SEDIMENT QUALITY IN CALIFORNIA BAYS AND ESTUARIES

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EXECUTIVE SUMMARY

Sediment quality in California bays and estuaries was evaluated using a multiple lines of evidence (MLOE) assessment framework. This framework has been proposed for adoption as part of the sediment quality objectives (SQOs) portion of California's water quality control plan for bays and estuaries. Chemistry, toxicity, and benthic community data, each representing an independent line of evidence (LOE) regarding sediment quality, from six surveys conducted over eight years were analyzed. The analysis consisted of three parts: 1) determining sediment condition at each sampling station (site) using the assessment framework; 2) establishing a single integrated data set with known spatial attributes from the combined data of each survey; and 3) analyzing the integrated data set using spatial statistics to determine the percentage of area corresponding to each sediment condition category.

The assessment framework was used to classify 381 sites into one of the following six condition categories:

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

Two levels of assessment were conducted. The first level used a combined data set from all surveys and evaluated statewide conditions. At the second level, spatial assessments were conducted independently for three regions within the state in order to investigate patterns related to differences in size of embayments, land use, and hydrological characteristics. The regions were: North, consisting of multiple small coastal embayments north of Point Conception to the Oregon border; South, which included multiple small coastal embayments south of Point Conception to the US-Mexico border; and the San Francisco Bay and its contiguous marine embayment areas (SFB).

Approximately 83% of the 1295 km^2 of California marine embayments included in the analysis were classified as having some degree of impact related to sediment contamination. Most of the area was classified as Possibly Impacted and less than 1% of the area was classified as Clearly

Impacted (Figure 4; Table 3). The statewide analysis results were dominated by the conditions present in SFB, which represented nearly 80% of the embayment area.

Large variations in sediment condition were present among the three geographic regions. The North region had the best sediment conditions, with 58% of the area classified as Unimpacted and no sites classified as Clearly Impacted (Figure 5; Table 4). Somewhat poorer sediment quality was observed in the South, with 43% of the area classified as Unimpacted and 2% classified as Clearly Impacted. A different distribution of sediment condition categories was present in San Francisco Bay; no sites were classified as Unimpacted and the proportion of area classified as Possibly Impacted (77%) was more than three times greater than that measured in the other regions.

The regional differences in sediment quality identified through the assessment framework were evaluated by analysis of the underlying LOEs (Chemistry, Toxicity, and Benthic Community) to examine various levels of response within each site's sediment. Sediment chemistry was least impacted in the North and most impacted in the South. The incidence of biological effects (toxicity or benthic community disturbance) was greatest in SFB and appeared to account for the comparatively high percent area classified as Possibly Impacted or Likely Impacted.

The large percentage of Possibly Impacted area within SFB suggests that sediment contaminants are more widespread and less concentrated in this region, possibly due to contaminant dilution and redistribution as a result of greater rainfall, high runoff inputs from urban and agricultural sources, and tidal mixing. There is also evidence that the relationship between sediment contamination and toxicity in SFB differs from that observed in other regions. As the causes of toxicity in California embayments have not been identified, the reason for this apparent difference in toxicity response cannot be determined. Unmeasured contaminants, such as current use pesticides, may be influencing these relationships. It is also possible that contaminant bioavailability differs between regions or that different contaminants are causing toxicity in each area.

The results of this study's integrated analysis using the assessment framework are consistent with previous studies of sediment quality in California bays and estuaries. However, use of the framework and combined survey data produced a more comprehensive and robust assessment of statewide sediment quality than has been achieved previously. Moreover, this study's assessment of sediment conditions on both statewide and regional scales can be used as a benchmark for future studies.

TABLE OF CONTENTS

INTRODUCTION

Sediment quality has an important influence on the overall condition of a water body. Sediments act as a reservoir for contaminants that can be transferred to the water column through physical disturbance, diffusion, and biological activities. Also, sediments are a primary source of contaminant exposure for sediment-dwelling organisms and animals that feed on the bottom, such as crabs and flatfishes. This exposure can produce adverse impacts on benthic communities and can also lead to indirect effects on wildlife and human health due to the accumulation of contaminants from the food chain.

Historically, sediment quality assessment has been an important feature of many California monitoring programs. It was a major focus in the Bay Protection and Toxic Cleanup Program (BPTCP; Anderson *et al.* 1997), the California Environmental Mapping and Assessment Program (EMAP; USEPA 2005), the San Francisco Regional Monitoring Program (SFEI 2005), and the Southern California Bight Regional Monitoring Program (SCCWRP 2003, 2007). Although numerous sediment quality surveys have recently been conducted, like the ones cited above, these studies focused on areas and used methods for data interpretation different from those used in this study, thereby preventing the integration of such data for analysis and inclusion in a statewide assessment of sediment conditions in California's embayments (bays and estuaries). Comprehensive sediment quality information is needed for California's 305(b) and 303(d) programs to establish priorities for water quality programs at the State and Regional Boards. The present study, under the auspices of the State Water Ambient Monitoring Program (SWAMP), is intended to provide this assessment.

Sediment is a complex matrix of components and forms. Consequently, evaluating contaminant impacts on beneficial uses based on a single line of evidence is problematic. For example, bulk measures of chemical concentration fail to differentiate between the fraction of a contaminant that is tightly bound to sediment and that which is biologically available. Multiple mechanisms of contaminant exposure, including uptake of chemicals from interstitial water, sediment ingestion, and bioaccumulation through the food web further complicate interpretation of sediment chemistry data.

For these reasons, sediment quality assessment often involves simultaneously evaluating multiple lines of evidence (MLOE) that measure both contaminant exposure and effects on organisms: an approach commonly known as the sediment quality triad (Long and Chapman 1985). Lines of evidence (LOEs), such as sediment chemistry, toxicity, and benthic community condition are often used. Virtually all of the ambient sediment quality monitoring programs in this country rely on more than one line of evidence (USEPA 1998, Crane *et al.* 2000, MacDonald and Ingersoll 2002, USEPA 2004). Such programs include the two largest nationwide estuarine monitoring programs: the United States Environmental Protection Agency (USEPA) EMAP and the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program, as well numerous regional monitoring programs. The California State Water Board BPTCP also relied primarily on MLOE to assess sediment quality in bays and estuaries throughout the state (Anderson *et al.* 1997, Fairey *et al.* 1998, Phillips *et al.* 1998, Anderson *et al.* 2001, Hunt *et al.* 2001).

Staff at the State Water Resources Control Board (SWRCB) has proposed draft sediment quality objectives (SQOs) that use an assessment framework based on an MLOE approach to evaluate sediment quality in embayments (SWRCB 2007). If adopted, these SQOs will become the regulatory standard against which ambient sediment quality is measured, influence management and regulatory decisions, and serve as the basis for evaluating water body impairment (e.g., 303(d) listings) with regard to sediment quality.

Previous statewide assessments of sediment condition in California have been limited in terms of data integration and interpretation. Results from a 1999 EMAP survey were used to describe the statewide extent of sediment contamination, toxicity, and benthic community characteristics, but these separate LOEs were not integrated to assess overall sediment condition (USEPA 2005). Recent 305(b) reports of California sediment quality have included data from multiple studies, but again the condition assessment was limited by a lack of integration of LOEs and the use of variable data interpretation approaches among studies (SWRCB 2006, USEPA 2004).

This report represents the first application of the proposed assessment framework on a statewide basis to evaluate sediment quality in California's marine and estuarine embayments. The focus of this analysis is on the direct effects of contamination on aquatic life due to sediment contact or ingestion, rather than effects on humans or wildlife due to indirect exposure through the consumption of fish and shellfish. For this assessment, data from recent EMAP, SWAMP, and southern California Bight surveys were combined and evaluated using a common set of assessment indicators within an assessment framework.

Two levels of assessment were conducted (Figure 1). The first level evaluated statewide conditions. The purpose of this level was to determine the percentages of the State's embayments with various levels of impact from sediment contamination. At the second level, spatial assessments were conducted independently for three regions within the state in order to investigate patterns related to differences in size of embayments, land use, and hydrological characteristics. The northern region (North) included multiple small coastal embayments north of Point Conception to the Oregon border. The North embayments were characterized by low population density, where agricultural use is important and freshwater inputs are relatively high. The southern region (South) included multiple small coastal embayments south of Point Conception to the US-Mexico border. These southern embayments were often surrounded by high population density, extensive commercial/industrial use, and low freshwater inputs. The third assessment region was the San Francisco Bay and its contiguous marine embayment areas (SFB). The hydrology of the SFB is different from the North and South in that runoff into SFB is nearly continuous, tidal mixing is strong, and agricultural and industrial uses are relatively high.

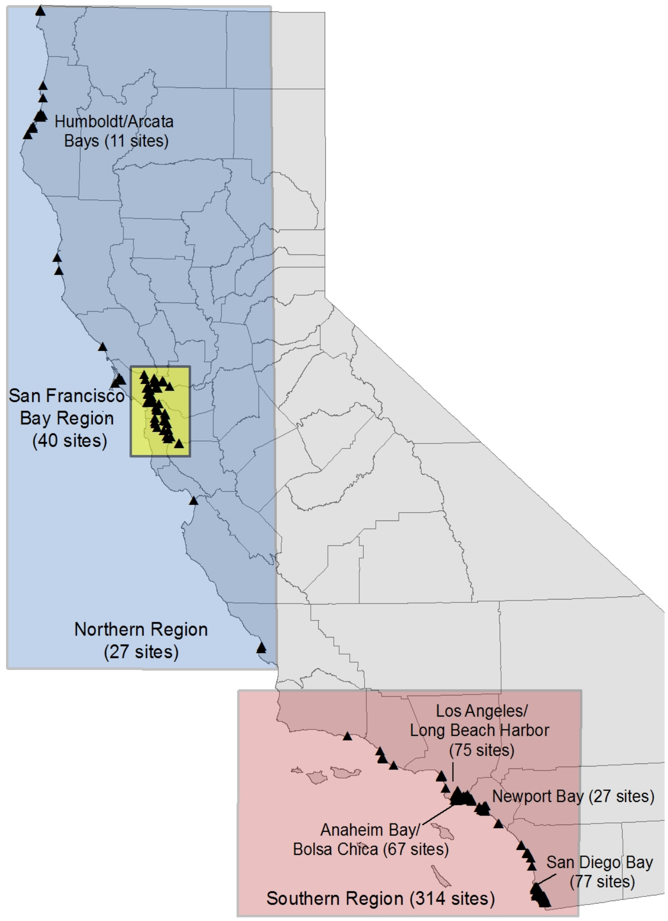

Figure 1. Distribution of sampling sites for the statewide assessment. The shaded boxes indicate the three regional assessment areas.

METHODS

The proposed assessment framework for California's SQOs (SWRCB 2007) was applied to data from multiple random stratified surveys conducted throughout the state to evaluate the sediment quality of marine embayments. The analysis consisted of three parts: 1) determining sediment condition at each sampling station (site) using MLOE response classifications or attributes; 2) establishing a single statewide data set with known spatial attributes based on the integrated data for all stations within each survey; and 3) analyzing the integrated data set using spatial statistics to determine the percentage of area corresponding to each sediment condition category. Spatial analyses were conducted for the state as a whole and regionally for northern California (North), the San Francisco Bay (SFB), and southern California (South).

Data

The statewide and regional estimates of sediment condition were based on data collected from six stratified random surveys with probability-based designs, conducted over eight years (Table 1). Probability-based designs were selected because the area represented by each site was known, allowing sampling results to be expressed as the percent area affected. In addition, each survey met the following criteria: (i) samples were collected within 10 years of the current analysis, (ii) site locations were subtidal areas within bays and estuaries, (iii) corresponding data for sediment chemistry, toxicity, and benthic macrofauna were available, and (iv) sampling and analysis methods were comparable to those specified in the proposed SQO assessment framework. Several recent regional surveys did not meet these criteria and were not used in this study for reasons that included lack of a probability-based design (e.g., San Francisco Bay Regional Monitoring Program) and lack of sediment toxicity data or comparable toxicity/benthic macrofauna measurement methods (e.g., selected Western EMAP (WEMAP) surveys).

Sample collection for each survey was conducted in the summer and used comparable methods; however, the surveys encompassed different years and geographic regions. Two WEMAP surveys examined embayments along the entire California coast in 1999 and 2005, while one survey was limited to San Francisco Bay (2000). Three surveys included only southern California embayments: two examined multiple embayments along the entire southern coast (1998, 2003), while the third was an intensive study of only Huntington Harbor and Anaheim Bay (2001). These surveys followed the USEPA's Generalized Random Tessellation Stratified (GRTS) design with the intent of balancing samples spatially while allowing for intensification in certain areas of interest (http://www.epa.gov/nheerl/arm/designpages/design&analysis.htm).

Table 1. Probability-based surveys and number of sites per region for each survey.

Survey	Year	Area (km^2)	Number of Sites		
			North	SFB	South
Southern California Bight Regional Monitoring Program	1998	122	0	0	113
	2003	135	0	0	102
WEMAP	1999	139	19	0	24
	2000	1020	0	40	0
	2005	139	8	0	15
Huntington Harbor and Anaheim Bay Survey	2001	1.4	0	0	60
Total			27	40	314

Determination of Sediment Condition

Three lines of evidence: sediment chemistry, toxicity, and benthic macrofaunal community condition (benthos) were evaluated at each site. The indices and thresholds described in the draft SQO policy for California were then used to assign sediment assessments to one of four response-level categories relevant to respective LOEs. Details of the specific measures used for each LOE are provided in SWRCB (2007). The LOE responses were then integrated using the assessment framework to determine the level of impact, if any, with respect to sediment contamination for each site. A summary of each LOE and the integration process is provided below.

Lines of Evidence

Chemistry. A combination of two sediment chemistry indices was used to determine the magnitude of chemical exposure at each site: the California Logistic Regression Model (CA LRM) and the Chemical Score Indicator (CSI). The CA LRM was developed using a logistic regression modeling approach that estimates the probability of acute toxicity in sediments based on the chemical concentration (Field *et al.* 2002, USEPA 2005) calibrated using California data (Bay *et al.* 2007a). The CSI was developed using California data and is based on the association of chemical concentration with benthic community disturbance (Ritter *et al*. 2007). Calculation of the CSI differed from Ritter *et al*. (2007) by not including data for cadmium in order to maintain consistency with the SWRCB draft policy. Index-specific thresholds were then applied and resulting CA LRM and CSI exposure categories were averaged to determine an overall response for the chemistry LOE. The response-level categories used to define chemical exposure assessments were:

- **Minimal Exposure** - Sediment-associated contamination may be present, but exposure is unlikely to result in effects.
- **Low Exposure -** Small increase in contaminant exposure that may be associated with increased effects, but magnitude or frequency of occurrence of biological impacts is low.
- **Moderate Exposure** - Clear evidence of sediment contaminant exposure at concentrations that are likely to result in biological effects.
- **High Exposure** - Contaminant exposure is highly likely to result in substantial biological effects.

Toxicity. The 10-day amphipod survival test using *Eohaustorius estuarius* was used to determine the magnitude of sediment toxicity at each site (USEPA 1994). Thresholds based on percentage survival and statistical significance were applied to assign test results to one of the following response-level categories used to define toxicity assessments (Bay *et al*. 2007b):

- **Nontoxic** - Response not substantially different from that in uncontaminated control sediments.
- **Low Toxicity** - A low magnitude response that differs from control survival, but is within the variability typical for that test and thus may not be a reproducible effect.
- **Moderate Toxicity** - High confidence that a statistically significant toxic effect is present.
- **High Toxicity** - High confidence that a toxic effect is present and the magnitude of response includes the strongest effects observed for the test.

Benthos. A combination of up to four benthic community condition indices was used to determine the magnitude of disturbance to the benthos at each site. The indices include approaches based on community metrics and abundance of individual species. The benthic indices used include:

Benthic Response Index (BRI), which was originally developed for the southern California mainland shelf and extended into California's bays and estuaries (Smith *et al.* 2001, 2003). The BRI is the abundance-weighted average pollution tolerance score of organisms occurring in a sample.

Index of Benthic Biotic Integrity (IBI), which was developed for freshwater streams and adapted for California's bays and estuaries (Thompson and Lowe 2004). The IBI identifies community measures that have values outside a reference range.

Relative Benthic Index (RBI), which was originally developed for California's Bay Protection and Toxic Cleanup Program (Hunt *et al.* 2001). The RBI is the weighted sum of: (i) several community metrics, (ii) the abundances of three positive indicator species, and (iii) the presence of two negative indicator species.

River Invertebrate Prediction and Classification System (RIVPACS), which was originally developed for British freshwater streams (Wright *et al.* 1993, Van Sickle *et al.* 2006) and adapted for California's bays and estuaries. The RIVPACS index calculates the number of reference taxa present in the test sample and compares it to the number expected to be present in a reference sample from the same habitat.

Not all indices were used in each region, due to the lack of calibration for some habitats. All four indices were used for most stations in the South (except that RIVPACS data were not available for the Huntington Harbor and Anaheim Bay survey) and portions of SFB. The RBI and IBI were used to evaluate the remainder of the SFB sites. The RBI was used to evaluate all of the North sites.

Thresholds specific to regional assemblages were applied to the results in order to classify each index result according to the level of disturbance. The resulting disturbance categories were then combined to provide an overall benthos LOE category. The four response-level categories used to define benthic condition assessments were:

- **Reference -** A community composition equivalent to a "least affected" or "unaffected" site.
- **Low Disturbance -** A community that shows some indication of stress, but could be within measurement error of unaffected condition.
- **Moderate Disturbance -** Confident that the community shows evidence of physical, chemical, natural, or anthropogenic stress.
- **High Disturbance -** Changes in the benthos are substantial enough to limit community function.

Integration of LOE Response Levels

The response-level categories within each of the three LOEs resulted in 64 possible combinations of outcomes (Appendix A). Each combination was associated with one of six final site condition classes. This was accomplished in a two-step process (Figure 2). Individual LOEs were first combined to form two intermediate classifications describing (i) the severity of biological effects and (ii) the potential for chemically mediated biological effects. These intermediate classifications were then integrated to determine the final MLOE assessment of site condition.

The benthos and toxicity LOEs were integrated to determine the severity of biological effects category for the site: Unaffected, Low Effect, Moderate Effect, or High Effect. The benthos LOE was given greater weight for determining this classification, as the benthic community is the resource to be protected. Moreover, the severity of effects classification reflects disturbance to the benthic community due to a variety of causes and is not intended to differentiate between effects that are due to chemical contaminants, physical disturbance of the habitat, or organic enrichment.

The potential for chemically mediated effects was determined using the toxicity and chemistry LOE categories data. These data were integrated to assign samples into one of four classifications describing the potential that the observed biological effects were caused by chemical contaminants: Minimal Potential, Low Potential, Moderate Potential, or High

Potential. The chemistry LOE was given slightly greater weight in determining this classification. The toxicity LOE was included in this classification because sediment toxicity is a measure of the bioavailability of sediment contaminants and also indicates whether unmeasured chemicals are present at levels of potential biological concern. The relationship of each LOE category to the intermediate response classifications is shown in Appendix A.

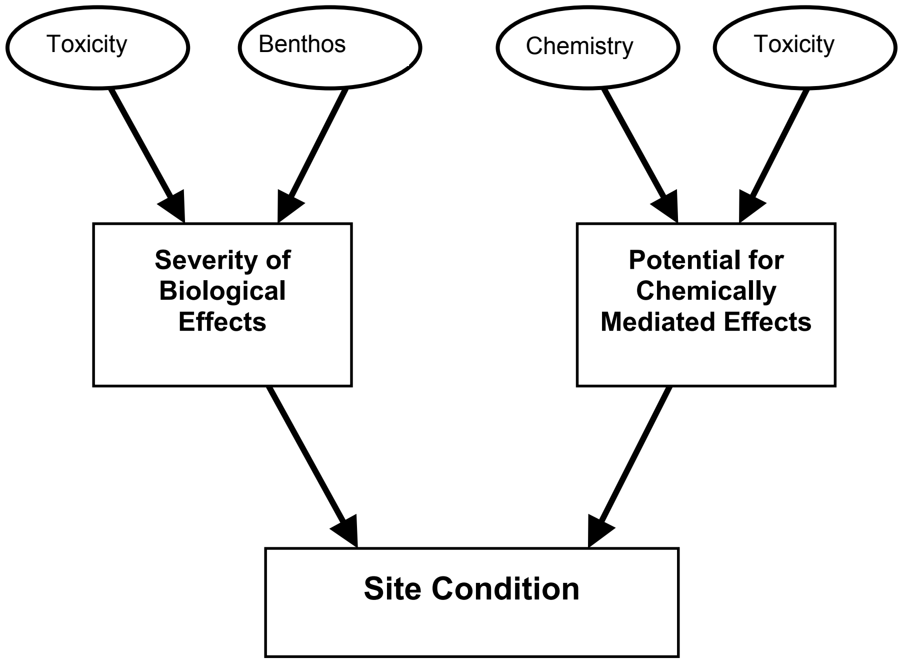

Figure 2. MLOE integration for site assessment.

The final MLOE site condition categories (Table 2; Appendix A) were based on the severity level of biological effects and the potential for chemically mediated effects. Six assessment classes were developed to describe the contaminant impact in terms of level of certainty and magnitude:

- **Unimpacted.** Confident that chemical contamination is not causing significantly adverse impacts to aquatic life in the sediment.
- **Likely Unimpacted**. Chemical contamination is not expected to cause adverse impacts to aquatic life in the sediment, but some disagreement among the LOEs reduces certainty that the site is Unimpacted.
- **Possibly Impacted.** Chemical contamination at the site may be causing adverse impacts to aquatic life in the sediment, but the level of impacts is uncertain because of disagreement between LOEs.
- **Likely Impacted.** Evidence of contaminant-related impacts to aquatic life in the site sediment is persuasive, in spite of possible disagreement among LOEs.
- **Clearly Impacted.** Sediment chemical contamination at the site is causing clear and significantly adverse impacts to aquatic life in the sediment.

- **Inconclusive.** Disagreement among the LOEs suggests that either data are suspect or additional information is needed for classification.

Two central concepts were incorporated in the determination of the impact categories: (i) both exposure and effect must be present in order to classify a site as impacted and (ii) a greater magnitude of effect or exposure results in a more severe impact assessment category.

Table 2. Relationship of intermediate LOE classifications to final MLOE site condition categories. Arrows indicate the sequence of classification. The site condition assessment resulting from each possible LOE combination is shown in Appendix A.

Potential for Chemically Mediated Effects	Condition Category	Severity of Biological Effects
High Potential	Clearly Impacted	High Effect
High Potential	Clearly Impacted	Moderate Effect
High Potential	Likely Impacted	Low Effect
Moderate Potential	Likely Impacted	High Effect
Moderate Potential	Likely Impacted	Moderate Effect
Low Potential	Possibly Impacted	High Effect
Low Potential	Possibly Impacted	Moderate Effect
Moderate Potential	Possibly Impacted	Low Effect
Minimal Potential	Likely Unimpacted	Moderate Effect
Minimal Potential	Likely Unimpacted	Low Effect
Low Potential	Likely Unimpacted	Low Effect
Moderate Potential	Likely Unimpacted	Unaffected
Minimal Potential	Unimpacted	Unaffected
Low Potential	Unimpacted	Unaffected
High Potential	Inconclusive	Unaffected
Minimal Potential	Inconclusive	High Effect
Moderate Potential	Inconclusive[1]	Low Effect

[1] Inconclusive category results when High toxicity, Minimal chemical exposure, and a Reference benthic community are present.

Determination of Percent Area of California Embayments for Each Site Condition Category

The random stratified sampling design for each of the six surveys considered in this study consisted of three main components used for tesselation: a sampling frame, stratification, and polygons. The sampling frame represented the boundaries of the survey. Some surveys included strata (e.g., ports, marinas), while no stratification was used in others. Different polygons (subregions within a stratum) were used to constrain sample point distribution or control sample density. Consequently, the area weights (proportional to the number of sites within a stratum) of individual sample points varied greatly between surveys.

In order to conduct a statewide assessment that was spatially representative, the survey designs were combined to produce a common sampling frame and level of stratification. Three strata (regions) were established: North, SFB, and South. Within each region, the polygons representing survey-specific sampling frames and different sample densities were compared for each survey and a single set of polygons were drawn that included all of the combined area sampled. New area weights were calculated for the sites within each region by dividing the area of each final polygon by the number of sites within the area. Figure 3 provides an example of combining survey data points and sampling polygons for Newport Bay in the South region.

Two years of survey data were combined for the North: WEMAP 1999 and WEMAP 2005. No stratification was used for the data from the 2005 survey. As a result, we used the polygons from the 1999 survey and recalculated area weights based on the number of samples from both surveys falling within these polygons. For San Francisco Bay, there was only one survey, WEMAP 2000, therefore no adjustment of polygons or area weights were needed.

In the South, combining the data and calculating new area weights were more complex, as five surveys were integrated. Polygons that overlapped among surveys were split into subpolygons that reflected disjoint areas. New area weights were calculated by dividing the area of each subpolygon by the number of samples that fell into that subpolygon, regardless of survey.

Estimates of the percent area representing various sediment condition classifications were calculated using the new area weights. The proportion of each region representing each MLOE condition category was calculated as the sum of the area weights of the samples that fell into that category divided by the sum of the area weights for all samples within the region. This proportion was then converted to a percentage. The area (km^2) represented by this percentage was calculated by multiplying the proportion by the total area of the region. Confidence intervals for these estimates were computed using the local variance estimator option in the EPA analysis tools (Stevens and Olsen 2003, http://www.epa.gov/nheerl/arm/designpages/design&analysis.htm).

Statewide estimates of condition were calculated in the same manner used for the regional estimates. The area weights of sites having the same MLOE sediment condition classification in all regions were summed and then divided by the sum of the area weights in all regions. This calculation was repeated for each MLOE site condition category. The statewide area corresponding to each an MLOE condition category was calculated by multiplying the proportion by the total area of the three regions.

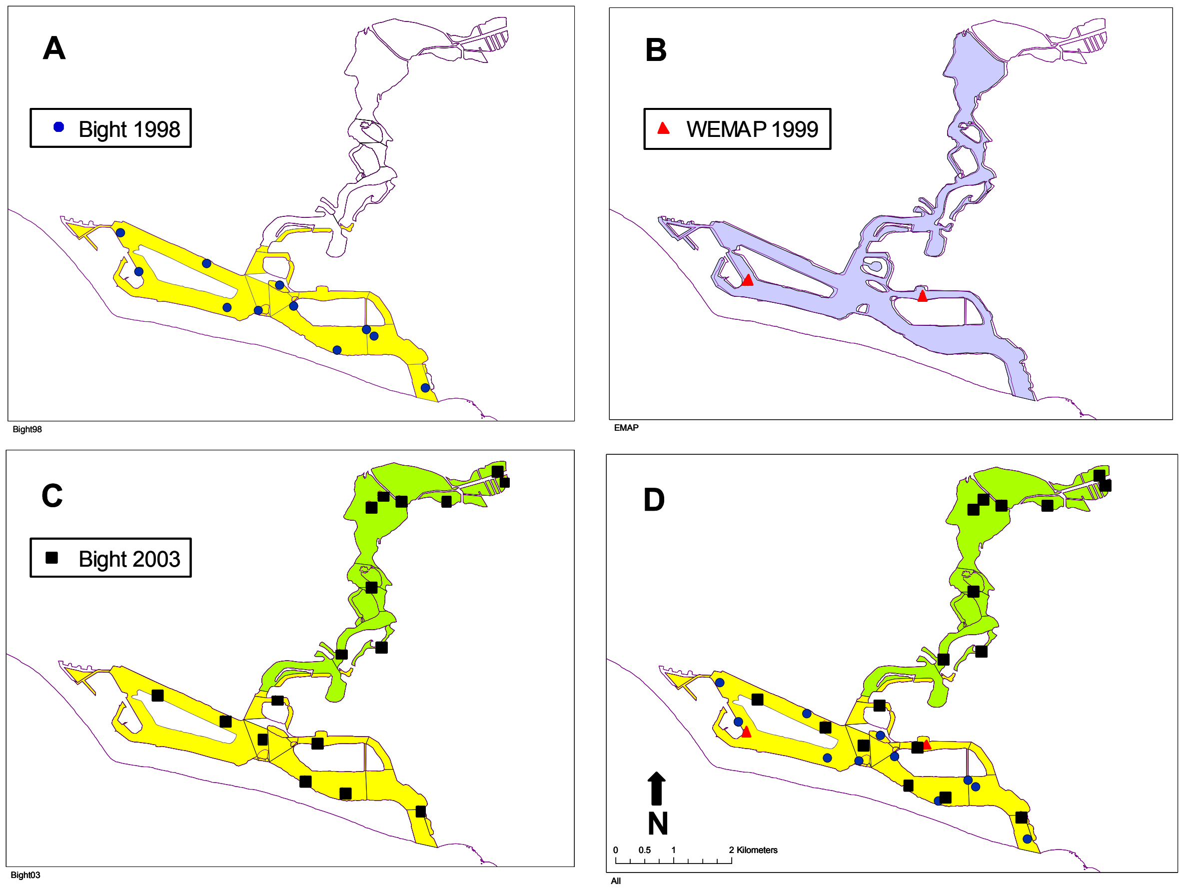

Figure 3. Combination of data from multiple surveys (illustrated for Newport Bay). Sampling polygon and data points for Southern California Bight Regional Monitoring Program 1998 survey restricted to lower bay (A). Sampling polygon and data points for WEMAP 1999 survey (B). Southern California Bight Regional Monitoring Program 2003 sample points associated with two separate polygons representing different sampling intensities (C). Combined data from all surveys associated with two polygons representing entire area sampled (D).

RESULTS

Statewide Assessment of Sediment Quality

Approximately 83% of the 1295 km^2 of California marine embayments included in the analysis was classified as having some degree of impact related to sediment contamination. Most of the area was classified as Possibly Impacted, the most uncertain classification, and less than 1% of the area was classified as Clearly Impacted, the most severe impact category (Figure 4; Table 3). The statewide analysis results were dominated by the conditions present in SFB, which represented nearly 80% of the embayment area.

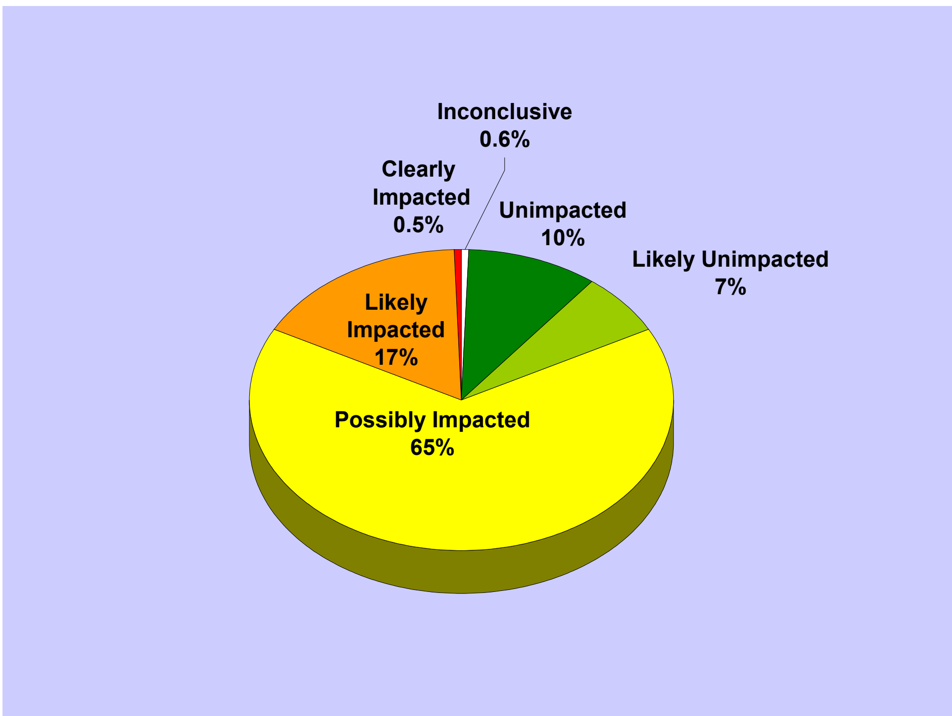

Figure 4. Percent area of California embayments for each sediment condition category as classified by the MLOE assessment framework.

Table 3. Statewide embayment sediment quality condition based on MLOE assessment. Further details on confidence limits and areas represented by each condition classification can be found in Appendix B.

Condition Category	Number of Sites	Percent Area	0.95 Confidence Limits
Unimpacted	131	10%	8 – 12%
Likely Unimpacted	57	7%	2 – 12%
Possibly Impacted	111	65%	55 – 76%
Likely Impacted	51	17%	7 – 26%
Clearly Impacted	25	0.5%	0 – 1%
Inconclusive	6	0.6%	0 – 1%
Total	381	100%	

Regional Assessment of Sediment Quality

Large variations in sediment condition were present among the three geographic regions. The North region had the best sediment condition, with 58% of the area classified as Unimpacted and no sites in the Clearly Impacted category (Figure 5; Table 4). Somewhat poorer sediment quality was observed in the South, with 43% of the area classified as Unimpacted and 2% classified as Clearly Impacted. A different distribution of sediment condition categories was present in San Francisco Bay; no stations were classified as Unimpacted and the proportion of area assigned to the Possibly Impacted category (77%) was more than three times greater than that measured in the other regions. The uncertainty in condition estimates varied among regions as a function of sample size. The estimates were most precise for the South, with 95th percentile confidence intervals of about 10%; confidence intervals for SFB and the North were usually two to three times greater (Table 4).

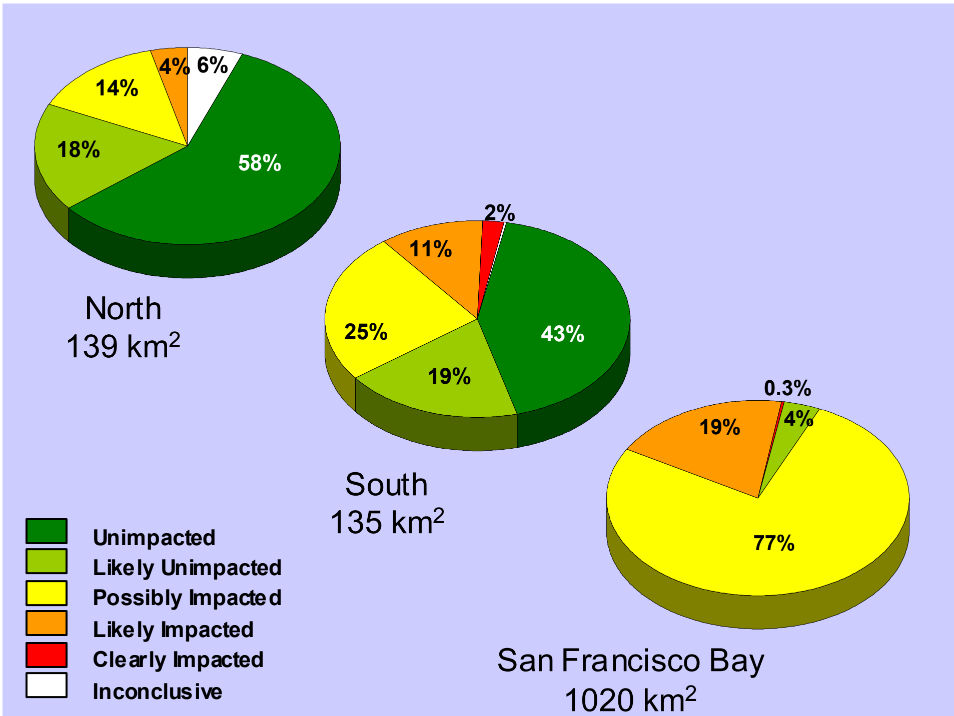

Figure 5. Percent area of sediment quality classification for regional MLOE assessments.

Table 4. Regional embayment sediment quality condition based on MLOE assessment. Further details on confidence limits and areas represented by each condition classification can be found in Appendix B.

Condition Category	Number of Sites	Percent Area	0.95 Confidence Limits
North			
Unimpacted	9	58%	37 – 80%
Likely Unimpacted	9	18%	1 – 34%
Possibly Impacted	4	14%	0 – 29%
Likely Impacted	2	4%	0 – 9%
Clearly Impacted	0	0%	-
Inconclusive	3	6%	0 – 12%
Total	27	100%	
SFB			
Unimpacted	0	0%	-
Likely Unimpacted	2	4%	0 – 10%
Possibly Impacted	28	77%	64 – 89%
Likely Impacted	9	19%	7 – 31%
Clearly Impacted	1	0.3%	0 – 1%
Inconclusive	0	0%	-
Total	40	100%	
South			
Unimpacted	122	43%	36 – 49%
Likely Unimpacted	46	19%	13 – 25%
Possibly Impacted	79	25%	19 – 30%
Likely Impacted	40	11%	7 – 15%
Clearly Impacted	24	2%	1 – 3%
Inconclusive	3	0.3%	0 – 0.6%
Total	314	100%	

Sediment Condition in Individual Embayments

A total of 381 sites were assessed in this study. Eight embayments contained 84% of the data and had sufficient numbers of sites to examine spatial patterns of condition within them (Figure 6; LOE combinations that resulted in the designated impact condition at each site are presented in Appendix C). Patterns of sediment condition could not be described for many of the small embayments because only one or two sites were located within them.

Two major spatial patterns of site condition were evident among the selected embayments. First, there was a greater proportion of Likely Impacted and Clearly Impacted sites in inner harbor and marina areas (e.g., Los Angeles and Huntington Harbors). Second, the more impacted sites tended to be located near the perimeters of the embayments where ports or commercial areas are situated (e.g., San Francisco and San Diego Bays).

Locations having the greatest severity of impacts (Clearly and Likely Impacted) were Huntington Harbor (a marina) and inner Los Angeles Harbor including Dominguez Channel. Sediment conditions were better at the deeper locations in Outer Los Angeles and Long Beach Harbors and outer Anaheim Bay, presumably due to increased distance from sources and better circulation. Similar trends were observed in the deeper waters of mid- and northern San Diego Bay, and Alamitos Bay. Typical of the North, most of the sites in Humboldt Bay were classified as Unimpacted or Likely Unimpacted (Figure 6).

Sites having Likely Impacted and Possibly Impacted sediment quality were most prevalent in Newport Bay and San Francisco Bay (Figure 6). Each of these embayments had over 80% of sites classified as either Likely Impacted or Possibly Impacted.

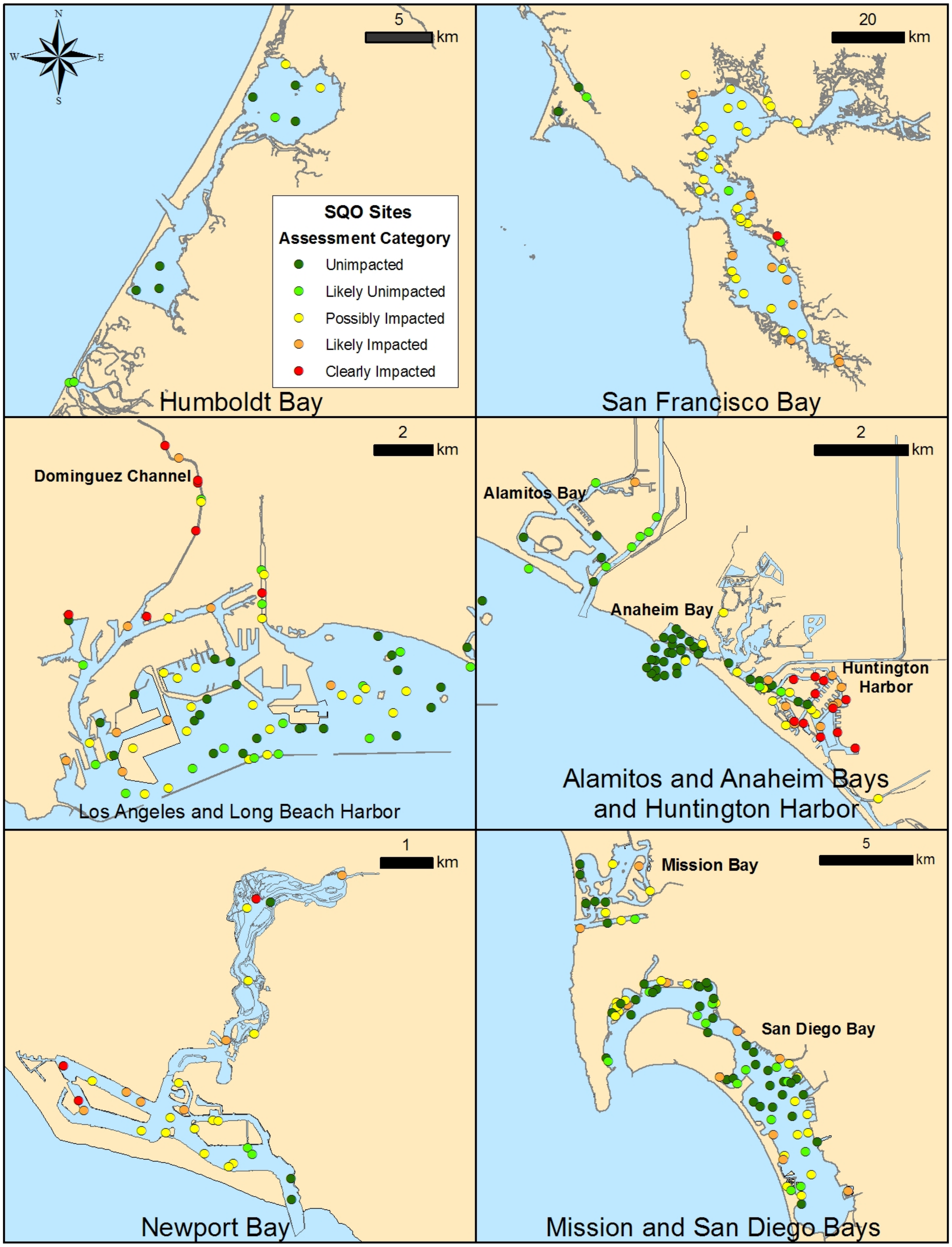

Figure 6. Sediment quality in selected California embayments. Further details for each site in these embayments are shown in Appendix C.

DISCUSSION

Sediment quality was found to be highly variable among California's marine and estuarine embayments. The SFB region had seven and one-half times the area of either the North or the South regions. As a result, the statewide assessment of condition in California embayments was dominated by the condition of SFB. A more representative view of the status of California's bays and estuaries was obtained from the regional analyses (Figure 5; Table 4), which found northern embayments to be the least impacted, and southern embayments to be less impacted than SFB. However, in contrast to the North and South, most of the SFB region was assessed as Possibly Impacted.

This study used an integrated analysis based on a novel MLOE assessment framework, resulting in a more spatially and temporally comprehensive and standardized analysis than previous studies of sediment quality in California bays and estuaries. Nevertheless, the results of this study are consistent with prior analyses. An assessment of coastal condition in 1999 (that included the WEMAP 1999 data used in the present study) found low levels of metal and organic contamination in embayments in the North and South regions (USEPA 2005). The 1999 survey also measured a similar extent of sediment toxicity to *E. estuarius* (19 - 24% of the area) as the present assessment.

The high prevalence in the South of sediment with Possibly, Likely, or Clearly Impacted conditions is consistent with previous studies by BPTCP. The BPTCP surveys also found a high frequency of sediment toxicity to amphipods, benthic community degradation, and elevated contaminant concentrations in multiple Southern embayments, including San Diego Bay, Newport Bay, Huntington Harbor, and Los Angeles Harbor (Fairey *et al.* 1998, Phillips *et al.* 1998, Anderson *et al.* 2001). The BPTCP program had different objectives, however, and focused on identifying the most highly impacted sites.

The widespread toxicity reported for SFB has been documented in BPTCP and regional monitoring studies since the 1980s (Anderson *et al.* 2007). While the spatial extent of toxicity calculated from the SFB data analyzed in this study appears to be somewhat larger than that found in the other studies, certain locations in SFB are consistently toxic to *E. estuarius* and other species. Prior studies have also observed benthic community degradation and reduced populations of localized clam species in portions of San Francisco Bay, with the greatest impacts associated with shallow water locations (Thompson *et al.* 2007).

SFB had a greater percentage of area in the Likely Impacted and Possibly Impacted condition than in the South where a greater portion of the area was classified in the most extreme category of Clearly Impacted (Figure 5). Whereas southern California is an area of greater industrial, commercial, and population concentration, the pattern in SFB suggests that sediment contaminants are more widespread and less concentrated, possibly due to contaminant dilution and redistribution as a result of greater rainfall, runoff, and tidal mixing.

Relationships Among LOEs

Because SFB sediment quality was so different from that in the North or South, further analyses and regional comparisons were conducted to investigate the results. The regional differences in sediment quality identified by the MLOE assessment were evaluated by analysis of the underlying lines of evidence (Chemistry, Toxicity, and Benthic Community). The percentage of area classified as having Moderate or High effects (i.e., affected) for each LOE were calculated for each region (Table 5). Sediment chemistry showed the lowest level of response in the North (1%) and greater impacts in the South and SFB. The North also had a low percentage of area with elevated toxicity (Table 5); however, a moderately high percentage of the area was classified as having affected benthos. This combination of results suggests that the benthos in the North might be affected by physical disturbance or noncontaminant stressors or that our indices are less well calibrated in this region.

The greater proportion of area with Possibly Impacted or Likely Impacted designations in SFB (Figure 5) was reflective of large percentages of this region's total area having either affected benthos or toxicity (Table 5; Appendix C). With lower percentages of areas of the South in the affected categories for benthos and toxicity (relative to SFB) and a moderate percentage affected for chemistry, the MLOE assessment framework seemed consistent in classifying most of the South as Unimpacted or Likely Unimpacted, although to a lesser degree than in the North (Figure 5). Thus, the patterns of individual LOE responses found in each region were consistent with the regional percentage area results.

Table 5. Percent of area affected for each LOE. Area 'Affected' = sum of percent area classified as moderate and high response categories.

	Percent Area Affected Per LOE		
Region	**Benthos**	**Toxicity**	**Chemistry**
North	27	17	1
SFB	34	85	20
South	23	28	40

There appeared to be a different relationship between chemistry and toxicity for the South and SFB. San Francisco Bay had high incidences of affected benthos and toxicity relative to the South, yet the extent of chemical contamination was lower in general (Table 5). The difference in this relationship is evident when the magnitude of toxicity (percent mortality) in a sample is compared to the magnitude of contamination between the regions (Figure 7). San Francisco Bay sediments tend to produce a greater toxic response than southern California sediments at similar levels of contamination (as represented by the CA LRM Pmax value). As the causes of toxicity in the South and San Francisco Bay were not identified in this study, the reason for this apparent difference in toxicity response cannot be determined. Unmeasured contaminants, such as current use pesticides, may be influencing these relationships. Prior studies in San Francisco Bay have shown a correlation between biological impacts and sediment contamination in general, but a specific chemical cause for the majority of the effects has yet to be identified (Thompson *et al.* 2007). It is also possible that regional differences in contaminant bioavailability or contamination patterns are affecting the relationship between chemistry and toxicity.

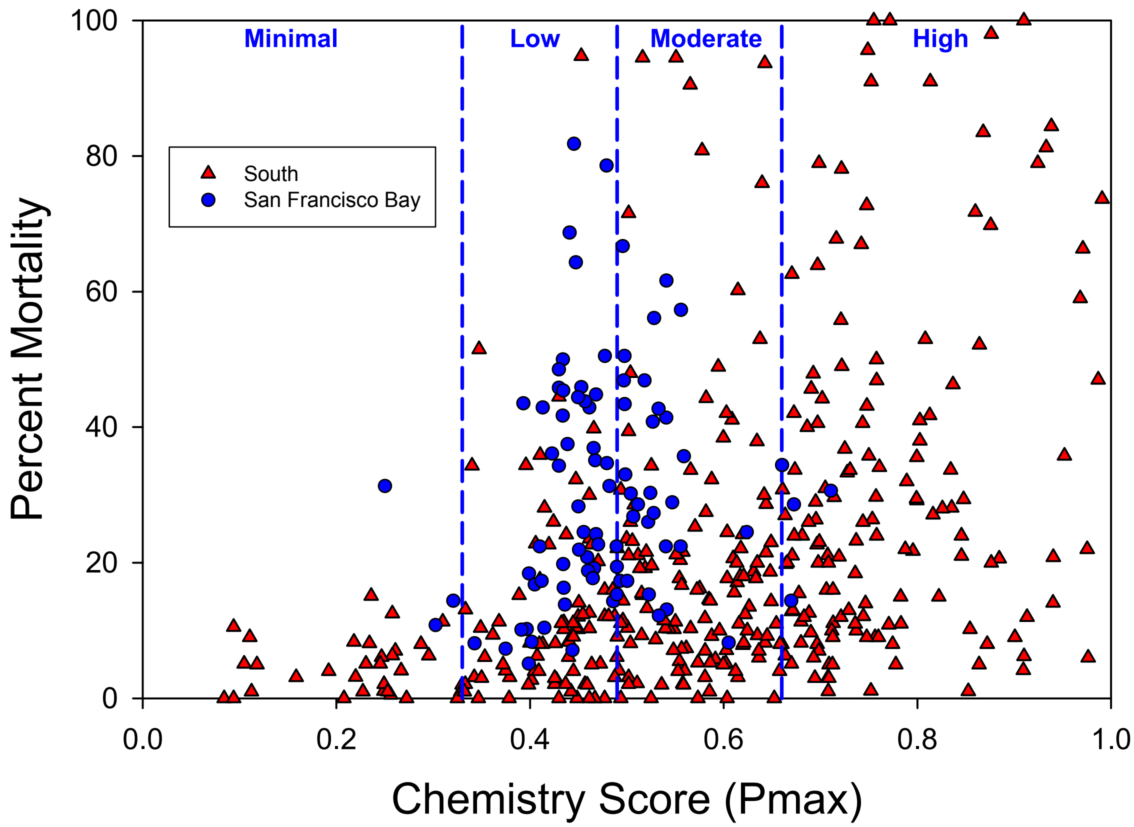

Figure 7. Toxicity:chemistry relationships in the South and SFB regions. The chemistry score is the CA LRM maximum probability of toxicity; dashed lines indicate the probability thresholds for the four response-level categories of chemical exposure.

Sources of Uncertainty

This assessment utilized a new approach and there are several sources of uncertainty in the results. First, the indices used to classify benthic community condition varied among regions due to a lack of habitat-specific calibration data for some of the indices. Four indices were used in the South, whereas only one index (RBI) was available for the North. Four benthic indices were also used in central SFB, but only the RBI and IBI were available for use in interpreting data from San Pablo Bay and the south Bay. All available indices were used wherever possible, as analyses have shown that the use of multiple indices gives a more accurate assessment of benthic community condition (Ranasinghe *et al.* 2007). To test the effect of using various combinations of benthic indices on the classifications, the analyses were repeated using only the RBI to classify benthic community condition in each region. While the percent of area classified as having affected benthos was increased when only the RBI was used, the effect on the overall sediment condition assessment was minor (Table 6).

The high abundance of nonindigenous species in SFB is another source of uncertainty in the benthic community evaluation. The effect of nonindigenous species on the assessments is expected to be small, since these species were included in the calibration of SFB benthic indices and prior analyses of southern California data indicate they do not confound the benthic index results. However, a detailed study to investigate the influence of nonindigenous species on the performance of the SFB benthic indices has not been conducted.

Table 6. Variability among regional area estimates based on benthic indices applied.

Region	Benthic Indices Applied	Benthos (% Moderate or High Disturbance)	MLOE (% Possibly, Likely, or Clearly Impacted)
North	All	27	18
North	RBI only	27	18
SFB	All	34	96
SFB	RBI only	85	100
South	All	23	38
South	RBI only	36	40

Another source of uncertainty is the limited number of sites available to characterize sediment quality in the North and SFB. In the present study, only 40 sites from a single survey were used in the SFB assessment, and only 27 sites were available to represent the North. Consequently, individual sites in the North and SFB had much greater area weights and a greater influence on the results than did individual sites in the South. This resulted in larger confidence intervals for the North and SFB area assessments (Table 4; Appendix B). However, even with these large intervals, statistically significant differences were observed between regions for some sediment condition categories.

A final source of uncertainty is related to the toxicity assessment. The results are based on only a single test of sediment toxicity: the 10-day amphipod survival test. While this is a widely used measure of sediment quality, the use of multiple tests is recommended for sediment quality assessment (Burton, Jr. *et al.* 1996, Greenstein *et al.* In press); the SQO assessment framework is intended to be used with at least two tests. The impact of using a single test in this assessment is unknown, but a greater proportion of the samples might have been identified as toxic if additional tests, especially those that measure sublethal effects, had been used.

Conclusions and Recommendations

The integration of multiple surveys and use of a standardized assessment framework provided a more comprehensive and robust assessment of California embayment sediment quality than has been achieved previously. This assessment yielded results that were consistent with expectations based on earlier studies, thus increasing confidence in the overall accuracy of the sediment condition assessments.

The SQO assessment approach used in this study provides a highly comparable and reproducible measure of sediment condition throughout the State. This approach identified regional differences is sediment condition and potentially different relationships between chemistry and toxicity that can only be detected by a statewide survey. Consequently, this evaluation of sediment condition at both statewide and regional scales can be used as a guide for prioritizing further research and management actions, as well as establishing a benchmark for future assessments.

Future statewide and regional assessments can be improved in several ways. The precision and confidence in the assessment can be improved by sampling more sites in SFB and North using methods that are compatible with the MLOE assessment framework. Future studies should also include multiple toxicity tests and benthic indices in order to provide greater confidence in the measurement of these lines of evidence. The environmental significance of sediments classified as Possibly Impacted is uncertain, as this category may indicate a minor level of contaminant effect, or substantial disagreement among the LOEs. Stressor identification studies, such as toxicity identification evaluations, are needed at Possibly Impacted sites to determine whether sediment quality at these sites is adversely impacted by contaminants.

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APPENDIX A. RELATION OF LOE CATEGORIES TO SQO MLOE ASSESSMENTS

Table A.1. Relationship of LOE response-level categories to intermediate classifications and final MLOE assessment site condition categories. Arrows indicate the sequence of classification.

Toxicity	Chemistry Exposure	Potential for Chemically Mediated Effects	Site Condition Category	Severity of Biological Effects	Benthic Disturbance	Toxicity
High	High	**High Potential**	**Clearly Impacted**	**High Effect**	High	High
Moderate	High	**High Potential**	**Clearly Impacted**	**High Effect**	High	Moderate
High	High	**High Potential**	**Clearly Impacted**	**Moderate Effect**	Moderate	High
Moderate	High	**High Potential**	**Clearly Impacted**	**Moderate Effect**	Moderate	Moderate
High	High	**High Potential**	**Likely Impacted**	**Low Effect**	Low	High
Moderate	High	**High Potential**	**Likely Impacted**	**Low Effect**	Low	Moderate
High	High	**High Potential**	**Likely Impacted**	**Low Effect**	Reference	High
High	Moderate	**Moderate Potential**	**Likely Impacted**	**High Effect**	High	High
Moderate	Moderate	**Moderate Potential**	**Likely Impacted**	**High Effect**	High	Moderate
Low	High	**Moderate Potential**	**Likely Impacted**	**High Effect**	High	Low
High	Low	**Moderate Potential**	**Likely Impacted**	**High Effect**	High	High
High	Minimal	**Moderate Potential**	**Likely Impacted**	**High Effect**	High	High
Moderate	Low	**Moderate Potential**	**Likely Impacted**	**High Effect**	High	Moderate
Low	Moderate	**Moderate Potential**	**Likely Impacted**	**High Effect**	High	Low
High	Low	**Moderate Potential**	**Likely Impacted**	**Moderate Effect**	Moderate	High
High	Minimal	**Moderate Potential**	**Likely Impacted**	**Moderate Effect**	Moderate	High
Low	Moderate	**Moderate Potential**	**Likely Impacted**	**Moderate Effect**	Moderate	Low
Moderate	Low	**Moderate Potential**	**Likely Impacted**	**Moderate Effect**	Moderate	Moderate
Low	Moderate	**Moderate Potential**	**Likely Impacted**	**Moderate Effect**	Moderate	Low
High	Moderate	**Moderate Potential**	**Likely Impacted**	**Moderate Effect**	Moderate	High
Moderate	Moderate	**Moderate Potential**	**Likely Impacted**	**Moderate Effect**	Moderate	Moderate
Nontoxic	High	**Moderate Potential**	**Likely Impacted**	**Moderate Effect**	High	Nontoxic
Low	High	**Moderate Potential**	**Likely Impacted**	**Moderate Effect**	Moderate	Low
Nontoxic	High	**Moderate Potential**	**Likely Impacted**	**Moderate Effect**	Moderate	Nontoxic

Table A.1 Continued

Toxicity	Chemistry Exposure	Potential for Chemically Mediated Effects	Site Condition Category	Severity of Biological Effects	Benthic Disturbance	Toxicity
Moderate	Minimal	**Low Potential**	**Possibly Impacted**	**High Effect**	High	Moderate
Low	Low	**Low Potential**	**Possibly Impacted**	**High Effect**	High	Low
Nontoxic	Moderate	**Low Potential**	**Possibly Impacted**	**Moderate Effect**	High	Nontoxic
Nontoxic	Moderate	**Low Potential**	**Possibly Impacted**	**Moderate Effect**	Moderate	Nontoxic
Moderate	Minimal	**Low Potential**	**Possibly Impacted**	**Moderate Effect**	Moderate	Moderate
Low	Low	**Low Potential**	**Possibly Impacted**	**Moderate Effect**	Moderate	Low
Moderate	Low	**Moderate Potential**	**Possibly Impacted**	**Low Effect**	Low	Moderate
Moderate	Moderate	**Moderate Potential**	**Possibly Impacted**	**Low Effect**	Low	Moderate
Low	High	**Moderate Potential**	**Possibly Impacted**	**Low Effect**	Low	Low
High	Minimal	**Moderate Potential**	**Possibly Impacted**	**Low Effect**	Low	High
High	Low	**Moderate Potential**	**Possibly Impacted**	**Low Effect**	Low	High
High	Moderate	**Moderate Potential**	**Possibly Impacted**	**Low Effect**	Low	High
High	Low	**Moderate Potential**	**Possibly Impacted**	**Low Effect**	Reference	High
High	Moderate	**Moderate Potential**	**Possibly Impacted**	**Low Effect**	Reference	High
Nontoxic	Minimal	**Minimal Potential**	**Likely Unimpacted**	**Moderate Effect**	Moderate	Nontoxic
Nontoxic	Minimal	**Minimal Potential**	**Likely Unimpacted**	**Moderate Effect**	High	Nontoxic
Nontoxic	Low	**Minimal Potential**	**Likely Unimpacted**	**Moderate Effect**	Moderate	Nontoxic
Nontoxic	Low	**Minimal Potential**	**Likely Unimpacted**	**Moderate Effect**	High	Nontoxic
Low	Minimal	**Minimal Potential**	**Likely Unimpacted**	**Moderate Effect**	Moderate	Low
Low	Minimal	**Minimal Potential**	**Likely Unimpacted**	**Low Effect**	Low	Low
Moderate	Minimal	**Low Potential**	**Likely Unimpacted**	**Low Effect**	Low	Moderate
Low	Low	**Low Potential**	**Likely Unimpacted**	**Low Effect**	Low	Low
Nontoxic	High	**Moderate Potential**	**Likely Unimpacted**	**Unaffected**	Reference	Nontoxic
Nontoxic	High	**Moderate Potential**	**Likely Unimpacted**	**Unaffected**	Low	Nontoxic
Moderate	Low	**Moderate Potential**	**Likely Unimpacted**	**Unaffected**	Reference	Moderate
Moderate	Moderate	**Moderate Potential**	**Likely Unimpacted**	**Unaffected**	Reference	Moderate
Low	Moderate	**Moderate Potential**	**Likely Unimpacted**	**Unaffected**	Reference	Low
Low	High	**Moderate Potential**	**Likely Unimpacted**	**Unaffected**	Reference	Low

Table A.1 Continued

Toxicity	Chemistry Exposure		Potential for Chemically Mediated Effects		Site Condition Category		Severity of Biological Effects		Benthic Disturbance	Toxicity
Nontoxic	Minimal		**Minimal Potential**		**Unimpacted**		**Unaffected**		Reference	Nontoxic
Nontoxic	Minimal		**Minimal Potential**		**Unimpacted**		**Unaffected**		Low	Nontoxic
Nontoxic	Low		**Minimal Potential**		**Unimpacted**		**Unaffected**		Reference	Nontoxic
Nontoxic	Low		**Minimal Potential**		**Unimpacted**		**Unaffected**		Low	Nontoxic
Low	Minimal		**Minimal Potential**		**Unimpacted**		**Unaffected**		Reference	Low
Moderate	Minimal		**Low Potential**		**Unimpacted**		**Unaffected**		Reference	Moderate
Nontoxic	Moderate		**Low Potential**		**Unimpacted**		**Unaffected**		Reference	Nontoxic
Nontoxic	Moderate		**Low Potential**		**Unimpacted**		**Unaffected**		Low	Nontoxic
Low	Low		**Low Potential**		**Unimpacted**		**Unaffected**		Reference	Low
Moderate	High		**High Potential**		**Inconclusive**		**Unaffected**		Reference	Moderate
Low	Minimal		**Minimal Potential**		**Inconclusive**		**High Effect**		High	Low
High	Minimal		**Moderate Potential**		**Inconclusive**		**Low Effect**		Reference	High

APPENDIX B. CALIFORNIA SQO ASSESSMENT RESULTS

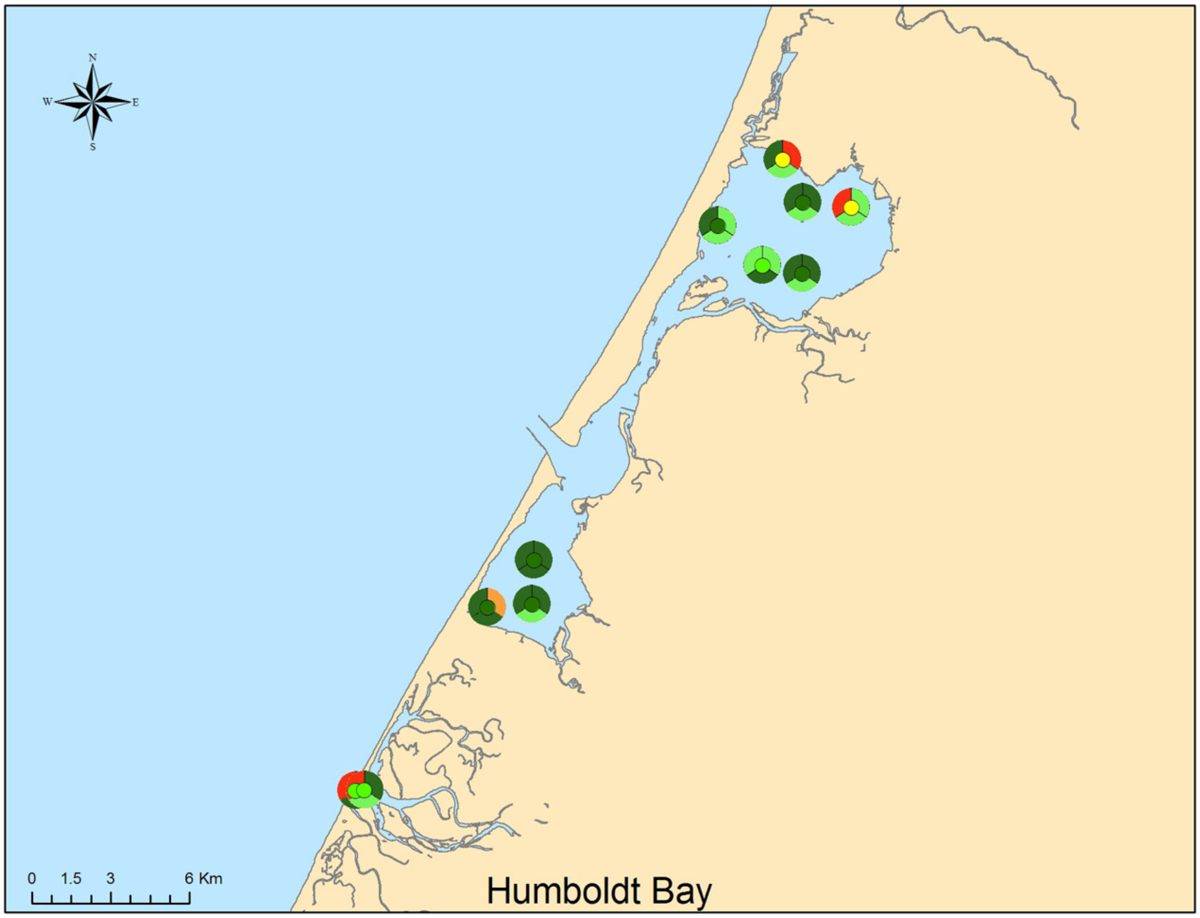
Table B.1. Statewide embayment sediment quality condition with confidence limits of the percent area and estimated area for each MLOE classification.

Area	Condition Category	No. of Sites	Estimated Portion (%)	0.95 LCB (%)	0.95 UCB (%)	Estimated Area (km^2)	0.95 LCB (km^2)	0.95 UCB (km^2)
Statewide	Unimpacted	131	10.0	7.9	12.2	129.5	101.7	157.4
Statewide	Likely Unimpacted	57	6.7	1.7	11.8	87.3	21.4	153.1
Statewide	Possibly Impacted	111	65.4	55.3	75.5	847.1	716.2	978.1
Statewide	Likely Impacted	51	16.8	7.1	26.4	217.4	92.3	342.5
Statewide	Clearly Impacted	25	0.5	0.0	1.0	6.3	0.2	12.5
Statewide	Inconclusive	6	0.6	0.0	1.2	7.4	0.0	15.5
Total		381	100			1295.1		

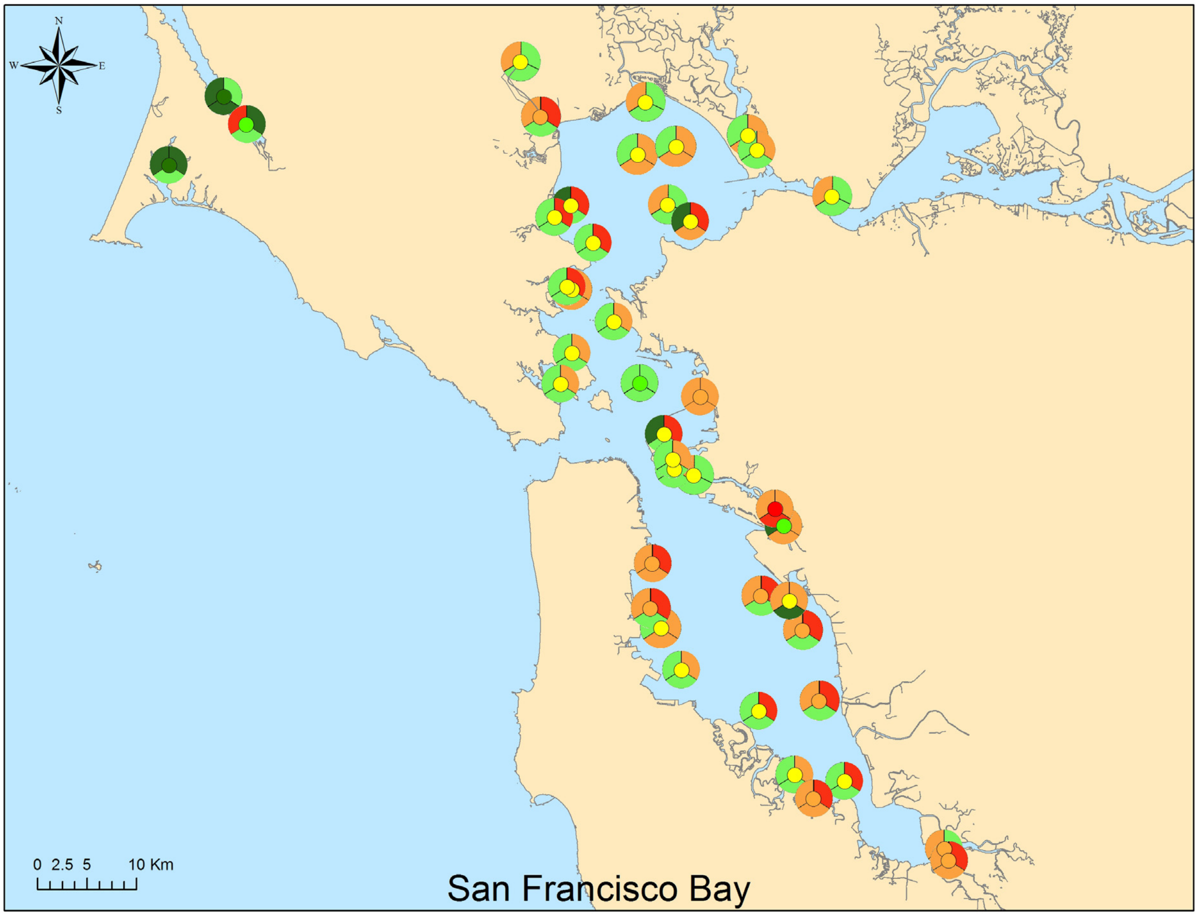
Table B.2. Regional embayment sediment quality condition with confidence limits of the percent area and estimated area for each MLOE classification.

Regional Area	Condition Category	No. of Sites	Estimated Portion (%)	0.95 LCB (%)	0.95 UCB (%)	Estimated Area (km^2)	0.95 LCB (km^2)	0.95 UCB (km^2)
North	Unimpacted	9	58.5	37.0	79.9	81.4	51.5	111.3
North	Likely Unimpacted	9	17.6	1.3	34.0	24.5	1.8	47.3
North	Possibly Impacted	4	14.4	0.0	29.2	20.1	0.0	40.6
North	Likely Impacted	2	3.8	0.0	8.7	5.2	0.0	12.1
North	Clearly Impacted	0	0.0	0.0	0.0	0.0	0.0	0.0
North	Inconclusive	3	5.8	0.0	12.3	8.0	0.0	17.1
Total		27	100.0			139.3		
SFB	Unimpacted	0	0.0	0.0	0.0	0.0	0.0	0.0
SFB	Likely Unimpacted	2	3.9	0.0	9.9	39.6	0.0	100.8
SFB	Possibly Impacted	28	76.7	64.3	89.2	783.1	655.7	910.3
SFB	Likely Impacted	9	19.1	7.0	31.1	194.4	71.7	317.2
SFB	Clearly Impacted	1	0.3	0.0	0.9	3.4	3.4	9.3
SFB	Inconclusive	0	0.0	0.0	0.0	0.0	0.0	0.0
Total		40	100.0			1020.5		
South	Unimpacted	122	42.9	36.5	49.3	58.1	49.4	66.8
South	Likely Unimpacted	46	18.9	13.2	24.6	25.5	17.8	33.2
South	Possibly Impacted	79	24.6	19.2	30.1	33.3	25.9	40.7
South	Likely Impacted	40	11.2	7.0	15.5	15.2	9.5	20.9
South	Clearly Impacted	24	2.1	1.0	3.2	2.8	1.4	4.4
South	Inconclusive	3	0.3	0.0	0.6	0.4	0.0	0.8
Total		314	100.0			135.3		

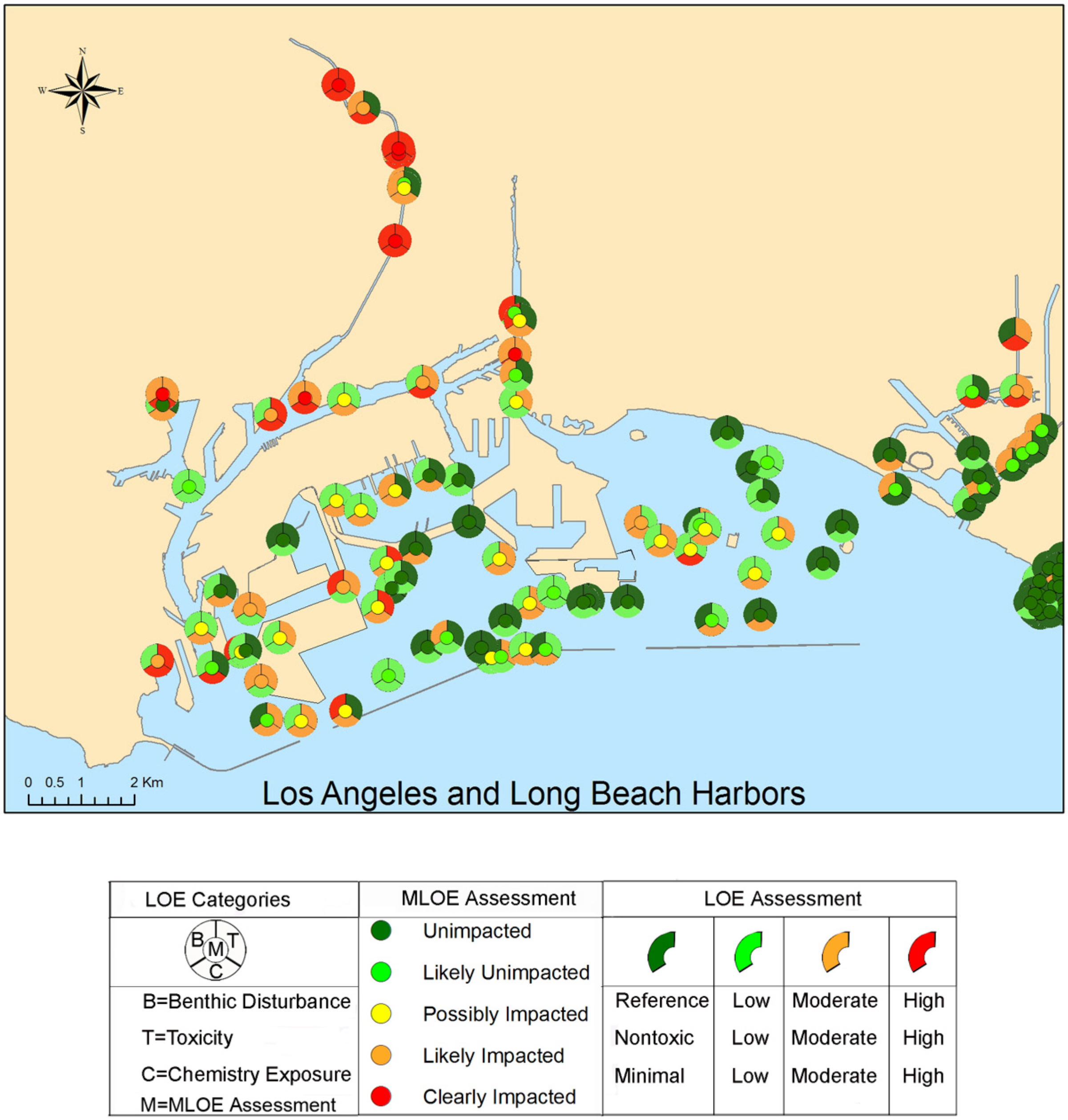
APPENDIX C. ASSESSED SEDIMENT CONDITION AND LOE CATEGORIES AT INDIVIDUAL STATIONS IN SELECTED CALIFORNIA EMBAYMENTS

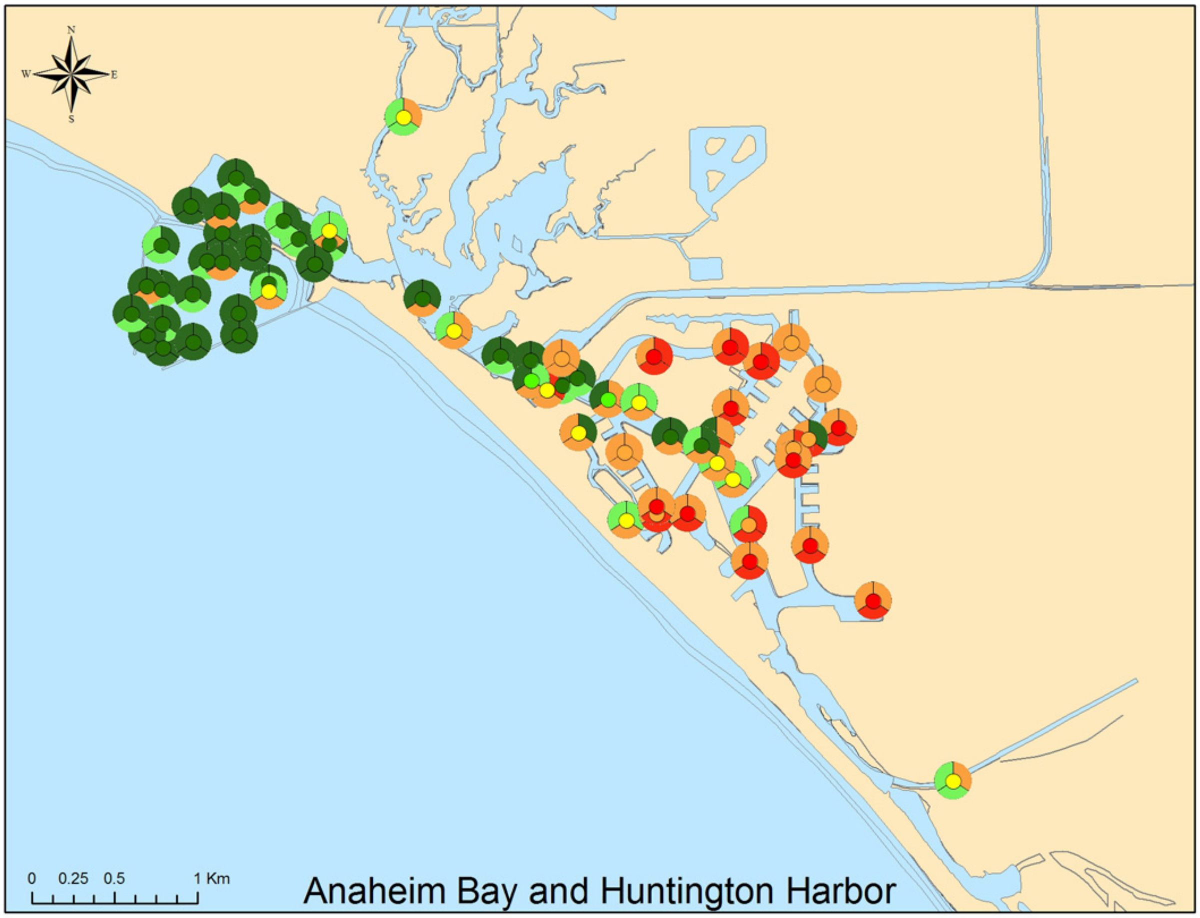


LOE Categories	MLOE Assessment	LOE Assessment			
B M T C	Unimpacted				
	Likely Unimpacted				
B=Benthic Disturbance	Possibly Impacted	Reference	Low	Moderate	High
T=Toxicity	Likely Impacted	Nontoxic	Low	Moderate	High
C=Chemistry Exposure	Clearly Impacted	Minimal	Low	Moderate	High
M=MLOE Assessment					

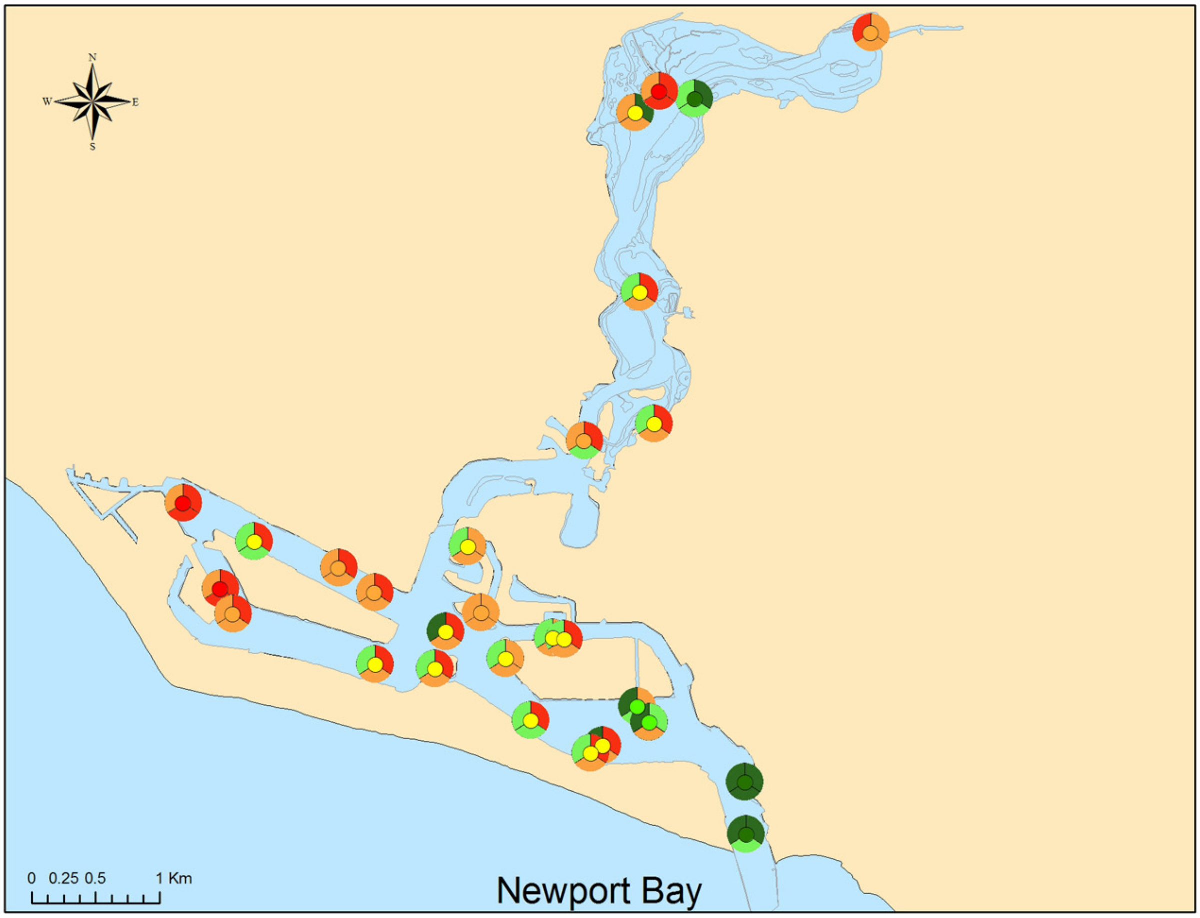


LOE Categories	MLOE Assessment	LOE Assessment			
B M T C	Unimpacted				
B=Benthic Disturbance	Likely Unimpacted	Reference	Low	Moderate	High
T=Toxicity	Possibly Impacted	Nontoxic	Low	Moderate	High
C=Chemistry Exposure	Likely Impacted	Minimal	Low	Moderate	High
M=MLOE Assessment	Clearly Impacted				

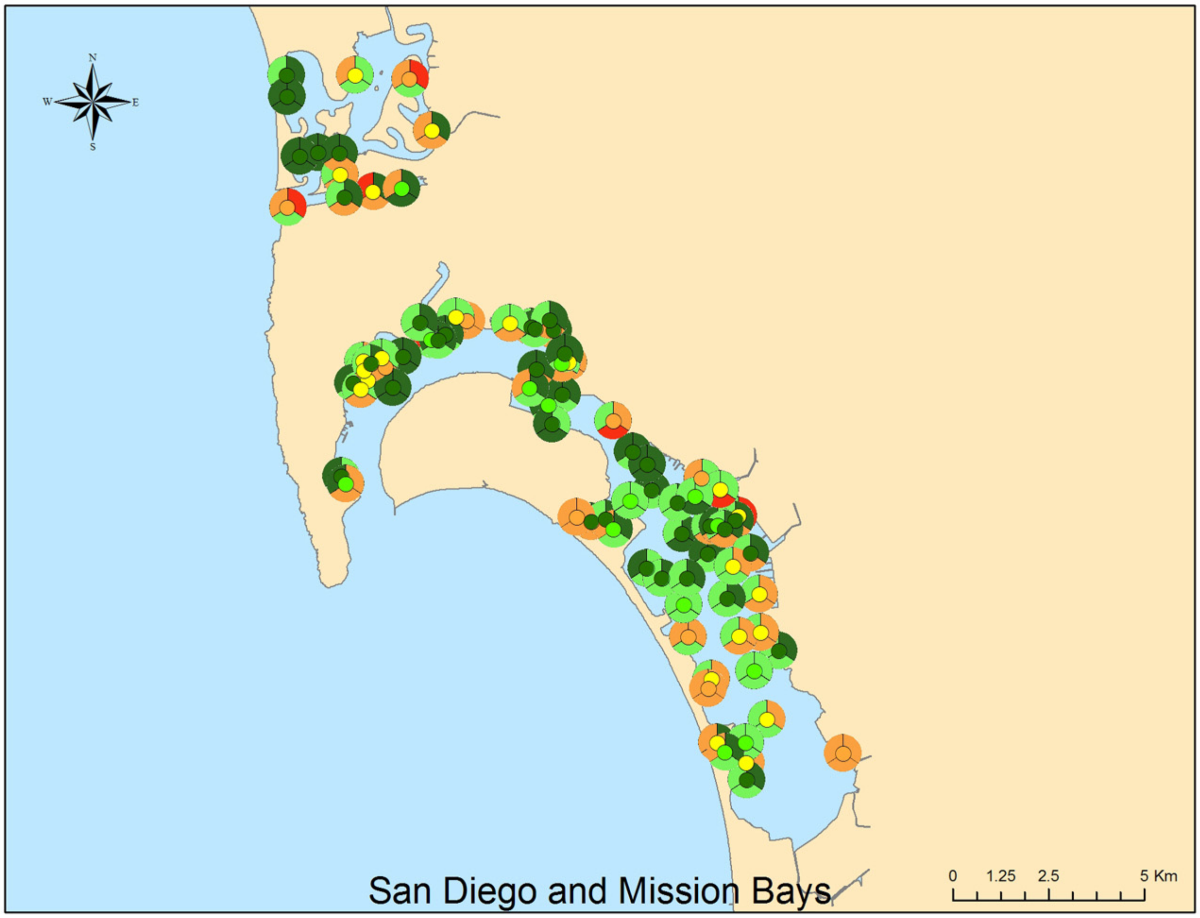

N
W
E
S
0 0.5 1 2 Km
Los Angeles and Long Beach Harbors
LOE Categories
B M T C
B=Benthic Disturbance
T=Toxicity
C=Chemistry Exposure
M=MLOE Assessment
MLOE Assessment
Unimpacted
Likely Unimpacted
Possibly Impacted
Likely Impacted
Clearly Impacted
LOE Assessment
Reference Low Moderate High
Nontoxic Low Moderate High
Minimal Low Moderate High



LOE Categories	MLOE Assessment	LOE Assessment			
B M T C	Unimpacted				
	Likely Unimpacted				
B=Benthic Disturbance	Possibly Impacted	Reference	Low	Moderate	High
T=Toxicity	Likely Impacted	Nontoxic	Low	Moderate	High
C=Chemistry Exposure	Clearly Impacted	Minimal	Low	Moderate	High
M=MLOE Assessment					



LOE Categories	MLOE Assessment	LOE Assessment			
B T M C	Unimpacted				
	Likely Unimpacted				
B=Benthic Disturbance	Possibly Impacted	Reference	Low	Moderate	High
T=Toxicity	Likely Impacted	Nontoxic	Low	Moderate	High
C=Chemistry Exposure	Clearly Impacted	Minimal	Low	Moderate	High
M=MLOE Assessment					



LOE Categories	MLOE Assessment	LOE Assessment			
B M T C	Unimpacted				
	Likely Unimpacted				
B=Benthic Disturbance	Possibly Impacted	Reference	Low	Moderate	High
T=Toxicity	Likely Impacted	Nontoxic	Low	Moderate	High
C=Chemistry Exposure	Clearly Impacted	Minimal	Low	Moderate	High
M=MLOE Assessment					