

Applying Sediment Quality Objective Assessments to San Francisco Bay Samples from 2008-2012

FINAL REPORT

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Executive Summary

In 2009, the State Water Resources Control Board (State Water Board) adopted a set of narrative sediment quality objectives (SQOs) and a standardized assessment framework to determine the impact of chemical contamination on benthic communities. The SQO framework uses multiple lines of evidence (MLOE), known as the sediment triad approach, to assess sediment quality as measured by chemistry, toxicity, and benthic community condition. This study performed SQO assessments on 125 of the Regional Monitoring Program (RMP) for Water Quality in San Francisco Bay's Status and Trends stations (25 each year) from 2008 through 2012. The goal of the study was to determine spatial and temporal trends in sediment quality throughout the Bay.

The Status & Trends sampling stations were selected based on the RMP's probabilistic (random, spatially balanced) sampling design. At each sampling site the following contaminants were sampled: trace metals (Cd, Cu, Pb, Hg, and Zn), polycyclic aromatic hydrocarbons (PAHs), pesticides (Chlordanes, Dieldrin, Trans Nonachlor, DDDs, DDEs, DDTs), and polychlorinated biphenyls (PCBs). The Chemistry LOE score was calculated by averaging the California Logistic Regression Model (CA LRM) and the Chemical Score Index (CSI) results. The toxicity LOE score was obtained by averaging the results from an acute and a sublethal toxicity test. The benthic infauna community condition score was the median of four benthic indices scores for polyhaline environments and the median of three benthic indices scores for mesohaline and oligohaline environments. The three LOE scores were then integrated to obtain an overall station assessment score (Clearly Impacted, Likely Impacted, Possibly Impacted, Likely Unimpacted, and Unimpacted).

None of the stations from 2008 through 2012 were listed as Clearly Impacted, suggesting that contamination in the Bay is generally not high enough to cause severe impacts on the benthic community. The most common station assessment was Possibly Impacted, over a third of the Bay was listed as such except for in 2009. The sediment quality also varied spatially. San Pablo Bay was the least impacted subembayment while South Bay and Suisun Bay were the two most impacted subembayments.

The majority of the stations were listed as Possibly Impacted because the Bay was characterized by Moderate or High toxicity from 2008 through 2012. In fact, both biological impacts (toxicity and benthic community condition) were observed without chemical exposure; chemical exposure was listed as Minimal or Low every year, only one station from 2008-2012 was listed as having Moderate Exposure. Despite the fact that the cause of Moderate toxicity remains unknown, it appears that sediment quality improved over time in the Bay. The percent area with poor sediment quality was highest in 2000 (96.3%), when the USEPA completed 40 SQO assessments in the Bay, and decreased to 53% by 2012. Additionally, the percent area listed as Likely Impacted was lower in 2011 and 2012 than the three previous years.

Introduction

Sediment quality is a measure of ecosystem health: benthic biota are directly exposed to chemicals in sediment, and sediment contaminants can be transferred up through the food chain, causing significant tissue contamination in higher trophic level species (Barnett et al., 2008;

Anderson et al., 2007). Therefore, understanding San Francisco Bay sediment quality is useful in determining if contaminants are adversely affecting aquatic life.

Although both chemistry and toxicity of San Francisco Bay sediments have been analyzed by the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) since 1993, the Program was missing a benthic community monitoring component until recently. Additionally, the chemistry and toxicity scores were not integrated to evaluate sediment quality. A single indicator cannot reliably evaluate whether contaminants in sediment pose a risk to ecosystem health (Bay and Weisberg, 2012). The State Water Resources Control Board (State Water Board) addressed this issue by adopting a set of narrative sediment quality objectives (SQOs) and a standardized assessment framework as part of their 2009 “Water Quality Control Plan for Enclosed Bays and Estuaries” (Beegan and Bay, 2012; SWRCB, 2009). The SQO framework uses a multiple line of evidence (MLOE) approach known as the sediment triad to assess sediment quality based on three lines of evidence: sediment chemistry, toxicity, and benthic community condition. Incorporating MLOE increases confidence in accurately predicting sediment quality. The sediment triad has been in use since Long and Chapman (1985) first described the MLOE approach. However, a standardized method for assessing sediment quality using MLOE was not established in California until 2009 when the State Water Board adopted the SQO assessment framework.

The sediment quality triad approach was employed in San Francisco Bay by the Bay Protection and Toxic Cleanup Program in 1997. However, that program targeted potential toxic hotspots and did not employ the exact SQO assessment framework now accepted by the State Water Board (Hunt et al., 2001). Thompson and Lowe (2008) were the first to apply the recently standardized SQO methodology; they retroactively completed SQO assessments on seven historical stations sampled by the RMP along the spine of the Bay from 1994 through 2001. However, spine sampling does not provide a representative assessment of the Bay nor does it characterize sediment quality in areas that are likely to be most contaminated (e.g., the margins of the Bay). SQO assessments were also conducted for samples collected at 40 stations in 2000 for a USEPA Western Environmental Monitoring and Assessment Program (WEMAP) survey that used a randomized sampling design (Barnett et al., 2008). Most of the Bay was listed as Possibly or Likely Impacted when the randomly selected stations were assessed. However, the 2000 survey included only one year of data; the precision and accuracy of the results would be improved by completing SQO assessments for San Francisco Bay sediment over multiple years (Barnett et al., 2008).

The current study completed SQO assessments for samples from 125 RMP Status and Trends (S&T) stations (25 each year) from 2008 through 2012. The goal of the study was to determine spatial and temporal trends in sediment quality throughout the Bay. Additionally, results from the previous two SQO studies were compared to the 2008-2012 results. The RMP S&T stations at the Sacramento and San Joaquin rivers were removed from the analyses because the benthic community indices were not calibrated for the freshwater environment. From 2008 to 2012 the RMP S&T program annually sampled sediment throughout the Bay, alternating between the wet and dry season. SQO assessments were conducted on samples from S&T stations because the program uses a randomized sampling design and because the inclusion of both wet and dry season samples allows an analysis of the effects of seasonality on sediment quality.

This study addressed the following two RMP management questions:

- 1) Are chemical concentrations in the Estuary at levels of potential concern and are associated impacts likely?
- 2) Have the concentrations, masses, and associated impacts of contaminants in the Estuary increased or decreased?

Methods

Sampling Design

Status & Trends sampling stations for this study were selected using the RMP's stratified, random sampling design (see 2011 Annual Monitoring Results [SFEI, 2013]). This random sampling design was adopted by the RMP in 2002 and is a more accurate spatial representation of ambient conditions than the RMP's old targeted, spine of the Bay sampling design. However, a subset of the historic RMP stations are still sampled to provide continuity in the long-term monitoring program.

Samples from 45 in-Bay stations (40 random and 5 historical) were collected during the dry season in 2008, 2009, and 2011; and 25 in-Bay station samples were collected during the wet season in 2010 and 2012. SQO assessments were conducted on all 25 of the wet-season samples; SQO assessments were performed on 25 dry-season sampling stations that were chosen randomly from each subembayment (all of the stations sampled every year were included).

Field Methods

At each station, samples for chemistry and toxicity evaluation were collected using a double 0.05 m² surface area Young-modified Van Veen grab. A composite sample for sediment chemistry and toxicity was obtained by combining the top 5 cm of sediment from two or three grab samples at each station. The Halar®-coated sampling equipment was cleaned with detergent, acid, and methanol, and then rinsed with ultrapure water between stations. Benthic infauna samples were collected with a 0.05 m² surface area Ponar grab and screened through 0.5- and 1.0-mm nested sieves before being placed into sample jars, relaxed in MgSO₄, and fixed with 10% buffered formalin.

Laboratory Methods

Sediment chemistry analysis included trace organic analyses by the East Bay Municipal Utility District (EBMUD) laboratory using EPA Method 8270 (PAHs), EPA Method 1668A (PCBs), and a modified version of EPA Method 1668A (pesticides). Mercury analyses were conducted by Brooks Rand Ltd. (BR) using EPA 1631 and a modified version of EPA 6020A. Other trace metal analyses were conducted by the City and County of San Francisco (CCSF) using a modified version of EPA digest Method 3050B and a modified EPA analysis Method 6020A.

Toxicity tests were conducted by the UC Davis-Granite Canyon Laboratory. Both an acute and a sublethal toxicity test were performed: 1) a 10-day whole-sediment acute toxicity test using the amphipod *Eohaustorius estuarius* with percent survival as the endpoint and 2) a 48-hour sediment-water interface sublethal toxicity (SWI) test using the bivalve *Mytilus galloprovincialis* with the percentage of embryos that developed normally and were alive as the endpoint. Five replicates were prepared for each test and the mean of the replicates' percent survival or development was reported. For the acute amphipod toxicity test, EPA Method 600/R-94-025 was used. For the sublethal bivalve test, EPA Method 600/R-95-136M was used.

Benthic organisms collected in infauna samples were sorted from sediments and debris and identified to the lowest practical taxonomic level, most often species, by CCSF-Oceanside Biology Laboratory and Moss Landing Marine Laboratories-Oakden Lab.

SQO Assessment Methods

Data compilation was performed by SFEI and sent to the Southern California Coastal Water Research Project (SCCWRP) for SQO assessment analyses. Three lines of evidence (LOEs) were used to assess sediment quality: chemistry, toxicity, and benthic community condition. Four response categories classified the level of chemical exposure, benthic disturbance, or toxicity (Table 1).

Table 1: Categorical scores for the three lines of evidence.

Category Score	Chemistry LOE	Benthic LOE	Toxicity LOE
1	Minimal Exposure	Reference	Nontoxic
2	Low Exposure	Low Disturbance	Low Toxicity
3	Moderate Exposure	Moderate Disturbance	Moderate Toxicity
4	High Exposure	High Disturbance	High Toxicity

The contaminants included in the chemistry LOE calculation are listed in Table 2. The chemistry LOE was calculated by integrating two sediment quality guideline values: 1) the California Logistic Regression Model (CA LRM) and 2) the Chemical Score Index (CSI) (Bay and Weisberg, 2012). The CA LRM uses logistic regressions to predict the probability of sediment toxicity based on pollutant concentrations (Bay et al., 2012). The CA LRM score is the highest p value (probability of observing a toxic effect) obtained from the regressions and is used to classify the chemistry exposure level. The CSI predicts the magnitude of benthic community disturbance based on contaminant concentrations (Ritter et al., 2012). The concentration of each contaminant is compared to threshold values and assigned a benthic disturbance category. The CSI score is the weighted average of each benthic disturbance category multiplied by a weighting factor (based on the strength of the association between the chemical score and the benthic response). The CA LRM and CSI are averaged to obtain a chemistry LOE score; the scores are then assigned to one of four response categories (Table 1).

Table 2: Sediment contaminants evaluated in the SQO assessments.

Cadmium (mg/kg)	LPAH (ug/kg) ^b	DDEs, total (ug/kg) ^d
Copper (mg/kg)	Alpha Chlordane (ug/kg)	DDTs, total (ug/kg) ^e

Lead (mg/kg)	Gamma Chlordane (ug/kg)	4,4'-DDT (ug/kg)
Mercury (mg/kg)	Dieldrin (ug/kg)	PCBs, total (ug/kg) ^f
Zinc (mg/kg)	Trans Nonachlor (ug/kg)	
HPAH (ug/kg) ^a	DDD, total (ug/kg) ^c	

^a Total HPAHs are equivalent to the sum of Pyrene, Fluoranthene, Benzo(a)anthracene, Chrysene, Benzo(a)pyrene, Benzo(e)pyrene, and Perylene

^b Total LPAHs are equivalent to the sum of Naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, Acenaphthene, Biphenyl, Fluorene, Phenanthrene, 1-methylphenanthrene, Anthracene

^c Total DDDs are equivalent to the sum of 2,4'-DDD and 4,4'-DDD

^d Total DDTs are equivalent to the sum of 2,4'-DDE and 4,4'-DDE

^e Total DDTs are equivalent to the sum of 2,4'-DDT and 4,4'-DDT

^f Total PCBs are equivalent to the sum of PCB 8, PCB 18, PCB 28, PCB 44, PCB 52, PCB 66, PCB 101, PCB 105, PCB 110, PCB 118, PCB 128, PCB 138, PCB 153, PCB 180, PCB 187, PCB 195

For polyhaline environments, salinity between 18 and 30 parts per thousand (ppt), the benthic LOE score is the median of four benthic index scores: 1) the Index of Biotic Integrity (IBI), 2) the Relative Benthic Index (RBI), 3) the Benthic Response Index (BRI), and 4) the River Invertebrate Prediction and Classification System (RIVPACS) (Ranasinghe et al., 2009). For mesohaline and oligohaline environments, salinities between 5 and 18 ppt and below 5 ppt, respectively, the benthic LOE score is the median of three benthic indices: 1) a modified IBI, 2) a modified RBI, and 3) the AZTI Marine Biotic Index (AMBI). The benthic indices LOE scores (reference, low, moderate, and high disturbance) were defined by a specific range of index values (Bay et al., 2009). For example, and RBI score of less than 0.43 is considered Reference, the category in which the benthic community at the station is similar to the community present in reference areas unimpacted by sediment contamination.

The toxicity LOE scores were based on the results of both the acute and sublethal toxicity tests (Greenstein and Bay, 2012). The scores were based on threshold levels of percent survival or percentage of larvae normal-alive, as well as whether the results were statistically different from the controls (Table 3). The average of the two scores became the overall toxicity LOE score (Nontoxic, Low, Moderate, or High toxicity).

Table 3: Category scores thresholds for the acute and sublethal toxicity tests

Category Score	1	2	3	4
	Nontoxic (%)	Low Toxicity (% of control)	Moderate Toxicity (% of control)	High Toxicity (% of control)
<i>Eohaustorius</i> Survival	90-100	82-89	59-81	<59
<i>Mytilus</i> Normal	80-100	77-79	42-76	<42

The SQO assessment framework evaluates two questions: 1) is there biological degradation? and 2) is the chemical exposure high enough to generate a biological response? (Bay and Weisberg, 2012). To answer whether there is biological degradation, the benthic and toxicity LOE scores are evaluated; the benthic score is given more weight because the benthic community condition is a more direct indicator of sediment quality than toxicity tests. To determine whether there is chemical exposure sufficient to cause a biological response, the toxicity and chemistry LOE scores are considered. The final data integration step combines the severity of the biological

effect and the potential for chemically-mediated effects to assign one of six station assessments (Table 4).

Table 4: SQO station assessment categories.

Station Assessment	Description
Unimpacted	Confident that contamination is not causing significant adverse effects to benthic macroinvertebrates at the station.
Likely Unimpacted	Contamination is not expected to cause adverse effects to benthic macroinvertebrates, but some disagreement among LOEs reduces certainty that the station is unimpacted.
Possibly Impacted	Contamination at the station may be causing adverse effects to benthic macroinvertebrates, but the level of impact is either small or is uncertain because of disagreement among LOEs.
Likely Impacted	Evidence of contaminant-related impacts to benthic macroinvertebrates is persuasive, in spite of some disagreement among LOEs.
Clearly Impacted	Sediment contamination at the station is causing clear and severe adverse effects to benthic macroinvertebrates.
Inconclusive	Disagreement among the LOEs suggests that either data are suspect or additional information is needed for classification.

It is important to note that the Possibly Impacted category has the highest uncertainty compared to the other station assessments. Additionally, both biological effects and chemical effects must be present for a station to be listed as Impacted (Bay and Weisberg, 2012).

Percent Area Calculation

The percent area that was represented by the various LOE categorizations and station assessments was determined using each subembayment's area weight (area of the sampling frame divided by the number of stations sampled). The affected area was calculated as the number of stations within a certain subembayment possessing a particular assessment (e.g., Possibly Impacted, Moderate Toxicity, Low Chemical Exposure, etc.) multiplied by the area weight of the particular subembayment. The affected area was then divided by the total area of the Bay to determine the percent area affected.

Each year, one or two of the sample stations were repeat stations (i.e., stations that are sampled every year by the RMP). The repeat stations were weighted equally with other sampling stations in the subembayments. Therefore, percent area represented by each station assessment and LOE from 2008 to 2012 may be biased because the repeat stations are overrepresented in the calculation.

The sediment quality in a subembayment or a certain year was defined as either “good” or “poor” based on the station assessment results. The percent area with poor sediment quality was the sum of the percent area represented by the Likely Impacted and Possibly Impacted station assessments (there were no Clearly Impacted stations). The percent area with good sediment quality was the sum of the percent area represented by the Likely Unimpacted and Unimpacted station assessments

Results

Bay-wide Sediment Quality

The SQO station assessments were compared across the Bay to elucidate spatial and temporal trends in sediment quality. Individual lines of evidence (chemistry, toxicity, and benthos) were also compared temporally and spatially.

None of the randomized sampling stations from 2008 to 2012 were listed as Clearly Impacted (Figure 1). The most common station assessment overall was Possibly Impacted, with 40% of the Bay classified as such from 2008 to 2012 (Figure 1A). Over a third of the Bay was categorized as Possibly Impacted every year, except in 2009. In 2009, 74% of the Bay had good sediment quality (Likely Unimpacted or Unimpacted; Figure 1C).

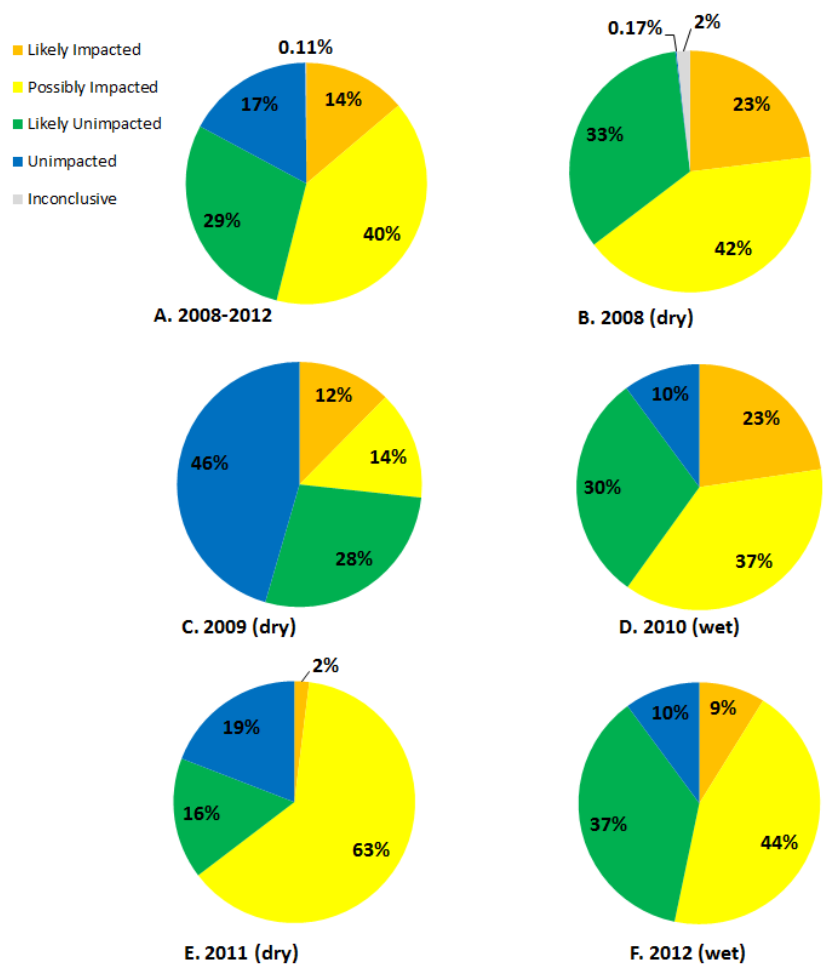


Figure 1. Percent area in the Bay classified as a particular station assessment from 2008 through 2012.

The prevalence of impacted areas appears to have decreased over time. From 2008 to 2010, 19% of the Bay was classified as Likely Impacted, while only 6% was listed as Likely Impacted for 2011 and 2012 combined. The decrease in the area classified as Likely Impacted coincided with an increase in the area listed as Possibly Impacted in 2011 and 2012 (including over 50% of the stations). Overall, the percent area with poor sediment quality (Possibly, Likely, or Clearly Impacted [latter in WEMAP only]) decreased from the 2000 WEMAP study to the 2008-2012 S&T sampling effort (Figure 2). The year with the lowest prevalence of sediment contamination/impacts was 2009, with only 27% of the Bay classified as having poor sediment quality.

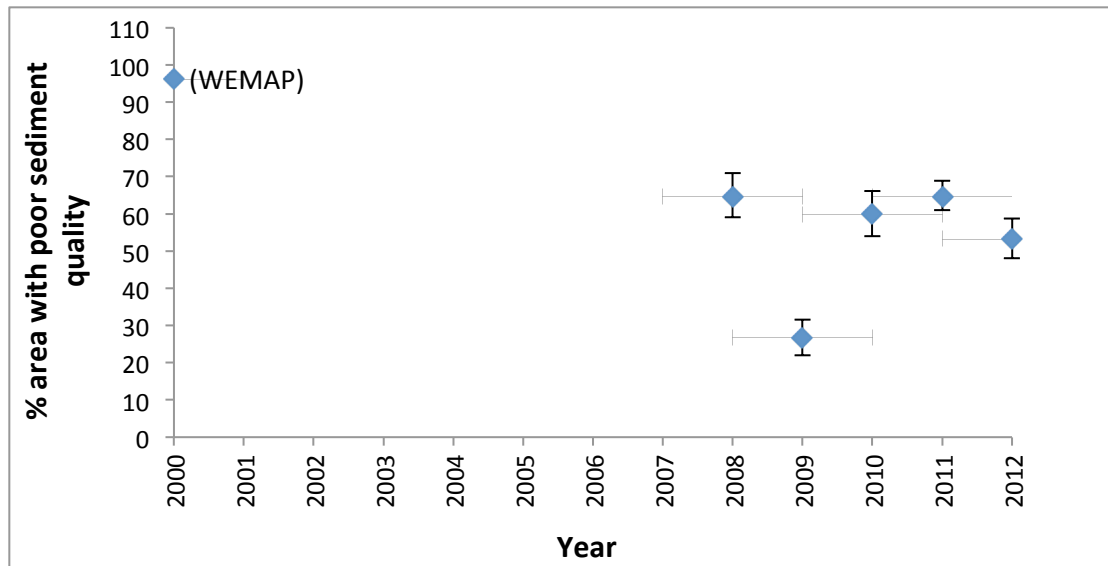


Figure 2: Percent area with poor sediment quality from the 2000 WEMAP survey and the 2008-2012 S&T sampling. Error bars indicate the 95% binomial confidence interval for the RMP S&T sampling years.

Sediment Quality in Individual Subembayments

Analogous to the results for the entire Bay, over a third of the area in each subembayment was classified as Possibly Impacted from 2008 through 2012, except for San Pablo Bay. Nearly half (48%) of San Pablo Bay was categorized as Likely Unimpacted. San Pablo Bay possessed the best sediment quality in the Bay; 80% of the subembayment possessed good sediment quality and none of the stations were listed as Likely Impacted from 2008 through 2012 (Figure 3F and Table 5).

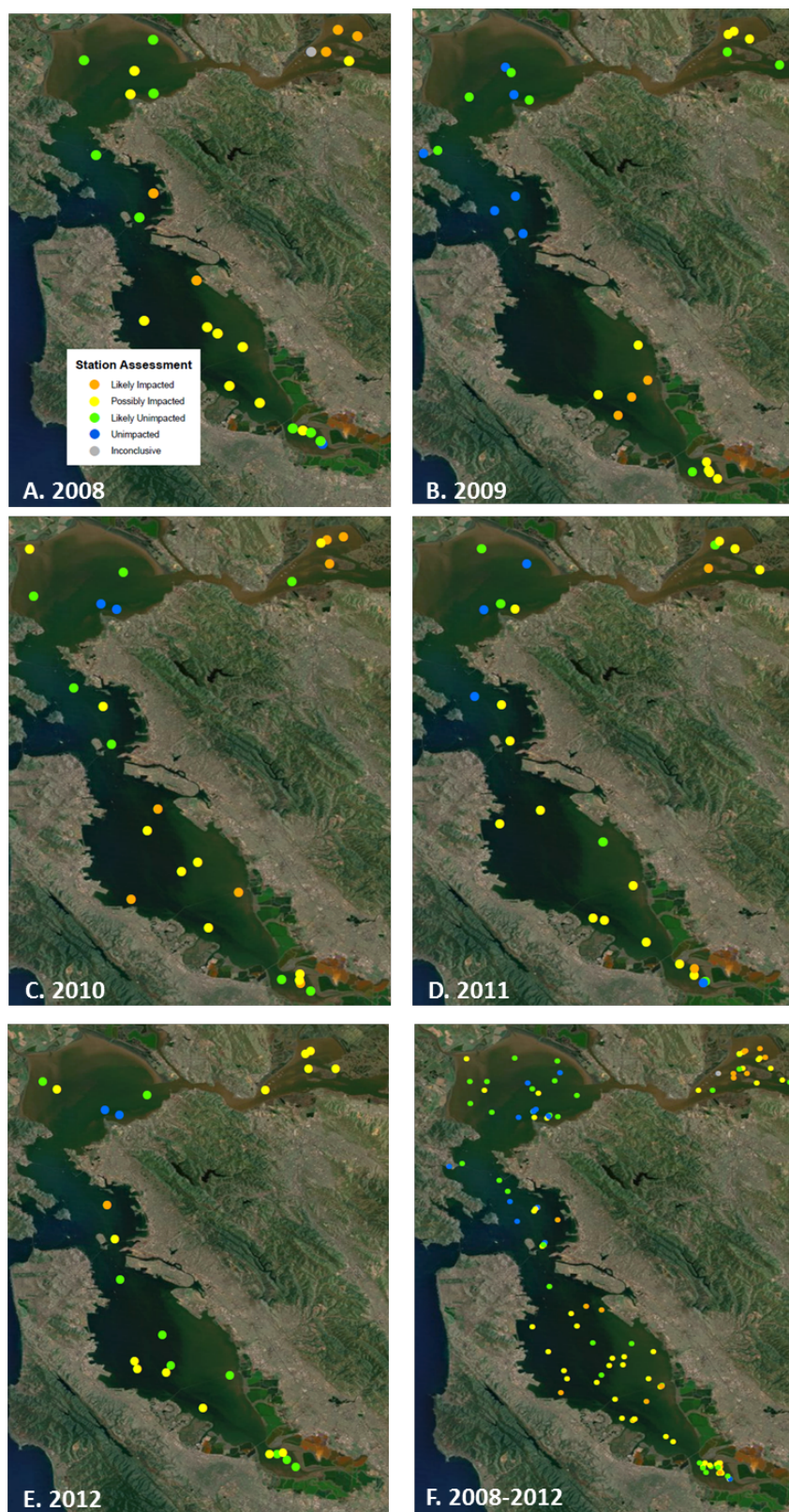


Figure 3: Spatial representation of station assessments for A) 2008, B) 2009, C) 2010, D) 2011, E) 2012, and F) 2008-2012.

The percent area of Lower South Bay with poor sediment quality was the same as in Central Bay (52%; Table 5). South Bay and Suisun Bay were significantly more impacted, 88% and 80% of these areas possessed poor sediment quality respectively.

Table 5: Percent area in each subembayment with poor sediment quality (Possibly and Likely Impacted), good sediment quality (Likely Unimpacted and Unimpacted), and inconclusive sediment quality from 2008 through 2012.

	% Area with Poor Sediment Quality	% Area with Good Sediment Quality	Inconclusive (%)
Suisun Bay	80	16	4
San Pablo Bay	20	80	0
Central Bay	52	48	0
South Bay	88	12	0
Lower South Bay	52	48	0

Individual Lines Of Evidence (LOE)

Individual LOE categorizations for sediment chemistry, toxicity, and benthic community condition were examined to determine if a particular LOE had a greater influence on the poor sediment quality in the Bay. Sediment condition in the Bay was driven by toxicity and benthic community condition, both of which reflect biological effects (Table 6). Chemical exposure was listed as Minimal or Low every year, except for 2008, when 20% of Lower South Bay was classified as having Moderate chemical exposure.

A substantial portion of the Bay was characterized by Moderate or High toxicity; 60% of Bay sediment was toxic from 2008 through 2012 (Table 7). In every year, except for 2009, over 50% of the Bay was listed as Moderately or Highly toxic. Similarly, over 50% of the area in each subembayment was classified as toxic from 2008 through 2012, except for San Pablo Bay, where only 36% of the area possessed Moderate or High toxicity (Table 6). The prevalence of toxic sediments appears to be lower in the northern subembayments. In Lower South Bay and South Bay over 70% of the area was listed as toxic, while 52% of Suisun Bay (and 36% of San Pablo Bay, as noted above) was classified as Moderately or Highly toxic (Table 6).

Benthic community condition was spatially and temporally more variable than toxicity. The benthic community was considerably more impacted in South Bay and Suisun Bay than in the other three subembayments; 48% and 72% of these areas, respectively, were Moderately or Highly degraded (Table 6). Temporally, the two years with the most impacted benthos were 2008 and 2010; about 40% of the Bay was Moderately or Highly disturbed (Table 7). In contrast, the benthic community condition in 2009 and 2011 was only Moderately or Highly disturbed in 24% and 2% of the Bay, respectively.

Table 6: Percent area with Moderate or High chemical exposure, toxicity, and benthic disturbance in each subembayment, 2008-2012.

	Chemical Exposure	Toxicity	Benthic Disturbance
Suisun Bay	0%	52%	72%
San Pablo Bay	0%	36%	4%
Central Bay	0%	68%	24%
South Bay	0%	76%	48%
Lower South Bay	4%	72%	8%

Table 7: Percent area with Moderate or High chemical exposure, toxicity, and benthic disturbance, 2008-2012.

	Chemical Exposure	Toxicity	Benthic Disturbance
2008	0.17%	73%	44%
2009	0%	29%	24%
2010	0%	72%	39%
2011	0%	74%	2%
2012	0%	53%	32%
2008-2012	0.03%	60%	28%

It is important to note that each subembayment was also characterized by considerable temporal variability. In Lower South Bay, for example, 100% of the area was Moderately Toxic in 2009, 2010, and 2012 (Table A-1). But in 2008, 100% of the area possessed Low toxicity. Similarly, 100% of the area in Suisun Bay had a Moderately or Highly disturbed benthos in 2008, 2010, and 2012. In 2009 and 2011, only 40% and 20% of the subembayment possessed an impacted benthos.

Conclusions

In general, contamination in the open Bay is not high enough to cause severe impacts on the benthic community. Although a substantial fraction of San Francisco Bay's sediment quality was poor (54%) and was characterized by Moderate or High toxicity (60% of Bay sediment) from 2008 through 2012, none of the stations were classified as Clearly Impacted. The Possibly Impacted assessment category characterized most of the impacted sediment, often because of the presence of moderate or high sediment toxicity without similar chemical exposure or benthic community disturbance responses. This result is consistent with the SQO assessment scores from the 2000 WEMAP survey; 77% of the Bay was classified as Possibly Impacted (Barnett et al., 2008).

Moderate toxicity is typical of San Francisco Bay. Approximately a third of Bay samples from 1991 through 1999 were listed as toxic (Phillips et al., 2008). Similar to the 2000 SQO assessment results (Barnett et al., 2008), Moderate or High toxicity and benthic community disturbance was observed in regions with Low or Minimal chemical exposure. The Low chemical exposure in the Bay is distinctive; in Southern California, there was a higher percent

area with High or Moderate chemical exposure than the Bay, with lower levels of toxicity and benthic community disturbance (Barnett et al., 2008).

The presence of biological impacts without chemical exposure could be because non-contaminant factors, such as sediment grain size and amphipod health (e.g. lipid content), are increasing the toxicity and negatively affecting the benthic community condition. To address this possibility, a 2014 study conducted by UC Davis and the Southern California Coastal Water Research Project will examine the effects of particle size and shape and animal health on *Eohaustorius estuarius* toxicity test results. Contaminants not included in the SQO assessment analysis, such as current use pesticides, could also be impacting benthic community disturbance or toxicity in the Bay. The current use pesticide fipronil, for example, is not included in the SQO assessment analysis; however, it is toxic to sensitive organisms at concentrations less than 1 µg/L and has been measured in the Bay.

The cause of the perennial and widespread moderate toxicity observed in the Bay is unknown. A Mission Creek Toxicity Identification Evaluation (TIE; Phillips et al. 2008) found that the cause of toxicity was most likely a mix of organic chemicals; however, specific contaminants or other non-contaminant stressors could not be positively identified. Identifying the cause(s) of baywide moderate toxicity is a priority information need.

Sediment quality may have improved over time in the Bay. The percent area with poor sediment quality was highest in 2000 (96.3%; Barnett et al., 2008) and decreased to 53% by 2012. Additionally, the percent area listed as Likely Impacted was lower in 2011 and 2012 than the three previous years. If the dry and wet seasons are analyzed separately, sediment quality still appears to have improved over time. The percent area designated as Likely Impacted was greater, and the percent area classified as Unimpacted was lower in the 2000 (Barnett et al., 2008) and 2008 dry season sampling years than in 2009 and 2011 (this study). However, when comparing sediment quality from 1994-2001 and 2008-2012 at BC11 and BD 41, two historical spine sampling stations in Central Bay and San Pablo Bay, there was no apparent trend over time. Comparing sediment quality across the entire Bay provided a clearer picture of time series trends than analyzing sediment quality at individual stations over time.

San Pablo Bay was clearly the least impacted subembayment. Although, toxicity was prevalent in all of the subembayments, including San Pablo Bay, the benthic community was more disturbed in South Bay and Suisun Bay. In order for a station to be listed as Likely Impacted, two LOEs must be listed as impacted. Therefore, South Bay and Suisun Bay were the two most impacted subembayments (88% and 80% of the area had poor sediment quality) because these regions were characterized by both an impacted benthos and toxic sediment.

Seasonality may be affecting the benthic community condition in Suisun Bay. The benthos in the subembayment was impacted in 2008, 2010, and 2012. Both 2010 and 2012 were wet season sampling years. However, sediment quality in 2008 was similar to the two wet season years, making the link to seasonality uncertain. The SQO guidance document (Bay et al., 2009) suggests choosing to conduct SQO assessments during the dry season to avoid the effects of seasonality on benthic community condition. The benthic indices included in the SQO assessment method may also affect the benthos score. A RMP funded study (expected in 2014) is

developing benthic indices that are specifically calibrated for the mesohaline regions of San Francisco Bay, which may improve the accuracy of the benthic community condition score in the mesohaline environments.

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Appendix

Table A-1: SQO MLOE results and station assessments for Lower South Bay from 2008-2012.

Lower South Bay					
<i>Year</i>	<i>Station Name</i>	<i>Chemical Exposure</i>	<i>Toxicity</i>	<i>Benthic Disturbance</i>	<i>Station Assessment</i>
2008	BA10	Low	Low	Reference	Unimpacted
	LSB037S	Moderate	Low	Low	Possibly Impacted
	LSB038S	Low	Low	Low	Likely Unimpacted
	LSB039S	Low	Low	Low	Likely Unimpacted
	LSB040S	Low	Low	Low	Likely Unimpacted
2009	BA10	Low	Moderate	Low	Possibly Impacted
	LSB002S	Low	Moderate	Low	Possibly Impacted
	LSB016S	Low	Moderate	Low	Possibly Impacted
	LSB082S	Low	Moderate	Low	Possibly Impacted
	LSB108S	Low	Moderate	Reference	Likely Unimpacted
2010	BA10	Nontoxic	Moderate	Low	Likely Unimpacted
	LSB002S	Low	Moderate	Moderate	Likely Impacted
	LSB072S	Low	Moderate	Low	Possibly Impacted
	LSB109S	Low	Moderate	Reference	Likely Unimpacted
	LSB140S	Low	Moderate	Low	Possibly Impacted
2011	BA10	Low	Low	Reference	Unimpacted
	LSB002S	Low	Moderate	Low	Possibly Impacted
	LSB024S	Low	Moderate	High	Likely Impacted
	LSB070S	Low	Low	Low	Likely Unimpacted
	LSB121S	Low	Moderate	Low	Possibly Impacted
2012	BA10	Minimal	Moderate	Low	Likely Unimpacted
	LSB002S	Low	Moderate	Reference	Likely Unimpacted
	LSB044S	Low	Moderate	Reference	Likely Unimpacted
	LSB045S	Low	Moderate	Low	Possibly Impacted
	LSB112S	Low	Moderate	Low	Possibly Impacted

Table A-2: SQO MLOE results and station assessments for South Bay from 2008-2012.

South Bay					
<i>Year</i>	<i>Station Name</i>	<i>Chemical Exposure</i>	<i>Toxicity</i>	<i>Benthic Disturbance</i>	<i>Station Assessment</i>
2008	BA41	Low	High	Low	Possibly Impacted
	SB037S	Low	Low	Moderate	Possibly Impacted
	SB038S	Low	Moderate	Low	Possibly Impacted
	SB039S	Low	Low	Moderate	Possibly Impacted
	SB040S	Low	High	Low	Possibly Impacted
2009	BA41	Low	High	Moderate	Likely Impacted
	SB002S	Low	High	Moderate	Likely Impacted
	SB016S	Low	Low	Moderate	Possibly Impacted
	SB060S	Low	Low	Moderate	Possibly Impacted
	SB106S	Low	Moderate	Moderate	Likely Impacted
2010	BA41	Low	Low	High	Possibly Impacted
	SB002S	Low	Moderate	Moderate	Likely Impacted
	SB087S	Minimal	Moderate	Moderate	Possibly Impacted
	SB091S	Low	Moderate	Moderate	Likely Impacted
	SB095S	Minimal	Moderate	Moderate	Possibly Impacted
2011	BA41	Low	Moderate	Low	Possibly Impacted
	SB002S	Low	Moderate	Low	Possibly Impacted
	SB024S	Low	High	Low	Possibly Impacted
	SB041S	Minimal	Moderate	Low	Likely Unimpacted
	SB102S	Low	Moderate	Low	Possibly Impacted
2012	BA41	Low	Moderate	Low	Possibly Impacted
	SB002S	Low	Moderate	Reference	Likely Unimpacted
	SB027S	Low	Moderate	Low	Possibly Impacted
	SB045S	Minimal	Low	Low	Likely Unimpacted
	SB097S	Minimal	High	Low	Possibly Impacted

Table A-3: SQO MLOE results and station assessments for Central Bay from 2008-2012.

Central Bay					
<i>Year</i>	<i>Station Name</i>	<i>Chemical Exposure</i>	<i>Toxicity</i>	<i>Benthic Disturbance</i>	<i>Station Assessment</i>
2008	BC11	Low	Moderate	Reference	Likely Unimpacted
	CB037S	Low	High	Moderate	Likely Impacted
	CB038S	Low	Moderate	Moderate	Likely Impacted
	CB039S	Low	Moderate	Reference	Likely Unimpacted
	CB040S	Low	Low	Moderate	Possibly Impacted
2009	BC11	Low	Low	Reference	Unimpacted
	CB001S	Low	Nontoxic	Low	Unimpacted
	CB043S	Low	Nontoxic	Low	Unimpacted
	CB075S	Low	Low	Low	Likely Unimpacted
	CB121S	Low	Nontoxic	Reference	Unimpacted
2010	BC11	Low	Moderate	Reference	Likely Unimpacted
	CB001S	Low	Moderate	Low	Possibly Impacted
	CB042S	Low	Moderate	Moderate	Likely Impacted
	CB055S	Low	Moderate	Reference	Likely Unimpacted
	CB122S	Low	Moderate	Low	Possibly Impacted
2011	BC11	Low	Moderate	Low	Possibly Impacted
	CB001S	Low	High	Low	Possibly Impacted
	CB023S	Low	Low	Reference	Unimpacted
	CB088S	Low	Moderate	Low	Possibly Impacted
	CB112S	Low	Moderate	Low	Possibly Impacted
2012	BC11	Low	Moderate	Low	Possibly Impacted
	CB001S	Low	High	Moderate	Likely Impacted
	CB046S	Low	High	Low	Possibly Impacted
	CB110S	Low	Moderate	Reference	Likely Unimpacted
	CB129S	Minimal	Nontoxic	High	Likely Unimpacted

Table A-4: SQO MLOE results and station assessments for San Pablo Bay from 2008-2012.

San Pablo Bay					
<i>Year</i>	<i>Station Name</i>	<i>Chemical Exposure</i>	<i>Toxicity</i>	<i>Benthic Disturbance</i>	<i>Station Assessment</i>
2008	BD31	Low	High	Low	Possibly Impacted
	SPB037S	Low	Low	Low	Likely Unimpacted
	SPB038S	Low	Moderate	Reference	Likely Unimpacted
	SPB039S	Low	Moderate	Reference	Likely Unimpacted
	SPB040S	Low	High	Reference	Possibly Impacted
2009	BD31	Low	Nontoxic	Low	Unimpacted
	SPB002S	Low	Moderate	Reference	Likely Unimpacted
	SPB016S	Low	Low	Reference	Unimpacted
	SPB080S	Low	Moderate	Reference	Likely Unimpacted
	SPB135S	Low	Low	Low	Likely Unimpacted
2010	BD31	Low	Low	Reference	Unimpacted
	SPB002S	Low	Low	Reference	Unimpacted
	SPB043S	Low	Moderate	Low	Possibly Impacted
	SPB051S	Low	Low	Low	Likely Unimpacted
	SPB120S	Low	Low	Low	Likely Unimpacted
2011	BD31	Low	Low	Low	Likely Unimpacted
	SPB002S	Low	Moderate	Low	Possibly Impacted
	SPB023S	Low	Moderate	Reference	Likely Unimpacted
	SPB088S	Low	Low	Reference	Unimpacted
	SPB132S	Low	Low	Reference	Unimpacted
2012	BD31	Low	Nontoxic	Low	Unimpacted
	SPB002S	Low	Low	Reference	Unimpacted
	SPB027S	Low	Low	Low	Likely Unimpacted
	SPB041S	Low	Low	Moderate	Possibly Impacted
	SPB110S	Low	Low	Low	Likely Unimpacted

Table A-5: SQO MLOE results and station assessments for Suisun Bay from 2008-2012.

Suisun Bay					
<i>Year</i>	<i>Station Name</i>	<i>Chemical Exposure</i>	<i>Toxicity</i>	<i>Benthic Disturbance</i>	<i>Station Assessment</i>
2008	BF21	Low	High	High	Likely Impacted
	SU037S	Low	Moderate	Moderate	Likely Impacted
	SU039S	Minimal	Low	High	Inconclusive
	SU040S	Low	Low	High	Possibly Impacted
	SU080S	Low	Moderate	Moderate	Likely Impacted
2009	BF21	Low	High	Low	Possibly Impacted
	SU016S	Low	High	Low	Possibly Impacted
	SU073S	Low	Moderate	Low	Possibly Impacted
	SU085S	Low	Reference	High	Likely Unimpacted
	SU090S	Low	Reference	High	Likely Unimpacted
2010	BF21	Low	High	Moderate	Likely Impacted
	SU060S	Low	Moderate	Moderate	Likely Impacted
	SU073S	Low	Low	Moderate	Possibly Impacted
	SU084S	Low	Moderate	Moderate	Likely Impacted
	SU109S	Minimal	Low	Moderate	Likely Unimpacted
2011	BF21	Low	High	Low	Possibly Impacted
	SU024S	Low	Moderate	Low	Possibly Impacted
	SU073S	Low	Low	Low	Likely Unimpacted
	SU044S	Low	Moderate	Moderate	Likely Impacted
	SU048S	Low	High	Reference	Possibly Impacted
2012	BF21	Low	Low	Moderate	Possibly Impacted
	SU027S	Low	Low	Moderate	Possibly Impacted
	SU073S	Low	Low	Moderate	Possibly Impacted
	SU128S	Low	Low	Moderate	Possibly Impacted
	SU131S	Low	Low	Moderate	Possibly Impacted