REGIONAL HARBOR MONITORING PROGRAM, 2008

Final Report

May 2010

WESTON SOLUTIONS

Regional Harbor Monitoring Program
2008
Final Report

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ACRONYMS AND ABBREVIATIONS

AB411	Assembly Bill 411
ANOVAs	Analyses of Variance
ASTM	American Society for Testing and Materials
AVS	acid volatile sulfides
AVS-SEM	acid volatile sulfide-simultaneously extracted metals
Bight	Southern California Bight
Bight ’98	Southern California Bight 1998 Regional Monitoring Study
Bight ’03	Southern California Bight 2003 Regional Monitoring Study
Bight ’08	Southern California Bight 2008 Regional Monitoring Study
BLM	Biotic Ligand Model
BMPs	Best Management Practices
BPTCP	Bay Protection and Toxic Cleanup Program
BRI	Benthic Response Index
CA LRM	California Logistic Regression Model
$CaCO_3$	calcium carbonate
Cal/EPA	California Environmental Protection Agency
COP	California Ocean Plan
CRG	CRG Marine Laboratories, Inc.
CSI	Chemical Score Index
CTD	conductivity-temperature-depth profiler
CTR	California Toxics Rule
DDTs	dichlorodiphenyltrichloroethanes
dGPS	differential Global Positioning System
DGT	diffusive gel technology
DO	dissolved oxygen
DOC	dissolved organic carbon
EC_{50}	median effective concentration
EDTA	Ethylenediaminetetraacetic acid
EI	Ecological Index
ER-L	effects range–low
ER-M	effects range–median
FeS	iron sulfide
FWI	freshwater Influenced
HydroQual	HydroQual, Inc.
IBI	Index of Biotic Integrity
ICP-MS	inductively coupled plasma – mass spectrometry
LC_{50}	median lethal concentration
LOE	line of evidence
MBAS	methylene blue active substances
mER-Mq	mean effects range–median quotient
$MgSO_4$	magnesium sulfate
MLLW	mean lower low water
MLOE	multiple lines of evidence
MPN	most probable number

MS4	Municipal Separate Storm Sewer System
MTBE	methyl-t-butyl ether
O&G	oil and grease
PAHs	polynuclear aromatic hydrocarbons
PBO	piperonyl butoxide
PCBs	polychlorinated biphenyls
pH	hydrogen ion concentration
P_{MAX}	maximum probability model
QA/QC	quality assurance/quality control
RBI	Relative Benthic Index
RHMP	Regional Harbor Monitoring Program
RIVPACS	River Invertebrate Prediction and Classification System
SCAMIT	Southern California Association of Marine Invertebrate Taxonomists
SCCWRP	Southern California Coastal Water Research Project
SDRWQCB	San Diego Regional Water Quality Control Board
SEM	simultaneously extracted metals
SIYB	Shelter Island Yacht Basin
SM	Standard Method
SP	solid phase
SPAWAR	U.S. Navy Space and Naval Warfare Systems
SPE	solid phase extraction
SQOs	sediment quality objectives
SSOs	site-specific water quality objectives
STS	sodium thiosulfate
SWAMP	Surface Water Ambient Monitoring Program
SWI	sediment-water interface
SWRCB	State Water Resource Control Board
TDS	total dissolved solids
TIEs	toxicity identification evaluations
TMDL	Total Maximum Daily Load
TOC	total organic carbon
TSS	total suspended solids
USEPA	United States Environmental Protection Agency
VRG	Vantuna Research Group
WER	water effect ratio
WESTON	Weston Solutions, Inc.
∑SEM:AVS	ratio of SEM to AVS

UNITS OF MEASURE

cm	centimeter
°C	degrees Celsius
ft	feet or foot
g	gram
kg	kilogram
L	liter
µg/g	microgram per gram
µg/L	microgram per liter
m	meter
mg/kg	milligram per kilogram
mg/L	milligram per liter
mL	milliliter
mm	millimeter
m/sec	meters per second
ng/g	nanogram per gram
ng/L	nanogram per liter
psu	practical salinity unit
%	percent

EXECUTIVE SUMMARY

The Regional Harbor Monitoring Program (RHMP) was developed by the Port of San Diego, the City of San Diego, the City of Oceanside, and the County of Orange in response to a July 24, 2003 request by the San Diego Regional Water Quality Control Board (SDRWQCB) under §13225 of the California Water Code. The RHMP is a comprehensive effort to survey the general water quality and condition of aquatic life and to determine whether beneficial uses are being protected and attained in Dana Point Harbor, Oceanside Harbor, Mission Bay, and San Diego Bay. The program is comprised of a core monitoring program supplemented by focused special studies. The RHMP was designed to answer questions regarding (1) the spatial distribution of pollutants and their impacts, (2) the safety of the waters for human contact, (3) the safety of fish for human consumption, (4) the abilities of the waters and sediments to sustain healthy biota, and (5) the long-term trends in harbor conditions. The core monitoring program assesses the conditions found in the harbors based on comparisons to historical reference values for the four harbors and comparisons of contaminant concentrations to known surface water and sediment thresholds using chemistry, bacterial, toxicology, benthic infaunal community, and demersal community indicators.

The RHMP Core Monitoring Program was conducted during the summer of 2008 from August 4-25, 2008 as a component of the 2008 Southern California Bight Regional Study (Bight '08). The harbors were partitioned into five strata, comprised of freshwater-influenced, marina, industrial, deep, and shallow areas. Seventy-five water and sediment quality stations were sampled and 18 trawls were performed, with stations positioned according to a stratified random sampling design. Surface water and sediment chemistry, sediment toxicity levels, and biological community conditions were quantified to determine the health and overall status of the harbors. To evaluate the contributions and spatial distribution of pollutants, concentrations of chemical indicators were compared among strata and among harbors. Assessments of the safety of the water for human body contact were based on indicator bacteria levels. The assessment of the safety of fish for human consumption is a component of the State Water Resource Control Board (SWRCB) Surface Water Ambient Monitoring Program (SWAMP) statewide bioaccumulation study. To determine whether the waters and sediments sustain healthy biota, a weight-of-evidence approach was used that combined the indirect lines of evidence (LOE) (chemistry and toxicity) with the direct LOE (benthic infauna and demersal communities). Lastly, determinations of long-term trends were based on comparisons of RHMP 2008 findings to historical conditions to evaluate whether conditions were improving or deteriorating. The results of RHMP 2008 are discussed in relation to the SDRWQCB questions. Based on the findings, special focused studies are proposed to further assess contaminants of concern and areas subject to significant contaminant loading.

What are the contributions and spatial distributions of inputs of pollutants?

Areas of the harbors most closely associated with human uses (i.e., the marina, industrial, and freshwater-influenced strata) tended to have higher chemical concentrations and greater exceedances of chemical thresholds in surface waters and sediments as compared to areas that were not closely associated with anthropogenic influences (deep and shallow strata). This was most notably the case for the marina stratum due to consistently high levels of copper both in the surface waters and sediments, as well as other metals (e.g., mercury and zinc) and organics in the sediments. The industrial stratum, which was located solely along the eastern shore of San

Diego Bay, also had elevated concentrations of metals and organics in sediments, while the primary elevated contaminants in the freshwater-influenced stratum were pesticides (i.e., chlordanes and pyrethroids) as well as zinc.

Are the fish safe to eat?
Assessments of the safety of fish for human consumption were performed as a component of the SWRCB statewide bioaccumulation study in the summer of 2009. The purpose of this study was to quantify regional fish tissue contamination in the Bight, focusing on areas where fishing primarily occurs and the tissues of the species that are commonly consumed. At the time of reporting, fish tissues were being analyzed for PCB congeners, DDT isomers and metabolites, toxaphene, chlordane, and mercury to determine areas of the Bight where fish are safe to eat and sites where advisories may be required.

Are the waters in the harbors safe for body contact activities?
The safety of the RHMP waters for human body contact was evaluated by measuring indicator bacterial levels. Indicator bacteria levels were consistently well below Assembly Bill 411 (AB411) standards for total and fecal coliforms and Enterococci, with the vast majority of the stations having bacterial levels that were below detection limits; 96% of stations for Enterococci, 75% for total coliforms, and 92% for fecal coliforms. Consistently low bacteria levels were observed across all strata, indicating that bacteria were not likely to occur at elevated levels throughout most areas of the harbors during summer months when rain events were extremely rare.

Do the waters and sediments in the harbors sustain healthy biota?
RHMP 2008 results demonstrated that overall conditions in the harbors were supportive of healthy biota. Of the more than 100 indicators assessed, copper was the only chemical to exceed established threshold levels for adverse biological effects in the water column (e.g., the acute California Toxics Rule [CTR]), and only copper, zinc, arsenic, mercury, total polychlorinated biphenyls (PCBs), total dichlorodiphenyltrichloroethanes (DDTs), and total chlordanes had average concentrations within strata or harbors that exceeded effects range-low (ER-L) values. Additionally, mercury was the only analyte with an average concentration that exceeded the effects range median (ER-M), with the mean exceedance occurring in the marina stratum.

The majority of the area within the RHMP harbors was found to be supportive of healthy biota based upon a weight-of-evidence approach that combines physical, chemical, and toxicological LOE with biotic LOE. However, areas immediately associated with anthropogenic disturbance and inputs of pollutants tended to have conditions that were less supportive of healthy biota; this was most notably the case for the marina stratum. Surface water chemistry and physical water quality parameters were largely supportive of healthy biota since all chemical physical indicators other than copper and dissolved oxygen (DO) occurred at concentrations below thresholds for toxic effects. Sediment chemistry exposure was also largely protective of healthy biota, since 77% of stations did not exceed a single ER-M for any analyte and 64% of stations were classified as either unimpacted or likely unimpacted by the SQO assessment. Additionally, 92% of the RHMP 2008 stations were classified as either nontoxic or as having low toxicity according to the sediment quality objective (SQO) assessment. Consistent with the sediment chemistry and toxicity lines of evidence, the biota of the RHMP harbors occurred at abundances and diversities indicative of healthy communities. Seventy-two percent of stations had benthic infaunal communities consistent with reference or low disturbance conditions according to the benthic

SQO LOE, and the demersal fish and invertebrate community was comprised of healthy individuals, with diversities and abundances of species that were consistent with prior Bight studies.

What are the long-term trends in water quality for each harbor?
RHMP-wide conditions were found to be improving over time based on comparisons of multiple lines of evidence (MLOE), including surface water chemistry, sediment chemistry, sediment toxicity, and benthic infaunal community health. Of the 23 primary and secondary indicators assessed for changes from historical conditions, 13 of the indicators showed significant improvement over historical conditions (i.e., higher percentages of RHMP 2008 stations across all areas of the harbors did not exceed thresholds for adverse effects or degraded conditions as compared to the historical percentages using the binomial test). Additionally, not a single indicator provided evidence of significant degradation from historical conditions. While this trend was apparent for RHMP-wide conditions, not all areas of the harbors (e.g., the marina stratum) showed improvement over time, nor were improvements with time as evident when assessing the subset of stations revisited from prior Bight studies. As a consequence, there were still a number of stations and strata that had conditions that exceeded thresholds.

Focused Special Studies
Based on the results of RHMP 2008, copper was found to be a contaminant of concern primarily within the marina stratum, with concentrations exceeding thresholds for adverse biological effects in the waters and sediments. Due to the known adverse effects of copper to marine organisms, focused special studies are proposed to (1) assess the extent of copper contamination within marinas and the potential for adverse effects (2009-2010), (2) identify causes of toxicity through toxicity identification evaluations (TIEs) in sediment and overlying water tests (2010-2011), (3) conduct water effect ratio (WER) studies to determine the bioavailability and toxicity of copper and support the development of site-specific water quality objectives (SSOs) (2011-2012), and (4) implement laboratory and field studies to determine whether marina sediments with elevated copper levels serve as sources or sinks for dissolved copper as copper concentrations in the overlying water decrease (2012-2013).

1.0 INTRODUCTION

The Regional Harbor Monitoring Program (RHMP) was developed by the Port of San Diego, the City of San Diego, the City of Oceanside, and the County of Orange in response to a July 24, 2003 request by the San Diego Regional Water Quality Control Board (SDRWQCB) under §13225 of the California Water Code. The RHMP is a comprehensive effort to survey the general water quality and condition of aquatic life in Region 9 harbors, and to determine whether beneficial uses are being protected and attained in Dana Point Harbor, Oceanside Harbor, Mission Bay, and San Diego Bay. The program is composed of a core monitoring program supplemented by special focused studies. The core monitoring program was designed to address the following five major questions posed in the SDRWQCB's request:

1. What are the contributions and spatial distributions of inputs of pollutants to harbors in the San Diego Region and how do these inputs vary over time?
2. Are the waters in the harbors safe for body contact activities?
3. Are fish in harbors safe to eat?
4. Do the waters and sediments in the harbors sustain healthy biota?
5. What are the long-term trends in water quality for each harbor?

To answer these questions, the RHMP study design was created through a multistep iterative process that included extensive research of historical information for the four harbors, detailed mapping of the harbors into strata, identification of indicators to be monitored, establishment of reference ambient values (i.e., threshold levels) and preset targets, and development of statistical tests to evaluate findings in a scientifically rigorous manner that is complimentary to the larger Southern California Bight (Bight) regional monitoring program. The RHMP utilized a weight-of-evidence approach to assess the condition of the harbors and compare findings to recent historical conditions to determine whether conditions were improving or deteriorating. Contaminants within surface waters and sediments, toxicity levels, and conditions of biological communities were quantified to determine the health and overall status of the harbors.

Understanding the spatial distribution of pollutants and their impacts (Question 1) required that indicators be compared among different areas of the harbors (i.e., strata) as well as among the individual harbors. Partitioning the harbors into five strata, classified as freshwater influenced, marinas, industrial, deep, and shallow, was essential to better understanding the impacts of specific activities and inputs of pollutants on surface waters and sediments through the assessment of physical conditions, chemistry, toxicity, and infaunal communities. The freshwater-influenced stratum included areas that may be affected by urban runoff. The marina stratum included areas in close proximity to docks and anchorages that may be impacted by boating and maintenance activities. The industrial stratum occured exclusively within San Diego Bay and includes areas in close proximity to heavy industrial activities. The two remaining strata, shallow and deep, encompassed portions of the harbors that did not meet the other categories and were classified by depth, using a 3.65-meter (m) depth cutoff (mean lower low water [MLLW]), as described in detail in Weston Solutions, Inc. (WESTON) 2005a.

To understand whether the waters are safe for human contact (Question 2), bacterial levels (i.e., Enterococci and total and fecal coliforms) were compared to Assembly Bill 411 (AB411) standards for REC-1 beneficial uses. Assessments of the safety of fish for human consumption (Question 3) will be performed as a component of the State Water Resource Control Board (SWRCB) statewide bioaccumulation study. To understand if the waters and sediments sustain healthy biota (Question 4), multiple indicators of harbor condition were measured at stations, including water and sediment contaminants, bacterial levels, sediment toxicity, benthic infaunal community condition, and the demersal fish and invertebrate community. Observed indicator levels were compared to established thresholds for adverse effects, such as the California Toxics Rule (CTR) and California Ocean Plan (COP) values for surface waters and effects range-low (ER-L), effects range-median (ER-M), benthic community indices, and sediment quality objectives (SQOs) for sediments, to establish whether conditions are likely to be protective of both human and biotic beneficial uses.

Assessing long-term trends (Question 5) involved comparisons of present-day conditions within harbors to historical conditions. Historical conditions of the harbors were determined based on reviews of prior studies performed over a 13-year period from 1994 to 2007 within San Diego Bay, Mission Bay, Oceanside Harbor and Dana Point Harbor. Using the historical dataset, preset targets were established as the percentages of historically-sampled stations at or below threshold levels. By comparing the observed percentages of stations sampled throughout the harbors during the RHMP to the preset targets, determinations were made as to whether conditions in the harbors have improved or have declined. Additionally, long-term trends were also assessed by revisiting stations previously monitored in the Southern California Bight 1998 and 2003 Regional Monitoring Studies (Bight '98 and Bight '03). For these stations, changes in sediment conditions (i.e., chemistry, toxicity, and infauna) were assessed over a 10-year period. Lastly, as the RHMP program progresses, proportions of stations below threshold levels within a given harbor or stratum can be tracked through time to further quantify changes in the health of the harbors (i.e., trends).

This report presents the results of the RHMP 2008 core monitoring study, which provided an assessment of the overall health of the harbors based on multiple lines of evidence (MLOE): water quality (Section 3.1), sediment quality (Section 3.2), and demersal fish and invertebrate communities (Section 3.3). The conclusions of RHMP 2008 are discussed in the context of the SDRWQCB §13225 questions, and in doing so, provide a basis for the proposed special focused studies (Section 4.5).

2.0 METHODS

2.1 Field Sampling

Field sampling was conducted by WESTON from August 4-25, 2008 in Dana Point Harbor, Oceanside Harbor, Mission Bay, and San Diego Bay as a component of the Southern California Bight 2008 Regional Monitoring Study (Bight '08). Sampling consisted of water quality sampling, sediment sampling for chemistry, toxicity, and benthic infaunal assessments, and trawling to quantify the demersal fish and macrobenthic invertebrate communities.

2.1.1 Station Selection

The locations of 75 stations were designated within the five strata using a probability-based, stratified-random sampling approach that was fully integrated into the Bight '08 regional monitoring study. Sediment and water quality station selection was performed by the Southern California Coastal Water Research Project (SCCWRP) in accordance with the Bight '08 Regional Marine Monitoring Survey Coastal Ecology Field Operations Manual (SCCWRP, 2008a). The harbors and bays (hereafter referred to as harbors) were portioned into five strata: freshwater-influenced areas, marinas, industrial, deep, and shallow. Uniformly sized hexagons were overlaid on maps of each of the harbors. Hexagons were set at 30.5 m per side. Fifteen stations were randomly selected within each of the five strata with the stipulation that at least one station was set in each strata per harbor. San Diego Bay contained all five strata, while Mission Bay and Dana Point Harbor contained four strata (all except industrial), and Oceanside Harbor had three (i.e., marina, deep, and shallow). Sampling was conducted within a 100-m radius of the nominal station coordinates in accordance with Bight '08 protocols as determined by a differential Global Positioning System (dGPS), and coordinates of sample locations were recorded.

Otter trawl sampling stations were selected using the probability-based, random sampling approach. All trawl stations were located within the Bight '08 Bays & Harbors stratum. Single trawl tows were conducted at 17 Bight '08 stations and one targeted site in Dana Point Harbor. There were three trawl stations in Dana Point Harbor, two stations in Oceanside Harbor, three stations in Mission Bay, and 10 stations in San Diego Bay.

The locations of the sediment and water quality sampling stations and trawl stations are shown for Dana Point Harbor (Figure 2-1), Oceanside Harbor (Figure 2-2), Mission Bay (Figure 2-3), and San Diego Bay (Figure 2-4, Figure 2-5, Figure 2-6). Stations were equally assigned among strata (i.e., 15 stations per stratum); however in Dana Point Harbor, the designated shallow station (6327) was sampled within 100 m of the sample location, resulting in the actual location being located within the marina stratum. Consequently, 16 marina and 14 shallow stations were sampled, while the three other strata had 15 stations. A total of four sediment and water quality stations were sampled in Dana Point Harbor, along with three in Oceanside Harbor, eight in Mission Bay, and 60 in San Diego Bay. The distribution of stations among harbors was largely reflective of the overall size of the harbors, with the requirement that at least one station be located in each type of stratum in each harbor to ensure that smaller harbors received a minimum number of stations.

San Diego Bay comprised 82.7% of the total area of the harbors, followed by Mission Bay (15.6%), Dana Point Harbor (1.2%), and Oceanside Harbor (0.5%). The shallow stratum comprised 53.4% of the area of the RHMP harbors followed by the deep (36.4%), marina (5%), industrial (4.7%), and freshwater-influenced (1%) strata.

The majority of Dana Point Harbor was comprised of the marina stratum (41%), with the deep (37%) and shallow (21%) strata comprising nearly all the remaining area. Freshwater-influenced areas were considered to be those areas that had either large storm drains (i.e., greater than 60 inches in diameter), creeks, or rivers. There were two small areas (1%) that were classified as freshwater influenced due to the presence of storm drains. One freshwater-influenced station (6328), two marina stations (6320 and 6327), and one deep station (6325) were sampled in Dana Point Harbor (Figure 2-1).

Over half of Oceanside Harbor was comprised of the marina stratum (55%), with the shallow (26%) and deep (18%) strata comprising the remaining area. There were no areas in Oceanside Harbor that met the criteria of being freshwater influenced, since there were no large storm drains, creeks, or rivers that drained directly into the study area. A total of three sediment and water quality stations were sampled in Oceanside Harbor within the marina (6288), shallow (6291), and deep (6294) strata (Figure 2-2).

Mission Bay was predominantly comprised of the shallow stratum (85%), followed by 10% deep, nearly 4% marina, and nearly 1% freshwater-influenced strata. Of the eight sediment and water quality stations, three were located in the shallow (6216), two in the marina (6204 and 6211), two in the deep (6212 and 6213), and one in the freshwater-influenced strata (6223) (Figure 2-3). The marina stations in Mission Bay were located near Dana Landing (6211) and in Quivera Basin (6204), and the freshwater-influenced station (6223) was located near Rose Creek Inlet. Although station 6219 was classified as shallow, it occurs immediately adjacent to freshwater-influenced strata at the end of Cudahy Creek.

In San Diego Bay, 47% of the bay is comprised of the shallow stratum, followed by 42% deep, 6% industrial, 4% marina, and 1% freshwater-influenced strata. Of the 60 sediment and water quality stations, 10 were located in the shallow, 11 in the deep, 15 in the industrial, 11 in the marina, and 13 in the freshwater-influenced strata (Figure 2-4 to 2-6). The marina stations in San Diego Bay were located in Shelter Island Yacht Basin (SIYB), America's Cup Harbor, Harbor Island Marina, and the Coronado Cays; freshwater-influenced stations were located at the mouths of Chollas Creek and Sweetwater River; Industrial stations occurred exclusively in San Diego Bay, located along the eastern shoreline, extending north from Sweetwater River to just south of Embarcadero Marina Park; and deep and shallow stations were located throughout the bay, with majority of the bay north of Coronado Bridge classified as deep and the predominance of the area south of the bridge classified as shallow. Sampling of the industrial stratum was limited by military restrictions, which precluded sampling in areas adjacent to military piers between Chollas Creek and Sweetwater River (Figure 2-5) Industrial stations 6087 and 6094 were sampled outside the area of military operations, within the 100-m radius of the assigned station location, in accordance with Bight '08 sampling protocols.

Of the 75 stations sampled, 28 stations were revisited station locations of prior Bight studies, including 15 stations from Bight '98 and 13 stations from Bight '03. Bight '98 revisited stations included three marina stations (6145, 6161, and 6211), two industrial stations (6125 and 6140), seven deep (6054, 6084, 6128, 6129, 6152, 6153, and 6155), and three shallow stations (6080, 6173, and 6216), with 13 stations located in San Diego Bay and two in Mission Bay. Bight '03 revisited stations included six marina stations (6025, 6027, 6157, 6159, 6177, and 6204) one freshwater influenced (6040), one industrial (6075), three deep (6093, 6154, and 6212), and two shallow stations (6071 and 6217), with 10 of the stations located in San Diego Bay and three in Mission Bay.

Figure 2-1. Sampling stations in Dana Point Harbor

Figure 2-2. Sampling stations in Oceanside Harbor

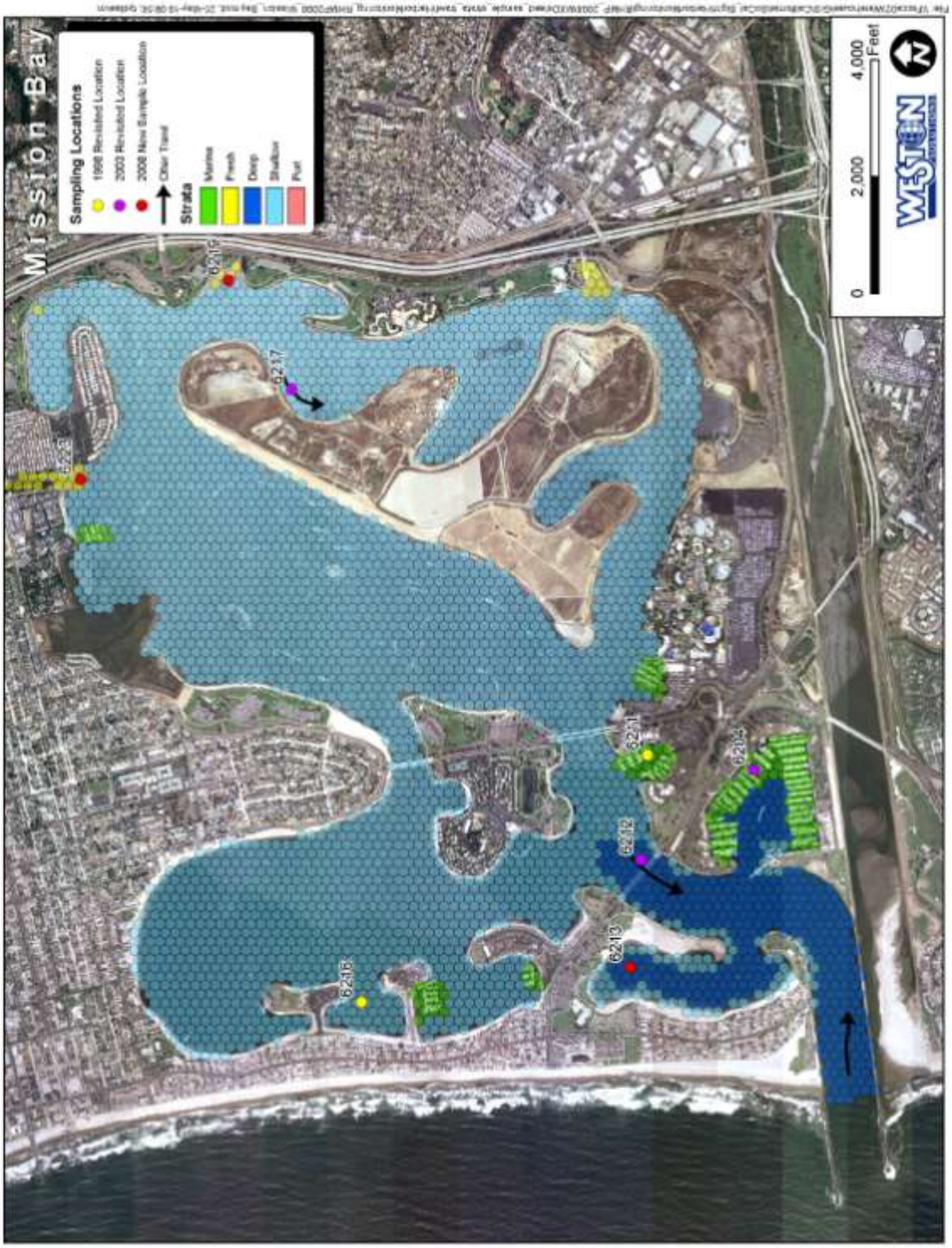


Figure 2-3. Sampling stations in Mission Bay

Figure 2-4. Sampling stations in northern San Diego Bay

Figure 2-5. Sampling stations in central San Diego Bay

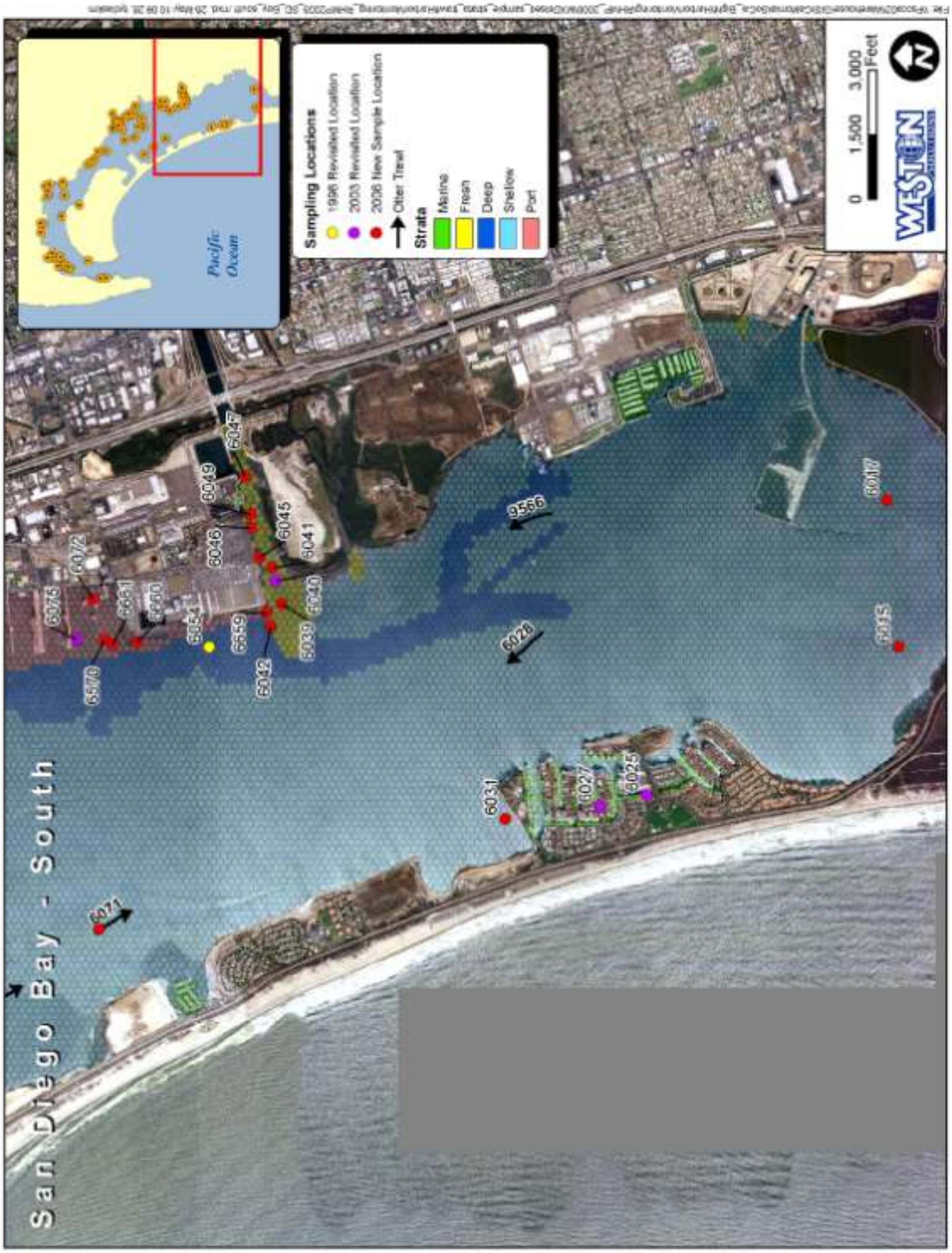


Figure 2-6. Sampling stations in southern San Diego Bay

2.1.2 Water Quality Sampling

Water quality sampling was performed by WESTON in August 2008. A total of 75 stations were sampled from five strata: 15 freshwater influenced, 16 marina, 15 industrial, 15 deep, and 14 shallow. Field observations and coordinates of sample locations were recorded on sediment sampling data forms. Station locations and sampling dates are listed in Appendix A.

Water column physical parameters were assessed using a Seabird SBE-25 Sealogger CTD (conductivity-temperature-depth profiler) equipped with sensors that measure temperature, specific conductance, dissolved oxygen (DO), hydrogen ion concentration (pH), and light transmission. Stations were located using a dGPS. DO and pH sensors were calibrated prior to the week of monitoring. Transmissivity, conductivity, and temperature were calibrated annually by Sea-Bird Electronics, Inc. Before beginning a cast, a 3-minute equilibration was performed to bring the CTD sensors to thermal equilibration with the ambient seawater and to ensure that all of the pumps had turned on. The CTD was lowered at a speed of 0.25-0.50 meters per second (m/sec) until it was within one meter of the bottom. The instrument operated at a scan rate of 8 scans/sec.

After casts in each harbor were performed, the data were downloaded and saved onto a field computer. Data were checked to ensure the CTD turned on properly, the depth was accurate, and that all water quality measurements were recorded throughout a cast. Data were transferred to a disk upon returning to the laboratory. A post cruise calibration was performed following each week of sampling.

Discrete water samples were collected at each station one meter below the surface using a Niskin bottle. Water samples were transferred to labeled sample containers and kept on ice. Additional data, including weather, wind speed and direction, and water color and odor, were recorded on field data sheets. Samples were analyzed for ammonia, dissolved organic carbon (DOC), total organic carbon (TOC), methylene blue active substances (MBAS), nitrate, oil and grease (O&G), total dissolved solids (TDS), total hardness (measured as calcium carbonate [$CaCO_3$]), total orthophosphate as P, dissolved and total metals, polynuclear aromatic hydrocarbons (PAHs), organophosphorus pesticides, and pyrethroids by CRG Marine Laboratories, Inc. (CRG). Methyl-t-butyl ether (MTBE) analysis was conducted by Calscience Environmental Laboratories, Inc. All samples were shipped on ice to CRG within 48 hours of sample collection. The CTD profiles and the samples for total and fecal coliforms and enterococci, were analyzed by WESTON. All of the bacteria samples were delivered to WESTON for analysis on ice within the 6-hour holding time.

2.1.3 Sediment Sampling

Sediment sampling was performed by WESTON in August 2008, following Bight ’08 protocols (SCCWRP 2008a). Sediment samples were collected at the same stations as those sampled for water quality, using a dGPS to locate the stations. Field observations and coordinates of sample locations were recorded on sediment sampling data forms on a field computer that was integrated with the dGPS unit. Appendix A shows the locations of the stations and sampling dates.

Benthic sediments were collected using a stainless steel, 0.1-m^2 Van Veen grab sampler. A minimum of four sediment grabs per station were collected for the following analyses: benthic infauna, chemistry, grain size, and toxicity. A sample was considered acceptable if the surface of the grab was even, there was minimal surface disturbance, and there was a penetration depth of at least 5 centimeters (cm). Rejected grabs were discarded and re-sampled. In accordance with Bight ’08 protocols, each of the infaunal samples was sub-sampled and split into three fractions. Sub-sampling was performed using two 0.01-m^2 subcores (considered to be fractions A and B) inserted into the Van Veen, while fraction C was considered to be the remaining sediment in the grab. The purpose of the subsampling was for a separate study being performed by SCCWRP that was focused on comparing benthic infauna results from a smaller surface area sampler than those from Van Veen samples in embayments (harbors, lagoons, and estuaries). Samples were analyzed as separate fractions to be in compliance with the Bight ’08 program; however, for the purposes of the RHMP, the data for all three fractions were combined as one sample.

Samples collected for infaunal analysis were rinsed through a 1.0-millimeter (mm) mesh screen and transferred to a labeled quart jar. A 7% magnesium sulfate ($MgSO_4$) seawater solution was added for approximately 30 minutes to relax the collected specimens. The samples were then fixed in a 10% buffered formalin solution. Infaunal samples were analyzed by WESTON.

Sediment toxicity and chemistry samples were collected from the top 5 cm of the grab, avoiding sediment within 1 cm of the sides of the grab. A total of 5 liters (L) of sediment was collected for acute and chronic toxicity and placed in five 1-L jars. Toxicity samples were kept on ice in coolers. Sediment to be analyzed for TOC, total nitrogen, acid volatile sulfides (AVS), trace metals, acid volatile sulfide-simultaneously extracted metals (AVS-SEM), PAHs, organophosphorus pesticides, chlorinated pesticides, polychlorinated biphenyls (PCBs), and pyrethroids was placed in one 250-ounce jar, stored at 4°C on ice, and frozen at – 20°C within 24 hours. These samples were shipped frozen to CRG within one week of collection for analyses. Approximately 150-200 grams (g) of sediment were collected for grain size analysis. Samples were each placed in a 1-quart Ziploc™ bag and kept on ice. The samples for acute and chronic toxicity and grain size were analyzed by WESTON.

2.1.4 Fish and Macroinvertebrate Trawl Sampling

Demersal fish and epibenthic macroinvertebrate samples were collected with a standard 25-ft. semi-balloon otter trawl with a 29-ft footrope, 1.5-inch mesh and 0.5-inch cod-end mesh, following Bight ’08 protocols (SCCWRP, 2008a). Trawls were towed along isobaths for five minutes (bottom time) at an approximate speed of 2.0 knots at each station. Station locations were determined using dGPS. Station information was recorded directly onto electronic field data forms created specifically for the Bight ’08 monitoring program. Trawl sample start and end coordinates were automatically recorded on the field computer, as well as interim coordinates along the trawl track. Trawl depths and bottom times were recorded with a Lotek™ temperature and pressure sensor mounted on the trawl door. Trawl station coordinates, sampling dates, and distance trawled are listed in Appendix A.

Upon retrieval of the trawl net and after determining that there were no obvious problems with the sampling procedure, the net contents were placed in a shallow tub for processing. All specimens were sorted by species and all fish and macroinvertebrates were counted and identified to the lowest possible taxon. Specimens that were unable to be identified in the field were preserved and returned to the laboratory for further identification, and a representative of each species encountered was retained as part of a project voucher collection. Very large organisms were vouched by photograph.

Fish specimens were measured in cm size classes. All specimens for each species were then combined and batch weighed to the nearest 0.1 kilogram (kg) to provide a wet weight biomass estimate for each species. If all the specimens for a species had a combined weight of less than 0.1 kg then the species lot was combined with other species having weights less than 0.1 kg to yield a composite taxa weight. Very large organisms were weighed individually and their biomass added to any other weights for that species. Macroinvertebrates were weighed using the same procedure as the fish. Each fish specimen was visually examined for abnormalities and disease symptoms (e.g., tumors, fin erosion, and internal and external lesions), which, if found, were noted on the field data sheets.

2.2 Laboratory Analysis

Laboratory analyses included chemical analyses of water and sediment samples, bacterial levels in water samples, sediment toxicity testing, and identification of benthic infaunal species.

2.2.1 Chemistry

Chemical analyses were performed on both water and sediment samples; a complete list of chemical analytes with corresponding analytical methods and detection limits is provided in Table 2-2. For water samples, analyses included ammonia, DOC, TOC, MBAS, nitrate, O&G, TDS, total hardness (measured as $CaCO_3$), total orthophosphate as P, dissolved and total metals, PAHs, organophosphorus pesticides, MTBE, and pyrethroids. For the sediment samples, TOC, total nitrogen, AVS, trace metals, AVS-SEM, PAHs, organophosphorus pesticides, chlorinated pesticides, PCBs, and pyrethroids were analyzed. All chemical analyses were conducted to meet or exceed the specifications of the SWAMP. Sediment samples were also analyzed for grain size (partitioned into gravel, sand, silt, and clay). A quality assurance/quality control [QA/QC] report for chemical analyses is provided as Appendix B-1.

Table 2-1. RHMP constituents monitored and corresponding analytical methods

Analyte	Method	Reporting Limit	Units
Water Samples			
pH	Collected in field	-	-
Specific Conductance	Collected in field	-	µS/cm
Dissolved Oxygen	Collected in field	-	mg/L
Temperature	Collected in field	-	ºC
Salinity	Collected in field	-	PSU
Transmissivity	Collected in field	-	%
General Chemistry			
Ammonia-N	SM 4500-NH3 F	0.03	mg/L
MBAS	SM 5540C	0.2	mg/L
Nitrate-N	SM 4500-NO3 E	0.025	mg/L
Oil & Grease	EPA 1664A	0.05	mg/L
Total Dissolved Solids	SM 2540C	5	mg/L
Total Hardness as CaCO3	SM 2340B	5	mg/L
Dissolved Organic Carbon	SM 5310B	5	mg/L

Analyte	Method	Reporting Limit	Units
Total Organic Carbon	SM 5310B	0.2	mg/L
Total Orthophosphate as P	SM 4500-P E	0.01	mg/L
Bacterial Indicators			
Enterococci	SM 9223B	10	MPN/100ml
Total and Fecal Coliforms	SM 9221B	20	MPN/100ml
Dissolved Metals			
Aluminum (Al)	EPA 1640	6	µg/L
Antimony (Sb)	EPA 1640	0.015	µg/L
Arsenic (As)	EPA 1640	0.015	µg/L
Barium (Ba)	EPA 200.8	0.5	µg/L
Beryllium (Be)	EPA 1640	0.01	µg/L
Cadmium (Cd)	EPA 1640	0.01	µg/L
Chromium (Cr)	EPA 1640	0.05	µg/L
Cobalt (Co)	EPA 1640	0.01	µg/L
Copper (Cu)	EPA 1640	0.02	µg/L
Iron (Fe)	EPA 1640	1	µg/L
Lead (Pb)	EPA 1640	0.01	µg/L
Manganese (Mn)	EPA 1640	0.02	µg/L
Mercury (Hg)	EPA 245.7	0.02	µg/L
Molybdenum (Mo)	EPA 1640	0.01	µg/L
Nickel (Ni)	EPA 1640	0.01	µg/L
Selenium (Se)	EPA 1640	0.015	µg/L
Silver (Ag)	EPA 1640	0.04	µg/L
Thallium (Tl)	EPA 1640	0.01	µg/L
Tin (Sn)	EPA 1640	0.01	µg/L
Titanium (Ti)	EPA 1640	0.07	µg/L
Vanadium (V)	EPA 1640	0.04	µg/L
Zinc (Zn)	EPA 1640	0.01	µg/L
Total Metals			
Aluminum (Al)	EPA 1640	6	µg/L
Antimony (Sb)	EPA 1640	0.015	µg/L
Arsenic (As)	EPA 1640	0.015	µg/L
Barium (Ba)	EPA 200.8	0.5	µg/L
Beryllium (Be)	EPA 1640	0.01	µg/L
Cadmium (Cd)	EPA 1640	0.01	µg/L
Chromium (Cr)	EPA 1640	0.05	µg/L
Cobalt (Co)	EPA 1640	0.01	µg/L
Copper (Cu)	EPA 1640	0.02	µg/L
Iron (Fe)	EPA 1640	1	µg/L
Lead (Pb)	EPA 1640	0.01	µg/L
Manganese (Mn)	EPA 1640	0.02	µg/L
Mercury (Hg)	EPA 245.7	0.02	µg/L
Molybdenum (Mo)	EPA 1640	0.01	µg/L
Nickel (Ni)	EPA 1640	0.01	µg/L
Selenium (Se)	EPA 1640	0.015	µg/L
Silver (Ag)	EPA 1640	0.04	µg/L
Thallium (Tl)	EPA 1640	0.01	µg/L
Tin (Sn)	EPA 1640	0.01	µg/L
Titanium (Ti)	EPA 1640	0.07	µg/L
Vanadium (V)	EPA 1640	0.04	µg/L
Zinc (Zn)	EPA 1640	0.01	µg/L

Analyte	Method	Reporting Limit	Units
Polynuclear Aromatic Hydrocarbons			
1-Methylnaphthalene	EPA 625	5	ng/L
1-Methylphenanthrene	EPA 625	5	ng/L
2,3,5-Trimethylnaphthalene	EPA 625	5	ng/L
2,6-Dimethylnaphthalene	EPA 625	5	ng/L
2-Methylnaphthalene	EPA 625	5	ng/L
Acenaphthene	EPA 625	5	ng/L
Acenaphthylene	EPA 625	5	ng/L
Anthracene	EPA 625	5	ng/L
Benz[a]anthracene	EPA 625	5	ng/L
Benzo[a]pyrene	EPA 625	5	ng/L
Benzo[b]fluoranthene	EPA 625	5	ng/L
Benzo[e]pyrene	EPA 625	5	ng/L
Benzo[g,h,i]perylene	EPA 625	5	ng/L
Benzo[k]fluoranthene	EPA 625	5	ng/L
Biphenyl	EPA 625	5	ng/L
Chrysene	EPA 625	5	ng/L
Dibenz[a,h]anthracene	EPA 625	5	ng/L
Dibenzothiophene	EPA 625	5	ng/L
Fluoranthene	EPA 625	5	ng/L
Fluorene	EPA 625	5	ng/L
Indeno[1,2,3-c,d]pyrene	EPA 625	5	ng/L
Naphthalene	EPA 625	5	ng/L
Perylene	EPA 625	5	ng/L
Phenanthrene	EPA 625	5	ng/L
Pyrene	EPA 625	5	ng/L
Organophosphorus Pesticides			
Bolstar (Sulprofos)	EPA 625	4	ng/L
Chlorpyrifos	EPA 625	2	ng/L
Demeton	EPA 625	2	ng/L
Diazinon	EPA 625	4	ng/L
Dichlorvos	EPA 625	6	ng/L
Dimethoate	EPA 625	6	ng/L
Disulfoton	EPA 625	2	ng/L
Ethoprop (Ethoprofos)	EPA 625	2	ng/L
Fenchlorphos (Ronnel)	EPA 625	4	ng/L
Fensulfothion	EPA 625	2	ng/L
Fenthion	EPA 625	4	ng/L
Malathion	EPA 625	6	ng/L
Merphos	EPA 625	2	ng/L
Methyl Parathion	EPA 625	2	ng/L
Mevinphos (Phosdrin)	EPA 625	16	ng/L
Phorate	EPA 625	12	ng/L
Tetrachlorvinphos (Stirofos)	EPA 625	4	ng/L
Tokuthion	EPA 625	6	ng/L
Trichloronate	EPA 625	2	ng/L
Volatile Organic Compounds			
Methyl-t-Butyl Ether (MTBE)	EPA 8260B	1	µg/L
Pyrethroids by NCI			
Allethrin	EPA 625 NCI	2	ng/L

Analyte	Method	Reporting Limit	Units
Bifenthrin	EPA 625 NCI	2	ng/L
Cyfluthrin	EPA 625 NCI	2	ng/L
Cypermethrin	EPA 625 NCI	2	ng/L
Danitol	EPA 625 NCI	2	ng/L
Deltamethrin	EPA 625 NCI	2	ng/L
Esfenvalerate	EPA 625 NCI	2	ng/L
Fenvalerate	EPA 625 NCI	2	ng/L
Fluvalinate	EPA 625 NCI	2	ng/L
L-Cyhalothrin	EPA 625 NCI	2	ng/L
Permethrin, cis-	EPA 625 NCI	25	ng/L
Permethrin, trans-	EPA 625 NCI	25	ng/L
Prallethrin	EPA 625 NCI	2	ng/L
Resmethrin	EPA 625 NCI	25	ng/L
Sediment Samples			
Analyte	**Method**	**Reporting Limit**	**Units**
General Chemistry			
Acid Volatile Sulfides	Plumb, 1981/TERL	0.1	mg/dry kg
Percent Solids	EPA 160.3	0.1	%
Total Nitrogen	SM 4500-N	4	mg/dry kg
Total Organic Carbon	SM 5310B	0.02	%
Grain Size Analysis	Plumb, 1981	-	-
Acute toxicity (*Eohaustorius*)	USEPA 1994a; ASTM E1367-03 (2006a), w/ modifications	-	%
Chronic toxicity (*Mytilus*)	Anderson, 1996 (modified); USEPA 1995	-	%
Benthic Infauna	-	-	-
Total Metals-Standard			
Aluminum (Al)	EPA 6020	5	µg/dry g
Antimony (Sb)	EPA 6020	0.05	µg/dry g
Arsenic (As)	EPA 6020	0.05	µg/dry g
Barium (Ba)	EPA 6020	0.05	µg/dry g
Beryllium (Be)	EPA 6020	0.05	µg/dry g
Cadmium (Cd)	EPA 6020	0.05	µg/dry g
Chromium (Cr)	EPA 6020	0.05	µg/dry g
Cobalt (Co)	EPA 6020	0.05	µg/dry g
Copper (Cu)	EPA 6020	0.05	µg/dry g
Iron (Fe)	EPA 6020	5	µg/dry g
Lead (Pb)	EPA 6020	0.05	µg/dry g
Manganese (Mn)	EPA 6020	0.05	µg/dry g
Mercury (Hg)	EPA 245.7	0.02	µg/dry g
Molybdenum (Mo)	EPA 6020	0.05	µg/dry g
Nickel (Ni)	EPA 6020	0.05	µg/dry g
Selenium (Se)	EPA 6020	0.05	µg/dry g
Silver (Ag)	EPA 6020	0.05	µg/dry g
Strontium (Sr)	EPA 6020	0.05	µg/dry g
Thallium (Tl)	EPA 6020	0.05	µg/dry g
Tin (Sn)	EPA 6020	0.05	µg/dry g
Titanium (Ti)	EPA 6020	0.05	µg/dry g
Vanadium (V)	EPA 6020	0.05	µg/dry g
Zinc (Zn)	EPA 6020	0.05	µg/dry g

Analyte	Method	Reporting Limit	Units
Total Metals-AVS-SEM			
Aluminum (Al)	EPA 200.8	0.926	µmol/dry g
Antimony (Sb)	EPA 200.8	0.0016	µmol/dry g
Arsenic (As)	EPA 200.8	0.0054	µmol/dry g
Barium (Ba)	EPA 200.8	0.003	µmol/dry g
Beryllium (Be)	EPA 200.8	0.0444	µmol/dry g
Cadmium (Cd)	EPA 200.8	0.0036	µmol/dry g
Chromium (Cr)	EPA 200.8	0.0038	µmol/dry g
Cobalt (Co)	EPA 200.8	0.0034	µmol/dry g
Copper (Cu)	EPA 200.8	0.0124	µmol/dry g
Iron (Fe)	EPA 200.8	0.4385	µmol/dry g
Lead (Pb)	EPA 200.8	0.0004	µmol/dry g
Manganese (Mn)	EPA 200.8	0.0072	µmol/dry g
Molybdenum (Mo)	EPA 200.8	0.0042	µmol/dry g
Nickel (Ni)	EPA 200.8	0.0066	µmol/dry g
Selenium (Se)	EPA 200.8	0.0048	µmol/dry g
Silver (Ag)	EPA 200.8	0.0094	µmol/dry g
Strontium (Sr)	EPA 200.8	0.0022	µmol/dry g
Thallium (Tl)	EPA 200.8	0.001	µmol/dry g
Tin (Sn)	EPA 200.8	0.0016	µmol/dry g
Titanium (Ti)	EPA 200.8	0.0086	µmol/dry g
Vanadium (V)	EPA 200.8	0.0078	µmol/dry g
Zinc (Zn)	EPA 200.8	0.003	µmol/dry g
Polynuclear Aromatic Hydrocarbons			
1-Methylnaphthalene	EPA 8270C	5	ng/dry g
1-Methylphenanthrene	EPA 8270C	5	ng/dry g
2,3,5-Trimethylnaphthalene	EPA 8270C	5	ng/dry g
2,6-Dimethylnaphthalene	EPA 8270C	5	ng/dry g
2-Methylnaphthalene	EPA 8270C	5	ng/dry g
Acenaphthene	EPA 8270C	5	ng/dry g
Acenaphthylene	EPA 8270C	5	ng/dry g
Anthracene	EPA 8270C	5	ng/dry g
Benz[a]anthracene	EPA 8270C	5	ng/dry g
Benzo[a]pyrene	EPA 8270C	5	ng/dry g
Benzo[b]fluoranthene	EPA 8270C	5	ng/dry g
Benzo[e]pyrene	EPA 8270C	5	ng/dry g
Benzo[g,h,i]perylene	EPA 8270C	5	ng/dry g
Benzo[k]fluoranthene	EPA 8270C	5	ng/dry g
Biphenyl	EPA 8270C	5	ng/dry g
Chrysene	EPA 8270C	5	ng/dry g
Dibenz[a,h]anthracene	EPA 8270C	5	ng/dry g
Dibenzothiophene	EPA 8270C	5	ng/dry g
Fluoranthene	EPA 8270C	5	ng/dry g
Fluorene	EPA 8270C	5	ng/dry g
Indeno[1,2,3-c,d]pyrene	EPA 8270C	5	ng/dry g
Naphthalene	EPA 8270C	5	ng/dry g
Perylene	EPA 8270C	5	ng/dry g
Phenanthrene	EPA 8270C	5	ng/dry g
Pyrene	EPA 8270C	5	ng/dry g
Organophosphorus Pesticides			
Bolstar (Sulprofos)	EPA 8270c	20	ng/dry g

Analyte	Method	Reporting Limit	Units
Chlorpyrifos	EPA 8270c	10	ng/dry g
Demeton	EPA 8270c	20	ng/dry g
Diazinon	EPA 8270c	10	ng/dry g
Dichlorvos	EPA 8270c	20	ng/dry g
Dimethoate	EPA 8270c	10	ng/dry g
Disulfoton	EPA 8270c	20	ng/dry g
Ethoprop (Ethoprofos)	EPA 8270c	20	ng/dry g
Fenchlorphos (Ronnel)	EPA 8270c	20	ng/dry g
Fensulfothion	EPA 8270c	20	ng/dry g
Fenthion	EPA 8270c	20	ng/dry g
Malathion	EPA 8270c	10	ng/dry g
Merphos	EPA 8270c	20	ng/dry g
Methyl Parathion	EPA 8270c	20	ng/dry g
Mevinphos (Phosdrin)	EPA 8270c	20	ng/dry g
Phorate	EPA 8270c	20	ng/dry g
Tetrachlorvinphos (Stirofos)	EPA 8270c	20	ng/dry g
Tokuthion	EPA 8270c	20	ng/dry g
Trichloronate	EPA 8270c	20	ng/dry g
Chlorinated Pesticides			
2,4'-DDD	EPA 8270C	5	ng/dry g
2,4'-DDE	EPA 8270C	5	ng/dry g
2,4'-DDT	EPA 8270C	5	ng/dry g
4,4'-DDD	EPA 8270C	5	ng/dry g
4,4'-DDE	EPA 8270C	5	ng/dry g
4,4'-DDMU	EPA 8270C	5	ng/dry g
4,4'-DDT	EPA 8270C	5	ng/dry g
Aldrin	EPA 8270C	5	ng/dry g
BHC-alpha	EPA 8270C	5	ng/dry g
BHC-beta	EPA 8270C	5	ng/dry g
BHC-delta	EPA 8270C	5	ng/dry g
BHC-gamma	EPA 8270C	5	ng/dry g
Chlordane-alpha	EPA 8270C	5	ng/dry g
Chlordane-gamma	EPA 8270C	5	ng/dry g
DCPA (Dacthal)	EPA 8270C	10	ng/dry g
Dicofol	EPA 8270C	5	ng/dry g
Dieldrin	EPA 8270C	5	ng/dry g
Endosulfan Sulfate	EPA 8270C	5	ng/dry g
Endosulfan-I	EPA 8270C	5	ng/dry g
Endosulfan-II	EPA 8270C	5	ng/dry g
Endrin	EPA 8270C	5	ng/dry g
Endrin Aldehyde	EPA 8270C	5	ng/dry g
Endrin Ketone	EPA 8270C	5	ng/dry g
Heptachlor	EPA 8270C	5	ng/dry g
Heptachlor Epoxide	EPA 8270C	5	ng/dry g
Methoxychlor	EPA 8270C	5	ng/dry g
Mirex	EPA 8270C	5	ng/dry g
Oxychlordane	EPA 8270C	5	ng/dry g
Perthane	EPA 8270C	10	ng/dry g
Toxaphene	EPA 8270C	50	ng/dry g
cis-Nonachlor	EPA 8270C	5	ng/dry g
trans-Nonachlor	EPA 8270C	5	ng/dry g

Analyte	Method	Reporting Limit	Units
PCB Congeners			
PCB003	EPA 8270C	5	ng/dry g
PCB008	EPA 8270C	5	ng/dry g
PCB018	EPA 8270C	5	ng/dry g
PCB028	EPA 8270C	5	ng/dry g
PCB031	EPA 8270C	5	ng/dry g
PCB033	EPA 8270C	5	ng/dry g
PCB037	EPA 8270C	5	ng/dry g
PCB044	EPA 8270C	5	ng/dry g
PCB049	EPA 8270C	5	ng/dry g
PCB052	EPA 8270C	5	ng/dry g
PCB056/060	EPA 8270C	5	ng/dry g
PCB066	EPA 8270C	5	ng/dry g
PCB070	EPA 8270C	5	ng/dry g
PCB074	EPA 8270C	5	ng/dry g
PCB077	EPA 8270C	5	ng/dry g
PCB081	EPA 8270C	5	ng/dry g
PCB087	EPA 8270C	5	ng/dry g
PCB095	EPA 8270C	5	ng/dry g
PCB097	EPA 8270C	5	ng/dry g
PCB099	EPA 8270C	5	ng/dry g
PCB101	EPA 8270C	5	ng/dry g
PCB105	EPA 8270C	5	ng/dry g
PCB110	EPA 8270C	5	ng/dry g
PCB114	EPA 8270C	5	ng/dry g
PCB118	EPA 8270C	5	ng/dry g
PCB119	EPA 8270C	5	ng/dry g
PCB123	EPA 8270C	5	ng/dry g
PCB126	EPA 8270C	5	ng/dry g
PCB128	EPA 8270C	5	ng/dry g
PCB138	EPA 8270C	5	ng/dry g
PCB141	EPA 8270C	5	ng/dry g
PCB149	EPA 8270C	5	ng/dry g
PCB151	EPA 8270C	5	ng/dry g
PCB153	EPA 8270C	5	ng/dry g
PCB156	EPA 8270C	5	ng/dry g
PCB157	EPA 8270C	5	ng/dry g
PCB158	EPA 8270C	5	ng/dry g
PCB167	EPA 8270C	5	ng/dry g
PCB168+132	EPA 8270C	5	ng/dry g
PCB169	EPA 8270C	5	ng/dry g
PCB170	EPA 8270C	5	ng/dry g
PCB174	EPA 8270C	5	ng/dry g
PCB177	EPA 8270C	5	ng/dry g
PCB180	EPA 8270C	5	ng/dry g
PCB183	EPA 8270C	5	ng/dry g
PCB187	EPA 8270C	5	ng/dry g
PCB189	EPA 8270C	5	ng/dry g
PCB194	EPA 8270C	5	ng/dry g
PCB195	EPA 8270C	5	ng/dry g
PCB200	EPA 8270C	5	ng/dry g

Analyte	Method	Reporting Limit	Units
PCB201	EPA 8270C	5	ng/dry g
PCB203	EPA 8270C	5	ng/dry g
PCB206	EPA 8270C	5	ng/dry g
PCB209	EPA 8270C	5	ng/dry g
Pyrethroids by NCI			
Allethrin	EPA 8270 NCI	2	ng/dry g
Bifenthrin	EPA 8270 NCI	2	ng/dry g
Cyfluthrin	EPA 8270 NCI	2	ng/dry g
Cypermethrin	EPA 8270 NCI	2	ng/dry g
Danitol	EPA 8270 NCI	2	ng/dry g
Deltamethrin	EPA 8270 NCI	2	ng/dry g
Esfenvalerate	EPA 8270 NCI	2	ng/dry g
Fenvalerate	EPA 8270 NCI	2	ng/dry g
Fluvalinate	EPA 8270 NCI	2	ng/dry g
L-Cyhalothrin	EPA 8270 NCI	2	ng/dry g
Permethrin, cis-	EPA 8270 NCI	25	ng/dry g
Permethrin, trans-	EPA 8270 NCI	25	ng/dry g
Prallethrin	EPA 8270 NCI	2	ng/dry g
Resmethrin	EPA 8270 NCI	25	ng/dry g

2.2.2 Toxicity

Sediment bioassay tests were used to quantify species-specific responses to exposure to surficial sediments under controlled laboratory conditions. In accordance with SQO and Bight '08 guidance, an acute solid phase (SP) toxicity test and a chronic sediment-water interface (SWI) test were used to assess sediment toxicity, as described below.

2.2.2.1 Solid Phase (SP) Testing

SP bioassays were performed to estimate the potential toxicity of the collected sediments to benthic organisms. Ten-day SP tests using the marine amphipod *Eohaustorius estuarius* were conducted in accordance with procedures outlined in the amphipod testing manual (United States Environmental Protection Agency [USEPA], 1994a) and the American Society for Testing and Materials (ASTM) method E1367-03 (ASTM, 2006a). On the day before test initiation, 2-cm aliquots of sample sediment were placed in each of five replicate glass jars followed by approximately 800 milliliter (mL) of prepared seawater. Five replicate controls were used to determine the health of the amphipods; this was done by exposing the amphipods to clean sediment following the same protocols used for the test sediments. The test chambers were left overnight to allow establishment of equilibrium between the sediment and overlying water. On day zero of the test, 20 amphipods were randomly placed in each of the test chambers. Amphipods that did not bury in the sediment within an hour were removed and replaced. Samples were monitored daily for obvious mortality, sublethal effects, and abnormal behavior. Water quality parameters, including DO, temperature, salinity and pH, were monitored daily. Overlying and interstitial ammonia were also measured at test initiation and test termination. At the end of the test, organisms were removed from the test chambers by sieving the sediment through a 0.5-mm mesh screen and the numbers of live and dead amphipods in each test chamber were recorded. Percent survival was calculated for control and test sediments. Tests were considered to be acceptable if there was >90% mean control survival.

A 96-hour reference toxicity test was conducted concurrently with the sediment test to establish sensitivity of the test organisms used in the evaluation of the sediments and to evaluate the potential influence of ammonia toxicity on the test organisms. The reference toxicant test was performed using the reference substance ammonium chloride with target concentrations of 15.62, 31.25, 62.50, 125.0, and 250.0 mg NH_4/L. Ten test organisms were added to each of four replicates for each concentration. Subsamples were obtained at test initiation and were used to measure actual ammonia concentrations and to calculate un-ionized ammonia concentrations. The concentrations of total ammonia and un-ionized ammonia that caused 50% mortality of the organisms (the median lethal concentration, or LC_{50}) were calculated from the data. The LC_{50} values were then compared to historical laboratory data for the test species with ammonium chloride. The results of this test were used in combination with the control mortality to assess the health of the test organisms.

2.2.2.2 Sediment-Water Interface (SWI) testing

SWI bioassays were performed to estimate the potential chronic toxicity of contaminants fluxed from sediments to overlying water. Forty-eight-hour bivalve *Mytilus galloprovincialis* SWI bioassays were conducted in accordance with procedures outlined in USEPA 1995 and Anderson *et al*. 1996. On the day before test initiation, 5-cm aliquots of sample sediment were placed in each of the five replicate glass chambers followed by approximately 300 mL of prepared seawater. Five replicate controls were used to verify that the test system was not causing toxicity; this was done by exposing the bivalve larvae to test chambers with screen tubes but no sediment. The test chambers were left overnight to allow establishment of equilibrium between the sediment and overlying water. On day zero of the test, polycarbonate screen tubes were lowered into each chamber so that larvae settled inside the screen tube were in close proximity to the sediment surface. Approximately 250 bivalve larvae were placed inside the screen tube in each of the test chambers. Water quality parameters, including DO, temperature, salinity and pH, were monitored daily. Overlying and interstitial ammonia were also measured at test initiation and test termination. At the end of the test, organisms were retrieved from the test chambers by removing the screen tubes and gently rinsing the larvae into glass shell vials with clean filtered seawater. The vials were preserved with formalin to be analyzed by microscope. After microscope counts were performed, the percent normal-alive embryo development was calculated for the control and test sediments. Tests were considered to be acceptable if there was >70% mean control normal-alive embryo development.

A 48-hour reference toxicity test was conducted concurrently with the SWI test to establish sensitivity of the test organisms used in the evaluation of the sediments and to evaluate the potential influence of ammonia toxicity on the test organisms. The reference toxicant test was performed using the reference substance ammonium chloride with target concentrations of 1.0, 2.0, 5.0, 7.0, 10, and 20 mg NH_4/L. Approximately 250 larvae were added to each of five replicates of these concentrations. Subsamples were obtained at test initiation and were used to measure actual ammonia concentrations and to calculate un-ionized ammonia concentrations. The concentrations of total ammonia and un-ionized ammonia that caused 50% mortality (LC_{50}) and 50% reduction normality (or median effective concentration [EC_{50}]) of the organisms were calculated from the data. The LC_{50} and EC_{50}values were then compared to historical laboratory data for the test species with ammonium chloride. The results of this test were used in combination with the percent control normal-alive embryo development to assess the health of the test organisms.

2.2.3 Infauna

Benthic infaunal samples were transported from the field to the laboratory and stored in a formalin solution for a minimum of 6 days. The samples were then transferred from formalin to 70% ethanol for laboratory processing. In accordance with the Bight ’08 Macrobenthic (Infaunal) Sample Analysis Laboratory Manual (SCCWRP, 2008b), the organisms were initially sorted using a dissecting microscope into five groups: polychaetes, crustaceans, molluscs, echinoderms, and miscellaneous minor phyla. While sorting, technicians kept a rough count for QA/QC purposes, as described in the following paragraph. After initial sorting, qualified taxonomists identified each organism to the lowest possible taxon, and species counts were tabulated. Taxonomists used the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) Edition 5 for nomenclature and orthography (SCAMIT, 2008).

A QA/QC procedure was performed on each of the sorted samples to ensure a 95% sorting efficiency. A 10% aliquot of a sample was re-sorted by a senior technician trained in the QA/QC procedure. The number of organisms found in the aliquot was divided by 10% and added to the total number found in the sample. The original total was divided by the new total to calculate the percent sorting efficiency. When the sorting efficiency of the sample was below 95%, the remainder of the sample (90%) was re-sorted.

2.2.4 Microbiology

Water samples were analyzed for total and fecal coliforms and Enterococci using Standard Method (SM) 9221B and E and IDEXX Enterolert™ methodology (SM 9223B). All results were reported to a most probable number (MPN) value with a minimum reporting limit of <20 MPN/100mL and a maximum reporting limit of 160,000 MPN/100mL for total and fecal coliforms. Samples analyzed for enterococci, had a minimum reporting limit of <10 MPN/100mL and a maximum of 24,196 MPN/100mL. All samples were delivered to the analytical laboratory within the 6-hour holding time requirement. Sample analysis was initiated immediately upon receipt.

2.2.5 Profile Data Processing

Sea-Bird CTD profile scans were uploaded to WESTON’s server daily for processing by Sea-Bird data processing software. Scans were averaged by 1-m depth intervals using Sea-Bird software to produce a manageable data set for analysis.

2.3 Data Analysis

In Phase I of this project, historical data were compiled to establish threshold levels and preset targets by which to measure changes in the harbors (Table 2-2). The majority of the data were from Bight ’98, Bight ’03 and the Bay Protection and Toxic Cleanup Program (BPTCP). Data that had similar detection limits (chemistry), test species (toxicity), and sampling equipment and screen size (benthic infauna) were used to determine threshold levels (WESTON, 2005b).

Threshold levels were established as concentration levels for chemical constituents, toxicity levels for bioassays, and diversity measures and the Benthic Response Index (BRI) for infauna (Smith *et al*., 2003). Preset targets were determined by defining the proportion of historical samples collected in the harbors that were below the established threshold levels. Preset target proportions were defined to be the constant in the binomial model for comparison to RHMP data from the harbors. Proportions of stations below the threshold level were compared to the preset target to determine differences between the historical conditions of the harbors and present-day conditions. For chemistry, toxicity, and the Shannon-Wiener Diversity Index and number of taxa benthic indicators, a significantly greater proportion of observed samples above the preset targets for all strata combined would indicate that water or sediment quality conditions are improving (WESTON, 2005b). In the case of BRI, conditions will be considered to be better than historical levels when the proportions of stations below the BRI score threshold are lower than the historical preset target, since this is indicative of a less degraded state or reference condition. A summary of the established threshold levels and preset targets is presented in Table 2-3.

Indicators were partitioned into primary and secondary indicators. Primary indicators for the study were selected because they are either major constituents of concern (e.g., copper in water) or they provide information on a suite of measurements (e.g., the mean ER-M quotient for sediments). Secondary indicators were used as supporting data to enhance the interpretation of the primary indicators (WESTON, 2005b). The selection of individual primary and secondary indicators for water column chemistry, sediment chemistry, sediment toxicity, and benthic infauna is further discussed in Sections 2.3.1 through 2.3.4.

Table 2-2. Studies used to establish reference ambient values

Study Name	Year	Dana Point Harbor	Oceanside Harbor	Mission Bay	San Diego Bay
Sediment Chemistry					
America's Cup Harbor	2001				X
Bight '98	1998	X		X	X
BPTCP	1994, 1996	X	X	X	X
Central SD Bay Nav. Channel Deepening	1998, 2003				X
Chollas Creek	2003				X
10th Avenue Marine Terminal	2002				X
National City Wharf Extension	1999				X
Navy Arco	2000				X
Navy P-326	2000				X
Paleta Creek	2003				X
Reference reconnaissance	2003				X
Sediment sampling	2003	X			
Toxic Hot Spots Sediment	2003				X
Water and Sediment Testing Project	2001-2003			X	
Bight '03	2003	X		X	X
RHMP Pilot Project	2005-2007	X	X	X	X
Benthic Infauna					
Ambient Bay and Lagoon Monitoring	2003		X	X	
America's Cup Harbor	2002				X
Bight '98	1998	X		X	X
Reference reconnaissance	2003				X
Switzer Creek	2002				X
Bight '03	2003	X		X	X
RHMP Pilot Project	2005-2007	X	X	X	X
Sediment Toxicity					
Bight '98	1998				X
Benthic Infauna Analysis	2003-2004	X			
National City Wharf Extension	1999				X
Water and Sediment Testing Project	2001-2003			X	
Bight '03	2003	X		X	X
RHMP Pilot Project	2005-2007	X	X	X	X
Water Column Chemistry					
Baywide Copper	2002				X
Dana Point monitoring	1992-2002	X			
Paco Bay Water measurements	1992-1999				X
RHMP Pilot Project	2005-2007	X	X	X	X

Table 2-3. Summary of threshold values and preset targets

Measure	Threshold Value	Preset Target
Primary Indicators		
Dissolved Copper (water)	4.8 µg/L	58%
Total Copper (water)	5.8 µg/L	51%
Mean ER-M Quotient	0.2	46%
BRI	31	55%
E. estuarius mortality	20%	55%
Secondary Indicators		
Dissolved Zinc (water)	90 µg/L	100%
Total Zinc (water)	95 µg/L	99%
Dissolved Nickel (water)	74 µg/L	100%
Total Nickel (water)	75 µg/L	100%
Sediment Arsenic	8.2 µg/g	52%
Sediment Cadmium	1.2 µg/g	92%
Sediment Chromium	81 µg/g	83%
Sediment Copper	175 µg/g	68%
Sediment Lead	46.7 µg/g	75%
Sediment Mercury	0.15 µg/g	26%
Sediment Nickel	20.9 µg/g	80%
Sediment Zinc	150 µg/g	45%
Sediment Total PAHs	4022 ng/g	79%
Sediment Total Chlordanes	2 ng/g	86%
Sediment Total DDTs	2 ng/g	54%
Sediment Total PCBs	22.7 ng/g	47%
Shannon-Wiener Diversity Index	2	76%
Number of Taxa	24	82%

Each of the primary and secondary indicators measured in the RHMP was plotted for visual comparison to the threshold levels and preset targets. Figure 2-7 shows an example of a distribution curve that can be used as a reference guide. Both the historical and current data were plotted as distribution curves with the current data overlying the historical data. The current data are shown as a step plot rather than a smooth curve to differentiate current data from historical data. The horizontal blue line is the threshold level for each indicator. The vertical green line is the preset target. The orange line represents where the distribution curve for the current data crosses the threshold level. When the orange line is to the left of the preset target then the proportion of samples that are below the threshold level is lower than the proportion of samples historically observed below this level. This would indicate that water or sediment quality conditions for that particular indicator have degraded from historical conditions throughout the harbors. If the orange line is to the right of the preset target then the proportion of samples below the threshold level is greater than the proportion of samples historically observed below the threshold. This would indicate progress towards improved water or sediment quality in the harbors. The results for each indicator were statistically compared to the preset target to determine if the percent of samples below the threshold level was higher or lower than historical conditions for the four harbors, as detailed in Section 2.3.7.

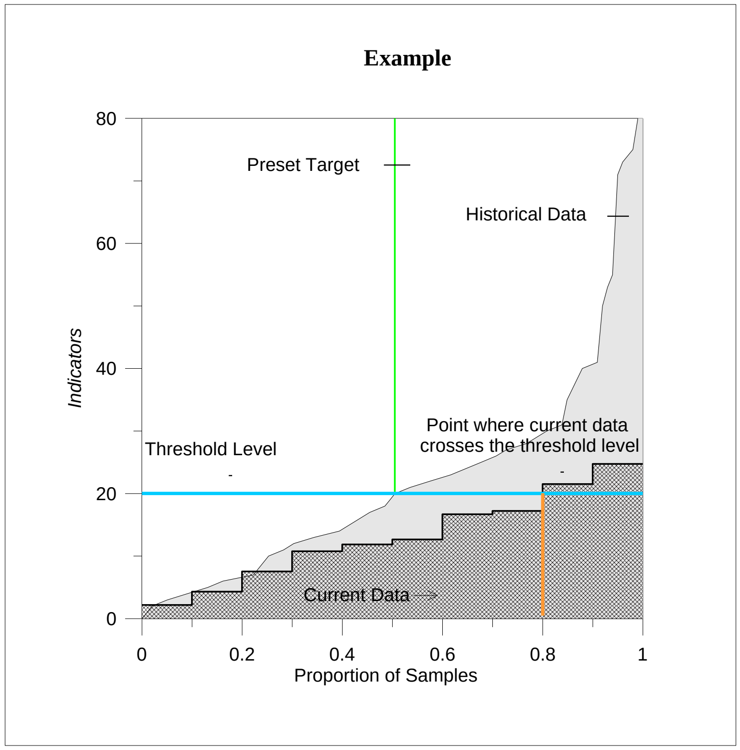


Figure 2-7. Example of a distribution curve that can be used as a reference guide

2.3.1 Water Column Chemistry

Historical observations of water column metal concentration were available for dissolved and total copper, nickel, and zinc (WESTON, 2005b). The data along with benchmark values from the CTR and the COP were evaluated to establish threshold levels. The CTR was created using both literature and toxicity test data, thus making it the best threshold level to use for aqueous metals (CTR, 2000). Only dissolved and total copper were selected as primary indicators for aqueous metals because of the large numbers of historical observations above the acute CTR for dissolved copper (4.8 micrograms per liter [µg/L]). Dissolved and total zinc and nickel were selected as secondary indicators. If the percent of current samples below the threshold level for a particular stratum was found to be greater than the preset target it would indicate that water quality in the stratum was better than historically observed across all five strata within the harbors (WESTON, 2005b). The threshold levels and preset targets for these metals are listed in Table 2-3.

2.3.2 Sediment Chemistry

For sediment chemistry, the mean ER-M quotient is the primary indicator for comparing results in the monitoring program to preset targets. Briefly, the ER-L and ER-M are two effects-based sediment quality values developed to help interpret sediment chemistry measurements and their potential for causing adverse biological effects (Long *et al*., 1995). These parameters were developed from an extensive database of sediment toxicity bioassays and chemistry measurements. The ER-L was calculated as the lower tenth percentile of the observed effects concentrations and the ER-M as the 50^{th} percentile of observed effects concentrations. Concentrations below the ER-L are not likely to result in biological effects, while concentrations above the ER-M are likely to result in biological effects (Long *et al*., 1995).

The ER-M quotient, which is the ratio of sample concentration to the ER-M, can be used to evaluate the likelihood of benthic effects based on cumulative sediment chemistry. The quotient is calculated by dividing each measured sediment chemical concentration by its respective ER-M. The mean ER-M quotient calculates an average quotient based on concentrations of all known contaminants relative to the ER-M values. Therefore, the mean ER-M quotient is a method of integrating the effects from multiple contaminants (Wenning *et al*., 2005). For the RHMP, the mean ER-M quotient was calculated using concentrations of arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, zinc, total detectable PAHs, total PCBs, total dichlorodiphenyltrichloroethanes (DDTs), and total chlordanes.

Based on recent projects with the SDRWQCB, the threshold level for the mean ER-M quotient was determined to be 0.2 to provide a more conservative measure than the more commonly used standard of 0.5. Samples with mean ER-M quotients above 0.2 were more likely to have adverse benthic effects associated with the sediment chemistry. Based on historical data, the preset target for the mean ER-M quotient was established at 46% across all strata. If the percent of current sediment samples with a mean ER-M quotient below 0.2 was significantly higher than 46%, then it indicated that the overall conditions of sediment quality were better than conditions historically observed within the harbors. If the percent of samples was lower than the preset target then other indicators such as individual chemical constituents were evaluated in conjunction with the mean ER-M quotient to help determine which chemicals were problematic in the harbors (WESTON, 2005b).

Total PAHs, total PCBs, total DDTs, total chlordanes and metals, including arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc were used as RHMP secondary indicators. These measures were used to help interpret the mean ER-M quotient by showing which of the chemicals occurred at concentrations that would contribute to an elevated mean ER-M quotient. The ER-L was determined to be the best threshold level for all of these secondary indicators except copper (WESTON, 2005b). The threshold level for copper was based on the level at which anthropogenic origins may be contributing to the overall copper concentrations in the sediment. To determine this concentration, historical data were used to plot copper concentrations against iron concentrations, both of which occur naturally in harbor sediments. Normalization to iron is a common approach to understanding the influence of potential enrichment via anthropogenic inputs since iron is a reliable indicator of “geological background” levels. When trace metals, such as copper, co-vary with iron, they are generally viewed as being within geological background, i.e., they are not attributed to anthropogenic influences (Schiff and Weisberg, 1999). At lower concentrations of copper within the historical dataset there is a constant linear relationship with iron; however, this relationship changes at a copper concentration of about 175 milligrams per kilogram (mg/kg) as shown in Figure 2-8. As a consequence, the threshold level for sediment copper was set at 175 mg/kg due to the relatively pronounced shift in the relationship between copper and iron. A higher percent of current samples below the threshold level compared to the preset target would indicate that the measure of sediment quality in the stratum was better than historically observed throughout the harbors (WESTON, 2005b). Table 2-3 shows the threshold levels and preset targets.

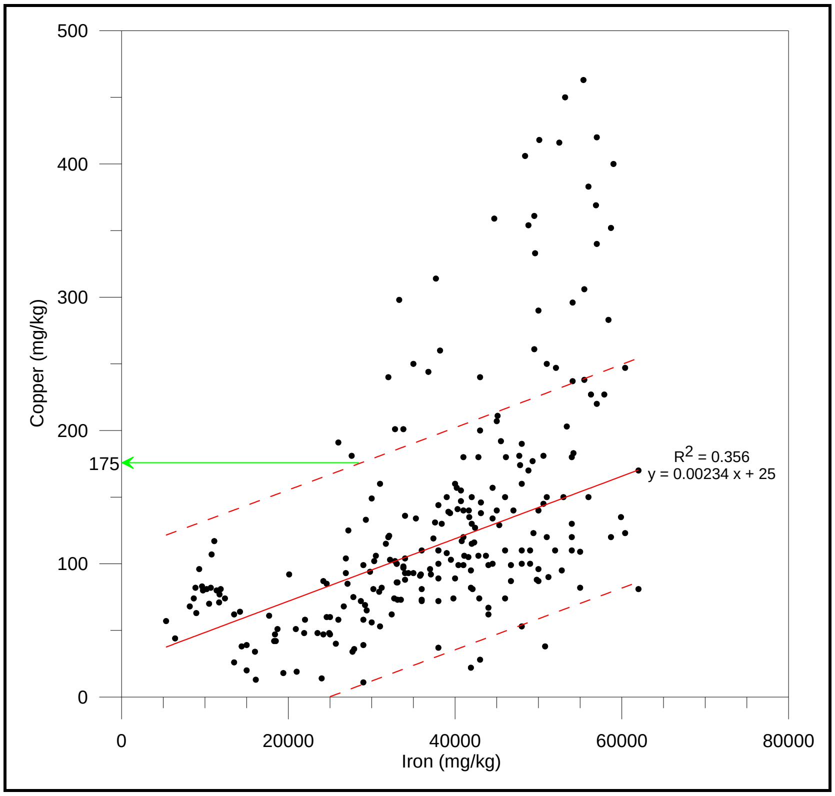


Figure 2-8. Relationship of copper to iron

Acid Volatile Sulfide-Simultaneously Extracted Metals Analysis

Bioavailability and potential toxicity of metals in sediments is affected by the physical properties of sediments (e.g., grain size) as well as well as the presence of other chemicals that interact with the metals (e.g., oxygen and sulfides). The measurement of AVS and the concentration of simultaneously extracted metals (SEM), referred to as the AVS-SEM portioning model, is a tool developed by the USEPA to predict the bioavailability and toxicity of sediments by estimating the capacity of sulfides to bind to metals (SCCWRP, 2008c).

In anoxic sediments, there is commonly a substantial reservoir of sulfide in the form of solid iron sulfide (FeS), referred to as AVS. The availability of metals such as cadmium, copper, nickel, lead, zinc, and silver is thought to be controlled in part by their precipitation as insoluble sulfide complexes. The stability constants for most metal-sulfide associates are very high, and exchange from metal sulfides to water is low, allowing the presence of excess AVS to influence the toxicity potential of these metals to benthic organisms by acting as a sink that immobilizes the biologically available, ionic form (Ankley *et al*., 1996). AVS is operationally defined as the amount of sulfides that can be volatilized during a cold acid extraction. The AVS-bound metals are extracted at the same time and are referred to as SEM. Laboratory and field experiments have shown that if the ratio of SEM to AVS is less than 1, there are likely to be no biologically available metals in solution, and metal toxicity is not anticipated (Di Toro *et al*., 2001). A ratio greater than 1 may indicate the potential for toxicity due to metal bioavailability; however, ratios greater than 40 provide a higher level of certainty in predicting metal toxicity (Di Toro *et al.*, 2001). AVS-SEM model predictions of metal toxicity were compared to actual results of sediment bioassay tests.

2.3.3 Sediment Toxicity

Historical toxicity test results for *E. estuarius* were used to establish the threshold levels for sediment toxicity. *E. estuarius* was selected as the test species due to its relatively high sensitivity to toxic substances and the availability of data for this species within the study area. Control-adjusted percent mortality, rather than survival, was assessed, since higher values indicate poorer conditions similar to chemical indicators. The threshold level was set at 20% mortality (i.e., 80% survival) – a value that is typically used as an indicator of non-toxic sediments. RHMP 2008 conditions were considered to be better than historical conditions if the current percentage of stations below the toxicity threshold value was greater than the preset target (i.e., more than 55% of samples show less than 20% mortality) (WESTON, 2005b).

The bivalve *M. galloprovincialis* SWI test was used as a secondary indicator of sediment toxicity. The endpoint used to measure toxicity was the control-adjusted percent normal-alive embryo development. The threshold level for normal development was set at 60% (i.e., a threshold value 10% below the control acceptability criterion consistent with the *E. estuarius* threshold. Since the secondary indicator of sediment toxicity for *M. galloprovincialis* is the percent normal-alive, lower toxicity levels (i.e., healthier conditions) are indicated by values above the threshold rather than below.

2.3.4 Benthic Infauna

Benthic infauna data were assessed using indices common to ecological community structure evaluations, including the BRI, Shannon-Wiener diversity index, abundance, and number of taxa. The BRI is the primary indicator for evaluating infaunal assemblages in the harbors. The numerical criterion (i.e., community response levels) for this index was calculated by applying an abundance-weighted-average gradient that was correlated with sediment/habitat quality to the pollution tolerance of infaunal species. The BRI used in this assessment was specifically developed for southern California marine bays and estuaries. A four-category scale of benthic condition was used to characterize the degrees to which habitat conditions deviate from reference conditions. Category 1 was characterized as a reference or unaffected community where the BRI indicated a benthic environment that would normally occur at a reference site for that habitat (Table 2-4). Category 2 was characterized as a low disturbance or a marginal deviation from the reference, which indicated some level of stress. Category 3 was characterized as a moderate disturbance or an affected community that exhibited clear evidence of stress from physical, natural, chemical or anthropogenic sources. Category 4 was characterized as a high disturbance or severely affected community that exhibited a high magnitude of stress (Ranasinghe *et al*., 2003).

Table 2-4. Characterization and BRI ranges for response levels of benthic community conditions

BRI Threshold	Category	Characterization	Definition
<39.96	Category 1	Reference	
≥39.96 – <49.14	Category 2	Low disturbance	>5% of reference species lost
≥49.15 – <73.27	Category 3	Moderate disturbance	>25% of reference species lost
≥73.27	Category 4	High disturbance	>75% of reference species lost

The BRI threshold level for the RHMP was set at 39.96, which was the currently established value for reference conditions in embayments. After applying this value to historical data, a preset target proportion was determined to be 55%. If more than 55% of the current samples were below the threshold level of 39.96, then the benthic infaunal community was considered to have a higher level of impairment relative to historically observed conditions. Alternatively, conditions were considered to be better than historical conditions if the current percentage of stations below the benthic infaunal community threshold value was greater than the preset target.

The Shannon-Wiener diversity index and number of taxa are used as secondary indicators. For both of these indicators, higher values indicate healthier benthic communities. The Shannon-Wiener diversity index takes into account the number of species and the evenness of the species, where higher values are indicative of greater diversity and/or evenness. Evenness provides an indication of the equality of different species abundances within a community. Number of taxa also provides a measure of diversity as it is a count of the number of species (or lowest taxonomic units) encountered within a sample. For Shannon-Wiener diversity, the threshold level was determined to be 2 with a preset target proportion of 76%. The threshold for number of taxa was 24 with a preset target of 82%. In contrast to all other indicators, a healthier state than historical harbor conditions occurred for the benthic community when the observed Shannon-Wiener diversity index and number of taxa are greater than the threshold levels (WESTON, 2005b).

2.3.5 Sediment Quality Objectives

Sediment quality from the four harbors was assessed using SQOs as described in the *Water Quality Control Plan for Enclosed Bays and Estuaries – Part 1 Sediment Quality* (SWRCB – California Environmental Protection Agency [Cal/EPA], 2009). The goals of the SQOs are to determine if pollutants in sediments are present in quantities that are toxic to benthic organisms.

The SQOs are based on a multiple-lines-of-evidence (MLOE) approach in which sediment toxicity, sediment chemistry, and benthic community condition are the lines of evidence (LOE). The MLOE approach evaluates the severity of biological effects and the potential for chemically-mediated effects to provide a final station level assessment. The specific methods associated with each LOE and the integration of the MLOE are described below.

2.3.5.1 Sediment Chemistry

Concentrations of chemicals detected in sediments were compared to the California Logistic Regression Model (CA LRM) and the Chemical Score Index (CSI). The CA LRM is a maximum probability model (P_{MAX}) that uses logistic regression to predict the probability of sediment toxicity. The CSI is a predictive index that relates sediment chemical concentration to benthic community disturbance to southern California benthic infauna. Sediment chemistry results according to CA LRM and CSI were categorized as having minimal, low, moderate, and high exposure to pollutants (Table 2-5). The final sediment LOE category was the average of the two chemistry exposure categories. If the average fell midway in between the two categories it was rounded up to the higher of the two.

Table 2-5. Sediment chemistry guideline categorization

Sediment Chemistry Guideline		Chemistry LOE Category
CA LRM	CSI	
<0.33	<1.69	**Minimal Exposure**
0.33 - 0.49	1.69 - 2.33	**Low Exposure**
0.50 - 0.66	2.34 - 2.99	**Moderate Exposure**
>0.66	>2.99	**High Exposure**

2.3.5.2 *Sediment Toxicity*

Sediment toxicity was assessed using two tests: a 10-day *E. estuarius* SP survival test and a sublethal SWI test using the mussel *M. galloprovincialis*. Sediment toxicity test results from each station were statistically compared to control test results to determine if they were significantly different; results were then categorized as nontoxic, low, moderate, and high toxicity. The average of the test responses then was calculated to determine the final toxicity LOE category (Table 2-6 and Table 2-7). When the average fell midway between two categories, the value was rounded up to the next higher response category.

Table 2-6. Sediment toxicity categorization values for *Eohaustorius estuarius*

% Survival of *E. estuarius* in Project Sediment		
If Significantly Different than Control Survival	If Not Significantly Different from Control	Toxicity LOE Category
90 – 100	82 – 100	**Nontoxic**
82 – 89	59 – 81	**Low Toxicity**
59 – 81		**Moderate Toxicity**
< 59	< 59	**High Toxicity**

Table 2-7. Sediment toxicity categorization values for *Mytilus galloprovincialis*

% Development of *M. galloprovincialis* in Project Sediment		
If Significantly Different than Control Development	If Not Significantly Different from Control	Toxicity LOE Category
80 – 100	77-79	**Nontoxic**
77-79	42-76	**Low Toxicity**
42-76		**Moderate Toxicity**
< 42	< 42	**High Toxicity**

2.3.5.3 Benthic Community Condition

Benthic community condition was assessed using a combination of four benthic indices: the BRI, Relative Benthic Index (RBI), Index of Biotic Integrity (IBI), and a predictive model based on the River Invertebrate Prediction and Classification System (RIVPACS), following the January 21, 2008 guidance provided by SCCWRP entitled *Determining Benthic Invertebrate Community Condition in Embayments* for southern California marine bays. All benthic invertebrates were identified to the lowest possible taxon using SCAMIT Edition 5 for nomenclature. It is important to note that current SQO guidelines are utilizing SCAMIT Edition 4 for species identification; however, the guidelines will be updated to Edition 5 when SCCWRP completes the analysis of all the Bight '08 benthic data. Each benthic index result was categorized according to four levels of disturbance, including reference, low, moderate, and high disturbance.

- **Reference:** equivalent to a least affected or unaffected site
- **Low Disturbance:** some indication of stress was present, but was within measurement error of unaffected condition
- **Moderate Disturbance:** clear evidence of physical, chemical, natural, or anthropogenic stress
- **High Disturbance:** High magnitude of stress

Specific categorization values specifically tailored to southern California marine bays were assigned for each index (Table 2-8). The final step in determining the benthic community condition was the integration of the four indices into a single category. In doing so, the median of the four benthic index response categories was computed to determine the benthic condition. If the median fell between two categories, the value was rounded to the next higher category to provide the most conservative estimate of benthic community condition.

Table 2-8. Benthic index categorization values for Southern California marine bays

Benthic Community Guideline				
BRI	**IBI**	**RBI**	**RIVPACS**	**Benthic Index Category**
< 39.96	0	> 0.27	> 0.90 to < 1.10	**Reference**
≥39.96 to <49.14	1	> 0.16 to ≤ 0.27	> 0.75 to ≤ 0.90 or ≥1.10 to < 1.26	**Low Disturbance**
≥49.15 to <73.27	2	> 0.08 to ≤ 0.16	> 0.32 to ≤ 0.74 or > 1.26	**Moderate Disturbance**
≥ 73.27	3 or 4	≤ 0.08	≤ 0.32	**High Disturbance**

2.3.5.4 Integration of Multiple Lines of Evidence

The station level assessment provided an indication of whether the SQOs were being met at each station of interest. The station level assessment was based on the severity of biological effects (i.e., integration of toxicity LOE and benthic condition LOE categories) and the potential for chemically-mediated effects (i.e., integration of toxicity LOE and chemistry LOE categories), using decision matrices presented in Table 2-9 and Table 2-10, respectively.

Table 2-9. Severity of biological effects category

Benthic Condition LOE Category	Toxicity LOE Category	Severity of Biological Effects Category
Reference	Nontoxic	**Unaffected**
Reference	Low Toxicity	**Unaffected**
Reference	Moderate Toxicity	**Unaffected**
Reference	High Toxicity	**Low Effect**
Low Disturbance	Nontoxic	**Unaffected**
Low Disturbance	Low Toxicity	**Low Effect**
Low Disturbance	Moderate Toxicity	**Low Effect**
Low Disturbance	High Toxicity	**Low Effect**
Moderate Disturbance	Nontoxic	**Moderate Effect**
Moderate Disturbance	Low Toxicity	**Moderate Effect**
Moderate Disturbance	Moderate Toxicity	**Moderate Effect**
Moderate Disturbance	High Toxicity	**Moderate Effect**
High Disturbance	Nontoxic	**Moderate Effect**
High Disturbance	Low Toxicity	**High Effect**
High Disturbance	Moderate Toxicity	**High Effect**
High Disturbance	High Toxicity	**High Effect**

Table 2-10. Potential for chemically mediated effects category

Sediment Chemistry Category	Toxicity LOE Category	Potential for Chemically Mediated Effects Category
Minimal Exposure	Nontoxic	**Minimal Potential**
Minimal Exposure	Low Toxicity	**Minimal Potential**
Minimal Exposure	Moderate Toxicity	**Low Potential**
Minimal Exposure	High Toxicity	**Moderate Potential**
Low Exposure	Nontoxic	**Minimal Potential**
Low Exposure	Low Toxicity	**Low Potential**
Low Exposure	Moderate Toxicity	**Moderate Potential**
Low Exposure	High Toxicity	**Moderate Potential**
Moderate Exposure	Nontoxic	**Low Potential**
Moderate Exposure	Low Toxicity	**Moderate Potential**
Moderate Exposure	Moderate Toxicity	**Moderate Potential**
Moderate Exposure	High Toxicity	**Moderate Potential**
High Exposure	Nontoxic	**Moderate Potential**
High Exposure	Low Toxicity	**Moderate Potential**
High Exposure	Moderate Toxicity	**High Potential**
High Exposure	High Toxicity	**High Potential**

2.3.5.5 *Station Level Assessment*

The station level assessment was determined by combining the severity of biological effects category with the potential for chemically-mediated effect category, which resulted in one of six possible station level assessments including unimpacted, likely unimpacted, possibly impacted, likely impacted, clearly impacted, and inconclusive (Table 2-11).

Table 2-11. Station level assessment matrix

Severity of Biological Effects Category	Potential for Chemically Mediated Effects Category	Station Level Assessment
Unaffected	Minimal Potential	**Unimpacted**
Unaffected	Low Potential	**Unimpacted**
Unaffected	Moderate Potential	**Likely Unimpacted**

Unaffected	High Potential	**Inconclusive**
Low Effect	Minimal Potential	**Likely Unimpacted**
Low Effect	Low Potential	**Likely Unimpacted**
Low Effect	Moderate Potential	**Possibly Impacted or Inconclusive**
Low Effect	High Potential	**Likely Impacted**
Moderate Effect	Minimal Potential	**Likely Unimpacted**
Moderate Effect	Low Potential	**Possibly Impacted**
Moderate Effect	Moderate Potential	**Likely Impacted**
Moderate Effect	High Potential	**Clearly Impacted**
High Effect	Minimal Potential	**Inconclusive**
High Effect	Low Potential	**Possibly Impacted**
High Effect	Moderate Potential	**Likely Impacted**
High Effect	High Potential	**Clearly Impacted**

2.3.6 Fish and Macroinvertebrates

Demersal fish and benthic macroinvertebrate total abundance, biomass, and community indices were calculated for demersal fish and benthic macroinvertebrates separately. Community indices included:

- Number of species or unique taxa
- Shannon-Wiener diversity: ($-\Sigma p_i$ X $\log(p_i)$), where p_i is the count for species “i” divided by the total count of the sample
- Dominance: number of species comprising 75% of the total count of the sample
- Evenness: Shannon-Wiener diversity index ÷ log(species count)
- Ecological Index: (%number + %weight) × (% frequency).

2.3.7 Statistical Analyses

The arithmetic mean and standard error were used as descriptive statistics for strata, while the area-weighted averages and area-weighted standard error were used to describe the harbors. Area-weighted averages for harbors were calculated by first calculating the average of each stratum in each harbor, and multiplied by the % of area covered by that stratum in that harbor. The weighted averages were then summed together to get the area weighted average for each harbor. The standard error was calculated similarly, by first calculating the standard deviation in each stratum, and then summing the weighted averages normalized to sample size to calculate the standard error of the mean for the total area.

$$se = \sqrt{\sum_{h=1}^{L} \left(\frac{W_h^2}{n_h} s_h^2\right)}$$

W= weight of the strata (% total area)
L=total number of strata
n=total samples
h=strata
s=standard deviation

A binomial model was selected to assess differences in the percentages of stations below benthic infaunal and sediment and water quality thresholds between the 2008 RHMP surveys and historical regional surveys following the methods of Cohen (1977). Results for each indicator were statistically compared to the preset target to determine if the proportion of samples below the threshold level was higher or lower. Differences were considered to be significant at $p \leq 0.10$, which indicates a 90% certainty that the difference detected is not due simply to chance. Generally, a statistically higher proportion of RHMP stations below the threshold compared to the preset target was considered to be indicative of an improved condition (the BRI being the exception), while a lower proportion of stations below the threshold indicated a degraded condition.

Differences in surface water, sediment, and benthic infaunal parameters were compared statistically among strata (marina, freshwater influenced, industrial, deep, and shallow) and among harbors (Dana Point Harbor, Oceanside Harbor, San Diego Bay, and Mission Bay) using Analyses of Variance (ANOVAs) or Kruskal-Wallis tests, depending on whether or not data met the criteria for parametric statistics. To determine whether parametric or nonparametric statistics were required, data were tested for normality and equality of variances. Normality was tested with Shapiro-Wilk tests and equality of variances was tested with Levene's tests. If data did not meet the criteria, then data transformations were performed to improve normality and equality of variances. Transformations included arcsine transformations for percentages and square-root and log transformations for the other indicators, following the methods of Zar (1999). If either untransformed or transformed data met requirements, then parametric statistical tests were used (one-way ANOVAs); otherwise, non-parametric tests were performed (Kruskal-Wallis tests). Rather than comparing proportions, these tests directly compared differences in the indicators (for example dissolved copper concentrations) among strata and among harbors. Differences were considered to be significant at $p \leq 0.05$, which indicates a 95% certainty that the difference were not due simply to chance. When significant differences were detected by ANOVAs or Kruskal-Wallis tests, follow-up pair-wise tests were performed to test for differences between any two given strata or harbors (significant at $p \leq 0.05$).

Regression analyses were performed to test the relationship between chemistry and grain size, toxicity and grain size, toxicity and chemistry, benthic community condition and chemistry and toxicity. Additionally, regression analyses were performed to compare the relationship between AVS-SEM ratios and observed toxicity levels and mean ER-M quotients. Significance levels were established at $p \leq 0.05$.

Paired t-tests were performed to compare differences in sediment chemistry, toxicity, and infauna indicators between Bight '98 revisited stations and RHMP 2008 stations and between Bight '03 revisited stations and RHMP 2008 stations. Analyses were performed separately for each analyte using a significance level of $p \leq 0.05$.

Multivariate cluster analysis was run separately on the fish and macroinvertebrate data to define similar station habitats and species communities, grouped by station and by species. Species included in the analysis were collected at a minimum of two trawl stations. The clusters were based on a Bray-Curtis dissimilarity distance matrix using an agglomerative, hierarchical clustering algorithm. All statistical analyses were performed using SAS® Institute software (SAS, 2002).

3.0 RESULTS

3.1 Water Quality

Water quality indicators included chemistry (metals and organics), indicator bacteria (Enterococci and total and fecal coliforms), and physical water quality parameters.

3.1.1 Chemistry

Surface water samples collected from 75 stations were analyzed for dissolved and total metals, hardness, DOC, TOC, total orthophosphate as P, O&G, nitrate, ammonia, MBAS, TDS, PAHs, organophosphorus pesticides, MTBE, and pyrethroids. Surface water chemistry results for primary and secondary indicators at all stations are reported in Appendix B, Tables B-2 to B-6 and mean concentrations are provided in Tables B-7 and B-8. Statistical significance values are provided in Appendix C.

Of all the metals analyzed (Table 2-2), only the primary indicator (copper) exceeded thresholds for dissolved and total concentrations, with the highest number of exceedances of the acute CTR threshold for dissolved copper occurring in the marinas (Figure 3-1). None of the metals exceeded COP standards. In 2008, there were fewer exceedances of thresholds for dissolved and total copper than historically observed, indicating that conditions improved when assessed across all strata of the RHMP harbors (Table 3-1). Surface water chemistry results are described in detail in the following sections.

Table 3-1. Percentages of stations below thresholds for surface water metals

Metal	Preset Target	RHMP 2008	FWI	Marina	Industrial	Deep	Shallow
Dissolved Copper	58	**79***	87	31	100	80	100
Total Copper	51	**72***	87	31	93	80	71
Dissolved Nickel	100	100	100	100	100	100	100
Total Nickel	100	100	100	100	100	100	100
Dissolved Zinc	100	100	100	100	100	100	100
Total Zinc	99	100	100	100	100	100	100

* Significant difference between 2008 RHMP and historical conditions ($p \leq 0.10$); green indicates a higher percentage.

3.1.1.1 Primary Indicators

Dissolved and Total Copper

Historically, 58% of the stations sampled did not exceed the CTR threshold for dissolved copper (4.8 µg/L) and 51% did not exceed the RHMP-established threshold for total copper (5.8 µg/L) when assessed across all areas of the harbors. The percentages of RHMP 2008 stations that did not exceed dissolved (79%) and total (72%) thresholds were significantly higher than preset targets (Table 3-1, Figure 3-2). However, the marina stratum had the highest number of exceedances with only 31% of the stations below the threshold for both dissolved and total copper. Thus, regional harbor copper concentrations in surface waters have improved from historical conditions, with the exception of the marinas.

Mean dissolved and total copper concentrations were similar among strata with the exception of the marina stratum (Figure 3-3). Mean dissolved copper concentrations were approximately two times higher in the marinas (6.87 $\pm$ 0.96 µg/L [mean $\pm$ standard error]) than the industrial stratum (2.89 $\pm$ 0.12 µg/L), the deep stratum (3.01 $\pm$ 0.63 µg/L), and the shallow stratum (2.78 $\pm$ 0.32 µg/L), resulting in a significant difference. Mean total copper concentrations in the marina stratum were also approximately two times higher than concentrations in the other four strata, also resulting in a significant difference.

The area-weighted-average dissolved copper concentrations for all harbors were below the acute CTR threshold, whereas area-weighted-average total copper concentrations exceeded the threshold in both Dana Point Harbor (5.98 $\pm$ 1.00 µg/L) and Oceanside Harbor (6.09 µg/L) due in large part to marina stratum comprising approximately half of the total area of the smaller two harbors (Figure 3-3).

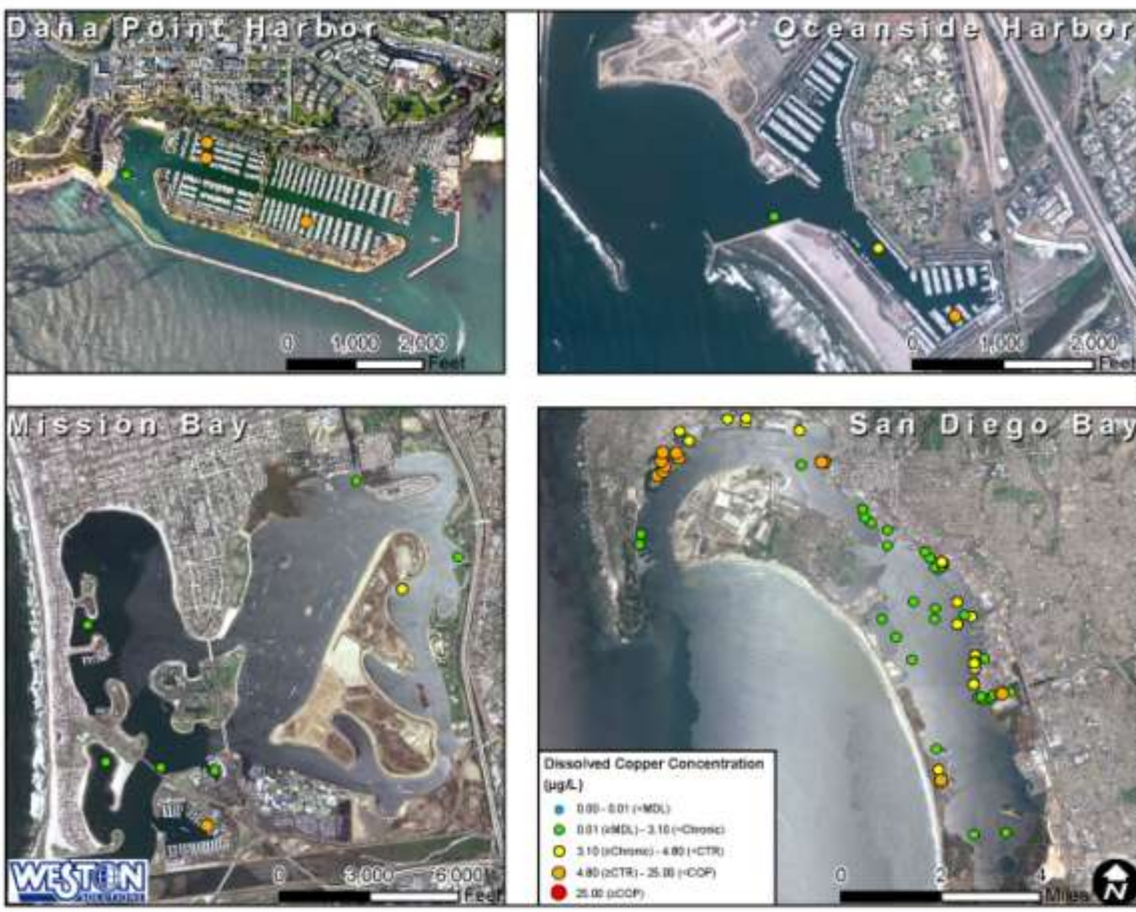


Figure 3-1. Distribution of dissolved copper concentrations in surface waters

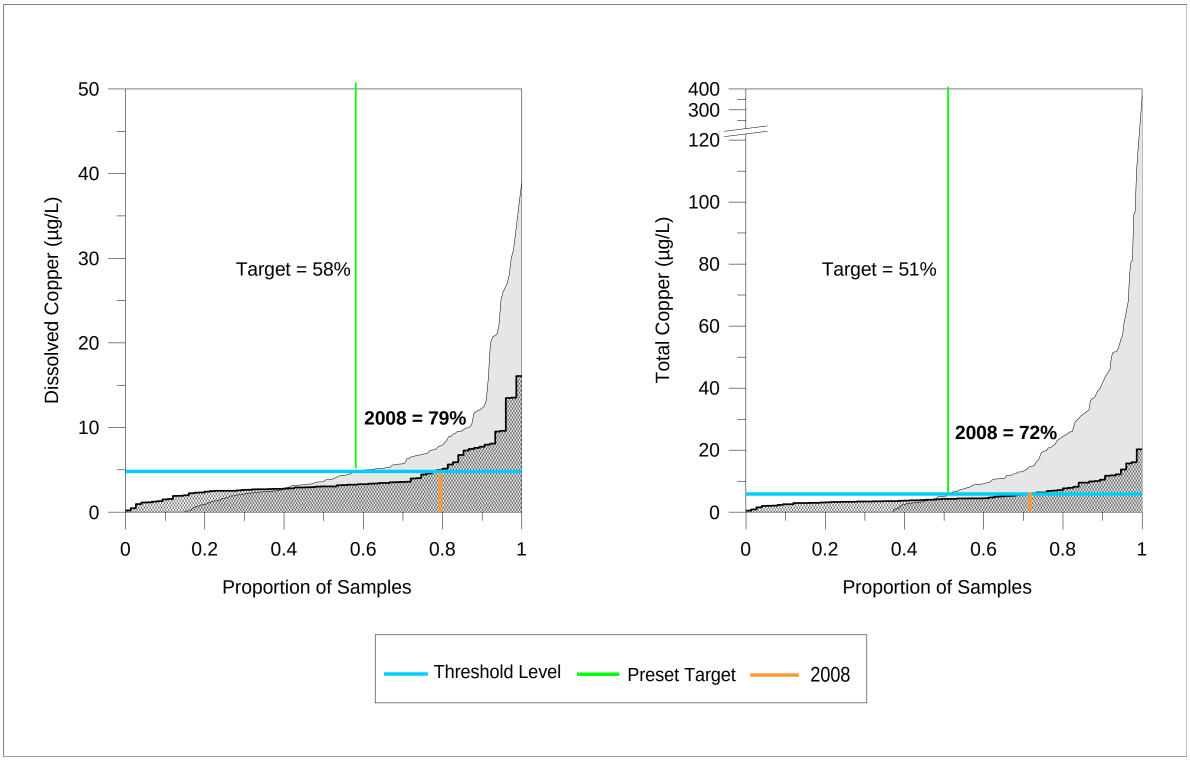


Figure 3-2. Cumulative distribution curves for surface water dissolved and total copper

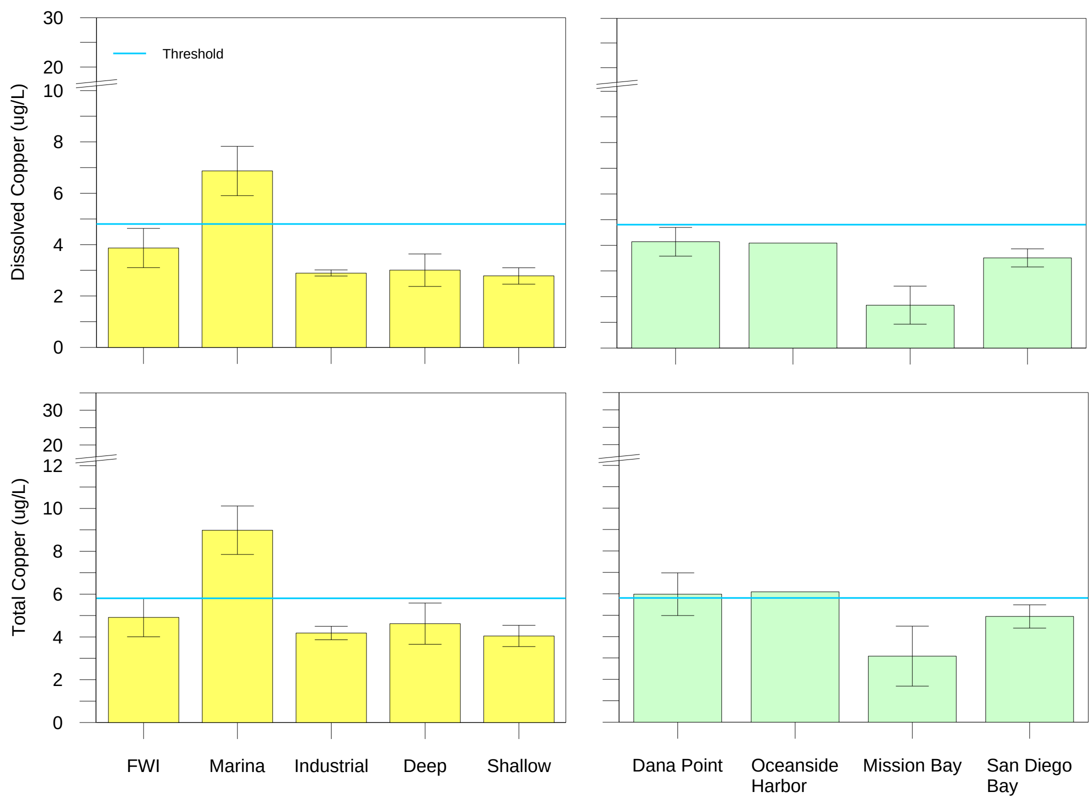


Figure 3-3. Comparison of surface water copper concentrations among strata (means) and harbors (area-weighted averages)

3.1.1.2 Secondary Indicators

Zinc

All stations had concentrations of dissolved and total zinc below CTR and COP thresholds. Historically, dissolved zinc concentrations were below the CTR at all stations and total zinc concentrations were below the threshold at 99% of stations. In RHMP 2008, all stations had dissolved and total concentrations below thresholds, consistent with historical conditions (Table 3-1). As such, there were no significant differences observed between historical and present-day conditions for dissolved and total nickel and zinc, indicating that current conditions have not changed from historical conditions.

Mean dissolved and total zinc concentrations were far below thresholds across all strata. The lowest concentrations were found in the industrial stratum with means of 3.05 ± 0.51 µg/L for dissolved zinc and 6.13 ± 0.58 µg/L for total zinc. The highest average concentrations of dissolved (17.40 ± 2.41 µg/L) and total zinc (19.38 ± 2.64 µg/L) were in the marina stratum, resulting in a significant difference between the marina and the other four strata (Figure 3-4).

There were large differences in area-weighted-average zinc concentrations among harbors, with Mission Bay having the lowest levels (Figure 3-4). Although there were differences among harbors, all harbors had area-weighted-average concentrations that were well below thresholds. Area-weighted-average dissolved and total zinc concentrations were 15 to 73 times higher in the other harbors as compared to Mission Bay, resulting in significant differences between Mission Bay and Dana Point Harbor and San Diego Bay for both dissolved and total zinc and Oceanside Harbor for total zinc.

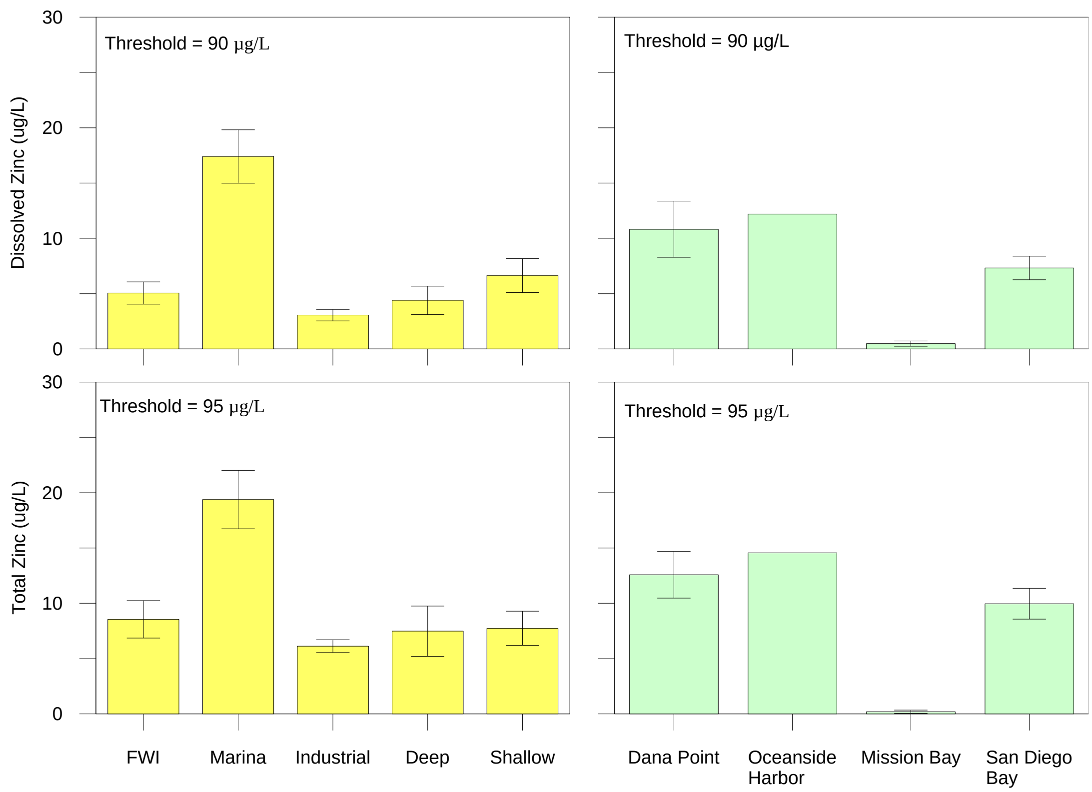


Figure 3-4. Comparisons of surface water zinc concentrations among strata (means) and harbors (area-weighted average)

Nickel

All stations had concentrations of dissolved and total nickel below CTR and COP thresholds. Preset target percentages were determined to be 100% for dissolved and total nickel (i.e., no historical stations exceeded thresholds). As such, there were no significant differences observed between historical and present-day conditions for dissolved and total nickel and zinc (Table 3-1). This indicated that current nickel concentrations were unlikely to adversely affect surface waters, consistent with historical conditions.

Mean concentrations of dissolved and total nickel were far below thresholds across all strata. Mean dissolved nickel concentrations ranged from 0.35 ± 0.03 within the marina stratum to 0.50 ± 0.02 µg/L within the industrial stratum as compared to a CTR threshold of 74 µg/L. In addition, mean total nickel concentrations ranged from 0.31 ± 0.05 µg/L for deep stations to 0.55 ± 0.02 µg/L for industrial stations as compared to a threshold of 75 µg/L. Although nickel concentrations were far below thresholds, there were significantly higher dissolved nickel concentrations in the industrial stratum as compared to the marina and deep strata. Additionally, total nickel concentrations were significantly greater in the freshwater-influenced and deep strata than in the marina and deep strata.

Area-weighted average concentrations for dissolved and total nickel were far below thresholds, with dissolved nickel average concentrations ranging from 0.24 in Oceanside Harbor to 0.48 ± 0.03 in San Diego Bay, with no differences among harbors. Total nickel concentrations were significantly lower in Mission Bay (0.08 ± 0.04 µg/L) than Dana Point Harbor (0.31 ± 0.02 µg/L) and San Diego Bay (0.48 + 0.03 µg/L) (Appendix B-8).

Other Dissolved and Total Metals

All other dissolved and total metals had concentrations below their respective CTR and COP thresholds within all five strata (Appendix B, Tables B-2 to B-6).

Total PAHs

Mean concentrations of total PAHs across all strata ranged from 13.29 $\pm$ 5.14 nanograms per liter (ng/L) in the marina stratum to 37.47 $\pm$ 9.25 ng/L in the freshwater-influenced stratum, and were below thresholds for adverse biological effects for all individual PAHs (Appendix B, Tables B-1 to B-6). Mean concentrations in the freshwater-influenced and industrial strata were 2.8 and 2.2 times higher, respectively, than the marina stratum, resulting in a significant difference (Figure 3-5).

Among harbors, area-weighted-average total PAH concentrations ranged from 2.02 $\pm$ 1.87 ng/L in Mission Bay to 32.37 $\pm$ 7.60 ng/L in San Diego Bay. San Diego Bay had mean concentrations that were 16 times higher than Mission Bay resulting in a significant difference. Within San Diego Bay, total PAHs ranged from 1.4 to 146.3 ng/L, and were on average highest in the deep (44.6 $\pm$ 15.3 ng/L) and freshwater-influenced strata (42.2$\pm$10.0 ng/L), followed by the industrial (29.9 $\pm$ 4.3 ng/L), shallow (23.1 $\pm$ 8.8 ng/L), and marina (18.1 $\pm$ 7.1 ng/L) strata, respectively.

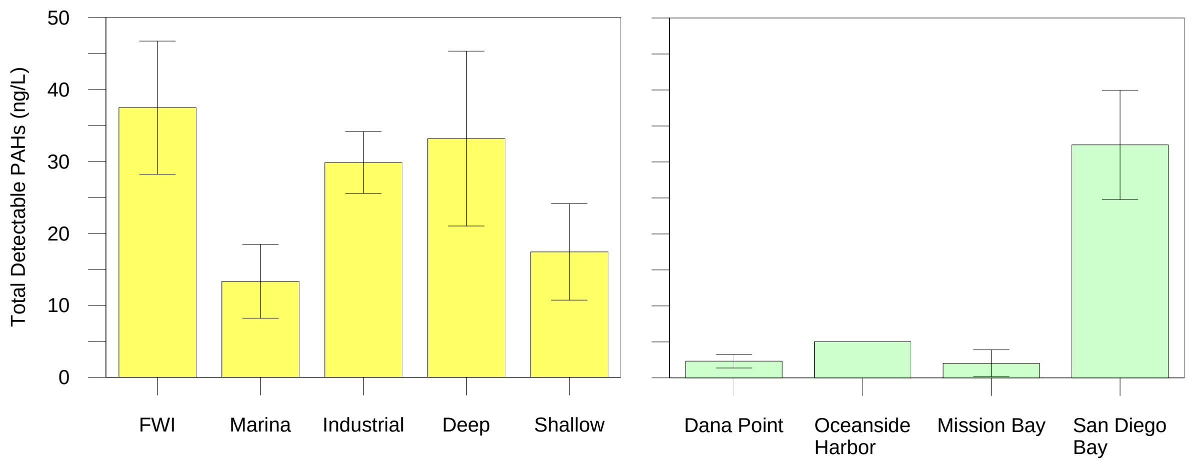


Figure 3-5. Comparison of surface water total PAHs among strata (means) and harbors (area-weighted averages)

Organophosphorus Pesticides, Volatile Organic Compounds, and Pyrethroids

Organophosphorus pesticides, volatile organic compounds, and pyrethroids were measured at concentrations below method detection limits for all stations (Appendix B, Tables B-2 to B-6).

General Chemistry

Results for ammonia, nitrate, DOC, TOC, MBAS, O&G, TDS, total hardness (measured as $CaCO_3$), and total orthophosphate as P are presented in Appendix B, Tables B-2 to B-6. Mean ammonia and nitrate concentrations across all strata were approximately 0.02 $\pm$ 0.00 milligrams per liter (mg/L) and 0.01 $\pm$ 0.00 mg/L, respectively (Appendix B, Table B-7). Mean DOC concentrations ranged from 0.75 $\pm$ 0.06 mg/L in the industrial stratum to 1.38 $\pm$ 0.56 mg/L in the freshwater-influenced stratum, and mean TOC concentrations ranged from 0.76 $\pm$ 0.06 mg/L in the industrial stratum to 1.18 $\pm$ 0.09 mg/L in the marina stratum. Mean MBAS concentrations across all strata were approximately 0.02 $\pm$ 0.00 mg/L, while O&G ranged from 0.50 $\pm$ 0.00 mg/L in the freshwater-influenced stratum to 0.87 $\pm$ 0.12 mg/L in the marina stratum. TDS mean concentrations ranged from 34,719 $\pm$ 503 mg/L in the deep stratum to 36,874 $\pm$ 1286 mg/L in the marina stratum. Mean concentrations for total hardness (as $CaCO_3$) ranged from 5943 ± 77.91 mg/L in the deep stratum to 6272 ± 102.44 mg/L in the shallow stratum. Total orthophosphate as P mean concentrations were approximately 0.03 ± 0.00 mg/L across all strata.

3.1.2 Bacteria

The results of the water analysis for Enterococci and total and fecal coliforms are presented in Appendix B, Table B-2 to B-6. The bacterial levels did not exceed AB411 threshold of 104 MPN/100mL for enterococci, 10,000 MPN/100mL for total coliforms, or 400 MPN/100mL for fecal coliforms at any station. Only three stations had detectable levels of Enterococci (i.e., counts of at least 10 MPN/100 mL) (Table 3-2). Nearly half of the stations had total coliform levels below detection limits, while 19 stations had total coliform counts ranging from 20 MPN/100 mL to 300 MPN/100 mL with the majority of them (51%) occurring in the marina stratum. Fecal coliform levels also were below detection limits at 92% of the stations, with only six stations having fecal coliform counts ranging from 20 MPN/100 mL to 40 MPN/100 mL.

Table 3-2. Percentages of stations below and above reporting limits for Enterococci and total and fecal coliform bacteria.

Indicator Bacteria	FWI	Marinas	Industrial	Deep	Shallow
Enterococci Concentration					
< 10 MPN/ 100mL	93	94	100	100	93
10 MPN/ 100mL	7	6	0	0	7
Total Coliforms					
< 20 MPN/100mL	93	49	66	73	93
20-300 MPN/100mL	7	51	34	27	7
Fecal Coliforms					
< 20 MPN/100mL	100	94	93	80	93
20-40 MPN/100mL	0	6	7	20	7

3.1.3 Physical Water Quality

Physical water quality profiles for the 75 stations from 1 m below the surface to 1 m above the benthos are presented in Appendix D, Tables D-1 to D-5, with averages at 1 m below the surface presented in Table D-6 for strata and D-7 for harbors. Measurements included temperature, salinity, pH, DO, and transmissivity. These measures, while not being compared to threshold levels, were useful in providing information about water quality that can help explain biological results and determine if the harbor waters can sustain a healthy biota.

Temperature

Temperatures did not change greatly with depth; differences between surface and bottom temperatures for any given station were generally less than 1-2 °C and at most 4.2 °C. Additionally, surface temperatures (i.e., within 1 m of the surface) did not vary substantially among harbors, ranging from an average of 22.4 ± 0.04 °C in Dana Point Harbor to 23.9 ± 0.17 °C in San Diego Bay. Temperatures also varied little among the five strata, ranging from 22.8 ± 0.38 °C in the deep surface waters to 24.8 ± 0.33 °C in the shallow stratum.

Salinity
Salinity varied little with depth, with a maximum difference of approximately 3 practical salinity units (psu) along any station's depth profile, while most stations had differences between surface and bottom waters less than 1 psu. Additionally, salinity values were very similar among all harbors and strata, with surface salinities ranging from 32.4 psu at a San Diego Bay shallow station to 36.4 psu at a San Diego Bay marina station).

pH
Values of pH were largely consistent with depth at all stations, ranging by no more than 0.4 units along the depth profile at any station. Across all stations, pH within surface waters ranged from 6.3 to 8.1, with average values being slightly basic in all harbors and strata. The average pH values ranged from 7.8 $\pm$ 0.12 in the shallow to 8.0 $\pm$ 0.03 in the marina stratum, and 7.8 $\pm$ 0.03 in San Diego Bay to 8.0 in the other three harbors.

Dissolved Oxygen
DO levels tended to decrease slightly with depth for most stations, with the most pronounced declines in DO levels occurring within the marina stratum. Five marina stations had DO levels below the Basin Plan water quality objective of 5.0 mg/L, and one San Diego Bay shallow station (6083) did as well. Four of the marina stations were located in San Diego Bay, occurring within SIYB (6161), Harbor Island Marina (6177), and Coronado Cays (6025 and 6027), and one was in the Quivera Basin of Mission Bay (6204). For all of these stations except one (6025), DO was above the threshold at the surface, but declined to levels below the threshold with depth. Although there were more exceedances of the Basin Plan threshold in the marina stratum, average surface DO levels were lowest in the freshwater-influenced stratum (6.3 $\pm$ 0.10 mg/L) and highest in the deep stratum (7.0 $\pm$ 0.13 mg/L). Similarly, average surface DO levels did not vary substantially among harbors, ranging from 7.1 $\pm$ 0.21 mg/L in Mission Bay to 6.4 $\pm$ 0.09 mg/L in Dana Point Harbor.

Transmissivity
Transmissivity of light tended to decrease with depth for all stations along depth profiles, although declines were most pronounced for the marina stratum, averaging approximately 21%, as compared to just over 10% in the shallow and between 5 and 6% in the deep, industrial, and freshwater-influenced strata. Average surface transmissivity was lowest in the shallow stratum (63.2 $\pm$ 2.7%) followed by the marina (66.6 $\pm$ 1.9%), deep (73.4 $\pm$ 1.5%), industrial (75.6 $\pm$ 1.5%), and freshwater-influenced (79.4 $\pm$ 1.6%) strata. Lowest transmissivity levels were detected at the shallowest stations (sometimes less than 2 m in depth) where low light penetration can be attributed higher levels of turbidity associated with propeller-driven disturbances. Differences in surface transmissivity among harbors were on average within 5%, ranging from 65.9 $\pm$ 4.7% in Oceanside Harbor to 73.3 $\pm$ 4.7% in Mission Bay.

3.2 Sediment Quality

Sediment indicators included chemistry (metals and organics), toxicity (acute and chronic assessments), and benthic infaunal community disturbance.

3.2.1 Chemistry

Sediment samples collected from 75 stations were chemically analyzed to determine concentrations of metals, total PAHs, total PCBs, total DDTs, and total chlordanes from which mean ER-M quotients were calculated. In addition, sediment samples were analyzed for AVS-SEM, organophosphorus pesticides, chlorinated pesticides (in addition to DDTs and chlordanes), pyrethroids, TOC, grain size, and total nitrogen. Sediment chemistry results for all stations are reported in Appendix B, Tables B-9 to B-13, and mean concentrations are provided in Tables B-14 for strata and B-15 for harbors. Statistical significance values are provided in Appendix C.

All stations had at least one indicator that exceeded an ER-L (Figure 3-6), while exceedances of ER-Ms were much less common, since 79% of all stations did not exceed a single ER-M for any analyte (Figure 3-7). ER-L exceedances were most common in the industrial stratum (118), followed by the marina (109), freshwater-influenced (82), deep (72), and shallow (54) strata (Appendix B, Tables B-9 to B-13). All secondary indicators, except cadmium, exceeded their ER-L values at least at one station. ER-M exceedances were most common in the marina stratum (12), followed by the industrial (8), deep (4), freshwater-influenced (3), and shallow (1) strata. Within the marina stratum, copper, mercury, the PAH dibenz[a,h]anthracene, total chlordanes, and total PCBs exceeded ER-Ms. Within the industrial stratum, copper, mercury, and total PCBs exceeded ER-Ms. Mercury and anthracene exceeded ER-Ms in the deep stratum, and both the freshwater-influenced and shallow strata had ER-M exceedances for total chlordanes.

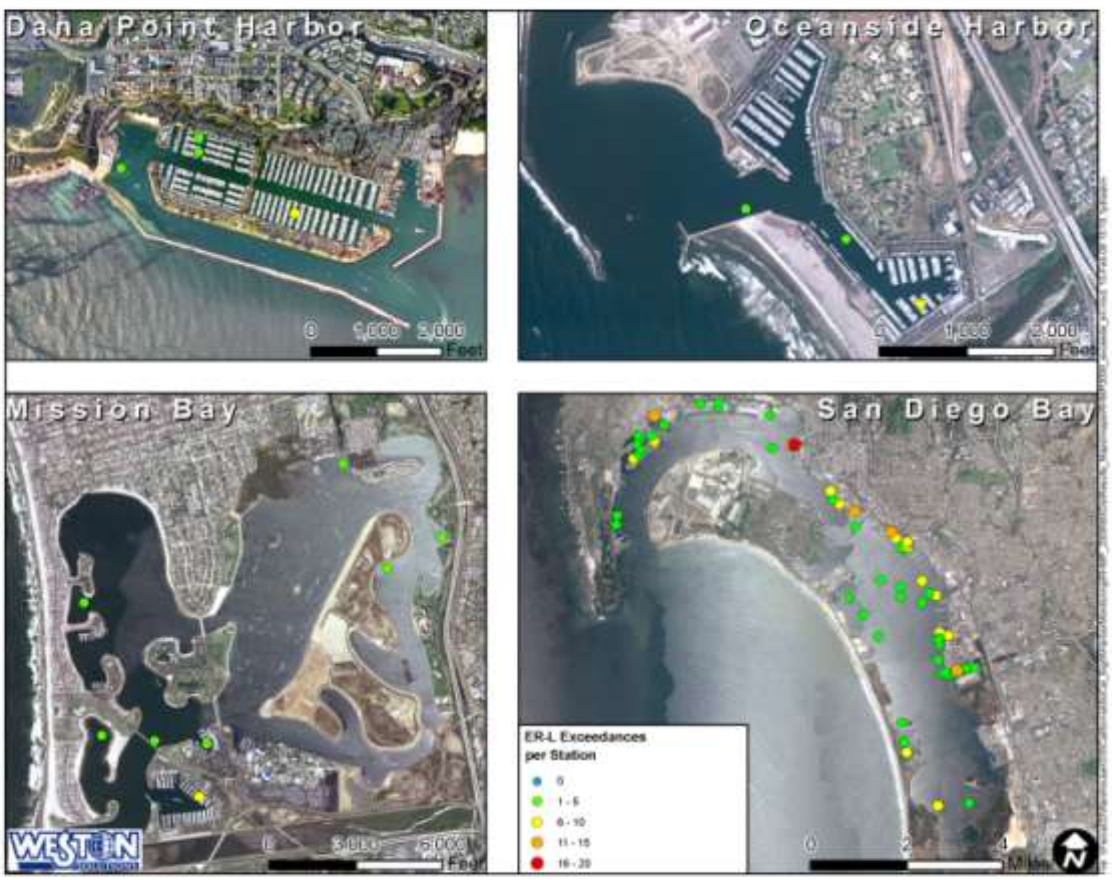


Figure 3-6. Spatial distribution of ER-L exceedances per station

Figure 3-7. Spatial distribution of ER-M exceedances per station

Of the 75 stations sampled, 52% had mean ER-M quotients below the 0.2 threshold, which was largely consistent with historical conditions (i.e., the preset target) (Table 3-3). Although there was not a statistically significant improvement in this overall sediment chemistry indicator, eight of the 12 secondary indicators had significantly higher percentages of stations below ER-L thresholds than the historical preset targets, providing evidence that overall sediment chemistry conditions within the harbors had improved; however, there still appeared to be specific strata with elevated levels of exceedances (i.e., the marina and industrial strata) as evidenced by the generally lower percentage of stations below the mean ER-M quotient threshold as compared to the other strata (Table 3-3). Accordingly, there were significant differences in both primary and secondary indicators among strata (mean ER-M quotient, chromium, copper, lead, mercury, zinc, total detectable PAHs, and total PCBs) and among harbors (copper, mercury, total detectable PAHs, and total PCBs), as discussed in detail in the following sections.

Table 3-3. Percentages of stations below thresholds for sediment chemistry indicators

Indicator	Preset Target	RHMP 2008	FWI	Marina	Industrial	Deep	Shallow
Mean ER-M Quotient	46	52	73	38	33	80	86
Arsenic	52	57	60	50	40	67	71
Cadmium	92	100*	100	100	100	100	100
Chromium	83	99*	100	100	93	100	100
Copper[1]	68	80*	93	37	73	100	100
Lead	75	89*	87	94	67	100	100
Mercury	26	31	53	25	7	33	36
Nickel	80	97*	100	87	100	100	100
Zinc	45	44	47	19	20	73	64
Total PAHs	79	88*	93	87	73	87	100
Total Chlordanes	86	89	67	87	100	100	93
Total DDTs	54	79*	73	56	100	87	79
Total PCBs	47	63*	67	44	33	87	86

[1] Reference ambient value for copper was not based on the ER-L, as described in Section 2.3.2.
* Significant difference between 2008 RHMP and historical conditions ($p \leq 0.10$); green indicates a higher percentage.

3.2.1.1 Primary Indicator

Mean ER-M Quotient

The mean ER-M quotient was the primary indicator of sediment chemistry for the RHMP. Historically, 46% of stations had mean ER-M quotients below the threshold for predicted adverse biological effects (0.2). In 2008, 52% of the stations were below the mean ER-M quotient threshold (Table 3-3, Figure 3-8). Although the current percentage of stations below the threshold was 6% greater than the historical preset target, the difference was not significant. Thus, based on the primary indicator, current sediment chemistry conditions across all strata did not significantly improve from historical conditions. However, it was notable that the comparison of the percentages of stations below the more commonly used 0.5 mean ER-M quotient threshold were indicative of a significantly improved present-day condition, since 93% of the RHMP 2008 stations were below the 0.5 threshold for adverse biological effects, while only 82% of the historical stations were (Figure 3-8).

Across all strata, mean ER-M quotients ranged from 0.13 $\pm$ 0.02 in the deep stratum to 0.35 $\pm$ 0.09 in the marina stratum (Figure 3-9). Both the marina (38%) and industrial (33%) strata had the lowest percentages of stations below the 0.2 threshold (Table 3-3). The mean ER-M quotients in the marina stratum were on average 2.7 times higher than in the deep stratum and 2.3 times higher than the shallow stratum, resulting in significant differences. Additionally, mean ER-M quotients within the industrial stratum were 2.3 times higher than the deep stratum, which also resulted in a significant difference.

Among harbors, the area-weighted-average mean ER-M quotient ranged from 0.15 ± 0.06 in Mission Bay to 0.26 in Oceanside Harbor. Although the area-weighted-average mean ER-M quotient for Oceanside Harbor was slightly above the threshold of 0.2, the other three harbors were below the threshold (Figure 3-9).

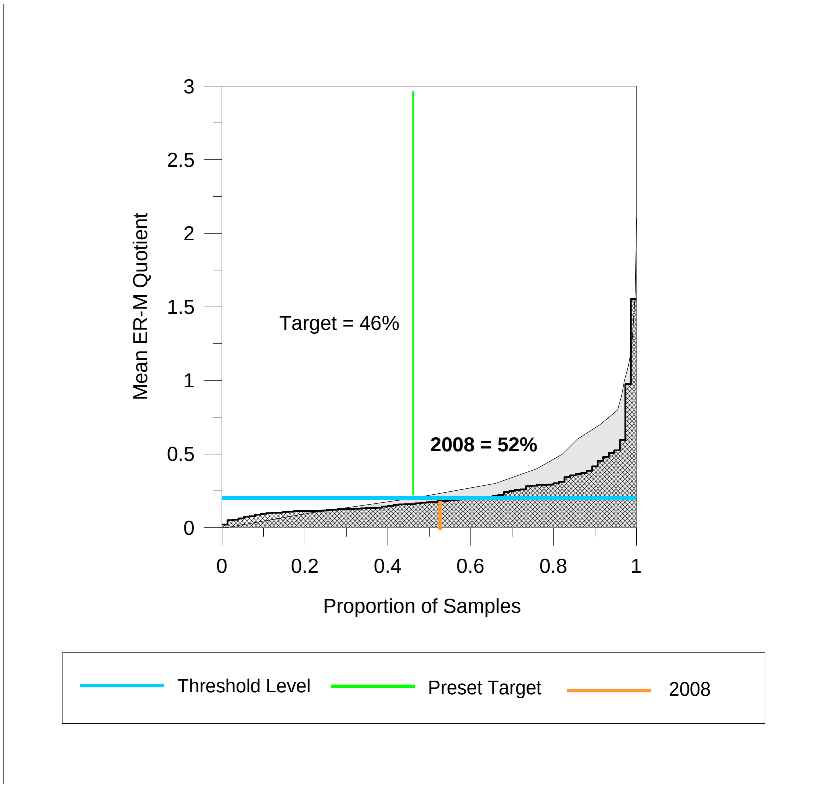


Figure 3-8. Cumulative distribution curves for sediment mean ER-M quotients

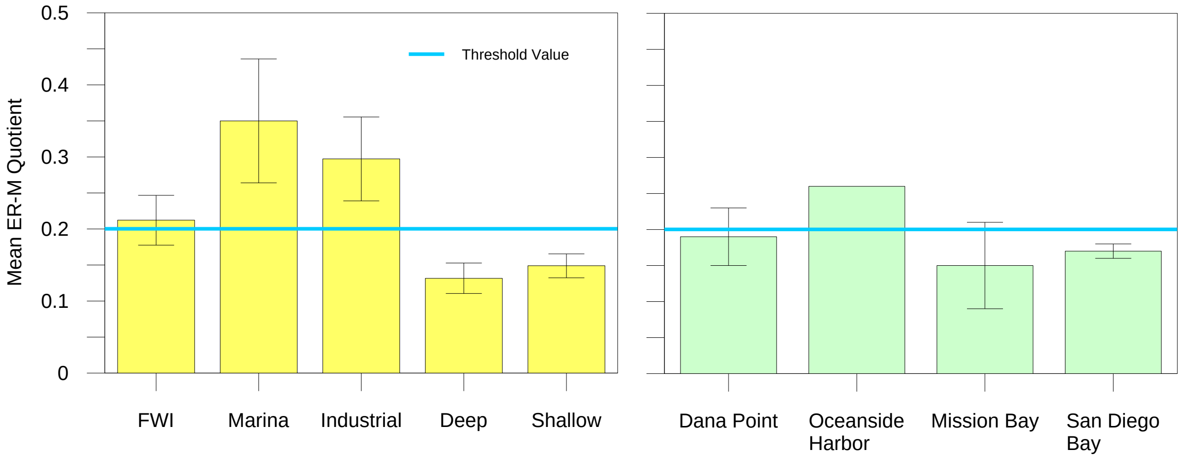


Figure 3-9. Comparisons of sediment average mean ER-M quotients among strata (means) and harbors (area-weighted averages)

3.2.1.2 Secondary Indicators

Eight metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), as well as total PAHs, total PCBs, total DDTs, and total chlordanes were identified as secondary indicators of sediment chemistry conditions since concentrations of these analytes were used to calculate mean ER-M quotients. Of the 75 stations sampled, ER-M exceedances were observed only for copper (five stations), mercury (12 stations), total chlordanes (five stations), and for the two individual PAHs, anthracene (two stations) and dibenz[a,h]anthracene (one station). Further analyses comparing differences from historical conditions (i.e., RHMP 2008 vs. preset targets), among strata, and among harbors are provided below.

Copper

Concentrations of copper exceeded the ER-L value of 34 micrograms per gram (µg/g) at 92% of the stations (Figure 3-10). The remaining stations (8%) that did not exceed the ER-L were located in the deep and shallow strata. Only four marina stations (25% of the stratum) and one industrial station (7%) exceeded the ER-M value of 270 µg/g. Although copper concentrations commonly exceeded the ER-L across all strata, elevated copper levels were partly due to high natural levels rather than entirely being due to anthropogenic influences. As a consequence, the threshold was set at 175 µg/g, as described in Section 2.3.2. Ten marina stations (63% of the stratum), four industrial stations (27%), and one freshwater-influenced station (7%) exceeded the threshold of 175 µg/g. Historically, the preset target for the percentage of stations below the copper threshold was 68%. In 2008, 80% of the stations did not exceed the threshold, resulting in a significant improvement over historical conditions (Table 3-3).

There were also notable differences among strata, with mean sediment copper concentrations ranging from 63.12 ± 8.05 µg/g in the shallow stratum to 215.96 ± 26.76 µg/g in the marina stratum (Figure 3-11). Of the five strata, only the marina stratum had a mean copper concentration that exceeded the threshold of 175 µg/g. The marina stratum also had the highest number of exceedances with 37% of the stations below the threshold (Table 3-3). Mean copper concentrations in both the marina and industrial strata were more than 3 times higher than the deep stratum and 2 times higher than the shallow stratum, resulting in significant differences. Additionally, the mean copper concentration in the freshwater-influenced stratum (108.55 ± 11.42 µg/g) was approximately 1.7 times that of the deep (65.32 ± 12.14 µg/g) and shallow strata (63.12 ± 8.05 µg/g), resulting in significant differences.

All four harbors had area-weighted-average copper concentrations that exceeded the ER-L value; however, only the area-weighted-average concentrations in Dana Point Harbor (203.20 ± 48.83 µg/g) and Oceanside Harbor (215.73 µg/g) exceeded the copper threshold of 175 µg/g (Figure 3-11). The area-weighted-average concentration in Mission Bay (36.32 ± 5.75 µg/g) was less than half that of San Diego Bay (83.04 ± 6.69 µg/g), which was less than half of both of the other harbors. Although inter-harbor differences were substantial, the low sample sizes within the two northern harbors limited the power to detect statistical differences.

Figure 3-10. Spatial distribution of sediment copper concentrations

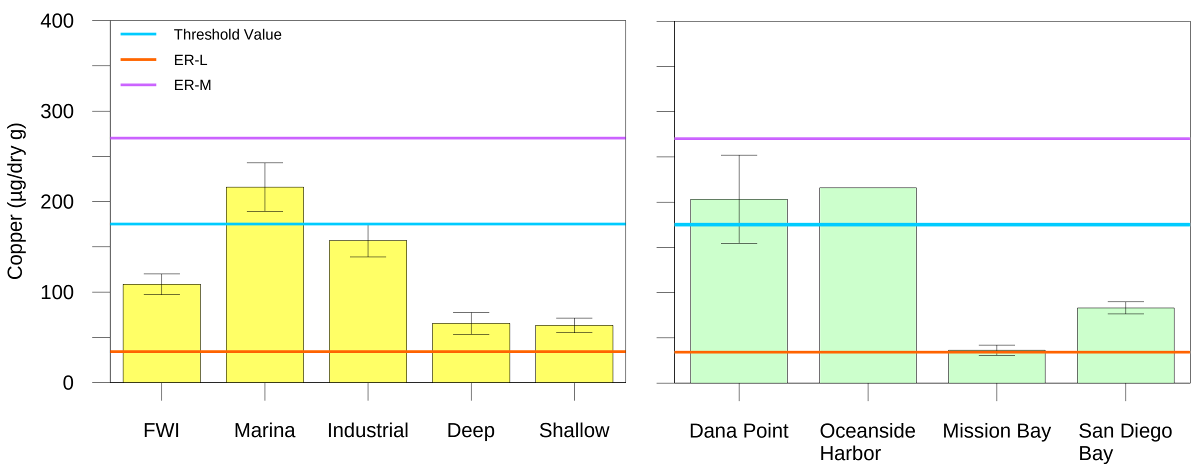


Figure 3-11. Comparisons of sediment copper concentrations among strata (means) and harbors (area-weighted averages)

Zinc

Concentrations of zinc exceeded the ER-L value of 150 µg/g at 44% of stations in RHMP 2008; however, there were no exceedances of the ER-M value of 410 µg/g (Figure 3-12). The present-day percentage of stations that exceeded the ER-L threshold was largely consistent with the historical preset target of 45% (preset target) (Table 3-3). Thus, zinc levels in sediments have neither significantly degraded nor improved when assessed across all strata.

Mean zinc concentrations exceeded the ER-L threshold in the freshwater-influenced (172.81 ± 13.14 µg/g), marina (218.94 ±19.74 µg/g), and industrial (202.50 ± 20.30 µg/g) strata, while average concentrations were below the ER-L in the deep and shallow strata (Figure 3-13). The marina and industrial strata had the highest number of exceedances, with 19% and 20%, of the stations below the ER-L threshold, respectively (Table 3-3). Mean zinc concentrations in the marina stratum were 1.5 times higher than the shallow stratum and two times higher than the deep, resulting in significant differences. There was also a significant difference between the industrial and deep strata, with mean zinc concentrations being 1.9 times higher in the industrial stratum.

Area-weighted-average zinc concentrations were higher in Dana Point and Oceanside Harbors as compared to Mission and San Diego Bays due in large part to the large proportion of the two northern harbors being comprised of the marina stratum. Area-weighted-average zinc concentrations exceeded the ER-L threshold in Dana Point Harbor (195.46 ± 8.51 µg/g) and Oceanside Harbor (238.53 µg/g), while concentrations in the southern bays did not (Figure 3-13). Additionally, none of the harbors had area-weighted-average zinc concentrations that exceeded the ER-M value.

Figure 3-12. Spatial distribution of sediment zinc concentrations

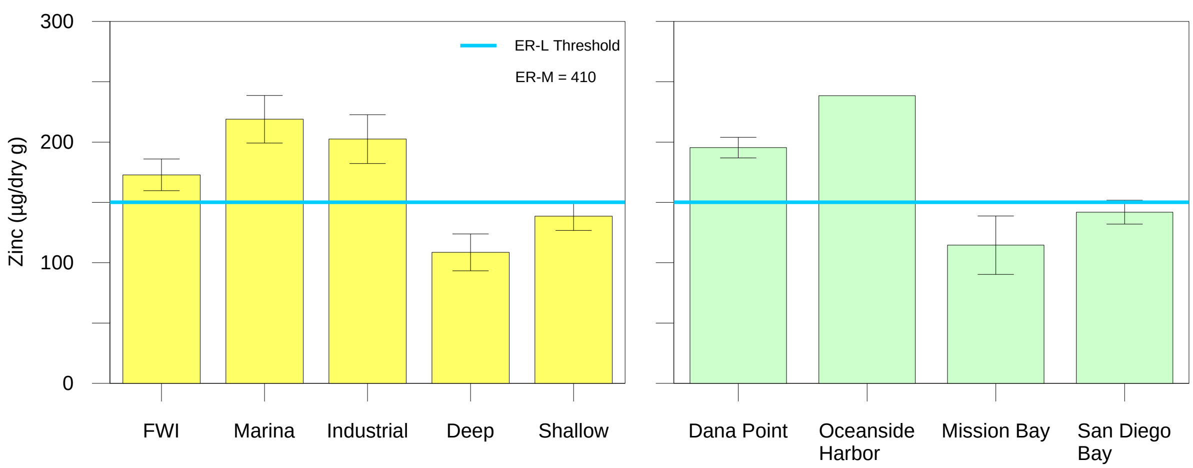


Figure 3-13. Comparisons of sediment zinc concentrations among strata (means) and harbors (area-weighted averages)

Lead

Concentrations of lead exceeded the ER-L value of 46.7 µg/g in the freshwater-influenced (two stations), marina (one station), and industrial strata (five stations), but there were no exceedances of the ER-M value of 218 µg/g. Historically, 47% of stations did not exceed the ER-L, while in 2008, 89% of the stations did not exceed the threshold, resulting in a significant improvement over historical conditions (Table 3-3).

Mean lead concentrations ranged from 17.96 ± 2.94 µg/g in the deep stratum to 41.66 ± 5.57 µg/g in the industrial stratum, with all five strata having mean concentrations below the ER-L (Figure 3-14). Although mean concentrations were below the threshold, there were substantial differences among strata. The mean lead concentration in the industrial stratum was 2.3 times higher than the deep stratum, resulting in a significant difference. Both the freshwater-influenced (28.99 ± 3.60 µg/g) and marina strata (29.62 ± 5.04 µg/g) had significantly higher lead concentrations than the deep stratum as well.

Among harbors, area-weighted-average lead concentrations were all below the ER-L threshold ranging from 12.75 ± 3.05 µg/g in Dana Point Harbor to 25.00 ± 7.42 µg/g in Mission Bay (Figure 3-14). Although area-weighted-average concentrations in Mission and San Diego Bays were nearly twice that of Dana Point Harbor, inter-harbor differences were not significant.

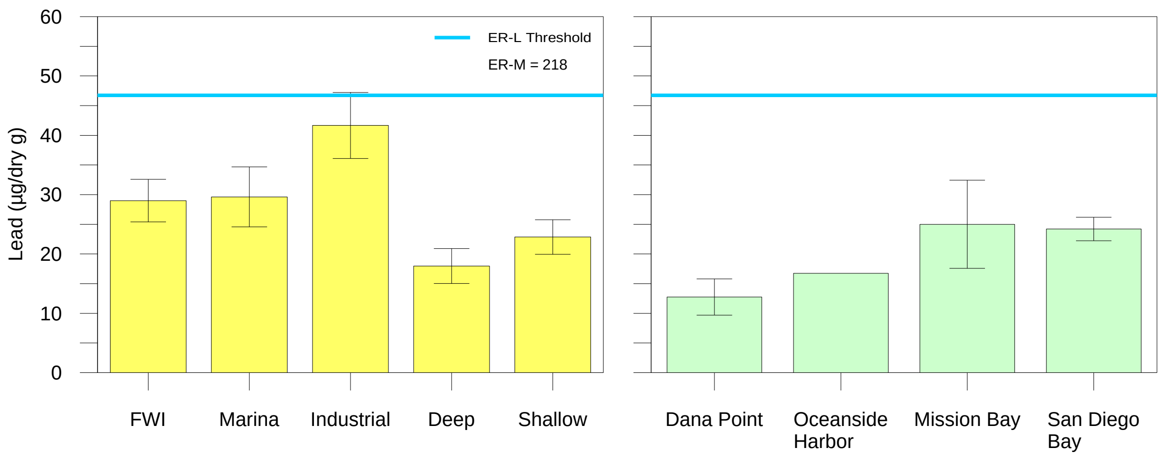


Figure 3-14. Comparisons of sediment lead concentrations among strata (means) and harbors (area-weighted averages)

Arsenic

Arsenic concentrations exceeded the ER-L threshold of 8.2 µg/g across all strata and in all harbors; however, there were no exceedances of the ER-M value of 70 µg/g. Percentages of stations below the arsenic ER-L did not improve significantly between the historical preset target of 52% and the RHMP 2008 percentage of 57%.

Mean arsenic concentrations ranged from 6.04 ± 0.68 µg/g in the deep stratum to 8.54 ± 0.74 µg/g in the industrial stratum (Figure 3-15). The marina and industrial strata had the lowest percentages of stations below the ER-L (40% and 50%, respectively), while the deep and shallow strata had the highest (67% and 71%, respectively) (Table 3-3). Although mean concentrations in the marina and industrial strata were above the threshold, while the means of the other three strata were below, there were no significant differences.

Among harbors, area-weighted-average arsenic concentrations were above the ER-L threshold in Oceanside Harbor (9.09 µg/g) and Mission Bay (8.97 ± 2.28 µg/g), while those of Dana Point Harbor and San Diego Bay were below (Figure 3-15). The area-weighted-average concentrations for all harbors were far below the ER-M.

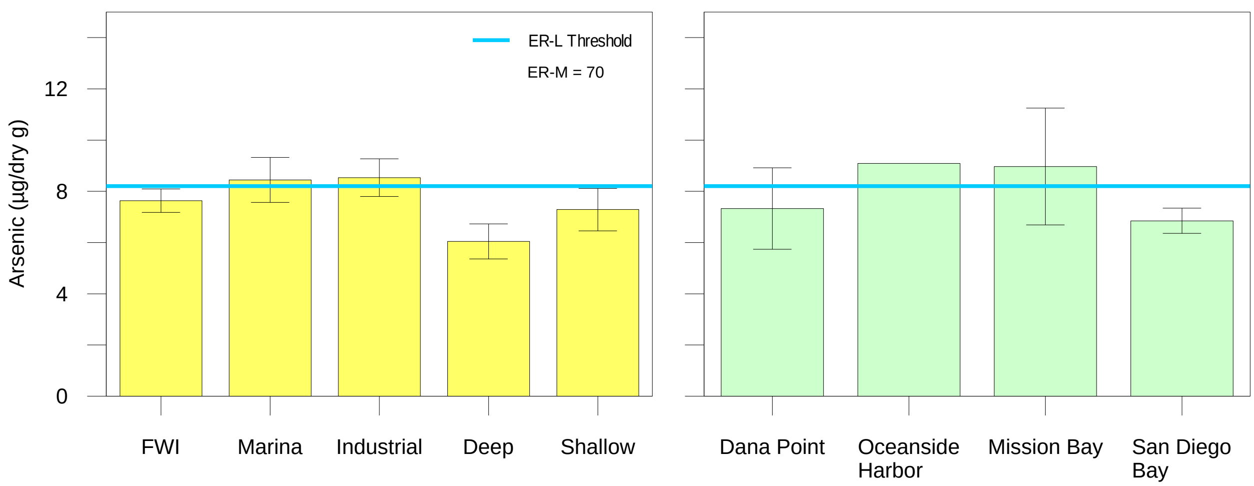


Figure 3-15. Comparisons of sediment arsenic concentrations among strata (means) and harbors (area-weighted averages)

Mercury

Mercury concentrations exceeded the ER-L threshold of 0.15 µg/g in 69% of the RHMP 2008 stations (Figure 3-16). Five marina stations (31% of the stratum), five industrial stations (33%), and two deep stations (13%) exceeded the ER-M value of 0.71 µg/g, with all exceedances occurring within San Diego Bay. The percentage of stations that did not exceed the ER-L slightly increased between the historical preset target (26%) and the 2008 survey (31%); however, the increase was not significant (Table 3-3).

Figure 3-16. Spatial distribution of sediment mercury concentrations

All five strata had mean mercury concentrations that exceeded the ER-L, and the mean concentration in the marina (1.05 + 0.36 µg/g) exceeded the ER-M (Figure 3-17). The mean mercury concentration in the marina not only exceeded the ER-M, but it was over four times as high as those of the freshwater-influenced (0.24 ± 0.05 µg/g) and shallow strata (0.24 ± 0.04 µg/g). Additionally, the mean mercury concentration in the industrial stratum was also approximately twice as high as the other three strata. Both the marina stratum had significantly higher concentrations than the freshwater-influenced, deep, and shallow strata; and the industrial stratum had significantly higher levels than the deep and shallow strata. Consequently, the marina and industrial strata had the lowest percentages of stations below the ER-L – 25% in the marina and 7% in the industrial strata (Table 3-3).

Area-weighted-average mercury concentrations were above the ER-L threshold in Oceanside Harbor (0.32 µg/g) and San Diego Bay (0.41 ± 0.06 µg/g), both of which were substantially higher than Dana Point Harbor and Mission Bay (Figure 3-17). None of the harbors had area-weighted-average concentrations above the ER-M value of 0.71 µg/g.

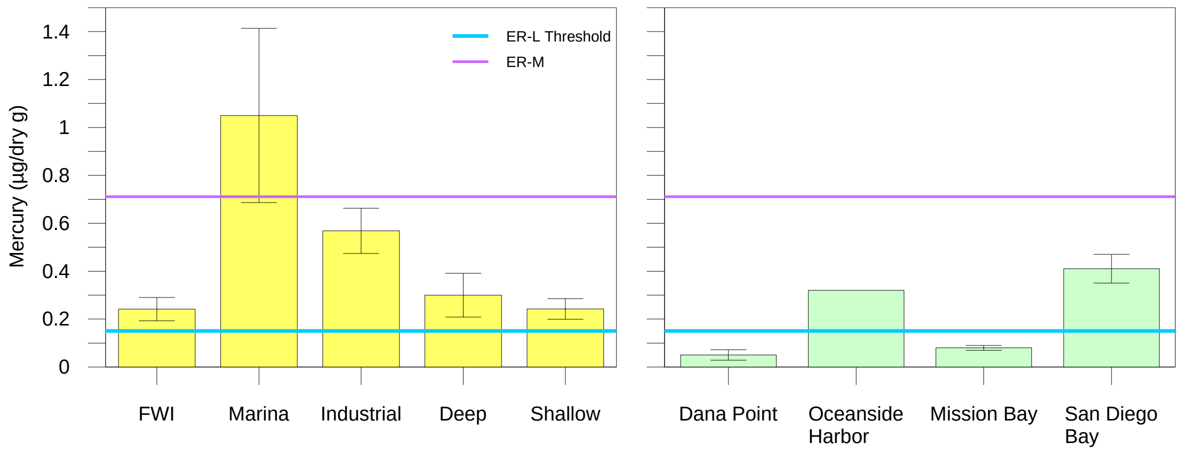


Figure 3-17. Comparisons of sediment mercury concentrations among strata (means) and harbors (area-weighted averages)

Cadmium, Chromium, and Nickel

For the three secondary indicators (cadmium, chromium, and nickel), most stations had concentrations that did not exceed their respective ER-Ls. Only one station in the industrial stratum exceeded the chromium ER-L threshold of 81 µg/g and only two stations in the marina stratum exceeded the nickel ER-L threshold of 20.9 µg/g. There were no ER-L exceedances for cadmium across all five strata. There were no ER-M exceedances for the three metals. Additionally, the percentages of stations within all strata below ER-Ls were all significantly greater than the historical preset targets, indicating current conditions have improved over historical conditions for all three indicators (Table 3-3).

Mean concentrations for all three of these metals were well below their respective ER-L thresholds with the lowest concentrations being in the deep stratum and the highest in the industrial stratum (Appendix B, B-14). The mean concentrations for cadmium and nickel were similar among the five strata resulting in no significant differences. There was a significant difference between the industrial and deep strata for chromium with mean concentrations being 1.4 times higher in the industrial stratum.

Among harbors, area-weighted-average concentrations for all three metals were below their respective ER-L thresholds (Appendix B, Table B-15). Area-weighted-average cadmium concentrations were similar across all four harbors, while those of chromium ranged from 32.94 ± 5.12 µg/g in Mission Bay to 48.23 µg/g in Oceanside Harbor. Area-weighted average nickel concentrations were more variable among harbors, with the concentration in San Diego Bay 9.85 ± 0.90 µg/g nearly half that of Oceanside Harbor (18.15 µg/g); however, there were no significant inter-harbor differences for all three indicators.

Total PAHs

Exceedances of the total PAH ER-L threshold of 4,022 nanograms per gram (ng/g) occurred exclusively within San Diego Bay. There were no exceedances of the ER-M value of 44,792 ng/g. Historically, 79% of samples had total PAH levels that did not exceed the total PAH ER-L threshold, while 89% of the RHMP stations did not exceed the threshold in 2008, resulting in a significant difference (Table 3-3). Accordingly, total PAH levels provide another indication that current conditions have improved from historical conditions.

All five strata had mean total PAH concentrations below the ER-L threshold; however, mean concentrations varied substantially among strata. The shallow stratum had the lowest mean concentration (326.08 ± 68.31 ng/g), which was approximately one fifth the mean levels of the freshwater-influenced, marina, and deep strata and nearly one tenth of the industrial stratum (3,083.45 ± 609.50 ng/g) (Figure 3-18). Consequently, total PAH concentrations in the industrial stratum were significantly higher than all other strata, and concentrations in the shallow stratum were significantly lower than the freshwater-influenced stratum.

Differences among harbors were also apparent, with area-weighted-average total PAH concentrations ranging from 108.91 ng/g in Oceanside Harbor to 1,396.11 ± 416.18 ng/g in San Diego Bay. However, area-weighted averages did not exceed the ER-L in any harbor (Figure 3-18).

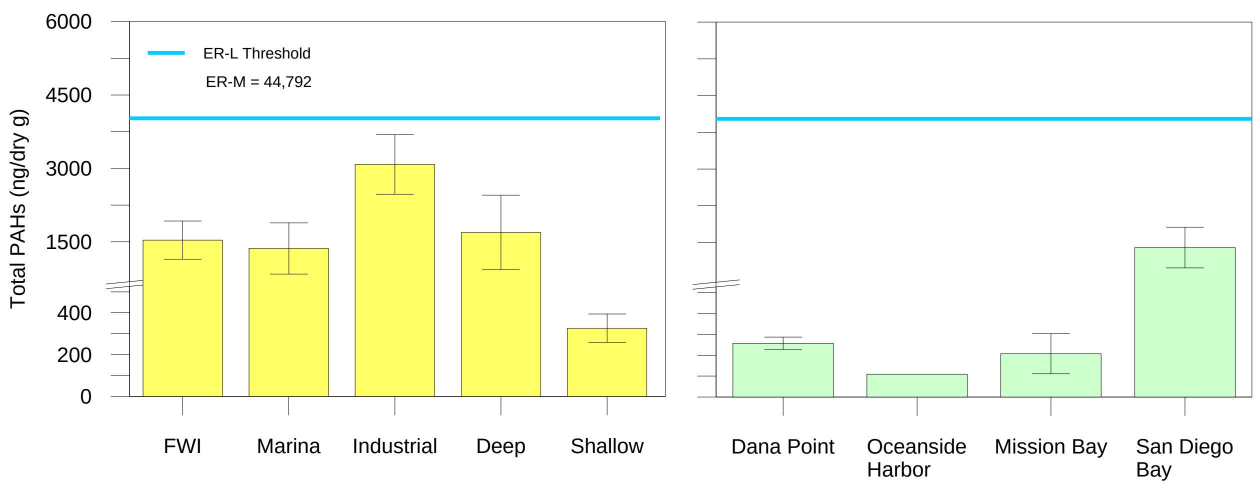


Figure 3-18. Comparisons of sediment total PAHs among strata (means) and harbors (area-weighted averages)

Total PCBs

Sixty-three percent of the 2008 stations had total PCB concentrations below the ER-L threshold of 22.7 ng/g, while 47% of the historical stations were below, resulting in a significant improvement (Table 3-3). Additionally, there were no exceedances of the ER-L within Mission Bay; however, there were three exceedances of the ER-M, including one marina station and two industrial stations, all of which occurred in San Diego Bay.

Mean concentrations of total PCBs ranged from 8.22 ± 2.48 ng/g in the shallow stratum to 161.39 ± 104.41 ng/g in the industrial stratum (Figure 3-19). Only the deep and shallow strata did not exceed the ER-L. The industrial and marina strata had the highest number of exceedances, with 33% and 44% of the stations below the ER-L threshold, respectively (Table 3-3). Mean total PCB concentrations in the industrial stratum were nearly 20 times higher than the shallow stratum and 14 times higher than the deep stratum, resulting in significant differences. Similarly, concentrations in the marina stratum were approximately 14 times those of the shallow and 10 times those of the deep strata, also resulting in significant differences.

Although San Diego Bay was the only harbor to have stations with ER-M exceedances, the area-weighted-average concentration in Oceanside Harbor (82.51 ng/g) was approximately 3 times higher than any other harbor, including San Diego Bay (Figure 3-19). The lowest area-weighted-average total PCB concentration occurred in Mission Bay (0.97 ± 0.69 ng/g), which was less than one twentieth the area-weighted-average concentrations of Dana Point Harbor and San Diego Bay, resulting in a significant difference between Mission Bay versus San Diego Bay.

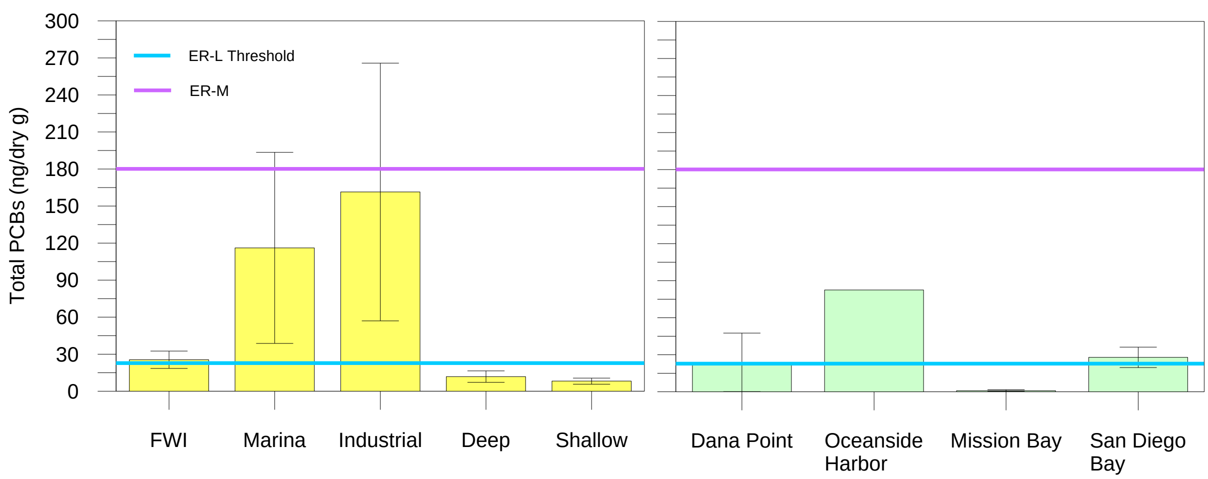


Figure 3-19. Comparisons of sediment total PCBs among strata (means) and harbors (area-weighted averages)

Total DDTs

Total DDT concentrations were below the ER-L (1.58 ng/g) at 79% of the stations sampled in 2008, while 54% of the historical stations were below the threshold, resulting in a significant improvement over historical conditions (Table 3-3).

All stations in the industrial stratum had total DDT concentrations below the method detection limit. In the remaining four strata, mean concentrations ranged from 1.07 $\pm$ 0.74 ng/g in the deep stratum to 5.52 $\pm$ 2.46 ng/g in the marina stratum (Figure 3-20). Although there was a high degree of variability, mean total DDT concentration in the marina stratum was approximately three times higher than in the other strata. Mean concentrations for the marina and freshwater-influenced strata exceeded the ER-L threshold, and both had the highest number of exceedances with 56% of marina and 73% of freshwater-influenced stations below the ER-L (Table 3-3). Statistical comparisons were not performed due to the high number of results below detection limits.

Three of the harbors had area-weighted-average total DDT concentrations above the ER-L threshold, ranging from 1.98 $\pm$ 1.87 ng/g in Mission Bay to 11.48 $\pm$ 2.63 ng/g in Dana Point Harbor (Figure 3-20). Only San Diego Bay was below the threshold with an area-weighted-average concentration of 0.45 $\pm$ 0.29 ng/g.

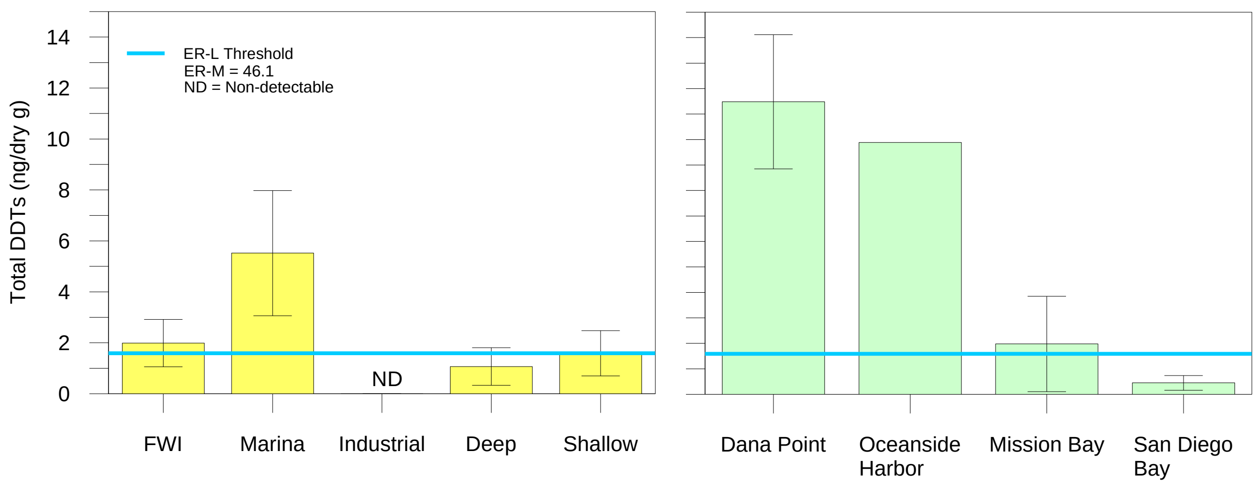


Figure 3-20. Comparisons of sediment total DDTs among strata (means) and harbors (area-weighted averages)

Total Chlordanes

Eighty-nine percent of 2008 stations had concentrations of total chlordanes below the ER-L threshold of 0.5 ng/g, which is consistent with the historical preset target of 86%, indicating that total chlordane levels in the harbors have not deteriorated (Table 3-3). Additionally, total chlordanes were not detected in either Dana Point or Oceanside harbors; nor were they detected in the deep and industrial strata. Total chlordane concentrations exceeded the ER-M of 6 ng/dry g at three freshwater-influenced stations, all occurring at the mouth of Chollas Creek; at one marina station in SIYB, which occurred immediately adjacent to a storm water outfall; and one shallow station in Mission Bay, which occurred immediately adjacent to the freshwater-influenced stratum where Cudahy Creek enters the bay.

Total chlordane concentrations ranged from 0.78 ± 0.54 ng/g in the marinas to 3.37 ± 1.54 ng/g in the freshwater-influenced stratum (Figure 3-21). Additionally, chlordane levels varied substantially within strata, with concentrations ranging from below detection limits to 7.1 ng/dry g in the marina stratum, where only two of the stations had detectable levels. The highest concentrations of total chlordanes were consistently encountered in the freshwater-influenced stratum, with 67% of the stations below the ER-L. Statistical comparisons were not performed due to the higher number of results below detection limits.

All of the stations in Dana Point and Oceanside harbors total chlordane concentrations below the method detection limit. The area-weighted-average concentration for San Diego Bay (0.09 ± 0.04 ng/g) was below the ER-L threshold, while the area-weighted-average concentration for Mission Bay (3.85 ± 3.85 ng/g) exceeded the threshold. This was due largely to the high chlordane concentration of 13.6 ng/dry g at shallow station 6219 at Cudahy Creek since chlordanes were not detected at any other Mission Bay station (Figure 3-21).

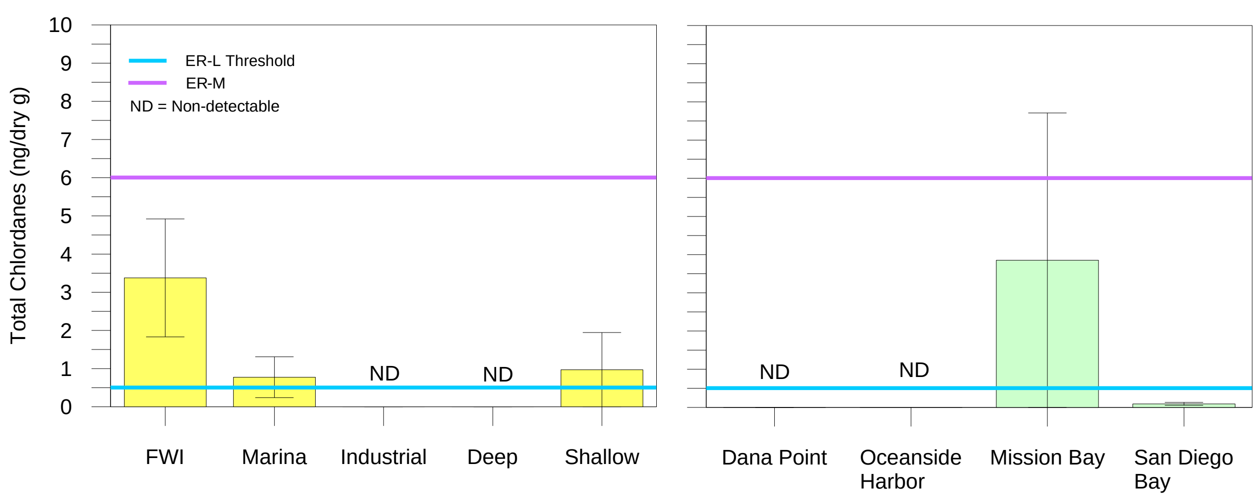


Figure 3-21. Comparisons of sediment total chlordanes among strata (means) and harbors (area-weighted averages)

Other Chlorinated Pesticides

With the exception of dicofol, all other chlorinated pesticides occurred at concentrations below method detection limits (excluding DDTs and chlordanes, which were previously described). Dicofol was detected at a concentration of 7.6 ng/dry g at one San Diego Bay marina station (Appendix B, Tables B-9 to B-13).

Organophosphorus Pesticides and Pyrethroids

Organophosphorus pesticides were not detected at any station throughout the four harbors. Additionally, most stations had concentrations of pyrethroids below method detection limits. Of the 13 pyrethroids assessed, only bifenthrin and cyfluthrin were detected. Bifenthrin concentrations ranged from below detection limits (<5 ng/dry g) to 13.0 ng/dry g. Cyfluthrin concentrations ranged from below detection limits (<5 ng/dry g) to 19.5 ng/dry g. Toxicity tests have shown the concentration at which 50% of test organisms (*E. estuarius*) experience a lethal toxic effect (i.e., the LC_{50}) for bifenthrin to be 8 ng/dry g. Currently there is no LC_{50} for cyfluthrin.

Of the 11 stations where bifenthrin was detected, seven occurred within the freshwater-influenced stratum within Dana Point Harbor, Mission Bay, and San Diego Bay; two were in the marina stratum of Dana Point Harbor; and two were in the shallow stratum of Mission Bay. Five of the stations exceeded the LC_{50}, with all occurring in the freshwater-influenced stratum. Two of the stations occurred at the mouth of Chollas Creek in San Diego Bay, one at the mouth of Rose Creek in Mission Bay, and one adjacent to a storm drain in Dana Point Harbor.

Cyfluthrin was detected at three stations, all of which were located at the mouth of Chollas Creek within the freshwater-influenced stratum. Concentrations ranged from 5.9 to 19.5 ng/dry g.

3.2.2 Acid Volatile Sulfide-Simultaneously Extracted Metals

The majority of RHMP 2008 stations (73%) had ratios of SEM to AVS (∑SEM:AVS) below the threshold ratio (40) for predicted metal toxicity due to bioavailability (Table 3-4). Additionally, ∑SEM:AVS were highly variable among stations, ranging from 0.09 at a deep station to 5,741 at a marina station in SIYB (Appendix B, Tables B-9 to B-13). Mean ∑SEM:AVS ratios ranged from 18.2 ± 8.98 in the shallow stratum to 418 ± 356 within the marina stratum. Both the marina and deep strata had mean ∑SEM:AVS ratios that exceeded 40 (Figure 3-22). Additionally, the marina stratum had the highest percentage of stations (38%) with a ∑SEM:AVS ratio greater than 40.

Table 3-4. Percentages of stations below the ∑SEM:AVS ratio threshold for predicted metal toxicity

Indicator	RHMP 2008	FWI	Marina	Industrial	Deep	Shallow
∑SEM:AVS ratio	73	73	62	80	67	86

San Diego Bay had the highest area-weighted-average ∑SEM:AVS (65.15 ± 24.62), which was approximately six times greater than the area weighted average of Dana Point Harbor and over 60 times greater than Oceanside Harbor and Mission Bay (Figure 3-22). Therefore, based on this ratio, only San Diego Bay was predicted to have sufficiently high concentrations of bioavailable metals to result in toxicity; however, observed toxicity levels were not notably different in San Diego Bay as compared to the other harbors (Section 3.2.4).

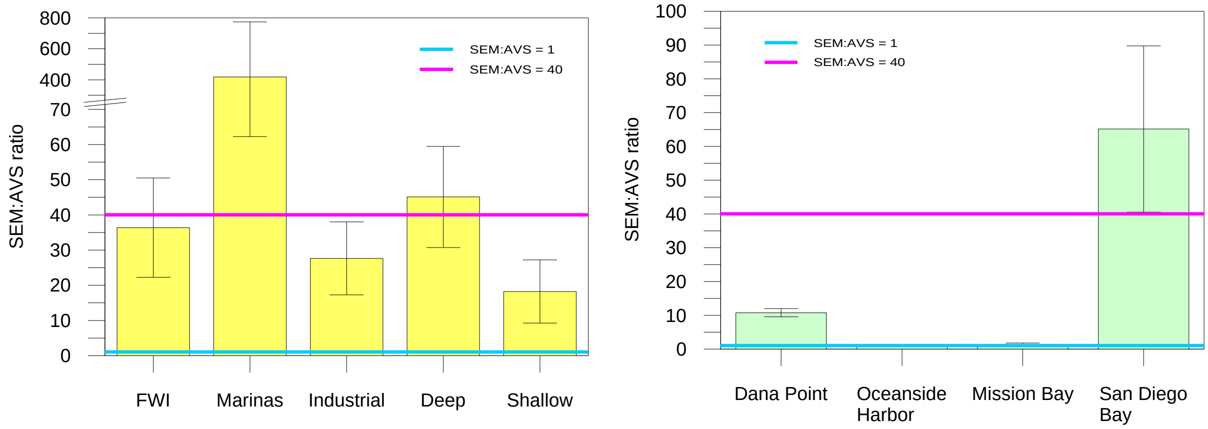


Figure 3-22. Comparisons of sediment ∑SEM:AVS among strata (means) and harbors (area-weighted averages)

The bioavailability of metals, as indicated by ∑SEM:AVS, was also positively associated with chronic toxicity levels, as measured by the *M. galloprovincialis* SWI chronic toxicity tests, and benthic community disturbance, based on the BRI. *M. galloprovincialis* normal-alive larval development was lower at higher ∑SEM:AVS, and BRI scores were higher at higher ∑SEM:AVS (Figure 3-23), potentially indicating that metal bioavailability may be explaining approximately 10% of the variability in both sediment indicators, based on regression analyses.

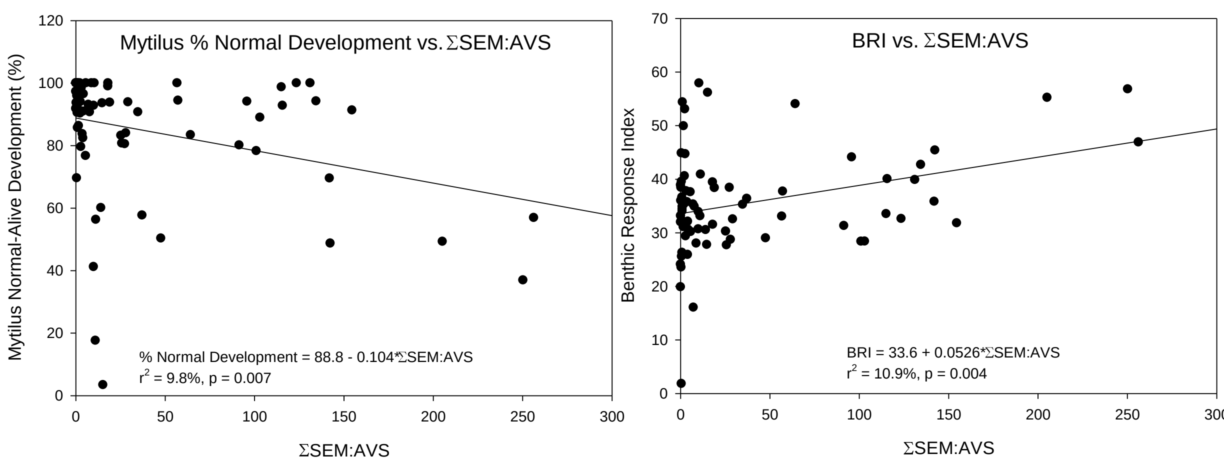


Figure 3-23. Relationship of ∑SEM:AVS to *M. galloprovincialis* normal-alive larval development and benthic response index

3.2.3 Grain Size and Total Organic Carbon

Sediment TOC and grain size data are provided in Appendix B, Tables B-9 to B-13 for TOC and B-16 for grain size. Mean values are presented in Tables B-14 for strata and B-15 for harbors. These measurements have no threshold levels for comparison; however, they can be used to help interpret biological responses, as well as understand the distribution of contaminants within sediments.

The majority of sediment samples collected within all strata were dominated by fine sediments (i.e., silt and clay) except in the deep stratum (mean = 45.35 ± 7.13%). Average percentages of fine sediment within the other four strata ranged from 58.49 ± 6.53% in the shallow stratum to 62.27 ± 6.03 % in the industrial stratum. Average percentages of fine sediments among the four harbors ranged from 56.82 ± 3.03% in San Diego Bay to 67.55 ± 14.01% in Oceanside Harbor.

Mean TOC concentrations ranged from 0.80 ± 0.14% in the deep stratum to 1.26 ± 0.20% in the freshwater-influenced stratum. Of the harbors, San Diego Bay had the lowest mean TOC concentration (1.00 ± 0.07%), while Mission Bay had the highest (1.67 ± 0.37%).

Stations with higher percentages of fine sediments had higher percentages of TOC as well, resulting in a significant positive relationship (Figure 3-24). Fine sediments and sediments with high percentages of TOC also had higher levels of chemical exposure, since mean ER-M quotient scores were significantly positively related to both factors (Figure 3-25). Although chemical exposure decreased with grain size, there were no other significant relationships between toxicity levels (as measured by acute and chronic tests) or benthic community condition with grain size (i.e., % fines) or TOC.

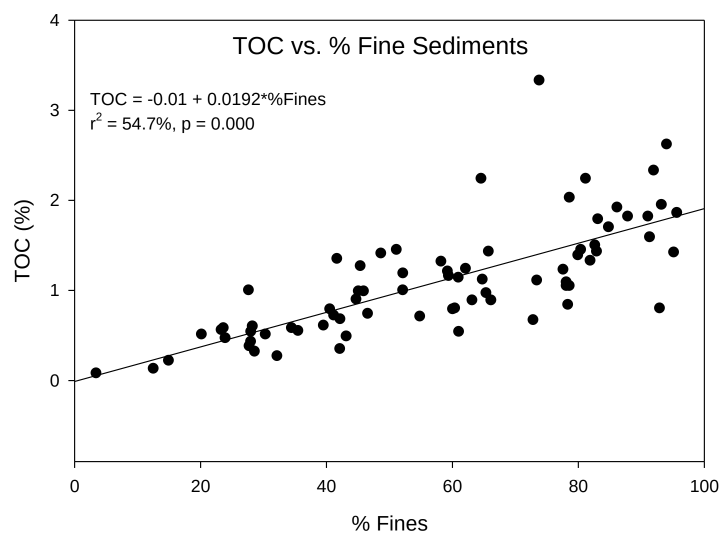


Figure 3-24. Relationship between TOC and & fine sediments

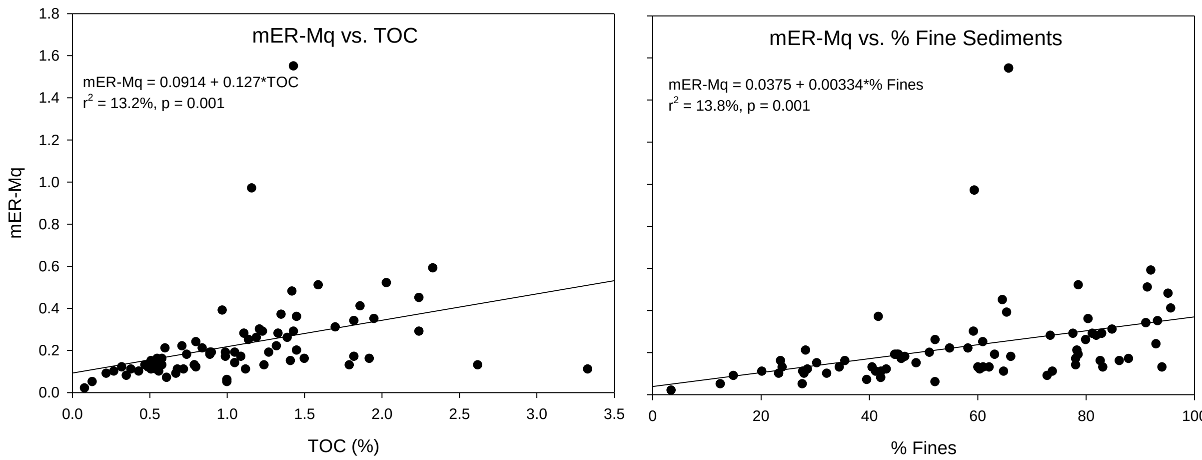


Figure 3-25. Relationship between mean ER-M quotient and TOC and % fine sediments

3.2.4 Toxicity

The 10-day *E. estuarius* SP acute toxicity test served as the primary indicator of sediment toxicity, and it was used to make historical comparisons. The 48-hour *M. galloprovincialis* SWI chronic toxicity test served as a secondary indicator of toxicity, consistent with SQO guidance and Bight '08 protocols. Test conditions and acceptability criteria are summarized in Appendices E-1 and E-2. Results of the sediment toxicity tests for all stations are presented in Appendix E, Table E-3 and mean toxicological results for both tests are provided in Tables E-4 for strata and E-5 for harbors. Statistical significance values are presented in Appendix C.

3.2.4.1 Primary Indicator

Eohaustorius estuarius

Historically, 55% of stations had toxicity levels that did not exceed the *E. estuarius* 20% mortality threshold (i.e., control-adjusted survival was greater than 80%), while in RHMP 2008, toxicity was below the threshold at 96% of the stations, resulting in substantial and significant improvement over historical conditions across all strata (Table 3-5, Figure 3-26). Additionally, toxicity levels were low across all strata, as evidenced by no less than 93% of any single strata in exceedance of the mortality threshold (Table 3-5).

Table 3-5. Percentage of stations below the threshold for acute toxicity

Indicator	Preset Target	RHMP 2008	FWI	Marina	Industrial	Deep	Shallow
E. estuarius % mortality	55	96*	93	100	93	100	93

* Significant difference between 2008 RHMP and historical conditions (p $\leq$ 0.10); green indicates a higher percentage.

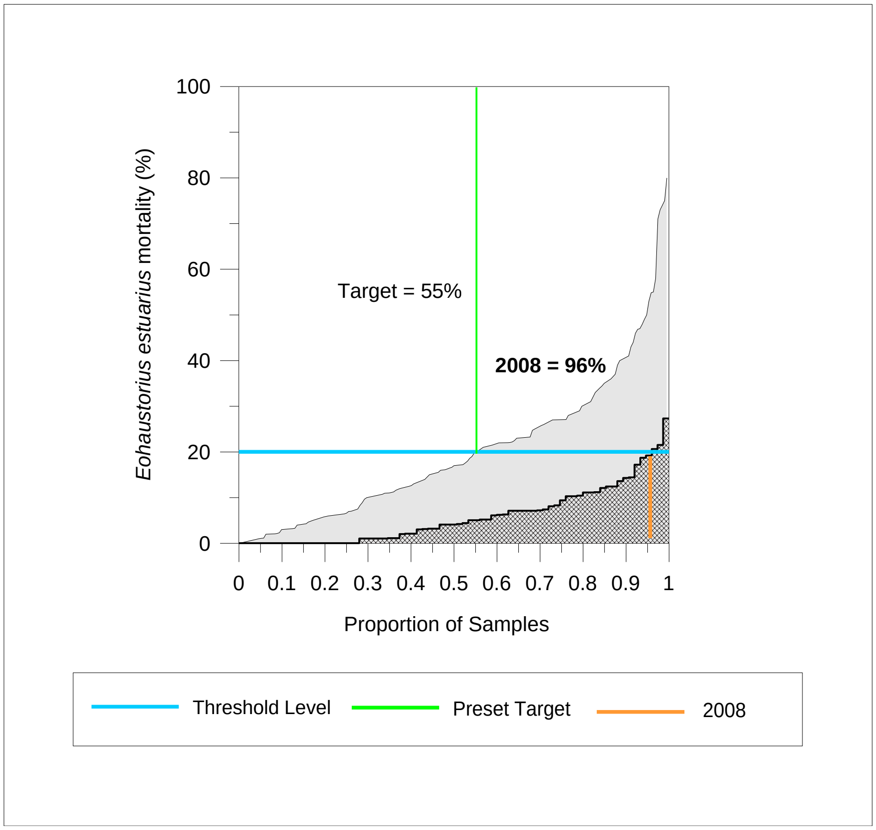


Figure 3-26. Cumulative distribution curves for *E. estuarius* mortality

Toxicity levels were low in every stratum, with mean control-adjusted survival greater than 91% across all strata (Figure 3-27). Additionally, only three of the 75 stations sampled had toxicity results that were worse than the threshold, with the lowest level of survival being 73%. Mean control-adjusted survival ranged from approximately 91% in the shallow, industrial and freshwater-influenced strata to greater than 95% in the deep and marina strata, resulting in significant differences among strata. Although the marina sediments often had the highest level of chemical concentrations and lowest mean ER-M quotients, toxicity (as measured by the SP test) was significantly lower in this stratum than the freshwater-influenced and industrial strata.

Toxicity levels were low across all four harbors, with no stations in Dana Point Harbor, Oceanside Harbor, and Mission Bay exceeding the toxicity threshold. In San Diego Bay, only three stations exceeded the toxicity threshold, with survival at these three stations ranging from 73% to 79%. The highest area-weighted average survival level was in Dana Point Harbor (100%), followed by Mission Bay (99 $\pm$ 1%), San Diego Bay (95 $\pm$ 2%), and Oceanside Harbor (92%) (Figure 3-27).

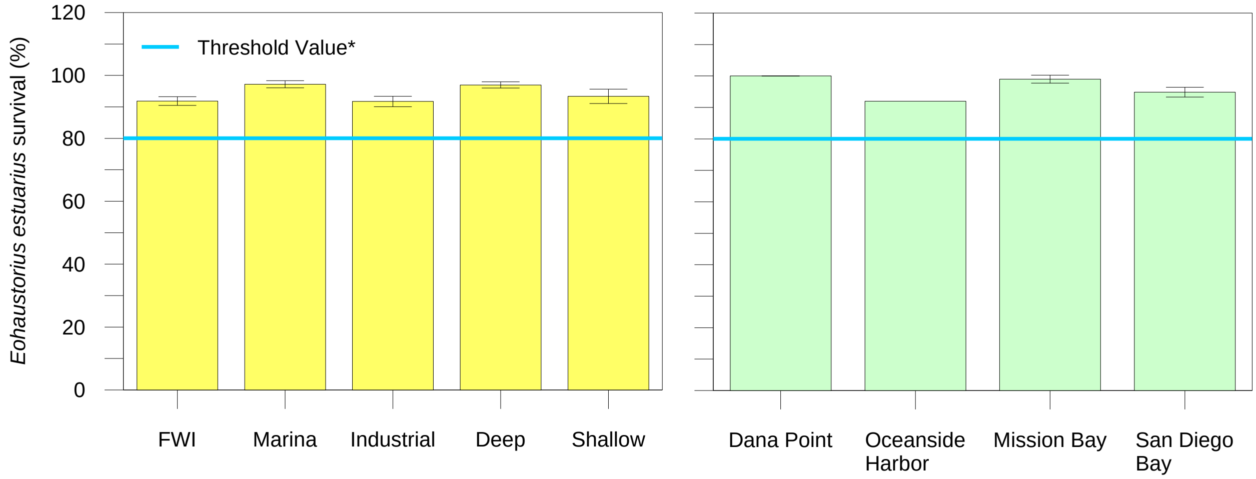


Figure 3-27. Comparisons of toxicity as measured by *E. estuarius* survival among strata (means) and harbors (area-weighted averages).

3.2.4.2 Secondary Indicator

Mytilus galloprovincialis

Chronic toxicity levels generally were found to be low in RHMP 2008 sediments, with 85% of stations having control-adjusted percentages of normal-alive larval development in excess of the 60% threshold (Table 3-6). The threshold value for normal-alive larval development was established at 60%, which was 10% below the control acceptability criterion consistent with the threshold value for the *E. estuarius* SP test. Normal-alive larval development percentages greater than 60% were considered to be below the chronic toxicity threshold.

Table 3-6. Percentages of stations below the threshold for chronic toxicity

Indicator	Threshold Value	RHMP 2008	FWI	Marina	Industrial	Deep	Shallow
M. galloprovincialis % normal alive	60	85	100	56	87	93	93

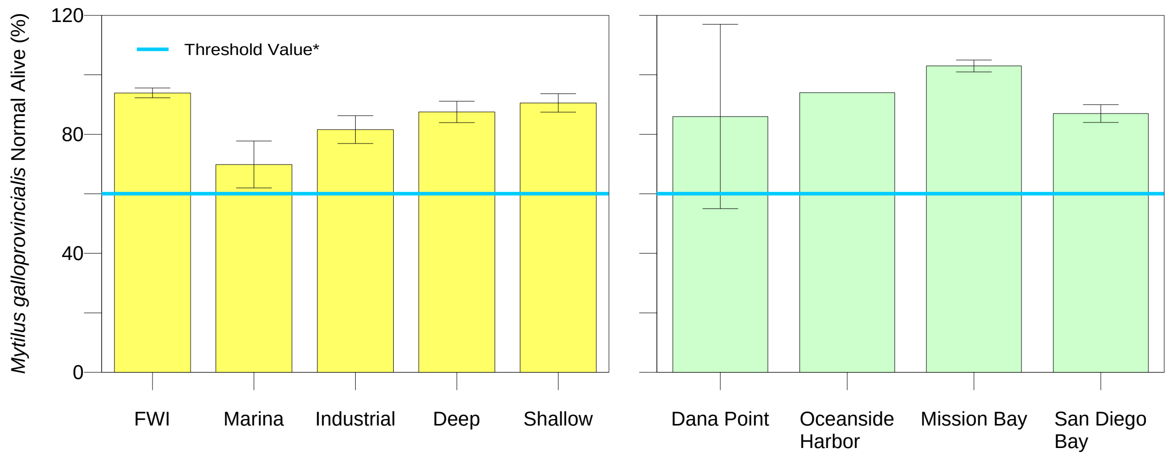
*Threshold value was established in 2008; historical data does not exist for the stations used in this analysis; therefore, significant differences were not calculated.

Spatial distributions of chronic toxicity levels are presented in Figure 3-28. Stations were considered to be nontoxic if control-adjusted percentages of normal-alive larval development were greater than 77% and were not significantly different from controls. Low toxicity was ascribed to percentages ranging from 50-77%. Moderate toxicity levels were ascribed to stations that were significantly different from controls, with percentages ranging from 45-70%. High toxicity stations were significantly different from controls and had survival less than 45%. Using this classification system, moderate to high levels of chronic toxicity occurred primarily within the marina and industrial strata, primarily within San Diego Bay.

Figure 3-28. Distributions of chronic toxicity levels, based on *M. galloprovincialis* normal-alive larval development toxicity tests

Unlike the acute toxicity test with *E. estuarius*, there was a greater level of variability in chronic toxicity levels among strata, with the marina stratum having the highest percentage of stations with toxicity levels exceeding the threshold (i.e., 56% of stations had percent normal-alive development below 60%). For all other strata, no more than 13% of stations had toxicity levels that exceeded the threshold. Additionally, all strata, including the marina stratum, had mean normal-alive larval development percentages above 60% (i.e., strata means did not exceed the chronic toxicity threshold). Mean normal-alive development percentages ranged from 69.9 ± 31.6% in the marinas to 93.9 ± 6.5% in the freshwater-influenced stratum, with significantly higher levels of normal alive larval development in the freshwater-influenced stratum than both the marina and industrial strata (Figure 3-29). There were often high degrees of variability in chronic toxicity levels within strata, with normal-alive larval development percentages ranging from 79.6 to 100% in the freshwater-influenced sediments, 3.4 to 100% in the marina sediments, 41.2 to 100% in the industrial sediments, 48.7 to 100% in the deep sediments, and 57.7 to 100% in the shallow sediments in 2008. In general, stations that occurred closer to the enclosed portions of yacht basins and marinas or in the vicinity of moorings tended to have the highest levels of chronic toxicity.

Area-weighted-average chronic toxicity levels for all harbors did not exceed the established chronic toxicity threshold, since normal-alive larval development ranged from 86 ± 31% in Dana Point Harbor to 100 ± 2% in Mission Bay. The extremely high variability in Dana Point Harbor (i.e., standard error of 31%) was due to the wide range of percent normal-alive development from 3.4% at one station to 100% at the three other stations. San Diego Bay also had a relatively wide range of toxicity, with percentages of normal-alive development extending 17.6% to 100%. In contrast, both Mission Bay and Oceanside Harbor had narrow ranges of toxicity, with percentages of normal-alive development from 92% to 100% in Mission Bay and 91.5% to 97.3% in Oceanside Harbor.



*Threshold value was established in 2008; historical data does not exist for the stations used in this analysis.

Figure 3-29. Comparisons of toxicity as measured by *Mytilus galloprovincialis* % normal-alive larval development among strata (means) and harbors (area-weighted averages).

3.2.5 Benthic Infauna

Benthic infaunal samples were collected and analyzed to determine the relative health of the benthic community. The primary indicator of benthic community status was the BRI, while the Shannon-Wiener diversity index and number of taxa were used as secondary indicators. Species names and abundances for each taxon encountered in all five strata are provided in Appendix F, Tables F-1 to F-5. Primary and secondary indicator values for all stations are provided in Table F-6 and mean benthic community indices are in Tables F-7 and F-8. Significance values for statistical tests are presented in Appendix C. For the BRI, lower values were indicative of a less disturbed benthic community, while for the secondary indicators (Shannon-Wiener diversity and number of taxa) lower values were associated with more disturbed benthic communities.

3.2.5.1 Primary Indicator

Benthic Response Index

Historically, 55% of stations were classified as having a reference benthic infaunal community (i.e., a BRI score ≤ 39.96), while 75% of the RHMP 2008 stations were classified as reference, resulting in a significant improvement in benthic community health over historical conditions (Table 3-7, Figure 3-30). Additionally, there was not a single benthic community classified as high disturbance according to the BRI, and the majority of stations across all strata other than the marina had reference infaunal communities, ranging from 79% to 87% (Table 3-7).

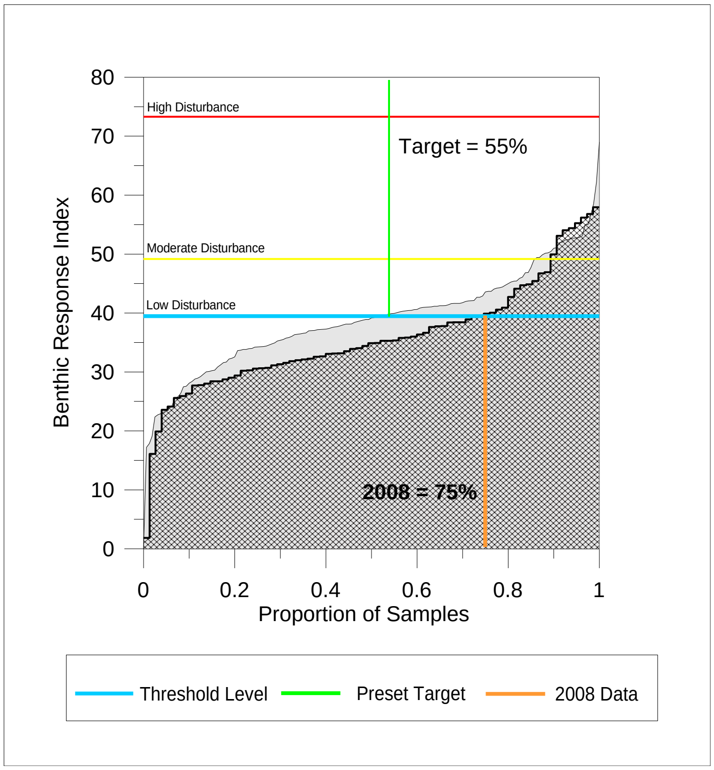


Figure 3-30. Cumulative distribution curve for the Benthic Response Index

Table 3-7. Percentage of stations with reference benthic infaunal community measures

Indicator	Preset Target	All Strata	FWI	Marina	Industrial	Deep	Shallow
BRI	55	75*	87	44	87	80	79
Shannon-Wiener[1]	76	91*	73	88	100	100	93
Number of Taxa[1]	82	85	73	75	93	93	93

* Significant difference between 2008 RHMP and historical conditions (p $\leq$ 0.10); green indicates a higher percentage.

[1] Reported as percentage of stations ABOVE the reference ambient value

The average benthic communities of the deep (BRI = 30.0 $\pm$ 2.2), industrial (35.1 $\pm$ 1.2), shallow (35.3 $\pm$ 2.9), and freshwater-influenced (35.9 $\pm$ 1.6) strata were characterized as having reference condition, while the average marina infaunal community was characterized as low disturbance (42.0 $\pm$ 3.0) (Figure 3-31). BRI values in the marina stratum were 1.4 times higher than the deep stratum, resulting in a significant difference. All stations in the deep and industrial strata had benthic communities classified as reference or low disturbance, while 93% of the freshwater-influenced and shallow strata and 62.5% of the marina stratum were similarly classified (Table 3-8). Additionally, the marina stratum had more than five times the number of stations classified as moderately disturbed than any other stratum.

Table 3-8. Percentages of strata classified by the four BRI categories.

Strata	Category 1 Reference (%)	Category 2 Low Disturbance (%)	Category 3 Moderate Disturbance (%)	Category 4 High Disturbance (%)
Freshwater Influenced	86.6	6.7	6.7	0.0
Marina	43.7	18.8	37.5	0.0
Industrial	86.7	13.3	0.0	0.0
Deep	80.0	20.0	0.0	0.0
Shallow	92.9	0	7.1	0.0

All harbors other than Dana Point Harbor had area-weighted-average benthic communities classified as reference, while the average community condition in Dana Point Harbor was determined to be low disturbance (43.9 ± 0.44) (Figure 3-31). All stations in Mission Bay were determined to be reference, while the communities of Dana Point Harbor and San Diego Bay ranged from reference to moderate. In Oceanside Harbor, two of the three stations were reference, but the third station had such low species counts due to a preservation issue, the BRI was not applicable.

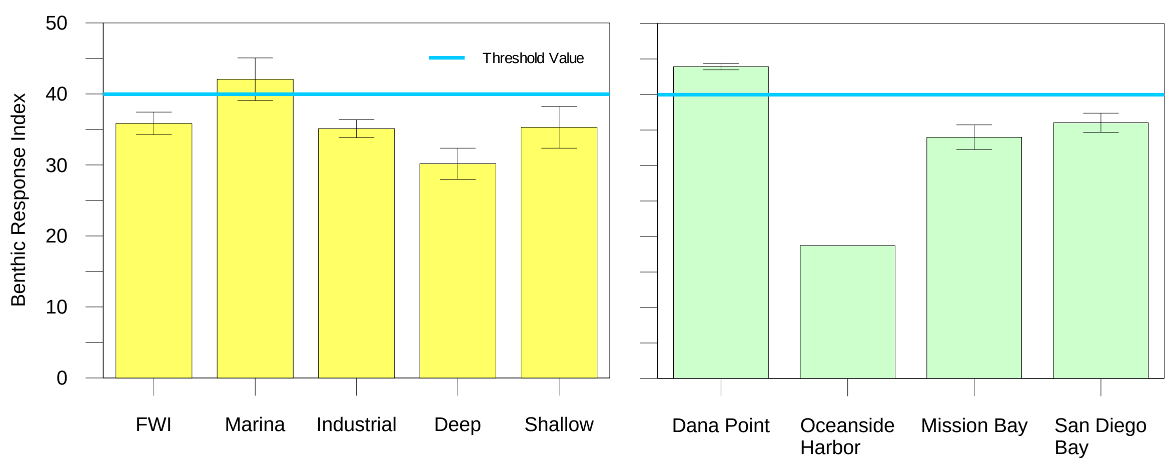


Figure 3-31. Comparisons of average Benthic Response Index values among strata (means) and harbors (area-weighted averages)

Benthic community condition, based on the BRI, was more disturbed at stations with elevated chemical exposure and chronic toxicity levels. There was a significant positive relationship between BRI scores and mean ER-M quotient values (Figure 3-32). Additionally, there was a significant negative relationship between BRI scores and % normal-alive larval development (Figure 3-32). Chemical exposure (i.e., the mean ER-M quotient) explained nearly 13% of the variability in BRI scores and toxicity explained 8%.

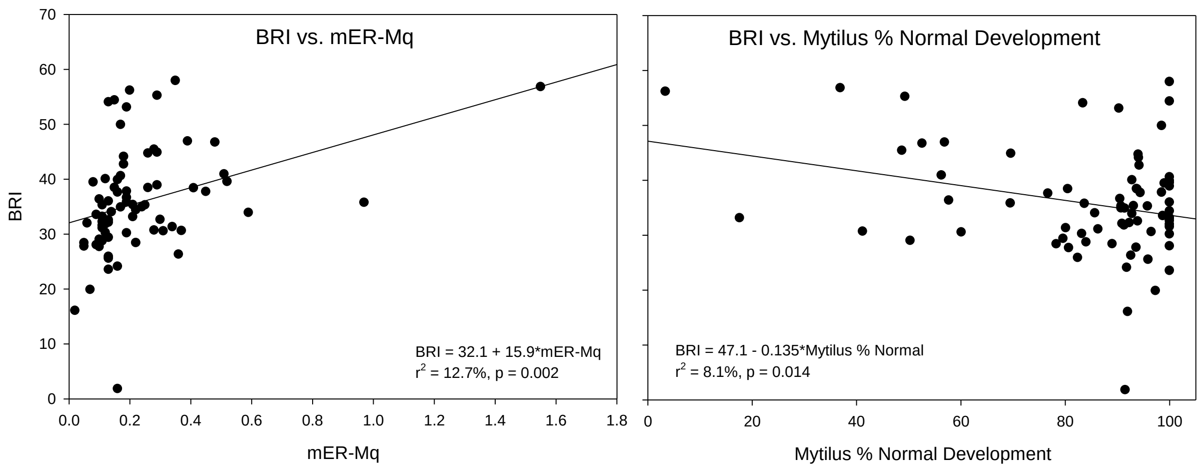


Figure 3-32. Relationship between BRI and mean ER-M quotient and *M. galloprovincialis* % normal alive larval development

3.2.5.2 Secondary Indicators

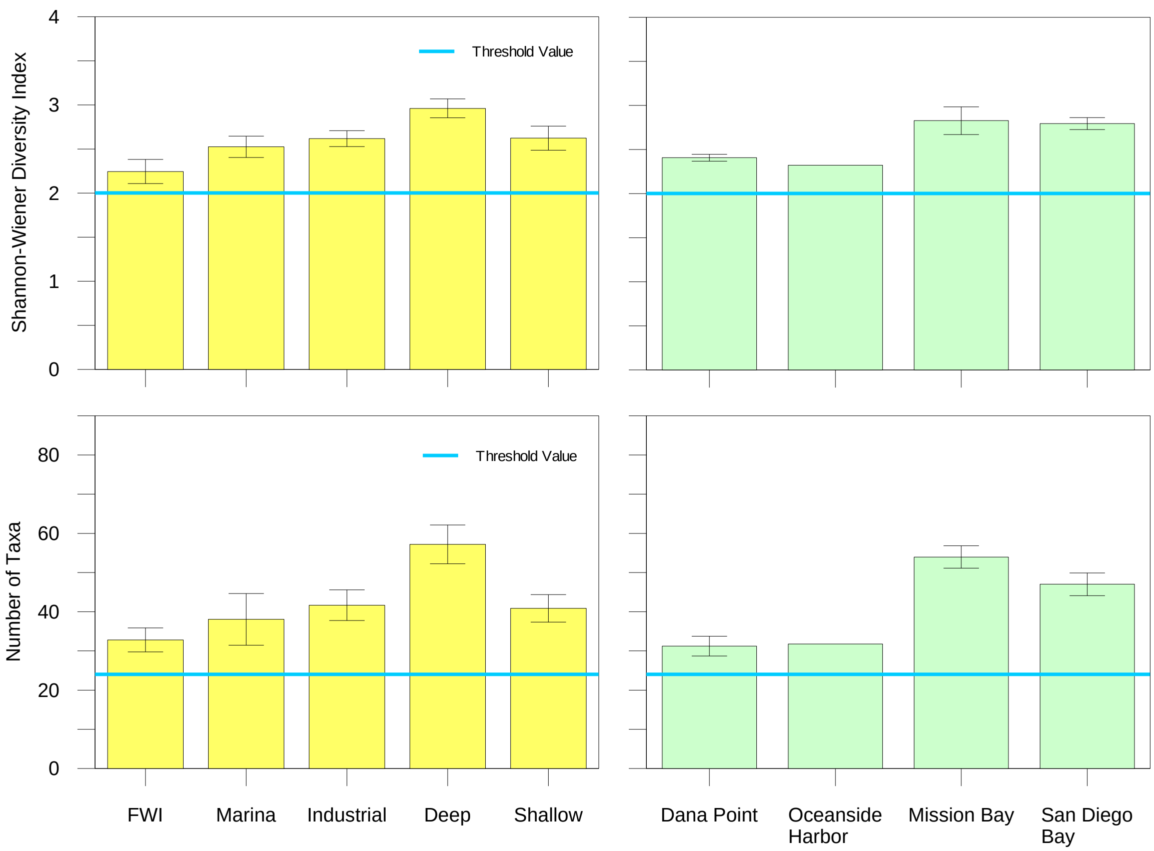
Shannon-Wiener Diversity Index and Species Richness

The Shannon-Wiener diversity index and species richness (i.e., number of taxa) were used as secondary indicators of benthic infaunal community condition. Since both indicators are a measure of diversity, higher values were indicative of healthier benthic infaunal communities; therefore, stations with Shannon-Wiener diversity index scores greater than two and species richness greater than 24 were considered to be indicative of a reference condition.

Historically, 76% of stations had reference Shannon-Wiener diversity scores, while 91% of RHMP 2008 stations were determined to be reference, resulting in a significant improvement over historic conditions (Figure 3-33). Percentages of stations with reference species richness numbers increased slightly from 82% historically to 85% in 2008. Based on both primary and secondary indicators, benthic communities appeared to be healthier than those historically encountered throughout the harbors.

All strata had mean Shannon-Wiener diversity and mean species richness values indicative of reference infaunal communities (Figure 3-33). Average diversity and richness scores were highest in the deep stratum and lowest in the freshwater-influenced stratum, resulting in significant differences between the deep and freshwater-influenced strata for both indicators.

All four harbors had area-weighted-average Shannon-Wiener diversity values and species richness values consistent with reference infaunal communities (Figure 3-33). The area-weighted-average Shannon-Wiener diversity values were largely consistent across the harbors, while the area-weighted-average species richness values for Mission Bay (54 $\pm$ 2.9) and San Diego Bay (47 $\pm$ 2.9) were over 1.5 times higher than those of Dana Point (31 $\pm$ 2.5) and Oceanside harbors (32).



Values ABOVE the threshold level indicate healthier benthic infaunal communities.

Figure 3-33. Comparisons of average benthic infaunal community measures among strata (means) and harbors (area-weighted averages)

3.2.6 Assessments of Bight '98 and '03 Revisited Stations

Of the 75 stations sampled during RHMP 2008, 28 stations were revisited from prior Bight studies, including 15 Bight '98 stations and 13 Bight '03 stations. Revisited stations occurred exclusively in Mission Bay (three '98 and two '03 stations) and San Diego Bay (twelve'98 and eleven '03 stations) as described previously in Section 2.1.1. Sediment chemistry indicators, including chemistry, toxicity, and infaunal communities were compared between studies to assess temporal changes.

3.2.6.1 Bight '98 to RHMP 2008 Comparisons

Sediment chemistry and infaunal community health did not change substantially from 1998 to 2008 at re-sampled stations; however, toxicity levels, as measured by *E. estuarius* acute toxicity tests, were significantly lower in 2008 than in 1998, improving by nearly 9% on average (Table 3-9). In both 1998 and 2008, the mean ER-M quotient was at or just below the threshold for potential adverse biological effects (0.2), while the mean BRI score was indicative of a reference condition in both years.

Of the metals and organics assessed for temporal changes, only cadmium showed a significant increase in concentrations, although the average concentration in 2008 was still far below the

ER-L of 1.2 µg/dry g. Lead and nickel concentrations significantly declined between 1998 and 2008, while all other metals, as well as total PAHs, did not change significantly over the 10-year period. For the other organics that served as secondary indicators of chemical exposure, chlordanes were not detected in both years, total DDTs were detected at three stations in 1998 and only one station in 2008, and total PCBs ranged from below detection limits to 123.8 ng/dry g in 1998 and from below detection limits to 142.3 in 2008. Therefore, overall concentrations of organics did not change substantially over the 10-year period.

Table 3-9. Comparisons of mean sediment indicators between stations# assessed in 1998 and 2008, including significance values for paired t-tests

Indicator	Bight '98		RHMP 2008		P-value
	Mean	SE	Mean	SE	
Mean ER-M Quotient	0.19	0.03	0.20	0.03	0.522
E. estuarius Survival (%)	86.8	3.4	95.6	1.2	**0.013***
BRI	32.24	2.21	33.61	1.91	0.157
Arsenic (µg/dry g)	7.75	0.71	7.57	0.83	0.806
Cadmium (µg/dry g)	0.14	0.02	0.24	0.03	**0.024***
Chromium (µg/dry g)	42.88	3.92	40.65	4.81	0.618
Copper (µg/dry g)	117.90	19.00	105.50	19.80	0.195
Lead (µg/dry g)	39.11	4.94	26.78	3.95	**0.004***
Mercury (µg/dry g)	0.53	0.13	0.61	0.17	0.174
Nickel (µg/dry g)	13.82	1.25	10.14	1.18	**0.003***
Zinc (µg/dry g)	160.60	18.70	149.10	20.00	0.341
Total PAHs (ng/dry g)	2160.00	575.00	1739.00	451.00	0.319

15 Bight '98 stations were revisited in RHMP 2008 (Section 2.1.1)
* Significant difference between Bight '98 and RHMP 2008 ($p \leq 0.05$);
green indicates a significantly higher result; yellow a lower result.

3.2.6.2 Bight '03 to RHMP 2008 Comparisons

Similar to the 10-year comparison, overall sediment chemistry exposure (based on the mean ER-M quotient) and benthic community health (as determined by the BRI) did not change significantly between 2003 and 2008, although, once again, there was a significant improvement in toxicity levels over the 5-year period (Table 3-10). In 2003, the mean ER-M quotient was just below the 0.2 threshold, while in 2008, the mean ER-M quotient was on average above it. In contrast, the mean BRI score in 2003 was just above the threshold for a reference community, while the mean BRI score in 2008 was just below the threshold.

For individual chemical indicators, there were no significant declines in concentrations, although cadmium, chromium, and zinc concentrations all increased significantly over the 5-year period. In the case of cadmium and chromium, mean concentrations were still well below ER-Ls in 2008; however, the mean zinc concentration for re-sampled stations increased to a concentration that exceeded the ER-L (150 µg/dry g). Of the organics assessed, total chlordanes were not detected at any station in 2003; they were detected at one station in 2008. Total DDTs also occurred below detection limits at most stations in 2003, with the exception of one station, and in 2008, with the exception of two stations. Total PCBs occurred at extremely low concentrations in 2003, ranging from below detection limits to 2.62 ng/dry g, while in 2008 the range extended from below detection limits to 1,597.3 ng/dry g.

Table 3-10. Comparisons of mean sediment indicators between stations# assessed in 2003 and 2008, including significance values for paired t-tests

Indicator	Bight '03		RHMP 2008		P-value
	Mean	SE	Mean	SE	
Mean ER-M Quotient	0.193	0.032	0.270	0.068	0.239
E. estuarius Survival (%)	80.8	4.3	94.7	2.1	**0.018***
BRI	40.28	2.64	37.77	3.11	0.088
Arsenic (µg/dry g)	6.79	0.99	7.60	0.97	0.234
Cadmium (µg/dry g)	0.15	0.02	0.24	0.02	**0.002***
Chromium (µg/dry g)	35.38	4.69	41.90	5.21	**0.045***
Copper (µg/dry g)	129.00	26.20	136.60	23.20	0.539
Lead (µg/dry g)	31.35	4.16	28.31	3.48	0.827
Mercury (µg/dry g)	0.54	0.19	0.57	0.18	0.732
Nickel (µg/dry g)	9.59	0.93	10.70	1.17	0.200
Zinc (µg/dry g)	144.10	18.00	179.70	20.40	**0.007***
Total PAHs (ng/dry g)	1105.00	442.00	1882.00	870.00	0.150

15 Bight '98 stations were revisited in RHMP 2008 (Section 2.1.1)
* Significant difference between Bight '03 and RHMP 2008 ($p \leq 0.05$);
green indicates a significantly higher result; yellow a lower result.

3.2.7 Sediment Quality Objectives

Sediment quality was assessed using the SQO guidelines, which are based on a MLOE approach in which the LOE are chemistry, toxicity, and benthic community condition. The MLOE approach evaluates the severity of biological effects and the potential for chemically-mediated effects to provide a final station-level assessment. The specific methods associated with each LOE and the integration of the MLOE are described in the *Water Quality Control Plan for Enclosed Bays and Estuaries – Part 1 Sediment Quality* (SWRCB and Cal EPA, 2009). Final SQO station assessments and individual LOE assessments for all stations are provided in Appendix G, within Tables G-1 and G-2, respectively.

3.2.7.1 Final SQO Station Assessment

The final SQO assessment identified 55% of the RHMP 2008 stations as unimpacted, 9% as likely unimpacted, 23% as possibly impacted, 11% as likely impacted, only one station (1%) as clearly impacted, and one station (1%) as inconclusive (Table 3-11, Figure 3-34 to Figure 3-37). Using an area-weighted average assessment, over 75% of the total area of the RHMP harbors was classified as unimpacted (71.4%) or likely unimpacted (4.4%), while 17.4% was possibly impacted, 6.5% likely impacted, and 0.3% as clearly impacted. The one station (6071) classified as clearly impacted was located in the marina stratum of San Diego Bay. Within the deep stratum, two of the stations (13%) were identified as likely impacted, both occurring in areas adjacent to the industrial stratum in San Diego Bay (6054 and 6072) (Figure 3-37). Both the freshwater-influenced and industrial stratum had one station (7%) identified as likely impacted.

Both stations were located in San Diego Bay with the freshwater-influenced station (6116) near the mouth of Chollas Creek and the industrial station (6133) located on the eastern edge of the bay just north of the Coronado Bridge. None of the stations in the shallow stratum were identified as likely impacted.

Table 3-11. Percentages of strata per final SQO assessment category

Strata	Final SQO Station Assessment				
	Unimpacted	Likely Unimpacted	Possibly Impacted	Likely Impacted	Clearly Impacted
RHMP 2008*	54.7	9.3	22.6	10.7	1.3
FWI	40.0	33.3	20.0	6.7	0.0
Marina	31.3	0.0	37.5	25.0	6.2
Industrial	53.3	6.7	33.3	6.7	0.0
Deep	80.0	0.0	6.7	13.3	0.0
Shallow	71.5	7.1	21.4	0.0	0.0

*Percentages do not sum to 100% due to inconclusive sample collected at OH Station 6291.

The deep and shallow strata, which were the two strata not directly associated with inputs of pollutants, had the highest percentages of stations classified as unimpacted or likely unimpacted (Table 3-11). Additionally, 73% of the freshwater-influenced, 60% of the industrial, and 31% of the marina strata were classified as unimpacted or likely impacted. The marina stratum had the highest percentage of stations identified as clearly or likely impacted (31%) as compared to 13% in the deep and 7% both in the freshwater-influenced and shallow strata. Moreover, the marina was the only stratum to have a median SQO final station assessment of possibly impacted, while the median SQO assessments were unimpacted for the deep, industrial, and shallow strata and likely unimpacted for the freshwater-influenced stratum.

Table 3-12. Percentages of harbors per final SQO assessment category

Harbor	Final SQO Station Assessment				
	Unimpacted	Likely Unimpacted	Possibly Impacted	Likely Impacted	Clearly Impacted
Dana Point Harbor	25.0	0.0	50.0	25.0	0.0
Oceanside Harbor*	33.4	0.0	0.0	33.3	0.0
Mission Bay	100.0	0.0	0.0	0.0	0.0
San Diego Bay	51.7	11.7	25.0	10.0	1.6

*Percentages do not sum to 100% due to inconclusive sample collected at OH Station 6291.

Sediment quality differed substantially among harbors. Mission Bay had the best sediment quality, with all 8 stations classified as unimpacted (Figure 3-36). The median sediment quality score in San Diego Bay was also unimpacted, while the area-weighted average was likely impacted, with 52% of the bay characterized as unimpacted and 12% likely unimpacted (Table 3-12, Figure 3-37). In both Oceanside and Dana Point Harbors, the median sediment quality score was possibly impacted, while the area-weighted averages were intermediate between likely unimpacted and possibly impacted for Dana Point Harbor and possibly impacted and likely impacted for Oceanside Harbor. In Dana Point Harbor, one station was unimpacted, two were possibly impacted, and one was likely impacted (Figure 3-34). In Oceanside Harbor, the three stations were classified as unimpacted, likely impacted, and inconclusive, with sediment quality decreasing from the harbor entrance to the inland terminus (Figure 3-35).

Figure 3-34. SQO assessments for Dana Point Harbor

Figure 3-35. SQO assessments for Oceanside Harbor

Figure 3-36. SQO Assessments for Mission Bay

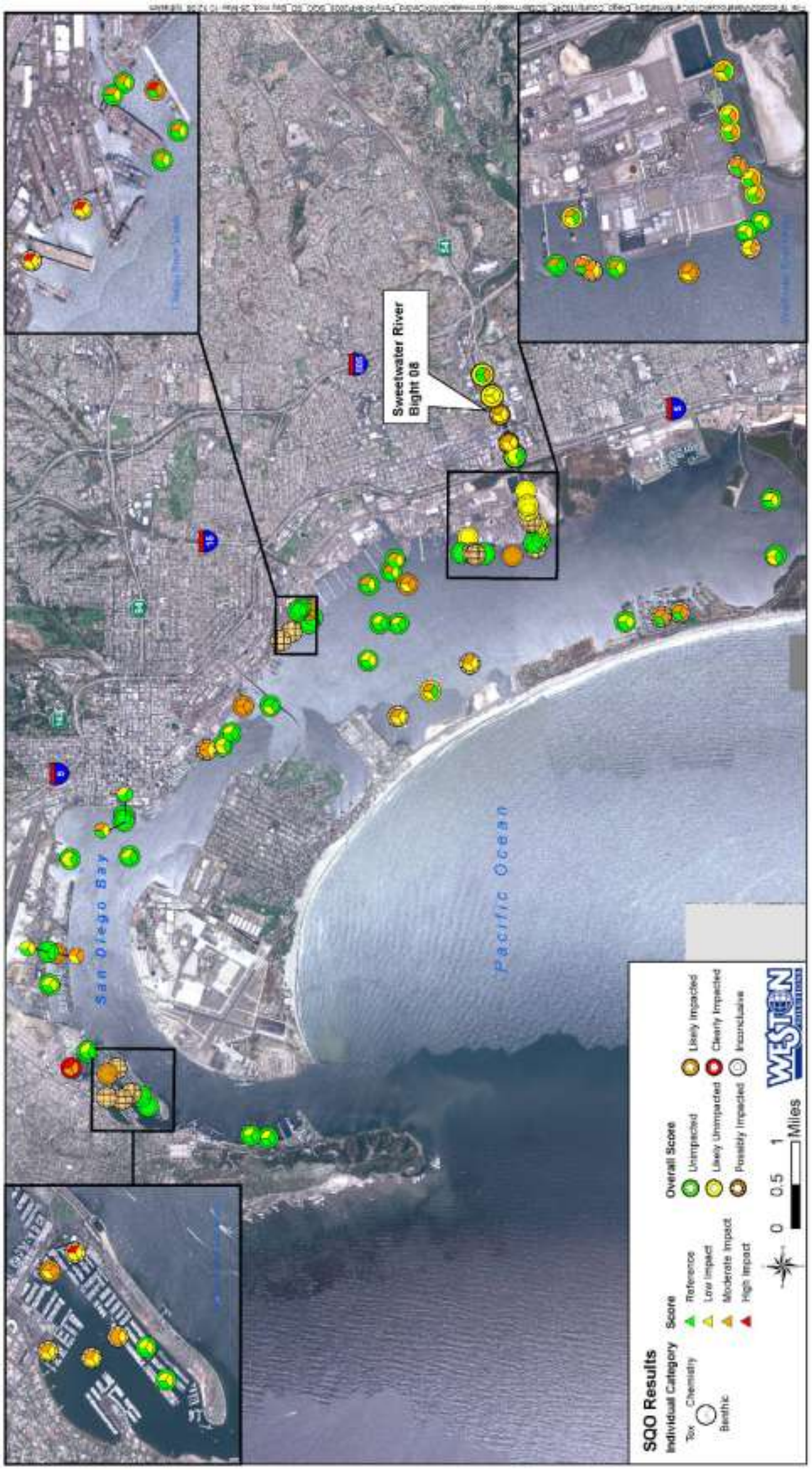


Figure 3-37. SQO Assessments for San Diego Bay

3.2.7.2 SQO Chemistry Line of Evidence

The SQO chemistry assessment categorizes sediments as having minimal, low, moderate, and high chemical exposure. Eighty-eight percent of RHMP 2008 stations were categorized as having moderate (49%) or low (39%) chemical exposure (Table 3-13). Of the remaining stations, five were categorized as having high chemical exposure, including two stations in the marina stratum (6157 and 6171), two in the industrial stratum (6125 and 6127), and one in the freshwater-influenced stratum (6116) (Appendix G, Table G-1). Three stations located in the deep stratum (6212, 6213, and 6129) and one station in the shallow stratum (6216) were categorized as having minimal levels of chemical exposure. Based on an area-weighted average assessment, approximately 63% of the total area of the harbors had low (52%) or minimal (11%) chemical exposure, while 36% had moderate and 1.3% high exposure. Across all stations, the median level of chemical exposure was determined to be moderate.

Table 3-13. Percentages of strata per SQO chemistry LOE category

Strata	Minimal	Low	Moderate	High
RHMP 2008	5.3	38.7	49.3	6.7
FWI	0.0	46.7	46.7	6.7
Marina	0.0	18.8	68.8	12.5
Industrial	0.0	20.0	66.7	13.3
Deep	20.0	53.3	26.7	0.0
Shallow	7.1	57.1	35.7	0.0

The deep (73%) and shallow (64%) strata were the only two strata to have stations with minimal levels of chemical exposure (Table 3-13). In contrast, 81% of the marina and 80% of the industrial strata were classified as having moderate or high chemical exposure. The freshwater-influenced stratum was intermediate, with 47% of the stations classified as low and 53% as moderate or high.

Sediment chemistry exposure levels differed substantially among harbors, with nearly 38% of Mission Bay stations having minimal chemical exposure as compared to only one station in San Diego Bay and none in the other harbors (Table 3-14). Mission Bay had the highest percentage of stations classified as having low or minimal chemical exposure (75%), while 42% of San Diego Bay, 33% of Oceanside Harbor, and 25% of Dana Point Harbor were similarly classified.

Table 3-14. Percentages of harbors per SQO chemistry LOE category

Harbor	Minimal	Low	Moderate	High
Dana Point Harbor	0.0	25.0	75.0	0.0
Oceanside Harbor	0.0	33.3	66. 7	0.0
Mission Bay	37.5	37.5	25.0	0.0
San Diego Bay	1.7	40.0	50.0	8.3

3.2.7.3 SQO Toxicity Line of Evidence

The SQO toxicity assessment classifies sediments as being non-toxic or has having low, moderate, or high toxicity based on the results of acute and chronic toxicity tests. Ninety-two percent of RHMP 2008 stations were categorized as either non-toxic (65%) or as having low toxicity (27%) (Table 3-15). Six stations were categorized as having moderate toxicity, with three in the marina stratum (6151, 6171, and 6327) and three in the industrial stratum (6133, 6140, and 6661). None of the stations were determined to be highly toxic. Based on an area-weighted average assessment, approximately 98% of the total area of the harbors was nontoxic (66.6%) or low toxicity (31.5%), while 2% of the area was moderately toxic. Across all areas of the harbors, the median level of toxicity was determined to be non-toxic.

Table 3-15. Percentages of strata per SQO toxicity LOE category

Strata	Non-Toxic	Low	Moderate	High
RHMP 2008	65.3	26.7	8.0	0.0
FWI	86.7	13.3	0.0	0.0
Marina	50.0	31.3	18.8	0.0
Industrial	53.3	26.7	20.0	0.0
Deep	73.3	26.7	0.0	0.0
Shallow	64.3	35.7	0.0	0.0

The freshwater-influenced stratum had the highest percentage of non-toxic stations (87%), followed by the deep, shallow, industrial, and marina strata, respectively (Table 3-15). Toxicity levels in the marina and industrial strata ranged from non-toxic to moderate, while levels in the freshwater-influenced, deep, and shallow strata were at most low.

All stations in Mission Bay were determined to be non-toxic, as were 75% of Dana Point Harbor, 67% of Oceanside Harbor, and 60% of San Diego Bay. San Diego Bay (8%) and Dana Point Harbor (25%) were the only two harbors to have stations with moderate levels of toxicity.

Table 3-16. Percentages of harbor stations per SQO toxicity LOE category

Harbor	Minimal	Low	Moderate	High
Dana Point Harbor	75.0	0.0	25.0	0.0
Oceanside Harbor	66.7	33.3	0.0	0.0
Mission Bay	100	0.0	0.0	0.0
San Diego Bay	60	31.7	8.3	0.0

3.2.7.4 Benthic Community Condition Line of Evidence

The SQO benthic community assessment classifies infaunal assemblages as being reference or as having low, moderate, or high levels of disturbance. Benthic infaunal assemblages were categorized as having reference or low disturbance conditions in 72% of the stations (Table 3-12). Twenty-seven percent of the stations were categorized as having moderate benthic disturbances, including eight stations in the freshwater-influenced stratum, eight in the marina, two in the industrial, and two in the deep stratum. Only one station (6291) located in the shallow stratum of Oceanside Harbor was not able to be classified, due to the paucity of species at that station (i.e., only three species comprised of three organisms) due to preservation issues. Based on an area-weighted average assessment, approximately 88% of the total area of the harbors had reference (50.2%) or low-disturbance benthic communities (37.5%), while 8.5% of the area had moderately disturbed communities.

Table 3-17. Percentages of stations per SQO benthic community LOE category

Strata	Reference	Low	Moderate	High
RHMP 2008*	30.7	41.3	26.7	0.0
FWI	6.7	40.0	53.3	0.0
Marina	12.5	37.5	50.0	0.0
Industrial	26.7	60.0	13.3	0.0
Deep	60.0	26.7	13.3	0.0
Shallow*	50.0	42.9	0.0	0.0

*Percentages do not sum to 100% due to inconclusive sample collected at OH Station 6291.

Benthic communities were most likely to be indicative of reference conditions in the deep (60%) and shallow (50%) strata, while reference communities occurred at 27% of industrial, 12% of marina, and 7% of freshwater-influenced stations. Communities indicative of moderate levels of disturbance were most prevalent in the freshwater-influenced (53%) and the marina (50%), while all other strata were largely comprised of reference and low-disturbance communities.

Mission Bay benthic communities ranged from reference (62.5%) to low disturbance (37.5%), having approximately twice the percentage of reference condition stations as all other harbors. Seventy-three percent of San Diego Bay stations were classified as reference or low disturbance, while only 33% (one station) of Oceanside Harbor and 25% (one station) of Dana Point harbor were determined to be reference. All other stations in Dana Point Harbor had moderately disturbed communities, and the two remaining stations in Oceanside Harbor were classified as moderate disturbance and inconclusive. Shallow station 6291 in Oceanside Harbor was classified as inconclusive due to a potential preservation issue that resulted in the presence of only three intact species in the sample.

Table 3-18. Percentages of harbor stations per SQO benthic community LOE category

Harbor	Minimal	Low	Moderate	High
Dana Point Harbor	25.0	0.0	75.0	0.0
Oceanside Harbor*	33.3	0.0	33.3	0.0
Mission Bay	62.5	37.5	0.0	0.0
San Diego Bay	26.7	46.7	26.7	0.0

*Percentage does not sum to 100% due to inconclusive sample collected at OH Station 6291.

3.3 Demersal Fish and Macroinvertebrate Community

Five-minute otter trawls were conducted at 18 stations to sample the demersal fish and macroinvertebrate communities. The results of the trawl surveys are presented in Appendix H; data on fish are provided in Tables H-1 to H-4 and macroinvertebrates in Tables H-5 to H-8.

3.3.1 Fish Community

Fish abundance for all 18 stations in the four harbors totaled 433 individuals representing 31 different species (Table H-1). The most abundant fish regionally were slough anchovy (*Anchoa delicatissima*) (61 individuals), barred sandbass (*Paralabrax nebulifer*) (56 individuals), and yellowfin croaker (*Umbrina roncador*) (53 individuals). Fish abundance per trawl was highest at south San Diego Bay Station 6028 with 65 individuals and was lowest at mid Mission Bay Station 6212 with one individual. The most frequently encountered fish species (i.e., the species collected at the most stations) was the barred sandbass (13 stations), California halibut (*Paralichthys californicus*) (12 stations), and spotted sandbass (*Paralabrax maculatofasciatus*) (11 stations).

By harbor, mean abundance per trawl was highest in Oceanside Harbor with 30 fish per haul, dominated by queenfish (*Seriphus politus*) (Table H-1). Dana Point Harbor had a mean of 27 fish per haul, dominated by white seaperch (*Phanerodon furcatus*), San Diego Bay had a mean of 26 fish per haul, dominated by slough anchovy, and Mission Bay had the lowest abundance with a mean of 12 fish per haul, dominated by yellowfin croaker.

Fish biomass for all stations totaled 51.7 kg (Table H-2). Fish species with the highest cumulative biomass regionally included round stingray (*Urobatis halleri*) (11.0 kg), spotted sandbass (8.0 kg), yellowfin croaker (6.0 kg), black croaker (*Cheilotrema saturnum*) (4.1 kg) and barred sandbass. Fish biomass per trawl was highest at north-central San Diego Bay Station 6172 with 7.9 kg of fish. Fish biomass was lowest at outer and mid Mission Bay Stations 6188 and 6212 with 0.2 kg of fish per trawl.

By harbor, mean biomass per trawl was highest in San Diego Bay with a mean of 3.5 kg of fish per haul, dominated by round stingray (Table H-1). Dana Point Harbor had a mean of 2.9 kg of fish per haul, dominated by white seaperch, Oceanside Harbor had a mean of 2.1 kg of fish per haul, dominated by black perch (*Embiotoca jacksoni*) and Mission Bay had the lowest biomass with a mean of 0.9 kg of fish per haul, dominated by round stingray.

3.3.1.1 Community Metrics

The Ecological Index (EI) was calculated for each species. This index is based on the percentage of individual fish collected, the percent biomass, and the percent frequency of occurrence. Table H-3 presents the ranked EI for all harbors combined, and Table H-4 presents the ranked EI of fish species collected from the four harbors separately.

Regionally, the top five most ecologically important species were spotted sandbass, barred sandbass, round stingray, yellowfin croaker, and California halibut. Sandbass and halibut are also important sportfish species.

In Dana Point Harbor, the most ecologically important species were white seaperch, California halibut, and spotfin croaker (*Roncador stearnsii*). In Oceanside Harbor, the most ecologically important species were black perch, spotfin croaker, and white croaker (*Genyonemus lineatus*). In Mission Bay, the most ecologically important species were yellowfin croaker, round stingray, and spotfin croaker. In San Diego Bay, the most ecologically important species were spotted sandbass, round stingray, and barred sandbass.

Mean species richness for all stations was 6.2 species per station (Table H-5). The regional mean Shannon-Wiener diversity index was 1.49, the evenness value was 0.93 for all stations, and the mean dominance index was 2.9. Species richness was highest at outer Oceanside Harbor Station 6294 with 12 species and was lowest at mid Mission Bay Station 6212 with 1 species. Shannon-Wiener diversity and evenness were highest at inner Oceanside Harbor Station 6295 with values of 2.02 and 0.97, respectively, and lowest at mid Mission Bay Station 6212 with values of 0.00 for both indices. Three stations had a dominance value of 1, where a single species comprised at least 75% of the catch. Inner Oceanside Harbor Station 6295 had the greatest dominance value with six species of fish comprising 75% of the catch.

3.3.1.2 Cluster Analysis

To assess regional fish assemblage structure, a Bray-Curtis dissimilarity matrix was created from all co-occurring fish species (Figure 3-38). Fish community assemblages were most similar between Dana Point and Oceanside Harbors, with four of the five stations clustering together, primarily due to the presence of white seaperch (*Phanerodon furcatus*) and spotfin croaker (*Roncador stearnsii*). Seven of the 10 San Diego Bay sites clustered due to the presence of California halibut, barred sandbass, and spotted sandbass. These three species were collected from at least one station in every harbor and were the most ubiquitous species in the study. The three Mission Bay sites were each in separate clusters based on co-occurrence of one or two species.

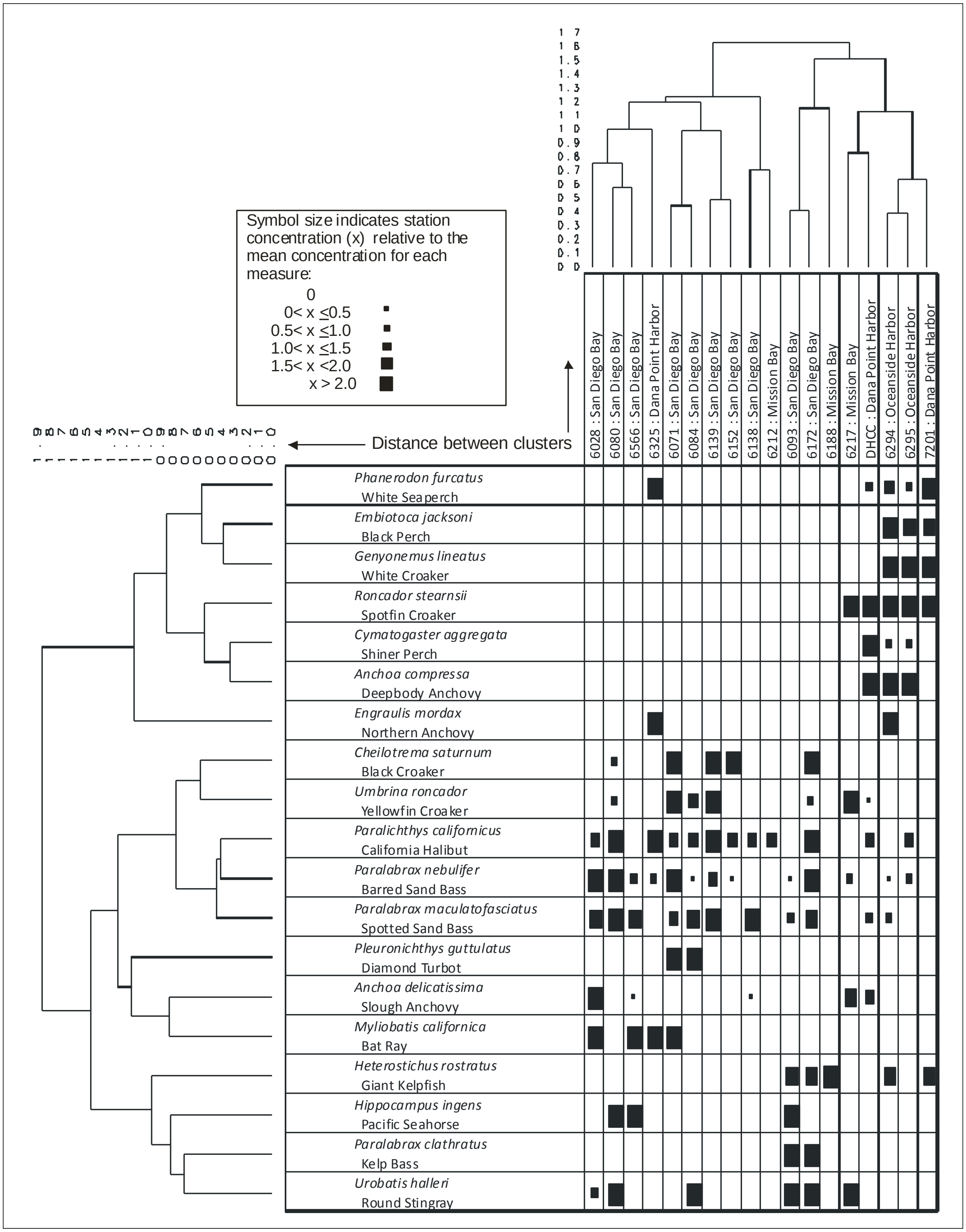


Figure 3-38. Cluster analysis of fish species and stations

3.3.1.3 Fish Health

There were no tumors, lesions, fin erosion, or other physical deformities noted on any fish collected from the four harbors. The overall condition of the fish appeared normal and most specimens had normal color and energy, with the exception of specimens that appeared to have been damaged by the trawl net. Five fish were noted to have external parasites, four of which were the common isopod *Nerocila* sp. plus one instance of the gill parasite *Elthusa vulgaris* (Table 3-19). This represented a frequency of parasitism of 0.6% of the specimens caught; however, the incidence of *Nerocila* was likely somewhat greater than on the four fish recorded, as free-swimming *Nerocila* were occasionally noted in the processing tubs that could not be associated with specific fish.

Table 3-19. Parasites noted on collected fish

Station	Harbor	Sample Date	Species	Common Name	Size Class (cm)	Anomaly	Comments
6071	San Diego Bay (central)	15-Aug-2008	*Umbrina roncador*	Yellowfin Croaker	13	Skin Parasite	*Nerocila* sp
6138	San Diego Bay (north)	14-Aug-2008	*Paralichthys californicus*	California Halibut	22	Skin Parasite	*Nerocila* sp
6139	San Diego Bay (central)	15-Aug-2008	*Cheilotrema saturnum*	Black Croaker	21	Gill Parasite	*Elthusa vulgaris*
6325	Dana Point Harbor	11-Aug-2008	*Myliobatis californica*	Bat Ray	35	Skin Parasite	*Nerocila* sp
6325	Dana Point Harbor	11-Aug-2008	*Phanerodon furcatus*	White Seaperch	17	Skin Parasite	*Nerocila* sp

3.3.1.4 Historical Comparison

Historical comparisons with the RHMP study were made with diversity, abundance and biomass data from prior Bight studies for the four harbors as a whole. Additional historical information from fish studies in San Diego Bay was compiled from Allen 1999 and Vantuna Research Group (VRG) 2006. The Allen and VRG studies combined information from numerous gear types (versus the RHMP study, which was limited to otter trawls) so comparisons must be made carefully.

Table 3-20 presents summary data comparing the RHMP 2008 study with the southern region bays and harbor stations sampled in the Bight ’98 and Bight ’03 trawl surveys (Allen *et al*., 2002, Allen *et al*., 2007). These values were calculated from the same four harbors that were sampled for the RHMP, but with different numbers of stations sampled in each survey. The mean number of species per trawl was quite similar in all three surveys, with nine species per trawl in RHMP 2008 and eight species per trawl in Bight ’98 and six species per trawl in Bight ’03. The total number of unique species caught was substantially higher in RHMP 2008, with 43 species compared with 26 in Bight ’98 and 17 species in Bight ’03. Mean abundance per trawl for RHMP 2008 was somewhat lower than the two prior Bight surveys, with a mean of 48 individuals per trawl compared with a mean of 60 Bight ’98 and 66 individuals per trawl in Bight ’03. Mean biomass per trawl was similar in all surveys, with 5.6 kg of fish per trawl for RHMP and 7.2 Bight ’98 and 6.1 kg of fish collected per trawl in Bight ’03.

Table 3-20. Comparison with Bight '98 and '03, southern region bays and harbors fish summary data*.

Species Diversity					
Program	No. of Stations	Total No. of Species	Range Per Trawl		Mean
			Min	Max	
Bight '98	21	26	3	15	8
Bight '03	9	17	3	11	6
RHMP '08	18	43	2	17	9
Abundance					
Program	No. of Stations	Total Abundance	Range Per Trawl		Mean
			Min	Max	
Bight '98	21	1340	6	464	60
Bight '03	9	593	10	215	66
RHMP '08	18	866	2	130	48
Biomass					
Program	No. of Stations	Total Biomass (kg)	Range Per Trawl (kg)		Mean (kg)
			Min	Max	
Bight '98	21	174.0	0.4	27.2	7.2
Bight '03	9	55.3	1.0	17.0	6.1
RHMP '08	18	101.0	0.1	15.8	5.6

*All trawl data were standardized to 10 minute tow times as described in the Bight '98 and '03 reports

For San Diego Bay, comparison of EI values from Allen 1999 and VRG 2006 were made (Table 3-21). Many of the highly ranked species were common to all three studies. The top three RHMP fish, spotted sandbass, barred sandbass, and round stingray were also in the top ten in both historical surveys. Most of the highly ranked species from the historical studies that were not highly ranked in the RHMP were pelagic or shallow water species that were caught by purse seine and/or beach seine nets (i.e., species not generally caught in high numbers in a trawl net). These included topsmelt (*Atherinops affinis*), northern anchovy (*Engraulis mordax*), and shiner perch (*Cymatogaster aggregata*). One notable species that was ranked in the top ten for the RHMP was the Pacific sea horse (*Hippocampus ingens*), which was ranked very low by Allen and was not collected by VRG. This species was limited to shallow stations in south San Diego Bay.

Table 3-21. Top ten ecologically important fishes in San Diego Bay and a comparison with historical surveys.

RHMP 2008		VRG 2006 (2005)		Allen 1999 (1994-1998)	
Species	Ecological Index	Species	Ecological Index	Species	Ecological Index
Paralabrax maculatofasciatus	3193	*Urobatis halleri*	4055	*Atherinops affinis*	3133
Paralabrax nebulifer	2413	*Atherinops affinis*	3454	*Engraulis mordax*	2715
Urobatis halleri	2120	*Anchoa delicatissima*	1912	*Urobatis halleri*	2271
Umbrina roncador	1576	*Anchoa compressa*	1456	*Anchoa delicatissima*	1857
Cheilotrema saturnum	1008	*Paralabrax maculatofasciatus*	1178	*Paralabrax maculatofasciatus*	1496
Anchoa delicatissima	597	*Cymatogaster aggregata*	580	*Paralabrax nebulifer*	565
Paralichthys californicus	513	*Engraulis mordax*	420	*Paralichthys californicus*	496
Myliobatis californica	193	*Myliobatis californica*	314	*Cymatogaster aggregata*	401
Hippocampus ingens	39	*Paralichthys californicus*	277	*Heterostichus rostratus*	219
Pleuronichthys guttulata	33	*Paralabrax nebulifer*	266	*Sardinops sagax*	216

Fish health was comparable to Bight ’98 and ’03 surveys. The incidence of anomalies was 0.6% in RHMP 2008, while in the Bight surveys it was 0.5% in 1998 and 0.9% in 2003.

3.3.2 Macroinvertebrate Community

Macroinvertebrate abundance for all stations totaled 496 individuals representing 21 different species (Table H-6). The most abundant macroinvertebrates regionally were the trailtip sea pen (*Acanthoptilum* sp.) (245 individuals), the tuberculate pear crab (*Pyromaia tuberculata*) (154 individuals), and the California bubble (*Bulla gouldiana*) (29 individuals). In general, macroinvertebrates had relatively patchy distributions. The California bubble and the sea slug navanax (*Navanax inermis*) were the most frequently encountered invertebrates and were each collected at eight of the stations. Macroinvertebrate abundance per trawl was highest at North-Central San Diego Bay Station 6152 with 234 individuals and was lowest at Oceanside Harbor Station 6295 with no macroinvertebrates collected. At Station 6152, 231 of the macroinvertebrates collected were trailtip sea pens.

By harbor, mean abundance per trawl was highest in San Diego Bay with a mean of 47 macroinvertebrates per haul (Table H-6). Dana Point Harbor had a mean of 6 macroinvertebrates per haul, Mission Bay had a mean of 3 macroinvertebrates per haul, and Oceanside Harbor had the lowest abundance with a mean of 1 macroinvertebrate per haul.

Macroinvertebrate biomass for all stations totaled at least 74.0 kg (Table H-7). Macroinvertebrate species with the highest cumulative biomass regionally were “orange” bay sponge (*Suberites latus*) (62.2 kg), “burgundy bay sponge” (*Tetilla* sp.) (8.6 kg), and California spiny lobster (*Panulirus interruptus*) (1.1 kg). Macroinvertebrate biomass per trawl was highest at North-Central San Diego Bay Station 6152 with 46.8 kg of macroinvertebrates per trawl, primarily due to the collection of large “orange” bay sponges. Macroinvertebrate biomass was lowest at Oceanside Harbor Station 6295 with no macroinvertebrates collected.

By harbor, mean biomass per trawl was highest in San Diego Bay with a mean of 7.3 kg of macroinvertebrates per haul, (Table H-7). Oceanside Harbor had a mean of 0.3 kg of macroinvertebrates per haul, Dana Point Harbor had a mean of 0.2 kg of macroinvertebrates per haul, and Mission Bay had the lowest biomass with a mean of 0.1 kg of macroinvertebrates per haul.

3.3.2.1 Community Metrics

The EI was calculated for each macroinvertebrate species the same as for fish. Table H-8 presents the ranked EI for all harbors combined, and Table H-9 presents the ranked EI of fish species collected from the four harbors separately.

Regionally, the top five most ecologically important species were the orange bay sponge, the trailtip sea pen, the tuberculate pear crab, the burgundy bay sponge and the California bubble snail (Table H-8). Distribution of these species was quite localized. For example, the orange bay sponge was collected only from the deeper stations in San Diego Bay.

In Dana Point Harbor, the most ecologically important species were the warty sea cucumber (*Parastichopus parvimensis*), navanax, and the California bubble. In Oceanside Harbor, the most ecologically important species was the California spiny lobster since it was the only macroinvertebrate collected. In Mission bay, the most ecologically important species were Pacific sand dollar (*D. eccentricus*), trailtip sea pen, and yellowleg shrimp (*Farfantepenaeus californiensis*). In San Diego Bay, the most ecologically important species were orange bay sponge, tuberculate pear crab, and trailtip sea pen.

Mean species richness for all stations was 3.2 species per station (Table H-10). The regional mean Shannon-Wiener diversity index was 0.76 and evenness value was 0.69 for all stations and the mean dominance index was 1.8. Species richness was highest at North San Diego Bay Station 6138 and South-Central San Diego Bay Station 6093 with 6 species per trawl. Shannon-Wiener diversity, evenness, and dominance were all highest at South-Central San Diego Bay site 6093. Community metrics had values of 0 at Oceanside Harbor Station 6295 as no macroinvertebrates were collected at that station.

3.3.2.2 Cluster Analysis

Macroinvertebrate clustering was similar to fish clustering (Figure 3-39). The outer harbor and outer bay sites clustered together and the South San Diego Bay sites clustered together while the Mission Bay sites were mixed. Some site clustering was driven by a single species (e.g., spiny lobster and orange bay sponge), indicating that many of the sites supported relatively unique assemblages of macroinvertebrates.

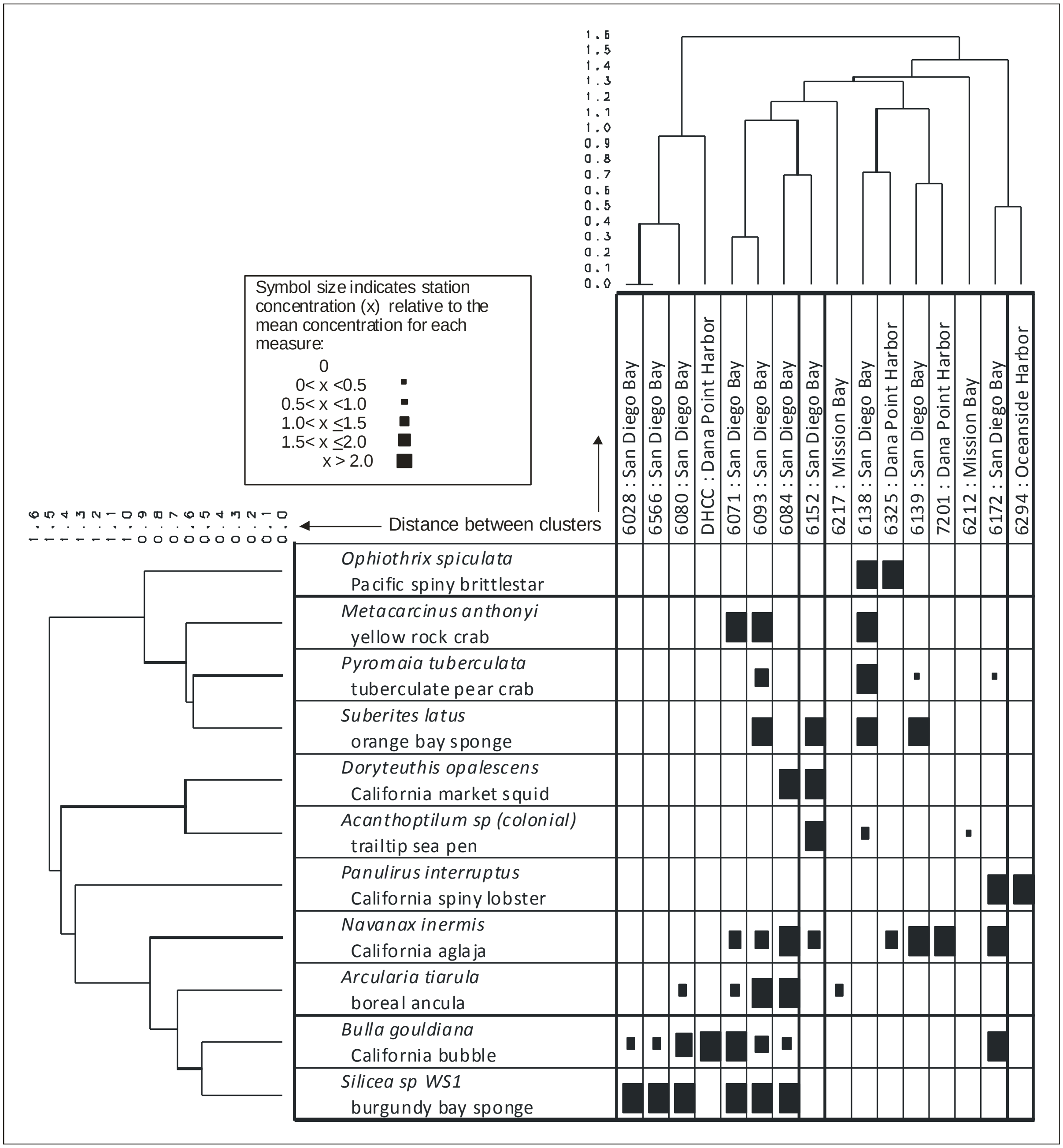


Figure 3-39. Cluster analysis of macroinvertebrate species and stations

3.3.2.3 Macroinvertebrate Health

There were no recorded incidents of health anomalies on the macroinvertebrates collected in the RHMP study as all collected specimens appeared to be in generally good health.

3.3.2.4 Historical Comparison

Table 3-22 presents summary data comparing the RHMP 2008 study with the southern region bays and harbor stations sampled in the Bight '98 and Bight '03 trawl surveys (Allen *et al*., 2002, Allen *et al*., 2007). The mean number of species per trawl was greater historically than in RHMP 2008, with seven species per trawl in Bight '98, six species per trawl in Bight '03, and three species per trawl in the RHMP 2008. Mean abundance per trawl was substantially higher in both of the prior Bight surveys, with a mean of 110 and 327 individuals per trawl compared with a mean of 28 individuals per trawl in the RHMP study. Mean biomass per trawl was 11.5 kg in Bight '98, 4.3 kg in Bight '03, and 4.1 kg in the RHMP.

Table 3-22. Comparison with Bight '98 and '03, southern region bays and harbors invertebrate summary data*

Species Diversity					
Program	No. of Stations	Total No. of Species	Range Per Trawl		Mean
			Min	Max	
Bight '98	21	49	1	18	7
Bight '03	9	29	0	14	6
RHMP '08	18	44	0	8	5
Abundance					
Program	No. of Stations	Total Abundance	Range Per Trawl		Mean
			Min	Max	
Bight '98	21	2379	4	772	110
Bight '03	9	2948	0	1950	327
RHMP '08	18	998	0	468	55
Biomass					
Program	No. of Stations	Total Biomass (kg)	Range Per Trawl (kg)		Mean (kg)
			Min	Max	
Bight '98	21	262.9	<0.1	125.4	11.5
Bight '03	9	39.0	0	20.6	4.3
RHMP '08	18	148.0	0	93.6	8.2

*All trawl data were standardized to 10 minute tow times as described in the Bight '98 and '03 reports

4.0 DISCUSSION

The results of RHMP 2008 are discussed in relation to the following five SDRWQCB 13225 questions:

1. What are the contributions and spatial distributions of inputs of pollutants?
2. Are the waters safe for human body contact?
3. Are the fish safe to eat?
4. Do the waters and sediments in the harbors support healthy biota?
5. What are the long-term trends in water quality?

In answering the first question relating to the contributions and spatial distributions of inputs of pollutants, concentrations of chemical indicators were compared among strata and among harbors. Assessments of the safety of the water for human body contact were based on indicator bacteria levels at the time of RHMP 2008. Assessments of the safety of fish for consumption will be assessed once data are available from the SWRCB bioaccumulation study. In order to determine whether the waters and sediments sustain healthy biota, a weight-of-evidence approach was used that combined the indirect lines of evidence (chemistry and toxicity) with the direct lines of evidence (benthic infauna and demersal fish and invertebrate communities). Lastly, determinations of long-term trends were based on comparisons of RHMP 2008 percentages of stations below threshold levels to historical percentages.

4.1 What are the Contributions and Spatial Distributions of Inputs of Pollutants?

Areas of the harbors most closely associated with human uses (i.e., the marina, industrial, and freshwater-influenced strata) tended to have higher chemical concentrations and greater exceedances of chemical thresholds in surface waters and sediments as compared to areas that were not closely associated with anthropogenic influences (deep and shallow strata). This was most notably the case for the marina stratum due to consistently high levels of copper both in the surface waters and sediments, as well as other metals (e.g., mercury and zinc) and organics in the sediments. The industrial stratum, which was located solely along the eastern shore of San Diego Bay, also had elevated concentrations of metals and organics in sediments, while the primary elevated contaminants in the freshwater-influenced stratum were pesticides (i.e., chlordanes and pyrethroids) as well as zinc.

4.1.1 Surface Waters

All chemical indicators in surface waters occurred at concentrations below CTR thresholds, with the exception of copper in marinas, indicating that most analytes, other than copper, were unlikely to result in toxic effects. Both dissolved and total copper concentrations exceeded thresholds throughout the majority of the marina stratum, indicating that marina surface waters may have toxic effects due to elevated copper concentrations. This finding is consistent with previous studies that have documented copper as a contaminant of concern in San Diego Bay marinas (McPherson and Peters, 1995; SDRWQCB, 2005) and the larger San Diego region (Schiff *et al*., 2006a). Since surface water copper levels generally were not elevated in any of the other strata, it appears that boating-related activities have a more detectable and persistent effect on copper concentrations in the harbors than do other inputs of pollutants (i.e., runoff and industrial inputs). Thus, elevated copper concentrations in surface waters appear to be most strongly related to the use of copper-based antifouling paints on boats. Areas with dense aggregations of vessels that occur in semi-enclosed portions of the harbors with reduced flushing tended to have the highest surface water copper concentrations. Consequently, many of these areas are 303(d) listed for copper, or in the case of SIYB have a Total Maximum Daily Load (TMDL).

Differences in the contributions and spatial distributions of inputs of pollutants were also apparent among harbors, with Mission Bay generally having the lowest surface water chemical concentrations. Copper and zinc surface water concentrations in Mission Bay were far below those of the two northern harbors while those of San Diego Bay were intermediate. Although there were often differences among the harbors, inputs of metals to surface waters were more closely associated with localized inputs of pollutants, specifically the presence of marinas, than any other spatial factor, since copper and zinc concentrations were consistently highest in the marina stratum for all four harbors.

In most instances, elevated concentrations for pollutants were more closely associated with a particular stratum rather than a specific harbor; however, PAHs appeared to be an exception. PAH levels were consistently higher in San Diego Bay than any of the other harbors. Within San Diego Bay, the lowest mean total PAH concentrations occurred within the marina stratum, while the highest were in the freshwater-influenced stratum. The most important sources of PAHs to RHMP waters are petroleum products and biproducts, as well as inputs from creosote pilings to a much lesser extent (Katz, 1998). The incomplete combustion of fossil fuels can result in the release of PAHs to the environment as can oil and gas spills (reviewed in Fairey *et al*., 1998). Within the San Diego Bay region, potential specific sources of PAHs include urban storm water discharges, groundwater flow from historical waste oil and drum disposal sites, shipping activities, and spills during fueling (reviewed in Fairey *et al*., 1998).

4.1.2 Sediments

The highest levels of sediment chemical exposure occurred in areas of the harbors associated with anthropogenic influences, most notably in the marina and industrial strata but also in the freshwater-influenced stratum. It was in these three strata that exceedances of ER-Ms primarily occurred and ER-L exceedances were most prevalent. Of the more than 100 analytes assessed, only copper, zinc, arsenic, mercury, total PCBs, total DDTs, and total chlordanes had average concentrations within strata or harbors that exceeded ER-Ls. Additionally, ER-M exceedances were only detected for copper, mercury, total chlordanes, total PCBs, and the PAHs anthracene and dibenz[a,h]anthracene. Therefore, the discussion of sediment chemistry primarily focuses on those analyltes with ER-M exceedances or with average concentrations for a given stratum or harbor in exceedance of ER-Ls. A brief summary of differences in inputs of pollutants among strata and harbors is provided, followed by a description of the chemicals of concern and their potential sources.

4.1.2.1 Differences among Strata

Differences in chemical exposure were readily apparent among the strata with the marina having the highest levels followed by the industrial and freshwater-influenced strata. The marina stratum had the greatest number of analytes with average concentrations above ER-Ls, including copper, zinc, arsenic, mercury, total PCBs, total DDTs, and total chlordanes. Marinas also had the greatest number of ER-M exceedances, indicating that adverse impacts to biota and habitat may be expected to be most pronounced in these areas as compared to all of the strata. The industrial stratum also had elevated levels, with average concentrations for copper, zinc, arsenic, mercury, and total PCBs above ER-Ls. The freshwater-influenced stratum had much lower metal concentrations than the marina and industrial strata; however, it had elevated levels of total chlordanes and zinc, with both indicators had average concentrations above ER-Ls. Additionally, pyrethroids only occurred at concentrations above detection limits within the freshwater-influenced stratum. In stark contrast to the three aforementioned strata, the deep and shallow strata were not closely associated with specific inputs of pollutants and, on average, had concentrations that were below established threshold levels for the majority of chemical indicators. This provides an indication that chemical exposure is more closely associated with specific inputs of pollution rather than larger spatial differences in contaminant exposure within the San Diego region.

4.1.2.2 Differences among Harbors

In assessing chemical exposure among harbors, there were several notable differences in chemical concentrations for specific analytes, although overall chemical exposure, as determined by the mean ER-M quotient, did not differ noticeably among harbors. Dana Point and Oceanside Harbors had average copper and zinc concentrations that exceeded the ambient threshold of 175 mg/kg for copper and the ER-L for zinc. Elevated copper and zinc concentrations appeared to be associated with boating activities since 55% of Oceanside Harbor and 41% of Dana Point Harbor were comprised of the marina stratum and concentrations tended to decline moving away from dense aggregations of vessels and toward the harbor mouths. Average total DDT levels were also highest in the two northern harbors, and it appears that the elevated levels at marina stations in these two harbors influenced the elevated average concentration within the marina stratum overall. Area-weighted average mercury concentrations also occurred well above the ER-L for Oceanside Harbor and San Diego Bay and were substantially higher than average concentrations in Dana Point Harbor and Mission Bay. Although, total PAH concentrations occurred at the highest levels in San Diego Bay, consistent with what was found in the surface waters, the average concentration in San Diego Bay is still below the ER-L. Lastly, the area-weighted average for total PCBs was approximately three times as high in Oceanside Harbor as in any other harbor. Therefore, based on inter-harbor comparisons, there appear to be differences in contaminant exposure among harbors; however, for the majority of indicators, the differences are most likely associated with localized inputs rather than larger-scale regional or inter-harbor differences, as described in the source analysis below.

4.1.2.3 Potential Sources of Chemicals of Concern

Chemicals of concern include those chemicals that exceeded sediment quality guideline ER-M thresholds or on average exceeded ER-L thresholds for an entire stratum or harbor.

Copper

Elevated copper levels were most evident in the marina stratum, where dense assemblages of vessels serve as sources of copper to the water column and the sediments. The widespread use of copper-based antifouling paints on boat hulls to reduce attachment and growth of fouling organisms has resulted in copper being the most common pollutant occurring at toxic levels in marinas nationwide (USEPA, 1993). Copper is released from hull paints into the water column by passive leaching and diffuses to the sediments where it can bind to sediment particles (Schiff *et al*., 2003a; Valkirs *et al*., 2003). Additionally, hull cleaning activities contribute particulates from paints that enter the sediments. It is for this reason that the two harbors with the greatest percentages of area comprised of marinas (i.e., Dana Point and Oceanside Harbor) had substantially elevated copper levels relative to Mission and San Diego Bays. The industrial stratum of San Diego Bay also had elevated copper levels, although concentrations were below the ambient threshold value. Copper-based paints of naval vessels also serve as one of the predominant sources of copper to the eastern shoreline of San Diego Bay between Chollas Creek and Sweetwater River (Katz, 1998). Additionally, inputs of copper from the larger watersheds (e.g., runoff and aerial deposition SDRWQCB, 2005) also serve as sources to RHMP harbors due to use of copper in brake pads, roofing materials, and gutters. As a consequence of the multiple sources of copper to harbors, the area-weighted average copper concentration for all areas of the harbors (76.4 µg/dry g) was far greater than levels commonly found in offshore sediments (6.6 µg/dry g) based on the Bight '03 inner shelf strata (Schiff *et al*., 2006b).

Zinc

Zinc largely had a similar distribution of elevated concentrations to copper, except that it also occurred at levels above the ER-L within the freshwater-influenced stratum. The highest levels of zinc concentrations, and inputs by inference to the water column and the sediments, like copper, were closely associated with boating activities. Zinc anodes are commonly used to prevent corrosion of motors and other metal parts on vessels, and zinc-based hull paints are also used on recreational vessels. In addition to boating, other sources of zinc within the larger watershed include tire, belt, and brake wear from automobiles. Consequently, zinc concentrations have been found to increase with proximity to roadways due to the inputs of aerial deposition and runoff (WESTON, 2009). As a potential consequence of the combined inputs of zinc from the watersheds and boating activities, the area-weighted-averge zinc concentration for the harbors was 135.0 µg/dry g, as compared to an average concentration of 34 µg/dry g in the sediments of the Bight inner shelf (Schiff *et al*., 2006).

Mercury

Mercury was the only analyte to have an average concentration that exceeded an ER-M. Although all strata had concentrations in excess of the ER-L, the highest levels were detected in the marina stratum followed by the industrial stratum. Previous studies have found elevated levels of mercury to be associated with marinas, areas near commercial shipping and naval operations, and in the vicinity of ship repair facilities in San Diego Bay (Fairey *et al*., 1998, Schiff *et al*., 2006b). Comparisons of mercury levels among harbors showed Oceanside Harbor and San Diego Bay to have the highest area-weighted average concentrations, which were at least three times greater than that of Dana Point Harbor and Mission Bay. This finding demonstrates that elevated levels of mercury may not always correlate with marinas and boating activities, and may be legacy issue in the sediments. This conclusion is further substantiated by the absence of elevated mercury levels in surface waters.

Chlordane

Elevated chlordane levels were most closely associated with areas subjected to freshwater influences, with ER-M exceedances occurring at the mouth of Chollas Creek, adjacent to a municipal separate storm sewer system (MS4) discharge in the marina stratum of SIYB, and at the mouth of Cudahy Creek in the shallow stratum of Mission Bay. Chlordane is an insecticide that was widely used until banned in 1983, and although it is no longer in use, it is reported to persist in soils and sediments for prolonged periods (Howard, 1990). Additionally, it was recognized as a chemical of concern in San Diego Bay and Mission Bay as a result of the BPTCP surveys conducted from 1992-1994 (Fairey *et al*., 1998). Similar to the findings of RHMP 2008, the BPTCP surveys encountered elevated chlordane concentrations in areas subjected to storm water runoff (i.e., at the northeastern portion of Mission Bay and at the mouths of storm drains, creeks, and rivers within San Diego Bay).

Arsenic

Arsenic inputs to embayments have been attributed to natural inputs as well as releases from paints, pesticides, wood preservatives, and brass. Arsenic was used as a wood preservative from the 1950s through 2004 in the form of chromate copper arsenate due to its toxicity to insects, bacteria, and fungi (Mandal and Suzuki, 2002). Arsenic occurred at concentrations that were on average slightly above the ER-L in the marina and industrial strata, as well as in Oceanside Harbor and Mission Bay, although in all instances arsenic concentrations were far below the ER-M and there were no significant differences among the strata or harbors. Additionally, the area-weighted-average arsenic concentration within RHMP harbors (6.95 µg/dry g), although elevated above that of the inner shelf of the Bight (4.2 µg/dry g), was not nearly as divergent as other metals, such as copper and zinc, that were closely associated with specific inputs of pollutants. Therefore, there was no evidence that a specific input of arsenic associated with a particular stratum or harbor was driving elevated concentrations in RHMP harbors.

Polychlorinated Biphenyls

Elevated levels of PCBs were particularly evident within the marina and industrial strata, as well as within Oceanside Harbor based on assessments of average levels. The highest concentrations of total PCBs were found in the industrial stratum within San Diego Bay, where two stations exceeded the ER-M. This finding is consistent with previous studies that have detected elevated PCBs both within the waters (Zeng *et al*., 2002) and sediments of central San Diego Bay (McCain *et al*., 1992). PCB contamination has largely been associated with industrial activities, specifically the production and refurbishing of electrical transformers and capacitors where PCBs have been used as cooling and insulating fluids. PCBs have also been incorporated into flexible PVC coatings for electrical wiring and components and have been used in hydraulic fluids. Based on known uses as well as the observed spatial distribution of PCBs, it appears that industrial in particular and boating activities secondarily serve as potential sources to RHMP sediments.

Polycyclic Aromatic Hydrocarbons

Elevated PAHs were most closely associated with the industrial stratum where average concentrations were nearly twice as high as the other strata, although they were on average below the ER-L. There were no ER-M exceedances for any single PAH or for total PAHs in the industrial stratum; rather, individual ER-M exceedances occurred for dibenz[a,h]anthracene within the marina stratum and anthracene within the deep stratum adjacent to Broadway Pier in San Diego Bay. These findings are consistent with the BPTCP survey, which also detected elevated PAH concentrations within the sediments adjacent to industrial areas within the central portion of San Diego Bay as well as within marinas (Fairey *et al*., 1998). The most important sources of PAHs to RHMP waters are petroleum products and biproducts. The incomplete combustion of fossil fuels can result in the release of PAHs to the environment as can oil and gas spills (reviewed in Fairey *et al*., 1998).

DDTs

DDT concentrations were found to be elevated both within the marina stratum, as well as most notably in Dana Point and Oceanside Harbors. The primary forms of DDT detected were 4,4'-DDE and DDD, respectively, which are two derivatives of DDT that are broken down in the environment. The primary source of DDT to the Southern California Bight originated from the Montrose Chemical Corporation in Torrance, CA, which manufactured DDT from 1943 to 1971 (Chartrand, 1988). During that period, DDT was disposed of into the sewer system and consequently entered the ocean environment at the White's Point outfall. The decrease in DDT concentrations from northern to southern RHMP harbors is consistent with a larger regional trend of decreasing DDT concentrations away from the Palos Verdes Shelf (Schiff *et al*., 2006b). However, since offshore waters from Dana Point to the Mexican border tend to have concentrations below 0.073 ng/L in the water column as compared to 2.6 ng/L in Santa Monica Bay (Zeng et al. 2005) it is more likely that observed elevated levels of DDT in northern harbors were more indicative of past agricultural land uses. In either case, current inputs of DDT to RHMP harbors are likely rare, as levels in the sediments are reflective of past rather than present inputs.

4.2 Are the Waters Safe for Human Body Contact Activities?

The primary indicator of the safety of the RHMP waters for human body contact was indicator bacterial levels. Indicator bacteria levels were consistently well below AB411 standards for total and fecal coliforms and Enterococci, with the vast majority of the stations having bacterial levels that were below detection limits (96% of stations for Enterococci, 75% for total coliforms, and 92% for fecal coliforms). Consistently low bacteria levels were observed across all strata, indicating that bacteria are not likely to occur at elevated levels throughout most areas of the harbors during summer months when rain events are extremely rare. This finding was consistent with the results of the RHMP Pilot Project, which did not detect a single Enterococci exceedance in the marina or freshwater-influenced strata for surveys conducted in August from 2005-2007. However, on-going monitoring programs that collect water samples along shorelines within the harbors periodically detect bacterial levels in excess of REC-1 water quality objectives within Dana Point Harbor, Mission Bay, and San Diego Bay, suggesting that exceedances are largely episodic.

Bacterial TMDLs are being enacted for Baby Beach in Dana Point Harbor, Tecolote Creek in Mission Bay, and Shelter Island Shoreline Park and Chollas Creek in San Diego Bay due to exceedances of indicator bacteria water quality objectives for REC-1 beneficial uses during both wet and dry weather periods (SDRWQCB, 2009a and 2009b). According to the TMDL Technical Reports, potential sources of bacteria include point and non-point sources of both anthropogenic and natural origins. Elevated bacterial levels tend to be attributed to runoff, which characterizes the freshwater-influenced stratum, including the mouths of Chollas and Tecolote

Creeks and MS4 discharges. Indicator bacteria also occur at elevated levels along sandy beaches where birds congregate and defecate (e.g., Baby Beach and Shelter Island Shoreline Park), as well as areas exposed to discharges of sewage from vessels and treatment facilities. Although the RHMP 2008 study design was able to provide a region-wide assessment of bacterial levels within the harbors during a period of dry weather, assessments of indicator bacterial levels within the harbors may be better achieved through targeted monitoring programs that perform repeated sampling through time in order to assess seasonal variability.

4.3 Are the Fish Safe to Eat?

Assessments of the safety of fish for human consumption were performed as a component of the SWRCB SWAMP statewide bioaccumulation study, with field work completed in the summer of 2009 and analytical chemistry currently underway as of the time of reporting. The purpose of this study was to quantify regional fish tissue contamination in the Bight, focusing on areas where fishing primarily occurs, the species that are commonly consumed, and the tissues that are consumed by humans (SCCWRP, 2009). Within the RHMP harbors, sampling was performed at the Dana Point Harbor Fishing Pier; the Oceanside Harbor Small Craft Fishing Pier; one site in Mission Bay; and at Shelter Island Fishing Pier, Tuna Harbor Park Pier, Embarcadero Marina Park Pier, Pepper Park Pier, and Bayside Park Pier in San Diego Bay. Tissue samples are in the process of being analyzed for PCB congeners, DDT isomers and metabolites, toxaphene, chlordane, and mercury. This study will help determine areas of the Bight where fish are safe to eat, and other areas where advisories may be required.

4.4 Do the Waters and Sediments in the Harbors Support Healthy Biota?

The majority of the area within the RHMP harbors was found to be supportive of healthy biota based upon a weight-of-evidence approach that combines physical, chemical, and toxicological LOEs with biotic LOE. Surface water chemistry and physical water quality parameters were largely supportive of healthy biota since all chemical indicators other than copper occurred at concentrations below thresholds for toxic effects and physical water quality parameters were well within the normal range for embayments, with the exception of decreasing DO levels and transmissivity within marinas at greater depths. Additionally, sediment chemistry concentrations were largely protective of healthy biota, since 77% of stations did not exceed a single ER-M for any analyte, 52% of stations had mean ER-M quotient scores below the 0.2 conservative threshold for toxic effects, and 64% of stations (i.e., 75% of the total area of the harbors) were classified as either unimpacted or likely unimpacted by the SQO assessment.

Assessments of toxicity provided even stronger evidence that the vast majority of the area within the RHMP harbors was protective of healthy biota, since 96% of stations were determined to be nontoxic according to the acute amphipod test and 85% were nontoxic according to the chronic mussel fertilization and development test. In accordance, 92% of the RHMP 2008 stations (i.e., 98% of the total areas of the harbors) were classified as either nontoxic or as having low toxicity according to the SQO toxicity LOE.

Consistent with the sediment chemistry and toxicity LOEs, the biota of the RHMP harbors occurred at abundances and diversities indicative of healthy communities. The vast majority (75%) of the benthic infaunal communities assessed was classified as reference condition according to the BRI, and 72% of stations (i.e., 88% of the total area of the harbors) were determined to have conditions consistent with reference or low disturbance according to the benthic SQO LOE. Additionally, the demersal fish and invertebrate community was comprised of diversities and abundances of species that were consistent with prior Bight studies, and these species were largely devoid of obvious lesions, tumors, or deformities that may be indicative of high levels of pollution. Therefore, both indirect (chemistry and toxicity) and direct (benthic infaunal and demersal communities) provide evidence that overall harbor conditions support healthy biota, although differences among strata and harbors were evident, as discussed as follows.

4.4.1 Assessments of Strata

Areas immediately associated with anthropogenic disturbance and inputs of pollutants tended to have conditions that were less supportive of healthy biota. This was most notably the case for the marina stratum, but it was also apparent to a lesser extent in the industrial and freshwater-influenced strata. Within the marina stratum, surface water dissolved copper concentrations and DO levels exceeded established thresholds for adverse biological effects, since low DO levels (i.e., below the 0.5 Basin Plan threshold) have the potential to adversely impact less mobile benthic and demersal species. Reductions in DO are likely due to the discharge of organics from vessels in low-flow areas, since the breakdown of organics depletes oxygen levels in sediments and overlying waters (Milliken and Lee, 1991). Additionally, transmissivity (i.e., levels of light penetration) in the marina stratum declined at approximately double the rate with depth as compared to the other strata, also increasing the potential for adverse biological effects. Reductions in light have the potential to limit the abundance of primary producers, such as eelgrass and algae, as well as animals that depend on these resources for food and habitat. Likely causes of increased turbidity include resuspension of sediments due to propeller-induced disturbance (Paulson and Da Costa, 1991), discharges from vessels, and eutrophication (i.e., the buildup of organic matter in the water column).

Sediment conditions were also less supportive of healthy biota within the marina stratum, with only 31% of marina stations classified as unimpacted or likely unimpacted due to higher levels of chemical exposure, higher toxicity, and higher benthic infaunal community disturbance. Within the industrial and freshwater-influenced strata, physical and chemical water column conditions were protective of healthy biota; however, 60% of the industrial stations and 73% of the freshwater-influenced stations were determined to be unimpacted or likely unimpacted according to the SQO final assessment as compared to approximately 80% in the deep and shallow strata. Similar to the marina stratum, the industrial stratum had a high proportion of stations with moderate to high chemical exposure (80%) and moderate toxicity (20%), while the benthic community condition was much less disturbed, with only 13% of stations classified as moderately disturbed and none as highly disturbed. The freshwater-influenced stratum had the highest percentage of stations with benthic communities classified as moderately disturbed (53%), while chemical exposure levels tended to be intermediate between the marina/industrial strata and the deep/shallow strata. Toxicity was also low in the freshwater-influenced strata, with 87% of stations classified as nontoxic and all other stations as having low toxicity. Therefore, the decreased capacities of the marina and industrial strata to support healthy biota appeared to be most closely associated with chemical exposure and toxicity, while the diminished health of the freshwater-influenced benthic infaunal communities may have been more closely related to disturbance and seasonal changes in physical water quality parameters, such as salinity during storm events. After all, benthic community measures are indicators of overall community health in response to both natural and anthropogenic disturbance and therefore may or may not be closely associated with inputs of pollutants and toxicity (Smith *et al.*, 2003).

4.4.2 Assessments of Harbors

Each of the harbors was found to have differing capacities to support healthy biota. Dana Point and Oceanside Harbors (i.e., the two harbors predominantly comprised of the marina stratum) tended to have higher levels of chemical exposure both within the sediments and water column, and consequently had the lowest percentages of stations determined to be unimpacted or likely unimpacted based on the SQO final assessments. San Diego Bay, with its exposure to both marina and industrial activities, also had elevated chemical exposure within these areas, while overall 63% of the bay was determined to be unimpacted or likely unimpacted based on the SQO final assessment. Consistent with the other harbors, Mission Bay also experienced the highest levels of chemical exposure within the marina stratum; however, its overall sediment and water quality conditions were most supportive of healthy biota, with all stations classified as unimpacted according to the SQO final assessment. Although Mission Bay had the least impacted sediment condition of the harbors, overall sediment and water quality conditions were not closely associated with demersal fish and invertebrate community health. For example, mean fish abundance was highest in Oceanside Harbor and mean fish biomass was highest in San Diego Bay, while abundance and biomass of fish within Mission Bay trawls were substantially lower than the other harbors. Additionally, macroinvertebrate abundance and biomass was highest in San Diego Bay, while those of all the other harbors were only a small fraction of San Diego Bay. Based on these findings, sediment quality within the harbors appears to be closely associated with localized disturbances and inputs of pollutants, while demersal community abundance and diversity appear to be driven by a wider array of factors (e.g., human collection, habitat heterogeneity, and harbor size) that extend beyond localized inputs of pollutants within harbors.

4.5 What are the Long-term Trends in Water Quality?

RHMP-wide conditions are improving over time based on comparisons of MLOE, including surface water chemistry, sediment chemistry, sediment toxicity, and benthic infaunal community health (derived from multiple studies over an 11-year time period, as shown in Table 2-2) and the current RHMP 2008 conditions. Of the 23 primary and secondary indicators assessed for changes from historical conditions, 13 of the indicators showed significant improvement over historical conditions (i.e., higher percentages of RHMP 2008 stations across all areas of the harbors did not exceed thresholds for adverse effects or degraded conditions as compared to the historical percentages using the binomial test). Additionally, not a single indicator provided evidence of significant degradation from historical conditions. While this trend was apparent for RHMP-wide conditions, it is important to note that not all areas of the harbors (e.g., the marina stratum) showed improvement over time, nor were improvements with time as evident when assessing the subset of stations revisited from prior Bight studies. As a consequence, there were still a number of stations and strata that had conditions that exceeded thresholds, as discussed in prior sections.

4.5.1 Surface Water Quality Trends

The overall trend for surface water quality conditions appeared to be positive since most analytes currently occur at levels below thresholds for adverse effects. Of all the physical, chemical, and microbiological indicators assessed, copper and DO were the only two to exceed water quality thresholds, and these exceedances were largely relegated to the marina stratum. All other water quality parameters did not exceed thresholds across all areas of the harbors, which in the case of the other indicator metals (nickel and zinc) were consistent with historical conditions. Further evidence of sustained improvement of water quality extends to concentrations of total PAHs, specifically within San Diego Bay. The replacement of creosote pilings along with changes in ballast water discharge practices at naval facilities in San Diego Bay have resulted in a sustained decrease in surface water total PAH concentrations from the 1990s with averages declining from 623.9 ng/L based on surveys conducted from 1990-1994 to 91.4 ng/L in 1997 (Katz, 1998) to 32.4 ng/L in RHMP 2008.

RHMP-wide exposure to total and dissolved copper concentrations has significantly improved over historical conditions since there were 21% more stations below thresholds in RHMP 2008 than in the historical dataset. However, this finding is tempered by the fact that area-weighted average dissolved copper concentrations for San Diego Bay, Oceanside Harbor, and Dana Point Harbor, while below the acute threshold of 4.8 µg/L, still exceeded the chronic threshold of 3.1 µg/L. For San Diego Bay, this finding is consistent with a prior naval study that detected dissolved copper levels in the bay to be on average 3.6 µg/L in 1997 (Katz, 1998) as compared to 3.5 µg/L in RHMP 2008. Additionally, copper levels in marinas do not appear to be improving since the current average concentration was determined to be 6.9 µg/L, which is well above threshold levels. The lack of improvement in dissolved copper levels, specifically within marinas, is not unexpected since copper-based antifouling paints are widely used across recreational vessels, contributing approximately 80% of the loading of copper to the water column in San Diego Bay (Valkirs *et al*., 1994), and transitions to alternative coatings are just getting underway.

4.5.2 Sediment Chemistry Trends

RHMP-wide sediment conditions have significantly improved over historical conditions. Of the 13 sediment chemistry indicators assessed for changes from historical conditions, eight showed significant improvements, while none of the indicators significantly declined, including metals (cadmium, chromium, copper, lead, and nickel) and organics (total PAHs, total DDTs, and total PCBs). However, comparisons of chemical exposure at stations revisited from prior Bight ’98 and ’03 surveys did not provide evidence of such a pronounced improvement in sediment chemistry concentrations, since most indicator concentrations were unchanged. Although there were differences in the findings of the two approaches to assessing temporal changes in sediment condition, both assessments provide evidence that conditions in the RHMP harbors are clearly not degrading from past conditions.

Within the San Diego region alone, the RHMP harbors have been subjected to a wide range of anthropogenic modifications and inputs of pollution over the decades ranging from discharge of sewage, industrial wastes, and storm water runoff, among others (reviewed by Katz, 1998). Due to the requirements for monitoring and pollution control instituted in the 1970s, programs have been developed to limit inputs of pollutants to the region's embayments, resulting in improved conditions within the bay (reviewed by Fairey *et al*. 1998). In recent years, even more efforts have been made to further reduce inputs of pollutants to the RHMP harbors through education, source control, and regional watershed management. Thus, the finding of improved conditions within RHMP harbor sediments for a number of analytes appears to be consistent with this multi-decadal trend of reduced pollution, providing evidence for the efficacy of regional pollution control efforts in improving conditions in RHMP harbors. This finding in no way diminishes the need for further efforts to reduce ongoing inputs of pollutants, since the RHMP harbors still have higher concentrations of chemicals compared to surrounding offshore waters (Schiff *et al*., 2006b). Rather, it supports the need for targeted approaches to reduce inputs of specific contaminants of concern (e.g., copper and mercury) in specific areas of the harbors, such as the marina and industrial strata, as well as through targeted reduction programs throughout watersheds.

4.5.3 Sediment Toxicity Trends

Sediment toxicity also significantly improved over historical conditions, with 96% of RHMP 2008 stations considered to be nontoxic as compared to 55% of the historical stations based on *E. estuarius* SP acute toxicity tests. This finding was corroborated by assessments of Bight '98 and '03 revisited stations, since acute toxicity levels were significantly lower in 2008 compared to the prior surveys. Moreover, this trend was consistent across all areas of the harbors, since at least 93% of each stratum, including the marina, industrial, and freshwater-influenced areas, did not exceed the acute toxicity threshold. *M. galloprovincialis* SWI chronic toxicity tests results were also consistent with the finding of low toxicity across all harbors, with 84% of stations considered to be nontoxic. Given the relatively low levels of toxicity throughout the harbors, it appears that exceedances of ER-Ms provides a better indication of potential toxic effects within RHMP harbors than do exceedances of the ER-Ls (Long *et al*., 1995). Additionally, the findings also indicate that a mean ER-M quotient threshold of 0.2 for adverse biological and toxic effects may be too low for the RHMP harbors. The more commonly used threshold of 0.5 for moderate toxic effects (Schiff *et al*., 2006b) appears to be a better predictor of toxicity, since 93% of RHMP 2008 stations were below the 0.5 mean ER-M quotient threshold consistent with observed levels of toxicity.

4.5.4 Benthic Infaunal Community Trends

Consistent with the chemistry and toxicity lines of evidence, benthic community condition, as measured by the BRI and Shannon Wiener diversity index, has significantly improved over historical conditions, with 75% of all RHMP 2008 stations having BRI scores indicative of a reference condition as compared to 55% for the historical dataset. Additionally, assessments of stations revisited from prior Bight surveys also provided evidence that benthic communities are either slightly improving or are remaining at reference conditions on average. The only stratum that did not follow this larger RHMP-wide trend was the marina stratum, since only 44% of that stratum had reference communities. The marina stratum, which had the greatest number of ER-M exceedances, also had the highest level of disturbance in infaunal communities.

4.5.5 Demersal Community Trends

The demersal community health appears to have remained relatively constant over the past 10 years, based on comparisons with prior Bight '98 and '03 surveys. The fish communities sampled in RHMP 2008 were largely similar to those of prior Bight surveys in terms of the mean number of fish caught per trawl and mean biomass per trawl, and the lack of visible abnormalities, while mean abundance per trawl was slightly lower. One notable difference in fish communities between the 2008 survey and prior surveys is that approximately twice as many fish species were caught in the current survey as in the two prior surveys, which again provides strong evidence of the harbors' capacity to sustain healthy fish assemblages. Similar to the fish, the demersal macroinvertebrates collected appeared healthy based on the absence of abnormalities or obvious disease; however, diversity, abundance, and biomass of invertebrates collected in 2008 were all lower than in prior Bight surveys. Based on this evidence alone, it is yet unclear if there is a trend of decreasing invertebrate diversity or biomass or if differences are due to natural inter-annual variability. However, in regards to the demersal fish community there is further evidence of long-term sustained and possibly improved health of Bight species, since the current study is well aligned with the long-term trend of decreasing incidences of fish diseases and anomalies in the Bight since the 1970's when Mearns and Sherwood (1977) reported an anomaly incidence of 5% (Allen *et al*., 2007) as compared to an incidence of anomalies of 0.6% in RHMP 2008.

4.6 Focused Special Studies

Focused special studies are used to further investigate and identify sources of pollutants and impacts of pollutants on water quality and aquatic resources. Unlike core monitoring, which uses a stratified random study design to make inferences about strata-wide or harbor-wide conditions, focused special studies target areas with known or suspected pollutant inputs or impaired water quality (e.g., SIYB in San Diego Bay). The focused monitoring program is directed at the following areas noted by the SDRWQCB in their July 24, 2003 request:

1. Areas subject to significant waste loading.
2. Areas influenced by significant land or water use patterns (such as industrial, marina, or port).
3. Areas identified as impaired pursuant to federal Clean Water Act Section 303(d).

Based on the results of RHMP 2008, the 2005-2007 Pilot Project, as well as numerous previous studies in the region (e.g., McPherson and Peters, 1995; SDRWQCB, 2005; Schiff *et al*., 2006a), copper was found to be a contaminant of concern primarily within the marina stratum. Sediment copper concentrations frequently exceeded the ER-L throughout all strata and the ER-M thresholds primarily within the marina stratum. Additionally, dissolved and total copper concentrations exceeded acute CTR thresholds within the marina stratum. Due to the known adverse effects of copper to marine organisms, focused special studies are proposed to (1) assess the extent of copper contamination within marinas and the potential for adverse effects, (2) identify causes of toxicity through toxicity identification evaluations (TIEs) in sediment and overlying water tests, (3) conduct water effect ratio (WER) studies to determine the bioavailability and toxicity of copper and support the development of site-specific water quality objectives (SSOs), and (4) use laboratory and field studies to determine whether marina sediments with elevated copper levels serve as sources or sinks for dissolved copper as copper concentrations in the overlying water decrease.

4.6.1 Extent of Copper Contamination within Marinas – 2009

The first special study to be conducted in 2009 and 2010 involves (1) a literature review to assess the extent of copper contamination within marinas, a review of sources, flux, and reported levels of toxicity and (2) analysis of predicted levels of toxicity using the Biotic Ligand Model (BLM). This study will provide the basis for subsequent special studies. Additionally, it will help assess the first component of SDRWQCB Question 1, "What are the contributions and spatial distributions of inputs of pollutants to harbors in the San Diego Region?" and Question 4, "Do the waters and sediments in the harbors sustain healthy biota?"

4.6.1.1 Literature Review

The first recommended special study involves a review of the existing literature and data to assess the extent of copper contamination within the RHMP harbors, specifically focusing on the marina stratum. This comprehensive literature review will include an assessment of sediment and surface water concentrations, copper loading, observed toxicity, and physical conditions within marinas that may affect copper bioavailability. Specifically, this task will include a review of the primary peer-reviewed literature as well as key regional reports. As a component of the review, existing RHMP surface water data will be analyzed using the BLM to determine copper bioavailability based on physical water-column conditions.

4.6.1.2 Biotic Ligand Model

The marine BLM is a framework for predicting metal speciation, complexation, and toxicity to aquatic organisms using site-specific water characteristics, i.e., pH, dissolved DOC, salinity, and total metal concentration (e.g., copper). The model takes into account water chemistry factors to determine the projected level of toxicity for a particular metal as measured by the metal's binding affinity to a biotic ligand (for example, the gills of an aquatic organism) (Niyogi and Wood, 2004). The copper BLM can be used to calculate EC_{50} values and predict SSOs for specific areas of the harbors.

Copper exists in multiple chemical forms depending on the physical conditions of the waters and sediments in which it occurs, including pH, alkalinity, and organic compounds; and the bioavailability and toxicity of copper is dependent on the form in which it occurs (i.e., elemental copper, copper ions, copper complexes with carbonates, chlorides, organically-bound copper, etc.). The most bioavailable forms of copper include inorganic or ionic forms of dissolved copper, which decrease in abundance, bioavailability, and toxicity with higher alkalinity, organic carbon, and dissolved and particulate organic matter.

To assess potential adverse effects of copper as determined by quantified physical surface water conditions, a marine BLM for copper will be used. HydroQual, Inc. (HydroQual) has developed a marine copper BLM that is under review by USEPA. This model was calibrated using toxicity data for *M. galloprovincialis* (Mediterranean mussel), *Strongylocentrotus purpuratus* (purple sea urchin), *Crassostrea gigas* (oyster), *Crassostrea virginica* (oyster), and *Dendraster excentricus* (sand dollar). Much of the data came from San Diego Bay provided by the U.S. Navy Space and

Naval Warfare Systems (SPAWAR). In accordance, the HydroQual copper BLM model is highly relevant to the RHMP harbors, and it has the potential to provide more realistic assessments of potential adverse effects of copper than CTR thresholds alone. By using site-specific water quality data, LC_{50} and EC_{50} values can be used to calculate site-specific WERs, which in turn can be used to estimate SSOs.

4.6.2 Toxicity Identification Evaluations – 2010

Water and sediment TIEs are recommended to identify the causes of toxicity within marinas. At stations where sediment and/or surface water toxicity are found to occur within marinas, TIEs will be used to experimentally examine the constituents likely to cause toxic effects. Typically, TIEs consist of several tiers of testing. Tier I involves procedures designed to provide general information for identifying the class of the toxic constituents within samples based on their chemical and/or physical characteristics (e.g., volatility, ionization state, degree of adsorption to particulates, polarity, oxidative state, pH sensitivity, and interaction with synergistic and antagonistic compounds). Classification characteristics are examined by comparing the results of toxicity tests conducted on un-manipulated samples to tests on samples that have been physically or chemically adjusted. Additional tiers of TIEs involve further manipulations and associated chemical analyses of samples to identify specific toxicants that are potential causative agents of toxicity. The 2010 special study will help determine the causes of toxicity within RHMP marinas, including copper and other cationic metals, and set the basis for follow-on WER study to be conducted in 2011. Additionally, it will help assess SDRWQCB Question 4: Do the waters and sediments in the harbors sustain healthy biota?

4.6.2.1 Initial Toxicity Determinations

For the assessment of surface water toxicity, grab samples will be collected from sites within SIYB and other marinas where toxicity was measured in previous studies. Bioassay tests will be performed with larvae of *M. galloprovincialis* (48-hr chronic toxicity – bivalve development test; ASTM E724-98 [ASTM, 2006b]) using water samples to verify that toxicity is persistent at these locations. If significant toxicity is observed, TIEs will be initiated within 2 weeks of confirmatory testing.

SWI TIEs will be conducted in accordance with USEPA guidance documents (USEPA, 1991 and 2007), using a phased approach. The first phase will involve the collection of water and sediment from two to four targeted areas within SIYB as well as other RHMP harbor marinas, which will be selected based on the aforementioned literature review. Confirmatory toxicity testing will be conducted using the mussel *M. galloprovincialis.*

For the assessment of sediment toxicity, Van Veen grab samples will be collected from stations within SIYB and other marinas where toxicity was measured during the 2008 RHMP (e.g., Dana Point Harbor and SIYB). Bioassay tests will be performed with larvae of *M. galloprovincialis*. Specifically, this 48-hr chronic toxicity bivalve development test will be conducted in accordance with ASTM E724-98 (ASTM, 2006b) using modifications associated with the SWI test (Anderson *et al*., 2001; SCCWRP, 2008d).

4.6.2.2 Toxicity Identification Evaluation Phase I Treatments

A full suite of TIE treatments (including several tests targeted at copper and other metals) will be used to evaluate the potential causative agents of toxicity in surface water and sediment from SIYB and other marinas/harbors (Table 4-1). Depending on the results of the first tier of TIE tests, additional studies may be conducted to confirm the identity of the causative agent(s). Pore water TIEs will be conducted to provide supplemental and confirmatory data in support of sediment TIE results. Chemical analyses of water or sediment extracts will also be used to verify TIE test results, and confirm the causative agent(s) of toxicity, when appropriate.

Table 4-1. TIE tier I treatments

Tier I Treatment	Matrix Tested	Purpose
Filtration	surface water, pore water	Detects filterable compounds (e.g., total suspended solids [TSS])
Aeration	surface water, pore water	Detects volatile, oxidizable, sublatable, or spargeable compounds
Graduated pH Adjustment	surface water, pore water	Detects pH dependent chemicals (e.g., ammonia and sulfides)
Ethylenediaminetetraacetic Acid (EDTA) Addition	surface water, pore water	Detects cationic metals (e.g., copper)
Sodium Thiosulfate (STS) Addition	surface water, pore water	Detects oxidative compounds (e.g., chlorine)
Solid Phase Extraction (SPE) over C_{18} Column, followed by Methanol Elution	surface water, pore water	Detects non-polar organics and some surfactants
Cation-Exchange Column, followed by Acid Extraction	surface water, pore water	Detects cationic metals (e.g., copper)
Piperonyl Butoxide (PBO) Addition	surface water, pore water, sediment	Detects organophosphate pesticides and pyrethroids
Carboxyl Esterase Addition	surface water, pore water, sediment	Detects pyrethroids
Temperature Reduction	sediment	Detects pyrethroids
SIR 300 Resin Beads	sediment	Detects cationic metals
Coconut Charcoal	sediment	Detects organic contaminants
Zeolite and/or *Ulva lactuca*	sediment	Detects unionized ammonia

4.6.3 Water Effect Ratios – 2011

A WER study is recommended to evaluate the relevance of regional water quality objectives (e.g., CTR thresholds) to a specific site based on the physical properties of the water at that site. Specifically, a WER study is warranted when previous studies at a site have indicated that there is a discontinuity between water quality objectives and observed toxicity. A WER may be useful when there are exceedances of water quality objectives in specific areas that have no (or inconsistent) corresponding toxicity, as determined by toxicity tests with the most sensitive test organisms. The results of this study will help answer SDRWQCB Question 4.

Because water quality objectives were developed based on laboratory studies in which filtered seawater was used, they do not account for many of the physical constituents that may interfere with the toxicity of potential chemicals of concern, such as copper. Rivera-Duarte *et al*. (2005) demonstrated that the bioavailability and toxicity of free copper ions within San Diego Bay was dependent upon the concentration of particulate and dissolved organic matter. Furthermore, Rosen *et al*. (2005) measured dissolved and total copper concentrations, particulate and dissolved organic matter, and toxicity using both the mussel *M. galloprovincialis* and the sea urchin *S. purpuratus* at numerous stations within San Diego. Their estimates of copper WERs for the whole bay ranged from 1.54 to 1.67, indicating that the copper CTR threshold may not be a relevant predictor of toxicity for San Diego Bay. Based on these studies and results of RHMP 2008, a WER is recommended for SIYB, since it is the only marina in the RHMP harbors to have a TMDL for dissolved copper. Additionally, the SIYB TMDL Technical Report indicates that a WER study may be appropriate for establishing an SSO for the basin (p. 63; SDRWQCB, 2005).

4.6.3.1 WER Phase I

To determine whether an SSO may be applied to SIYB, as well other marinas within the RHMP harbors, a WER study will be initiated using a phased approach. The first phase of the study will involve the collection of water from two specific areas within the marina for preliminary toxicity testing using two highly sensitive marine species – the 48-hour mussel (*M. galloprovincialis*) development test and the sea urchin (*S. purpuratus*) fertilization test. The results of initial testing are critical to the development of the WER experimental design because the WER cannot be conducted on samples that demonstrate significant toxicity. Results of this phase will provide an indication of the most appropriate location for the collection of water for use in the WER study (i.e., a location in which there is no toxicity, but is representative of typical concentrations of physical constituents). Phase I will also include a preliminary copper spiking study or range-finding test for each test species. Results of these efforts will allow the use of a more precise range of concentrations for the next phase of toxicity tests, which will determine the EC_{50}s and associated WERs for each test species.

4.6.3.2 WER Phase II

Phase II of the WER study will involve the collection of water samples at two flow regimes (ebb and flood tide) at one station in SIYB (the location of which will be determined in phase 1) for testing of copper-spiked SIYB seawater using *M. galloprovincialis* and the *S. purpuratus*. Chemical analysis will include the full suite of metals and general chemistry measures for one water sample collected at each event, and dissolved and total copper concentrations for all concentrations used in all bioassay tests conducted. All bioassay tests conducted as part of this WER study will be performed in accordance with USEPA WER guidance (USEPA, 1994b). Results of the copper spiking tests at each event for each species' EC_{50}s will be compared to the EC_{50} for copper in filtered seawater collected from a reference site. Based on test results, a WER will be calculated for each test species and event. Determination of the final WER will be dependent on the results of the most sensitive test, from which an SSO will be calculated.

The results of the SIYB WER study will be presented in a final report that analyzes and presents the data and findings in a manner that is consistent with USEPA WER guidance (USEPA, 1994b). Additionally, the report will compare the findings of the WER to the predictions of the BLM for SIYB to estimate the reliability of the BLM in predicting SSOs and EC_{50}s to begin to assess the applicability of future WER studies for other marinas throughout the four harbors and bays.

4.6.4 Sediment Copper Flux – 2012

The fourth proposed special study will involve laboratory and field studies to assess the potential for copper-laden sediments within marinas to serve as a net source or sink of copper into and out of the water column depending on the concentration of copper within the overlying water. Performing laboratory and field copper flux studies will be crucial to understanding and predicting the effectiveness of converting vessel hull paints from copper-based to non-copper-based products as a means of reducing dissolved copper concentrations in the water column to below threshold levels. Although sediments in the region's marinas appear to be serving as a sink for copper at current water column concentrations, it has yet to be tested if reductions in water column copper concentrations to levels approaching the CTR threshold will shift sediments from a net sink to a source. Such a study will greatly increase understanding of the efforts required to reduce copper concentrations within the water column, and in the case of SIYB meet TMDL objectives. The sediment flux focused special study will help assess the potential for copper-rich marina sediments to serve as a source or sink for copper under varying environmental conditions, and in so doing help answer the first component of SDRWQCB Question 1.

4.6.4.1 Laboratory Experiment

A 30-day laboratory copper flux study will be conducted using sediment cores collected within SIYB, since it is a location that is representative of some of the highest sediment copper concentrations within RHMP marinas. Treatments will include exposing cores to four copper concentrations in overlying water (Control or below detection limit, 0.5 μg/L or just above the detection limit, 3.1 μg/L or equivalent to the chronic CTR threshold, and 4.8 μg/L or equivalent to the acute CTR threshold), with five replicate chambers per concentration. An example sediment core test chamber and the completed assemblies within a water bath are depicted in Figure 4-1.

All test chambers will be held at 17.6°C $\pm$ 1°C, for the duration of the experiment. This temperature should reflect the average temperature of water in San Diego Bay throughout the year (Valkirs *et al*., 2003). Photoperiodic cycles of 14 hours of light and 10 hours of dark will be used to represent average winter and summer conditions. Daily water quality measurements will be taken throughout the entire test period to accurately maintain test conditions.

At the end of the experiment, aliquots of the overlying water will be removed for analysis of dissolved copper, total copper, DOC, and other relevant physical parameters. The sediment core will be analyzed for total copper, TOC, grain size, and other physical parameters in sediment as well as dissolved copper and DOC in pore water.

Figure 4-1. Core setup (A) and experimental setup (B) for sediment copper flux study

4.6.4.2 Field Study

A field study will be performed to determine *in situ* flux of copper into and out of the sediments. Sediments have the potential to release copper back into the water column by two methods: diffusive flux of pore waters into the water column and resuspension of sediments within the water column, which can lead to desorption (reviewed in SDRWQCB, 2005). Based on the results of the literature review, as well as the RHMP Pilot Project and 2008 RHMP, study locations will be established where (1) sediment copper concentrations and overlying water copper concentrations are both high and (2) sediment copper concentrations are high and the overlying water copper concentrations are relatively low. This will allow for comparisons of copper flux between sites with relatively similar sediment copper concentrations but different overlying surface water copper concentrations. In doing so, we will attempt to answer the question, "Will marina sediments with elevated copper concentrations be likely to switch from being a net sink of copper when overlying water copper concentrations are high to a net source of copper when overlying water copper concentrations are low?" In assessing this question, we will be able to determine whether there will be a diminishing return on Best Management Practices (BMPs) that convert vessel hull paints from copper-based to non-copper-based products in marinas as overlying water copper concentrations decline. This would be hypothesized to occur in the event that the diffusion gradient from the water to the sediments reverses and sediments become a net source to copper. Additionally, this study will help validate the results of diffusive models.

Benthic flux chambers have been used for decades to evaluate the flux of metals at the sediment-water interface in both laboratory and field studies (Westerlund *et al*., 1986; Zago *et al*., 2000; Turetta *et al*., 2005; Point *et al*., 2007; Chapman *et al*., 2009). However, this method is highly labor intensive and costly because it involves the design and construction of benthic flux chambers and the subsequent deployment and operation of chambers by multiple SCUBA divers.

Each benthic chamber (n = 3) would be constructed with a surface area of 0.2 m^2, an internal volume ranging from 40 to 75 L, and will be equipped with a flow meter to ensure that water flow in each enclosure is held constant in order to maintain oxygen concentrations, pH and temperatures. The chambers will also be equipped with a probe to log *in situ* measurements of DO, pH, and temperature.

In recent years, a new technology called diffusive gel technology (DGT) has become readily available through the manufacturer, DGT Research Ltd. This technology also has been widely used in laboratory and field studies to evaluate time-integrated changes in metal concentrations in pore water, at the sediment-water interface or in the water column (Davison and Zhang, 1994; Zhang *et al*., 1995; Scaly *et al*., 2003; Larner *et al*., 2006; Camusso *et al*., 2006; Dunn *et al*., 2007; Roulier *et al*., 2008). A preliminary study will be performed in the laboratory to determine if the costs associated with the use of benthic flux chambers can be minimized by using the chambers in conjunction with DGT devices. Specifically, a laboratory validation study will be performed to evaluate whether the DGT method has sufficiently high sensitivity in measuring copper concentrations and flux to be comparable to the alternative method of taking grab samples. This study will involve spiking copper into filtered seawater at a range of environmentally realistic concentrations (e.g., 0.5 to 16 μg/L), placing DGT discs in solution for varying lengths of time, and extracting the discs in accordance with published methods (Davison and Zhang, 1994; Zhang *et al*., 1995) and the manufacturer. At predetermined intervals ranging from 6 to 168 hrs, DGT discs will be removed and analyzed using inductively coupled plasma mass spectrometry (ICP-MS). Results will be compared to direct measurements of copper in water of replicates without DGT discs. If the results indicate the sensitivity of the DGT device is sufficient to detect significant differences among environmentally realistic exposure concentrations, then the DGT method will be pursued for use in conjunction with benthic flux chambers for the field study. Alternatively, if no significant differences in copper uptake are found among treatments using the DGT devices, then the more sensitive method involving benthic flux chambers and frequent grab samples will be used in the field study. Both methods are briefly described below.

Benthic Flux Chambers

Benthic flux chambers will be used to assess copper flux at the sediment-water interface in accordance with Point *et al*. (2007). Three replicate benthic flux chambers will be placed at (1) a marina site with both elevated sediment and water copper concentrations and (2) three chambers will be placed at a site with elevated sediment copper concentration and lower copper concentration in the water column. To minimize disturbance of the sediments, SCUBA divers will be used to place chambers at the site and to periodically collect water samples from the chambers via sampling ports. Temperature, oxygen, and pH will be measured using attached YSI probes, and a flow meter attached to each chamber will be used to maintain constant levels of oxygen as described in detail by Point *et al*. (2007). These methods have been shown to reduce oxygen fluctuation and depletion, and to be suitable for maintaining *in situ* conditions and equilibriums similar to the surrounding waters. Benthic chambers will be deployed at each site for 2 to 6.5 hrs, during which time samples will be collected at consistent increments using polypropylene syringes (alternatively, pending the outcome of the laboratory validation study, DGT devices could be used to minimize constant diver-mandated sampling and cost of deployment and retrieval). All samples collected by divers will be analyzed for copper by ICP-

MS and the physico-chemical parameters described above. Calculation of copper flux will be determined from the following equation:

$$F = \frac{(C_f - C_i)V}{(T_f - T_i)A}$$

where (C_f - C_i) is the difference of concentration determined between the final and the initial samples, (T_f - T_i) is the total incubation time, between the final and the initial samples, V is the volume of water enclosed in the chamber and A is the surface area covered by the benthic chamber on the sediment surface. A positive flux signifies a transfer from the sediment to the water column, and the opposite trend is indicative of a negative flux.

DGT Method

To assess copper flux using the DGT method in conjunction with benthic flux chambers, DGT devices will be prepared as described by DGT Research Ltd (www.dgtresearch.com) and one disc will be placed in each of the three replicate benthic flux chambers at two or more sites within marinas (i.e., sites will be chosen because they demonstrate similarly elevated sediment copper concentrations but with varying copper water concentrations). Additional DGT discs will be deployed outside of chambers at the sediment water interface and suspended within the water column to provide an alternate assessment of the nature of copper flux over a broader spatial extent within marinas. DGT discs and benthic flux chambers will be deployed by SCUBA divers and left in place for 1 to 24 hrs (or the optimal duration determined in the laboratory validation study) at each location. At the time of deployment and retrieval, water temperature, pH, DO, and salinity will be measured *in situ*. In addition, one grab sample per location will be taken for additional analysis of physico-chemical parameters including dissolved organic carbon, total suspended particulates, ammonia, and dissolved sulfides. Upon collection, DGT devices will be analyzed for copper by ICP-MS. Calculation of the accumulated copper will be in accordance with the manufacturer and Davison and Zhang (1994). Results of this field study should provide confirmation of the results obtained in the laboratory experimental study.

5.0 CONCLUSION

The RHMP 2008 core monitoring program used a MLOE approach that integrated water and sediment quality assessments with biological community monitoring to effectively answer SDRWQCB §13225 questions regarding inputs of pollutants, the suitability of the harbor environment to support biota and human beneficial uses, and long-term trends in conditions. The results clearly demonstrated that the majority of the area within the harbors had sediment and water quality conditions that were supportive of biological resources and human uses. SQO assessments determined that 64% of RHMP stations and 74% of the harbor area (i.e., based on the area-weighted average) had unimpacted or likely unimpacted sediment conditions, and there were no exceedances of chemical water quality thresholds at 79% of stations. Bacterial levels also did not pose a threat to human health, since all indicator bacteria levels were below AB411 standards. Additionally, assessments of long-term trends showed that RHMP-wide conditions were improving over historical conditions, with 13 of 23 primary and secondary indicators showing significant improvement over historical conditions. However, areas associated with localized anthropogenic inputs of pollutants, most notably the marina stratum and also the industrial and freshwater-influenced strata, had conditions that were less suitable for supporting healthy biota. The marina stratum had consistently high levels of copper both in the surface waters and sediments, as well as mercury, zinc, and organics in the sediments. The industrial stratum, which was located solely along the eastern shore of San Diego Bay, also had elevated concentrations of metals and organics in sediments, while the primary elevated contaminants in the freshwater-influenced stratum were pesticides (i.e., chlordanes and pyrethroids) and zinc. As a consequence of the finding of localized elevated levels of copper both in the water and sediments of the marina stratum, special focused studies will investigate (1) the extent of copper contamination and potential for adverse environmental effects, (2) causes of toxicity using TIEs, (3) the potential to develop a SSO for SIYB using a WER study, and (4) copper flux dynamics from sediments to overlying waters. These studies will have particular relevance to the management of RHMP resources in areas determined to have water and sediment quality impacts and are subject to regulatory actions, such as Clean Water Act 303(d) listings and TMDLs.

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