



Development of Benthic Community Condition Indices – San Francisco Bay

Contract#: 1038

Phase I Final Report

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Introduction

Benthic community assessment is often used as an indicator of ecosystem condition and has become a central element of regulatory programs such as the California's sediment quality objectives (SQO) for bays and estuaries. Benthos are the indicators of choice for monitoring and assessment for several reasons, including:

- Limited mobility makes them reflective of impacts at the site where they are collected.
- Several animal phyla and classes are sensitive to impacts to their environments and can be used to differentiate certain types of effects.
- Life-histories are short enough that the effects of one-time impacts disappear within a year but long enough to integrate the effects of multiple impacts occurring within seasonal time scales.
- Living in the bottom sediments, benthos have high exposure to common anthropogenic impacts, such as sediment contamination, high sediment organic carbon, and low bottom dissolved oxygen.
- They are important components of aquatic food webs, transferring carbon and nutrients from suspended particulates in the water column to the sediments by filter feeding and serving as forage for bottom-feeding fishes.

For benthic data to be useful in a regulatory context, they must be synthesized into some manner of index that can be interpreted in relation to scientifically valid criteria or thresholds that distinguish “healthy” from “unhealthy” benthic communities. While reducing complex biological data to index values has disadvantages, the resulting indices remove much of the subjectivity associated with ad hoc data interpretation. Such indices also provide a simple means of communicating complex information to managers, tracking trends over time, and correlating benthic responses with stressor data.

To date, benthic indices have been calibrated and validated for two nearshore habitats in California, 1) southern California marine bays, and 2) polyhaline (high salinity) portions of San Francisco Bay. Indices have not yet been developed for other habitats throughout the State due to a lack of sufficient calibration/validation data, compounded by a poorer understanding of benthic community stressor-response relationships in lower salinity or naturally disturbed habitats. The lower salinity portions of estuaries are particularly challenging because they are subject to relatively broad ranges of natural environmental conditions (e.g., salinity, dissolved oxygen, turbidity), which produces an endemic fauna adapted to tolerate environmental (and possibly anthropogenic) stress. These challenges for assessment can, however, be overcome through compilation of robust data sets and careful identification of reference conditions to anchor indices.

With the long-term goal of developing a benthic index for the mesohaline/ North and South Bay portions of San Francisco Bay, the objective of Phase I of this study was to provide the following

necessary underpinnings for index development: 1) delineation of the mesohaline/ mid-bay habitats; 2) assembling all relevant biotic and abiotic data for those habitats into a single database; 3) establishing a definition of reference and severely degraded conditions for the system. The results of this analysis will serve as the foundation for index development and validation in Phase II of the study.

Findings from Phase I

Below, we summarize the approach and findings from each task in Phase I and detail how they will support Phase II of the project.

Task 1 – Delineation of the Mesohaline Habitat

Goal: Refine the spatial definitions of the mesohaline habitat in San Francisco Bay for use in California's SQO program by accounting for additional data and analyses conducted since the original SQO habitat delineations.

Approach – Original habitat definitions for SQO assessment in San Francisco Bay were based upon a Pacific coast-wide macrobenthic community analysis detailed in Ranasinghe et al. (2012). Thompson et al. (2013) conducted a similar, subsequent analysis focused solely on macrobenthic community assemblages in San Francisco Bay. This newer study incorporated ~3.5X as many samples from the San Francisco Bay estuary as Ranasinghe et al. (2012), thereby refining macrobenthic community assemblage definitions and providing greater spatial resolution in the lower-salinity portions of the system. Given these advances, these new assemblage definitions were used as a starting point for refining geographic boundaries for the different macrobenthic communities of the San Francisco Bay estuary to be used in the SQO assessments. These delineations define relatively discrete communities that require different assessment approaches or tools within the SQO framework due to changes in benthic community composition occurring naturally across the estuarine gradient.

Results – Thompson et al. (2013) used a cluster analysis based upon Bray-Curtis dissimilarity values of macrobenthic communities to define 5 different community assemblages for San Francisco Bay that roughly follow a gradient in salinity: polyhaline, mesohaline, oligohaline, tidal freshwater, and a coarse sand assemblage. Note that the spatial extent of these assemblages and habitats, though named after estuarine salinity zones, are not bounded by the abiotic salinity definitions traditionally associated with those names (i.e., ASLO, 1958).

The relative fidelity and exclusivity of each taxon in the 5 assemblages was calculated to assess the taxonomic contiguousness of these assemblages as discrete habitats. Samples dominated by taxa with low fidelity and exclusivity to their assigned Thompson et al. (2013) assemblage were assigned to a more appropriate habitat classification. Samples from the adjusted assemblages were then plotted into a geographic information system using their latitude and longitude to evaluate the spatial contiguousness of these new habitat definitions. There was good spatial clustering of samples within each assemblage, with the exception of the coarse sand assemblage

(Figure 1), so these plots were used to delineate habitat definitions (Table 1). The characteristic taxa of each habitat (i.e., those with high assemblage exclusivity and fidelity) are presented in Appendix A.

Table 1 Macrobenthic community assemblages in the San Francisco Bay estuary used to define habitats for use in California Sediment Quality Objectives, modified from Thompson et al. (2013)

Habitat Name	Definition
Polyhaline	From Golden Gate Bridge to the Richmond San Rafael Bridge in the North and the western shore of the South Bay to San Mateo and the mouth of San Leandro Bay in the South
Mesohaline	The main portions of San Pablo Bay north of the Richmond-San Rafael Bridge; excluding the tributaries and the eastern edges of San Pablo Bay. Additionally, the southeastern parts of the South Bay and the area south of the Dumbarton Bridge
Oligohaline	Northern tributaries of San Pablo Bay through Suisun Bay to the western tip of West Island
Tidal Freshwater	East of the western tip of West Island to the head of tide in the San Joaquin Delta
Course Sand	Various points throughout the entire bay, thought to be scoured by currents

Those samples assigned to the coarse sand assemblage, which despite having a distinct, relatively depauperate benthic community, were spread throughout polyhaline, mesohaline, and oligohaline habitat zones. The unifying characteristics of these samples was and that they were from areas thought to experience hydrodynamic scour, which produces well-sorted coarse sand and gravel environments. The resultant benthic community was characterized by consistent observations of the polychaete *Heteropodarke heteromorpha* (Appendix A).

The mesohaline habitat included two areas separated by the higher salinity polyhaline habitat. The southern mesohaline habitat included shallow portions to the east and south of the Central and South Bay, as well as areas to the south of the Dumbarton Bridge. The northern mesohaline habitat extended from the Richmond-San Rafael Bridge north into San Pablo Bay, excluding areas in northernmost and easternmost San Pablo Bay under the influence of freshwater flow from the tributaries (Table 1; Figure 2). Table 2 details the characteristic taxa associated with this habitat. This geographic area was the focal point of our subsequent work.

Product – A map of the different habitats in the San Francisco Bay estuary and lists of their characteristic macrobenthic taxa.

Table 2. Characteristic taxa of the San Francisco Bay estuary mesohaline habitat. Fidelity is a measure of the frequency of occurrence of a taxon in the mesohaline-habitat samples relative to those from across the estuary. Exclusivity is a measure of the percent of a taxon's total estuary-wide abundance that was found within the mesohaline habitat.

TaxonName	Group	Fidelity (%)	Exclusivity (%)	Mean Abundance (# 0.05 m ⁻²)
<i>Ampelisca abdita</i>	Arthropoda : Amphipoda	86.1	31.9	303.5
Tubificidae	Annelida : Oligochaeta	77.0	15.7	37.2
<i>Heteromastus</i> spp.	Annelida : Polychaeta	68.9	85.8	14.6
<i>Monocorophium acherusicum</i>	Arthropoda : Amphipoda	63.1	9.2	49.5
<i>Neanthes succinea</i>	Annelida : Polychaeta	62.3	91.7	7.7
<i>Corbula amurensis</i>	Mollusca : Bivalvia	59.0	66.6	243.0
<i>Streblospio benedicti</i>	Annelida : Polychaeta	54.1	95.1	46.2
<i>Nippoleucon hinumensis</i>	Arthropoda : Cumacea	48.4	54.9	30.4
<i>Harmothoe imbricata</i> Cmplx	Annelida : Polychaeta	44.3	37.2	4.7
<i>Synidotea laticauda</i>	Arthropoda : Isopoda	42.6	73.6	2.7
<i>Grandidierella japonica</i>	Arthropoda : Amphipoda	38.5	53.5	16.1
<i>Glycinde picta</i>	Annelida : Polychaeta	38.5	26.6	1.8
<i>Sabaco elongatus</i>	Annelida : Polychaeta	33.6	46.8	5.9
<i>Theora lubrica</i>	Mollusca : Bivalvia	31.1	76.6	5.3
<i>Musculista senhousia</i>	Mollusca : Bivalvia	30.3	40.3	1.7

Figure 1. A map of the San Francisco Bay estuary with samples from the 5 different assemblages described in Thompson et al. (2013)

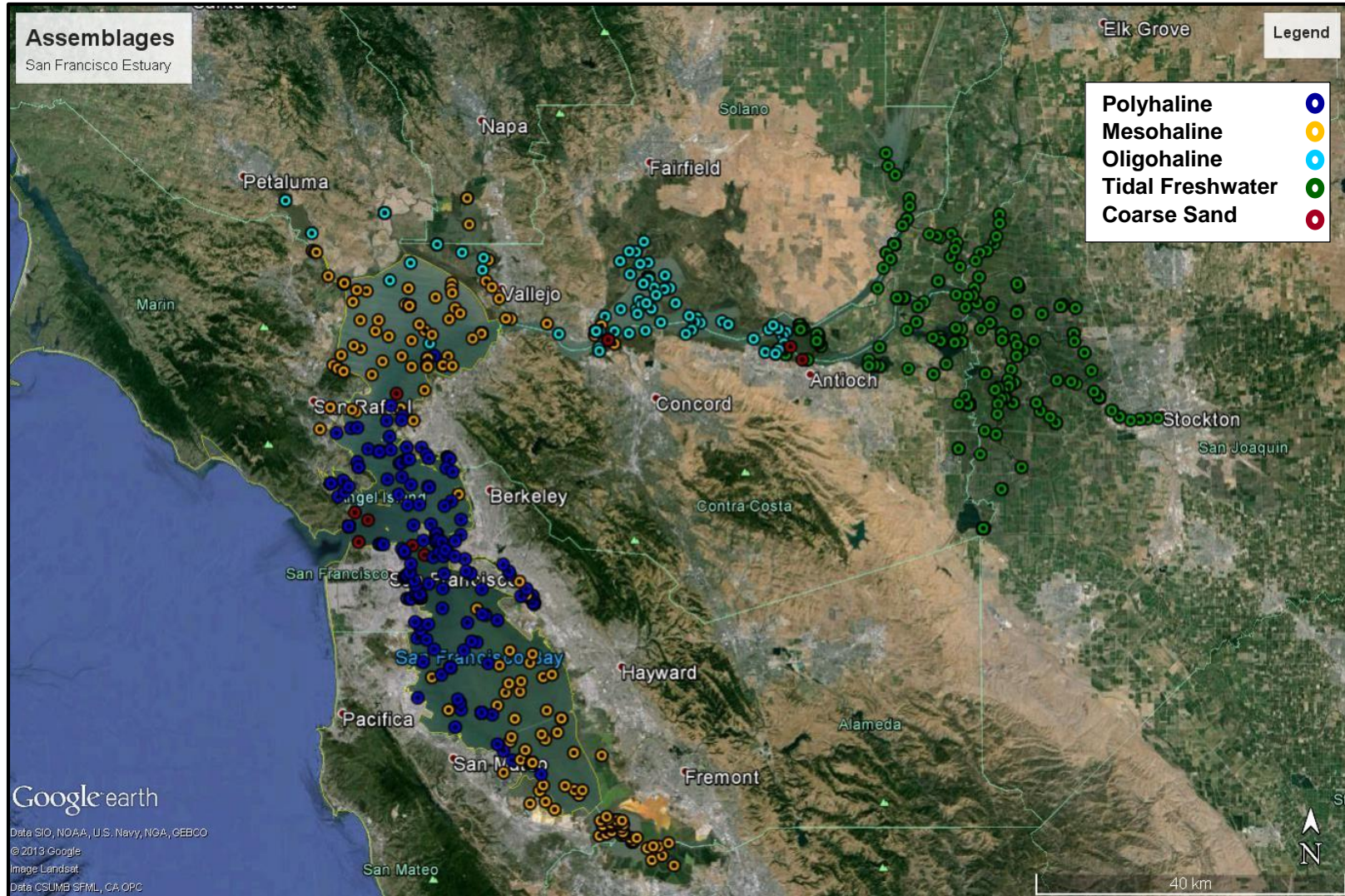
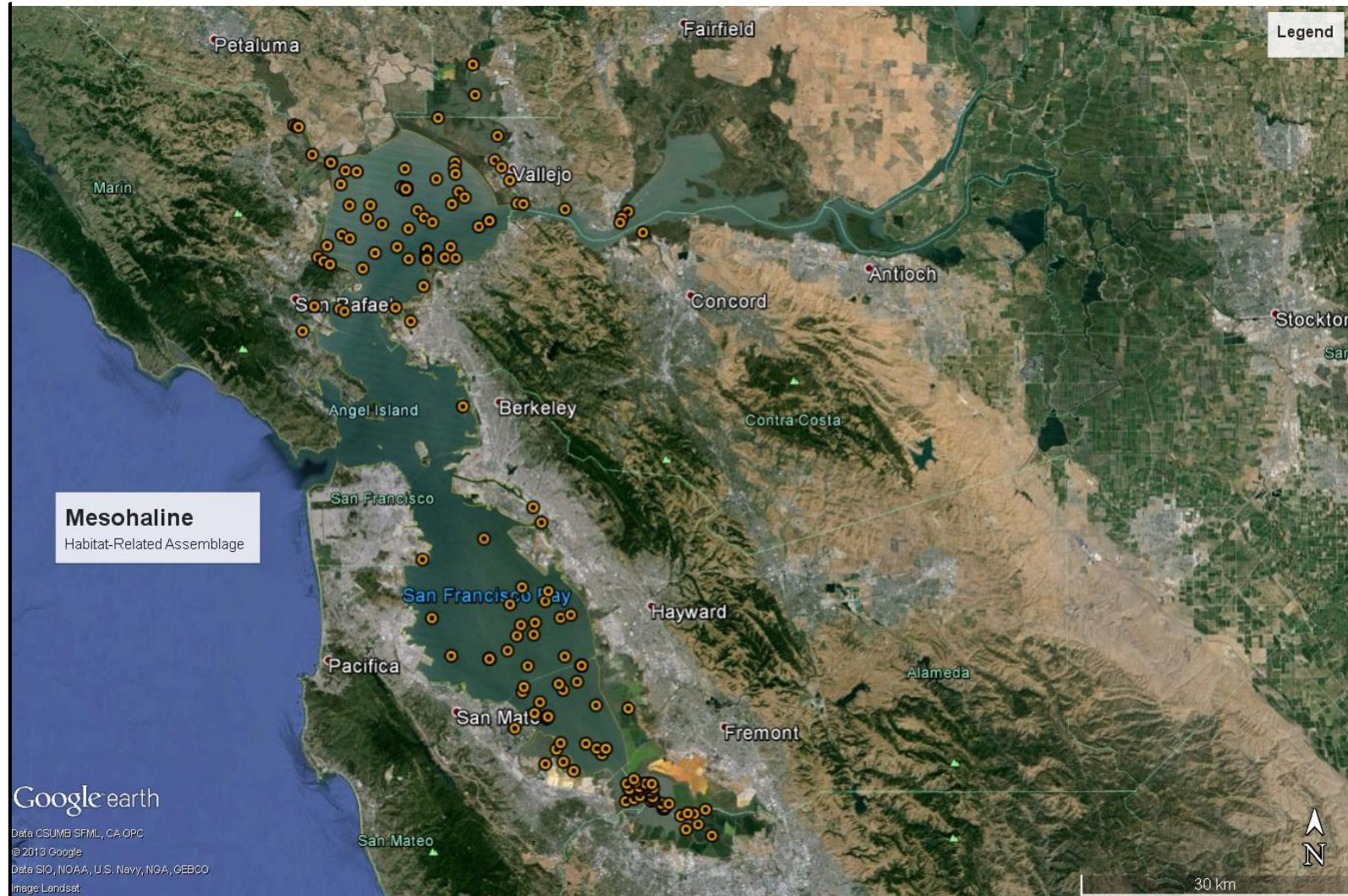


Figure 2. A map of San Francisco Bay estuary highlighting only samples classified as mesohaline in Thompson et al. (2013).



Task 2 – Data Assembly and Standardization

Goal – To assemble all of the available biology, environmental, and stressor data available for the San Francisco Bay estuary that would be used in developing a macrobenthic community assessment tool(s) into a single relational database.

Approach – Macrobenthic abundance and environmental data (e.g., habitat, contaminant, toxicity) from all available San Francisco Bay benthic sampling efforts were aggregated into a single relational database. As these data were from a variety of sampling programs that used different types of sampling gear and taxonomic standards, the data had to be transformed and updated to create a uniform, comparable standard across all samples. Additionally, all samples were assigned to their appropriate new habitat classification so that they could be used in this and future SQO-related work.

Results – Data from 6,857 benthic samples collected during 2,336 sampling events at 486 different sites across all habitat types were compiled. These data came from 11 different sampling programs and were collected from 1992 to 2012 (see database for details). Some combinations of depth, sediment composition, or salinity data were available for 2,068 of those sampling events. Sediment contaminant data were available for only 236 sampling events. Sediment toxicity test data, typically amphipod survival tests, were available for 159 sampling events.

Within the mesohaline habitat described under Task 1, data were available from 1,361 benthic samples from 497 sampling events at 141 different sites. Depth, sediment composition, or salinity data were available for 497 sampling events. Sediment contaminant data were available for 83 sampling events and sediment toxicity data were available for 68 sampling events.

As noted above, these data from across the entire estuary were collected by a number of different sampling programs across two decades. Two byproducts of this are that 1) different sediment grabs with different surface areas were used; and 2) the taxonomic level (e.g., subclass vs. species for oligochaetes) and taxonomic standards (e.g., *Dorvillea annulata* vs. *Schistomeringos annulata*) varied across years. The largest sediment grab used was a 0.05-m² ponar grab, so all abundance data were standardized to # individuals per 0.05 m². Taxon names were standardized to Southern California Association of Marine Taxonomists species list Edition 6 (SCAMIT 2011).

There were detectable differences in species richness across the different types of gear used for collecting samples, with samples taken with larger gear having more species; this problem is not as easily correctable as the abundance differences. However, the differences in species richness among gear types were not uniform along the salinity gradient. The most pronounced effects were in the higher-diversity polyhaline habitats; there were smaller differences in the mesohaline, and no differences among gear types in the oligohaline or tidal freshwater portions of the estuary. As a consequence, care will have to be taken in selection of data for use in the creation of any subsequent assessment index, especially those using species richness/diversity or the presence/absence of rare taxa.

Product – MS Access database of benthic, environmental, and toxicity data

Task 3 - Establishing a Definition of Reference and Degraded Conditions

Goal – Use expert knowledge of benthic ecology in lower-salinity estuarine ecosystems to create definitions of reference and degraded macrobenthic communities that can then be used to develop and validate benthic condition indices for use in SQO assessments.

Approach – A clear definition of reference condition is one the first key steps in developing a habitat assessment tool (Stoddard et al. 2006; Muxika et al. 2007; Hawkins et al. 2010). Understanding the reference condition anchors expectations when evaluating novel sites; doing so makes it possible to determine how different samples are from reference and potentially to chart a path towards recovery to that state. There are a variety of ways to set reference expectations for a system (e.g., Hughes et al. 1986; Reynoldson et al. 1997; Ranasinghe et al. 2009), but given the lack of proven conceptual models and the associated difficulty in defining reference conditions in integrative and transitional habitats like estuaries in general, and San Francisco Bay in particular, we chose to develop reference/degraded definitions using the knowledge of experienced benthic ecologists. A panel of nine expert benthic ecologists with experience in lower-salinity estuaries and/or San Francisco Bay was assembled to evaluate the condition of macrobenthic community samples. The experts were asked to evaluate the condition of 30 benthic samples from the mesohaline habitat that were selected from along gradients of habitat quality (e.g., sediment contaminants, sediment toxicity, and community parameters).

The expert panel members were given only information on benthic community composition (taxa names and abundance) and environmental characteristics (depth, sediment composition, and salinity) where available. They were not given information on sample location, sediment contaminants, or sediment toxicity. The experts were asked to assign samples into 1 of 4 condition categories – undisturbed through severely degraded – and rank all of the samples from best to worst.

Table 3 Categorical assignments of the condition of macrobenthic samples made by the panel of benthic experts. 1 - Least disturbed; 2 - Low disturbance; 3 - Moderate disturbance; or 4 - Highly disturbed

Sample ID	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
Mesohaline Sample 1	3	2	2	1	3	2
Mesohaline Sample 2	3	4	3	3	3	3
Mesohaline Sample 3	4	4	3	3	3	3
Mesohaline Sample 4	2	1	3	3	1	3
Mesohaline Sample 5	3	4	1	4	3	3
Mesohaline Sample 6	2	1	1	2	2	3
Mesohaline Sample 7	4	3	3	4	3	3
Mesohaline Sample 8	1	1	1	1	1	1
Mesohaline Sample 9	2	1	3	4	1	3
Mesohaline Sample 10	1	1	1	3	1	2
Mesohaline Sample 11	4	4	1	4	3	3
Mesohaline Sample 12	1	1	1	2	1	2
Mesohaline Sample 13	2	2	3	3	1	3
Mesohaline Sample 14	2	2	1	1	1	2
Mesohaline Sample 15	2	1	1	4	1	3
Mesohaline Sample 16	4	3	1	3	4	3
Mesohaline Sample 17	3	4	2	4	3	4
Mesohaline Sample 18	3	3	3	2	3	3
Mesohaline Sample 19	4	4	1	4	3	4
Mesohaline Sample 20	3	4	3	3	2	4
Mesohaline Sample 21	3	1	2	2	2	2
Mesohaline Sample 22	3	4	3	4	4	3
Mesohaline Sample 23	2	3	1	4	2	3
Mesohaline Sample 24	2	2	3	4	2	3
Mesohaline Sample 25	2	2	1	1	1	3
Mesohaline Sample 26	1	1	1	1	2	1
Mesohaline Sample 27	1	1	1	2	1	2
Mesohaline Sample 28	4	3	3	3	2	3
Mesohaline Sample 29	3	2	1	2	2	3
Mesohaline Sample 30	2	2	3	3	3	3

Table 4. Rank assignments of the relative condition of macrobenthic samples 1 (best) to 30 (worst) made by the panel of benthic experts

Sample ID	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
Mesohaline Sample 1	24	11	18	4.5	19.5	4.5
Mesohaline Sample 2	21	28	29	18	26.0	23.5
Mesohaline Sample 3	29	26	20.5	16	19.5	23.5
Mesohaline Sample 4	12	10	25	18	5.5	17
Mesohaline Sample 5	16	27	15	26.5	22.0	23.5
Mesohaline Sample 6	10	5	6	6.5	15.0	11.5
Mesohaline Sample 7	28	20	26.5	26.5	22.0	23.5
Mesohaline Sample 8	1	4	11	2	5.5	1.5
Mesohaline Sample 9	6	8	24	29	5.5	11.5
Mesohaline Sample 10	4	1	1	12	5.5	7.5
Mesohaline Sample 11	27	25	14	22	22.0	23.5
Mesohaline Sample 12	5	7	8	9	5.5	4.5
Mesohaline Sample 13	8	15	20.5	13	5.5	11.5
Mesohaline Sample 14	11	12	13	4.5	5.5	7.5
Mesohaline Sample 15	13	6	2	24	5.5	23.5
Mesohaline Sample 16	25	18	10	24	29.5	17
Mesohaline Sample 17	20	29	16	20	28.0	29
Mesohaline Sample 18	22	23	20.5	10.5	26.0	11.5
Mesohaline Sample 19	30	22	5	21	24.0	29
Mesohaline Sample 20	18	24	26.5	18	13.0	29
Mesohaline Sample 21	23	9	17	6.5	17.5	4.5
Mesohaline Sample 22	17	30	29	29	29.5	23.5
Mesohaline Sample 23	15	19	9	24	12.0	17
Mesohaline Sample 24	14	17	24	29	11.0	23.5
Mesohaline Sample 25	9	14	12	3	5.5	11.5
Mesohaline Sample 26	2	3	3	1	17.5	1.5
Mesohaline Sample 27	3	2	4	10.5	5.5	4.5
Mesohaline Sample 28	26	21	29	14.5	15.0	17
Mesohaline Sample 29	19	13	7	8	15.0	17
Mesohaline Sample 30	7	16	20.5	14.5	26.0	11.5

Results – Eight of the nine experts returned evaluations of the samples. However, three of the experts who work together at the same institution consolidated their evaluations together, which resulted in having only 6 sets of sample evaluations to compare.

After the initial evaluation of samples, the experts had relatively good agreement with each other in their assignment of categories (Table 3). One sample was assigned to the same category by all experts, nine were within one category of each other (i.e., 1 or 2, 2 or 3), with an additional 12 samples within or two categories of each (e.g. 1, 2 or 3 and 2 or 3 or 4). There was only a moderate level of agreement in sample ranks among the six experts (Table 4). The average Spearman’s correlation coefficient in ranks among the six experts was 0.524, with correlations between individual experts ranging from 0.78 – 0.30 (Table 5). This degree of correlation among results, especially before a formal consensus-building meeting, is good and is equivalent or better than that seen in other similar types of expert opinion exercises (e.g., Weisberg et al. 2008; Teixeira et al. 2010; Ranasinghe et al. 2013).

Table 5. Spearman's correlation coefficients of condition ranks for each the 30 samples (Table 4) evaluated by the benthic expert panel. Comparisons were made with the experts' rank of a sample to each other, the mean and median rank for a sample, as well as the overall correlation among all of the experts.

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
Expert 1		0.697	0.370	0.358	0.651	0.620
Expert 2	0.697		0.594	0.539	0.705	0.779
Expert 3	0.370	0.594		0.376	0.297	0.363
Expert 4	0.358	0.539	0.376		0.311	0.745
Expert 5	0.651	0.705	0.297	0.311		0.453
Expert 6	0.620	0.779	0.363	0.745	0.453	
Correlation w/ Mean Rank	0.807	0.922	0.658	0.639	0.785	0.766
Correlation w/ Median Rank	0.833	0.916	0.632	0.546	0.783	0.694
Mean Correlation w/ Other Expert	0.539	0.663	0.400	0.466	0.483	0.592
Mean Correlation Among all Experts	0.524					

For purposes of defining reference/degraded conditions and validating any future indices, good and bad have been defined as those samples assigned to condition categories 1 and 2 (good) or 3 and 4 (bad) (e.g., Smith et al. 2001; Ranasinghe et al. 2009; Tiexiera et al. 2012). Based on those definitions, the mesohaline dataset evaluated by the experts would have 5-6 good sites and 4-5 bad sites; all with good agreement amongst the experts. Continuing work with the expert panel to build consensus and rectify differences on those samples they nearly agree upon (e.g., all 1’s

and 2's, with one 3) will likely increase the number of good and bad validation sites available for future use.

In describing their evaluation process, all of the experts used some combination of abundance, diversity, dominance, and their perceptions of the component taxa's tolerance or sensitivity to disturbance. Experts 2, 3, 4, and 6 focused primarily on whole community metrics like species richness, diversity, and evenness to rank and organize sites and then used species composition information to refine their sample order. Conversely, experts 1 and 5 relied more on their perceptions of the tolerance, sensitivity and natural history of the fauna to inform their evaluations, especially the relative abundance of stress-sensitive or tolerant taxa in a given sample. This kind of information will be used in helping to craft assessment tools for the mesohaline portions of San Francisco Bay.

Summary

With the completion of Phase I, the ground work to create a robust macrobenthos-based assessment tool for use in California's SQO framework in mesohaline San Francisco Bay is completed. The habitat (i.e., the San Francisco Bay mesohaline community) has been geographically delimited, data for the calibration and validation of an index have been aggregated, and reference/degraded conditions have been reasonably well defined. The next step in this process will be the development of a tool to assess the condition of the macrobenthic community that is responsive to anthropogenic disturbance and accounts for the natural gradients of mesohaline estuarine systems.

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Appendix A – Characteristic Taxa of Each San Francisco Bay Estuary Habitat

TaxonName	Group	Polyhaline		Mean Abundance (# 0.05 m ²)
		Fidelity (%)	Exclusivity (%)	
<i>Tubificidae</i>	Annelida : Oligochaeta	90.8	15.2	33.6
<i>Ampelisca abdita</i>	Arthropoda : Amphipoda	89.3	68.0	602.6
<i>Mediomastus</i> spp.	Annelida : Polychaeta	83.2	98.9	28.4
<i>Dorvillea (Schistomeringos) annulata</i>	Annelida : Polychaeta	82.4	97.6	11.8
<i>Monocorophium acherusicum</i>	Arthropoda : Amphipoda	74.0	90.8	453.7
<i>Corophium heteroceratum</i>	Arthropoda : Amphipoda	73.3	97.6	99.8
<i>Glycinde picta</i>	Annelida : Polychaeta	72.5	72.3	4.6
<i>Harmothoe imbricata</i> Cmplx	Annelida : Polychaeta	71.8	62.5	7.4
<i>Exogone lourei</i>	Annelida : Polychaeta	71.0	97.6	56.3
<i>Sphaerosyllis californiensis</i>	Annelida : Polychaeta	65.6	96.5	13.9
<i>Euchone limnicola</i>	Annelida : Polychaeta	59.5	97.2	28.6
<i>Leptochelia dubia</i>	Arthropoda : Tanaidacea	58.0	99.2	42.3
<i>Capitella capitata</i> Cmplx	Annelida : Polychaeta	58.0	87.3	4.5
<i>Sabaco elongatus</i>	Annelida : Polychaeta	53.4	53.2	6.2
<i>Nephtys cornuta</i>	Annelida : Polychaeta	51.9	97.2	2.9
<i>Nippoleucon hinumensis</i>	Arthropoda : Cumacea	51.1	36.8	19.0
<i>Eudorella pacifica</i>	Arthropoda : Cumacea	51.1	98.9	25.1
<i>Armandia brevis</i>	Annelida : Polychaeta	48.9	98.5	2.8
<i>Typosyllis</i> spp.	Annelida : Polychaeta	47.3	62.2	5.6
<i>Cirriformia</i> spp.	Annelida : Polychaeta	46.6	89.9	4.3
<i>Amaeana occidentalis</i>	Annelida : Polychaeta	46.6	92.1	2.9
<i>Leitoscoloplos pugettensis</i>	Annelida : Polychaeta	44.3	85.9	1.4
<i>Grandidierella japonica</i>	Arthropoda : Amphipoda	43.5	38.7	10.8
<i>Photis brevipes</i>	Arthropoda : Amphipoda	43.5	100.0	77.4
<i>Glycinde armigera</i>	Annelida : Polychaeta	42.7	77.5	3.0
<i>Monocorophium insidiosum</i>	Arthropoda : Amphipoda	38.9	90.8	30.9
<i>Polydora cornuta</i>	Annelida : Polychaeta	38.9	80.9	4.4
<i>Heteromastus</i> spp.	Annelida : Polychaeta	37.4	11.2	1.8
<i>Caprella californica</i>	Arthropoda : Amphipoda	37.4	89.6	8.3
<i>Molgula manhattensis</i>	Chordata : Ascidiacea	35.9	89.5	12.7
<i>Musculista senhousia</i>	Mollusca : Bivalvia	32.8	59.7	2.3

TaxonName	Group	Mesohaline		Mean Abundance (# 0.05 m ⁻²)
		Fidelity (%)	Exclusivity (%)	
<i>Ampelisca abdita</i>	Arthropoda : Amphipoda	86.1	31.9	303.5
Tubificidae	Annelida : Oligochaeta	77.0	15.7	37.2
<i>Heteromastus</i> spp.	Annelida : Polychaeta	68.9	85.8	14.6
<i>Monocorophium acherusicum</i>	Arthropoda : Amphipoda	63.1	9.2	49.5
<i>Neanthes succinea</i>	Annelida : Polychaeta	62.3	91.7	7.7
<i>Corbula amurensis</i>	Mollusca : Bivalvia	59.0	66.6	243.0
<i>Streblospio benedicti</i>	Annelida : Polychaeta	54.1	95.1	46.2
<i>Nippoleucon hinumensis</i>	Arthropoda : Cumacea	48.4	54.9	30.4
<i>Harmothoe imbricata</i> Cmplx	Annelida : Polychaeta	44.3	37.2	4.7
<i>Synidotea laticauda</i>	Arthropoda : Isopoda	42.6	73.6	2.7
<i>Grandidierella japonica</i>	Arthropoda : Amphipoda	38.5	53.5	16.1
<i>Glycinde picta</i>	Annelida : Polychaeta	38.5	26.6	1.8
<i>Sabaco elongatus</i>	Annelida : Polychaeta	33.6	46.8	5.9
<i>Theora lubrica</i>	Mollusca : Bivalvia	31.1	76.6	5.3
<i>Musculista senhousia</i>	Mollusca : Bivalvia	30.3	40.3	1.7

TaxonName	Group	Oligohaline		Mean Abundance (# 0.05 m ⁻²)
		Fidelity (%)	Exclusivity (%)	
<i>Corbula amurensis</i>	Mollusca : Bivalvia	86.1	32.7	184.1
<i>Marenzelleria viridis</i>	Annelida : Polychaeta	74.7	97.2	14.6
Tubificidae	Annelida : Oligochaeta	57.0	5.4	19.7
<i>Nippoleucon hinumensis</i>	Arthropoda : Cumacea	46.8	5.9	5.1

TaxonName	Group	Tidal Freshwater		
		Fidelity (%)	Exclusivity (%)	Mean Abundance (# 0.05 m ⁻²)
<i>Tubificidae</i>	Annelida : Oligochaeta	94.2	63.8	120.1
<i>Corbicula fluminea</i>	Mollusca : Bivalvia	92.9	94.5	33.8
<i>Gammarus daiberi</i>	Arthropoda : Amphipoda	70.8	99.4	60.4
<i>Prostoma graecense</i>	Nemertinea	42.2	98.0	2.5
<i>Manayunkia speciosa</i>	Annelida : Polychaeta	41.6	100.0	70.9
<i>Americorophium simpsoni</i>	Arthropoda : Amphipoda	40.3	90.4	17.5
<i>Americorophium spinicorne</i>	Arthropoda : Amphipoda	39.0	99.2	74.4
<i>Pisidium compressum</i>	Mollusca : Bivalvia	36.4	100.0	4.1
<i>Laonome</i> spp.	Annelida : Polychaeta	31.2	46.5	3.0
<i>Melanoides tuberculata</i>	Mollusca : Gastropoda	31.2	98.5	2.2

TaxonName	Group	Course Sand		
		Fidelity (%)	Exclusivity (%)	Mean Abundance (# 0.05 m ⁻²)
<i>Heteropodarke heteromorpha</i>	Annelida : Polychaeta	60.0	85.8	13.2

Appendix B – Database Details

SF Bay Benthic Data for SFEL.accdb

This database was assembled by Ananda Ranasinghe and David Gillett. Any questions should be directed to David Gillett (davidg@sccwrp.org). It contains data from benthic sampling events from across all habitats in the San Francisco Bay estuary, spanning a time period from 1992 to 2012. Briefly, this database centers around benthic, environmental, or sediment toxicity data collected during unique sampling events. A sampling event is defined as a unique combination of the place (StationID) and time (SampleDate). Replicate samples (SampleNo) may have been taken during a sampling event, depending upon the sampling program.

Below is a brief description of each table in the database. Naming conventions for the tables are as follows: **data** – tables contain data produced from the sampling efforts; **ref** – tables provides explanatory information or details about different fields or codes in the data tables; **station-info** contains location/date-time information for each sampling event. Clicking on the relationships view of the database will illustrate how the different tables and fields are related to each other. Each field within the tables is annotated to describe the data contained within.

data – amphipod-toxicity-info – The results of sediment toxicity tests for each sampling event. Primary keys for the table are StationID, SampleDate, and SampleNo. The table contains measures of % survival for each sample and if that number indicates significant toxicity, as defined by the SOP for that test. Data are presented based upon the species of amphipod used in the test (*Eohaustorius estuarius* or *Ampelisca abdita*), as well as being combined into a general, amphipod toxicity measure.

data – benthos – The abundance (# 0.05 m⁻²) of each taxon identified in a sample. Primary keys for the table are StationID, SampleDate, SampleNo, and TaxonName. The samples were collected with different types and size of sampling gear, so all abundances have been standardized to the number per 0.05 m².

data – environmental – Measures of the environmental data associated with each macrobenthic sample. Primary keys are StationID, SampleDate, SampleNo, and ParCode. Data in the table include measures of sediment composition, sediment contaminants (individual constituents, as well as, ERL and ERM quotients and sums), TOC, TN, and overlying water quality. Each parameter is represented by 4-digit numerical code. Translations of the code are provided in the ref – parameters table. Empty cells indicates that no valid data were available.

metadata – Comments on individual data records. Primary key is MetaDataID. The metadata table is linked to every data table, which has a field for a MetaDataID on each record.

ref – data sources – A reference table explaining the ProjectCode field: the name of the project the data were originally collected under and the agency associated with that project. Primary keys are SourceAgency and Project. Project details were not available for every project, so only abbreviations are currently available.

ref – habclass – A reference table explaining each HabClass code associated with each sampling event in the station-info table. Primary key is HabClass. Habitat descriptions and criteria are from Ranasinghe et al. (2012) and Thompson et al. (2013).

ref – parameters – A reference table explaining each 4-digit ParCode from the environmental table. Primary key is ParCode. Units of measure were not available for most of the parameters.

ref- taxa – A reference table with detailed taxonomic information for each TaxonName in the data – benthos table. Primary Key is TaxonName.

station-info – A table of station and sampling event information, including number of replicate samples collected, location, sampling gear, and the source of the data. Primary keys are StationID and SampleDate. The table also contains information about old station IDs and old habitat membership.