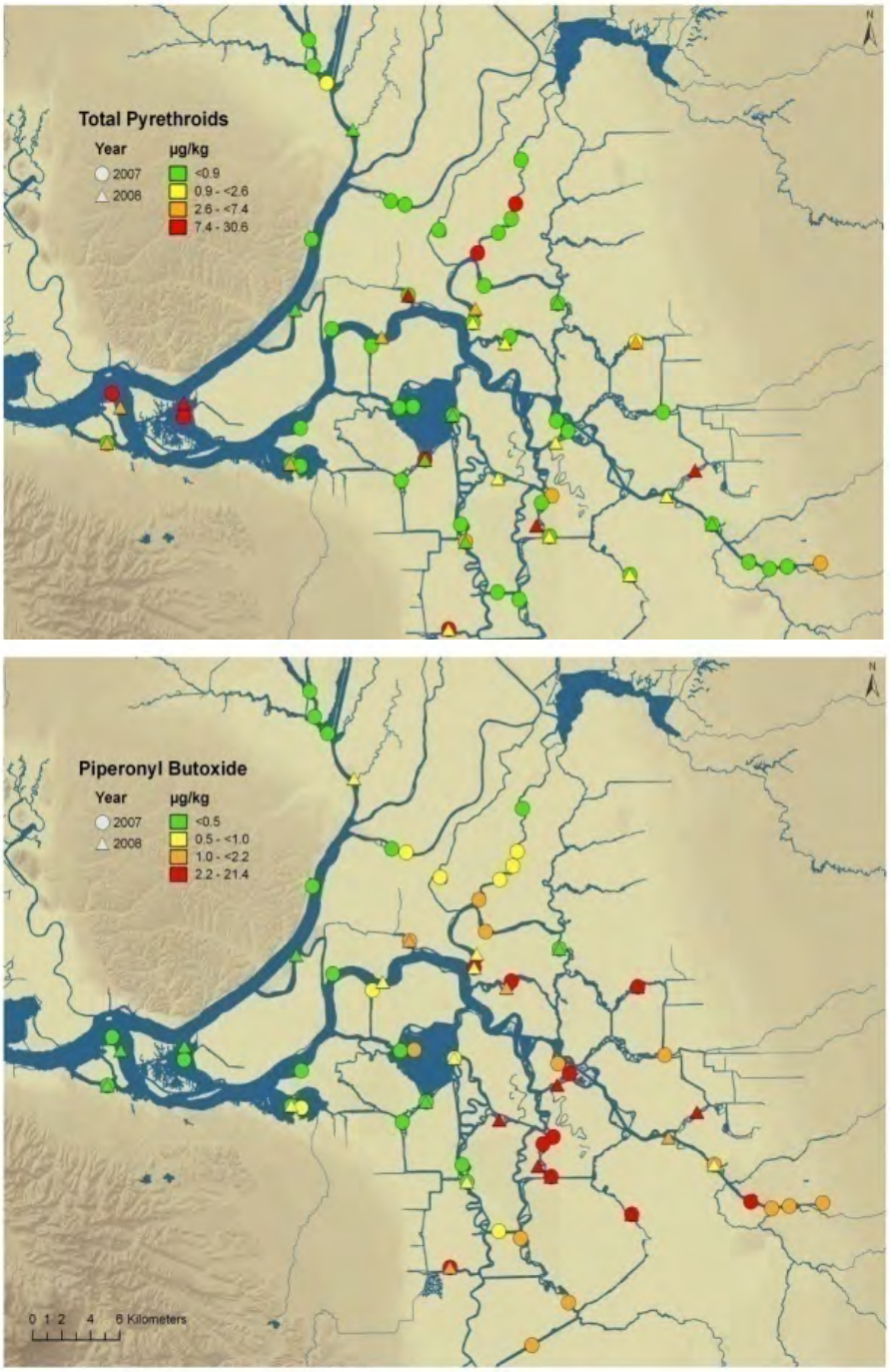

Figure 5. Sediment concentration ranges for pyrethroids and piperonyl butoxide. Samples with results above detection limits are in groups based on quartiles for each constituent. All non-detects were assigned to the lowest category (coded green).

Limited preexisting sediment chemistry data exists for the lower, tidal freshwater reaches of the San Joaquin/ Sacramento River Delta. Therefore, making a comparison to previous studies conducted in the Delta to get a regional perspective is challenging. Three prior studies conducted upstream and downstream of the Delta Survey study area were selected. A direct comparison was somewhat problematic because these studies did not measure the same list of constituents and their sample collection stations rarely overlapped with the Delta Survey stations. Only stations from these previous studies that were located near the lower Delta were selected for comparison (Figure 6). Comparisons were limited to only those constituents that were measured by three or more studies.

Chemical concentrations in Delta Survey sediments were similar to concentrations from other studies conducted in the Delta area. The SFEI Regional Monitoring Program (RMP) 2006-2008 (https://www.sfei.org/rmp/amr) found similar concentrations of metals, legacy and currently discharged pesticides in Suisun Bay and at the confluence of the Sacramento and San Joaquin Rivers. The UC Davis (UCD) Irrigated Lands Monitoring Project did not measure metals, but measured legacy and currently discharged pesticides in samples collected from agricultural drainages and found concentrations similar to those measured in the Delta Survey (Lowe et al. 2007). Another study, the Proposition 13 PRISM Grant (PRISM), also found similar metal and organic concentrations when compared to those found in the Delta Survey (De Vlaming et al. 2006). For example, DDE and bifenthrin (a pyrethroid pesticide) were detected with low frequency and at relatively similar concentrations by all the studies used for comparison (Figure 7).

A few compounds were found at higher concentrations by other studies when compared to the concentrations found in the Delta Survey samples. For example, chlorpyrifos was found at higher concentrations by the UCD study when compared to the levels found in the Delta Survey. While average chlorpyrifos concentrations in the Delta Survey samples were 1 µg/kg, the average concentrations found in the UCD study averaged 37 µg/kg. However, it is important to note that the samples from the UCD study were collected near storm drainages.

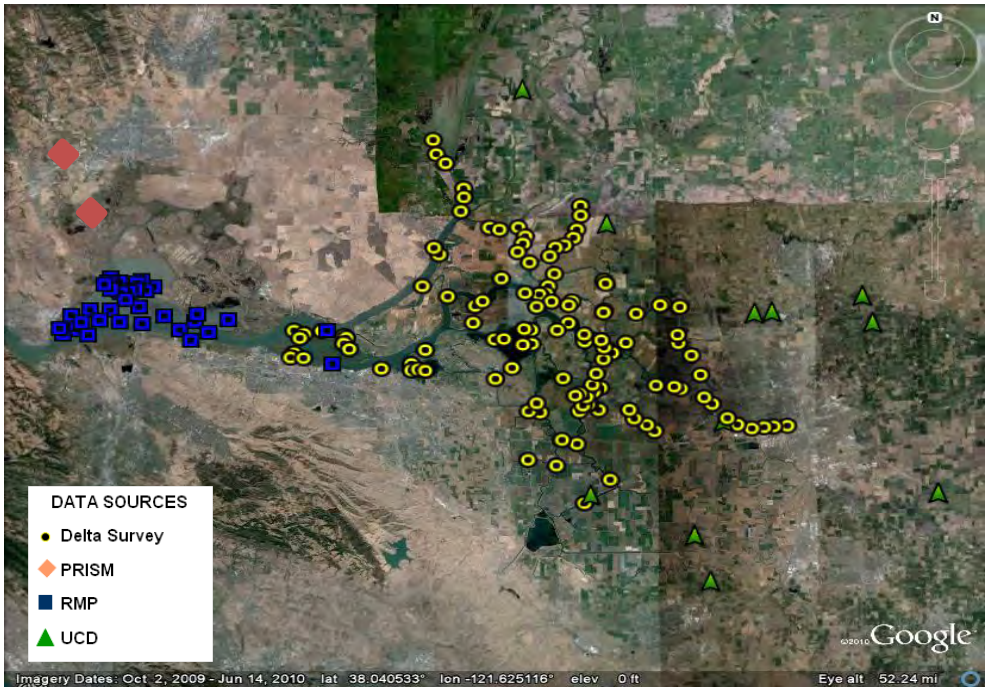

Figure 6. Sampling sites of studies previously conducted in the Delta.

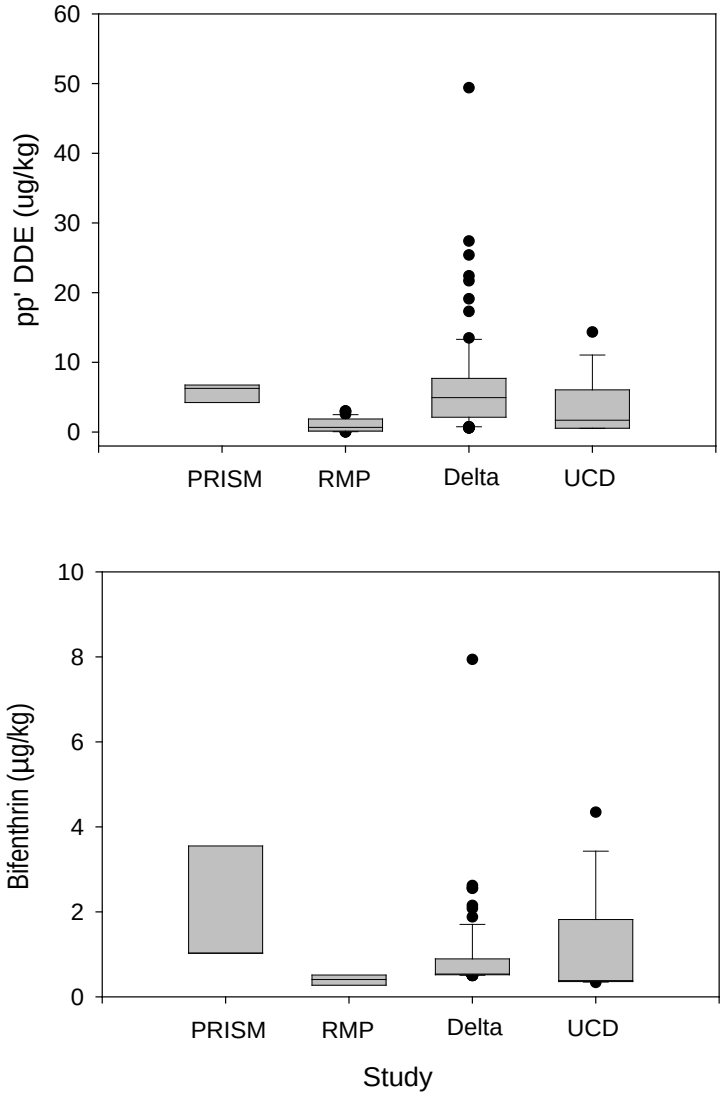

Figure 7. Comparison of sediment concentrations from the Delta Survey and previous studies conducted in the Delta. The box plots show the 10th, 25th, 50th (median), 75th, and 95th percentiles, where sufficient data were available. Boxes with fewer lines had similar concentrations in all the samples measured for that particular study making some percentile values similar.

Chemical concentrations in the Delta sediments were low when compared to samples collected throughout other California embayments. The concentrations in the Delta samples covered a narrower range when compared to those from other California embayments (Figure 8). For example, 26% of the California embayment samples had copper concentrations equal to or greater than 100 mg/kg, while only 2% of the samples from the Delta Survey had such concentrations. This pattern was also observed for the concentrations of organic compounds. For example, 50% of the samples from other California embayments had PAH levels equal or greater than 1000 µg/kg, while only 3% of the Delta samples had such concentrations.

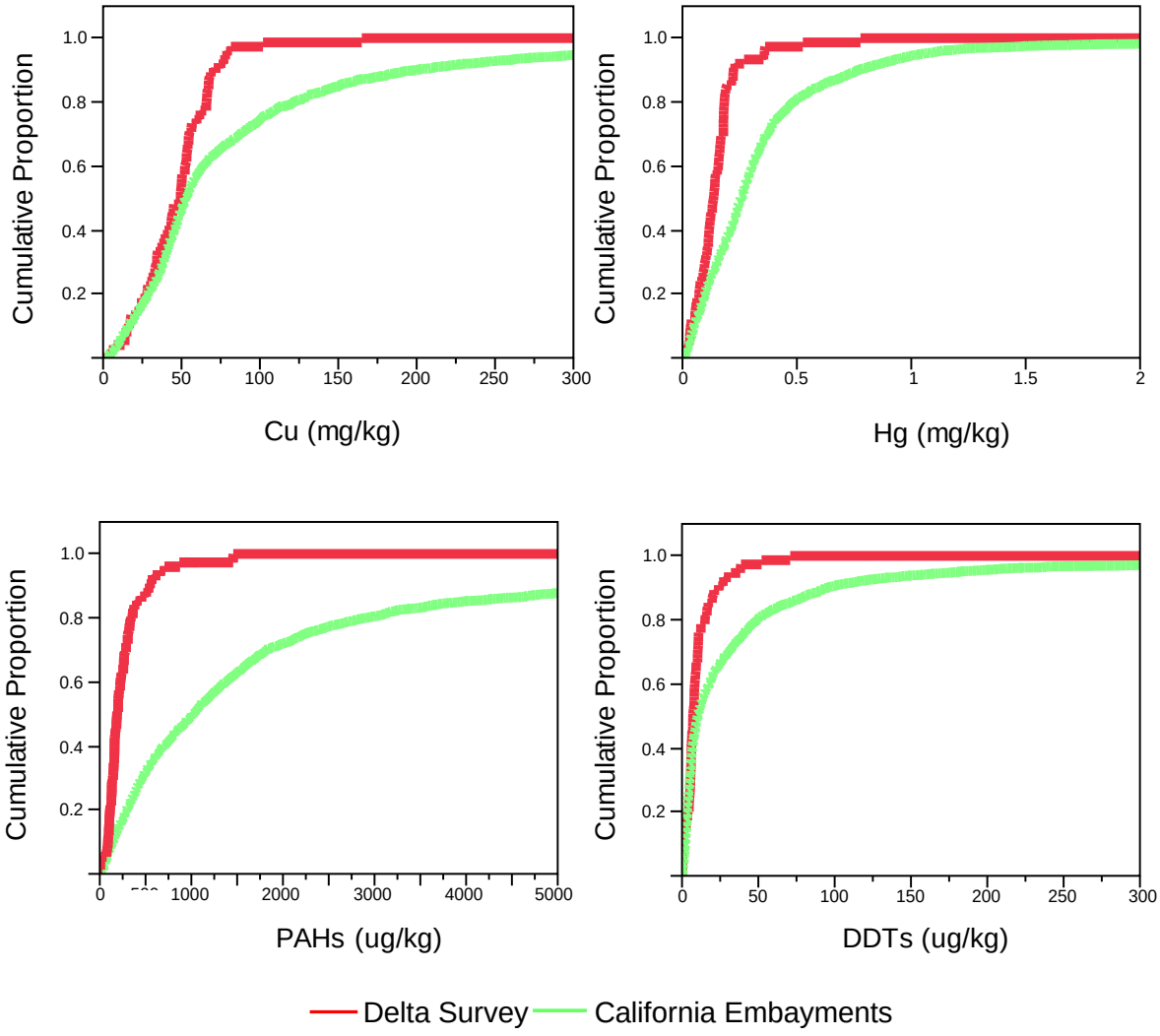

Figure 8. Cumulative distribution of Cu, Hg, PAHs, and DDTs concentrations for samples collected during the Delta Survey and in other California embayments.

Chemistry Indices

Chemical indices indicated a low potential for toxicity associated with Delta sediment contamination. The results from the metals index based on the difference between SEM and AVS (SEM-AVS) concentrations showed low potential for toxicity since most samples were < 0 (Figure 9). This indicates that the divalent metals in the sediments (Ag, Cu, Cd, Hg, Ni, Zn) were strongly bound to sulfides and were not bioavailable. Thus, there is a low potential for toxicity due to metals such as cadmium, copper, lead, nickel, and zinc. Toxic unit calculations for total pyrethroids, bifenthrin, and PAHs showed that the concentrations of these analytes had little acute toxic potential as most samples had TU < 1 (Figure 10). Only 1 station had TU > 1 for pyrethroids, indicating the potential to cause toxicity. This station was not toxic to either of the species tested. Bifenthrin was the most prevalent pyrethroid detected and accounted for most of the calculated Tus for most samples.

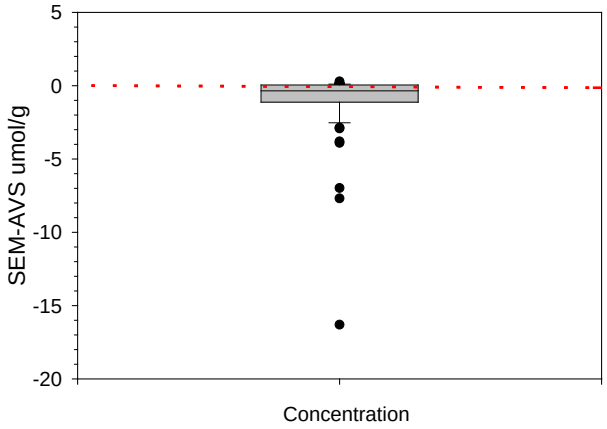

Figure 9. Trace metal SEM-AVS index results. The box plot shows the 10th, 25th, 50th (median), 75th, and 90th percentiles. Values above the red dashed line had a greater potential to be bioavailable.

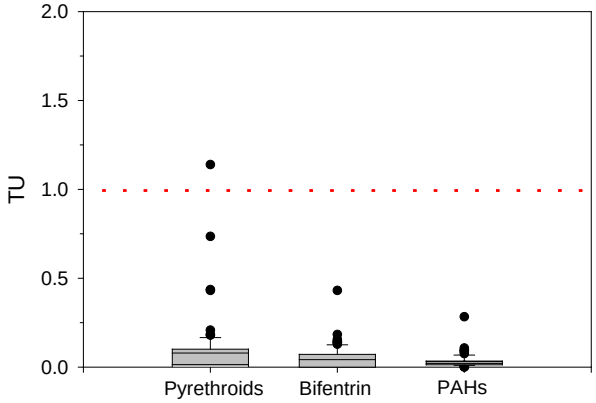

Figure 10. Toxic units for total pyrethroids, bifenthrin and PAH sums. The box plot shows the 10th, 25th, 50th (median), 75th, and 90th percentiles. Values above the red dashed line had a greater potential to cause toxicity. Results for total pyrethroids includes bifenthrin.

Data analysis using the CALRM also showed that most of the sediments collected in the Delta Survey had low toxicity potential. The majority of the stations sampled in the Delta Survey had chemical concentrations that placed them into the minimal and low exposure categories (Figure 11). A total of 15 stations were in the Minimal category; contamination at these stations may have been present, but exposure would be unlikely to result in biological effects. Forty-seven Delta samples were classified as presenting Low chemical exposure. Sediments in this category had elevated contaminant concentrations which could be associated with biological effects, but the severity of biological impacts was expected to be low. Only 12 stations were classified in the Moderate category, indicating a level of chemical exposure likely to result in biological effects. One station was classified in the High exposure category, indicating a greater likelihood of strong adverse biological effects. Sediment from this station was not toxic to either of the species tested.

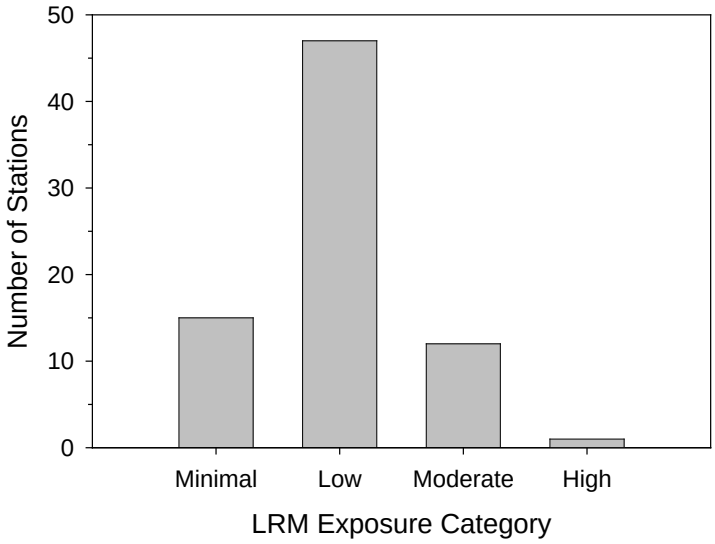

Figure 11. Number of stations associated with logistic regression model (CALRM) exposure categories.

Toxicity

Exposure to sediments from the Delta produced little mortality to amphipods and midges, but decreases in growth and biomass were more prevalent. Mortality was usually observed at different stations from those where sublethal effects were observed. Sublethal effects were observed in both sampling events. In 2007, only 2-3% of the stations had sediments that were lethal to one of the test species (Table 2). Sublethal effects were observed in 14% of the 2007 samples. In 2008, no mortality was observed in either toxicity test species, and no sublethal effects were observed in the amphipod tests. In contrast, *C. dilutus* had decreased growth or biomass when exposed to sediments from 28% of the stations sampled in 2008.

Table 2. Percent of stations with toxicity. For *H. Azteca*, N=100 in 2007 and N=44 in 2008. For *C. dilutus*, N=50 in 2007 and N=25 in 2008.

Species	2007		2008	
	Survival	Any Endpoint	Survival	Any Endpoint
Hyallela azteca	3	17	0	0
Chironomus dilutus	2	16	0	28
	Growth	Biomass	Growth	Biomass
Hyallela azteca	13	14	0	0
Chironomus dilutus	10	14	24	24

There was little agreement between the midge and the amphipod toxicity responses. Only 1% of the sediment samples produced a sublethal toxic response both species (Figure 12).

The magnitude of sublethal responses in midges was greater than that in amphipods. Approximately 60% of the sediment samples produced a greater than 20% decrease in midge biomass while only 14% of the samples caused a similar effect on amphipod biomass (Figure 13).

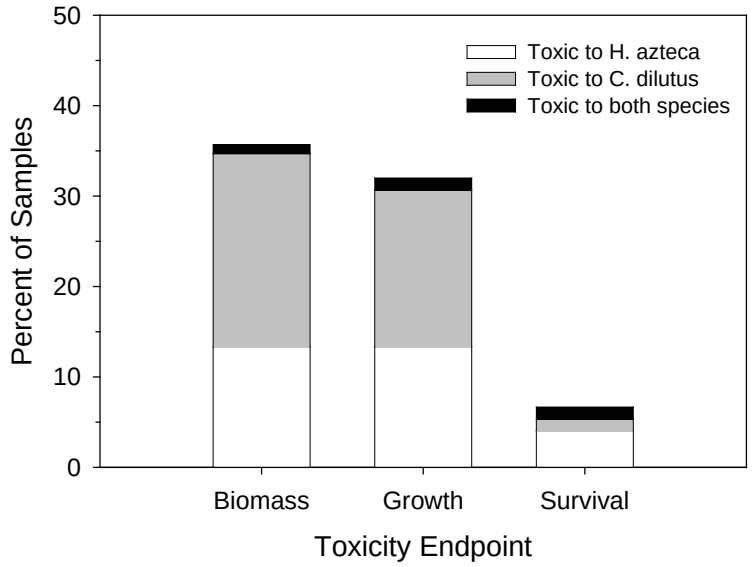

Figure 12. Percent of samples toxic to both or either test species. Data were combined for 2007 and 2008 (N=75 for each species).

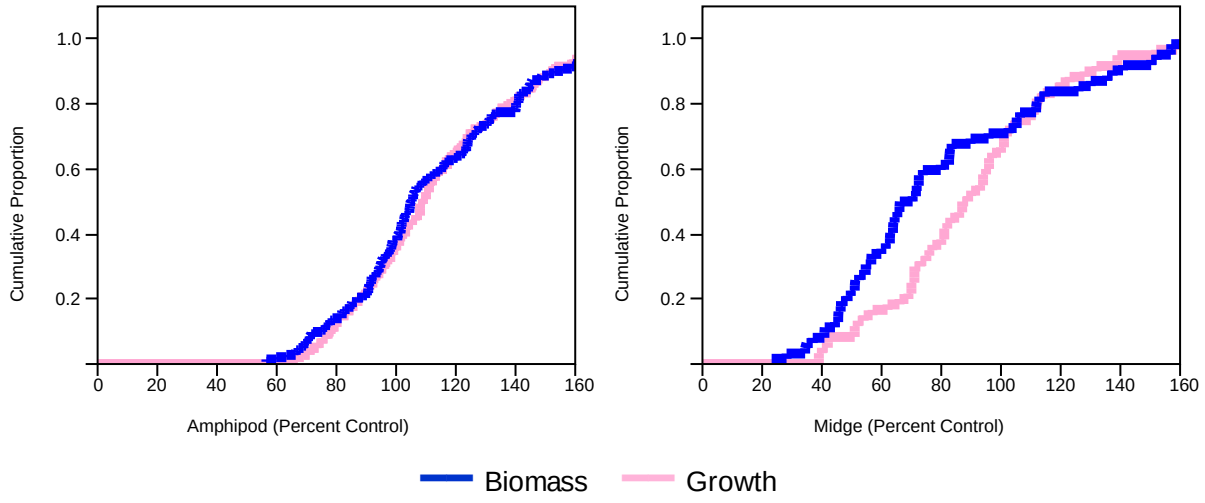

Figure 13. Magnitude of sublethal responses for amphipod and midge sublethal endpoints. Mean biomass and mean growth expressed as mg (N= 75).

No patterns in toxicity prevalence were found relative to specific areas of the Delta. Some toxicity was observed in sediments from stations located in slough areas (e.g., New York, Whiskey, Indian, Latham), as well as in channels (e.g., Stockton Channel; Figure 14). However, 67% of the study sites exhibited no toxicity to either test species. There was also little consistency in toxicity incidence between the two time periods. Of the 23 stations that were sampled during both years, only one station exhibited toxicity during both sample events.

The incidence and magnitude of Delta sediment toxicity was lower than the toxicity observed in other California coastal embayments. The amphipod and midge data from the Delta Survey were compared to survival results for the estuarine amphipod *Eohastorius estuarius* in other California embayments (Figure 15). No significant toxicity (defined as less than 20% mortality) was observed in 56% of the *E. estuarius* samples, while 94% and 92% of Delta samples were not toxic to *H. azteca* and *C. dilutus*, respectively. While 12% of the other California embayment samples had at least 50% mortality, none of the Delta samples produced a similar level of mortality.

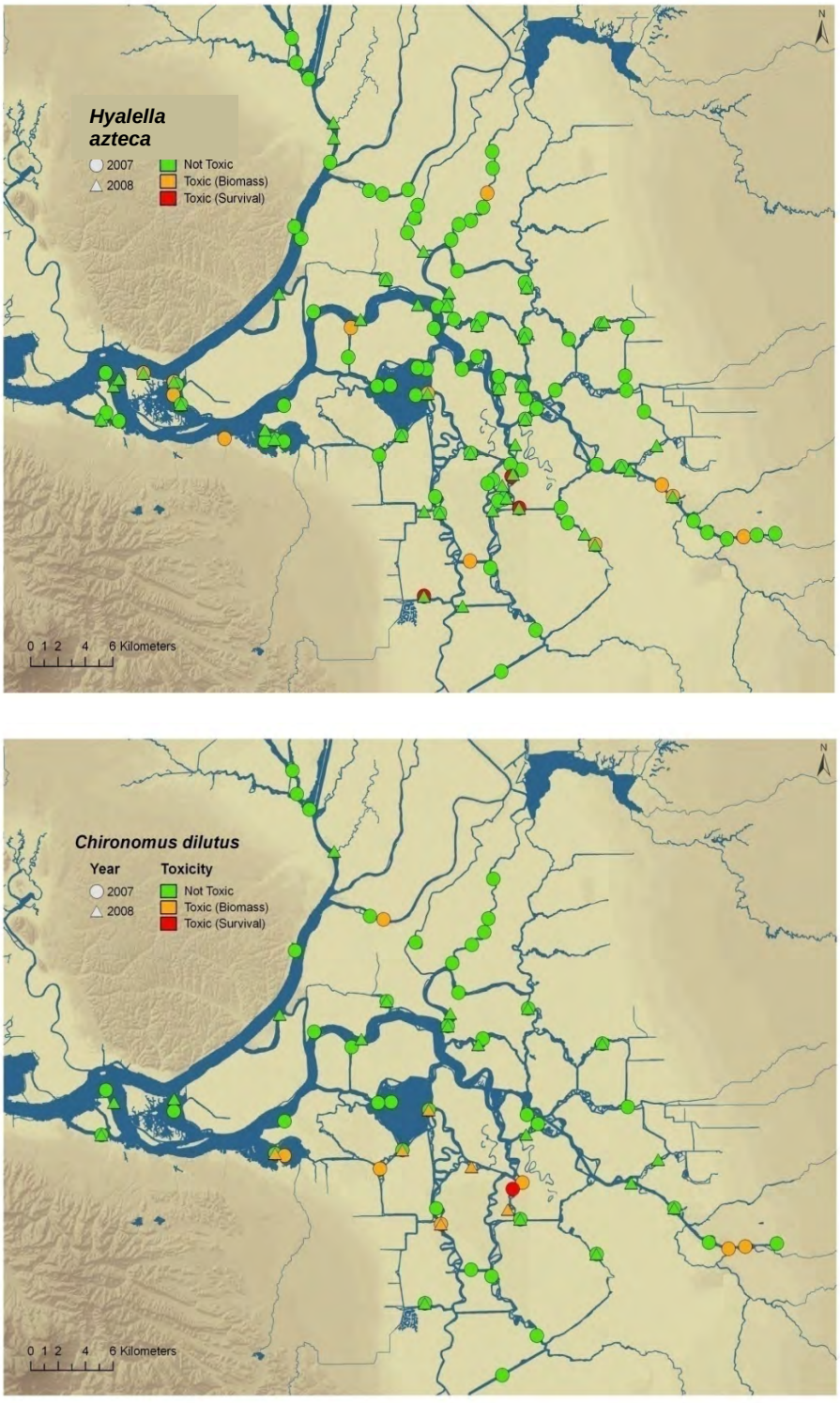

Figure 14. Location of toxicity results for Delta samples.

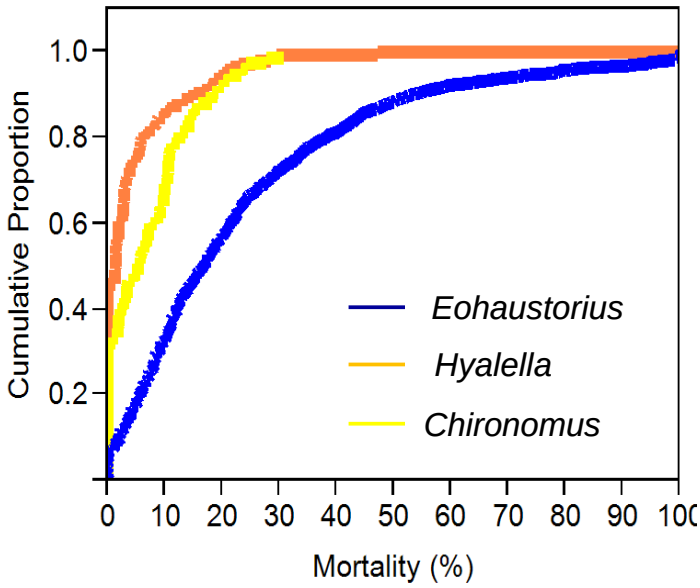

Figure 15. Comparison of mortality responses in test organisms used in the Delta Survey (*Hyalella* and *Chironomus*) and *Eohaustorius* mortality data from other California embayments (*E. estuarius* N= 1065; *H. azteca* N= 144; *C. dilutus* N= 75).

Benthic Community

The species collected during the Delta Survey were representative of a tidal freshwater assemblage and dominated by annelids, arthropods, and mollusks. The species most commonly found in the Delta sediment samples was the freshwater clam *Corbicula fluminea,* which occurred in 90% of the samples. The oligochaete worm *Limnodrilus hoffmeisteri* was present in 80% of the samples (Table 3). Approximately 17% of the taxa in the Delta samples were non-indigenous (Lee et al. 2003), including most of the dominant species such as *C. fluminea* and the amphipod *Gammarus daiberi*. The freshwater polychaete worm *Manayunkia speciosa* had the highest average abundance among the samples, with a maximum abundance of 1820 individuals in a sample collected in 2007. This species accounted for 17% of all organisms collected in the Delta Survey. The amphipod *G. daiberi* also had high average abundance with a maximum of 1200 individuals present in a sample that was collected in 2007. This amphipod species accounted for 15% of all organisms collected. Those two taxa along with the amphipod *Americorophium spinicorne* accounted for 46% of all organisms collected. All other single taxa accounted for less than 8% of the organisms. Brief profiles for the most abundant species are included in Appendix D.

Table 3. The most common (% occurrence) and abundant taxa, and their abundance range (Max and Min) in the Delta Survey samples (N=143).

Taxon Name	% Occurrence	Abundance		
		Mean	Min	Max
Corbicula fluminea	90	38	1	188
Limnodrilus hoffmeisteri	80	47	1	336
Gammarus daiberi	73	94	1	1200
Varichaetadrilus angustipenis	66	39	1	390
Manayunkia speciosa	60	107	1	1820
Americorophium spinicorne	55	83	1	1976
Bothrioneurum vejdovskyanum	54	7	1	139
Pisidium compressum	48	7	1	87
Prostoma graecense	48	3	1	56
Aulodrilus japonicus	47	7	1	185
Ilyodrilus frantzi	47	6	1	62
Americorophium stimpsoni	44	48	1	1236
Quistadrilus multisetosus	35	14	1	681
Hyalella azteca	25	25	1	1000
Cyprideis sp. A	11	11	1	930

A total of 126 taxa were collected in the Delta Survey samples, but the average number of taxa present in each sample was relatively low. Only an average of 17 taxa per sample was found, although two samples collected in 2008 had up to 39 different taxa. Despite these two samples having similar numbers of taxa they were dominated by different organisms; one by amphipods and the oligochaete *Varichaetodrilus angustipenis*, and the other by *C. fluminea* and *L. hoffmeisteri*. The lowest diversity occurred in a sample collected in 2007, where only five specimens of *C. fluminea* were collected. The average total abundance per sample was 557 organisms in 2007 and 743 in 2008 (Table 4).

Table 4. Mean (range) number of taxa and total abundance in samples from 2007 (N=99) and 2008 (N=44) sampling periods.

	Mean	
Parameter	**2007**	**2008**
Number of Taxa	16 (1 - 37)	17 (3 - 39)
Total Abundance	557 (5 - 2655)	743 (10 - 3132)

A temporal shift in dominant taxa was observed between sampling events. Annelids accounted for 98% of the total abundance in 2007, but arthropods accounted for 99% in 2008. Although the maximum number of taxa and total abundances occurred in 2008, there were no differences in mean total abundance or mean number of taxa between the 2007 and the 2008 samples.

Spatial differences in species composition were observed that reflected three general Delta sub-habitat types. These sub-habitats were: main and open channels dominated by amphipods (*Americorophium spp*., *G. daiberi*), smaller cross-channels and back bays dominated by *M. speciosa* and *G. daiberi,* and the more distal freshwater channels dominated by oligochaetes. Despite differences in dominance, the fauna within these sub-habitats had 50 to 60% similarity. Some organisms collected in the Delta Survey samples were characteristic of environments with submerged aquatic vegetation (e.g., tubificids).

The species composition was in general consistent with previous studies conducted in the Delta (Thompson et al. 2011). Only one species, the polychaete *Laonome* spp., was not present in the Delta Survey list of dominant taxa but was found in previous studies. When comparing the taxa numbers to those reported by previous Delta studies, the Delta Survey collected fewer taxa (126) than the approximately 250 estimated from prior studies (Fields and Messer 1999). The benthic community characteristics reported in previous studies are summarized in Tables 5 and 6. The mean total abundance and number of taxa reported by Fields and Messer (1999) were also higher than those observed in this study.

Table 5. Dominant taxa of the tidal freshwater assemblage (N=154) as described in Thompson et al. 2011.

Species	% Occurrence	Mean Abundance
Corbicula fluminea	93	34
Limnodrilus hoffmeisteri	72	39
Gammarus daiberi	71	61
Varichaetodrilus angustipenis	71	35
Bothreonerium vejdovskyanum	46	6
Manayunkia speciosa	41	71
Americorophium stimpsoni	39	18
Americorophium spincorne	38	75
Laonome spp	30	3
Quistadrilus multisetosus	25	7

Table 6. Mean, minimum, and maximum number of taxa and total abundance per sample in the tidal freshwater assemblage as described in Thompson et al. 2011.

Category	Mean	Min	Max
Number of Taxa	9	1	29
Total Abundance	496	3	2617

The dominant taxa in the Delta were different from those in the adjacent oligohaline assemblage in Suisun Bay (Table 7). The polychaete *Marenzellaria viridis* was only found in the oligohaline habitat. The mean number of taxa per sample in the oligohaline samples was only five, considerably lower than in the tidal freshwater portion of the Delta (Table 8). Dominant taxa common to both assemblages included *Laonome* spp., *C. fluminea*, and *A. spinicorne*. Differences between the Delta tidal freshwater community and adjacent oligohaline assemblage may be attributed to differences in salinity which averaged 10.9 psu for the oligohaline assemblage (Thompson et al. 2011), indicating that the oligohaline fauna are more tolerant to saline conditions. It is possible that seasonal changes in freshwater inflows affecting salinity in oligohaline regions allowed only a small number of taxa to exist in this habitat (Jassby et al. 1995).

Table 7. Dominant taxa of the oligohaline assemblage in Suisun Bay as described in Thompson et al. 2011 (N=79).

Taxon	% Occurrence	Mean Abundance
Corbula amurensis	84	184
Marenzelleria viridis	75	15
Tubificidae	57	20
Nippoleucon hinumensis	47	5
Corophium aliense	22	35
Grandidierella japonicus	19	4
Laonome spp	13	6
Corbicula fluminea	13	4
Mya arenaria	10	5
Americorophium spincorne	6	1

Table 8. Mean, minimum and maximum number of taxa and total abundance per sample in the oligohaline assemblage.

Category	Mean	Min	Max
Number of Taxa	5	1	13
Total Abundance	85	1	1466

Abundances of individual taxa may be changing seasonally in the Delta. While the Delta Survey was spatially intensive, it only included samples from one wet and one dry period. Other studies included a time series sampling effort that more accurately reflected seasonal and annual variation in the benthos of the Delta. Previous studies found seasonal effects that are thought to depend on hydrologic and salinity changes (Peterson and Vayssiere 2010), as well as in physical events such as sediment scour (Thompson et al. 2000; Thompson et al. 2011). Together, the Delta Survey and previous studies data showed that the benthic organisms collected in the Delta can be consistently classified as components of a tidal freshwater assemblage despite some seasonal shifts which may be strongly influenced by changes in salinity and other conditions.

Summary and Recommendations

The results of this survey indicate that sediment quality in the Delta is generally good. A lack of sediment toxicity in most samples, together with multiple chemical indices that show a low potential for biological effects from sediment contamination, supported this finding. Although some chemicals were found at higher concentrations (e.g., PAHs) there was no relationship between these samples and sediment toxicity. Perhaps other contaminants or stressors not measured were responsible for the toxicity observed. The cause of the sublethal effects found in some of the samples cannot be attributed to specific compounds using the results of this study. Additional studies examining a wider range of compounds would be needed to further examine sublethal effects.

A complete evaluation of Delta sediment quality could not be conducted in this study due to a lack of reliable indices to evaluate benthic community condition. Information on benthic community health is an essential component of the sediment quality triad approach used in California's sediment quality objectives program (SWRCB 2008) and national sediment quality monitoring programs (USEPA 2015). Subsequent to this survey, much progress has been made in developing and validating benthic indices for use in low salinity habitats such as the Delta. Recently, Pelletier et al. (2018) have validated the performance of a newly re-calibrated benthic index (M-AMBI) that has been modified for application along the environmental gradients of estuaries in US coastal waters – including San Francisco Bay. Recent work by Gillett et al. (2019) demonstrated the applicability of the M-AMBI to the tidal freshwater Delta, although additional validation is needed for application in Delta monitoring and regulatory programs.

This study has produced some of the most comprehensive sediment quality information currently available for the Sacramento-San Joaquin River Delta. In addition to benthic index validation, further studies are needed to understand how the presence of these chemicals in the sediment may affect other organisms in the Delta ecosystem.

The results of this study can inform future monitoring of pesticides and toxicity in the Delta, including efforts of the Delta Regional Monitoring Program, Department of Pesticide Regulation Environmental Monitoring Program, and the Interagency Ecological Program. The study's outcomes can also inform future research funding opportunities. As noted in the Introduction, the monitoring of pesticides and other contaminants in sediments should be part of a holistic approach to studying and monitoring the status of the Delta ecosystem. The potential effects of multiple stressors (e.g., water chemistry, flows, temperature, turbidity, invasive species) and their interactions should be considered in the assessment of the health of the food web and target fish species such as those of concern in the Pelagic Organism Decline.

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APPENDIX A

Station Information

Table A-1. Station locations and locality descriptions S= amphipod toxicity and benthic data available. T= amphipod and midge toxicity, chemistry and benthic data available.

Station	Year	Sample Type	Latitude	Longitude	Locality
CS01	2007	T	38.2357	-121.6786	Cache Slough
CS02	2007	T	38.2456	-121.6890	Cache Slough
CS03	2007	T	38.2606	-121.6924	Cache Slough
D28A-L	2007-08	T	37.9701	-121.5742	Old River
D4-L	2007-08	S	38.0581	-121.8194	Sacramento River
EMP-0001	2007-08	T	37.8733	-121.5253	Victoria Canal
EMP-0002	2007-08	S	38.0760	-121.5017	Little Potato Slough
EMP-0003	2008	T	38.1052	-121.7057	Sacramento River
EMP-0005	2007-08	T	37.9493	-121.4455	Whiskey Slough
EMP-0006	2007-08	T	37.9724	-121.5082	Latham Slough
EMP-0007	2007-08	T	38.1066	-121.4990	Little Potato Slough
EMP-0010	2007-08	T	38.0840	-121.5409	Potato Slough
EMP-0012	2007-08	T	38.0525	-121.7944	Sherman Lake
EMP-0018	2007-08	S	38.0465	-121.5046	San Joaquin River
EMP-0019	2007-08	T	38.1127	-121.6165	Sevenmile Slough
EMP-0021	2007-08	S	37.9965	-121.4227	San Joaquin River
EMP-0022	2007	T	37.9958	-121.5061	Latham Slough
EMP-0023	2007-08	T	38.0962	-121.5662	Mokelumne River
EMP-0024	2007-08	T	38.0301	-121.8551	New York Slough
EMP-0025	2008	T	38.0888	-121.6380	San Joaquin River
EMP-0026	2007-08	T	38.0430	-121.5829	Old River
EMP-0030	2007-08	T	38.0062	-121.5480	Connection Slough
EMP-0034	2007-08	S	38.0453	-121.5234	San Joaquin River
EMP-0035	2008	S	38.1994	-121.6581	Cache Slough
EMP-0037	2007-08	T	38.0833	-121.4378	White Slough
EMP-0038	2007-08	T	38.0263	-121.5023	Columbia Cut
EMP-0039	2008	S	38.0972	-121.5900	San Joaquin River
EMP-0044	2008	T	38.0506	-121.8444	San Joaquin River
EMP-0045	2007-08	T	38.0166	-121.7112	Big Brake
EMP-0046	2007-08	T	38.0177	-121.6054	Sand Mound Slough
EMP-0049	2007-08	T	37.9197	-121.5884	Indian Slough
EMP-0053	2007	S	38.0297	-121.4030	Fourteenmile Slough
EMP-0054	2007	S	38.0879	-121.5602	Potato Slough
EMP-0065	2007	T	37.8981	-121.4961	Middle River
EMP-0067	2007	S	38.1386	-121.6867	Sacramento River

Table A-1. Continued…

Station	Year	Sample Type	Latitude	Longitude	Locality
EMP-0069	2007	T	37.9555	-121.3521	San Joaquin River
EMP-0070	2007	S	37.9782	-121.5207	Mildred Island
EMP-0071	2007	S	38.1094	-121.5007	Little Potato Slough
EMP-0073	2007	T	38.0484	-121.6142	Franks Tract
EMP-0074	2007	T	38.0879	-121.5372	Potato Slough
EMP-0076	2007	S	38.0505	-121.7919	Sherman Lake
EMP-0078	2007	T	37.9801	-121.5780	Old River
EMP-0082	2007	T	38.0389	-121.5014	San Joaquin River
EMP-0085	2007	S	37.9980	-121.4434	San Joaquin River
EMP-0086	2007	S	37.9898	-121.5296	Middle River
EMP-0087	2007	T	38.1174	-121.5567	Mokelumne River (South Fork)
EMP-0088	2007	S	38.0292	-121.8403	New York Slough
EMP-0089	2007	T	38.0838	-121.6463	Fishermans Cut
EMP-0093	2007	T	38.0371	-121.7030	San Joaquin River
EMP-0098	2007	S	38.0437	-121.4768	Disappointment Slough
EMP-0101	2007	S	38.0812	-121.4156	Bishop Cut
EMP-0102	2007	S	37.9992	-121.5150	Middle River
EMP-0103	2007	S	38.0956	-121.5739	San Joaquin River
EMP-0105	2007	T	38.0061	-121.6243	Sand Mound Slough
EMP-0106	2007	S	38.0422	-121.5931	Franks Tract
EMP-0109	2007	S	38.0157	-121.7189	Big Brake
EMP-0113	2007	T	37.9407	-121.5498	Bacon Canal
EMP-0114	2007	S	37.9723	-121.4737	Turner Cut
EMP-0115	2007	S	38.1846	-121.6617	Cache Slough
EMP-0116	2007	T	38.0585	-121.8510	San Joaquin River
EMP-0118	2007	S	38.0650	-121.5415	San Joaquin River
EMP-0120	2007	T	38.0445	-121.7948	Sherman Lake
EMP-0122	2007	S	38.0825	-121.5771	San Joaquin River
EMP-0129	2007	T	37.9363	-121.5330	Middle River
EMP-0130	2007	S	38.0746	-121.4649	White Slough
EMP-0131	2007	T	38.0940	-121.6773	San Joaquin River
EMP-0133	2007	S	37.9627	-121.3634	San Joaquin River
EMP-0134	2007	S	37.9771	-121.5259	Mildred Island
EMP-0135	2007	S	38.1410	-121.5981	Georgiana Slough
EMP-0137	2007	T	38.0480	-121.6250	Franks Tract
EMP-0138	2007	S	38.0579	-121.5836	Old River
EMP-0145	2007	S	37.9628	-121.4683	Whiskey Slough
EMP-0146	2007	S	38.0526	-121.5237	San Joaquin River
EMP-0149	2007	S	37.9849	-121.3892	San Joaquin River

Table A-1. Continued…

Station	Year	Sample Type	Latitude	Longitude	Locality
EMP-0150	2007	T	37.9917	-121.5142	Mildred Island
EMP-0151	2007	T	38.1477	-121.5450	Mokelumne River (North Fork)
EMP-0153	2007	S	38.0659	-121.6488	Fishermans Cut
EMP-0154	2007	S	38.0589	-121.5913	Franks Tract
EMP-0157	2007	T	38.0154	-121.7033	Big Brake
EMP-0158	2007	S	37.9877	-121.5344	Middle River
EMP-0162	2007	T	38.0329	-121.4925	San Joaquin River
EMP-0165	2007	T	38.0428	-121.4176	Disappointment Slough
EMP-0170	2007	S	38.0575	-121.5543	San Joaquin River
EMP-0174	2007	T	38.1458	-121.6923	Sacramento River
EMP-0198	2008	S	37.9713	-121.5302	Middle River
EMP-0199	2008	S	38.1296	-121.5847	Georgiana Slough
EMP-0211	2008	T	38.2087	-121.6583	Cache Slough
EMP-0213	2008	T	38.0089	-121.3929	Fourteen mile Slough
EMP-0214	2008	S	37.9863	-121.5220	Mildred Island
EMP-0221	2008	S	38.0225	-121.7188	Big Brake
EMP-0225	2008	S	37.9135	-121.5565	Woodward Canal
EMP-0230	2008	S	38.0111	-121.5106	Middle River
EMP-0261	2008	S	37.9560	-121.4541	Whiskey Slough
EMP-0262	2008	T	37.9787	-121.5184	Mildred Island
EMP-0270	2008	S	37.9714	-121.5873	Rock Slough
EMP-0277	2008	T	37.9942	-121.4155	San Joaquin River
EMP-0278	2008	S	37.9930	-121.5129	Mildred Island
EMP-0279	2008	T	38.1042	-121.5638	Mokelumne River
EMP-0293	2008	S	38.0849	-121.4349	White Slough
EMP-0300	2008	S	38.0548	-121.8397	San Joaquin River
EMP-0677	2007	S	38.0517	-121.4185	Bishop Cut
EMP-0692	2007	S	38.0343	-121.8509	Middle Slough
EMP-0696	2008	S	38.0386	-121.7887	Sherman Lake
EMP-0701	2007	S	38.0778	-121.5008	Little Potato Slough
GS02	2007	T	38.1499	-121.5919	Georgiana Slough
GS03	2007	S	38.1575	-121.5891	Georgiana Slough
MR01	2007	T	38.1363	-121.5617	Mokelumne River (North Fork)
MR02	2007	S	38.1454	-121.5551	Mokelumne River (North Fork)
MR04	2007	T	38.1557	-121.5346	Mokelumne River (North Fork)
MR05	2007	S	38.1643	-121.5309	Mokelumne River (North Fork)
MR06	2007	S	38.1794	-121.5262	Mokelumne River (North Fork)
MR07	2007	T	38.1895	-121.5264	Mokelumne River (North Fork)

Table A-1. Continued…

Station	Year	Sample Type	Latitude	Longitude	Locality
NB-0001	2007	S	38.0176	-121.7526	New Bridge Marina
P8-R	2007-08	T	37.9778	-121.3802	San Joaquin River
SAC01	2007	S	38.1671	-121.5970	Sacramento River
SAC02	2007	T	38.1648	-121.6182	Sacramento River
SAC03	2007	T	38.1670	-121.6295	Sacramento River
SJR01	2007	T	37.9513	-121.3358	San Joaquin River (Stockton Channel)
STC01	2007	T	37.9526	-121.3220	San Joaquin River (Stockton Channel)
STC02	2007	S	37.9533	-121.3111	San Joaquin River (Stockton Channel)
STC03	2007	T	37.9539	-121.2957	San Joaquin River (Stockton Channel)

APPENDIX B.

Summary of Chemical Methods

Percent solids

Percent solids were determined using USEPA Method 160.3. A solid sample was homogenized, and an aliquot was measured into a pre-weighed vessel, dried in an oven overnight, weighed again and the percent of dried solid material was calculated.

Grain Size

Grain size samples were analyzed according to Plumb, 1981. Sediment samples were wet-sieved through a No. 230 (0.0625 mm) U.S. Standard Sieve. The fine fraction (silt and clay) was collected in a 1-liter graduated cylinder. Sediment retained on the No. 230 sieve was washed with distilled water into a pre-labeled and pre-weighed beaker and oven dried at for 24 hours at 105°C. After drying, the soil was passed through a No. 10 U.S. Standard Sieve to determine the percent gravel and a No. 230 sieve to determine the percent sand. Sediment passing the No. 230 sieve was added to the fine fraction in the graduated cylinder. The fine fraction was stirred and aliquoted using a pipette for determination of the percent silt (< 0.0625 mm to 0.0039 mm) and percent clay (< 0.0039 mm). Sample results were reported in percent gravel, sand, silt, and clay on a dry-weight basis.

Total Organic Carbon (TOC)

TOC analyses followed procedures described in USEPA 9060A. Sample preparation consisted of drying, homogenization, and acidification with a dilute (≤5%) HCl solution to remove inorganic carbon, rinsing to neutrality, and drying in an oven at 70°C until analyzed. Samples were combusted in a high-temperature (900°C) furnace in a stream of oxygen to form CO2. Interfering gases, such as halogens, sulfur, nitrogen oxides, and water were removed by chemical scrubbers prior to CO2 measurement. Sample results were reported in percent TOC on a dry-weight basis.

Total Nitrogen

Total Nitrogen samples were analyzed according to USEPA 351.3. Samples were heated in the presence of concentrated sulfuric acid, K2SO4, and HgSO4, and evaporated until sulfur trioxide (SO_3) fumes were obtained and the solution became colorless or pale yellow. The residue was cooled, diluted, and was treated and made alkaline with a hydroxide-thiosulfate solution. The resulting solution was distilled, and ammonia was determined after distillation by Nesslerization, titration, or potentiometry.

Trace Elements

Homogenized sediments were digested in nitric/hydrochloric acids to obtain “near-total” (or total recoverable) concentrations of trace metals using USEPA Standard Methods (USEPA 1638 Modified) that does not decompose the silicate matrix of the sediment. Because of this, any element that is tightly bound as a naturally occurring silicate may not be fully recovered. Extracts were analyzed for aluminum, arsenic, cadmium, copper, iron, manganese, nickel, lead, silver, and zinc by inductively coupled plasma mass spectrometry (ICP-MS). Sample digests for arsenic were analyzed by ICP-MS in DRC mode to obtain lower detection limits, which should enable quantifiable results for arsenic in all sediments.

Selenium samples were digested with a heated nitric: hydrochloric acid mix by USEPA Method 200.2. The samples were then diluted with HCl and deionized water. Prior to analysis, samples were heated again with HCl and $K_2S_2O_8$, and then diluted to volume with HCl and water to 6M HCl. While still warm, sulfinamide were added along with NH_2-OH-HCl to reduce the samples. Samples were then brought up to volume with 4M HCl. Analysis was performed using hydride generation with NaBH4 addition, cryogenic trap pre-collection, H2/Air flame quartz furnace decomposition, and Atomic Absorption detection (HGAAS; BRL method BR-0020 (similar to USEPA 1632)).

Sediment samples for total mercury analysis were stored frozen until analysis. Samples were digested using acid (60:40 solution of HNO_3:H_2SO_4) and oxidized with bromine monochloride (BrCl). Analysis of sediment digests were accomplished by the USEPA 1631 Appendix method using tin-chloride reduction, gold-amalgamation, and detection by cold vapor atomic fluorescence spectrometry (CVAFS).

Trace Organics

Sediment Extraction (all organic analytes)

Samples were homogenized and extracted using pressurized fluid extraction, PFE (also termed accelerated solvent extraction (ASE) using USEPA Method 3545, and gel-permeation cleanup (GPC) using USEPA Method 3640A. This extraction and initial cleanup procedure were used for all trace organic analytes of interest in the sediment samples. The PCBs, organochlorine pesticides (OC-pesticides), and pyrethroid analytes had an additional Florisil cleanup procedure (USEPA Method 3620B). The PAHs had an additional silica gel/alumina cleanup. PAHs were additionally separated using silica gel (USEPA Method 3630C)/alumina (USEPA Method 3610B) column chromatography and then analyzed using USEPA Method 8270CM (GC-MS (in SIM mode) using an Agilent 6890/5973 MSD instrument). PCBs were analyzed by GC-MSMS (Varian Model 1200 Triple Quadrupole Mass Spectrometer). An array of surrogate standards was added to the various extracts prior to analyses.

Selected OC-Pesticides were analyzed by GC-MSMS (Varian Model 1200 Triple Quadrupole Mass Spectrometer) and the remainder of the OC-pesticides was analyzed by method 8081 BM GC-ECD (Agilent 6890 dual micro-ECD equipped with 60 m DB5 and DB17 columns). Pyrethroid pesticides were analyzed by method 8081 BM GC-ECD (Agilent 6890 dual miro-ECD equipped with 60 m DB5 and DB17 columns) with confirmation analysis by GC-MSMS or

LC-MSMS. The PBO analyte were quantified by LC-MS. Carbamate pesticides were analyzed by LC-MSMS (USEPA method 632M).

Table B-1. Sediment methods and reporting units.

Water/Sediment Quality Parameters	Method	Reporting Units
% clay (< 4 µm)	Plumb, 1981	% dry weight
% silt (4 µm–62 µm)		% dry weight
% sand (2 mm > 62 µm)		% dry weight
% gravel (> 2 mm)		% dry weight
% solids (reported by both chemistry labs)	USEPA 160.3	% dry weight
Depth (station depth)	Shipboard measure	M
Conductivity, temperature profile	CTD cast	various
Salinity at bottom	CTD cast	psu
pH (porewater, interstitial sediment)	pH meter shipboard	pH
Total Organic Carbon (TOC)	USEPA 9060A	%
Total Nitrogen (TN)	USEPA 351.2	%

Table B-2. Trace elements methods and reporting limits.

Trace elements:	Method	MDL (mg/kg dry weight)
Aluminum (Al)	USEPA 1638M (ICP-MS)*	28
Cadmium (Cd)		0.02
Copper (Cu)		0.28
Iron (Fe)		10.8
Lead (Pb)		0.2
Manganese (Mn)		0.12
Nickel (Ni)		0.5
Silver (Ag)		0.05
Zinc (Zn)		0.3
Arsenic (As)	USEPA 1638M (ICP-DRC-MS)	0.2
Selenium (Se)	BR-0020 (HGAA)**	0.007
Mercury (Hg)	USEPA 1631 Appendix (CVAFS)	0.00005

* = Near total extraction

** = Method is a modified USEPA method 1632

Table B-3. Trace organics methods and reporting limits.

Reporting units – µg/kg dry weight.

PAHS USEPA 8270M (GC-MS (SIM)) (Target RL 5 µg/kg)	OC-PESTICIDES USEPA 8081AM (GC-ECD/GC-MSMS) (Target RL 0.6-10 µg/kg)	OTHER SYNTHETIC COMPOUNDS
1-Methylnaphthalene	**Cyclopentadienes**	**PCB congeners (IUPAC numbers)**
1-Methylphenanthrene	Aldrin	**USEPA 8082M (GC-MSMS)**
2,3,5-Trimethylnaphthalene	Dieldrin	**(Target RL 1 µg/kg)**
2,6-Dimethylnaphthalene	Endrin	8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 87, 95, 97, 99, 101, 105, 110, 118, 128, 138, 141, 149, 151, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, 203, 206, 209
2-Methylnaphthalene	**Chlordanes**	
Acenaphthene	alpha-Chlordane	**Pyrethroids**
Acenaphthylene	cis-Nonachlor	**USEPA 3645, 3640A, 3620B**
Anthracene	gamma-Chlordane	**(GC-MSMS/LC-MSMS/GC-ECD)**
Benz(a)anthracene	Heptachlor	**(Target RL 1-10 µg/kg)**
Benzo(a)pyrene	Heptachlor Epoxide	Bifenthrin
Benzo(b)fluoranthene	Methoxychlor	Cyfluthrin
Benzo(e)pyrene	Oxychlordane	Beta-Cyfluthrin
Benzo(ghi)perylene	trans-Nonachlor	Cypermethrin
Benzo(k)fluoranthene		Delta/Tralomethrin (coelutes)
Biphenyl	**DDTs**	Esfenvalerate/Fenvalerate
Chrysene	o,p'-DDD	Fenpropathrin
Dibenz(a,h)anthracene	o,p'-DDE	L-Cyhalothrin
Dibenzothiophene	o,p'-DDT	Permethrin
Fluoranthene	p,p'-DDD	Permethrin, cis
Fluorene	p,p'-DDE	Permethrin, trans
Indeno(1,2,3-cd)pyrene	p,p'-DDT	
Naphthalene	p,p'-DDMU	
Perylene		**Carbamates**
Phenanthrene		**USEPA 3645, 3640A (LC-MSMS)**
Pyrene	**Hexachlorocyclohexane (HCH)**	**(Target RL 20 µg/kg)**
	alpha-HCH	Aldicarb
Alkylated PAHs	beta-HCH	Captan
C1-Chrysenes	gamma-HCH	Carbaryl
C2-Chrysenes		Carbofuran
C3-Chrysenes		Methiocarb
C1-Dibenzothiophenes		Methomyl
C2-Dibenzothiophenes		
C3-Dibenzothiophenes		
C1-Fluoranthene/Pyrenes		
C1-Fluorenes		

Table B-3. Continued…

Reporting units – µg/kg dry weight.		
PAHS **USEPA 8270M (GC-MS (SIM))** **(Target RL 5 µg/kg)**	**OC-PESTICIDES** **USEPA 8081AM (GC-ECD/GC-MSMS)** **(Target RL 0.6-10 µg/kg)**	**OTHER SYNTHETIC COMPOUNDS** **USEPA 3645, 3640A, 3620B (GC-MSMS/LC-MSMS)** **(Target RL 20 µg/kg)**
C2-Fluorenes	Dacthal	DCPA
C3-Fluorenes	Endosulfan (I, II, & sulfate)	Fipronil
C1-Naphthalenes	Hexachlorobenzene	Fipronil desulfinyl
C2-Naphthalenes	Mirex	Fipronil sulfide
C3-Naphthalenes	Oxadiazon	Fipronil sulfone
C4-Naphthalenes	Tedion	Metolachlor
C1-Phenanthrene/Anthracenes		Trifluralin
C2-Phenanthrene/Anthracenes		Piperonyl butoxide (PBO)
C3-Phenanthrene/Anthracenes	**Urea Pesticides**	
C4-Phenanthrene/Anthracenes	Diuron	
	Linuron	
	Organophosphate Pesticides	
	Chlorpyrifos	
	Parathion Ethyl	
	Parathion Methyl	

APPENDIX C.

Chemistry Data Summary

Table C-1. Summary of sediment concentration results. N= 50 sites for 2007 and 25 sites for 2008. Calculation of means incorporated ½ MDL value for all non-detects. When non-detects occurred for a given constituent the minimum MDL value was given in the "minimum" column. When a given constituent was not detected within any batch the maximum MDL value was given in the "maximum" column.

	2007				2008			
Analyte	Mean	Minimum	Maximum	% Detects	Mean	Minimum	Maximum	% Detects
Aldicarb (µg/kg)	0.85	< 1	3.84	32	0.25	< 0.5	<0.5	0
Aldrin (µg/kg)	0.44	<0.50	1	2	0.97	< 1.07	<3.49	0
Arsenic (mg/kg)	8.93	1.95	28.2	100	8.24	2.23	16.2	100
Bifenthrin (µg/kg)	0.44	< 0.5	2.62	22	1.4	< 0.5	7.94	88
Cadmium (mg/kg)	0.37	0.02	1.56	100	0.3	0.054	0.501	100
Captan (µg/kg)	0.5	< 1	<1	0	0.25	< 0.5	<0.5	0
Carbaryl (µg/kg)	0.17	< 0.1	1.32	66	0.18	< 0.1	1.6	16
Carbofuran (µg/kg)	0.03	< 0.05	0.17	8	0.12	< 0.05	0.701	24
Chlordane (µg/kg)	0.49	< 0.57	<1.75	0	0.92	<0.89	2.68	8
Chlorpyrifos (µg/kg)	0.54	< 0.25	5.13	50	0.73	< 0.529	3.02	16
Clay <0.0039 mm (%)	25.63	0.18	51.45	100	16.7	0.45	39.5	100
Copper (mg/kg)	51.31	3.73	165	100	38.84	6.79	74.9	100
Cyfluthrin (µg/kg)	1.11	< 2	6.26	2	1	< 2	<2	0
Dacthal (µg/kg)	0.1	< 0.12	<0.36	0	0.34	< 0.25	3.28	4
DDTs (µg/kg)	11.97	< 0.27	70.87	90	8.21	< 0.54	32.04	88
Diazinon (µg/kg)	NA	NA	NA	NA	11.21	< 12.5	< 40.5	0
Dieldrin (µg/kg)	0.45	< 0.52	<1.6	0	2.2	< 1.12	7.11	52
Diuron (µg/kg)	16	< 0.2	93.2	96	27.46	< 0.2	203	92
Endosulfan I (µg/kg)	0.58	< 0.68	<2.07	0	1.31	< 1.45	<4.73	0
Endosulfan II (µg/kg)	0.71	< 0.83	<2.52	0	1.59	< 1.77	<5.76	0
Endosulfan sulfate (µg/kg)	0.57	< 0.66	<2.02	0	1.27	< 1.42	<4.61	0

Table C-1. Continued…

Analyte	2007 Mean	2007 Minimum	2007 Maximum	2007 % Detects	2008 Mean	2008 Minimum	2008 Maximum	2008 % Detects
Endrin (µg/kg)	0.2	< 0.22	0.95	2	0.42	< 0.467	<1.52	0
Fines <0.0625 mm (%)	63.05	0.56	99.62	100	48.92	1.08	89.2	100
HCH, alpha (µg/kg)	Rej	Rej	Rej	Rej	0.61	< 0.68	<2.21	0
Heptachlor (µg/kg)	0.37	< 0.43	<1.32	0	0.83	< 0.92	<3	0
Heptachlor epoxide (µg/kg)	0.25	< 0.3	<0.91	0	0.57	< 0.64	<2.08	0
Hexachlorobenzene (µg/kg)	0.79	< 0.42	15	10	0.95	< 0.9	4.16	4
HPAH (µg/kg)	199.12	< 0.6	848.5	98	232.17	4.27	1305.9	100
Lambda-cyhalothrin (µg/kg)	0.55	< 1	2.93	2	0.5	< 1	<1	0
Lead (mg/kg)	15.47	2.42	121	100	10.24	2.64	16.9	100
Linuron (µg/kg)	0.15	< 0.2	1.6	8	0.66	< 0.2	4.71	24
LPAH (µg/kg)	65.03	< 0.6	605.2	98	47.69	< 0.65	151.49	96
Mercury (mg/kg)	0.15	0.01	0.78	100	0.15	0.018	0.358	100
Methiocarb (µg/kg)	0.25	< 0.5	<0.5	0	0.25	< 0.5	<0.5	0
Methomyl (µg/kg)	0.05	< 0.1	<0.1	0	0.05	< 0.1	<0.1	0
Methoxychlor (µg/kg)	1.26	< 0.18	9.16	96	0.34	< 0.38	<1.23	0
Mirex (µg/kg)	0.31	< 0.36	<1.11	0	0.7	< 0.78	<2.53	0
Nickel (mg/kg)	74.43	11.7	159	100	58	14.2	110	100
Nitrogen, Total Kjeldahl (mg/kg)	1112.1	773	1660	100	2248.3	187	5610	100
Nonachlor, cis- (µg/kg)	Rej	Rej	Rej	Rej	0.72	<0.8	<2.6	0
Nonachlor, trans- (µg/kg)	Rej	Rej	Rej	Rej	0.45	< 0.5	<1.62	0
Oxadiazon (µg/kg)	0.56	< 0.66	<2.01	0	1.27	< 1.41	<4.59	0
Oxychlordane (µg/kg)	0.49	< 0.57	<1.75	0	1.11	< 1.23	<4	0
PAHs (µg/kg)	264.14	< 0.6	1453.7	98	279.85	4.27	1457.39	100
Parathion, Ethyl (µg/kg)	NA	NA	NA	NA	1.22	< 1.36	<4.42	0
Parathion, Methyl (µg/kg)	NA	NA	NA	NA	1.76	< 1.96	<6.38	0
PCBs (µg/kg)	7.57	< 0.15	152.25	76	9.17	1.51	24.01	100

Table C-1. Continued…

Analyte	Mean	Minimum	Maximum	% Detects	Mean	Minimum	Maximum	% Detects
	2007				2008			
Permethrin (µg/kg)	3.17	< 4	24.8	14	4.48	< 4	29.9	24
Selenium (mg/kg)	0.3	< 0.005	1.42	96	0.32	0.07	0.76	100
Silver (mg/kg)	0.16	< 0.04	0.7	94	0.14	< 0.04	0.41	96
Sum of Chlordanes (µg/kg)	0.37	< 0.43	<1.33	0	0.89	< 0.86	2.68	8
Sum of HCHs (µg/kg)	0.18	< 0.21	<0.66	0	0.48	< 0.53	<1.73	0
Sum of Pyrethroids (µg/kg)	2.5	< 1.81	24.8	32	4.6	< 1.81	30.59	92
Tedion (µg/kg)	1.1	< 1.29	<3.94	0	Rej	Rej	Rej	Rej
Total Organic Carbon (%)	2.76	0.06	11.99	100	2.98	0.28	8.22	100
Zinc (mg/kg)	108.89	10.7	608	100	81.21	26.9	117	100

NA= indicates that no data for that constituent were generated within that year.

Rej= samples were analyzed, but the results for that year were rejected due to QA/QC issues.

APPENDIX D

Brief Profiles of the Most Common Macrobenthic Taxa

The profiles presented in this appendix have been compiled from (Fields and Messer 1999).

M. speciosa is a small (~4 mm) colonial worm that lives in a mud tube. Native to eastern North America, it was first collected in the Delta in 1963 and was probably introduced to the region in water used to transport game fish, though it could also have been introduced via freshwater ballast (Cohen and Carlto 1998). It is one of the few freshwater polychaete species in North America. They are suspension feeders, which reproduce by budding and releasing young adult worms from the parental tube.

Corbicula fluminea. This is an introduced freshwater clam. Native to Asia, it was first collected in the Delta in 1945 (Cohen and Carlto 1998). Its maximum size is approximately 60 mm. *C. fluminea* is a filter feeder and broods offspring within its mantle cavity.

Limnodrilus hoffmeister. It is uncertain whether this is a native species or not. It is a small (~10 mm) burrowing worm. It is the most common and abundant of the 54 species of oligochaetes collected from the Delta, and it is probably the most common aquatic oligochaete in the world. *L. hoffmeisteri* feeds on organic detritus from ingested sediment, and it is considered to be tolerant to many types of stressors.

Gammarus daiberi. This amphipod is an introduced species. It was first collected in DWR benthic samples in 1983. It may have been introduced from the East Coast, and it is a large species growing up to 15 mm in length. It is a vegetation and detritus feeding amphipod widespread and common in the central and eastern Delta, but it is also occasionally collected west of Carquinez Strait. *G. daiberi* is a strong swimmer and spends much of its time in the water column, particularly at night. It is often collected in zooplankton samples.

Americorophium spinicorne. This amphipod species is a native to the Delta but is usually not collected west of Grizzly Bay where more saline estuarine waters are present. It is a detritus feeding, tube building amphipod that may grow to 10 mm in length. This species is sensitive to many types of environmental perturbations.